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TECHNOLOGY ASSESSMENT OF ADVANCED GENERAL AVIATION AIRCRAFT

FINAL REPORT

June, 1971

Distribution of this report is provided in the interest of information exchange. Responsibility for the contents resides in the author or organization that prepared it.

Prepared under Contract No. NAS2-5972 by
C. H. Hurkamp, W. M. Johnston, and J. H. Wilson
The Advanced Concepts Department
LOCKHEED-GEORGIA COMPANY
Marietta, Georgia

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National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

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TABLE OF CONTENTS

Section No.	Title	Page No.
1.0	INTRODUCTION	1
2.0	ACKNOWLEDGEMENTS	2
3.0	SCOPE OF STUDY	3
4.0	REQUIREMENTS AND CONSTRAINTS	3
5.0	TECHNOLOGY INVESTIGATION	7
5.1	Aerodynamic Design	7
5.1.1	High Lift Systems	7
5.1.2	Drag Configuration	13
5.1.3	Longitudinal Stability	14
5.1.4	Landing Distance	19
5.2	Propulsion	19
5.2.1	General	19
5.2.2	Reciprocating Engines	21
5.2.3	Turbine Engines	22
5.2.4	Rotary Combustion Engines	24
5.2.5	Engine Type Analysis	27
5.2.6	Propulsion Engine Emissions	31
5.2.7	Selection of Propulsor	34
5.2.8	Propeller Technology	35
5.2.9	Propeller Performance and Noise	38
5.2.10	Engine Noise Control	46
5.2.11	Rotor Noise Control	50
5.2.12	References	51
5.3	Structures and Materials	52
5.3.1	General	52
5.3.2	Load Factors	52
5.3.3	Gust Alleviation	52
5.3.4	Structural Materials	53
5.3.5	Application of Composite Material to Aircraft Structure	59
5.3.6	Production Design Techniques	61
5.3.7	References	63
5.4	Aircraft Avionics & Instrumentation	64
5.4.1	General Technology Review	64
5.4.2	Aircraft Related Systems	77
5.4.3	Mission Related Systems	82
5.4.4	General Conclusions	90
5.4.5	References	93
5.5	Landing Gear	97
5.5.1	Wheel Type Landing Gears	97
5.5.2	Air Cushion Landing System	100
5.5.3	References	113
5.6	Functional Subsystems	114
5.6.1	Environmental Subsystems	114
5.6.2	Fuel Subsystem	117
5.6.3	Flight Control Subsystem	117
5.6.4	Auxilary Power Subsystems	119
5.6.5	References	119

TABLE OF CONTENTS (Continued)

Section No.	Title	Page No.
5.7	Utility and Convenience Features	120
5.7.1	Roadability	120
5.7.2	All-Terrain Capability	121
5.8	Safety	123
5.8.1	General Considerations	123
5.8.2	Damage Tolerance and Crashworthiness	125
5.8.3	Fire Protection	129
5.8.4	Attitude Stabilization	130
5.8.5	Environmental Factors	130
5.8.6	References	132
5.9	VTOL Technology	135
5.9.1	Introduction	135
5.9.2	Hovering Capability	135
5.9.3	Forward Speed Capability	138
5.9.4	Balanced Power Performance	140
5.9.5	Compound Rotorcraft	140
5.9.6	Rotor Design	142
5.9.7	Tilt Proprotor and Tilt Wing-Propeller Problem Areas	143
5.9.8	Power Transmission	148
5.9.9	Weight Trends	150
5.9.10	Other Design Factors	150
5.9.11	References	152
6.0	SELECTION OF BASELINE DESIGNS	153
6.1	General	153
6.2	Category I Candidates	153
6.3	Category II Candidates	159
6.4	Category III Candidates	161
6.5	Category IV Candidates	163
6.6	References	167
7.0	PARAMETRIC ANALYSIS	168
7.1	Methodology	168
7.2	Statistical Weight Data	170
7.3	Statistical Cost Data	178
7.3.1	General	178
7.3.2	Initial Cost Data Collection and Correlation	179
7.3.3	Development Cost	194
7.3.4	Cost Projections of Mfg. Materials and Methods	198
7.3.5	Operating Cost	202
7.4	Configuration Evaluation	208
7.5	Results of Parametric Programs	208
7.5.1	Category I Aircraft	208
7.5.2	Category II Aircraft	213
7.5.3	Category III Aircraft	221
7.5.4	Category IV Aircraft	226
7.6	Cost Comparison	227
7.7	References	232

TABLE OF CONTENTS (Continued)

Section No.	Title	Page No.
8.0	SENSITIVITY ANALYSIS	233
8.1	General Procedure	233
8.2	Configuration Evaluation	235
8.3	Effect of Advanced Technology Applications	236
8.3.1	Aerodynamic Features	236
8.3.2	Propulsion Systems	236
8.3.3	Airframe Structure	243
8.3.4	Combined Propulsion and Airframe Structure Technology	246
8.3.5	Autogyro Configuration (Category II)	257
8.3.6	Utility and Convenience Features	262
8.3.7	Adv. Avionics & Auto. Flight Control	266
8.4	Effect of Safety Features	271
8.5	Effect of Environmental Factors	277
8.5.1	Cabin Pressurization and High Cruise Altitude	277
8.5.2	Effect of External Noise Level	280
8.5.3	Effect of Engine Emission Abatement	284
8.6	Effect of Performance Variables	286
8.6.1	Effect of Field Length Variation	286
8.6.2	Effect of Cruise Speed Variation	290
8.6.3	Effect of Cruise Range Variation	296
8.7	Effect of Growth Factors	300
8.7.1	Effect of Increased Seating Capacity	300
8.7.2	Effect of Yearly Production Rate	308
8.8	Summary	311
9.0	RECONFIGURATION OF BASELINE DESIGNS	315
9.1	General	315
9.2	Category I Recommendations	316
9.3	Category II Recommendations	321
9.4	Category III Recommendations	325
9.5	Category IV Recommendations	330
10.0	PROJECTION OF GENERAL AVIATION USE POTENTIAL	333
10.1	Relation of Price to Production Quantities	333
10.2	Factors Affecting Growth of General Aviation	337
10.3	Summary	339
10.4	References	340
11.0	CONCLUSIONS	341
11.1	Specific Conclusions	341
11.1.1	Category I Aircraft	341
11.1.2	Category II Aircraft	341
11.1.3	Category III Aircraft	342
11.1.4	Category IV Aircraft	343
11.2	General Conclusions	344
11.2.1	Impact of Advanced Technology	344
11.2.2	Impact of Environmental Factors	345
11.2.3	Impact of Educational Programs	346
11.2.4	Impact of Available Facilities	346
11.2.5	Impact of Federal Regulations	346
11.2.6	References	347

TABLE OF CONTENTS (Continued)

Section No.	Title	Page No.
12.0	RECOMMENDATIONS	348
12.1	Aircraft Research & Development	348
12.2	Related Areas	349
Appendix I	NASA Specification for "Technology Assessment of Advanced General Aviation Aircraft"	350
Appendix II	Drag Calculation	355
Appendix III	Selection of Props by Conventional Means	360
Appendix IV	Avionics and Instrumentation	362

FIGURE AND TABLE INDEX

Number	Title	Page No.
3.1	Study Flow Diagram	4
4.1	Summary of Baseline Design Requirements	6
5.1.1	Single Slotted (Cat. I and Cat. III) System	8
5.1.2	Flap Drag vs. Trimmed Max. Lift Coeff.	10
5.1.3	Flaperon	11
5.1.4	Double Slotted Flap	12
5.1.5	Horizontal Tail Sizing	16
5.1.6	Horizontal Tail Areas	18
5.2.1	Engine Matrix	20
5.2.2	Hybrid Engine Schematic	20
5.2.3	Experimental Rotary Combustion Engine RC6	25
5.2.4	4RC6 Engine Cross Sections	25
5.2.5	Rotating Combustion Cycle	26
5.2.6	Rotating Combustion Aircraft Weight vs. Power	28
5.2.7	Payload Fraction vs. Power Per Pound of Gross Weight	29
5.2.8	Effect of Mixture Change for Typical Unsupercharged Engine	33
5.2.9	Augmentation Ratio vs. Flight Mach No.	33
5.2.10	Comparative Propulsor Performance	36
5.2.11	Fiberglass Shell, Steel Spar Propeller Blade	37
5.2.12	Integral Gear Box	37
5.2.13	Weight Trends (Propeller & Gear Box)	37
5.2.14	Summary of Propellers Investigated	38
5.2.14.1	Sample Calculations for Noise Level - Category I	39
5.2.14.2	Category I Propeller Selection for 75 PNdb Av. Noise Level at 500 Ft.	40
5.2.15	Static Thrust vs. Cruise Efficiency - Category I	41
5.2.16	Category II - Propeller Selection for 75 PNdb Av. Noise Level at 500 Ft.	42
5.2.17	Static Thrust vs. Cruise Efficiency - Category II	43
5.2.18	Static Thrust vs. Cruise Efficiency - Category III	44
5.2.19	Propeller Comparison	45
5.2.20	Static Thrust vs. Cruise Efficiency - Category I - 3 Blade Prop	47
5.2.21	Propeller RPM for 75 PNdb Noise Level	48
5.2.22	Effect of Acoustic Treatment - T/F Engine	48
5.3.1	Specific Tensile Strength vs. Specific Tensile Modulus	55
5.3.2	Graphite-Epoxy Window Panel Photo	57
5.3.3	Near-Term Composite Wing Design	59
5.3.4	Integrally Moulded Spar-Rib Construction	60
5.4.1	Avionics Systems Classification	76
5.4.2	General Aviation Avionics Cost	91
5.5.1	Soil Strength Required to Support Ground Overpressure	101

FIGURE AND TABLE INDEX (Continued)

Number	Title	Page No.
5.5.2	Typical Trunk Plenum	103
5.5.3	Typical Cross-Section through Elastic Trunk	104
5.5.4	Reaction to Roll and Pitch Angles	106
5.5.5	Typical Cross-Section through Inelastic Trunk	110
5.6.1	Typical System Schematic for Pressurized Twin Engine Aircraft	115
5.6.2	Anti-Icing and Stall Delay Device	115
5.8.1	OH-6A Crash Safety	127
5.8.2	Crashworthiness Comparison of Plastic vs. Elastic Deformations	127
5.8.3	Ideal Impact Energy Absorption Capabilities for Various Materials	127
5.8.4	Ideal Crashworthiness Weight Penalties	127
5.8.5	Proposed Cost - Effectiveness Optimization for Crash Survivability Design Criteria	127
5.9.1	VTOL Hovering Parameters	136
5.9.2	Vertical Lift Capability vs. Disc Loading	137
5.9.3	Rotor Operating Conditions	139
5.9.4	Helicopter Maximum Speed Trend	141
5.9.5	Rigid Rotor Details	144
5.9.6	Conversion Corridor	145
5.9.7	Wing Angle-of-Attack in Transition	145
5.9.8	Effect of Stall on Power Required for Transition	147
5.9.9	Effect of Flap on Wing Angle of Attack	147
5.9.10	Power Transmission Trend	149
5.9.11	VTOL Weight Trends	151
6.1	Category I - Preliminary Configuration Evaluation	154
6.2	Category II - Preliminary Configuration Evaluation	155
6.3	Category III - Preliminary Configuration Evaluation	156
6.4	Category IV - Preliminary Configuration Evaluation	157
6.5	Category I - Candidates	158
6.6	Category II - Candidates	160
6.7	Category III - Propeller Caondidates	161
6.8	Category III Turbofan Candidate	164
6.9	Category IV Candidates	165
7.1.1	Parametric Flow Diagram	169
7.2.1	Wing Weight Variation	171
7.2.2	Empennage Weight Variation	172
7.2.3	Fuselage Weight Variation	173
7.2.4	Landing Gear Weight Variation	174
7.2.5	Fixed Equipment Weight Variation	175
7.2.6	Weight Empty Variation	176
7.3.1	Price of Current Light Aircraft as a Function of Weight-Speed	180
7.3.2	Reciprocating Engine Price vs. Horsepower	181
7.3.3	Turbine Engine Cost - Horsepower Trend	182
7.3.4	Rotating Combustion Engine Cost - Horsepower Trend	184

FIGURE AND TABLE INDEX (Continued)

Number	Title	Page No.
7.3.5	Propeller Assembly Price-Weight Trend	185
7.3.6	Airframe List Price Trend with Weight - Speed Product	186
7.3.7	OEM Other Equipment Cost Trend with Weight-Speed	187
7.3.8	Estimated Cost Summary: Typical 4-Place Contemporary Aircraft	188
7.3.9	Manufacturing Manhours and Material Cost per Pound of Empty Weight	190
7.3.10	Manufacturing Manhours and Material Cost Divided by Weight Empty - Max. Speed Factor	191
7.3.11	Helicopter Manufacturing Manhours vs. Weight - Speed Trend	192
7.3.12	Initial Cost Estimating Model Block Flow	193
7.3.13	Comparison of Actual and Model Estimated Cost (FAF) of Contemporary Aircraft	195
7.3.14	Airframe Development Cost Breakout	197
7.3.15	Material Cost Projections	199
7.3.16	Production Cost for Adv. Material Use	199
7.3.17	High Production Rate Cost Element Reduction Factors	201
7.3.18	Operating Cost Factors Summary	203
7.3.19	Inspection and Maintenance Cost per Flight Hour Trend	204
7.3.20	Reserve for Overhaul Cost Trend with Power	206
7.3.21	Aircraft - Mile Cost Trend with Utilization	209
7.3.22	Typical Percentages of Operating Cost Elements	210
7.5.1	Category I Tractor Parametric Analysis	211
7.5.2	Category I Pusher Parametric Analysis	212
7.5.3	Category I Tractor Comparison of Conventional and Low Noise Props	214
7.5.4	Category I Parametric Analysis Results	215
7.5.5	General Arrangement: Category I Baseline Aircraft	216
7.5.6	Category II Single Propeller Parametric Analysis	217
7.5.7	Category II Twin Propeller Parametric Analysis	218
7.5.8	Category II Parametric Analysis Results	219
7.5.9	General Arrangement: Category II Baseline Aircraft	220
7.5.10	Category III Twin Tractor Parametric Analysis	222
7.5.11	Category III Tractor - Pusher Parametric Analysis	223
7.5.12	Category III Parametric Analysis Results	224
7.5.13	General Arrangement: Category III Baseline Aircraft	225
7.5.14	Category IV Parametric Analysis Results	228
7.5.15	General Arrangement: Category IV Helicopter	229
8.1.1	Sensitivity Analysis Procedure	234
8.3.1	Category I Comparison: Effect of Adv. Propulsion	239
8.3.2	Category II Comparison: Effect of Adv. Propulsion	239
8.3.3	Category III Comparison: Effect of Adv. Propulsion	240

FIGURE AND TABLE INDEX (Continued)

Number	Title	Page No.
8.3.4	Category IV Comparison: Effect of Adv. Propulsion	240
8.3.3.1	Category III Comparison: Twin Engine Prop. vs. Single Turbofan	241
8.3.3.2	General Arrangement: Category III Single Turbofan	242
8.3.5	Category I Comparison: Effect of Adv. Materials	244
8.3.6	Category II Comparison: Effect of Adv. Materials	244
8.3.7	Category III Comparison: Effect of Adv. Materials	245
8.3.8	Category IV Comparison: Effect of Adv. Materials	245
8.3.9	Category I Comparison: Effect of Adv. Propulsion & Materials	247
8.3.10	Category II Comparison: Effect of Adv. Propulsion & Materials	247
8.3.11	Category III Comparison: Effect of Adv. Propulsion & Materials	248
8.3.12	Category IV Comparison: Effect of Adv. Propulsion & Materials	248
8.3.9.1	Effect of Adv. Technology: Category I	249
8.3.10.1	Effect of Adv. Technology: Category II	250
8.3.11.1	Effect of Adv. Technology: Category III	251
8.3.12.1	Effect of Adv. Technology: Category IV	252
8.3.13	General Arrangement: Category I Adv. Technology	253
8.3.14	General Arrangement: Category II Adv. Technology	254
8.3.15	General Arrangement: Category III Adv. Technology	255
8.3.16	General Arrangement: Category III Adv. Technology	255
8.3.17	General Arrangement: Cat. II Autogyro	258
8.3.18	Category II Comparison: Fixed Wing vs. Autogyro	261
8.3.19	General Arrangement: Cat. I Roadable A/C	263
8.3.20	Category I Comparison: Effect of Providing Roadability	264
8.3.23	Category I Comparison: Effect of Adv. Avionics	269
8.3.24	Category II Comparison: Effect of Adv. Avionics	269
8.3.25	Category III Comparison: Effect of Adv. Avionics	270
8.3.26	Category IV Comparison: Effect of Adv. Avionics	270
8.4.1	Category I Comparison: Effect of Safety Provisions	275
8.4.2	Category II Comparison: Effect of Safety Provisions	275
8.4.3	Category III Comparison: Effect of Safety Provisions	276
8.4.4	Category IV Comparison: Effect of Safety Provisions	276
8.5.1	Category I Comparison: Effect of Press. & High Cruise Alt.	278
8.5.2	Category II Comparison: Effect of Press. & High Cruise Alt.	278
8.5.3	Category III Comparison: Effect of Press. & High Cruise Alt.	279
8.5.5	Category II Comparison: Effect of External Noise Level	282
8.5.6	Category III Comparison: Effect of External Noise Level	283

FIGURE AND TABLE INDEX (Continued)

Number	Title	Page No.
8.5.7	Category IV Comparison: Effect of External Noise Level	283
8.5.8	Effect of Noise Level on Price	285
8.6.1	Category I Comparison: Effect of Field Length Variation	287
8.6.2	Category II Comparison: Effect of Field Length Variation	287
8.6.3	Category III Comparison: Effect of Field Length Variation	288
8.6.3.1	Effect of Field Length on Price	289
8.6.4	Category I Comparison: Effect of Cruise Speed Variation	291
8.6.5	Category II Comparison: Effect of Cruise Speed Variation	291
8.6.6	Category III Comparison: Effect of Cruise Speed Variation	292
8.6.7	Category IV Comparison: Effect of Cruise Speed Variation	292
8.6.7.1	Effect of Cruise Speed on Price	294
8.6.7.2	Effect of Cruise Speed on Operating Cost	295
8.6.8	Category I Comparison: Effect of Cruise Range Variation	297
8.6.9	Category II Comparison: Effect of Cruise Range Variation	297
8.6.10	Category III Comparison: Effect of Cruise Range Variation	298
8.6.11	Category IV Comparison: Effect of Cruise Range Variation	298
8.6.12	Effect of Cruise Range on Price	299
8.7.1	Category I Comparison: Effect of Increased Seating Cap.	301
8.7.2	Category II Comparison: Effect of Increased Seating Cap.	301
8.7.3	Category III Comparison: Effect of Increased Seating Cap.	302
8.7.4	Category IV Comparison: Effect of Increased Seating Cap.	302
8.7.5	General Arrangement: Cat. I 6-Place A/C	303
8.7.6	General Arrangement: Cat. II 6-Place A/C	
8.7.7	General Arrangement: Cat. III 9-Place A/C	305
8.7.8	General Arrangement; Cat. IV 6-Place Helicopter	306
8.7.9	Effect of Seating Cap. on Price & Seat-Mile Cost	307
8.7.10	Effect of Yearly Production Rate on Price	309
8.7.11	Effect of Yearly Production Rate	310
8.8.1	Effect of Technology & Noise Levels on Price vs. Weight X Speed	312
8.8.2	Effect of Added Provisions on Price vs. Weight X Speed	313
9.1	Category I Comparison: Basic vs. Recommended Configurations	317

FIGURE AND TABLE INDEX (Continued)

Number	Title	Page No.
9.2	General Arrangement: Category I Recommended Configurations	318
9.3	Comparison Between Recommended & Baseline Configurations; Category I	320
9.4	Category II Comparison: Basic vs. Recommended Configurations	322
9.5	General Arrangement: Category II Recommended Configuration	323
9.6	Comparison Between Recommended & Baseline Configurations; Category II	324
9.7	Category III Comparison: Basic vs. Recommended Configurations	326
9.8	General Arrangement: Cat. III Recommended Configuration	326
9.9	Comparison Between Recommended & Baseline Configurations; Category III	328
9.10	Category IV Comparison: Basic vs. Recommended Configurations	331
9.11	Comparison Between Recommended & Baseline Configurations; Category IV	332
10.1	Cost Per Pound Variation with Annual Production Volume	334
10.2	Past and Projected General Aviation Aircraft Deliveries Per Year	335
10.3	Price Classifications of General Aviation Aircraft	336
10.4	1968 Utilization of General Aviation Aircraft	336

1.0 INTRODUCTION

1.0 INTRODUCTION

This study contract was awarded on 15 June 1970. The object is to assess the potential impact of advanced technology in 1985 on four classes of general aviation aircraft and to recommend areas where further research and development will help to realize the potential improvements. The four categories include conventional, STOL and V/STOL performance in 4 to 9 place aircraft, with helicopters included in the study. The requirements for each category are listed under Section 6.1 and in Appendix I. The study procedure consists of:

(a) establishing an optimized design configuration in each category, based on present technology;

(b) investigating and pinpointing the most promising areas of applicable technology;

(c) applying the selected advanced technology to each of the present technology designs;

(d) assessing the results and making recommendations.

The areas of advanced technology include those of aerodynamics, propulsion, structural materials, avionics, flight safety, automatic control, noise and emission abatement. These are assessed individually and in combination by means of a computerized analysis. The recommended combinations are then studied to determine their potential impact on the over-all transportation system, after which the areas of technical support are recommended.

Reference lists are placed at the end of Sections or principal Subsections (see Table of Contents).

It should be emphasized that the final results of the study, in the form of recommended configurations in each of the four categories specified by NASA, indicate long range <u>potential</u> and not predictions. In order to help develop this potential, extensive government support is required in the areas of technology research and development, the expansion of small airfields, pilot training assistance and other educational programs.

A summary of this report is provided in a separate volume, NASA CR 114338.

2.0 ACKNOWLEDGEMENTS

The Lockheed-Georgia Company study team was led by C. H. Hurkamp, under the direction of R. H. Lange, Manager, Advanced Concepts Department. The study team comprised the following members:

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3.0 SCOPE OF STUDY

The study follows the guidelines and constraints of paragraphs 1.4 and 1.5 of the Statement of Work in Appendix I. This document, which formed part of the RFP for this study, was interpreted by the Contractor in his Technical Proposal, Lockheed-Georgia Company Report ETP 943. The overall scope was illustrated in the Study Flow Diagram, Figure 3.1.

The first step of establishing requirements is to identify the constraints imposed by the RFP along with FAA requirements and any modifications agreed upon by the contractor and NASA. The second step is the identification of the projected applicable technology, in each of the areas listed, by specialized engineering personnel in each discipline and with the aid of published reference data and consultation with cognizant representatives of NASA, Lockheed and other organizations in the fields of airframe, engine, materials, avionics and applicable subsystems. In the third step, the most appropriate lines of technological development are selected for application to the sensitivity analysis. The fourth step is that in which two or more candidate configurations are investigated for each of the four specified categories. These configurations are then optimized by the use of parametric programs, using initial and operating cost as criteria. Present state-of-the-art is applied so that a base can be established for advanced technology sensitivity analysis.

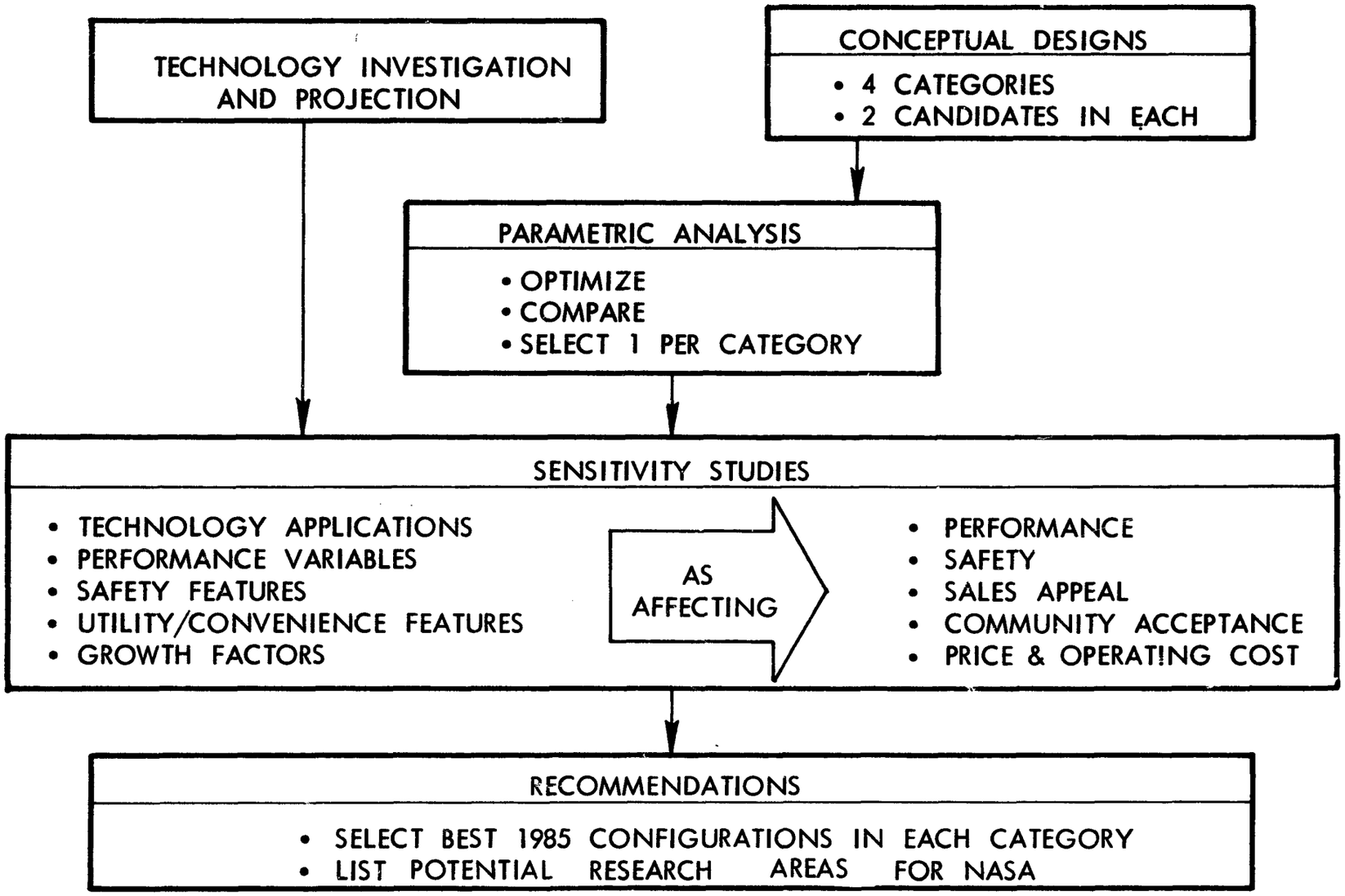
In the fifth step, the candidate configurations within each category are compared, and one or more out of each is selected for sensitivity studies. The sixth step consists of applying variable characteristics to the selected configurations to determine the effectiveness of each variable toward improving the desired characteristics. These variables fall under five headings: Technology, Safety, Environmental Performance and Growth. For each technology variable the future state-of-the-art is related to that of the present, so that its effect on the characteristics listed can be determined. Advanced technology is first applied in the form of advanced propulsion systems and advanced structural materials. After separate assessment, the two are combined to establish advanced technology configurations, which are used as baseline designs for assessing all the other variables. These include the remaining technology items, extra safety provisions, environmental factors, performance variables and growth factors. The results of the sensitivity studies are then examined in the seventh step to determine optimum combinations and to recommend a selected future configuration in each category.

Finally, the eighth step fulfills the principal purpose of the study by defining the recommended areas of study, research and development recommended to assist in promoting technology which will enhance the future growth of general aviation.

4.0 REQUIREMENTS AND CONSTRAINTS

The general constraints applicable to this study are listed in paragraph 1.5 of the Statement of Work contained in Appendix I. They are tabulated in Figure 4.1.

FIGURE 3.1 STUDY PLAN



Certain interpretations of the NASA requirements and additional constraints were agreed upon by the NASA and Lockheed Study Managers:

- All costs will be expressed in 1970 dollars.
- The range requirements will be in statute miles.
- The 9.0g positive maneuver load factor requirement will be evaluated in the Sensitivity Analysis. The baseline designs will have FAR Normal Category load factors.
- The required external noise level of 75 PNdb at 500 ft. will be applied to the baseline designs.
- Lift-off and touchdown will be made at 1.20 V_s.
- Takeoff and landing requirements will be met at sea level standard conditions with altitude performance at standard temperature.
- In connection with the structural load factors, FAR Part 23 specifies 3.80 as the maximum positive limit load factor for maximum design gross weight. All loads are assumed to be limit loads, with a factor of 1.5 applied to define ultimate loads.
- In connection with the required noise level it was proposed that the level of 75 PNdb at 500 ft. be defined as the average noise levels at angles of 60 to 120 degrees with the heading of the propeller, as defined in Hamilton Standard Report SP67148.
- The extra safety provisions will be evaluated in two groups: structural and systems. The former group will include a 9g design maneuver load factor, a 13 ft/sec design rate of sink and a crash resistant design cabin environment. The latter group will include an automatic wing leveling device, an automatic flare device, fuel tanks remote from the passenger cabin, a fire retardant system for the fuel, an anti-icing system and a crash locating device. The two groups will be evaluated singly and in combination.

FIGURE 4.1 SUMMARY OF BASELINE DESIGN REQUIREMENTS

CATEGORY	I	II	III	IV
CRITICAL FIELD LENGTH (FT.)	1000	500	1500	VTOL
RANGE (STAT. MILES)	500	500	1500	500
CRUISE SPEED (KNOTS)	130	200	250	150
MIN. NO. OF SEATS	4	4	6	4

COMMON REQUIREMENTS

EXTERIOR NOISE LEVEL	75 PNdb AT 500 FT.
WEIGHT ALLOWANCE PER SEAT	220 LBS. (INCLUDING BAGGAGE)
FUEL RESERVE	45 MIN.

5.0 TECHNOLOGY INVESTIGATION

This section of the report covers an examination of present and emerging technology in the disciplines governing the design of aircraft in each of the four categories. They include aerodynamics, propulsion, structure and materials, avionics, landing gear, functional subsystems, safety techniques, utility and convenience features and VTOL technology. The investigation of each technology area will conclude with recommended approaches for each appropriate category of aircraft.

5.1 Aerodynamic Design

Aerodynamic technology investigation covers the areas of high lift systems, drag configuration and stability and control considerations, which will be discussed in that order.

5.1.1 High Lift Systems

The investigation of non-augmented high lift systems by the NASA has been active for over 40 years. Configurations have been developed which can be applied in an optimum manner to any conventional configuration. While augmented systems have also been subject to extensive investigation, their complication and attendant cost make them unsuitable for application to general aviation aircraft. They would only be appropriate to the STOL airplane candidates of Category II, which are single engined, with which minimum flight speed would have to be based on the power-off condition.

In checking on previous experience with leading edge slats, it was found that the weight and cost of the aircraft actually increase when slats are used. The weight of the slats and the reflection of this weight on the weight of the aircraft results in a substantial penalty. The ground roll portion of the take-off is actually reduced, but the distance over 50 feet is increased on comparable aircraft, which have essentially the same power, but a higher gross weight. Thus, it is believed that slats are not a desirable addition to the high lift configuration on any category of conventional airplanes being investigated. The slat might be quite beneficial if chances of a leading edge stall condition existed. However, with the comparatively thick sections used on these aircraft and with the techniques presently available for leading edge stall prevention, such as leading edge droop and increased leading edge radius, it is not believed slats will be necessary for this purpose.

Two flap systems have been investigated for Categories I, II, and III. The characteristics of the flap system are shown in Table 5.1.1. A single slotted system would be appropriate for Category I and Category III aircraft, while a double slotted flap system would be better suited to the Category II STOL aircraft. In the case of both these systems, slotted ailerons, that are drooped with the flaps, can be used. It is possible that the aft flap of the double flap system could be used for lateral control, but the considerable aft movement of the total system precludes any straight-forward way of actuating the aft flap by a correctional lateral control system.

TABLE 5.1.1

SINGLE SLOTTED (CAT. 1 & CAT. III) SYSTEM

(All Values of C_{L_M} are untrimmed)

Max. Lift Coeff. (C_{L_M})	Profile Drag Coeff. (C_{D_P})	Interf. C_D (C_{D_1})	Induced C_D (C_{D_1})	Total C_D Due to Flaps (C_D)
2.0	.0038	.0015	.0040	.0093
2.2	.0100	.0040	.0090	.0230
2.35	.0397	.0159	.0205	.0761
DROOPED AILERONS				
2.16	.0058	.0023	.0062	.0143
2.36	.0120	.0048	.0114	.0282
2.51	.0417	.0166	.0165	.0748

CAT. II DOUBLE FLAP CONFIGURATION

(Untrimmed Values)

2.2	.0105	.0042	.0072	.0219
2.4	.0162	.0065	.0127	.0354
2.6	.0240	.0096	.0189	.0525
2.8	.0378	.0152	.0286	.0816
3.0	.0670	.0268	.0390	.1328
3.07	.0875	.0350	.0430	.1655

NOTE: Flap data was obtained from NASA TR 723 for Double Slotted Flaps and NASA TR 664 for Single Slotted Flaps. Data was also obtained from Royal Aeronautical Society Data Sheets Volume 4, page 01.01.01 to 08.01.01, R&M2622 by A. D. Young dated 1947 British Ministry of Supply.

The untrimmed maximum lift is 3.07 for the double flap with 30 degrees of aileron droop, and 2.51 for the slotted flaps with 20 degrees of aileron droop. The slotted flaps without aileron droop would have a maximum lift coefficient of 2.35. When an average configuration is assumed trimmed to 20 percent center of gravity, the maximum lift coefficient for the double flaps would be 2.8. For the slotted flaps with aileron droop, the maximum lift coefficient would be 2.42. The slotted flaps without aileron droop would yield a maximum lift coefficient of 2.28. In the case of the Category 2 aircraft, in which double flaps are used maximum lift coefficients of 2.8, 2.6, and 2.4 were investigated. These coefficients were obtained by varying flap deflection.

Three different types of high lift systems were developed for use on the parametric computer program. They are:

1. Single slotted flaps
2. Single slotted flaps with ailerons drooped 20°.
3. Double flaps with ailerons drooped 30°.

Fifteen percent chord leading edge slats can be used with any of the above mentioned trailing edge devices.

Figure 5.1.2 shows flap drag as a function of lift coefficient for single slotted flaps and double flaps.

The method of combining full span flaps with ailerons is shown in Figure 5.1.3. The 2-h flap described in NACA TR664 is ratioed up to a length of 32.5 percent chord. The trailing edge of the flap cove is located where the fixed wing skin would terminate for a 25% chord simple flap. The "flaperon" is then hinged so that the nose is in the optimum position for a 30-degree flap deflection. Normal aileron action of 20 degrees up and 15 degrees down, in reference to any amount of flap droop position, is governed by a simple linkage inside the wing.

The double slotted arrangement, developed from data presented in NACA TR723, is illustrated in Figure 5.1.4. A major advantage is that the combined length of the two segments equals 40% of chord, but the nested length is only 33% of chord, which does not impose an undue penalty on the wing box structure ahead of the flaps. Tracks are used so that each segment is in the optimum position in relation to its slot lip throughout the full range of travel.

It was assumed that one engine will be used for the investigation of Categories I and II. As a consequence, all of the airport operations were conducted at speeds considerably above the power-off stall speed. Category III was investigated for both single and twin engine configurations.

In the case of the Category II STOL aircraft, the landing condition is quite critical, necessitating spoilers and very effective braking in order to meet the 500-foot landing requirement. In the case of the Category I and II aircarft, the field lengths are not as difficult to meet as the Category II requirement, so that it is unnecessary to have as sophisticated an approach to airport performance. Neither spoilers nor better-than-average braking should be required for these aircraft.

In summation, the single slotted flaps are proposed for use in Categories I and III, while the double flaps appear to fit the Category II requirements. In addition, the effect of drooping the ailerons, which are of the slotted type, might be appropriate for both flap configurations. These data become part of the input in both take-off and landing calculations. The flaps have three effects on airplane drag:

1. An increase in parasite drag due to the effective flap plate area of the flaps

2. An increased interference drag due to the discontinuity at the fuselage.

3. An increased induced drag due to the effect of the flaps on span load distribution.

FIGURE 5.1.2 FLAP DRAG VS. TRIMMED MAX LIFT COEFF.

C_{DO_f} - Incremental Profile Drag Coeff. Due To Flap Deflect.

C_{D_f} - Increment in Total Drag Coeff. Due to Flap Deflect.

δ_f - Flap Deflection

δ_a - Aileron Droop Deflection

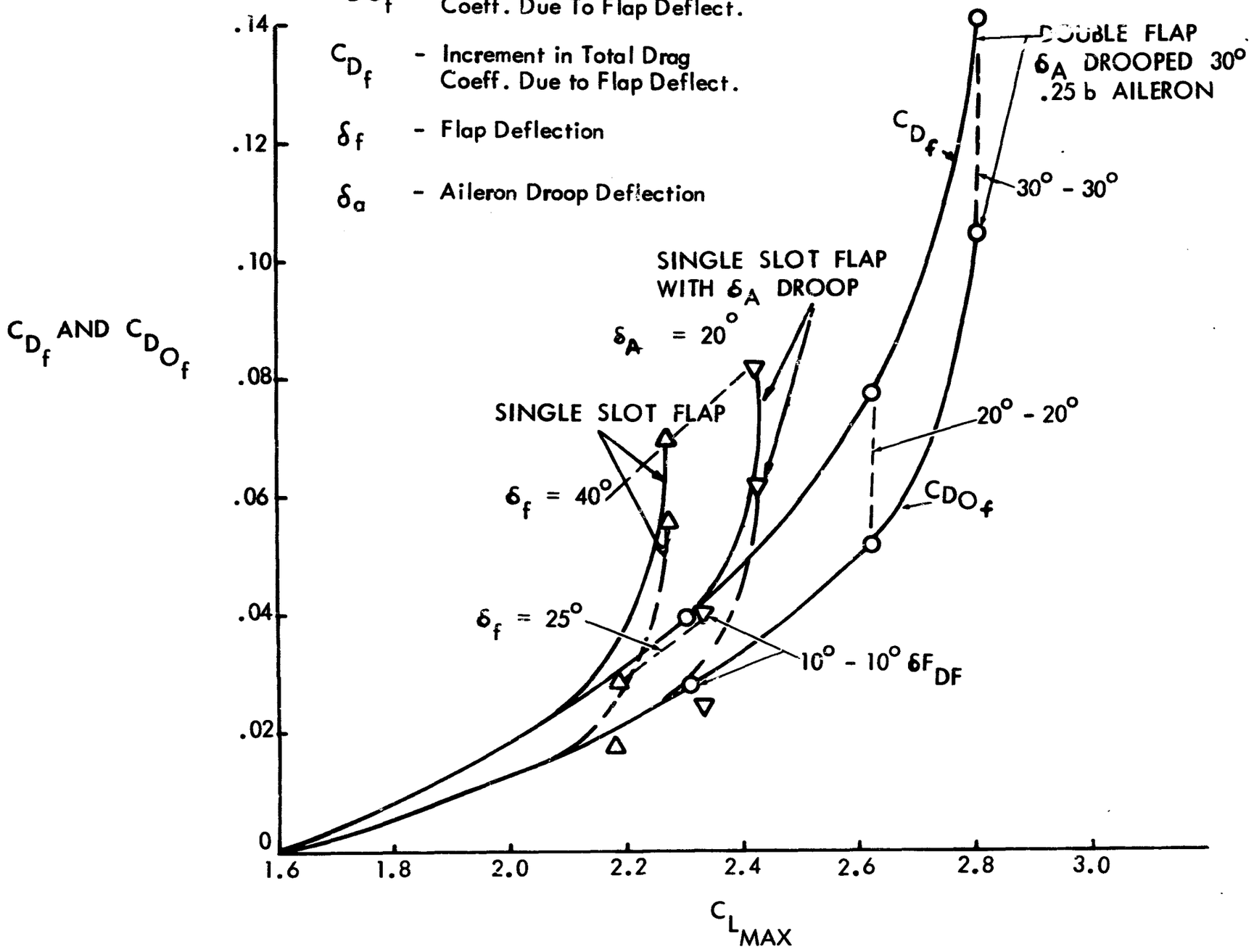


FIGURE 5.1.3 32.5 PERCENT CHORD FLAPERON
(REF NACA TR 664)

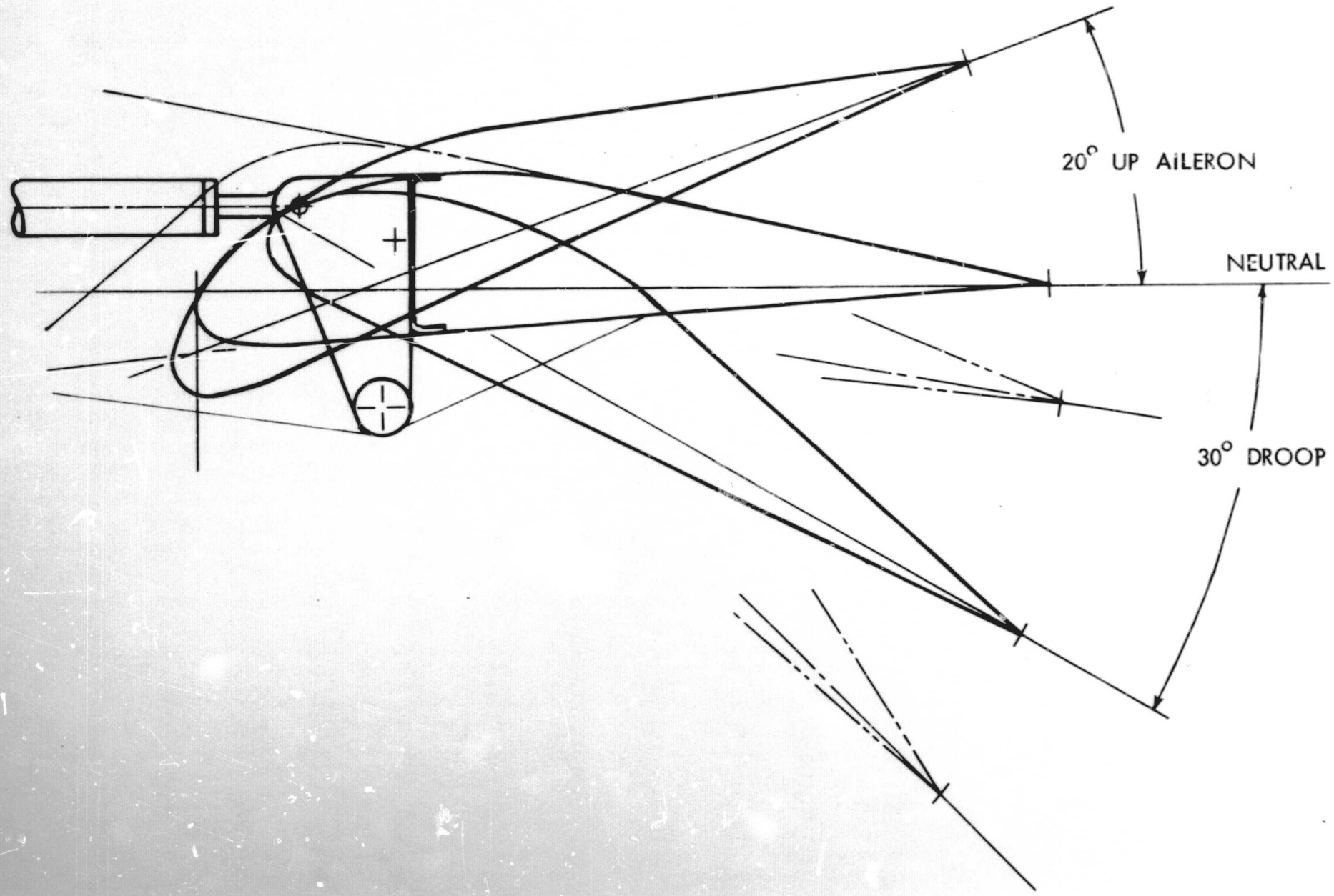
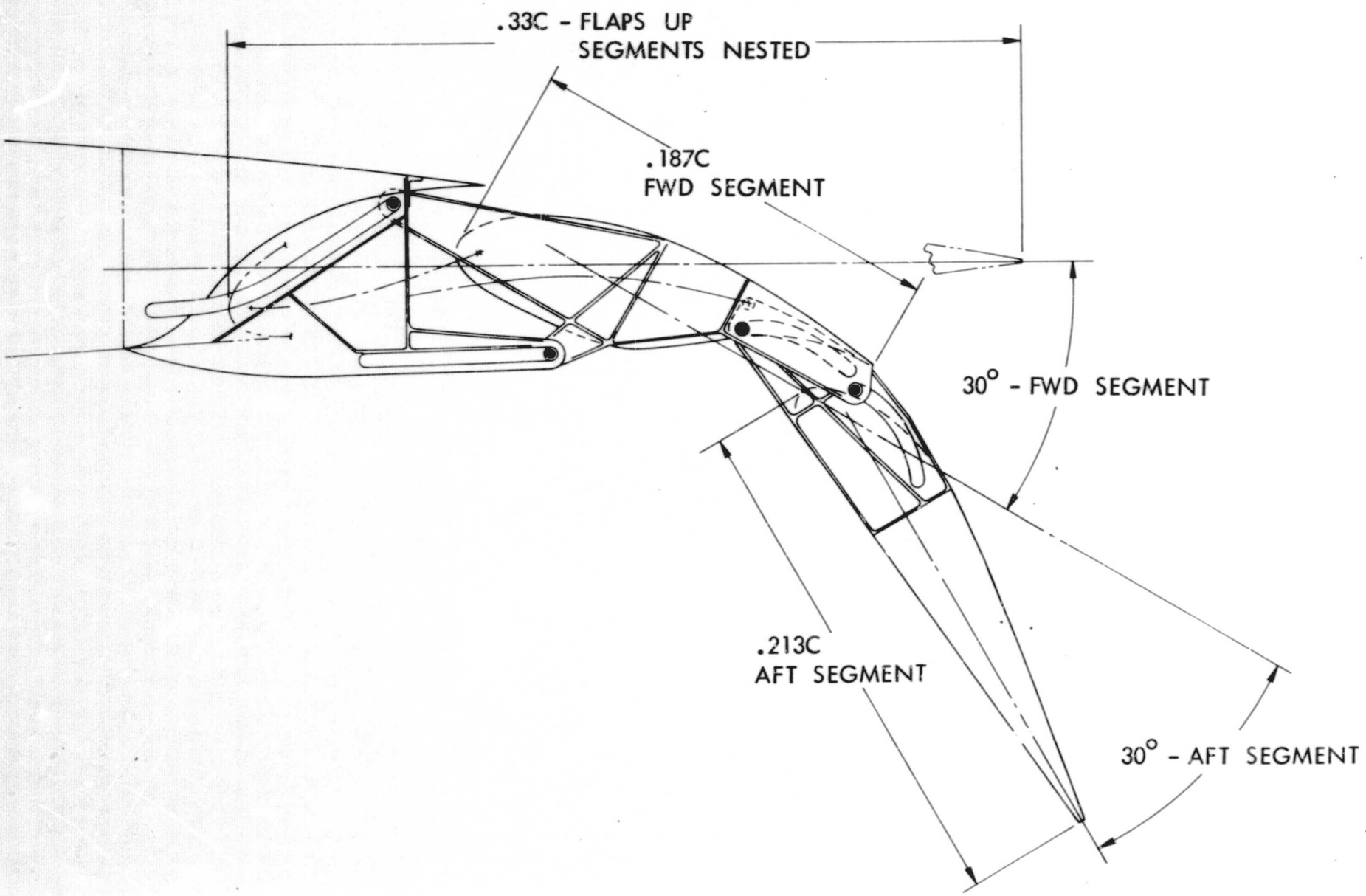


FIGURE 5.1.4 33 PERCENT CHORD
DOUBLE SLOTTED FLAP

(REF NACA TR 723)



5.1.2 Drag Configuration

No new technology is available for the application of drag reduction, other than that of applying the tried and true principles of good aerodynamic design. This includes proper streamlining of the fuselage and the avoidance of bad interference effects at the junctures of principal components, such as the wing-fuselage intersection.

Pusher propeller configurations are included in the Category I and II applications. Previous examples in the general aviation industry have proven to result in abnormally high drag, due to maintaining a short length of fuselage between the full-width cross-section and the propeller spinner. The examples investigated in this study employ extension shafting between the engine and propeller. The fuselage itself is faired to a two-dimensional wedge in the vertical plane, with a superimposed streamlined body, connecting the air induction scoop and the propeller spinner faired in the horizontal plane. This method is believed to result in drag comparable to that of a well-designed tractor propeller airplane, since it is not subject to slipstream impingement.

Both fixed and retractable landing gear was investigated for Category I, while the other three categories have only the latter.

In this task it is first necessary to determine the skin friction of each component being considered. In order to do this, the Reynolds number must first be determined. A typical cruise altitude of 7500 feet will be used for the first investigation which is a reasonable altitude for 75% power on reciprocating engines. This altitude will be changed for the turbo-supercharged or turbine powered configurations, as appropriate.

The methodology for applying drag calculations to the parametric analysis is set forth in Appendix II.

5.1.3 Longitudinal Stability and Control

The selection of the horizontal tail for any type of aircraft is a question of meeting the static and dynamic stability and control requirements. For a small airplane the major dynamic requirements are the phugoid oscillation and the short period longitudinal oscillation. The phugoid oscillation will not be heavily damped, on these present study airplanes, because of the very clean configuration of these aircraft, but the period will be long and easily controllable, due to low cruise lift coefficient. The short period oscillation is always heavily damped on small aircraft, and should not create a problem. Normally, one would expect the static requirements to select the tail size for a small airplane.

The horizontal tail area used in the parametric study was determined from correlation studies of satisfactory tail areas for the type of aircraft being considered. Thus, using typical airplane dimensions, it was found that the horizontal tail area could be determined as a function of fuselage width. It was found that this method was conservative, giving a value of .30 for tail area divided by fuselage area for a typical category I airplane. This value is close to the value of .31 for the fixed stabilizer plus elevator and trim tab, the configuration requiring the greatest tail area.

The vertical tail area was also selected by correlative data on typical airplanes for the selected category. The requirements of the vertical tail are not as straight forward as the requirements of the horizontal tail, but still would have a requirement of giving good directional stability, plus providing a proper amount of yawing power to hold a yaw angle of at least 10 degrees for cross wing airport operations. In addition, yawing power should be sufficient to hold wings level during a stall. The method of determining vertical tail area for the parametric, which is similar to the horizontal tail relationship, is given on page

Typical configurations were analyzed using the vertical tail area determined in the parametric, and were found to have sufficient control (yawing power) and directional stability.

The rearmost usable center of gravity is normally set by the size, lift curve slope, position, and length of the horizontal tail, since the airplane center of gravity location and the horizontal tail determines the basic airplane stability. The most forward center of gravity position is determined by the total power of the tail in being able to meet critical control requirements, which may be any one of several conditions, including stall in free air, nose wheel lift-off for a tricycle geared airplane, or hold-off in ground effect, at a very low speed (1.05 stall speed). A simplified analysis is made, in which the control power in free air is the forward C.G. constraint, and a change in negative moment equal to 0.10 of the lift coefficient is used for the aft C.G. limit. A 15 percent center of gravity travel is used as typical for these types of aircraft. The method of determining the aft C.G. is the consideration of the moment of the fuselage or/and nacelles as a

body about the center of gravity, to which is added the destabilizing moment of the wing air flow of the fuselage, and the effect of wing fuselage intersection. This results in substantially forward C.G. bias on the pusher airplanes, since the destabilizing effect of the fuselage requires that a forward center of gravity be used in order to get a negative slope of the d_{C_M} / d_{C_L} curve. Increments of tail area are then taken and the aft C.G. for stability is plotted as a function of tail area.

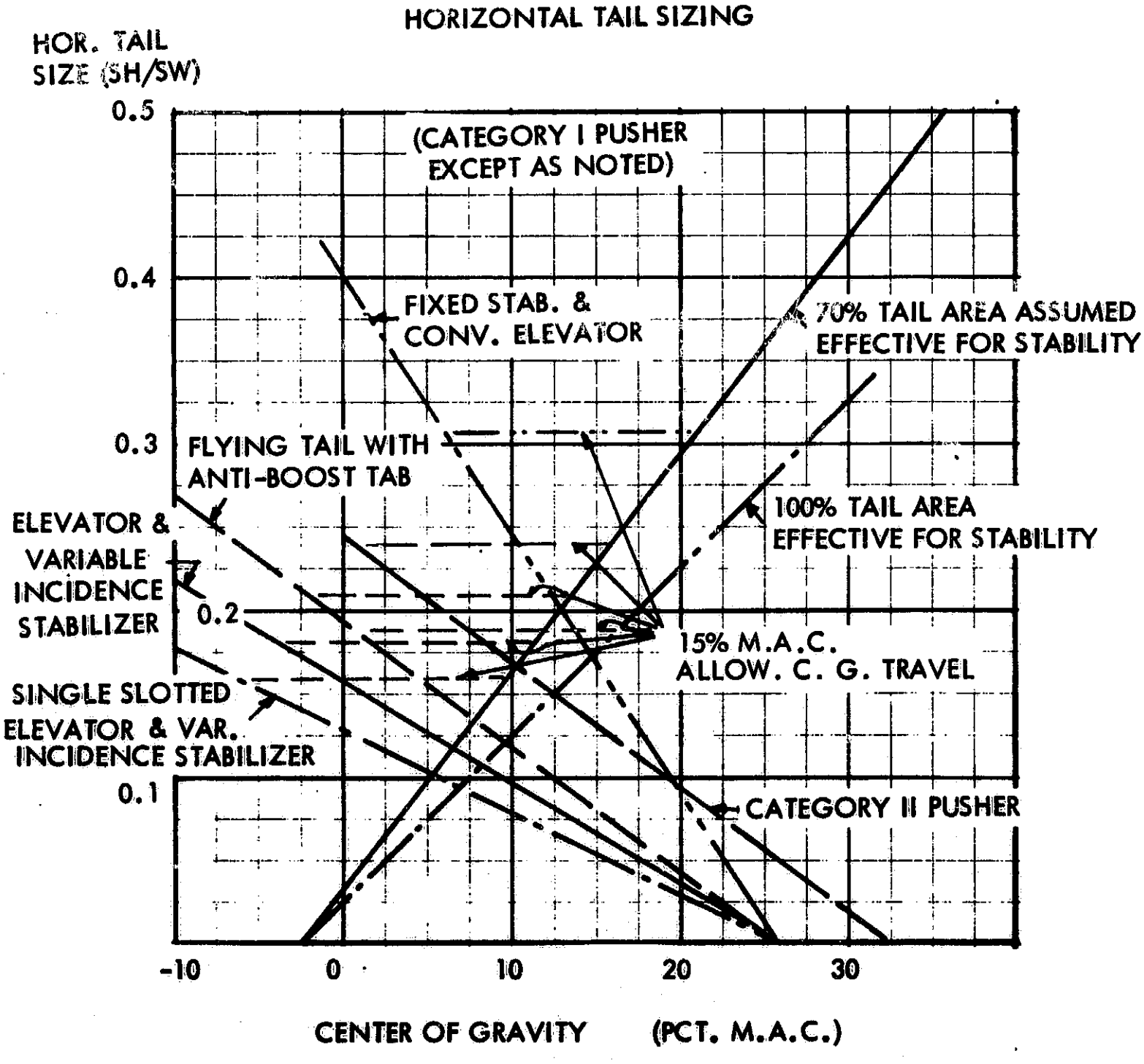
In computing the most forward center of gravity condition, it is necessary to determine the pitching moment and slope of the d_{C_M}/d_{C_L} curve of the airplane less tail, and from these data to find the pitching moment at the stall. It is then possible to find center of gravity where the moments become balanced out without a horizontal tail. The condition for the Category I airplane is with maximum flap deflection. Increments of tail size are then taken, and the appropriate center of gravity shift as a result of this moment is then computed. The tail input in this case is mainly a question of the maximum download that can be realized from the horizontal tail.

The graph covering the selection of the horizontal tail for a Category I pusher airplane is shown in Figure 5.1.5. This graph delineates a horizontal tail selection of minimum area for several different configurations. The aspect ratio of the horizontal tail is assumed to be 4.0 for all configurations studied The elevator chord is assumed 25 percent of the stabilizer chord. The following configurations were studied:

1. Variable incidence stabilizer and conventional elevator.
2. Variable incidence stabilizer and slotted elevator.
3. "All flying tail" with anti-boost tab.
4. Fixed stabilizer and conventional elevator with trim tab.

FIGURE 5.1.5

HORIZONTAL TAIL SIZING



The variable incidence stabilizer with conventional elevator is a configuration that has found favor since the early days of aviation and is used on such airplanes as the Piper Cub, the Cessna 180, the Boeing 707 series, and many others. This system can be made to develop the maximum lift of which the elevator and stabilizer are capable. Beside this, the system is redundant, since a failure of the elevator controls will leave the stabilizer operational to provide longitudinal stability and trim. Conversely, if the stabilizer jams, the elevator can normally be used to control the airplane through an acceptable speed range.

The variable incidence stabilizer with slotted elevator is a more effective configuration than a conventional elevator and variable incidence stabilizer, as it is capable of a higher maximum lift coefficient, just as a slotted flap is more effective than a plain flap.

The all-flying tail is quite popular presently, being fitted on both American and European light aircraft. This system has the virtue of being somewhat less expensive than the other competitive configurations, but does not have as much power as that of the variable incidence stabilizer, with either conventional or slotted elevator, since the anti-boost tab is quite small, and is used for trim. The tab moves in the opposite direction to that of the surface for trim at a critical forward C.G. condition, and is not as powerful as an elevator in augmenting force due to both size and deflection. Another disadvantage of the flying tail is the much greater change in moment with deflection, compared to the more conventional systems. This system results in an over-control tendency during landing, if the forces are light. If the system is balanced to give the proper forces, then the loss in force due to excessive tab deflections would require a larger size of horizontal tail. At the aft center of gravity stability requirement, there is little to choose between the various configurations. The flying tail can be hinged so that the stick-free neutral point is essentially equal to the stick-fixed neutral point, with the stick force coming from the tab. However, a stabilizer-elevator combination can be used the same way, with either springs or an anti-boost tab for control forces. The present design practice for elevators, however, would indicate a slightly more forward stick-free neutral point than would be the case with an all-flying tail, but this is not necessarily the case.

In regard to redundancy, all of the systems appear better than the all-flying tail, which would seem to have very light forces if the tab failed and might result in a major structural failure. In addition, failure of the tab system would make the tail more subject to flutter. However, in the event of loss of the primary control, the tab could still be used to fly the airplane.

Table 5.1.6 shows a comparison of horizontal tail area to wing area ratio (S_T/S_W) for the selected Category I pusher airplane and one tail configuration of the Category II pusher.

TABLE 5.1.6 HORIZONTAL TAIL AREAS

(a) CATEGORY I

CONFIGURATION	S_T/S_W
Fixed Stabilizer with Conv. Elevator	.302
Flying Tail with Anti-Boost Tab	.205
Elevator & Variable Incidence Stabilizer	.178
Variable Incidence Stabilizer with Single Slotted Elevator	.153
Variable Stabilizer	.163
Flying Tail	.184
Rear C.G. Equal To:	
25% -	.360
30% -	.427
35% -	.490

(b) STOL AIRCRAFT - CATEGORY II

Variable Stabilizer	.203

All of these cases, except where the rearmost center of gravity is arbitrarily selected, are for a 15 percent center of gravity travel. The minimum area ratio is .153, and the maximum is .302, which is almost a factor of 2 increase. The slotted elevator and variable incidence stabilizer combination has minimum area, and the fixed stabilizer and conventional elevator have the maximum area, mainly due to the fact the stabilizer must be at an incidence that will not cause an undue cruise drag penalty.

If the horizontal tail is assumed balanced with regard to angle-of-attack, ($C_{h_\alpha} = 0$) so that the stick-free and stick-fixed neutral points are the same, a further 10 percent saving in area can be effected. Some type of artificial feel or an anti-boost tab would be required for stick force.

Another interesting comparison is the horizontal tail area requirement for the Category II STOL airplane, configured as a pusher. This airplane requires a 15 percent larger tail area than that of the Category I vehicle, in order to meet the critical design conditions. The major reason for this increase is the larger pitching moments due to the double slotted flaps used on this airplane.

The additional data show the tail area required if the aft limit, because of configuration restrictions, has to be set at 25 and 30 percent center of gravity. It is obvious that either of these restrictions would result in substantially more tail area than would be the case for an optimum tail

selected for 15 percent C.G. travel. If the area is selected for stability at aft C.G.'s, then the elevator would not be critical, and the elevator chord could be less than 25 percent of the stabilizer chord.

5.1.4 Landing Distance

Field length is determined in the parametric analyses by calculating the take-off distance over a 50 ft. obstacle. As a check, however, landing distances were calculated for selected airplanes in three categories. It is assumed that all airplanes have a gliding speed of 1.2 times the stall speed at 50 feet, in all cases, and that a flare is conducted appropriate to the landing sink speed with at least 10 percent excess lift. A ground roll friction (braking) coefficient of 0.4 is used for all categories. No special devices are employed for Category I, but it is assumed that lift spoilers would be actuated at ground contact in Categories II and III, resulting in much more weight on the wheels, hence more effective braking, plus some increase in aerodynamic drag. No reverse thrust capability is assumed for any of these aircraft. The following landing performance was calculated:

Cat.	Field Length Reqt. (ft.)	Ldg. R/S (ft/sec)	Air Dist. from 50' (ft)	Ground Roll (ft)	Total Dist. from 50 ft. (ft)
I	1000	5	411	338	749
II	500	7	161	286	447
III	1500	3	503	590	1093

From the above, it is obvious that the landing requirement is not critical for any of the selected aircraft.

5.2 Propulsion

5.2.1 General

The four categories of aircraft in this study are expected to vary in gross weight between 2,500 and 10,000 lbs. Their cruising speeds vary from 130 to 250 knots as minimum requirements, but are expected to reach speeds of 250 to 300 knots in Category III. The speed range is generally in the spectrum best served by propeller drive, although high by-pass turbofans are possible candidates in the higher speed range. The shaft horsepower range of interest is expected to vary from 150 to 600.

Figure 5.2.1 shows a matrix of the various types of propulsion systems which can be considered. The selection of promising types from this matrix centers about whether or not the gas turbine or some other type, can replace the conventional piston engine used predominantly in small general aviation today. Gas turbine shaft engines are used in helicopters and in some high performance, relatively expensive, business aircraft. Turbofan engines are also used in this category. The remainder of general aviation aircraft use the opposed-cylinder, reciprocating type, which has been produced for over 30 years. Its closest competitors in the 1985 time period appear to be the gas turbine and the rotary combustion (RC), or Wankel, engine. The former is inherently much lighter in pounds per horsepower, but faces a formidable handicap in cost per horsepower, presently being 4 times as expensive as the RC engine. The RC engine, on the other hand, is also potentially lighter in weight, but its inherent simplicity

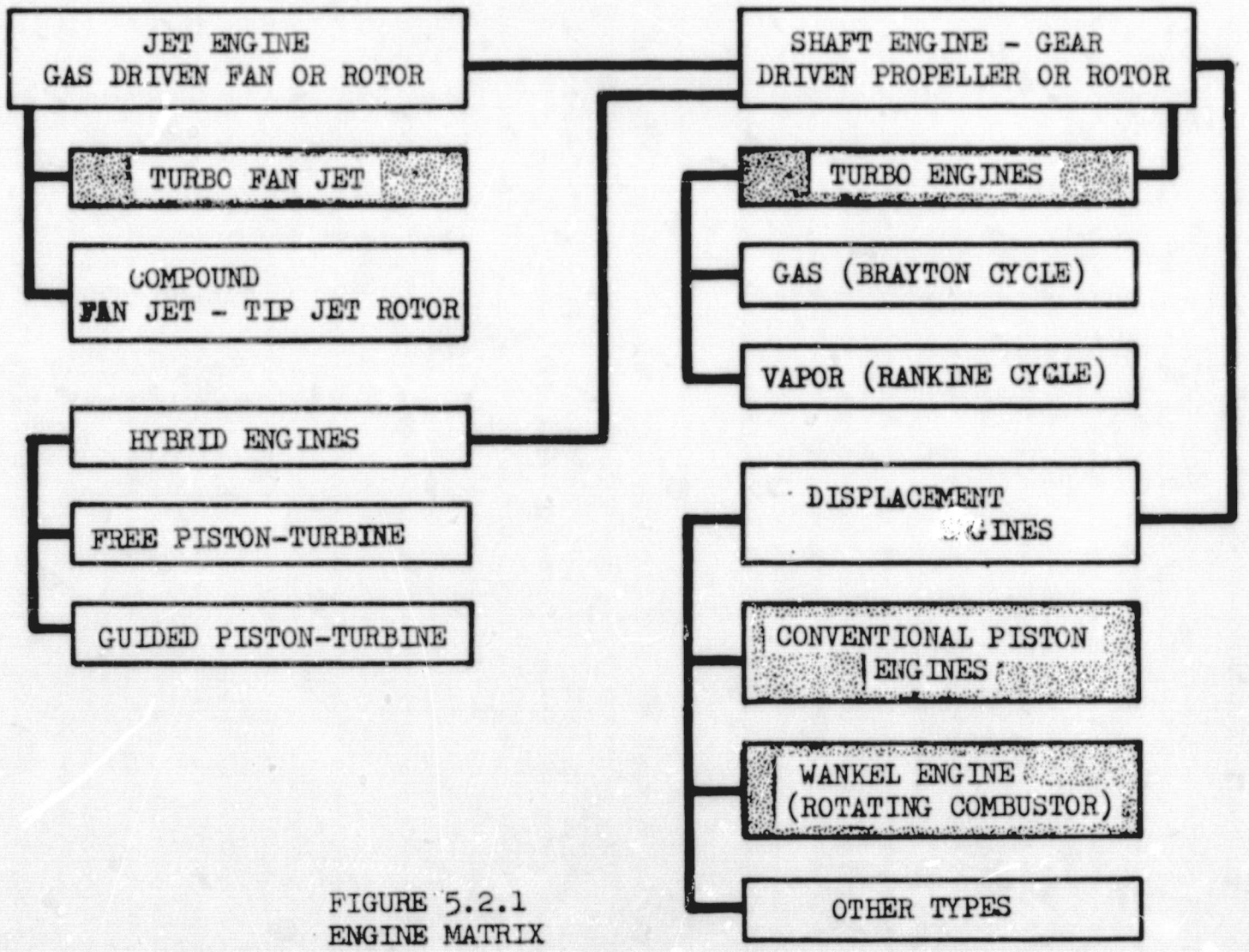


FIGURE 5.2.1
ENGINE MATRIX

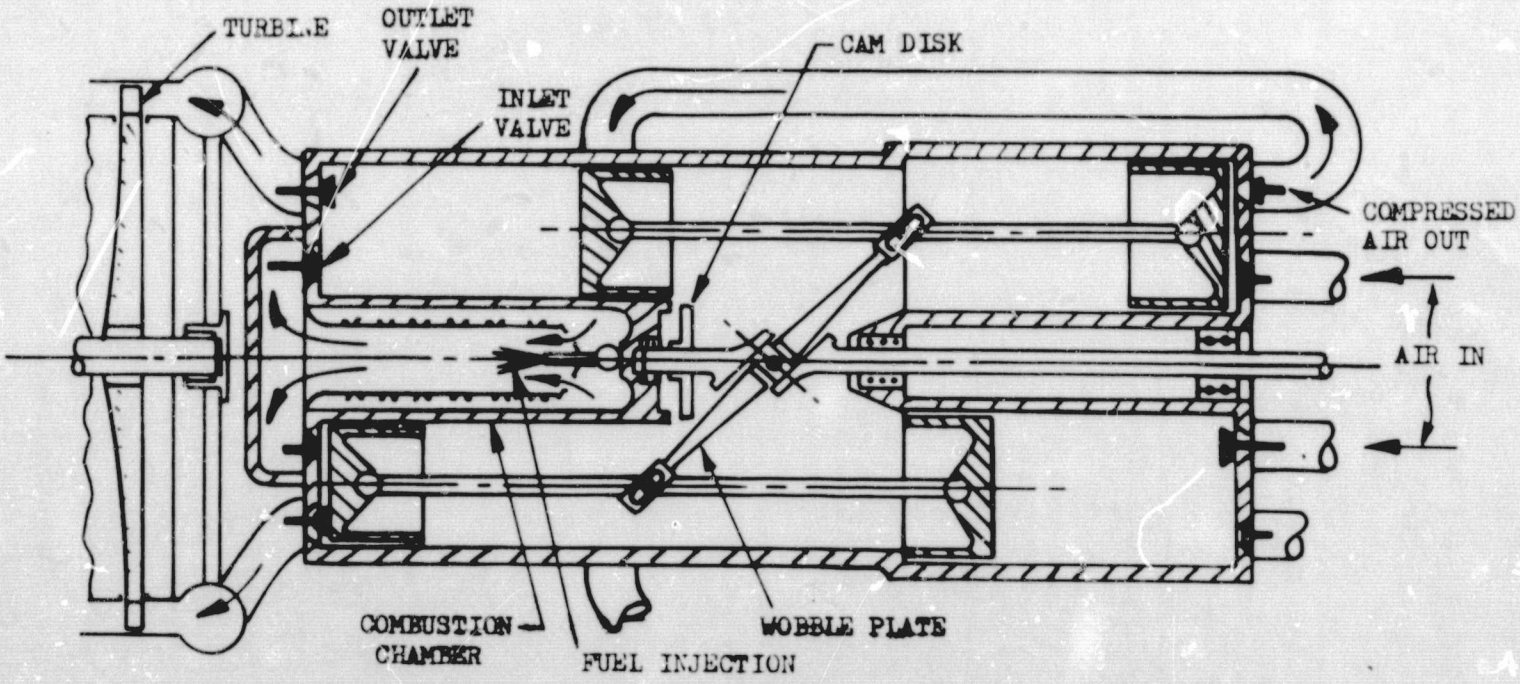


FIGURE 5.2.2 GUIDED PISTON - TURBINE HYBRID ENGINE SCHEMATIC

and its use of materials and processes similar to those of reciprocating engines gives it an even lower cost potential.

Applications in this study are limited to those in the shaded blocks. The other possibilities illustrated in Figure 5.2.1 are not presently under active development for aircraft. Some development of the vapor cycle engine is being directed toward automotive use, in view of impending anti-pollution legislation. This may lead to developments along other lines, as well. One promising line of development is the guided piston - turbine engine, a schematic of which is shown in Figure 5.2.2. In this arrangement, which operates on the Brayton cycle, similar to the cycle used by gas turbines, the working piston and compressor are linked directly by a straight rod. The advantage of this system lies in the use of a positive displacement compressor, so that the high rotational speeds of the normal gas turbine compressor are not necessary. Then too, the energy for driving the compressor is extracted before the turbine is reached. The turbine also has a requirement for high speed, but use of compounding, or a radial design, would considerably simplify this task. The external forces become relatively small, and a wobble plate guides the pistons to assure the necessary sequence of operations. There is only one combustion chamber, and the turbine can be of any practical type. This concept promises specific fuel consumption as good or better than that of the conventional piston engine, will weigh less than the latter and cost less than the turbine engine. Of prime importance, however, is the fact that, since the process of combustion is continuous the emission of air pollutants can be reduced to a minimum.

The scope of this study is limited to engine types on which reliable data exist. This narrows the field down to three types: the reciprocating, the gas turbine and the rotary combustion. For future development, however, possibilities such as the Brayton and Rankine cycles should not be ignored, since the problem of atmospheric pollution is becoming of ever-increasing concern.

5.2.2 Reciprocating Engines

The majority of piston engines used in today's general aviation aircraft are produced by two manufacturers. Until recently, relatively little in the way of new development has been applied, with the accent placed on improvements in reliability and specific fuel consumption (SFC). Two developments worthy of particular attention are fuel injection and the turbocharger. The former does away with the carburetor, and its icing problem and simplifies the achievement of optimum fuel/air ratio for minimum SFC. The latter increases the performance of the airplane at altitude by maintaining sea level power to altitudes of 15,000 to 20,000 ft.

The Lycoming Division of Avco Corporation has recently completed a cost study of present state-of-the-art reciprocating engines, with particular attention to high production volumes. While their report was not made available for review in this report, Dr. H. E. Schmitt of the Lockheed-Georgia study team visited Lycoming and discussed the study with their people. The study was essentially performed for a family of engines with 4, 6, and 8 cylinders. Obviously no effort was made to project engine weight much beyond present state-of-the-art and performance was restricted to essentially present technology. One finding of their study was that an 8-cylinder engine with twice the horsepower of the 4-cylinder did cost somewhat less than twice as much.

The high production rate would decrease the cost, but the investment for automation would inhibit this trend. Real savings would not materialize unless production numbers would approach one million or more. In regard to HP per pound of engine weight, Lycoming considers one HP per pound to become eventually feasible. It would require 4500 rpm and a BMEP of 200 psi, 40-50 psi over present practice. One inherent problem is the valve mechanism at high speeds which necessitates overhead cam shafts. A liquid cooled, 2-cycle engine might be a possibility in connection with a turbo charger, but the pollution problem would be harder to solve due to the high fuel/air ratio required in certain operating conditions. However, there is no indication, anywhere, that such an engine will be developed soon, though fuel injection could solve the SFC problem encountered with this type engine in the past. The turbocharger will give about 10% more T.O. horsepower per pound of engine weight.

A new development in this field is exemplified by Teledyne Continental's recently announced line of "Tiara" engines. These engines operate at RPM's up to 4400, compared with about 3000 for conventional types. A 2:1 reduction gear is provided, so that the propeller shaft can be an extension of the cam shaft. A patented, torsional vibration control eliminates pendulum dampers, reduces vibratory torque in the crankshaft, propeller gearing, propeller and accessory systems. This unit, termed VTC, is integral with the crankshaft and reduces torque by means of automatic dual frequency controls, whereby the propeller shaft is driven either solidly or flexibly by the quill shaft. The action of this unit serves to reduce stress in the engine parts, resulting in lighter weight. The manufacturer claims that these engines will have less weight per horsepower, deliver more power per cubic inch, reduce cooling loss and vibratory torque and provide smoother, quieter operation. They are claimed to be potentially less expensive by preserving a high percentage of commonality among components. Specific weight of the 320 hp, Model 6-320 engine is 1.10 lbs/hp, compared with 1.46 for conventional engines in the same power category.

5.2.3 Turbine Engines

Turbine engines applicable to aircraft of interest to this study include the turboshaft and turbofan types. Small contemporary turboshaft engines have a power range of 300 to 800 shp, and are in active production for aircraft and helicopter applications. Characteristics of several turboshaft engines are as follows:

T.O. ESHP	Weight (lbs)	Lbs/ESHP	SFC (cruise)
400	155	.39	.70
605	325	.54	.66
830	289	.35	.61

The first engine in this table has considerably more development, and therefore has a lower specific weight than the second engine. While the average SFC of these engines is about 30 percent higher than that of reciprocating engines, the specific weight is about 65 percent less. They would therefore be highly desirable powerplants for general aviation aircraft, if it were not for their difference in cost - $40 to $50 per hp, as against $10 to $15 for reciprocating engines. Although turbine engines are inherently simpler than piston engines by virtue of fewer parts, the material and fabrication cost of high temperature-resistant alloys is the predominant factor.

Any future cost reduction will await development in metallurgy and fabrication processes. The NASA Lewis Research Center is addressing this problem as applied to pure jet and fan-jet types. Their primary application is military - for drones and short range subsonic missiles. Dr. H. E. Schmitt of the Lockheed study team discussed this development with Mr. Harold Gold at Lewis, who hopes that this engine development can be applied to general aviation aircraft, as well. In Reference 5.2.1, Cummings and Gold describe the cost obstacles of applying turbine engines to general aviation aircraft. They point to the current pure range of $22,000 to $65,000 for turbojet and turbofan engines in the desired thrust range, as well as $35,000 for a 600 HP turboshaft engine. These prices compare with $10,200 to $17,400 for piston engines rated from 285 to 425 HP. Their objective is to achieve a cost level of $5.00 per pound of thrust for a 1000 lb. thrust engine, in an effort to achieve high performance at low cost.

Their approach to the problem is to work with comparatively low pressure ratios: 4 for turbojets and 6 for turbofans, together with a turbine inlet temperature of 1300°F. In aircraft designed to cruise at 450 mph at 25,000 ft., SFC's of 1.20 and 0.90 can be obtained with turbojets and turbofans, respectively. The latter is of more interest to general aviation application, because of longer range and lower noise level capabilities. Their proposed 1000 lb. thrust, 2.5 by-pass ratio, turbofan engine uses a single-shaft, two-bearing design for the core engine, with a 15 inch diameter fan in which the RPM is geared down 2 to 1. The 650 HP gearing system can be produced for approximately $600. No specific weight data are given for the turbofan application; however, a figure of 0.285 lbs. per lb. of thrust is cited for the short flight endurance, turbojet engine designed for drone application. Application of the NASA Lewis concept to a turboshaft engine would require a further gear reduction of 15:1 and some loss in horsepower due to gear friction.

Conventional turbofan engines, in the low thrust category, are under development by some manufacturers. One of the smallest is rated at 430 lbs. thrust. Turbomeca, in France, is developing models varying from 1,350 to 1,900 lbs. thrust. These designs are unique, in that they include reduction gearing and variable pitch fan blades. The variable pitch fan assembly can also be mounted on any turboshaft engine to become, in effect, a shrouded propeller. Hamilton Standard is working on the same concept, termed the "prop fan." The Turbomeca turbofan engines operate at a pressure ratio of 8:1 to 10:1, against 20:1 of large engines, and will be operated like constant speed turboprop engines. In a still higher thrust category, United Aircraft of Canada is producing a new model, the JT15D, rated at 2200 lbs. thrust. Representative characteristics of available turbofans in the low thrust rating category is as follows:

T. O. Thrust (lbs)	Weight	Thrust/Weight	Remarks
430	61	7.0	Short life applications
1364	530	2.6	geared, variable pitch fan
2200	480	4.6	conventional design.

No comparative cost data are available on the above models. However, it is believed that they reflect the present high cost relationship to piston engines, hence will be used only on high performance, expensive, business aircraft. Normally SFC and thrust/weight ratio improve as rated thrust is increased. However, the first engine in this list is a short life product without the auxiliary equipment of a normal service engine, and is therefore quite light.

Since the reliability of turbofans is already high in comparison to piston engines, and their characteristics generally improve with size, it is believed that the business aircraft of the future might have only one engine, instead of the usual two. There is, also a cost advantage in so doing, since the cost per pound of thrust decreases considerably with increased size.

5.2.4 Rotary Combustion Engines

The rotary combustion (RC), or Wankel, engine represents the latest trend in displacement engines. It is named for the German engineer, Felix Wankel, who investigated the principle as early as 1926 and pursued his work in a research institute, from 1951 on, with the assistance of German industry. Curtiss-Wright has obtained a licensing agreement and has since done a considerable amount of development of the engine for both automotive and aircraft applications. Automobiles with RC engines now in production work are NSU in Germany and Mazda in Japan. General Motors also presently has a licensing agreement with Curtiss Wright for RC engine production.

Figure 5.2.3, obtained from Reference 5.2.2, shows a cut-away drawing of Curtiss-Wright's experimental RC6 engine. Figure 5.2.4 shows a cut-away view of the Curtiss-Wright Model 4RC6 engine which has four rotors attached to the shaft and is designed to produce 400 hp. Figure 5.2.5, from the same reference, shows the rotor position in each step of the cycle. The rotary motion of the engine, in comparison to reciprocating motion, affords complete freedom from mechanical vibration. The engine is inherently simple by virtue of relatively few parts; is lightweight; has an efficient operating cycle and is potentially inexpensive. The biggest development problem has been the apex seals at the corners of the rotor.

Dr. H. E. Schmitt, of the Lockheed-Georgia study team, discussed the status of RC engine development with Curtiss-Wright (C-W) personnel during a visit to their facility. The discussion was primarily related to aircraft applications, one of which was the Lockheed "Q-Star" low noise level airplane. Subsequent discussions were held between Curtiss-Wright representatives and members of the Lockheed study team and, later, with representatives of Lockheed Missiles and Space Company. The engine in the Q-Star is a modified automotive engine and is actually the only Wankel engine built by C-W which has been flight tested, so far. It is a liquid cooled engine rated 185 HP at 5000 rpm. It is developed from the RC2-60 with two rotating chambers of 60 cu. in. displacement per chamber. Operation in the Q-Star has been very satisfactory, with no flight delays or cancellations chargeable to engine malfunction. The RC2-60 weighs 237 lbs. including required accessories.

A survey of opinions concerning liquid versus air cooled aircraft engines conducted by C-W showed no objection against a liquid cooled engine. C-W considers it possible to increase engine speed up to 10,000 rpm eventually, which would nearly double the present power output. The engine can be run on JP4 or gasoline, although JP4 requires a power reduction of about 10-15%. The rotor of the RC engine is oil cooled, and a considerable fraction of the heat must be dissipated this way. Consequently, a RC engine would never be truly air-cooled. Total heat rejection is 45% of indicated power and about 15% is removed by the oil which cools the rotor.

C-W has about 45,000 hours running time accumulated during their RC engine development and feel confident that the seal problem is essentially solved. Cost estimates based on a production of 5000 per year show a somewhat lower cost per HP for the RC engine, compared with present reciprocators; $8/HP for the RC against $11/HP for the recips. Turbo-supercharged engines might reach

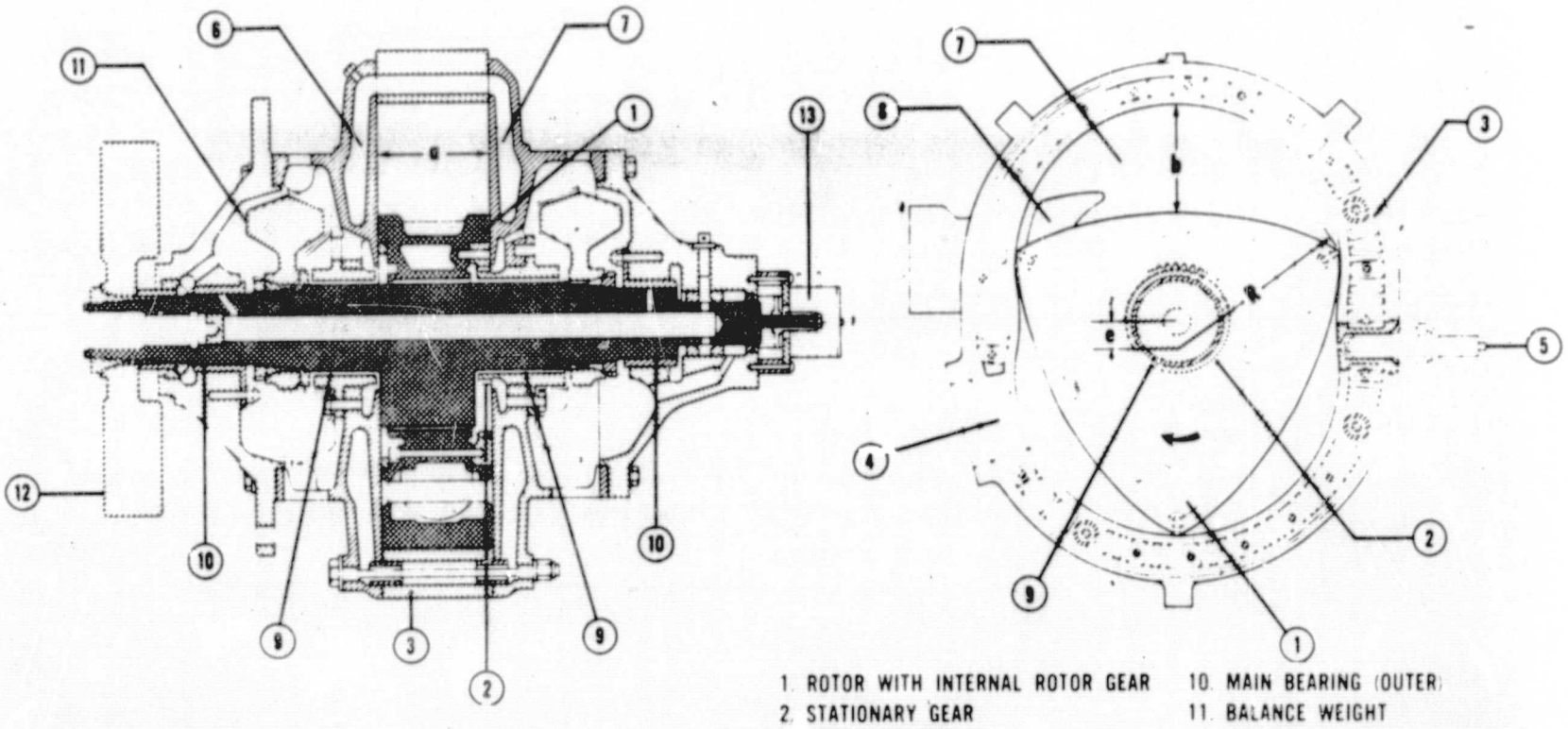


FIGURE 5.2.3

EXPERIMENTAL ENGINE RC6

1. ROTOR WITH INTERNAL ROTOR GEAR
2. STATIONARY GEAR
3. ROTOR HOUSING
4. EXHAUST PORT
5. SPARK PLUG
6. SIDE HOUSING – DRIVE SIDE
7. SIDE HOUSING – ANTI-DRIVE SIDE
8. INTAKE PORT
9. MAIN BEARING (INNER)
10. MAIN BEARING (OUTER)
11. BALANCE WEIGHT
12. FLYWHEEL
13. IGNITION CONTACT MAKER

a AXIAL WIDTH OF CHAMBER
R GENERATING RADIUS
e ECCENTRICITY
k R e
b MAXIMUM BREADTH OF CHAMBER

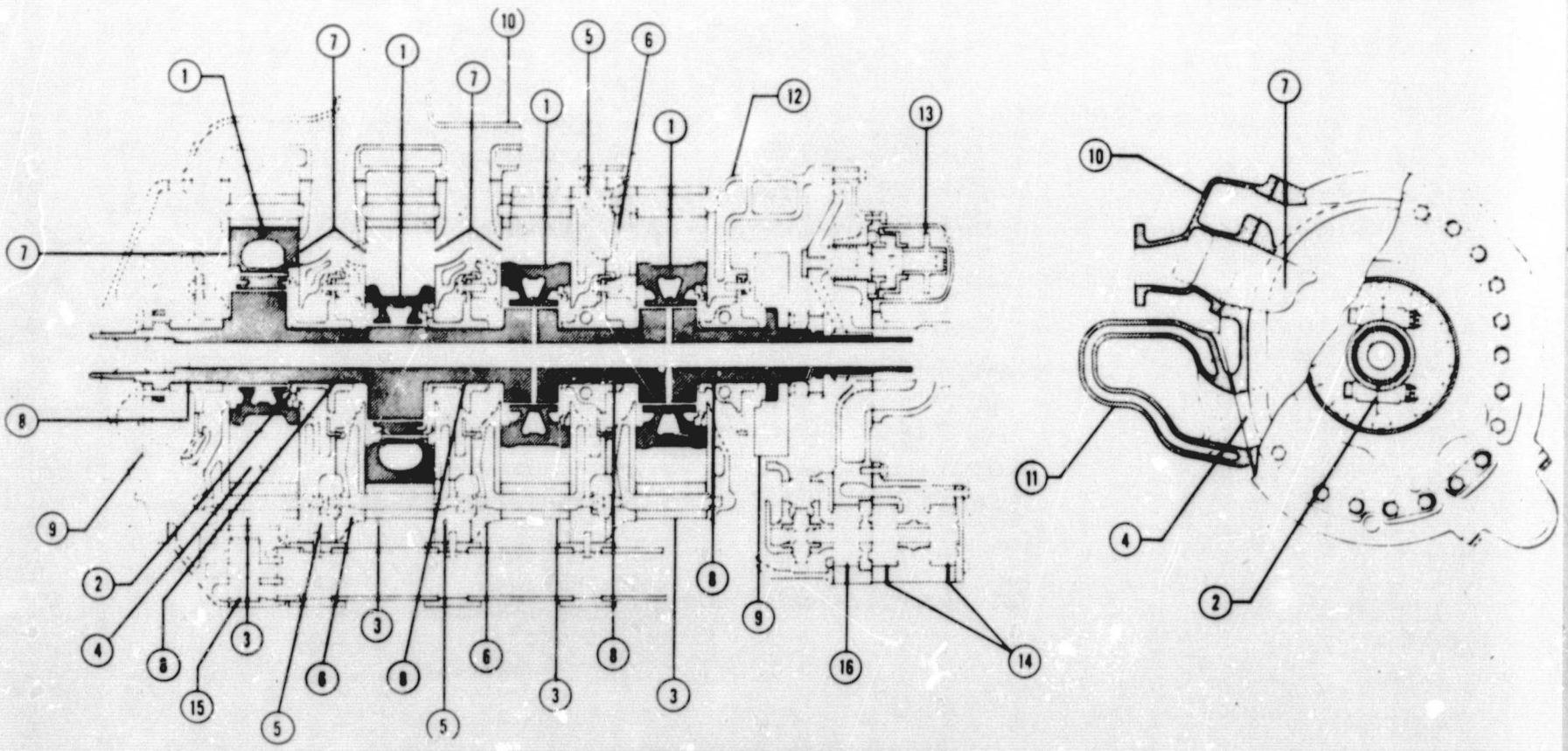
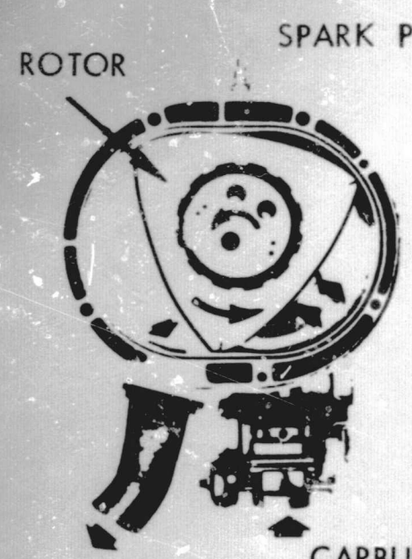


FIGURE 5.2.4 4RC6 ENGINE CROSS SECTIONS

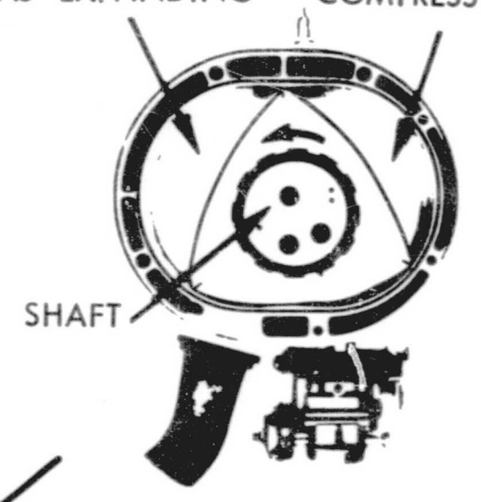
1. ROTOR
2. SPLIT STATIONARY GEAR WITH MAIN BEARING
3. ROTOR HOUSING
4. EXHAUST PORT
5. SIDE HOUSING – DRIVE SIDE
6. SIDE HOUSING – ANTI-DRIVE SIDE
7. INTAKE PORT (DUAL INTAKE)
8. MAIN BEARING
9. FLYWHEEL CUM BALANCE WEIGHT
10. INTAKE MANIFOLD
11. EXHAUST MANIFOLD
12. ACCESSORY GEAR BOX HOUSING
13. IGNITION CONTACT MAKERS
14. OIL PRESSURE PUMPS
15. OIL SCAVENGE PUMP – FRONT
16. OIL SCAVENGE PUMP – REAR

FIGURE 5.2.5

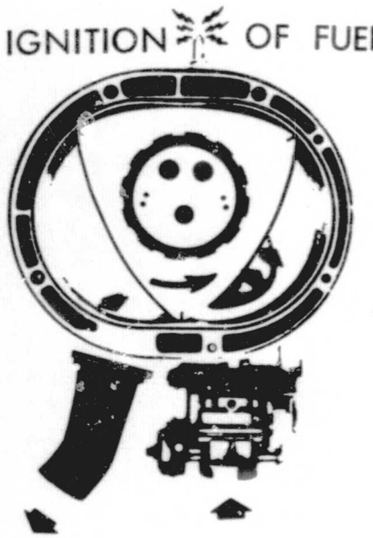
ROTATING COMBUSTION CYCLE



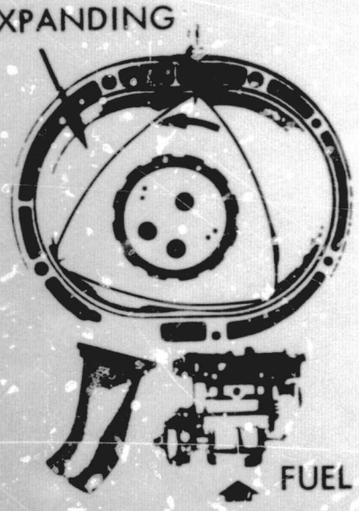
FUEL-AIR INTAKE



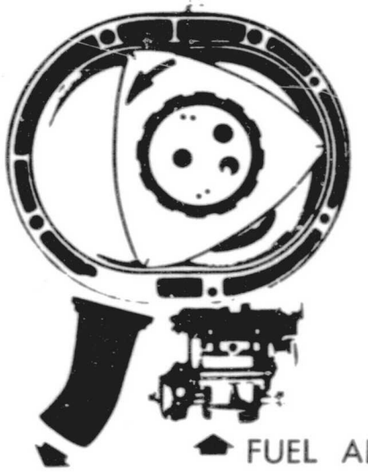
FUEL- AIR COMPRESSION



FUEI -AIR IGNITION



POWER STROKE - GAS EXPANDING -
INTAKE OPENING - EXHAUST CLOSING



EXHAUST FULL OPEN

EXHAUST

$18-20/HP. For production numbers of 100,000/year the general consensus is that cost could be expected to drop by 50%. The conclusion from the above is that an RC type, if fully developed, could be built for less than $8/HP and a specific weight of 0.6-0.8 lbs./HP. Specific fuel consumption would not vary much and stay around 0.45 to 0.50 lbs./HP/hr.

For application to the advanced technology aircraft in the sensitivity analyses of Section 8.0, Figure 5.2.6 shows the anticipated trend of weight versus horsepower for this type of engine in the 1980 and subsequent time period. The graph was received from the Curtiss-Wright Corporation on 23 December 1970 and will be used in the sensitivity analyses.

5.2.5 Engine Type Analysis

The selection of engine types for the relatively small general aviation aircraft of the mid 80's has to depend not only on performance but cost. It is generally a fact that the more horsepower per pound of engine weight are generated, the higher the cost in dollars per horsepower, and it is essential to know the approximate relation between the payload/gross weight ratio and the installed horsepower/engine weight ratio as an indicator of potential aircraft performance. For example, if the cost per horsepower would be one-half for an engine weighing twice as much, nothing is gained if the aircraft weight for a required payload increases at a rate as fast as the engine weight. An equation was developed which brings the various weight groups of an airplane in relation to the payload/gross weight ratio. The equation is based on the four major weight groups:

1) Structural weight and avionics
2) Engine weight and its accessories
3) Propeller and gear weight
4) Fuel weight

Each one can be refined to any degree desired. Various consistent assumptions are made and some of the preliminary results are plotted for each category in Figure 5.2.7, where the payload/gross weight ratio is plotted against the engine horsepower/weight ratio. Take-off acceleration is assumed as 0.3g for Categories I and III and 0.6g for Category II. The static thrust of the propeller is assumed to be 4 lbs/HP. The specific fuel consumption is assumed to be independent from engine weight or size and is fixed at 0.5 lbs/HP/hr. In each case, a turboshaft engine representing present state of the art (circles) with an HP/lb of 2.22 and an SFC of 0.64 is plotted as a comparison. There are already large turboshaft engines which have SFC's as good or better than 0.5 but to duplicate this in a small engine of 300 HP would be costly even after another 10 years of development.

As cost is an important objective, the question then is: What is the least expensive way to achieve weight reduction as long as the latter can mean total cost reduction? For instance, it is not the cost of fuel per se, but every pound of fuel which has to be carried requires a larger engine. This means a larger airplane, and the initial investment most likely goes up. To keep cost and performance in the proper balance it is therefore necessary to know when the returns of a particular effort diminish. The curves illustrate this fairly well. Category I is a relatively slow and short range aircraft. It is quite obvious that there is little gained with an engine which generates

FIGURE 5.2.6 ROTATING COMBUSTION AIRCRAFT ENGINE WEIGHT VS. POWER (LIQUID-COOLED, 1980 TIME FRAME)

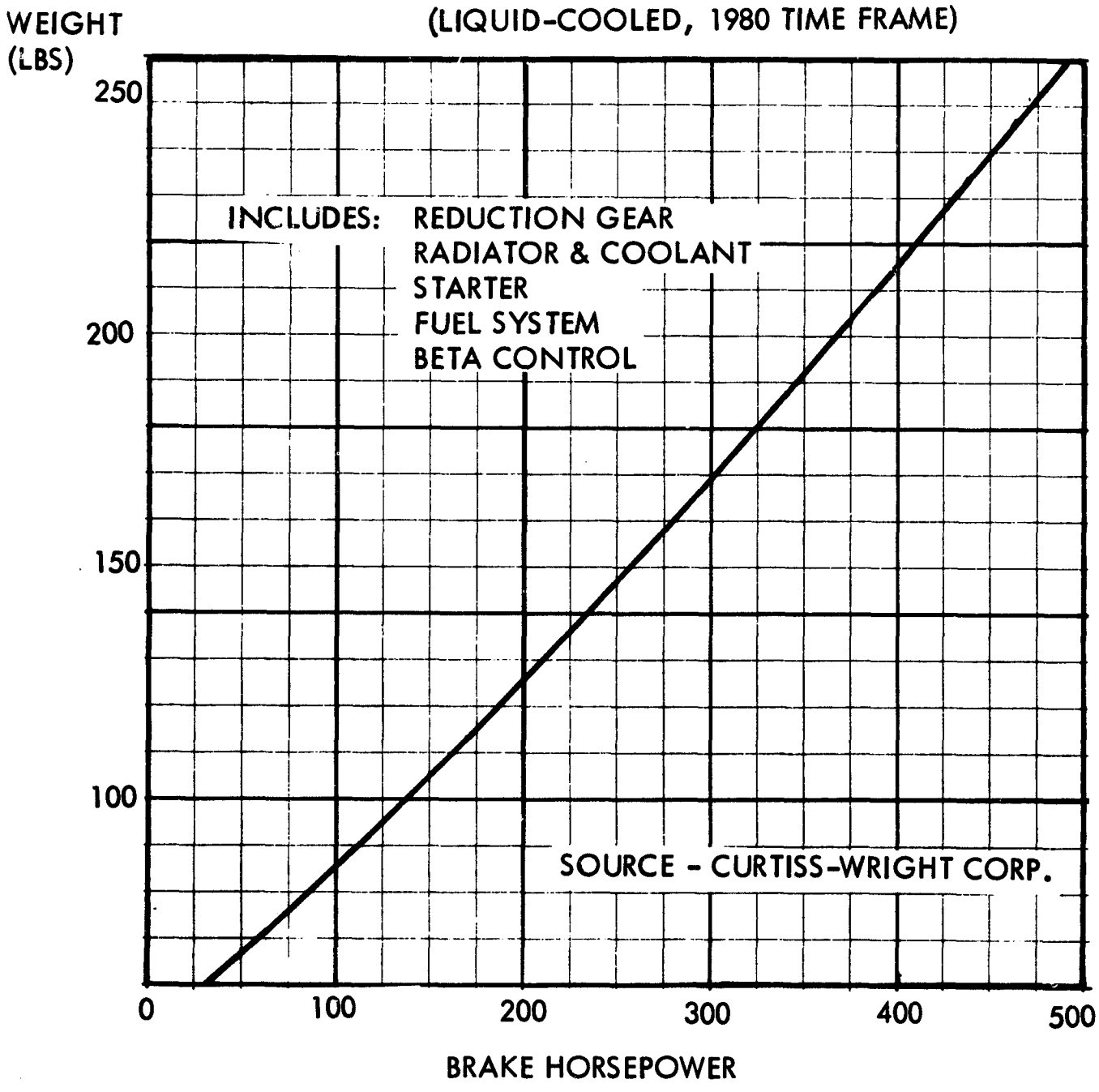
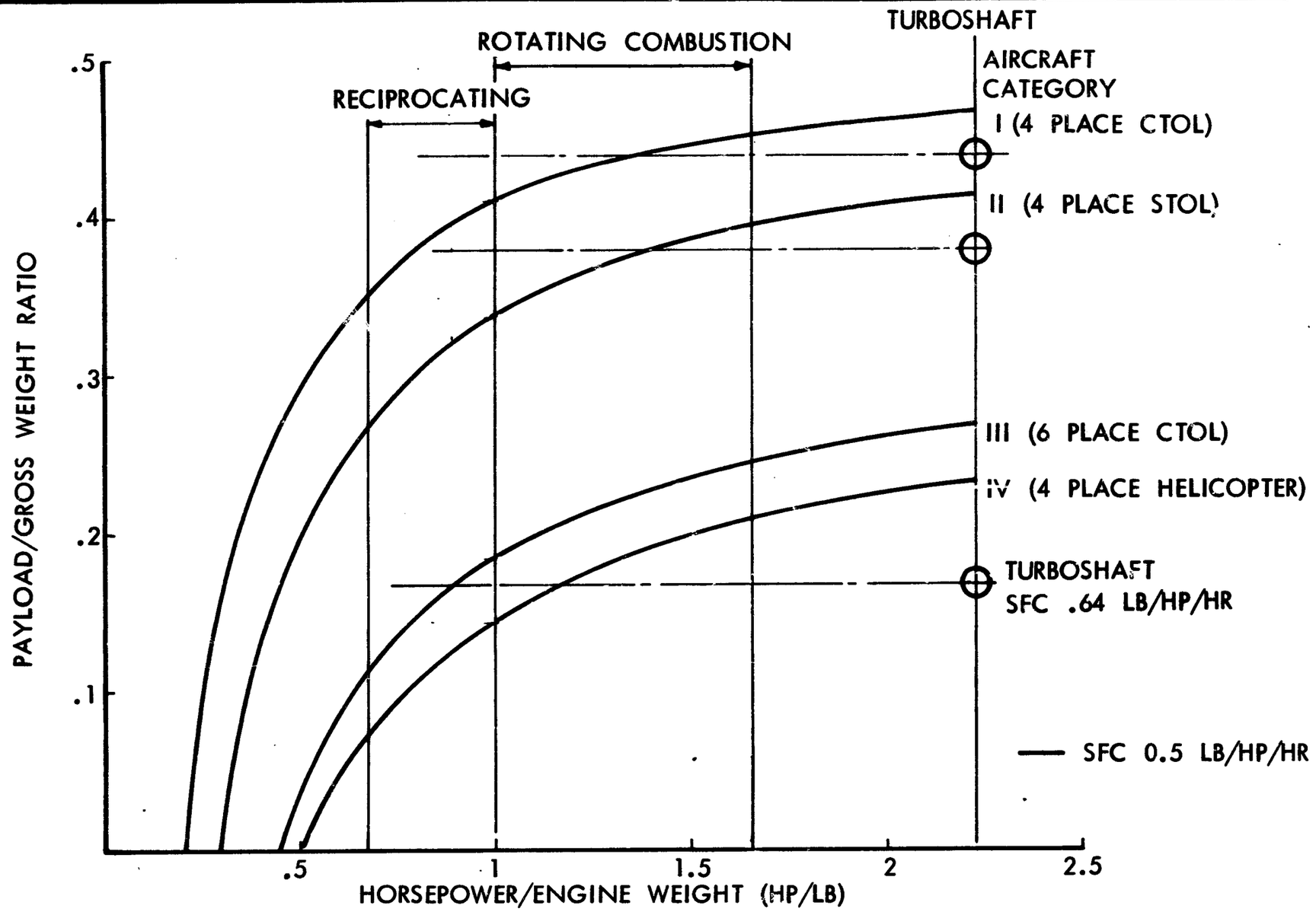


FIGURE 5.2.7 PAYLOAD FRACTION VS POWER PER POUND OF ENGINE WEIGHT



more than one horsepower per pound of engine weight. However, going from 0.66 HP/lb (or a specific engine weight of 1.5 lb/HP, which represents good present state-of-the-art) to 1 HP/lb pays, especially if cost per horsepower is not increasing. In case of the RC engine which is already close to 1 HP/lb, cost estimates predict $8-10 per horsepower. The SFC of the RC engine has been demonstrated at slightly below 0.5 lb/HP/hr; however, there is little chance that this will change very much in the future because of the thermodynamic limitations of this concept, and further development will mainly affect cost and weight. The high cost of the turboshaft engine and its higher SFC, for the time being, would exclude a turbo engine in this category. What can be said for Category I is true, also, for Category II, if not quite to the same degree.

The trend of the curve for Category III, which has a fairly high speed, long range requirement clearly shows that as long as the SFC of the turboprop is not reduced to the same level of the displacement type engine, there is no sense using a turboshaft engine even if the costs could be disregarded.

Thus, the conclusion would be that an engine of 1 HP/lb and an SFC of 0.5 lb/HP/hr would be an excellent match for Categories I, II, and III. Such an objective should not be unrealistic, even under stringent cost considerations. The RC engine has a good potential to meet this requirement at low cost. The question then is if there are other concepts suitable for reaching the same goal, which might have a potential for lower fuel consumption. This would require a separate study to find the real answer.

The trend for helicopters in Category IV, with a cruise speed of 150 knots and a range of 500 statute miles, is shown in the lowest curve of Figure 5.2.7. The situation here is not quite as clear-cut as in Category III. One thing is clear, however: A reciprocator with the present HP/lb ratio of 0.66 would result in a very low payload ratio of .065, while with a turbine of present vintage one might achieve a payload ratio of 0.18, nearly 3 times as much. This is to be expected and is the reason why the turboshaft engine has made the helicopter what it is today. An engine with a HP/lb ratio of one and an SFC of 0.5 or better could compete with the turbine at least as long as the SFC of the turbine is higher than 0.6 lb/HP/hr. A definite conclusion for the helicopter is made more difficult, at this point, because the rotors and gears represent a larger portion of the total cost than the propeller in a wing-borne aircraft, and the cost of the engine becomes a smaller fraction of the overall cost. The parametric analyses in Section 7.0 is based on present technology propulsion systems. They show the reciprocating engine to be best in Category I and the turboshaft in Categories II, III and IV. However, for the sensitivity analyses of Section 8.0, 1985 technology must be applied. Using the data of Figure 5.2.6 for the RC engine, along with reliable projections for reciprocating and turboprop types, a representative comparison is made in the ensuing table for application to Categories I and III:

1985 PROPULSION POTENTIAL

TYPE OF ENGINE	Rotating Combustion		Recip-rocating		Turboprop	
Category	I	III	I	III	I	III
Assumed Gross Weight (lbs)	2400	8000	2700	11,000	2500	8800
Cruise Speed (kts)	140	250	140	250	140	250
Cruise H.P.	120	724	135	1000	125	795
Cruise S.F.C.(lbs/hp-hr)	0.46	0.46	0.46	0.46	0.65	0.60
Fuel Req. for 500 n.mi.(lbs)	197	665	223	920	291	950
Max. Rated H. P.	145	1100	162	1520	150	1210
Engine Specific Wt. (lbs/hp)	0.66	0.50	1.20	1.00	0.60	0.40
Engine Wt. (lbs).	96	550	194	1520	90	484
Engine Plus Fuel Weight	293	1215	416	2440	381	1434

While the above comparison will not necessarily be consistent with the results of the sensitivity analyses, it can be considered reasonably accurate. Weight-wise, in both Categories, the rotating combustion engine shows to advantage over competitive types.

Although the cost comparison is not shown, the indicated cost of the rotating combustion engine, per horsepower, is considerably less than that of its nearest competitor, the turboprop, and somewhat less than that of the reciprocating engine. Since the RC engine uses less fuel, per trip, its installation will result in minimum operating cost. For these reasons, the RC engine has been selected as the representative advanced technology power-plant in all Categories.

5.2.6 Propulsion Engine Emissions

The contribution to the general air pollution by small aircraft engines is relatively insignificant as compared to the pollution caused by automobiles. About 60% of United States pollution comes from automobiles alone, while the part contributed by aircraft is less than 2%. To begin with, an aircraft engine is relatively efficient, and its manner of operation assures an optimum fuel/air ratio most of the time. Only during take-off is the fuel/air ratio enriched up to 20% beyond the stoichiometric ratio (.067), and this is done at maximum power. Extended operation at idle and/or low power is rare, except at airports under high traffic density conditions. Incomplete combustion occurring under these conditions is responsible for most of the carbon monoxide and hydrocarbons contributing to the pollution of air. Oxides of nitrogen are probably created in the high temperature flamefront, and their concentration is essentially a function of the maximum cycle temperature and can be reduced by turbulence during combustion. These emissions are quite toxic, and will

require additional research by the engine manufacturers in order to achieve a tolerable level. Modern aircraft engines have fuel injection and dual ignition, which are both helpful in reducing emissions. The use of exhaust reactors or afterburners might never be necessary. If aircraft engines of the future, including the RC type, will have turbochargers, the exhaust is exposed to hot surfaces which should affect the exhaust gases to the same degree as that of a reactor. A final answer would have to be obtained from experimental data.

Figure 5.2.8 shows the relation of power versus fuel-air ratio for a typical aircraft engine. Actually it is typical of any reciprocating engine using gasoline as fuel and an Otto cycle. Maximum power is obtained at a rich mixture, (fuel/air ratio of .08) while the exhaust temperature reaches a maximum with some loss in power near stoichiometric conditions. Below stoichiometric, on the lean side, power is lost rapidly while the curve on the rich side is fairly flat. In other words, fuel enrichment reduces exhaust temperature with little or no loss in power, which is the reason why a rich mixture is selected for takeoff.

In cruise, a leaner misture saves fuel but can overheat the engine if pushed too far. In small aircraft, the selection of the fuel mixture is presently not automatic and is left to the pilot. He can be assisted by instrumentation or he depends on his feel; that is, he leans the mixture to a point where the rpm drops or the engine becomes rough, and then he backs up on the throttle to a slight degree. Improvements in the methods of controlling the fuel-air mixture in small aircraft engines, such as electronically-controlled fuel injection, would be the first step in reducing their contribution to air pollution without sacrificing the important consideration of fuel economy.

Reference 5.2.3 reports the results of a government contracted program directed toward measuring the exhaust emission of a light aircraft with piston engines. The tests included measurement of the extent of natural afterburning. The flight test cycles on which the data were taken were: T.O. - Cruise-Landing (TCC) of 34.2 min. and Landing - T.O. (LTO) without a cruise mode. Times of operation during the cruise mode were 6.5 min. with rich mixture and 2.5 min. with lean mixture. The measured amount of pollutants, in terms of pounds per fuel consumed, were:

Carbon Monoxide	0.847
Hydrocarbons	0.0210
Nitrogen Oxides	0.0102

Since the operational cycles were primarily with rich mixture and uncharacteristic of normal airplane operation, the measured figures for operation with lean mixture are more meaningful. They were, respectively:

CO	0.326
HC	0.0061
NO	0.0463

Present automobiles are 0.525, 0.066 and 0.018 respectively, but must be reduced by 1972 to 0.176, 0.015, with no standard for NO. HEW has proposed Federal Standards, effective in 1975, of 0.050, 0.002 and 0.0041, respectively. Aircraft will, no doubt, be required to have the same pollutant levels as automobiles, and the engine manufacturers will have to design accordingly.

FIGURE 5.2.8 EFFECT OF MIXTURE CHANGE FOR TYPICAL UNSUPERCHARGED ENGINE

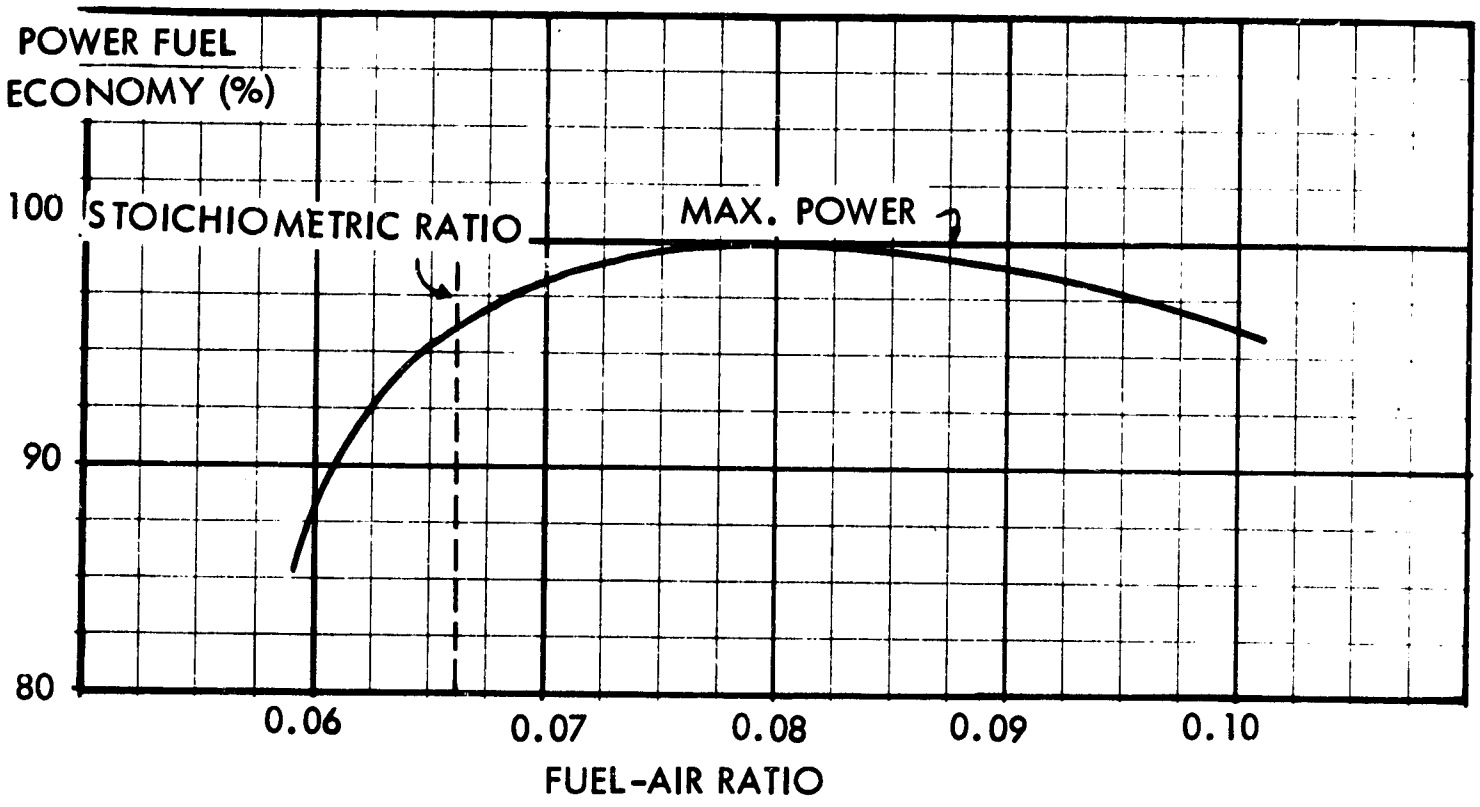
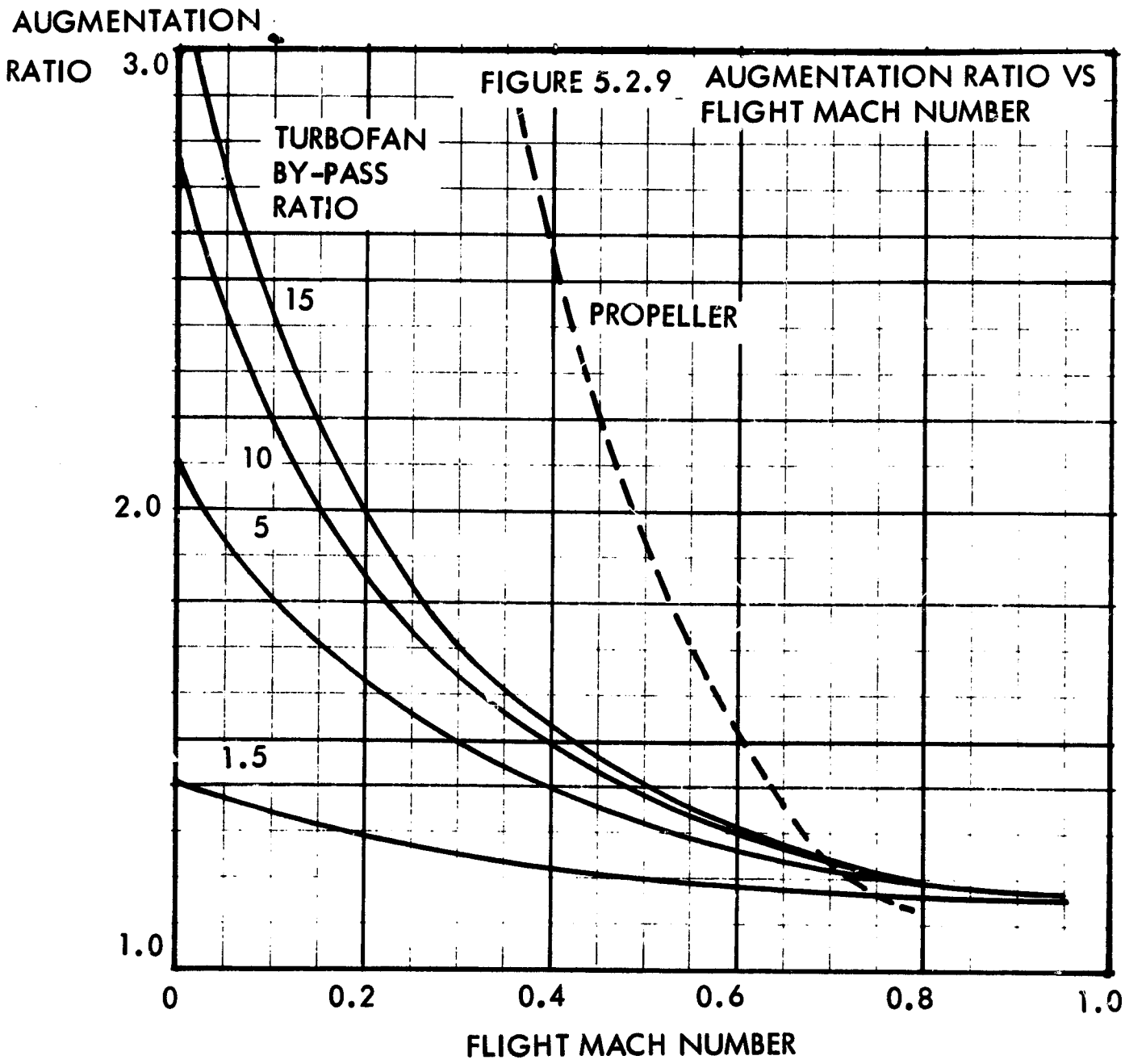


FIGURE 5.2.9 AUGMENTATION RATIO VS FLIGHT MACH NUMBER



In the case of turbo engines, pollution is presently judged by the visibility of a smoke trail. (The latter can be eliminated by proper design of the combustion chamber, and much work has been done on this problem recently, with resultant decrease in visible smoke trails.) The problem can be solved by more careful mixing of fuel and air in the primary zone of the combustion chamber, especially by avoiding over-rich fuel zones. The remedial work is underway, and many of the commercial airlines are retrofitting their engines with combustion chambers which do not smoke visibly. Exhaust gas emission control will significantly reduce the emission of all major contaminants to an acceptable level. There is a difference between the chemical build-up of gasoline and the heavier fuels used in gas turbines and diesel engines. With over-rich fuel mixtures, gasoline forms carbon monoxide, while with heavier fuels carbon is emitted, which in contrast to carbon monozide is visible. A surplus of air in the combustion zone does eliminate this phenomenon in either case. Although the Otto cycle does not work very well with mixtures leaner than stoichiometric, close control of the fuel-air ratio will reduce the pollution problem. Reference 5.2.10 deals with reducing the emissions from a rotary combustion engine by means of an exhaust reactor.

No reliable data are presently available with which to assess the future cost of pollution control in aircraft engines. In the sensitivity analyses of Section 8.0, propulsion system weights are made conservative to account for anti-pollution equipment.

5.2 7 Selection of Propulsor

Because of the comparatively low cruising speeds in all categories, the pure jet engine is eliminated from this study. Consequently, any comparison is based on shaft engines and turbofans of various types, and their performance and cost factors will affect the total cost of the airplane. If cost per horsepower is reduced, without change in horsepower per pound of engine weight, nothing will change but the cost of the engine. If cost per HP is unchanged, but HP per pound of engine weight is increased, less horsepower is needed because the airplane becomes lighter and less expensive at the same time. This can be concluded from Figure 5.2 7, showing that it is important not to waste any horsepower by inefficient or poorly matched fan or propellers.

The shaft torque can be generated either by a turbine or displacement type engine. The curves on Figure 5.2.7 are based on a propeller. The diagram developed by Hamilton Standard in Figure 5.2.9 shows clearly that the propeller is giving the most thrust for the least shaft horsepower. This is especially true for speeds not exceeding 250 knots. However, the difference between propeller and fan becomes less pronounced at speeds between 300 and 400 knots. If a relatively inexpensive turbofan is possible, as developed by the Lewis Research Center, a Category III airplane with cruise speeds substantially higher than 250 knots might become cost effective. Accurate cost estimates would require more detailed engine performance data which are not yet available. The combination of a propeller and a rotating combustion engine ($10.00 per horsepower and 4 lbs/HP T.O. thrust) could result in a cost of only $2.50 per lb. of thrust. When the cost of the propeller is added, the cost per pound of thrust is still only about $3.00. This figure compares with the most optimistic one of $5.00 for future turbofans, which would have much higher fuel costs.

In Figure 5.2.10, augmentation ratio is plotted versus flight Mach number for bypass ratios from 1.5 to 15 of a turbofan. Augmentation ratio is the ratio of the thrust of the turbofan engine to the thrust of the primary hot gas as if it would come from a straight turbo-jet. The specific thrust of the straight turbo-jet (gas generator) is assumed to be 80 lbs/lb/sec. The trend of the curves is similar to those of the Hamilton Standard diagram (Figure 5.2.9). At high subsonic speeds the augmentation ratios seem to converge, and a more thorough analysis would be necessary to establish the differences especially if installation effects are introduced. However, in the 250 knot speed range of interest for Category III, the propeller is superior by far. At higher speeds of 350 - 375 knots, its superiority might be traded for some other benefit of the turbofan or prop fan.

