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Abstract

Five NASA engine-oriented propulsion programs of major importance to civil aviation are presented and discussed. Included are programs directed at exploring propulsion-system concepts for (1) energy-conservative subsonic aircraft (improved current turbofans, advanced turbofans, and advanced turboprops), (2) supersonic cruise aircraft (variable-cycle engines), (3) general aviation aircraft (improved reciprocating engines and small gas turbines), (4) powered-lift aircraft (advanced turbofans), and (5) advanced rotorcraft. These programs reflect the opportunities still existing for significant improvements in civil aviation through the application of advanced propulsion concepts.

Introduction

The evolution of aviation to the present generation of aircraft has taken place over a surprisingly few decades. History has shown that pacing the major advancements in this field has been the development of appropriate propulsion systems. Indeed, to a great extent, the first Wright Brothers' flights were dependent on the attainment of a suitable lightweight engine system. The era of high-speed high-altitude flight, as we know it now, had to await the advent of the gas turbine engine.

NASA and its predecessor, NACA, have over their years of existence contributed in a major way to the advancements in aeronautics. Such contributions spanned the complete spectrum of disciplines - aerodynamics, propulsion, structures, avionics, stability, etc. The recognition of the importance of propulsion, in particular, resulted in the establishment of a special laboratory, the Lewis Research Center, for propulsion research, now devoted primarily to jet and fan engine propulsion systems.

Through the combined efforts of government and industry, the gas turbine engine has developed into a state of high sophistication. Although one might think that such sophistication both in the engine and aircraft would lead to a maturing of the technology, such is not the case. In particular, the propulsion area presents some very exciting opportunities that could expand and modify the character of aviation dramatically from what we see today. The importance of such advances has been noted in various studies of future aviation needs (e.g. 1,2).

Although NASA's programs include a broad range of discipline activities in propulsion related areas, and also provide support in many areas to the military, the scope of this paper will be limited to engine programs specifically related to civil aviation. Propulsion work for five major aircraft applications will be described: energy-conservative subsonic transports, supersonic cruise transports, general-aviation aircraft, powered-lift transports, and rotorcraft. Some comments on applications looming on the distant horizon will also be included.

Energy-Conservative Subsonic Transport Propulsion

The commercial fleet of air transports has evolved from its initial piston-engine propulsion systems, through turbojets, and now to turbofans. In this progression, it was always important to strive for minimum fuel consumption for the sake of better airplane range and operating efficiency. Due to low fuel costs, however, this was not of overwhelming importance in comparison with other desirable characteristics, such as higher speed, larger size, durability, maintainability, and lower noise. But since the oil embargo, the current recognition of dwindling petroleum reserves, and the sudden increase in fuel prices, the importance of fuel efficiency has come to the forefront.

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As a result of this increased significance of fuel efficiency, NASA in 1976 embarked on a major technology program with the ambitious goal of ultimately reducing the required fuel usage in subsonic commercial aircraft by a factor of two. [3] Part of the achievement of this goal would be through improved aerodynamics of the aircraft (high apsect-ratio wing, super-critical airfoils, winglets, laminar flow, etc.) as well as by using lightweight aircraft structures through the liberal application of composites.

Major attention was also given to the propulsion systems. In this area, three distinct programs (improved current turbofans, advanced turbofans, and advanced turboprops) were evolved, each having different goals, risks, and timing. The program goals of fuel savings and direct operating cost are identified in Figure 1.

Engine Component Improvement (ECI)

This program seeks to make a near-term improvement in the existing and near-future airplane fleet. [4,5] It thus is limited to whatever modifications can be economically made to current engines, either for future production or through retrofit. Through contracts with the manufacturers of the JT8D, JT9D, and CF6 engines--which power practically all of the present jet fleet--it is hoped to achieve at least a 5-percent reduction in fuel usage. At the same time, no penalty in DOC will be accepted. Figure 2 shows a cutaway view of an "improved" current engine. On the right-hand side is listed a few of the items of potential improvement.

Another area of potential improvement is illustrated in Figure 3. As indicated, engines when first placed into service suffer a noticeable short-term deterioration in fuel consumption. In the longer term, the rate of loss levels off somewhat, but still continues. Some, but not all, of this loss is recovered as the engine is periodically repaired. The causes of this deterioration are presently not well understood, but are believed to include the items listed on the left-hand side of Figure 2. A diagnostic program to identify these causes is in process. This should then permit finding economically feasible ways to minimize the losses, which can be as high as 8 percent.

The ECI program, started in 1977, will continue for 5 years and is funded at [illegible]0 million dollars.

Energy Efficient Engine (E^3)

The second program [4,5] involves developing and verifying the technology for a future generation of all-new turbofan engines that have rather challenging goals in reducing fuel consumption and DOC. A seen from Figure 1, the goals include a minimum of 12 percent improvement in sfc as compared to the most advanced turbofans of today and at least a 5 percent improvement in DOC. The engines must, of course, meet the noise and emission standards that might be in force at that time.

Figure 4 compares current and advanced engines and lists some of the advanced technology features under consideration. The presently-favored concept is a two-spool arrangement with direct drive of the fan and with mixed exhaust flow. About half of the sought-for gain is to be achieved through various component improvements beyond the current state-of-the-art. Increased aerodynamic efficiencies, tighter clearances (including active clearance control), reduced turbine cooling air, and better materials are considered key ingredients. The other half of the gain arises from the improved cycle that can be designed around these better components. Principal features include a modest increase in turbine-inlet temperature, a substantial increase in cycle pressure ratio, some increase in bypass ratio, and exhaust mixing.

The E^3 Project is planned to be an 8-year program that started in 1976. The two major commercial engine manufacturers are participating on a cost-sharing basis. Preliminary design studies by P&W and GE have just been completed. Initiation of the detailed design and experimental efforts is expected by March 1978. The ultimate objective of this program includes the design and testing of an advanced experimental core and an integrated core-low spool system. Thus, it is a very major effort. The total program funding is approximately 200 million dollars.

High Speed Turboprop

The initial NASA studies of ways to reduce fuel consumption considered a wide variety of unconventional propulsion systems. [6,7] Of these, [illegible] felt to have the greatest potential was the advanced turboprop. As indicated in Figure 1, this approach has a possible high payoff. However, it also represents a high risk.

The key characteristic that makes the turboprop of such great interest is the expectation of high propulsive efficiency at the flight speeds typical of modern jet transports (Fig. 5). Figure 6 shows a model of an advanced design (provided under contract to Hamilton Standard) under test in a Lewis wind tunnel. It incorporates such features as thin airfoils, swept leading edges, and multiple blades. Preliminary experiments suggest tnat the goal of 80 percent propeller efficiency at Mach 0.8 is achievable.