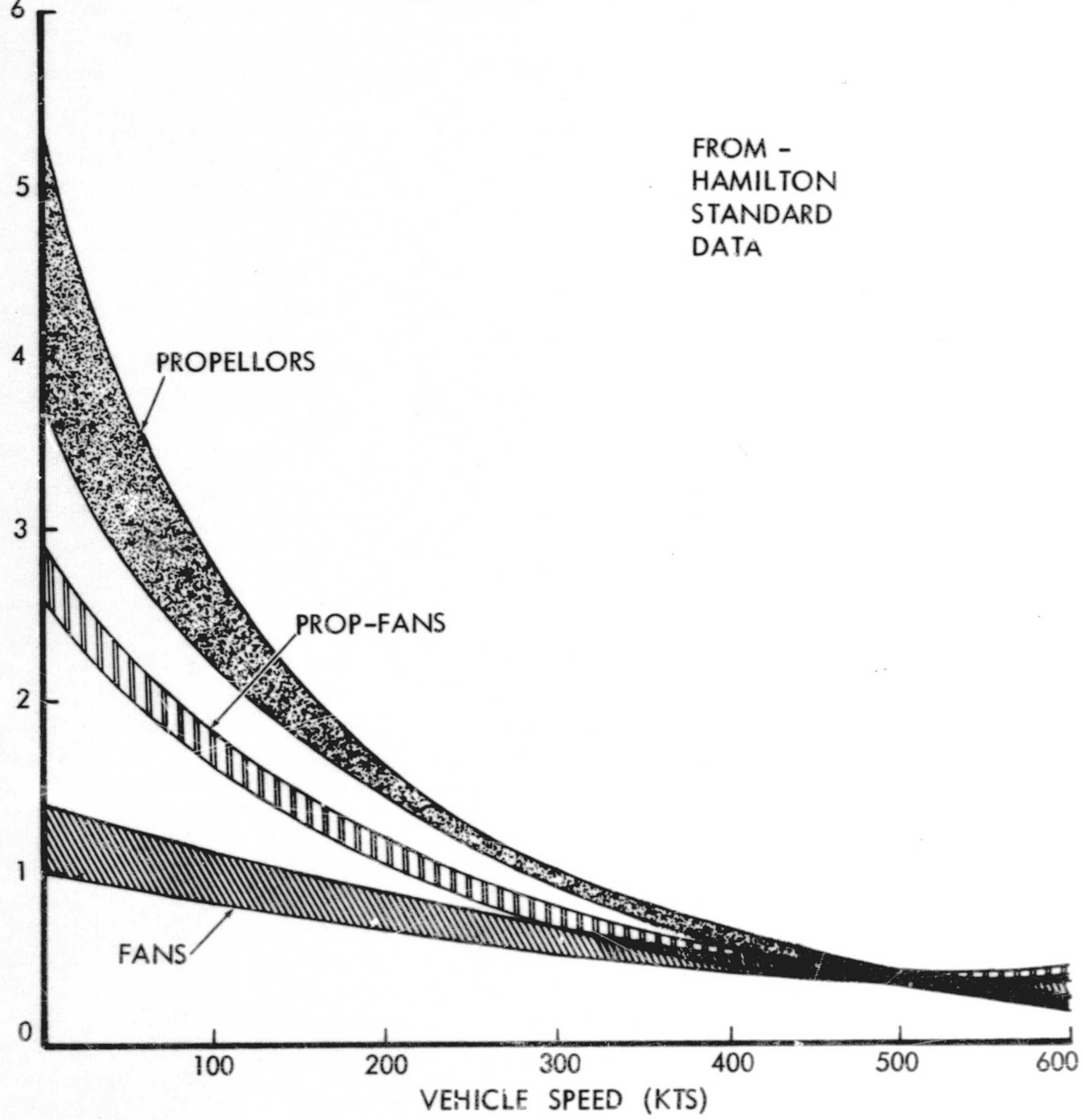
The prop fan is essentially a turbofan with extremely high bypass ratio, that employs variable pitch fan blades. Its performance is between the propeller and turbofan. Better takeoff thrust is obtained than would be the case with a turbofan, but not as good as a propeller. However, it is comparable to the turbofan, and superior to the propeller, at higher speeds (Mach 0.6 and above.) The prop fan is very quiet, because of the multiplicity of blades, and the shrouding.

The conclusion from these considerations is that the propeller will remain the dominant form of propulsor, except for aircraft with exceptionally high speed performance. As future possibilities, the turbofan and the "prop fan" should be assessed for Category III airplanes.

5.2.8 Propeller Technology

Most general aviation aircraft use aluminum propellers produced by two principal manufacturers. The larger propeller-driven commercial aircraft use Hamilton-Standard propellers, since other manufacturers are no longer active in the propeller field. Hamilton Standard has been very active in the development of improved propellers, with particular accent on achieving lighter weight and higher reliability. Their programs have been aimed at the large, high powered units used in transport aircraft, particularly those designed for VTOL and STOL operation. Some outstanding developments have included the fiberglass blade with steel spar; the integral reduction gear concept; the variable camber propeller and many others. While these improvements can be incorporated in future applications to general aviation aircraft, no active development is going on at the present time. Figure 5.2.11 from Reference 5.2.4 shows the lightweight blade concept, which is said to reduce weight by 50 percent while providing fail-safe and field-repairable structure. Figure 5.2.12, also from Reference 5.2.4, shows the integral gear box concept, which also effects reduced weight (by 20 to 30 percent) besides providing a smaller envelope, improved reliability and earlier maintainability. Figure 5.2.13, again reproduced from Reference 5.2.4, shows the weight saved by improved design in both areas, between 1960 and 1967. Development targets for 1974 call for a 3 percent increase in static thrust efficiency, a 7 percent increase in cruise efficiency, a 15% reduction in weight due to new design concepts and an additional 20 percent due to new materials. Reference 5.2.6 summarizes Hamilton Standard's design program for achieving improved maintainability. One noteworthy feature is a quick disconnect blade retention concept.

FIGURE 5.2.10 COMPARATIVE PROPULSOR PERFORMANCE



FROM - HAMILTON STANDARD DATA

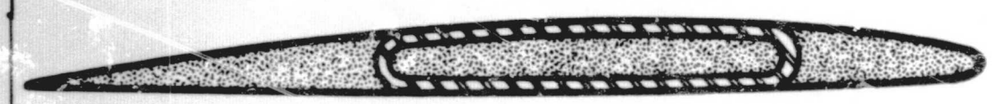


FIGURE 5.2.11 FIBERGLASS SHELL, STEEL SPAR BLADE

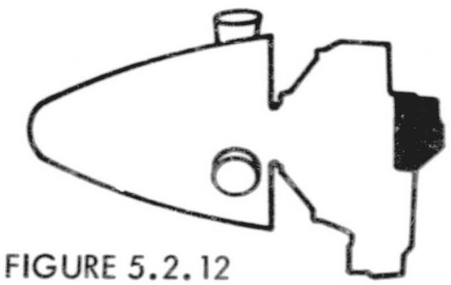
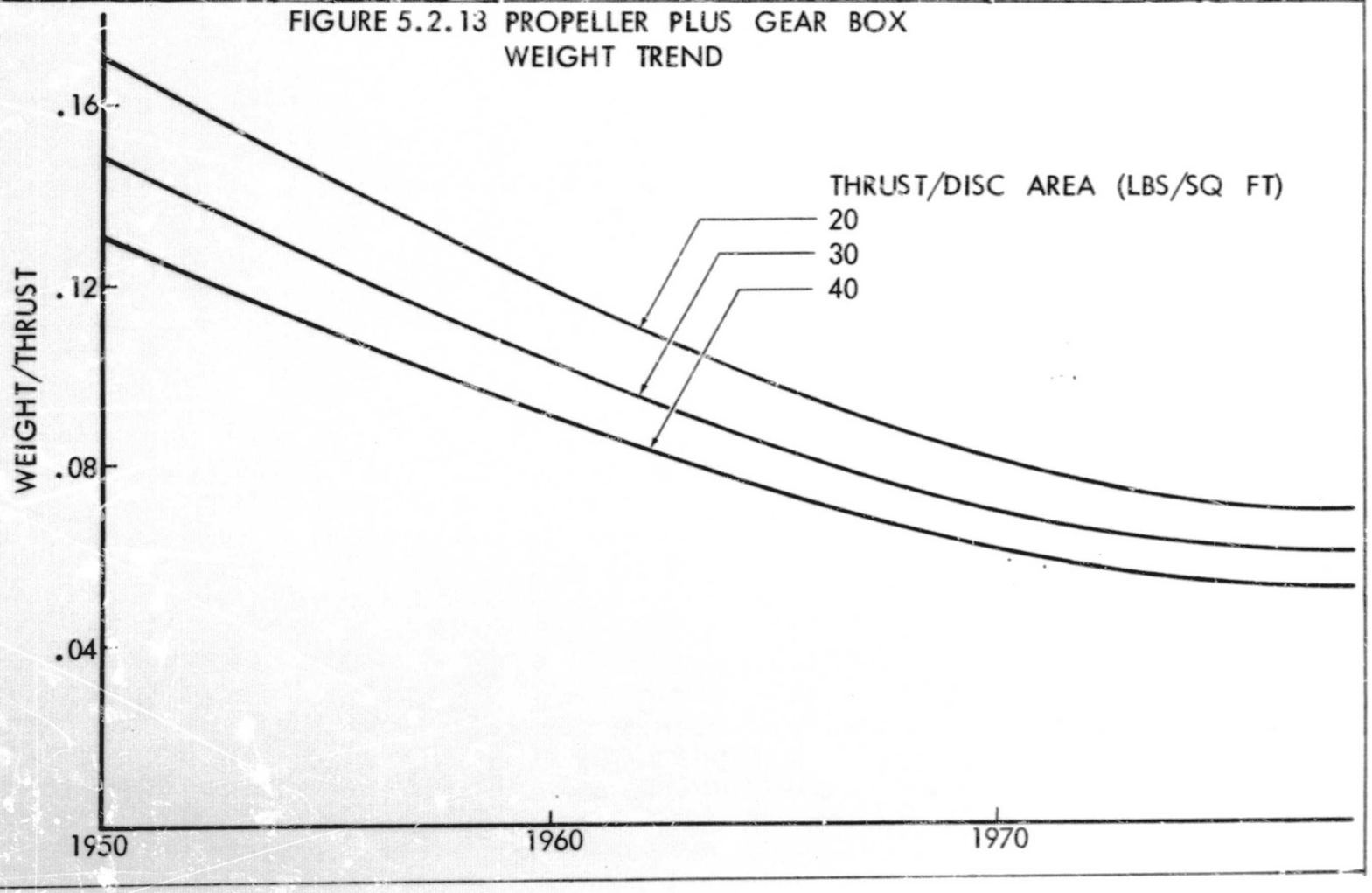


FIGURE 5.2.12 INTEGRAL GEAR BOX

FIGURE 5.2.13 PROPELLER PLUS GEAR BOX WEIGHT TREND



Hamilton Standard's NASA-sponsored study (Ref. 5.2.4) not only addresses the noise problem but also outlined several interesting approaches to simplified, lightweight, low cost design. The "prop-fan" concept was also investigated for general aviation use and showed promise as a candidate propulsor for airplanes at the high end of the speed spectrum.

5.2.9 Propeller Performance and Noise

In order to select propellers for the airplanes covered in this study, several diameters at three activity factors (100, 140, 180) and 4 design blade lift coefficients were investigated (0.15, 0.30, 0.50 and 0.70). Table 5.2.14 shows the propellers that were investigated for Category I and Category II. The same propellers checked for Category II were also analyzed for Category III.

TABLE 5.2.14

SUMMARY OF PROPELLERS INVESTIGATED

CAT.	DIAM.	AF	DES.C_L	H.P.
I	8	100	.15	225
	9	140	.30	
	10	180	.50	
II, III	11	100	.15	400
	12	140	.30	
	13	180	.50	
	14		.70	

NOTE: All the combinations of diameter, activity factor, and design lift coefficient are analyzed for each category. All propellers are 4-bladed, but 3-bladed propellers have also to be checked for Category I at the same values given for the Category I investigation.

It was originally thought that an unduly large penalty would occur as a result of the directivity of sound. However, the latest Hamilton Standard data indicates very little influence due to directivity. In the sample, the rotational speed for constant noise level would be changed by only 30 RPM, which can be compensated by slight changes in activity factor or diameter, as a result of directivity. The average value from 60 to 120 degrees with the propeller shaft is compared to the maximum value of noise which occurs at 105 degrees.

All propellers in this selection were four-bladed, but three-bladed propellers have been investigated for Category I. Propeller comparisons for three categories of airplanes are presented. All are analyzed for a noise level of 75 PNdb at 500 feet, using an average directivity correction between 60 and 120 degrees. A sample of the noise analysis is given on Table 5.2.14.1.

TABLE 5.2.14.1

SAMPLE CALCULATIONS FOR NOISE LEVEL - CATEGORY I

(9 ft. Diam. Propeller - 225 HP)

Propeller R.P.M.	1500	1300	1100	1000	
Tip Speed (ft/sec)	707	613	518	471	
Tip Mach No.	.633	.549	.464	.423	
db Level due to Tip Mach No. & Power	80.7	77.5	74.25	72.7	
Correction for Diam. & No. Blades = + 1.7 db					
Fundamental Noise Level	82.4	79.2	75.95	74.4	
Correction at 500 ft.	0	0	0	0	
Directivity Azimuth	60°	75°	90°	105°	120°
db correction	-1.0	-.6	0	+.4	-.2
maximum (60° to 120°)	+.4	+.4	+.4		+.4
average (60° to 120°)	-.3	-.3	-.3		-.3
PNdb correction	2.0	1.4	.55		.05
Total Max. Noise Level (PNdb)	84.8	81.0	76.9		74.85
Total Average Noise Level (PNdb)	84.1	80.3	76.2		74.15
RPM for Max. Noise Level = 1010					
RPM for Average Noise Level = 1040					

Propellers can be selected for a noise level of 75 PNdb with static thrust varying from 4 pounds to 6 pounds of thrust per horsepower, Conventional propellers, with unrestrained noise level, can also be selected for comparison.

The performance of the Category I propellers is listed in Table 5.2.14.2 and plotted in 5.2.15. It can be seen that an efficiency of 86 percent can be realized with static thrust values of 4 to 6 pounds of thrust per horsepower. From the graph, it can be seen that a propeller diameter of 8 feet with an activity factor of 140 and a design C_L = .35 will yield 4 pounds of static thrust per horsepower, with a cruise efficiency of 86 percent, for an engine rated at 225 horsepower, with cruise conditions of 130 knots at 7500 feet. By going to a larger diameter propeller, it is possible to obtain 6 lbs. of static thrust per horsepower and a cruise efficiency of 86 percent. The diameter would be 9 feet, the activity factor would be 180, at a design lift coefficient of 0.55.

TABLE 5.2.14.2

CATEGORY I PROPELLER SELECTION FOR 75 PNdb AVERAGE NOISE LEVEL AT 500 FT.

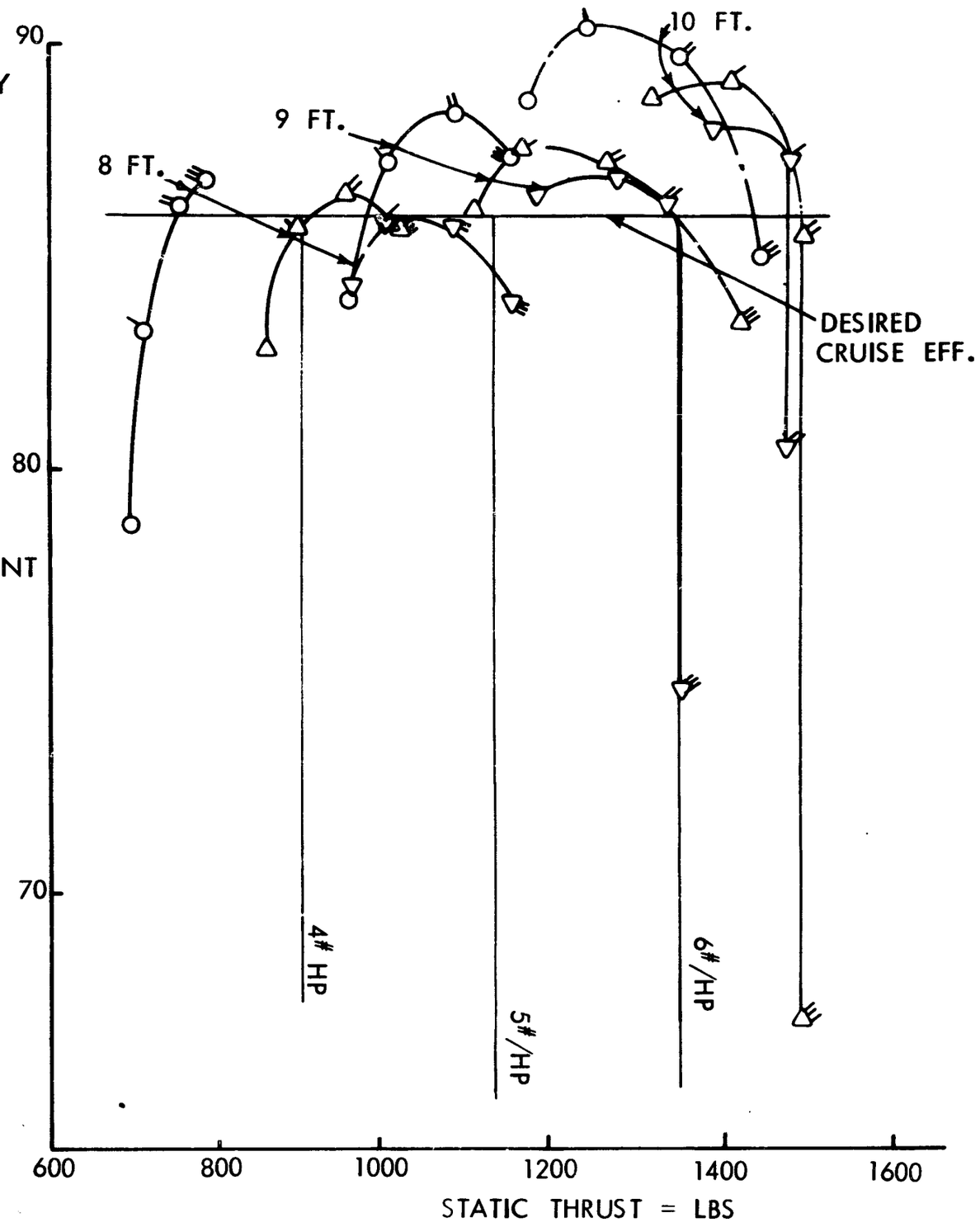
(225 hp normal rating; 169 hp for cruise at 92% take-off rpm; 130 kts. cruise speed at 7500 ft.)

DIAM/RPM	DESIGN C_L								
8/1060	.30			.50			.70		
Activity Factor	100	140	180	100	140	180	100	140	180
T.O. Thrust	711	892	1007	751	950	1078	786	1016	1149
Cruise Eff.(%)	83.3	85.7	85.8	86.2	86.5	85.7	86.8	85.6	82.9
9/1030	.30			.50			.70		
Activity Factor	100	140	180	100	140	180	100	140	180
T.O. Thrust	1001	1161	1273	1081	1261	1337	1149	1321	1354
Cruise Eff. (%)	87.2	87.5	86.8	88.4	87.2	85.25	87.4	83.5	74.8
10/1000	.30			.50			.70		
Activity Factor	100	140	180	100	140	180	100	140	180
T.O. Thrust	1240	1410	1478	1351	1492	1474	1440	1492	1440
Cruise Eff. (%)	90.4	89.1	87.3	89.7	85.5	80.5	85.0	67.0	-

The Category II study of single propellers is based on 400 horsepower. The results are listed in Table 5.2.16 and plotted in Figure 5.2.17. The propeller is selected for high static thrust (6 lbs/hp) with a diameter of 13 ft , an activity factor 170, and a design lift coefficient of .25. The cruise efficiency is 86 percent. For a static thrust level of 5 lb. per horsepower, and an efficiency of 86 percent, a propeller of 11 ft. diameter, 170 activity factor, and a design lift coefficient of .35 would be selected. For the static thrust level of 4 lbs/hp, a diameter of 11 ft., with 90 activity factor, a .65 design lift coefficient at 86 percent cruise efficiency would meet the design requirements.

FIGURE 5.2.15

STATIC THRUST VS CRUISE EFFICIENCY
CATEGORY I-4 BLADE
225 HORSEPOWER
75 PNDB NOISE LEVEL
130 KTS CRUISE SPEED



LEGEND
O 100 A.F.
Δ 140 A.F.
▽ 180 A.F.
NO FLAG = .15 DES C_L
1 FLAG = .30 DES C_L
2 FLAGS = .50 DES C_L
3 FLAGS = .70 DES C_L

TABLE 5.2.16

CATEGORY II PROPELLER SELECTION FOR 75 PNdb AVERAGE NOISE LEVEL AT 500 FT.

(400 hp normal rating; 300 hp for cruise at
92% t.o. rpm; 200 kts. cruise speed at 7500 ft.)

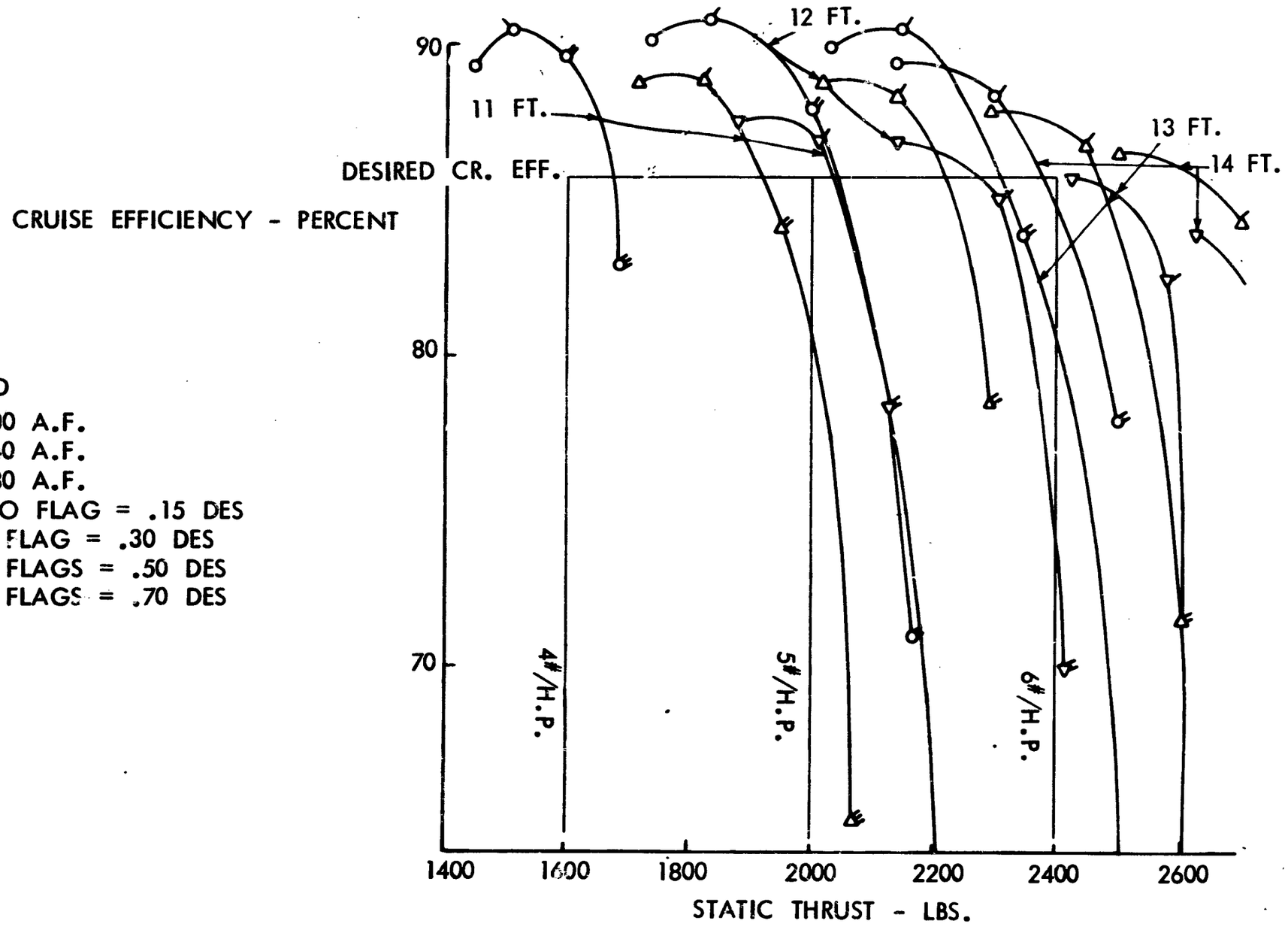
DIAM/RPM	DESIGN C_L								
11/815	.30			.50			.70		
Activity Factor	100	140	180	100	140	180	100	140	180
T.O. Thrust (lbs)	1501	1810	2002	1590	1943	2120	1678	2061	2208
Cruise Eff. (%)	90.5	88.9	87.0	89.7	84.2	78.5	83.0	65.	
12/790									
T.O. Thrust(lbs)	1824	2130	2297	1991	2283	2408	2158	2394	2408
Cruise Eff. (%)	90.9	88.4	85.2	88.0	78.5	70.0	71.0	-	-
13/770									
T.O. Thrust(lbs)	2136	2439	2571	2334	2598	2598	2505	2610	2532
Cruise Eff.(%)	90.6	86.9	82.6	84.0	71.5	58.0	-	-	-
14/745									
T.O. Thrust(lbs)	2290	2695	2746	2493	2797	2708	2620	2720	2404
Cruise Eff. (%)	88.5	84.5	79.5	78.0	66.5	-	-	-	-

Category II was also investigated with twin propellers and similar selection data were derived. The results are not shown because the twin propeller installation was not chosen later.

The Category III propeller selection charts are plotted in Figure 5.2.18. They have inordinately large diameters, due to the extreme difficulty of matching cruise and take-off requirements, particularly if the criteria of 6 pounds of thrust/hp is used. At this static thrust value, however, the cruise efficiency is 84%, as compared to 86% that can be maintained by propellers in the other categories of aircraft. For a moderate static thrust performance of 5 lb. thrust/hp, a diameter of 13 ft., an activity factor of 100, and design lift coefficient of .15 would be required.

The selection of conventional (noisy) propellers for Category I and II is calculated in Appendix III. A comparison of these propellers with low noise level propellers is given in Table 5.2.19.

FIGURE 5.2.17 STATIC THRUST VS. CRUISE EFFICIENCY
CATEGORY 2 -1 PROPELLER
400 HORSEPOWER
75 PNDB NOISE LEVEL
200 KT. CRUISE SPEED

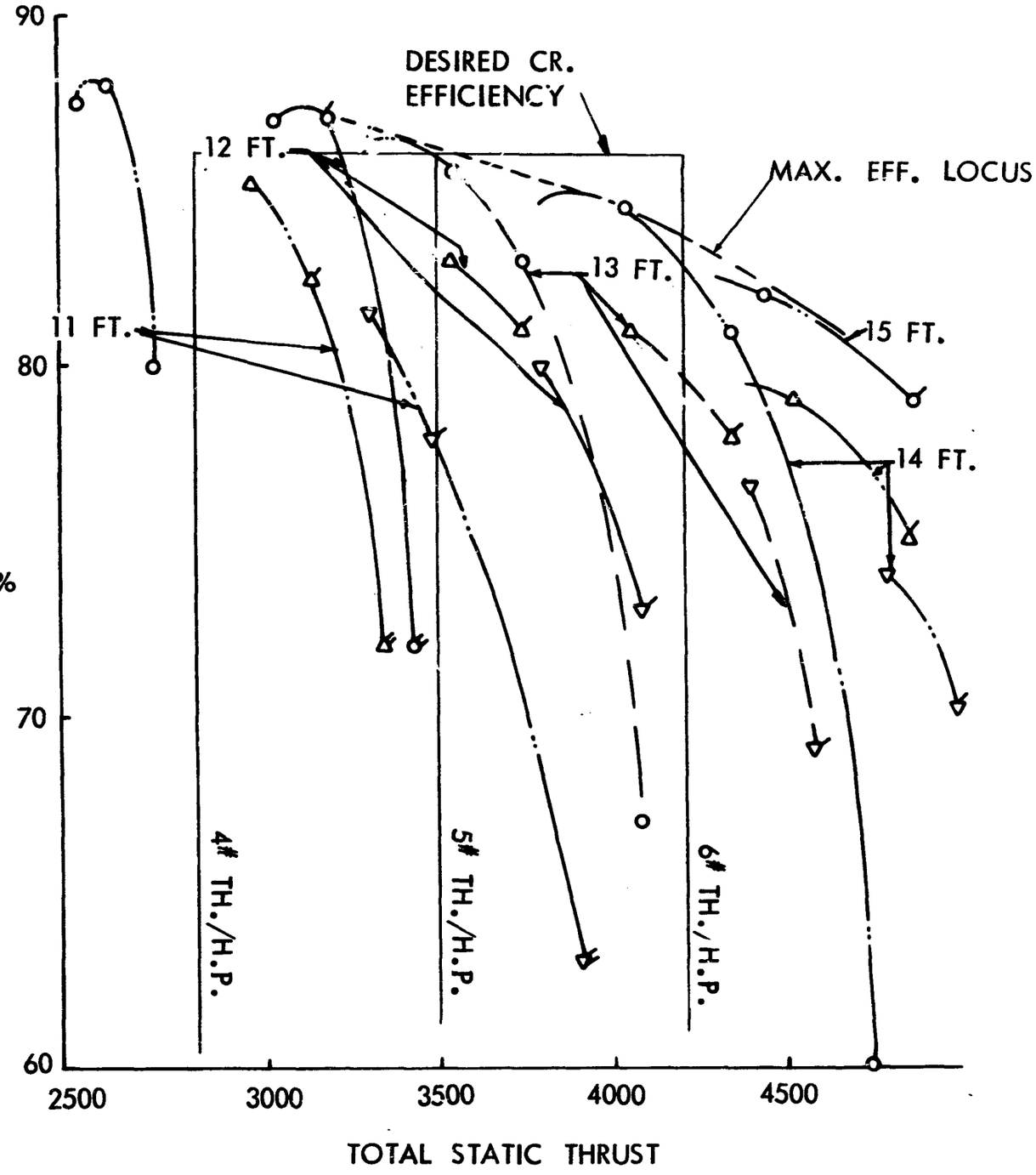


LEGEND
- o 100 A.F.
- Δ 140 A.F.
- ▽ 180 A.F.

NO FLAG = .15 DES
1 FLAG = .30 DES
2 FLAGS = .50 DES
3 FLAGS = .70 DES

FIGURE 5.2.18

STATIC THRUST VS. CRUISE EFFICIENCY
CATEGORY III, 2 PROPELLERS
350 H.P./PROPELLER
75 PNDB NOISE LEVEL
250 KN CRUISE SPEED



LEGEND

- o 100 A.F.
- Δ 140 A.F.
- ▽ 180 A.F.

NO FLAG = .15 DES. C_L
1 FLAG = .30 DES. C_L
2 FLAGS = .50 DES. C_L
3 FLAGS = .70 DES. C_L

TABLE 5.2.19

PROPELLER COMPARISON

Diam.	No. Bl.	A.F.	Noise Level PNdb	Static Thrust Lb.	Cruise Eff. %	T.O. R.P.M.
Category I						
6.25	2	150	100	853	83	2600
8	4	140	75	900	86	1060
9	4	180	75	1350	86	1030
	Category I power = 225 HP @ 2600 RPM @ T.O. 169 HP @ 2400 RPM @ CR. Cruise Speed = 130 Kts.					
Category II - Single Propeller						
7	2	150	106	1596	87.4	2600
11	4	90	75	1600	86.0	815
11	4	170	75	2000	86.0	815
13	4	170	75	2400	86.0	770
	Category II power = 400 HP @ 2600 @ T.O. 300 HP @ 2400 @ CR. Cruise Speed = 200 Kts.					
Category II - Twin Propeller						
10.25	4	170	75	1350	86	870
8.2	4	140	75	900	86	920
	Category II power is same as Category I per propeller					
Category III - Twin Engine						
14.4	4	100	75	2100	84	677
10.8	4	140	75	1400	86	748
	Category III power = 350 HP/ENG. @ 2600 RPM @ T.O. 263 HP/ENG. @ 2400 RPM @ CR. Cruise Speed = 250 Kts.					

In the parametric analysis a change in propeller diameter which actually varies with the square root of the ratio of horsepower is used in order to maintain static thrust at the same value of pounds per horsepower. This is the correction factor for powers other than the power for which the propellers are selected in the preceding examples. A check revealed that the cruise efficiency would also tend to remain at the same value for this correction.

Figure 5.2.20 gives the results for a 3 blade propeller in Category I which can be compared with the 4 blade propeller of Figure 5.2.15. In the 3-blade case, the diameters required are 10 ft. for 6 lb/hp and 9 ft. for 4 lb/hp. Both of these values are 1 foot greater in diameter than for the equivalent 4-bladed propeller. Since ground clearance and landing gear height are critical considerations, the 3-bladed propeller investigation was discontinued. The other categories are even more critical than Category I in this respect.

The propeller RPMs required for the 75 PNdb noise level are plotted in Figure 5.2.21. It can be seen that the allowable RPMs, in addition to being a function of diameter and the number of propellers, also show a very marked effect due to horsepower. Twin propeller configurations have lower RPMs than a single propeller, as a result of a 3 db noise level increase due to 2 propellers. Very low RPMs and large diameters are required for acceptable values of static thrust and cruise efficiency. As a result of the 75 PNdb requirement, the inordinately low propeller RPM requires a very high numerical gear ratio, particularly with turboshaft engine drive. In addition, the cruise conditions are very difficult to match with take-off conditions. This is especially true of the Category III aircraft which have a cruise speed of 250 knots.

The Lockheed Missile and Space Company (LMSC) at Sunnyvale, California, was visited in order to obtain data on noise measurements from the Q-Star and the YO-3A aircraft, both experimental 'quiet' aircraft developed by LMSC. Tests were being run on the YO-3A, which has a 210 horsepower engine driving a 3-bladed constant speed propeller, which operates at a 63 to 65 PNdb noise level at 70 knots at 500 feet. The propeller is computed to have a noise level of 75 PNdb for the static case, based on the Hamilton Standard method. Two resonators and a glass pack muffler were used on the engine for noise suppression, reducing its noise level by approximately 50 PNdb. The YO-3A in takeoff and in flight was very quiet when observed at distances of 100 to 500 feet. The noise was never objectionable, and was similar to the sound of moderate traffic moving at speeds of 30 to 35 mph.

5.2.10 Engine Noise Control

It has been demonstrated on numerous occasions that the exhaust noise level of piston engines can be reduced below that of the propeller. As previously stated, the use of resonators and fiberglass-insulated mufflers are effective means of achieving this end.

FIGURE 5.2.20 STATIC THRUST VS. CRUISE EFF.
CATEGORY 1 - 3 BLADE

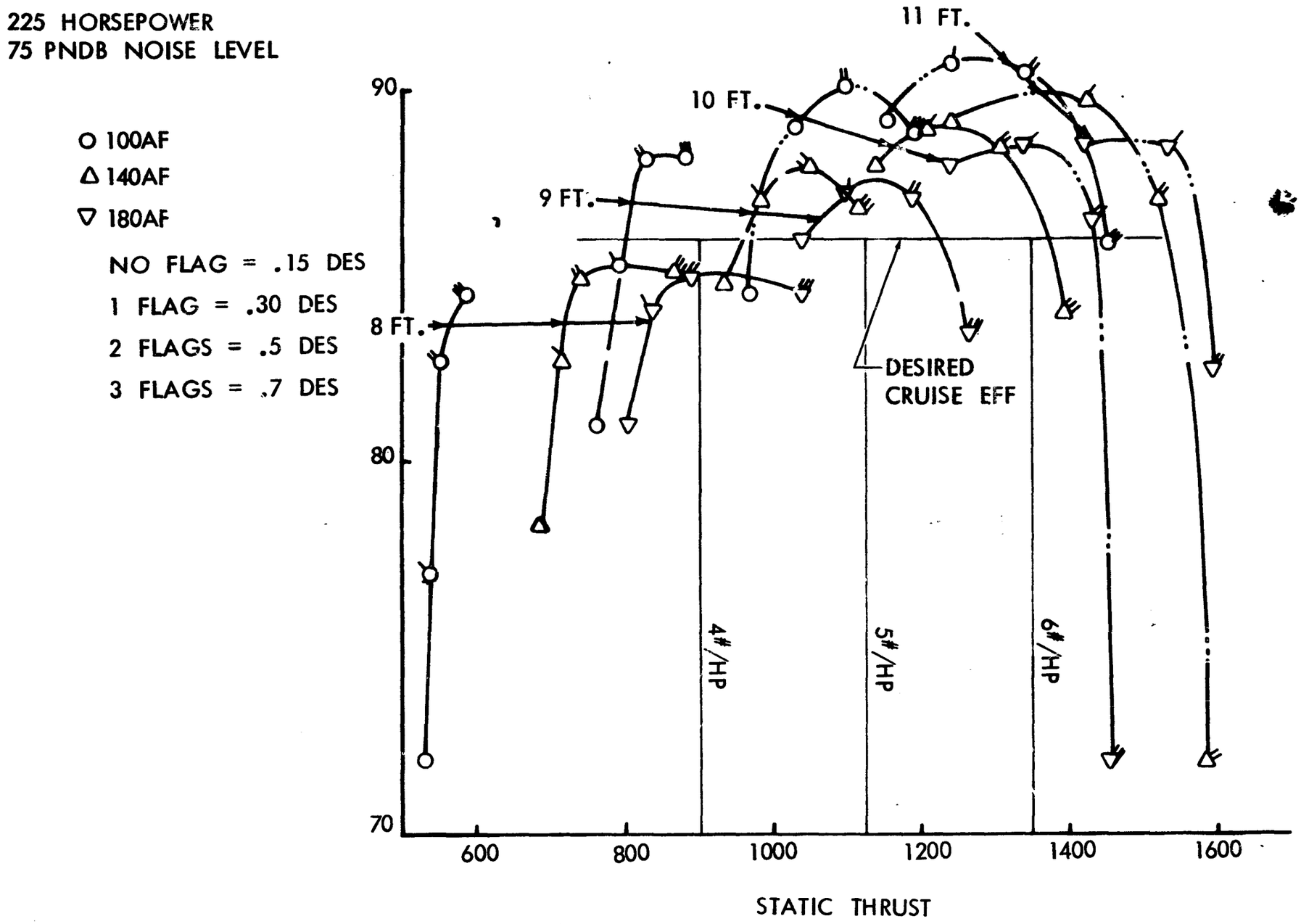


FIGURE 5.2.21 PROPELLER SPEED FOR 75 PNDB NOISE LEVEL

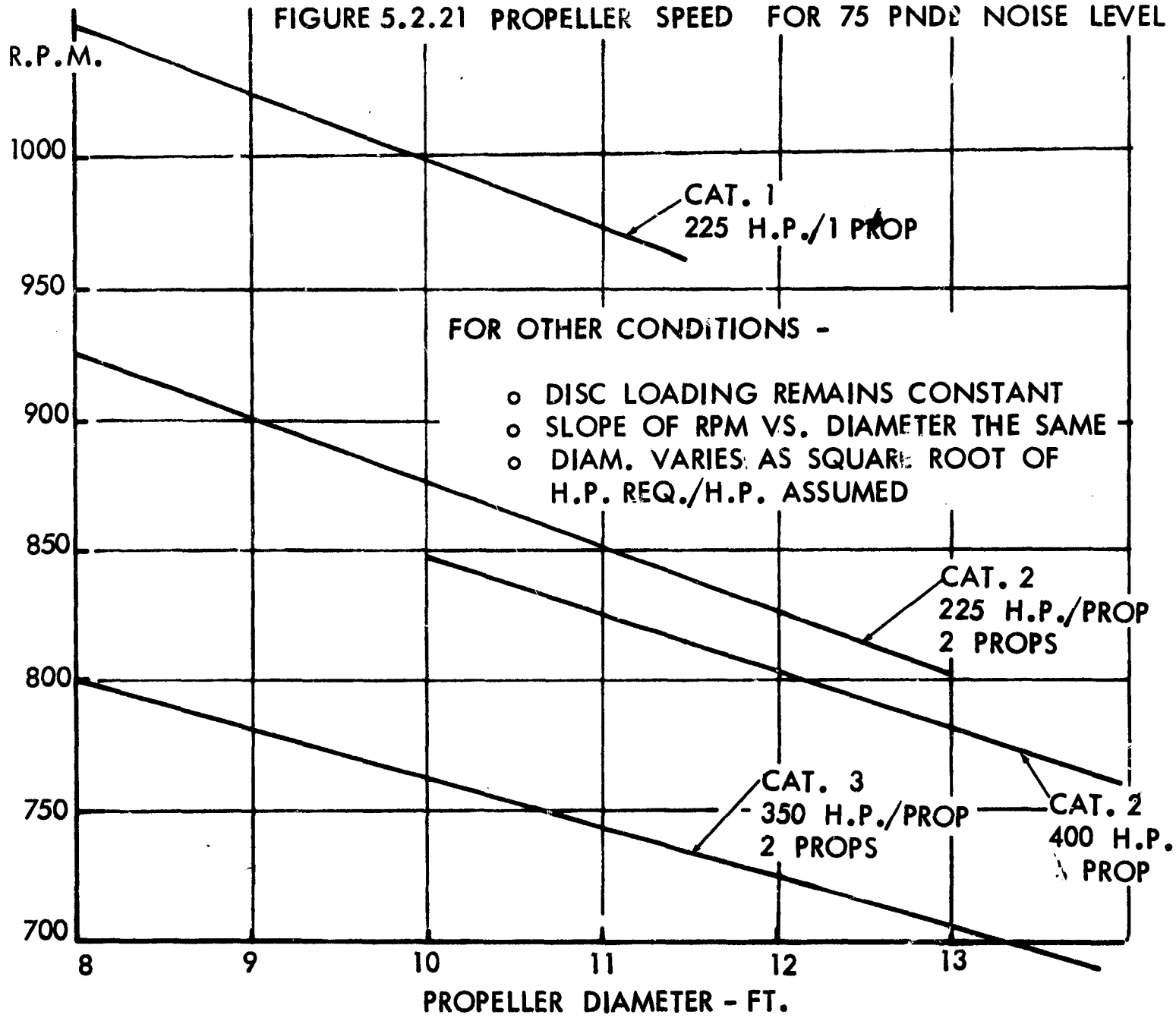
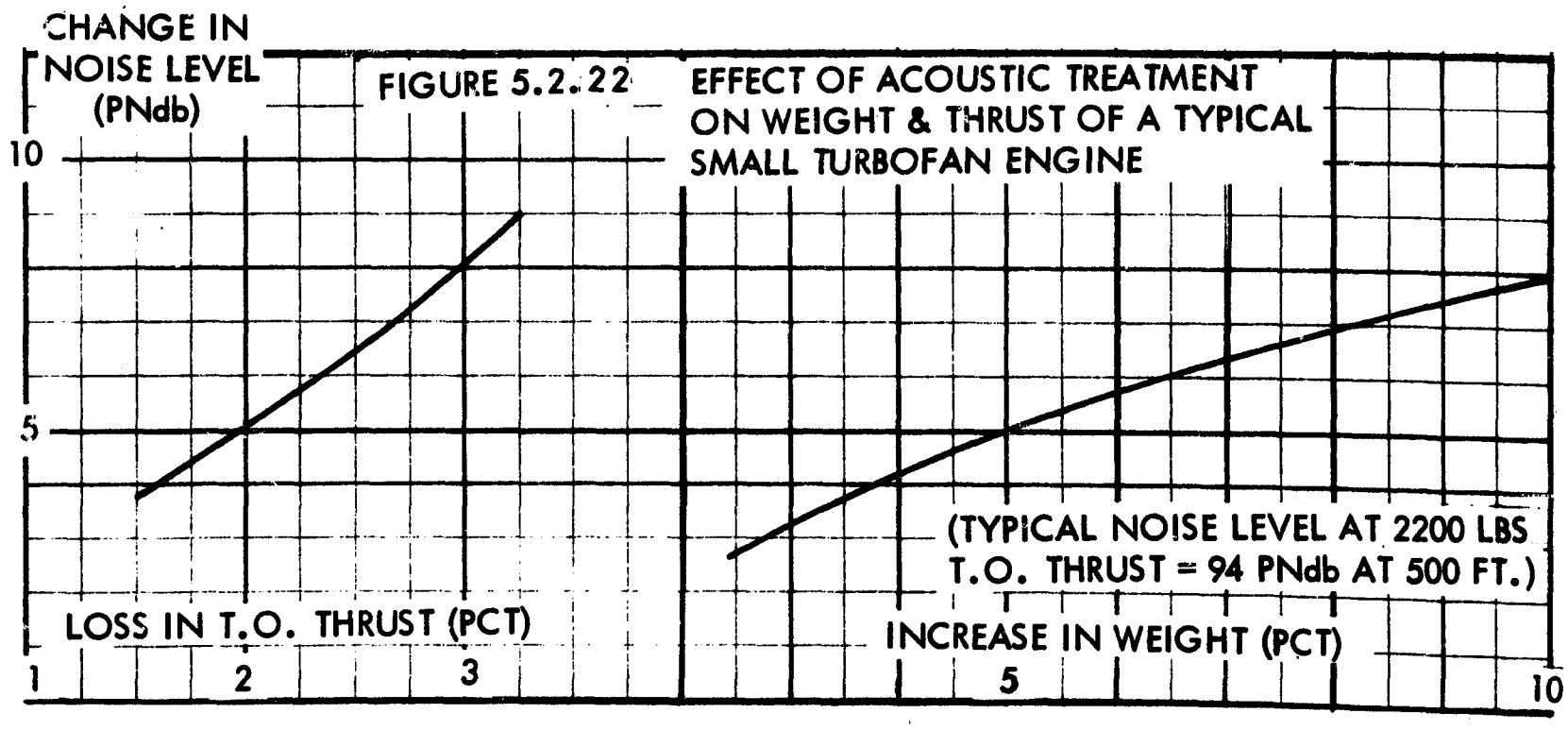


FIGURE 5.2.22 EFFECT OF ACOUSTIC TREATMENT ON WEIGHT & THRUST OF A TYPICAL SMALL TURBOFAN ENGINE



The quieting of turbofan engines is another matter. Since it is not believed possible, without a break-through, to reduce the noise level of turbofans in the 2000 - 3000 lb. thrust category to 75 PNdb at 500 ft., the turbofan-engined candidate in Category III was evaluated in the sensitivity study program. Figure 5.2.22 shows the effect of reducing the noise level of a typical small turbofan engine on weight and thrust loss. It appears that a reduction of about 8 PNdb from the noise level of a 2500 lb. thrust turbofan (about 93 PNdb) is about the practical limit, which would result in a level of 85 PNdb. These data were obtained from Pratt and Whitney of Canada.

Actual noise measurements of 85 DB at 1520 ft. were obtained from an aircraft equipped with two 2200 lb. thrust turbofan engines. A 10 DB increment would be necessary in order to obtain a noise level at 500 ft. Thus, 95 DB would be the noise level at 500 feet, as compared to 97 DB at 500 feet from Figure 5.2.22. It would seem that this engine has a lower noise level than was originally estimated but there is another possibility, and that is that some acoustic treatment was used on the nacelles.

5.2.11 Rotor Noise Control

The rotor noise problem of helicopters and proprotors can be treated in a similar manner to that of propeller noise, although it is specialized to some degree. Reference 5.2.15 summarizes the results of Sikorsky's research in the prediction and control of rotor noise, which was partly funded by Army contracts. It resulted in an improved procedure for the prediction of main rotor vortex noise for a single rotor helicopter. Both the overall sound pressure level and the spectrum shape of the vortex noise from square-tipped blades can be calculated as a function of tip speed, blade area and thrust. It was found that the geometry of the blade tip can alter both levels and spectrum shape appreciably. Blades with twisted, trapezoidal tips, designed to provide elliptical aerodynamic loading at the tip, showed reductions from 2 to 10 db (with decreasing frequency) in low pitch and reductions up to 5 db in high pitch. Two computerized analyses were developed for rotational noise prediction, which demonstrated the importance of the higher harmonics of airload and the chordwise distribution of loading for accurate rotational noise prediction. Measured noise levels from the NH-3A helicopter showed close agreement with calculations. Guidelines for the control of rotational noise include holding the Mach number of the advancing blade tip below 0.85, decreasing blade loading and avoiding blade-vortex interactions. A general objective is a rotor system that eliminates the higher harmonics of airload, thereby reducing those of noise and reducing the acoustic annoyance and detectability characteristics of the helicopter.

Another treatment of the helicopter noise problem is given in Ref. 5.2.16 and more applicable to the small helicopters of interest to this study. The noise characteristics are shown to be general functions of size and tip speed. Surveys of subjective judgments made at Los Angeles, London Airport and Farnborough showed that perceived noise levels below 80 PNdb were of no concern. The perceived noise levels of conventional helicopters of 4,000 lbs. gross weight at 250 ft. vary from 85 to 96 PNdb with turbine power and from 96 to 106 PNdb with piston engine power. The Bell 206A at 250 ft. varies from 80 to 86 PNdb, close to the noise of automobiles at 50 ft. Its military counterpart, the OH-58A, with a gross weight of approximately 3000 lbs., was analyzed both in modified and redesigned versions for noise reduction. The modified version had swept tip main rotor blades operating at a tip speed of 600 fps and a 4-blade, double swept tip tail rotor operating at a tip speed of 530 fps. Sound absorbing materials were applied to the engine cowling and firewalls and absorptive silencers in the exhaust stacks. Hovering noise levels at 283 ft. were reduced by 6 to 9 PNdb and by as much as 13 PNdb in forward flight. The redesigned version had a double swept tip main rotor with 100% increase in solidity and an increased diameter tail rotor. Both rotors operated at a tip speed of 530 fps. In this case, the power and gross weight of the helicopter were increased, and the same sound absorbing treatment was applied. The redesigned version was 2 to 3 PNdb quieter than the modified version under all conditions. Noise levels at 283 ft. averaged about 80.6 PNdb in hovering and about 80.0 PNdb in forward flight and would appear to meet or surpass the 75 PNdb at 500 ft. requirement of this study.

5.2.12 References

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5.2.2	Dr. Max Bentele Wright Aero. Div. Curtiss-Wright Corp.	Curtiss-Wright's Experimental Rotating Combustion Engines
5.2.3	Scott Research Laboratories Study for the Air Pollution Control Office, Environmental Protection Agency. Dec. 1970	A Study of Exhaust Emissions from Reciprocating Aircraft Power Plants
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5.2.7	Charles Jones SAE 886D, August 1964	The Curtiss-Wright Rotating Combustion Engine Today
5.2.8	Charles Jones, Curtiss-Wright Corporation SAE 650723, Oct. 1965	New Rotating Combustion Powerplant Development
5.2.9	Charles Jones Curtiss-Wright Corp., SAE 670194, Nov. 1966	The Rotating Combustion Engine-Compact, Lightweight Power for Aircraft
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5.2.11	David E. Cole, Univ. of Michigan, Charles Jones, Curtiss-Wright Corp., SAE 700074, January 1970	Reduction of Emissions from the Curtiss-Wright Rotating Combustion Engine with Exhaust Reactor
5.2.12	R. F. Schaefer 68-050159-F, July 1968 Prepared under Contract N00019-68-C-0116, Dept. of the Navy, Naval Air Systems Command, Washington, D.C. 20360	Application of the Rotating Combustion Engine for Low Noise Level Aircraft

5.2.12 References (Cont'd.)

5.2.13	M. Berkowitz, W. Hermes, H. Lamping (CW-WR-6[illegible]-078F) January 1970	Rotating Combustion Engine Evaluation for Low Noise Level Aircraft Applications
5.2.14	H. R. Corwin, R. R. Dehoroch CW-WR-70-060E, June 1970 Prepared under Contract N00019-70-C-0436 for Naval Air Systems Command Washington, D. C. 20360 by Curtiss-Wright Corp., Wood-Ridge, N. J. 07075	An Acoustical Flight Evaluation of a Rotating Combustion Engine (U)
5.2.15	R. G. Schlegel & W. E. Bausch, Sikorsky Aircraft Division Journal of the American Helicopter Society - Oct. 1967	Helicopter Noise Prediction and Control
5.2.16	C. R. Cox, Bell Helicopter Co. Journal of the American Helicopter Society, January 1970	Helicopter Noise Reduction and Its Effect on Operations

5.3 Structure and Materials

5.3.1 General

The application of advanced materials, structural design, and manufacturing techniques to general aviation aircraft has been investigated by San Diego Aircraft Engineering, Inc. in a previous NASA study. The results are recorded in References 5.3.1 and 5.3.2 and include close attention to the element of cost. These references are used in this study, along with information from other sources to obtain data for the costing analysis in Section 7.3. Comparatively little can be added to the San Diego study; however, some additional source material has been examined and is reported herein.

5.3.2 Load Factors

In general, based on the VGH recorder data of Reference 5.3.4, the general aviation operations for normal category aircraft are contained within the design flight envelope as established by FAR Part 23, Airworthiness Standards-Normal, Utility, and Acrobatic Category Airplanes. They will be used in evaluating the baseline designs, which will later be analyzed for the effect of higher load factors.

5.3.3 Gust Alleviation

The free-wing aircraft concept described in Reference 5.3.5 appears to be unsatisfactory. During the past 26 years of research and development, an aircraft of this type has never been successfully flown. The lateral handling qualities are unsatisfactory; longitudinal maneuvering characteristics may have

to be augmented; and lateral control stability augmentation may have to be provided. The free-wing aircraft concept requires too much development and too many complicated mechanisms to devise a satisfactory system.

Other methods of gust alleviation bear investigation, since general aviation aircraft tend to have low wing loading and high aspect ratio, both of which result in high gust sensitivity, with resulting discomfort in rough air. While low wing loading is inherent, devices for reducing the effective aspect ratio (hence the lift curve slope) have been proposed. Aeroelastic design of the wing which causes the outer portion to reduce incidence as it deflects upward, and vice-versa, may have promise, but would require detailed design investigation beyond the scope of this study.

5.3.4 Structural Materials

Over the last four decades, aluminum alloy has been the principal material used for aircraft structure, although general aviation lagged the rest of industry in its use by about ten years. Many believe that aluminum will continue to be the primary structural material for aircraft, based on two premises: First, the industry has the "know-how" and heavy investment in applicable machinery and tooling; second, the aluminum suppliers have been active in developing higher strength-to-weight ratio materials; they and others have pioneered new processes, including adhesive bonding, weld-bonding, automatic riveting and many others.

Lately, however, the plastics revolution which has affected many other industries has been having serious effects on the aircraft industry. Fiber Reinforced Plastics (FRP) is a term encompassing the glass fibers now in fairly general use and the newer high strength/modulus fiber composites, such as boron/epoxy and graphite/epoxy. To quote the May 1970 issue of Materials Engineering:

> "All-glass reinforced plastics aircraft--on the boards for some time now -- appear to be moving closer to actual production according to reports from PPG Industries. During the next five years industry sources estimate that the use of GRP in aircraft will leap from 40-million to 140-million lbs. annually. North American Rockwell's Columbus Div. has successfully tested a glass reinforced plastic wing for a jet aircraft built to the specs of the Navy's T-2B jet trainer. Subjected to extensive structural tension and shear tests, the wing withstood forces much greater than it was designed for... In another development, Reinforced Plastics, Inc., an affiliate of Bellanca Aircraft Engineering, is building an aircraft entirely made of GRP. Objective is to produce an aircraft which, pound-for-pound, is stronger than aluminum, plus being more corrosion resistant and aerodynamically cleaner. Bellanca is building an experimental single- and twin-engine GRP aircraft with retractable wheels with a 5-6 seating capacity. Full production of four models is expected by late this year and 12 models may be finished by 1971... Windecker Research has just announced type certification of its Eagle I aircraft by the Federal Aviation Administration. This 4-place, low-wing, single-engine, retractable-wheel aircraft is made entirely of GRP. It features highly polished contours and curves with integral fairings."

The San Diego study (References 5.3.1 and 5.3.2) dealt extensively with the use of FRP. Reference 5.3.7 applied fiberglass to the design of a conventional

low-wing aircraft, designed in accordance with Part 3 of FAR, using ultimate load factors of + 12g and -6g. Minimum weight analyses were performed on various panel configurations to assess the effect of orthotropic material tailoring on structural performance. Extensive use was made of sandwich construction. It was concluded that the use of large diameter S-glass fibers in an epoxy matrix shows considerable advantage, for compression applications, on a strength/density basis over currently available composite and metallic materials. The tensile strength, however, is about 67% that of filament wound, glass-epoxy composites. Another study, by Goodyear, is reported in Ref. 5.3.10 in which fiberglass was applied extensively to the structure of a light armed reconnaissance airplane. Sections V and VI of the report deal extensively with the subjects of Construction Techniques and Structural Evaluation.

The new generation of fibers which lend themselves to composite structure, particularly in a plastic matrix include boron, graphite and a newer, potentially lower cost synthetic. The Lockheed-Georgia Company, and many other aerospace organizations, have experimented extensively with boron and graphite from laboratory specimens to flightworthy components. The material cost factor weighs against the extensive use of these materials at the present time, especially boron. While graphite has a lower cost potential, the new synthetic material could eventually be competitive with fiberglass.

A comparison between two of the most promising composite materials and three high strength/weight ratio metals is shown in the table below:

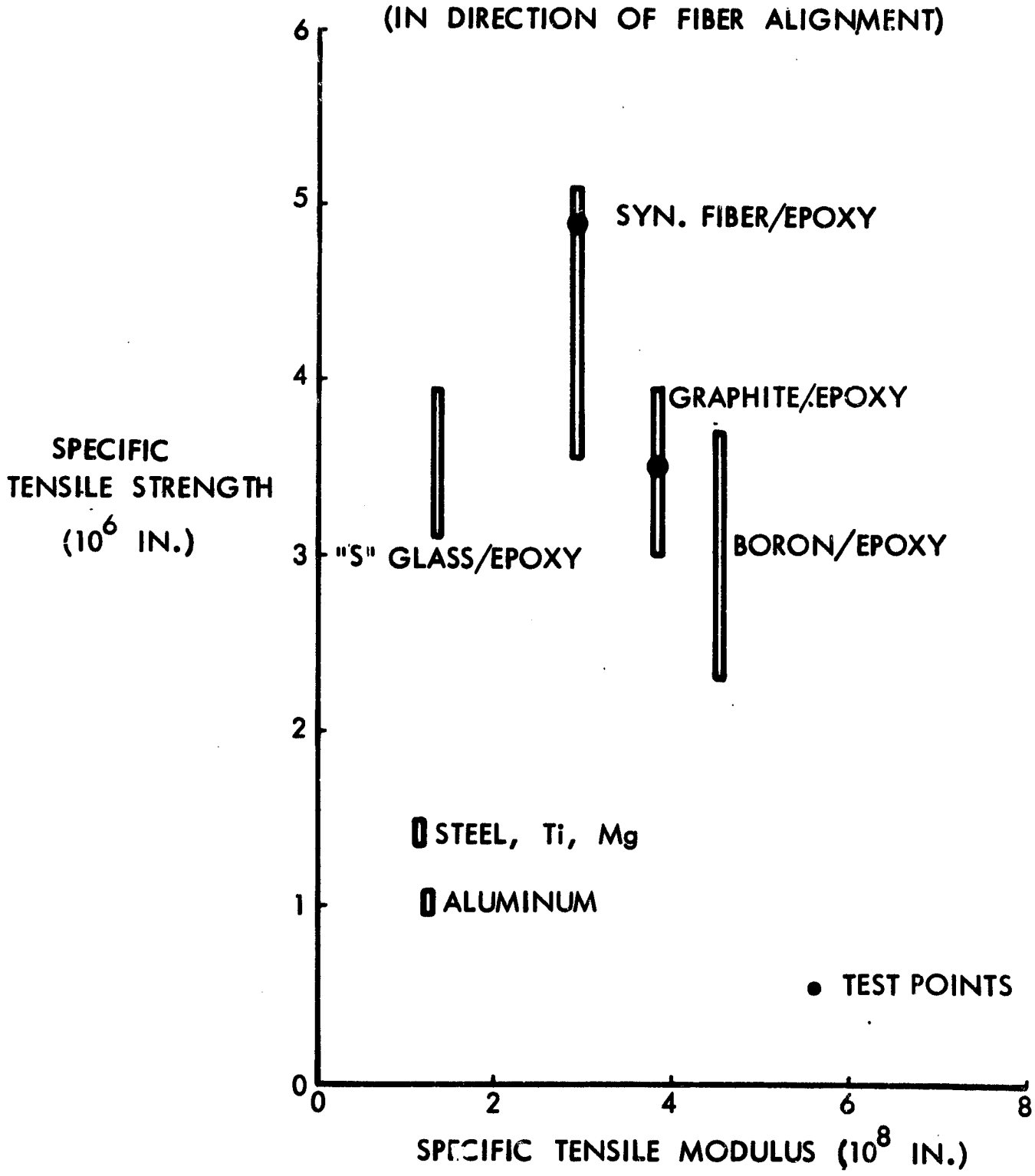
Material	Density (lbs/in^3)	Compressive Strength (psi)	Ratio ($X10^{-6}$)
Synthetic/Epoxy	0.050	50,000	1.00
Graphite/Epoxy	0.053	20,000-90,000	0.38 - 1.70
7075-T6 Aluminum	0.101	73,000	0.72
2024-T6 Aluminum	0.100	47,000	0.47
Ti-6AL-4V Titanium	0.160	155,000	0.97

Figure 5.3.1 shows, graphically, a comparison between candidate structural materials for general aviation aircraft. The terms "specific tensile strength" and "specific modulus" are the physical values divided by their density. It is a plot of specific tensile strength against specific modulus of single filaments when the fibers are aligned in an epoxy matrix. Metals are shown for purpose of comparison. Composite reinforced metals (compound composites) have shown significant improvements in highly loaded, fatigue and fracture critical structure. Selected structural components have been evaluated using the following composite reinforced metals: Graphite-Titanium, Graphite-Aluminum, Boron-Titanium, and Boron-Aluminum.

5.3.5 Application of Composite Material to Aircraft Structure

Much attention is being given to the application of composite materials for use in primary aircraft structure because of potential weight and cost savings. Most of the major airframe contractors are currently undertaking, under Air Force sponsorship, the design and construction of components fabricated from a variety of composites. Historically, the first components to be service tested were non-structural or parts of secondary structure, such as wing tips,

FIGURE 5.3.1 SPECIFIC TENSILE STRENGTH VS. SPECIFIC TENSILE MODULUS OF COMPOSITES (IN DIRECTION OF FIBER ALIGNMENT)



landing gear doors, etc. With experience, sufficient confidence was gained to proceed with fabrication of primary structural components. At the present time, Grumman Aircraft is proceeding with design of advanced composite wing structures and has a boron horizontal tail in production for the F14. McDonnell-Douglas has a limited number of boron rudders for F4 aircraft in production. General Dynamics/Fort Worth has an F-111 boron horizontal tail now undergoing flight testing. Northrop has several components on the F5 aircraft constructed from graphite filament composites.

In general, experimental programs presently underway are for components of fighter and cargo aircraft, and thus the interest in boron or graphite filament composite construction. Experience gained during these programs will be valuable to general aviation manufacturers, but it is believed, because of differences in aircraft size and operating requirements, general aviation will approach the problem from a different viewpoint, and perhaps develop somewhat different techniques, compared to those used by the designers of military aircraft. It may develop that the major benefits to general aviation may be in terms of lower labor costs rather than higher strength/weight ratios. For example, wing loadings of fighter aircraft usually are in the region of 100 psf or higher, whereas values of 15-30 are more common for general aviation aircraft. Since load factors are lower in general aviation aircraft, the use of high strength composite materials for the wings may not be required simply to meet strength requirements for normal and utility category aircraft. Composites of minimum thickness may, however, result in structure with the ability to sustain higher load factors, and still be lighter than corresponding thicknesses of aluminum. For example, 3 plies of synthetic/epoxy would have a thickness of about .020 inches, be 50% lighter than .020 aluminum, and yet have 140% more tensile strength.

An example of the design simplification which can be achieved by bonded construction is shown graphically by the photographs in Figure 5.3.2. A one-half size window panel for the Lockheed JetStar was fabricated of graphite/epoxy composites in a single stage layup and cure by the Lockheed-Georgia Company. The study, conducted to determine the feasibility by manufacturing a relatively complex structural area, resulted in a very rigid panel of excellent quality. The design required a minimum of fabrication and assembly time. A total of 68 design and supervisory man-hours, plus 78 man-hours to make the tooling and the part, was required. The following conclusions were drawn from the investigation:

- Low cost, lightweight tooling is suitable for the one-stage, integrally bonded structure.

- The one-stage, integrally bonded structure produces a high strength, high modulus and lightweight structure with dimensional and contour stability.

- The time required for producing this relatively complex panel was 7 man-hours per square foot. A structure representative of less complex areas of the fuselage would have required less time.

- The assembly can be laid up to final dimensions, which reduces machining requirements.

Experience accumulated on the C-5 boron slat now being flight tested would permit simplification of the design if it were to be done over again. This

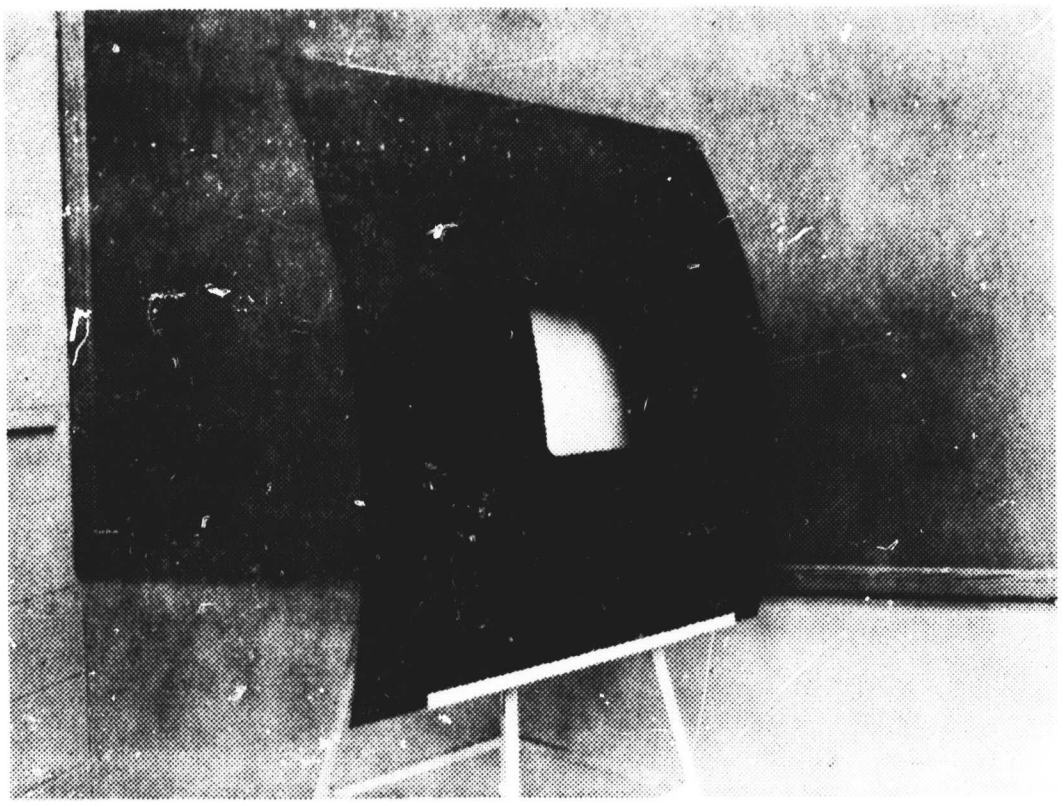
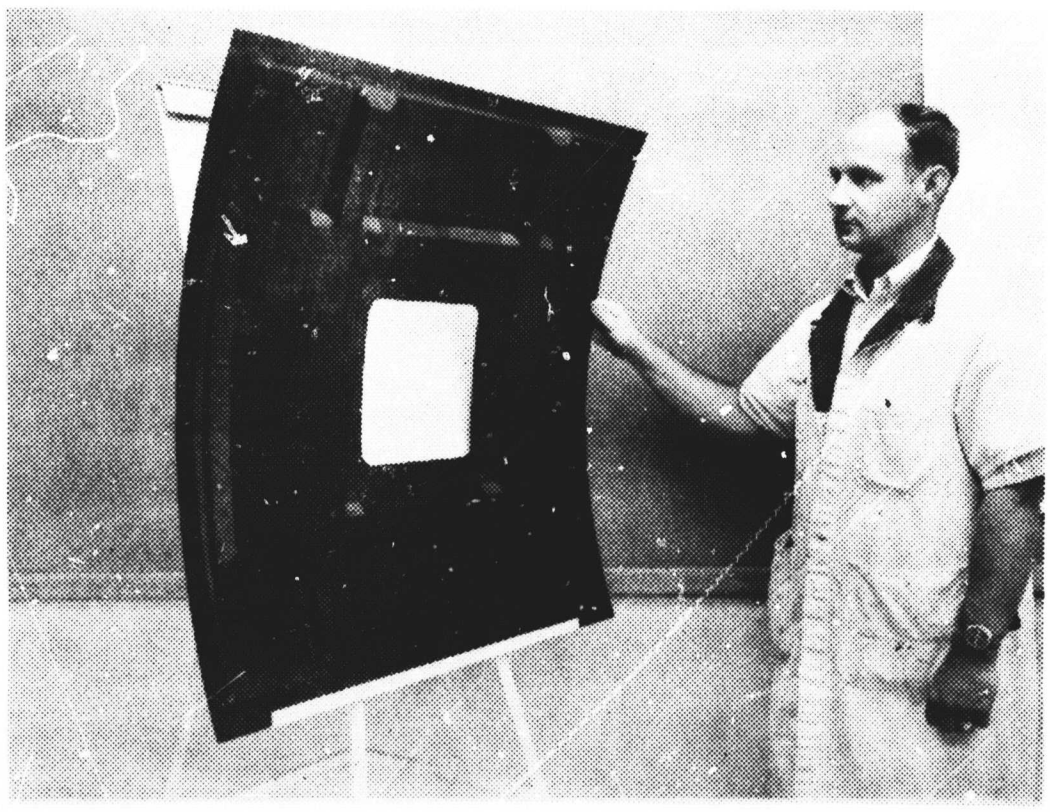


FIGURE 5.3.2 LOCKHEED-GEORGIA
GRAPHITE-EPOXY WINDOW PANEL
(Half Size JetStar Part)



illustrates the well known fact that, much as we may like to predict technology advances arbitrarily, the truth is that these advances are the result of an accumulation of knowledge based on experience.

In References 5.3.1 and 5.3.2, considerable thought was given to manufacturing techniques for the use of composite construction which could result in significant cost reductions. The use of compression molded, high modulus, graphite-reinforced plastic components for wing primary structure, glass-reinforced plastic moldings for fuselage components, and injection moldings where appropriate, all appear to reflect a reasonable projection of the state-of-the-art. Near-term wing design for fiber reinforced composite construction would probably plan on fabricating the major components separately, as illustrated in Figure 5.3.3. The spars would be compression molded, using undirectional fibers in the caps, and optimum fiber orientation for the spare webs. Web stiffeners would be molded in as required. Ribs could be injection molded to result in precise wing contour control. Due to high strength and rigidity of the spars, the skins would not be used for primary wing bending strength. Chordwise stiffeners would be molded integrally inside the skins to maintain contour. As experience is gained, and again depending upon economic considerations, fabrication of spars and ribs as a unit, shown in Figure 5.3.4, could result in a marked reduction of assembly time.

Much has been envisioned of "one-piece molded airplanes," but there are, of course, practical limits to how far one can go in this direction. A highly significant factor which must be considered in high volume production is specialization of labor. A major factor in the production rates achieved by automobile manufacturers is high speed production of many components in widely scattered locations. The use of highly skilled labor is held to a minimum and production rates are not limited by problems of assembly sequence which would be present with unitary construction. The degree to which smaller parts will be fabricated and molded together in larger assemblies will be determined by the economics of specific situations, and will depend to a large degree on the amount of experience a given manufacturer has gained. It is believed that the trend will be towards more unitary construction, but the rate at which progress is made towards this goal depends on experience.

Reference 5.3.11 describes Bede's application of molded, hollow fiberglass ribs, assembled to a single tubular spar (which serves as fuel tanks) and bonded with epoxy. They form part of a kit for home-building the BD-4 airplane.

It is not within the scope of this study to develop the detail design of general aviation aircraft structure fabricated from advanced materials. However, based on the promise shown to date, it is apparent that the funding of such a program by an agency of the government would be of great benefit to the general aviation industry.

The application of composites to helicopter systems is reported in Reference 5.3.12. Quoting from Section 11.1.1 of that document:

> "The rotor blade is critical for both fatigue strength and deflection. Therefore, materials with high specific fatigue strength and high specific modulus of elasticity offer great advantage. Rotor blade design includes natural frequency tuning. Tuning is necessary to avoid resonant response which occurs if the structural natural frequency is near the system exciting frequencies. Composite

FIGURE 5.3.3 NEAR-TERM COMPOSITE WING DESIGN

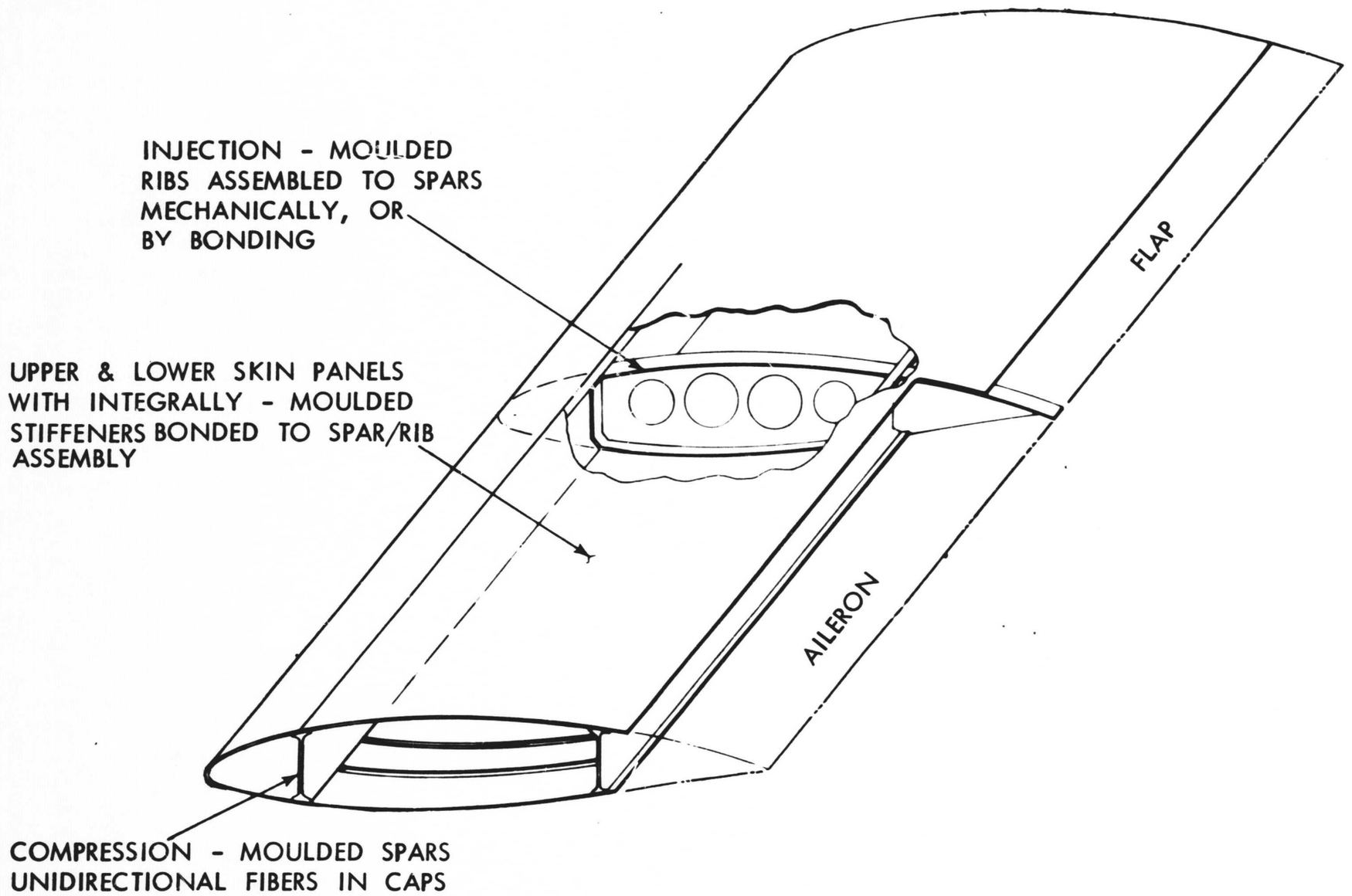
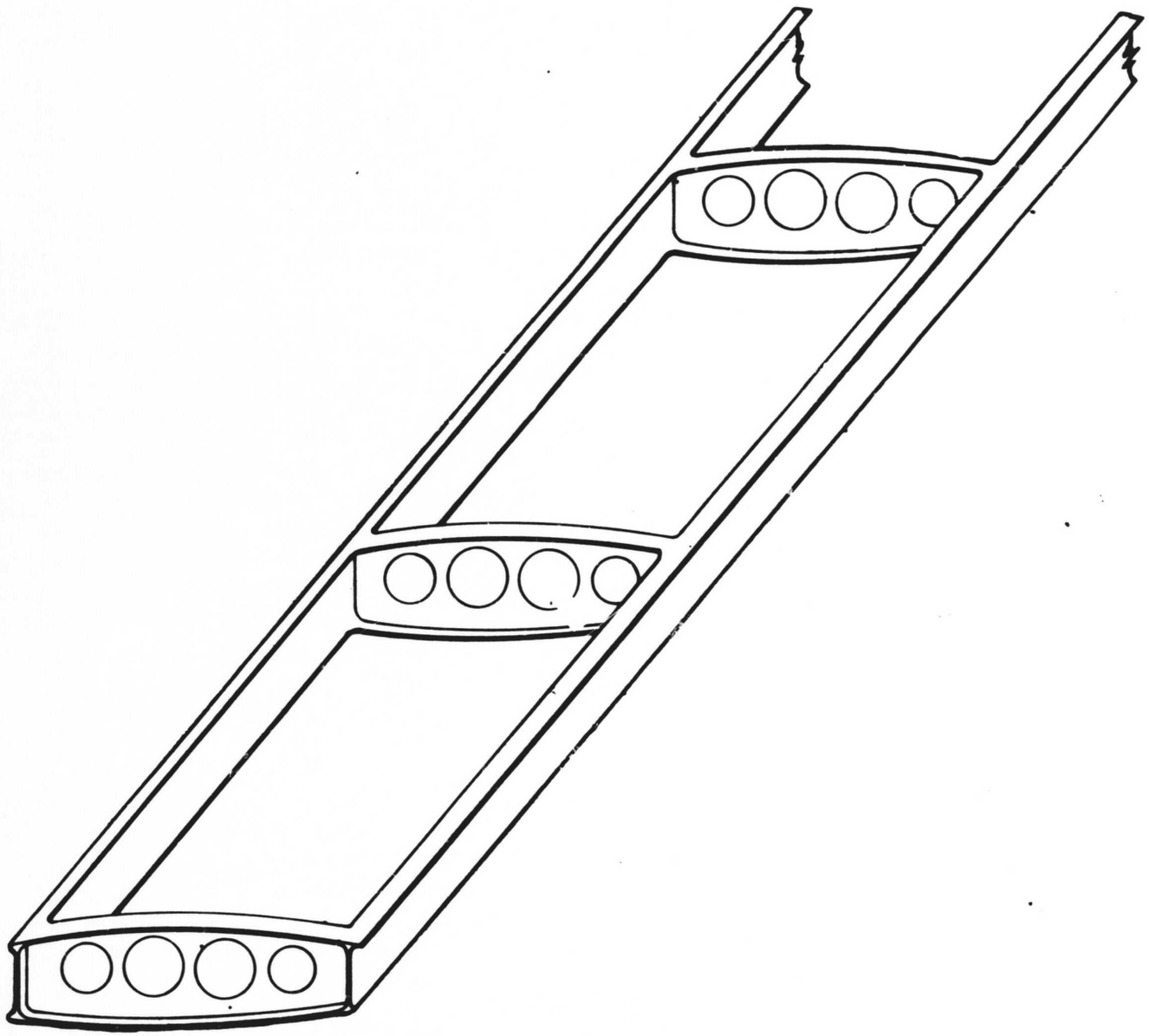


FIGURE 5.3.4 INTEGRALLY MOULDED SPAR-RIB CONSTRUCTION



materials offer the advantage of permitting blade natural frequency tuning without any penalty in weight. A wide stiffness range, and therefore a wide frequency range, is afforded by composites through variations in fiber orientation.

"A detailed application analysis and cost-effectiveness study was conducted by the Boeing Company, Vertol Division, under Contract AF33(615)-5275. This study pertains to the use of boron composites for the U.S. Army CH-47 helicopter. The results are summarized here to show the potential payoff for the use of advanced composites in a typical medium transport helicopter. The application analysis indicated that significant weight savings could be realized from the use of boron composites for the CH-47 dynamic components. The results are as follows:

	Basic Weight	Boron Composite Weight	Percent Savings
Rotor hub and rotor controls	410	360	12.2
Transmissions	432	325	24.8
Drive shafting	138	66	52.2

The weight reduction factors adapted for the sensitivity studies dealing with the effect of advanced materials are listed in Section 7.2.

5.3.6 Production Design Techniques

The production design of general aviation aircraft available in today's market follows along conventional lines, using materials and processes similar to those of military and commercial transport aircraft, but with primary emphasis on simplicity and low cost. Since a great many models are being offered to the public, and the production volume is low in comparison to that of the automotive industry, relative cost per pound is widely different.

Some attempts have been made in the past to reach high production volume by heavy initial investment in low cost techniques and tooling. One notable case is that of the Republic "Seabee," a post-World War II, 4-place amphibian. Its production design details are described in Reference 5.3.9. Aluminum alloy was used extensively and accent was placed on designing for the minimum number of component parts. This trend was especially evident in the design of the wing and tail panels, which employed spars covered by one-piece beaded skin, with ribs places only at the end locations. In comparison to conventional construction, this technique resulted in about a 75 percent reduction in the number of parts and 80 to 95 percent reduction in man-hours. Although the hull structure was relatively complicated in comparison to a landplane fuselage, similar percent reductions were made with reference to a conventional hull. Despite these efforts, the Seabee was the victim of a temporary collapse in the general aviation market and never achieved its anticipated high production status.

The application of advanced composites such as boron and graphite to general aviation aircraft in the time span under consideration must assume material

development and attendant cost reductions comparable with those of materials, such as aluminum, that have successfully cycled through the exotic-to-expensive-to-everyday applications. Indeed, new materials in the composites field are already being developed that will challenge the exotic materials of the early 1970's.

Throughout the development of these raw materials, new material forms and advanced manufacturing methods are being developed. It is these new material forms and manufacturing methods that will reduce the manufacturing cost of aircraft in the 1980's regardless of the specific materials used.

Some of these methods or forms require a reorientation of thinking, since they change undesirable characteristics into the desirable with a given material or process. An example of this is injection moulding. With the advent of short fiber-reinforced injection moulded parts, this process changed from one suitable for the fabrication of non-structural parts, such as knobs and small accessories, to one for the fabrication of structural members, such as doors, fittings and frames or any other parts economically justifiable. Parts have already been successfully moulded using short-fiber fiberglas and graphite in nylon matrices. Significant strength improvements are realized and material characteristics stabilized. Polyester and epoxy systems suitable for injection moulding are already under development.

Traditionally, paper has not been thought of as a structural material. In 1970, Lockheed developed the initial capability of fabricating paper from short graphite fibers. The product can be used with thermosetting or thermo-curing resin systems to afford a wide range of structural shapes in thin sections fabricated by an economical process. The use of such a product form affords a wide range of potential in aircraft manufacture. As an example, it affords the opportunity to mould small aircraft in the half shell.

The chopped fiber spray systems, often used in tool fabrication, can be much more closely controlled by automation of the system, giving precise controls over fiber and resin content and buildup. This improvement will afford economical means of fabrication suitable for airframe construction.

More traditional construction methods are also being combined to give improved and economical manufacturing methods. One of these is "Weldbonding," or spotwelding through an adhesive system. Weldbonding is a relatively new metal-to-metal joining technique which utilizes spotwelding in conjunction with adhesive bonding. The spotweld is accomplished through the uncured bondline, thus obviating the necessity for the costly curing cycles usually associated with bonding and autoclaving.

The weldbonding system is an economical joining technique and lends itself to automation for long production runs. It affords advantages in high vibration areas. No holes are created for joining, and it is suitable for joining minimal gages of metal. It is ideally suited for fabricating wing skins, control surfaces, and the attachment of doublers to skins or webs.

5.3.7 References

	Author and Source	Title
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5.3.3	Grumman Aircraft Engineering Corporation, Bethpage, New York	Advanced Composite Wing Structures-AF Contract F33615-68-C-1301
5.3.4	Joseph W. Jewel, Jr. and Marian E. Brazziel Langley Research Center Langley Station, Hampton, Va.	Initial Report on Operational Experiences on General Aviation, LWP-532, January, 1968.
5.3.5	Richard F. Porter and Joe H. Brown, Jr., Battelle Memorial Institute	Evaluation of the Gust-Alleviation Characteristics and Handling Qualities of a Free-Wing Aircraft. NASA CR-1523
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5.3.8	D. H. Emero and V. W. Alvey North American Aviation, Inc. AIAA Journal of Aircraft, May-June 1967	Structures Cost Effectiveness
5.3.9	Aviation, May 1946, pp 46-62	The Republic Seabee
5.3.10	Goodyear Aerospace Corp., GER-11463 5 March 1964	Light Armed Reconnaissance Airplane (GA-39)
5.3.11	Flight Magazine August 1969 (pp 38-42)	Bede's Breakthrough
5.3.12	U. S. Air Force	Structural Design Guide for Advanced Composite Material Application

5.4 Avionics and Instrumentation

5.4.1 General Technology Review

The ultimate emergence of general aviation as a principal mode of transportation depends to a major extent, on the development of guidance in the airspace. Flying without adequate guidance is equivalent to driving on unmarked highways.

Looking into the future is an uncertain occupation. What will general aviation operations look like in 1985? In starting on this road, one has no choice but to start from where we are today, move forward in the present direction, look for forks in the road ahead, and be alert to the entrance of new technology along the way. By 1985 it will be readily possible to carry out complete automatic flight from take-off to landing, in three dimensions, and to a preplanned flight schedule. This will be accomplished through an on-board dead-reckoning computer updated by present position inputs from navigation sensors. The most probable nav-aid will be an improved VOR/DME system with barometric altitude providing the 3rd dimension. Control to a pre-planned flight schedule - part of the flight plan - is a fourth dimension of time, and will control ground speed through thrust variations so that the flight plan will be made good to the required tolerances. Final approach and landing guidance will be obtained from a microwave landing system now under current development.

During flight, progress will be shown on solid-state displays that provide TV-like presentations of aircraft attitude and flight parameters and a navigation display showing progress along the chosen route in three dimensions. A calibrated slow/fast display will show time progress. In the fully automatic mode, automatic mode switching will be accomplished, although one may revert to manual flight control and direct use of the navigation/instrumentation systems. While VOR/DME is considered the most probable source of position fixing, it is recognized that a satellite system may come into being that will provide the required accuracy. Also, the Omega system will be operational during this time-period, and, with development of proper airborne hardware, could provide the necessary navigation fixing.

The flight operation just described will be performed by many aircraft in common airspace. It is the function of the air traffic control system to assure that these aircraft are safely separated. The normal procedure is for each aircraft operator to file a flight plan that is accepted or modified as necessary to resolve conflicts. The probable means for tracking all aircraft will be an improved ATC radar beacon system that will provide both altitude reporting and individual aircraft identification. A communications link between the aircraft and the ATC system is necessary to complete the control function. The ATC system of 1985 will be highly automated. It will maintain automatic track of all aircraft under control and probably conduct conflict predictions and provide flight path changes to resolve the conflicts. Under these conditions, a data link can inject flight path changes directly and automatically into the aircraft guidance system. If the ATC system of 1985 does not include automatic conflict resolution, this function will be accomplished by human intervention over voice communications channels. In any case, voice communications will continue to be available as a back-up mode.

What has been described is the full IFR mode of operation. General aviation aircraft will continue to operate VFR in "mixed" airspace where some aircraft are operating under instrument flight rules. Because of the hazards evident

even today, a concept of intermittent positive control (IPC) has been proposed by the Department of Transportation Air Traffic Control Advisory Committee (Reference 5.4.7) This concept allows VFR flight with free movement of aircraft, but with all aircraft being automatically tracked, threats determined, and commands being given to the aircraft via a data link to resolve the conflict. The mechanism to accomplish this is an expanded capability ATC beacon system that includes 3-dimensional tracking, individual aircraft identity, and a data link providing individual aircraft addressing.

5.4.1.1 The National Airspace System - Introduction - The National Airspace System (NAS) is the assembly of equipment, installations, people, procedures, and regulations that make up a system to control the movement of all aircraft flying under instrument flight rules (IFR) in the U.S.A. The NAS also provides some services to aircraft operating under visual flight rules (VFR). The system is developed, installed, and operated by the Federal Aviation Administration (FAA). (Reference 5.4.5) All users of the airspace - airlines, general aviation, military - make use of the NAS as their needs dictate. The cost of the system operated by the FAA has been borne by the Federal Government, and the cost of the airborne part of the system has been and will continue to be borne by the user. Recently the Congress enacted legislation that will impose user charges on the airlines and general aviation to cover the approximate costs of the ground portion of the system chargeable to these segments of aviation. The users have always had a strong voice in determining the nature of the NAS. Now that the airline and general aviation interests are paying additional amounts, they will demand an even stronger voice.

The NAS has been beset by many troubles during the last decade. Governmental expenditures for airways facilities were decreasing each year through the 1960's, while the air traffic was increasing. The crunch first became readily visible in 1968 and has been intensifying ever since. There is no visible way for the situation to get better for a couple of years. The immediate push is to train more controllers and the FAA is doing this. Unfortunately, it takes considerable time to train a controller to full journeyman status. The real "solution" to the problem is, of course, to develop and expand the system to the point where the volume of traffic can be handled with delays that are acceptable, and at the same time up-grading the level of safety of the system. This process is under way, but it will be some time before the effects are fully felt in the field. A thorough review of the situation is contained in the Twenty-Ninth Report by the Committee on Government Operations, 91st Congress, 2nd Session. (Reference 5.4.44).

Planning activity under way includes the recently enacted Airways and Airports Modernization Act, which opens the door to a major improvement in the NAS by making funds available, on a stable basis, for research and development, and for implementation of facilities and equipment. This will allow the plans that have been and are being made to be implemented. The FAA established their Annual National Aviation System Planning Review Conference beginning in April 1969 and continuing in April 1970. The material covered by these conferences is contained in National Aviation System Plan documents published in January 1969 and March 1970.(References 5.4.5 and 5.4.6.)In addition, the Department of Transportation established its Air Traffic Control Advisory Committee in the summer of 1968. The committee's report was published in December 1969. (Reference 5.4.7) While parts of this report remain controversial, nevertheless, it is a milestone report and is the best guide available to the probable course of development and implementation for the NAS.

Probable Course of Development - The NAS will continue with programs presently under way, since they are generally proceeding along necessary lines: continued automation of the data handling in the ATC centers; continued improvement in nav-aids and implementation of area navigation; continued implementation of altitude reporting - air and ground. On a longer term basis more innovative changes will take place as they evolve from present and future planning and development. Satellite systems are being increasingly viewed as candidates for surveillance, communication, and/or navigation.

New Airspace Concepts - A new concept that is especially significant to General Aviation is recommended by the D.O.T. Air Traffic Control Committee. This is the concept of Intermittent Positive Control (IPC). IPC is applied to VFR airspace and requires a data acquisition system that provides the ATC Center with identity, position and altitude information on all aircraft in the designated airspace, and the ATC computer, through a data link, automatically advises aircraft of threats. The DOTATC Committee recommends expanding the capability of the ATCRBS to include the data link and identity functions. This is an evolutionary change to the present system to provide a major airline aircraft normally fly under an IFR clearance and general aviation aircraft commonly fly VFR.

Navigation - VORTAC is the U.S. and ICAO standard short range Nav-aid. There is good reason to believe it will retain this status for decades. Its implementation continues to be expanded in the U.S. and abroad. A major improvement in its capability has been initiated by the recent introduction of area navigation to the NAS. R-NAV will be increasingly used by general aviation. Some single engine and many light twins will use the simpler, course-line computer types. High performance general aviation jets may be as well equipped as medium size airline jets. The VOR portion of VORTAC is being improved in accuracy both in the ground as well as the airborne elements of the system. (Reference 5.4.23). This will allow increasing precision of navigation in the decade ahead.

Satellites have considerable potential for navigation, but will likely be put to use first serving airline type operation on over-ocean routes. Eventually, satellite systems may have application to the domestic air traffic control system.

The Department of Transportation has recently (May 1970) released its NATIONAL PLAN FOR NAVIGATION (Reference 5.4.43). It covers the areas of responsibility of the Federal Aviation Administration and the U. S. Coast Guard. It presents a plan for the operation, development and implementation of existing and possible future navigation systems for civil aviation and maritime requirements.

ATC - The air traffic control function will demand an increasing implementation of the altitude reporting feature in the airborne ATC transponder. Future development will cause the ATCRBS to be modified to accomplish the Intermittent Positive Control concept if that concept is adopted. The major ATC changes will be increased automation in the ground environment aimed at the continued reduction in routine data handling by air traffic control personnel. The introduction of data link will contribute to automation by transferring the routine type voice communications to the data link. Segregation of airspace based on aircraft capabilities will continue to be a part of the NAS. The high performance general aviation aircraft will be well equipped and will fly without inhibition in the system. Aircraft of lesser performance will be the major problem area due to economic as well as weight and space limitations.

Communication - VHF voice communications will continue in use indefinitely. The need for more channels will cause 50 khz and then 25 khz channel spaced equipment to be generally available to general aviation aircraft. Satellite communications across the oceans will be introduced and will be used occasionally by general aviation aircraft. A data link will be introduced and will provide ATC communications for use in IFR airspace. Its installation will likely be mandatory in some airspace eventually. However, smaller General Aviation aircraft will always have access to some categories of airspace using voice communication only. Solid state equipment will continue to be used, with evolutionary improvements in reliability and some size reduction will occur.

5.4.1.2 General Aviation's Status

The world of General Aviation is a highly diversified one from an avionics standpoint. There are a few large high performance transport category aircraft operating as general aviation aircraft that are avionics-wise equal to equivalent airline aircraft. Their avionics is airline-type and is of little concern here. General aviation ranges on down through the spectrum to small single engine aircraft with little to no avionics. The center of the problem area is with the larger single engine and the smaller twin engine aircraft, in which operators desire to fly in congested areas and at times on instruments. Here economics is the direct or secondary controlling factor. The cost of a complete avionics installation suitable for reliable IFR operation represents a considerable dollar cost as well as consuming valuable weight and space in the airframe. Avionics manufacturers supplying the general aviation market exhibit a diversity of equipment to select from. The higher priced lines are generally qualified to FAA Technical Standard Orders (Reference 5.4.24) and are satisfactory for IFR operations. A lesser quality and lower priced line of equipment is available from several manufacturers. Its major usage is in single engine aircraft. Equipment price is a very sensitive parameter in general aviation avionics. Factors that increase performance and reliability yet hold the line on cost and weight are much to be sought after.

5.4.1.3 Integration of Man and Machine

What is meant here is configuring the airplane so that it matches the characteristics and needs of the man in the pertinent flight regimes. Aspects of integration include layout of instruments and controls, selection of control modes, simplification of control activities, and integrated presentation of information. For the latter purpose, the cathode ray tube (CRT) shows considerable promise. Attitude related data, now presented on the attitude director indicator (ADI), can be presented on a CRT with great flexibility of arrangement. This flexibility of arrangement can be a curse, since it tends to inhibit standardization. This, in turn, is not conducive to safety but will be confusing to pilots who are called on to fly different arrangements. Horizontal situation-related data can also be presented on a CRT. Now that vertical guidance is about to become a functional part of area navigation, a new problem is presented: how is vertical navigation guidance best presented? One problem that is present with the CRT is that brought about by the extreme range of illumination that must be dealt with from black of night to full sunlight at high altitude.

5.4.1.4 Conceptual Design Sensitivity Factors

- Automation vs. Manual Operation - The incentive for automation comes from the increasing complexity of operating more advanced airplanes and the more involved operations in the air traffic control system. A classic example of automation is the autopilot. Stability augmentation systems (SAS) will play an increasing role

in the future. Other possibilities for simplifying the pilot's task would be providing a speed control that programs lift devices and power settings, or maneuvering controls similarly related to these devices.

Area navigation is opening up a new arena for the increasing use of automation. The simplest computer that is practical is probably the one that accepts way point data on two waypoints - the one in use and the one coming up next. This is feasible, but it requires the pilot to set up a new waypoint every time he passes one. There are operational situations, such as entering a terminal area, where this could be burdensome. The airlines, in their Mark I R-NAV system (Reference 5.4.15), have specified that a storage capability of at least six waypoints be provided. Their Mark II system (reference 5.4.16) is capable of storing hundreds of waypoints as well as data on hundreds of VORTAC facilities. One arrangement that has been proposed for the Mark I R-NAV would use a plastic card with a magnetic oxide surface on which waypoint data is recorded before takeoff. The card is inserted in a slot in the R-NAV control panel and read into storage by pressing a button.

Single pilot aircraft flown on IFR represent a difficult design problem since one man must manage everything including two engines in the case of light twins. The single engine aircraft, in a slightly different sense, is also a severe design problem because this aircraft can least afford the cost and weight of automation aids.

Redundancy - Redundancy in general aviation aircraft has been used for a long time - two engines, dual VHF navigation and communication, etc. More sophisticated forms of redundancy are used in airline and military aircraft where continuity of service is demanded for safety or mission performance reasons. Dual redundancy is used where a fail-safe situation is acceptable. Here, a failure in one of the channels is detected by a parallel monitoring channel and the fault annunciated or the system disconnected. A dual system is acceptable where its loss permits continued operation even though with less efficiency or convenience. Triple redundancy is used where a fail-operational capability is needed. Three parallel channels, suitably monitored, can detect a faulty channel, and annunciate and isolate it. This leaves dual channels still available and now operating in a fail-safe mode. The flight crew would, of course, be alerted and since triply redundant systems are installed only for very critical systems, the first failure would be a signal for some change in flight plan. For example, if the system is required for continued safe flight, a landing at the next available airport might be the action. The above concepts will, undoubtedly, see increasing application in general aviation aircraft.

It is worth pointing out that there are situations where dual systems are fail operational. This occurs where an independent means exists to detect which of the dual systems failed. This may be true in the examples given at the beginning of this section. Another example

would be a two-engine, two-generator airplane where the failure of a single generator could very well allow the airplane to continue in a normal operational manner, but with a reduced level of safety.

Integration of Systems - This subject means different things to different people. There are two meanings that can be attached that are useful here.

- Integration in a technical sense
- Integration in a human factors sense.

In regard to technical or engineering integration, there is a major controversy underway on the national level. It is Universal Integrated Comm/Nav/Ident (UCNI) (Reference 5.4.18) vs. the Super Beacon System (Reference 5.4.7) vs. satellites for domestic ATC (Reference 5.4.17). The contest is going on in the D.O.T./FAA/NASA Washington, D.C. arena with D.O.D., the airlines, general aviation, and the avionics industry all involved in accordance with their individual interests. It is important that the controversy be resolved as soon as possible so that NAS development and implementation can proceed. Closely related to this system integration subject, but still to a degree independent of it is the concept of integrating many aircraft functions into a central general-purpose computer. The advent of small, versatile airborne digital computers based on solid state microminiaturization techniques has made this readily possible. Further developments in such computers will make this sort of thing even more attractive for the future. The question is not whether digital computers will be used, but how they will be used. The operational application of the aircraft is a major factor in determining the degree of integration. E.g., a single engine air-superiority fighter might logically use a substantial amount of integration. A multi-engine airline aircraft, due to safety and economic constraints related to dispatchability, is not a good candidate for centralized digital computer integration. Some background material on this subject is contained in References 5.4.19, 5.4.20, and 5.4.21. The safety constraints that require independence of system function in transport category aircraft generally apply to general aviation aircraft. A broad rule is that a failure in one essential system should not cause loss of function in another essential system.

Human factors integration refers to the interface between pilot and the aircraft. This can, to a considerable degree, be independent of the technical level of integration - in fact it is important that this be so. Presentation of information and actuation of controls should be standardized in the interests of pilot proficiency and from a piloting standpoint, technical integration practices are of secondary importance.

Two main instruments that are used in modern aircraft are the attitude director indicator (ADI) occupying the top position directly in front of the pilot, and the horizontal situation indicator (HSI) just below the ADI. Up to the present these instruments have been electromechanical in nature, but much effort is being directed towards cathode ray tube (CRT) replacements for both instruments. The electronic ADI (EADI) is already in flight test status. It will probably see operational use in the next year or so in an airline aircraft or a multi-engine general aviation aircraft.

The electronic HSI (EHSI) is taking a somewhat different development route. The airlines, and the avionics manufacturers supporting them, are developing map displays to be an optional attachment to an area navigation system. The purpose of the map display is for pilot orientation and will be useful mainly in the terminal area.

They are being developed as moving chart, optical projection, and CRT types. Initial implementation will see a single installation with the conventional HSI remaining. The next step could well be to replace this HSI with an EHSI and eliminate the map display orientation aid.

A further step could be to make the EADI and EHSI identical electrically and mechanically so that they were physically interchangeable. This would reduce spares requirements. The aircraft installation design could be made so that in case of failure, the basic functions of the failed instrument could be switched into the still functioning one. This approach has both economic and operational benefits.

- Standardization - Standardization has much to offer in two areas: operational and technical

  - Operational - What is meant here is, basically, cockpit standardization. This is a broad subject and should not be approached from the avionic/instrumentation viewpoint. The SAE has had committee work in this field for many years. Committee S-7 has directed its efforts to transport category aircraft. The more recently established Committee A-23: "Cockpit/Cabin Standardization - General Aviation Aircraft" is also active. Its work should be encouraged.

  - Technical - The airline industry through the medium of the Aeronautical Radio, Inc. (ARINC) airlines Electronic Engineering Committee (AEEC) has had an effective mechanism for the standardization of avionics for many years. The Radio Technical Commission for Aeronautics (RTCA) has carried on a coordinating activity in aeronautical electronics with its beginnings before World War II. See Reference 5.4.22 for further information.

    A standardization activity for general aviation similar to the ARINC AEEC work could have considerable economic benefits. The situation is somewhat different in general aviation in that the interests that would have to get together are fragmented and are of more diversified viewpoint. It appears that it would at least be worth exploring the possibilities through the medium of RTCA.

5.4.1.5 Application of Advanced Techniques

- LSI - Large scale integration (LSI) refers to the state of development that solid state electronics has reached at the present time. This is a complex and rapidly moving business. It had its beginning in the invention of the transistor two decades ago. It has developed a tremendous mementum, and it is probably rather futile to try to be very specific about how things will be 15 years from now.

  Present trends clearly indicate that small (a few pounds), versatile digital computers will see increasing application. Some of them will be general purpose and others will be a fixed program type depending on application. Reliability must increase at a rate greater than complexity does or all is in vain - and there must be a decreasing cost trend.

- Digital vs. Analog Techniques - The industry is in the midst of a change over to digital techniques for computation, data transfer, and display. Such things as digital air data computers and inertial navigation computers are seeing service in transport category aircraft, some of which are in general aviation aircraft. These devices will filter down into the smaller aircraft as cost and weight are reduced. Digital autopilots are definitely on their way. Even though digital techniques are here to stay and their use will expand, analog devices of an integrated, solid state nature are also developing and will continue to do so. Operational amplifiers, intermediate frequency amplifiers, and major segments of television receivers are now built on a chip. It should not be forgotten that nature is basically analog - temperatures and pressures along with aircraft control surfaces vary in a smooth and continuous manner.

5.4.1.6 Safety

The subject of general aviation safety is addressed in Section 5.8. This subsection applies only to that which is governed by avionic systems.

Redundancy is widely used in avionics system design. It can be applied in a number of ways. Operational redundancy is illustrated by an airplane with a single navigation system, a single communication system, and a single ATC radar beacon transponder. The failure of any one of these systems is compensated for by the

others together with the necessary procedural changes. If the navigation system fails, the pilot can be directed by radar vectors from the ATC controllers. If the communication system fails, the pilot is required by regulation to hold to his flight plan as it existed at the time of failure and ATC maintains clear airspace on this basis. If the ATCRBS transponder fails, the aircraft may be tracked by primary radar with a pilot report providing altitude, or the pilot may provide his complete position from his navigation system and instruments.

Dual systems may provide a fail-safe or a fail-operational capability depending on circumstances. A dual-channel monitored autopilot is fail-safe during a Category II landing where a single failure would normally cause an annunciated disconnect. In cruise mode, time, altitude and procedures may allow isolation of a single fault so that automatic single channel flight may continue, thus giving a fail-operational capability from a dual channel system. A dual, independent radio communication system is normally fail-operational since a single failure in either system is readily detectable.

A good discussion of the proper uses of redundancy for safety is given by N. Braverman of the FAA in Reference 5.4.19.

Self-Test - A self-test system is an integral part of a particular system or equipment which may be used to determine functional performance of that system or equipment. Self-test may be in two forms:

> Pilot's Self-Test - A self-test system for use on the ground or in flight by the flight crew.
>
> Maintenance Self-Test - A self-test system for use on the ground by maintenance personnel for routine check-out or trouble shooting. This may be the pilot's self-test, or it may be a system testing the removable units of the system individually.

Integrity Monitoring - This is the function and circuitry within an equipment which is intended to provide a continuous check on the performance of the equipment and which warns when unsatisfactory performance occurs.

ARINC characteristic 578, the latest airline ILS receiver specification (Reference 5.4.39), provides an example of the most advanced state-of-the-art integrity monitoring. It defines a receiver suitable for future Category III all-weather landing systems. The monitor integrity requirements, quoted below, are the most stringent known and are considered necessary for this critical landing use:

"3.5.3 Monitor Integrity

Both localizer and glide slope monitors should be designed such that the calculated Mean Time Between Undetected Failures (MTBUF) of the guidance channel AFCS deviation outputs and the associated monitors of the ILS receiver is not less than 10^6 hours, the equipment designer's goal being the full monitoring of the guidance channels. The MTBUF calculation should be the result of a failure mode and effect analysis which includes:

(a) Passive and active components open and short and/or
(b) Most probable changes of component values and characteristics which would result in the receiver exceeding its specified performance-limits. "

Detailed requirements and recommendations for other avionic systems are contained in ARINC Report No. 415-3 on the subject of failure warning and functional test. (Reference 5.4.40).

5.4.1.7 Reliability

A minimum level of reliability is a necessity, and, of course, 100% reliability is the desired goal. It is now known how to design to a specified reliability requirement and how to demonstrate achievement of it by testing programs. (Reference 5.41). It is an expensive process, however, and is not, and probably cannot, be applied to general aviation avionics. The general aviation industry is highly competitive. Cost of equipment is important. At the same time the user demands satisfactory performance from the avionics he purchases. Most manufacturers are conscientiously striving to produce quality equipment within the price range they have chosen to compete in. The manufacturers of the higher priced lines of equipment usually secure FAA Technical Standard Order approval. Those who serve the lower priced segment of the market generally do not. There has been a desire on the part of the regulatory authorities to change the regulations to require approved avionics in general aviation aircraft for many years. There is little doubt that this would improve the quality and reliability of avionics, but whether the improvement is worth the cost has been a debated point for a long time. Action and plans are under way to produce a more satisfactory situation. The RTCA, through its Special Committee 116, is preparing Minimum Operational Requirements (MOC) for avionic systems. MOC's have been issued by RTCA for five avionic systems (Reference 5.4.45). Two of these MOC's have been referenced in FAA Advisory Circulars (Reference 5.4.46) as one means of demonstrating compliance with the referenced requirements. The FAR's at present do not require compliance with these Minimum Operational requirements, but there are indications that this situation is changing. The October 1970 issue of the AOPA PILOT contains an article (Reference 5.4.47) that indicates FAA has Notices of Proposed Rule Making (NPRM) that "could, for the first time in aviation history, lead to the formal establishment of mandatory Federal "Minimum Operational Characteristics" (MOC) for electronic equipment installed in general aviation aircraft." Facets of the reliability problem include:

- Redundancy - Redundancy does contribute to reliability. Where two independent systems of like nature are installed, the probability of a single failure is doubled, but the probability of complete loss of service (requiring two failures) is substantially reduced. Operational redundancy can be achieved by the use of multiple dissimilar systems, as was discussed in Section 5.4.1.6 entitled: Safety.

- Relation to Safety - A reliable system is not necessarily a safe system. A system that has an occasional undetected failure is unsafe to the extent this occurs. Braverman in reference 5.4.19 brings this out clearly. A system of only modest reliability can be a safe system if its failures are always known and a backup exists.

- Reliability Achievement - Reliable equipment must start by use of reliable parts. Parts that are in large-scale production under carefully controlled conditions that have a known history of high relisbility in service should be selected. This means that especially built parts are not good selections. The design and construction must be such that the parts are operated conservatively as far as electrical and environmental stresses are concerned. General aviation aircraft are outdoors most of the time, and the exposure subjects them to temperature and humidity conditions that can, over several years, cause failure of electrical components and intermittent high resistance contacts in switches, potentiometers and plugs.

5.4.1.8 Economy

The cost of avionics is in the original cost and installation in the airplane plus the cost of maintenance. Original cost is controlled by producing a simple and straight forward design and achieving a production rate that is in the mass production category. This allows the production people to become proficient and the development costs to be spread over a large number of units. The design should standardize on components in large scale production to take advantage of the lower prices that will result. Maintenance costs will continue to be a problem. Avionics must be built compactly so that unless clever design concepts are used, many components will be difficult to change. The installation in the airframe is often crowded with equipment inaccessability a serious problem.

5.4.1.9 Maintainability

Relation to Economy - Until avionics are developed that require no maintenance, the cost of keeping it operating will be a continuing expense. This millennium is not yet here and careful consideration must continue to be given to accessability and ease of adjustment.

Relation to Safety and Reliability - Maintainability has a direct bearing on both safety and reliability. If maintenance is difficult to accomplish, it will inevitably be poorly done as a general rule. The result is poor or no performance when the equipment is needed and then a repeat of the maintenance operation is required.

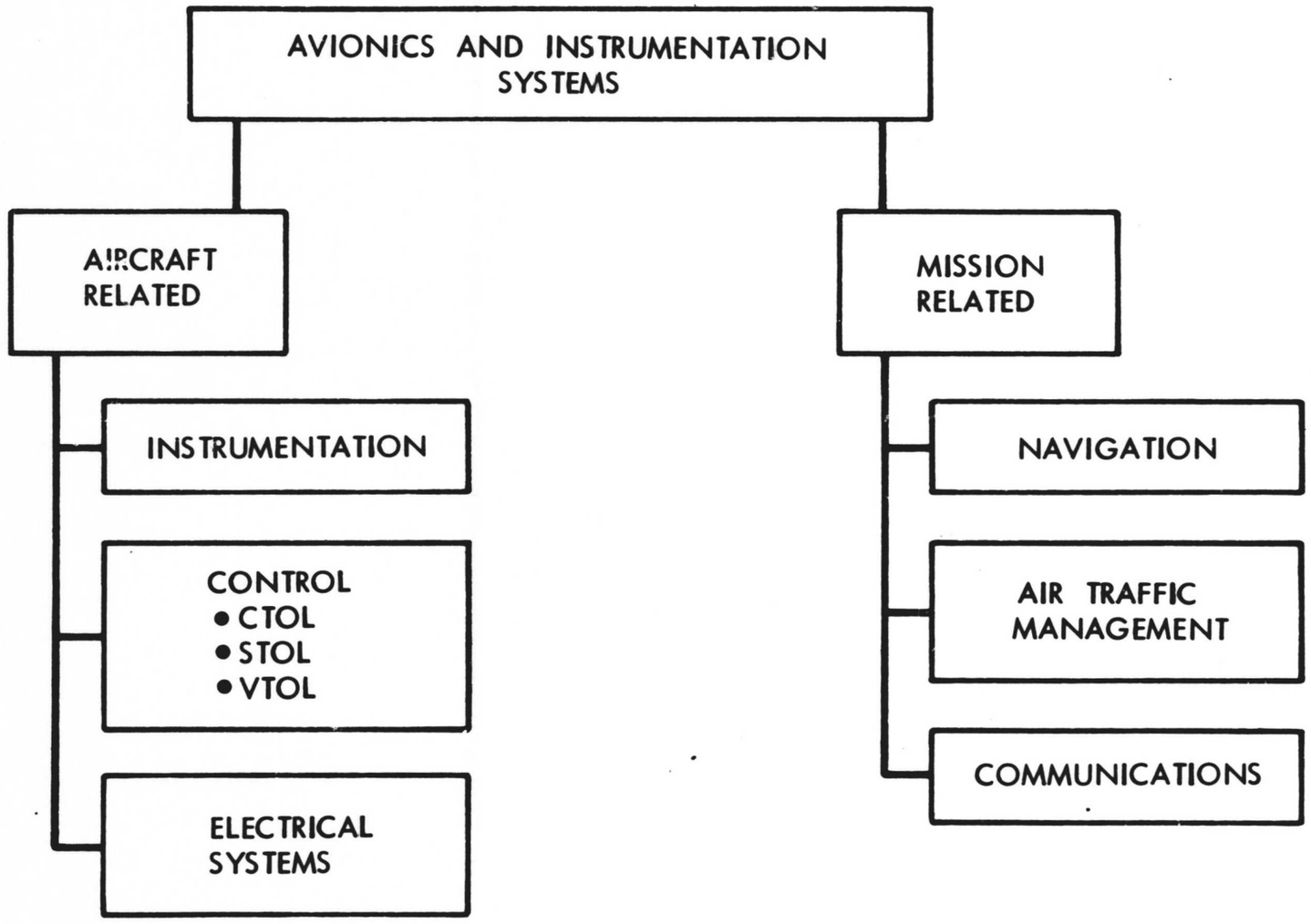
5.4.1.10 Systems Classification

Classification - Avionic systems can be conveniently classified into aircraft related or mission related. Figure 5.4.1 shows this division.

Aircraft Related Systems - What is meant here are systems that are basic to the aircraft independent of the way the aircraft is to be used. Obviously, a basic one is the electrical generating system. Also falling in this category

FIGURE 5.4.1

AVIONIC SYSTEMS CLASSIFICATION



are systems that provide heading, attitude, airspeed, altitude, and others relating to direct and immediate control of the aircraft such as basic autopilot, stability augmentation and similar items.

Mission Related Systems - Systems in this category are those that contribute to the operational use of the aircraft. Or, more specifically, those systems that allow the aircraft to move freely through the National Airspace System. These, of course, include those systems that provide navigation, communication, and air traffic management functions.

5.4.2 Aircraft Related Systems

5.4.2.1 Instrumentation

Flight - Flight instruments are those basic to providing visual information for pilot control of the short term movements of the aircraft. These include maintaining straight and level flight in a desired direction and airspeed, and accurately controlled turns climbs and descents. This is in contrast to navigation avionics which provides geographical position of the aircraft and information for its guidance. Flight instruments include:

Artificial Horizon - Artificial horizons - attitude indicators - have been in use for many years. They have been improved over the years, but they still possess inherent limitations in their usual implementation in general aviation and many airline aircraft. The best available attitude signal sources are derived from inertial quality gyros that are used in inertial navigation systems such as the ARINC 561 type (Reference 5.4.27). These are now and will continue to be out of reach of most general aviation aircraft users for many years. The limitations of the usual vertical gyros stem from the drift rate in a free mode. This results in the use of gravity type sensors that torque the gyro to the dynamic vertical. In straight and level flight and for turns of short duration, adequate performance is obtained. A sustained turn will result in erection toward the dynamic vertical with false guidance information resulting. It may be that this limitation in V.G.'s is one reason why holding patterns are race-tracks rather than circles - the straight segments are needed for re-erection of the gyro. Error in pitch is present under the accelerations of take-off also. Erection cut-off sensors are sometimes used during periods of acceleration and are helpful if the quality of the gyro is adequate for the situation. There are no significant attitude problems of this nature for CTOL aircraft during approach to landing. However, there may be a problem with STOL aircraft where a relatively high cruising speed must be reduced to well under 100 knots over a short approach distance. The limiting factor on these accelerations should be what the crew and passengers will tolerate and not hardware limitations. It is probable that the conventional vertical gyro will continue to be the main source of a vertical reference in most general aviation aircraft.

Compass - The earth's magnetic field is, and will continue to be, the source of heading reference in general aviation aircraft. The VOR system and the airways will continue to be referenced to magnetic north. Those few aircraft operators able to afford inertial navigation systems will have true north available to them. This will be mainly useful for long range flight outside the continental U.S.A. The gyro-magnetic compass will continue to be used for instrument flight purposes, while the fluid stabilized magnetic compass will continue as a standby and backup and as the primary heading reference in some aircraft that are flown VFR only. There probably will not be appreciable improvements in gyro-magnetic compass accuracy because instrumentation errors in the better gyro-magnetic compasses today are comparable to the anomalies in the earth's magnetic field.

Air Data Systems - Historically, general aviation aircraft have obtained airspeed, altitude, and vertical speed from individual pneumatic-mechanical instruments operating from dynamic and static pressure sources. These instruments will continue in use since they have reached a rather high state of development. Their performance is described by the pertinent FAA Technical Standard Orders (References 5.4.28, 5.4.29, 5.4.30) as the minimum acceptable for IFR flight.

Of recent years, central air data computers have come into wide scale use in transport category aircraft. In addition to dynamic and static pressure, they make use of outside air temperature so that parameters depending on temperature, Mach number and true air speed, can be computed.

Altitude - A particularly critical flight parameter is altitude. On its accurate measurement depends safety of flight in regard to vertical separation. Present airways vertical separation standards are 1000 feet up to 29,000 feet MSL with 2000 foot separations above 29,000 feet. Reducing separations to 1000 feet above 29,000 feet would double the available airways there. This would be a tremendous help, particularly over the North Atlantic routes. In spite of considerable effort in this direction, such a reduction does not appear immediately feasible. Further discussion on this subject is in Reference 5.4.7, Volume 2, Appendix C-6, entitled: Altimetry.

A relatively new requirement exists for digitized altitude to be used for altitude reporting purposes through the air traffic control transponder beacon. It is likely that all IFR aircraft eventually will be required to carry this capability. Altitude is digitized in accordance with international standards and is referenced to 1013.2 millibars (29.92 inches of mercury). See Reference 5.4.31 for further details. Since altitude is referenced to actual MSL pressure for the lower altitude routes, the

ground ATC system must make the necessary correction so that the aircraft-reported altitude can be properly compared to its assigned altitude. On high altitude routes, where 1013.2 millibars is the reference, no ground correction is required.

Flight Director - Flight directors have been developed over the years to provide guidance commands to the pilot to allow him to adhere accurately to a desired flight path. The computation involved is similar to that in the autopilot and, in fact, in recent years the same computer has been used to supply command signals for automatic control and instrumentation readout. The flight director commands are displayed as a part of the artificial horizon. The detailed method of display varies considerably from designer to designer and tends to be proprietary in nature. Flight directors are now in use in general aviation aircraft and will continue to be. Evolutionary improvements in the electro-mechanical type of presentation will continue. Electronic displays are being developed and are discussed below.

Integrated Displays - Much development effort is going into the use of cathode ray tubes (CRT) for integrated displays that are in some cases similar to present-day electromechanical attitude director indicators (ADI), but because of the inherent flexibility available through modern TV and digital techniques, the designer has many choices in the type, quantity, and manner of presentation. For example, a CRT display has been demonstrated with the artificial horizon across the middle with a synthetic pattern above and a live TV picture looking down the approach and landing path below the artificial horizon line. Other parameters, such as airspeed and altitude, can be easily added. Displays of this type are, of course, quite expensive in terms of what can be afforded in typical general aviation aircraft at the present time. They will see service in the near future in advanced transport and military aircraft. There is every expectation that this general category of display will eventually be within the general aviation price range.

One problem area is inherent in the flexibility with which CRT type displays can be synthesized. There has been displayed over the years a diversity of opinion on how flight directors should be configured. Because of the electromechanical nature of the present type of ADI, a considerable constraint is imposed on those who want something different. This constraint will be considerably relaxed for the new electronic types. A diversity of presentations in the industry is not desiarble from the safety and training standpoint. Industry efforts to control this situation through the development of standards would be highly desirable.

Another form of integrated display that is highly refined in electromechanical form is the horizontal situation indicator (HSI). Another operationally related device is the pictorial display. There are two forms of pictorial displays that have

been highly developed: the moving map and the optical projection type. There is a trend towards use of a CRT for this type of presentation - probably prompted by the high degree of flexibility of this method. The ARINC AEEC has a pictorial display characteristic in work that is intended to interface with the ARINC Mark I, II, and III area navigation systems.

CRT's have a drawback in aircraft service. They are fragile, and they are awkward devices to mount in a cockpit instrument panel. Developments in light-emitting solid state technology show promise as a replacement for the CRT that would overcome these two deficiencies.

5.4.2.2 Control

- CTOL Aircraft - Flight control of conventional take-off and landing aircraft is in a reasonably mature state. Control of the surfaces by direct cable control is standard for general aviation aircraft. There is a wide variety of autopilots available to the single and light twin engine aircraft users. (Reference 5.4.32). They start with simple single axis stabilization and run the gamut up through the three axis with multimode capability. It is believed that the normal competetive forces in the avionics industry will provide most of the incentives needed for continued development and refinement in the AFCS/FD area. The complete elimination of direct cable controls (fly-by-wire) may eventually come to meet specialized needs, but it is likely to be a fall-out of developments in the V/STOL area where requirements tend to push more in that direction.

  There is some interest in applying anti-skid systems to light aircraft, and there is no reason why this cannot be done successfully with worthwhile benefits. The heart of an anti-skid system lies in solid state microelectronics which can be small and light enough for even single engine aircraft with proper development.

- STOL Aircraft - Instrumentation and controls suitable for full IFR final approach and landing are to some degree available, but much additional work is needed. A problem area is the rapid deceleration and accurate flight path control required during a short approach that may be a curved path, flare, and landing. How is the required flight control action best presented to the pilot? What is required in the automatic flight control system, including speed control, to make the transition to a landing? How are vertical navigation progress and commands best displayed? An approach to answers to these questions is given in Reference 5.4.33 entitled V/STOL Vertical Situation Display. How can control be exercised to a time schedule to fulfill a flight plan-assigned landing time? Future requirements seem to dictate that answers to these questions be achieved in a suitable sensor/computer combination - and the computation will probably be predominantly digital. Full fly-by-wire may be the way to go if the safety and reliability requirements can be accurately stated, and if the designers can meet them within economic restraints.

- VTOL Aircraft - Instrumentation and controls suitable for full IFR transition and landing are in a developmental stage with much to be done. For example, Reference 5.4.34, entitled: VTOL Flight Investigation to Develop a Decelerating Instrument Approach Capability, describes NASA's program with a CH-46C in-flight simulator. In the CONCLUDING REMARKS of this paper is found the following: "Tests performed with an in-flight simulator have demonstrated that pilot-in-the-loop decelerating approaches can be performed to an instrument hover at the pad by augmenting an available situation display with control-command information. It should be emphasized that these tests were largely exploratory, and the system was developed only to the point necessary to define the nature of problems associated with performing decelerating approaches. The performance results presented in this paper, therefore, should only be considered indicative of the potential of this display/control concept - not its ultimate capability."

  In addition to the above, Reference 5.4.35, entitled: Control Characteristics of Vectored Thrust V/STOL Vehicles in the Transition Regime, contains the following significant statements: "Perhaps as a consequence of the difficulty of controlling airspeed and vertical velocity in transition flight, no V/STOL vehicle to date has demonstrated the ability to operate on steep flight paths during landing and takeoff under instrument flight conditions. This position is untenable in a vehicle whose main purpose is to operate from limited sites in all weather conditions."

  "A revision of power and thrust vector control engineering appears overdue and offers to improve the V/STOL vehicle's ability to fly accurately at that airspeed and flight path best suited to a particular operation terminal requirements."

  The instrument and control problems associated with VTOL aircraft bear similarities to those of STOL aircraft, but there are differences also. The main divergence is associated with the final flare and touchdown. A STOL aircraft landing bears considerable resemblance to that of a CTOL aircraft in that the STOL touches down on a runway (although short) with a substantial forward velocity. A VTOL aircraft arrests its forward velocity essentially completely at touchdown, or before. The landing control design problem can be further complicated by aircraft designs that can be operated as VTOL or STOL aircraft at the choice of the operator.

5.4.2.3 Electrical Systems

- Direct Current Systems - The first electrical system in an airplane was undoubtedly powered by a battery. To this has been added an engine-driven d-c machine. This is still true of essentially all general aviation aircraft and is likely to continue this way indefinitely. Developments in a-c systems for transport category aircraft may make it desirable to use a-c systems in larger general aviation aircraft in the future. A major improvement in d-c systems has occurred by the introduction of an a-c

generator whose output is rectified by efficient and reliable solid-state silicon diodes. This eliminates the commutator thus simplifying construction, improving reliability and reducing maintenance. Solid-state devices for voltage control have also been introduced. In aircraft with more than one generator, paralleling of the d-c outputs to a common bus with controlled load distribution between generators is standard practice. 14-volt systems are most used, but 28-volt systems are available for larger aircraft where power needs and voltage drop considerations in power distribution circuits require it.

Small quantities of a-c power is needed in many small aircraft. Rotary inverters have a long history of use for this purpose and an equally long history of maintenance expense. Solid-state inverters are now well developed and widely available and are taking over the job of supplying small amounts of a-c power in aircraft whose basic generating system is direct current.

Alternating Current Systems - Alternating current systems are well developed and in use in many military and large commercial aircraft. Alternators are engine driven through constant speed drives so that the system frequency can be held closely to 400 Hertz. It is normal practice to synchronize the generator outputs through a tie bus arrangement, but to provide for adequate utilization load division when the generators operate independently. Direct current is supplied by transformer-rectifier units in airplanes that use a-c generators as their basic power source. Two or more units are normally used to provide power source redundancy and reliability.

Application of Advanced Technology - Solid-state technology is seeing increasing use in electrical generating systems and particularly in the associated control circuitry. This trend will continue and will result in increased reliability and reduced weight.

A radical change in a-c generation is under development that eliminates the constant-speed drive. This is a variable speed, constant frequency (VSCF) system where the power is generated by a direct drive alternator and transformed in a solid-state device to constant frequency alternating current. Initial development is for military application, but ultimate availability for advanced general aviation aircraft of the future is likely.

5.4.3 Mission Related Systems

5.4.3.1 Navigation

- VOR/DME - VOR/DME is the portion of VORTAC that will be used by General Aviation. VORTAC is a co-located VOR and TACAN. Civil airway users use VOR for bearing and the distance part of TACAN, thereby getting a rho/theta position fix. Military users get both bearing and distance from TACAN. This state of affairs is the compromise worked out in the early 1950s over the conflict between military and civil aviation as to what the U.S.Standard short range navigation aid would be. VORTAC is protected by ICAO agreement through 1975, with an expected extension to 1985.

VOR is widely used by general aviation. There is a good selection of airborne VOR systems available for all categories of aircraft. Accuracy improvements in the ground and airborne equipment are moving forward, so that the future should see an evolutionary improvement in accuracy, reliability, and modest reductions in weight and cost.

DME, on the other hand, has not had as widespread implementation. It is used to some extent in the higher performance end of the aircraft spectrum, but due to the higher cost, wide scale implementation has been slowed. Recent application of solid state integrated circuits and digital techniques to airline type DME indicates coming benefits to general aviation DME. Reliable, lower cost DME of adequate performance is necessary for the future usefulness of area navigation to general aviation.

Area Navigation - Area navigation (R-NAV) was established by FAA Advisory Circular AC 90-45, entitled: Approval of Area Navigation Systems for Use in the U.S. National Airspace System, dated 8/18/69. (Reference 5.4.9) Much of the background work for this document was done cooperatively between government and industry operating through the Radio Technical Commission for Aeronautics.

Past navigational methods, based on the use of VORTAC ground facilities, produce routes which lead directly over a station. This results in restriction in routes, but was a necessity until there was a widespread implementation of DME at VOR facilities. Now that this has been accomplished, position fixing anywhere within the area of coverage of a VORTAC is done by the airborne VOR/DME installation. Now, with the use of suitable computer equipment, it is quite feasible to fly arbitrary courses within the ground facility coverage. AC 90-45 deals only with navigation in the horizontal plane, but it must be recognized that it is quite feasible to provide guidance in the vertical dimension also. Barometric altimetry is a satisfactory sensor for this purpose and it is now possible to provide guidance in three dimensions. Negotiations are under way between FAA and industry to generate guidelines for vertical navigation (V-NAV) added to AC 90-45 to make it a 3-dimensional "volume" navigation document. This will be a very important set of rules. It will be the basis for NAS navigation in the coming decade. It must be a living document - it must change as experience shows the need. V-NAV work is now going on in RTCA Special Committee 116E. (Reference 5.4.25)

The airline industry will be able to afford the hardware (and software) necessary to implement R-NAV. The corporate jet segment of general aviation will need it and want it, but will feel heavily constrained by the cost. The result will be many operators of aircraft wanting service from the NAS, but ill equipped to receive it. This is an unsatisfactory situation.

Approach and Landing - General aviation aircraft have the same overall need for approach and landing guidance that other segments of aviation have. The conventional ILS is widely used. The higher performance general aviation aircraft flown by business aircraft operators are usually equipped with airline-type ILS or equipment designed for the general aviation market, but with essentially "airline" performance.

FAA has published Advisory Circular AC 91-16: "CATEGORY II OPERATIONS - GENERAL AVIATION AIRPLANES" dated 8/7/67, (Reference 5.4.26). This sets standards for general aviation that correspond to AC 120-20: "CRITERIA FOR APPROVAL OF CATEGORY II LANDING WEATHER MINIMA", dated 6/6/66, intended for transport category aircraft. (Reference 5.4.27) The general aviation rules are somewhat less restrictive than the transport category ones.

Conventional ILS - Conventional ILS is that which is standardized by ICAO for worldwide use and is heavily implemented in the USA. FAA plans call for a total of 980 conventional ILS installations to be in service through 1980. (Reference 5.4.5) The majority of these will be available to general aviation. Since the trend towards restricted usage of a few major airports by general aviation aircraft is likely to continue, there will be some such airports not generally available.

Conventional ILS will continue to be useful to general aviation indefinitely. There will be a continuing trend to lower minimums and more use of the glide slope in addition to the localizer and markers. It is unlikely that more than a minority of single engine aircraft will operate to minimums below Category I, however. The wider installation of autopilots in the future will permit automatic flight control guidance from the ILS. Reliable and fail safe design will provide safer and more consistent approaches.

A low-cost localizer system has been developed by Cubic Corp. It is reported (reference 5.4.42) that it is now installed at five small airports and has received FAA approval for use in the National Airspace System. The installed cost is reported to be $25,000. Such a low-cost device is a welcome nav-aid for small airports.

Microwave ILS - Considerable effort has been invested in trying to find a landing aid superior to the conventional ILS. This search leads into the microwave part of the spectrum. There is a desire for the new system to provide for V/STOL, civil and military, requirements as well as for conventional aircraft, and to provide superior guidance to the runway surface.

The aviation community, government and industry, is cooperating in the Radio Technical Commission for Aeronautics to develop a precision-guidance-system concept for approach and landing and an associated signal structure. The work is being done in the RTCA Special Committee 117 (SC-117), entitled "A New Guidance System for Approach and Landing." It appears that the system selected will be a version of the scanning beam concept that has been under development by Airborne Instruments Laboratory (AIL) among others. The RTCA SC-117 system will cater to all classes of aircraft. The FAA is cooperating in this work. Assuming a successful completion, the FAA will probably adopt the SC-117 recommendations.

FAA has scheduled 62 microwave ILS and 36 V/STOL ILS through 1980 for a total of 98 installations (Reference 5.4.5). It is presumed that these will be in conformance with the SC-117 standards as finally adopted. Many of these new-type ILS will be available to the general aviation user. He will be faced with the same problem as the airline operator, however. This is the need to operate into airports, some of which will have conventional ILS only, while others will have microwave ILS only. The airline operator will probably solve his problem by carrying both systems. This "solution" is less acceptable to general aviation, however, and the more likely course of action for the latter will be a demand for more ground installations of low-priced conventional ILS.

When the SC-117 microwave ILS goes into a prototype hardware development stage, a portion of the development effort should be devoted to building and evaluating airborne equipment specifically for general aviation use.

Pilot/Navigation Interface - The design of navigation controls and indicators continues to be a challenge. The airways grow more complex and the airplane systems and controls multiply to cope with the increasing demands of airway complexity and precision of flight. The same man has to perform adequately in the more demanding environment. It would appear that the most demanding situation is imposed on the single-pilot airplane flying IFR in a congested terminal area. This would mainly include single-engine and light-twin aircraft.

The design of navigation controls and indicators must not be pursued in relative isolation. It must be done in the overall cockpit environment and it should culminate in trials in a live simulator and/or an actual airplane. There needs to be standardization in the man/machine interface. Possible ways to achieve this are discussed in Section 5.4.1.3.

Advanced Techniques - Satellites offer a promise for major improvement in the NAS. Studies have been done that show some of the possibilities for configuring such a system. (References 5.4.1 and 5.4.7)It seems inevitable that satellites will eventually play a major role in navigation and air traffic control. There is considerable controversy surrounding the subject, however. For

example, the time-scale for implementation mentioned in Reference 5.1 is 1975, whereas Reference 5.4.7 looks to 1990 as an implementation time. User cost is another such area. Estimates down to $1000 for a general aviation type installation have been made. In any case, when satellites are put to use in the NAS, they will not be unique to General Aviation. They will be a part of the common system serving all segments of aviation when fully implemented. General aviation planning should be directed to assure that the developing satellite system is fully responsive to general aviation needs.

In considering advanced techniques such as satellite systems where there are choices to be made as to the location where certain computations are done, it must be remembered that the Congress has established user charges where the NAS user will bear system costs in approximate proportion to his usage. Even though the general aviation user carries only the minimum equipment in his airplane, and the computations are done at a central ground facility, he will be paying for the computing service.

- Weather Radar - Avoidance of severe weather is a requirement of instrument flight. Weather radar in the airplane has been used successfully for this purpose for some years. While airborne radar has looked at weather from its first use, the development of weather radar for thunderstorm avoidance was done for airline use by a joint United Air Lines/RCA program in the early 1950's. This resulted in C-Band being chosen by United as the optimum frequency. There is by no means universal agreement on this, however, and the majority of weather radars in use today are X-Band. There is one Ku-Band (15.5 Kmz) available for general aviation. It is the Bendix RDR-110, with the entire system weighing 20.5 pounds. It uses a 12 inch diameter sector-scanning antenna and is advertised as having a 90-mile range. While airborne weather represents a fairly mature development situation there are a few considerations such as:

  - There is some expressed need to install a weather radar on a conventional single-engine propeller-driven airplane. This can be done by putting the radar in a pod and mounting on a wing so it can scan forward outside the propeller disc, or it might be feasible to look through the propeller disc with the antenna mounted just below the engine and faired into the cowling.

  - It may be feasible to combine the radar display in an integrated fashion in an electronic attitude director indicator (EADI) or an electronic map-type display. Operational considerations should play a major part in determining the exact configuration. There is an obvious possibility for the saving of instrument panel space here also.

Other Nav-Aids - While VORTAC seems certain to continue to be the domestic nav-aid, other aids that are now in use and will continue to show promise for the future include:

Loran - Loran A operates at 2 mhz and is a medium range, medium accuracy system that has been used for decades mainly for over-ocean operations. It should continue to be available and will see use by business aircraft mainly outside the USA. Loran C is a newer development operating on 100 khz and is longer range and higher accuracy than Loran A. It will continue to be available for over-ocean operations. It probably will not see much general aviation use. Reference 5.4.43 provides further information on Loran A and C.

Omega - This U. S. Navy system operates on 10-14 khz and will give world-wide coverage by 1972. Airborne equipment is not yet fully developed.

The National Plan for Navigation (Reference 5.4.43) indicates continued worldwide operational use through at least 1982. There will be continuing development of airborne receivers in the expectation that Omega can become the internationally standardized long range nav-aid.

Inertial Navigation - This self-contained airborne system will see use mainly in the larger business aircraft and then for long range over ocean operations. Advances in laser gyros and small digital computers which reduce cost and weight, while increasing reliability, will enhance the usefulness of INS. Hybrid systems that are up-dated by fixing nav aids, such as VORTAC, are on their way to use in airline R-NAV service and will filter down into general aviation service.

ADF - The L-MF automatic direction finder is a mature system that will be in use indefinitely. It will have a decreasing role domestically, although the continuing availability of L/MF ground stations will permit ADF's to still be useful. Outside the USA (e.g. Central and South America) there will be many places where non-directional beacons will be the only nav-aid available.

Recent studies by Electro Technical Analysis Corp. (References 5.4.2 and 5.4.3) indicate the possibility of increasing the range of operation by 2 or 3 times by the use of coherent detection techniques which provide pass bands of a few Hertz, and up to 20 db. improvement in signal to noise ratio. The resulting receiver is also considerably less susceptible to thunderstorm and own-aircraft noise. A deficiency is the inability to identify the ground facility to its maximum navigational range of usefulness. This may be a difficult problem to resolve, since it could require modification to existing ground facilities.

5.4.3.2 Air Traffic Management

- Air Traffic Control Radar Beacon System - The ATCRBS has been adopted as the U. S. National Standard system to supply position, identity and altitude on each aircraft to the ground air traffic control system. The details of the ATCRBS are well covered in Volume 2, Appendix E-5 of Reference 5.4.7. FAA has plans for the installation of a total of 255 automated radar terminal systems (ARTS II and III). See page 53 of Reference 5.4.5. A full capability transponder, which is needed for use with ARTS II and III calls for the full 4096 identity code capability as well as altitude reporting. This, in turn, requires an altitude sensor that can deliver digital altitude data to the transponder. This adds up to considerably more money than many of the general aviation users can afford. There has been a trend of decreasing prices for transponders underway for some time. Whether prices for the full system can be brought down to where all users who really need the ATCRBS can afford it is problematical. It should be pointed out that there will be casual VFR flying in less congested airspace for many years to come that will not require a transponder.

- Intermittent Positive Control - The concept of Intermittent Positive Control (IPC) has been recommended by the D.O.T. Air Traffic Control Advisory Committee (Reference 5.4.7, Vol. 1). Under IPC, conflicts between aircraft under surveillance, controlled or uncontrolled, would be predicted, safe maneuvers calculated, and appropriate commands automatically transmitted to the aircraft and displayed to the pilot. Control would be applied only when a collision is possible, hence the term "intermittent". To accomplish IPC, a redevelopment and enlargement of the ATCRBS functions would be required. Each aircraft must have its own individual identity, and an open data link must be continuously available between air and ground ready for an avoidance command if and when it is required. Study reported in Reference 5.4.7 indicates that the ATCRBS can be modified to provide this added capability. This will tend to increase the cost of the airborne equipment. Since heavy participation by general aviation is necessary for IPC to be successful, cost is a vital factor. Should the decision be made to implement IPC, general aviation needs must receive full consideration in the development and implementation program.

- Communications - General aviation aircraft participate in air traffic control communications along with other aircraft flying in the National Airspace System. Channel assignments are in the 118-136 MHz band and these assignments are made in accordance with FAA Advisory Circular AC No. 90-11A (Reference 5.4.10). This Advisory Circular recommends a 90-channel communications capability for VFR operation, and a 360-channel capability for IFR operation. The latter capability provides all available channels on a 50 MHz channel spacing basis. There is no known plan to split channels to a 25 KHz basis, but this could happen in the next decade depending on the nature of the developing NAS. If voice communication

remains the basic mode of ATC communications, channel splitting may be necessary. Planning for the future calls for increasing automation in the ATC system. This, in turn, leads to a need for a data link. The FAA, in Reference 5.4.6 pages 48-49, indicates the need for a data link that presumably would operate on VHF communication channels. However, in Reference 5.4.7 (page 7, volume 1) the D.O.T. ATC Advisory Committee recommends a data link as a part of an expanded ATCRBS and that this will handle anticipated system loads through 1990. After this, satellite systems would become operational. Obviously, important policy and system configuration decisions must be made before development can progress. As a matter of information, the airline industry is advocating a data link as a part of VHF communications. It would include two modes: one for company communications, and the other for ATC use. The Airline Electronics Engineering Committee has a draft characteristic in work for such a data link. (See Reference 5.4.11).

Voice air/ground communications will be available in the NAS indefinitely. Automation, aided by a data link, will be increasingly implemented and put voice communications into more of a back-up role. It is obvious that the planning and development that goes into the definition of the NAS must fully include the needs of general aviation.

- <u>Collision Avoidance Systems</u> - The continuing occurrence of mid-air collisions provides increasing incentive for a solution to this problem to be found. A basic purpose of an air traffic control system is to avoid collisions, of course, and the intensity with which collision avoidance systems are pursued is a measure of the basic deficiency of the ATC system.

  Collision avoidance research has been going on for many years. One major effort, carried out by the Air Transport Assn. for the airlines, appears to be a success in that the system does perform. It is a cooperative system, however, and is quite costly in its full implementation ($40,000 per aircraft). It is advertised as being able to accommodate less expensive versions with less protection down to a simple pilot warning indicator (PWI) that might cost less than $500. (See Reference 5.4.12). This ATA system should be fully evaluated for general aviation. There still remains a need for a CAS that is non-cooperative - one that an aircraft user can install in his own airplane and receive protection from all other aircraft that may be a threat. Research and development work must continue because the threat will continue indefinitely.

- <u>Clear Air Turbulence Detection</u> - Clear air turbulence is a threat mainly to fast, high-flying aircraft. Jet aircraft are the major category affected and they comprise a small minority of general aviation aircraft at present. They will be a minority for many years, but increasing in numbers nevertheless. CAT has been the subject of considerable research (References 5.4.13 and 5.4.14). Airborne equipment operating in the infrared has been developed and flight tested. The most recent equipment was service

tested by Pan American Airways, with poor results. There were too many false alarms, and not all CAT was detected. Work on CAT avoidance will continue since the problem is not going away. General Aviation's interests are essentially the same as the rest of the aviation community, and research and development efforts should be cooperative.

5.4.3.3 Communications

Communications is an air traffic control tool that has been discussed in Section 5.4.3.2. A second usage is for mission (military) or operational (airline) control of aircraft. The role of air traffic control is simply to keep aircraft moving to their chosen destinations safely. ATC has no authority to influence destination choice except in the interests of safety. General aviation usually has no requirement for mission or operational control, although some operators of corporate fleets do make use of it to a degree.

Crash Locater Beacons are on the verge of being widely required by regulation. Several states, notably California, have been active and the FAA has a draft TSO prepared for a beacon that would transmit simultaneously on 121.5 and 243 MHz. In addition, the Radio Technical Commission for Aeronautics Special Committee 119: Minimum Performance Standards - Emergency Position Indicating Radio Beacons - is making good progress. It is expected that such devices will come into universal use in the next few years.

5.4.4 General Conclusions

Present and emerging technology in the field of avionics will provide equipment for general aviation use that will enhance the utilization and safety of the airplane. The cost of this equipment will continue to be a restraining influence. An interesting fact is disclosed by Figure 5.4.2 which shows how much avionics added to the base cost of a wide variety of general aviation aircraft in 1968. While there is some scatter in the data points, the figure indicates that the cost added is about 28% of the base price. It is expected that this is a relatively stable number for projection into the future.

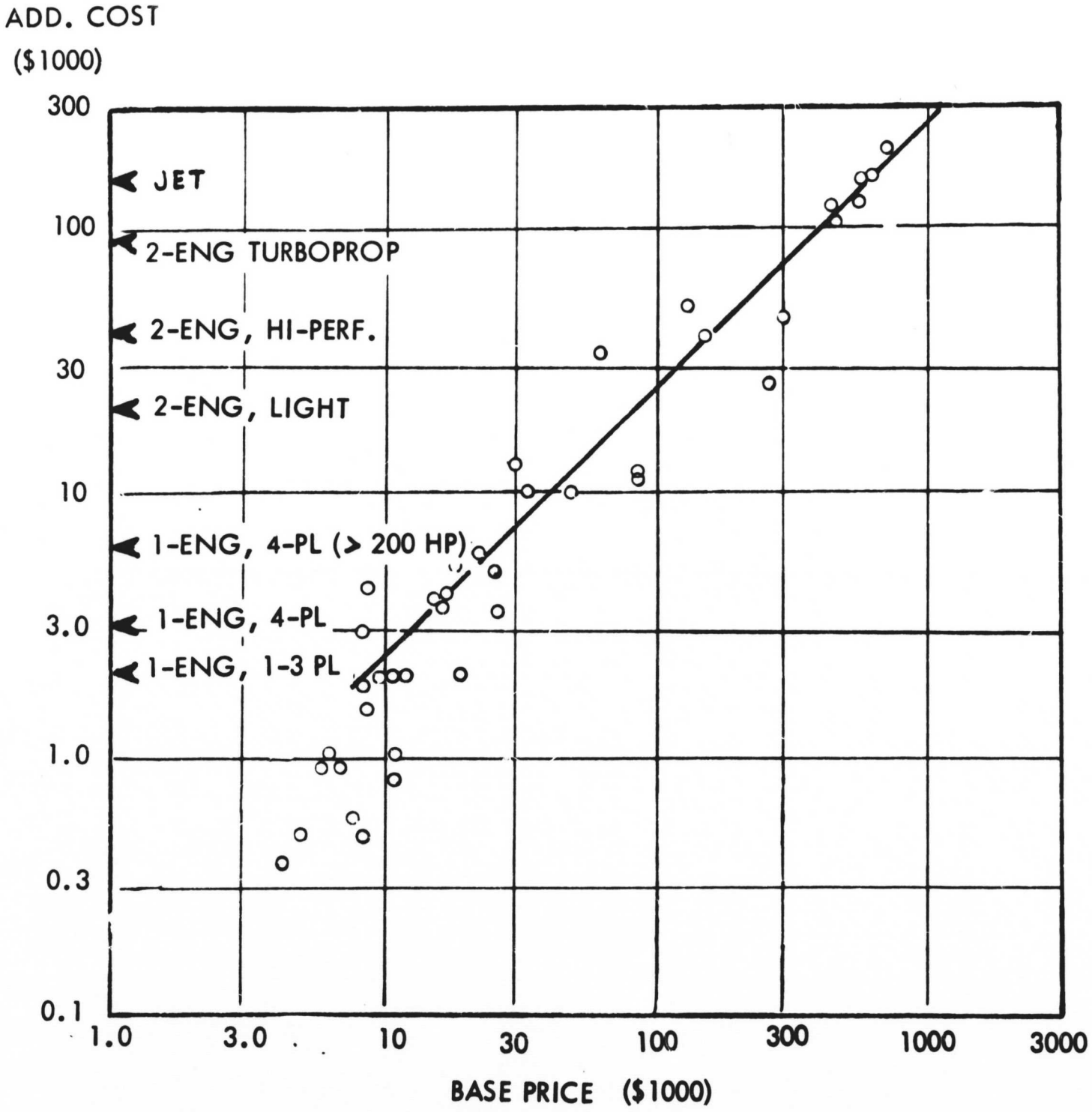
One trend in avionics is that towards increasing sophistication of equipment. The up-coming need for area navigation equipment is a major contributor. This constraint should gradually diminish as development in two key areas occurs. One is in the area of small digital computers based on Large Scale Integrated (LSI) circuits and on Cathode Ray Tube (CRT) technology to provide versatile flight data displays.

Typical avionics "packages" have been listed as applicable to the present technology, baseline aircraft derived parametrically in Section 7.0. The cost of these aircraft, however, does not reflect any avionic equipment. More sophisticated avionics, including that required for fully automatic flight control, has been selected for evaluation in the sensitivity analyses of Section 8.0 and has been evaluated in Section 8.3.7.

In order to gain added insight into the status and probable future direction of general aviation avionics, several representative organizations were contacted by letter and questionnaire. Four responses were received, and they are summarized in Appendix IV.

FIGURE 5.4.2

GENERAL AVIATION AVIONICS COST
(1968 INDUSTRY AVERAGES)



The equipment applicable to Category I and II baseline aircraft is as follows:

Operational Assumptions:

(a) Positive control capability (no true IFR) - requires VOR, with localizer as an option.

(b) Short-range communications - VHF.

(c) ATC transponder, no altitude reporting.

(d) Single pilot operation. (No instrument rating).

Avionic System List (Good quality non-TSO'ed)

System	Typical Weight	Typical Price - 1970
1 ea. VOR/LOC/VHF COMM	9.6 lbs.	$1,725
1 ea. ATC Transponder	8.0 lbs.	$700
	17.6 lbs.	$2,425

The equipment applicable to Category III and IV baseline aircraft is as follows:

Operational Assumptions:

a) IFR capability using R-NAV for enroute, and ILS for approach.

b) Short range communications - VHF

c) ATC Transponder, no altitude reporting

d) Basic autopilot-heading and altitude hold

e) A single pilot can operate the complete airplane (instrument flight rated)

Avionic System List (General aviation type - TSO'ed)

System	Typical Weight	Typical Price - 1970
1 ea VOR/LOC/GS/MKR	4 lbs	$4,140
1 ea DME	18 lbs	$4,417
1 ea R-NAV	12 lbs	$3,195
1 ea VHF COMM	13 lbs.	$2,160
1 ea ATC Transponder	4 lbs.	$1,366
1 ea Autopilot	18 lbs.	$4,495
1 ea ADF	5 lbs.	$ 895
	74 lbs.	$20,268

5.4.5 References

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5.4.7 Report of Department of Transportation Air Traffic Control Advisory Committee, Volumes 1 and 2, December 1969.

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5.4.28 FAA TSO - C2b: Airspeed Indicator (pilot static)

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DO-140 Airborne Area Navigation Systems
DO-141 Airborne DME Systems
DO-144 Airborne ATC Transponder Systems

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5.5 Landing Gear

Landing gear technology investigation includes the emerging and potential improvements in conventional wheel gear arrangements, as well as assessing the potential of the Air Cushion Landing System.

5.5.1 Wheel Type Landing Gears

Wheel type landing gears can be categorized by arrangement: nosewheel, tailwheel, bicycle, quadricycle, or multi-wheeled, and by mechanical design; fixed or retractable. While the first generation of general aviation aircraft utilized the fixed, tailwheel gear, the present generation uses the nosewheel arrangement predominantly and offers both fixed and retractable designs to fit the price and performance classes. The principal elements of a landing gear comprise the tires, wheels, brakes, energy absorbers, supporting structure and retracting system, if any. In lieu of the last item, wheel fairings are often applied to fixed gears. The purpose of this investigation is to examine the various elements of the wheel-type landing gear and point to any promising instances in which advanced technology can effect reductions in weight and cost, or improve reliability and maintainability. The nosewheel arrangement is widely used because it offers a level floor, better taxi vision, easier landing, inherent directional stability, ease of steering and resistance to nose-over. The choice between fixed and retractable gears for the future must be examined as an analytical trade-off. The retractable type, in the future, may become a higher-priced option such as power steering or automatic transmission in automobiles.

5.5.1.1 Tires - Many types of tires have been developed for aircraft and are usually categorized by pressure range. For general aviation use, only the low pressure (up to 50 psi) type need be considered because of available runway composition. Soil and pavement conditions relative to penetration are categorized by California Bearing Ratio (CBR) and combinations of wheels with tire pressures are classified by the number of passes, or repeated passages, that the aircraft can make over terrain having a given CBR, before experiencing pavement cracking or deep rutting of soil. The majority of Category I aircraft use the 6.00-6 tire on the main gear and 5.00-5 or 6.00-6 on the nose gear, with the tire pressures varying from 25 to 45 psi.

Category III aircraft generally use 6.50-8 to 6.50-10 tires on the main wheels, which have pressures as high as 75 to 80 psi. These aircraft, however, are usually operated from asphalt or concrete runways. The Category II and IV aircraft would probably have tire sizes and pressures close to those of Category I.

It is obviously desirable to use the lowest possible tire pressure to permit operation from soft or rough terrain when necessary. This is especially important for the STOL and VTOL types, which may be used for off-runway operation. Large diameter "balloon" tires with small hubs were used extensively in the 1930's, but have since disappeared. Large tires create high drag in fixed gear installations and present space problems for retractable gears. A new development by a leading manufacturer is the expandable tire, which folds like an accordion, when deflated, to about 2/3 its inflated diameter. It

thus helps to solve the space problem for retractable gears; however, its main virtue is the ability to run on a deflated tire without danger of detachment from the rim.

5.5.1.2 Wheels and Brakes - Wheel design has largely been standardized by the Tire and Rim Association. Aircraft wheels are generally fabricated from aluminum or magnesium alloy forgings, although pressed steel sheet has been used in some instances. For the future, it is possible that the use of high strength plastics or fiber composite materials might be used to achieve lighter weight units. Brakes for light-plane use are predominantly the single disc type, using steel discs and one or more contact pads. It is doubtful that any significant improvement can be made in the type of brake, although some weight saving can be made by using graphite or beryllium for the disc. The choice of materials will be primarily dictated by cost.

The STOL aircraft in Category II require higher braking capacity in order to preserve a balanced field length. The high thrust-to-power ratio propellers, selected on the basis of low noise level, could provide a significant contribution to braking if reverse pitch is used. Additional braking capacity may be necessary, however, and the application of brakes to the nose wheel might prove to be effective. The use of anti-skid systems, as developed for high landing speed aircraft, would permit full realization of the friction coefficients associated with type of terrain in use.

5.5.1.3 Shock Absorbers - Many types of shock absorbers have been used in aircraft. Table 9-1 of Ref. 5.5.5 lists these and grades them with numbers ranging from 1 (excellent) to 7 (very bad) as follows:

Type	Simplicity	Weight	Pct. Efficiency	Reliability	Recoil. Damping
Spring	2	7	50	1	6
Spring-oil	3	7	70	3	4
Rubber	2	6	60	1	5
Rubber-oil	3	6	70	3	4
Air	4	3	65	5	6
Oleo-pneumatic	4	1	80	3	1
Liquid Spring	4	2	75	3	1

The present popularity of the oleo-pneumatic shock absorber is evidenced by its high standing in the above list. Where high rates of descent are required, it is difficult to find a better shock absorber. In exceptional cases, double-acting oleo-pneumatic shock absorbers can be used. The spring concept can take the form of coiled springs or cantilever beams of tapered planform, sometimes laminated. This type is used extensively in single engine type aircraft. It derives its recoil damping by sideward scrubbing of the tire. Though relatively inefficient and heavy, it scores mainly on simplicity (hence low cost) and reliability. The spring material presently in use is steel; however, uni-directional fiberglass is a promising substitute and might result in lower weight. Advanced fiber composites offer even greater promise. Another simple concept, which has been

used in helicopter practice, is the use of metal tension strips (usually stainless steel) attached between a hard point on the structure and a short arm attached to a pivoted gear structure which moves upward and backward in the vertical plane. The strips are designed to deflect within their elastic limit, and if permanent set should occur, they can be easily and inexpensively replaced.

Low cost oleo-pneumatic shock absorbers reached their peak of simplicity in the design of an amphibian aircraft in 1946 (see Section 5.3.6). They were designed for low static pressure to facilitate servicing, so that single o-ring seals could be used. The cylinders were made from tubing stock, and the single passage of a pull-broach completed the machining. The end seals and piston guides were retained with snap rings. The design of the low-pressure, hydraulic retraction actuators was similar, and a significa.. break-through in cost was achieved.

While the aircraft configuration usually dictates the type of shock absorption selected for the landing gear, it can generally be stated that the cantilever spring gear appears to be best adapted to high wing, fixed gear aircraft. For low wing aircraft, with either fixed or retractable gear, the oleo-pneumatic type is preferred. However, special circumstances might call for variations to the above choices.

5.5.1.4 Structure and Retraction System - This portion of the gear is subjected to the widest variance in design concept since it must maintain compatibility with the airplane configuration. Chapters 8 and 10 of Ref. 5.5.5 cover the many possibilities, which are too numerous to mention here. The general rule for designers is: Keep It Simple. Simplicity pays off in cost, reliability and maintainability and, more often than not, results in light weight.

5.5.1.5 Auxiliary Functions - In addition to providing rolling, braking and shock absorption, the landing gear often provides other functions. These include steering, cross-wind landing and, very rarely. kneeling. Steering is applied to the nosewheel mechanically or through a hydraulic actuator, which can provide shimmy damping, as well. It is controlled either by action of the rudder pedal, lateral motion of the control column or a special steering wheel. Of these, the first method is used universally in general aviation aircraft; however, the control column action is more natural and more related to the steering of automobiles.

Cross-wind landing provisions are incorporated in some large aircraft, but have been applied to lightplanes on a few occasions in the past. They consist of limited, castered swiveling freedom for the main wheels, with a centering lock for occasions when swiveling is not desired. The desirability of providing cross-wind landing gear is debatable. With conventional gear, landings in 20-25 knot cross winds, are regularly made by the technique of landing into the wind, then kicking the rudder for alignment with the runway prior to touchdown. This results in touching one wheel first and sometimes causes the

wing tip on that side to come into close proximity with the ground. The inclusion of a castered main gear depends on its effect on weight and cost. If these factors are minor, such provision could be incorporated to achieve a higher level of safety.

5.5.2 Air Cushion Landing System

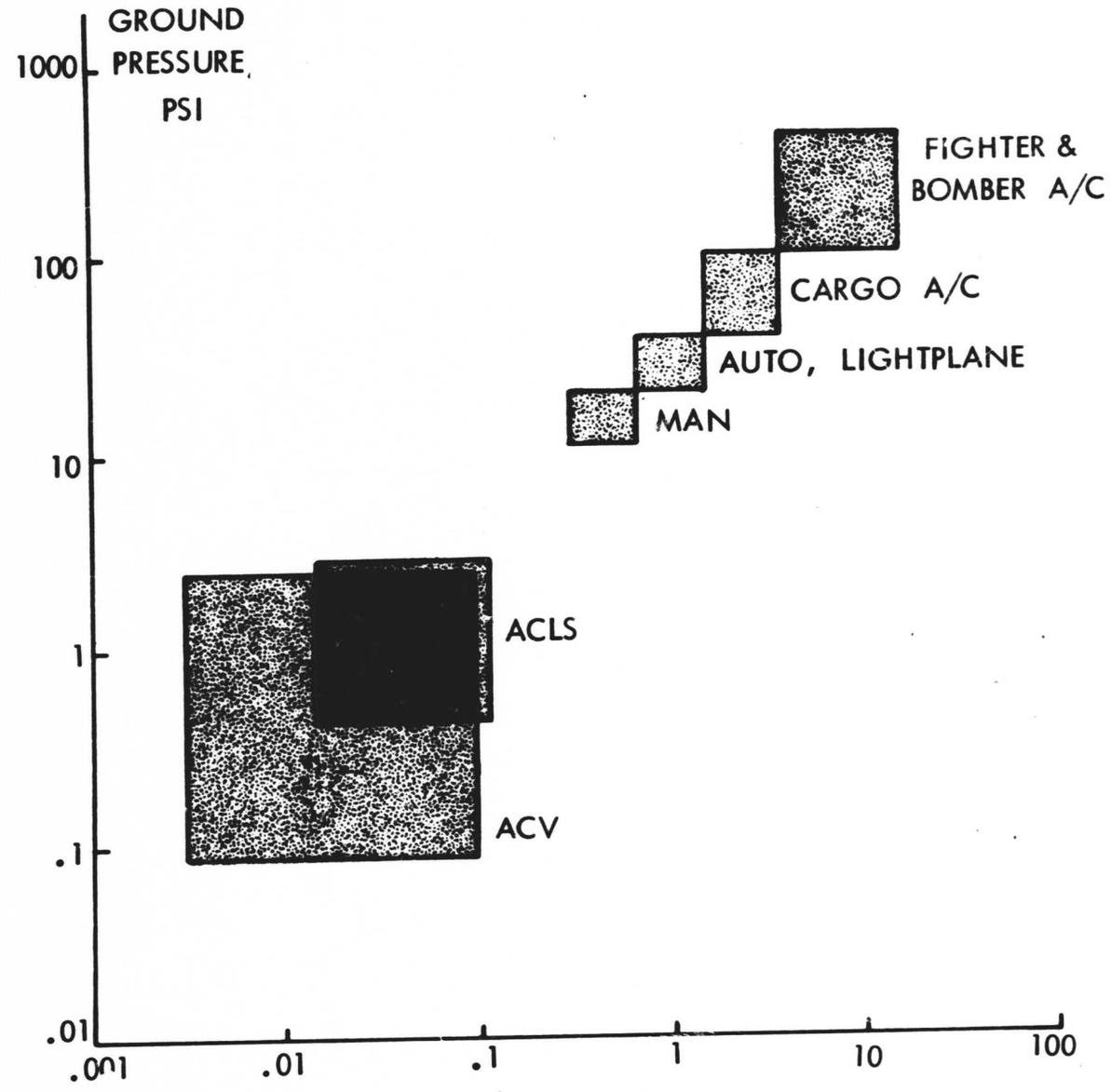
The Air Cushion Landing System (ACLS) is an extension of the Air Cushion Vehicle (ACV) technology which has been extensively developed in Great Britain, the Soviet Union and the United States. Air Cushion Vehicles are presently being used as patrol vehicles by the U.S. Army in Vietnam with great success. This vehicle is powered by one 1150 SHP turbine engine, weighs 10 tons and has a top speed of 60 knots. The Soviet Union and Great Britain are presently operating similar vehicles of weights of 22 and 168 tons respectively.

The feasibility of the Air Cushion Landing System concept has been under investigation during the last five years under sponsorship of the Air Force Flight Dynamics Laboratory, with Bell Aerosystems as the prime contractor. Extensive analyses and model tests have been accomplished and are reported in References 5.5.1 and 5.5.2. The most recent activity has consisted of a flight and ground test program of an ACLS installed on a Lake LA-4 single engine aircraft, which is reported in Reference 5.5.3. The LA-4 ground tests have demonstrated the craft's ability to negotiate the following terrain: 15 to 24 inch high grass, plowed ground, 4 to 14 inch diameter by 2 to 6 inch high tree stumps, 3 foot wide water filled ditches, 3 foot wide by 1 foot deep ditches, soft muddy ground, snow in 6 inch drifts, wet sand, and water. Take-offs and landing have been made from macadam, concrete (wet and dry), long grass and snow (4 to 8 inches deep), and water.

Excellent ground flotation, tolerance for surface roughness, and operation from water are the chief benefits offered by the ACLS. Ground flotation quantifies the ability of an aircraft to land and take-off repeatedly from low strength runways. This factor is defined by the number of times an aircraft can pass over a runway of a given soil bearing strength without destroying the surface by excessive rutting. The soil bearing strength is generally specified in terms of an index called California Bearing Rating (CBR). A CBR of 4 is roughly equivalent to a wet putting green; a CBR of 9 is equivalent to the average outfield in a baseball park. It is desirable to incorporate as much flotation as possible when designing a landing gear, except as constrained by an associated weight penalty. Wheel type landing gears concentrate load on a small area of ground contact, therefore producing a high ground pressure. High flotation, rough field wheel type landing gears are bulky, heavy, and difficult to install. On the other hand, the ACLS distributes the aircraft's weight over a large area and produces very low ground pressures.

A comparison of ground overpressure and flotation capability is shown in Figure 5.5.1 The ordinate this graph shows the ground overpressures for various modes of transportation. The abcissa shows the approximate required surface strength to support the mode of transportation without producing ruts deeper than one-half inch. It may

FIGURE 5.5.1 SOIL STRENGTH REQUIRED TO SUPPORT GROUND OVERPRESSURE



be seen that the flotation provided by an ACLS is an order of magnitude better than that of conventional wheel-type landing gears. In fact, it actually exceeds the flotation of a man on foot.

To quote Mr. Kennerly Digges in Reference 5.5.4:

"The Air Cushion Landing System is similar to the air cushion vehicle support system in principle. However, the ACLS has a number of requirements which are not imposed on ACVs. These requirements are as follows:

- o Retraction: The ACLS must retract to provide an acceptably low drag during flight.
- o Pitch and Roll Stiffness: The ACLS must have adequate stiffness to provide support during takeoff rotation, landing flare, and cross-wing operations.
- o Vertical Energy Absorption: The ACLS must absorb vertical sink rates in order of 10 fps without exceeding the g limit of the airframe.
- o Braking: The ACI must provide deceleration rates of 10 ft/sec^2, and ground friction to resist side drift and yawing.
- o Steering: The ACLS must provide for steering and close-quarter maneuvering.
- o Power and Weight: The ACLS must operate at an acceptably low power level and the total weight must be competitive with conventional high-flotation gear."

The ACLS developed under Air Force sponsorship includes the following major components:

- o A low pressure, high volume air supply
- o An elastic trunk plenum with peripheral jet exits
- o A braking system
- o A ground maneuvering system

A typical trunk plenum is shown in Figure 5.5.2 from Reference 5.5.3. A typical cross-section of an elastic trunk is shown in Figure 5.5.3 The following description is quoted from Mr. Digges in Reference 5.5.4:

"The trunk portion of the air cushion system must retract during flight to reduce drag. The extension and retraction are accomplished by simple elastic deformation of the trunk material. --- When the trunk is inflated, the elastic material is loaded to its design point. At this point, it elongates approximately 250% to form a deep, flexible duct around the perimeter of the aircraft fuselage. When not inflated, the trunk shrinks back elastically and hugs the fuselage.

"The trunk is made up of a laminate of natural rubber and nylon, the same materials which are used in aircraft tires. The nylon is placed in the

FIGURE 5.5.2 ACLS TYPICAL TRUNK PLENUM

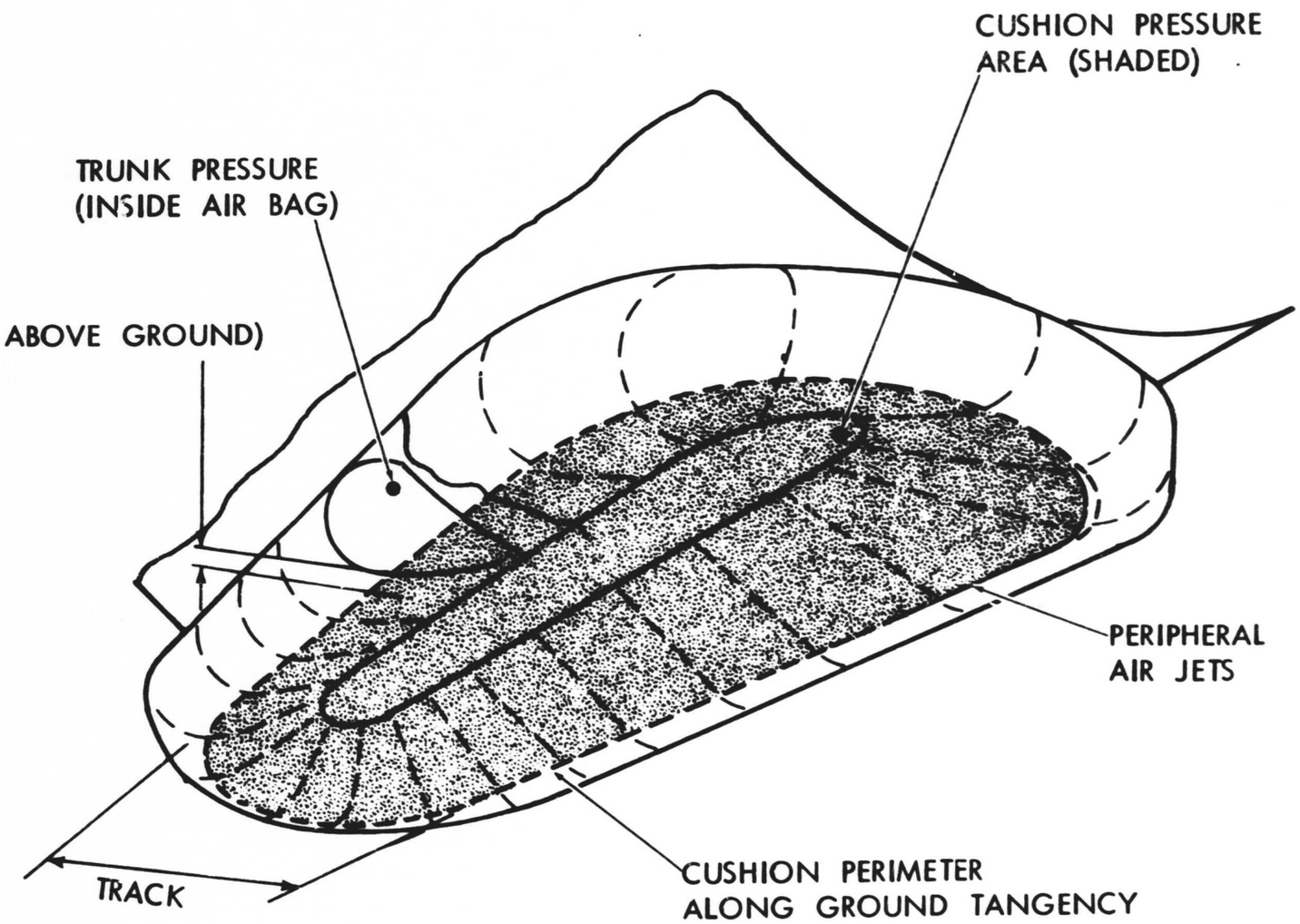
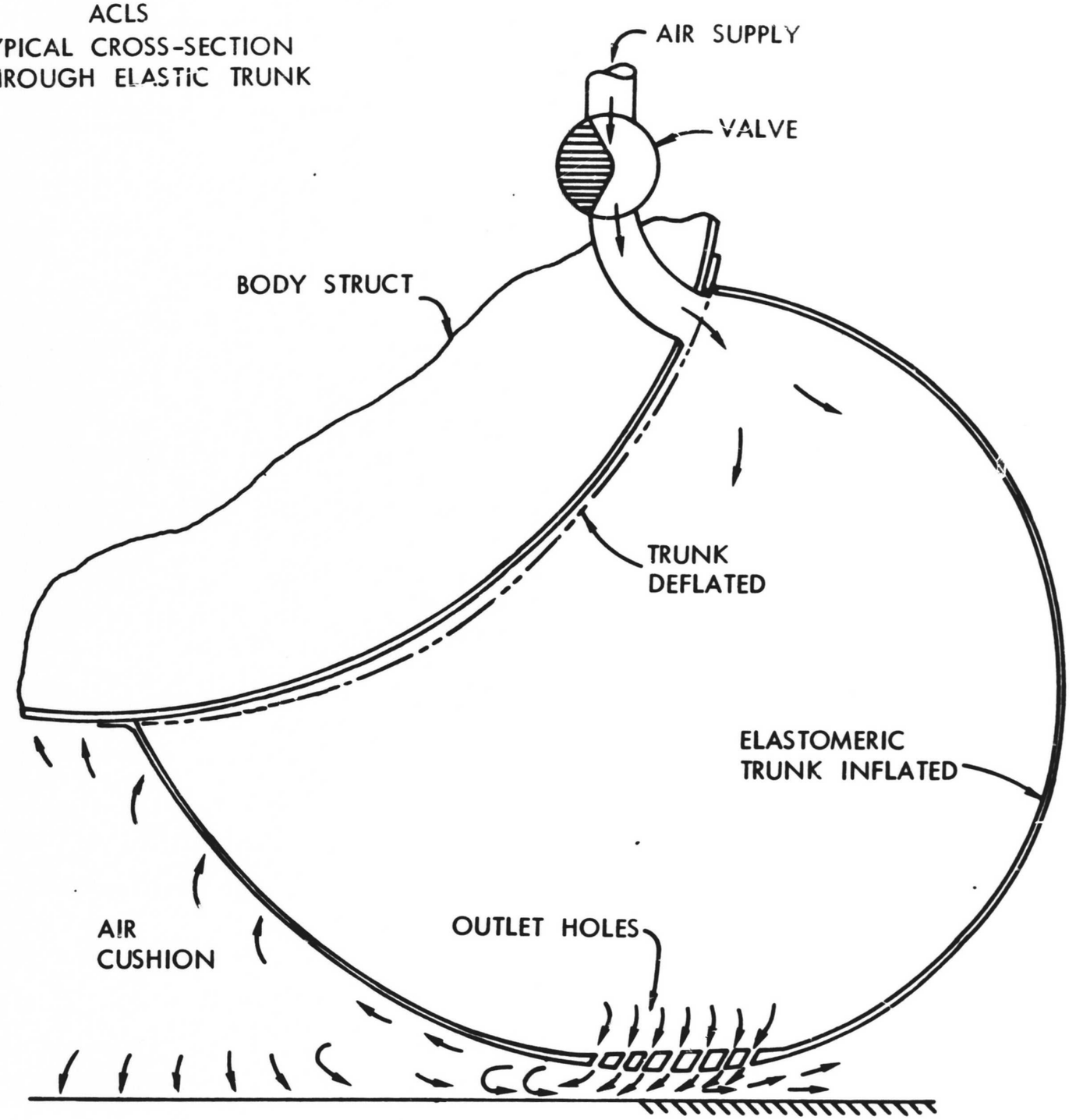


FIGURE 5.5.3

ACLS
TYPICAL CROSS-SECTION
THROUGH ELASTIC TRUNK



laminate in a slack condition. Consequently, the nylon carries no load until the design point is approached. As the design point is exceeded, the nylon becomes taut and picks up the load.

"The conventional landing gear contributes drag in two ways -- parasite drag and roll friction. The ACLS also has two drag components -- parasite drag and momentum drag. The momentum drag is caused by ingesting large amounts of air and changing the direction of air flow.

"The parasite drag of the inflated trunk is approximately equal to the parasite drag caused by the extended wheels and doors. The momentum drag of the ACLS was found to be less than the rolling resistance of wheels. However, rolling resistance occurs only when the wheels contact the ground, while momentum drag occurs whenever the ACLS fan is operating. The net result is that the total drag of an ACLS is less than that of wheels during the takeoff, but slightly greater immediately after takeoff.

"--- The rolling resistance of wheels is a relatively small portion of the total drag. This is true as long as the takeoff is made from a hard surfaced runway. However, when aircraft operate from low strength soil runways the wheels rutting can increase drag to the point where takeoff is impossible. Since the air cushion landing system will not rut the soil, its advantage in reducing takeoff distance from soft runways is obvious.

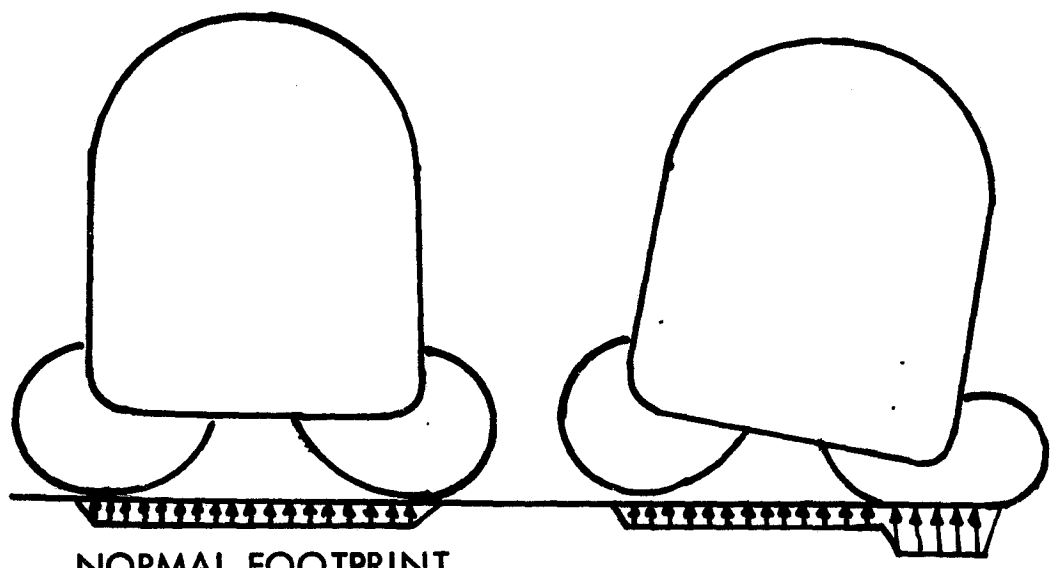
"Pitch and Roll Stiffness. The mechanism by which roll and pitch angles are reacted is shown in Figure (5.5.4) (The upper left hand view) shows the approximate footprint pressure of the ACLS under equilibrium conditions. The aircraft is totally supported by the cushion of air maintained under the fuselage. Under a roll angle, the footprint pressure changes. In addition to the cushion of air, the trunk is supporting the aircraft. The pressure in the trunk is roughly twice the pressure in the cushion. Thus, the footprint pressure changes as shown in (the upper right hand view), and a large restoring moment is developed whenever the bag is flattened against the ground.

"(The lower view) shows the support offered by the LA-4 trunk during takeoff rotation and flare. As the aircraft flares, the aft portion of the trunk is forced against the ground. The trunk pressure, acting over the large trunk area which is flattened against the ground, produces a force which partially supports the aircraft.

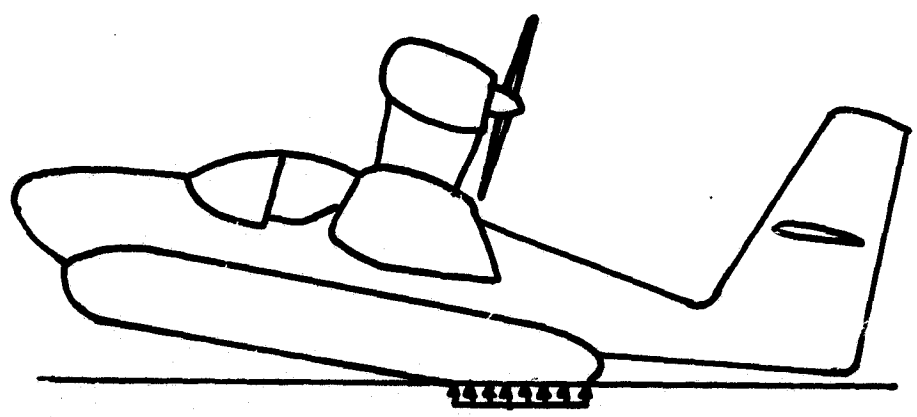
"Landing flare angles up to 12° (the maximum possible for the aircraft) were conducted on the LA-4. After 14 takeoffs and landings, no wear was noted on the aft portion of the trunk. This portion is flattened against the ground in every operation. The explanation for this lack of wear is that the pressure on the two sides of the trunk is equalized by air jets which provide air film support, as in an air bearing.

"The amount of load support offered by the trunk is a function of the trunk length, the trunk pressure, the trunk configuration, and material elasticity as well as the trunk deflection.

FIGURE 5.5.4 ACLS REACTION TO ROLL AND PITCH ANGLES



TRUNK DISTORTION IN ROLL



TRUNK DISTORTION IN PITCH

"If other considerations dictate a trunk stiffness and moment arm which result in inadequate roll stiffness, then wing-tip outriggers would be required.

"Landing Energy Absorption. In a conventional shock strut, landing energy is absorbed by compressing a small amount of fluid to a high pressure and squirting it through a hole. In the ACLS, landing energy is absorbed by compressing a large amount of fluid beneath the fuselage and squirting it through the air gap between the trunk and the ground.

"Drop tests of air-cushion models have demonstrated that the ACLS has excellent energy absorption and damping. (In comparison with a conventional system in which) both systems have approximately equivalent shock attenuating characteristics (max sink rate per g). - - - - the conventional shock strut is structurally limited to a load factor of 3 g's. The ACLS eliminates the point loading which is characteristic of the conventional shock strut. Instead, the loading approximates a uniformly distributed load acting over the entire underside of the fuselage. This improved load distribution allows a more efficient loading of the structure which in turn should permit higher structural load factors -- perhaps to 7 g's or the maximum g limit of the aircraft fuselage. The cushion stiffness may be varied to permit higher or lower sink rates per g of structural loading. This flexibility, combined with the more efficient load distribution, offers airframe designers sink rate absorption capabilities not presently available in conventional landing gear and at no structural weight penalty.

"It must also be noted that the initial landing impact is only part of the total energy absorption requirement. During the ground roll, additional demands are placed on the shock absorbing system by the impacting of random obstacles and irregularities on the landing surfaces. In some cases these loads are more severe than the initial landing impact. Because of its excellent obstacle negotiating capability - - - - and soft, flexible trunk, the ACLS has the potential of substantially reducing this type of loading.

"Braking. The ACLS braking system consists of expandable "pillows" located along the bottom surface of the trunk. When these pillows are inflated, they press a brake lining down against the landing surface. At the same time, the section of the trunk between the pillows is forced up. The pressure under the fuselage is bled off through the large daylight clearance between the pillows, and a large portion of the aircraft weight is transferred to the brake linings. The brake lining material wears and can be replaced in a manner similar to conventional brake linings. The braking force which can be developed is dependent upon the coefficient of sliding friction between the brake lining and the landing surface. Conventional wheel gear, in conjunction with the anti-skid system, develops a coefficient of friction of about 0.4 on dry concrete.

"- - - 1020 steel possesses a friction coefficient of around 0.3 throughout the (average) landing velocity range - - -. Its wear rate is such that 90 full brake stops could be accomplished before relining is required.

"- - - Maximum precicted temperature (of a typical stop is) 262°F, well below the range which could cause degradation of the rubber trunk to which

it is attached.

"The brakes press against the landing surface with a contact pressure of about 14 psi. Such a low pressure would not harm a concrete or asphalt runway. It is anticipated that the damage to soil runways would be much less than for braking conventional tires. High flotation tires have contact pressures which range between 40 and 100 psi.

"The braking problem is one of the most critical in ACLS design; however, a number of additional solutions to anticipated problems are available. If increased braking force is desired (as for a maximum performance assault landing), materials with high-friction coefficients can be chosen. For example, wire brushes offer a significant improvement in friction coefficient on concrete. The friction coefficient developed by the wire brush on soil was found to exceed its friction coefficient on concrete.

"Additional aircraft weight could be put on the braking system by ducting the air-cushion cavity to the fan intake. This would cause a pressure less than atmospheric to exist under the fuselage. As a result, a vertical load greater than the aircraft weight could be applied to the brakes.

"Finally, if brake heating is found to be a problem, insulation could be placed between the brake pads and the trunk to which they are attached.

"Steering and Ground Handling. Steering of the ACLS is accomplished by aerodynamic control and by differential braking. As a result, ACLS steering is not as precise as conventional nose-wheel steering. Flight tests of the LA-4 show that the taxi, takeoff and landing in high crosswinds is possible and that the center line of the runway can be followed. Low-speed maneuverability is quite good; however, considerable side slip occurs in high-speed turns.

"- - - Since the air cushion system requires power in order to carry load, a separate support must be provided when the aircraft is parked. The technique envisioned is to inflate a pressure-tight bladder inside the trunk, similar to a bladder inside a football. The aircraft would then rest on the air-filled trunk. The air pressure could be varied to allow kneeling. If it is desired to move the aircraft into a hangar for maintenance, it could be moved either on the air cushion or on special detachable hangaring wheels.

"Weight and Power. Results of the programs conducted to date indicate that the ACLS is lighter than high-flotation wheeled gear. The power requirements are approximately 10% of the (total) power required.

"The power requirements can be estimated by extrapolating the performance of the ACLS models which have been tested. For the purpose of this estimate, the ACLS is assumed to behave as a plenum chamber. This is a conservative assumption since the peripheral jet system is, in general, more efficient than the plenum chamber system.

"The ACLS provides a penalty in takeoff distance on hard-surfaced runways due to the drain in engine power. However, on soft runways this power drain is more than compensated for by the elimination of wheel sinkage and rutting. This feature offers V/STOL aircraft a significant weight savings as well as a breakthrough in flotation and rough field performance.

"Conclusions. The air-cushion landing system offers a breakthrough in aircraft ground flotation. The system has been successfully tested on a small aircraft. Solutions to all major technical problems have been demonstrated.....

"The major advantages of the system are as follows:

Operates on Soft Surfaces
Negotiates Obstacles and Steps
.....
Reduces Weight
Reduces Aircraft Ground Loads
Provides Crosswind Landing Gear
Provides Kneeling Capability

The major disadvantages of the system are as follows:

Requires Power
Less Precise Steering
Less Stiffness
Creates Dust and Noise
Requires Special Ground Handling with Power Off"

A typical ACLS application is shown in Figure 5.5.5. The ACLS has been applied to a Category I aircraft, and an effort has been made to improve upon the major disadvantages of the system as set forth by Mr. Digges. Power for energizing the cushion is obtained by diverting the exhaust cooling air into the trunk. An engine-driven blower is used to energize the flow through the radiator of a liquid-cooled, rotating combustion engine installation. Thus, the required power is obtained without significant penalty, since the blower, or an equivalent engine exhaust ejection system, would be necessary for a pusher propeller installation.

Figure 5.5.6 shows a section through the trunk. In comparison with the elastic trunk of Figure 5.5.3, an accordion-fold, inelastic trunk is shown in Figure 5.5.6. This permits the use of conventional rubberized fabric material, which is easily installed and removed and requires no further development. It would be molded in the folded condition to assist the process of retraction, which is further assisted by the use of limited stretch, elastic straps. When retracted, the comparatively stiff tread forms the slot closure. Radial stiffness is imparted to the tread by molding steel wires in the rubber, across the tread (a suggestion by representatives of a leading manufacturer). This permits the use of a continuous peripheral slot instead of the hole pattern used in the LA-4 application and should result in a better discharge coefficient.

Another difference from the LA-4 application is the use of a tricycle taxi gear, with positive nose wheel steering. This gear is used only for taxiing and possibly takeoff, and is retracted for landing. It is designed only to

FIGURE 5.5.5 TYPICAL CROSS-SECTION THROUGH INELASTIC ACLS TRUNK

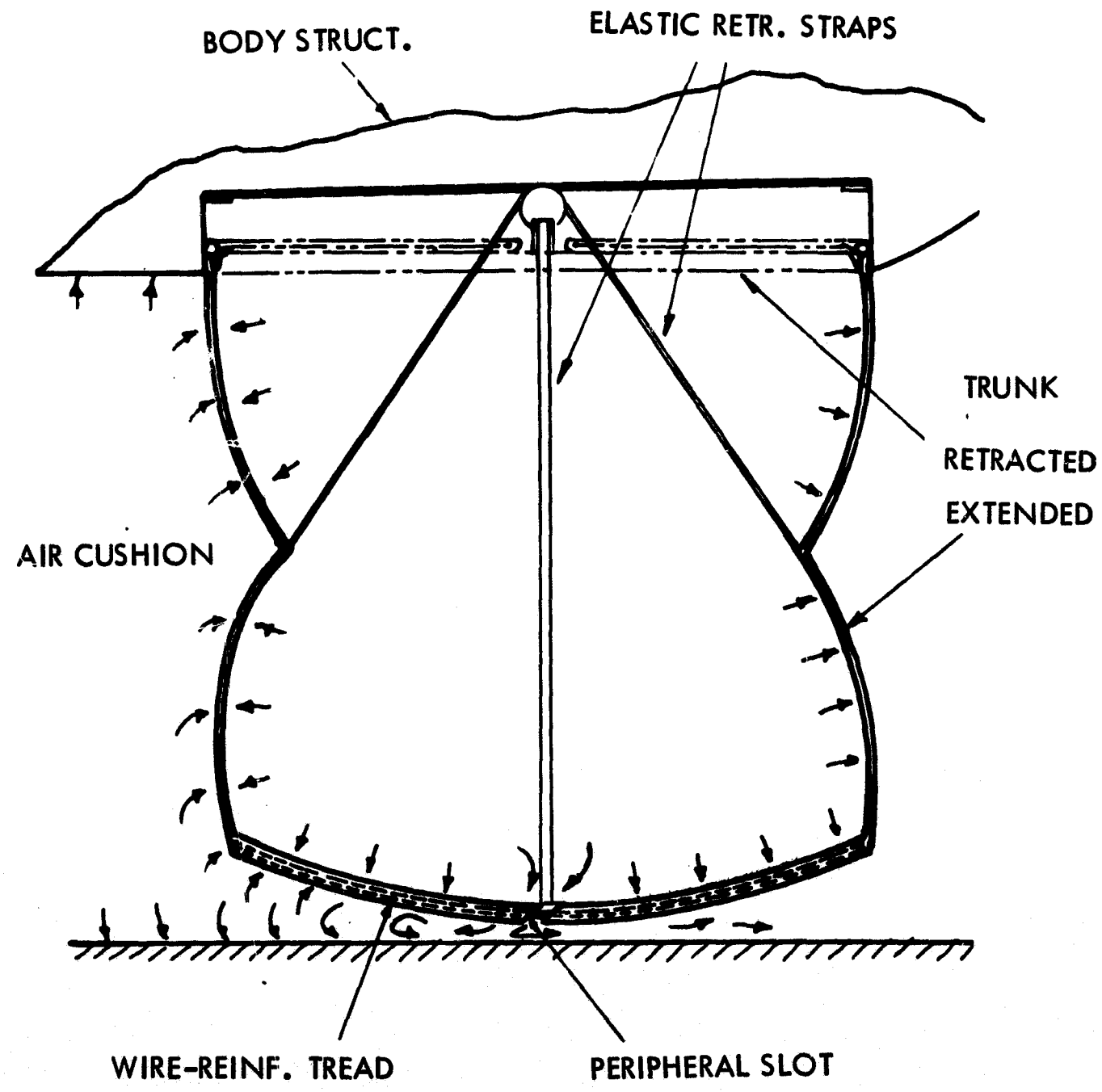
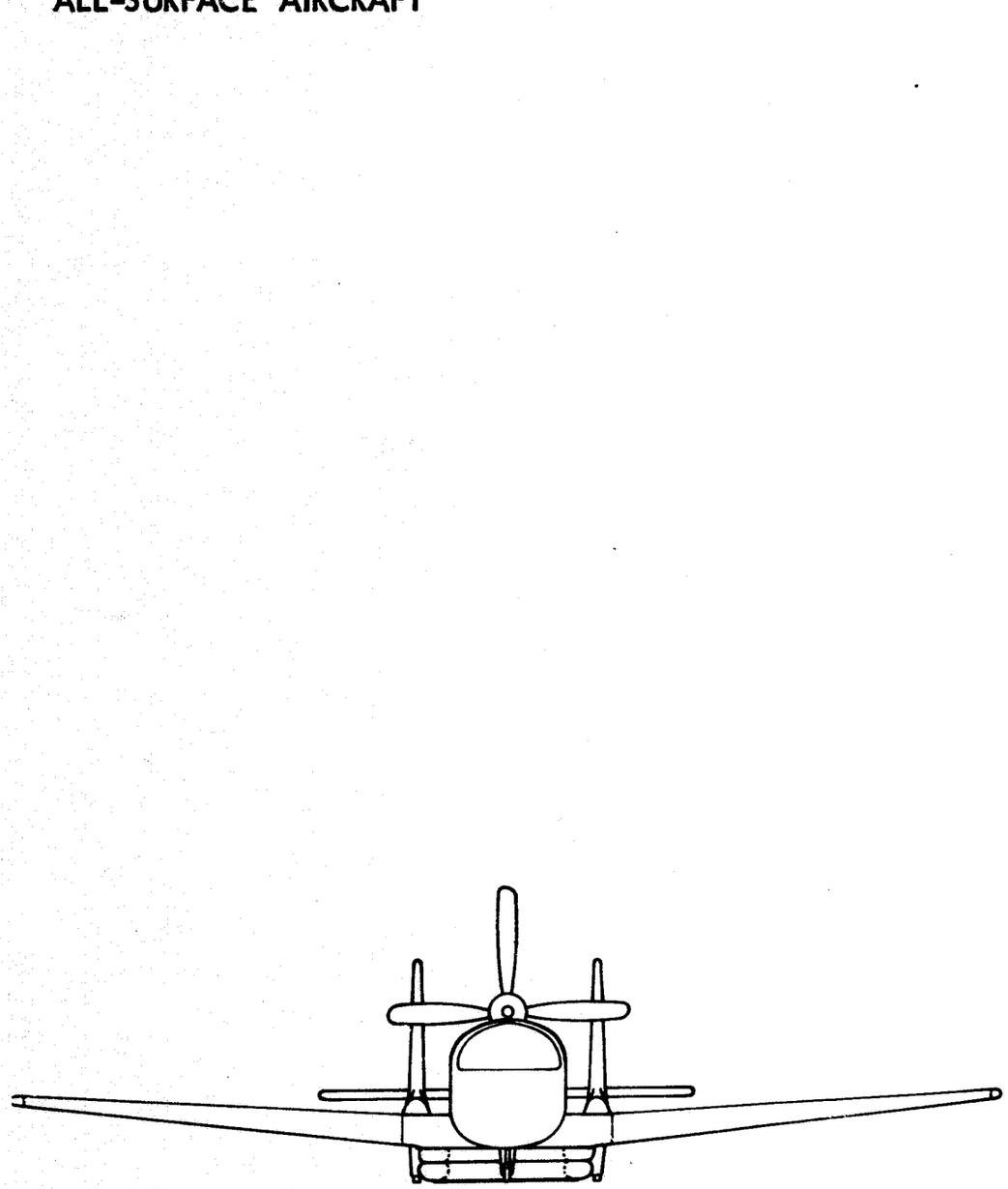
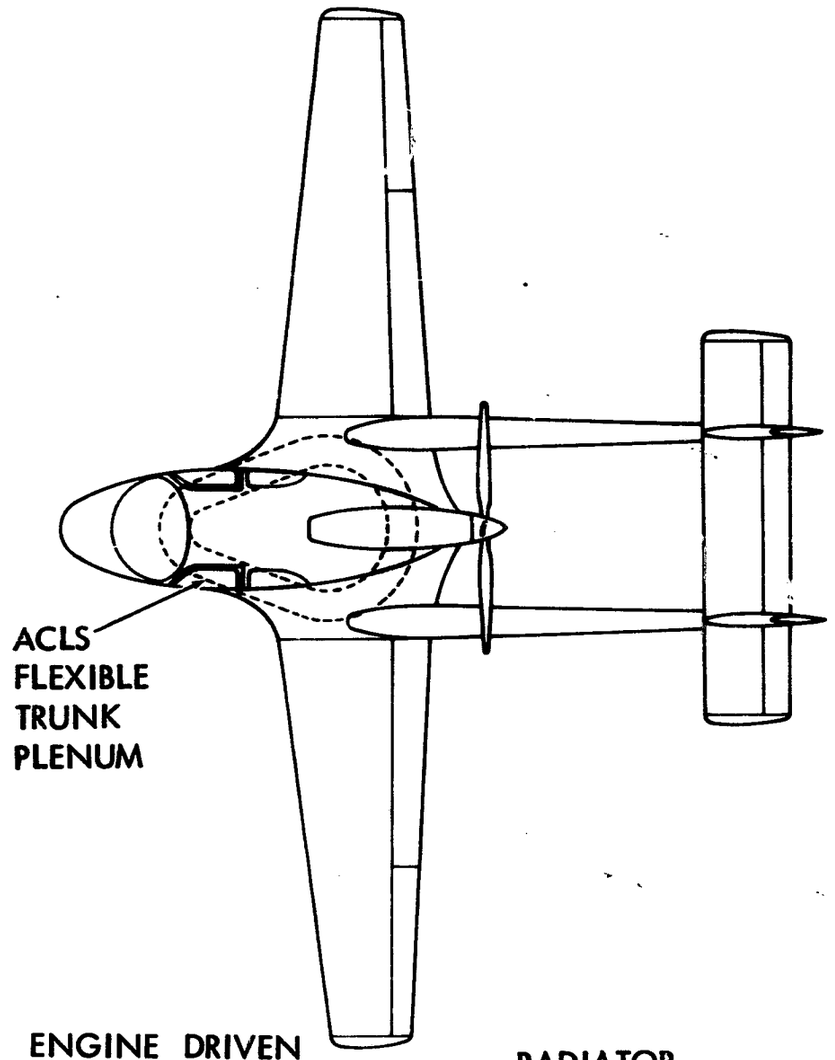
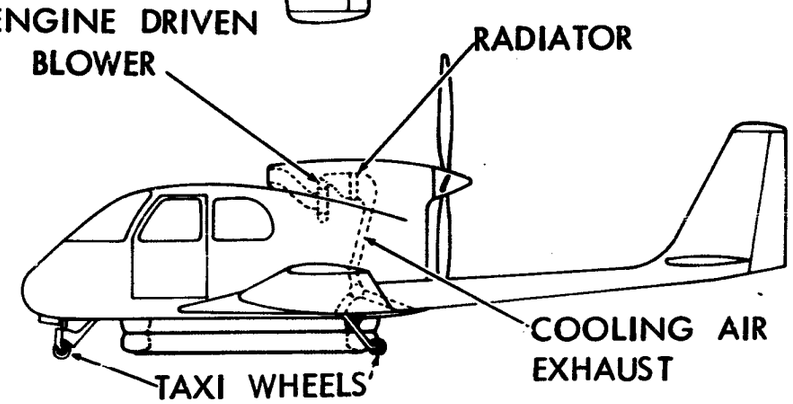


FIGURE 5.5.6
ALL-SURFACE AIRCRAFT







support the static weight of the aircraft at 1.0 g. Although this feature imposes a weight and cost penalty, it eliminates three of the major disadvantages cited by Mr. Digges: less precise steering, less stiffness and the requirement for special ground handling with power off. It also eliminates the need for an inner bladder in the trunk and the maneuvering air jets used in the LA-4. Since the wide tread and long wheel base of the auxiliary gear provides stability in all directions, a true peripheral system can be used, with a considerable reduction of engine power. This mitigates another one of the disadvantages cited, leaving only the creation of dust and noise. The first is basic, but its effect on engine air ingestion can be countered by the use of a high, protected inlet scoop, as shown in Figure 5.5.5. The extra noise cited by Mr. Digges is believed to be that created by the fan. It can be made lower than that of the engine/propeller combination by the use of the low rotational speed and acoustic insulation.

Although the provision of braking in the ACLS was not cited as a disadvantage, Mr. Digges called it one of the most critical problems in ACLS design. The problem can be eliminated in this example by the provision of adequate reverse thrust made possible by the large, high activity propeller required for low noise level. This will result in a braking system with no replacement and maintenance problems (per se), with lower weight and cost, and will provide braking independent of surface conditions.

While use of the ACLS has been applied only to Category I aircraft in this study, it is equally applicable to those in the other three categories. The ACLS installation would be highly suitable for "bush" operation, for instance, where a wide variety of terrain, including water, snow and ice, is encountered.

5.5.3 References

No.	Source	Title
5.5.1	T. D. Earl, Bell Aerosystems Co., Air Force Technical Report, AFFDL-TR-67-32 - May 1967	Air Cushion Landing Gear Feasibility Study
5.5.2	T. D. Earl and R. H. Cooper, Bell Aerosystems Co., Air Force Technical Report AFFDL-TR-68-124 - Jan. 1969	Air Cushion Landing Gear for Aircraft
5.5.3	C. L. Stauffer, Bell Aerosystems Co., Air Force Technical Report, AFFDL-TR-69-23, Sept. 1969	Ground/Flight Test Report of Air Cushion Landing Gear (LA-4)
5.5.4	Kennerly Digges, Air Force Flight Dynamics Laboratory, May 1970	Air Cushion Landing System Requirements
5.5.5	H. G. Conway R. Ae. S. Textbook Chapman & Hall, Ltd. London	Landing Gear Design

5.6 FUNCTIONAL SUBSYSTEMS

5.6.1 Environmental Subsystems

Environmental control of the airplane interior includes that of temperature and pressure. Most low-price general aviation aircraft are equipped with heaters only. Air conditioning (without pressurization) is just now being offered, and pressurization is restricted to the high priced turbocharged and gas turbine-driven aircraft.

Reference 5.6.1 describes a lightweight, "low-cost," engine-driven refrigerated air conditioner, which can be installed in small, single engine aircraft (the quotations around "low-cost" refer to its price as being "under $1,500"). The unit is belt-driven by the engine and weighs approximately 43 lbs. installed. It absorbs about 5 hp when the engine is idling, dropping to about 2.5 hp in cruise flight. The installation consists of an air evaporator unit and cabin blower assembly, a condenser or heat exchanger and a belt-driven compressor with a clutch. The unit provides a 20-degree temperature differential and moves 250 cu.ft. of air per minute. Although the requirements for FAA certification are more demanding than those for automobile air conditioners and the present potential market is much less, it would appear that lower cost units could be offered at such time in the future as the volume potential should increase. Certainly the price factor can be brought below the ratio of 6 times that of typical automotive units. It is also possible that reverse air cycling or a "heat pump" unit can be developed to provide heating, as well.

Reference 5.6.2 describes typical pressurization systems for representative twin-engine 6-8 place business aircraft, typifying Category III. Pressurization in a high performance aircraft with turbocharged piston or turbine power enables the operator to realize the full performance potential of the aircraft by cruising at optimum altitude. These systems utilize bleed air from the engine turbochargers and provide air conditioning.
They can provide a 5.5 psi pressure differential for a sea level cabin up to 12,000 ft., and 8,000 ft. cabin at 24,000 ft. and a 10,000 ft. cabin at 29,000 ft. (operational ceiling). While the main air supply is bled from the turbochargers, two auxiliary pumps (one per engine) provide a secondary supply to maintain pressurization, even with the throttle closed for descent. Cabin altitude is selected with a variable rate-of-change control, normally 500 ft./min. Cabin temperature is controlled thermostatically by regulating the outputs of a 45,000 BTU gas heater and a 24,000 BTU freon air conditioner. The cabin air is changed every 90 seconds, after being filtered, dehumidified and temperature-conditioned. Figure 5.6.1 shows a diagram of a typical system, obtained from Reference 5.6.2.

The provision of cabin pressurization requires not only a complicated air supply system, but also a fuselage structure capable of withstanding the pressure differential. For this purpose, a circular

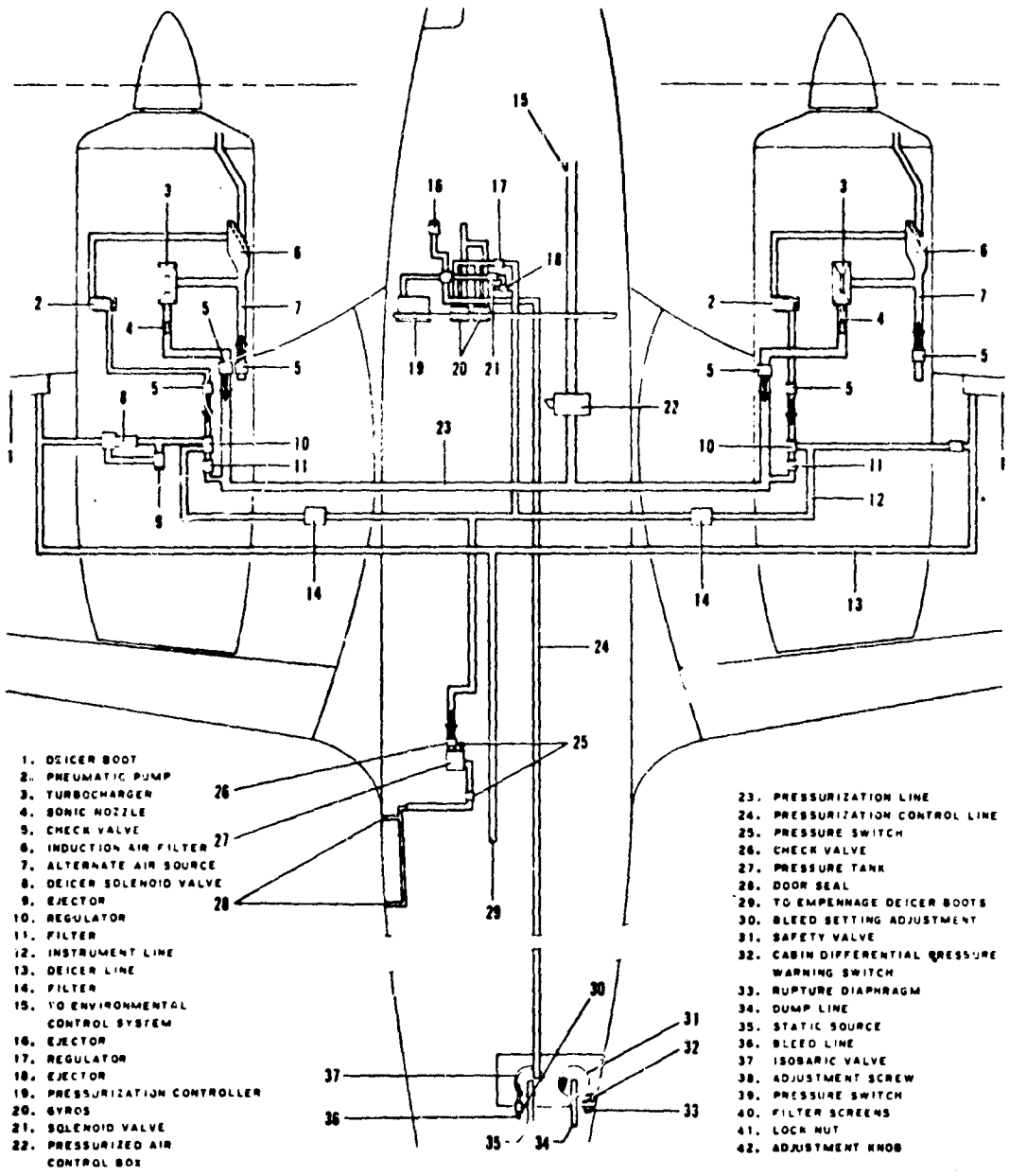


FIGURE 5.6.1 TYPICAL SYSTEM SCHEMATIC FOR PRESSURIZED TWIN-ENGINE A/C

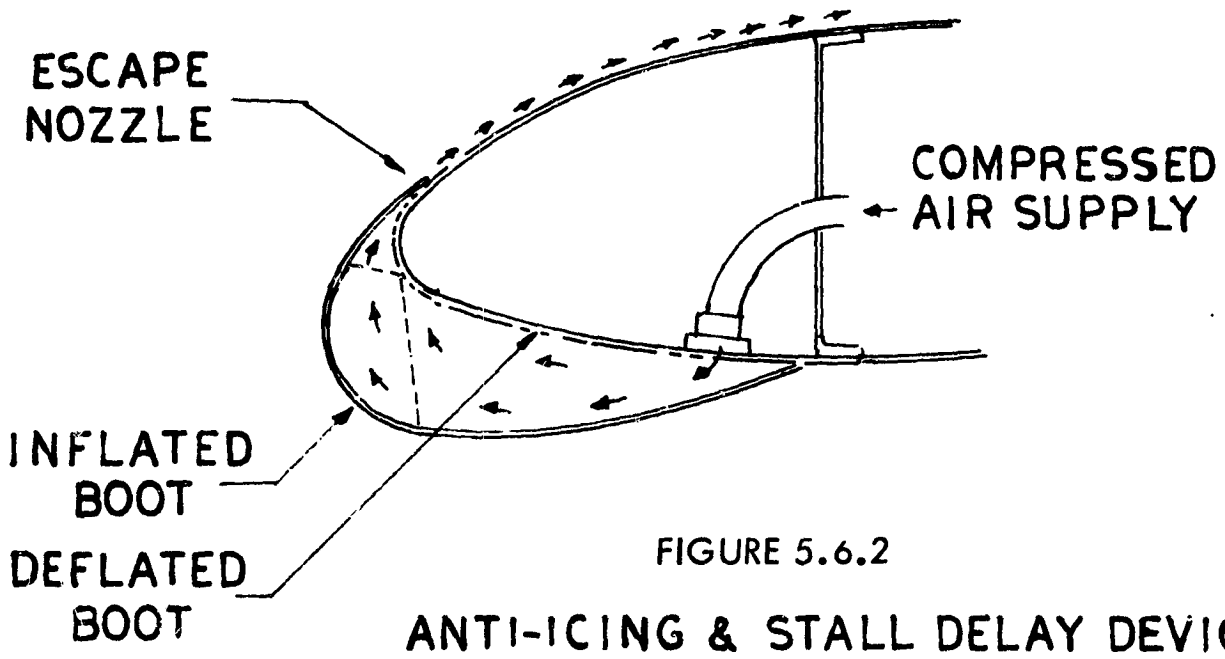


FIGURE 5.6.2

ANTI-ICING & STALL DELAY DEVICE

cross-section is ideal, since the stresses become pure hoop tension. Since it is not practical to pressurize the entire fuselage, concave pressure-resistant bulkheads are installed at the front and rear boundaries of the cabin. A weight penalty is exacted for the structural provisions, as well as for the air supply system; however, the use of fiber composite material should reduce the structural weight penalty to a considerable degree. The best approach toward the reduction of weight and cost of the air supply system appears to be that of "packaging" the system in a minimum number of installed units, as opposed to the present method of spreading the system over a large area of the aircraft.

Environmental control of the exterior of the aircraft includes anti-icing (or deicing) of the wing, tail and engine components and treatment of the windshield for clear vision against the hazards of ice, fog and rain. Ice prevention on aerodynamic surfaces is confined to the leading edges. It takes the forms of anti-icing by temperature rise or de-icing by the use of inflatable boots. Anti-icing systems utilize the circulation of hot air or electrical resistance wires imbedded in an insulating blanket. The source of hot air can be obtained from an engine exhaust heat exchanger or an engine-driven compressor (or bleed from a turbocharger). The electrical system requires extra generator capacity, even though the current is cycled through the resistance wires. However, it is simpler from an installation standpoint.

A unique approach to the solution of the leading edge icing problem would be the provision of an inflatable, expandable boot, which when expanded would provide a blunt, drooped contour to the leading edge. The pressurized air, at higher temperature, would circulate through the boot and exit through a narrow slot along the upper surface. The system would be used in all takeoff and landing operations to delay the stall, as well as when icing conditions are encountered. Figure 5.6.2 shows a cross-section view of this device.

Windshield treatment can utilize resistance wires, ejected fluid or hot air blowing for ice and fog removal. The hot air system is the least costly method, as evidenced by its use on automobiles. As for rain removal, there appears to be no better answer than wipers, which can be electrically or pneumatically actuated.

Engine component ice prevention systems use hot air for carburetor heating - however, fuel injection engines do not have this requirement. Turbine engines require de-icing of the inlet and guide vanes, which is usually obtained by the use of compressor bleed air in a system that is integral with the engine.

5.6.2 Fuel Subsystem

General aviation aircraft fuel systems are categorized by gravity feed and pressurized systems. The former is characteristic of high wing, single engine aircraft, since there can be a head of fuel maintained above the engine pump in all upright attitudes, assuming that the fuel is stored in the wing. Low wing, single engine aircraft require a pressurized system if operation at high altitudes is required. Pressurization takes the form of a booster pump in the fuel sump. In twin engine aircraft, the engine and fuel tanks are on essentially the same level, and boost pumps are not used unless unusually high altitude operation is desired. The use of compressed air above the fuel to achieve pressurization is not approved because of structural difficulty, the danger of leaking fuel through joints and the maintenance of a potentially explosive fuel-air mixture. Tanks are usually installed in the wings and are either integral with the structure or are the rubberized fabric, bladder type. Fuel flow control from more than one tank is controlled by manual valving or automatically by a flow equalizer. A warning light is usually provided to indicate a low level in the main supply so that the pilot can valve in his reserve supply. In some cases, wing tip tanks are used, which under average cruise conditions do not create appreciable drag, since the added parasite drag is counteracted by the lower induced drag due to end plating effect.

Future improvement of fuel systems should be directed at: (a) improved safety; (b) higher reliability through simplicity. Safety considerations imply location of tanks in the outer panels, remote from the fuselage and the avoidance of crash fires. This subject is discussed in Section 5.8. of this report. Reference 5.6.3 contains a collection of papers which relate closely to the subject. Some of the topics discussed include fire detection techniques, reduction of vapor flammability with additives, new concepts in fuel containment and the use of gelled and emulsified fuels. Item (b) implies the design of a simplified system which requires no management or C.G. control functions and incorporates gravity feed, if the configuration permits. The prospect of obtaining lighter weight systems which incorporate the above improvements is dim, since the new structural materials are not applicable to fuel systems.

5.6.3 Flight Control Subsystem

Some of the newer developments, such as automatic flight control systems (AFCS), fly-by-wire systems and fluidics point toward revolutionary flight control systems. There is little doubt but what these developments will sooner or later be extensively incorporated in military aircraft and commercial transport aircraft. However, there is much doubt about their applicability to general aviation aircraft, with the possible exception of the large expensive business aircraft. The reason for doubt is, primarily, economics and secondarily the manner of operation.

As opposed to the long and frequent periods of continuous operation with military combat aircraft, as well as with military and commercial transports, general aviation aircraft are operated sporadically and for relatively short periods of time. Thus the need for 2- or 3- axis autopilots and stability augmentation devices may not merit their cost, assuming that the aircraft are inherently stable and easily controlled. Fly-by-wire systems can become a weight-saving item on large aircraft, but would have little effect on the aircraft of interest to this study. Even if they did reduce weight, the "black box" complication would price them out of the market, and the aircraft would still be required to have a back-up mechanical system.

Fluidic systems are potentially a lighter weight means of transmitting control signals. Reference 5.6.4 compares the weight and cost of a heading hold system biased with integral of sideslip. The conventional mechanization weighs 44.15 lbs. and costs $6,484. The same system, designed for pure-fluid components, weighs 25.43 lbs. and costs $3,344. This example shows that the use of fluidics can effect considerable economy in the design of instrumentation systems.

Attitude stabilization by the use of an inexpensive, single-axis autopilot is another improvement (see Section 5.8.) which is already being introduced for wing leveling. The remainder of potential improvements applies to the details of the system. These include:

- Simplified, reliable control transmission systems, eliminating any change of jamming or malfunction
- More attention to human factors in cockpit layout
- The application of high strength, high modulus, fiber composite material to cables to reduce weight and increase service life.
- Reduction of friction in the system to reduce pilot effort and stickiness.
- Development of means of obtaining automatic longitudinal trim as a function of speed and flap position.
- In twin engine aircraft, automatic directional trim with one engine inoperative.
- Use of elevator tab combinations to provide longitudinal stability over a greater C. G. range. (The Curtiss-Wright "V-tab" system, developed in the 1940's and tested on the C-46 airplane, achieved this objective.)

5.6.4 Auxiliary Power Subsystems

In general aviation aircraft, such means of power transmission are used primarily for retractable landing gear, wheel brakes and flap actuation. At the present time, hydraulics are used to the virtual exclusion of pneumatics. Electrical power transmission systems are fairly common and are discussed in Section 5.4.2.3. The choice between hydraulic, pneumatic and electrical systems is made primarily by the preference of the designers, although in military and commercial transport aircraft it is subject to rigorous analysis and trade studies. While hydraulic systems involve the problem of fluid leakage and a potential fire hazard with flammable fluid, they are used extensively, as in automotive practice. Electrical systems, while free of these problems, are generally heavier than hydraulics.

Pneumatic systems may have the best long-range potential. Their source can be manifold pressure, or engine-driven pumps, with reciprocating or rotary combustion engines, and compressor bleed with turbine engines. The power, in the form of compressed air, can be delivered to high speed air turbines, to displacement-type air motors or to linear actuators. It can be stored in accumulator tanks for emergency use. In addition to the applications mentioned at the beginning of this subsection, the compressed air can be used for anti-icing (see 5.6.1) and possibly for boundary layer control concepts. While hydraulic system leakage is easy to detect, pneumatic system leakage is not readily visible. One solution is the use of thin rubber sleeves surrounding the joints which will become inflated or punctured when leakage occurs. The remote valving of pneumatic systems could be done by fluidics, rather than electrical solenoids or actuators. This would utilize the same working fluid and might create a more reliable system.

5.6.5 References

5.6.1	Flight Magazine March 1969 - p. 39	Air Conditioner for Single Engine Aircraft
5.6.2	Flight Magazine May 1970 - pp. 40-43	Pressurized Navajo and Turbo Comanche C
5.6.3	The Daniel & Florence Guggenheim Aviation Safety Center	Aircraft Fluids Fire Hazard Symposium; 1966 Proceedings
5.6.4	NASA CR-758 Honeywell, Inc.	Study of Fluid Flight Path Control System

5.7 Utility and Convenience Features

5.7.1 Roadability

A long sought-after feature for light aircraft has been some means for the owner to keep his plane at his place of residence and move it over the road to the nearest airfield whenever he wants to fly. Removal of the wings is a practical impossibility for most low wing aircraft, and wing removal from a high wing aircraft is too time consuming, since it involves disconnecting the controls, fuel lines, electrical wiring, and the pitot line. Although the owner saves up to $50 per month by avoiding tie-down or hangar rent, the effort involved is hardly worthwhile.

The majority of small boat owners keep their "rigs" (boat & trailer units) at home and hitch them to their cars, proceed to launching ramps and complete their operations with a minimum of effort. This capability has popularized boating to the point where it is now a major industry. Although airplanes are far more expensive than boats, it is safe to assume that a similar capability might have a sizable impact on the market. To provide the airplane owner with equal convenience to that of the boat owner, he must be able to fold the wings (and horizontal tail if required) without any auxiliary effort except for latching and unlatching; and to utilize a standard trailer hitch installed at the back of his car.

Going one step further, the owner's convenience and utilization might be augmented by divorcing the airplane from the car by making it automotive on the road. This capability requires a wheel drive, since the hazard created by propeller drive would be obviously unacceptable. With wheel drive, the owner could drive his airplane to the nearest airfield, fly to a distant airfield and proceed by road to his ultimate destination. Such a convenience would have considerable appeal to business owners; more so than to private owners, probably, because of the increased price of the airplane.

The provision of roadability has been developed in the past in a few instances, but has never reached the true production stage. If it is ever to do so, the conceptual design must effect minimum compromise to the performance and flying qualities of the airplane; to its safety both in the air and on the road; to impose minimum effort on the part of the owner in his utilization of the airplane and to hold the price within reasonable limits. This is a very large order, and the optimum solution is beyond the scope of this investigation. However, in order to provide some indication of the economics, an example has been selected and evaluated in Section 8.3.6.

Road Automotive Version - The features required for road automotive capability, in addition to wing folding, include:

- Steerable nose wheel linked to the rotation of the control wheel. (Wing folding automatically disconnects the ailerons from the control wheel.)

- Front and rear lightweight bumpers with a trailer hitch installed on the rear bumper. The front bumper is easily attachable for use on the road

only and is foldable for stowage in the baggage compartment. It includes clips for securing the propeller in the 45 degree position.

- A central combined headlight and landing light (automobile sealed beam unit). The rotating beacon serves as a tail light.

- An Auxiliary Power Unit (APU) installed in the fuselage below the baggage compartment. This is an air-cooled rotary combustion type having a rating of 30 horsepower, at 5,000 RPM and a weight of 56 lbs. It drives a variable volume hydraulic pump of 18 gpm capacity, with a system pressure of 3000 psi.

- A 3000 psi hydraulic system consisting of the pump described above, a reservoir and two hydraulic motors, with V-belt drive to the rear wheels. The system provides reverse flow at variable pressure by the inclusion of a 4-way valve. This system is installed in addition to the conventional brake system.

Towable-Only Version - This version has the wing and tail folding features previously described, but does not include the APU and hydraulic drive features.

Both versions were analyzed for their effect on weight and cost in comparison to those of the Category I baseline design, reflecting 1985 technology. The propeller was selected on the basis of the 75 PNdb noise level constraint. In assessment of operating cost, the analysis includes deletion of the cost of hangar space or tie-down rental. The recommended configuration for Category I, described and analyzed in Section 9.0, includes wing folding and towability.

5.7.2 All-Terrain Capability

Amphibious aircraft in the general aviation field have been represented by many different models. While none of them have achieved the production status attained by the more popular land plane models, serious attempts have been made in this direction during past intervals. Since the amphibian offers increased utility by its ability to use waterways, in addition to airfields on the ground, there must be obstacles which override the obvious advantages. They can be summarized as follows: increased cost and inferior performance. The classic approach to amphibian design is to use a planing hull with a stepped bottom and fit it with a retractable landing gear. The propeller must then be raised to clear the water, which usually places it, and the engine, on an overhead pylon. The increased drag and weight of this arrangement must be countered by the addition of engine horsepower and wing area. This adds to both the initial and operating costs, while never coming up to the performance level achieved by well designed landplanes. Another, less popular, design approach is the use of twin floats with retractable landing gear. Then, of course, there is the seaplane, or flying boat, which does not have land operational capability and is almost as badly handicapped, performance- and price-wise, as the amphibian.

There has recently appeared a new technological development, which promises to give the operator not only amphibious, but also operation from any type of surface, with considerably less compromise. This development is the Air Cushion Landing System (ACLS), which has been under active, government-sponsored, development over the last five years. It stemmed from the Air Cushion Vehicle (ACV), which has recently attained limited operational status. Since the ACLS is described in Section 5.5.2, it will not be repeated here. It suffices to say that its incorporation permits operation of the aircraft from terrain of any degree of softness or roughness, as well as snow, ice and water. It is thwarted only by hills, ditches and large obstacles. The gear usually consists of a flexible trunk plenum, which can either be retracted or stretched tightly over the fuselage skin. This element of the gear usually weighs less than a conventional wheel gear; however, the weight of the air supply system has to be assessed. Also, if positive ground control on reasonably firm surface is desired, the weight of a taxiing gear presents an additional item.

The recommended configuration for Category I in Section 9.0 includes the installation of an ACLS with auxiliary wheel gear. The "accordion" type of trunk, described in Section 5.5.2, was chosen, which is retractable into a shallow trench under the wing and cabin floor. Since the stiff tread material becomes flush with the exterior surface, no doors are required. The trunks are circular in planform. The cushion area provides a ground contact pressure of only 0.67 psi. The enclosed volume of the plenum and the circumscribed cushion provides adequate excess buoyancy allowing the aircraft to be moored on the water with its power off.

The engine drives the overhead propeller shaft through multiple V-belts, as well as a centrifugal blower. The fan air is induced from an overhead scoop and the output is ducted to a radiator which cools the water-jacketed engine. The exhaust from the radiator is ducted downward to a 2-way selector valve. The valve directs the flow into the trunk plenum for surface proximity operations and to a rearward exhaust nozzle for flight. Adequate pressure and flow are available in the exhaust air for operating the ACLS, and the temperature is low enough (about 175°F) for compatibility with the rubberized fabric trunk.

A retractable, tricycle taxi gear is provided for positive steering and maneuverability on the ground. Contact pressure is maintained by pneumatic (air spring) struts, which also function as actuators for retraction and extension. This gear is designed to support no more than the static weight of the aircraft for parking, power-off. It is retracted for landing and takeoff and supports only a small portion of the weight during taxi operations. Although the ACLS trunk can be equipped with braking pads of the type described in Section 5.3.2, it is believed that the large, high thrust propeller can provide adequate braking if reverse pitch capability is provided. This type of braking is independent of surface conditions.

The operational advantages of the all-terrain aircraft should increase its marketability, since an insignificant addition to cost is involved. The trunk unit and auxiliary taxi gear can be obtained at about the same weight and cost of a conventional retractable wheel gear. This approach should appeal

to the sportsman owner for distant hunting and fishing expeditions, as well as to the business owner, who can make use of unpaved areas or waterways. The latter include the "bush" pilots, who operate most of the time from rough country, including water, snow and ice. The use of an ACLS is not confined to Category I, which is used only as an example, and should have equal appeal in the other three categories.

5.8 SAFETY

5.8.1 General Considerations

Safety is a fundamental,ever present requirement in aircraft design and operation. Without a certain minimum level of safety the desired utility of aircraft becomes unavailable. Because of the paramount nature of safety, regulations are issued by the FAA to establish a minimum level of airworthiness. For general aviation this is FAR Part 23 (reference 5.4.36).The operation of such aircraft is governed by FAR Part 91 (reference 5.4.37). It is basic to safe design that one of two situations exist: (1) a failure can not occur; or (2) if a failure can occur, there is a way out. An example of (1) could be at least some of the basic airplane structure. An example of (2) could be the engine in a single-engine airplane where the backup to an engine failure is the skill of the pilot in a dead-stick landing. Operational safety which is governed by avionic systems has been discussed in Section 5.4.1.6. This section will cover other aspects of the subject.

In a bulletin released in June 1966, the Aviation Safety Center at Cornell had the following recommendations applicable to general aviation aircraft:

- Fire - A modified fuel which will not burn explosively....Suppression of ignition sources, fuel containment, and fast acting extinguishants.

- Pilot Error - Research to determine why.... crew members commit errors that result in accidents.

- Airport and Navigational Aids - Extend navigational and landing aids at inadequately equipped airports, especially where short range jets are being introduced.

- Emergency Evacuation - Review cabin exit design and evacuation procedures via systems analysis.

- Collision Avoidance - Intensify development on airborne collision warning devices to anticipate increased congestion.

- Air Turbulence - Incorporate information developed in turbulence studies. Continue activities in detection and forecasting.

° Weather Information - Utilize data from a Turbulence Information Center to improve accuracy and prompt dissemination of information on weather hazards.

° V/STOL Development - Accelerate research in problems of stability, controllability and reliability with emphasis on safety.

° General Aviation - Increase efforts to educate and train owners and pilots to improve competence in flying and navigation. Support improved weather services and provide better stability and crashworthiness in design of private aircraft.

° Economics of Safety - Cost effectiveness analysis should be encouraged to support adoption of safety developments.

There seems to be general agreement in the literature as to what the problem areas are, and it is interesting to note that many of the recommended solutions lie outside the realm of aircraft and engine design. Reference 5.8.1 shows that there were 898 accidents in 1969 which resulted in fatal or serious injury or where an aircraft received substantial damage. The causes listed below are taken from the "Cause/Factor" table.

Item	Cause	No. of Times Listed	% of Total
1	Pilot	1038	76.9
2	Airframe	47	3.5
3	Engine	85	6.3
4	Systems	7	.5
5	Instruments	1	-
6	Weather	73	5.4
7	Terrain	62	4.6
8	Misc.	38	2.8
		1351	100.0

(The reason that the total number of times listed exceeds the total number of accidents is because more than one cause was given for most accidents.)

It is apparent that pilot error was responsible for the bulk of accidents, and only about 13% of the accidents were attributed to airframe/engine causes (the sum of items #2, 3, 4, & 8). A breakdown of pilot-caused accidents indicates the major cause of fatal crashes to be:

° Pilot continued VFR flight into adverse weather.
° Pilot failed to obtain or maintain adequate flying speed.
° Pilot became spatially disoriented.
° Pilot's inadequate preflight preparation.
° Pilot's unwarranted low flying.

The conclusions of Reference 5.8.13 state that "the designer cannot pass the responsibility through the instructor to the pilot," and that "60-70% of all accidents ... have causes ... which can be affected by the designer." Reference 5.8.29 lists many design features of aircraft which are conducive to pilot error. However, even if all aircraft were perfect, the accident rate would be reduced by perhaps a relatively small amount. The fact that pilots, not aircraft, are the major cause of accidents has long been recognized by the FAA, which is active in trying to upgrade the proficiency of both pilots and instructors in an effort to improve the safety record of general aviation. The aircraft industry has done a good job, though admittedly not perfect, of designing safe aircraft, and major improvement of the safety record can come mainly from improved pilot performance.

With the problem in proper perspective, there are of course some things which can be done to protect man from himself. References 5.8.13 and 5.8.29 discuss design-induced pilot errors and conclude with recommendations such as simpler fuel management controls and fuel gages, standardized cockpit control shapes and locations, and more reliable landing gear position indicators. To this list could be added some additional items, such as:

- Carburetor ice warning and automatic application of heat
- Easy stall, with adequate warning and automatic spin recovery
- Cross-wind landing gear

The industry and the FAA are generally familiar with the problems (practically all of which are detail design problems) and their solutions. From an examination of the literature, it is apparent that desirable safety features are well known, and that no engineering breakthroughs are required. With proper attention to design, improvements in safety could be provided for little or no additional weight. The cost of incorporating these items would be primarily in terms of additional design time involved.

As in the case of modern military and commercial transport aircraft, the general aviation aircraft industry should strive to achieve the following goals:

- Easier maintainability - which will result in the performance of more maintenance operations, thereby enhancing safety.

- Increased reliability - which will result in less failures, hence greater safety --- also less maintenance required, more hours flown, more skill developed --- and again, greater safety.

- Less complication - which requires fewer pilot tasks, hence less chance of pilot error.

5.8.2 Damage Tolerance and Crashworthiness

Structural safety is governed by FAA regulations which have proved to be adequate for all except extreme operating conditions. In cases where damage is

unavoidable, present technology offers many possibilities of avciding crashes, and where crashes are inevitable, of minimizing the chances of severe injury and loss of life.

All military and transport aircraft manufacturers use damage tolerance criteria in the design of aircraft structure. The entire structure, with the possible exception of the landing gear, is designed to be damage tolerant. The damage tolerant load level used is either: maximum limit load; nominally 80 percent of design limit load; or the most probable limit load based on the mission profile analysis concept. The general agreement is that the last named method of developing the damage tolerant load is the most desirable one. Structure is demonstrated to be damage tolerant by analysis or tests, where it is demonstrated that sufficient residual structural strength remains to adequately carry the damage tolerant load. Cracks that result from fatigue failures are assumed to be the major source of damage in damage tolerance considerations. However, damage due to blown engine parts, fire, explosion, etc., is also assumed.

Damage tolerant structures take the form of multispar wings and tail surfaces with redundant structure, alternate load paths and crack stoppers. Such provisions exact some penalties in weight and cost, but close attention to good design practice can minimize them. Although damage tolerant structures are not usually offered in the general aviation industry, their inclusion is strongly recommended and can provide a higher level of safety than non-redundant over-strength structural members.

The doctrine of crashworthiness is based on the contention that there will always be combinations of circumstances which can and do result in unusually severe impacts with the ground, despite the fact that the aircraft may be designed to high levels of safety. To aid in the design for crash safety, one of the most comprehensive reports on crash statistics is embodied in Reference 5.8.28. In aircraft design practice, the subject has been relegated to minor importance in the past. However, it is gaining increasing impetus in automobile design, and may do likewise in general aviation, as the number of vehicles in service increases. The provision of reasonable crash safety might become one of the factors which will induce more people to use flying in lieu of ground transportation.

Reference 5.8.6 treats this subject very thoroughly in its application to helicopter structures. However, most of the text is applicable to airplane structures, as well. Figure 5.8.1, from that paper, shows a longitudinal cross-section of the OH-6A helicopter, noting the provisions designed to increase crash safety. The record of this craft has been exceptionally good. One of them attained a vertical impact velocity of 30 fps in a crash, involving no injury to the pilot and relatively minor injury to the observer. Another, involving 20 fps and peak vertical accelerations of 12 to 15 g in the cockpit area, had similar results. Figure 5.8.2, also from Ref. 5.8.6, compares the effects of plastic versus elastic deformations, indicating the desirability of using a maximum amount of plastic deformation. Figure 5.8.3 shows the ideal

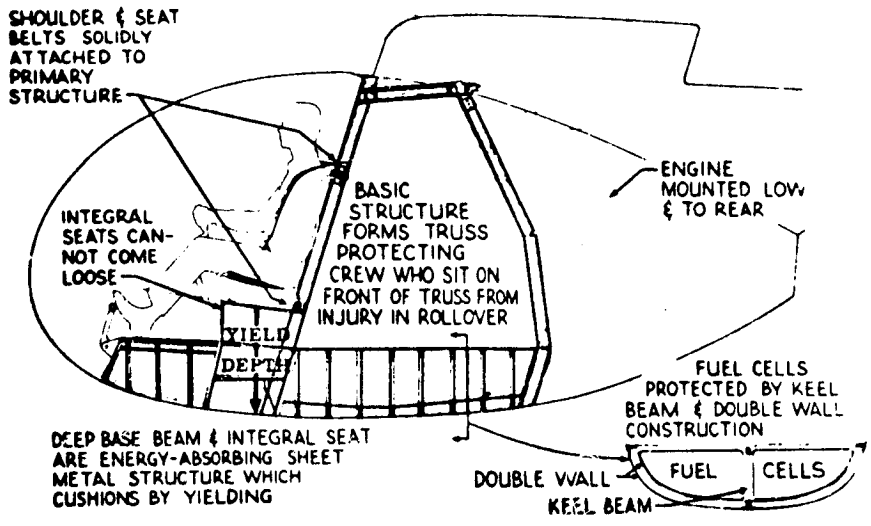
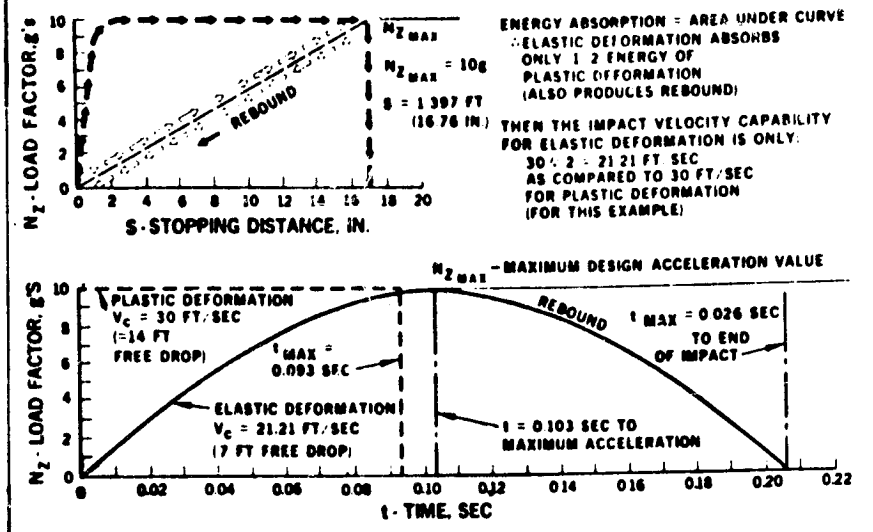
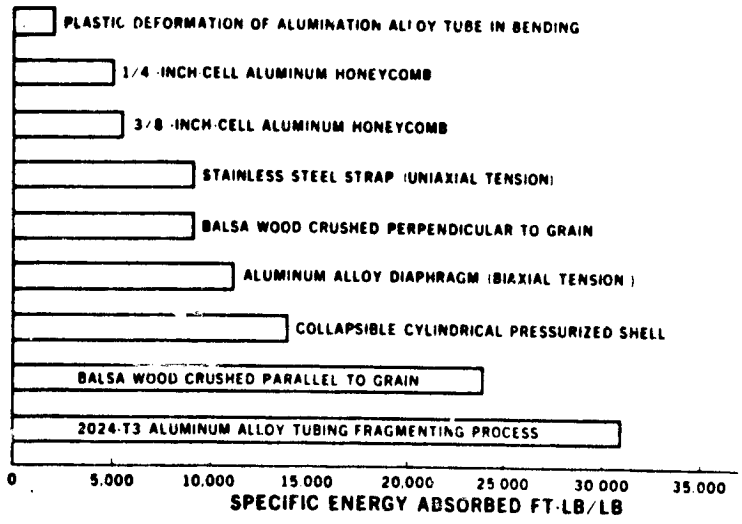


FIGURE 5.8.1 OH-6A Crash Safety



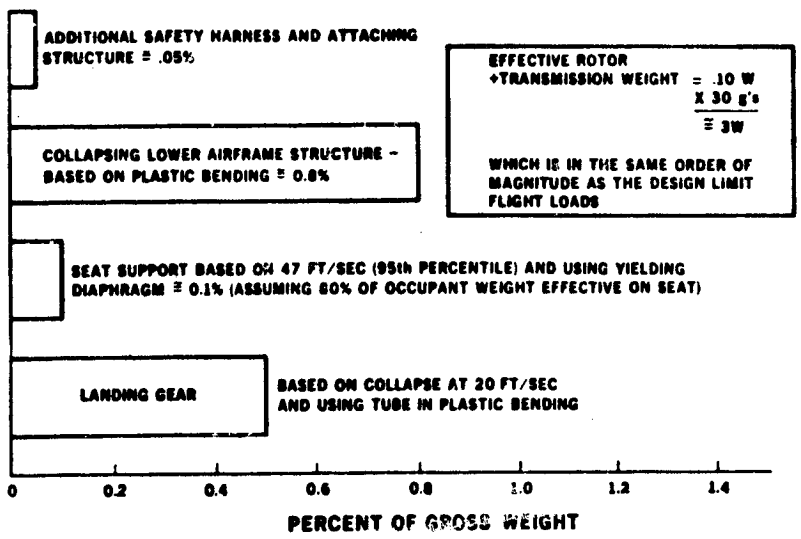
Crashworthiness Comparison of Plastic Versus Elastic Deformations

FIGURE 5.8.2



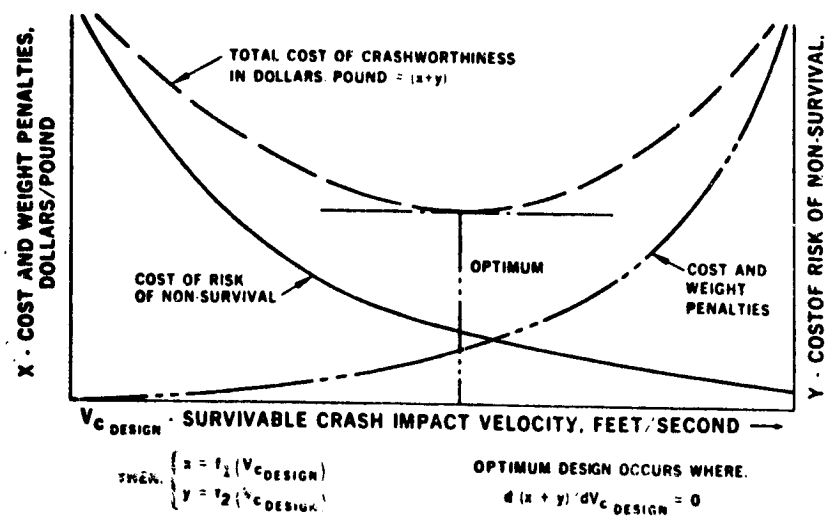
Ideal Impact Energy Absorption Capabilities Versus Weight for Various Materials

FIGURE 5.8.3



Ideal Crashworthiness Weight Penalties in Percent of Design Gross Weight (For the Stated Impact Velocities)

FIGURE 5.8.4



Proposed Cost-Effectiveness Optimization for Crash Survivability Design Criteria

FIGURE 5.8.5

energy absorption capabilities, versus weight, for various materials. The more advanced of the current helicopters provide crash load factors from 2.5 to 5.0 times the minimum FAA requirements, with weight peralties as indicated in Figure 5.8.4.

A proposed cost effectiveness method for arriving at an optimum crashworthiness design criteria objective for a particular design is shown in Figure 5.8.5. Both cost and weight penalties can be estimated in terms of dollars per pound of vehicle weight during the preliminary design phase, and similarly the cost of the probability of nonsurvival in crashes of various impact velocities can be estimated, using insurance methods. The total of the cost of provisions against crash risk, plus the cost of the remaining risk of nonsurvival equals the total cost per pound assigned to the aircraft from the crashworthiness standpoint. The minimum point on the curve at $d(x+y)/dV_c = o$ indicates the optimum crash impact velocity that should be used for design. The authors of Ref.5.8.6 conclude that design for crashworthiness and survivability must be approached as an impact problem, rather than one of strength or acceleration, since excessive strength, without adequate provision for deformation under load, has been shown to decrease, rather than increase, the chances for survival of the occupants.

In this context, the air cushion landing gear concept, described in Section 5.5.2 should serve as an excellent crash arrester in a vertical impact situation resulting from a takeoff or landing accident. Energy is dissipated by escape of the air through the peripheral slot, and the deformation distance is comparatively large. Of more importance, however, is the fact that the load is reacted uniformly over the bottom of the aircraft, rather than at concentrated joints, causing the substructure to act as an efficient secondary impact absorber.

Pressurized fabric structures for aircraft have been developed, culminating in completely inflatable airplanes. While structural and aerodynamic limitations prevent the widespread use of inflatable structure, it could be applied to potential impact areas, such as the nose of the fuselage, with pressure relief, or blowout valves to control the energy dissipation upon impact.

Reference 5.8.10 lists some desired crashworthiness features as follows:

- Secure seat tie-down and seat energy absorption properties
- Secure occupant restraint
- Removal of lethal objects and surfaces from the occupant-impact envelope
- Secure attachment of interior furnishings
- Suppression of fire and smoke
- Quick routes for evacuation

The effect on aircraft weight and performance of a landing gear designed for higher sink speeds, and the effects of designing the primary structure for higher load factors, together with structural crashworthiness, has been determined in the sensitivity analyses. There is a strong feeling that landing gear collapse due to hard landings, or structural failures due to unqualified

pilots who lose control in IFR weather and overload the structure, are insufficient causes for the industry to redesign landing gear and structure. This would amount to penalizing the entire general aviation community, in terms of additional cost and/or reduced performance, for the occasional benefit of a few of their unqualified members. If the increased cost is considered reasonable, changes may be worthwhile.

Since engineering solutions in the areas of structural design for crashworthiness and survivability are presently known, evaluations can be made of increases in weight and associated costs. Although weight increases may be nominal, the additional engineering and testing required may be significant. Looking at the problem objectively, however, crash avoidance is far more cost-effective than crash survivability. Therefore, design effort and financial investment can be applied more profitably in pursuit of accident prevention.

5.8.3 Fire Prevention

Use of tear-resistant bladder fuel tanks with self-sealing, breakaway fittings offers a reduction in fire hazard following a crash, but present systems are comparatively heavy and expensive. Automatic fuel shutoff devices in the event of a crash would also assist in fuel containment. Their use will be evaluated in the sensitivity analysis portion of the study. Ref. 5.8.25 treats this subject in detail.

Explosion prevention systems have been developed for military aircraft operating in the combat zone. They take the form of gas inerting systems and the use of reticulated foam-filled tanks. The latter system utilizes the principle of wetting the foam to preserve a fuel-air mixture too rich for ignition and can be considered to have higher reliability.

Fire occurrence in the air is less likely than that following a crash, but nevertheless deserves consideration. The most common source of this occurrence is the power plant. Fuel leakage into the engine compartment must be counteracted by the provision of adequate drainage. Electrical devices in such areas should be encapsulated. Fire detection, warning and extinguishing system installation should follow the practice of military and commercial transport aircraft.

The installation of wing tip tanks represents an approach to the enhancement of crash safety by locating the fuel as far from the cabin as possible. These tanks, in some cases, can be jettisoned and in other cases can be equipped with impact-breakaway fittings and fuel line connections. The increased parasite drag of these units is offset by reduced lift-induced drag, due to end plate effect. Moreover, their mass distribution tends to relieve maneuvering and gust loads, but is detrimental to landing loads. They have been used sparingly, in the past, on general aviation aircraft and are believed to be less desirable and no safer than the use of flexible fuel cells located in the outboard portion of the wings.

A less likely cause of in-flight fire is lightning strikes. These usually initiate at extremities of the airplane - nose, tail and wing tips. Since

wing tips are close to wing fuel tanks, this poses a question of relative safety. The aforementioned fuel-air explosion prevention systems are equally effective, in this case. The bonding of metal surfaces is good practice. In the case of plastic structures, sprayed-on aluminum coating is advisable.

5.8.4 Attitude Stabilization

A single axis autopilot is certainly a useful piece of equipment, primarily for relieving the pilot during long trips. It is used primarily about the roll axis as a "wing leveler." It may also have some virtue in terms of added safety, should an unqualified pilot find himself in instrument weather conditions.

The major obstacle to more widespread use of this device is cost. The lowest priced single axis autopilot listed in the 1970 Business and Commercial Aviation Planning and Purchasing Handbook is $495, with prices going up to $2,000. However, it is included as standard equipment in some aircraft. This equipment is discussed more fully in Section 5.4. From a safety point of view, the inclusion of single axis autopilots would seem to be desirable.

A discussion with aviation insurance underwriters on this subject disclosed, however, that no dollar value (in terms of reduced premiums) could be placed on this feature until operating experience had been gained over a long period of time. Their rate structure is based primarily on aircraft valuation and pilot experience. The aircraft valuations are more or less standard, but much emphasis is placed on pilot qualifications. For example, a pilot who is instrument rated can expect a premium reduction of from 25 - 40%. This correlates with previous findings in this study that the pilot is the weak link in the safety chain.

5.8.5 Environmental Factors

The following statement on this subject has been contributed by Mr. George M. Cash, head of the Aerosystems Research Department of Cornell Aeronautical Laboratory:

> "With regard to the question of the application of advanced technology to general aviation aircraft, the real question is exactly what areas must be attacked in order to increase the utility and safety of these aircraft. It is true that many costly changes could be made to both the aircraft and their environment, but the effects on utility or safety may be minimal. Unfortunately, the serious problem areas facing general aviation seem to boil down to operations in unfavorable weather, primarily thunderstorms, icing and high winds, and single-engine operations at night. Other advancements could be made in peripheral areas and these will be mentioned briefly.
>
> "Operations in thunderstorm areas are usually considered questionable for any aircraft, but especially so for aircraft with relatively light wing loadings and low excess power. The pendulum, after several air carrier accidents, seems to be definitely swinging back toward wide avoidance,

rather than radar assisted penetration of storm areas. Even with modern air carrier aircraft, actual penetrations of the main cell are avoided if at all possible. It would seem that design changes directed toward building general aviation aircraft capable of routinely penetrating thunderstorms would never be acceptable. Rather, efforts should be directed toward better weather forecasts and readily accessible information as to exactly where the storms are located and what they are doing. This information would not be used for inflight vectoring, as the burden on ATC would be unacceptable, but would allow the pilot to make an accurate, and safe, go-no-go decision. As it is now, the forecasts are generally conservative to the point where trips are unnecessarily delayed or cancelled. After a few such experiences, pilots sometimes ignore the forecasts with occasionally upsetting or disastrous consequences.

"Icing encounters are somewhat different. Feasible changes could be made to the aircraft to allow operation in particular situations and include:

1. Propeller deicing (electric),
2. Windshield deicing (electric/hot air),
3. Airframe deicing (pneumatic/hot air).

"As with thunderstorms, however, one of the most dangerous aspects concerns the uncertainty associated with the forecasts. The extent and severity of the icing must be quantitatively given, and the effects of a given level of icing must be known for any particular airplane. Only then can maximum utility be achieved safely. Much information which should be readily available through airline pilot reports or data link (ceilings, cloud tops, freezing levels) is simply not accessible to the general aviation pilot.