Many issues must be addressed before turboprops can be accepted as a viable propulsion system. These include noise and vibration, structural design of reduction gears and thin blades (especially using composite materials), propeller/nacelle/wing aerodynamic interactions, and reliability/maintainability. These will all be considered in the program that was initiated in 1976 under base technology funding and enters a formal project phase in 1978. The first phase is basically an exploratory activity that will cost 7.4 million dollars over a 3-year period. If successful, later phases may involve larger models and subsequent flight tests. [8]

Fuel Specifications

Another issue that should be discussed when considering the fuel consumption of future engines is the nature of the fuel that is expected to be available for use by those engines. Present jet fuels are produced to rather tight tolerances on physical and chemical characteristics. Less stringent specifications would allow wider sources and thus greater availability of aviation fuels. A more extreme situation is the prospect of aviation fuel being obtained in the future from non-petroleum sources such as shale and coal. NASA has initiated a program to identify the characteristics of potential future fuels and to assess the impact of those fuels on engine design and operation. Another part of that program includes an evaluation of the energy used in the refining process, in order to minimize the total energy required to operate the aircraft.

Supersonic Cruise Transport Propulsion

One of the most challenging propulsion goals lies in the area of advanced supersonic transports. It is generally acknowledged that the feasibility of such an aircraft depends upon major advancements in propulsion. The engine system, including inlets and nozzles, must operate efficiently at both supersonic and subsonic conditions, be quiet during takeoff and landing, and have acceptable emissions. Although no development program is in process or even in the offing, NASA since 1973 has been engaged in work aimed at advancing the state-of-the-art in these areas. This will generate the information needed for decision making and preserve the option of undertaking future development.

Variable-Cycle-Engine Technology

No single engine cycle can completely satisfy all of the conflicting requirements at supersonic and subsonic flight conditions as well as meet stringent noise goals. Extensive studies of many alternative approaches have finally led to the concept of the variable-cycle engine as having the best potential for satisfying the requirements.[9,10] Such an engine would be designed with flexibility in cycle operation and bypass ratio to allow it to operate more like a turbojet at supersonic cruise conditions, and like a moderate bypass ratio engine at subsonic conditions.

Each of the engine companies involved in the program has its preferred variable-cycle engine system. The P&W engine (Fig. 7) is a duct burning turbofan featuring considerable flow variation in the components and a cycle with an inverse turbine inlet temperature schedule. As opposed to more conventional engines, takeoff is at a reduced temperature and maximum inlet temperature is employed at supersonic cruise.

The GE "double bypass" engine (Fig. 8) features flow being diverted around the engine in various ways depending upon the mode of operation. Valving is provided at both the front and rear portions of the engine to permit the desired flow distribution.

Complex, variable-geometry inlets and exhaust systems are needed with both of these engines. A sophisticated control system is necessary to allow all of the components to function in the most effective manner throughout the flight. Advanced components and materials are also desired here as they were in the E^3 program.

The increasing public sensitivity to aircraft noise is an especially critical issue for supersonic engines, which require high exhaust velocities for efficient cruising. The corresponding jet noise would be unacceptable if alleviating measures were not taken. The variable cycle features just mentioned aid considerably in this regard, as they permit takeoff with lower and, hence, quieter velocities. Further quieting can be achieved with jet noise suppressors; however, the associated weight and thrust losses impose undesirable penalties.

An alternate concept for noise suppression that is applicable to engines that have two exhaust streams [11] has been explored under this program. This "coannular" effect is illustrated in Figure 9. For a given thrust, if the velocity in the outer stream is higher than that of the core stream, tests have shown that up to 10 PNdB of noise suppression can be achieved. The improvement is reduced, but still substantial, when compared to the case where the two streams are completely mixed before emerging from the nozzle. The data to date has been obtained only on small-scale experimental nozzles. Also, other noise sources such as core and duct-burner noise must still be reckoned with.

The recognition that some of the advanced technology elements must be explored on a rather large scale has prompted the initiation of the "variable-cycle engine component" program (Fig. 10). This program [12] uses existing engines as the test-bed to explore several of the critical technologies. The P&W program utilizes the F100 engine as the facility and will explore principally the duct burner performance and noise and nozzle performance including the coannular effect. GE utilizes a J101 engine and will explore the front valving characteristics, as well as the coannular effects on performance and noise.

This variable component test program was initiated in 1976 as a 5-year effort and is funded at 22 million dollars. It is expected that it is the first step in a longer range activity that could grow into a variable-cycle experimental engine program.

Emissions

One of the major concerns regarding future supersonic transports is that of emissions into the stratosphere.[13] Primarily, it is feared that the generation of nitrogen oxides may reduce the concentration of naturally occurring ozone, permitting more ultraviolet radiation to reach the earth's surface with detrimental consequences to plant and animal life. Although the issue is still unresolved, the available studies suggest that a large reduction in engine NO_x production is prudent.

NASA already had a program under way (Experimental Clean Combustor Program) where advanced concepts were being explored in an attempt to substantially reduce emissions from those of current combustors. This program was expanded in 1973 to include the problems relevant to supersonic aircraft. [14] The favored concepts emerging from the program are illustrated in Figure 11. In general, these combustors differ from the conventional type by possessing two stages - a pilot stage and a main stage. This allows the combustor to be optimized somewhat independently for low emissions both in the vicinity of the airport and at high-altitude cruise. Figure 12 shows that this approach offers a considerable improvement over current technology, but substantial further advances are still required to meet the goal of approximately 3 g/kg.

Several other approaches that promise greater potential reductions are shown in the figure. They are now being explored in a comprehensive research program called Stratospheric Cruise Emissions Reduction Program (SCERP). The results will be applicable not only to supersonic aircraft but also to high-altitude subsonic transports.

General Aviation Aircraft Propulsion

Another area of aircraft propulsion in which NASA has recently increased its activities is that related to general aviation. This field of aeronautics embraces basically all civilian aircraft other than the commercial carriers and, therefore, covers a wide span of types from single-engine piston aircraft up to the high-speed high-altitude business jets. Three major areas of activity are currently under way.

QCGAT

Figure 13 presents a distribution of civil aviation aircraft by engine horsepower and flight speed. As indicated above, one distinct group in the general aviation field is the business jet, which is a fairly large aircraft flying at speeds similar to those of commercial airliners. The Quiet Clean General Aviation Turbofan project (QCGAT) was initiated with the objective of applying the noise and emissions technology, previously developed for large turbofan engine applications, to the smaller general aviation fan engine, and, in particular, provide a means for NASA to transfer this technology to the smaller general aviation engine manufacturers. [15]

Two contracts totaling approximately 8 million dollars are currently in process with Garrett AiResearch and AVCO-Lycoming. The AiResearch program involves an experimental engine using the core from the TFE731. Figure 14 shows a schematic of this experimental engine. Features include a fan of increased diameter and reduced pressure ratio, 1.49, (as compared to the TFE731) which when combined with a jet mixer will reduce the jet velocity and, hence, noise substantially. It also includes a higher work extraction turbine and a reduced emissions combustor. Its rated thrust level is 3900#.