"For routine instrument approaches, a simple heading hold or more elaborate approach coupler would be very valuable, especially for single pilot operations. A simple autopilot also greatly assists the pilot during the enroute phase.

"Night flying would probably increase if there were more lighted (alternate) airports, much better enroute weather information and better lighting in the cockpits. Instrument faces are often hidden in dark corners and map lights are sometimes essentially useless. These seemingly trivial points can be a real source of aggravation.

"Some peripheral items could be greatly improved, especially in the area of getting information to the pilot. All flight information should be computerized and made available, by route, to pilots at any airport. A complete printout of all weather, airport and facility information should be a routine matter. The present system of a four-volume set of airman's information manuals seems unwieldy and outmoded. At controlled airports, ground handling should be done through the use of lighted directional signs. Runway and wind information, etc., could be given in the same way. Standard departure and approach paths should be utilized, including definite corridors for high performance aircraft. Airport terminal information service (ATIS) should be provided on outlying VOR's not at the VOR servicing the airports. By the time the pilot can understand

the sometimes garbled voice information, he is quite close to the airport. Charting for VFR is improving, but approach control frequencies, rather than tower frequencies, should be shown. These are relatively small points, but they do add to the complexity of the present operation.

"In summary, better services primarily in the transmission of information to the pilot, especially weather, are required. This is vital when dealing with thunderstorms and icing. Design changes will probably not alleviate the thunderstorm problem, but could definitely assist operations during icing conditions. More accurate weather information would increase both utility and safety in both cases."

Avoidance of adverse weather conditions could be made independent of ground control by the inclusion of weather radar. The present obstacle, however, is cost, since the most inexpensive units cost from $6,600 to $7,800. Until a reliable, low cost weather radar is developed, reliance must be placed on ground-based information. Additional discussion of this subject is included in Section 5.4.

5.8.6 References

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5.9 VTOL Technology

5.9.1 Introduction

VTOL aircraft, in the present and emerging state-of-the-art, fall into four main categories: fixed rotor, tile rotor, retractable rotor and fixed wing. The first three fall into the low disc loading classification, while the fourth, exemplified by jet - and fan-lift systems, has inherently high disc loading. Since it is necessary to have low disc loading in order to meet the low noise level constraint of this study, fixed wing concepts have not been considered. Low disc loading is desirable not only from the noise standpoint, but also because of ground erosion considerations. While the minimum cruise speed constraint, in Category IV, of 150 knots can be met with a pure helicopter design, it was considered expedient to look at configurations with a higher speed potential. Either the tilt wing or the tilting rotor can, at least, double the minimum required cruise speed. "Compounding" the helicopter can increase its speed to 200 knots or more. The technology relating to these approaches will be examined in the following subsections.

5.9.2 Hovering Capability

A true VTOL aircraft must be capable of sustained hovering flight, and this requirement excludes the autogyro, which is basically an STOL vehicle. Figure 5.9.1 presents a plot of disc loading versus power loading for several groups of VTOL configurations of interest to this study. The autogyro has been included for reference only. Each group is represented by a shaded area surrounding a number of discrete points which represent actual aircraft (except for the tilt rotor area obtained from Ref. 5.9.3). Superimposed on this plot are lines indicating "Figure of Merit," a function of power loading times the square root of disc loading. This parameter has long been used to indicate the hovering efficiency of helicopters. It can be seen that, as the disc loading is increased, the more gradual decrease in power loading creates higher Figures of Merit.

This does not necessarily mean that the high disc loading configurations are more efficient in the overall sense. Figure 5.9.2 presents a similar plot, obtained from Ref. 5.9.3. In that paper, the ordinate was labeled "Vertical Lift Efficiency," which the authors consider to be a more meaningful criterion than "Figure of Merit" - they contend that the latter criterion should be used to calculate the vertical lifting efficiency in any one class of geometrically similar rotors, fans, etc. The ordinate of the graph represents the pounds of weight lifted per shaft horsepower and is the same as "power loading." The solid curve represents an average for advanced technology aircraft. The dashed curve, in the realm of helicopters, represents the single rotor configuration, which is below the average because of the power required for the tail rotor. The tilting proprotor, on the other hand has counter-rotating main rotors, as does the tilt wing, requiring no torque correction, which puts it above the average.

Reference 5.9.12 points to the downward variation of optimum disc loading with hover time for a typical VTOL mission. As helicopters decrease in size, the magnitude of the optimum disc loading range decreases. The balance between disc loading and power loading must be optimized on a cost basis and be made compatible with the desired cruising speed, the noise constraint and the anticipated surface conditions.

FIGURE 5.9 .1

VTOL HOVERING PARAMETERS

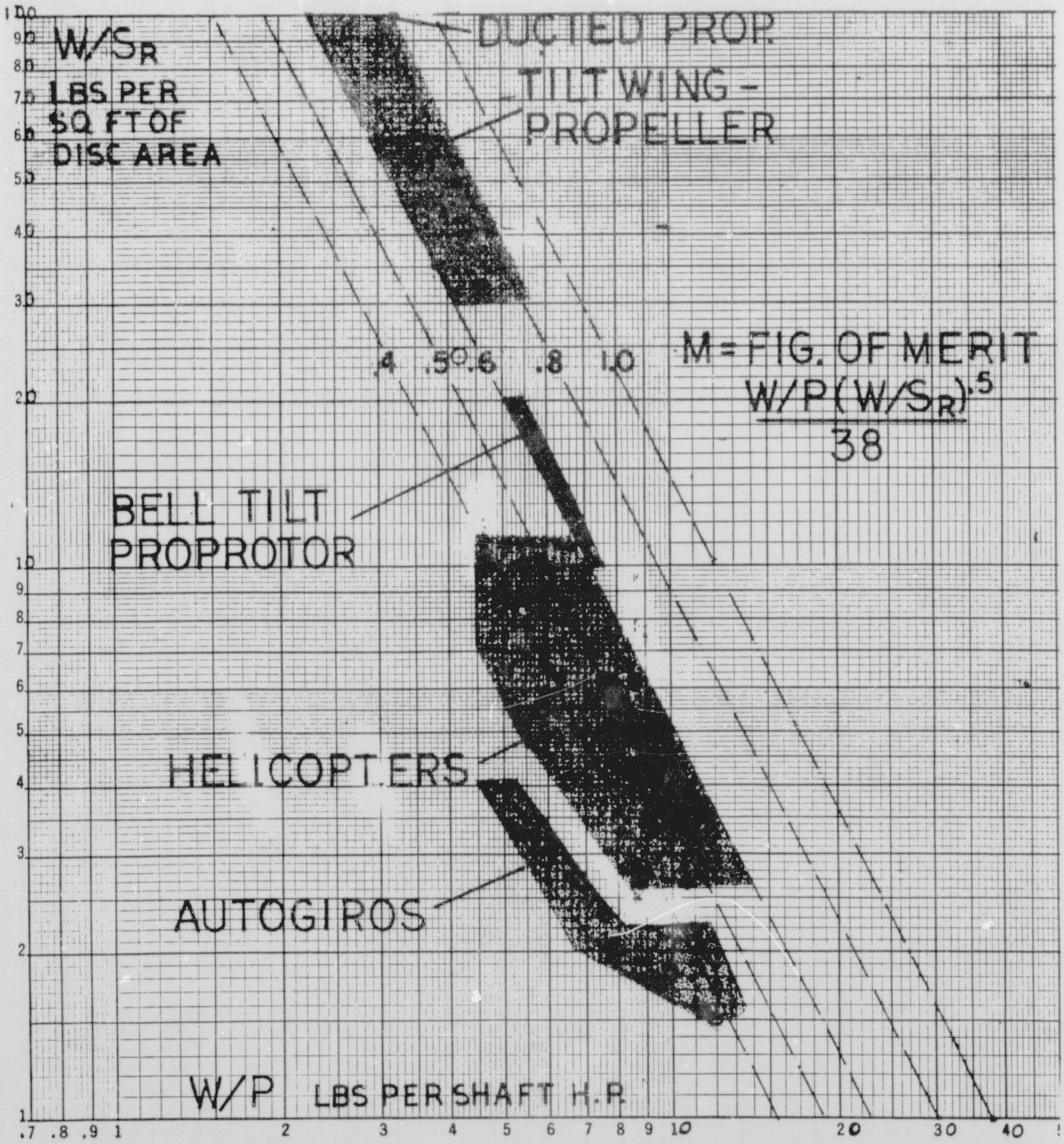
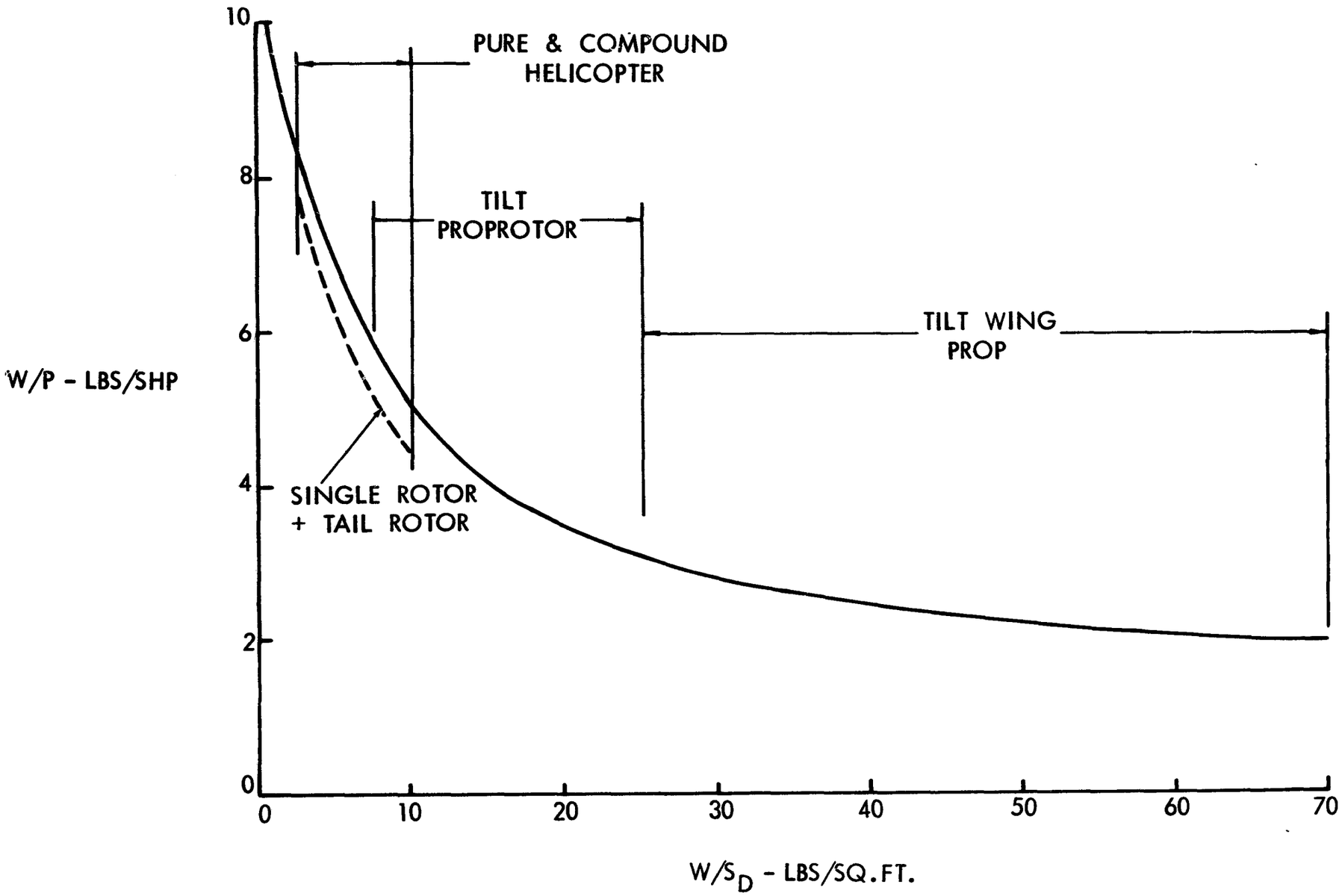


FIGURE 5.9.2 VERTICAL LIFT CAPABILITY VS. DISC LOADING



5.9.3 Forward Speed Capability

The helicopter, in which the rotor disc is tilted to relatively small angles to achieve forward speed, is basically subject to a speed constraint. To quote Ref. 5.9.1:

> "All rotary-wing aircraft have a theoretical maximum speed which cannot be exceeded without stowing, retracting, or in some way eliminating the rotor. Assuming a rotor has constant blade tip speed, as the rotorcraft itself approaches this speed in forward flight, a retreating blade tip approaches a net zero forward velocity, so that the entire blade is stalled. A faster rotational speed can delay such stalling of the rotor blades, but another limit is set by the net velocity of the advancing blade tips. Here the flight speed is added to the rotational speed and the blade tips approach sonic velocity (Mach 1) with accompanying compressibility effects of buffeting and increased drag. Thus the speed of rotation on a fast rotary-wing aircraft is a compromise between the two extremes set by the advancing and retreating blades in forward flight."
>
> "In Figure 5.9.3, forward speed is plotted against rotor blade tip speed. The (hatched) diagonal lines show what might be considered theoretical forward speed limits for rotary-wing craft, given the rotor rotational speed. The tip-speed ratio is the forward speed divided by the blade-tip rotational speed; at a tip-speed ratio of 1.0 (shown by the diagonal line on the left), there is reversed airflow over the complete length of a retreating rotor blade. At a tip Mach number of 1.0 (shown by the diagonal line on the right), an advancing rotor blade is likely to encounter severe compressibility effects. As might be expected, the two diagonal black lines intersect at a point where both the forward speed and the blade-tip rotational speed are equal to half the speed of sound - 380 mph at sea level."
>
> "However, there are obvious difficulties in the way of a rotorcraft aspiring to attain this speed. The lower diagonal line on the right represents a constant blade tip Mach number of 0.95 and the one on the left represents a constant tip speed ratio of 0.75 - here 75% of the inner blade length is in reversed airflow due to the slower rotational speeds of the blades nearer to the hub. The two lower diagonal lines intersect at a point representing a forward speed of about 300 mph - a speed generally accepted to the the practical maximum speed for a rotary wing aircraft."
>
> "The shaded area on Figure 5.9.3 shows combinations of forward speeds and rotor speeds which have been evaluated by flight testing to date. The left portion of this area, at the lesser blade-tip speeds, represents autogyro flight experience; the right portion, pure-helicopter experience; and the top portion, experience of compound helicopters which, understandably, have attained somewhat higher forward speeds than pure helicopters."

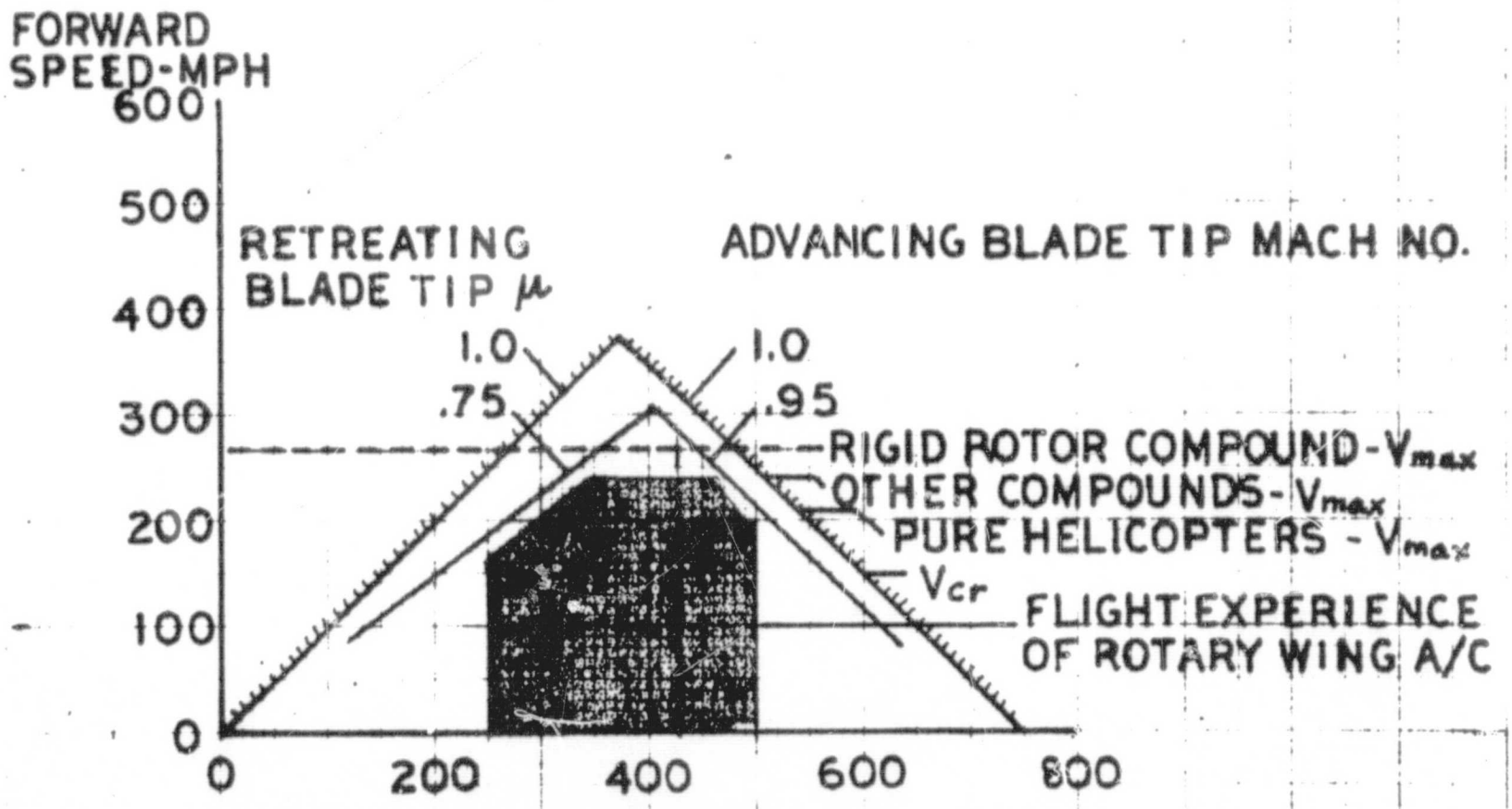


FIGURE 5.9.3 ROTOR OPERATING CONDITIONS

"The shaded area also represents the extent of hinged-rotor experience. Although flapping highes made the earlier developments on rotocraft possible, they have become an increasing embarrassment as performances have approached the apex of the intersecting diagonal lines on Figure 5.9.3. Consequently, the development of non-articulated rotors, semi-rigid rotors, and partially stiff blades has been an industry goal for many years as a necessary adjunct to extend the performance of the helicopter to the 300-mph mark. The dash lines on Figure 5.9.3 intersect at 272 mph, which indicates the extent to which this promise has been fulfilled to date by the XH-51A series of rigid-rotor helicopters. The XH-51A compound which achieved this mark is only a test vehicle, but the knowledge gained will hopefully pave the way for large rigid-rotor compound-helicopter transports with cruise speeds in excess of 250 mph, as well as faster helicopters for application in many other commercial and military roles."

"Figure 5.9.4 is self explanatory, and gives some idea of helicopter development by plotting, against time, the maximum speeds of some outstanding rotary-wing craft."

5.9.4 Balanced Power Performance

Ref. 5.9.6 explains this concept in the following words:

"A fundamental characteristic of low-disc-loading VTOL aircraft beyond the helicopter --- is that they have sufficient installed engine power to permit attainment of relatively high subsonic cruise speeds, provided they are of reasonably clean aerodynamic design. It can be shown that the cruise speed

$$V_{cr} = 326 \frac{\eta L/D}{W/shp} \quad \text{(knots)}$$

where η is propulsive efficiency, L/D is airframe lift/drag ratio and W/shp is gross weight power loading in pounds/horsepower, all for the ambient conditions at any cruise point."

The pure helicopter is capable of economic, sustained cruising speeds of 125 to 175 knots, while the compound helicopter can reach 200 knots, or higher. Above that level, however, the tilt rotor, tilt wing-propeller or retractable rotor concepts must be resorted to, provided that low disc loading must be maintained. Ref. 5.9.6 shows that the tilt proprotor concept is capable of attaining a cruise speed as high as 400 knots, including an L/D ratio of 14.3 and a propulsive efficiency of 86%, with a power loading as high as 10 lbs/shp.

5.9.5 Compound Rotorcraft

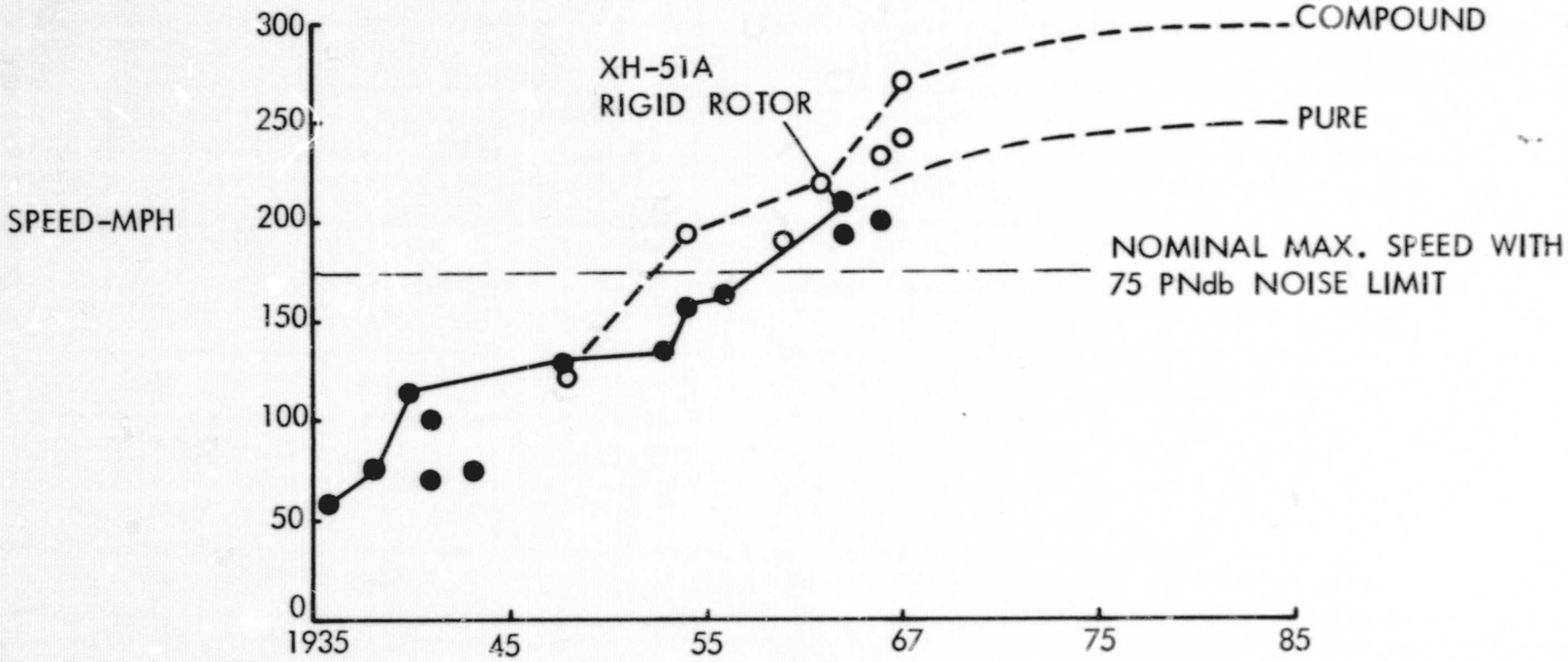
Combinations of rotors with wings are described in Ref. 5.9.12 as follows:

"All of the lift systems can be combined with wings to unload a rotor in forward flight and relieve stall and compressibility effects. The speed potential can be increased further with auxiliary propulsion. The tilt proprotor transfers all of the lift to the wing in high-speed flight and then continues as an airplane with the proprotor serving as a propeller.

FIGURE 5.9.4

HEL.COPTER MAXIMUM

SPEED TREND



> Stoppable rotor systems also transfer all lift to the wing in high-speed flight, using auxiliary propulsion for forward flight. After the rotor is stopped, it can be feathered, faired, or retracted to reduce its drag, indicating the speed potential of a fixed-wing airplane. The lifting fans may be independent of the wing and rotate 90° for propulsion in high-speed flight. Alternatively, the fans may be buried in the wing and faired over for high-speed flight with an auxiliary system for propulsion. The direct jet lift devices with a wing are similar to the fan combinations."

Two VTOL configurations have been examined in this study: the pure helicopter and the tilt wing-propeller. This is not to imply that the compound helicopter and the fixed wing-tilt proprotor concepts are not competitive. The study investigators were more familiar with the design procedure for the two concepts which were analyzed.

5.9.6 Rotor Design

Helicopter rotor systems are classified by configuration (or arrangement) and by type. Configurations include: single rotor, tandem rotors, side-by-side rotors, and coaxial rotor. Types include: fully articulated, semi-rigid (or teetering) and fully rigid. In the classification of rotor arrangement, Reference 5.9.12 offers a good description:

> "The most familiar rotor configuration is the single main rotor with antitorque tail rotor arrangement. The advantage of this type is the relative simplicity, with the saving in weight compensating for the small power loss due to the tail rotor. The tandem rotor configuration offers the advantage of large fuselage volume. Disadvantages are high transmission and shafting weight and a loss in efficiency in forward flight. The side-by-side configuration is more efficient in forward flight, because of the aspect ratio effect, but suffers from fuselage drag and/or high structural weight. This configuration also requires extensive gearing and shafting. In the coaxial machine, the net rotor torque is largely eliminated by using two superimposed rotors, rotating in opposite directions. The coaxial design offers the advantage of compact over-all dimensions defined only by the rotor diameter and the directional control configuration. The rigid rotors, hub, and controls become more complex. Intermeshing rotors are essentially equivalent to a side-by-side design with a high degree of overlap and are quite similar to coaxial types. Some lifting efficiency is sacrificed for compactness and transmission simplicifications."

Ref. 5.9.10 shows how these configurations compare based on NASA wind tunnel tests. The power requirements of the tandems are substantially greater than those of the single-rotor or side-by-side configurations for the same mean load per blade. However, that the power penalty is only a single ingredient of the overall "efficiency" of a configuration, and should not be construed as evidence that the tandem is undesirable. One advantage of the tandem arrangement is that it offers a higher range of C.G. travel compared to that of other arrangements.

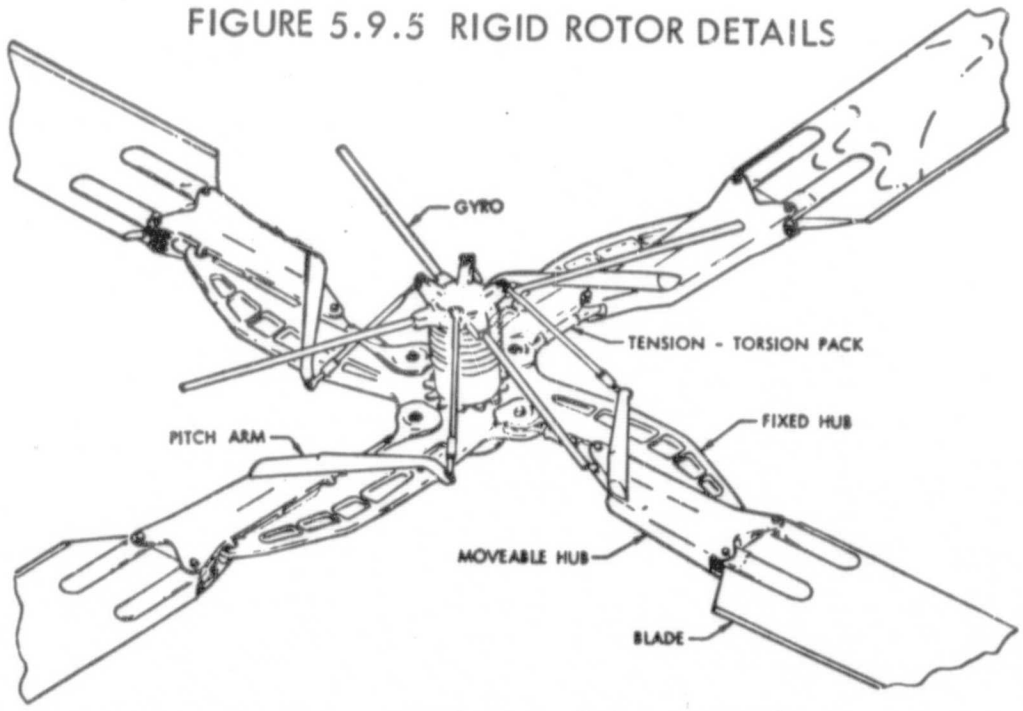
Reverting to the discussion of individual rotor design concepts, one reason for the present speed limitations of helicopters below the potential discussed in Section 5.9.3 is the poor stability and control characteristics associated with the conventional helicopter's hinged rotor system. The speeds obtained by XH-51A versions - 201 mph for the pure helicopter and 272 mph for the compound modification - are significant because they represent the increased future potential of the helicopter. An even higher speed, 316 mph, was obtained with the Army/Bell HPH compound helicopter, flown in 1969 and 1970. The XH-51 versions had a "rigid" rotor design, while that of the HPH was semi-rigid. Rigidity is a matter of degree, since no structure can be completely rigid under load. Increased rigidity raises the level of stability, as well as increasing the margin of control power. Representative drawings of the hub and blade, as applied to the AH56A "Cheyenne" helicopter, are shown in Figure 5.9.5, obtained from Ref. 5.9.2.

5.9.7 Tilt Proprotor and Tilt Wing-Propeller Problem Areas

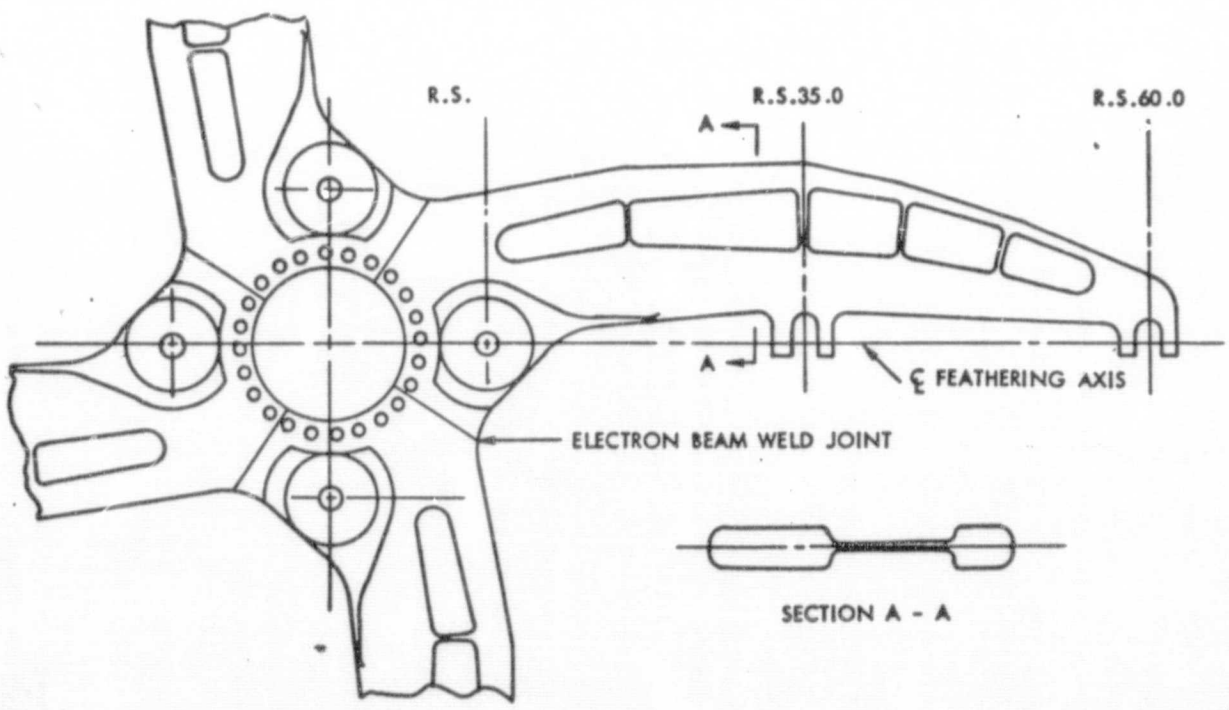
In the tilt proprotor concept, the wing is rigidly fixed to the fuselage, and only the engine-propeller units are rotated. While this system has the disadvantage of generating a higher download in hovering, due to projected wing area in the slipstream, it presents less problems in the low speed portion of the transition due to wing stall, provided that it flies within the "conversion corridor" shown in Figure 5.9.6, obtained from Ref. 5.9.8, in which the conversion angle is measured from the vertical position. This diagram typifies a concept which resulted from the Army's Composite Aircraft Definition Phase, reported in July 1967. This model had a disc loading of 12, a wing loading of 73 and a power loading of 4.1. During the process of conversion, lift is gradually shifted from the rotors to the wings, with no discontinuities in flight characteristics. The helicopter mode is defined by a conversion angle of less than 15 degrees and the conversion mode from 15 to 90 degrees. The minimum conversion speed limit is that imposed by wing stall, and the upward curve of this boundary at speeds below 70 knots results from rotor downwash on the wing, reducing the latter's angle of attack. The minimum conversion speed is defined as 120% of the stall speed. When limited by the maximum speed boundary, the corridor is approximately 70 knots wide. While this could be considered tolerant enough to eliminate the need for scheduling conversion angle with speed, safety considerations might dictate the use of a scheduling device for general aviation use.

The control system of the tilting proprotor configuration utilizes separate actions for helicopter and high speed (airplane) flight. In the helicopter mode, roll is controlled by differential collective pitch; pitch is controlled by tilting the tip path plane of both rotors by simultaneous fore-and-aft cyclic pitch changes and yaw is controlled by differential fore-and-aft cyclic pitch changes, tilting the tip path plane of one rotor forward and that of the other aft. Thus the cyclic pitch control is termed "Monocyclic," since it tilts the rotors in one plane only. Airplane controls for high speed flight consist of conventional ailerons and elevator; however, differential collective proprotor pitch is used for yaw (Ref. 5.9.8 does not state why rudders are not used). Control sensitivity, expressed in terms of radians/sec^2 per inch of stick travel, increases with speed in the pitch and roll attitudes, until conversion speed is

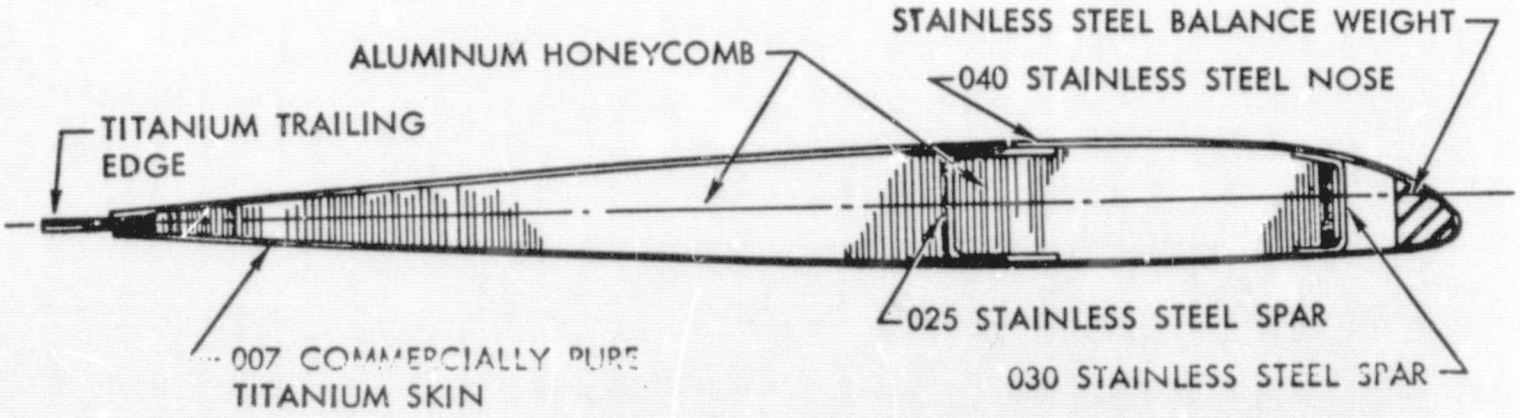
FIGURE 5.9.5 RIGID ROTOR DETAILS



AH56A Main Rotor Assembly



Main Rotor Fixed Hub



Main Rotor Basic Blade Section

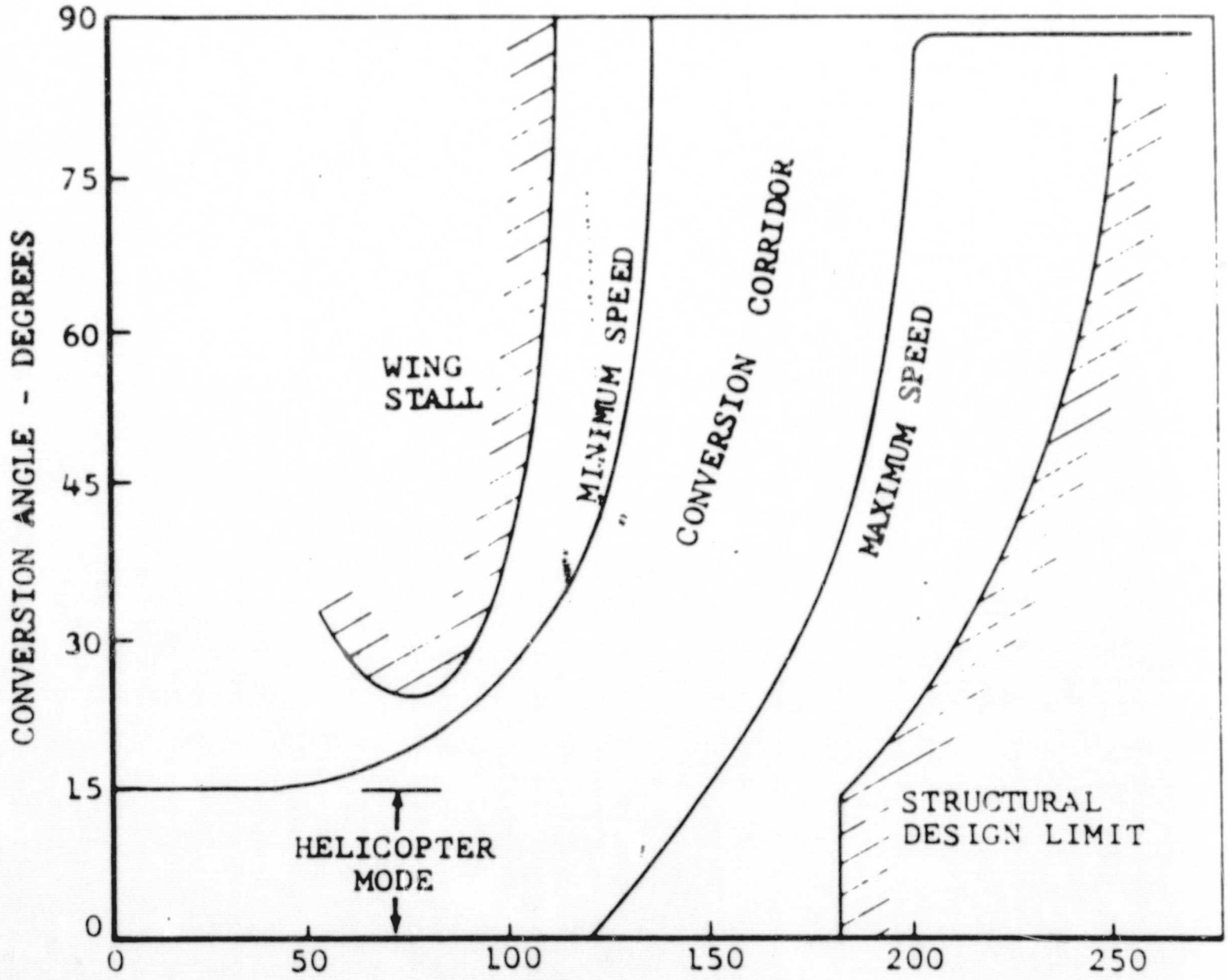


FIGURE 5.9.6 CONVERSION CORRIDOR

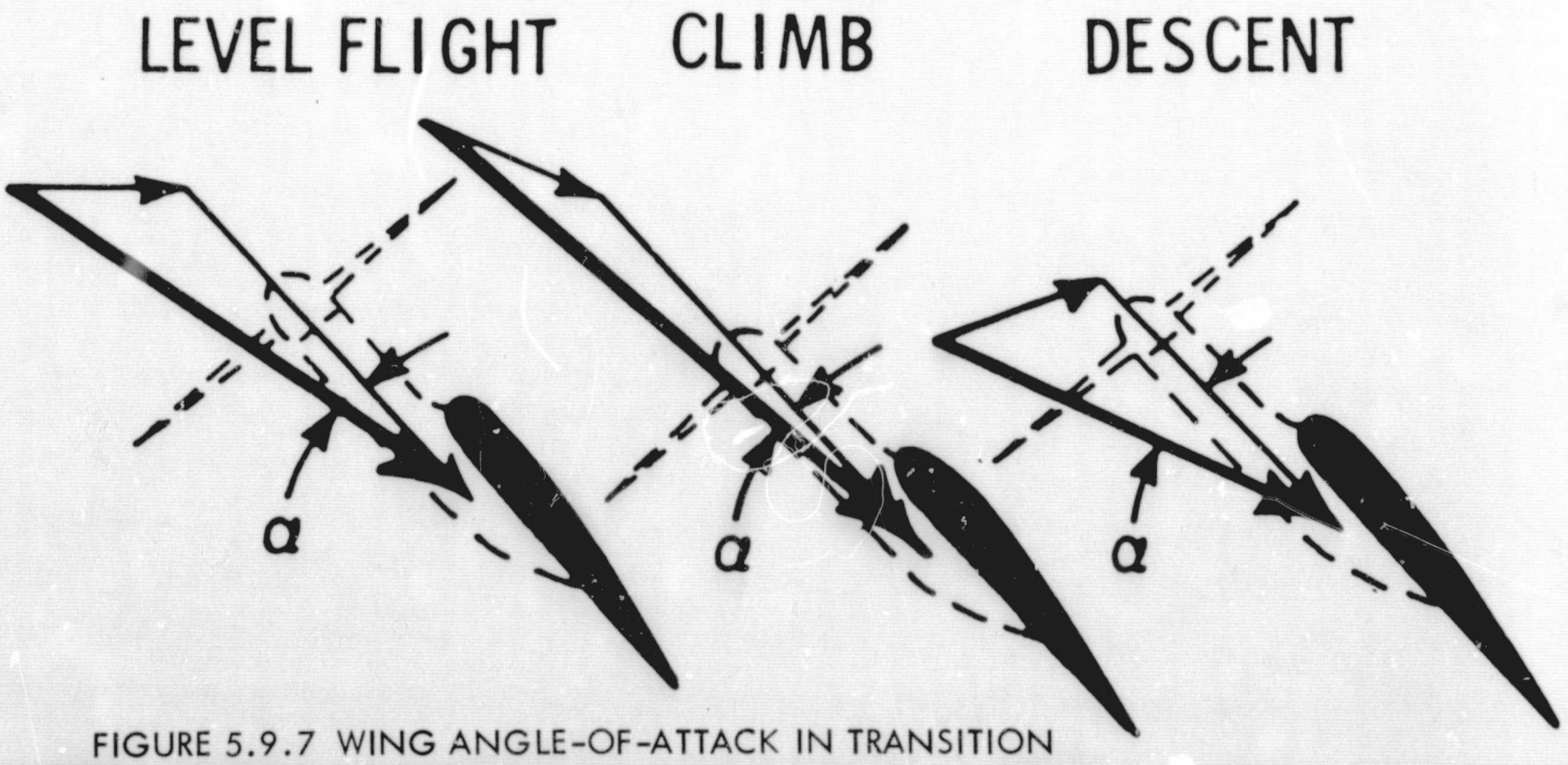


FIGURE 5.9.7 WING ANGLE-OF-ATTACK IN TRANSITION

reached. The change-over from helicopter to airplane controls while the discs are rotated decreases the sensitivity, particularly in the direction of roll. After conversion, control sensitivity increases with speed in the conventional manner. Yaw control sensitivity remains substantially constant throughout the flight range.

Other tilt proprotor problems, according to Ref. 5.9.6, which were encountered with the XV-3 aircraft and for which solutions were eventually determined, include:

- Large flapping amplitudes
- Proprotor/pylon dynamic stability
- Short-period aircraft dynamic stability
- Oscillatory blade loads in gusts and maneuvers

In the tilt wing-propeller concept, the wing remains at a constant incidence angle to the propeller, and the entire assembly is rotated. The propeller slipstream blowing over the wing tends to keep the wing from stalling during the transition despite the high angle-of-attack of the combination; however, stalling is still likely to occur in some conditions. Some of the factors involved are illustrated by the velocity vector diagrams of Figure 5.9.7, obtained from Ref. 5.9.11. In all three conditions - level flight, climb and descent - the angle-of-attack between the resultant velocity vector and the thrust line, plus the wing incidence angle relative to the thrust line, become the actual angle-of-attack of the wing. If this angle should exceed the normal stall angle of the wing section, the wing will stall, and the amount of lift lost is a function of the tilt angle in relation to the flight path. In climb, the direction of the free stream velocity vector is more favorable, and the thrust vector is greater than for level flight, both of which decrease the wing angle-of-attack. Conversely, in descent, the free stream velocity vector is less favorable and the thrust vector is of less magnitude, both of which aggravate the tendency toward wing stall.

The effect of wing stall on power required in the transition is shown in Figure 5.9.8 (also from Ref. 5.10.11). The power-required curve for a tilt wing without a flap, which stalls during the transition, is far above the ideal curve throughout most of the transition speed range. When a flap is added to a wing of the same size, the absence of stalling reduces the power-required curve to close proximity with the ideal curve. The higher portion of this curve, between hover and 5 knots, reflects a small portion of thrust lost by deflecting the slipstream - however, the flap setting can be programmed to zero for hovering, if desired.

The effect of slipstream deflection by a flap on the wing angle-of-attack is shown in Figure 5.9.9 from Ref. 5.9.11. In order to eliminate the effect of the basic lift coefficient of the wing as a variable, the unflapped wing was assumed to be large enough to give the same maximum lift as the flapped wing, in the power-off condition. Both combinations are shown at an angle-of-attack which will produce the same resultant slipstream direction after leaving the wing. In this case, both lift and net drag (zero) are the same. The angle-of-attack of the flapped configuration is lower because it turns the slipstream through a large angle. Although this angle is 6 degrees for the flapped wing, in comparison with 16 degrees for the unflapped wing, the difference is partially offset by the fact that the flapped wing stalls at a lower angle (by 5 degrees in this case).

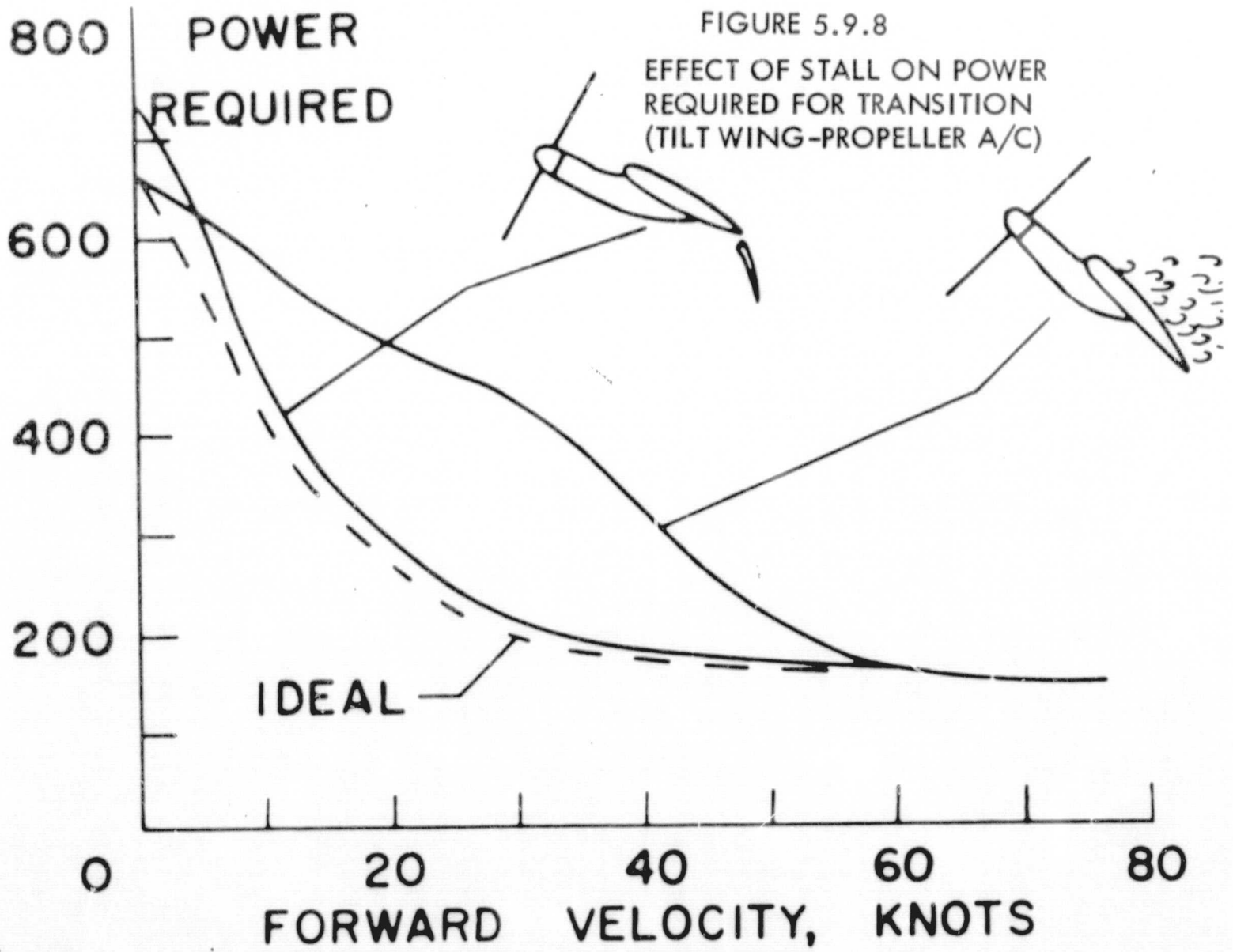


FIGURE 5.9.8
EFFECT OF STALL ON POWER REQUIRED FOR TRANSITION (TILT WING-PROPELLER A/C)

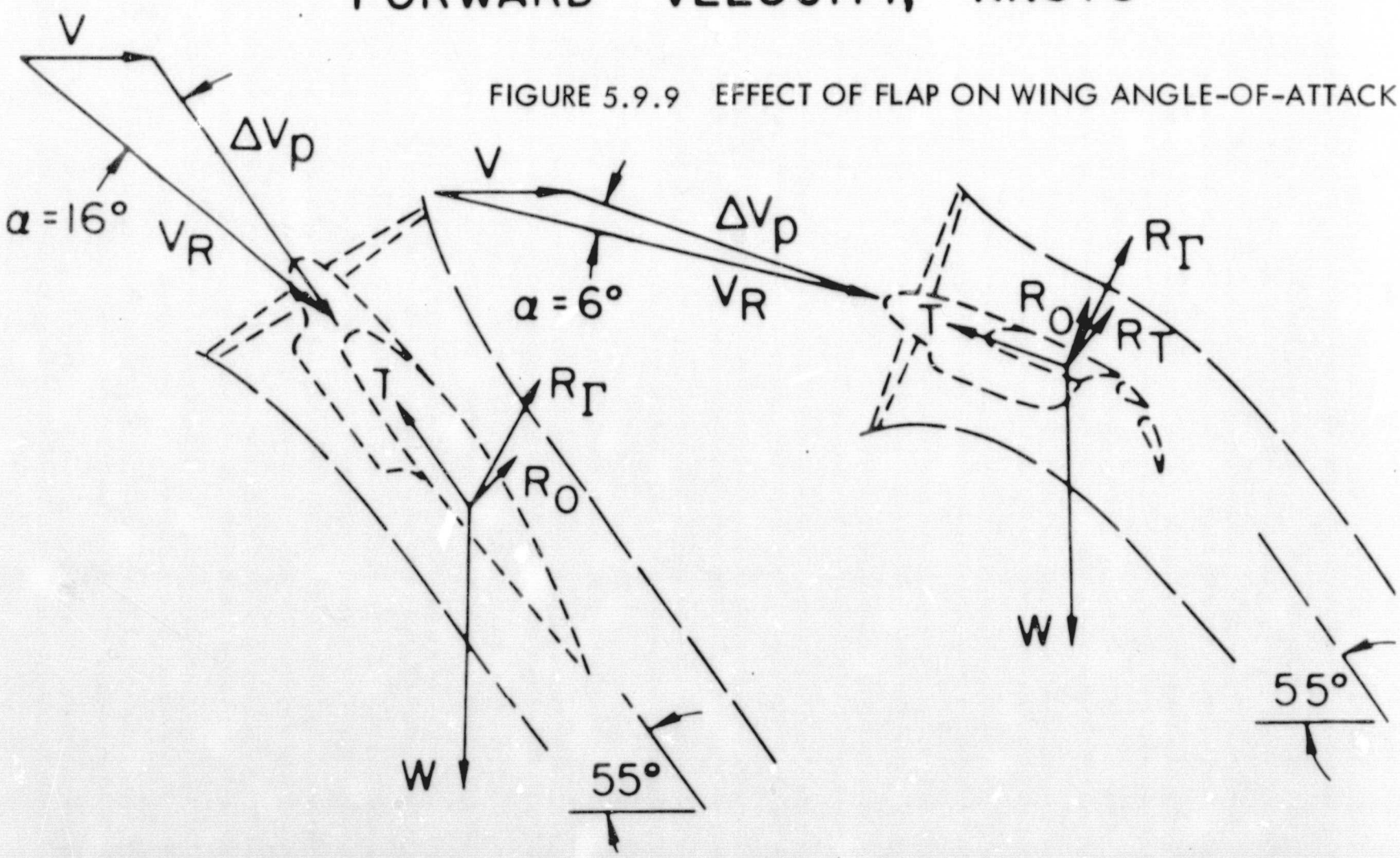


FIGURE 5.9.9 EFFECT OF FLAP ON WING ANGLE-OF-ATTACK

An exact method of determining the amount of wing and flap required to avoid stall in a descent had not been developed at the date of Ref. 5.9.11. A chart, however, shows that a ratio of extended wing chord (including slat and flap along the line of curvature) to propeller diameter of about 0.7 is required to preserve satisfactory handling qualities at a 5-degree descent angle. This ratio is rather high, considering the relatively large propeller diameters required to maintain the constrainted noise level and the desire to hold wing area to a minimum for efficient cruise flight. One possible alternative is to employ blowing over the upper surface from a slot just aft of the leading edge, in connection with an expandable boot, as shown in Section 5.6, Figure 5.6.2. This device would perform double duty as an anti-icer in adverse weather.

5.9.8 Power Transmission

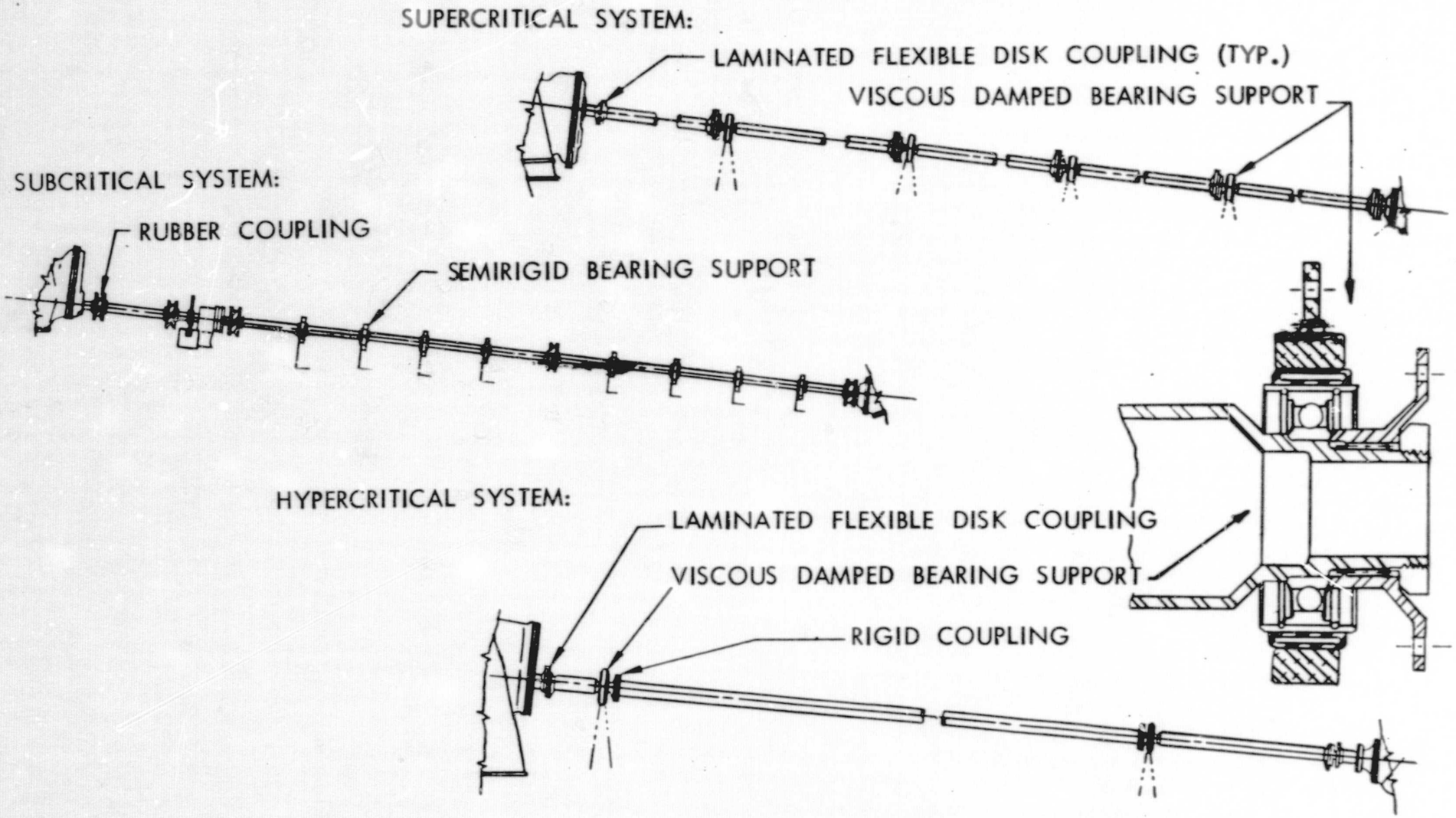
All rotor and propeller VTOL aircraft, as well as some propeller STOL aircraft, incorporate transmission systems which effect large reductions in RPM between the engine and the rotor/propeller. In addition, there is the problem of remote drive, which is manifested in tail rotors, interconnected propellers or rotors and remote reaction control fans. The helicopter, propeller and specialized gearbox manufacturers have developed lightweight and reliable gear transmission systems, including shafting with couplings and bearing supports.

There does not appear to be much improvement in gearing available for the future, unless some of the new materials, such as high-strength alloy steel, titanium and fiber composites can be applied. The noise aspect of gearing may become critical when propeller and engine noise outputs are reduced to the desired level. One possible substitute is the use of belt drives, with which both the problems speed reduction and remote location might be solved. While V-belt and "timing" belt drives have been used extensively in low power transmission applications, little if any experience has been accumulated with drives combining high power and high speed at the driving end. It would appear that this is an appropriate area for future research, making full use of new material technology.

The development of drive shafting has proceeded along the line of achieving weight reduction by increasing rotational speed, and hence torque for a given level of power transmitted. Figure 5.9.10, from Ref. 5.9.4, shows three systems as evolved by a leading helicopter manufacturer for tail rotor drive, categorized by speed ranges. The small diameter, sub-critical system (up to about 6000 RPM) incorporates multiple semi-rigid bearing supports although others have used large diameter shafting, with relatively few supports, in this speed range. The super-critical system uses fewer bearing supports, which incorporate viscous damping and adjacent flexible couplings at either end, with rigid intermediate shaft connection. While only one viscuous damped support is required, a second would be added for fail-safe design. This system has the dual attractions of light weight and low cost.

The patented viscuous damped bearing support is shown in an inset to Figure 5.9.10. It incorporates an elastomeric, torus shaped element, filled with a fluid which has a viscosity that is relatively insensitive to temperature changes. The spring rate can be controlled between 200 and 3000 lbs/in., allowing for considerable variance in airframe spring rate at the various bearing locations. It would appear that further weight reduction in shafting could be realized by the use of fiber-composite materials.

FIGURE 5.9.10 POWER TRANSMISSION TREND



FROM BURROUGHS & LASTINE
SIKORSKY AIRCRAFT DIV. OF VAC
AHS 5/65

5.9.9 Weight Trends

Figure 5.9.11, from Ref. 5.9.3, shows the probable weight reduction trend of VTOL aircraft, expressed as the percent of Weight Empty to Gross Weight. The dash lines are extrapolations of the weight ratios from 1980 (the limit used in Ref. 5.9.3) and 1985, the time frame of interest to this study. They are representative of fully equipped aircraft with free turbine engines and military interiors (except for armor and survival equipment). The solid lines assume the use of titanium and high strength steel for highly stressed structure but not fiber composites. Hence, the extrapolated lines at the same reduction rates would seem valid when considering the introduction of composites in the later period. The aircraft have minimum hovering ceilings of 4,000 ft. at 90°F.

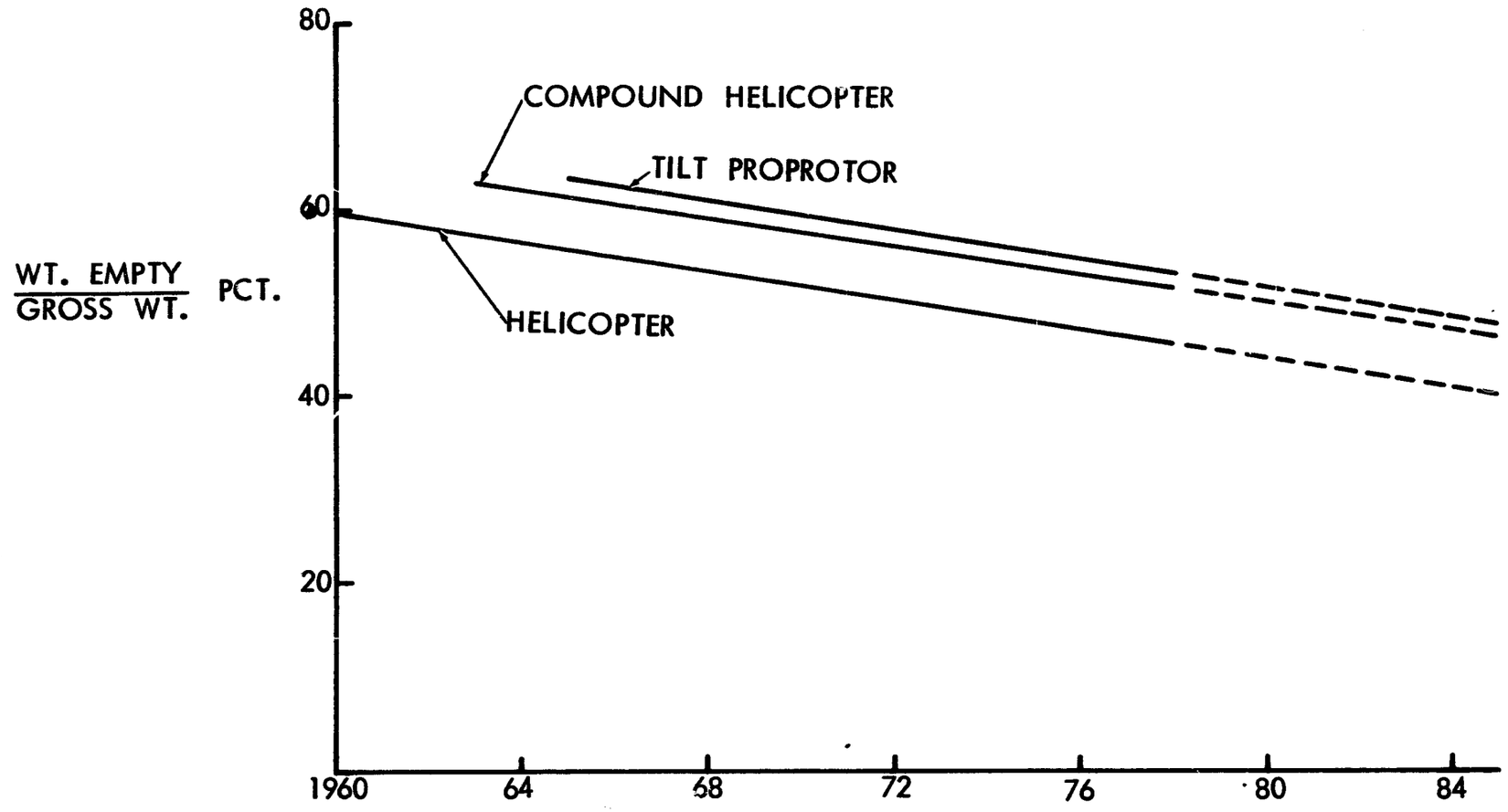
5.9.10 Other Design Factors

A list of additional design considerations, obtained from Reference 5.9.12, is as follows:

- Thrust match
- SFC (hover and cruise)
- Installation penalities
- Engine-out or autorotation safety
- Development and production cost
- Service availability
- Simplicity
- Maintainability
- Reliability
- Ground Effects
- Power response in hovering
- Vibratory loads and frequencies
- Control power and damping
- Instrumentation and displays

In the design of VTOL aircraft for this study, all of the above listed factors, as well as those discussed previously have been considered, although the scope of the study does not permit detail design investigations. While the pure helicopter emerges at the optimum configuration under the constraints imposed, a more detailed study might show the tilt proprotor concept to advantage, with particular reference to its higher speed capability

FIGURE 5.9.11 VTOL WEIGHT TRENDS



FROM BROWN & FISCHER
BELL HELICOPTER COMPANY
10/67

5.9.11 References

5.9.1	D. R. Segner & D. R. Wyrick Lockheed-California Co. "Horizons" - Summer, 1965	"Flight Characteristics of a Compound Helicopter"
5.9.2	A. M. James & J. Fairchild Lockheed-California Co. 24th Annual National Forum, May 1968 - American Helicopter Society	"Rigid Rotor Development - Structural Design and Testing"
5.9.3	E. L. Brown & J. W. Fischer Bell Helicopter Company AIAA 4th Annual Meeting October 1967	"Comparative Projections of Helicopters, Compound Helicopters and Tilting Proprotor Low Disc Loading VTOL Aircraft for Civil Applications"
5.9.4	L. R. Burroughs & J. L. Lastine Sikorsky Aircraft Division 21st Annual National Forum, 1965 American Helicopter Society	"Some Considerations in the Design of a Large Single Rotor Helicopter Transmission System"
5.9.6	R. L. Lichten Bell Helicopter Co. 7th ICAS, Rome, Sept. 1970	"Design Problems and Solutions for Five Types of Low-Disc-Loading, High-Speed, VTOL Aircraft"
5.9.8	K. G. Wernicke, Bell Helicopter Co., Journal of the American Helicopter Society, April 1969	"Tilt Proprotor Composite Aircraft; Design State of the Art"
5.9.9	L. H. Ludi U.S. Army Aviation Material Laboratories - Journal of the American Helicopter Society, January 1968	"Composite Aircraft Design"
5.9.10	R. J. Huston & R. J. Tapscott NASA Langley Research Center Annals of N.Y. Academy of Sciences March 1963 (VTOL Aircraft)	"Results of Some Wind Tunnel and Flight Studies with Helicopters at NASA"
5.9.11	M. O. McKinney, R. H. Kirby, W. A. Newsom - NASA Langley Research Center - Annals of N. Y. Academy of Sciences March 1963 (VTOL Aircraft)	"Aerodynamic Factors to be Considered in the Design of Tilt-Wing V/STOL Airplanes"
5.9.12	AIAA VTOL Systems Committee AIAA Journal of Aircraft July-August 1969	VTOL - 1968

6.0 SELECTION OF BASELINE DESIGNS

6.1 General

The candidate baseline aircraft designs in the four categories are subject to the constraints listed below. Candidate designs for each category were selected intuitively by a procedure to be explained subsequently. The selection of one baseline design in each category was based on the results of the computerized parametric analysis program reported in Section 7.1. The selected baseline designs are then subjected to the sensitivity analysis program, using the same methodology as that of the basic parametric program.

SUMMARY OF BASELINE DESIGN REQUIREMENTS

Category	I	II	III	IV
Critical Field Length (ft.)	1000	500	1500	VTOL
Range (stat. miles)	500	500	1500	500
Cruise Speed (knots)	130	200	250	150
Min. No. of Seats	4	4	6	4

Common Requirements

Exterior Noise Level	75 PNdb at 500 ft.
Weight Allowance per Seat	220 lbs (including baggage)
Fuel Reserve	45 Min.

A number of practical configuration combinations were evolved for consideration in each category. An intuitive selection process was implemented in order to reduce the numbers to 2 or 3 for analysis and optimization. This was accomplished by creating a point system, assigning weighted maximum point values to such criteria as cost, safety, flying qualities, performance, comfort, reliability and growth potential.Members of the study team and the Advisory Committee (see Section 2.0) were asked to assign points for each criterion to all of the configurations nominated in each category. Results are shown in Figures 6.1, 6.2, 6.3 and 6.4.

6.2 Category I Candidates

Preliminary effort was directed toward single engine designs with tractor and pusher propellers. These are sketched in Figure 6.5. The drawings are preliminary in nature, to provide a basis for the parametric optimization analysis. The only unusual feature of these designs is the installation of large diameter propellers to meet the noise level criterion discussed in Section 5.2.9 This required a longer than normal landing gear.

In this category, particularly, the choice between high-wing and low-wing configurations requires careful consideration. Both types are exemplified in current models which have high sales volume. The advantages possessed by each configuration are as follows:

FIGURE 6.1 CATEGORY I PRELIMINARY CONFIGURATION EVALUATION

4-PLACE; 1000' FIELD
500 MI. RANGE, 130 K V_{CR}

ALL SINGLE ENGINE



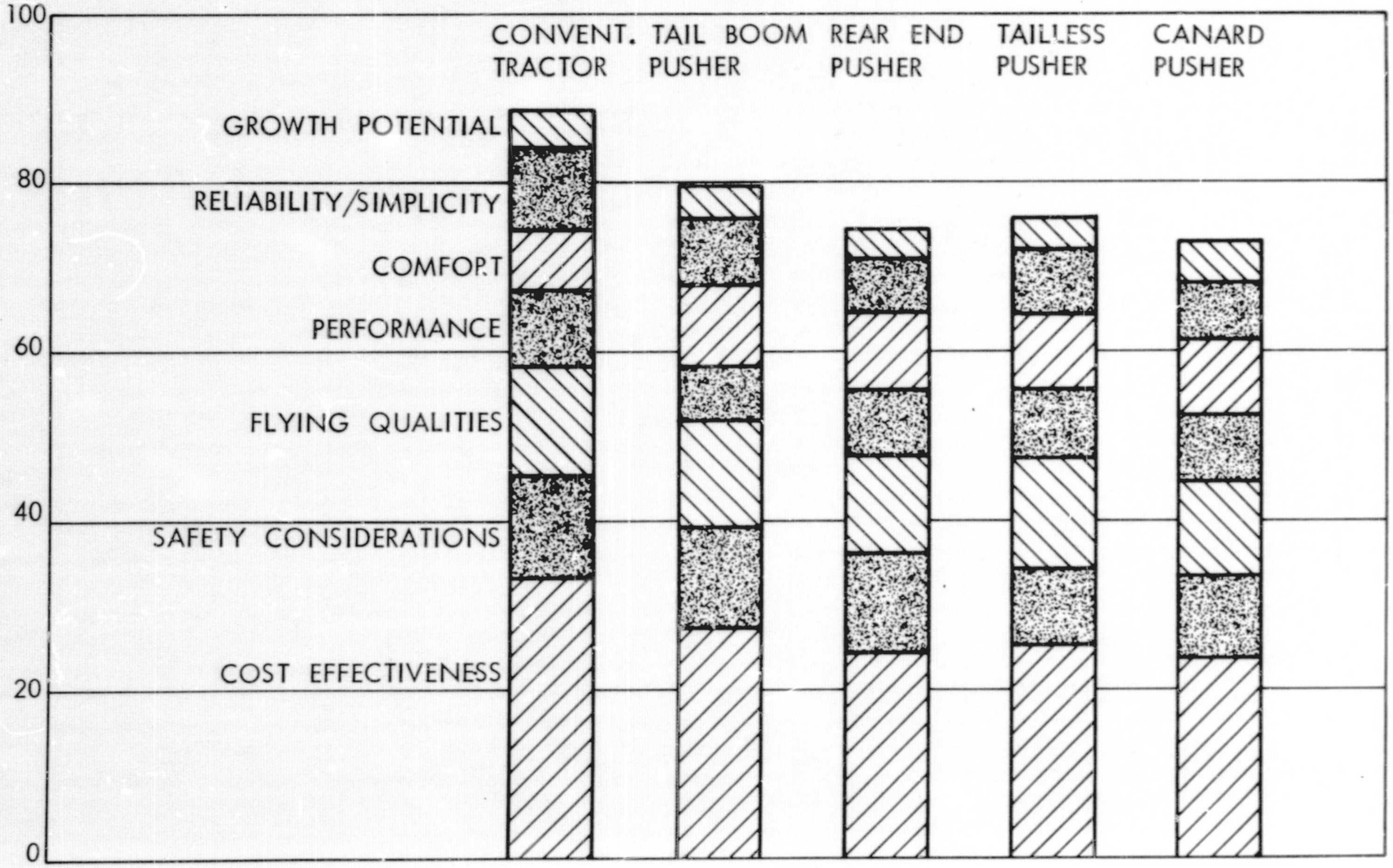


FIGURE 6.2 CATEGORY II PRELIMINARY CONFIGURATION EVALUATION

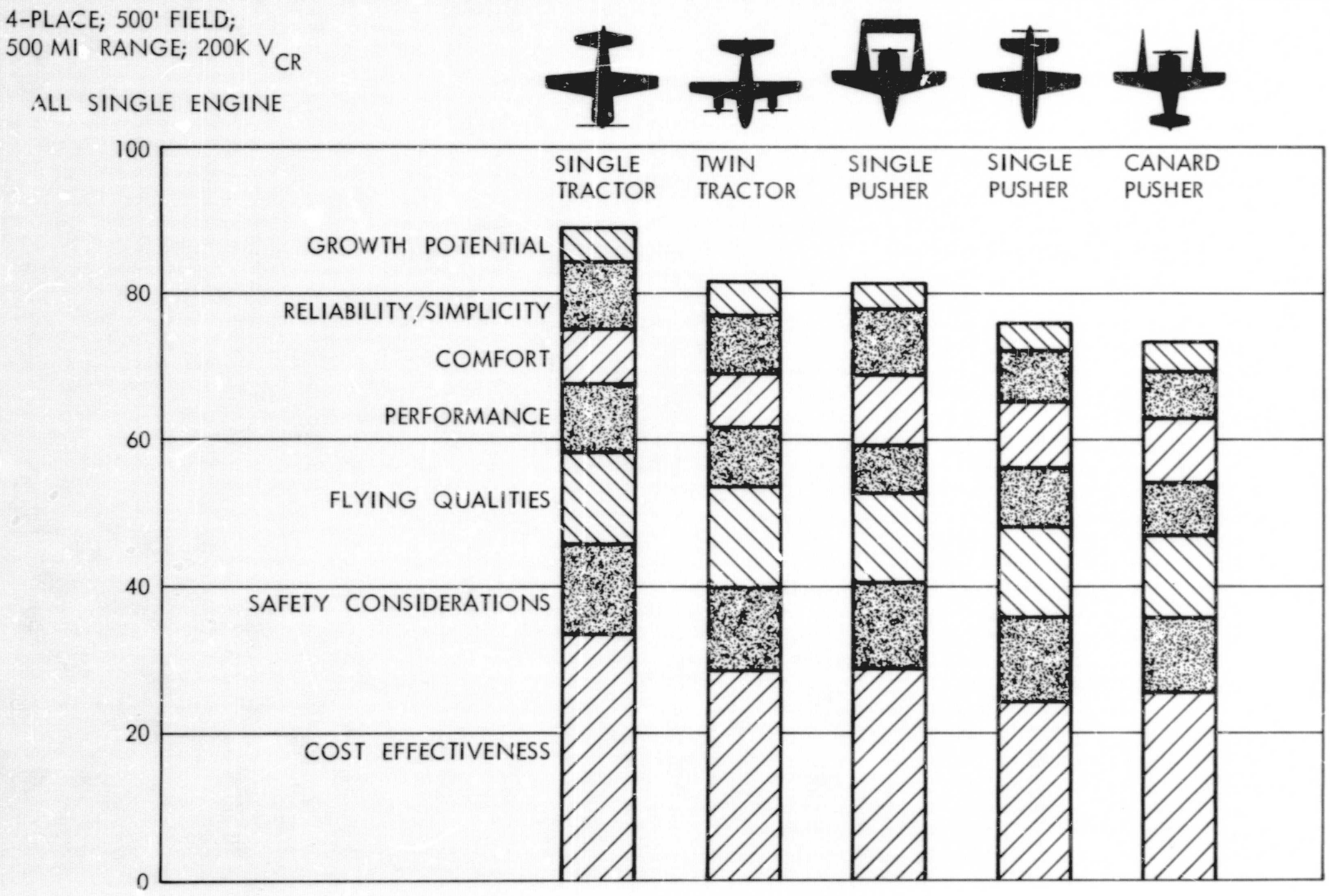


FIGURE 6.3 CATEGORY III PRELIMINARY CONFIGURATION EVALUATION

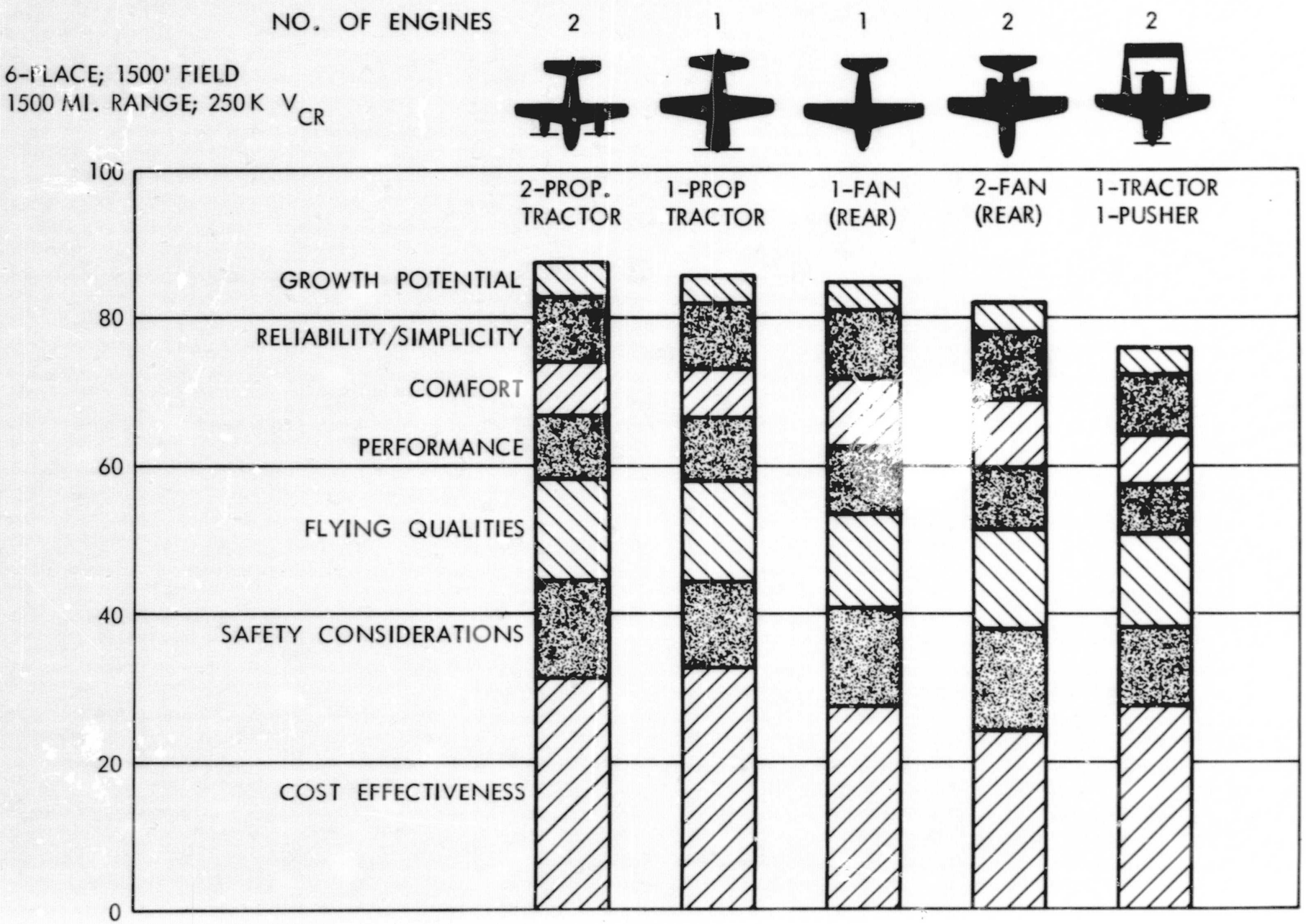
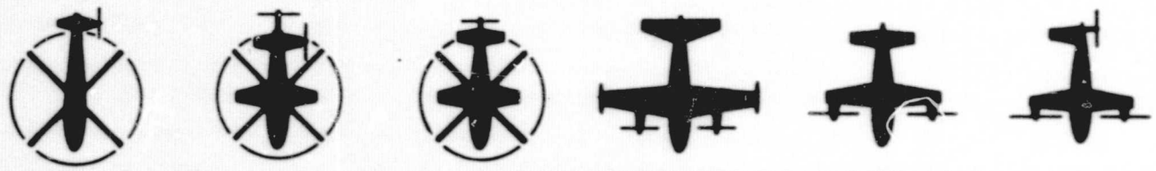


FIGURE 6.4 CATEGORY IV PRELIMINARY CONFIGURATION EVALUATION

4-PLACE; VTOL; 500 MI. RANGE:
150 K V_{CR}

ALL SINGLE ENGINE



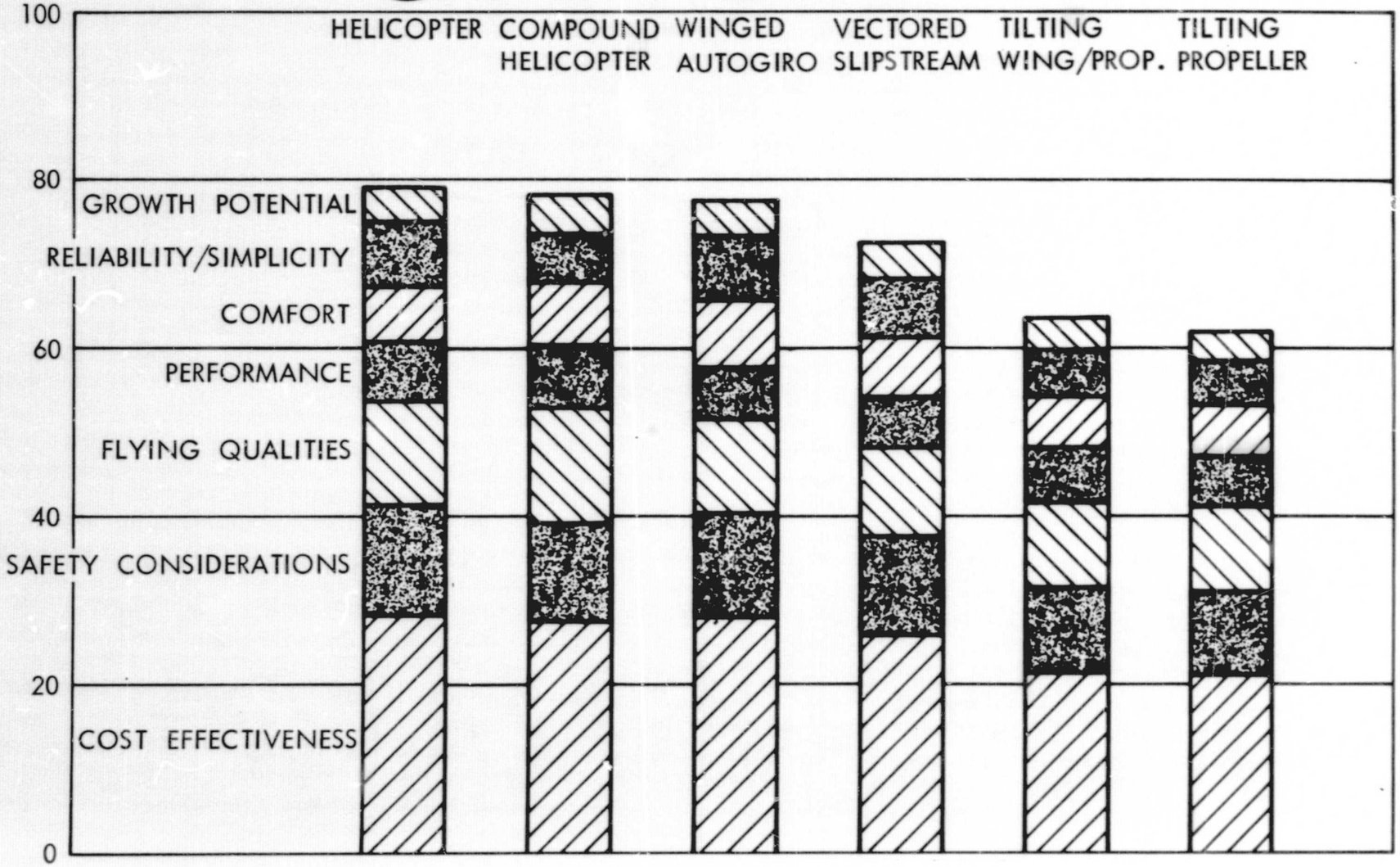
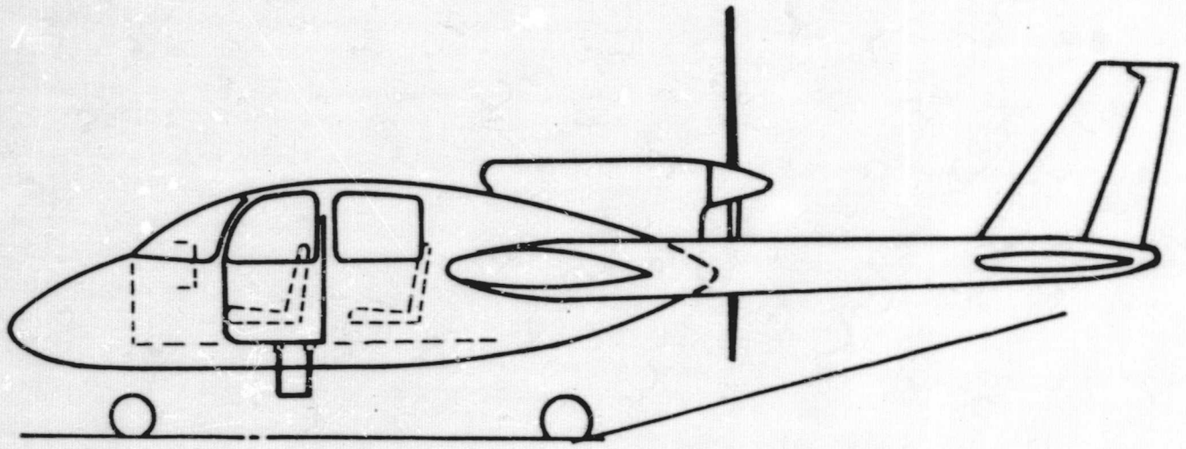
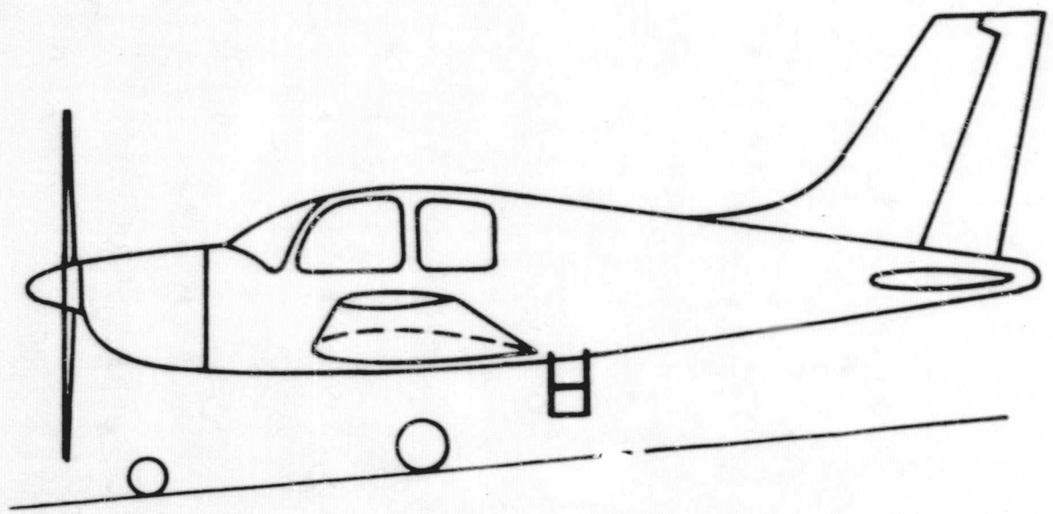


FIGURE 6.5 CATEGORY I CANDIDATES
(4 PLACE, 1000' FIELD)



MIDWING PUSHER



LOW WING TRACTOR

Low Wing	High Wing
° Permits wide track landing gear and lighter weight fixed or retractable gear.	° Good downward visibility
° Small pitch trim change with flap deflection	° Easier access to cabin
° Easier refueling & inspection	° Gravity fuel feed
° Better vision when turning in airport traffic pattern	° Cooler (shaded) cabin in summertime
	° Sheltered entry in rainy weather
	° Better lateral stability

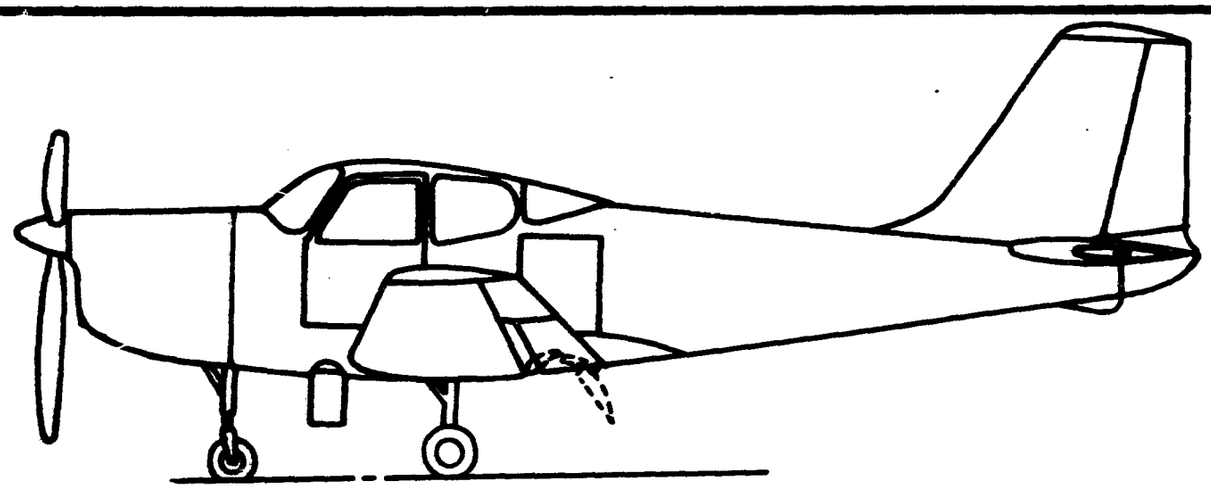
Since the pros and cons nearly balance each other, a decision in the matter is difficult and within the degree of accuracy of the input data for a computerized comparison. For the competitive examples in this study, the low wing arrangement has been chosen for the tractor and a mid-wing for the pusher. In the latter case, the wing position is to the rear of the cabin, and its position can be fixed by minimum drag considerations. The cost comparison between the tractor and pusher is shown in Section 7.5 and favors the pusher to a small degree. There are also other considerations as follows:

Tractor Advantages	Pusher Advantages
° Short length	° Excellent visibility
° Small C. G. travel	° Lower noise level in cabin
° Lighter weight	° Compatibility with radar installation
° Lower drag	° Better cabin access (compared with low wing tractor)
° Higher lift with flaps down due to propeller slipstream deflection.	° Smaller tail required to meet stability requirements
° Better crash protection	
° Stiffer tail support structure	

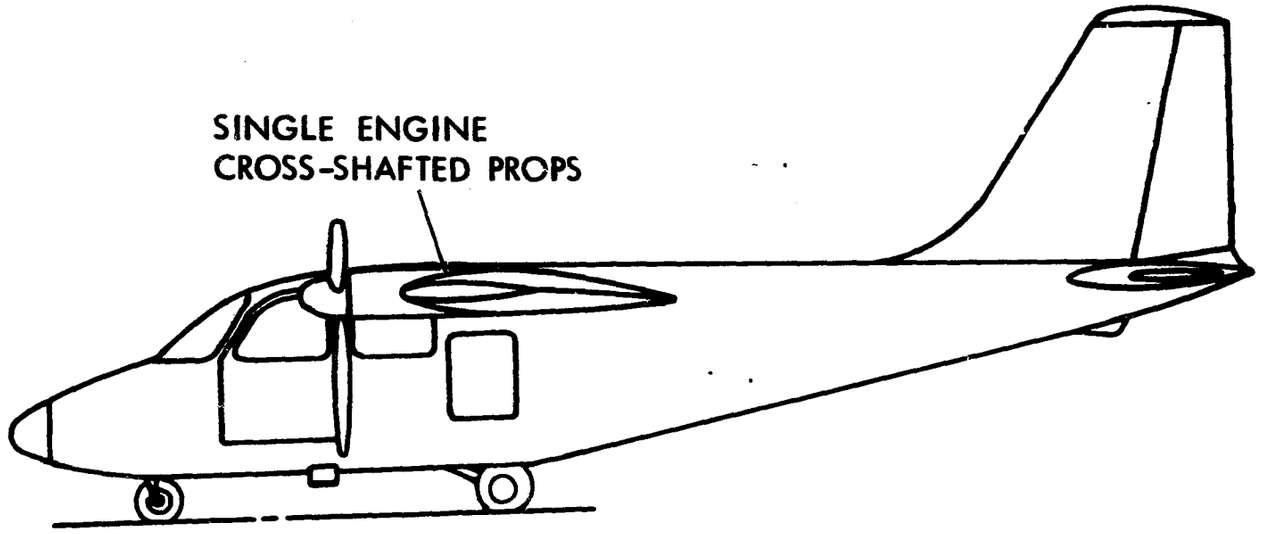
6.3 Category II Candidates

The 500 ft. over 50 ft. takeoff and landing requirement of this category requires an optimum combination of wing loading and power landing, with the latter being better expressed as thrust-to-weight ratio. Previous investigation of 500 ft. STOL aircraft in the transport category have shown that this requirement exacts gross weight and operating cost figures nearly as high as those of VTOL aircraft. This is less likely to be the case of the much smaller aircraft in Category II, since they are more tolerant of low-wing loading. The candidate aircraft illustrated in Figure 6.6 shows two concepts: single and dual tractor propellers, each driven by a single engine. A basic

FIGURE 6.6 CATEGORY II CANDIDATES
(4-PLACE, 500' FIELD)



SINGLE PROPELLER
LOW WING



DUAL PROPELLER
HIGH WING

necessity for this category is the use of high lift flaps which incorporate considerable rearward travel. Figure 5.1.4 in Section 5.1, illustrates an example of the type of flap required.

A low-wing arrangement is shown for the single propeller design, because the use of a large diameter propeller places the cabin in a high position above the ground, leaving ample room for the wing to be placed under the floor without becoming too close to the ground. For the dual propeller design, however, a high-wing configuration was chosen, since the propellers are mounted on the wing. In this case the engine power is transmitted through a right angle gear box by cross shafting to a longitudinal shaft from each propeller. The reduction gearing is incorporated in outboard right angle boxes.

In the final analysis, a single pusher propeller installation was chosen, similar to that of Category I. While the impingement of the propeller slipstream on the wing, with deflected flap, augments the maximum lift coefficient to a considerable degree, the resulting minimum speed is not usable in a single engine aircraft because it immediately becomes higher following engine failure. If engine failure should occur immediately after takeoff or on a powered landing approach and minimum speed were established on a power-on basis, wing stall and a possible crash landing would result. The pusher configuration, in addition to its previously cited advantages, is more compatible with large propeller diameters in maintaining a reasonably low cabin floor level.

6.4 Category III Candidates

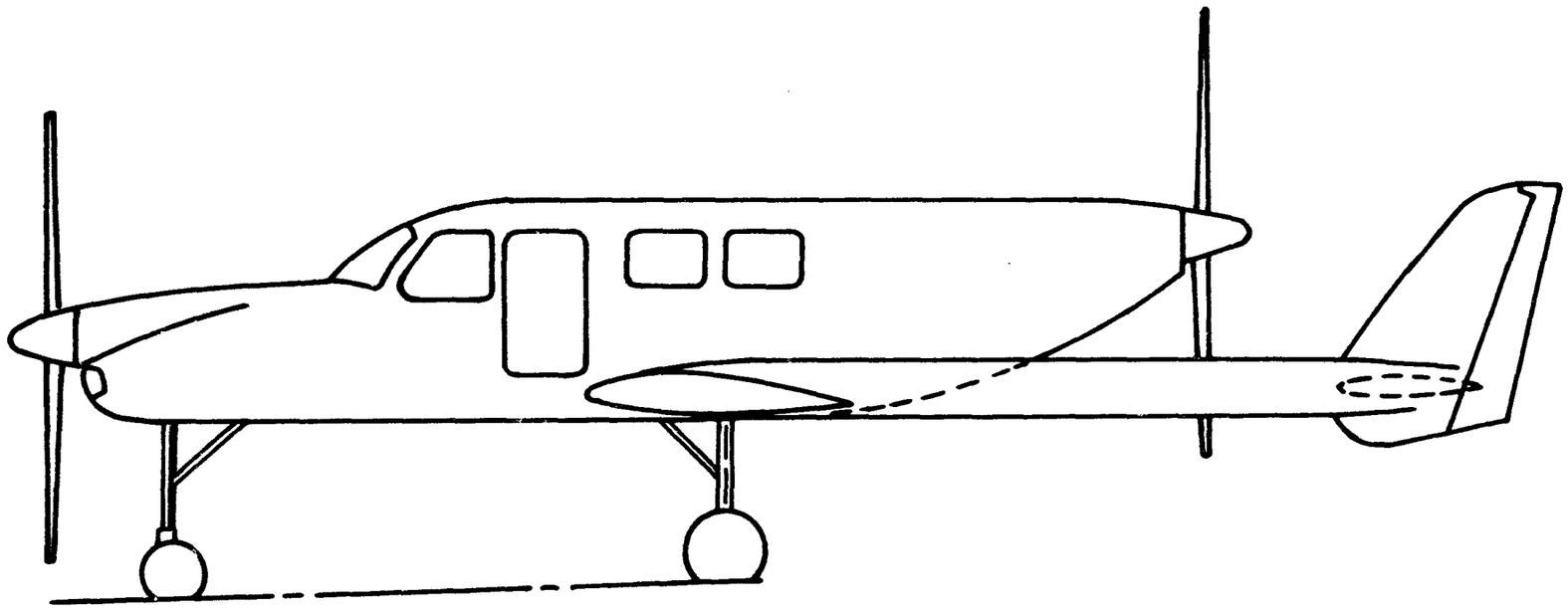
Since this category of aircraft is directed primarily toward business use, it is believed that comfort and roominess should be stressed. The seating arrangement consists of 3 rows of 2 seats abreast with a center aisle. Since the specified cruising range is 1500 miles at 250 knots, the maximum endurance will be over 5 hours. This is believed to necessitate the installation of a lavatory.

Two design approaches were selected for baseline aircraft analysis, and are illustrated in Figure 6.7. They include one with high wing, twin tractor propellers and one with low wing, tractor-pusher propellers.

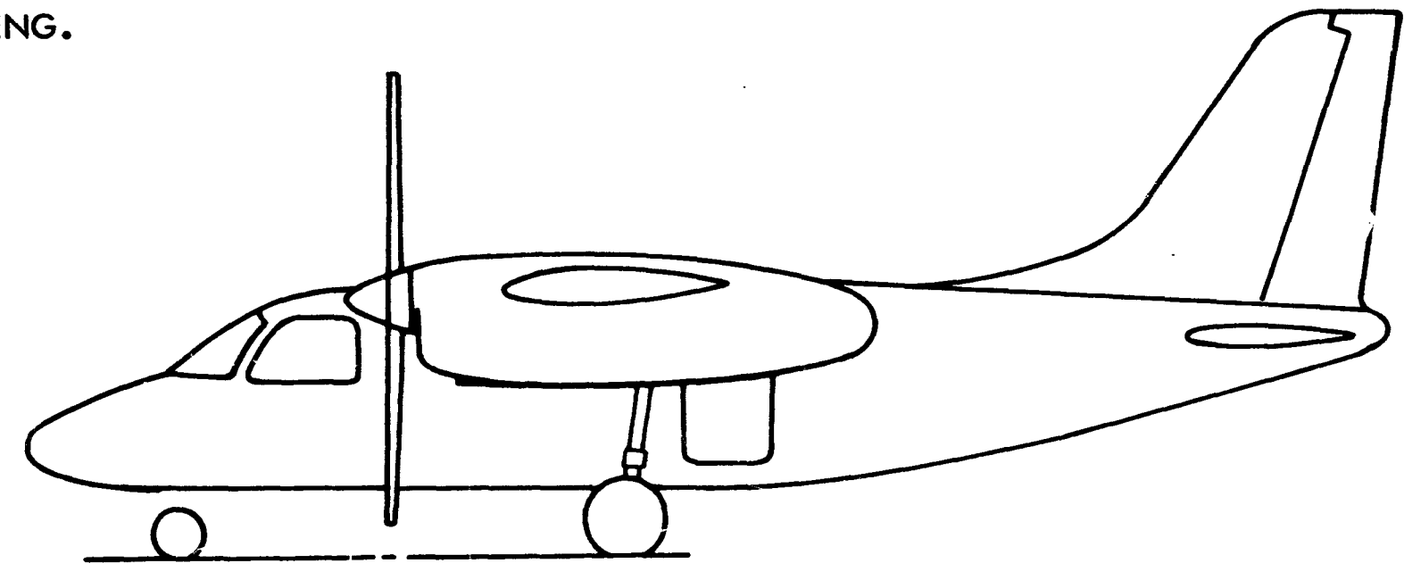
The former has the high wing location because of the large propeller diameter required to meet the external noise level constraint, coupled with the desire for easy cabin access. While the design is essentially clean, aerodynamically, and should exhibit a high L/D ratio, the problem of obtaining satisfactory control with one engine inoperative requires careful attention to the directional and lateral control devices. The large propellers ahead of the wing result in superior flap effectiveness for takeoff and landing by the use of slipstream deflection. However, with the large diameter propellers required for low noise level, cross-shafting is required for control with one engine inoperative.

The latter configuration has a current example in general aviation and its principal virtue lies in the centerline thrust arrangement, eliminating the problem of trim and control with one engine inoperative. A low-wing arrangement is indicated, both to provide for satisfactory retraction of the main landing gear, and to locate the tail booms at a low level so that the ventral fins

FIGURE 6.7 CATEGORY III PROPELLER CANDIDATES
(6 PLACES, 1500' FIELD)



LOW WING, TWIN ENG.
TRACTOR/PUSHER



HIGH WING, TWIN ENG.
TRACTOR

protect the aft propeller at lift-off and touchdown attitudes. The large, low-noise level propellers result in a configuration which does not have eye appeal, since the cabin floor must be approximately 5'5" above the ground, with a correspondingly long landing gear. This also requires high access steps similar to those of a large transport aircraft.

These two approaches were assessed for the choice of a baseline configuration. In the sensitivity analysis, a third candidate configuration designed for turbofan propulsion was evaluated. This configuration, shown in Figure 6.8, is an attempt to evaluate the attractiveness of high cruising speed, which is a number one consideration with purchasers of business aircraft. At speeds of 350 - 400 knots, turbofan propulsion becomes attractive. Even though Category III requirements do not call for speeds this high, it is believed that, by 1985, turbine engine costs could be reduced to the point where they would become more nearly competitive with displacement engines. Certainly the speed advantages of turbofan propulsion are attractive, especially at ranges of 1000 - 1500 miles. Because of the demonstrated reliability of turbine engines, compared to reciprocating engines, it is believed that single engine aircraft would gain acceptance in the small business aircraft category, and this, of course, would help to make the overall cost more attractive. In this example, the wing and engine are sized to meet the range, takeoff and landing requirements, with cruise speed a fall-out. This configuration would, of course, have a pressurized cabin for cruising at high enough altitude in order to attain the most economical performance.

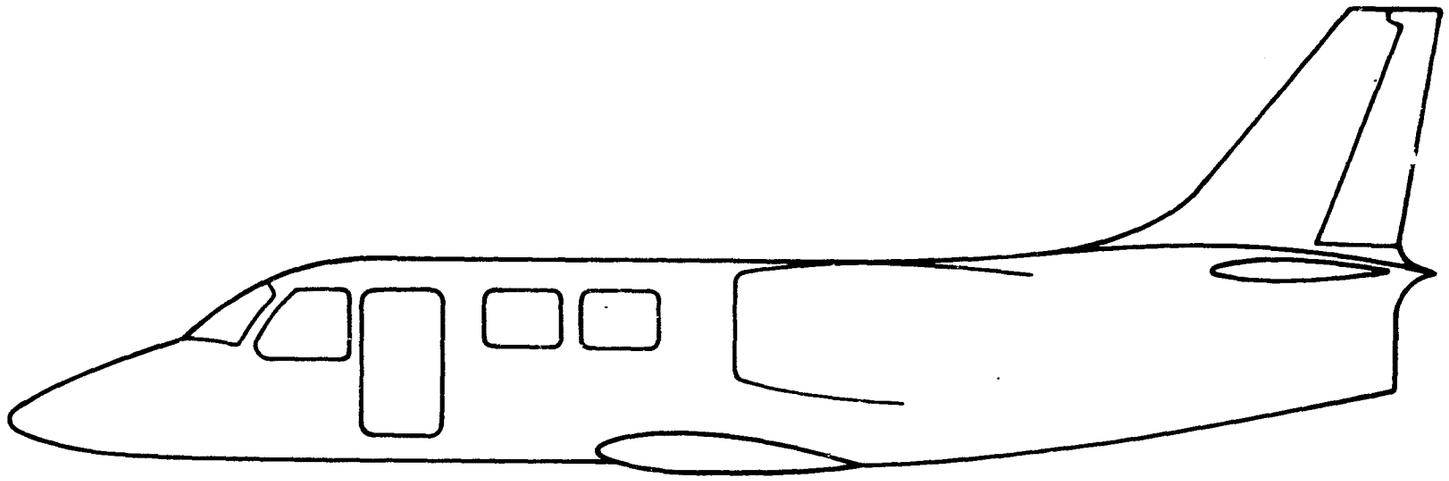
6.5 Category IV Candidates

Category IV requirements specify a 4-place vehicle that will cruise 500 statute miles at 150 knots with a 45-minute fuel reserve. The selected candidate configurations are the helicopter, and the tilt wing-propeller, both shown in Figure 6.9.

There are four currently available U. S. commercial helicopters that approach the study requirements, three of which have turbo shaft engines. Each of these vehicles are 5-place with cruise speeds between 110 and 115 knots and ranges between 200 to 390 miles with no fuel reserve. All of them fall short of the requirements set forth in the study ground rules.

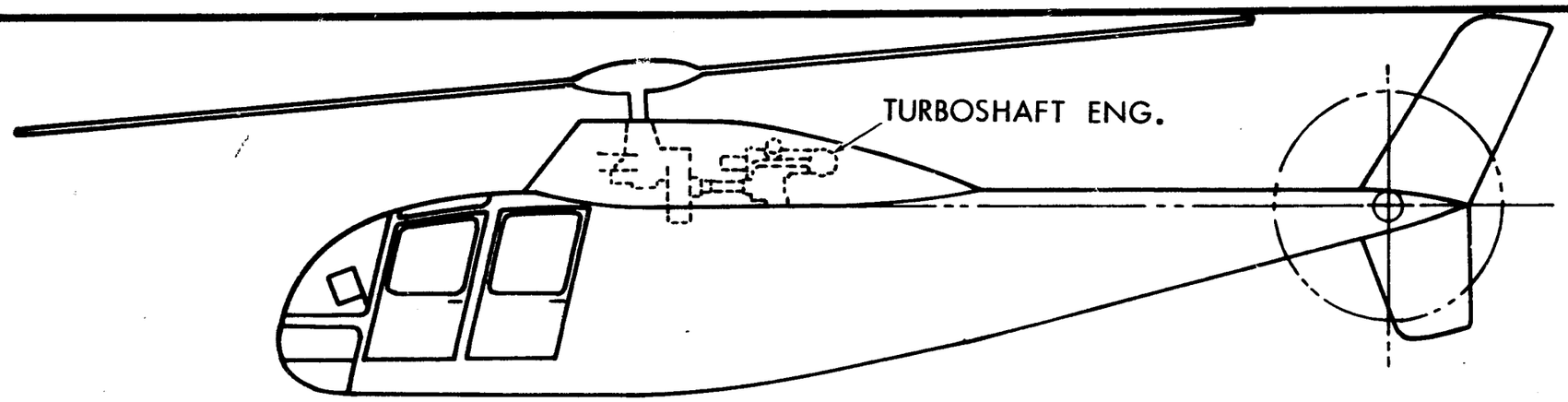
Section 5.9 covers the technology applicable to the helicopter from both aerodynamic and dynamic standpoints. Low noise level, good low speed and hover capability and high speed performance are not completely compatible in rotor design. Rotor tip speed, number of blades and rotor solidity ratio must be compromised in order to satisfy the aircraft flight spectrum. Low tip speed and solidity are desirable for efficient hover performance. For the high speed forward flight condition, however, the tip speed and solidity must meet the requirement that retreating blade stall and rotor vibration are within acceptable limits. Developments in both rigid and semi-rigid rotor systems, plus increased power-to-weight ratio turbine engines indicate that the performance parameters of this study can be achieved without the necessity of compounding .

FIGURE 6.8 CATEGORY III TURBOFAN CANDIDATE
(6 PLACE, 1500' FIELD)

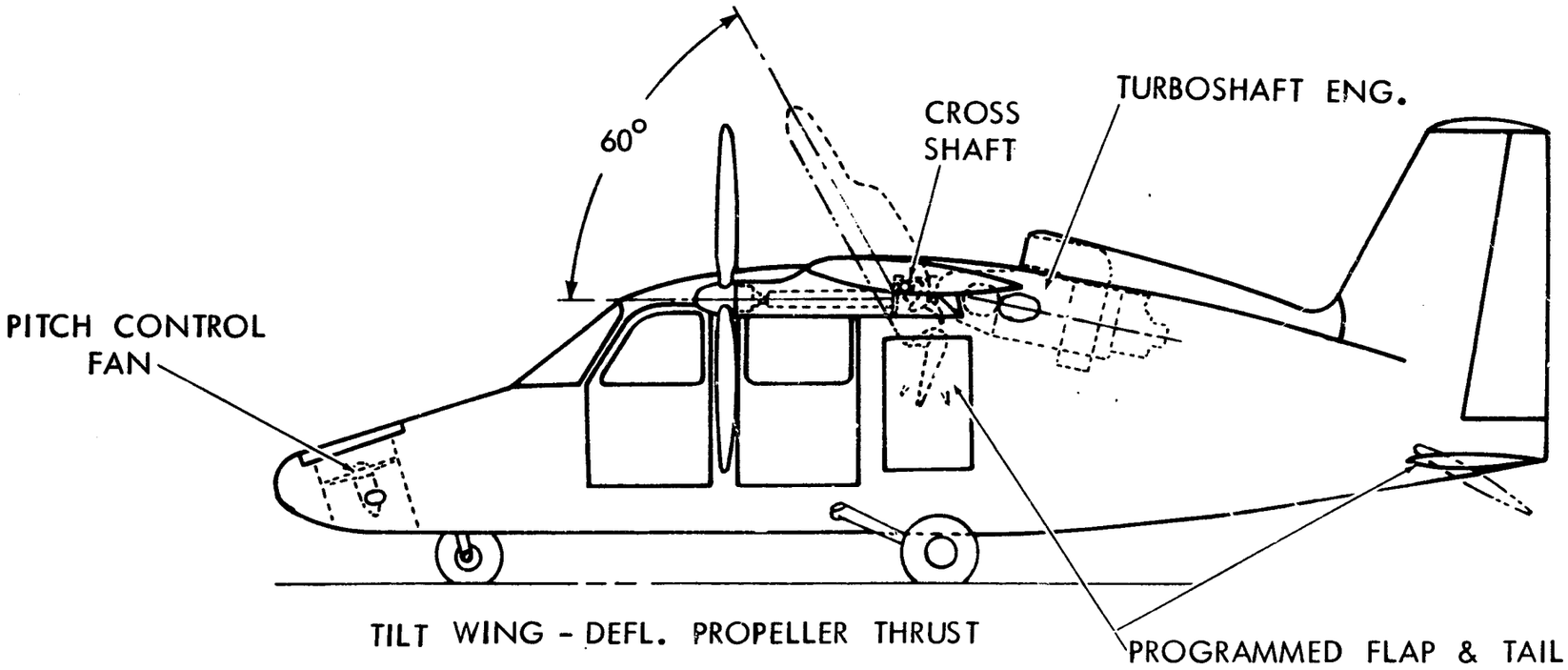


LOW WING: SINGLE ENGINE

FIGURE 6.9 CATEGORY IV CANDIDATES
(4-PLACE, VTOL)



HELICOPTER



The following rotor parameters were used for the baseline helicopter design:

- 4-Bladed Main Rotor
- Solidity = 0.10
- Disc Loading = 3.4
- Rotor Tip Speed = 550 Ft./Sec.

Turboshaft engines currently in U. S. production that meet the power requirements are rated over a range of 300 to 600 hp. Although these engines are fairly expensive when compared with reciprocating engines of the same power, it is felt that the price could be substantially reduced with high production rates. Further, it is felt that due to the installed weight of a 400-plus HP reciprocating engine the helicopter gross weight would increase to the point where the total airframe cost might increase enough to offset the difference in basic engine costs.

In selecting a candidate in the non-rotary wing field, the requirement for low noise level dictates low disc loading, which implies a means of obtaining vectored propeller thrust. The two principal approaches to this objective are the tilt wing and the deflected slipstream configurations. Tilt wing designs have been exemplified by the VZ-2, the X-18, the XC-142, and the CL-84. Deflected slipstream designs for VTOL have been exemplified by the VZ-3 and the VZ-5. All of the above listed models have been flight tested with various degrees of success. From the experience derived thus far, two general conclusions can be drawn:

(1) The tilt wing approach results in the best means of converting propeller thrust to direct lift; however, operation in the transition, with the wing tilted at an intermediate angle, has resulted in a number of accidents, blamed for the most part on wing stall.

(2) The vectored slipstream approach, in which a wide chord flap system is used to turn the slipstream through angles of 60° to 70°, is inefficient, creating thrust losses of 15 to 20 percent. Smaller deflection angles, however, have progressively lower thrust losses, accompanied by safer stall margins.

From the foregoing evidence, the most logical approach appears to be one in which both the tilt angle and the deflection angle are used in combination. This approach is illustrated in Figure 6.9. A single shaft turbine engine is used to drive two propellers through a system of lateral cross-shafting, as in the STOL design of Section 6.3. A relatively small, untapered wing, mounting two, 4-bladed propellers, is hinged to the fuselage along the transmission shaft axis. The wing can be tilted to an angle of 90° above the horizontal and has a 40-percent chord, slotted flap, which is mechanically linked to the tilt action and programmed to deflect to optimum angles compatible with the angles of tilt. A possible configuration for hovering combines a 60° tilt angle with a 40° flap deflection, which according to Reference 6.2 produces a vertical lift vector with a thrust loss of only 1 to 2 percent. However, a 90° tilt with zero flap angle would be more conventional. Combinations used in the transition are with decreasing tilt angle and increasing flap angle as a function of increasing air speed.

A critical element of any VTOL design is the means of obtaining satisfactory trim and control about all axes. Longitudinal trim and control are obtained from the use of a forward ducted fan, having variable pitch blades, described in Reference 6.4. This location of the fan permits the nose-down pitching moment of the hovering airplane to be trimmed with a lifting force. When the wing tilt angle is reduced to 30°, representative of STOL operation, the all-movable horizontal tail becomes immersed in the slipstream, which will probably obviate the need for fan thrust. At some selected angle of tilt (probably 30°), this action can be phased out and assumed by the ailerons. The latter are inset into the outer portion of the full span flaps, where they are immersed in the slipstream and provide directional control in hovering and in the slow speed portion of the transition.

Except for the introduction of wing tilt and the limited use of slipstream deflection, the design bears some similarity to that of the VZ-3, flight tests of which are reported in Reference 6.3. The limitations of that vehicle were adverse ground effect and poor flight path control. Subsequent research and development, however, have served to overcome most of the early difficulties.

6.6 References

6.1 R. E. Kuhn and W. C. Hayes, Jr., NACA T. N. 3918, 1957 — "Wind Tunnel Investigation of Effect of Propeller Slipstreams on Aerodynamic Characteristics of a Wing Equipped with a 50 Percent Chord Slotted Flap."

6.2 R. E. Kuhn - NACA T. N. 3919, 1957 — "Investigation of Effectiveness of a Wing Equipped with a 50 Percent Chord Sliding Flap, a 30 Percent Chord Slotted Flap and a 30 Percent Chord Slot in Deflecting Propeller Slipstreams Downward for Vertical Take-off."

6.3 H. L. Turner and F. J. Drinkwater III - NASA TN D-1891 — "Some Flight Characteristics of a Deflected Slipstream V/STOL Aircraft"

6.4 Dowty-Rotol Brochure T.507 — "600 Lb. Thrust, 19.5 inches Diameter Turbo-Fan for V.T.O.L. Aircraft"

6.5 Hamilton-Standard Report PDB 6605, 1966 — "Generalized Performance and Weight Data for Variable Pitch Fans"

7.0 PARAMETRIC ANALYSIS

7.1 Methodology

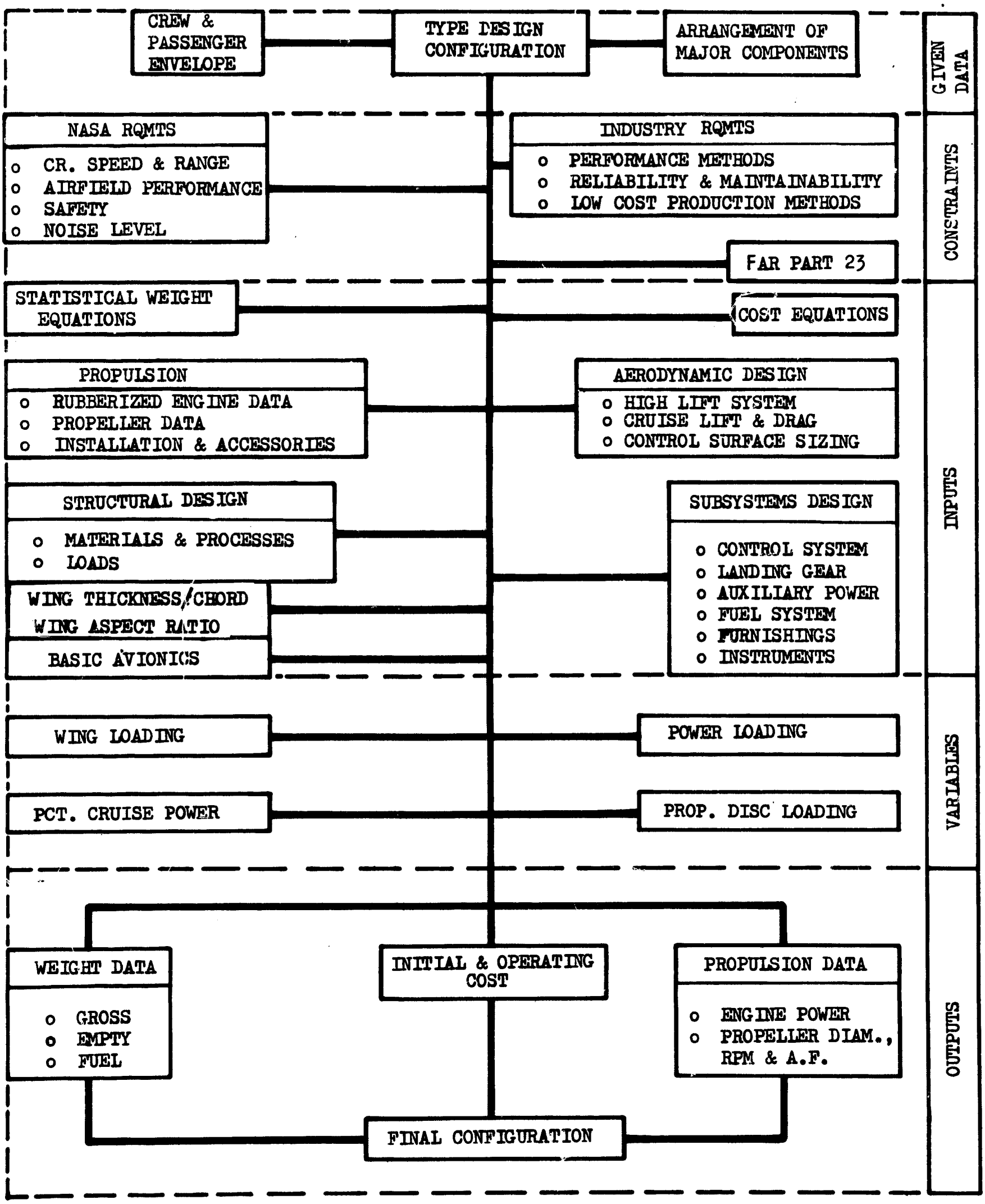
The parametric analysis procedure used in this study is applicable to optimization of the present technology baseline designs, covered in this section, and to the sensitivity analyses, covered in Section 8.0. The computerized analysis has the capability of estimating performance, costs, and weights. Figure 7.1.1 shows a flow diagram of the procedure. Three different flap configurations can be employed in addition to leading edge slats. The program has the capability of employing either conventional reciprocating engines, advanced reciprocating engine/rotating combustion engines, or turboprop engines. The program can select propellers for various noise levels. The various types of structural material to be investigated and advanced aerodynamic features can also be analyzed.

Initial inputs to the analysis comprise aspect ratio, cruise speed and altitude, cruise propeller efficiency and cruise profile drag coefficient. The cruise profile drag coefficient is determined on the basis of dimensional data and cruise speed utilizing a separate subroutine. Cruise power is then determined after which the range, specific fuel consumption and the weight subroutine are entered, using an assumed gross weight. On the basis of the assumed gross weight, a gross weight is calculated. If this calculated gross weight is not within a specified tolerance of the assumed gross weight, iterations are performed, using the calculated gross weight as the assumed weight, until the assumed and calculated weight are essentially equal.

In all cases, the take-off speed is assumed to be 1.2 times the power-off stall speed, since a great number of the configurations are single engine, where the aircraft should be in an acceptable flight regime even with an engine failure. After take-off, it is assumed that the airplane follows a curvilinear flight path until a steady state rate of climb is set up, which is continued to 50 feet. 10 percent excess lift is always available during the pull-up to establish the climb to 50 feet.

Climb is assumed at normal (take-off power, except that the variation in power with altitude for a normally aspirated engine is assumed. It is assumed in this study that the induced drag is equal to twice the zero lift drag rather than three times the zero lift drag, which is the point for minimum power required. This point is used, rather than the minimum power point, in order to facilitate engine cooling and to cover more distance during climb. Rate of climb is obtained at an altitude equal to two-thirds of the cruise altitude. Time to climb is found by dividing cruise altitude by climb rate, and the engine power times the specific fuel consumption times climb time give fuel used during climb, and distance is climb velocity times climb time. The cruise range is assumed to be the range required for the category airplane plus an additional 45 minutes at cruise speed, less the climb distance. Thus, for Category 1:

FIGURE 7.1.1 PARAMETRIC FLOW DIAGRAM



$$R_C \text{ (nautical mi.)} = \frac{500}{1.152} + \frac{130 \times 45}{60} - D_C$$

$$= 434 + 97.5 - D_C = 531.5 - D_C$$

D_C is climb distance, and the other number refer to the distances reserves and speeds for Category I. The total fuel is determined by a take-off allowance equal to 5% of the engine horsepower in pounds, plus the climb fuel used, plus the cruise fuel. The fuel used in cruise is corrected for the median weight during the mission.

The computer programs incorporate the facility of using propellers designed for 75 PNdb noise level with high, moderate or average take-off thrust characteristics. (6, 5 and 4 lbs. per horsepower) with cruise efficiencies of 86 percent when possible. The only place it was not possible to use 86 percent efficiency is the Category III high thrust level airplane, where it was not found possible to obtain above 84 percent cruise efficiency. For comparison purposes, propellers having normal noise characteristics (95 to 110 PNdb) and intermediate noise (85 PNdb) are also included in the computer procedures.

In all the computer runs presently conducted, the airplanes have a 15 percent airfoil thickness ratio, and an aspect ratio of 8. Cruise speed is a variable input, in addition to range and field length.

7.2 Statistical Weight Data

Weight equations were developed for input to the parametric studies. The general equations for wing, empennage, fuselage, landing gear and fixed equipment are shown in Figures 7.2.1, 7.2.2, 7.2.3, 7.2.4 and 7.2.5, respectively. Engine and propeller weights reflect actual weights of representative engines or projected state-of-the-art. The Weight Empty relationship to that of actual aircraft is shown in Figure 7.2.6. The figures included are intended to reflect the major parameters considered in the parametric analysis of the conventional airplanes. A separate set of equations have been developed for the VTOL category from data collected by the Lockheed California Company's Rotary Wing Division.

The following list of symbols are applicable to Figures 7.2.1 - 7.2.5:

K_w = Wing Configuration Constant

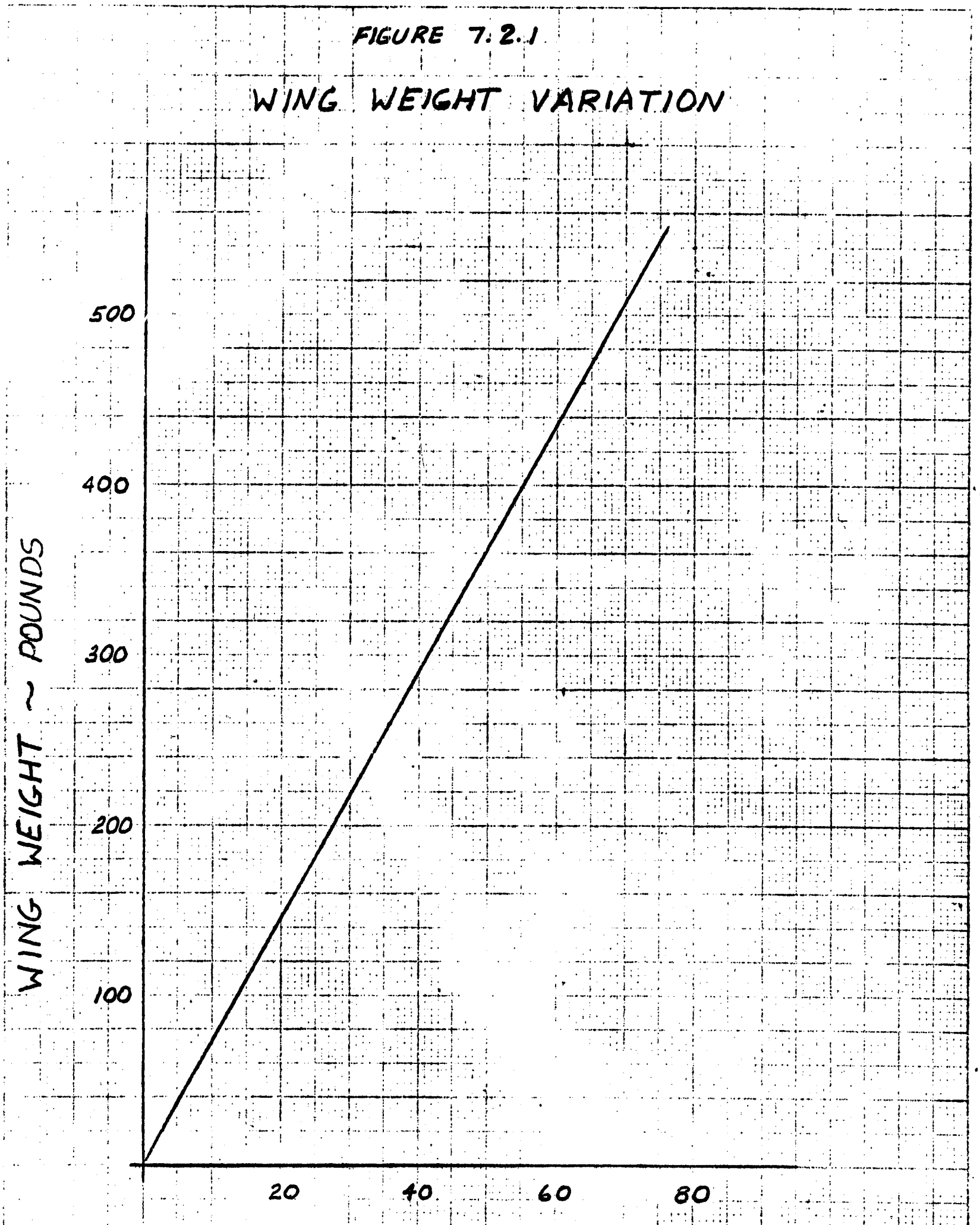
W_g = Design Gross Weight

N = Design Ultimate Load Factor

S_w = Wing Planform Area

AR = Wing Aspect Ratio

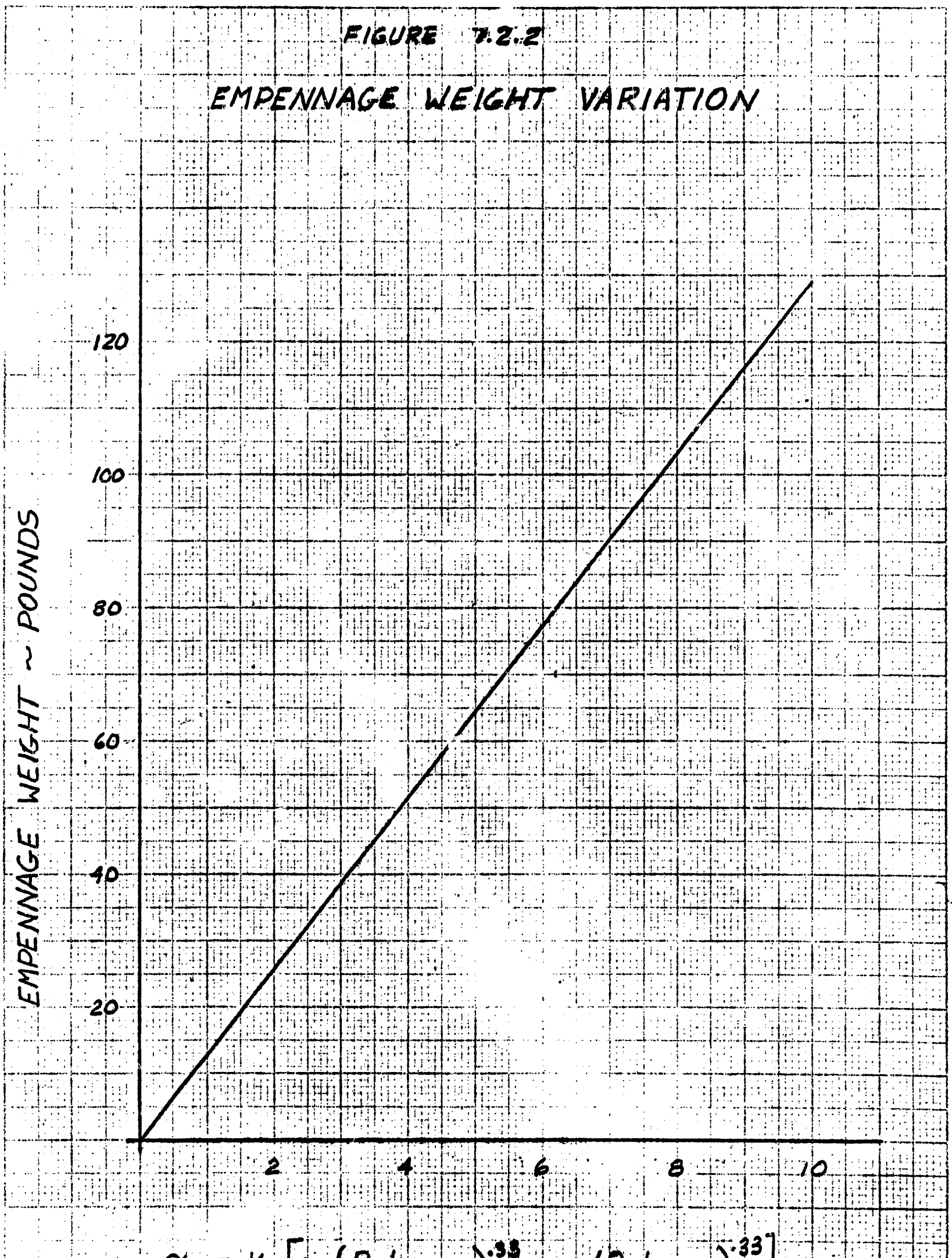
FIGURE 7.2.1



$$\alpha = K_W (W_G N)^{.6} (S_W AR)^{.8} \left(\frac{1+\lambda}{T/C}\right)^{.4} \times 10^{-3}$$

FIGURE 7.2.2

EMPENNAGE WEIGHT VARIATION



$$\alpha = K_E \left[S_h \left(\frac{P_h b_h}{T_h \cos \Lambda_h} \right)^{.33} + 1.6 S_v \left(\frac{P_v b_v}{T_v \cos \Lambda_v} \right)^{.33} \right] \times 10^{-2}$$

FIGURE 7.2.3

FUSELAGE WEIGHT VARIATION

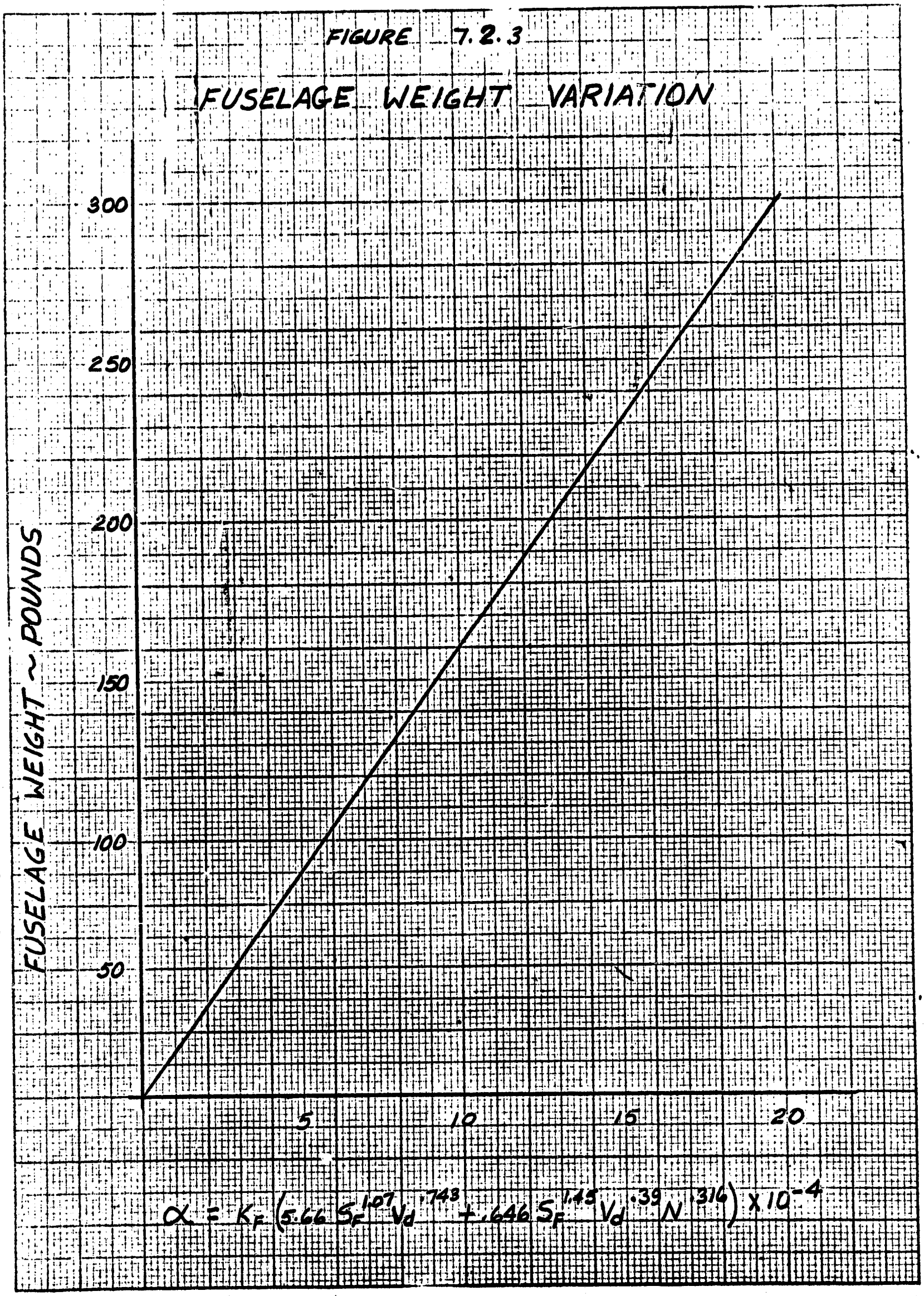


FIGURE 7.2.4

LANDING GEAR WEIGHT VARIATION

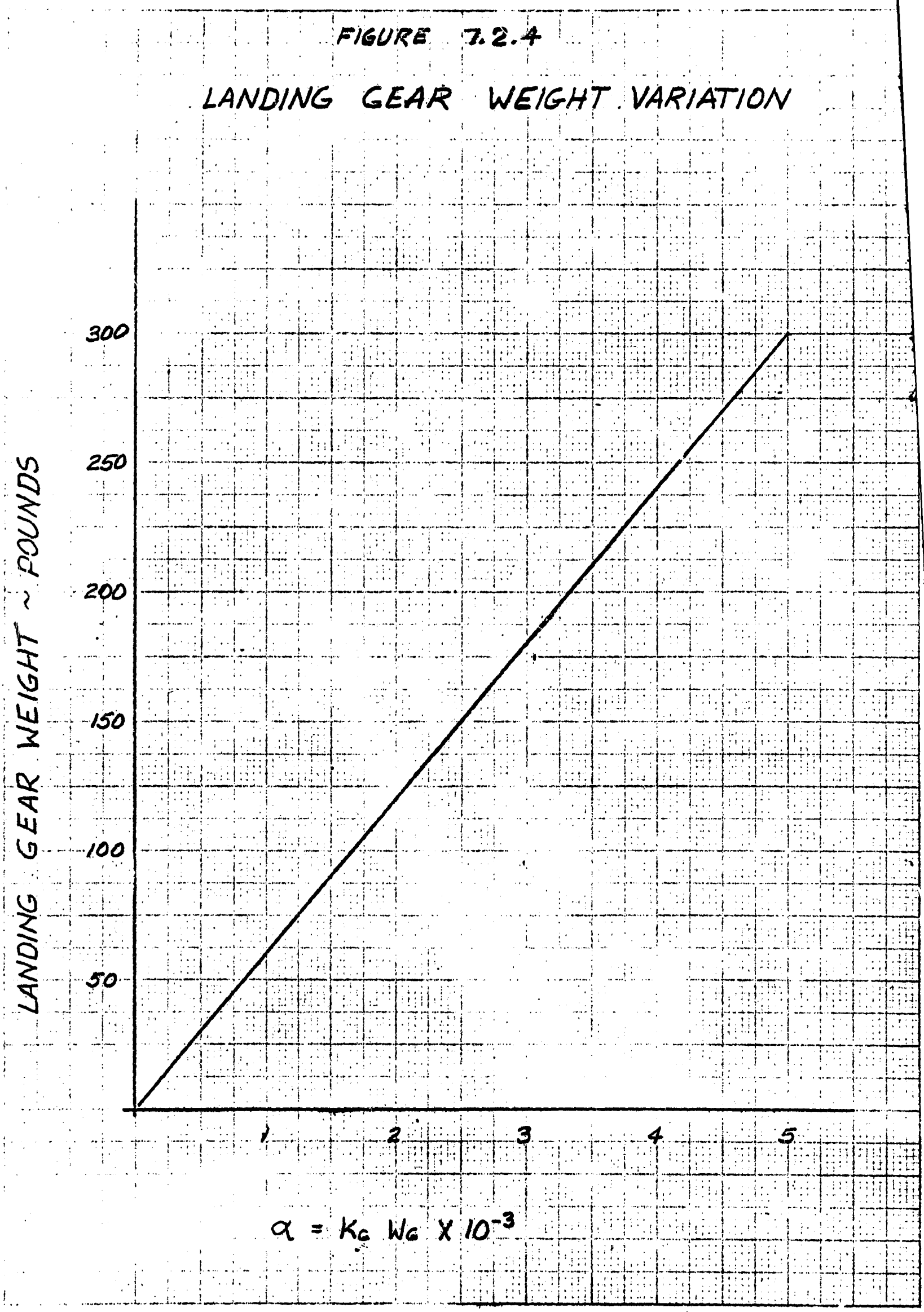


FIGURE 7.2.5

FIXED EQUIPMENT WEIGHT VARIATION

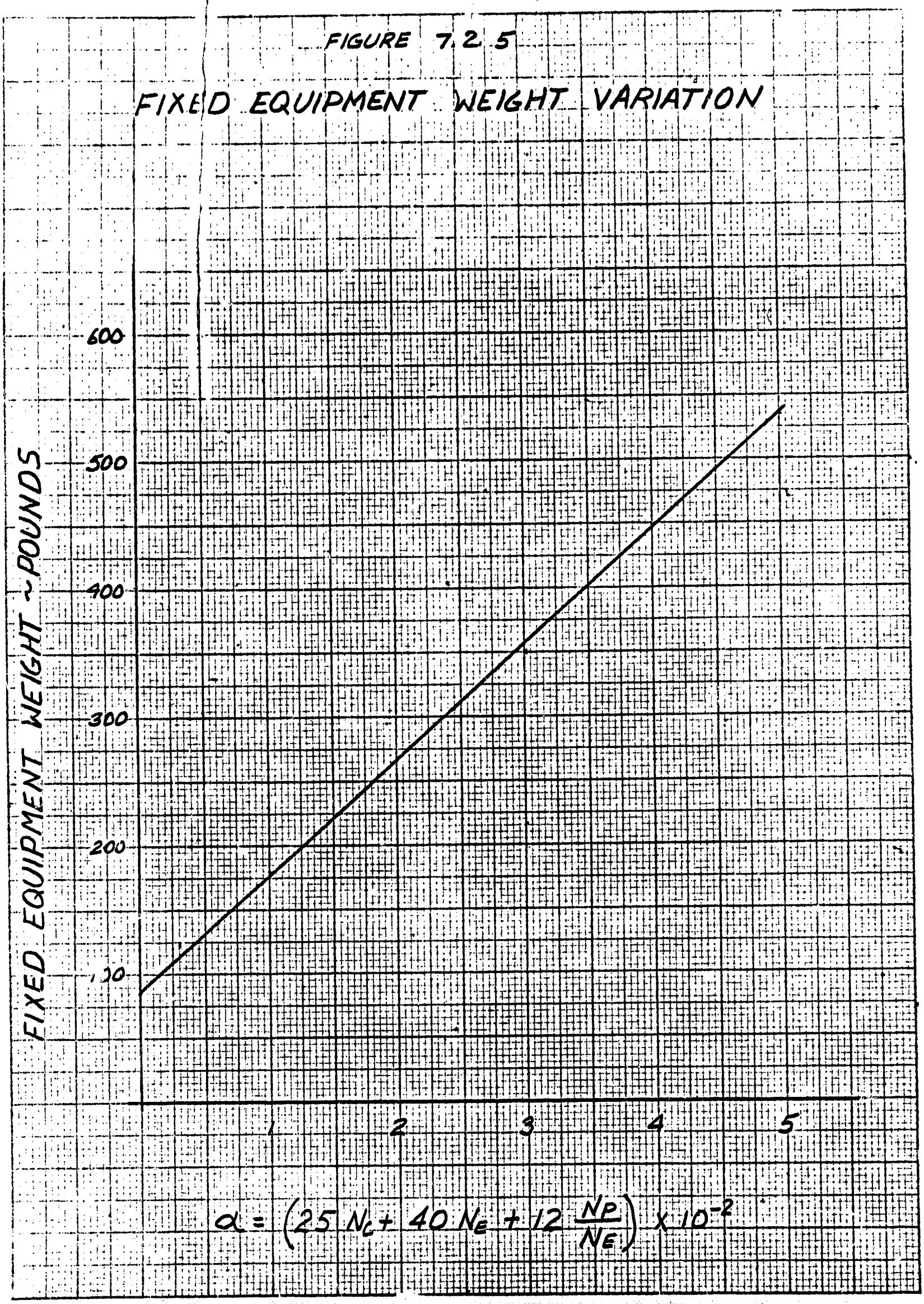
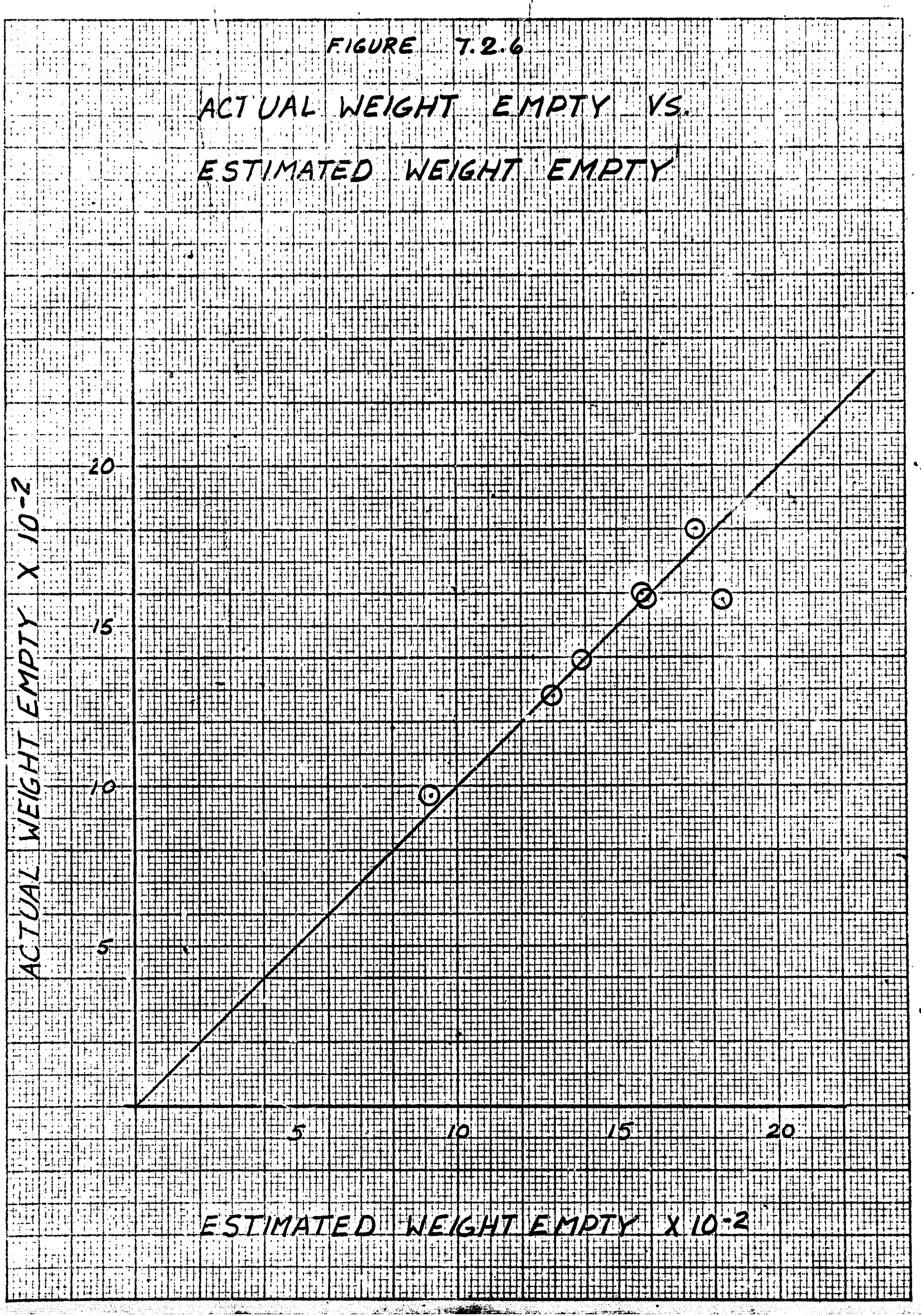


FIGURE 7.2.6

ACTUAL WEIGHT EMPTY VS.

ESTIMATED WEIGHT EMPTY



λ = Wing Taper Ratio

T/C = Wing Thickness to Chord Ratio

K_e = Empennage Configuration Constant

S_h = Horizontal Planform Area

P_h = Horizontal Unit Loading

b_h = Horizontal Span

T_h = Horizontal Thickness

$\text{Cos}\Lambda_h$ = Horizontal Sweep Angle

S_v = Vertical Planform Area

P_v = Vertical Unit Loading

b_v = Vertical Span

T_v = Vertical Thickness

$\text{Cos}\Lambda_v$ = Vertical Sweep Angle

K_f = Fuselage Configuration Constant

S_f = Fuselage Wetted Area

V_d = Design Dive Speed

K_g = Landing Gear Configuration Factor

N_c = Total Number of Passengers

N_e = Number of Engines

N_p = Number of Props

In assessing the impact of using advanced fiber-composite materials in the 1985 time period, the following factors are applied to the various weight groups for which subroutines have been developed:

Item No.	Group	Factor	Category
1	Wing	.800*	All
2	Fuselage	.800*	All
3	Empennage	.818	All
4	Nacelle	.822	All
5	Landing Gear	.950	All
6	Reduction Gearing	.752	All
7	Propeller	.860	All
8	Rotor	.850	IV
9	Drive Shafting	.478	IV

Items 1 through 5 were obtained from a proprietary study by the Lockheed-Georgia Company. Items 1 and 2 marked *, however, were arbitrarily increased from lower factors which are considered to be more applicable to the large transport aircraft analyzed in the theoretical study. Items 6, 8 and 9 were obtained from a Boeing Vertol Division study under contract to the Air Force, as reported in Section 5.3.5. Item 7 was obtained from a Hamilton Standard study.

Reference has been made to NASA CR-73258 "Potential Structural Materials and Design Concepts for Light Airplanes," in which some specific application studies were directed to the wing and empennage of a typical 4-place aircraft design. The tables on pages 218 and 224 of that report show weight reduction factors of 0.84 to 0.86 applied to conventional aluminum structure as representing the best design approach investigated in the study. It is believed that, with the use of more effective material and structural techniques potentially available in the 1985 time period, values of approximately 0.80 can be obtained. The establishment of more credible factors than those listed would involve a far greater effort than that included in the scope of this study.

7.3 Cost Data and Analysis

7.3.1 General Objectives and Procedure

A basic purpose of the cost analysis of this study was to develop a general aviation aircraft cost estimating tool that would predict conceptual design aircraft cost (initial and operating) with reasonable accuracy from minimum design and performance inputs. In addition, the cost estimating procedure was to be used to evaluate the effects of basic technology tradeoffs, safety provisions, performance, and large production rates on costs of selected designs. Basic steps in the general approach to accomplish these objectives are as follows:

- Collect cost/price data on contemporary aircraft and systems.
- Determine through regression analysis and other means the best correlation of available cost data with known physical and performance variables.
- Derive fundamental manufacturing cost data and cost estimating relationships from correlations. Incorporate the various relationships into a model subroutine for the general design computer program.
- Make cost estimate predictions to aid in the selection of designs within each category. Include Value Engineering estimates for unconventional construction/material designs.
- Determine, for selected designs in each category, the effect of technology tradeoffs on cost.

- Determine the sensitivity of initial cost and operating cost to changes in safety and performance variables.

- Determine the effect of large production rates on costs of selected designs.

7.3.2 Cost Data Analysis and Model Development

Considerable cost and price data on general aviation aircraft and associated systems were compiled from the current literature. Efforts were also made to obtain data from outside sources, including the major light aircraft manufacturers. Basically, manhours and material (cost) per pound of airframe weight, overhead rate, installed equipment cost, and other costs were requested for several classes of aircraft. While some pertinent data were obtained in this manner, the data obtained were limited because each manufacturer of commercial aircraft considers his particular cost structure data to be highly proprietary. Some aircraft cost data, however, were received from T. L. Galloway, the NASA Technical Monitor for this study.

With regard to propulsion system costs, contacts were made with leading manufacturers to obtain cost data on engines and propellers. List price data were obtained from some of these companies along with an indication of the approximate discount that is normally allowed to the original equipment manufacturers (OEM)of aircraft. In some cases an approximate OEM cost estimate was released.

References which have been examined and used for cost data and guiding information throughout this study are listed in Section 7.7.

Many correlations between aircraft and propulsion system physical and performance characteristics and compiled cost data were investigated. Although in most cases several correlations of cost data with various independent variables were investigated, only the more reasonable correlations are presented here. For an overview, total prices of contemporary light aircraft in several categories are shown in Figure 7.3.1, which shows total aircraft FAF prices as a function of the empty weight-speed (maximum cruise) product. These FAF prices do not normally include any avionics cost. Although the reasons for the price variation are many, the correlation is reasonable and the graph offers a quick means by which one can estimate the list price of contemporary aircraft (made in U. S.) on the basis of size and speed.

As part of the effort to develop a parametric relationship for airframe cost, propulsion costs and other costs were developed. The list price trend of several categories of horizontally-mounted reciprocating engines with horsepower are shown in Figure 7.3.2. Original equipment manufacturer (OEM) costs of these engines range from about 60 to 65% of the list prices. The straight line trends indicate the basis for deriving a parametric cost estimating relationship from these data. Similar cost trends applicable to gas turbine engines are shown in Figure 7.3.3. Turboprop refers to

FIGURE 7.3.1 PRICE TREND OF GENERAL AVIATION AIRCRAFT WITH WEIGHT-SPEED PRODUCT

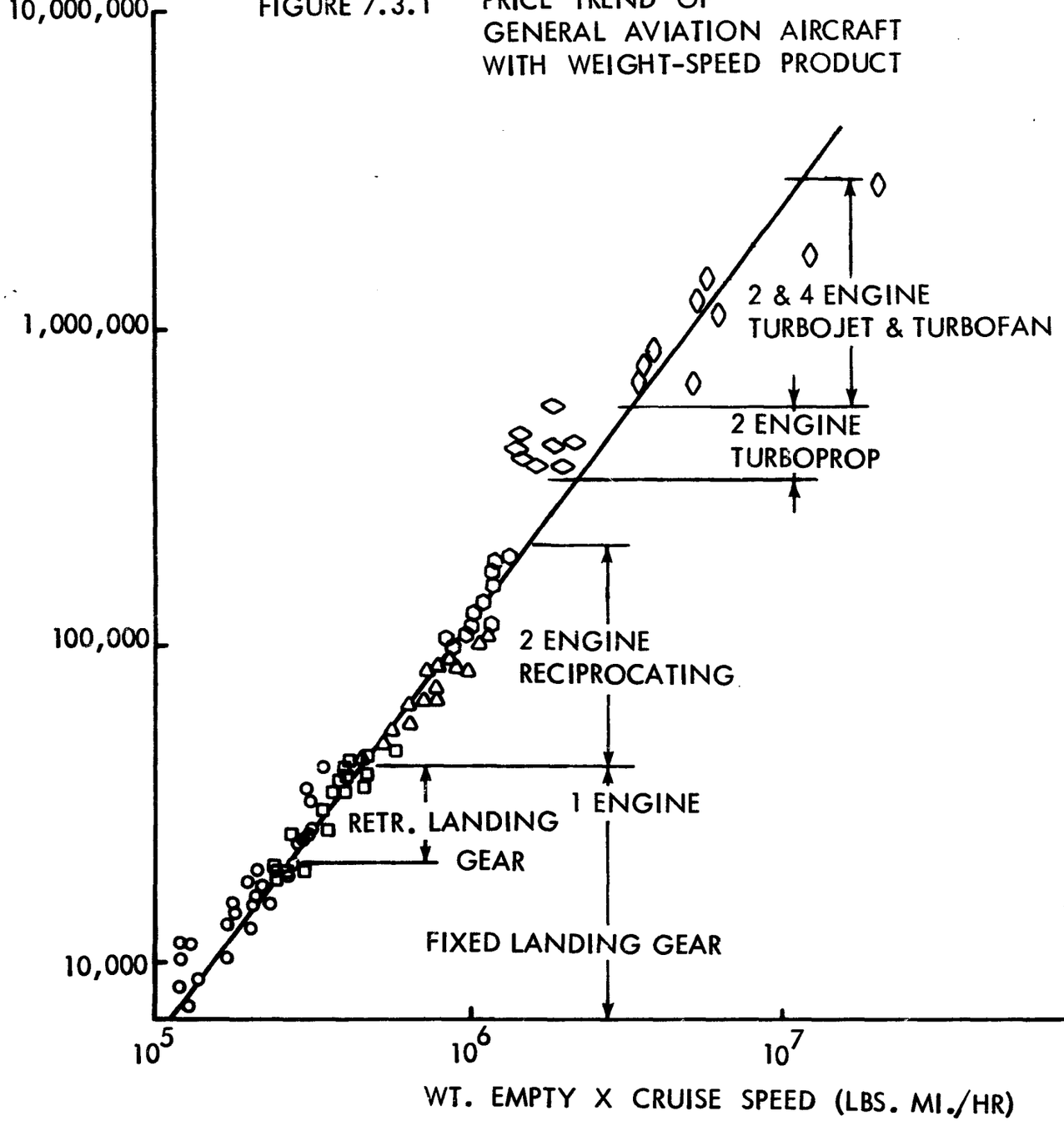


FIGURE 7.3.2

RECIPROCATING ENGINE PRICE
VERSUS HORSEPOWER

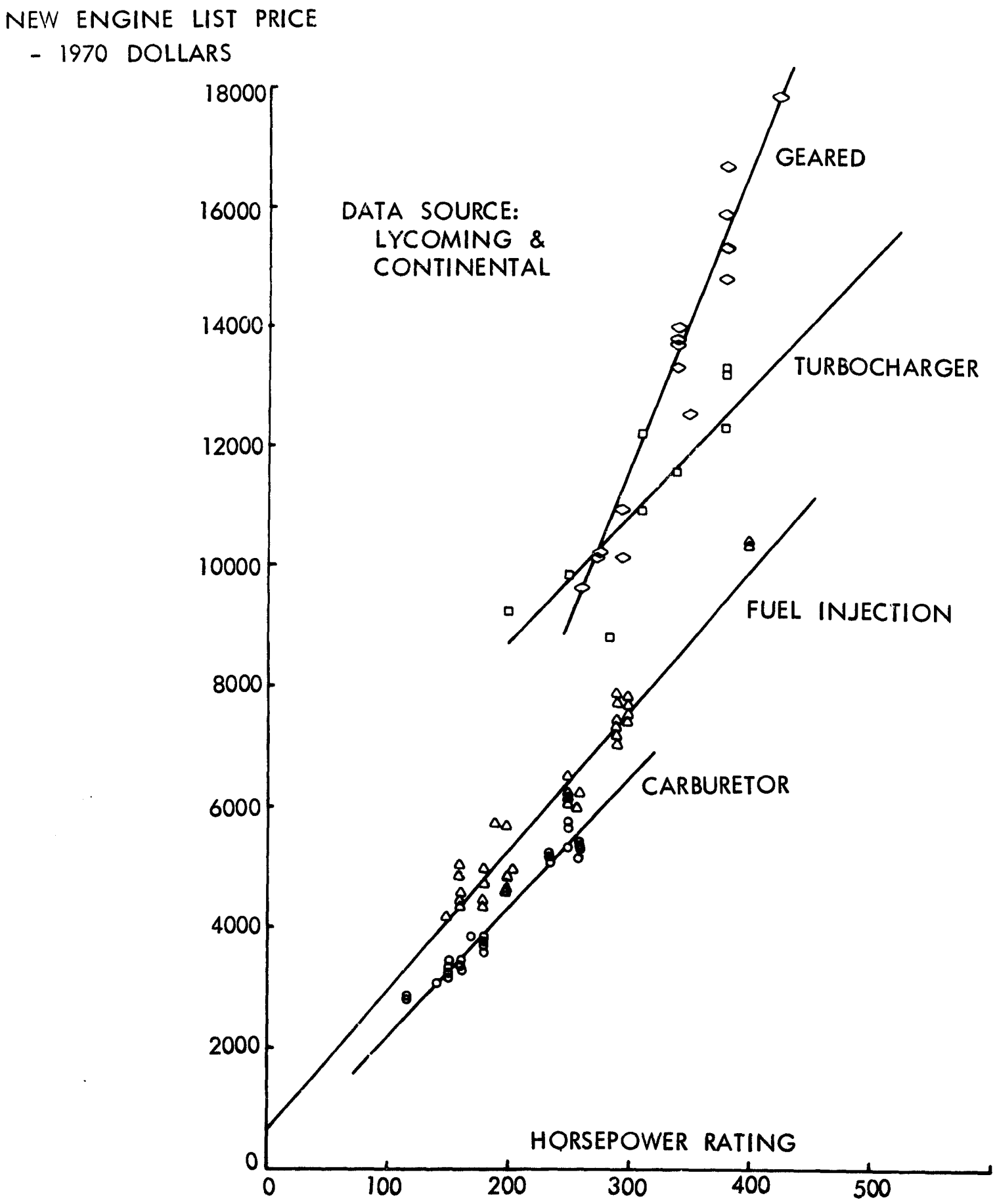
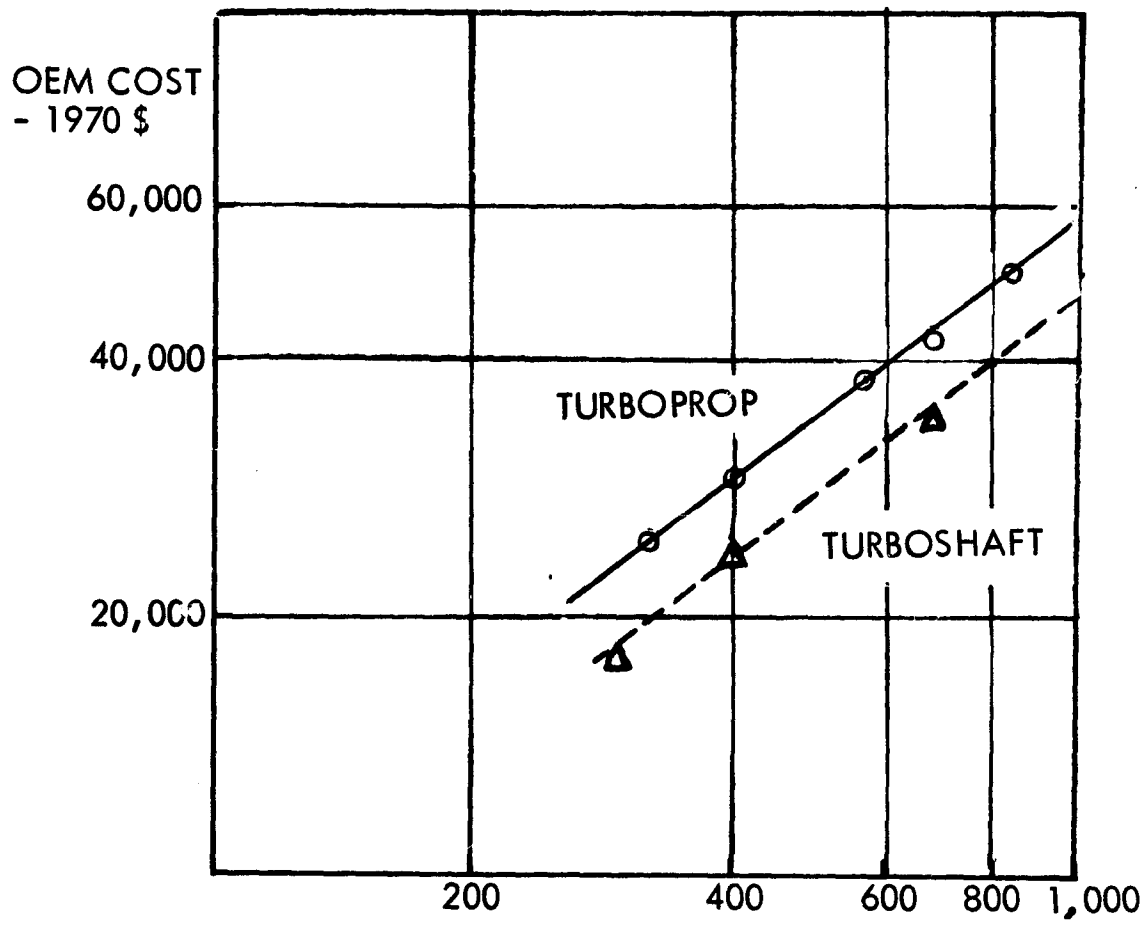


FIGURE 7.3.3

TURBINE ENGINE COST TREND



the inclusion of suitable reduction gearing for propeller drive, while turboshaft refers to inclusion of only a single stage of gearing. Engine costs shown in this graph represent approximate OEM costs based on estimates and data obtained from manufacturers.

Data related to the rotating combustion (RC) engine for aircraft applications were obtained from the Curtiss-Wright Corporation. These data are shown in Figure 7.3.4 where the approximate OEM cost of the RC engine is shown as a function of horsepower. The solid line represents the cost trend for "currently available" RC engines and the dashed line represents the projected cost trend for RC engines in the 1985 time frame. Both trends are based on 1970 dollars. The projected (1985) costs for the RC engine will result in about a 42% reduction from the current OEM costs.

Some representative propeller assembly (less spinner) prices as a function of assembly weight are illustrated in Figure 7.3.5 for two, three, and four blade propellers. Generally OEM costs for propellers are about 60 to 65% of list prices. Variation in the propeller prices within a given type is due primarily to design, construction and material differences; however, the straight line trend shown in Figure 7.3.5 seems to provide a reasonable estimating relationship over the entire range shown.

Allocations from aircraft list prices have been made for a number of aircraft (with normal production rates of about 100/year or greater) by subtracting out the OEM cost of engines, propellers, and other equipment to obtain what is called the "airframe list price." Results of this process are shown in Figure 7.3.6 where this airframe price is plotted as a function of the aircraft empty weight - maximum cruise speed product. For each aircraft the cost of the particular engine and propeller was subtracted from the list price, not just an average cost as exemplified by the straight line trends shown in other graphs. An average trend of other purchased equipment cost, shown in Figure 7.3.7 as a function of weight-speed product, was developed from rough estimating relationships and from data submitted by a manufacturer. Three of the points shown in Figure 7.3.7 were derived from equipment cost data submitted by one of the major manufacturers. Other equipment cost is defined here as cost of purchased equipment, excluding propulsion equipment. Avionic cost is usually considered as an optional cost and is not included in the other equipment cost of Figure 7.3.7. Costs of optional avionics packages, applicable to the aircraft of this study, are listed separately in Section 8.3.7.

In an effort to arrive at more basic airframe cost quantities, the results shown in Figure 7.3.6 and 7.3.7 were analyzed further. Retail marketing discounts; manufacturer's profit goals; engineering, tooling, sales and G&A costs; and purchased equipment costs were deducted from the list price of each particular aircraft. Basic percentages of selling prices given in a management planning brochure of the old Consolidated Vultee, Stinson Division (Reference 7.3.15) and the typical cost breakdown shown in NASA CR-1285 (Reference 7.3.11) were used as a guide for this process. These two references show very close agreement in the percentage of selling price of the various items which determine the list price. The typical procedure used is summarized in Table 7.3.8, where the cost breakdown

FIGURE 7.3.4

COST VS H.P. TREND FOR
ROTATING COMBUSTION ENGINES

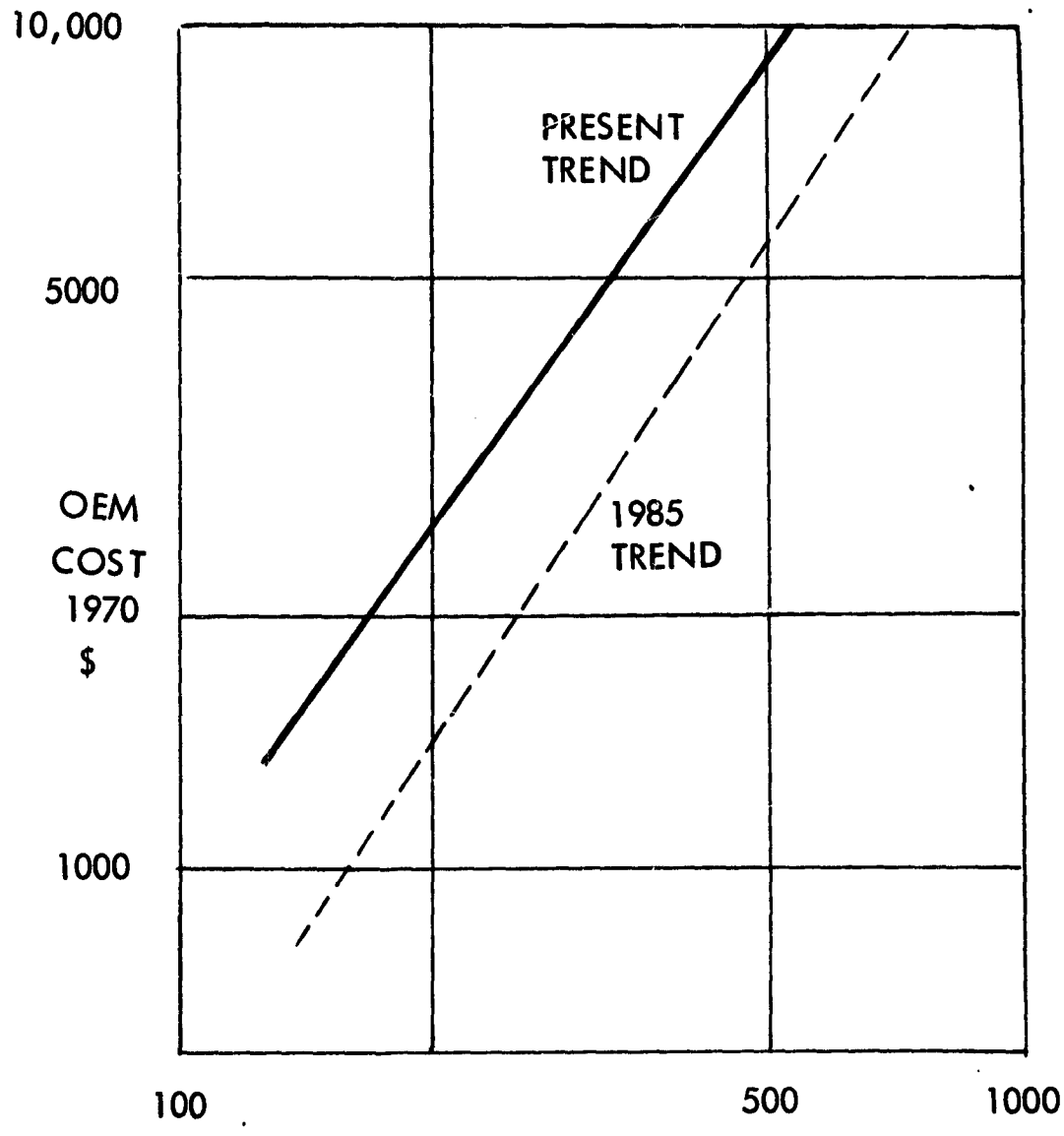


FIGURE 7.3.5.

PROPELLER ASSEMBLY PRICE - WEIGHT TREND

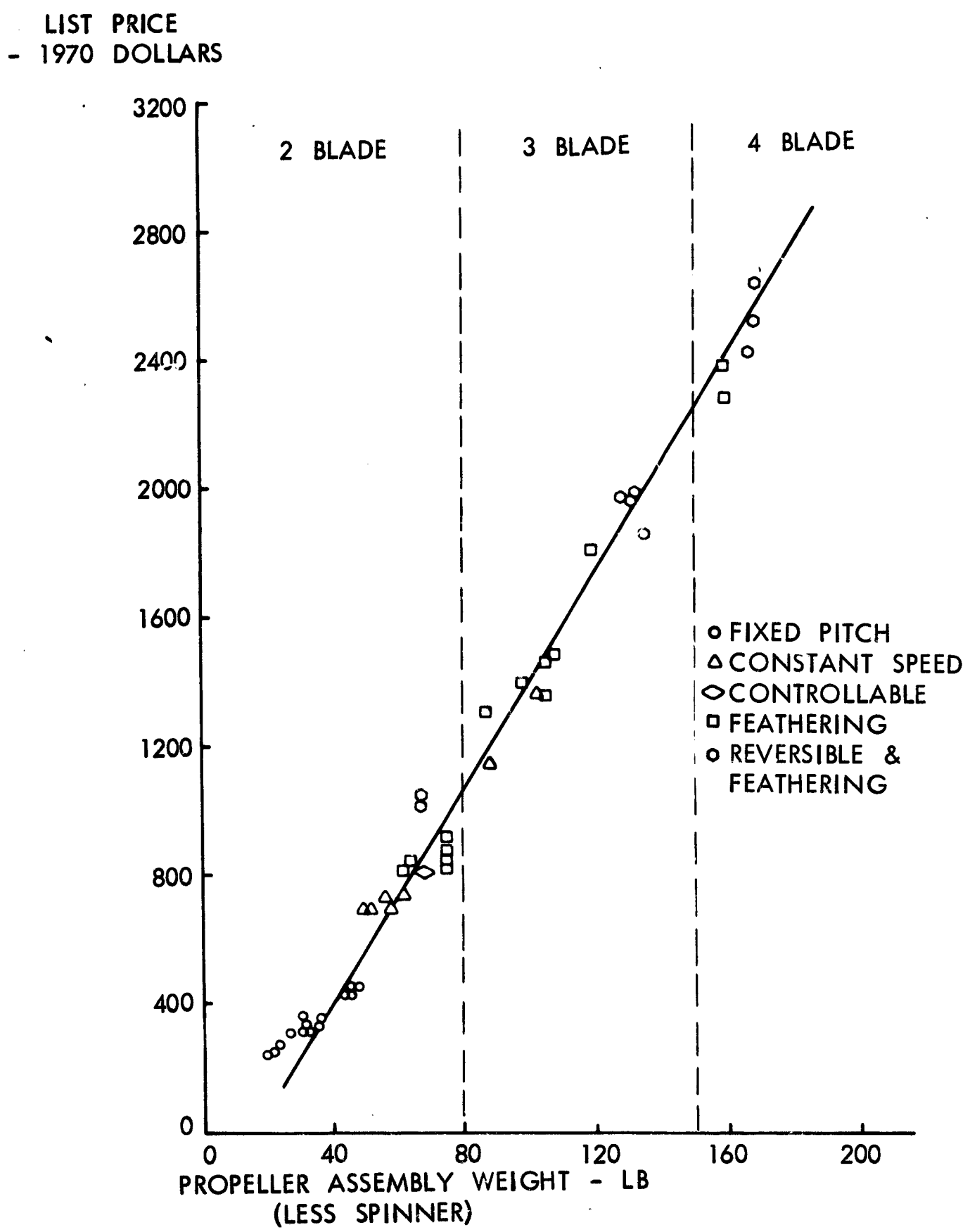


FIGURE 7.3.6

AIRFRAME LIST PRICE
TREND WITH WEIGHT SPEED PRODUCT

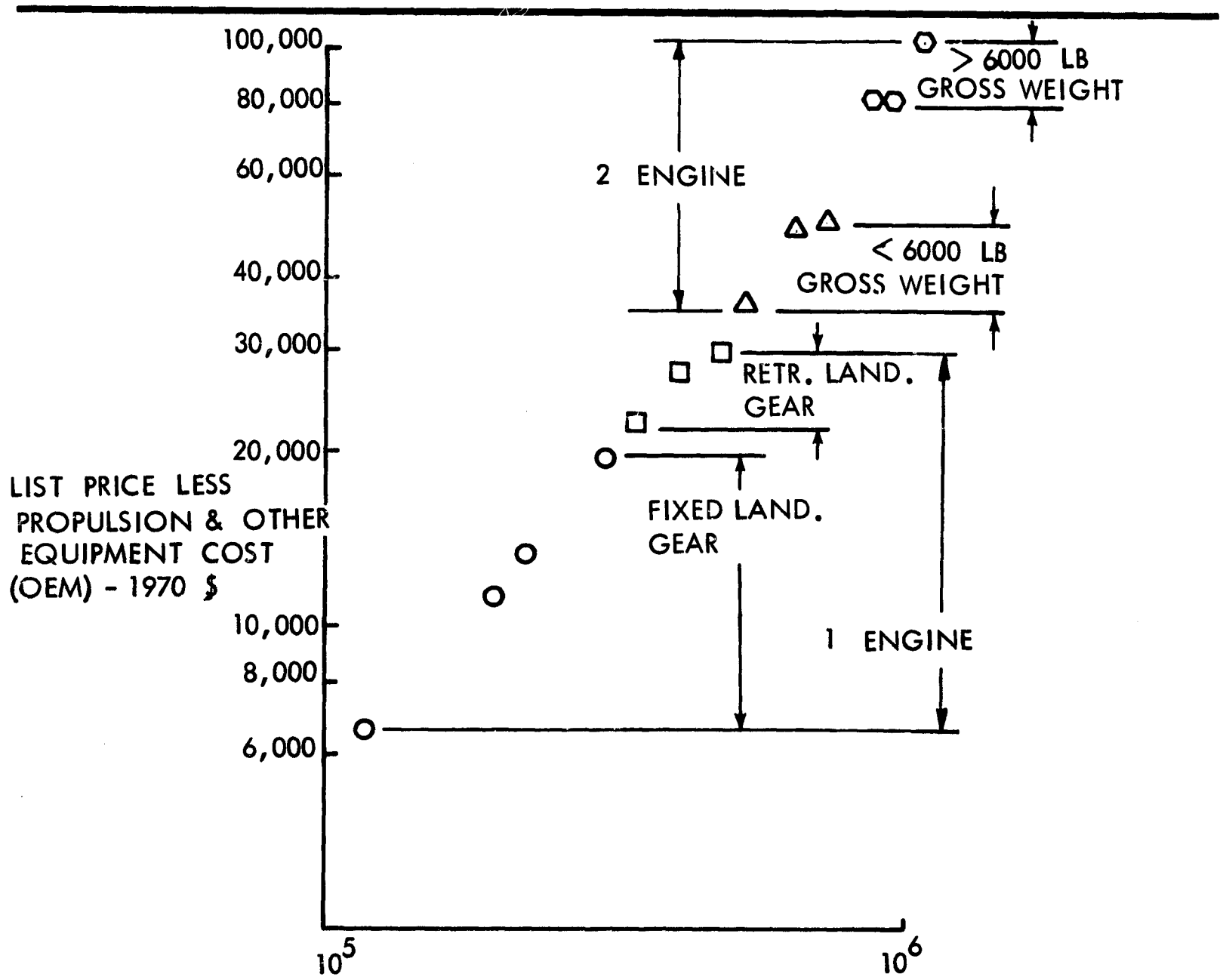


FIGURE 7.3.7

OEM OTHER EQUIPMENT COST
TREND WITH WEIGHT - SPEED PRODUCT

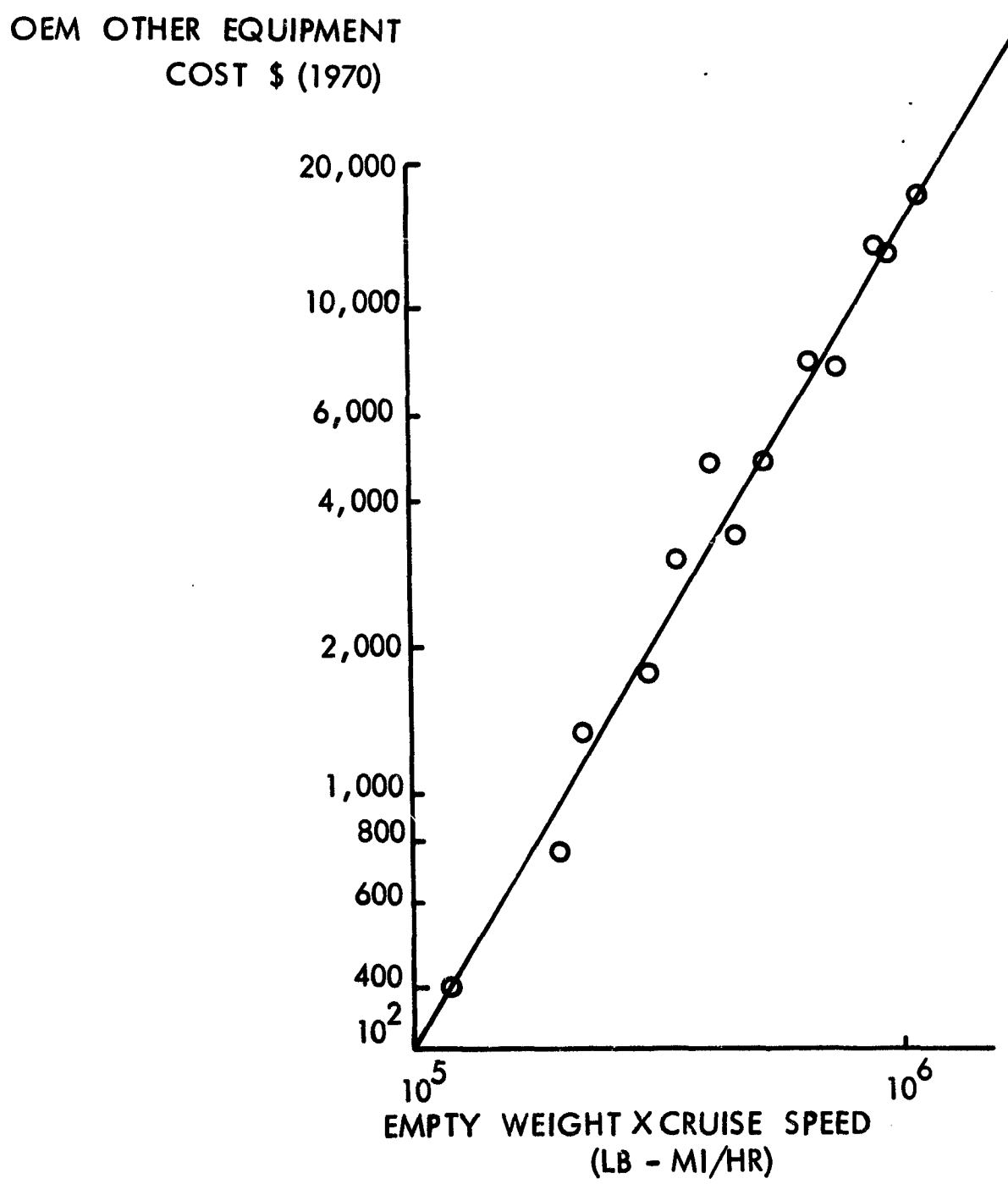


FIGURE 7.3.8

ESTIMATED COST SUMMARY;
TYPICAL 4-PLACE
CONTEMPORARY AIRCRAFT

EMPTY WEIGHT = 1470 LBS.

ITEM	DOLLARS (1970)	% OF LIST
LIST PRICE	17,500	100
LESS RETAIL MARK-UP	4,380	25
DEALER COST	13,120	75
LESS MANUFACTURER'S PROFIT (10% EST.)	1,190	6.8
MANUFACTURER'S COST	11,930	68.2
LESS ENGR., TOOLING, SALES, G&A (EST.)	2,900	16.6
DIRECT MANUFACTURING COST	9,030	51.6
LESS ENGINE AND INSTALLATION COST	2,460	14.1
	6,570	37.5
LESS PROPELLER & ASSOCIATED PARTS	365	2.1
	6,205	35.4
LESS OTHER EQUIPMENT	1,350	7.7
AIRFRAME COST	4,855	27.7
LESS MATERIAL COST (EST.)	785	4.5
	4,070	23.2
LESS MANUF. LABOR OVERHEAD (132% DIRECT)	2,310	13.2
MANUFACTURING LABOR COST	1,760	10.0

LABOR MANHOURS (@ $3.10/HR.) = 570

of a typical 4-place contemporary aircraft is estimated. Basic percentages will vary slightly with size, production rate, and equipment list of the aircraft. Trends of these percentages with the weight or weight-speed of the aircraft were approximated on the basis of assumptions and other information that was obtained from the study consultant, Mr. A. W. Mooney.

This general procedure has been performed for a number of aircraft (with relatively high production rates) covering the basic range of categories to be investigated in this study. Results of manufacturing manhours and material cost per pound of empty weight versus empty weight for various aircraft are displayed in Figure 7.3.9. Several points shown on these plots represent data obtained from a manufacturer; the other points are estimates based on aircraft and equipment price lists, certain assumptions and percentage trends. The results do not seem to indicate an economy of scale over the range of weights covered, which could in part be attributed to the differences in where each aircraft may be on a learning curve established by its particular production run. These results should be very reasonable for the middle range aircraft. When normalized on the basis of empty weight-maximum speed, the basic manufacturing manhours and material cost show a flat distribution with weight-speed product as shown in Figure 7.3.10.

Helicopter manufacturing manhour data have been obtained from a report dealing in part with military helicopter airframe production cost. The report was prepared by the Lockheed California Company (Reference 7.3.12) and the helicopter data were based on the results of a DoD Cost Research Symposium Paper (Reference 7.4.13). The data were adjusted (with 87% learning curve) to a quantity of helicopters in the 400 to 500 range, which was assumed to be appropriate for civil helicopters in the present investigation. Results of the helicopter data adjustment are presented in Figure 7.3.11. Included is a data point taken from the San Diego Aircraft Engineering study (Reference 7.3.11), which shows the cost breakdown of a light civil helicopter. The point tends to agree with the military helicopter trend very well.

With the available fundamental cost quantities, manhours and material cost as a function of aircraft physical parameters, along with propulsion, other equipment, marketing and other expense trends, a procedure was developed for estimating the initial cost of conceptual fixed-wing aircraft. A simplified block flow of the procedure is shown in Figure 7.3.12. The input block term "complexity factors" relates to the inclusion of factors used to modify various cost equations in the procedure to account for unconventional construction and materials or for other special purposes. For conventional aircraft these complexity factors were normally set at unity. Complexity factors were applied primarily in the manufacturing cost block as shown in Figure 7.3.12. The procedure made provision for including optional equipment, such as avionics, but no optional equipment was normally included in the cost estimating of baseline designs.

FIGURE 7.3.9.

MANUFACTURING MANHOURS AND MATERIAL COST

PER POUND OF EMPTY WEIGHT

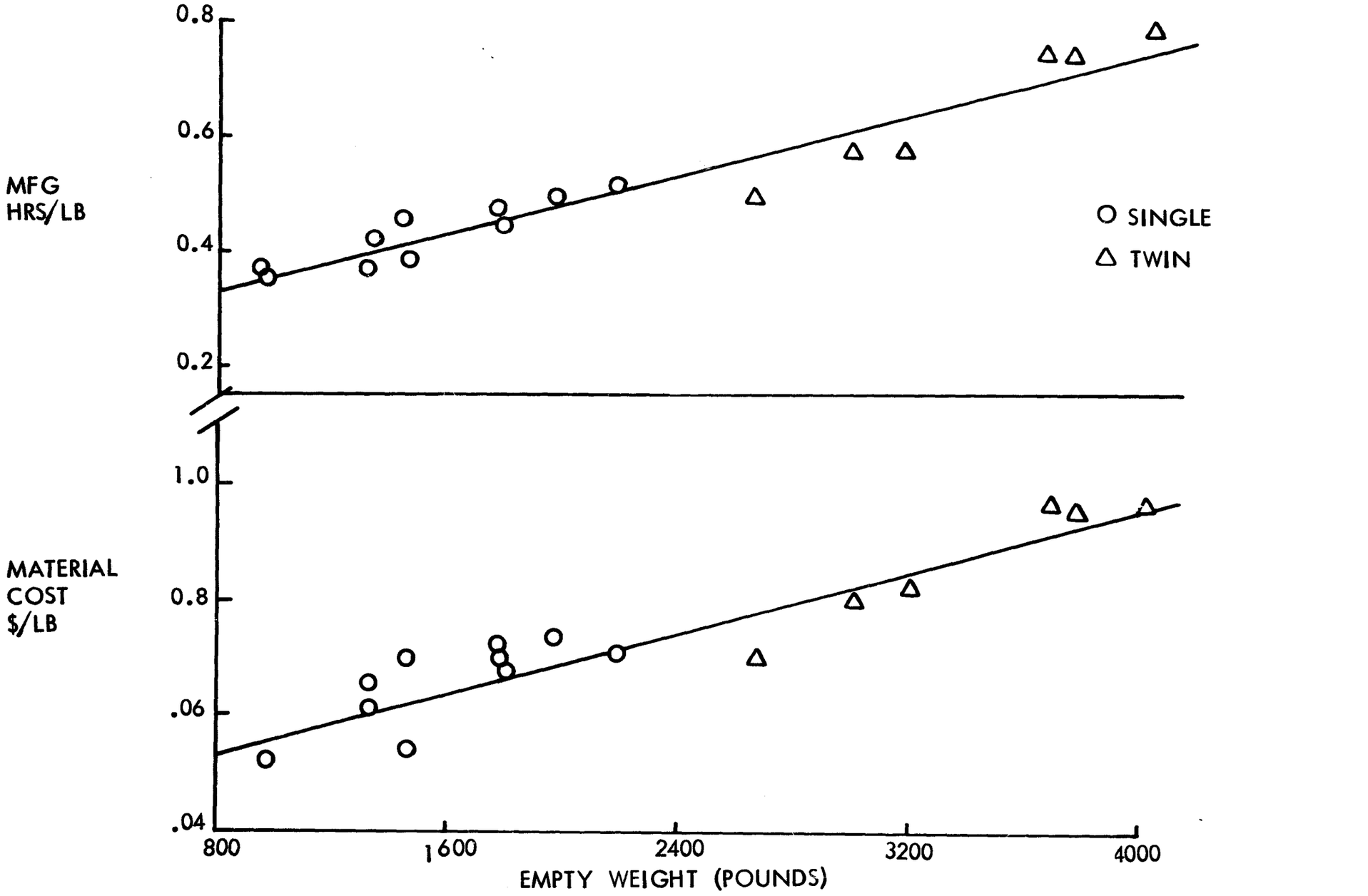


FIGURE 7.3.10

MANUFACTURING MAN-HOURS AND MATERIAL COST DIVIDED BY WEIGHT EMPTY X MAX. SPEED FACTOR

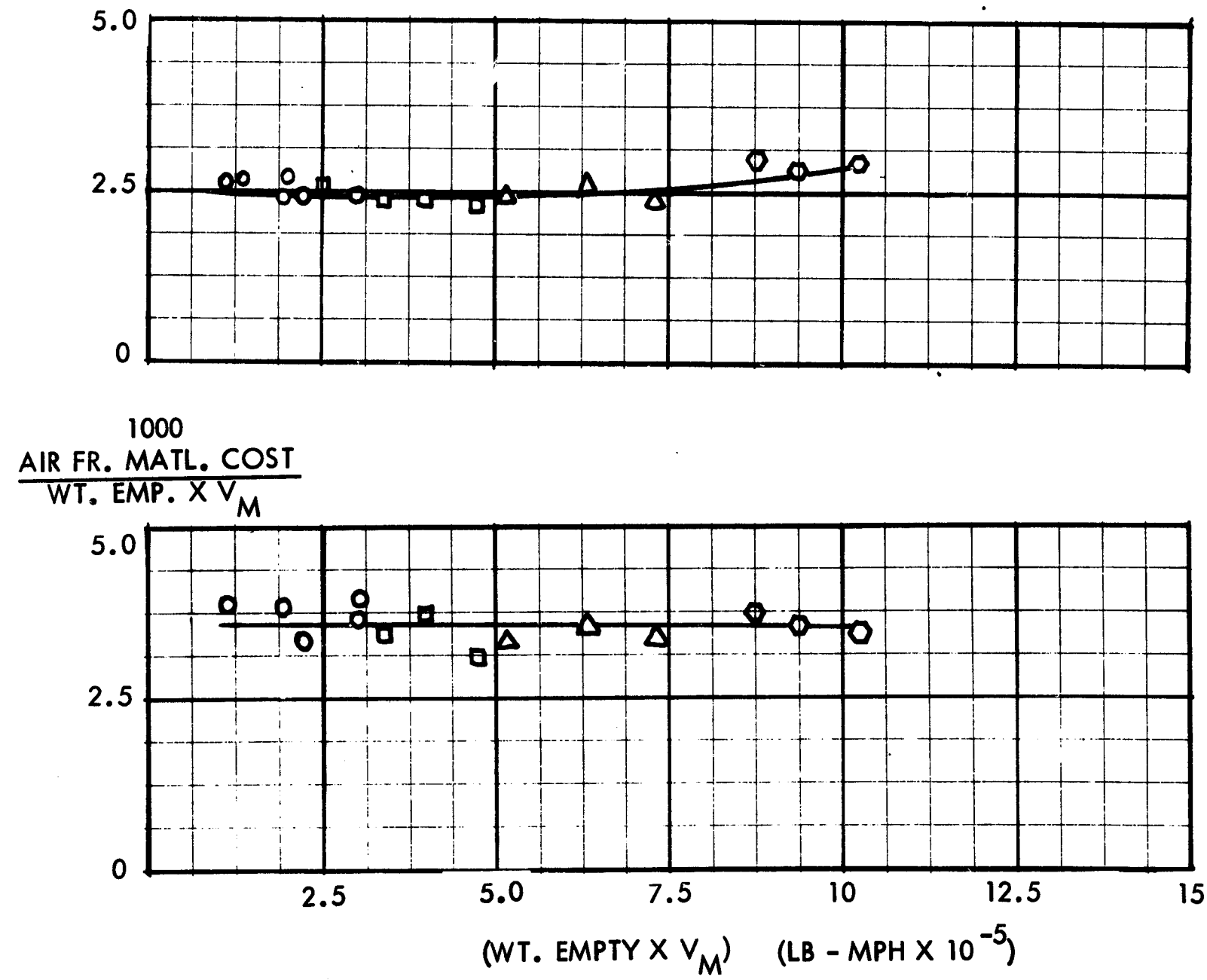


FIGURE 7.3.11

HELICOPTER MANUFACTURING MANHOURS TREND
WITH WEIGHT-SPEED PRODUCT

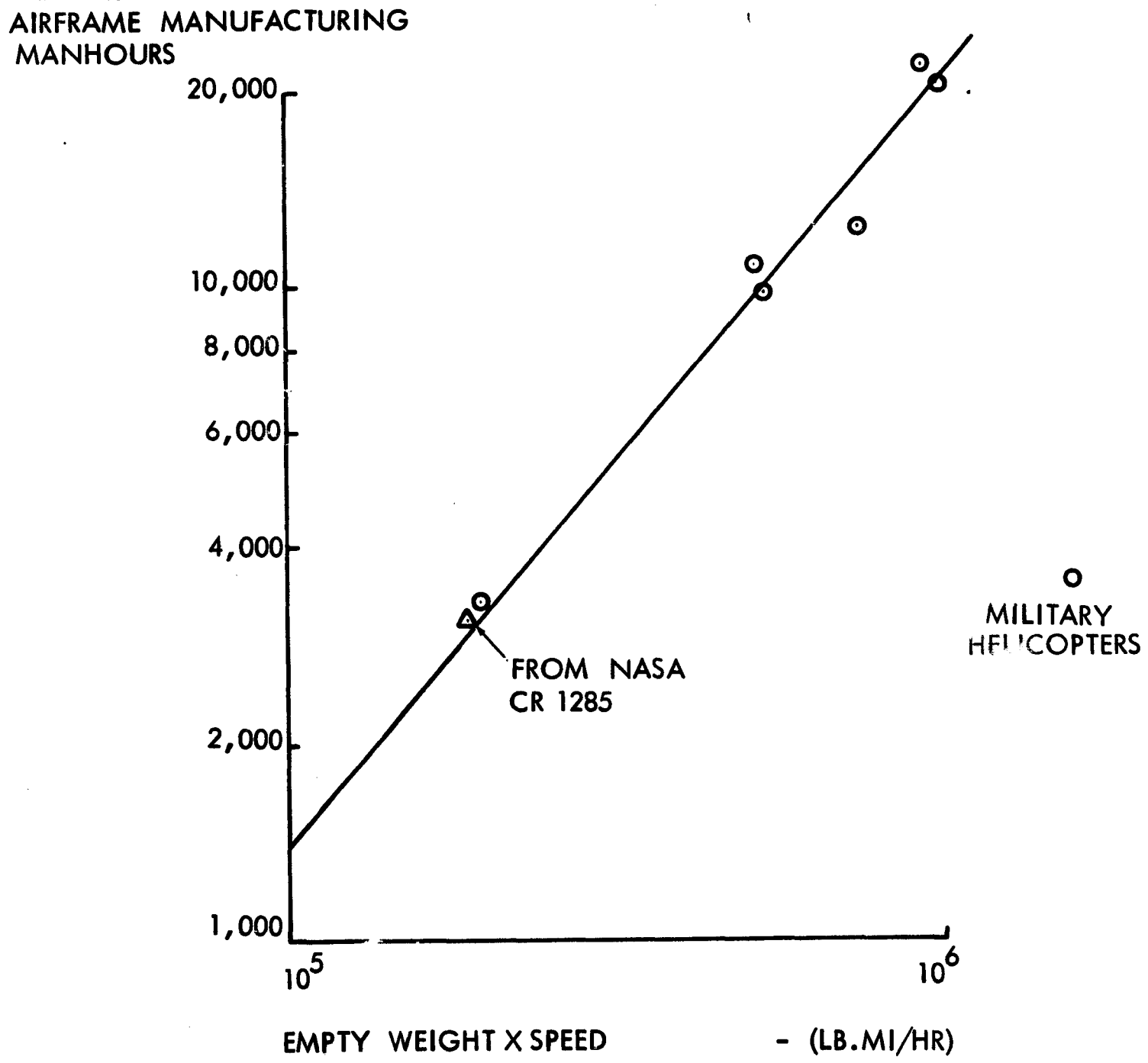
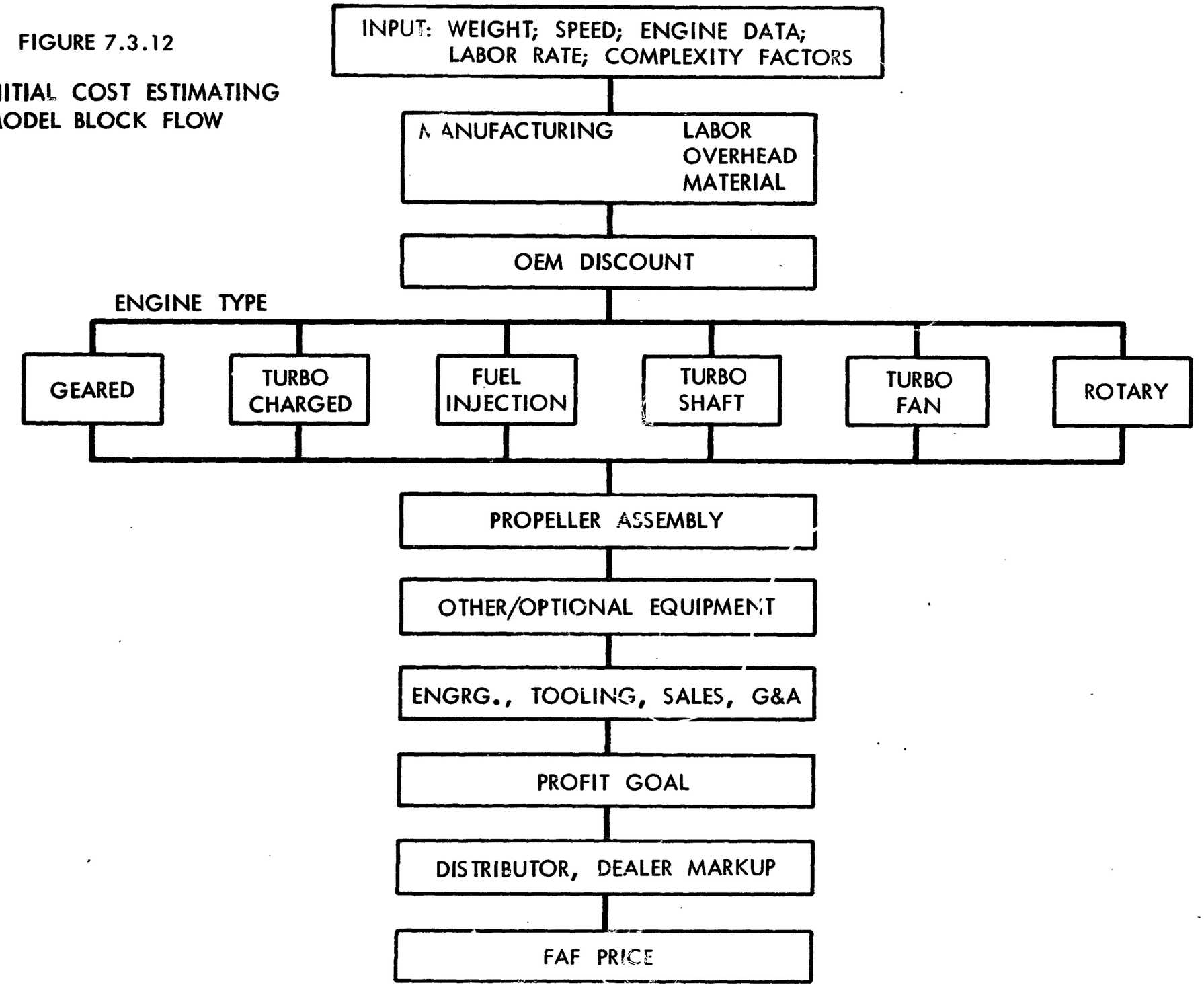


FIGURE 7.3.12

INITIAL COST ESTIMATING MODEL BLOCK FLOW



Similarly, a procedure was developed for helicopter (single main rotor) cost. Both procedures were programmed as subroutines for the general design computer program.

Since it is important that cost models produce realistic estimates when applied to contemporary aircraft, some preliminary runs were made with the fixed-wing cost model routine to compare the model estimated cost (FAF) with the actual cost of contemporary aircraft. Results for several contemporary aircraft are presented in Figure 7.3.13. Optional avionics costs are not included in either the actual or model-estimated cost of the contemporary aircraft. In general the cost prediction of contemporary aircraft with reasonable production quantity and design features seems to be within 10% of the aircraft actual cost. Preliminary runs with the helicopter cost model indicate that the model predicted cost for a well known contemporary model agrees to within 7% of the actual list price.

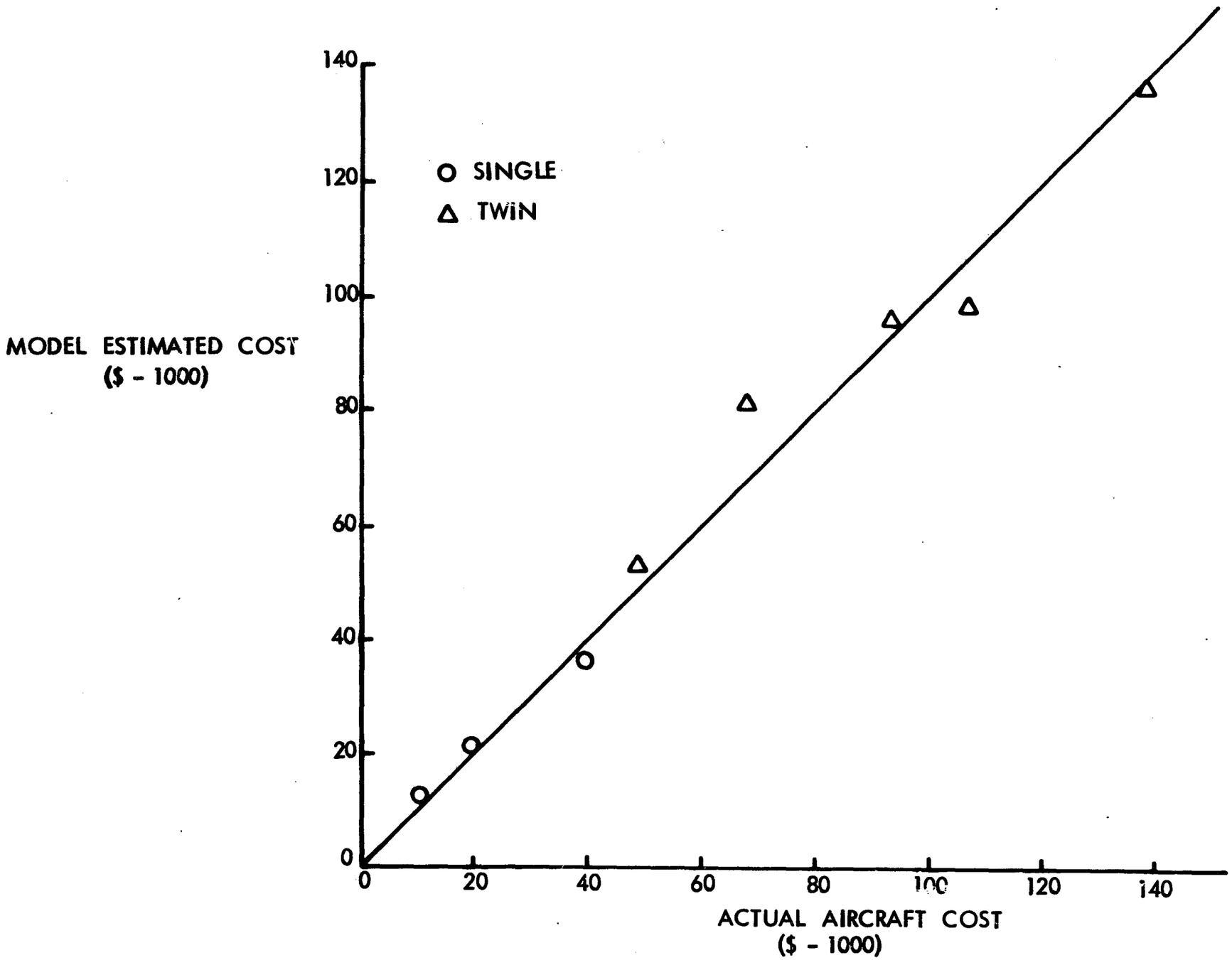
7.3.3 Development Cost

In many cases it is difficult to determine what constitutes development cost or when it begins and ends. This situation could be especially true of small general aviation aircraft where basic airframe models will generally have a long production run with several minor modifications, improvements and model changes along the way. Also some models are derivatives of military models in which original development costs have been funded by the Government.

Another factor is the accounting system used. For a typical 4-place aircraft the development costs could be amortized over 2000 to 3000 (about 3 years) aircraft when market analyses may indicate that 4000 to 5000 could be sold. If 7000 or more are actually sold before the model is completely dropped, the original amortization would not reflect the true development cost per aircraft unit. Competition would tend to make development amortizations follow a rough trend, but variations like a factor of two or more are not uncommon, especially between new manufacturers and old established manufacturers.

No independent analysis has been made of development cost for the designs of this study. This is because an analysis of this type is very difficult to generalize and highly speculative without historical data with which to base computations. The initial cost (and any inherent associated development cost) for baseline designs is assumed to be based on comparable numbers of contemporary aircraft of the same class. That is, the designs tend to evolve into being and are costed on the basis of production numbers of similar contemporary aircraft. Any development cost would be amortized over the same number of aircraft as normally done for similar contemporary aircraft. Only the ranges of these numbers are conjectured for current conditions. For the Category I class aircraft the development amortization may be spread over 1000 to 3000 units, while the Category II, III and IV designs might involve from 200 to 600 units.

FIGURE 7.3.13. COMPARISON OF ACTUAL AND MODEL ESTIMATED PRICE OF CONTEMPORARY AIRCRAFT



Since development costs for this study can only be identified in the most general way, allocations for this expense are estimated as a rough percentage of list price. Specifically, for Table 7.3.8, the development engineering and basic or initial tooling could be broken out of the Engineering, Tooling, Sales and G&A cost item as shown in Table 7.3.14 where estimates of the unfolding costs are presented. The numbers in parentheses represent the approximate percentage of list price and the development cost of about $1000 represents the engineering and tooling costs that might be amortized per unit to introduce a typical, 4-place aircraft.

The breakdown of costs shown in Table 7.3.14 is based on percentages of estimates made in an old planning brochure of the Consolidated Vultee Aircraft Company (Reference 7.3.15). Basic costs are allocated over 2000 to 3000 aircraft units. On the basis of 2500 units the airframe development costs for this class of aircraft (about $1000/unit) would be about $2,500,000. Since the gross weight for this aircraft is 2500 pounds, the approximate development cost would be about $1000 per pound of gross weight. This result is in good agreement with the total "launching costs" (development costs) presented by Peter Masefield in Reference 7.3.16. He says that experience in Europe shows that total launching costs of a well-tooled, new, all-metal light aircraft run consistently at abour $840/lb of gross weight. This figure is based on 1966 prices and would be equivalent to about $1000/lb of gross weight in 1970 dollars. This cost of about $1000/lb of gross weight for aircraft of this class has also been given as a rule of thumb in Reference 7.3.17. This, of course, is a rough average cost factor and variations could be large. The basic breakout in the Masefield Paper is shown below:

Launching Costs	% of Total
Design	20
Prototype Build and Test	20
Structural and Systems Test Work	6
Tooling	23
"Initial Batch" Costs	23
Demonstration Aircraft	8
Total	100

Spot checks on several contemporary aircraft up to 6400 pounds of gross weight indicates the development cost factor of about $1000/lb tends to agree (within 50%) with development cost based on a percentage (5 to 7%) of list price. This agreement is based on the allocation of development costs over a number of units typified by the ranges given above. The gross weight cost factor or the list price percentage factor are both highly generalized development cost factors and should be applied only for rough planning estimates.

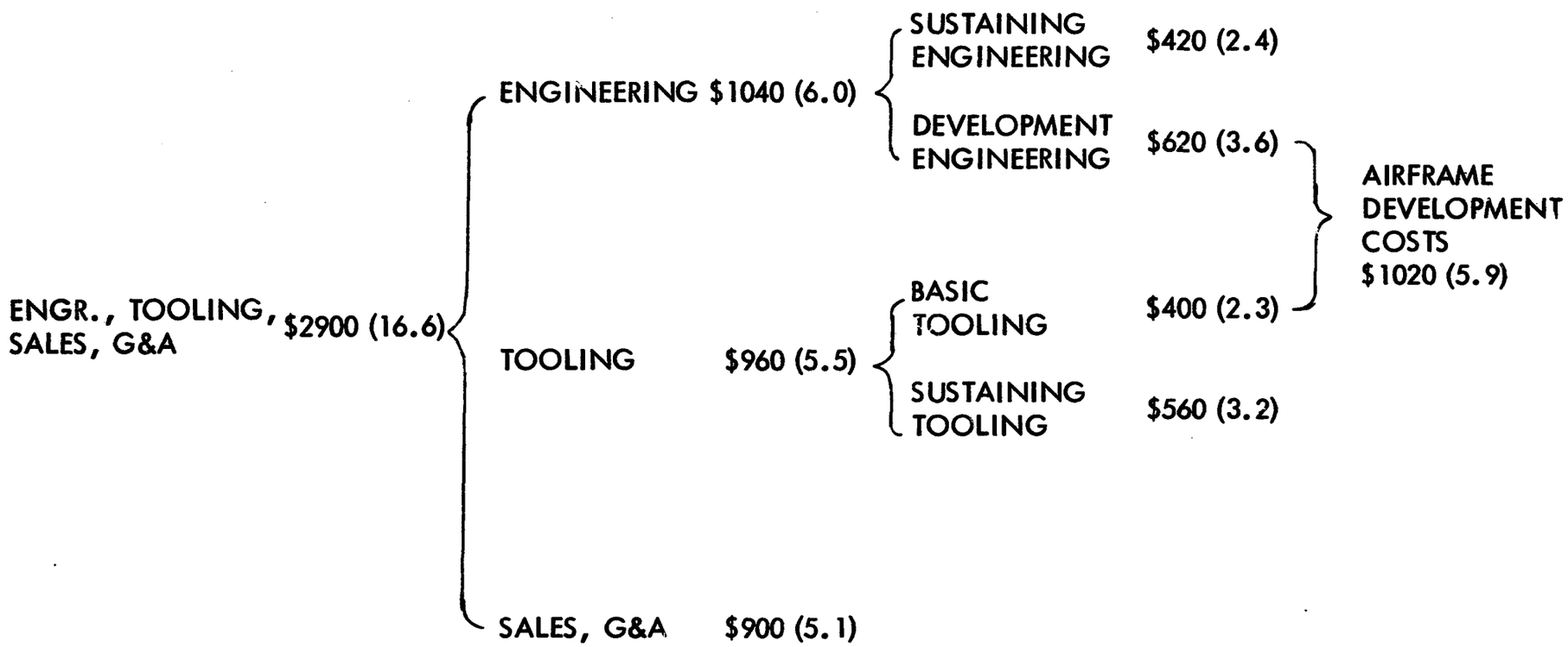


FIGURE 7.3.14 AIRFRAME DEVELOPMENT COST BREAKOUT
(ROUGH ESTIMATE FOR TYPICAL 4-PLACE AIRCRAFT)

Note that the development costs discussed here do not include the development cost associated with propulsion systems. Of course, any cost associated with the development of an engine is passed on to the airframe manufacturer. The variation of engine development cost and the number of units over which it is amortized can cover even larger ranges than airframes. The same thing can be said for avionics systems that may be used in general aviation aircraft.

7.3.4 Cost Projections of Manufacturing Materials and Methods

An important aspect of the cost data research is the collection and development of cost projection data for advanced materials and manufacturing methods for the 1985 time frame. For these analyses all costs are estimated for 1970 dollars with respect to general monetary value; however, cost of graphite fiber composite and other new materials are based on projected reductions expected during the 1980 - 1985 period.

Some of the general projections of material cost for future years are shown in Figure 7.3.15. Data for the preparation of these trends were taken from various sources. Prime sources were from Astronautics and Aeronautics and available Lockheed Value Engineering data. This graph indicates that the synthetic fiber material described in Section 5.3.5 is very promising, particularly when its physical properties are considered.

At the projected material costs in the mid-1980s, advanced material costs will still be a major part of the total component production cost. The remaining major area for cost reduction lies in the manufacturing methods for these materials. The Lockheed-Georgia Company Value Engineering Organization has made attempts to project the effect of automatic tape laying equipment and other improvements on the process of preparing graphite filament composites. From these efforts a projection of the material and fabrication (use on aircraft) cost penalty per pound of weight saved (by using the lighter material) has been developed as a function of the graphite composite material cost per pound. The effects of automation in preparing the material were estimated in this projection. With the use of this projected cost penalty per pound of weight saved, the additional cost incurred with the use of graphite composite for light general aviation aircraft was estimated. A 20% weight reduction in the airframe was assumed for this analysis over the range of airframe weights of 840 to 2400 pounds. Results of this analysis are shown in Figure 7.3.16 where the ratio of the cost of using graphite composite material to that of conventional aluminum is presented as a function of graphite material cost. For the cross-hatched band this ratio is the sum of the conventional production cost (labor and material) plus the cost incurred by the use of graphite material to affect a 20% weight saving, divided by the conventional production cost. The plot diverges into a band because of the range of airframe weights considered. Since this analysis is based on projected airframe production technology, such a plot is speculative.

FIGURE 7.3.15 MATERIAL COST PROJECTIONS

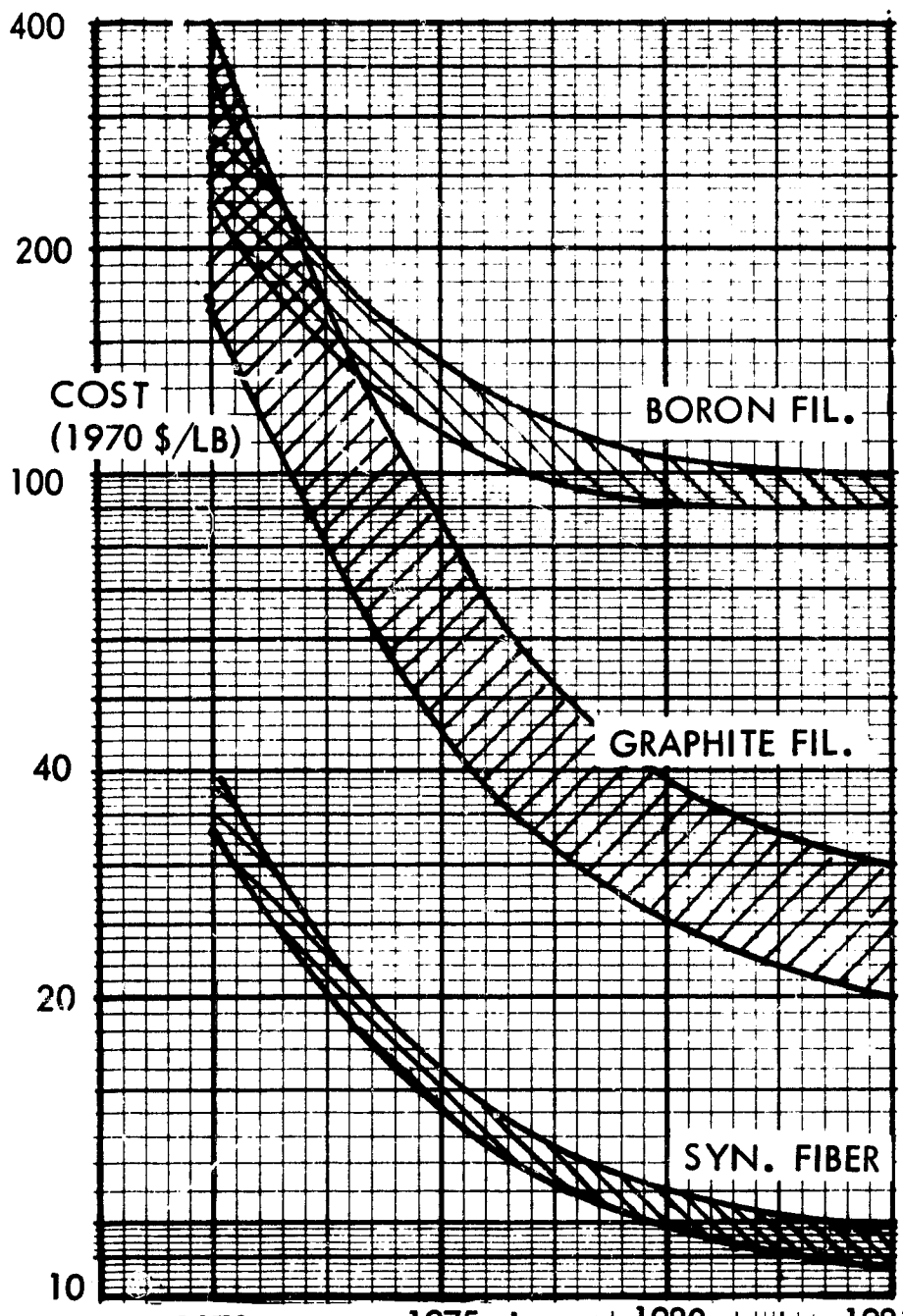
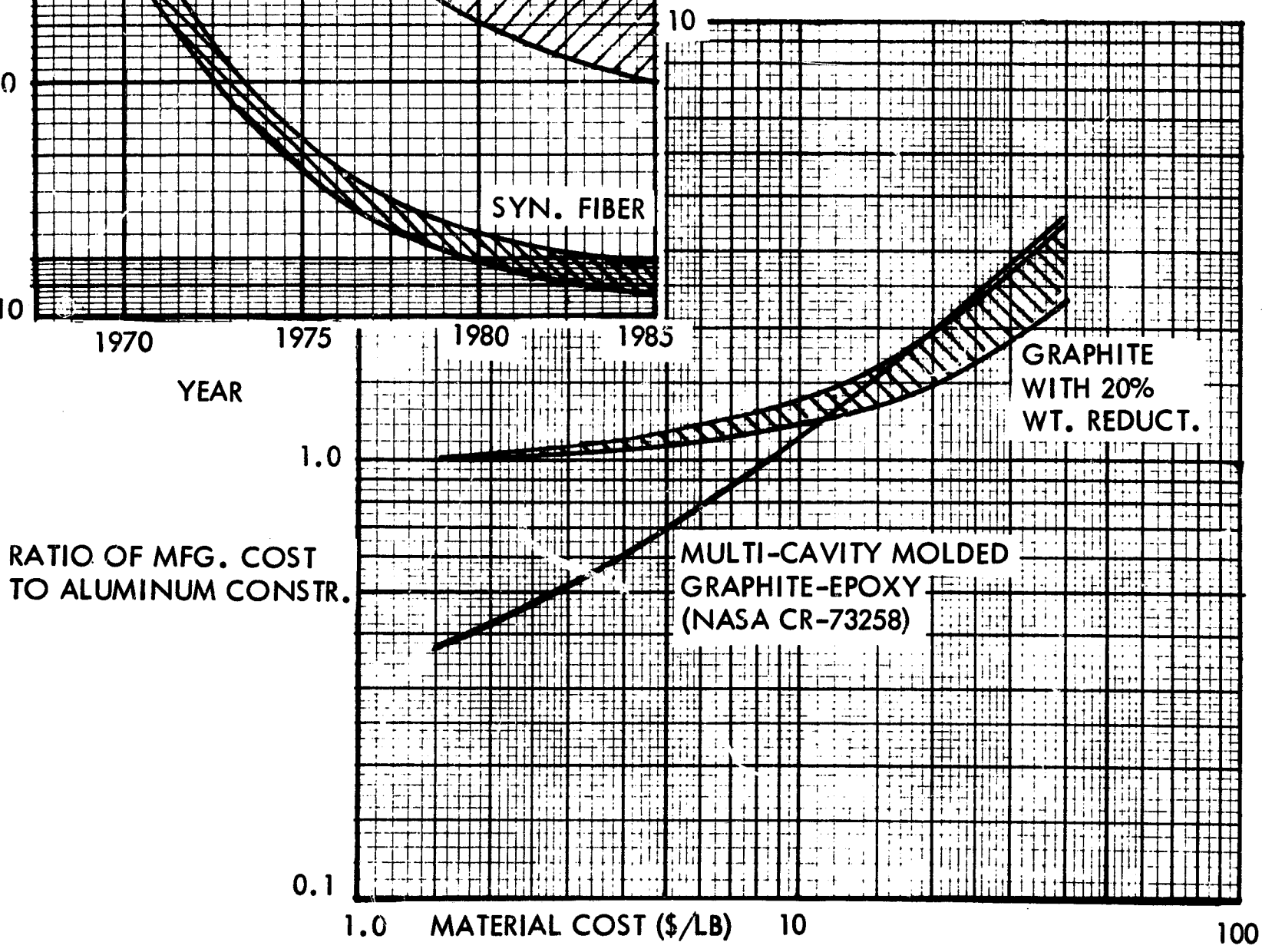


FIGURE 7.3.16.

PRODUCTION COST FOR ADV. MATERIAL USE
(1985 TECHNOLOGY)



Also shown in Figure 7.3.16 is a plot of the ratio of manufacturing cost of a light aircraft wing using graphite/epoxy (multi-cavity molded) for skins and spars to that using conventional aluminum. This ratio was derived from data presented in Figure 244 of the San Diego Aircraft Engineering Report (Reference 7.3.11). The moldable reinforced materials tend to show a greater potential for overall cost saving than does the continuous fiber cross lamination material because of high production rates. The data shown in Figure 7.3.16 were applied to the cost model in the sensitivity analyses to estimate the overall effect of substituting the composite material for aluminum. The high strength composite material is assumed to be used only in highly stressed portions of the structure, because of its relatively high cost. In other areas, glass fiber composite material would be used to preserve manufacturing similarity.

Manufacturing labor and material cost reduction factors have also been estimated for application to the cost model to determine the effect of production rate on unit cost. Theory generally holds that unit cost can be described by a U-shaped function with production rate, that is, cost declines as production rate increases, then is insensitive to rate over some range, and eventually begins to rise again due to the constraining capacity of the production facility. However, empirical results (published) of the interaction between volume and rate effects are scanty, although cumulative volume will, of course, increase with rate.

For this analysis it is assumed that learning-curve theory can be applied to production rates in the same manner as it is applied to cumulative volume up to 100,000 units per year. That is, for a production rate of 1000 per year, a cumulative quantity of 1000 is assumed to have been produced during the year. For large cumulative outputs to be possible within a year, sufficient floor space, tooling and production equipment must be available. No attempt has been made to estimate the cost of such capital equipment or its effect on the unit cost. It is assumed that the necessary facilities and equipment exist to produce the aircraft at rates up to 100,000 per year during the 1985 period.

The cost reduction factors which were estimated are summarized in Table 7.3.17. Listed under aircraft category are the four basic categories of aircraft that are under investigation in this study. The adjacent column shows a typical average rate of production (units/year) that is currently applicable to each category of aircraft for a single manufacturer. The cost element for aircraft in part (a) of the figure refers to the manufacturing labor or material for the basic airframe production. Reduction factors are shown separately for labor and material for the three production rates, 10^3, 10^4 and 10^5 units per year. A similar display of cost reduction factors is given for three engine types in part B of the figure. Learning-curve slopes (%) listed under the figure are typical slopes which have been observed for past airframe and engine production projects. These slopes were applied to the base line production rate (present production rate column) to obtain the reduction factors for each rate and cost element. The reduction factors listed in Table 7.3.17 are applied to the specific cost elements within the cost model to estimate an overall effect of the

TABLE 7.3.17

HIGH PRODUCTION RATE

COST ELEMENT REDUCTION FACTORS

AIRCRAFT CATEGORY	PRESENT PRODUCTION RATE (ROUGH EST.)	COST ELEMENT	1000/YR	10,000/YR	100,000/YR
		(a) Airframe			
I	600	Labor	0.85	0.41	0.20
		Material	0.93	0.66	0.48
II	300	Labor	0.68	0.36	0.16
		Material	0.84	0.59	0.41
III	200	Labor	0.60	0.29	0.14
		Material	0.78	0.54	0.38
IV	150	Labor	0.72	0.47	0.32
		Material	0.80	0.55	0.39
		(b) Engine			
ENGINE TYPE					
PISTON	4000	-	1.0	0.85	0.62
TURBINE	1500	-	1.0	0.78	0.52
ROTARY COMBUSTION	1000	-	1.0	0.65	0.44

NOTE: Quantity Curve Slopes assumed were:

Airframe

Labor 80%
Material 90%

Engine 90%

higher production rates. It is believed that these reduction factors are conservative, certainly obtainable, if greater automation and automotive production techniques can be applied.

7.3.5 Operating Cost

An operating cost model, which estimates operational costs characteristic of the four aircraft Categories, was developed. The model is based on cost information obtained from various sources such as reports, trade journals, insurance companies, and manufacturer's brochures. A prime source of information and guidance is a report published by the Federal Aviation Administration (Reference 7.3.18). This report presents estimates of operating cost of aircraft representative of the general aviation fleet; however, it does not include helicopters or other VTOL aircraft.

The items which could be considered as aircraft operating costs are many. For the analytical purposes of this study, the items included are believed to be those most closely associated with the operation of the aircraft. The basic elements of operating cost used in the model are summarized in Figure 7.3.18 where the elements, cost factors, and some typical values are shown for each of the four Categories. The cost elements are separated into variable or direct costs, which vary with flying time, and fixed or indirect costs, which accrue on an annual basis independent of aircraft flying time. This separation in some respects is arbitrary, as some fixed cost items will vary with use to some extent and some variable costs may be slightly independent of use. A brief description of each cost element listed in Figure 7.3.18 is given below:

VARIABLE COSTS

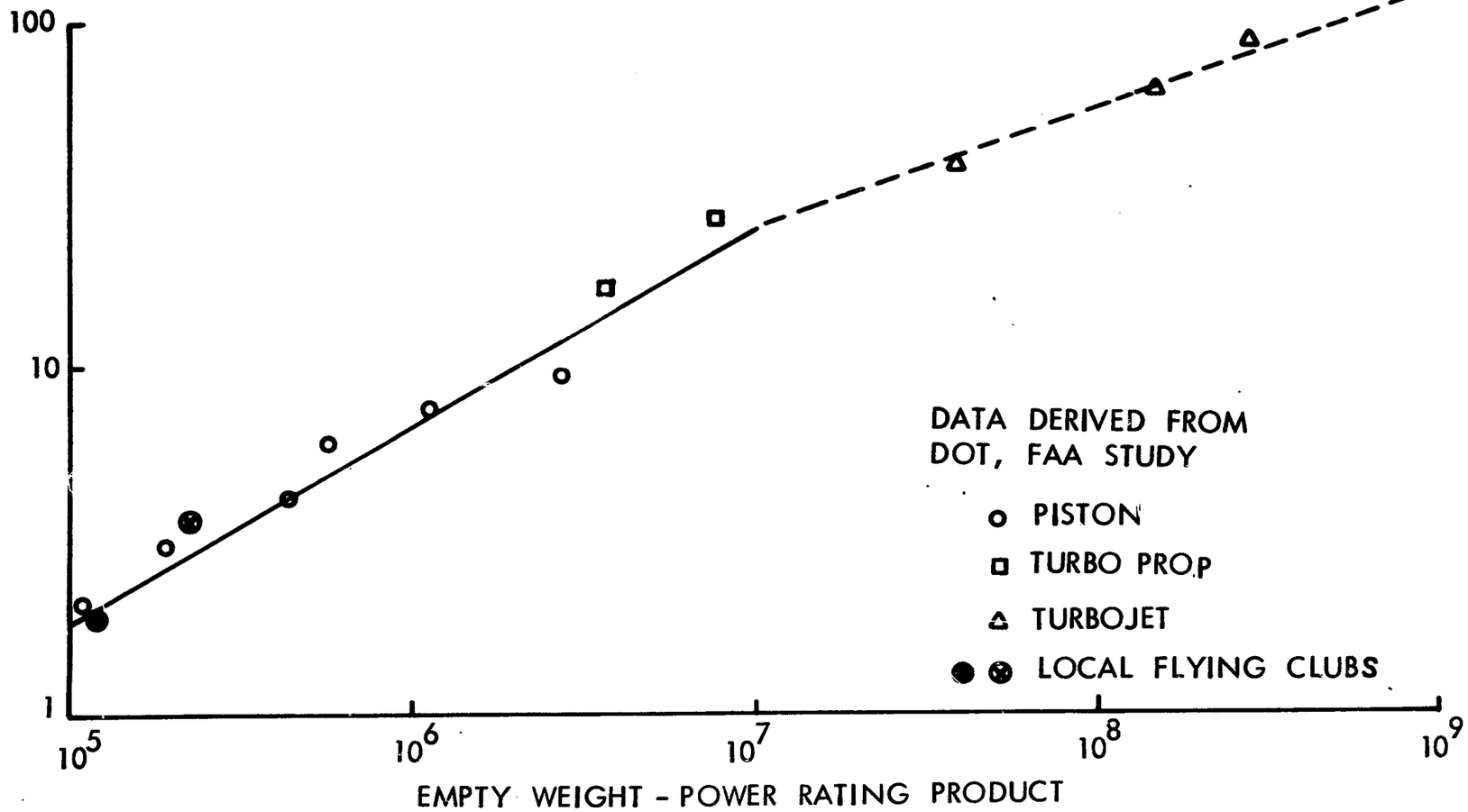
A. Fuel and Oil. Fuel and oil cost vary most closely with aircraft operation. Fuel costs are based on an average consumption rate (computed in the design program) and an average price per gallon. A price of 46 cents/gal was used for aircraft requiring only 91 octane aviation fuel and a price of 50 cents/gal was used for aircraft requiring 100 octane fuel. For jet fuel, a price of 27 cents/gal for jet fuel was used for turbofan and turboprop aircraft. The cost of oil was assumed to be 20 cents/hr for both piston and turbine aircraft.

B. Inspection and Maintenance. The FAA requires an annual inspection of all general aviation aircraft. In addition, aircraft carrying passengers for hire or used in flight instruction must have an inspection every 100 operating hours. Maintenance costs (labor and parts) include the upkeep and repair of the airframe, engine, propeller, electrical equipment and other accessories. Since the cost for inspection and maintenance can vary widely according to the size and complexity of the aircraft, two generalized cost estimating relationships, based on aircraft empty weight and total power, were developed for this cost element. A graphical representation of these CERs is shown in Figure 7.3.19 where the cost per flight hour is presented as a function of aircraft empty weight multiplied by the total horsepower (or thrust in lbs) of the aircraft engine(s). The plotted points represent data which was derived from information given in a FAA study report (Reference 7.3.18). On the log-log scale one straight line approximates the piston and turboprop trend fairly well, while a separate straight

FIGURE 7.3.18 OPERATING COST FACTORS SUMMARY

ELEMENT	CATEGORY I	II	III	IV
VARIABLE COST (HOURLY)				
FUEL & OIL	AVG. FLOW, COST/GAL.			
INSPECTION & MAINT.	EMPTY WEIGHT, TOTAL POWER			
RESERVE FOR OVERHAUL	TOTAL ENGINE POWER			
PARKING, LANDING, SPARES	$.55	$.90	$1.70	$1.70
FIXED COST (ANNUAL)				
DEPRECIATION	20 YEAR LINEAR			
INSURANCE				
HULL	4%	3%	2%	8 to 12%
LIABILITY	$200	$300	$450	$400 to $800
FAA USE TAX	$25 + GW CHARGE			
STORAGE	$300	$600	$900	$600
PILOT	-	-	$15,000	$15,000
MISCELLANEOUS	$100	$150	$200	$200

FIGURE 7.3.19
INSPECTION AND MAINTENANCE COST PER
FLIGHT HOUR TREND



line seems to approximate the turbofan aircraft trend. Notice that the turbofan points tend to be common to either straight line trend. The circle with an X and the darkened circle represent points derived from separate local flying clubs. One club has eight aircraft, and a weighted average was plotted. For the other club the plotted point represents a single aircraft. Both local flying club points tend to fit the overall trend well. Most brochures and manuals published by the aircraft manufacturers will show inspection and maintenance costs somewhat lower than the straight line trends of Figure 7.3.19. This is because their costs are based on the most optimum conditions for new aircraft. The trend lines presented in Figure 7.3.19 tend to represent an approximate cost of actual operating aircraft averaged over a period after the aircraft have accumulated a few years of age.

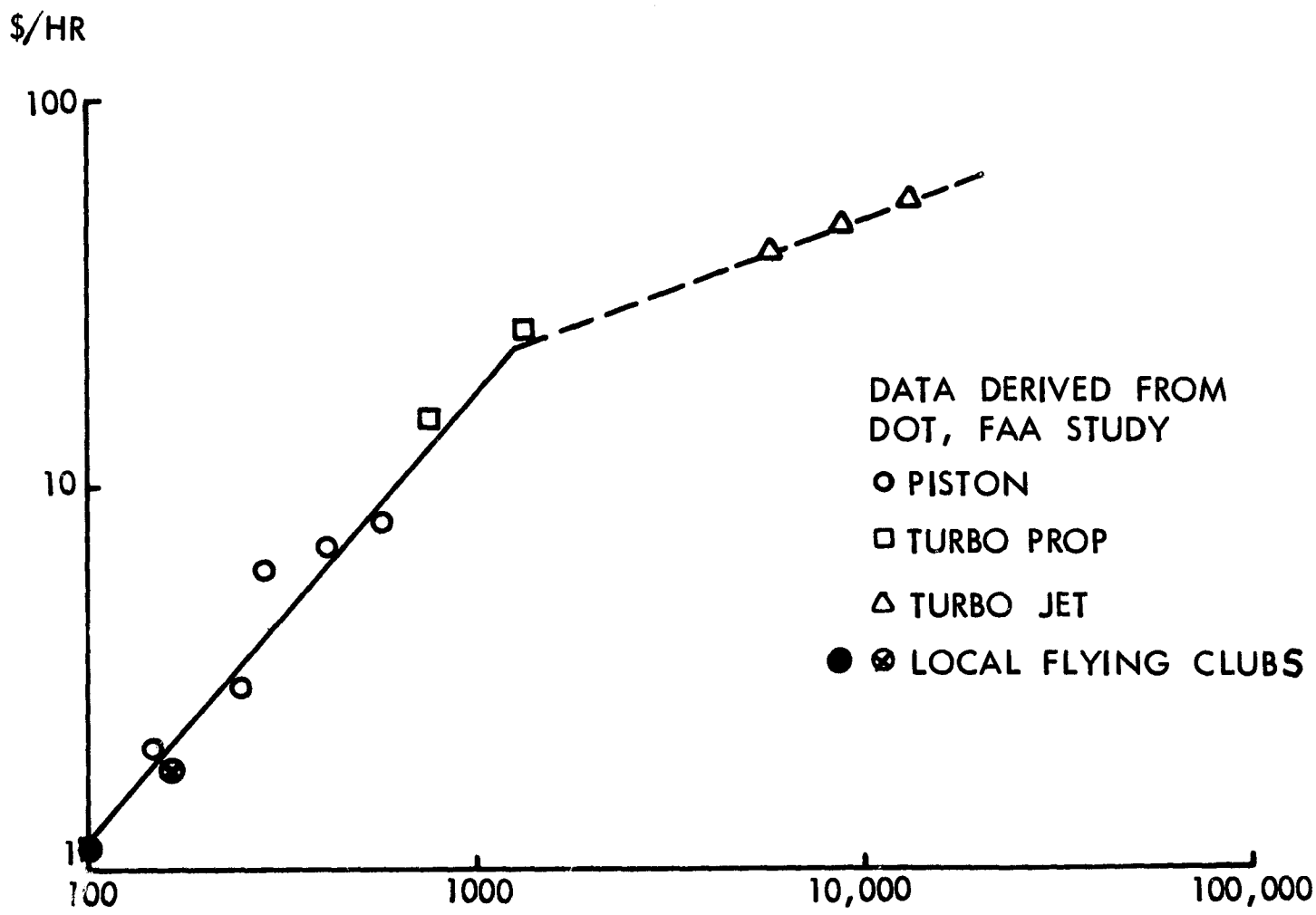
For Category IV aircraft the cost per hour presented in Figure 7.3.19 must be multiplied by a factor of 1.6 to approximate the added complexity of a VTOL machine. This factor was derived from an investigation of depot and base maintenance cost per flight hour for comparable fixed-wing and rotary-wing aircraft listed in the Air Force Cost and Planning Factors Manual (Reference 7.3.19). Military versions of civil fixed wing aircraft were compared with military helicopters approximating the Category IV requirements. Aircraft included were T-41, U-3A, U-4A, UH/1 and the HH-43. This brief comparison indicated that a factor of 1.6 represents a rough average factor applicable to the Category IV aircraft of the present study.

C. Reserve For Overhaul - With time some of the major equipment or parts of an aircraft must be replaced or overhauled. Primarily this overhaul applies to the engine(s), propeller(s) and other propulsion equipment. However, the overhaul or replacement can include the airframe, avionics and other equipment. Reserve for overhaul is another cost element which can have a wide variation with aircraft size and complexity. Therefore two generalized CERs were developed to approximate this cost. The graphical representation of these CERs is shown in Figure 7.3.20 where the cost per flight hour is given as a function of total horsepower or thrust (lbs) of the aircraft engine(s). All the comments made previously for the inspection and maintenance CERs shown in Figure 7.3.19 apply in a similar manner to Figure 7.3.20. This includes the complexity factor of 1.6 to approximate the reserve for overhaul cost for VTOL aircraft.

D. Parking, Landing Fees, Parts. Payments for parking fees (when the aircraft is away from home base) and landing fees are also operating costs that vary with use. Also operators of the larger aircraft frequently find it desirable to carry a small inventory of spare parts for replacement. These type of costs depend primarily on the utilization of the aircraft. Landing and parking fees for Categories I, II and III account for about 65 to 75% of the total listed in Figure 7.13.19 with the balance in spare parts inventory maintenance. For Category IV, the percentages are reversed; parking and landing fees are reduced and account for about 30% of the total with the generally higher spares required for the VTOL aircraft accounting for about 70%. The values shown in Figure 7.3.18 are typical average values roughly applicable to each particular Category.

FIGURE 7.3.20

RESERVE FOR OVERHAUL
COST TREND WITH POWER



FIXED COSTS

A. Depreciation. Normally for business purposes the depreciation of an aircraft is carried out on a more rapid scale than the aircraft's useful life. However, for the analytical purposes of this study a depreciation scheme was chosen to allocate the cost of the aircraft into annual periods over the useful life of the aircraft, which is assumed to be about 20 years. This simple 20-year scheme should give a reasonable estimate of depreciation.

B. Insurance. Insurance costs for general aviation aircraft tend to vary over a very wide range because of the many variables which determine the rates. Principal among these variables are pilot experience, aircraft performance, and aircraft use. The hull insurance rates shown in Figure 7.3.19 represent rough average values that would be applicable to aircraft in each category with an experienced pilot. The annual liability insurance premiums listed for each category in Figure 7.3.18 represent average premiums that would be incurred for typical liability package plans applicable to each aircraft class. Hull and liability rates for VTOL aircraft are given a rough range.

C. FAA Use Tax. This is the use tax which became effective July 1, 1970. Basically, the tax provides for a $25 annual charge for aircraft with a gross weight of 2500 lbs or less. For piston aircraft with a gross weight greater than 2500 lbs the charge is $25 plus 2 cents per pound of gross weight. For turbine aircraft the charge is $25 plus 3.5 cents per pound of gross weight.

D. Storage. Storage costs for aircraft are difficult to determine because storage rates vary widely with geographical location, such as rural airports versus urban airports. The values listed in Figure 7.3.18 tend to be rough averages for each category.

E. Pilot. Only the Category III and Category IV aircraft are assumed to require a professional pilot. An allowance of $15,000 per year is assumed for this expense. Pilot expense as assumed here can account for a significant percentage (20 to 25% for Category III and 16 to 20% for Category IV) of the total operating cost, depending on the annual utilization of the aircraft and inputs applied to the other cost elements.

F. Miscellaneous. Miscellaneous fixed costs include allowances for navigation charts, manuals, minor damage not covered by insurance and aircraft modernization. The expenses shown for this element in Figure 7.3.18 are rough averages for each Category.

There are other costs which are or can be associated with the ownership of general aviation aircraft. Principal among such costs are financing costs and state and local taxes. They were not included in the present model because they tend to vary widely and are only indirectly associated with the operation of aircraft.

7.3.4.1 Typical Operating Cost Results.

Some typical operation cost results estimated by the computational model are shown in Figure 7.3.21 where aircraft cost per mile is shown as a function of annual utilization for all four categories. The typical results in Figure 7.3.21 for baseline designs show the relative magnitude of operating cost for the Categories very well, and the graph also indicates the importance of higher utilization to reduce the aircraft-mile cost. Some typical percentages of the total operating cost are shown in Table 7.3.22 for the basic cost elements for each category. These percentages are indicative of the relative magnitude of costs among the various elements. Percentages for Categories I and II are based on 300 hours/year utilization while percentages for Categories III and IV are predicated on the basis of 500 hours/year utilization. It is assumed that these utilization rates will be roughly representative for the two divisions of the four Categories.

Many of the cost estimates (both initial and operating) developed for this study are based primarily on generalized cost estimating relationships applied to conceptual configurations in which assumptions and unknowns are involved. Consequently, absolute results can have rather large inherent uncertainties. In the context of relative cost and general trends with physical parameters, these cost results are more meaningful.

7.4 Configuration Evaluation

These data are covered in detailed discussions of the four categories of aircraft in Section 7.5.

7.5 Results of Parametric Programs

The first step in the parametric analysis was the establishment of baseline designs in each of the four categories. The program optimized the competitive configurations in each category. These were then compared and one was selected as a basic configuration for the sensitivity studies. The investigation of non-augmented high lift systems by the NASA has been active for over 40 years. Configurations have been developed which can be applied in an optimum manner to any conventional configuration. While augmented systems have also been subject to extensive investigation, their complication and attendant cost make them unsuitable for application to general aviation aircraft. They would only be appropriate to the STOL airplane candidates of Category II, which are single engined, with which minimum flight speed would have to be based on the power-off condition.

7.5.1 Category I Aircraft

Category I aircraft are equipped with present technology reciprocating engines. Cruising takes place at an altitude of 7,500 ft. at 75% of normal engine power. Figures 7.5.1 and 7.5.2 show the vairation of gross weight, power, propeller diameter, initial and operating cost as functions of cruising speed. A cruising speed of 145 knots (167 mph) was chosen as representing the highest speed obtainable without appreciable increase in operating cost. Points are shown for the use of fixed landing gear at the minimum required speed of 130 knots. Although some weight reduction is achieved, the increased power required results in significant increases in the initial and operating costs.

FIGURE 7.3.21.