The AVCO-Lycoming program involves essentially a new experimental turbofan based upon an upgraded turboshaft engine core (LTS101). It is substantially smaller than the AiResearch engine, having approximately 1600# rated thrust and designed for smaller aircraft flying at somewhat reduced flight speeds. A schematic of this engine is shown in Figure 15. The fan pressure ratio is quite low (1.31) and the bypass ratio correspondingly high (9.1). It also has a low emissions combustor, a high work single-stage turbine, and a mixer for noise reduction.

These two programs were initiated at the beginning of 1977 and are approximately 2 years in duration. Upon completion of the contract effort, the experimental engines will be delivered to NASA for further evaluation.

GATE

Referring again to Figure 13, it is apparent that there is a large group of aircraft models categorized by horsepowers and flight speeds lower than those addressed by QCGAT. In fact, about 98 percent of the 170,000 planes in the present fleet are in this category. Of this large number, turbine power has been able to capture only 10 percent of the engine market--specifically, turboprops have sole reign at the higher horsepower part of the spectrum. At still smaller sizes, the reciprocating engine is unchallenged.

The purpose of the General Aviation Turbine Engine (GATE) program is to seek advanced technologies that will enhance the attractiveness of very small civilian turbine engines. Particular emphasis will be placed upon cost, as this factor has been the major deterrent to the extension of the gas turbine engine down to these smaller general aviation applications.

The GATE program is now in the definition stage. Four small-gas-turbine contractors were selected to help provide this definition: Detroit Diesel Allison, Teledyne, AiResearch and Williams Research. Elements of this definition program are shown in Figure 16 and include (1) a general study of the market needs for such an engine, (2) determination of engine technologies and design features that are considered optimum for each aircraft type, (3) an evaluation of the "common core" concept to permit, in addition to simplification, the use of the relatively expensive core for a wide range of engine types, and (4) the contractor's view of what the GATE program would be in terms of scope, schedule, and cost. The first two phases have been completed.

The results of these studies are intended to provide the basis for decision making regarding proceeding into a subsequent experimental engine program.

Reciprocating Engine Technology

As already noted, the vast majority of today's general aircraft are powered by reciprocating engines. One objective of the NASA activity is to aid the industry to reduce emissions. Some of the work is being done in-house. For example, Figure 17 shows the results of tests to correlate emissions level with ambient temperatures and humidity. Other work, some partly funded by FAA, is being done under contracts with AVCO-Lycoming and Teledyne-Continental. These efforts range from minimal adjustments to fuel-air ratio and spark advance through more significant modifications such as variable valve timing and exhaust air injection.

Another objective is to seek general improvements in the performance and flexibility of the engines. Included here are lower cooling penalties, improved integration with the airframe, and multifuel capability for lessened reliance on specialized aviation gasoline.

A related activity involves the exploration of other advanced propulsion system concepts in addition to the gas turbine already discussed. For example, the turbocharged rotary concept sketched in Figure 18 is being studied. Another concept being considered is a lightweight Diesel engine. It is hoped that this program will identify propulsion systems that better meet emissions requirements and have improved performance than the conventional reciprocating engine in use today.

Powered Lift Transport Propulsion

For many years it has been suggested that one significant method for improving the U.S. air transporation system would be through the use of small airfields located in close proximity to the traveler's residence or business (e.g. [1]). This would both relieve congestion at the major airports and minimize ground travel time. These close-in fields would probably have especially stringent noise constraints and also be limited in available runway lengths. Conventional aircraft would be unable to accommodate these limitations. However, special short-haul airplanes that employed the propulsion system to augment the wing lift can be envisioned for this application.

In 1974, NASA initiated the Quiet Clean Short-Haul Experimental Engine (QCSEE) program to explore the propulsion systems needed for such an airplane. A 30-million-dollar contract was awarded to GE to design and build two engines utilizing an existing core. One engine is intended for under-the-wing (UTW) installation as pictured in Figure 19. Lift augmentation is obtained by deflecting the exhaust jet with the trailing-edge flaps. The other engine is generally similar, but is intended for over-the-wing (OTW) installation utilizing upper-surface blowing to obtain jet lift. The prospective aircraft using these engines would be similar to the Air Force's YC-14 and -15.

Many of the features of the engines were the product of an extremely severe noise goal of 95 EPNdB along a 500-foot sideline during both takeoff and landing. As a result, the engines are relatively high bypass-ratio devices with low fan pressure ratio. Figure 20 lists some of the design values for the UTW version. Also shown is a sketch of the engine, calling out the numerous advanced technologies that have been incorporated in the design. These technologies are important for other applications besides short haul. They are relevant to many of the present concepts for Navy V/STOL vehicles and apply in some degree to all advanced engines such as E^3 or the advanced turboprop.

The QCSEE program is well down the road, with the OTW engine currently at Lewis for evaluation. Testing of the UTW engine has been completed at the contractor's site with delivery to take place in the very near future. [16]

Rotorcraft Propulsion

Over the years of the evolution of the helicopter, or what is termed herein rotorcraft, the principal activity has been for military applications. Civil applications have been handicapped by high purchase and operating costs, short range, low speed, and poor passenger comfort. Nevertheless, the helicopter's unique hovering capability permits its use when no other vehicle will serve. As a result, in recent years the growth rate for helicopter sales has been very high.

In the past, the only significant government support of rotorcraft propulsion system technology has been through the Army. In recent years, this effort has been augmented to some degree through a unique joint program where Army-funded civilian engineers have been located at NASA research centers and work shoulder-to-shoulder with NASA personnel. Another joint activity is the Rotor Systems Research Airplane, a flying experimental facility to test advanced rotor systems. NASA is now expanding one area of traditional expertise into a focused program specifically aimed at advancing rotorcraft transmission technology. As indicated in Figure 21, advanced technologies in lubricants, bearings, seals, and gears will be applied to improve the mechanical reliability of these transmissions. Lighter weight will also be a goal of this 5 year, 7 million dollar program, which is just getting under way.

A broader helicopter engine program is also being contemplated. Although not clearly defineed at this time, objectives of this program could be to explore advanced features for turboshaft engines such as increased emergency power capability, better part-power sfc, and improved low-cycle-fatigue resistance. Also to be explored are advanced engine systems that would permit substantial increases in cruise speed. Such an engine system might be used in an advanced rotorcraft such as that shown in Figure 22, which would employ a twin rotor system called the "Advancing Blade Concept" and a "Fan-Shaft" engine; one that could operate as a turboshaft unit during the hover mode and as a fan engine at cruise. The engine, shown schematically in Figure 23, could be a small version of the QCSEE UTW engine utilizing a variable-pitch fan but including a right-angle power takeoff within the gearing system. Concepts such as these will constitute the basis for future rotorcraft propulsion programs.

Other Horizons in Propulsion

The previous sections have described some of the technology activities under way or being initiated to advance propulsion technology for civil aircraft. The programs are near term in that they cover aircraft types already in use and that could be expected to achieve operational status in the next 10-15 years.

There are other aircraft on the horizon that could come into being by the turn of the century if there were sufficient motivation--principally economic. Three of these, under study by NASA, will be briefly described here.

Large Cargo Aircraft

Predictions have periodically been made for a decade or more that the air cargo market was on the brink of an enormous expansion. This has not come to pass for numerous reasons, some of which have little to do with the characteristics of the airplane per se. However, it is clear that, if the potential market could justify its development, a much improved, more economical, dedicated air-freighter could be constructed. With proper design, it could not only lower direct ton-mile costs of the airplane but also lead to improvements in the ground-side costs of the total cargo-handling system.

An approach to such improvements is the concept of very large airplanes that are configured for convenience in loading and inter-modal transfers. The spanloader designs illustrated in Figure 24 are one way of attaining this objective. These are being extensively studied by the Langley Research Center and its contractors. In this approach, cargo is contained in the thick wings rather than in the fuselage. The distributed weight along the span relieves the bending moments and permits a lighter structure.[17]

Whether there are unique propulsion problems for such aircraft has not yet been examined in any depth. The propulsion/airframe integration probably involves some unusual aspects. Beyond that, there is an opportunity for innovative approaches to mechanical and structural design of the engines, if not to the basic thermodynamic cycles.

Hydrogen-Fueled Aircraft

The long-term certainty of diminishing petroleum resources makes it desirable to consider alternative fuels, particularly if the alternative offers other benefits to the airplane. Hydrogen is a candidate fuel in this category.[18] It possesses a heating value (BTU per pound) nearly three times as high as that of conventional kerosene or JP fuel. This substantially reduces the fuel weight required for a given range. However, a disadvantage of hydrogen is apparent in the sketch of a typical hydrogen-fueled transport shown in Figure 25. Even after being liquefied, hydrogen is only one-tenth as dense as kerosene. The fuel cannot be contained in the limited volume available in the wings; instead the fuselage must be enlarged to hold bulky fuel tanks. This causes drag and weight penalties. Further weight penalties are caused by the necessary insulation to prevent boil-off or air condensation.

The engines, except for the fuel system, are envisioned to be rather conventional. If anything, the combustor and turbine design problems are lessened. The main technical problems are in the airframe and fuel system. Other concerns involve the economics of manufacturing and distributing the fuel to the appropriate airports and the operational techniques of refueling the aircraft. Since pure hydrogen is not found naturally in significant amounts, its general usage is critically dependent on the manufacturing process (e.g., conversion from coal or shale). In the long run, it may come into use principally as an intermediary for the use of non-fossil-fuel energy (nuclear, fusion, or solar) to provide aircraft propulsion power.

Hypersonic Aircraft

Although supersonic aircraft have not found their way into commercial use in great numbers, there are those who speculate that not only will they come to pass, but that they could be followed by the evolution of a commercial aircraft of even higher speeds. Such aircraft, shown in Figure 26, would operate at extreme altitudes and flight Mach numbers (greater than 6) and would require hydrogen as the fuel so that it could be used as a heat sink to keep the engine, and perhaps the airframe, temperature at tolerable levels.

The propulsion system indicated on the figure and considered most attractive at this time is the supersonic combustion ramjet, or Scramjet. This engine, in the concept illustrated, consists of a combustor mounted on the flattened bottom of the fuselage. The forebody acts a compression surface, decelerating the airstream and raising its pressure. The still-supersonic stream is heated within the combustor and then is expanded against the aft section of the fuselage. The many unusual problems in fluid flow, combustion, structures, and cooling have been extensively investigated by NASA. An experimental engine, built under contract to Garrett, has been successfully tested at simulated speeds up to Mach 7. A continuing research program on engine components and airplane integration is in process at the Langley Research Center.[19]

Concluding Remarks

This paper has presented a brief description of the major programs under way or being planned by NASA in advancing the propulsion technology for civil aviation. From the discussion, it is clear that NASA's aeronautics program reflects the recognition that advancements in both conventional and unusual aircraft are paced by advancements in propulsion. It also reflects the confidence that, although substantial improvements have already been made, vast opportunities still exist for extending the horizons of aviation in the future.

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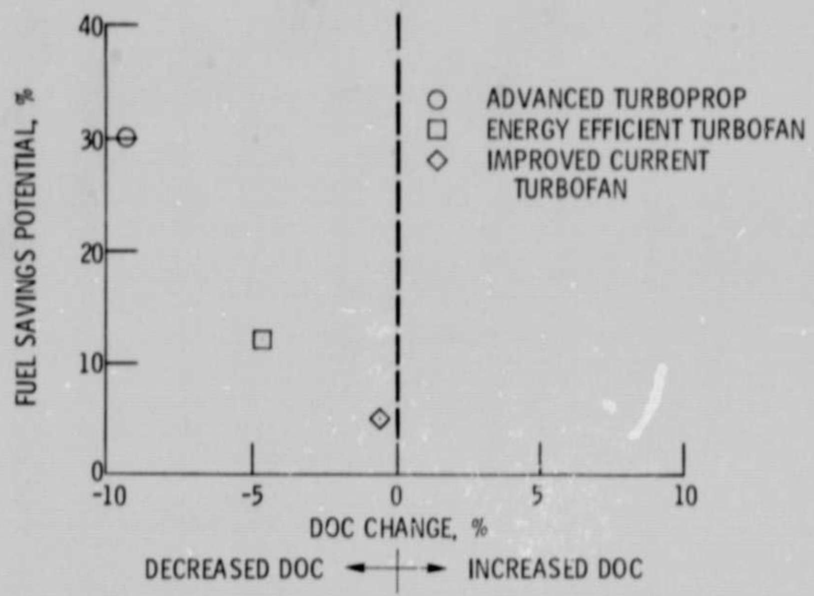


Figure 1. - Energy efficiency goals relative to present technology turbofan. Medium-to-long range airplane.