AIRCRAFT - MILE COST
TREND WITH UTILIZATION

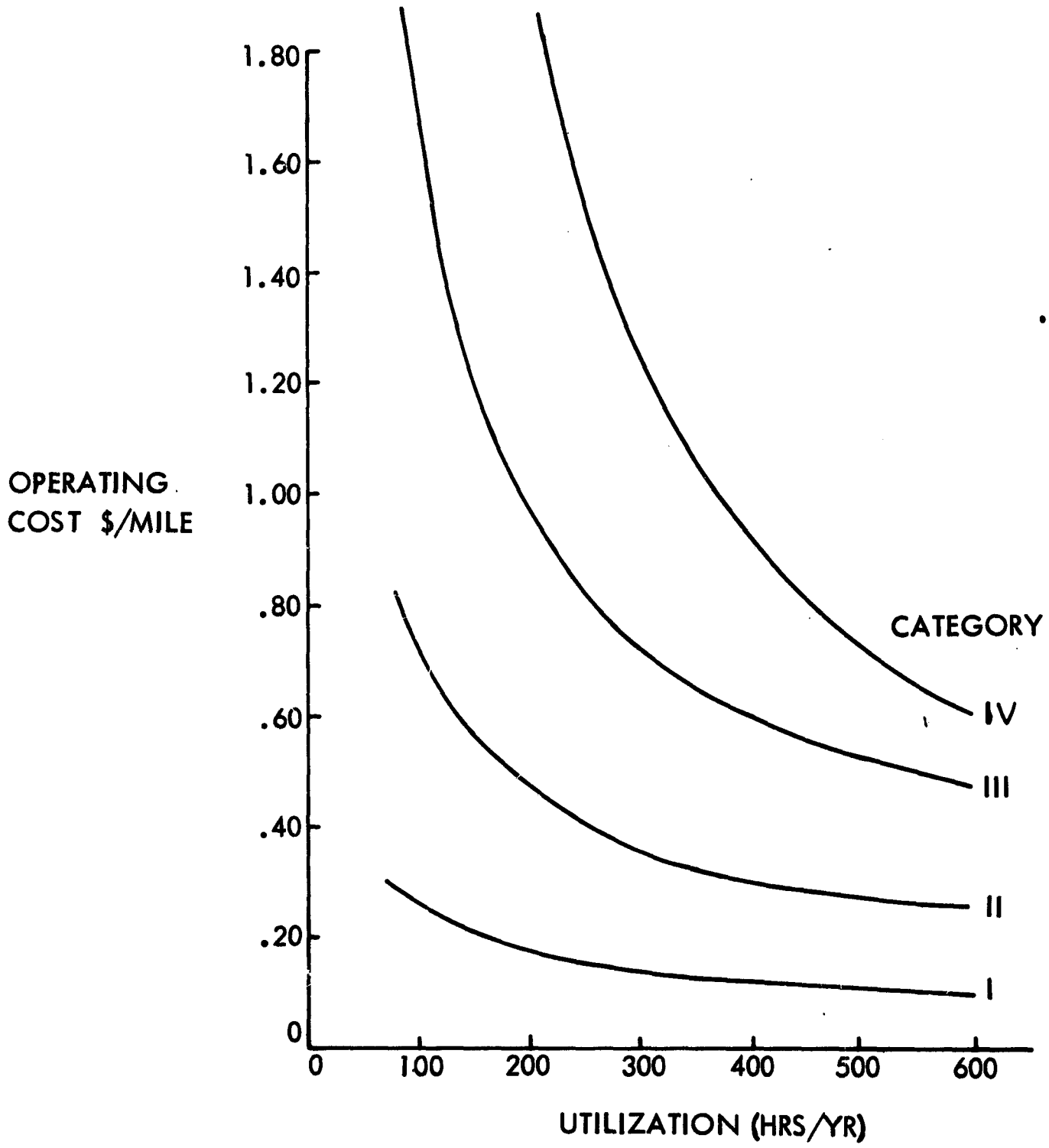


TABLE 7.3.22

TYPICAL PERCENTAGES *
OF OPERATING COST ELEMENTS

COST ELEMENT	PERCENT OF TOTAL CATEGORY			
	I	II	III	IV
VARIABLE (HOURLY)				
Fuel and Oil	28.0	17.6	16.1	9.3
Inspection and Maintenance	15.4	12.3	11.9	11.2
Reserve for Overhaul	11.0	12.3	12.6	10.6
Parking, Landing, Spares	2.6	1.4	1.2	1.1
TOTAL VARIABLE	57.0	43.6	41.8	32.2
FIXED (ANNUAL)				
Depreciation	17.8	31.3	24.2	17.6
Insurance	17.5	20.3	10.3	29.3
FAA Use Tax	1.3	0.9	0.5	0.3
Storage	4.8	3.1	1.3	0.8
Pilot	0.0	0.0	21.6	19.5
Miscellaneous	1.6	0.8	0.3	0.3
TOTAL FIXED	43.0	56.4	58.2	67.8
TOTAL VARIABLE & FIXED	100	100	100	100

* NOTE: Typical percentages for baseline designs in each category. Categories I and II based on 300 Hrs/Yr and Categories III and IV based on 500 Hrs/Yr.

FIGURE 7.5.1 CATEGORY I - TRACTOR
PARAMETRIC ANALYSIS

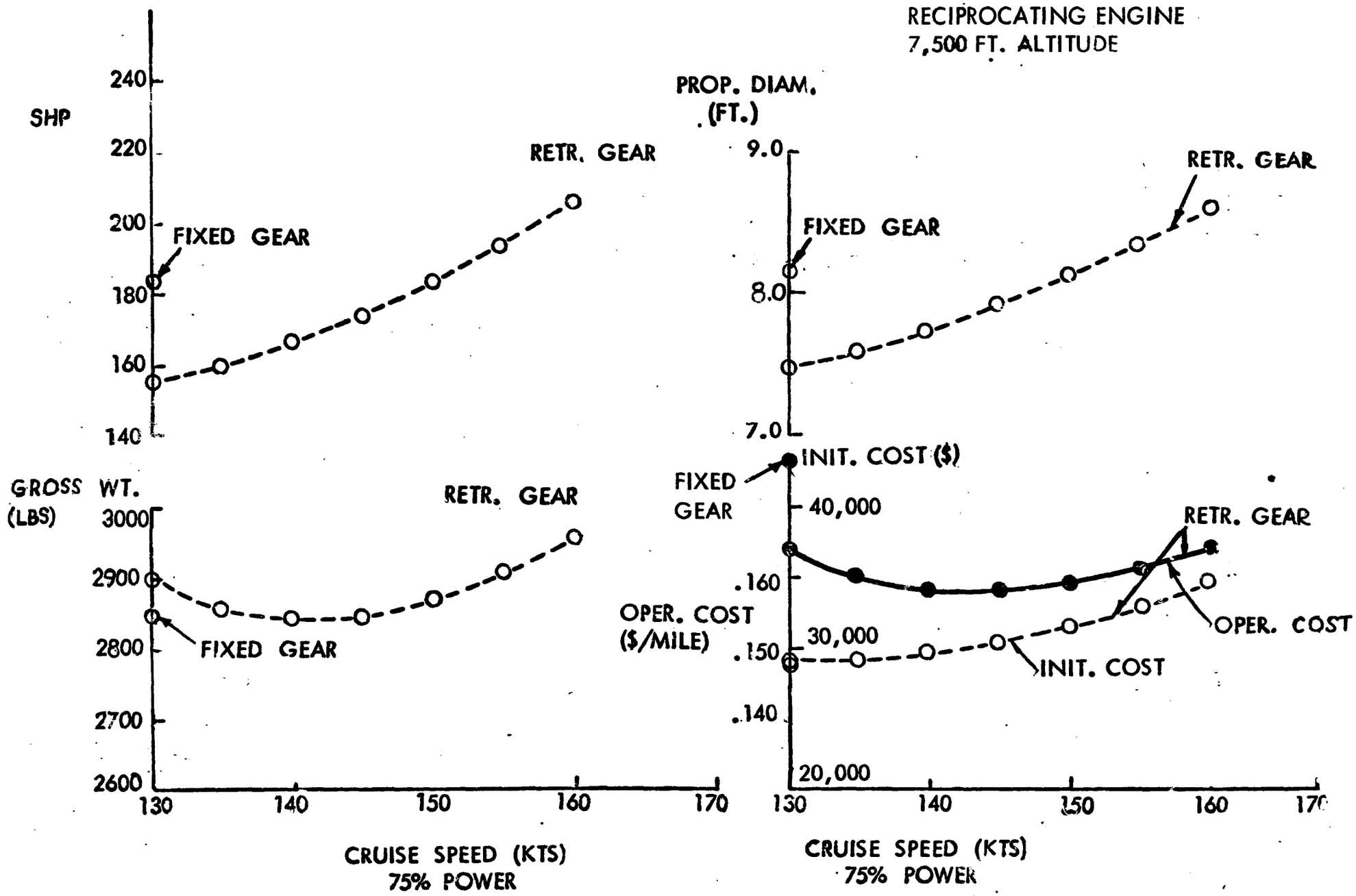


FIGURE 7.5.2 CATEGORY I - PUSHER
PARAMETRIC ANALYSIS

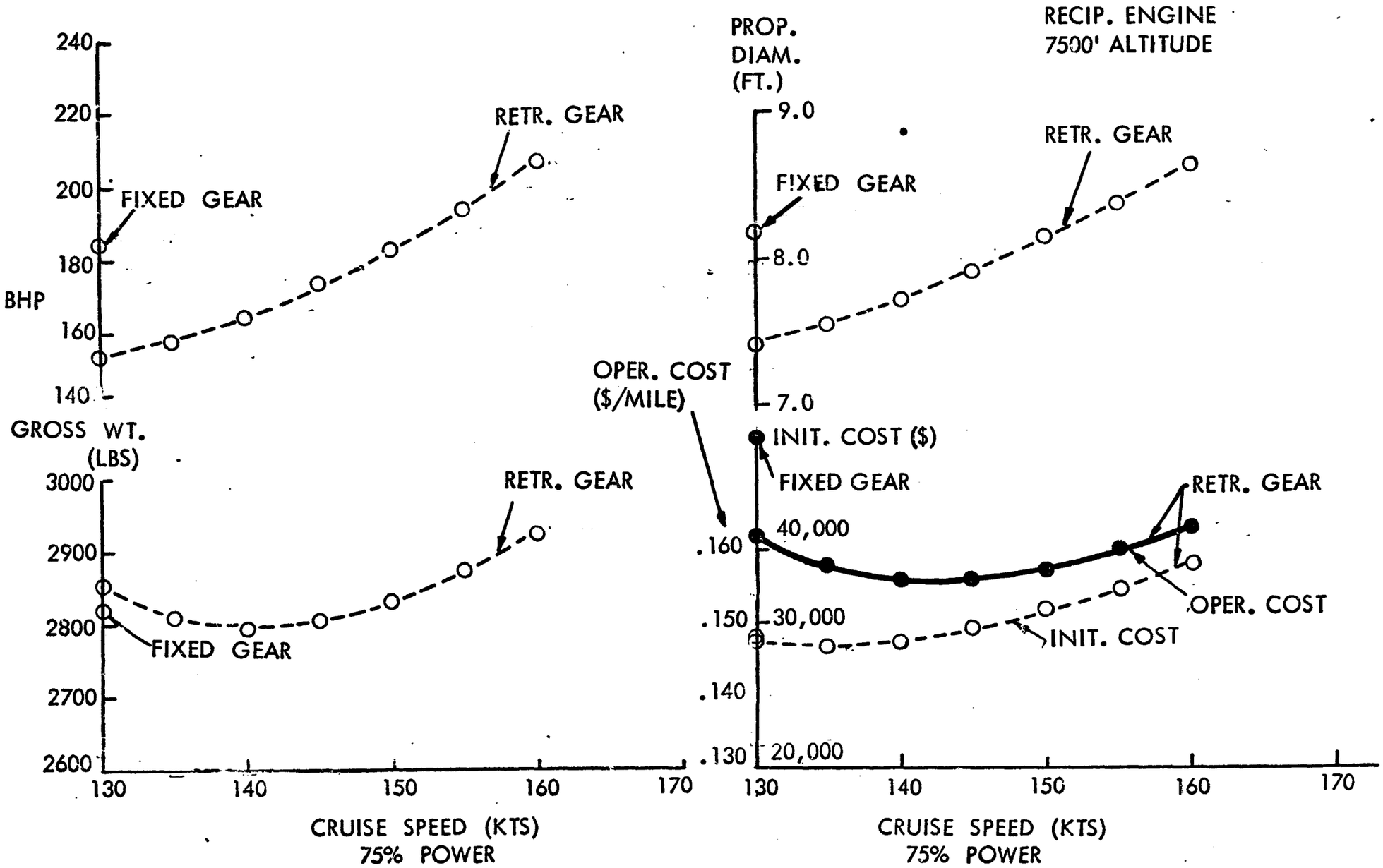


Figure 7.5.3 compares the effect of low noise level propellers with that of conventional propellers. These data show that in Category I an airplane equipped with low noise level propellers is actually less expensive to own and operate than a similar machine equipped with conventional propellers. The conventional machine would cost about 18.0 cents per mile to operate, as opposed to 15.5 cents for the conventional airplane, based on 300 hours per year utilization. The major effect causing this result is the high static thrust obtainable from the low noise level propellers, which decreases the engine power required and increases the wing loading for the same take-off distance. It is felt that this is a significant result.

Conventional propellers are selected in order to give 4.5 lb. of static thrust per horsepower, with a cruise efficiency of 86 percent. This represents the upper limit of static thrust and cruise efficiency for propellers driven by ungeared engines. The low noise level propellers are selected for 6 and 5 pounds per horsepower of static thrust with 86 percent cruise efficiency where possible. The lower static thrust propellers are, of course, smaller in diameter. In general, the 6 pound per horsepower static thrust rating is optimum in Category I.

A comparison of the Category I pusher and tractor aircraft candidates, shown in Figure 7.5.4, reveals that the pusher is marginally lighter and less expensive than the tractor, but all the data are very close.

Figure 7.5.5 shows the mid-wing, pusher propeller configuration selected as the baseline design for Category I. While its marginal weight and cost advantages over the tractor are probably within the degree of accuracy of the input data, the pusher was selected for qualitative reasons. These include:

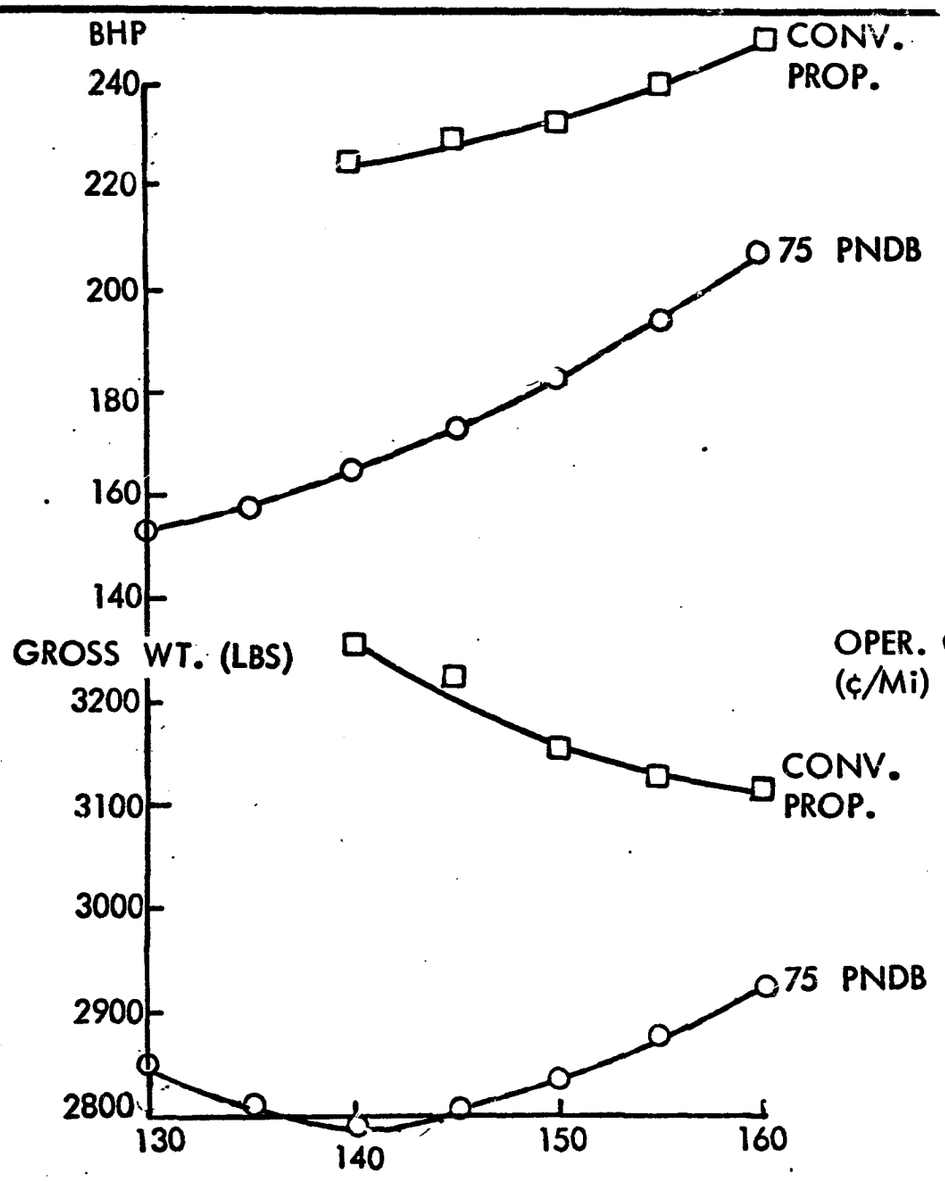
- Superior vision
- Low interior noise level
- No obstruction to future use of radar
- Easy access to cabin
- Safety from contact with whirling propeller on the ground.

7.5.2 Category II Aircraft

Figures 7.5.6 and 7.5.7 show the variation in gross weight, power, propeller diameter and operating cost with percent of cruise power for reciprocating and turboprop engines for the single and twin propeller aircraft configurations respectively. It is readily apparent that the turboprop engine versions excel by wide margins. A tabular comparison of the two versions at optimum cruise power settings is given in Figure 7.5.8. The single propeller airplane weighs 29% less, requires 9% less power, costs 39% less to buy and 29% less to operate than the twin propeller configuration.

Figure 7.5.9 shows a pusher configuration, similar to that of Category I and requires an explanation. The two candidates evaluated in the parametric analysis had tractor propeller installations. The selected configuration had a single propeller. The tractor installations were originally selected because

FIGURE 7.5.3
CATEGORY I - TRACTOR
COMPARISON OF CONVENTIONAL AND LOW NOISE PROPS
RECIP. ENGINES - 7500 FT. ALT.



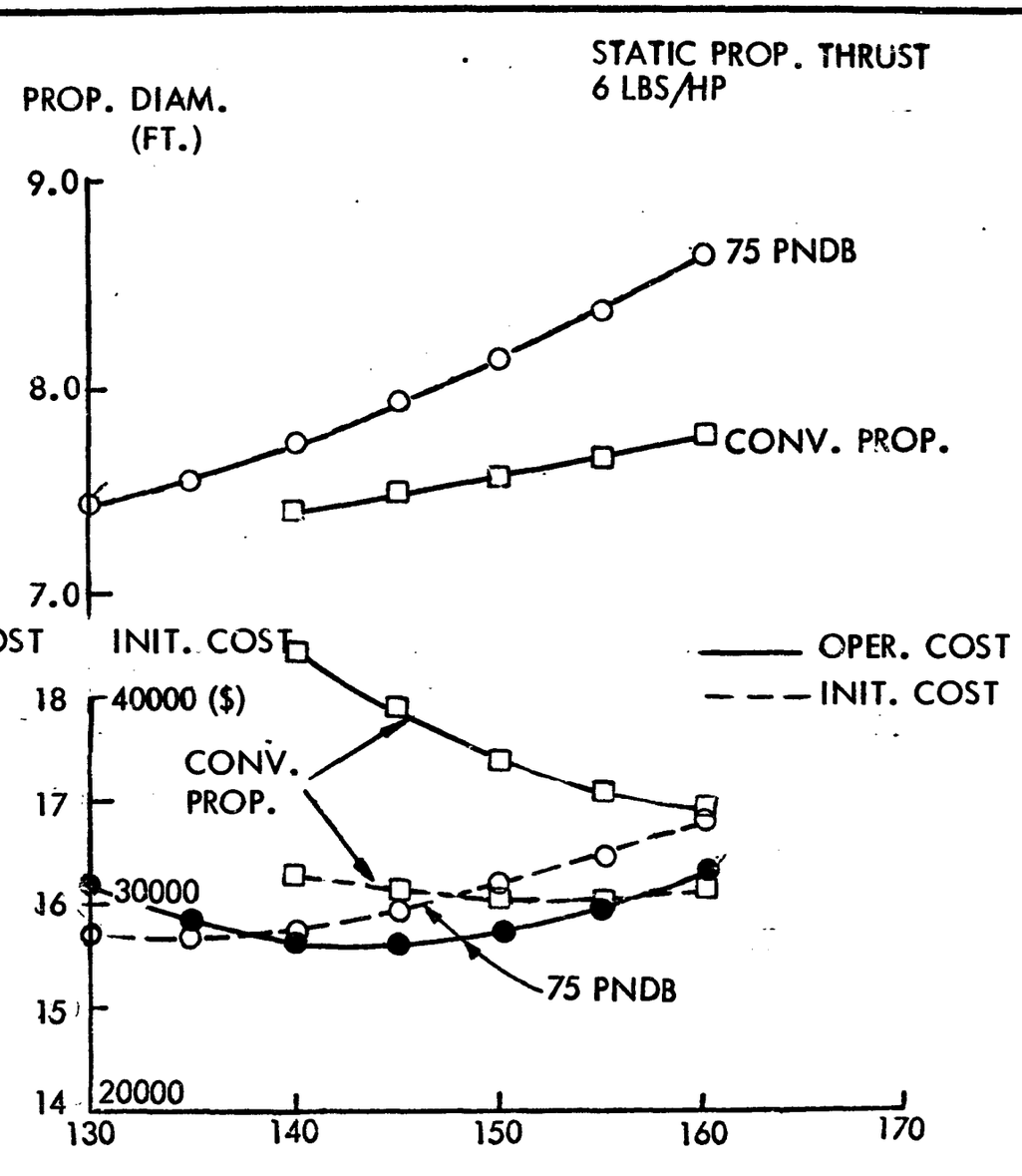


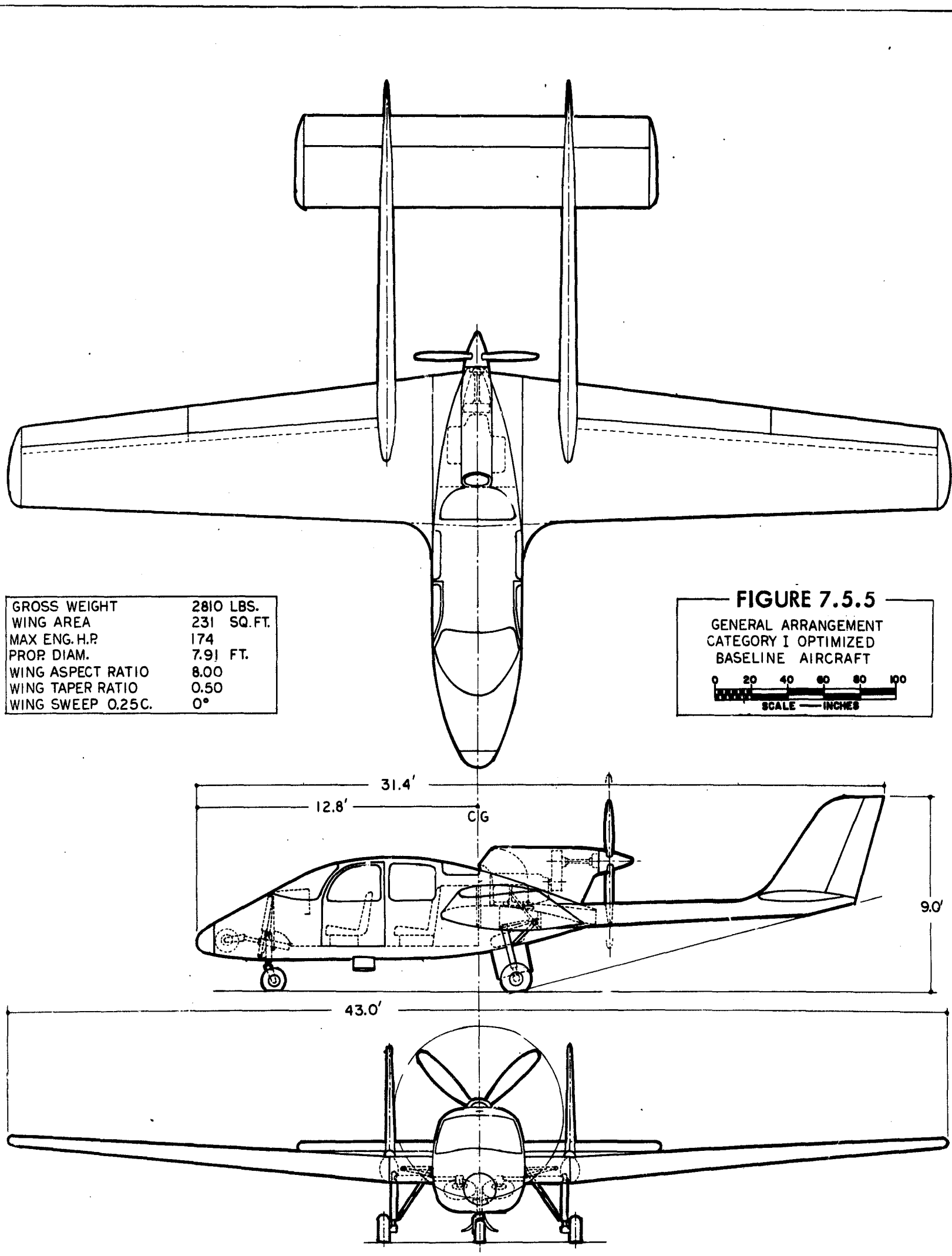
FIGURE 7.5.4

CATEGORY I PARAMETRIC

ANALYSIS RESULTS

CONFIGURATION	TRACTOR	PUSHER
GROSS WT. (LBS.)	2,847	2,810
TYPE OF ENGINE	RECIP	RECIP
T.O. BHP	175	174
CRUISE SPEED (KTS)	145	145
CRUISE POWER (PCT. NORM.)	75	75
PROP. THRUST (LBS/HP)	6.0	6.0
PROP. DIAM. (FT)	7.91	7.91
WING LOADING (LBS./SQ.FT.)	11.84	12.16
INITIAL COST ($)	30,373	29,669
* OPERATING COST ($/MILE)	0.158	0.156

* 300 HRS/YEAR



GROSS WEIGHT	2810 LBS.
WING AREA	231 SQ.FT.
MAX ENG. H.P.	174
PROP. DIAM.	7.91 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP 0.25C.	0°

FIGURE 7.5.5

GENERAL ARRANGEMENT
CATEGORY I OPTIMIZED
BASELINE AIRCRAFT

0 20 40 60 80 100
SCALE — INCHES

FIGURE 7.5.6 PARAMETRIC ANALYSIS: CATEGORY II SINGLE PROP.

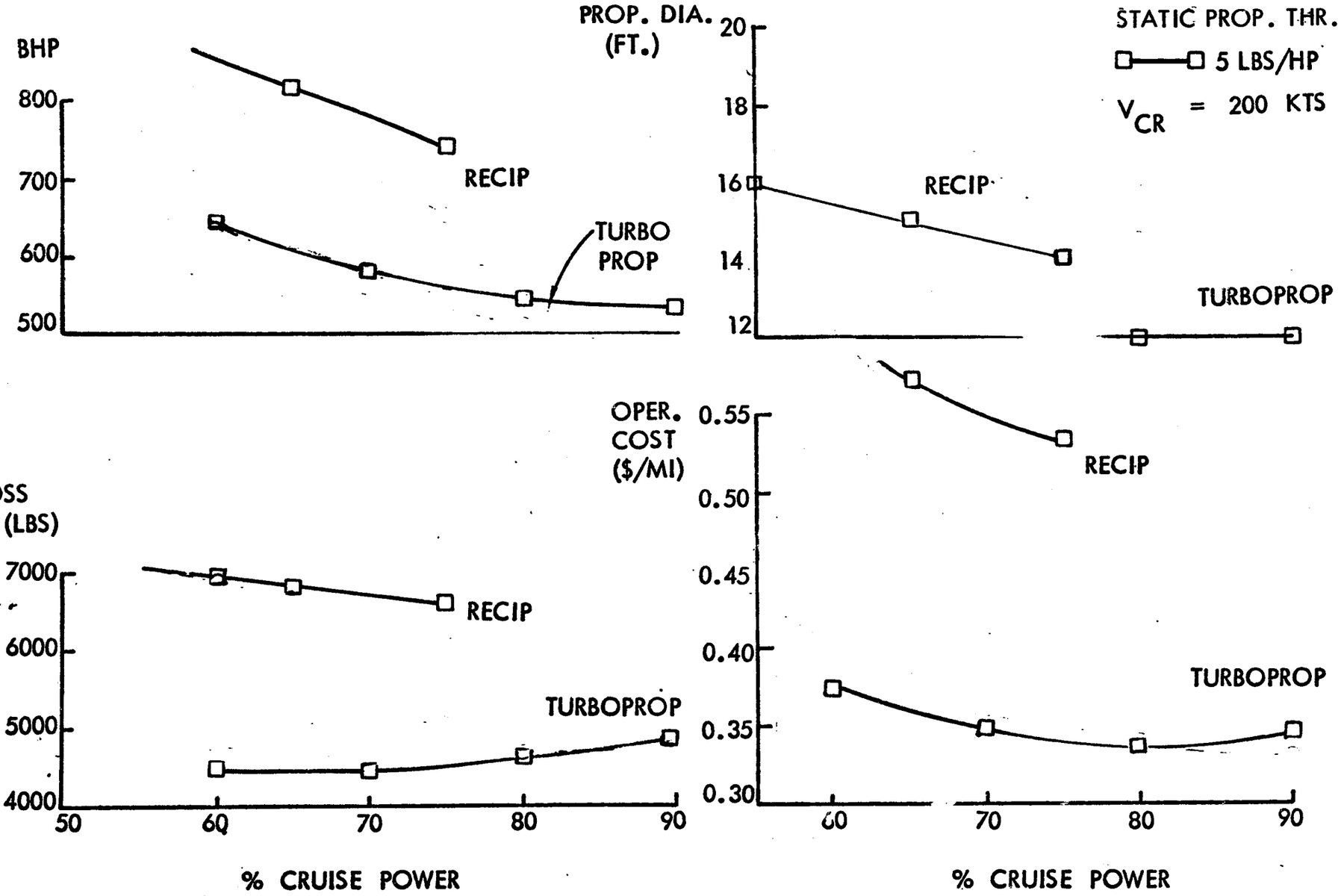


FIGURE 7.5.7 PARAMETRIC ANALYSIS
CATEGORY II - TWIN PROPELLER

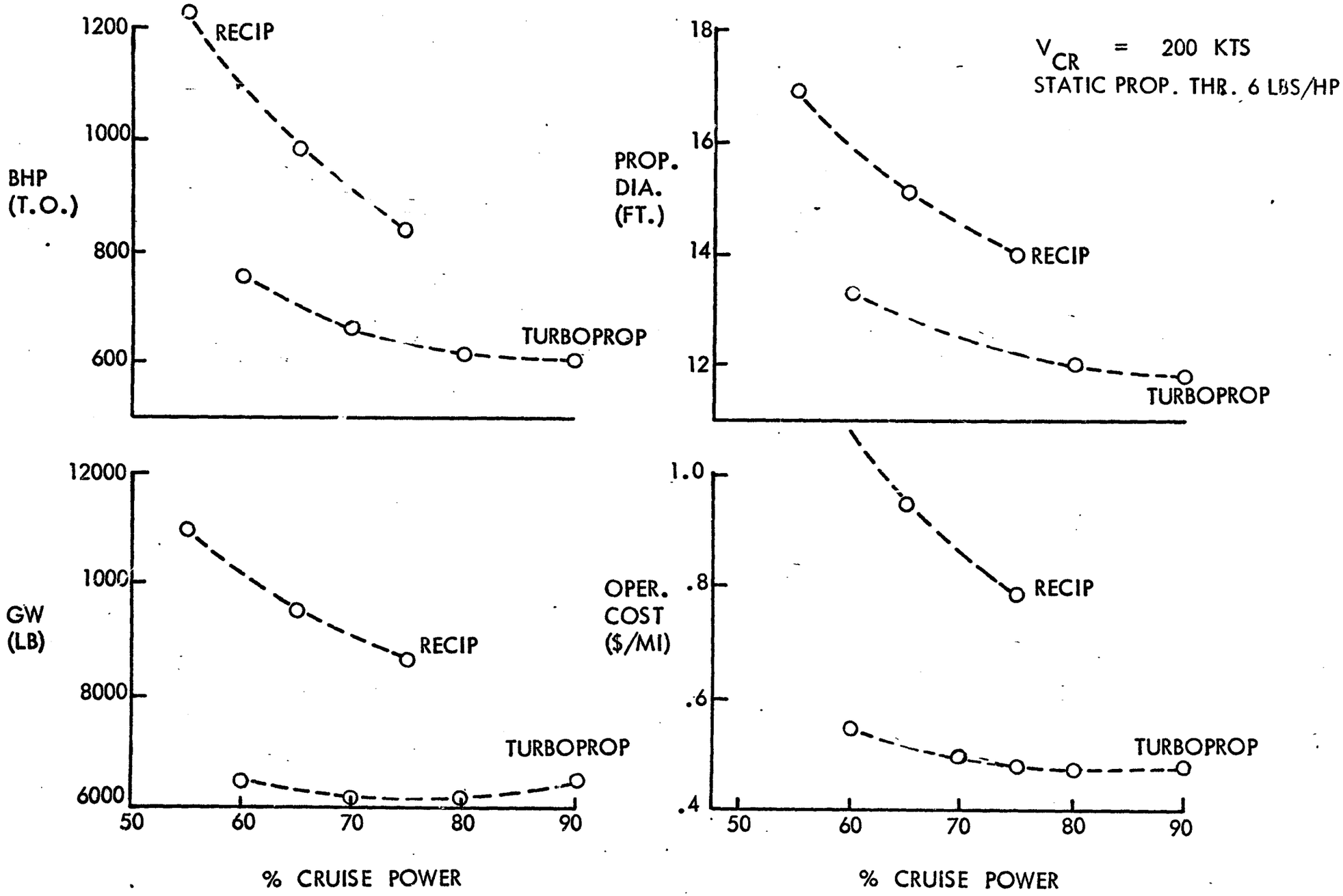


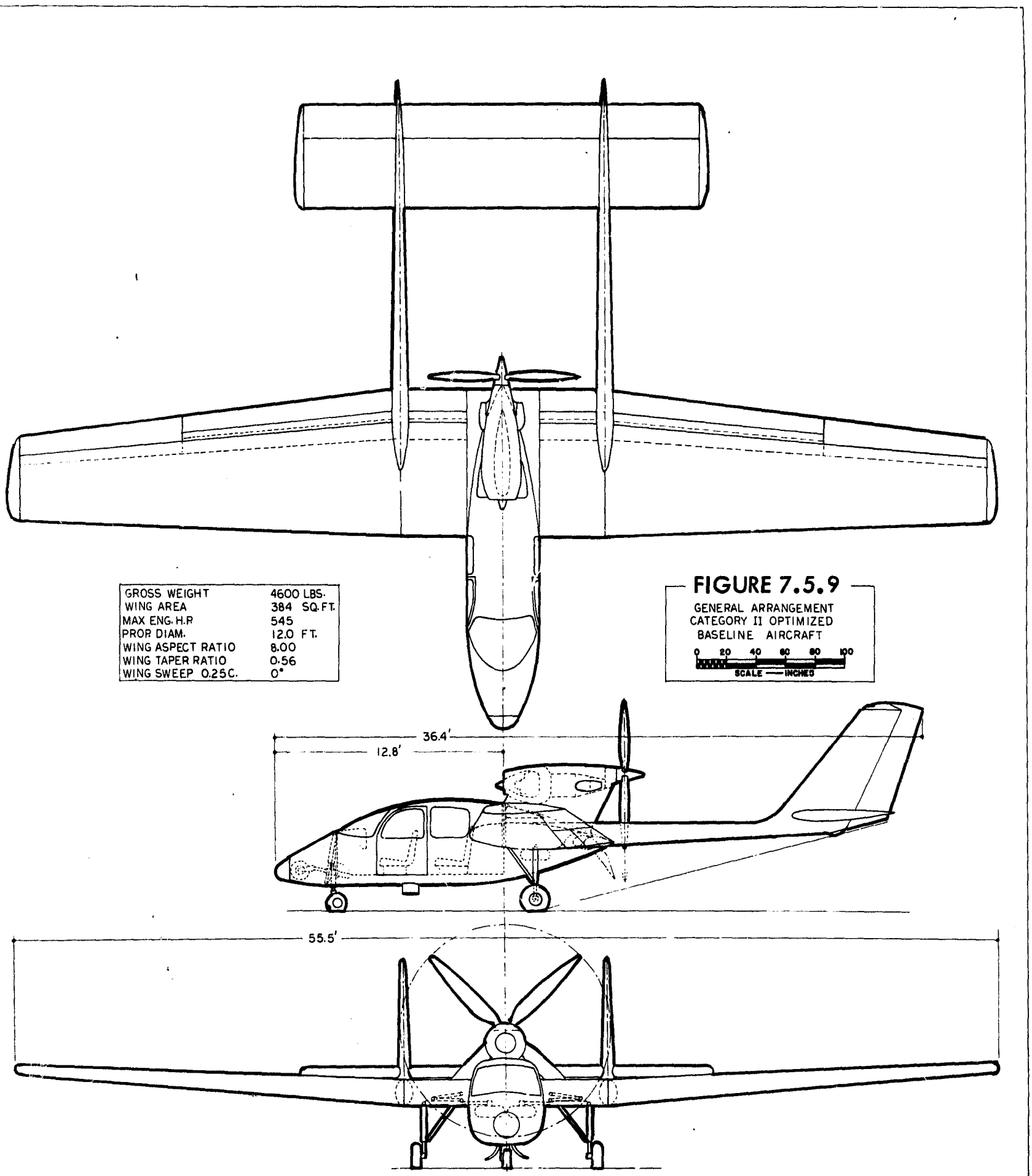
FIGURE 7.5.8

CATEGORY II PARAMETRIC

ANALYSIS RESULTS

CONFIGURATION	SINGLE PROP.	TWIN PROP.
GROSS WT. (LBS)	4,600	6,450
TYPE OF ENGINE	TURBOPROP	TURBOPROP
T.O. BHP	545	600
CRUISE SPEED (KTS)	200	200
CRUISE POWER (PCT. NORM.)	80	90
PROP. THRUST (LBS/HP)	5.0	6.0
PROP. DIAM. (FT.)	12.0	11.8
WING LOADING (LBS/SQ. FT.)	12.0	11.4
INITIAL COST ($)	131,500	215,000
* OPERATING COST ($/MILE)	0.335	0.475

* 300 HRS/YEAR



GROSS WEIGHT	4600 LBS.
WING AREA	384 SQ.FT.
MAX ENG. H.P	545
PROP DIAM.	12.0 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.56
WING SWEEP 0.25C.	0°

FIGURE 7.5.9

GENERAL ARRANGEMENT
CATEGORY II OPTIMIZED
BASELINE AIRCRAFT

0 20 40 60 80 100
SCALE — INCHES

of the apparent advantage of the effect of propeller slipstream over the flapped wing in providing lift augmentation. However, the takeoff and landing distances were determined on the basis of power-off stall speed, because the aircraft has only one engine, the failure of which during takeoff and landing procedures could be disastrous. It was therefore reasonable to assume that the pusher configuration in this Category would compare with the tractor in the same manner as in Category I. The same qualitative reasons for selecting the pusher are applicable, especially the matter of access to the cabin. The 12 ft. propeller diameter, in a tractor, would place the cabin floor 54 inches above the ground, whereas the comparable height of the floor for the pusher propeller aircraft is only 25 inches above the ground.

Comparison between Figures 7.5.5 and 7.5.9 illustrates graphically the penalty of size (and consequent weight and cost) required to reduce the field length from 1000 ft. to 500 ft. Wing area is increased by 66%, wing span by 29%, overall length by 18%, gross weight by 64% and engine horsepower by 214%. The effect of advanced technology should have an appreciable effect in reducing the size, weight and power of the Category II aircraft, probably to a greater extent than in Category I.

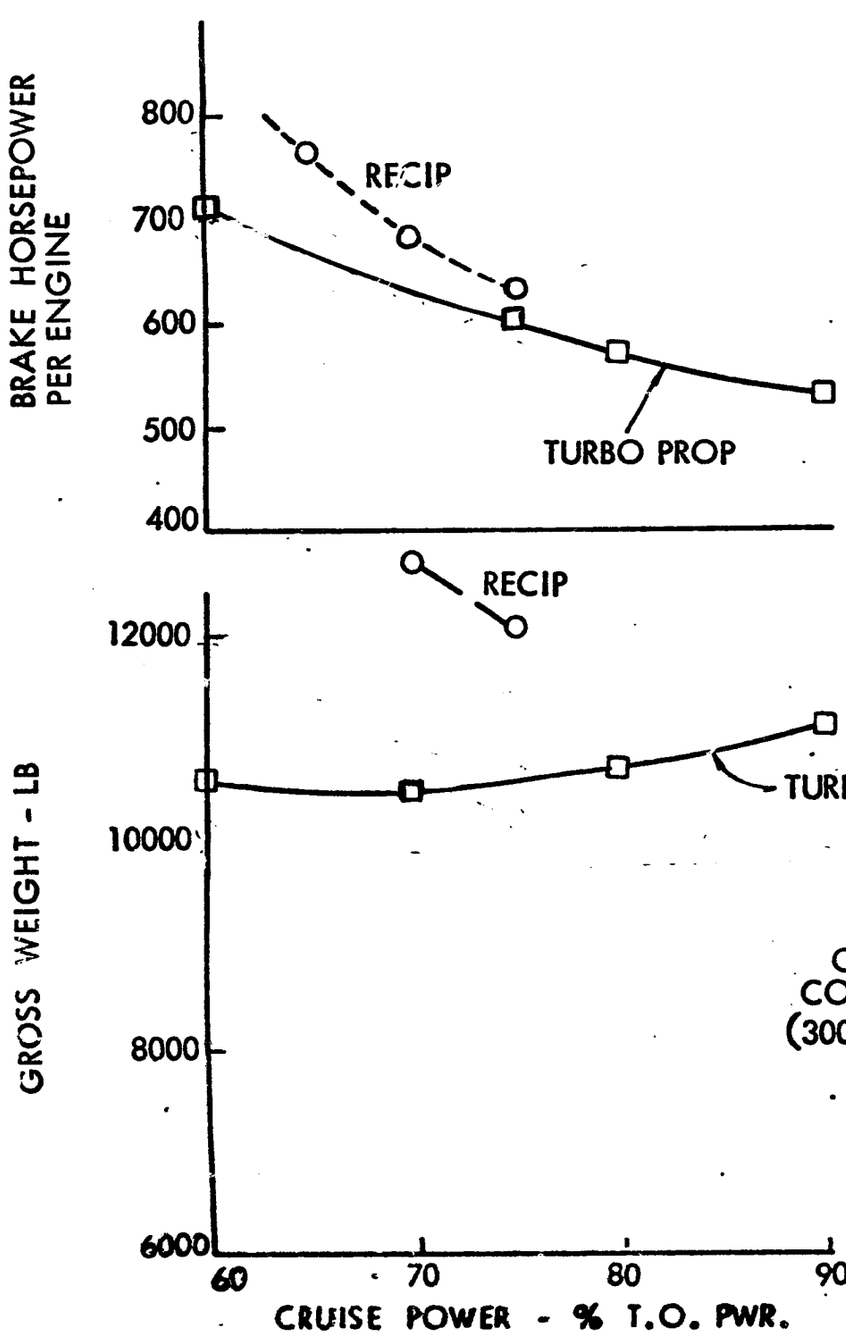
7.5.3 Category III Aircraft

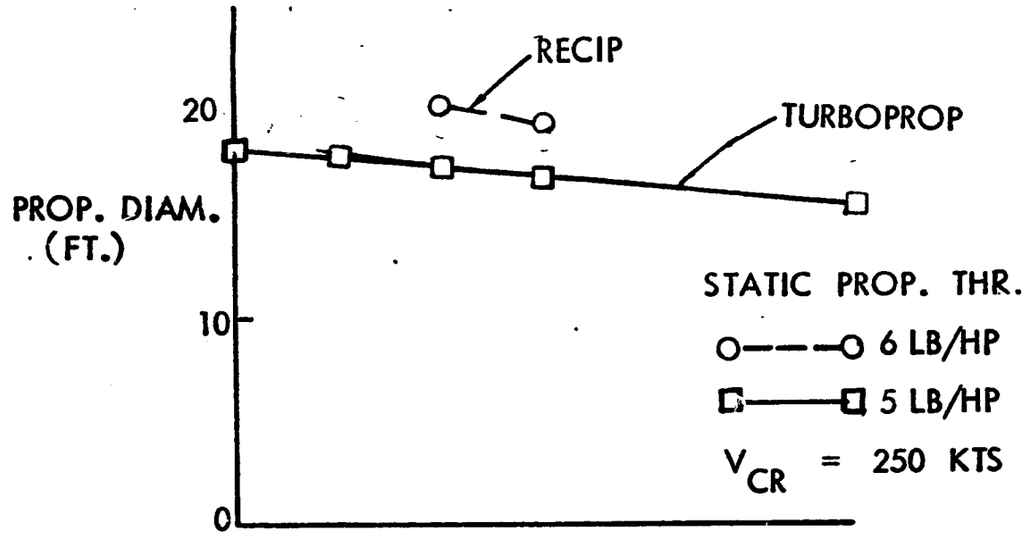
A tractor-pusher arrangement and a conventional twin tractor were evaluated in Category III. The tractor-pusher arrangement suffers markedly from the rear propeller operating in the wake of the forward propeller, so that effectively, twice the power of either engine is being absorbed in the same diameter, with the result that the propulsive efficiency is degraded from the value that could be obtained from separated propellers of the same diameter, as was used in the conventional twin tractor installation. 5 lb. of thrust per horsepower is the maximum obtainable, from a practical standpoint, with this configuration.

Figures 7.5.10 and 7.5.11 show the variation in gross weight, power, propeller diameter and operating cost with percent cruise power for reciprocating and turboprop engines. Here again, the turboprops show to best advantage and were selected for the baseline aircraft. A comparison of weight, cost and other important characteristics between the two configurations is tabulated in Figure 7.5.12. It can be seen that the twin tractor airplane weighs 13% less, requires 4.5% less power, costs 16.5% less to buy and 9.5% less to operate, than the tandem twin.

Figure 7.5.13 shows the optimized twin tractor propeller configuration selected on the basis of the parametric analysis. The most significant characteristic of this design is the large propeller diameter required to meet the noise constraint of 75 PNdb at 500 ft., as well as the 1500 ft. takeoff and 250 knot cruise speed requirements. At the indicated maximum engine horsepower, it is necessary to limit the propeller tip speed to 450 ft/sec., which sets the rotational speed at 493 RPM.

FIGURE 7.5.10 PARAMETRIC ANALYSIS: CATEGORY III TWIN TRACTOR





OPERATING COST - $/ST. MI. (300 HR/YR. UTIL.)

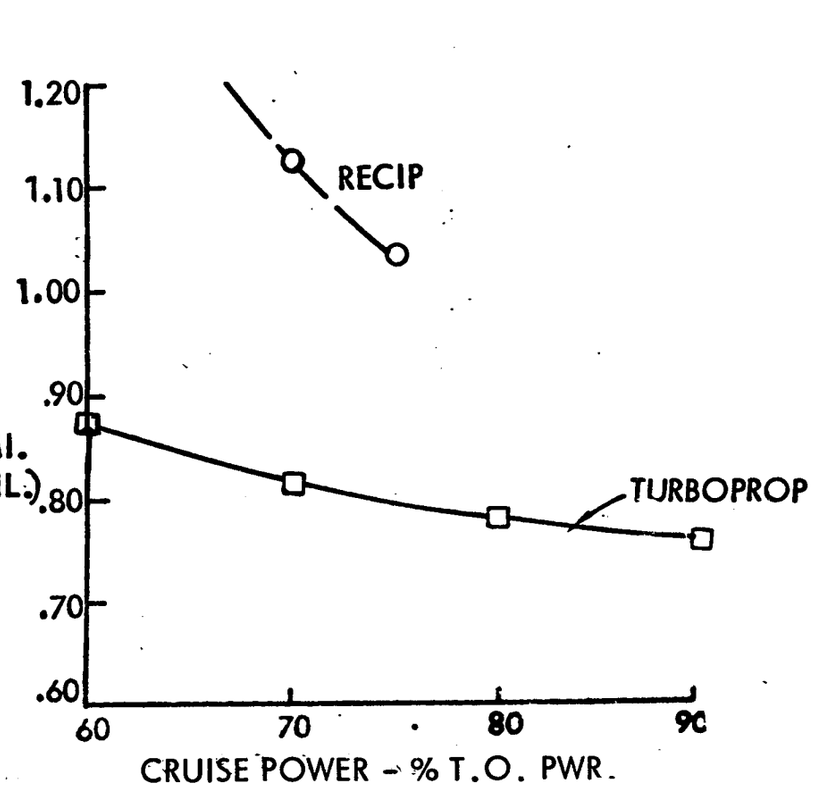


FIGURE 7.5.11 CATEGORY III - TRACTOR-PUSHER

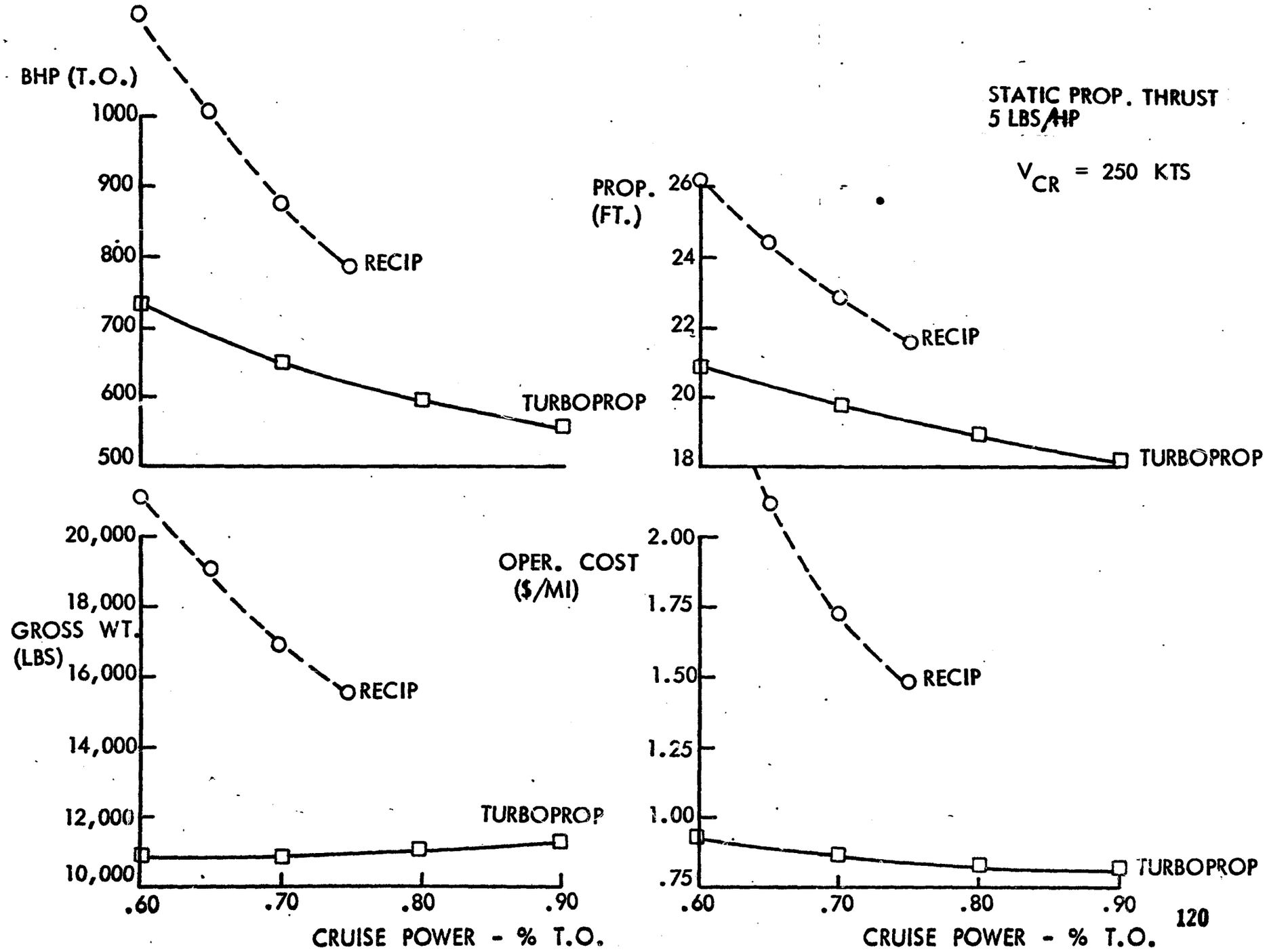


FIGURE 7.5.12
CATEGORY III PARAMETRIC
ANALYSIS RESULTS

CONFIGURATION	TRACTOR-PUSHER	TWIN TRACTOR
GROSS WT. (LBS.)	11,283	9,778
TYPE OF ENGINE	TURBOPROP	TURBOPROP
T.O. BHP /ENGINE	557	532
CRUISE SPEED (KTS)	250	250
CRUISE POWER (PCT. NORM.)	90	90
PROP. THRUST (LBS/HP)	5.0	6.0
PROP. DIAM. (FT.)	18.2	17.7
WING LOADING (LBS/SQ. FT.)	29.4	40.9
INITIAL COST ($)	426,181	356,000
*OPERATING COST ($/MILE)	0.82	0.74

*300 HRS/YEAR

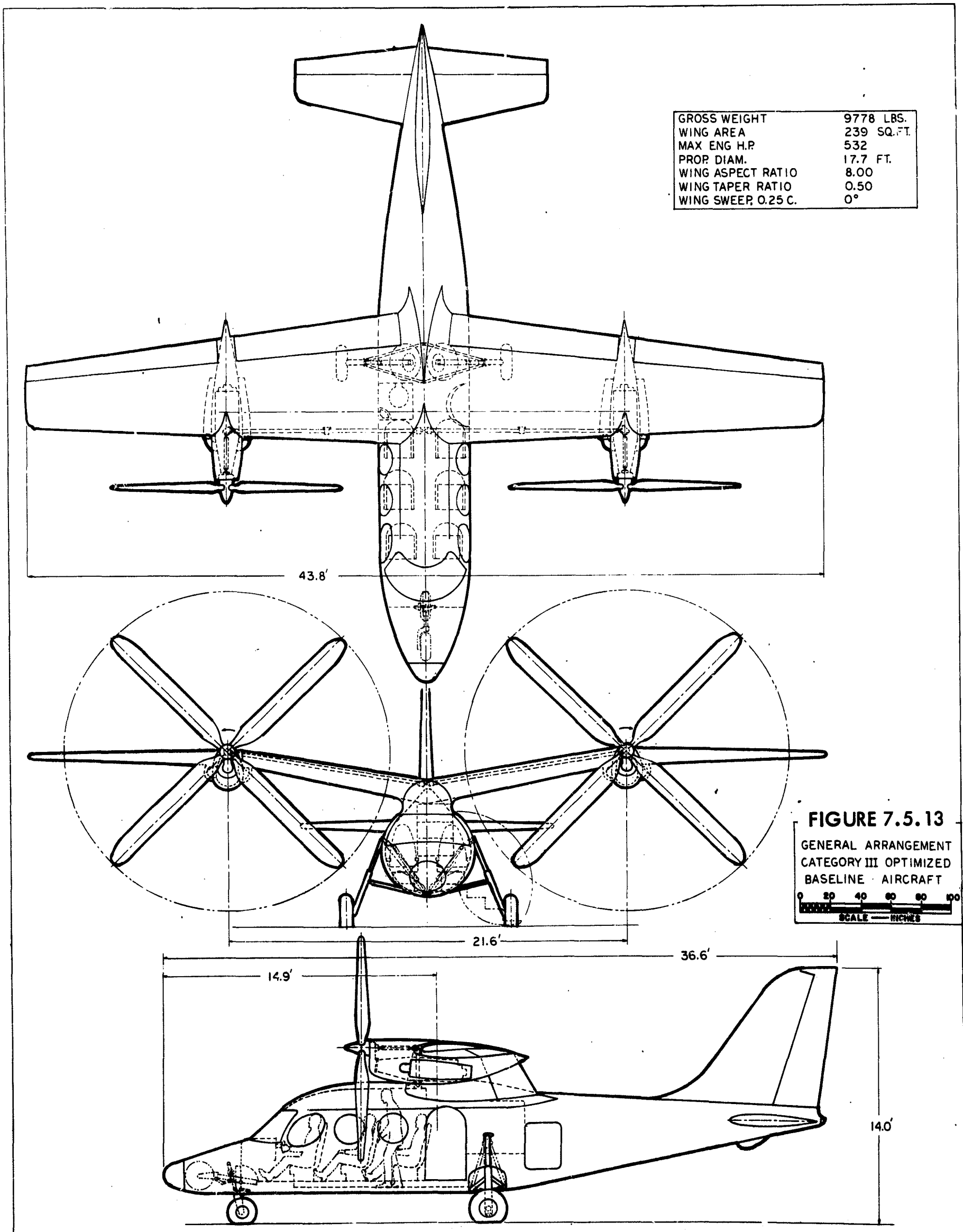


FIGURE 7.5.13

GENERAL ARRANGEMENT
CATEGORY III OPTIMIZED
BASELINE AIRCRAFT

In order to avoid an uncomfortably high cabin height above the ground, a high "gull wing" configuration was chosen. Placement of the propellers halfway out on the wing span, together with the high thrust-to-power ratio, calls for cross-shafting the propellers in order to avoid uncontrollable yaw and roll with one engine out. It is also necessary to have counter-rotating propellers to neutralize the inherently high torque. With cross-shafting, no control problems are encountered when flying on one engine. The use of supercritical speed shafting, within the present state-of-the-art, does not exact a serious weight penalty - certainly less than that of sizing the lateral and directional control surfaces to resist an asymmetrical thrust condition.

Although the baseline aircraft is designed to cruise at 7,500 ft., the fuselage cross section is adaptable to the future use of cabin pressurization, which is evaluated in the sensitivity analysis of Section 8.5.1. The six seats are arranged in two parallel rows with a depressed center aisle having 5' - 6" headroom. The entrance door is hinged at the floor level and is equipped with steps for access to the cabin. A lavatory is placed opposite the door. Racks for carry-on luggage are placed at the right of the entrance, and additional baggage space is accessible from the exterior. The main landing gear is placed immediately aft of the entrance and is designed to have essentially vertical wheel travel when absorbing the landing shock. The wheels retract flush with the contour, using inflatable fairings to smooth out the intersecting surfaces.

7.5.4 Category IV Aircraft

The candidate configurations selected for comparative analysis, were the helicopter and the tilt wing - propeller. The configuration of the helicopter and the tilt wing - propeller candidates were achieved using a minimum number of variables. In the case of the helicopter, constant disc loading and solidity ratios were used, and the cruising speed and altitude remained invariant at 150 knots and 5,000 ft.

Rotor tip speed was held at 600 ft/sec in cruise and 550 ft/sec during hover. The cruise power condition proved to be the more critical for engine selection. Fuel weight was programmed as a function of cruise power for the required mission endurance and an SFC of 0.65, typical of turboshaft engines, plus 5 minutes operation at hovering power. The program then selected a gross weight at which the required weight empty (established by integration of the component weights) became equal to the available weight empty (established as the gross weight minus the required fuel plus payload).

The tilt wing - propeller configuration was established in a similar manner. The geometrical arrangement adopted was similar to that illustrated in Figure 6.9, except that thrust axis tilt to a full 90° was allowed, and the maximum depressed position on the ground was established at 30° to avoid an abnormally long landing gear and high cabin floor. Several variations of speed and wing loading were made. A propeller thrust-to-horsepower ratio of 5.4 was established, representing a maximum value to 6.0 (programmed to meet the 75 PNdb noise constraint) and a factor of 0.9 to give a 10% margin for hovering.

Figure 7.5.14 presents a comparison between the two candidates when analyzed to meet the constraints of this study. Both candidates have very high initial cost. Although that of the helicopter is over ten times that of the Category I candidate, it is still 72% that of the tilt wing. The magnitude of these costs are influenced primarily by weight, complexity and power required. The use of turbine engines is very influential in escalating the cost. The only advantages possessed by the tilt wing are: higher cruise speed (being twice that of the helicopter) and consequent lower operating cost. Although operating cost is a criterion of selection, the magnitude of the difference in initial cost leads to the logical selection of the helicopter as the baseline configuration in Category IV. The higher speed advantage of the tilt wing may not be worth the price, if VTOL aircraft will be used mostly for short trips.

The baseline helicopter configuration is illustrated in Figure 7.5.15. Its single rotor/tail rotor configuration was selected as representative of the majority of light commercial helicopters now offered on the U. S. market. The tip speed of the main and tail rotors is limited to 550 ft/sec. in hovering and low speed flight, under the 75 PNdb at 500 ft. noise level constraint, based on studies by the Bell Helicopter Company (Ref. 5.2.16) In cruise, the tip speed is increased to 600 ft/sec, at 5000 ft. cruise altitude. At a cruise speed of 150 knots, a blade loading of 34 lbs/sq. ft. is maximum in order to avoid retreating blade stall. This resulted in the selection of a 0.10 solidity ratio, using a 4-blade rotor. The same geometry applies to both the main and tail rotors. In line with conventional design practice, the engine and transmission are mounted in the pylon. The tail rotor drive shaft is assumed to operate at supercritical speed. The fuel tank is located behind the passenger compartment. The baggage compartment is located immediately above the fuel tank. The main element of the retractable landing gear is located immediately aft of the fuel tank/baggage compartment area. The nose gear is retractable to a semi-exposed wheel position under the cabin floor.

7.6 Cost Comparison

For comparison purposes a check was made between the cost of the basic aircraft of NASA CR-73258 (Reference 7.3.11) and the cost of a Category I design which has evolved out of the present study. Appendix T of NASA CR-73258 states that a contemporary sheet metal airplane, comparable to the NASA far term guidelines specified for the San Diego Study, would cost about $20,150. As indicated in NASA CR-73258 on page 21, this cost of $20,150 is based on 1966 dollars. On the basis of economic escalation alone, the cost would be about $25,000 in 1970 dollars. The Category I present technology baseline airplane of this study has an initial cost of $22,171, exclusive of avionics.

A comparison of the basic requirements of the San Diego study and the present study are summarized in Figure 7.6.1. Although not specified it is assumed that the range requirement for the San Diego study is comparable to that of the present study. The requirements for cruise speed, takeoff distance,

FIGURE 7.5.14
CATEGORY IV PARAMETRIC
ANALYSIS RESULTS

CONFIGURATION	TILT-WING-PROPELLER	HELICOPTER
CRUISE SPEED (KTS)	300	150
TYPE OF POWER PLANT	TURBOSHAFT	TURBOSHAFT
GROSS WEIGHT (LBS)	6918	5646
PROPELLER OR ROTOR DIAMETER (FT)	(2) 19.9	(1) 47.2
MAX. RATED HORSEPOWER (TOTAL)	1282	641
WING AREA (SQ. FT.)	133	-
WING SPAN (FT.)	25.0	-
DISC LOADING (PROP. OR ROTOR) (LBS/FT.^{2})	11.24	3.40
WEIGHT EMPTY (LBS.)	4756	3502
FUEL WEIGHT (LBS)	1262	1265
INITIAL COST ($)	376,000	270,406
* OPERATING COST ($/MILE)	1.03	1.39

* 300 HRS/YR

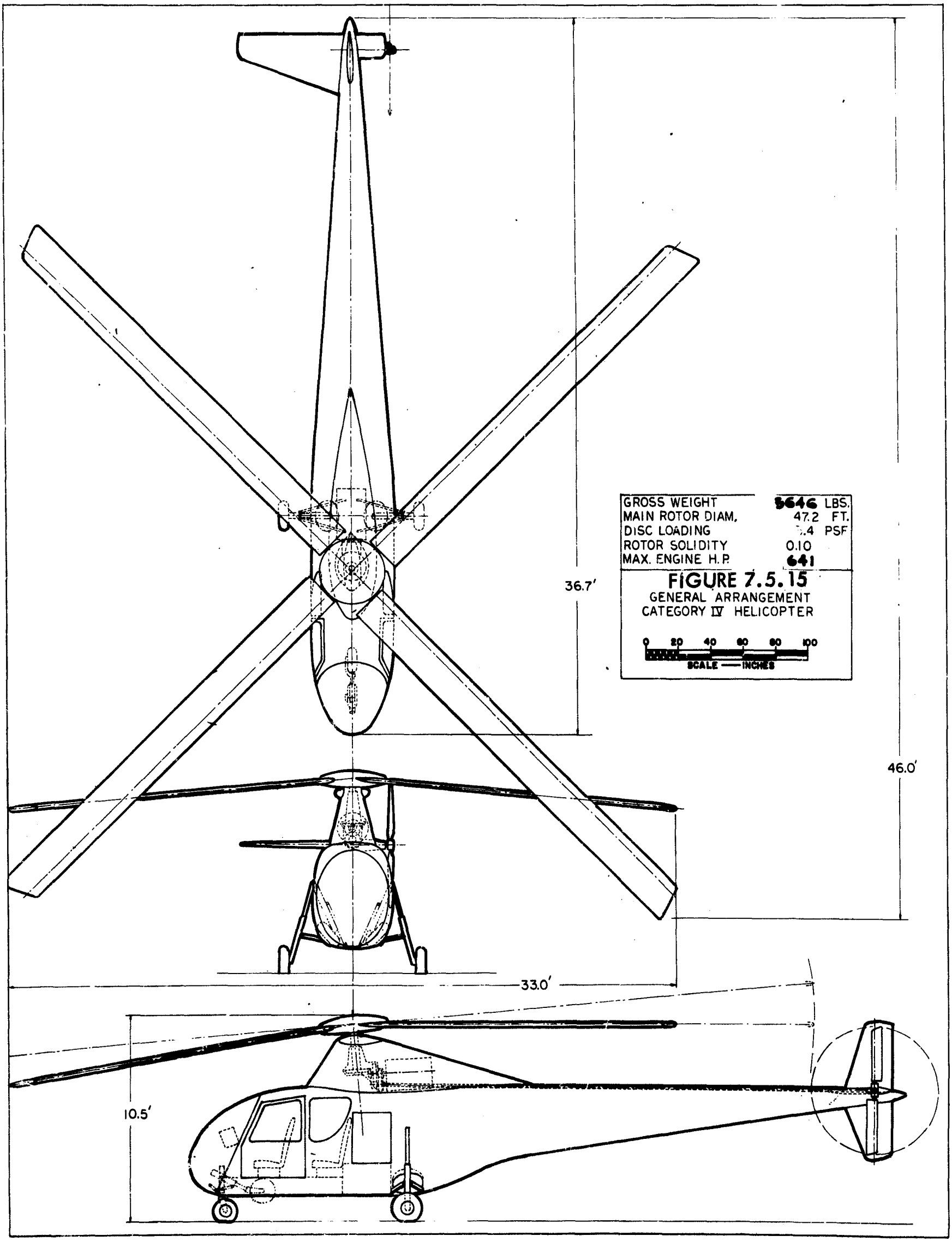


FIGURE 7.5.15
GENERAL ARRANGEMENT
CATEGORY IV HELICOPTER

FIGURE 7.6.1

COMPARISON OF BASIC REQUIREMENTS

REQUIREMENT	PRESENT STUDY * GUIDELINES, CONSTRAINTS	SAN DIEGO STUDY ** FAR TERM GUIDELINES
Range, miles	500	500 ***
Cruise Speed, kts	130	130
Takeoff Distance/50', ft	1000	1000
Seats	4	4
Payload per seat, lbs	220	220
Noise Level @ 500', PNdb	75	not specified
Fuel Reserve, min	45	30

NOTES:

* Appendix I

** From NASA CR-73258

*** Assumed

number of seats, and payload are the same, however, the baseline design of this study has a cruise speed of 145 knots as selected on the basis of minimum operating cost. A noise level of 75 PNdb or less was not required for the San Diego study. There is a 50% increase in fuel reserve time above the San Diego study. Other requirements, which are only applicable to one study or the other, are not particularly influential.

In comparison to the airplane evolved in the San Diego study, the somewhat lower initial cost of the baseline aircraft in this study is believed to be attributable to the requirement for a lower noise level. The comparison between conventional and low noise level propellers on the Category I airplane was shown in Figure 7.5.3, with a lower initial cost indicated for the quiet propeller installation, due to the lower level of engine power required. Thus, general agreement appears to have been reached in the two studies.

7.7 References

7.3.1 Aircraft Bluebook, Aircraft Dealers Service Association, Second Quarter 1970.

7.3.2 Aircraft Price Digest, Aircraft Appraisal Association of America, Spring Edition 1970.

7.3.3 Aviation Week, Forecast and Inventory Issue, March 9, 1970.

7.3.4 Business and Commercial Aviation, April 1970.

7.3.5 Avco Lycoming Division, Engine Price List, 1970.

7.3.6 Teledyne Continental Motors, Engine Prices, 1970 (telephone conversation)

7.3.7 Allison Division of General Motors, Engine Prices, 1970 (per local representative)

7.3.8 United Aircraft of Canada, Engine Prices, 1970 (per local representative)

7.3.9 Hartzell Propeller, Inc., Propeller Price List, 1970

7.3.10 McCauley Industrial Corporation, Propeller Price List, 1969

7.3.11 Potential Structural Materials and Design Concepts for Light Aircraft, San Dieto Aircraft Engineering, Inc., NASA CR-1285, March 1969.

7.3.12 Cost Estimating Relationships, Lockheed-California Company Report LR23130, December 1969.

7.3.13 G. R. Asher, "Helicopter Manhour and Cost Estimating Relationships," Research Symposium 15-16 March 1967.

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7.3.15 Management Planning Brochure, Consolidated Vultee, Stinson Division, 1946.

7.3.16 Peter Masefield, Journal of the Royal Aeronautical Society (Louis Bleriot Lecture, April 1966): "Light Aviation - Problems, Prospects and Performance"

7.3.17 L. P. Greene, "Technical Challenge and Task of General Aviation in the 1970s," AIAA Paper 69-819 presented at Aircraft Design and Operations Meeting July 14-16, 1969, Los Angeles, California.

7.3.18 DOT/FAA Office of Policy Development, February 1969: "General Aviation Operating Costs"

7.3.19 Air Force Manual 172-3, January 1970, "Cost and Planning Factors Manual"

8.0 SENSITIVITY ANALYSIS

8.1 General Procedure

The purpose of the sensitivity analysis operation is to assess the impact of advanced technology and other factors as applied to the baseline designs, developed in Section 7.0, which represent the present state-of-the-art.

Figure 8.1.1 illustrates the general procedure followed in this analysis. The effect of the use of advanced engines and that of advanced materials on the configurations in each of the four categories are evaluated separately and then combined to establish advanced technology baseline designs, representative of the 1985 time frame. The factors listed below the box in this figure titled "Advanced Technology Baseline Designs" are then applied separately. Those on the right side of the vertical line represent the addition of new physical features or configuration changes required to achieve the desired effect. Those on the left side represent changes in environmental and performance requirements, as well as growth factors.

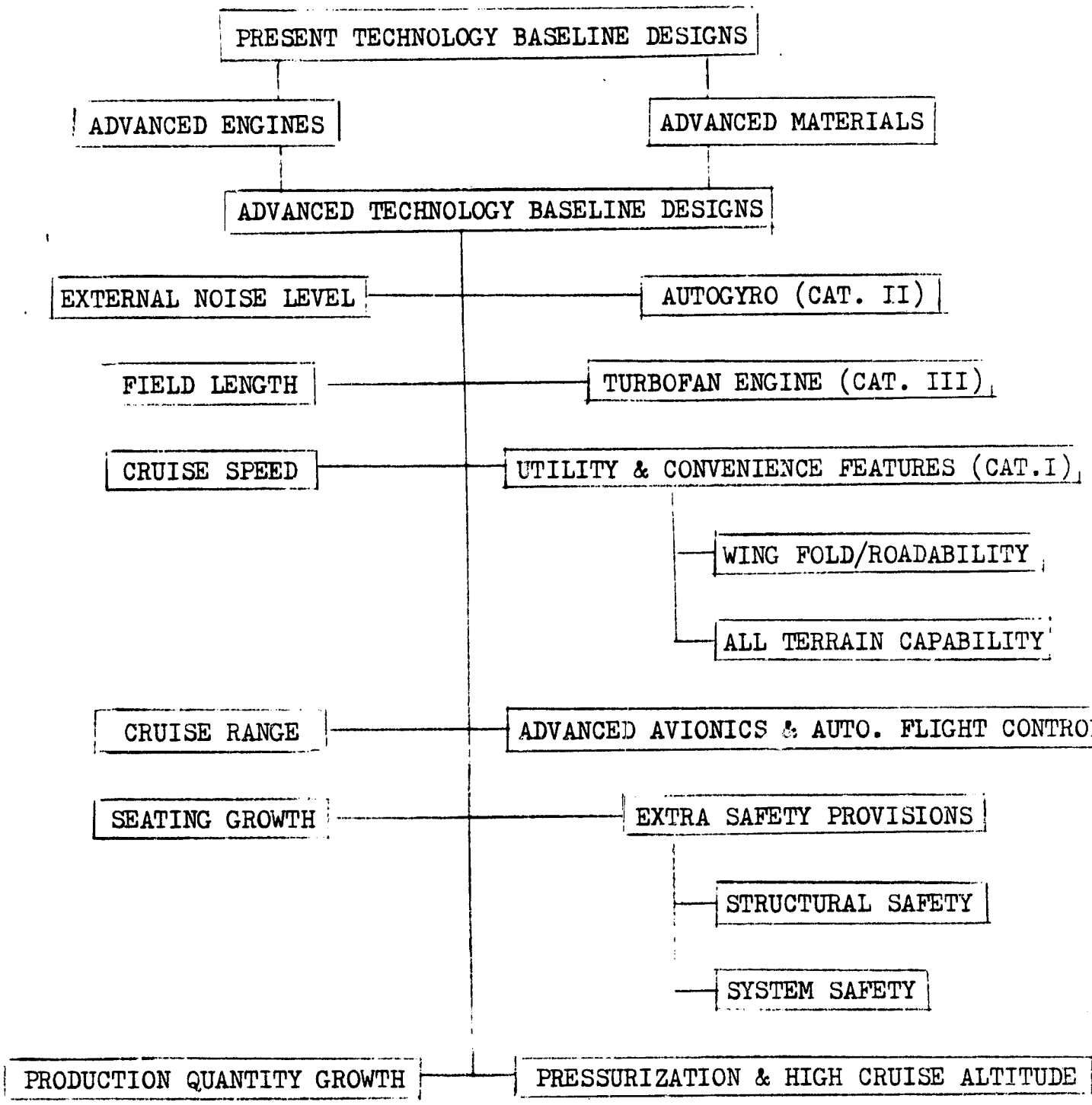
The separate analyses were programmed for the computer in the same manner as described in Section 7.0. The variation of inputs is explained under each of the appropriate subsection headings, with a subsequent tabular comparison showing the effect of each assessment on the advanced technology configuration in each of the four categories. The output data include the following characteristics:

Gross Weight	Cruise Power (pct.)
Weight Empty	Propeller Diameter
Fuel Capacity	Wing Loading
Max. Engine H.P.	Initial Cost
Cruise Speed	Operating Cost

in addition to certain others as appropriate to the category or the assessment.

FIGURE 8.1.1

SENSITIVITY ANALYSIS PROCEDURE



Program inputs were then combined to assess certain desirable combinations, and these are reported in Section 9.0.

The Advanced Technology Baseline Designs are illustrated in general arrangement (3-view form). Other similar illustrations include the special configurations in Categories I, II and III, and the seating growth versions in all categories. The remaining assessments are not illustrated, since they reflect similar geometry to the Advanced Technology Baseline Designs. Section 9.0 includes illustrations of the recommended combinations in each of the four categories.

As in the case of the present technology baseline aircraft analyzed in Section 7.0, no avionics are included in the advanced technology designs. However, the effect of adding advanced avionic systems is assessed in Section 8.3.7.

8.2 Configuration Evaluation

These data are covered in detailed discussion of the sensititivy analysis in Sections 8.3 through 8.7.

8.3 Effect of Advanced Technology Applications

8.3.1 Aerodynamic Features

These include high lift devices and low drag configurations, both of which were investigated in Section 5.1 and applied to the Present Technology Baseline Designs evolved in Section 6.0. More advanced devices, such as boundary layer control, jet flap, laminar flow control, etc. were considered and rejected for reasons of high cost and loss of safety following engine failure. The extensive research applied in the past toward the development of airfoil sections, lift augmentation devices and low drag configuration enables the designer to select optimum combinations for any given application. Progress in this area has been evolutionary, rather than revolutionary, in the past and will probably continue thusly in the future. While future break-throughs in this area may develop prior to 1985, none can be foreseen at this time. The Advanced Technology Baseline Designs, therefore, relfect present state-of-the-art with regard to aerodynamic features, which are carefully selected to produce optimum aircraft configurations.

8.3.2 Propulsion Systems

Four different types of power plant were investigated in Section 5.2. They include three engine/propeller systems, namely reciprocating, gas turbine and rotating combustion engines; plus one gas reaction system, the turbofan. Subsequent parametric analysis, reported in Section 7.0, disclosed that the rotating combustion engine is optimum for Category I, while the gas turbine shaft drive is superior for Categories II, III, and IV -- all based on present state-of-the-art. However, the future technology projected for the rotating combustion engine establishes its superiority in all four categories of aircraft and has led to its selection as the representative advanced technology power plant. This does not necessarily rule out the reciprocating

engine, gas turbine or hybrid engine if either of them can be accelerated in development to achieve a competitive position. Based on present technology a sessment, however, the rotating combustion engine is believed to have the best potential.

In order to compare the use of propellers with jet propulsion, a single engine turbofan configuration was evolved for Category III only, and compared with the twin engine/propeller design. Rather than isolating this assessment to propulsion only, it is covered later, following the assessment of advanced materials, so that Advanced Technology Baseline Designs can be compared. The rationale for the use of one turbofan, instead of two, is based on two considerations: cost and relative safety. Since the turbofan engine has a relatively high specific cost, which decreases with increase of thrust rating, the use of two smaller engines in place of one larger unit would nearly double the engine cost. Comparing the relative chances of engine failure, the reliability of the turbofan engine has already been established at a high level and will no doubt improve in the years ahead. Development of the rotating combustion engine lags considerably behind that of the turbofan, although the two might become equal by 1985. The addition of the propeller adds another element of risk as regards potential propulsion failure. The present psychology of corporate aircraft owners, who represent potential buyers of Category III aircraft, favors the use of two or more engines as a carry-over from the experience of previous years, when engines were less reliable. Engine failure today represents a very small percentage of total aircraft accidents and should further decrease to negligible amount by 1985. With proper education, the users of Category III aircraft will not consider the extra cost of two engines to be a worthwhile expenditure.

Figures 8.3.1, 8.3.2, 8.3.3 and 8.3.4 present tabular comparisons of the Baseline Aircraft with present and advanced technology engines. The characteristics of the present technology baseline designs in these tables differ from those listed in Section 7.5, as the result of more refined inputs to the analysis. The values were not corrected in Section 7.5 because they are valid in serving the purpose of comparing configurations. In terms of initial aircraft cost, the advanced technology rotating combustion engine effects a 16% reduction over the reciprocating engine in Category I, and much larger reductions over the gas turbine in Categories II (50%), III (29%) and IV (35%). Operating costs at 300 hrs/yr are reduced by 6.5% in Category I; 17.5% in Category II; 5.0% in Category III; and 20.0% in Category IV.

Figure 8.3.3.1 presents a tabular comparison in Category III between the twin engine/propeller Advanced Technology Aircraft with pressurization and high altitude cruise capability (described in Section 8.5.1) and the single turbofan design. Both aircraft have had the application of advanced structural materials, covered in Section 8.3.3. Both candidates are designed to cruise at 20,000 ft. and include cabin pressurization. At this altitude, the optimum cruising speed of the turbofan aircraft is 300 kts (50 kts in excess of the minimum requirement). The difference in requirements between the two is in the area of external noise level, being 75 PNdb for the propeller aircraft and 85 PNdb for the turbofan, both at 500 ft. distance. While the effect of the higher noise level and that of high altitude operation have been separately assessed for the propeller-driven aircraft, they have not been analyzed in combination. The initial cost of this aircraft is 65% higher than that of the twin engine/propeller design. Despite that handicap, its operating cost at 300 hrs/yr is only 4% higher. The latter characteristic, plus the convenience of higher cruise speed should result in preference by a large segment of potential corporate owners. Figure 8.3.3.2 shows the general arrangement of this aircraft.

FIGURE 8.3.1
CATEGORY I COMPARISON:
EFFECT OF ADVANCED PROPULSION

(Single Engine Pusher; 4-Place; 1000 ft. Field Length; 500 Mi.Range; 75 PNdb @ 500 ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.5	Not Avail.
Type of Engine		Recip.	Rot. Comb.
Gross Weight	(lbs)	2674	2558
Weight Empty	(lbs)	1565	1456
Fuel Capacity	(gal)	40	39
Max. Engine H.P.		169	164
Cruise Speed	(kts)	145	145
Cruise Power	(pct. normal)	75	75
Propeller Diameter	(ft)	7.80	7.68
Wing Loading	(lbs/sq.ft.)	12.70	13.01
Initial Cost (1970 basis)	($)	22,171	18,660
Operating Cost- 100 hrs./yr.	($/mile)	0.249	0.226
- 300 hrs./yr.		0.135	0.126
- 500 hrs./yr		0.112	0.106

FIGURE 8.3.2
CATEGORY II COMPARISON:
EFFECT OF ADVANCED PROPULSION

(Single Engine Pusher; 4-Place; 500 Ft.Field Length; 500 Mi.Range; 75 PNdb @ 500 ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.9	Not Avail.
Type of Engine		Turboprop	Rot. Comb.
Gross Weight	(lbs)	4274	4012
Weight Empty	(lbs)	2570	2575
Fuel Capacity	(gal)	126	95
Max. Engine H.P.		516	512
Cruise Speed	(kts)	200	200
Cruise Power	(pct. normal)	90	75
Propeller Diameter	(ft)	11.92	11.88
Wing Loading	(lbs/sq. ft.)	12.42	13.39
Initial Cost (1970 basis)	($)	122,293	61,391
Operating Cost- 100 hrs/yr	($/mile)	0.668	0.456
- 300 hrs/yr		0.320	0.264
- 500 hrs/yr		0.251	0.226

FIGURE 8.3.3
CATEGORY III COMPARISON:
EFFECT OF ADVANCED PROPULSION

(2 Engine/Propeller; 6-Place; 1500 ft.Field Length; 1500 Mi.Range; 75PNdb @ 500 ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.13	Not Avail.
Type of Engine (2 installed)		Turboprop	Rot. Comb.
Gross Weight	(lbs)	9,187	8,740
Weight Empty	(lbs)	4,751	5,120
Fuel Capacity	(gal)	482	382
Max. H.P. per engine		511	528
Cruise Speed	(kts)	250	250
Cruise Power	(pct. normal)	90	75
Propeller Diameter	(ft.)	17.4	17.7
Wing Loading	(lbs/sq.ft.)	41.7	44.8
Initial Cost (1970 basis)	($)	335,885	239,036
Operating Cost- 100 hrs/yr	($/mile)	1.686	1.605
- 300 hrs/yr		0.715	0.680
- 500 hrs/yr		0.521	0.496

FIGURE 8.3.4
CATEGORY IV COMPARISON
EFFECT OF ADVANCED PROPULSION

(Single Engine Helicopter; 4 Place; 500 Mi. Range; 75 PNdb @ 500 ft)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.15	Not Avail
Type of Engine		Turboshaft	Rot. Comb.
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600
Cruise Speed (5000 ft. alt.)	(kts)	150	150
Solidity Ratio		0.100	0.100
Gross Weight	(lbs)	5646	4502
Weight Empty	(lbs)	3501	2871
Main Rotor Diameter	(ft)	46.0	41.1
Disc Loading	(lbs/sq.ft)	3.40	3.40
Max. Engine H.P.		641	539
Initial Cost (1970 Basis)	($)	270,406	175,287
Operating Cost- 100 hrs/year	($/mile)	3.465	2.764
- 300 hrs/year		1.388	1.107
- 500 hrs/year		0.670	0.774

FIGURE 8.3.3.1
CATEGORY III COMPARISON
TWIN ENGINE/PROPELLER VS. SINGLE TURBOFAN

(Advanced Technology; 6 Place; 1,500 Ft. Field Length; 1,500 Mile Range.)

Configuration		2 Eng./Prop.	Single Turbofan
Noise Level at 500 ft. (PNdb)		75	85
General Arrangement Figure No.		N.A.	8.3.3.2
Cruise Altitude	(ft)	20,000	20,000
Cabin, Pressurization		Yes	Yes
Cruise Speed	(kts)	250	300
Gross Weight	(lbs)	6624	8776
Weight Empty	(lbs)	3692	3594
Fuel Capacity	(gal)	279	591
Propeller Diameter	(ft)	13.09	-
Max. H.P. per Engine		378	-
Static Thrust per Engine	(lbs)	-	2875
Wing Loading	(lbs/sq.ft.)	33.95	29.63
Initial Cost (1970 Basis)	($)	136,234	207,321
Operating Cost - 100 hrs/yr	($/Mile)	1.141	1.165
- 300 hrs/yr		0.510	0.532
- 500 hrs/yr		0.384	0.405

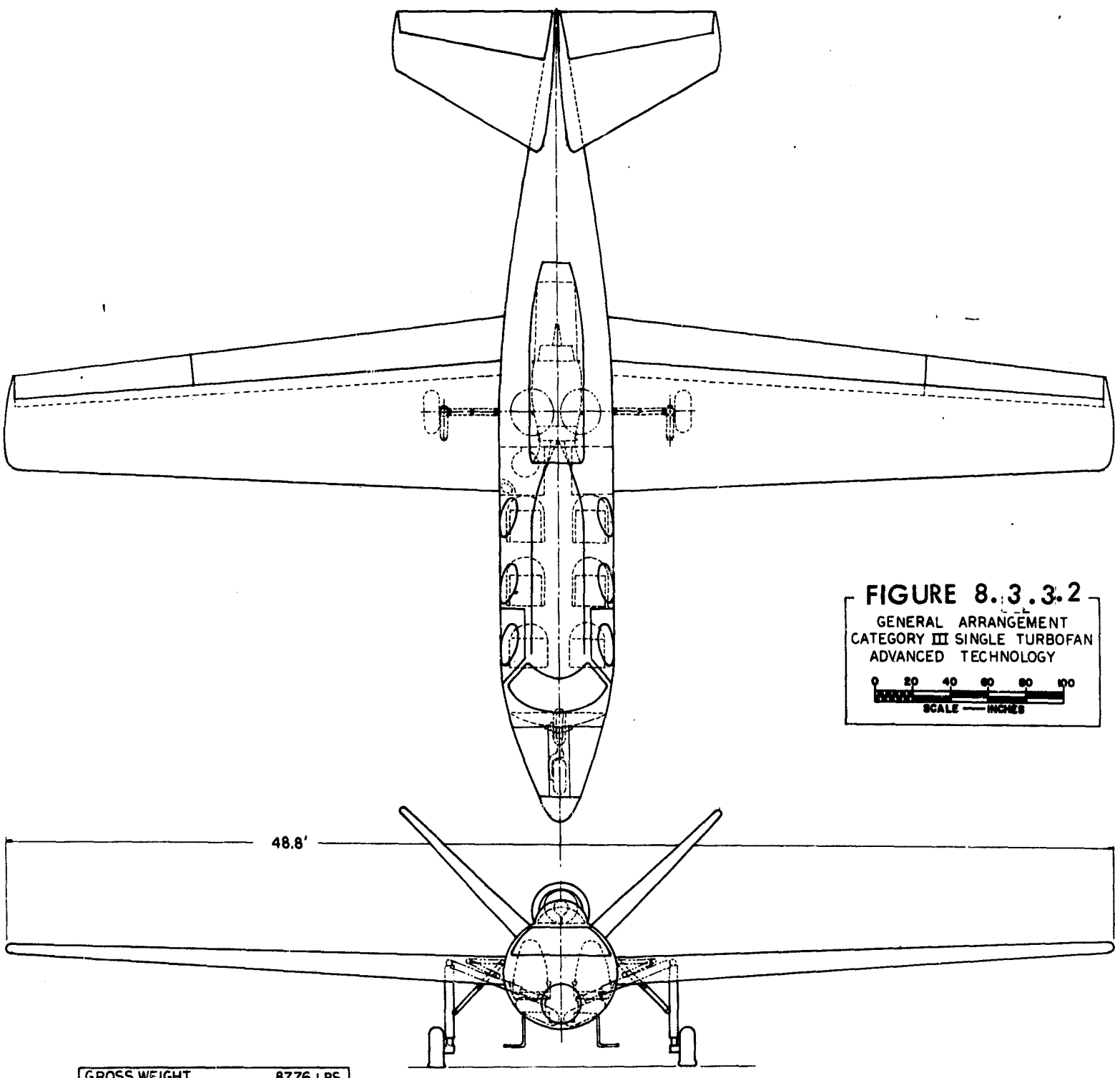
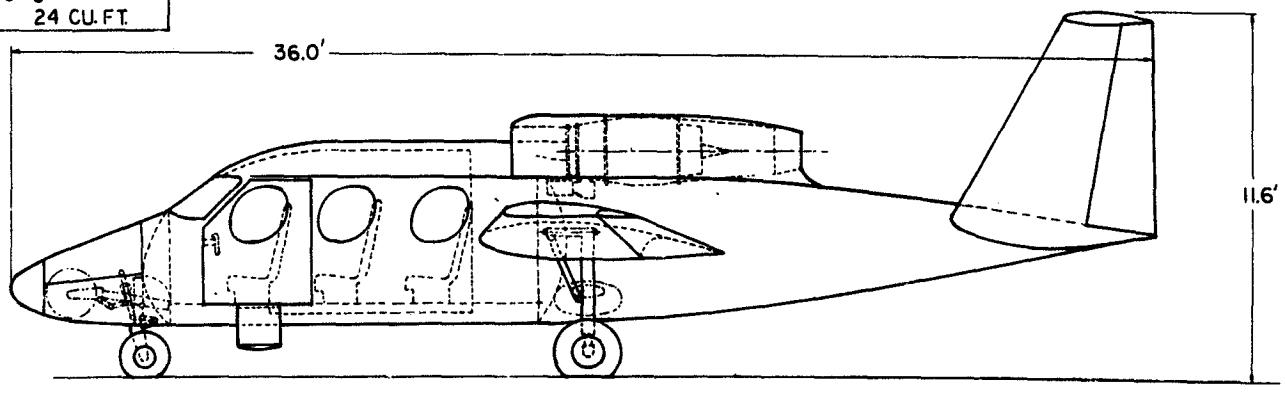


FIGURE 8.3.3.2
GENERAL ARRANGEMENT
CATEGORY III SINGLE TURBOFAN
ADVANCED TECHNOLOGY

0 20 40 60 80 100
SCALE — INCHES

GROSS WEIGHT	8776 LBS.
WING AREA	296 SQ. FT.
MAX. ENG. THRUST	2875 LBS.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP 0.25 C.	0°
BAGGAGE SPACE	24 CU. FT.



8.3.3 Airframe Structure

Referring to Section 7.2, weight reduction factors were established and tabulated for the principal items of airframe structure and mechanical systems. The cost factors for purchasing and applying the advanced structural materials are covered in Section 7.3. Tabular comparisons for each of the four Categories are shown in Figures 8.3.5, 8.3.6, 8.3.7 and 8.3.8.

Despite the higher cost of composite materials, the offsetting factors of lighter weight and applicability to lower cost production processes result in net cost savings. When compared with the Present Technology Baseline Designs, which utilize conventional aluminum alloy and steel materials, the use of advanced materials and processes reduces the initial aircraft cost by 17% in Category I; 19% in Category II; and 13% in Categories III and IV. Operating costs at 300 hrs/yr. are reduced by 12.0% in Category I; 15.5% in Category II; 6.5% in Category III; and 11.0% in Category IV.

FIGURE 8.3.5
CATEGORY I COMPARISON:
EFFECT OF ADVANCED MATERIALS

(Single Engine Pusher; 4-Place; 1000 Ft.Field Length; 500 Mi.Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.5	Not Avail.
Type of Engine		Recip.	Recip.
Gross Weight	(lbs)	2674	2370
Weight Empty	(lbs)	1565	1279
Fuel Capacity	(gal)	40	37
Max. Engine H.P.		169	155
Cruise Speed	(kts)	145	145
Cruise Power	(pct. normal)	75	75
Propeller Diameter	(ft)	7.80	7.48
Wing Loading	(lbs/sq.ft.)	12.70	13.59
Initial Cost (1970 basis)	($)	22,171	18,356
Operating Cost- 100 hrs./yr.	($/mile)	0.249	0.216
- 300 hrs/yr.		0.135	0.119
- 500 hrs/yr.		0.112	0.100

FIGURE 8.3.6
CATEGORY II COMPARISON:
EFFECT OF ADVANCED MATERIALS

(Single Engine Pusher; 4-Place; 500 Ft.Field Length; 500 Mi. Range; 75 PNdb @ 500 ft)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.9	Not Avail.
Type of Engine		Turboprop	Turboprop
Gross Weight	(lbs)	4274	3552
Weight Empty	(lbs)	2570	1959
Fuel Capacity	(gal)	126	110
Max. Engine H.P.		516	451
Cruise Speed	(kts)	200	200
Cruise Power	(pct. normal)	90	90
Propeller Diameter	(ft)	11.92	11.16
Wing Loading	(lbs/sq.ft.)	12.42	13.29
Initial Cost (1970 basis)	($)	122,293	99,323
Operating Cost- 100 hrs/yr	($/mile)	0.668	0.559
- 300 hrs/yr		0.320	0.270
- 500 hrs/yr		0.251	0.212

FIGURE 8.3.7
CATEOGRY III COMPARISON:
EFFECT OF ADVANCED MATERIALS

(2 Engine/Propeller; 6 Place; 1500 Ft.Field Length; 1500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.13	Not Avail.
Type of Engine (2 installed)		Turboprop	Turboprop
Gross Weight	(lbs)	9187	8410
Weight Empty	(lbs)	4751	3992
Fuel Capacity	(gal)	482	479
Max H.P. per engine		511	504
Cruise Speed	(kts)	250	250
Cruise Power	(pct. normal)	90	90
Propeller Diameter	(ft)	17.4	15.1
Wing Loading	(lbs/sq.ft.)	41.7	36.20
Initial Cost (1970 basis)	($)	335,885	291,559
Operating Cost- 100 hrs/yr.	($/mile)	1.686	1.565
- 300 hrs/yr.		0.715	0.669
- 500 hrs/yr.		0.521	0.489

FIGURE 8.3.8
CATEGORY IV COMPARISON
EFFECT OF ADVANCED MATERIALS

(Single Engine Helicopter; 4 Place; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.15	Not Avail.
Type of Engine		Turboshaft	Turboshaft
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600
Cruise Speed (5000 ft. alt.)	(kts)	150	150
Solidity Ratio		0.100	0.100
Gross Weight	(lbs)	5646	4660
Weight Empty	(lbs)	3501	2690
Main Rotor Diameter	(ft)	46.0	41.8
Disc Loading	(lbs/sq.ft)	3.40	3.40
Max. Engine H.P.		641	553
Initial Cost (1970 Basis)	($)	270,406	235,036
Operating Cost- 100 hrs/year	($/mile)	3.465	3.100
- 300 hrs/year		1.388	1.240
- 500 hrs/year		0.970	0.868

8.3.4 Combined Propulsion and Airframe Structure Technology

Figures 8.3.9, 8.3.10, 8.3.11 and 8.3.12 show the effect of projecting the baseline designs in each of the four Categories into the 1985 time frame by combining the effects of propulsion and airframe structure technology. The major points of comparison are illustrated in bar chart form in Figures 8.3.9.1, 8.3.10.1, 8.3.11.1, and 8.3.12.1. The resulting configurations are illustrated in Figures 8.3.13, 8.3.14, 8.3.15 and 8.3.16. They become new baseline designs for evaluation of the remaining sensitivity studies.

When compared with the Present Technology Baseline Designs, substantial reductions are effected in both initial and operating costs. Initial cost is reduced by 30% in Category I; 63% in Category II; 48% in Category III; and 43% in Category IV. Operating cost at 300 hrs/yr. is reduced by 17% in Category I; 31% in Category II; 16% in Category III; and 27% in Category IV. These reductions emphasize the importance of advanced technology applications, which can be brought about by continued research and development, dissemination of technical information to the general aviation industry and the ensuing competition between manufacturers.

FIGURE 8.3.9
CATEGORY I COMPARISON:
COMBINED EFFECT OF ADVANCED PROPULSION AND MATERIALS (ADV. TECHNOLOGY)

(Single Engine Pusher; 4 Place; 1000 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.5	8.3.13
Type of Engine		Recip.	Rot. Comb.
Gross Weight	(lbs)	2674	2285
Weight Empty	(lbs)	1565	1199
Fuel Capacity	(gal)	40	36
Max. Engine H.P.		169	152
Cruise Speed	(kts)	145	145
Cruise Power	(pct. normal)	75	75
Propeller Diameter	(ft)	7.80	7.39
Wing Loading	(lbs/sq.ft.)	12.70	13.89
Initial Cost (1970 basis)	($)	22,171	15,589
Operating Cost- 100 hrs./yr.	($/mile)	0.249	0.198
- 300 hrs./yr.		0.135	0.112
- 500 hrs./yr.		0.112	0.095

FIGURE 8.3.10
CATEGORY II COMPARISON:
COMBINED EFFECT OF ADVANCED PROPULSION AND MATERIALS (ADV. TECHNOLOGY)

(Single Engine Pusher; 4 Place; 500 Ft. Fielt Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.9	8.3.14
Type of Engine		Turboprop	Rot. Comb.
Gross Weight	(lbs)	4,274	3,336
Weight Empty	(lbs)	2,570	1,978
Fuel Capacity	(gal)	126	84
Max. Engine H.P.		516	452
Cruise Speed	(kts)	200	200
Cruise Power	(pct. normal)	90	75
Propeller Diameter	(ft)	11.92	11.16
Wing Loading	(lbs/sq. ft.)	12.42	14.32
Initial Cost (1970 basis)	($)	122,293	45,034
Operating Cost- 100 hrs/yr.	($/mile)	0.668	0.371
- 300 hrs/yr.		0.320	0.221
- 500 hrs/yr.		0.25 1	0.191

FIGURE 8.3.11
CATEGORY III COMPARISON:
COMBINED EFFECT OF ADVANCED PROPULSION AND MATERIALS (ADV. TECHNOLOGY)
(2 Engine/Propeller; 6 Place; 1500 Ft.Field Length; 1500 Mi.Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.13	8.3.15
Type of Engine (2 Installed)		Turboprop	Rot. Comb.
Gross Weight	(lbs)	9187	7523
Weight Empty	(lbs)	4751	4119
Fuel Capacity	(Gal)	482	361
Max. H.P. per engine		511	500
Cruise Speed	(kts)	250	250
Cruise Power	(pct. normal)	90	75
Propeller Diameter	(ft)	17.4	15.06
Wing Loading	(lbs/sq.ft.)	41.7	40.0
Initial Cost (1970 basis)	($)	335,885	172,517
Operating Cost- 100 hrs/yr.	($/mile)	1.686	1.293
- 300 hrs/yr.		0.715	0.601
- 500 hrs/yr.		0.521	0.462

FIGURE 8.3.12
CATEGORY IV COMPARISON
COMBINED EFFECT OF ADVANCED PROPULSION AND MATERIALS (ADV. TECHNOLOGY)
(Single Engine Helicopter; 4 Place; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced
General Arrangement Figure No.		7.5.15	8.3.16
Type of Engine		Turboshaft	Rot. Comb.
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600
Cruise Speed (5000 ft. alt.)	(kts)	150	150
Solidity Ratio		0.100	0.100
Gross Weight	(lbs)	5646	3804
Weight Empty	(lbs)	3501	2259
Main Rotor Diameter	(ft)	46.0	37.8
Disc Loading	(lbs/sq.ft)	3.40	3.40
Max. Engine H.P.		641	477
Initial Cost (1970 Basis)	($)	270,406	153,289
Operating Cost- 100 hrs/yr.	($/Mile)	3.465	2.518
- 300 hrs/yr.		1.388	1.007
- 500 hrs/yr.		0.670	0.705

FIGURE 8.3.9.1 EFFECT OF ADVANCED TECHNOLOGY, CATEGORY I

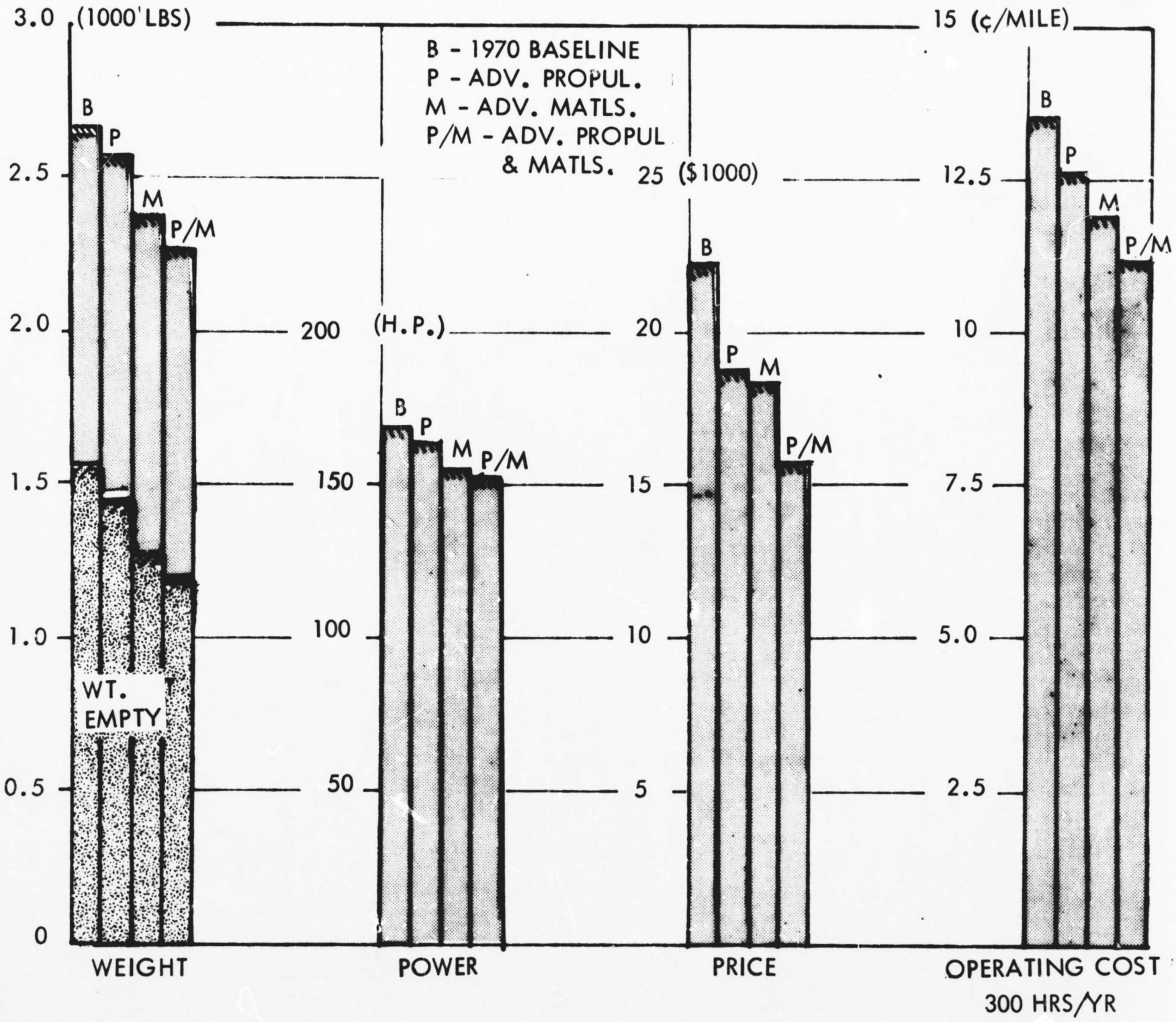


FIGURE 8.3.10.1 EFFECT OF ADVANCED TECHNOLOGY, CATEGORY II

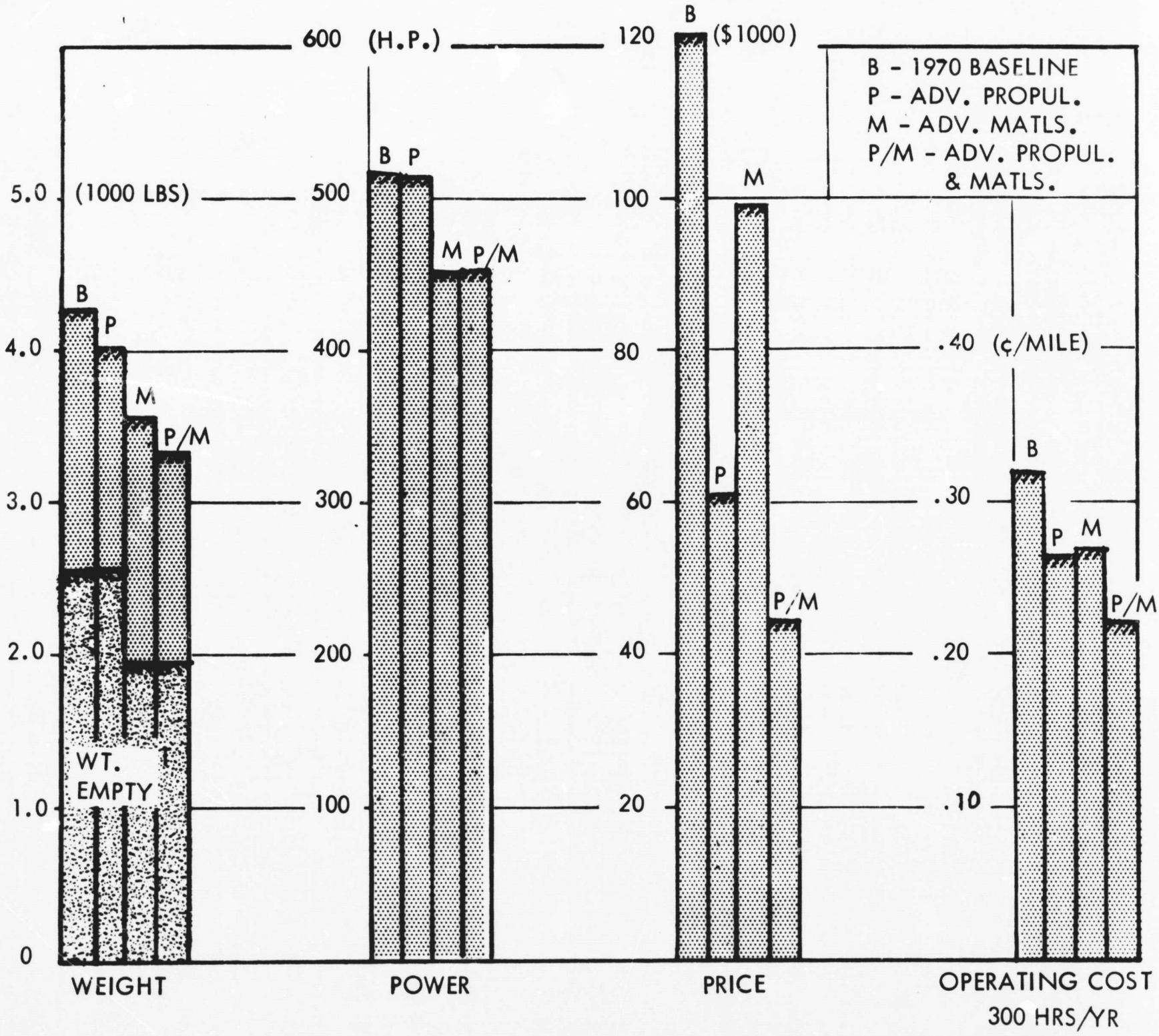


FIGURE 8.3.11.1 EFFECT OF ADVANCED TECHNOLOGY, CATEGORY III

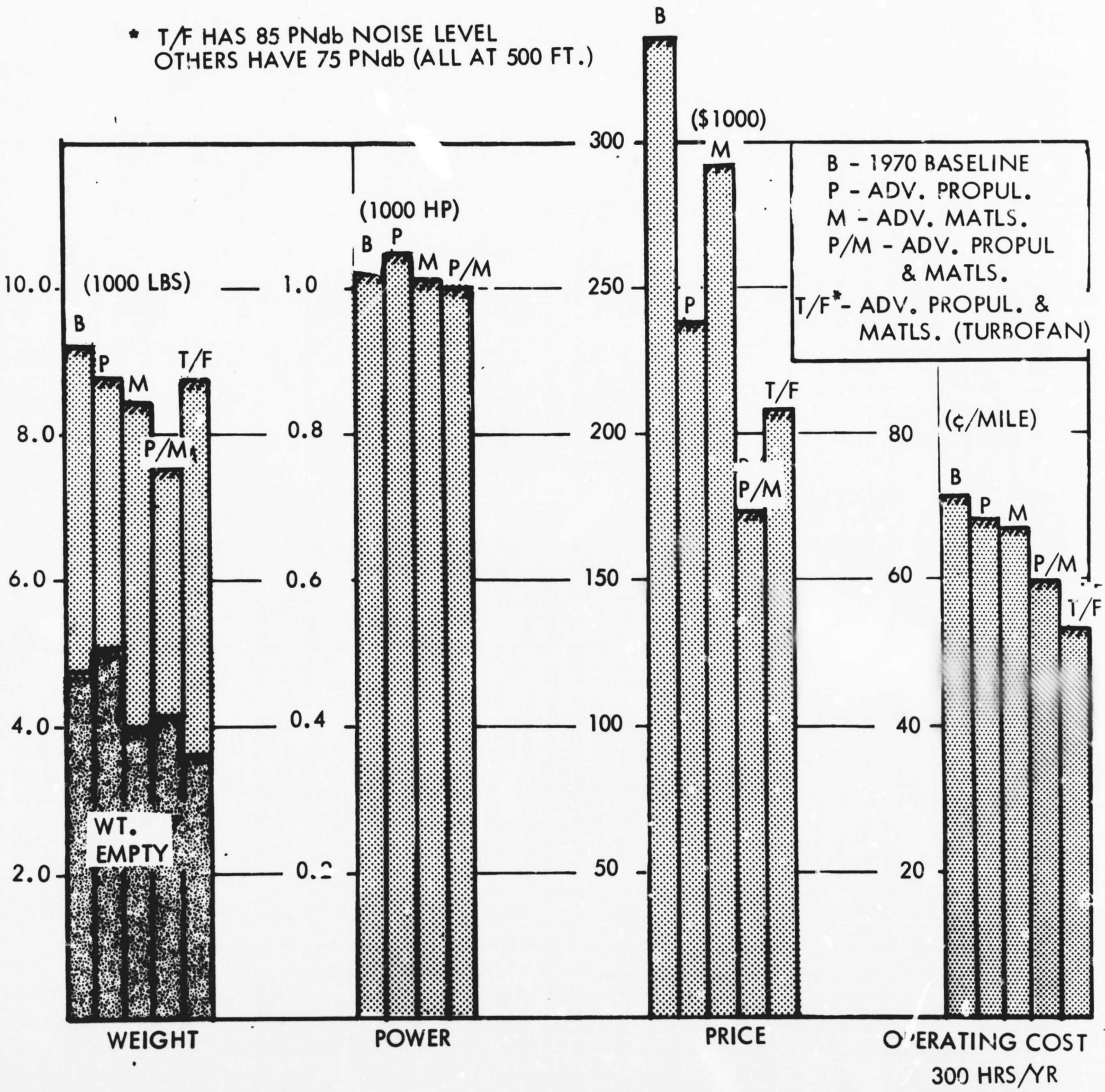
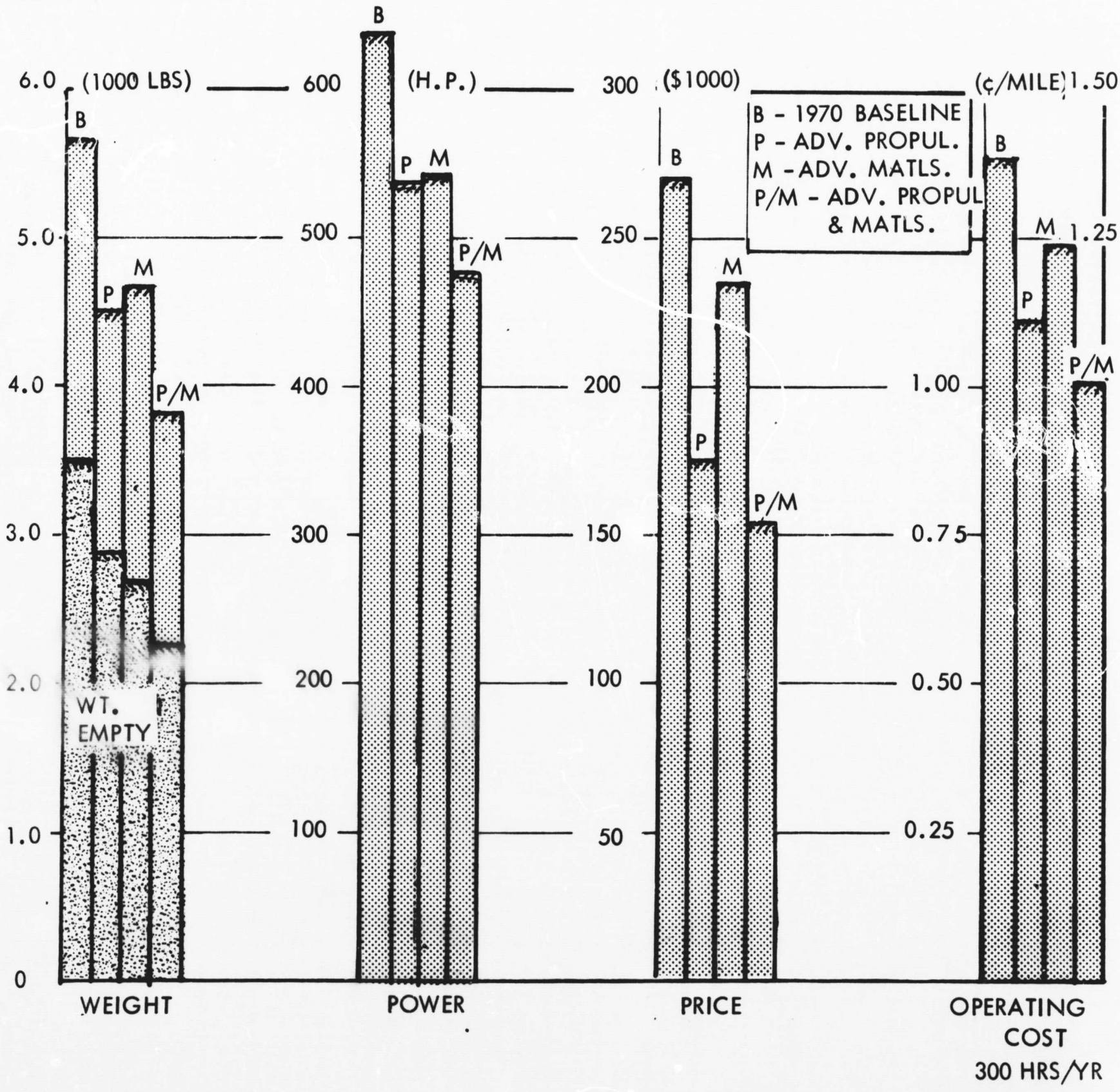
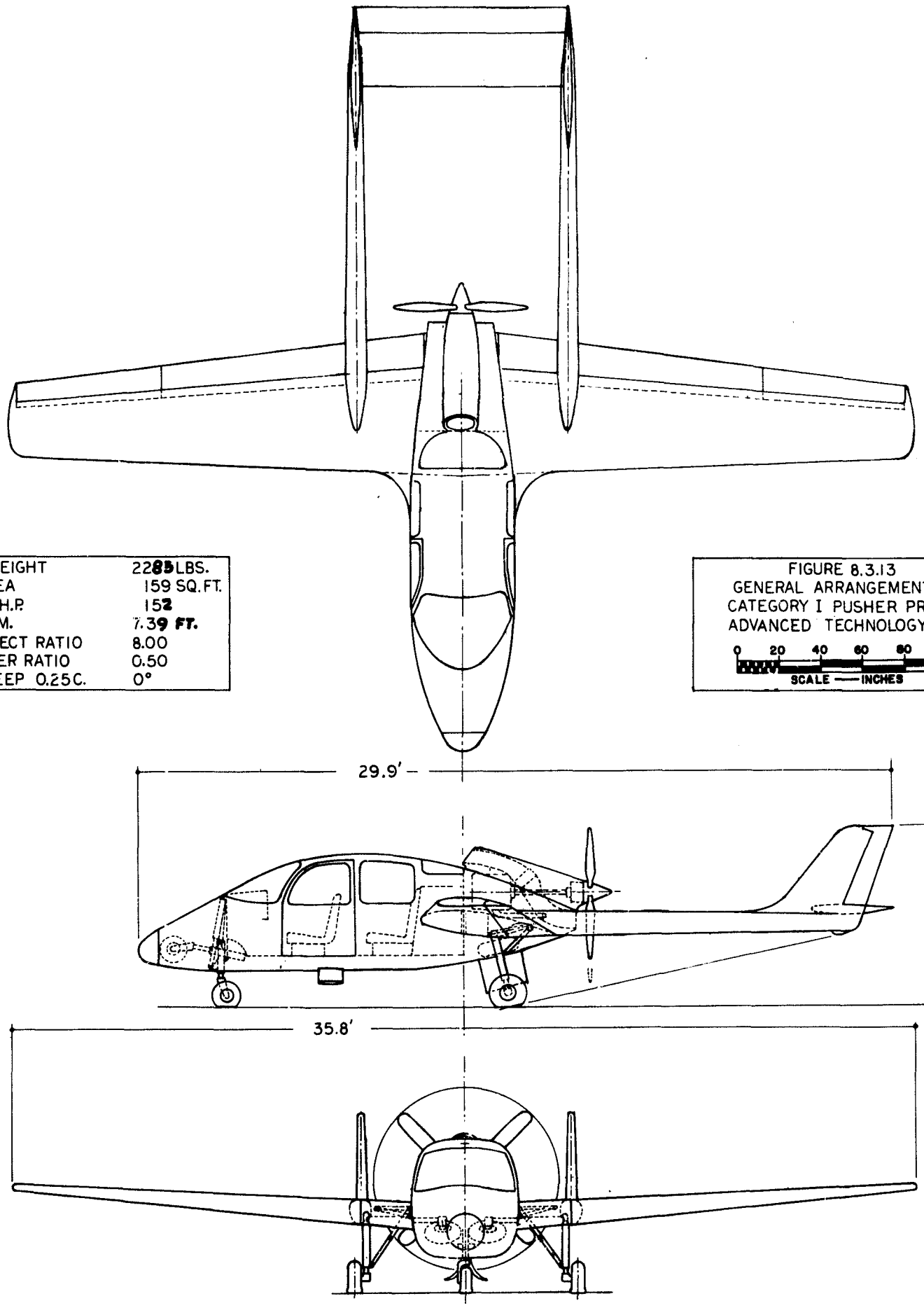


FIGURE 8.3.12.1 - EFFECT OF ADVANCED TECHNOLOGY - CATEGORY IV

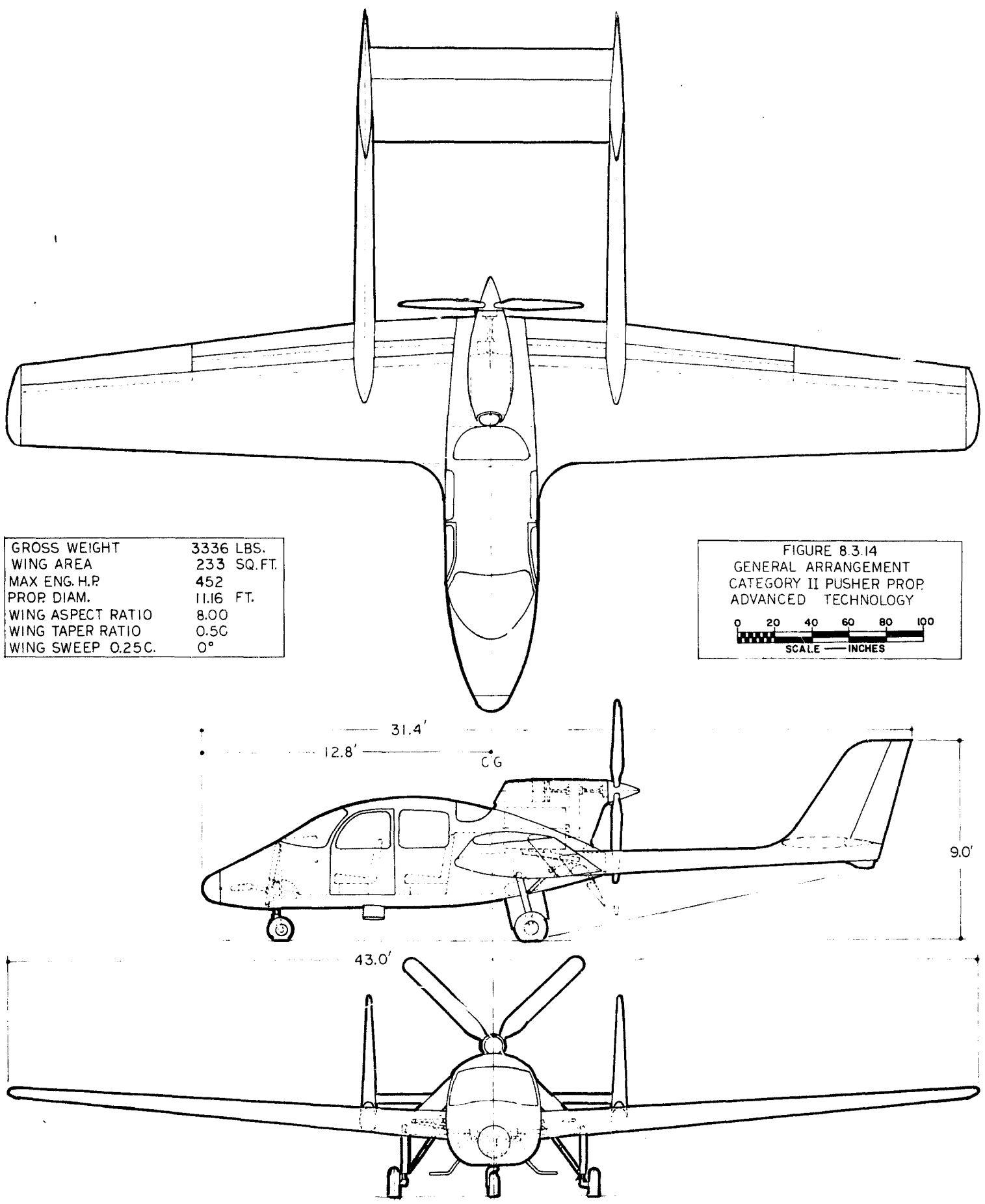




GROSS WEIGHT	2285 LBS.
WING AREA	159 SQ. FT.
MAX ENG. H.P.	152
PROP. DIAM.	7.39 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP 0.25C.	0°

FIGURE 8.3.13
GENERAL ARRANGEMENT
CATEGORY I PUSHER PROP.
ADVANCED TECHNOLOGY

0 20 40 60 80 100
SCALE — INCHES



GROSS WEIGHT	3336 LBS.
WING AREA	233 SQ.FT.
MAX ENG. H.P.	452
PROP. DIAM.	11.16 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.5C
WING SWEEP 0.25C.	0°

FIGURE 8.3.14
GENERAL ARRANGEMENT
CATEGORY II PUSHER PROP.
ADVANCED TECHNOLOGY

0 20 40 60 80 100
SCALE — INCHES

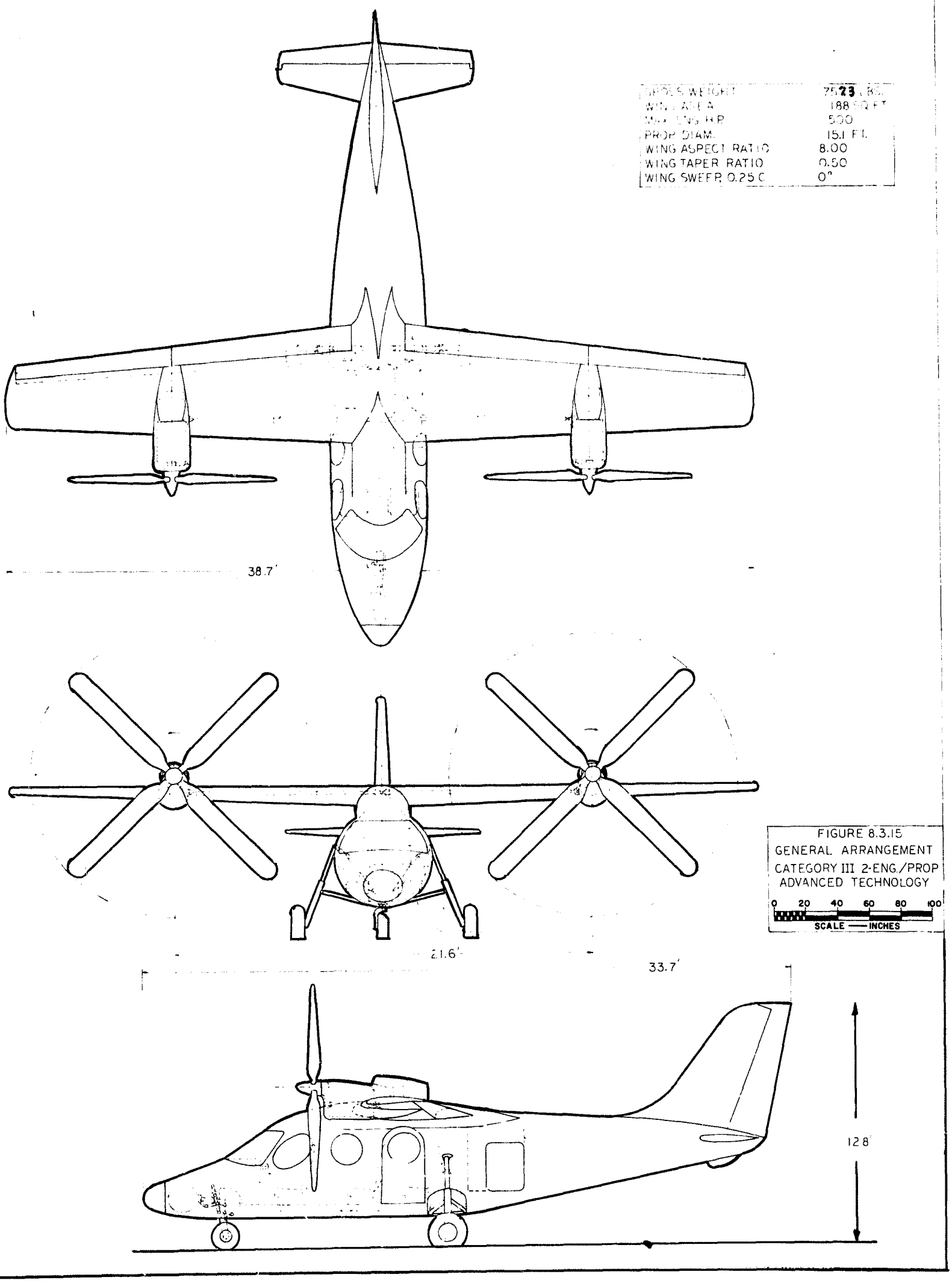
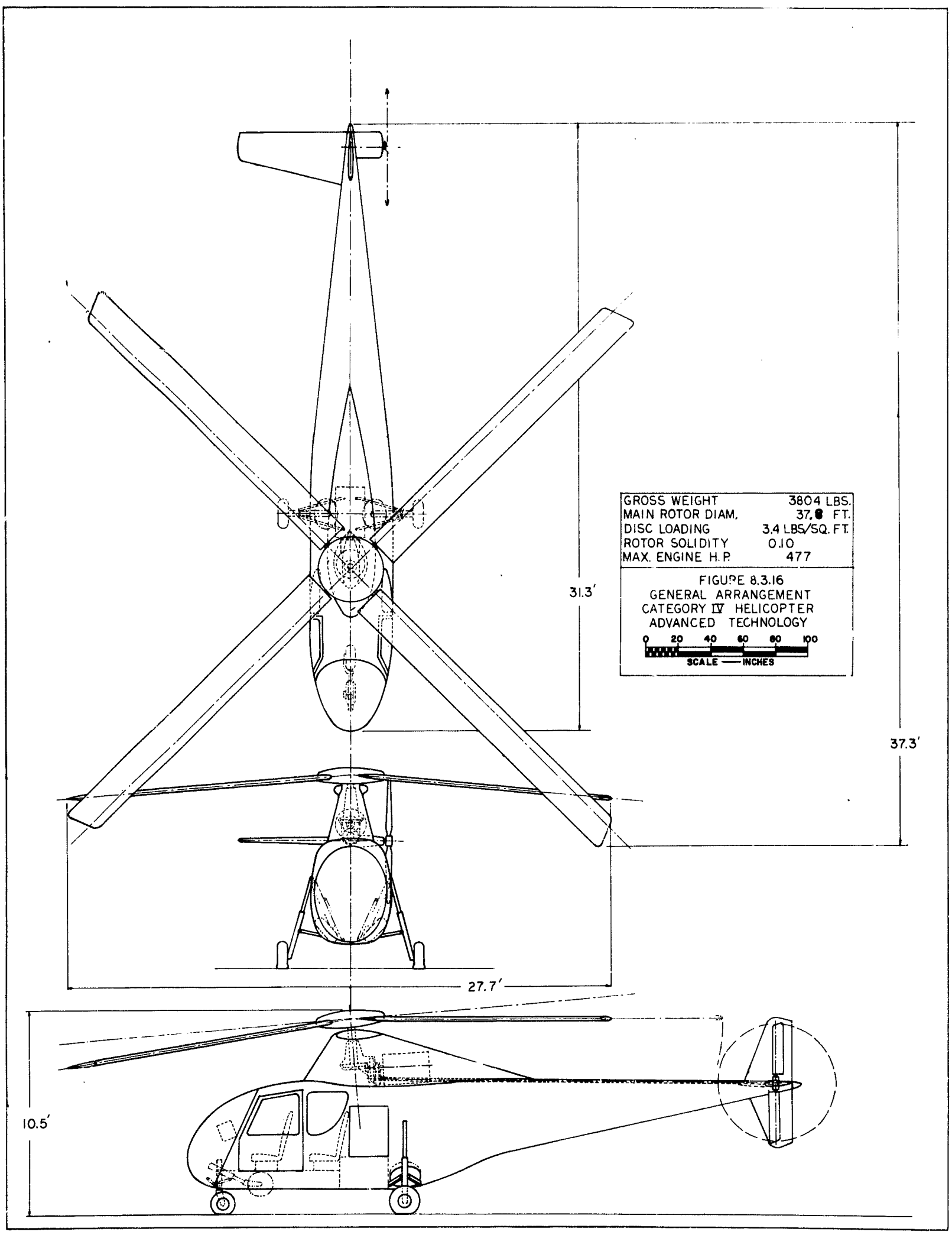


FIGURE 8.3.15
GENERAL ARRANGEMENT
CATEGORY III 2-ENG./PROP
ADVANCED TECHNOLOGY


31.3'
37.3'
27.7'
10.5'
GROSS WEIGHT 3804 LBS.
MAIN ROTOR DIAM. 37.8 FT.
DISC LOADING 3.4 LBS/SQ. FT.
ROTOR SOLIDITY 0.10
MAX. ENGINE H.P. 477
FIGURE 8.3.16
GENERAL ARRANGEMENT
CATEGORY IV HELICOPTER
ADVANCED TECHNOLOGY
0 20 40 60 80 100
SCALE — INCHES

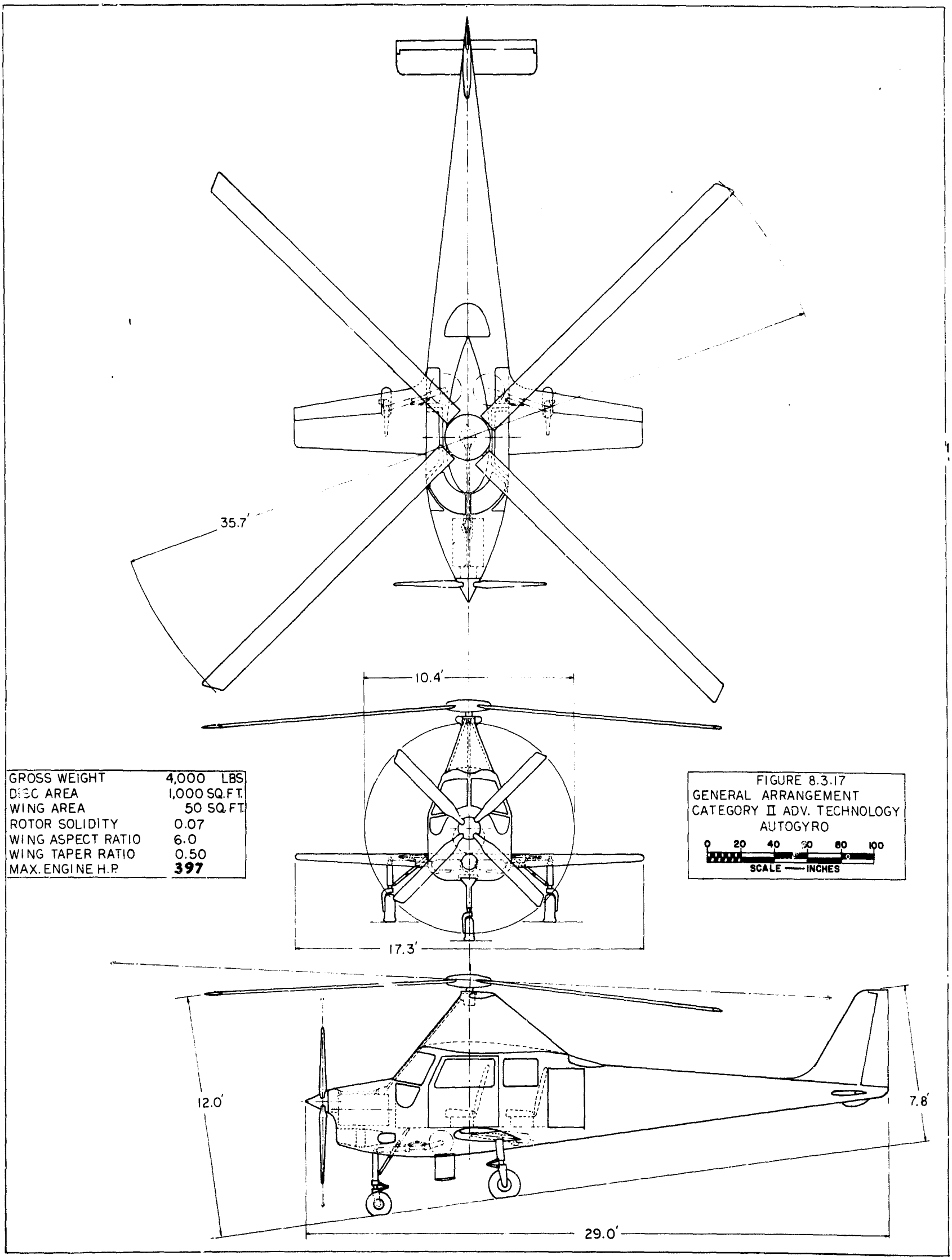
8.3.5 Autogyro Configuration (Category II)

The autogyro configuration was not considered as a baseline candidate in Category II. Since it was programmed for the sensitivity analyses, the effects of advanced technology in both the propulsion and structural areas were included at the start.