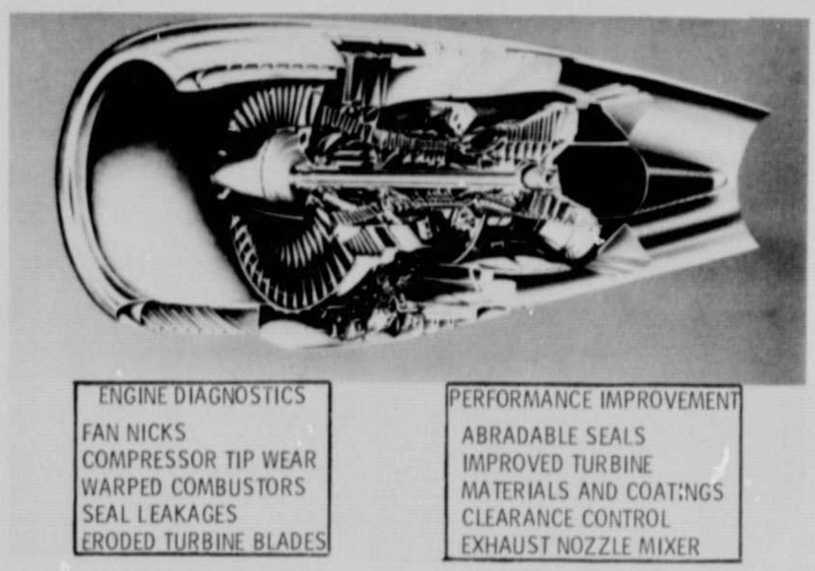


Figure 2. - Engine component improvement.

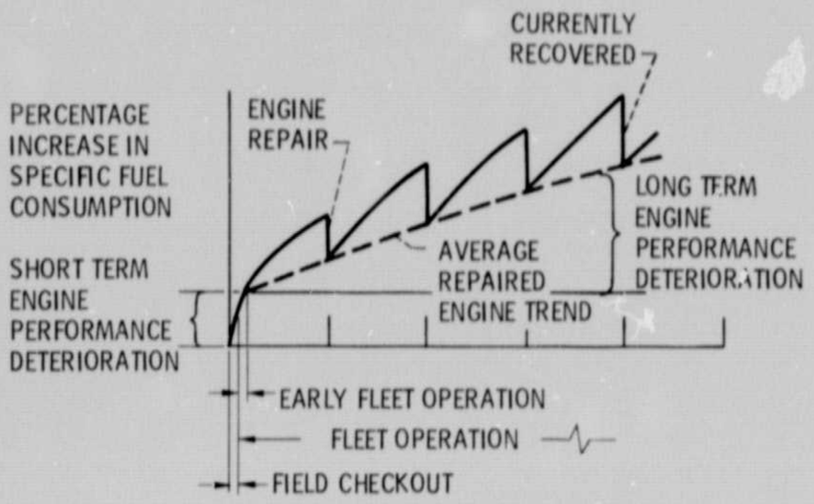
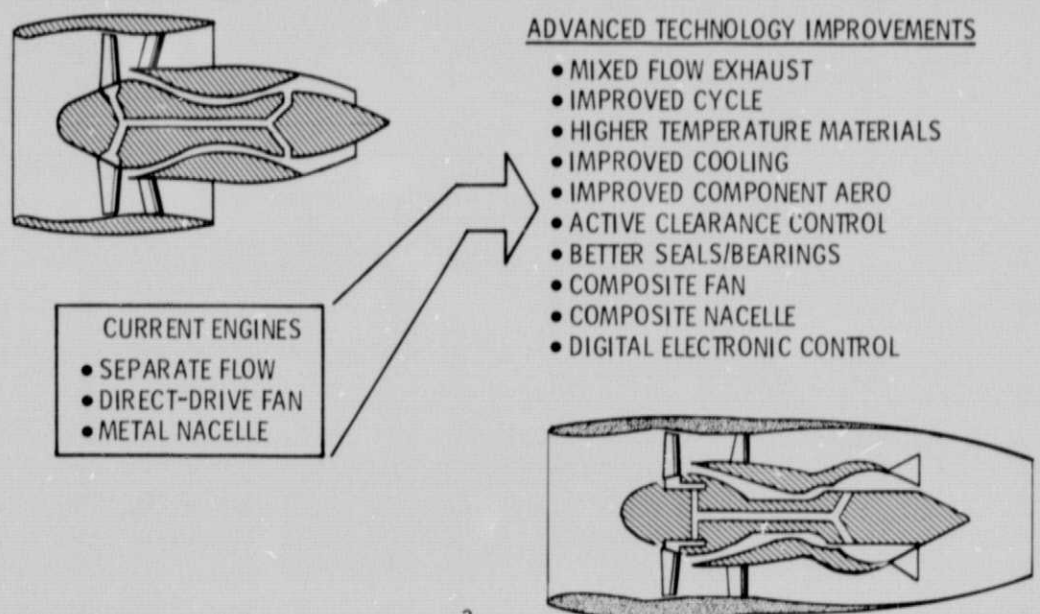


Figure 3. - Engine component improvement engine diagnostics. SFC performance deterioration trends for typical engine.



CURRENT	CYCLE	E^3
22 - 30	OVERALL PRESSURE RATIO	37 - 45
4 - 5	BYPASS RATIO	6 - 9
2200 - 2500	COMBUSTOR EXIT TEMP (^{0}F)	2500 - 2700

Figure 4. - Energy efficient engine.

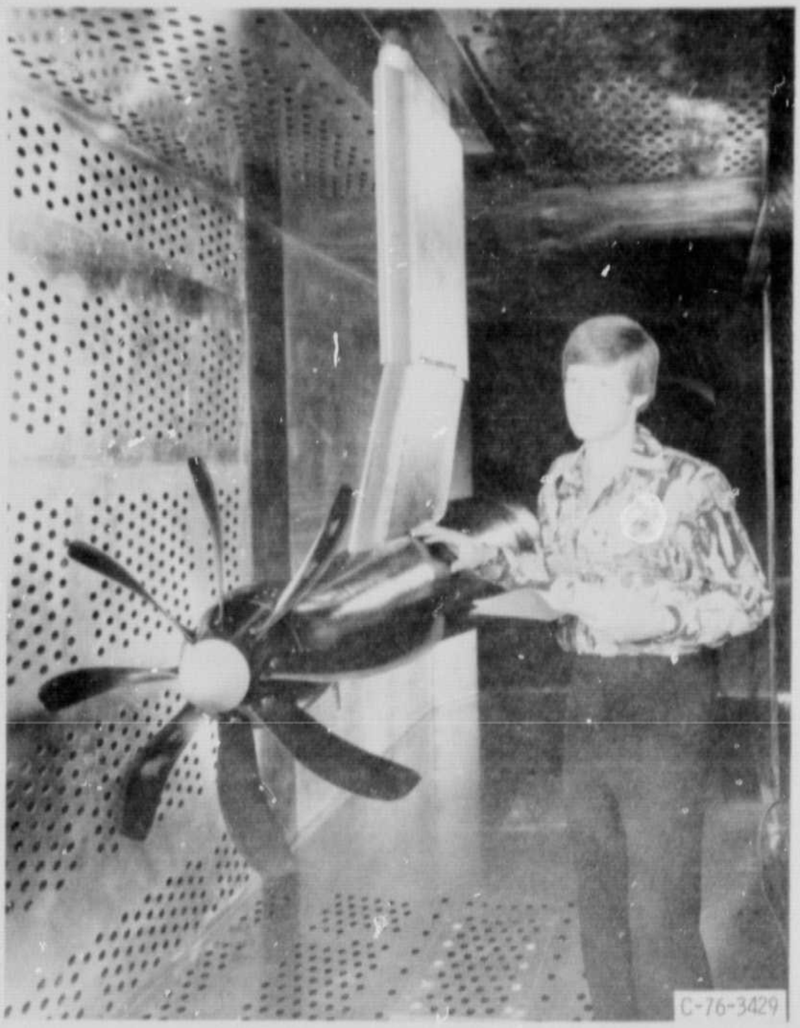
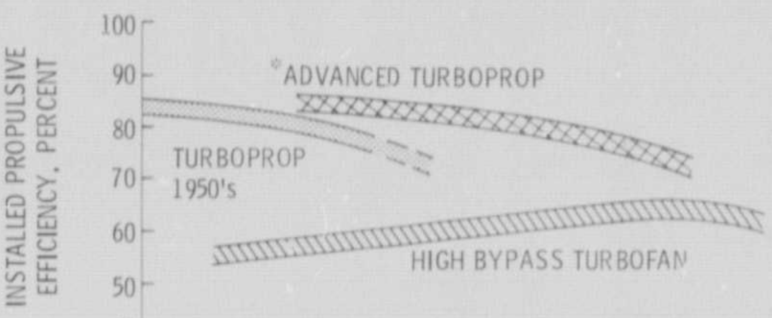


Figure 5. - Advanced propeller model.



*PROJECTION BASED ON 1976 MODEL WIND TUNNEL TESTS

Figure 6. - Propulsive efficiency.

E-9373

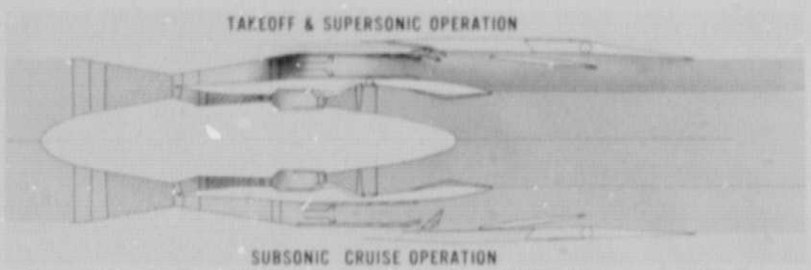


Figure 7. - Pratt and Whitney conceptual variable-stream-control engine.

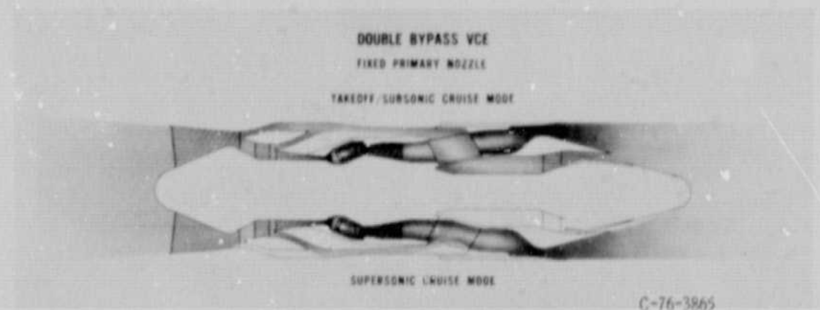


Figure 8. - General Electric conceptual double-bypass, variable-cycle engine.

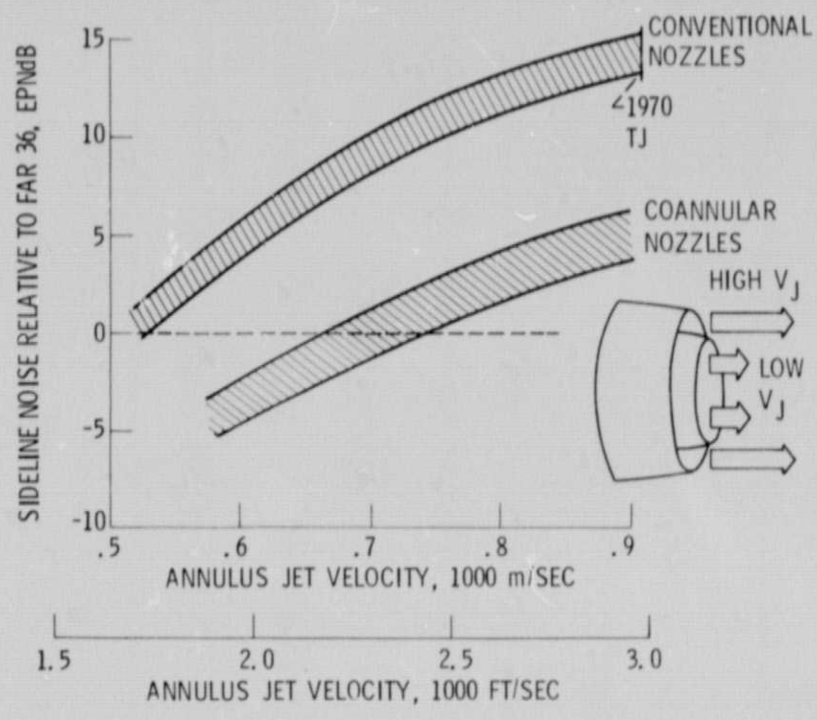


Figure 9. - Noise reduction with coannular nozzle.