Although the autogyro can come close to matching the vertical performance of the helicopter, it is not a true VTOL configuration, and hence has been placed in the STOL Category. The inclusion of rotor run-up by the engine, prior to takeoff, with the blades in flat pitch, permits vertical takeoff with respect to ground distance. However, the rotor becomes immediately disconnected from the engine at lift-off, and the transition into forward flight must rely on rotor inertia until effective forward speed is established by propeller thrust.

It has been assumed that the engine will turn the rotor to a 33% increase over its steady state RPM prior to lift-off, permitting a vertical "jump" to 50 ft., whereupon sufficient forward speed to establish the selected rotor RPM at minimum power must be reached within 500 ft. of the takeoff point, without loss of altitude.

The general arrangement is shown in Figure 8.3.17. The tractor propeller installation was chosen to minimize the cabin height above the ground by the use of positive attitude with respect to the ground. The 200 knot cruising speed requirement of Category II requires the use of a fixed wing to assume 90% of the total lift in cruise, in order to avoid retreating blade stall problems and maximize the L/D ratio. A precedent for this design philosophy was the Air Force/Army XV-1 "Convertiplane," pioneered by the McDonnell Aircraft Corporation and developed during the period between 1951 and 1956. It differed from the design presented here



GROSS WEIGHT	4,000 LBS
DISC AREA	1,000 SQ.FT.
WING AREA	50 SQ.FT.
ROTOR SOLIDITY	0.07
WING ASPECT RATIO	6.0
WING TAPER RATIO	0.50
MAX. ENGINE H.P.	**397**

FIGURE 8.3.17
GENERAL ARRANGEMENT
CATEGORY II ADV. TECHNOLOGY
AUTOGYRO

0 20 40 60 80 100
SCALE — INCHES

by the use of a jet-powered rotor, which permitted true hovering. In cruise flight the wings assumed 90% of the total lift. The development program was wholly successful, although there was no subsequent production (the main objection being rotor noise).

The steady-state rotor tip speed selected is 550 ft/sec, under the 75 PNdb at 500 ft. noise constraint. This speed is consistent with that of the helicopter, discussed in Section 7.5.4. A solidity ratio of 0.07, in combination with an operational blade lift coefficient of 0.48 were selected for minimum rotor drag, which are consistent with a rotor disc loading of 4.0. The wing area was selected using a nominal wing loading of 80 (an actual wing loading of 72 in cruise flight). Drag analysis was consistent with that of the fixed wing aircraft, with the addition of the rotor and a 50% increase of body drag due to rotor interference. The propeller was selected on the basis of the thrust required for acceleration to the speed for minimum T/W in 500 ft. This was found to occur at a rotor blade advance ratio of 0.15, equivalent to about 48 knots, and permits a 750 ft/min. rate of climb after passing the obstacle. The propeller tip speed was programmed for the noise constraint, as a function of thrust/power.

The total drag in cruise flight is expressed as $0.053\ W_g + 3.0q$, from which cruise power can be programmed as $0.0366\ W + 242$ at V_{cr} = 200 knots. Takeoff power is determined by acceleration requirements and is governed by a required thrust/weight ratio of 0.368 at 48 knots. At gross weights above 3,750 lbs, takeoff power exceeds cruise power. The required cruise fuel is determined from cruise power, using an SFC of 0.46, characteristic of the rotating combustion engine. The gross weight, minus the required fuel and payload, establishes an available weight empty figure, which is matched to the required weight empty, determined by integrating the component weights.

Figure 8.3.18 presents a comparison between the autogyro and fixed wing configurations in Category II, showing the latter to be superior with respect to weight and cost. The calculated price is higher by a factor of 4.6, which reflects the higher cost per pound of rotary wing hardware. Nevertheless, the autogyro, though theoretically a STOL aircraft, can be termed a V/STOL for all practical purposes. The table below compares the autogyro in Category II with the helicopter in Category IV:

		Autogyro	Helicopter
General Arrangement Figure No.		8.3.17	8.3.16
Gross Weight	(lbs)	4,000	3,804
Weight Empty	(lbs)	2,559	2,259
Main Rotor Diameter	(ft)	35.7	37.8
Rotor Disc Loading	(lbs/sq.ft)	4.00	3.40
Max. Engine H.P.		397	477
Cruise Speed	(kts)	200	150
Initial Cost (1970 Basis)	($)	207,000	153,289
Operating Cost - 300 hrs/yr.	($/mile)	0.930	1.007

The autogyro therefore might be considered a more desirable candidate than the helicopter in Category IV, since its cruise speed is 50 knots faster and its operating cost at 300 hrs/yr. is 6% less. However, it is 35% more expensive to buy.

FIGURE 8.3.18

CATEGORY II COMPARISON

FIXED WING VS. AUTOGYRO;

ADVANCED PROPULSION AND MATERIALS TECHNOLOGY

Configuration		Fixed Wing	Autogyro
General Arrangement Figure No.		8.3.14	8.3.17
Type of Engine		Rot. Comb.	Rot. Comb.
Gross Weight	(lbs)	3,336	4,000
Weight Empty	(lbs)	1,978	2,559
Fuel Capacity	(gal)	84	93
Max. Engine H.P.		452	397
Cruise Speed	(kts)	200	200
Cruise Power	(pct. normal)	75	98*
Propeller Diameter	(ft)	11.16	10.40
Wing Loading	(lbs/sq.ft)	14.32	80.0
Initial Cost (1970 basis)	($)	45,034	207,000
Operating Cost (300 hrs/year)	($/mile)	0.84	0.93

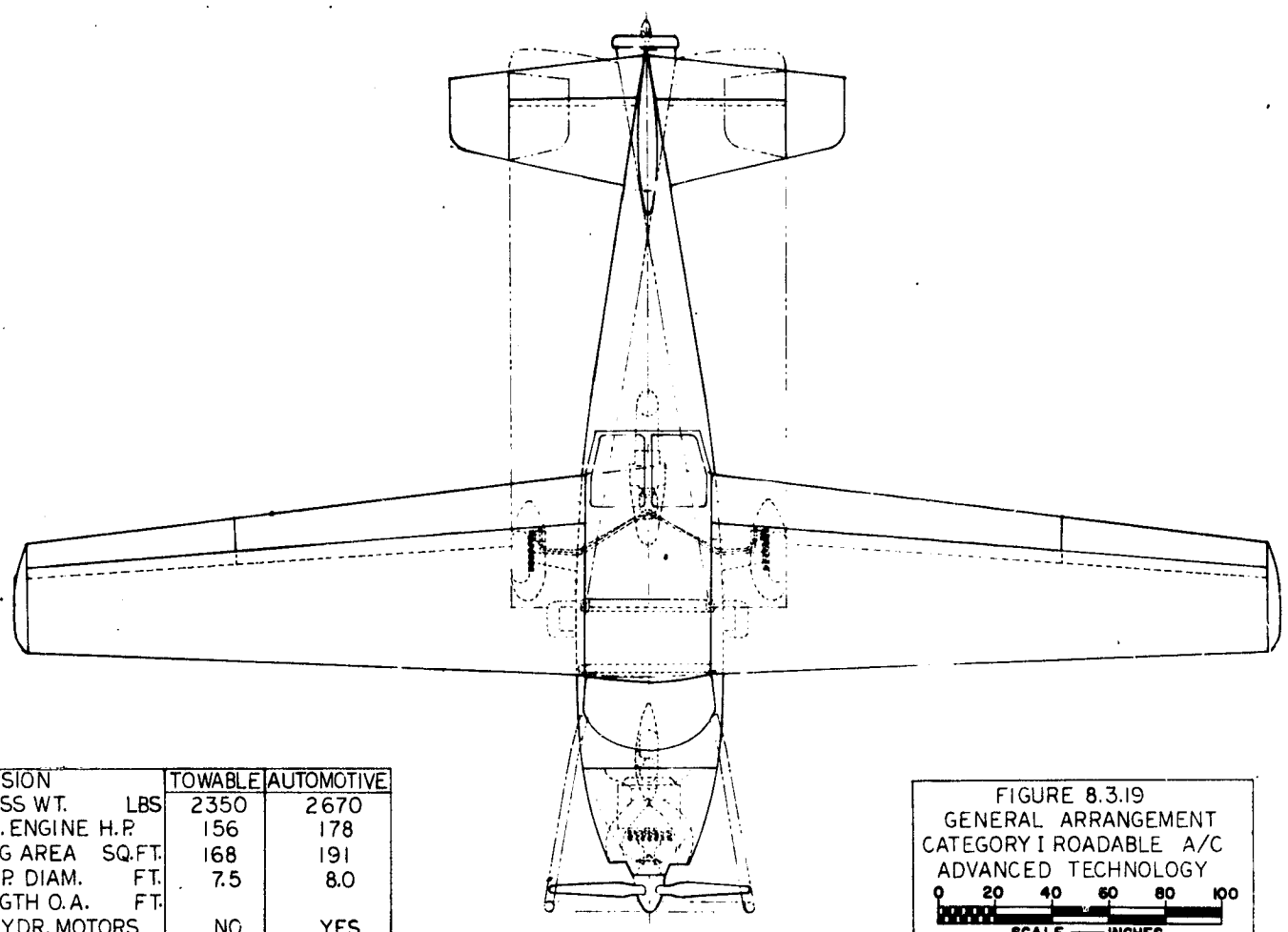
* flat rated

8.3.6 Utility and Convenience Features (Category I)

8.3.6.1 Wing Folding and Roadability - The design and utility philosophy of these features are discussed in Section 5.7.1. A tractor propeller design is analyzed with technology projected to the 1985 time frame.

Two configurations were analyzed: towable and automotive. Both are equipped with manual wing folding, fixed rear bumper with trailer hitch and a removable front bumper. The automotive version features ground traction main wheels, which are powered by a 50 hp APU through a variable volume, hydraulic drive system. This system will permit speeds up to 50 mph on the ground and the ability to negotiate a 10% grade. The system regulates speed against load, similar to the action of an automatic transmission.

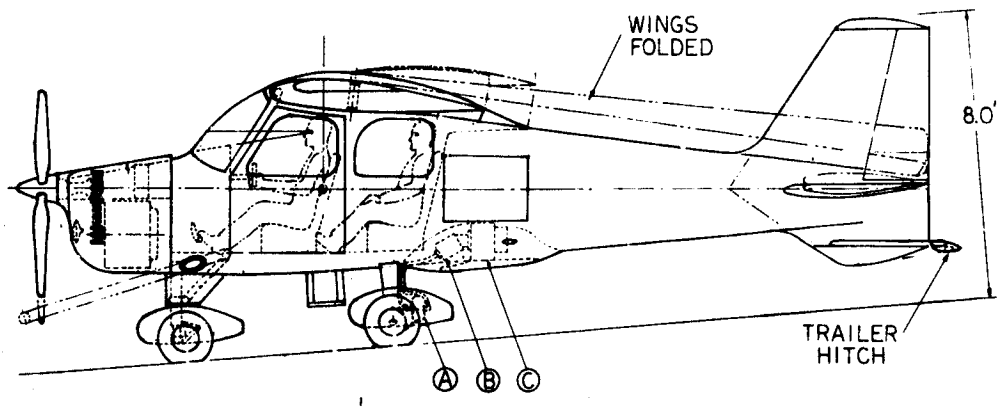
Figure 8.3.19 illustrates the general arrangement and Figure 8.3.20 shows a comparison with the advanced technology baseline pusher design of Category I. The towable version has a 7.5% lower initial cost, due to the fixed (versus retractable) landing gear, but a 10% higher operating cost due to higher drag. The operating cost of the roadable vehicles reflects the absence of tie-down or hangaring cost. The automotive version has a 17% higher initial cost and a 27% higher operating cost at 300 hrs/year. It is doubtful that the latter would appeal to a large section of potential owners, despite the added convenience. Extensive operation on the road might result in extra maintenance problems, plus the risk of damage by collision with automobiles. More frequent FAA inspections would no doubt be required, creating an offsetting inconvenience. It is therefore concluded that the towable version offers appreciable convenience advantages with but a modest increase in operating cost, but that the automotive version would probably not be competitive with conventional aircraft.



VERSION	TOWABLE	AUTOMOTIVE
GROSS WT. LBS	2350	2670
MAX. ENGINE H.P.	156	178
WING AREA SQ.FT.	168	191
PROP. DIAM. FT.	7.5	8.0
LENGTH O.A. FT.		
Ⓐ HYDR. MOTORS	NO	YES
Ⓑ HYDR. PUMP	NO	YES
Ⓒ AUX. POWER UNIT	NO	YES

FIGURE 8.3.19
GENERAL ARRANGEMENT
CATEGORY I ROADABLE A/C
ADVANCED TECHNOLOGY

0 20 40 60 80 100
SCALE — INCHES



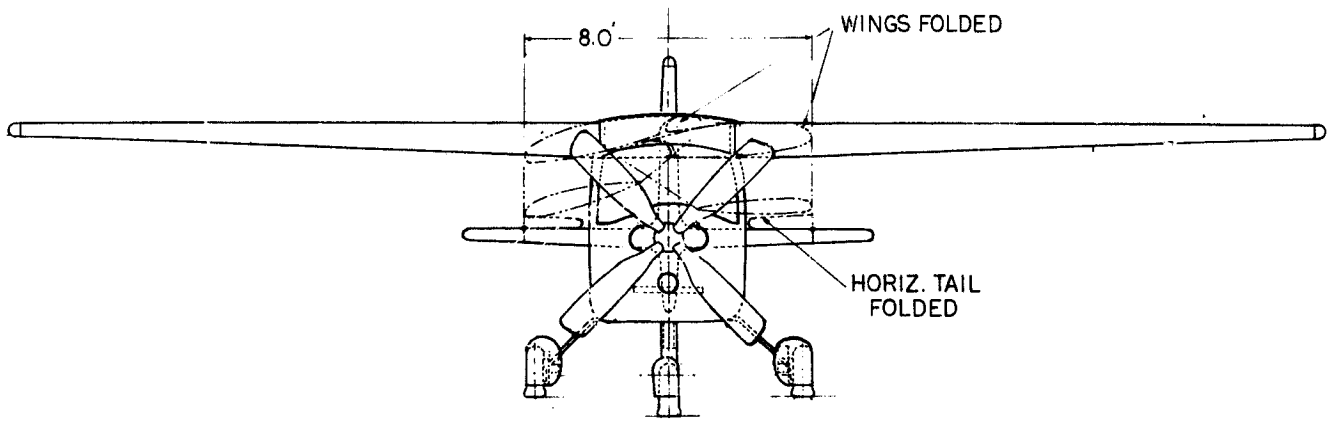


FIGURE 8.3.20

CATEGORY I COMPARISON:

EFFECT OF PROVIDING ROADABILITY;

ADVANCED PROPULSION AND MATERIALS TECHNOLOGY

Configuration		Advanced Conventional	Towable	Automotive
General Arrangement Figure No.		8.3.13	8.3.19	8.3.19
Type of Engine		RC	RC	RC
Gross Weight	(lbs)	2285	2350	2670
Weight Empty	(lbs)	1199	1210	1490
Fuel Capacity	(gal)	36	40	47
Max. Engine H.P.		152	156	178
Cruise Speed	(kts)	145	140	140
Cruise Power	(pct.normal)	75	75	75
Propeller Diameter	(ft)	7.39	7.53	8.04
Wing Loading	(lbs/sq.ft.)	13.89	14.0	14.0
Initial Cost (1970 basis)	($)	15,589	14,400	18,250
Operating Cost- 100 hrs/year.	($/mile)	0.198	0.220	0.253
- 300 hrs/year		0.112	0.124	0.143
- 500 hrs/year		0.095	0.105	0.121

8.3.6.2 All-Terrain Operation

The application of an air cushion landing gear to achieve this objective is discussed in Sections 5.5.2 and 5.7.2. To date, only one application has been made to a general aviation aircraft -- the installation by Bell Aerosystems in a Lake LA-4. It can therefore be stated that very little in the way of technical data is available at the present time. Previous studies performed by the Lockheed-Georgia Company, with application to transport aircraft in the 100,000 to 200,000 lbs gross weight range, have shown that there is an appreciable saving in landing gear weight possible, particularly when an additional power plant to energize the cushion is not required. Since a reasonably accurate analysis of the situation is not presently feasible, it has not been attempted separately. However, an air cushion gear installation, in combination with wing folding and some performance trades, has been analyzed and is covered subsequently in Section 9.0.

8.3.7 Advanced Avionics and Automatic Flight Control

The baseline aircraft of this study do not include any avionics equipment. Section 5.4 contains a full discussion of the present and predicted future course of avionics for general aviation use. The objects in achieving an automatic flight control capability are increased schedule availability of the aircraft and greater safety under IFR conditions. The investigation conducted in this study has led to the inclusion of the following airborne equipment in two alternate packages having varying degrees of utility, reliability and cost. Both have automatic flight control capability. The equipment lists are as follows:

CATEGORY I - VFR OPERATION IN CONTROLLED AIRSPACE

Function	Quantity
VHF Communication	Single
VOR/DME Navigation	Single
Area Navigation Computer	Single
ATC Transponder (1)	Single
Estimated Installed Weight (lbs)	40
Estimated Installed Cost (2)	$6000

Notes:

(1) Includes the intermittent positive control (IPC) functions of altitude reporting, individual identity, and data link.

(2) Computed at $150 per pound of avionics weight, this is considered reasonable for future Category I aircraft.

(3) Controls and Indicators are assumed to be an integral part of the equipment which is instrument panel mounted.

CATEGORY II - IFR OPERATION, MIN. CAPABILITY

Function	
VHF Communication	Single
VOR/ILS/DME Navigation	Single
Area Navigation Computer	Single
Displays(3)	ADI/HSI
Autopilot/Flight Director	Yes
ATC Transponder(1)	Single
Estimated Installed Weight (lbs)	70
Estimated Installed Cost(2)	$17,500

NOTES:

(1) Includes IPC/IFR functions of altitude reporting, individual identity, and data link.

(2) Computed at $250 per pound of avionics weight. This is considered reasonable for future Category II aircraft used for IFR operations.

(3) ADI/HSI separately mounted. Some controls may be integral with the equipment and instrument panel mounted.

CATEGORIES III & IV - IFR OPERATION, MAX. CAPABILITY.

VHF Communication	Dual
VOR/DME Navigation	Dual
Area Navigation Computer	Dual
Microwave ILS	Dual
ATC Transponder(1)	Single
Displays	EADI/EHSI
Autopilot/Flight Director	Yes
Weather Radar	Yes
Collision Avoidance System	ATA-Compatible
Estimated Installed Weight (lbs)	150
Estimated Installed Cost (2)	$48,000

*With altitude reporting, individual identity and data link

NOTES:

(1) Includes IPC/IFR functions of altitude reporting, individual identity, and data link.

(2) Computed at $250 per pound of avionics weight. This is considered reasonable for future Category II aircraft used for IFR operations.

Categories III and IV aircraft are also evaluated with the minimum capability IFR equipment of Category II. For these Categories the maximum capability equipment is designated "A" and the minimum capability equipment is designated "B".

Figures 8.3.23, 8.3.24, 8.3.25 and 8.3.26 present tabular comparisons between the basic and advanced avionics technology aircraft in the four categories. As expected, the resulting increases in weight and size are modest and the increases in initial aircraft cost are in line with the average that operators are paying in proportion to the basic price of the aircraft. It is doubtful if such equipment will ever be offered as standard because a large majority of operators have individual preferences.

FIGURE 8.3.23
CATEGORY I COMPARISON
EFFECT OF ADVANCED AVIONICS AND AUTOMATIC FLIGHT CONTROLS

(Advanced Technology; Single Engine Pusher; 4 Place; 1000 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced Avionics
General Arrangement Figure No.		8.3.13	N.A.
Gross Weight	(lbs)	2285	2358
Weight Empty	(lbs)	1199	1266
Fuel Capacity	(gal)	36	37
Cruise Speed	(kts)	145	145
Max. Engine H.P.		152	155
Propeller Diameter	(ft)	7.39	7.46
Wing Loading	(lbs/sq.ft)	13.89	13.68
Initial Cost (1970 Basis	($)	15,589	21,589
Operating Cost - 100 hrs/yr.	($/Mile)	0.198	0.300
- 300 hrs/yr.		0.112	0.147
- 500 hrs/yr		0.095	0.116

FIGURE 8.3.24
CATEGORY II COMPARISON
EFFECT OF ADVANCED AVIONICS AND AUTOMATIC FLIGHT CONTROL

(Advanced Technology; Single Engine Pusher; 4 Place; 500 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced Avionics
General Arrangement Figure No.		8.3.14	N.A.
Gross Weight	(lbs)	3336	3465
Weight Empty	(lbs)	1978	2027
Fuel Capacity	(gal)	84	86
Max. Engine H.P.		452	459
Cruise Speed	(kts)	200	200
Propeller Diameter	(ft)	11.16	11.32
Wing Loading	(lbs/sq.ft)	14.32	14.15
Initial Cost (1970 Basis	($)	45,034	62,534
Operating Cost - 100 hrs/yr	($/Mile)	0.371	0.446
- 300 hrs/yr		0.221	0.248
- 500 hrs/yr		0.191	0.208

FIGURE 8.3.25
CATEGORY III COMPARISON
EFFECT OF ADVANCED AVIONICS AND AUTOMATIC FLIGHT CONTROL

(Advanced Technology; Twin Engine/Prop; 6 Place; 1,500 Ft. Field Lengtn; 1500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Baseline	Advanced Avionics A	Advanced Avionics B
General Arrangement Fig. No.		8.3.15	N.A.	N.A.
Gross Weight	(lbs)	7523	7809	7651
Weight Empty	(lbs)	4119	4211	4160
Fuel Capacity	(gal.)	361	368	364
Max H.P. per Engine		500	510	504
Cruise Speed	(kts)	250	250	250
Propeller Diameter	(ft)	15.16	15.21	15.18
Wing Loading	(lbs/sq. ft)	39.97	39.35	39.69
Initial Cost (1970 Basis)	($)	172,517	227,066	190,017
Operating Cost- 100 hrs/yr.	($/Mile)	1.293	1.436	1.345
- 300 hrs/yr.		0.601	0.652	0.619
- 500 hrs/yr.		0.462	0.495	0.474

FIGURE 8.3.26

CATEGORY IV COMPARISON
EFFECT OF ADVANCED AVIONICS AND AUTOMATIC FLIGHT CONTROL

(Advanced Technology; Single Engine Helicopter; 4-Place; 500 Mi. Range; 7t PNdb @ 500 Ft.)

Configuration		Baseline	Advanced Avionics A	Advanced Avionics B
General Arrangement Figure No.		8.3.16	N.A.	N.A.
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600	550/600
Cruise Speed (5000 ft. alt.)	(kts)	150	150	150
Solidity Ratio		0.100	0.100	0.100
Rotor Diameter, Drain	(ft.)	37.8	39.5	38.6
Disc Loading	(lbs/sq.ft.)	3.40	3.40	3.40
Gross Weight	(lbs)	3804	4162	3964
Weight Empty	(lbs)	2259	2422	2332
Max. Engine H.P.		477	509	491
Initial Cost (1970 Basis)	($)	153,287	213,992	170,787
Operating Cost- 100 hrs/yr.	($/Mile)	2.518	2.965	2.663
- 300 hrs/yr.		1.007	1.188	1.073
- 500 hrs/yr.		0.705	0.831	0.750

8.4 Effect of Safety Features

8.4.1 General

The requirements and constraints imposed on this study include the evaluation of safety features over and above those presently required by the FAA. These are listed in Section 4.0. Rather than evaluate each item separately, which would be time-consuming and relatively inconclusive, it was decided to assign the required items to two groups: structural safety and system safety. These groups are evaluated separately and in combination.

8.4.2 Extra Structural Safety

This term is not meant to imply that the basic aircraft configurations are unsafe, since they are designed to meet current FAA regulations. The items included in this package provide an extra margin of safety against the relatively few instances when abnormal conditions are encountered. These include severe maneuvers and gusts; hard and moderate crash landings. They include the following provisions:

(a) 9.0 g ultimate maneuver load factor, (or 6.0 g limit load factor) which call for increased strength in the wing, fuselage and tail. Since load factor appears in the statistical weight formulas applied to the computer programs as an experimental term, the effect can be readily expressed in terms of added weight, hence higher cost. This factor represents a 58% increase over that of the baseline designs. This does not apply to the helicopter configuration of Category IV which due to rotor flexure cannot develop applied load factors exceeding about 3.5 g.

(b) 13 ft/sec design rate of sink, which directly effects the weight and cost of the landing gear. In order to preserve

the same maximum load transmitted to the body structure as does a landing gear designed for the standard 10 ft/sec. rate, the shock absorber stroke must be increased. Using the basic energy formula, an 80% increase of stroke is required, which was found to increase the length of the average gear applied to this study by 30% since length appears as an exponential term in the statistical landing gear weight formula; The effect can readily be expressed in terms of added weight and cost.

(c) Crash Resistant Structure, which is difficult to define without a detailed analysis of each design. After reviewing similar applications, it was decided to use a weight increase factor of 1.10 applied to that of the fuselage. With careful design practice, impact velocities of 20 to 30 ft/sec. with vertical accelerations of 12 to 15 g. can be sustained, with zero to relatively minor injury of the occupants. This weight allowance includes shoulder harness, integral seats, and extra restraint of the engine and other potentially lethal items. It also implies a base structure of energy absorbing material, which cushions the impact shock by yielding.

8.4.3 Extra Systems Safety.

Again, this term implies an extra degree of safety over that of present general aviation aircraft systems. Its purpose is to provide extra safety in abnormal weather, prevent fire after severe impact and offer pilot control aids, particularly in the landing operation. It also includes provision for locating the airplane after a forced landing.

The systems safety package includes the following items:

(a) A wing, tail, and propeller anti-icing system, which can take a number of forms. For most purposes, the leading edge flexible boot type is best for the wing and tail, while intermittent electrical resistance heat is usually best for the propeller. The total subsystem weight is estimated to be 0.5 lbs. per sq. ft. of wing area.

(b) A lateral stabilization, or wing leveling device to insure level landings and to relieve the work load during cruise flight. This is a single axis autopilot of a type currently provided in contemporary aircraft, and is estimated to weigh 3 lbs. and cost $600 in 1985.

(c) An automatic landing flare system, measuring height above the runway by using a radio altimeter and outputting a signal to an actuator in the form of a stick puller, or a series actuator in the elevator control system. The main components are: radio altimeter; accelerometer; flare computer; actuator. The estimated installed weight is 7.0 lbs., with an installed cost of $2500 in 1985.

(d) A crash locater beacon, which is actuated by impact and transmits an identifiable signal which enables search parties to locate the disabled aircraft. It is estimated to weigh 2 lbs. and cost $100 in 1985.

(e) Remote fuel tank location, to avoid spilling fuel in the vicinity of the cabin, following a crash. These units can be either in the outboard half of the wing or can be streamlined tip tanks. The effect of the latter is generally to reduce the lift-induced drag enough to offset the increase in zero lift drag. The internal tanks would be constructed of tear-resistant, flexible material. An additional weight allowance of 0.05 lbs. per lb. of fuel has been made for this provision.

(f) A fire retardant system for the fuel system to prevent the outbreak of fire if the fuel tanks become ruptured. This can be either a pressurized gas inerting system or the use of reticulated foam in the tank. The latter method inhibits fire by enriching the gasoline/air mixture by causing particles of fuel to cling to the foam, and is in present use by the military to prevent fire due to the entrance of incendiary bullets. An additional weight allowance of 0.05 lbs. per lb. of fuel has been made for this provision.

8.4.4 Extra Total Safety

This term implies a combination of Extra Structural Safety and Extra System Safety.

Figures 8.4.1, 8.4.2, 8.4.3 and 8.4.4 compare the separate effects of adding Extra Structural Safety and Extra System Safety, and their combined effect, on the basic advanced technology aircraft in each of the four categories. Except for Category I, the addition of Extra Syster Safety is less costly than that of Extra Structural Safety. The former is believed to be more effective in providing a higher level of safety, since statistics show a relatively small number of severe or fatal accidents due to structural failure.

The Extra Total Safety package increases the initial cost by 71% in Category I; 75% in Category II; 50% in Category III and 16% in Category IV. The operating cost at 300 hrs/yr. is increased by 32% in Category I; 37% in Category II; 18% in Category III; and 8% in Category IV. The price of extra safety is, therefore, quite high and the willingness of prospective buyers to pay the price for extra peace of mind is questionable. The one category in which extra safety appears to be reasonably priced is Category IV. The helicopter does not require the additional weight allowance for high maneuver loads, and the provisions for high rate of descent and automatic flare enhance the inherent safety provided by autorotative landing capability. The effect on insurance rates have not been included for lack of specific information. A 50% rate reduction would bring about, approximately, a 10% reduction in operating cost.

FIGURE 8.4.1
CATEGORY I COMPARISON
EFFECT OF SAFETY PROVISIONS

(Advanced Technology; Single Engine Pusher; 4 Place; 1,000 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Basic	Extra Struct. Safety	Extra System Safety	Extra Total Safety
General Arrangement Figure No.		8.3.13	N.A.	N.A.	N.A.
Gross Weight	(lbs)	2285	2563	2494	2868
Weight Empty	(lbs)	1199	1461	1268	1592
Fuel Capacity	(gal)	36	39	38	42
Max. Engine H.P.		152	164	161	177
Cruise Speed	(kts)	145	145	145	145
Propeller Diameter	(ft.)	7.39	7.68	7.61	7.99
Wing Loading	(lbs/sq.ft)	13.89	13.00	13.20	12.25
Initial Cost (1970 Basis)	($)	15,589	20,276	20,201	26,350
Operating Cost -100 hrs/yr.	($/mile)	0.198	0.235	0.228	0.276
-300 hrs/yr.		0.112	0.129	0.129	0.147
-500 hrs/yr.		0.095	0.108	0.103	0.120

FIGURE 8.4.2
CATEGORY II COMPARISON
EFFECT OF SAFETY PROVISIONS

(Advanced Technology; Single Engine Pusher; 4 Place; 500 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Basic	Extra Struct. Safety	Extra System Safety	Extra Total Safety
General Arrangement Figure No.		8.3.14	N.A.	N.A.	N.A.
Gross Weight	(lbs)	3336	3929	3749	4541
Weight Empty	(lbs)	1978	2499	2137	2803
Fuel Capacity	(gal)	84	94	91	104
Max. Engine H.P.		452	505	489	560
Cruise Speed	(kts)	200	200	200	200
Propeller Diameter	(ft)	11.16	11.80	11.60	12.43
Wing Loading	(lbs/sq.ft)	14.32	13.49	13.72	12.83
Initial Cost (1970 Basis)	($)	45,034	62,438	54,181	78,453
Operating Cost- 100 hrs/yr.	($/Mile)	0.371	0.457	0.416	0.537
- 300 hrs/yr.		0.221	0.263	0.244	0.302
- 500 hrs/yr.		0.191	0.224	0.209	0.255

FIGURE 8.4.3
CATEGORY III COMPARISON
EFFECT OF SAFETY PROVISIONS

(Advanced Technology; 2-engine/propeller; 6 Place; 1,500 Ft. Field Length; 1,500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Basic	Extra Struct Safety	Extra Systems Safety	Extra Total Safety
General Arrangement Figure No.		8.3.15	N.A.	N.A.	N.A.
Gross Weight	(lbs)	7523	8434	8139	9348
Weight Empty	(lbs)	4119	4902	4319	5270
Fuel Capacity	(gal)	361	38[illegible]	376	408
Max. H.P. per Engine		500	532	521	564
Cruise Speed	(kts)	250	250	250	250
Propeller Diameter	(ft)	15.06	15.53	15.38	15.99
Wing Loading	(lbs/sq.ft)	39.97	38.13	38.69	36.61
Initial Cost (1970 Basis)	($)	172,517	226.065	190,057	259,423
Operating Cost- 100 hrs/yr.	($/mile)	1.293	1.449	1.348	1.552
- 300 hrs/yr.		0.601	0.666	0.626	0.713
- 500 hrs/yr.		0.462	0.510	0.482	0.545

FIGURE 8.4.4
CATEGORY IV COMPARISON
EFFECT OF SAFETY PROVISIONS

(Advanced Technology; Single Engine Helicopter; 4 Place: 500 Mi. Range; 75 PNdb @ 500 Ft.)

Configuration		Basic	Extra Struct. Safety	Extra System Safety	Extra Total Safety
General Arrangement Figure No.		8.3.16	N.A.	N.A.	N.A.
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600	550/600	550/600
Cruise Speed (500 ft.alt.)	(kts)	150	150	150	150
Solidity Ratio		0.100	0.100	0.100	0.100
Rotor Diameter, Main	(ft)	37.8	38.7	38.7	39.8
Disc Loading	(lbs/sq.ft)	3.40	3.40	3.40	3.40
Gross Weight	(lbs)	3804	4001	3999	4212
Weight Empty	(lbs)	2259	2431	2348	2532
Max. Engine H.P.		477	495	495	514
Initial Cost (1970 Basis)	($)	153,287	166,276	163,408	177,389
Operating Cost- 100 hrs/yr.	($/mile)	2.518	2.630	2.608	2.734
- 300 hrs/yr.		1.007	1.053	1.044	1.092
- 500 hrs/yr.		0.705	0.738	0.731	0.765

8.5 Effect of Environmental Factors

8.5.1 Cabin Pressurization and High Cruise Altitude

These provisions are applied to the basic advanced technology aircraft in Categories I, II and III. The helicopter in Category IV cannot fly at its design cruise speed at altitudes in excess of 5000 ft. because of its low rotor RPM, which would create retreating blade stall in lower density air. The low RPM is a result of the noise level constraint. Flight above 5000 ft requires reduced weight and speed.

The application of cabin pressurization has been discussed in Section 5.6.1. It calls for a circular or near circular fuselage cross-section, so that the loads due to internal pressure can produce hoop tension stresses in the skin, rather than bending stresses in the frames. The use of fiber composite material, joined adhesively, provides adequate sealing without penalty. The rotating combustion engines are equipped with turbo-chargers, to provide sea level pressure to the engine air intake system at altitudes up to 20,000 ft. The air supply for pressurizing the cabin is bled from the turbocharger, passed through an intercooler and admitted to the cabin through a pressure regulator. A maximum cabin pressure differential of 4.5 psi is used. Refrigeration at low altitude is not provided, since it would become optional equipment, as in automobiles.

The weight and cost of the complete turbocharger system and intercooler are incorporated in the pressurized aircraft data. In addition, the fuselage weight is increased 10 percent for pressurization loads. The effect of this change on the total increase in cost and weight of the airplane is also included It is assumed that the turbocharger bleed connection, and pressure regulator bleed valve,would be included in the weight and cost increases due to the above allowances.

Figures 8.5.1, 8.5.2, and 8.5.3 present tabular comparisons between the basic and high altitude versions of the advanced technology aircraft in Categories I, II and III. Category I shows only a 3% increase of initial cost, and a 5% decrease in operating cost - the latter being due to lower fuel consumption. The main disadvantage is a reduction of wing loading, causing a 47% increase of wing area. This complicates the problem of ground handling and storage, as well as increasing gust sensitivity. An increase in

FIGURE 8.5.1
CATEGORY I COMPARISON
EFFECT OF PRESSURIZATION AND HIGH CRUISE ALTITUDE

(Advanced Technology; Single Engine Pusher; 4 Place; 1000 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.

Cruise Altitude	(ft)	7500	20,000
Cabin Pressurization		No	Yes
General Arrangement Figure No.		8.3.13	N.A.
Gross Weight	(lbs)	2285	2339
Weight Empty	(lbs)	1199	1268
Fuel Capacity	(gal)	36	34
Max. Engine H.P.		152	133
Cruise Speed	(kts)	145	145
Propeller Diameter	(ft)	7.39	6.91
Wing Loading	(lbs/sq.ft.)	13.89	9.64
Initial Cost (1970 Basis)	($)	15,589	15,992
Operating Cost- 100 hrs/yr.	($/mile)	0.198	0.194
- 300 hrs/yr.		0.112	0.106
- 500 hrs/yr.		0.095	0.088

FIGURE 8.5.2
CATEGORY II COMPARISON
EFFECT OF PRESSURIZATION AND HIGH CRUISE ALTITUDE

(Advanced Technology; Single Engine Pusher; 4 Place; 500 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Cruise Altitude	(ft)	7500	20,000
Cabin Pressurization		No	Yes
General Arrangement Fig. No.		8.3.14	N.A.
Gross Weight	(lbs)	3336	3274
Weight Empty	(lbs)	1978	1965
Fuel Capacity	(gal)	84	71
Max. Engine H.P.		452	367
Cruise Speed	(kts)	200	200
Propeller Diameter	(ft)	11.16	10.05
Wing Loading	(lbs/sq.ft)	14.32	10.97
Initial Cost (1970 Basis)	($)	45,034	41,823
Operating Cost- 100 hrs/yr.	($/mile)	0.371	0.333
- 300 hrs/yr.		0.221	0.192
- 500 hrs/yr.		0.191	0.163

FIGURE 8.5.3
CATEGORY III COMPARISON
EFFECT OF PRESSURIZATION AND HIGH CRUISE ALTITUDE

(Advanced Technology; 2 engine/propeller; 6 Place; 1,500 Ft. Field Length; 1,500 Mi. Range; 75 PNdb @ 500 Ft.)

Cruise Altitude	(ft)	7,500	20,000
Cabin Pressurization		No	Yes
General Arrangement Figure No.		8.3.15	N.A.
Gross Weight	(lbs)	7,523	6,624
Weight Empty	(lbs)	4,119	3,692
Fuel Capacity	(gal)	361	279
Max. H.P. per engine		500	378
Cruise Speed	(kts)	250	250
Propeller Diameter	(ft)	15.06	13.09
Wing Loading	(lbs/sq.ft.)	39.97	33.95
Initial Cost (1970 Basis)	($)	172,517	136,234
Operating Cost- 100 hrs/year	($/mile)	1.293	1.141
- 300 hrs/year		0.601	0.510
- 500 hrs/year		0.462	0.384

design cruise speed would partially offset this effect, but with some cost penalty.

Category II shows a 7% reduction of initial cost and a 13% decrease in operating cost. Wing loading is also reduced, but the increase in wing area is partly offset by a reduction in gross weight, becoming only 17.5%. The high altitude version in this category is therefore highly recommended.

Category III shows a 21% reduction of initial cost and a 15% decrease in operating cost. The wing area increase is only 3.5%. The high altitude version is advantageous in every way.

In summation, high altitude operation with a pressurized cabin is fully recommended for the aircraft in Categories II and III. In Category I it should be acoompanied by the provision of a higher cruise speed, hence more engine power, to offset the requirement for more wing area. High altitude operation in Category IV is not feasible.

8.5.2 Effect of External Noise Level

The methodology for selecting propellers to meet a required noise level is covered in Section 5.2.9. The standard noise constraint for the baseline aircraft in all categories is 75 PNdb at 500 ft. This is believed to be the lowest practical level which can be achieved in the 1985 time frame. To assess the penalties, if any, due to quiet operation, two higher levels were selected for evaluation: 85 PNdb and 95-110 PNdb (propellers optimized without regard to noise).

During the parametric analysis stage, the present technology baseline aircraft were analyzed with both 75 PNdb and "noisy" propellers. The results showed that the low noise level propeller in Category I

resulted in both lower initial and operating costs, (see Figure 7.5.3) because the lower engine power required, by virtue of higher thrust-to-horsepower ratio, had a cost reducing effect enough to overcome the increased cost of the larger propeller required.

The opposite effect was noted in Categories II and III. The advanced technology aircraft in Category I was therefore not analyzed for higher noise levels.

Figures 8.5.5, 8.5.6 and 8.5.7 compare the effect of increasing the noise level in Categories II, III and IV, respectively. Category II shows 3% and 19% reductions of initial cost with noise levels of 85 and 107 PNdb, respectively, and respective operating cost reductions at 300 hrs/yr of 2% and 6.5%. The reduction of propeller diameter is significant only at the high noise level. The Category II aircraft, having STOL capability, would be operated, normally, in densely populated areas and therefore will require a low noise level, with 75 PNdb recommended.

Category III shows 27% and 40% reductions of initial cost with noise levels of 85 and 110 PNdb, respectively, and respective operating cost reductions at 300 hrs/yr of 10% and 14%. In this case, operation would take place at principal and satellite airports, where a higher noise level is tolerated. Although the FAA is recommending a maximum level of 95 PNdb for all aircraft, it is believed that Category III aircraft should be designed for a lower level, with 85 PNdb recommended.

Category IV shows no cost difference at the 85 PNdb noise level, because the same rotor tip speed is maintained in cruise flight, and the power required for cruise sizes the helicopter. The higher tip speed in hovering produces the higher noise level. Going to 95 PNdb, the decrease of initial cost amounts to only 1% and that of operating cost

FIGURE 8.5.5
CATEGORY II COMPARISON
EFFECT OF EXTERNAL NOISE LEVEL

(Advanced Technology; Single Engine Pusher; 4 Place; 500 Ft. Field Length; 500 Mi. Range)

External Noise Level	(PNdb @ 500 ft.)	75	85	107
General Arrangement Fig. No.		8.3.14	N.A.	N.A.
Gross Weight	(lbs)	3336	3278	3113
Weight Empty	(lbs)	1978	1926	1752
Fuel Capacity	(gal.)	84	83	83
Max. Engine H.P.		452	447	449
Cruise Speed	(kts)	200	200	200
Propeller Diameter	(ft)	11.16	10.21	7.42
Propeller Thrust	(lbs/hp)	5.0	5.0	4.5
Propeller RPM		764	1122	2577
Propeller Tip Speed	(ft/sec)	446	600	1000
Wing Loading	(lbs/sq.ft)	14.32	14.42	13.37
Initial Cost (1970 Basis)	($)	45,034	43,475	36,227
Operating Cost- 100 hrs/yr.	($/mile)	0.371	0.363	0.334
- 300 hrs/yr.		0.221	0.217	0.207
- 500 hrs/yr.		0.191	0.188	0.181

FIGURE 8.5.6
CATEGORY III COMPARISON
EFFECT OF EXTERNAL NOISE LEVEL

(Advanced Technology; 2 engine/propeller; 6 Place; 1500 Ft. Field Length; 1500 Mi.Range)

External Noise Level	(PNdb @ 500 ft)	75	85	110
General Arrangement Figure No.		8.3.15	N.A.	N.A.
Gross Weight	(lbs)	7,523	6,766	6,364
Weight Empty	(lbs)	4,119	3,480	3,098
Fuel Capacity	(gal)	361	341	338
Max. H.P. per Engine		500	475	467
Cruise Speed	(kts)	250	250	250
Propeller Diameter	(ft.)	15.06	11.00	7.56
Propeller Thrust	(lbs/hp)	5.0	5.0	4.5
Propeller RPM		578	1040	2569
Propeller Tip Speed	(ft/sec)	455	600	1020
Wing Loading	(lbs/sq.ft.)	39.97	41.81	38.04
Initial Cost (1970 Basis)	($)	172,517	125,499	102,884
Operating Cost- 100 hrs/yr.	($/mile)	1.293	1.157	1.093
- 300 hrs/yr.		0.601	0.544	0.518
- 500 hrs/yr.		0.462	0.421	0.403

FIGURE 8.5.7
CATEGORY IV COMPARISON
EFFECT OF EXTERNAL NOISE LEVEL

(Advanced Technology; Single Engine Helicopter; 4-Place; 500 Mi. Range)

Noise Level (PNdb at 500 ft.)		75	85	95
General Arrangement Fig. No.		8.3.16	*	*
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	600/600	700/700
Cruise Speed (5,000 ft. alt.)	(kts)	150	150	150
Solidity Ratio		0.100	0.100	.0545
Rotor Diameter, Main	(ft)	37.8	37.8	37.8
Disc Loading	(lbs/sq.ft)	3.40	3.40	3.40
Gross Weight	(lbs)	3804	3804	3804
Weight Empty	(lbs)	2259	2259	2248
Max. Engine H.P.		477	477	450
Initial Cost, 1970 Basis	($)	153,287	153,287	151,800
Operating Cost- 100 hrs/yr.	($/mile)	2.518	2.518	2.476
- 300 hrs/yr.		1.007	1.007	0.990
- 500 hrs/yr.		0.705	0.705	0.692

* Fig. 8.3.16 is applicable.

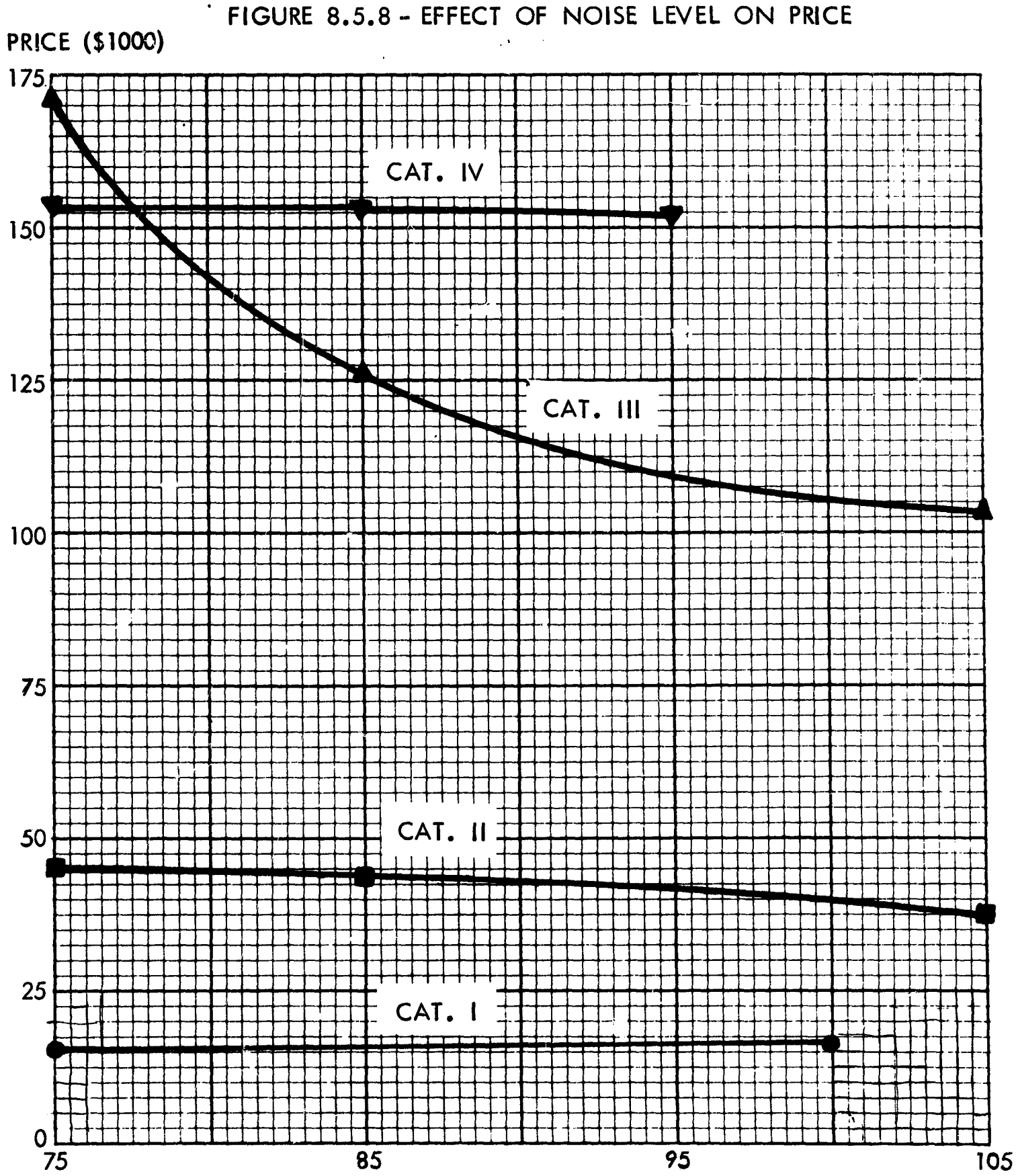
at 300 hrs/yr. is only 2%. As is the case for Category II, normal operation will take place in densely populated areas. Maintenance of a 75 PNdb noise level at 500 ft. imposes no particular penalty and is recommended.

Figure 8.5.8 presents a graphic plot of the effect of noise level on price. It is seen to have a slightly increasing trend in Category I, because of more power required to produce the required propeller thrust as tip speed is increased. Price decreases with noise level in Category II to a mild extent, but is reduced drastically in Category III. As for Category IV, however, there is no appreciable effect on price between 75 and 95 PNdb.

8.5.3 Effect of Engine Emission Abatement

This subject is discussed in Section 5.2.6, where it is pointed out that all aircraft contribute less than 2% to the total air pollution. Nevertheless, it is believed that the controls imposed on automobiles of the future will have equal application to aircraft. At the present time, it is not known what form the pollution control will take, hence an analysis of the effect on size and cost would be purely speculative. Close control of the fuel-air mixture is essential, and it has been assumed that engine technology in 1985 will include electronically controlled fuel injection systems. As to other devices, if necessary, it can only be assumed that whatever is technically feasible will be required by law, hence integral with the engine. The equipment included with the rotating combustion engine, plus the item called "miscellaneous propulsion equipment" are believed to have sufficient weight and cost allowances to include adequate emission controls. For these reasons, this subject was not separately evaluated.

FIGURE 8.5.8 - EFFECT OF NOISE LEVEL ON PRICE



8.6 Effect of Performance Variables

8.6.1 Effect of Field Length Variation

The effect of field length variation is based on takeoff distance over a 50 ft. obstacle, using the procedure described in Section 5.1. As shown in Section 5.1.4, landing distance is less critical. The calculated effects of takeoff distance in each category is based on use of the same flap system throughout.

Figure 8.6.1 compares the Category I advanced technology aircraft when designed for field lengths of 1000, 1500 and 2000 ft. The first one represents the basic requirement, the second is representative of most contemporary aircraft in this size category, while the third would be considered excessive. The 1500 ft. aircraft has an initial cost reduction of 8.5% with only a 2.0% further reduction by designing to 2000 ft. Operating cost follows a similar pattern. Since practically all airfields have a ground length of at least 1500 ft., the requirement for 1000 ft. over the obstacle is considered to be too severe, and 1500 ft. is the recommended airfield length.

Figure 8.6.2 presents a similar comparison for Category II, this time investigating distances of 1000 and 1500 ft. for comparison with the 500 ft. baseline requirement. The 1000 ft. aircraft has an initial cost reduction of 26%, with only a 4% further reduction by designing to 1500 ft. Operating cost again, behaves similarly. A 1.27 ft. reduction or propeller diameter is an added bonus for 1000 ft. operation and results in a more attractive appearance. Since the ground distance involved in a 1000 ft. takeoff operation is only 548 ft., this field length is believed to be adequate for areas of dense population and is recommended.

Figure 8.6.3 shows the Category III airplane, with its field length increased to 2000 and 2500 ft. Again, the same effect on cost is noted, with initial cost decreasing by 7.5% for 2000 ft and only 2.5% more for 2500 ft. Operating cost, an important consideration for this category, decreases by 3% for 2000 ft. and 5% for 2500 ft. For the type of operation visualized for this category of aircraft, a 2000 ft. field length is considered adequate and economically justified.

FIGURE 8.6.1
CATEGORY I COMPARISON
EFFECT OF FIELD LENGTH VARIATION

(Advanced Technology; Single Engine Pusher; 4 Phase; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Design Takeoff* Dist. over 50 ft.	(ft)	1000	1500	2000
Ground Distance	(ft)	463	695	878
General Arrangement Figure No.		8.3.13	N.A.	N.A.
Gross Weight	(lbs)	2285	2208	2184
Weight Empty	(lbs)	1199	1139	1120
Fuel Capacity	(gal.)	36	33	33
Max. Engine H.P.		152	141	138
Propeller Diameter	(ft.)	7.39	7.13	7.05
Wing Loading	(lbs/sq.ft.)	13.89	18.60	22.09
Initial Cost (1970 Basis)	(F)	15,589	14,313	13,922
Operating Cost- 100 hrs./yr.	($/mile)	0.198	0.186	0.183
- 300 hrs./yr.		0.112	0.105	0.103
- 500 hrs./yr.		0.095	0.089	0.087

* Critical for establishing field length

FIGURE 8.6.2
CATEGORY II COMPARISON
EFFECT OF FIELD LENGTH VARIATION

(Advanced Technology; Single Engine Pusher; 4-Place; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Design Takeoff* Dist. over 50 ft.	(ft.)	500	1000	1500
Ground Distance	(ft)	223	548	676
General Arrangement Figure No.		8.3.14	N.A.	N.A.
Gross Weight	(lbs)	3336	2934	2870
Weight Empty	(lbs)	1978	1677	1630
Fuel Capacity	(gal)	84	66	63
Max. Engine H.P.		452	355	338
Propeller Diameter	(ft.)	11.16	9.89	9.65
Wing Loading	(lbs/sq.ft)	14.32	26.84	35.66
Initial Cost (1970 Basis)	($)	45,034	33,481	31,715
Operating Cost- 100 hrs/yr.	($/mile)	0.371	0.295	0.283
- 300 hrs/yr.		0.221	0.175	0.167
- 500 hrs/yr.		0.191	0.151	0.144

* Critical for establishing field length

FIGURE 8.6.3
CATEGORY III COMPARISON
EFFECT OF FIELD LENGTH VARIATION

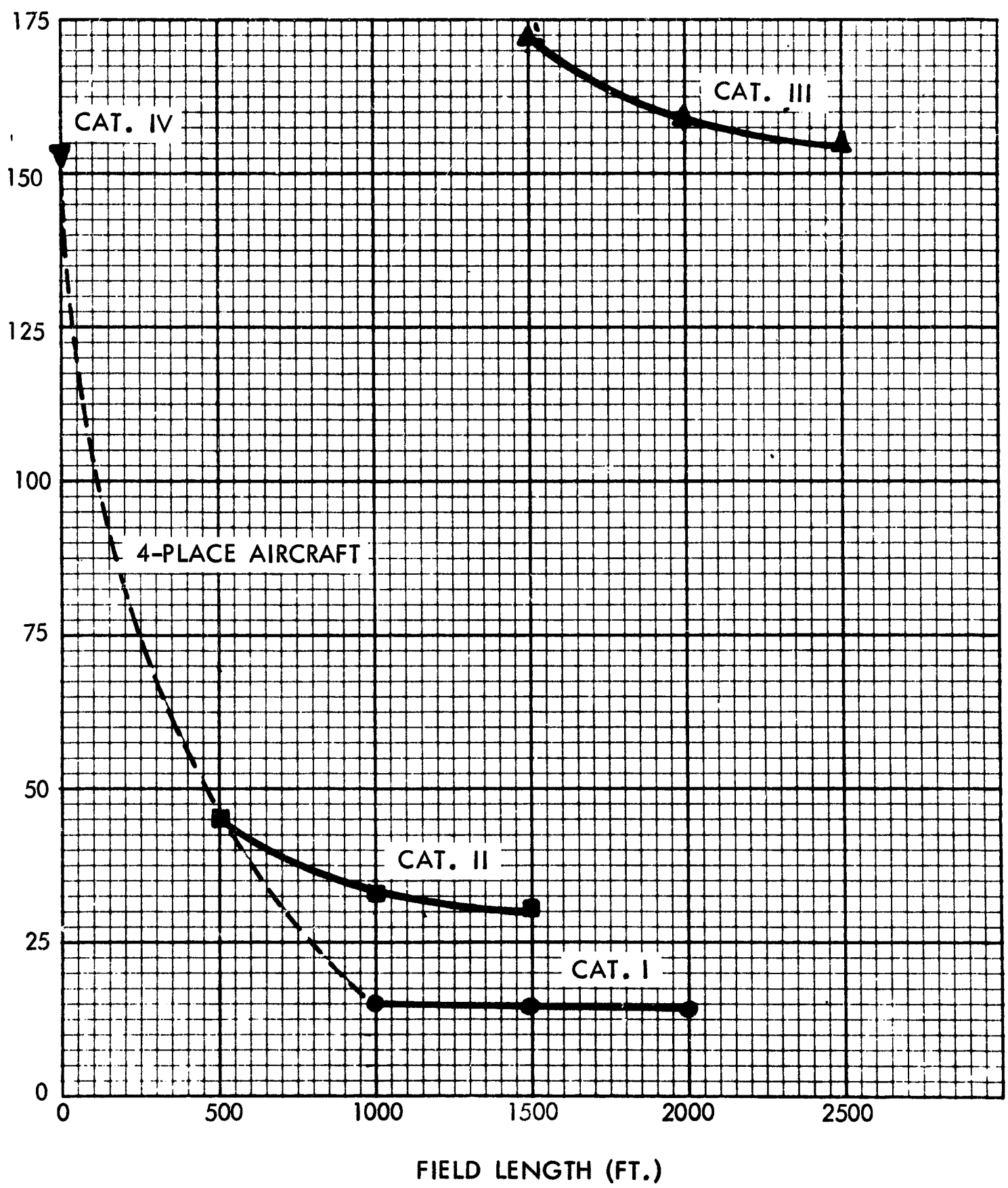
(Advanced Technology; 2 engine/propeller; 6 Place; 1,500 Mile Range; 75 PNdb @ 500 Ft.)

Design Takeoff* Dist. over 50 ft.	(ft.)	1500	2000	2500
Ground Distance	(ft.)	962	1279	1513
General Arrangement Figure No.		8.3.15	N.A.	N.A.
Gross Weight	(lbs)	7523	7241	7158
Weight Empty	(lbs)	4119	3937	3873
Fuel Capacity	(gal)	361	344	340
Max. H.P. per Engine		500	476	468
Propeller Diameter	(ft)	15.06	14.70	14.57
Wing Loading	(lbs/sq.ft)	39.97	48.30	53.75
Initial Cost (1970 Basis)	($)	172,517	159,402	154,896
Operating Cost- 100 hrs/year	($/Mile)	1.293	1.247	1.231
- 300 hrs/year		0.601	0.577	0.569
- 500 hrs/year		0.462	0.443	0.436

* Critical for establishing field length

Figure 8.6.3.1 presents a graphic plot of the effect of design field length on price. The Category I airplane is affected to a minor degree between 1000 and 2000 ft., but that of Category II shows a sharp decrease in price between 500 and 1000 ft., as does the Category III airplane between 1500 and 2000 ft. The Category IV helicopter has been added as a single point and connected to the minimum field length points of Categories I and II, by a dash-line curve. This curve illustrates, graphically, the cost of attaining a design field length less than 1000 ft. with a 4-place aircraft.

FIGURE 8.6.3.1 - EFFECT OF FIELD LENGTH ON PRICE



8.6.2 Effect of Cruise Speed Variation

Figure 8.6.4 compares the effect of design cruise speed in Category I. It was previously analyzed for the present technology baseline aircraft, which resulted in a selection of 145 knots. Repetition of the analysis for the advanced technology aircraft shows the same trend, with operating cost at a minimum up to 145 knots. Despite the 7% lower initial cost attained by reducing the speed to 130 knots, the operating cost of the 145 knot baseline design is lower for 100 hrs/year utilization. Since both the initial and operating costs of the 160 knot version are higher, the design speed of the baseline design appears to be justified.

Figure 8.6.5, applicable to Category II, deals with design cruise speeds 25 knots above and below the minimum required figure of 200 knots. The initial cost is reduced by 25% and operating cost at 300 hrs/yr. by 12% by designing to 175 knots. The effect of designing to 225 knots is to increase the initial cost by 45% and the operating cost by 20%. The main function of a STOL aircraft is to provide fast transportation between centers of population with a minimum of ground travel required. Therefore, 200 knots appears to be a minimum desired speed, and anything higher is too penalizing.

Figure 8.6.6 is applicable to Category III, where the specified minimum speed is 250 knots. Since any increase above this level would severely penalize a propeller-driven aircraft, the advanced technology aircraft was analyzed for two lower speeds. At 225 knots, the initial cost drops by 31% and operating cost at 300 hrs/yr. by 9%. At 200 knots, the percentage reductions are 52% and 14% respectively. Although the initial cost advantages of designing to lower speeds are significant, business aircraft are usually assessed on the basis of operating cost, and high cruise speed is considered an asset. It is therefore concluded that the 250 knot speed should be retained.

FIGURE 8.6.4
CATEGORY I COMPARISON
EFFECT OF CRUISE SPEED VARIATION

(Advanced Technology; Single Engine Pusher; 4 Place; 1000 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Cruise Speed (7,500 ft. alt.)	(kts)	130	145	160
General Arrangement Figure No.		N.A.	8.3.13	N.A.
Gross Weight	(lbs)	2279	2285	2346
Weight Empty	(lbs)	1208	1199	1241
Fuel Capacity	(gal)	33	36	40
Max. Engine H.P.		130	152	182
Propeller Diameter	(ft.)	6.83	7.39	8.09
Wing Loading	(lbs/sq.ft)	9.74	13.89	18.17
Initial Cost (1970 Basis)	($)	14,462	15,589	17,949
Operating Cost- 100 hrs/yr.	($/mile)	0.203	0.198	0.204
- 300 hrs/yr.		0.112	0.112	0.117
- 500 hrs/yr.		0.094	0.095	0.100

FIGURE 8.6.5
CATEGORY II COMPARISON
EFFECT OF CRUISE SPEED VARIATION

(Advanced Technology; Single Engine Pusher; 4 Place; 500 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Cruise Speed (7,500 ft.alt.)	(kts)	175	200	225
General Arrangement Figure No.		N.A.	8.3.14	N.A.
Gross Weight	(lbs)	3075	3336	3784
Weight Empty	(lbs)	1792	1978	2304
Fuel Capacity	(gal.)	70	84	105
Max. Engine H.P.		342	452	616
Propeller Diameter	(ft)	9.71	11.16	13.03
Wing Loading	(lbs/sq.ft)	10.83	14.32	16.90
Initial Cost (1970 Basis)	($)	33,842	45,034	65,018
Operating Cost- 100 hrs/yr.	($/mile)	0.333	0.371	0.447
- 300 hrs/yr.		0.195	0.221	0.267
- 500 hrs/yr.		0.168	0.191	0.231

FIGURE 8.6.6
CATEGORY III COMPARISON
EFFECT OF CRUISE SPEED VARIATION

(Advanced Technology; 2 engine/propeller; 6 Place; 1,500 Ft. Field Length; 1,500 Mi. Range; 75 PNdb @ 500 Ft.)

Cruise Speed (7,500 ft. alt.)	(kts)	200	225	250
General Arrangement Figure No.		N.A.	N.A.	8.3.15
Gross Weight	(lbs)	5,774	6,536	7,523
Weight Empty	(lbs)	3,039	3,502	4,119
Fuel Capacity	(gal)	245	297	361
Max. H.P. per Engine		281	377	500
Propeller Diameter	(ft)	11.29	13.07	15.06
Wing Loading	(lbs/sq.ft)	27.85	34.37	39.97
Initial Cost (1970 Basis)	($)	83,419	118,319	172,517
Operating Cost- 100 hrs/yr.	($/mile)	1.188	1.210	1.293
- 300 hrs/yr.		0.516	0.536	0.601
- 500 hrs/yr.		0.382	0.413	0.462

FIGURE 8.6.7
CATEGORY IV COMPARISON
EFFECT OF DESIGN CRUISE SPEED

(Advanced Technology; Single Engine Helicopter; 4-Place; 500 Mi. Range; 75 PNdb @ 500 Ft.)

Cruise Speed	(kts)	120	135	150
General Arrangement Fig. No.		Not Avail.	Not Avail.	8.3.16
Rotor Tip Speed: Hover/cruise	(ft/sec)	550/600	550/600	550/600
Solidity Ratio		.0618	.0850	0.100
Rotor Diameter, Main	(ft.)	33.6	36.0	37.8
Disc Loading	(lbs/sq.ft)	3.40	3.40	3.40
Gross Weight	(lbs)	2995	3440	3804
Weight Empty	(lbs)	1768	2032	2259
Max. Engine H.P.		229	351	477
Initial Cost (1970 Basis)	($)	88,279	119,483	153,280
Operating Cost- 100 hrs/yr.	($/mile)	1.851	2.164	2.518
- 300 hrs/yr.		0.705	0.852	1.007
- 500 hrs/yr.		0.476	0.589	0.705

Figure 8.6.7 compares the advanced technology helicopter characteristics at two cruise speeds lower than the specified 150 knots, which is the maximum attainable speed under the 75 PNdb noise level constraint. Any higher speed, along with the low rotational speed necessary, would create stall of the retreating blade. The effect of lower cruise speeds on cost is significant. At 135 knots, initial cost and operating cost at 300 hrs/yr are reduced by 22% and 16% respectively. At 120 knots they are reduced, respectively, by 42% and 30%. VTOL aircraft are generally used within metropolitan areas, rather than cross-country, so that the value of high cruise speed is questionalbe. A compromise speed reduction to 135 knots is recommended in this case, even though such aircraft might be used for longer trips.

Figure 8.6.7.1 illustrates, graphically, the effect of speed on price for aircraft in all categories. In Category I, the three design points evaluated have been joined to a fourth point at 200 knots. This point represents a Category II aircraft designed for 1000 ft. field length, making it directly comparable to the design points of Category I. The price of speed is seen to increase, percentage-wise, with size and reduced field length. Figure 8.6.7.2 shows the same effect on operating cost, though to a lesser expense, since speed, in itself, has a mitigating effect on cost per mile.

FIGURE 8.6.7.1 - EFFECT OF CRUISE SPEED ON PRICE

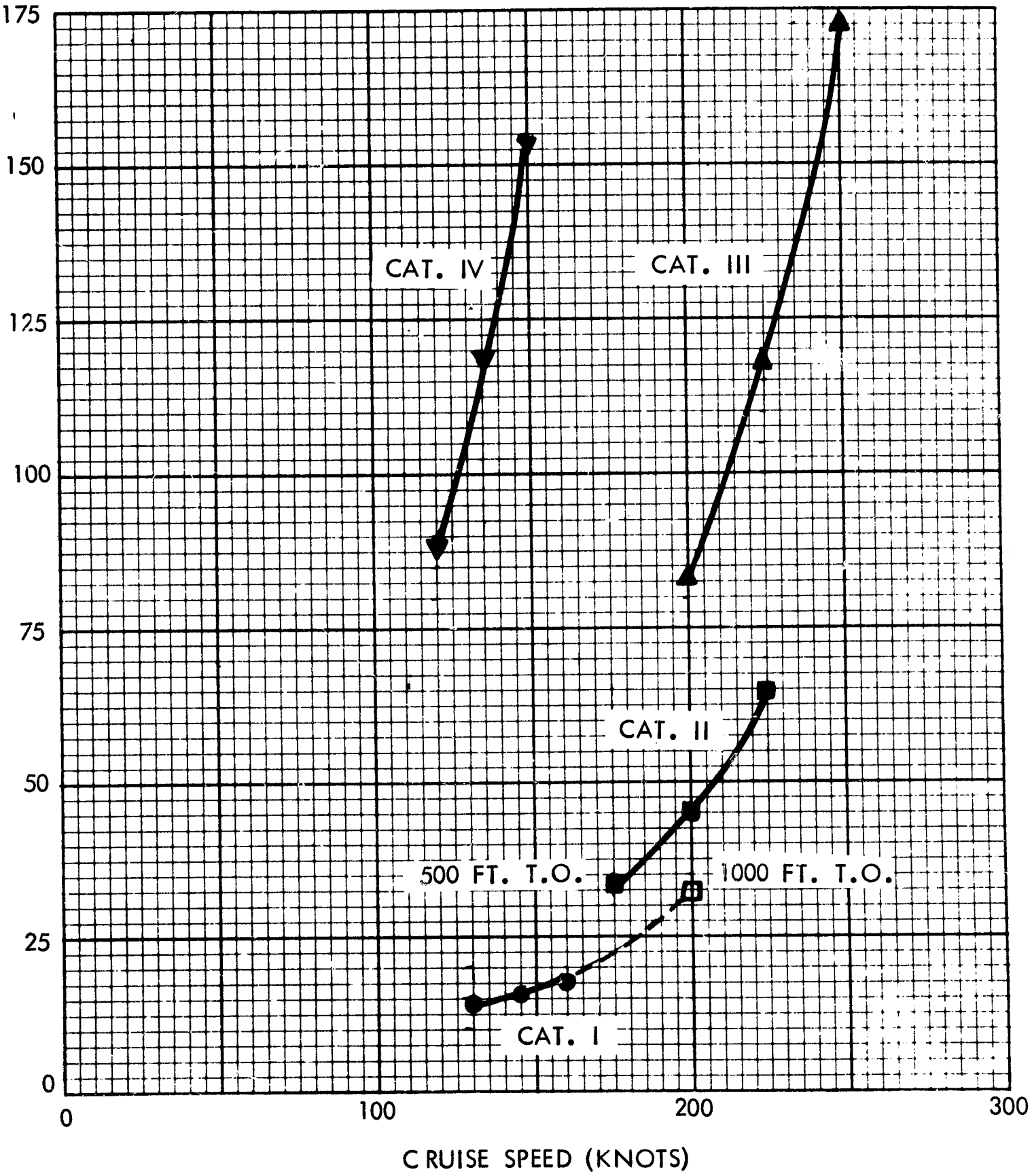
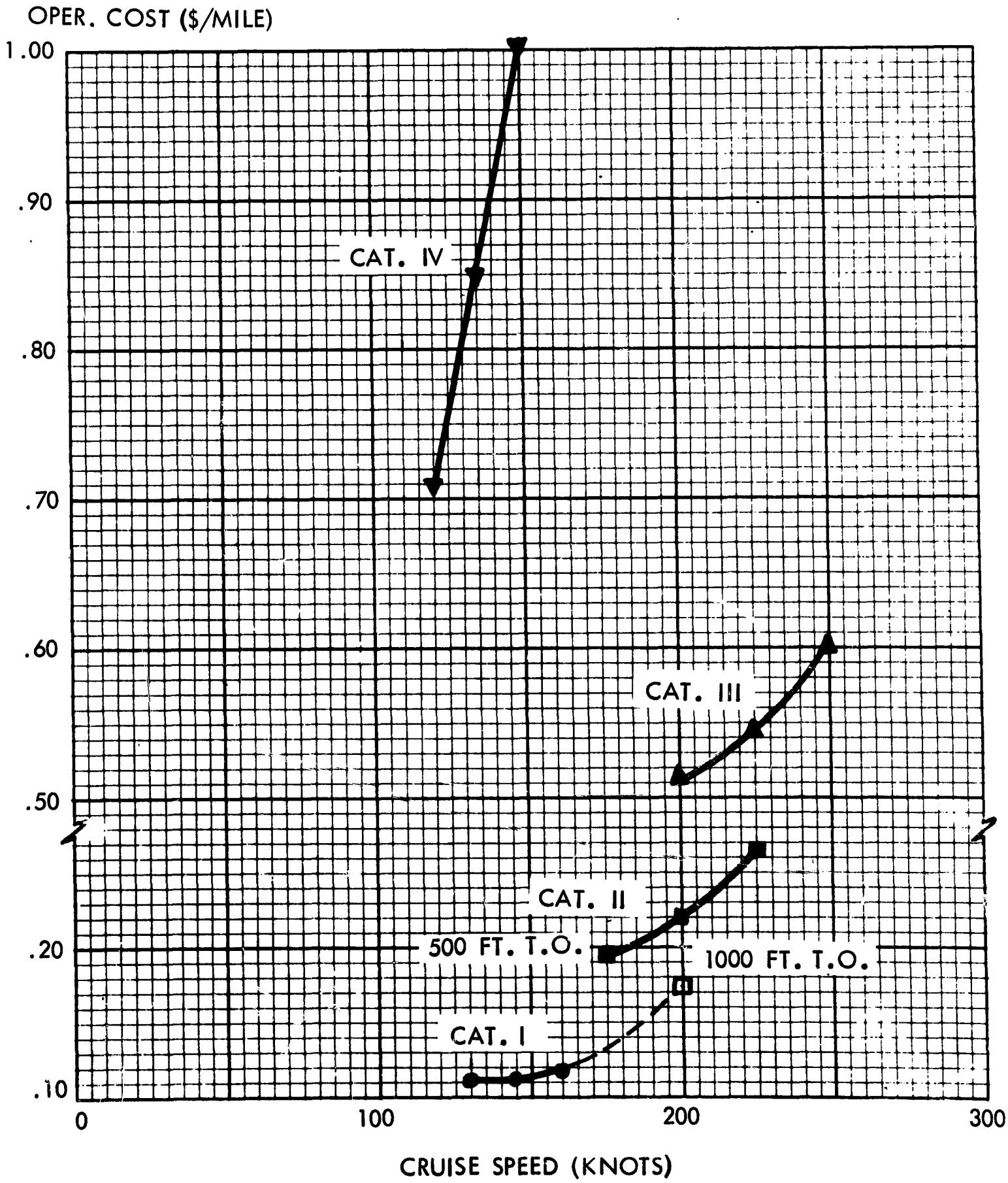


FIGURE 8.6.7.2 - EFFECT OF CRUISE SPEED ON OPERATING COST



8.6.3 Effect of Cruise Range Variation

Figures 8.6.8, 8.6.9, 8.6.10 and 8.6.11 assess the effect of range on the characteristics of the advanced technology aircraft in Categories I, II, III and IV. The effect on initial cost of increasing or decreasing the specified 500 mile range by 50% in Categories I and II is relatively insignificant, being in the order of 5%. However, it is interesting to note that the operating cost is minimum at 500 miles. Thus, there is no good reason for changing it.

Category III shows a more significant effect on cost when the 1500 mile range is varied by plus and minus 500 miles. Initial cost is reduced by 12% and increased by 16%, while operating cost at 300 hrs/yr. is reduced by 4.5% and increased by 6.5%. Although the 2000 mile range is desirable for a business aircraft, the cost differential appears too high to justify it. Therefore, it is recommended that the 1500 mile range figure be retained.

Category IV shows equally insignificant cost changes when the specified 500 mile range is varied by 50% in each direction. Initial cost is reduced by 12.5% and increased by 17%, while operating cost at 300 hrs/yr. is reduced by 8% and increased by 11%. As previously mentioned, VTOL aircraft are usually operated within metropolitan areas or on short hops between cities. For this and economic reasons it is believed that the 250 mile range figure is justifiable, although the situation may change in the future.

Figure 8.6.12 presents a graphic plot of the effect of design range on price. As is true of speed effect, increased range penalties increase, percentage-wise, with increased size and reduced field length.

FIGURE 8.6.8
CATEGORY I COMPARISON
EFFECT OF CRUISE RANGE VARIATION

(Advanced Technology; Single Engine Pusher; 4-Place; 1000 Ft. Field Length; 75 PNdb @ 500 Ft.)

Cruise Range (incl. 45 min. Reserve)	(stat.mi.)	250	500	750
Cruise Speed (7,500 ft. alt.)	(kts)	145	145	145
General Arrangement Figure No.		N.A.	8.3.13	N.A.
Gross Weight	(lbs)	2166	2285	2413
Weight Empty	(lbs)	1162	1199	1240
Fuel Capacity	(gal)	22	36	51
Max. Engine H.P.		147	152	157
Propeller Diameter	(ft)	7.26	7.39	7.52
Wing Loading	(lbs/sq.ft.)	14.34	13.89	13.45
Initial Cost (1970 Basis)	($)	14,844	15,589	16,437
Operating Cost- 100 hrs/yr.	($/mile)	0.204	0.198	0.201
- 300 hrs/yr.		0.115	0.112	0.114
- 500 hrs/yr.		0.097	0.095	0.096

FIGURE 8.6.9
CATEGORY II COMPARISON
EFFECT OF CRUISE RANGE VARIATION

(Advanced Technology; Single Engine Pusher; 4 Place; 500 Ft. Field Length; 75 PNdb @ 500 Ft.)

Cruise Range (incl. 45 min. Reserve)	(stat.miles)	250	500	750
Cruise Speed (7500 ft. alt.)	(kts)	200	200	200
General Arrangement Figure Number		N.A.	8.3.14	N.A.
Gross Weight	(lbs)	3045	3336	3699
Weight Empty	(lbs)	1871	1978	2117
Fuel Capacity	(gal.)	52	84	121
Max. Engine H.P.		427	452	484
Propeller Diameter	(ft)	10.84	11.16	11.55
Wing Loading	(lbs/sq.ft)	14.83	14.32	13.79
Initial Cost (1970 Basis)	($)	41,181	45,034	50,235
Operating Cost- 100 hrs/yr.	($/mile)	0.377	0.371	0.390
- 300 hrs/yr.		0.225	0.221	0.231
- 500 hrs/yr.		0.194	0.191	0.200

FIGURE 8.6.10
CATEGORY III COMPARISON
EFFECT OF CRUISE RANGE VARIATION

(Advanced Technology; 2 engine/propeller; 6 Place; 1,500 Ft. Field Length; 75 PNdb @ 500 Ft.)

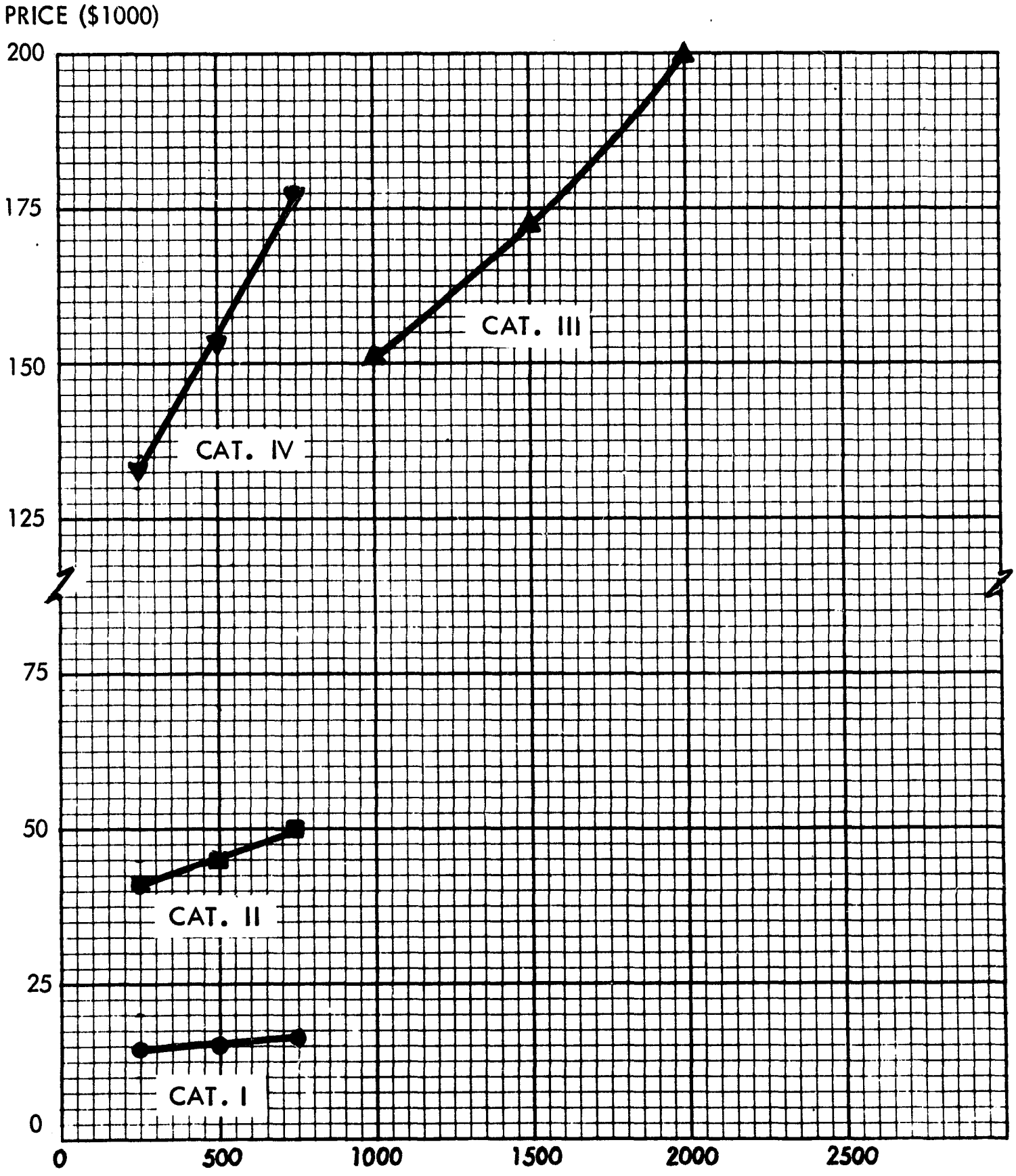
Cruise Range (incl. 45 min. Reserve)	(stat.mi.)	1000	1500	2000
Cruise Speed (7,500 ft. alt.)	(kts)	250	250	250
General Arrangement Figure No.		N.A.	8.3.15	N.A.
Gross Weight	(lbs)	6533	7523	8683
Weight Empty	(lbs)	3812	4119	4500
Fuel Capacity	(gal.)	243	361	497
Max. H.P. per engine		467	500	540
Propeller Diameter	(ft.)	14.55	15.06	15.66
Wing Loading	(lbs/sq.ft.)	42.46	39.97	37.69
Initial Cost (1970 Basis)	($)	151,440	172,517	200,305
Operating Cost- 100 hrs/yr.	($/mile)	1.244	1.293	1.373
- 300 hrs/yr.		0.575	0.601	0.640
- 500 hrs/yr.		0.441	0.462	0.493

FIGURE 8.6.11
CATEGORY IV COMPARISON
EFFECT OF VARIABLE CRUISE RANGE

(Advanced Technology; Single Engine Helicopter; 4 Place; 75 PNdb @ 500 Ft.)

Cruise Range (45 min.Reserve)	(stat.mi.)	250	500	750
General Arrangement Figure No.		N.A.	8.3.16	N.A.
Cruise Speed (5000 ft. alt.)	(kts)	150	150	150
Solidity Ratio		0.100	0.100	0.100
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600	550/600
Rotor Diameter	(ft)	34.9	37.8	41.3
Gross Weight	(lbs)	3245	3804	4537
Weight Empty	(lbs)	2009	2259	2596
Disc Loading	(lbs/sq.ft)	3.40	3.40	3.40
Max. Engine H.P.		429	477	543
Initial Cost (1970 Basis)	($)	134,087	153,287	179,691
Operating Cost- 100 hrs/yr.	($/mile)	2.320	2.518	2.800
- 300 hrs/yr.		0.928	1.007	1.120
- 500 hrs/yr.		0.650	0.705	0.785

FIGURE 8.6.12 - EFFECT OF CRUISE RANGE ON PRICE



8.7 Effect of Growth Factors

8.7.1 Effect of Increased Seating Capacity

Figures 8.7.1, 8.7.2, 8.7.3 and 8.7.4 compare the advanced technology baseline aircraft with growth versions having a 50% increase in seating capacity. Category I growth from 4 to 6 seats increases the initial cost by 51% and the operating cost per mile at 300 hrs/yr. by 32%, while reducing the seat-mile cost by 10%. Category II growth from 4 to 6 seats has respective increases of 44% and 27%, accompanied by a 14.5% reduction in seat-mile costs. Category III growth involves an increase of from 6 to 9 seats, which increases the initial cost by 26% and the operating cost at 300 hrs/yr. by 12%, while reducing the seat-mile cost by 25%. Category IV involves a 4 to 6 seat growth, with a 33% increased initial cost, a 20% increased operating cost at 300 hrs/yr. and a 20% reduced seat-mile cost.

No conclusions can be drawn with regard to Categories I, II and IV, since there is presently a demand for both sizes, though a considerably smaller market for the larger size. Category III defines, primarily, a business aircraft, where seat-mile costs become a consideration. But, here again, the desired size is established by market demand.

The seating growth versions are illustrated in Figure 8.7.5 for Category I; Figure 8.7.6 for Category II; Figure 8.7.7 for Category III; and Figure 8.7.8 for Category IV. In the first three categories, the extra seats are provided by increasing the fuselage length, while the helicopter in Category IV, which is less tolerant to center-of-gravity range, utilizes 3-abreast seating with increased width.

Figure 8.7.9 shows the number of seats plotted graphically against price and seat-mile cost for all four categories. With respect to the latter criterion, Category I aircraft provide the most economical transportation, followed by those of II, III and IV, in that order.

FIGURE 8.7.1
CATEGORY I COMPARISON
EFFECT OF INCREASED SEATING CAPACITY

(Advanced Technology; Single Engine Pusher; 1000 Ft. Field Length; 500 Mi.Range 75 PNdb @ 500 Ft.)

No. of Seats		4	6		
General Arrangement Figure No.		8.3.13	8.7.2		
Gross Weight	(lbs)	2285	3163		
Weight Empty	(lbs)	1199	1581		
Fuel Capacity	(gal)	36	46		
Max. Engine H.P.		152	193		
Cruise Speed	(kts)	145	145		
Propeller Diameter	(ft.)	7.39	8.33		
Wing Loading	(lbs/sq.ft.)	13.89	11.88	Cost Per Seat Mile	
Initial Cost	($)	15,589	23,605	4	6
Operating Cost - 100 hrs/yr	($/mile)	0.198	0.268	0.050	0.045
- 300 hrs/yr		0.113	0.148	0.028	0.025
- 500 hrs/yr		0.095	0.124	0.024	0.021

FIGURE 8.7.2
CATEGORY II COMPARISON
EFFECT OF INCREASED SEATING CAPACITY

(Advanced Technology; Single Engine Pusher; 500 Ft. Field Length; 500 Mi. Range; 75 PNdb @ 500 Ft.)

No. of Seats		4	6		
General Arrangement Figure No.		8.3.14	8.7.4		
Gross Weight	(lbs)	3336	4409		
Weight Empty	(lbs)	1978	2498		
Fuel Capacity	(gal)	84	103		
Max. Engine H.P.		452	554		
Cruise Speed	(kts)	200	200		
Propeller Diameter	(ft)	11.16	12.36	Cost Per Seat Mile	
Wing Loading	(lbs/sq.ft)	14.32	13.14	4	6
Initial Cost (1970 Basis)	($)	45,034	64,806		
Operating Cost - 100 hrs/yr	($/mile)	0.371	0.481	0.093	0.080
- 300 hrs/yr		0.221	0.281	0.055	0.047
- 500 hrs/yr		0.191	0.241	0.048	0.040

FIGURE 8.7.3
CATEGORY III COMPARISON
EFFECT OF INCREASED SEATING CAPACITY

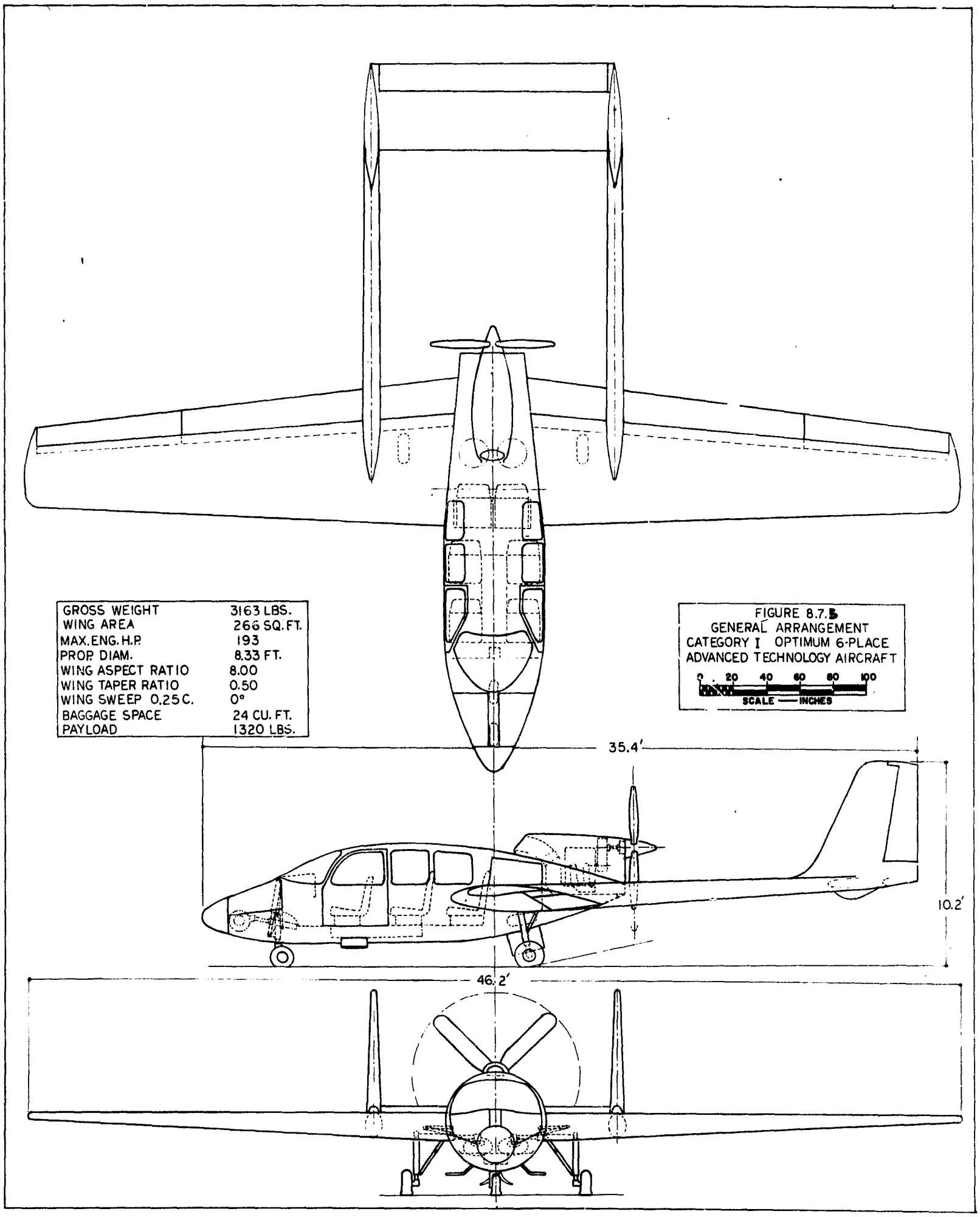
(Advanced Technology; 2-engine/propeller; 1,500 ft. Field Length; 1,500 Mi. Range; 75 PNdb @ 500 Ft.)

				Cost per Seat Mile	
Number of Seats		6	9		
General Arrangement Figure No.		8.3.15	8.7.6		
Gross Weight	(lbs)	7523	9082		
Weight Empty	(lbs)	4119	4773		
Fuel Capacity	(gal)	361	405		
Max. H.P. per Engine		500	560		
Cruise Speed	(kts)	250	250		
Propeller Diameter	(ft)	15.06	15.94		
Wing Loading	(lbs/sq.ft)	39.97	37.41		
Initial Cost (1970 Basis)	($)	172,517	220,535	6	9
Operating Cost - 100 hrs/year	($/mile)	1.293	1.448	0.215	0.161
- 300 hrs/year		0.601	0.675	0.100	0.075
- 500 hrs/year		0.462	0.520	0.077	0.058

FIGURE 8.7.4
CATEGORY IV COMPARISON
EFFECT OF INCREASED SEATING CAPACITY

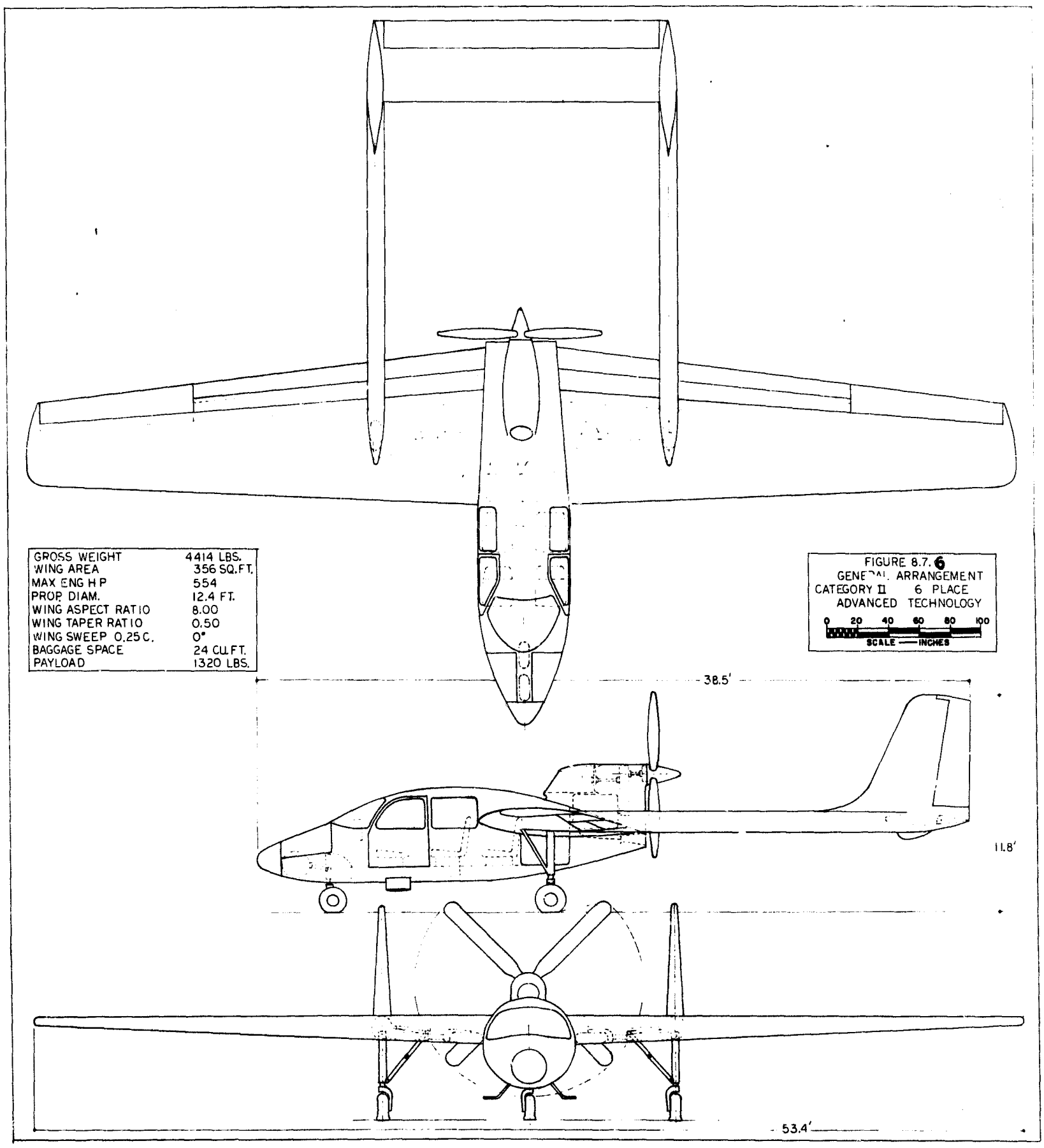
(Advanced Technology; Single Engine Helicopter; 500 Mi. Range; 75 PNdb @ 500 Ft.)

				Cost per Seat Mile	
Number of Seats		4	6		
General Arrangement Figure No.		8.3.16	8.7.8		
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600		
Cruise Speed (5000 ft.alt.)	(kts)	150	150		
Solidity Ratio		0.100	0.100		
Rotor Diameter, Main	(ft)	37.8	43.6		
Disc Loading	(lbs/sq.ft)	3.40	3.40		
Gross Weight	(lbs)	3804	5055		
Weight Empty	(lbs)	2259	2913		
Max. Engine H.P.		477	589		
Initial Cost (1970 Basis)	($)	153,287	204,592	4	6
Operating Cost - 100 hrs/yr	($/mile)	2.518	3.030	0.629	0.505
- 300 hrs/yr		1.007	1.211	0.252	0.202
- 500 hrs/yr		0.705	0.849	0.176	0.141



GROSS WEIGHT	3163 LBS.
WING AREA	266 SQ.FT.
MAX.ENG.H.P.	193
PROP. DIAM.	8.33 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP 0.25C.	0°
BAGGAGE SPACE	24 CU. FT.
PAYLOAD	1320 LBS.

FIGURE 8.7.5
GENERAL ARRANGEMENT
CATEGORY I OPTIMUM 6-PLACE
ADVANCED TECHNOLOGY AIRCRAFT



GROSS WEIGHT	4414 LBS.
WING AREA	356 SQ.FT.
MAX ENG H P	554
PROP. DIAM.	12.4 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.50
WING SWEEP 0.25 C.	0°
BAGGAGE SPACE	24 CU.FT.
PAYLOAD	1320 LBS.

FIGURE 8.7.6
GENERAL ARRANGEMENT
CATEGORY II 6 PLACE
ADVANCED TECHNOLOGY

0 20 40 60 80 100
SCALE — INCHES

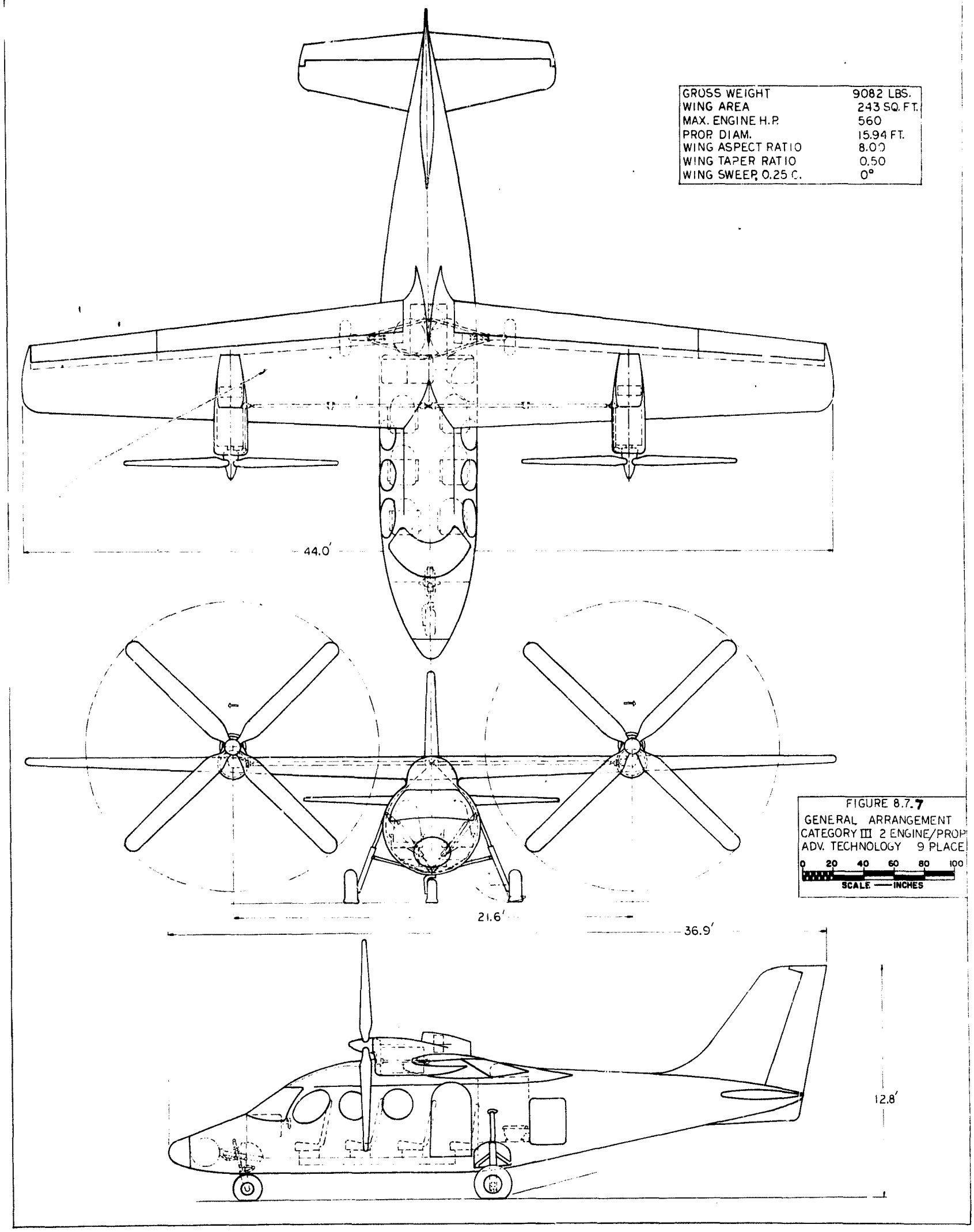
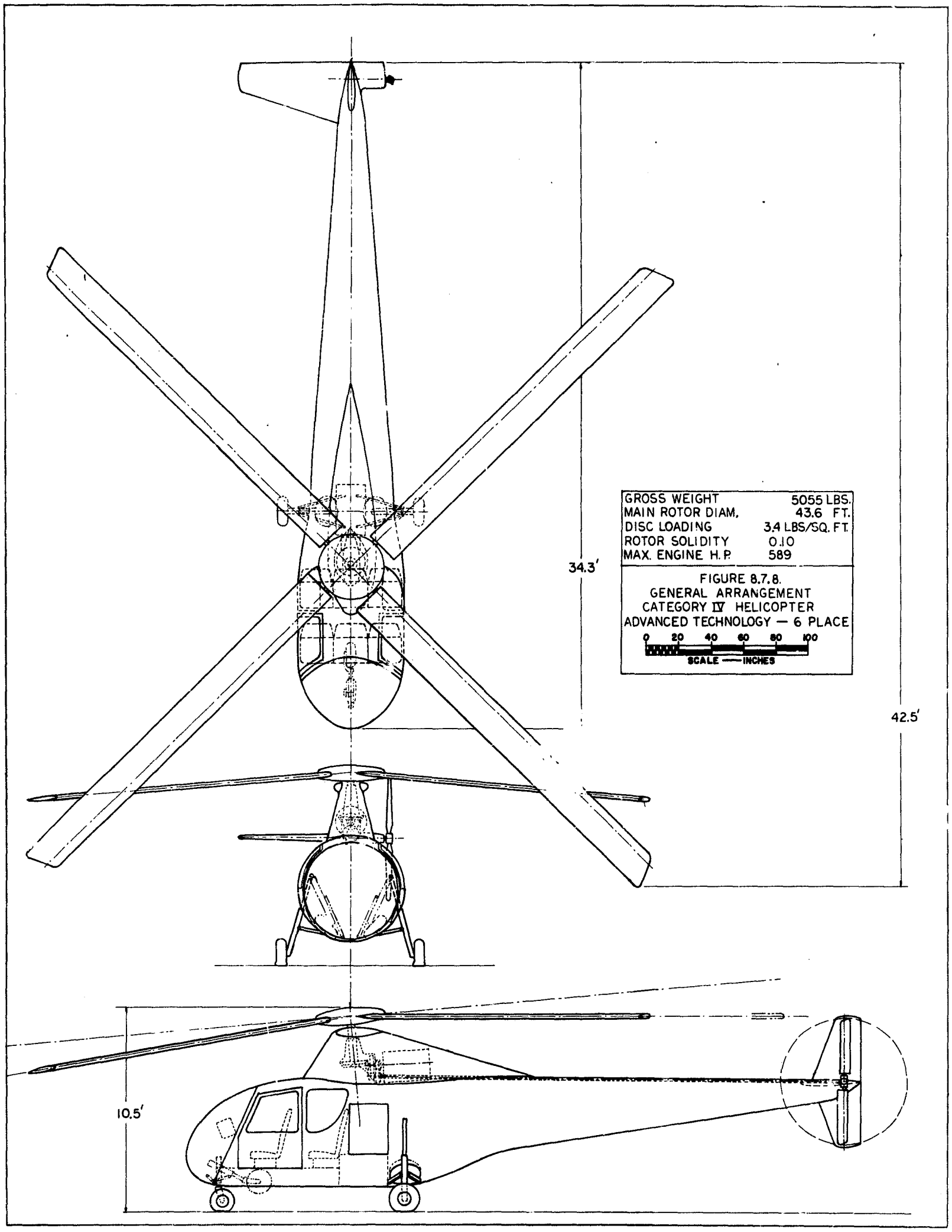


FIGURE 8.7.7
GENERAL ARRANGEMENT
CATEGORY III 2 ENGINE/PROP
ADV. TECHNOLOGY 9 PLACE

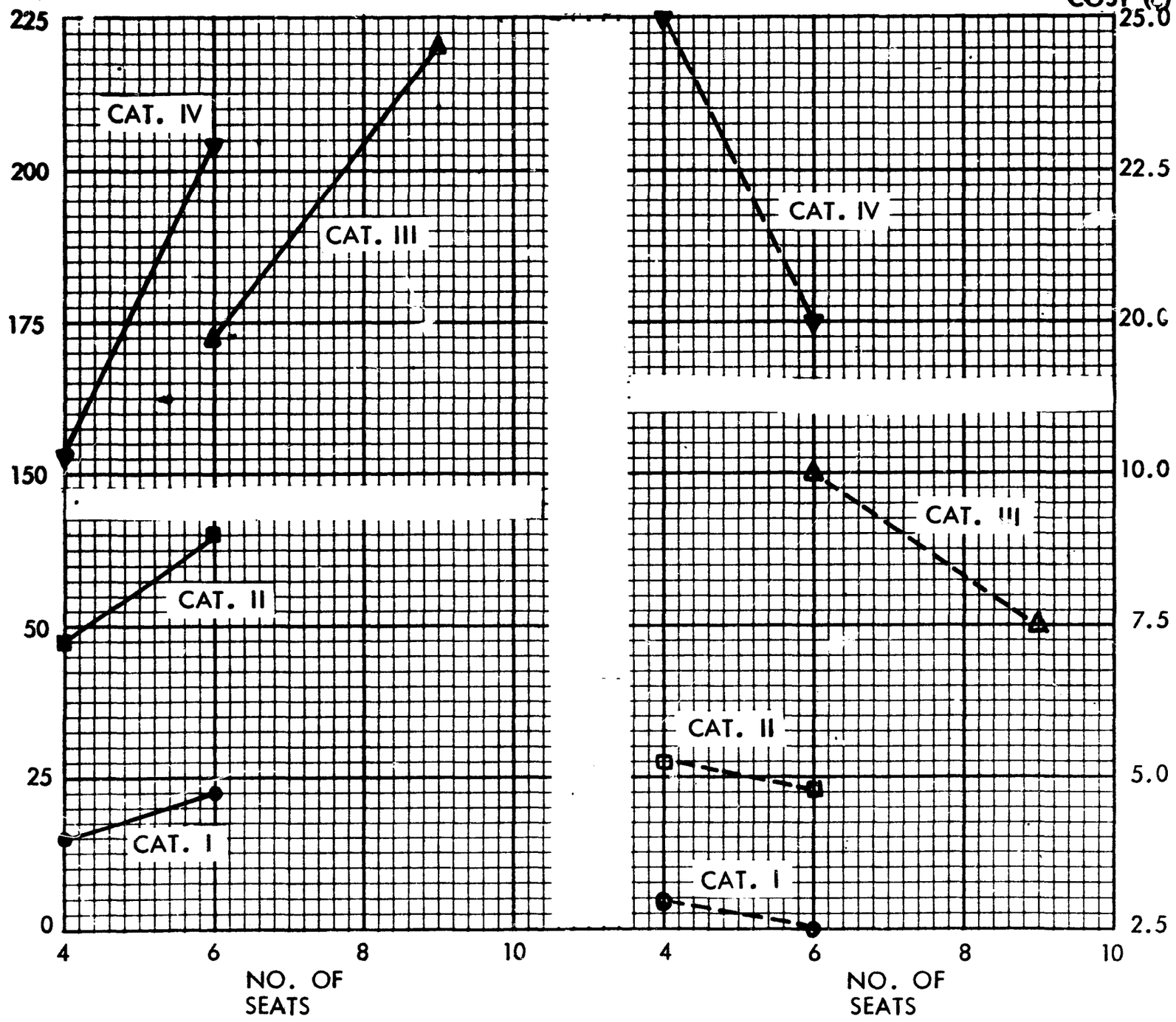


GROSS WEIGHT	5055 LBS.
MAIN ROTOR DIAM.	43.6 FT.
DISC LOADING	3.4 LBS/SQ. FT.
ROTOR SOLIDITY	0.10
MAX. ENGINE H.P.	589

FIGURE 8.7.8.
GENERAL ARRANGEMENT
CATEGORY IV HELICOPTER
ADVANCED TECHNOLOGY — 6 PLACE

0 20 40 60 80 100
SCALE — INCHES

FIGURE 8.7.9 - EFFECT OF SEATING CAPACITY ON PRICE AND SEAT-MILE COST



8.7.2 Effect of Yearly Production Rate

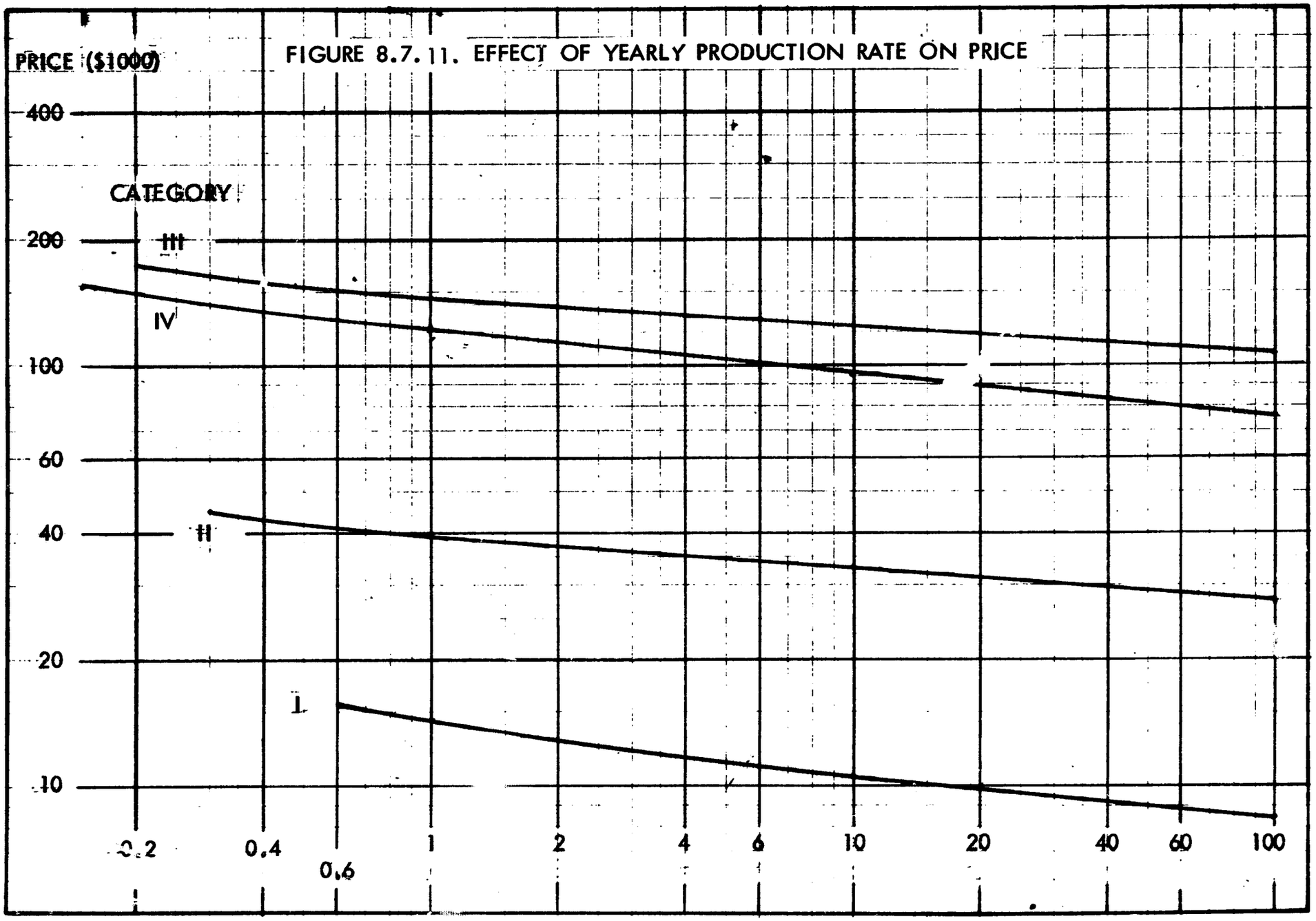
Figure 8.7.10 shows the effect of increased yearly production rate on initial and operating costs in the four categories of advanced technology aircraft. The first column deals with the nominal costs, based on rates similar to those of contemporary aircraft. Thereafter, rates of 1000, 10,000 and 100,000 aircraft per year are priced, using the rationale developed in Section 7.3. The points are plotted on a log-log scale in Figure 8.7.11. These data will be discussed in Section 10, in an effort to assess the impact of advanced technology on the market potential of future general aviation aircraft.