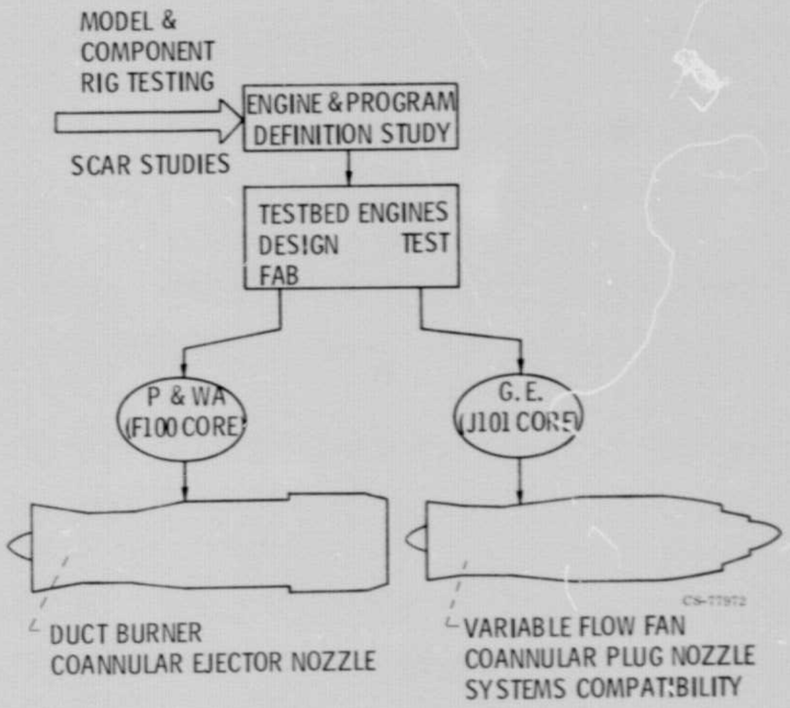
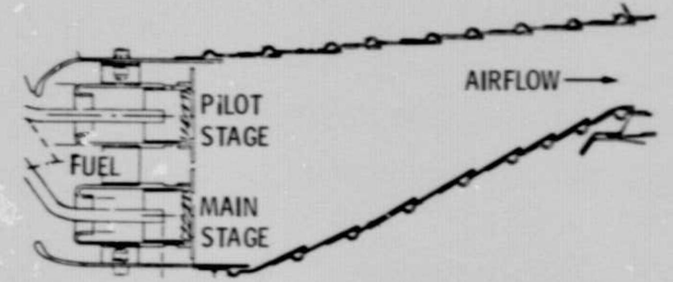
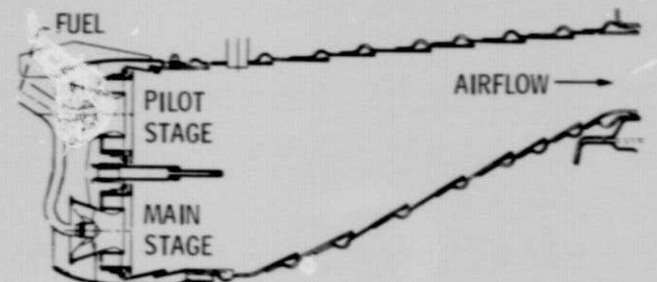


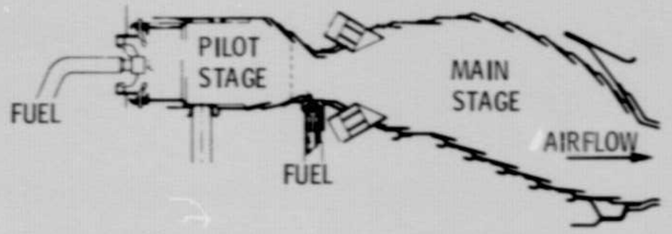
Figure 10. - Variable-cycle engine component test program.



(a) SWIRL-CAN MODULAR CONCEPT.



(b) DOUBLE-ANNULAR CONCEPT.



(c) VORBIX CONCEPT.

Figure 11. - Advanced combustor concepts.

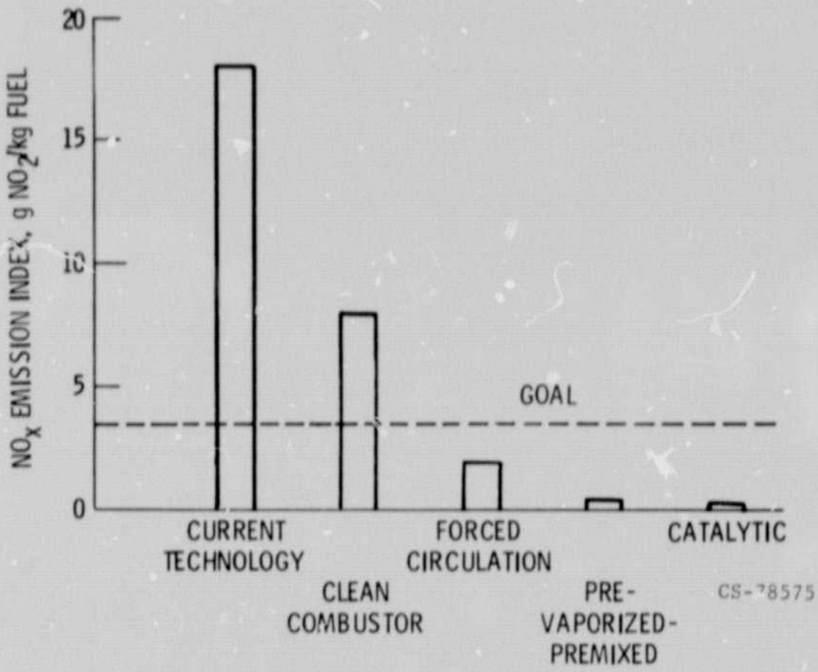


Figure 12. - Cruise NO$_X$ emissions. Simulated Concorde operating conditions.

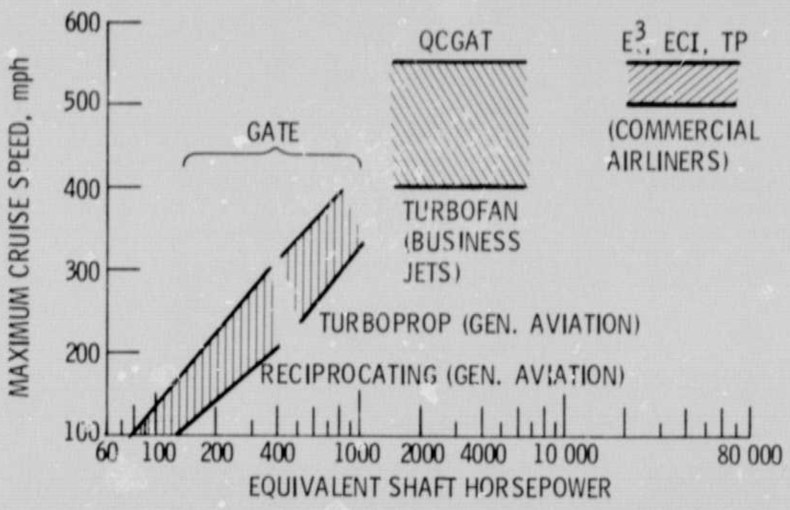


Figure 13. - Propulsion for civil aviation.

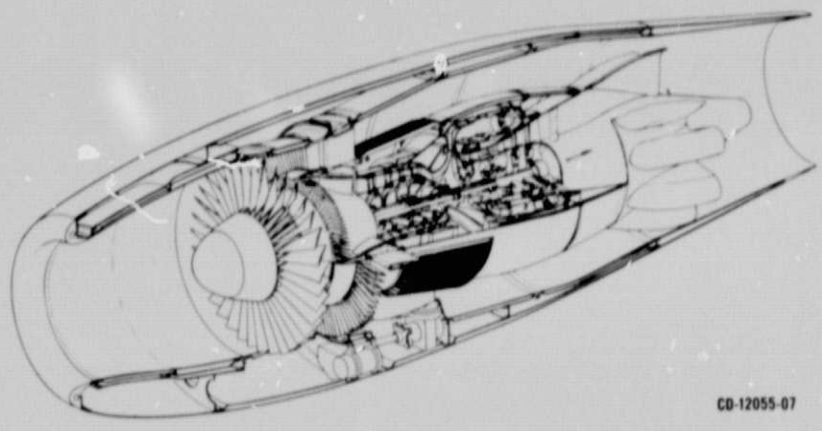


Figure 14. - Garrett Airesearch QCGAT engine.