FIGURE 8.7.10
EFFECT OF YEARLY PRODUCTION RATE
(Advanced Technology Versions)

CATEGORY I (Single Engine Pusher)					
No. of A/C per year		600*	1,000	10,000	100,000
Initial Cost (1970 Basis)	($)	15,589	14,346	10,602	8,386
Operating Cost - 100 hrs/yr.	($/mile)	0.198	0.191	0.170	0.157
- 300 hrs/yr.		0.112	0.110	0.102	0.098
- 500 hrs/yr.		0.095	0.093	0.089	0.086
CATEGORY II (Single Engine Pusher)					
No. of A/C per year		300*	1,000	10,000	100,000
Initial Cost (1970 Basis)	($)	45,034	39,188	33,060	27,381
Operating Cost - 100 hrs/yr.	($/mile)	0.371	0.348	0.325	0.304
- 300 hrs/yr.		0.221	0.213	0.206	0.198
- 500 hrs/yr.		0.191	0.186	0.182	0.177
CATEGORY III (Twin Engine/Propeller)					
No. of A/C per year		200*	1,000	10,000	100,000
Initial Cost (1970 Basis)	($)	172,517	145,754	124,289	109,011
Operating Cost - 100 hrs/yr.	($/mile)	1.293	1.225	1.171	1.133
- 300 hrs/yr.		0.601	0.578	0.560	0.547
- 500 hrs/yr.		0.462	0.449	0.438	0.430
CATEGORY IV (Single Engine Helicopter)					
No. of A/C per Year		150*	1,000	10,000	100,000
Initial Cost (1970 Basis)	($)	153,287	122,966	94,961	76,418
Operating Cost - 100 hrs/yr.	($/mile)	2.518	2.315	2.130	2.000
- 300 hrs/yr.		1.007	0.926	0.853	0.801
- 500 hrs/yr.		0.705	0.648	0.596	0.560

* Quantities for baseline configurations.

FIGURE 8.7.11. EFFECT OF YEARLY PRODUCTION RATE ON PRICE



8.8 Summary

Figure 8.8.1 shows the graphic effect of advancing technology and lower noise level on price. All of the aircraft represented exclude avionics. The low solid curve is taken from Figure 7.3.1 and represents a statistical average of 1970 aircraft in the categories defined on the right. The abscissa is the product of empty weight and maximum cruise speed, which accounts jointly for the effects of weight and complexity.

The long-dashed curve represents the 1970 (present technology) "quiet" airplanes derived as the baseline configurations in Section 7.0 of this study. They are more expensive, increasingly with larger size and improved performance. The short-dashed curve represents the 1985 "quiet" airplanes derived as the advanced technology baseline airplanes in Section 8.3.4. This curve lies about midway between the other two and shows that low noise level aircraft can be obtained with but a modest increase in cost.

The high solid curve represents 1970 turbine helicopters. The two triangular symbols below this curve represent present technology (upper) and advanced technology (lower) helicopters designed for low noise levels. The reason for the present technology low noise level designs lying below the 1970 average curve is mainly because they are powered by rotating combustion engines instead of higher priced turbines.

Figure 8.8.2 shows a similar graph, confined to the advanced technology aircraft of this study, to show the effect of added provisions. The advanced technology baseline airplanes in Categories I, II and III are joined by the dashed curve. All curves, except that marked "Advanced Avionics and Automatic Flight Control," exclude avionics. High altitude cruise capability with a pressurized cabin results in lower price airplanes, particularly as size and speed are increased.

The addition of extra safety provisions causes the small, low speed airplanes to be more expensive, but the curves become more coincident as size and speed are increased. The provisions of advanced avionics and

FIGURE 8.8.1 EFFECT OF TECHNOLOGY & NOISE LEVELS ON PRICE VS WEIGHT-SPEED PRODUCT (EXCLUDING AVIONICS)

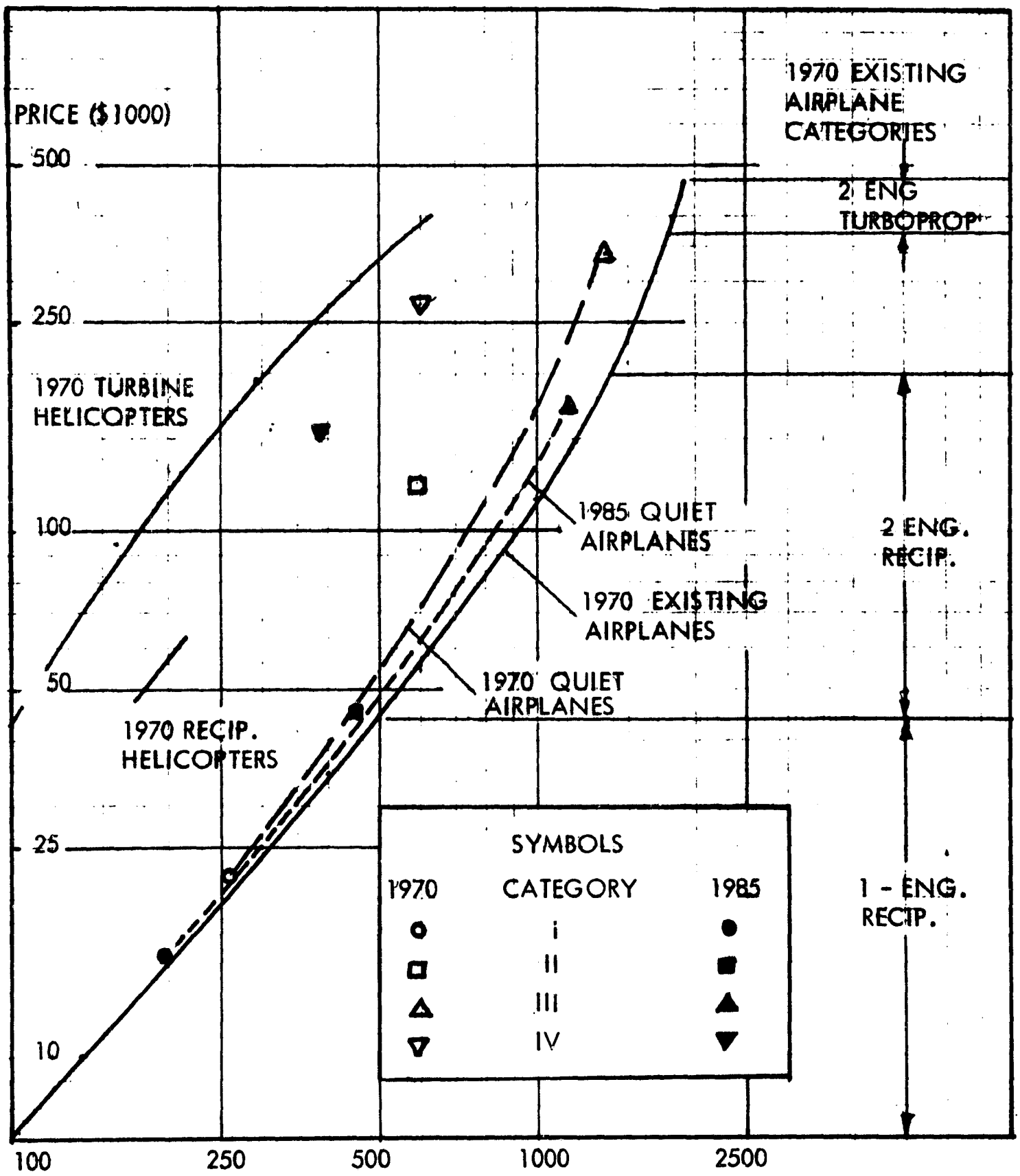
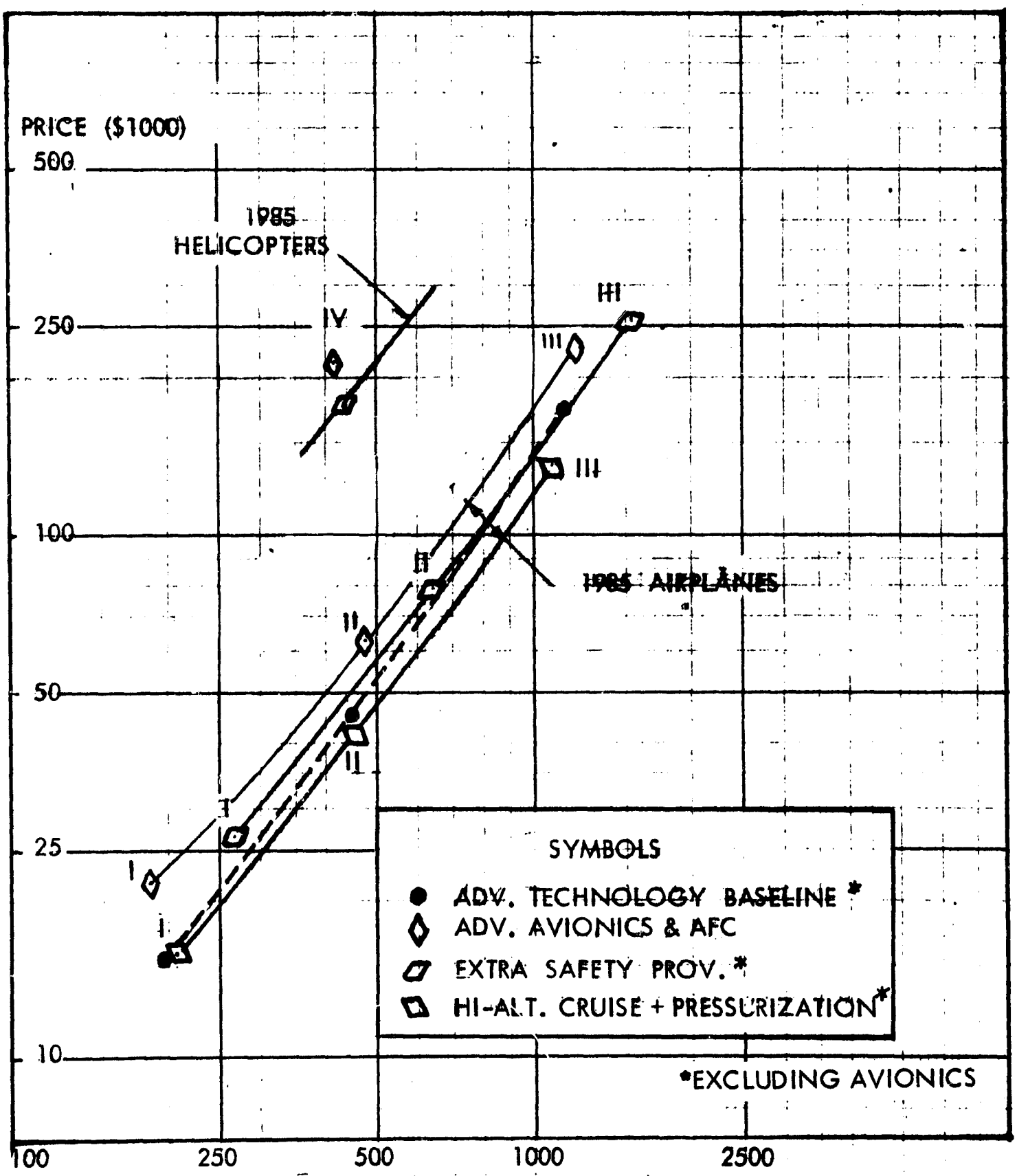


FIGURE 8.8.2 EFFECT OF ADDED PROVISIONS ON PRICE VS WEIGHT-SPEED PRODUCT (ADVANCED TECHNOLOGY AIRCRAFT)



automatic flight control (AFC) exact sizable penalties for small, slow aircraft. These penalties decrease with size and speed.

The advanced technology helicopter was assessed only for extra safety and advanced avionics. The former can be obtained without apparent penalty, but the latter is penalizing to an appreciable extent.

The effects brought out in the sensitivity analyses will become instrumental in choosing recommended configurations in the next section of this report. The general attempt to be made will be to provide the highest degrees of performance, utility and safety at reasonable cost, so that a maximum impact can be made on the potential usage of general aviation aircraft in the 1980's.

9.0 RECONFIGURATION OF BASELINE DESIGNS

9.1 General

The sensitivity analyses reported in Section 8.0 established optimum advanced technology baseline aircraft in each category by applying advanced propulsion and material utilization techniques to the present technology baseline aircraft developed in Sections 6.0 and 7.0. Subsequently, the impact of advanced avionics and automatic flight control, extra structural and system safety, high altitude operation, variable noise level, increased seating capacity and variable performance, which included field length, speed and range, were assessed.

From the results of the sensitivity analyses, tentative recommendations are made. The object of this portion of the study is to combine these recommendations and to reconfigure the advanced technology baseline aircraft into designs which are believed to provide the maximum stimulus to general aviation of the future. The term "stimulus" relates to increased production and marketing, hence greater use by the public. This effect will hopefully tend to alleviate the over-all transportation problem in this country by diverting a substantial proportion of the total passenger-miles from airline and surface modes to unscheduled general aviation.

9.2 Category I Recommendations

Figure 9.1 presents a comparison between the baseline advanced technology configuration and three alternates, designated A, B, and C.

Alternate A adds advanced avionics and extra system safety features, without departing from conventional design practice, in trade for a 500 ft. longer field length, for which a rationale was stated in Section 8.6.1. High altitude cruise capability, with pressurization, is not included because of its effect on wing area. The combined effect is to increase the gross weight by 200 lbs. (or 8.75%) and the initial cost by $10,911. or 70%.

Alternate B offers additional speed performance, convenience and utility in exchange for 500 ft. of field length and 100 miles of range. The cruise speed is increased by 10 knots, or 7%; wing folding is provided for home storage and roadable towing; and all-terrain capability is provided by the use of an air cushion landing gear. Initial cost is about the same and operating cost is 6% lower. Alternate C adds advanced avionics and system safety features to the B configuration.

Alternates B and C are believed to offer the prospective buyer the most for his money and should provide the needed stimulus toward increased utilization in a category which includes about 30% of the total number of general aviation aircraft in use. The owner will be able to travel to terminal points close to his objectives, with less reliance on ground travel, by using waterways and open fields, rather than prepared airstrips. He will not be confined to operate from one particular airfield, but with home storage, towability and all-terrain capability, he will have widely diversified options. Although the extra structural safety provisions are not included, adherence to FAA regulations will provide the same degree of assurance possessed by the buyers of today's aircraft, most of whom take this quality for granted. As for the avionics equipment and extra system safety provisions, the operator can pay more to get more, as he does when buying a car. Compared with contemporary aircraft, the reduced noise level will remove his neighbor's objection to close-in operation, and his own comfort will be enhanced by the lower external noise plus the rearward location of the engine and propeller, as well as by improved all-around visibility.

Figure 9.2 shows a general arrangement drawing of the Alternate B aircraft. Its relatively small wing is the result of the increased field length and cruising speed. The engine rating is about the same as that of the basic aircraft since it tends to increase with speed and decrease with field length. The wing is placed in the "high" position and is foldable backward in the horizontal plane. Its small size eliminates the need to overlap the folded wings, as is the case in Figure 8.3.19. When spread, the wings are latched to the fuselage at the leading edge and, when folded, they are

FIGURE 9.1

CATEGORY I COMPARISON

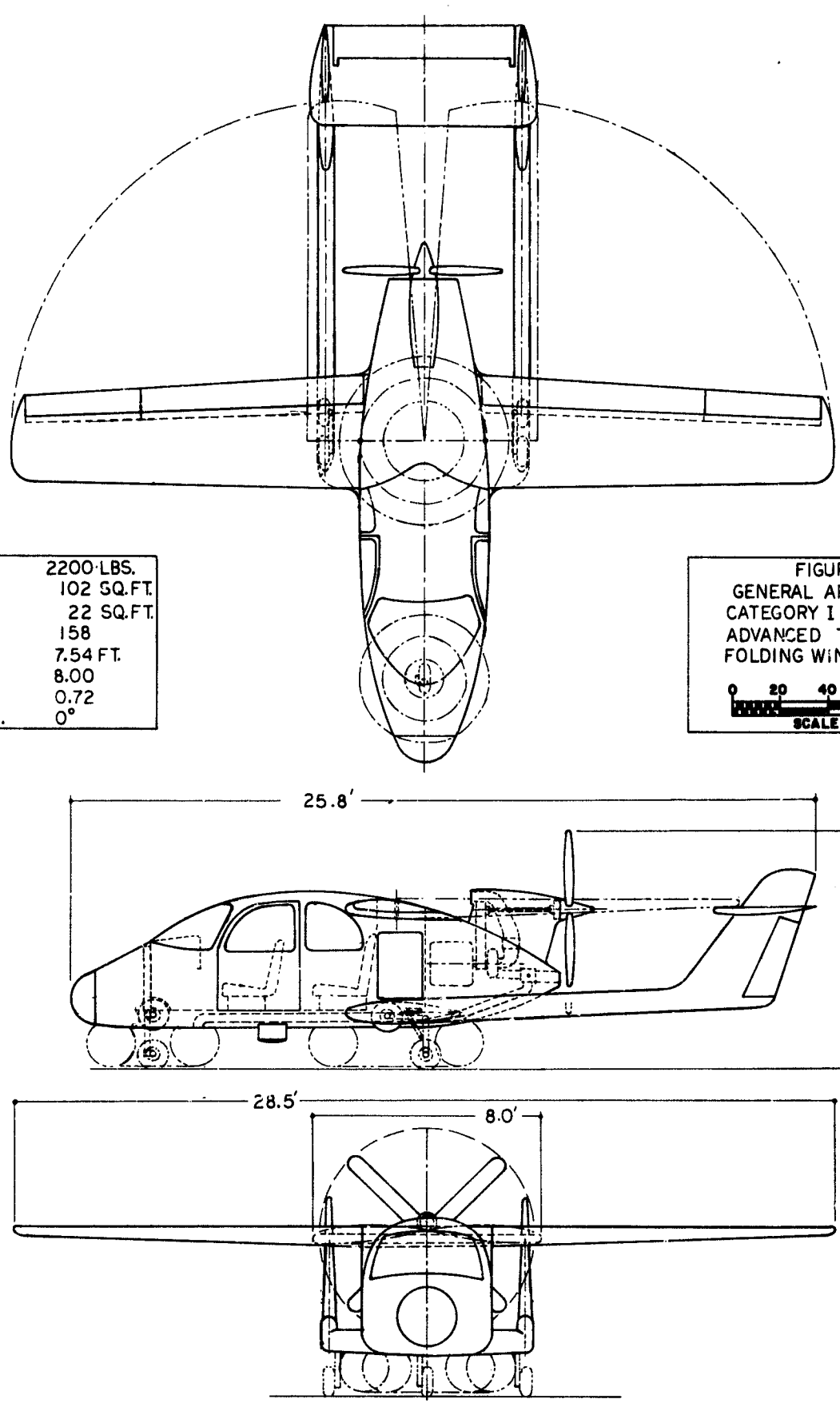
BASIC VS. RECOMMENDED ADVANCED TECHNOLOGY CONFIGURATIONS

(Single Engine Pusher; 4 Place; 75 PNdb @ 500 ft., 7,500 ft. Cruise Alt.)

CONFIGURATION COMBINATION		BASIC	A	B	C
General Arrangement Figure No.		8.3.13	N.A.	9.2	**
Design Takeoff Dist.* Over 50 Ft.	(ft)	1000	1500	1500	1500
Ground Distance	(ft)	463	695	695	695
Type of Retractable Landing Gear		Tricycle	Tricycle	Air Cushion	Air Cushion
Wing Folding Provisions		No	No	Yes	Yes
Towing Provisions		No	No	Yes	Yes
Cruise Speed	(kts)	145	145	155	155
Range (45 min. reserve)	(stat. mi)	500	500	400	400
Avionics System		None	Advanced	None	Advanced
Structural Safety Provisions		Basic	Basic	Basic	Basic
System Safety Provisions		Basic	Extra	Basic	Extra
Gross Weight	(lbs)	2,285	2,485	2,200	2,400
Weight Empty	(lbs)	1,199	1,387	1,209	1,397
Fuel Capacity	(gal)	36	38	29	31
Max. Engine H.P.		152	160	158	172
Propeller Diameter	(ft)	7.39	7.60	7.54	7.60
Wing Loading	(lbs/sq ft)	13.89	13.24	21.62	21.50
Initial Cost (1970 Basis)	($)	15,589	26,500	15,497	26,408
Operating Cost - 100 hrs/yr		0.198	0.383	0.186	0.381
Operating Cost - 300 hrs/yr		0.112	0.176	0.105	0.175
Operating Cost - 500 hrs/yr		0.095	0.133	0.089	0.132

* Critical for establishing field length

** Same overall dimensions as 8.3.13



GROSS WEIGHT	2200 LBS.
WING AREA	102 SQ.FT.
AIR CUSHION AREA	22 SQ.FT.
MAX. ENGINE H.P.	158
PROPELLER DIAM.	7.54 FT.
WING ASPECT RATIO	8.00
WING TAPER RATIO	0.72
WING SWEEP, 0.25 C.	0°

FIGURE 9.2
GENERAL ARRANGEMENT
CATEGORY I PUSHER PROP.
ADVANCED TECHNOLOGY
FOLDING WING, ALL-TERRAIN

0 20 40 60 80 100
SCALE — INCHES

latched to the horizontal tail. Folding is a manual operation, but power folding would exact very small weight and cost penalties. Prior to folding the wings, the 4-blade propeller is positioned at 45° to clear the wing trailing edges. Towing provision can be incorporated by installing a streamlined trailer hitch (not shown) at the nose of the aircraft.

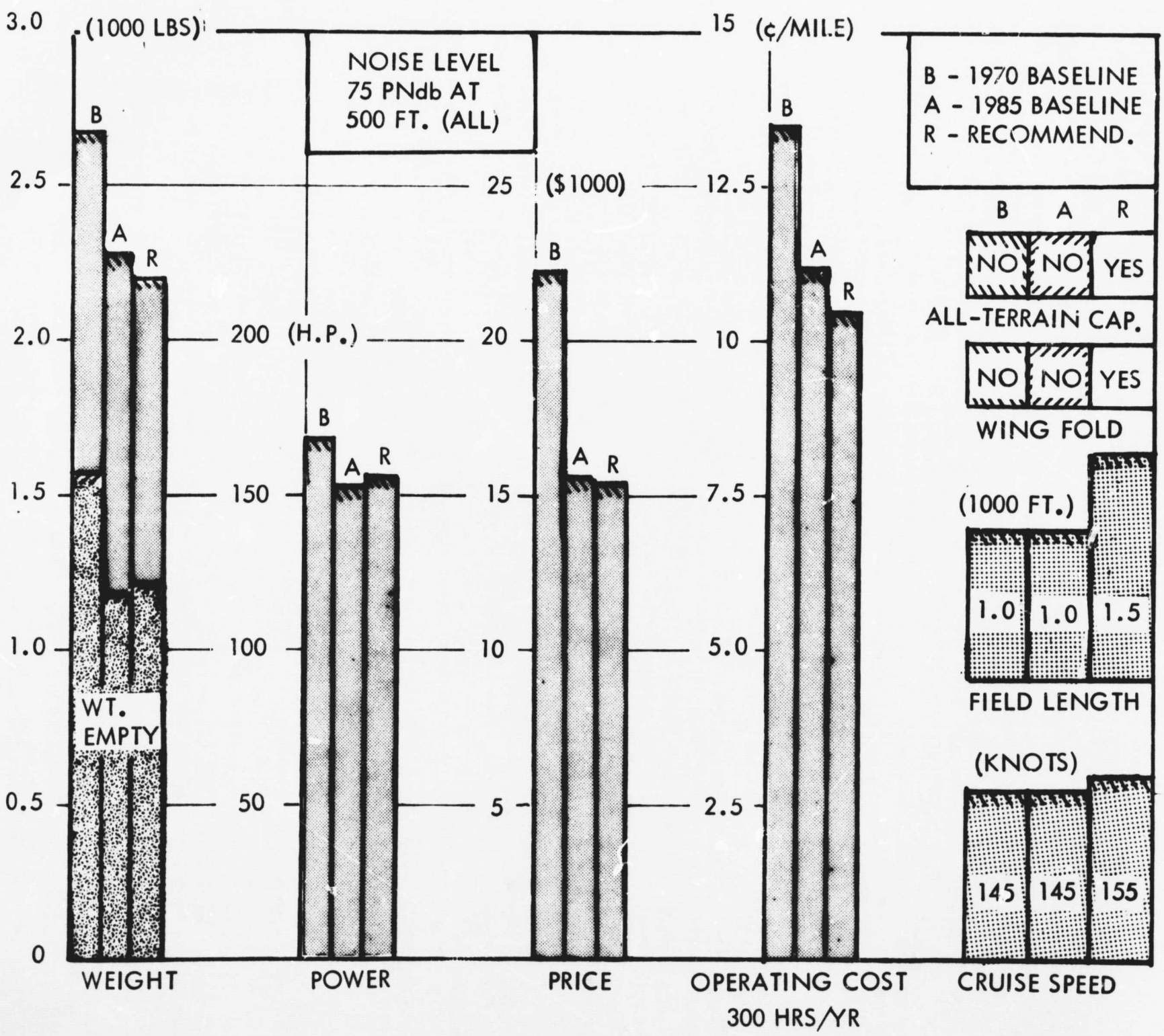
The empennage is supported by twin booms supported by sponson structures projecting from the bottom of the fuselage. The locally increased width provides a mounting base for the main air cushion trunk, rearward of the center-of-gravity. The main and auxiliary trunks are constructed of plasticized fabric material and are circular in planform. They follow the design principle shown in Figure 5.5.5 and are retractable into the floor structure. Their total confined area provides a flotation pressure of 100 lbs. per sq. ft. or 0.7 psi, which will "float" the aircraft at a mean height of about 2 inches above the ground. As previously mentioned, the trunks will mold themselves to clear irregular terrain or ground obstacles. While the trunks are equipped with peripheral hole patterns for continuous flow while "hovering," interior air-tight bladders may be deployed for power-off flotation on water. Power for activating the cushion, as well as for cooling the engine, is obtained from a centrifugal, engine-driven blower. This unit sucks air through the radiator, compresses it to about 2 psig and exhausts it through a diverter valve, which directs compressed air into the trunks upon demand. The power loss to activate the cushion system is negligible, and there is a net benefit to takeoff performance by eliminating ground friction. This effect was not accounted for in the takeoff calculation, which implies that the 695 ft. ground run is somewhat conservative.

An auxiliary retractable, tricycle taxi gear is provided for power-off, ground handling purposes, including towing. It is stressed only for 1.5g and is not used in takeoff and landing operations. The combined weight of the wheel and air cushion gears is estimated to be less than that of a conventional wheel type landing gear.

The resulting compact, high performance, low noise level and terrain-tolerant aircraft can be produced for sale at an attractive price, based on the average production rate of contemporary aircraft. However, its novel features could easily create the demand for higher production rates, with diminishing costs as shown in Figure 8.7.11.

Figure 9.3 presents a bar chart comparison between the recommended and the present and advanced technology baseline configurations. Except for the sacrifice in extended field length, the recommended design (Alternate B) shows to considerable advantage over the present technology configuration and is slightly better, performance-wise, than the advanced technology baseline. When its extra utility is considered, the recommended design appears to merit the research and development required for realization.

FIGURE 9.3 COMPARISON BETWEEN RECOMMENDED AND BASELINE CONFIGURATIONS, CATEGORY I



9.3 Category II Recommendations

The additions made to the advanced technology baseline aircraft in this category include high cruise altitude capability with cabin pressurization, advanced avionics and automatic flight control system, and the extra system safety provisions. These features are obtained in trade for an additional 500 ft. of field length. The resulting effects on size, weight and cost are shown in Figure 9.4.

The gross weight is decreased by 8% and the rated engine power is reduced by 32%. The initial cost is only $5,054 or 11.2% higher. Operating cost at 300 hours/year is reduced by 12%, with the possibility that the airplane will be used more frequently because of IFR capability, tolerance to adverse weather and extra safety provisions. Figure 9.5 shows the general arrangement of this aircraft, which is similar to, and smaller than, the basic model.

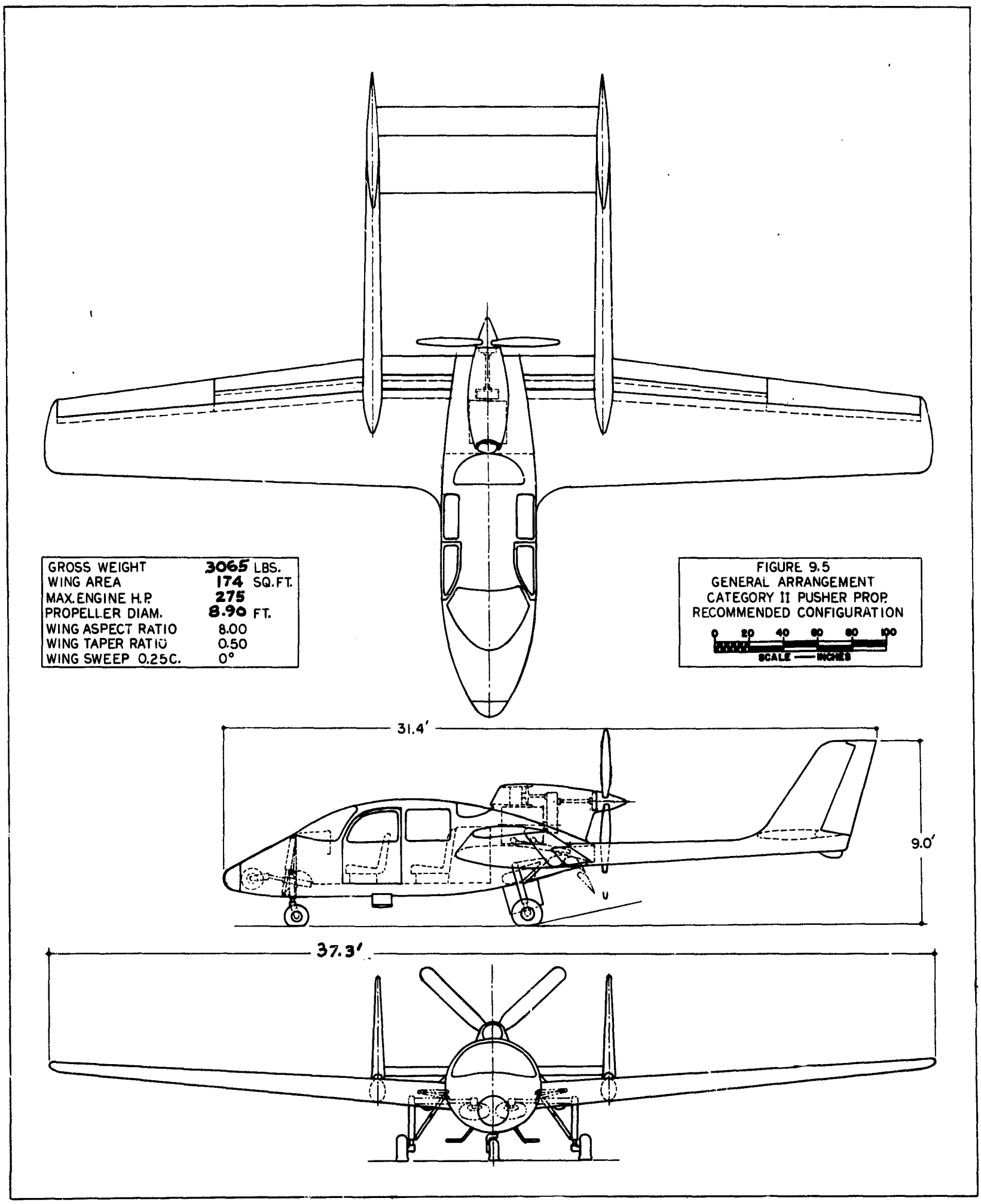
To assess the merit of this configuration, it is necessary to consider its use. This aircraft is a high performance (200 knot cruise), STOL type with a low external noise level. It should attract the small business owner who has frequent travel between city centers and wishes to make use of close-in airfields to minimize ground transportation. Since he wants to maintain schedule reliability, he requires IFR and all-weather capability. For cruise comfort, he will want cabin pressurization. In going from 500 to 1000 ft. field length, a ground distance of only 212 ft. has been added, and it is fairly certain that the airplane will be able to utilize all existing "STOL strips." The low noise level will remove current objections to close-in operation. One final consideration is price, and the $50,000 price tag is not considered excessive when the type of operator is considered. While an aircraft of this kind may not attract a high volume market, a demand for 1000 to 3000 per year may be reasonable in 1985.

Figure 9.6 shows a bar chart comparison between the recommended design and the baseline configurations representing 1970 and 1985 state-of-the-art.

FIGURE 9.4
CATEGORY II COMPARISON
BASIC VS. RECOMMENDED ADVANCED TECHNOLOGY CONFIGURATIONS
(Single Engine Pusher; 4 Place; 500 Mi. Range; 75 PNdb @ 500 Ft.)

General Arrangement Figure No.			8.3.14	9.5
Design Takeoff Dist.* over 50 Ft.		(ft)	500	1000
Ground Distance		(ft)	223	435
Cruise Speed		(kts)	200	200
Cruise Altitude		(ft.)	7,500	20,000
Cabin Pressurization			No	Yes
Avionics and Automatic Flight Control System			None	Advanced
Structural Safety Provisions			Basic	Basic
System Safety Provisions			Basic	Extra
Gross Weight		(lbs)	3336	3065
Weight Empty		(lbs)	1978	1835
Fuel Capacity		(gal.)	84	57
Max. Engine H.P.			452	275
Propeller Diameter		(ft)	11.16	8.90
Wing Loading		(lbs/sq.ft.)	14.32	17.68
Initial Cost (1970 Basis)		($)	45,034	50,088
Operating Cost -	100 hrs/yr	($/mile)	0.371	0.333
	300 hrs/yr		0.221	0.194
	500 hrs/yr		0.191	0.136

* Critical for establishing field length

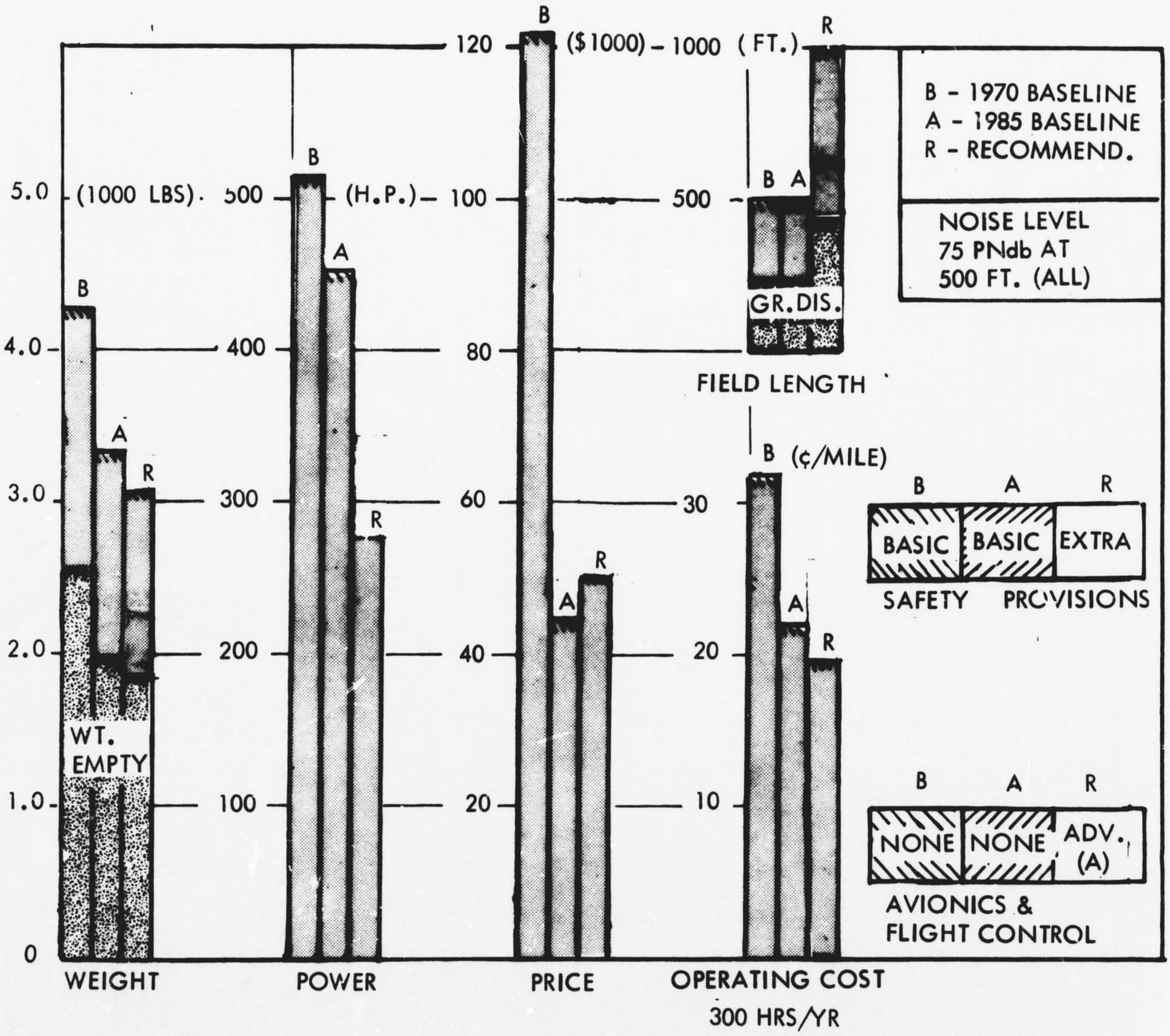


GROSS WEIGHT	3065	LBS.
WING AREA	174	SQ.FT.
MAX. ENGINE H.P.	275	
PROPELLER DIAM.	8.90	FT.
WING ASPECT RATIO	8.00	
WING TAPER RATIO	0.50	
WING SWEEP 0.25C.	0°	

FIGURE 9.5
GENERAL ARRANGEMENT
CATEGORY II PUSHER PROP.
RECOMMENDED CONFIGURATION

0 20 40 60 80 100
SCALE — INCHES

FIGURE 9.6 COMPARISON BETWEEN RECOMMENDED AND BASELINE CONFIGURATIONS, CATEGORY II



9.4 Category III Recommendations

The Category III airplane is configured for the corporate owner market, in the medium-to-large business bracket. His requirements call for long range operation at high cruising speeds, use of medium length airstrips, a comfortable interior -- but, above all, a high degree of schedule reliability, with maximum independence of weather.

The advance technology baseline aircraft in this category is illustrated in Figure 8.3.15. From an appearance standpoint, its main objection is the large diameter propellers, required to meet the 75 PNdb noise level constraint.

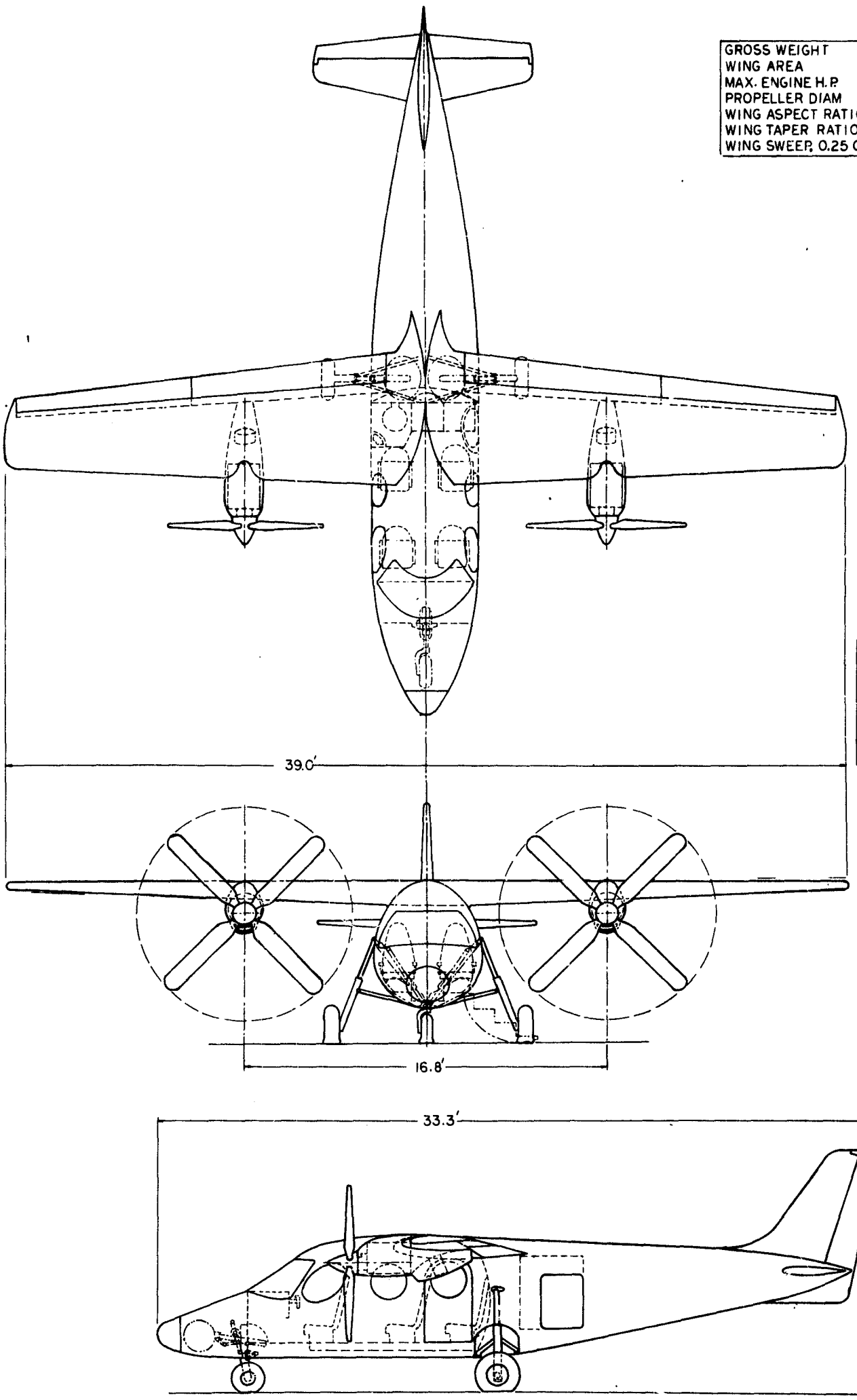
The baseline propeller-driven aircraft was provided with high altitude cruise capability with cabin pressurization; advanced avionics and automatic flight control system, and the extra structural and system safety packages. These items were traded for an 85 PNdb noise level and a 500 ft. increase in field length to a not unreasonable 2000 ft. The results are tabulated in Figure 9.7 and the reconfigured general arrangement is shown in Figure 9.8. Figure 9.9 shows a bar chart comparison with the present and advanced technology baseline designs.

In comparison to the baseline aircraft, the propellers have been reduced to a reasonable size, and cross-shafting is no longer required. Gross weight has been reduced by 2.5% and rated engine power by 22%. Despite the incremental effect of advanced avionics and automatic flight control, initial cost suffers only a 13.5% increase to a figure just below $200,000. Using previous rationale on the effect of greater schedule reliability on utilization, to increase that figure by 67%, the operating cost comparison shows a reduction of 30%. In summary, it is believed that the additional features, without unreasonable pricing, plus the low operating cost, will provide the necessary market stimulus to this category of aircraft.

FIGURE 9.7
CATEGORY III COMPARISON
BASIC VS. RECOMMENDED ADVANCED TECHNOLOGY CONFIGURATIONS
(2 engine/propeller; 6 Place; 1,500 Mile Range)

General Arrangement Figure No.		8.3.15	9.7
Exterior Noise Level (PNdb @ 500 ft)		75	85
Design Takeoff Dist.* over 50 Ft.	(ft.)	1500	2000
Ground Distance	(ft)	962	1196
Cruise Speed	(kts)	250	250
Cruise Altitude	(ft)	7,500	20,000
Cabin Pressurization		No	Yes
Avionics and Automatic Flight Control System		Basic	Advanced
Structural Safety Provisions		Basic	Extra
System Safety Provisions		Basic	Extra
Gross Weight	(lbs)	7523	7328
Weight Empty	(lbs)	4119	3898
Fuel Capacity	(gal)	361	292
Max. H.P. per Engine		500	390
Propeller Diameter	(ft)	15.06	9.98
Wing Loading	(lbs/sq.ft.)	39.97	38.51
Initial Cost (1970 Basis)	($)	172,517	195,969
- 100 hrs/yr		1.293	1.299
Operating Cost - 300 hrs/yr	($/Mile)	0.601	0.567
- 500 hrs/yr		0.462	0.421

* Critical for establishing field length

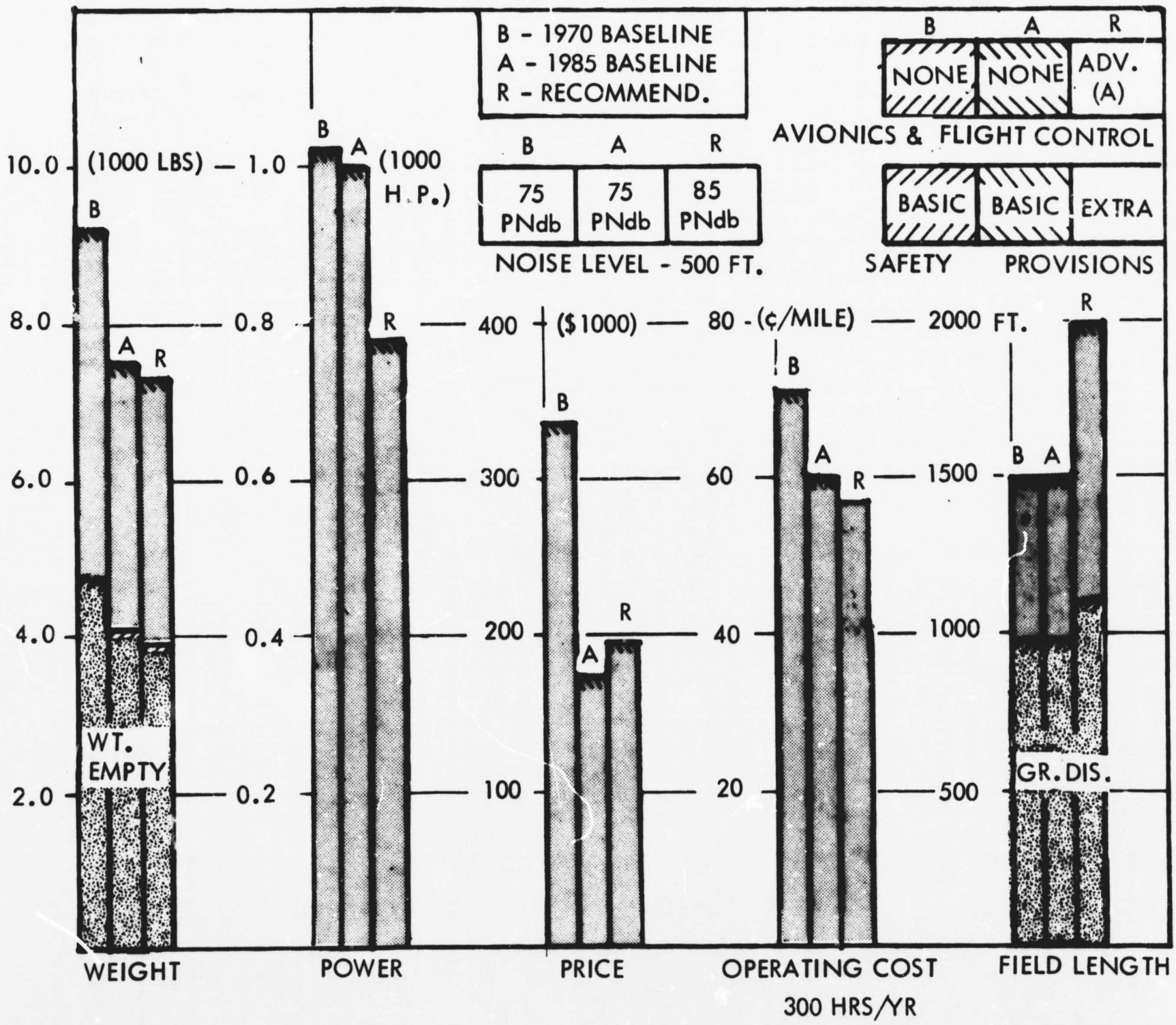


GROSS WEIGHT	7,328 LBS.
WING AREA	190 SQ. FT.
MAX. ENGINE H.P.	390
PROPELLER DIAM	9.98 FT.
WING ASPECT RATIO	8.0
WING TAPER RATIO	0.50
WING SWEEP, 0.25 C.	0°

FIGURE 9.8
GENERAL ARRANGEMENT
CATEGORY III 2-ENG./PROP.
RECOMMENDED CONFIGUR'N

0 20 40 60 80 100
SCALE — INCHES

FIGURE 9.9 COMPARISON BETWEEN RECOMMENDED AND BASELINE CONFIGURATIONS, CATEGORY III



There remains only the reconsideration of the turbofan powered aircraft as a candidate. This configuration, as shown in Figure 8.3.3.2, would be admissible if the noise level constraint is increased to 85 PNdb. The general arrangement, shown in Figure 8.3.3.1,provides a 20% increase in cruise speed but with a 65% increased initial cost over that of the baseline aircraft. Operating cost, however, to which the market is believed to be more sensitive, shows a slight reduction. In comparison to the recommended propeller aircraft, it lacks the advanced avionics and extra safety provisions, costs 5.5% more to buy and 26% more to operate. The turbofan candidate was not analyzed for the extra features, in trade for a 2000 ft. field length, but the resulting configuration is estimated to be considerably more expensive than the propeller-driven candidate. The former offers higher cruising speed and a more modern appearance and might attract a sizable segment of the market, despite higher cost.

One possible compromise, not evaluated in this study, is the use of twin "prop-fans" driven by rotating combustion engines. The prop-fan concept has been suggested by Hamilton Standard in their NASA-contracted propeller technology study for general aviation aircraft and is simply defined as a multi-bladed, controllable pitch, shrouded propeller of comparatively small diameter. Any future study should include this possibility.

9.5 Category IV Recommendations

The public, as well as the aviation industry and associated government agencies, have been led to believe that advanced technology will someday admit VTOL operation without serious compromise of speed, range and cost. The investigators of this study feel that such a situation is not predictable for the 1985 time period without a break-through in the areas of propulsion and aerodynamics.

The helicopter configuration, selected for Category IV, is designed primarily for the business owner whose principal transportation problem is rapid transit within a metropolitan area or between closely spaced areas of dense population. He would like to dispense with ground travel altogether, making use of "helipads" on roof tops, in city parks and other convenient locations. To become fully accepted by the public, the aircraft must have a low external noise level. To be fully useful to the operator, it must have all-weather capability and extra safety provisions - the latter being due to flight in a forest of obstacles. The operator should be willing to accept a slightly lower cruise speed and a shorter range in trade for the additional provisions, since these characteristics will not seriously impede his operations.

A comparison between the advanced technology baseline and recommended configurations is tabulated in Figure 9.10. The latter includes advanced avionics and automatic flight control; extra structural and system safety provisions. It is designed for a 15 knot reduction in cruise speed, which amounts to 10%, and a 50% reduction in range to 250 miles. This results is practically the same rotor diameter with 15% less solidity. Gross weight and rated power are virtually unchanged. The recommended configuration has the same appearance as that of the baseline design, hence Figure 8.3.16 is applicable to its general arrangement.

Initial cost is 35% higher, slightly exceeding $200,000. With 67% higher utilization, due to its all-weather capability and enhanced safety, the operating cost is 12.5% lower. The market potential for a VTOL aircraft is limited principally by high initial cost and, to some degree, by low cruising speed. Despite the perennial enthusiasm for VTOL, the investigators see no prospect of a cost break-through in the foreseeable future. Nevertheless, a comparatively small market will continue to exist and is predicted to enjoy normal growth through the years. The appearance of two or three place helicopters and autogyros, with price tags of $20,000 to $25,000, will possibly generate a larger market. However, they will not reach the level of utility and schedule availability as can the helicopter design of this study. Thus, the future of VTOL aircraft for general aviation remains largely unpredictable. It would be conservative, however, to predict a normal, evolutionary growth.

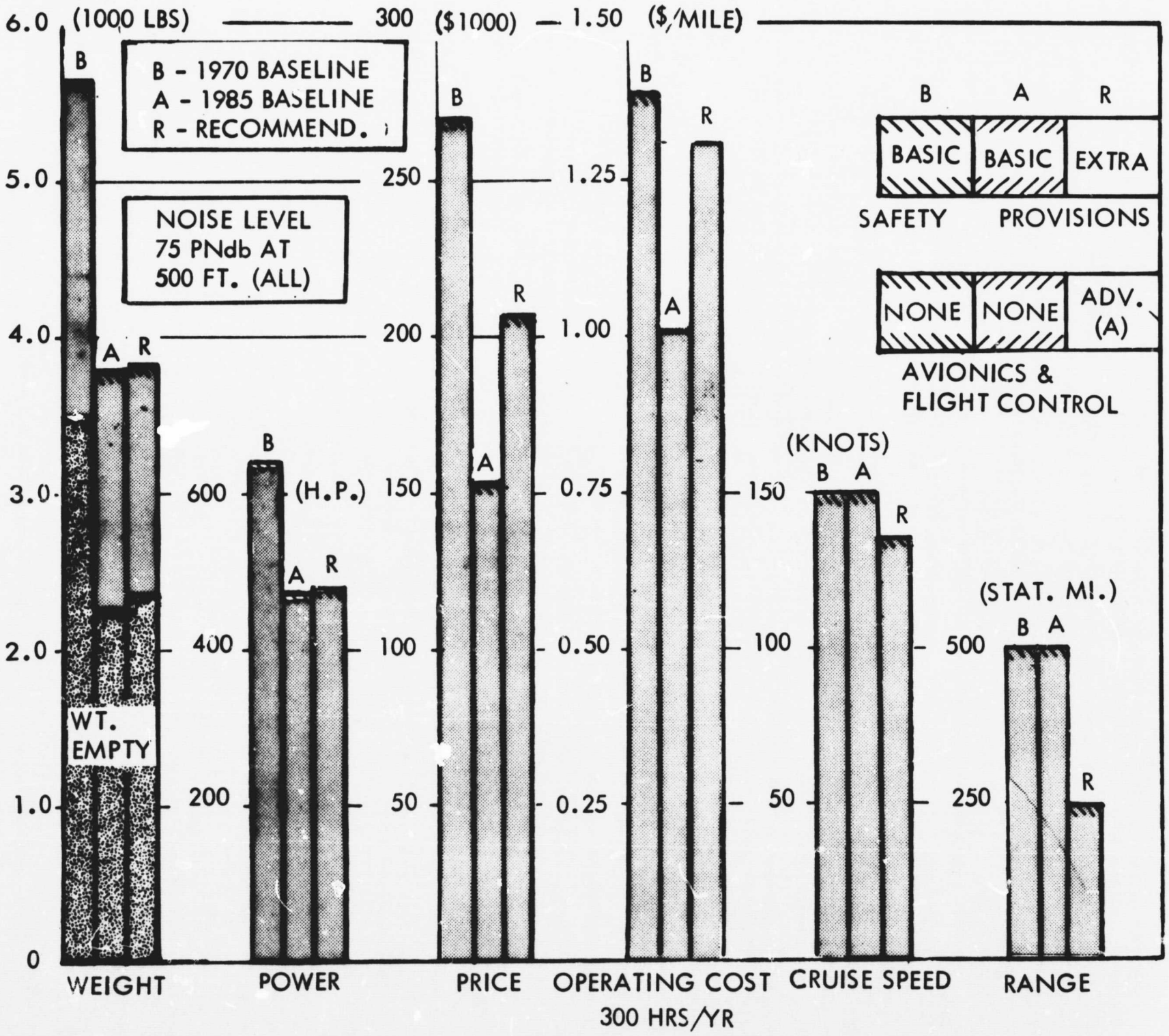
Figure 9.11 shows a bar chart comparison between the recommended design and the present and advanced technology baseline configurations. Despite the high cost level, in comparison to that of fixed wing aircraft, considerable reduction can be made over today's prices, with the inclusion of added utilization potential. Research and development support of the helicopter appears to be warranted, although to a lesser degree than that accorded to other categories of aircraft.

FIGURE 9.10
CATEGORY IV COMPARISON
BASIC VS. RECOMMENDED ADVANCED TECHNOLOGY CONFIGURATIONS
(Single Engine Helicopter; 4 Place; 75 PNdb @ 500 Ft.)

General Arrangement Figure No.		8.3.16	*
Avionics and Automatic Flight Control System		Basic	Advanced
Structural Safety Provisions		Basic	Extra
System Safety Provisions		Basic	Extra
Cruise Speed (5000 ft. alt.)	(kts)	150	135
Cruise Range (45 min. Reserve)	(stat.mi.)	500	250
Solidity Ratio		0.100	0.085
Rotor Tip Speed: Hover/Cruise	(ft/sec)	550/600	550/600
Rotor Diameter	(ft)	37.8	37.9
Gross Weight	(lbs)	3804	3830
Weight Empty	(lbs)	2259	2349
Disc Loading	(lbs/sq.ft)	3.40	3.40
Max. Engine H.P.		477	480
Initial Cost (1970 Basis)	($)	153,287	207,895
Operating Cost - 100 hrs/yr	($/mile)	2.58	3.36
Operating Cost - 300 hrs/yr	($/mile)	1.01	1.31
Operating Cost - 500 hrs/yr	($/mile)	0.68	0.881

* Same as 8.3.16

FIGURE 9.11 COMPARISON BETWEEN RECOMMENDED AND BASELINE CONFIGURATIONS, CATEGORY IV



10.0 PROJECTION OF 1985 GENERAL AVIATION USE POTENTIAL

10.1 Relation of Price to Production Quantities

Figure 10.1 presents a composite graph of cost per pound versus annual production rate showing, on the one hand, actual cost versus delivery rate of general aviation aircraft and automobiles in 1967 and, on the other hand, cost per pound of the Category I aircraft of this study, obtained from Figure 8.7.11. Aircraft costs exclude avionics.

The 1967 general aviation aircraft relate to Category I of this study. The dashed curve represents the Category I aircraft with costs adjusted to reflect 1967 dollars for direct comparison. Extension of the Category I curve to 100,000 units per year enters the quantitative realm of automobile production. It is disappointing to note that aircraft cost per pound exceeds that of automobiles by a factor of approximately 6. The reasons for this situation include higher cost materials and parts fabrication pr[illegible] and inability of aircraft manufacturers to achieve production line as[illegible] techniques approaching those of the automotive industry. The higher deg[illegible] quality control required and the stringency of FAA inspection are contrib[illegible] factors. It is possible, however, that production techniques can be develo[illegible] with composites which will reduce the cost per pound below the levels estimated in this study.

Cost per pound is not an indicator, per se, of the market potential of aircraft, and the unit cost comparison is a better criterion. At the 100,000 per year production level, the price of an advanced technology airplane in Category I is priced at about $8,400 and is comparable to a car retailing for about $3,000 which results in a factor of 2.8 instead of 6. If the cost per pound can be reduced to $5, the unit cost will drop to about $6000, and the factor of increase will be only 2.0. However, a yearly quantity of 100,000 by 1985 represents about one-third of the entire general aviation fleet forecast for 1985 and hence is highly optimistic.

Figure 10.2 shows the actual number of new general aviation aircraft deliveries per year from 1945 through 1970 with a projection to 1985, based on fleet size estimates and an average attrition rate of 4.5% per year. By 1985, the annual delivery rate might reach 60,000, despite the fall-off between 1968 and 1970.

Figure 10.3, using data obtained from Reference 10.1, shows a breakdown of the general aviation aircraft sold in 1969 into price groups, represented as fractions of the total. Superimposed in the outer circle are the boundaries represented by the price ranges in Categories I, II and III. The data were obtained from Ref. 10.1, selecting 1969 as the last year for which such data were published (1970 is probably not representative, due to the adverse economic situation). Approximately 500 small helicopters were sold in 1969, comprising about 4% of the total of general-aviation aircraft. It can be assumed that the increasing demand for VTOL capability will give these aircraft at least a 5% share by 1985.

Categories I, II, III and IV combine to represent 45% of the total general aviation aircraft market by numbers of aircraft. Category I represents 30%, while Categories II, III and IV represent 5% each. Applying these percentages to the 60,000 total number of aircraft predicted for 1985, the following numbers in each category can be projected:

FIGURE 10.1 - COST PER POUND VARIATION WITH ANNUAL PRODUCTION VOLUME FOR AIRCRAFT AND AUTOS

REFERENCES: AUTOMOTIVE INDUSTRIES 1967
BUSINESS AND COMMERCIAL AVIATION APRIL 67
FLIGHT MAY 1967

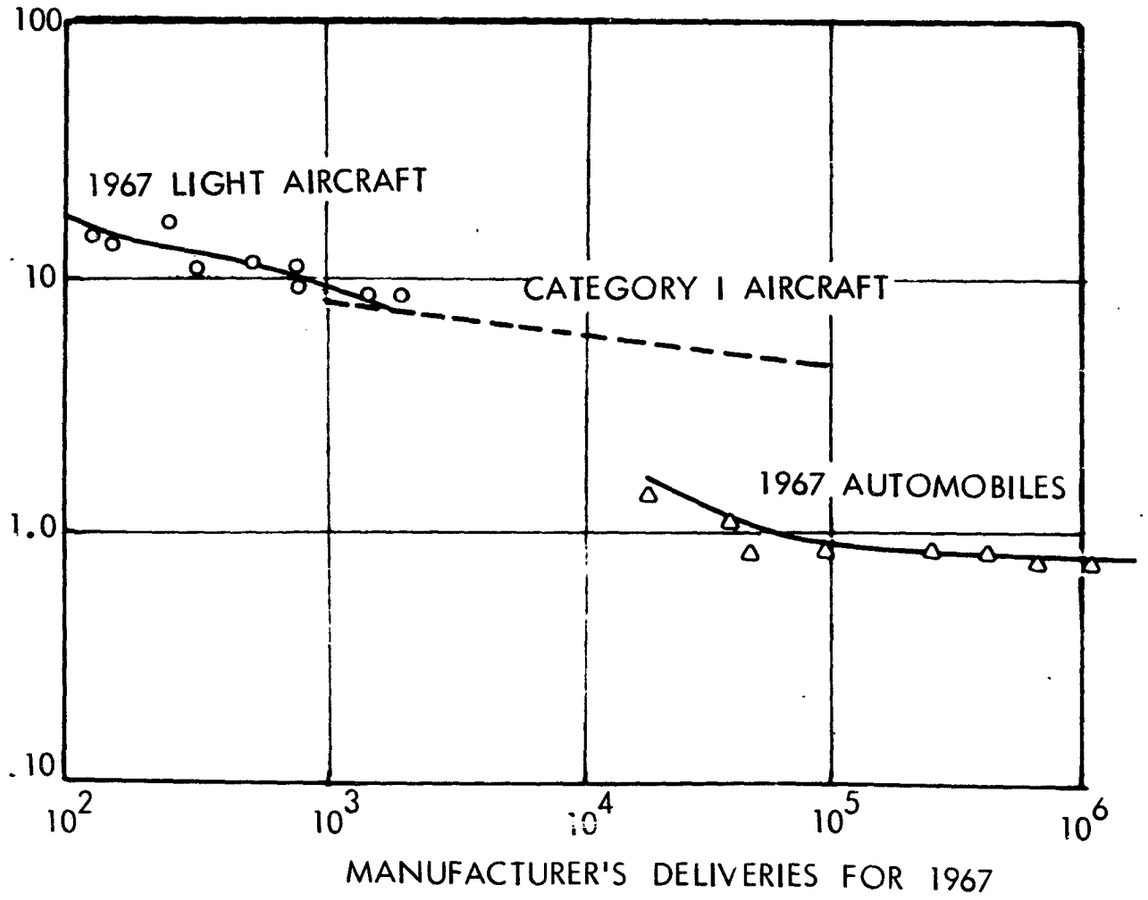


FIGURE 10.2 - PAST & PROJECTED GENERAL AVIATION AIRCRAFT DELIVERIES PER YEAR

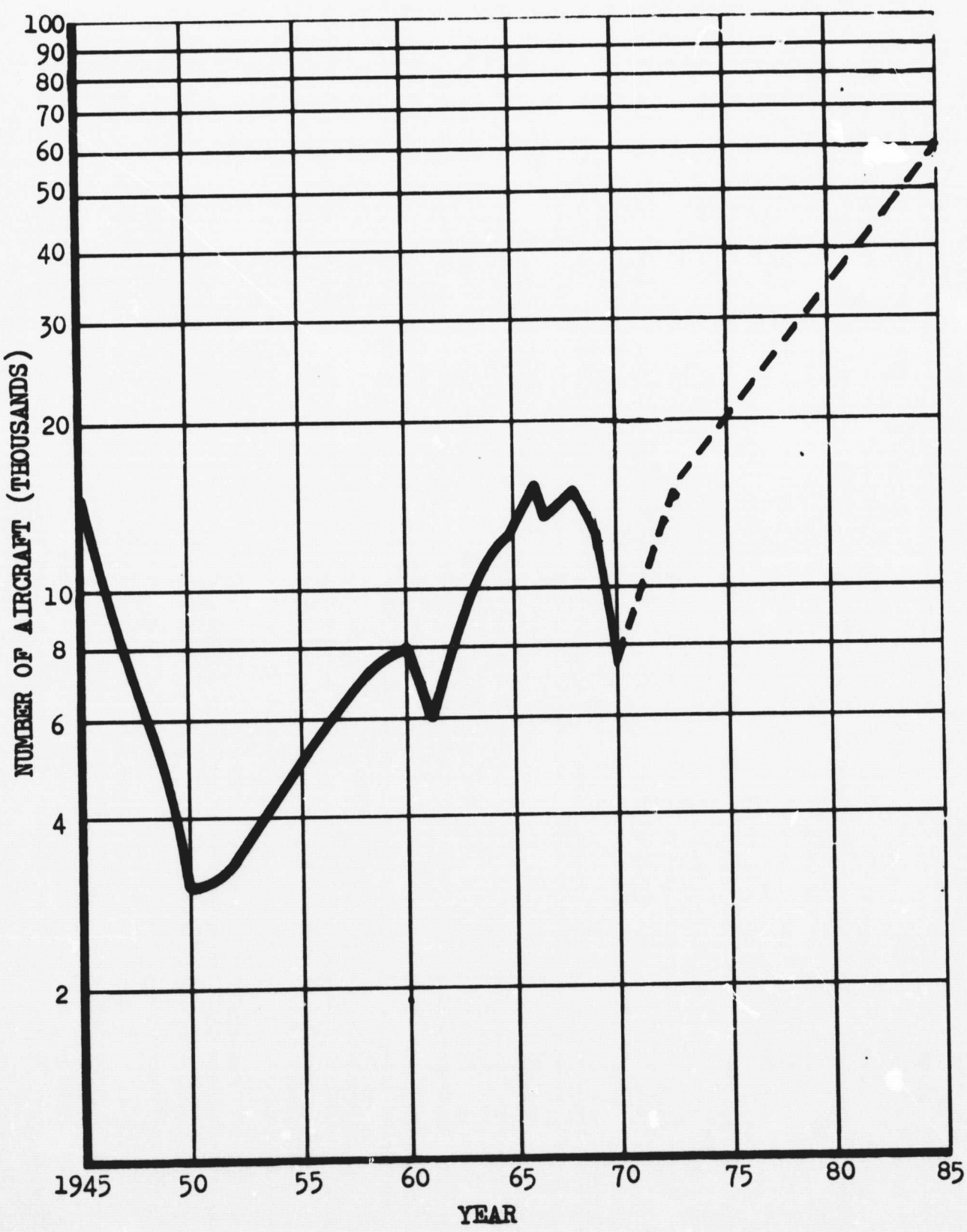
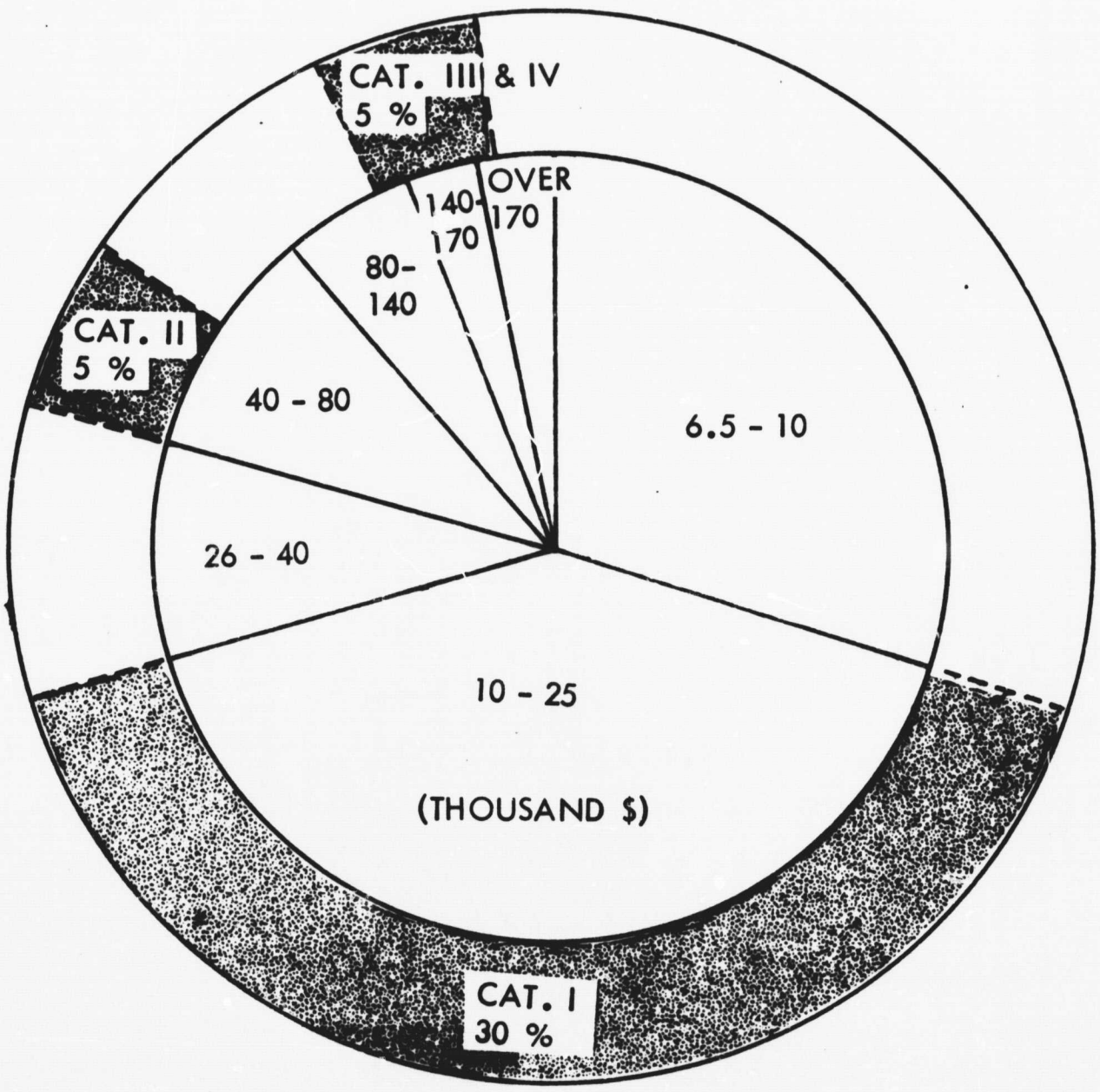


FIGURE 10.3 - PRICE CLASSIFICATIONS OF GENERAL AVIATION AIRCRAFT DELIVERED IN 1969 AND THEIR RELATIONSHIP TO CATEGORIES I, II & III

(EXCLUDING AVIONICS)



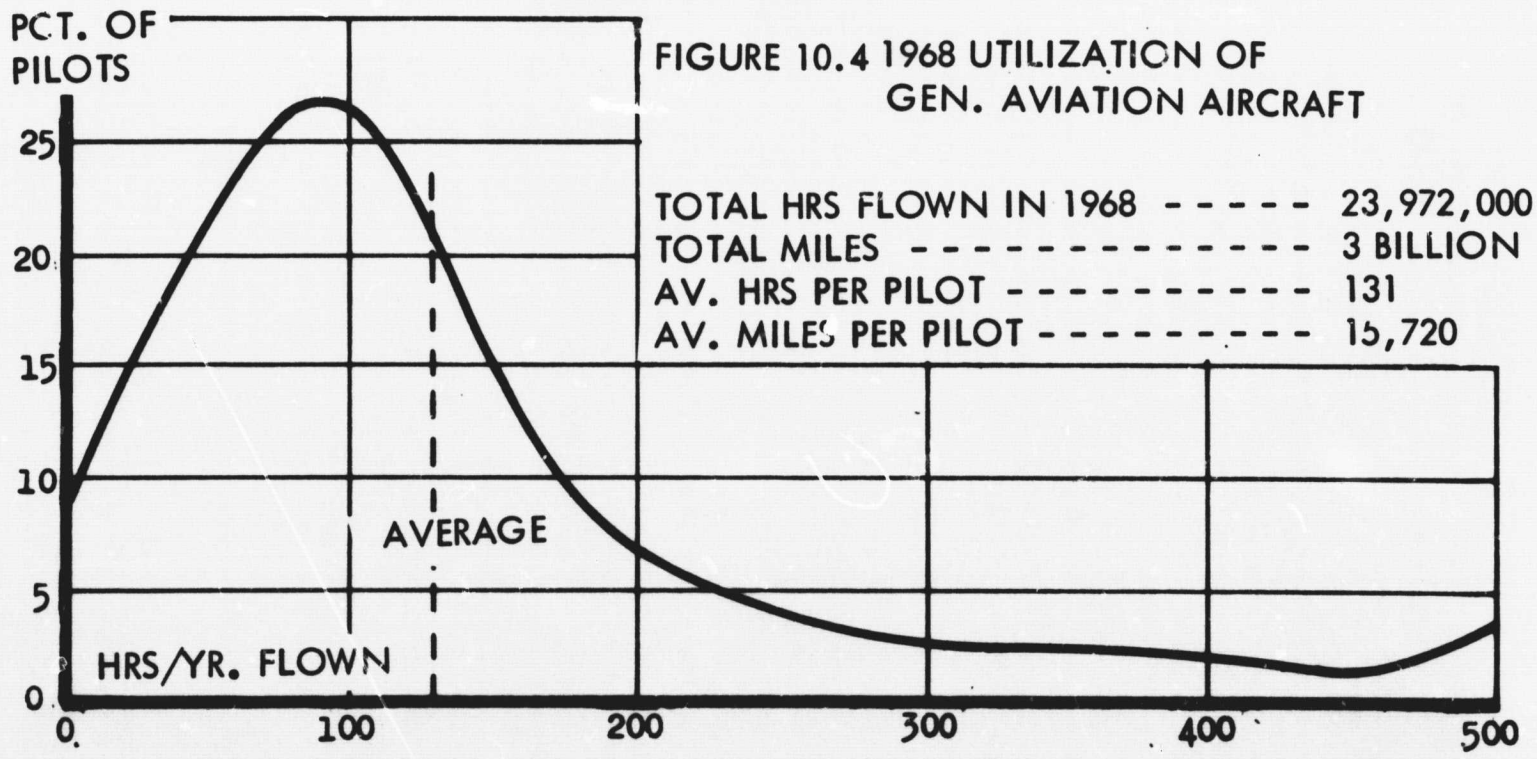


FIGURE 10.4 1968 UTILIZATION OF GEN. AVIATION AIRCRAFT

TOTAL HRS FLOWN IN 1968	23,972,000
TOTAL MILES	3 BILLION
AV. HRS PER PILOT	131
AV. MILES PER PILOT	15,720

Category	Projected 1985 Deliveries
I	18,000
II, III, & IV	3,000 (each)

Assuming that one manufacturer delivers one-third of the total number in each category, his yearly production rate and corresponding price tag according to Figure 8.7.11 is as follows:

Category	Annual Production Rate	Price
I	6,000	$11,000
II	1,000	39,000
III	1,000	146,000
IV	1,000	122,000

The projected yearly delivery rate for 1985, as shown in Figure 10.2, represents a potential figure which can be attained by growth of the population and the GNP and unconstrained by adverse factors.

10.2 Factors Affecting the Growth of General Aviation

Reference 10.7 cites the Speas Report (Reference 10.6) and a subsequent report by Sanborn Aviation Associates on the same subject. The former report forecasted unconstrained potential, while the latter pointed up the danger of possible roadblocks in the years ahead. These include declining airplane utility, insufficient emphasis on education, and airport saturation. The Sanborn report states that the potential market can never exist until the general aviation community combines its resources to "make the market" - creating new markets for tomorrow, rather than counting yesterday's receipts. It goes on to say that there are no limits to the growth of general aviation, except those which are self-imposed, since ample buying power exists in both the business and personal airplane markets.

Addressing the subject of utility, this characteristic affects the market for all general aviation aircraft. The privately owned aircraft market, represented by Category I, is particularly affected in this respect. Figure 10.4, obtained from Ref. 10.2, shows the utilization of general aviation aircraft in terms of hours per year flown by percentage of licensed pilots. The majority of hours flown per pilot lies in the 50 to 150 hours per year bracket, and the average figure for all pilots is 131 hours per year. This figure can be translated, at average speeds, to about 15,000 miles per year, which is equal to the mileage accumulated by the automobile driver. However, the hourly utilization of aircraft has a much higher potential because of the difference in average speed. For instance, the use of aircraft for commuting over longer distances would result in greatly increased hourly utilization. This requires a high degree of reliability and capability for all-weather operation, as well as safety and economy. High utilization demands a higher degree of convenience, with closer location of the airfield to the user.

Noise and high values of real estate tend to keep airfields at remote locations, but the availability of quiet aircraft with home storage and all-terrain capability appears to be a possible solution. In addition to business and commuting, the use of general aviation for pleasure accounts for at least half of the total hours flown. Future increase of leisure time might make private aircraft approach pleasure boats in popularity, provided that the obstacles of price, operating economy and convenience can be overcome.

Business flying accounts for the majority of general aviation flying hours, exceeding the combined total of all the U. S. airlines and represents nearly 75% of the dollar volume of the general aviation aircraft market. It embraces the small business organizations operating single engine aircraft, characteristic of Categories I and II, the medium size companies operating small twins, exemplified by Category III and the large corporations which operate professionally flown, multi-engine propeller and jet aircraft. So far, the last named segment of the market seems to have received the highest emphasis, leaving the market for the smaller business aircraft with the greatest potential. According to Ref. 10.7 (quoting the Sanborn Report) the growth in business flying during the 1960's was the only major aviation activity which expanded at a slower rate than that of the GNP. The primary resistance factors were cited as lack of utility and education, as well as the impact of scheduled jet service by the airlines. Out of the potential number of business organizations, only one company out of 14 is now operating business aircraft. The obstacles to high utilization are uncertain schedule reliability and high operating cost. The results of this study show that the aircraft recommended in Categories II, IV and particularly III, can be equipped to operate in adverse weather conditions, provide an extra degree of safety and comfort, and use close-in airfields without creating an undesirably high noise level - all at reasonable cost by the use of advanced technology available in the ensuing years.

The matter of education includes the attraction of new pilots in growing numbers. The Sanborn Report states that 1.4 million new pilot starts will be needed in the 1970's just to offset the attrition losses and that 2.1 million will be required through 1980 to meet the Speas forecast (Ref. 10.6). Another facet of education is that of teaching the potential business manager how he can use aircraft reliably and economically, with a "positive, profit-oriented basis for justification," according to Ref. 10.7. One example of how this can be accomplished is Reference 10.3, which shows, in terms of time-value, that general aviation can become the dominant economic mode for the short haul transportation of multiple business travelers, particularly under the impact of advanced technology.

Safety is yet another facet of education. The extra features added to the recommended aircraft configurations of this study do not add to performance and do increase the cost of ownership. Additional safety features in automobiles, including seat belts, shoulder straps, padded dashboards and collapsible steering columns, had to be legislated because the average driver takes safety for granted. A sizable portion of potential aircraft owners, however, are deterred by the fear of accidents and this situation can only be counteracted by education.

Even with the provisions of increased utility and education, the potential growth of general aviation can be hamstrung in the future by airport saturation. The Sanborn Report claims that, of the 10,690 U. S. airports on record, barely 7,000 are open to the public; only 2,474 have paved runways.

The report states that a minimum of 2,570 new airports are required before the industry can begin to realize its growth potential and that the attending cost will be about $2.8 billion. However, lower cost airstrips or "air parks" can be created in greater numbers, closer to the domiciles of the users, provided that low noise level aircraft can be developed, with high flotation landing gear to avoid the necessity of paving, and with home storage provisions to avoid hangaring and unsheltered parking. These facilities can be made attractive, grass fields with neat "service stations," so that visual pollution, as well as noise and air pollution can be minimized. By using the Air Cushion Landing System, lakes, bays and other waterways can be used. Most of these facilities can be created, by private business or by aviation-oriented residential communities, some of which now exist. Nevertheless, government financial aid is essential in this respect.

Another deterrent to the growth of general aviation is the impact of future Federal Air Regulations (FAR's). Stricter Air Traffic Control (ATC) is already emerging and, unfortunately, in complicated forms when applied to metropolitan areas. Although ATC is an ever-increasing problem, its solution must take a more simplified course, otherwise existing and potential pilots will lose their initiative. Stricter pilot licensing requirements will have a similar effect. It will be far more advantageous to the growth of general aviation for the government to stick to the present FAR's and for the industry to improve their products in such ways that stricter FAR's will not become necessary. Although careless flying, like careless driving, can never be wholly eliminated, much can be done by the designer to minimize the incidence of "pilot error."

10.3 Summary

The potential growth of general aviation, as forecast by the Speas Report, can be realized or exceeded by the year 1985 only by implementing the following requirements:

- Increased utility
- Increased safety
- Increased dependability
- Reasonable prices
- Economical operation
- Effective educational programs
- Increased airfield facilities
- Uncomplicated operational procedures

The Federal Government can cooperate in this endeavor by taking the following actions:

- Provide technological assistance by funding effective research and development programs.

- Cooperate with state and local governments in the financial support of new airfield construction.

- Establish a system of air traffic control with which the average general aviation pilot can cope.

- Exercise restraint in the establishment and administration of Federal Air Regulations.

The rest is up to the industry, which must rouse itself from complacency and increase its tempo in product improvement, striving all the while to give the customer better utility, safety and reliability for his dollar. Without close cooperation between industry and government, the growth of general aviation will not accelerate and may even slow down in the years to come. If general aviation should grow to its full potential, it will become a major contributor toward solving the nationwide transportation problem.

10.4 References

No.	Source	Title
10.1	Aviation Week & Space Technology - March 9, 1970	U. S. Business & Utility Aircraft Shipments 1969 (p. 194)
10.2	Aircraft Owners and Pilots Association	1969 Profile of Flying and Buying
10.3	H. M. Drake, G. C. Kenyon and T. L. Galloway - AIAA Paper 69-818, July 1969	Mission Analysis for General Aviation in the 1970's
10.4	L. P. Greene, AIAA Paper 69-819	Technical Challenge and Task of General Aviation in the 1970's
10.5	Federal Aviation Agency Office of Policy Development Economics Division, July 1966	General Aviation: A Study and Forecast of the Fleet and Its Use in 1975
10.6	R. Dixon Speas Associates Report for GAMA, 1969	The Magnitude and Economic Impact of General Aviation 1968 - 1980
10.7	R. J. Hoffman Business and Commercial Aviation, Sept. 1970	Those Bullish Predictions for General Aviation - Where Did They Go Wrong?

11.0 CONCLUSIONS

The conclusions of this study are divided into two categories: specific (directly related) and general. The former deals with the specific categories of aircraft studied under the constraints imposed by the NASA, and the latter covers the subject matter which leads into the recommendations for follow-on activity.

11.1 Specific Conclusions

11.1.1 Category I Aircraft

This category is directed toward ownership by individuals or small businesses; in any event, by those in the medium income bracket, which accentuates the necessity for low price. Of equal importance, however, is the necessity for a high degree of utility. The inclusion of advanced avionics, to the extent of prodivind VFR capability with accurate navigation provisions and the further inclusion of extra system safety features can be obtained for a price increment of about 70%, which can be optional.

The recommended configuration of Section 9.2 includes the extra utility features of wing folding for home storage, towability along the road and an air cushion landing system for all-terrain operation. A 20% reduction in range is traded for an additional 10 knots of cruise speed.

No compromise with the 75 PNdb noise level at 500 ft. is recommended, but the design field length can be increased to 1500 ft., consistent with contemporary aircraft in the same category.

The pusher propeller configuration appears to exact no penalties in weight and cost and should result in good visibility and a quiet interior. As in the case of the other three categories, the rotating combustion engine is the optimum power plant.

This airplane can be priced under the average of today's aircraft of similar size and performance, with an operating cost approaching ten cents per mile at a 300 hr/yr utilization rate, which is comparable to that of an automobile when depreciation is included.

11.1.2 Category II Aircraft

The 500 ft. field length constraint, along with the 75 PNdb noise level, are directed toward operation in and out of close-in metropolitan airfields. Since this is basically a 4-place aircraft, the price should be held within reasonable limits, even though the speed range of minimum to maximum has been raised. Since the 500 ft. field length requirement results in an abnormally large, high powered and expensive airplane, it should be compromised

and 1000 ft. is recommended on the belief of its compatibility with the intended type of operation. No compromises with the 200 knot cruise speed and the 75 PNdb noise level are advisable.

Since this aircraft, by virtue of its performance and price levels, is directed primarily toward business ownership, and since it will be operated in areas of dense air traffic and ground obstacles, the installation of advanced avionics with IFR capability and automatic flight control devices is recommended. For the same reasons, the extra system safety provisions, the use of turbocharged engines and the provision of cabin pressurization appear worthwhile. This aircraft is estimated to cost $50,000, its high degree of utility should result in a rate of utilization approaching 300 hours per year with an operating cost approaching 20 cents per mile. It is believed that the recommended combination would appeal to an appreciable number of potential operators.

As in the case of Category I, the pusher propeller concept, using a rotating combustion engine, is recommended for the same reasons. The autogyro approach was investigated as a potential candidate but found to be considerably more costly.

11.1.3 Category III Aircraft

This category is directed toward the small to medium business owner, whose use is primarily for trips between widely spaced population centers. Although the aircraft would be flown, primarily, from satellite, rather than major, airports,short field performance is not a necessity, and should defer to the attainment of high cruising speed, schedule availability, comfort and safety.

For the above reasons, the inclusion of high altitude operation with cabin pressurization; advanced avionics with automatic flight control and equivalent airline capability; and extra safety provisions (both structural and system types) are recommended. In order to maintain reasonable levels of initial and operating cost, it is recommended that some of the imposed constraints be compromised.

The noise level can be increased to 85 PNdb and still be comfortably below that of similar aircraft operating from satellite airports. This would have the effect of reducing the propeller size from an abnormally large diameter to a more conventional size. The field length can be increased from 1500 to 2000 ft. and still be well within the limits of appropriate airports.

The recommended configuration is the high wing type, with twin engines and tractor propellers. However, with the admission of the 85 PNdb noise level, a turbofan-powered aircraft becomes a candidate. It would have, at least, a 50 knot increase in cruise speed, but offset by a 65% increased price. These two factors tend to offset each other and equalize the operating

cost. A single turbofan is recommended in lieu of a twin engine installation, in the interest of minimizing the price. It is also justified by the higher reliability level of the turbofan, in comparison to engine-propeller combinations. There is believed to be a market for both types of aircraft in this category, although a study in greater depth might narrow the choice to one.

11.1.4 Category IV Aircraft

The VTOL market has been definitely established and is presently represented solely by the helicopter. Since the technology relating to fixed wing VTOL concepts has been developing rapidly over the last 20 years, a comparison was made between the helicopter and a tilt wing - propeller configuration. Although both types are very expensive by non-VTOL standards, the helicopter still appears to be the best bet. Although the tilt wing provides a 100% increase in cruise speed, it is over 30% more expensive to buy and operate.

The necessity for high cruise speed and long range in this category is questionable, since it is directed toward operation over short distances, primarily within metropolitan areas, if this remains the principal mission in 1985. Of greater necessity is the need for advanced avionics and automatic flight control aids, as well as extra structural and system safety provisions. Again, no compromise with the 75 PNdb noise level constraint is recommended.

It is concluded that a cruise speed of 135 knots and a cruise range of 250 miles be established in favor of incorporating the advanced avionics, automatic flight control and extra safety provisions. These trades result in a price slightly in excess of $200,000, and an anticipated high utilization rate would permit operation at 88 cents per mile. Thus, the price of achieving useful VTOL capability will continue to be high, causing these craft to be restricted to special applications.

It would appear that a broader look at the VTOL/STOL segment of general aviation would be in order. It is possible that an autogyro could be designed for a lower level of cruise performance than that specified for Category II, which would fulfill the requirements of both Categories II and IV. It would conceivably be operated at a reduced weight when near-vertical takeoff and landing is required and loaded to a heavier gross weight for STOL operation. Such an investigation should be made in a depth which is beyond the scope of this study.

11.2 General Conclusions

The potential is at hand to expand the activities of general aviation so that it will become a major element in the U. S. transportation system by 1985. The impact of advanced technology, aided by government-sponsored research and development, can result in quieter, safer and more useful aircraft at significantly lower cost, in terms of the present dollar value. Greater public acceptance, however, will depend on parallel influences. These include compliance with pollution standards, increased pilot training, unbiased educational programs, increased airfield facilities and sensible federal regulations. The close coordination of all these activities would give definite assurance to the growth of general aviation.

11.2.1 Impact of Advanced Technology

The main purpose of this study is to assess the impact of advanced technology. As used in this context, the term should be preceded by the word "emerging." While the 1985 time period is being addressed for the assessment of effect, the necessary research and development to make full use of the applicable technology, at that time, must be accomplished in the intervening period. Emerging technology applicable to general aviation aircraft has the following aspects:

(a) Aerodynamic Design, including high lift devices, airfoil development, low drag configuration and accent on improved stability and control without benefit of augmentation. A large amount of research has been accomplished by NASA in the past, some of which has been directed particularly toward general aviation application. References 11.1, 11.2 and 11.3 summarize this information. Additional research related to suitable airfoil sections, simple and effective high lift devices, handling qualities and guidelines for low drag design should be pursued.

(b) Propulsion Systems, embracing both the prime mover and the propulsor. The most promising type of power plant for general aviation use appears to be the rotating combustion engine, which combines the potential of light weight, low fuel consumption with low initial and maintenance costs. As for propulsors, the propeller is the most efficient for all applications except high speed business aircraft and the only known device capable of maintaining the desired noise level of 75 PNdb at 500 ft. While the turbofan is a strong competitor in the business aircraft category, a detailed comparison should be made with the multi-bladed, shrouded, shaft-driven propeller, currently termed a "prop-fan."

(c) Avionics Systems, which include the functions of communication, identification, navigation, collision warning and automatic control from takeoff to landing. They primarily serve the purpose of attaining higher utilization of the aircraft with increased tolerance to adverse weather. However, at the present and in the foreseeable future, systems which combine to contribute the greatest benefit to the user are attainable only at very high prices and require considerable improvement in reliability and maintainability. They have a definite place in the business aircraft category, which is dependent on high utilization rate and maximum schedule availability for increased usage in the future.

(d) Structural Design, including the use of advanced materials and processes to achieve lighter weight structures at lower cost. This is contrary to the present trend with conventional materials and processes. The emergence of composites, with high strength-to-weight ratios, offers the best chance of achieving the desired results. Presently, the materials are too costly for general aviation use, and not enough knowledge of optimum processing techniques has been accumulated. This area, therefore, is in acute need of research and development support.

(e) Safety Provisions, which embrace the structural and systems areas. The former area includes tolerance to higher load factors, higher rates of sink and crash landings. Use of composite materials can bring about these desires without severe compromises in weight, performance and cost. The systems area includes tolerance to adverse weather, reduction of the incidence of fire and the ability to make consistently safe landings. These are, again, opposed by the cost barrier and require development toward simplification. Another facet of safety is the study of human factors toward the reduction of design-induced pilot errors.

(f) Utility and Convenience Features, which include home storage, limited roadability and all-terrain (including amphibious) capability. The provisions of wing folding and towability on the road have been sparsely applied in the past and do not represent advanced technology applications - only design ingenuity. All-terrain capability is another matter and has been achieved in the past only with serious compromises of cost and performance. However, the advent of the air cushion landing system gives promise of providing the desired capability with little, if any, compromise and is in need of further research and development aid.

(g) VTOL and STOL Technology, covering both rotary and fixed wing approahces. While the results of this study indicate the superiority of the helicopter as the best VTOL candidate and the fixed wing (over the autogyro) as the best STOL candidate, analyses in greater depth might reverse these conclusions. In any event, these aircraft must be capable of quiet operation, since they are intended for use in densely populated areas. Further conceptual studies are needed in this area, with emphasis on cost reduction as a major objective. It must be remembered, however, that metropolitan operation involves closely regulated traffic, requiring a high degree of pilot training, as well as the best possible avionics equipment. This, in itself, will restrict the potential numbers of such aircraft and probably hold the line on high prices for some time to come.

11.2.2 Impact of Environmental Factors

Great emphasis is currently being placed on reducing the extent to which the air is being polluted by noise and noxious gas emission. Aircraft are primary offenders in the first case and minor ones in the second case. While the military and transport aircraft contribute the most of both types, the general aviation community must face up to the same problems. The results of this study have shown that the noise problem is capable of solution in the low to medium speed categories of aircraft, which use propellers. Some progress is being made by the engine manufacturers in reducing the noise level of turbofans and should be supported by continued research. As for gas emission, the automotive industry is becoming increasingly regulated and is sponsoring its own

research and development. Similar regulation will, no doubt be applied to the aviation industry, and government-supported R&D effort will be needed.

11.2.3 Impact of Educational Programs

The primary item, in this line, is pilot training, which must be accelerated, along with the application of advanced technology to aircraft, if the anticipated growth of general aviation is to be realized. Government support in this area can take the form of subsidies and the greater use of general aviation for the performance of government functions, creating more job opportunities. Other programs can deal with the increasing utility of general aviation aircraft, particularly by business organizations. To be credible, these must emanate from independent sources, rather than the industry. The same type of program can serve to educate the public on the safety and environmental aspects. The last two types of educational programs should be timed to follow the development of appropriate technology applications, so that the element of wishful thinking can be eliminated.

11.2.4 Impact of Available Facilities

The growth of general aviation can be stunted by the limited availability of airfields and service facilities, if for no other reasons. Government aid to small and large communities is needed to establish a larger number of small airfields available to general aviation activity. Convenient locations will do much toward relieving congested traffic conditions at major airports, beside encouraging more individuals and business organizations to use general aviation. Much in the way of encouragement can be given to this program if low noise standards, acceptable to the communities, can be set. For the smaller aircraft, a level comparable to that of an expressway can be attained economically and would do much to encourage the growth of small airfields.

11.2.5 Impact of Federal Regulations

General aviation activity is becoming increasingly sensitive to the application of Federal Air Regulations. While those dealing with the safety aspects of the aircraft have not been changed significantly in recent years, regulations dealing with air traffic have become increasingly severe, primarily because of airline activity. Some of the regulations governing traffic patterns are not easily comprehended by the average pilot and have a dampening effect on general aviation activities. On the other side of the coin, some of the regulations dealing with the handling qualities of the aircraft should be stiffened, in light of present technology, to require that the industry provide better and safer flight characteristics. These include such things as stick force and lateral - directional stability. Stalling should take place without induced roll or violent pitch and spins should become difficult to enter and self-recoverable,hands off. The day is long past when the image of the aviator was that of a daredevil.

11.2.6 References

11.1. Smetana, F. O., A Study of NACA and NASA Published Information of Pertinence in the Design of Light Aircraft, Vol. I - Structures, NASA CR-1484, North Carolina State University, Raleigh, N. C., Feb. 1970.

11.2 Summey, D. C., J. C. Williams III, and J. N. Perkins, Same as above, Vol. II - Aerodynamics and Aerodynamic Loads, NASA CR-1485, North Carolina State University, Raleigh, N. C., Feb. 1970.

11.3 Moore, C. J. and D. M. Phillips, Same as above, Vol. III - Propulsion Subsystems, Performance, Stability and Control, Propellers, and Flight Safety, NASA CR-1486, North Carolina State University, Raleigh, N. C., Feb. 1970.

12.0 RECOMMENDATIONS

As a result of this study, key problem areas are identified in which additional research could enhance the safety, utility, and economy of general aviation aircraft and thus make it a more widely accepted form of transportation.

Although the emphasis of this study is on technical factors, it is evident that in order to understand, and accordingly respond to, consumer demands much more detailed study is required in various related areas. Those areas, while not necessarily the responsibility of NASA, are presented here, as it is strongly believed that government support should be applied. These recommendations are categorized as Technology Areas and Related Areas.

12.1 Technology Areas

(a) The structural design study of a representative airplane, using composite materials and appropriate production processes, to verify or refute the assumptions made in this study with respect to weight and cost factors.

(b) A detailed study, utilizing advanced technology of a rotating combustion engine installation driving a low noise level propeller. This study would also include an investigation of emission control devices. Future development, test and certification procedures might follow.

(c) A detailed study, followed by wind tunnel tests, of applying improved handling qualities to a representative advanced technology general aviation aircraft. Such a program might also include flight simulation. (This area of research would follow the recent work by NASA and Princeton University and be directed toward future possibilities.)

(d) A detailed study of extra safety provisions applied to a representative airplane, which include both structural and systems applications.

(e) A design study of the application of automatic flight control to advanced technology aircraft, applying current and emerging state-of-the-art in the fields of avionics and automatic flight control.

(f) A design study of an application of the air cushion landing system to a representative airplane. As a later phase, an actual installation could be made and flight tested.

(g) A study of Category II (STOL) and Category IV (VTOL) aircraft in greater depth, comparing logical candidates. This might include the evolution of a compromise design, such as an autogyro, which would serve both purposes.

(h) A study of the "prop-fan" versus the turbofan engine in a high performance business aircraft, with emphasis on attaining reasonably low noise levels.

12.2 Related Areas

(a) Facilities Development - Conduct a study of existing general aviation airfields and service facilities and plan an orderly expansion program, investigating all constraints (such as noise, real estate values, air pollution and others). Governmental support budgets for such a program would be determined.

(b) Federal Air Regulations - Conduct a survey of present FAR's as related to emerging technology, future traffic conditions, proliferation of small airfields, environmental effects and other considerations. Make recommendations for changes which might promote the growth of general aviation without compromising safety aspects; also those which would tend to increase safety without inhibiting growth.

(c) Licensed Pilot Availability - Conduct a forecast study of the number of licensed pilots expected to be available between 1970 and 1985, considering the impact of influential factors such as cessation of hostilities in Southeast Asia, increasing attractiveness of aircraft ownership, employment opportunities due to the growth of business aviation, possible new uses of aircraft and other considerations. Relate the numbers to available pilots to the anticipated numbers of aircraft, categorizing pilot-owners, pilot renters and employed pilots. In the event that the pilot forecast appears to be a constraint on the potential numbers of aircraft forecast for the future, recommend an increased training program and the extent of government funding support required.

(d) General Aviation Forecast - Following the completion of the study phases recommended in Sections 12.1 and 12.2, conduct an over-all study of general aviation through 1985, assessing the impact of all influential factors. This should result in realistic estimates of the yearly fleet size, new aircraft deliveries and functional categories of ownership (recreation, business, agricultural, taxi, etc.). By dividing the potential owners into income groups, forecast the numbers of aircraft in size and performance categories. Account for the influences brought to light in the related studies, plus those of population increase and dispersal, growth of the GNP, increase of leisure time, reduction in the fear of accidents and other factors. The report, when completed, should be given the widest possible circulation in an attempt to stimulate the growth of general aviation.

APPENDIX I

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MOFFETT FIELD, CALIFORNIA

SPECIFICATION
FOR

"TECHNOLOGY ASSESSMENT OF ADVANCED GENERAL AVIATION AIRCRAFT"

Specification A-15983 November 13, 1969

1. STATEMENT OF WORK

1.1 INTRODUCTION

Studies of possible 1985 short-haul transportation, by NASA's Mission Analysis Division, have shown that general aviation has the potential of performing an increasingly important role in the national transportation system. In order to realize this potential fully, the cost, performance, and operational characteristics of this class of aircraft must be improved. The NASA, through in-house and contractual studies, is attempting to identify critical technology areas where additional research may increase the safety, utility, and economy of general aviation.

The Mission Analysis Division has sponsored studies aimed at identifying potential advances in light aircraft structures, piston engine propulsion, and avionics for general aviation aircraft. These studies mainly considered approaches for improving the economics and safety of this class of aircraft without any consideration of advanced aircraft configurations. The intent of the present study is to assess the impact of advanced technology applicable to general aviation aircraft for the 1985 time period.

The conceptual design emphasis should be placed on examining configurations that take advantage of new philosophies in design, manufacturing, and operational practices. However, the designs must be supported by a realistic projection of technology and economics, substantiated by sound engineering analysis. This study will provide a baseline for the broad parametric type of studies being performed by the Mission Analysis Division.

1.2 OBJECTIVES

The objectives of this study are: (a) to assess the technology applicable to general aviation aircraft in the 1985 time period and evaluate the areas offering the most potential for improvements in

safety, economy, and operational capabilities; (b) by means of conceptual designs, provide data, tradeoffs, assessments, etc., for the purposes of future mission analysis; (c) to identify key technology requirements where additional research may increase the safety, utility, and economy of general aviation aircraft.

1.3 DESCRIPTION AND SCOPE

This will be a nine-month study assessing aircraft technology related to general aviation aircraft of the 1985 time period. An important facet of the study will be to relate the influence of advanced technology and new design philosophies on the cost, performance, and operational capabilities of this class of aircraft. Applicable technologies are to be evaluated for use in conceptual aircraft meeting the requirements of the Appendix. This analysis will include sensitivity studies and be of sufficient depth to justify the use of the results in the broad parametric studies being performed by the Mission Analysis Division. The study will be conducted according to the following guidelines and constraints.

1.4 GUIDELINES

1.4.1 The contractor will assess the advances in technology applicable to general aviation aircraft and indicate the areas yielding the greatest improvements in safety, economy, operational capabilities, user and community acceptance.

1.4.2 The contractor will apply the results of the technology assessment to the conceptual design of at least four aircraft meeting the requirements of the Appendix. The technical proposal should indicate possible design concepts meeting the requirements and may also propose the study of additional designs. The conceptual designs should show imagination and ingenuity, however, they should be technically sound and justifiable for the 1985 time period.

1.4.3 The contractor will assess the benefits and penalties on the performance, cost, and operational characteristics of the conceptual designs for incorporating the safety requirements outlined in the Appendix.

1.4.4 The conceptual designs will evaluate a variety of propulsion schemes. Comparisons should also be made regarding number and type of propulsion unit necessary to meet the performance requirements of each conceptual design.

1.4.5 The conceptual designs will consider and evaluate design features that improve the economics of owning and operating general aviation aircraft. Emphasis should be placed on design features that improve utility as well as those that affect such cost items as fuel, inspection and maintenance, overhaul, storage, and insurance.

1.4.6 The conceptual designs will investigate and evaluate the effect emission and noise control regulations might have on the performance and cost of the designs.

1.4.7 The conceptual designs will meet the handling qualities specified in the Federal Air Regulations at both extremes of center of gravity travel. The contractor may incorporate any augmentation system that is justifiable and feasible to provide the necessary stability and control.

1.4.8 Conceptual designs with optimized cruise performance above 8000 feet will evaluate the benefits and penalties associated with cabin pressurizationa.

1.4.9 The conceptual designs should consider design approaches that have the potential of increasing the seating capacity by 50 percent.

1.4.10 The contractor will evaluate the influence of VFR and IFR flight requirements on the conceptual designs.

1.4.11 At the conclusion of the study the contractor will identify key technology requirements where additional research may increase the safety, utility, and economy of general aviation.

1.5 CONSTRAINTS

1.5.1 The studies will be made for the 1985 time period. The contractor will assume advanced technology, including such areas as aerodynamics, materials and structures, avionics and propulsion. The effects of assuming advanced technology will be indicated.

1.5.2 The results of appropriate previous and current studies of aircraft design should be considered in determining feasible general aviation concepts.

1.5.3 The conceptual designs will comply with the appropriate Federal Air Regulations regarding aircraft design and operation. Any inadequacies or restrictions in these regulations which may prevent the application of promising technology will be identified and possible modifications to the regulations suggested and justified. If no regulations are appropriate, the contractor will use design criteria accepted by the industry and based on sound engineering judgement. The conceptual designs must meet the safety requirements listed in the Appendix.

1.5.4 The noise level for the conceptual designs will not exceed 75 PNdb outdoors at a distance of 500 feet from the aircraft.

1.5.5 The effect of production rate on aircraft cost will be shown for rates of 1000 to 100,000 aircraft per year.

1.5.6 All costs should be expressed in 1969 dollars.

1.5.7 Details of these ground rules may be modified by mutual agreement between the contractor and the Mission Analysis Division.

AIRCRAFT REQUIREMENTS

The conceptual aircraft resulting from this study must meet the requirements in this Appendix. These requirements are of a mission nature to encourage the contractor to use ingenuity and imagination in his designs. The designs must be supported and justified by sound engineering procedures. There are four design categories. These are minimum design requirements.

General. The following requirements are applicable to all categories.

(1) The weight allowance for each seat will be 170 pounds for the occupant plus 50 pounds of baggage. Each seat will be allotted 4 cubic feet of baggage space.

(2) The minimum performance requirements for each category must be met with all seats occupied, full baggage, and enough fuel and oil for taxi, takeoff, approach, landing and 45 minutes reserve at normal cruise power.

(3) The cruise altitude will be optimized according to the mission requirements.

(4) Safety requirements: (a) design load factor of 9g; (b) a method to provide automatic wing leveling; (c) a crash locating device; (d) a landing gear design sink speed of 13 feet per second; (e) a crash resistant cabin environment; (f) fuel remote from the passenger cabin; (g) fire retardant incorporated for fuel and propulsion system; (h) anti-icing equipment; (i) automatic landing flare device.

(5) The operating cost will include the cost for fuel and oil, inspection and maintenance, reserve for engine and propeller overhaul, storage, insurance, and depreciation. It will be calculated for utilization rates of 100, 300 and 500 hours per year.

(6) The resulting conceptual design of each category listed below will be the most economical design that meets the requirements. The sensitivity of initial cost and operating cost to changes in field length, range, and cruise requirements will be shown by individually varying each requirement. No field length sensitivity analysis is required for Category IV.

Category I. - This concept should be the most economical aircraft in terms of purchase price and operating costs. It must meet the following requirements.

(1) The critical field length will not exceed 1000 ft.
(2) The range will not be less than 500 miles.
(3) The normal cruise speed will not be less than 130 knots.
(4) The minimum number of seats will be four.

Category II. This concept will provide good field performance but not be VTOL. The requirements for this category follow.

(1) The critical field length will not exceed 500 ft.
(2) The range will not be less than 500 miles.
(3) The normal cruise speed will not be less than 200 knots.
(4) The minimum number of seats will be four.

Category III. This concept should provide the greatest productivity and meet the following requirements.

(1) The critical field length will not exceed 1500 feet.
(2) The range will not be less than 1500 miles.
(3) The normal cruise speed will not be less than 250 knots.
(4) The minimum number of seats will be six.

Category IV. This concept must have VTOL capability and meet the following requirements.

(1) The range will not be less than 500 miles.
(2) The normal cruise speed will not be less than 150 knots.
(3) The minimum number of seats will be four.

APPENDIX II - DRAG CALCULATION

II-1 Zero Lift Drag

RN = "K" x V(Kts) x L
RN = Reynolds Number
K = 8930 for 7500 feet
K = 6440 for 20,000 feet
V = 130 kts for Cat. 1
= 200 kts for Cat. 2
= 250 kts for Cat. 3

L = Characteristic Streamwise Length

$L_w = (Sw/AR)^{.5}$ for wings
where S_w = Wing area
AR = wing aspect ratio

L_H (Hor. Tail) = .935 x W_f where W_f = max fuselage width
L_V (Vert. Tail) = 1.26 x H_f where H_f = max fuselage height

For each of the above components the C_f (skin friction coefficient) can be found by the following formula:

$$C_f = \left(\frac{.242}{\log_{10}((RN)C_f)} \right)^2$$

C_f = flat plate turbulent skin friction coefficient (general)
This is the flat plate C_f value at cruise velocity and characteristic fuselage length. The following data are necessary for fuselage C_D determination:

1. Length
2. Max. height
3. Max. width
4. Max. cross sectional area
5. Vision provision

   (a) full canopy
   (b) windshield and side windows (low wing)
   (c) windshield and side windows (high wing)
   (d) item (c) + rear window

In order to reduce the flat plate skin friction drag C_{ff} to 3-dimensional drag terms, it is necessary to multiply the basic C_{ff}

by $1 + \left(\frac{1}{\text{fineness ratio}} \right)$
C_{ff} = fuselage flat plate turbulent skin friction drag coefficient.

$$C_{ff_1} = C_{ff} \times \left(1 + \frac{1}{L_f/D_f}\right)$$

C_{ff_1} = fuselage skin friction drag coefficient correct for fineness ratio.
$D_f = (S_f \times 4/\pi)^{.5}$ where D_f = fuselage effective diam.

and S_f = Max cross-sectional area of fuselage.
L_f = Fuselage length

Various allowances must be made to correspond to actual conditions on a tractor airplane installation. They are:

10% for slipstream (tractor)
5% engine nacelle
4% windshield items (b) & (c) above
4% aft vision items (a) & (d) above
5% roughness
5% deviation from streamline
133% max multiplying factor
114% min. multiplying factor - does not include provision for rear vision, roughness (assume smooth plastic), or slipstream.

$C_{ff} = C_{ff_1}$ (1 + appropriate allowances)

C_{ff} = fuselage skin friction drag with all corrections

$C_{D_o} = (C_{ff} \times S_f \times K \times L_{e_f} / D_{e_f}) / S_w$

K = 3.1

For nacelles, the same estimation procedure is used as was used for the fuselage. The RN is found as in the first equation, and the C_{f_N} is determined by the same formula used for the fuselage.

Appropriate allowances for nacelles are:

10% for slipstream (tractor installation)
5% engine provision
5% roughness
5% deviation from streamline

$C_{f_N} = C_{f_{N_1}}$ (1 + appropriate allowances)

$C_{D_{C_N}} = C_{f_N} (S_N \times K \times L_N/D_N) / S_W$

The drag of booms are determined by the same method as was used on the nacelles, except for the factor K = 3.4 rather than 3.1.

For wing drag, after the C_{f_W} for the wing has been determined, (flat plate) correction factors for various wing thickness are as follows:

t/c	K_2
.09	1.32
.12	1.42
.15	1.53

where $C_{f_{W_1}} = K_2 \; C_{f_W}$

The following allowances are considered applicable for the wing:

10% roughness (normal sheet metal)
4% slipstream (tractors)
4% gaps, etc.
18% - possible total

$C_{f_{W_{11}}} = 1.18 \; C_{f_{W_1}}$ (maximum)

$C_{D_0} = 2C_{f_{W_{11}}}$ (use full wing area to compensate for interference)

The tail surfaces are selected by correlative data. The same factor for thickness should be used on the tail surfaces as on the wing, corresponding to the proper thickness. 5% should be added for roughness, 4% for interference and 5% for gap drag, with 10% for the effect of propeller slipstream, plus using all of the tail area, including that covered by the fuselage.

$S_H = 3.5 \; (W_f)^2$

$S_V = 2.4 \; (H_f)^2$

These values are to be multiplied by 1.3 for pusher-tractor configurations:

Where S_H = Horizontal tail area
W_f = Maximum fuselage width
S_V = Vertical tail area
H_f = Total fuselage height

These methods do not give proper tail areas for all conditions, but will give representative values for the configurations investigated. The tail drag will be

$$C_{D_{0_H}} = C_{f_H} \; (K_{thick.}) \; (\text{roughness \& interf. factors}) \; \frac{(3.5)(W_f)^2}{S_W}$$

$$C_{D_{0_V}} = C_{f_V} \; (K_{thick.}) \; (\text{roughness \& interf. factors}) \; (2.4) \; \frac{(H_f)^2}{S_W}$$

The total zero lift drag equation then becomes:

$$C_{D_{0_{TOT}}} = C_{D_{0_{WING}}} + C_{D_{0_{FUSE.}}} + C_{D_{0_{TAIL}}} + C_{D_{0_{GEAR}}} \quad \text{(if applicable)}$$

$$+ C_{D_{0_{NACELLE}}} \text{(if applicable)} + C_{D_{0_{BOOMS}}} \text{(if applicable)} + C_{D_0} \text{(misc.)}$$

The zero lift drag procedure specified in the paragraphs above give the method of determining the drag coefficient of the various major items of the aircraft except antennas and non-retractable gear, which will be discussed in the following paragraphs.

The zero lift drag was evaluated from Lockheed Report ER 6223, "Aerodynamics Method Manual" dated 1964, and "Fluid Dynamic Drag" by Sighand Hoerner, dated 1958, and K. D. Woods' "Air Vehicle Design."

The drag of the landing gear, when it is not retracted, or the drag of a retractable gear extended, will be determined by a formula of the following nature:

$$LG = K \left(\frac{W}{1000} \right)^{.5}$$

where

LG = flat plate area of gear

W = airplane gross weight

K = constant, varying from .7 for a well streamlined, short gear on a low wing airplane to a value of 2.0 for a retractable gear extended. Data contained in "Air Vehicle Design" by K. D. Wood was used as a reference for landing gear drag, as was S. F. Hoerner's "Fluid Dynamic Drag." These data were correlated with General Aviation Aircraft published data.

The drag of the appropriate antennas and air scoops are added to the drag of the complete airframe.

The cooling drag also has to be evaluated. In assessing the cooling drag, two reference reports were used. They were: "The Aerodynamics of the Cooling of Aircraft Reciprocating Engines" by A. S. Hartshorn and L. F. Nicholson, dated 1956, published by the British Ministry of Supply and the "Lycoming Aircraft Engine Installation Manual," dated 1958. It was found that a good average value for cooling would be 2.5 percent of the engine power for cruise and 6 percent of the engine power for climb, with an optimum cowl flap configuration. With an installation having no variable geometry, the cooling could easily reach 10 to 12 percent of the power available for cruise, or even higher. The most effective cooling method would be the use of a fan, with variable geometry exit, in the case of a normal air cooled reciprocating engine. Another method of cooling that is quite efficient is the use of exhaust augmentor tubes. The present study will concentrate on the use of cowl flaps or fixed cooling geometry, but the other methods mentioned will be investigated in a cursory manner for comparison purposes.

The above values of 2.5 percent power loss due to cooling drag for cruise, and 6 percent during climb, are incorporated in the C_{D_o} of all aircraft investigated.

II-2 Lift Induced Drag

The aerodynamic lift drag is determined on the basis of investigations which indicates a maximum efficiency factor of 0.9 for the wing alone, whereas an efficiency factor of .8 would be more representative of a general aviation configuration, fitted with a normal fuselage. The value of 0.8 is used in all calculations of lift drag. The formula would be

$$C_{D_i} = \frac{C_L^{\,2}}{\pi\, AR e}$$

in which

C_{D_i} = induced drag coefficient

C_L = lift coefficient

AR = wing geometric aspect ratio = $\frac{b^2}{S}$

π = 3.1416

where b = wing span

S = wing area

e = efficiency factor

The lift drag would have to be added to the total C_{D_o} to obtain the complete airplane in the clean configuration. Thus:

$$C_{D_T} = C_{D_o} + C_L^{\,2} / \pi\, AR e$$

where C_{D_T} = total drag coefficient

However, for a high lift configuration, the flap drag as determined in 5.1.2, would have to be added to the total $C_{D_T}{}_L = C_{D_o} + C_L^{\,2}/\pi\, AR e + C_{D_f}$

where C_{D_f} total flap drag at the appropriate C_L, including interference, effect of flaps or induced drag, and flap zero lift drag.

APPENDIX III

SELECTION OF PROPS BY CONVENTIONAL MEANS

<u>Category I Airplane</u>

ASSUME HP = 225 @ 2600 RPM
CRUISE PWR (HP) = 169 @ 2400 RPM

TRY 6.35 FT. DIAM. PROP - 2B1.-150AF

$$\text{Take-off } C_p = \frac{225}{2000x(2600)^3(6.25)^5} = \frac{.1125}{17.57 \times .0954} = .0671$$

$$C_T/C_p = 2.1$$

$$\text{STATIC THRUST} = \frac{2.1X200X33000}{2600 \times 6.25} = \frac{853\#}{225}$$

$$\text{STATIC THRUST/HP} = \frac{853}{225} = 3.8\ \#/HP$$

$$\text{Cruise } C_p = \frac{169/.7983}{2000x/3.27x.0964} = .0827$$

$$J = V/ND = \frac{101.3X130}{2400 \times 6.25} = .878$$

$$= 83\%$$

$$V_t = 851 \text{ ft/sec}$$

$$M_t = .762$$

$$D_B = 85.7 @ .762\ M_t$$

10.8 @ 2BL, 6.25 Diam.
96.5 - Total overall PNdb
3.5 - Correction to PNdb
100.0 PNdb NOISE LEVEL

Category II Airplane

ASSUME H.P. = 400 (TAKE-OFF)
CRUISE H.P. = 300
RPM = 2600 @ %.0., 2400 @ Cruise
7 FT. DIAMETER

$$C_p = \frac{400 \times 1}{2000 \times (2.6)^3 (7)^5} = .0675$$

$C_T/C_p = 2.2$ (2B1., 150 AF)

$$\text{STATIC THRUST} = \frac{2.2 \times 400 \times 33000}{2600 \times 7} = 1596\#$$

$$\text{THRUST/HP} = \frac{1596}{2000} = 3.99 \text{ \#/HP}$$

CRUISE EFFICIENCY

$$C_p = \frac{300/.7983}{2000 \times 13.27 \times .168} = .0845$$

$$J = \frac{V}{ND} = \frac{101.3 \times 200}{2400 \times 7} = 1.21$$

= 87.4% (150 AF, 2BL.)

TIP SPEED = 953 Ft./Sec.

TIP M = 953/1116.89 = .853

BASIC SOUND LEVEL = 92.8
DIAM. & NO/BL = 10
102.8

CONVERSION TO PNdb = 3
105.8

APPENDIX IV

AVIONICS AND INSTRUMENTATION

Several representative organizations were contacted by letter and questionnaire to gain added insight into the status and probable future direction of general aviation avionics. Responses were received from the Aircraft Owners and Pilots Assn., the Aradar Corp., Collins Radio Co., and Narco Avionics Division of Narco Scientific Industries. The questions asked and the range of answers are given below.

1. Do you foresee the availability of DME and area navigation computers at a price that will allow them to be used as widely as VOR is? Is there any development effort that could help bring this about?

   Answer: It is unlikely that the price of DME and area Nav computers can be brought down to match VOR because they are inherently more complex. However, it is entirely reasonable to expect significant price reductions as a result of improved technology. The extent of implementation in general aviation aircraft will be proportional to the advantages that accrue when flying in the R-NAV airways system.

2. In regard to a possible alternate navigation system, the Dept. of Transportation's National Plan for Navigation indicates that the OMEGA system will be operational world-wide by 1972 and will continue through at least 1982. Do you consider OMEGA as a potential supplement or replacement to VOR/DME that would be advantageous to general aviation?

   Answer: The consensus is in favor of OMEGA as a supplementary nav-aid, but difficulties are recognized. Much development is needed, and problem areas include putting an antenna for such a low frequency system on a small airplane, the problem of VLF atmospherics, how best to resolve the inherent ambiguities, and how to fit a hyperbolic system into the airways structure.

3. The Department of Transportation Air Traffic Control Advisory Committee has recommended the Intermittent Positive Control (IPC) concept as a major contribution to safety of flight in mixed airspace. This would require extensive redevelopment of the ATC radar beacon system. Do you consider this recommendation viable operationally and economically?

   Answer: The IPC concept is considered viable, but with reservations. The accuracy of the radar sensor for the intended purpose was questioned. It was pointed out that extensive ground facilities to process the data and display it on a real-time basis was necessary.

4. There is some expressed need to install weather radar on conventional single-engine propeller-driven airplanes. This is by pod-mounting the radar outside the propeller disc, or it might be feasible to look through the propeller disc with the antenna mounted below the engine and faired into the cowling. Do you have any suggestions that could lead to the availability of weather radar for single engine aircraft?

   Answer: The responses indicated that weather radar on single engine aircraft was practical and if a sufficient volume of business were to materialize, the problem of cost and where to put the antenna would be solved. One of those responding stated that an experimental antenna built into the leading edge of the wing of a single-engine aircraft was flying and initial tests looked promising.