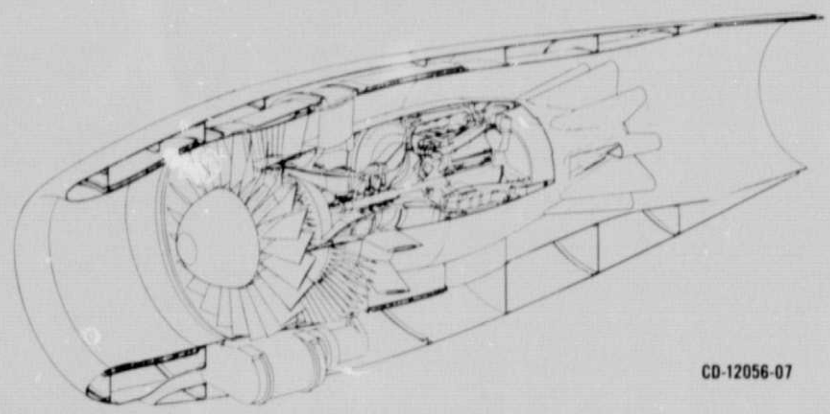


Figure 15. - AVCO Lycoming QCGAT engine.

TASK I

FORECAST 1985 G.A. MARKET

ESTIMATE MARKET IMPACT OF ADVANCED TECHNOLOGY TURBINES

INCLUDE AIRPLANES AND HELICOPTERS

IDENTIFY DESIRABLE ENGINE SIZES AND MISSIONS

↓

TASK II

TRADEOFF ANALYSIS

TURBOSHAFT/PROP <1000 SHP
TURBOFAN <1500 lb THRUST

IDENTIFY HIGH PAYOFF TECHNOLOGIES

DETERMINE "OPTIMUM" ENGINE (SIZE, CYCLE, CONFIGURATION, FEATURES) FOR EACH MAJOR APPLICATION

COMPARE ADVANCED ENGINES WITH CURRENT ENGINES (TURBINES & RECIPS)

↓

TASK III

EVALUATE COMMON CORE CONCEPT

MULTIPLE APPLICATIONS FOR SINGLE CORE, E.G. - TS, TP, TF

COMMONALITY OF PARTS & DESIGN
- OTHER AIRCRAFT ENGINES
- AUTOMOTIVE OR OTHER APPLICATIONS

↓

TASK IV

RECOMMEND TECHNOLOGY PROGRAM PLAN

COMPONENT TECHNOLOGIES

EXPERIMENTAL CORE OR ENGINE

PROVIDE BASELINE CONCEPTUAL ENGINE DESIGN

Figure 16. - Gate study tasks.

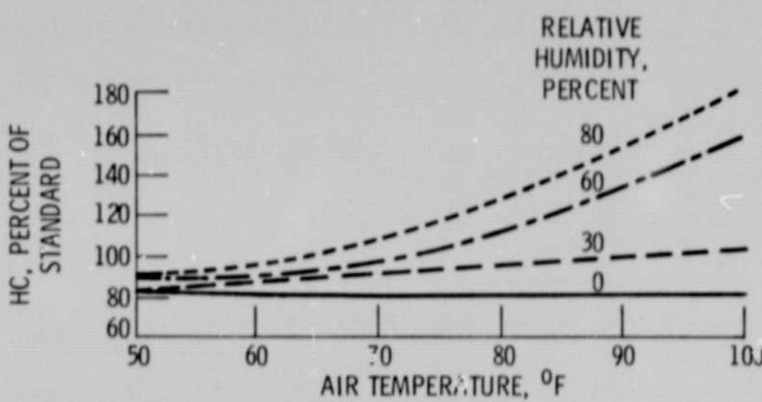


Figure 17. - Effect of temperature and humidity on emissions. (EPA cycle.)

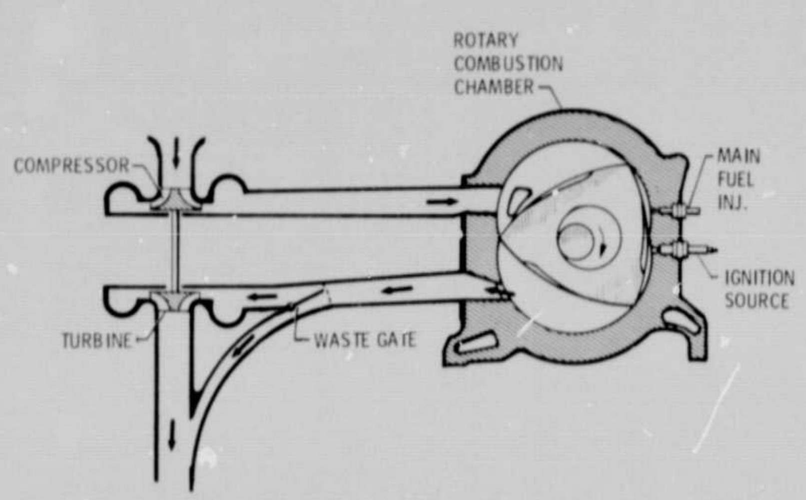


Figure 18. - Stratified-charge rotary multi-fuel engine (turbocharged).

E-7373

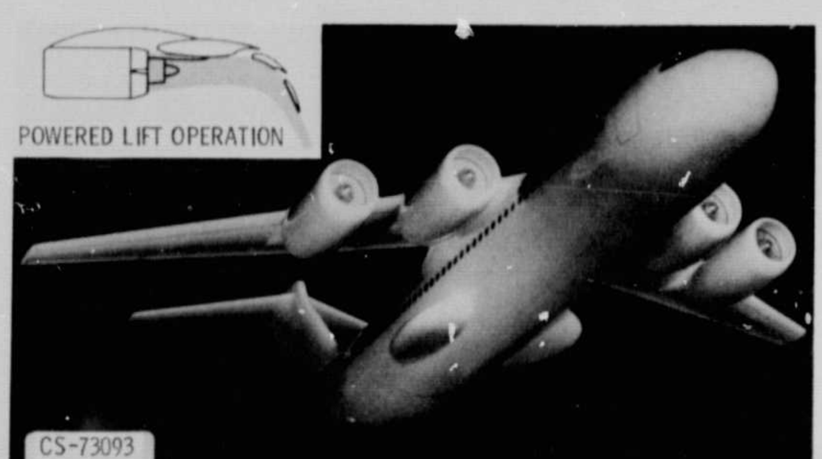
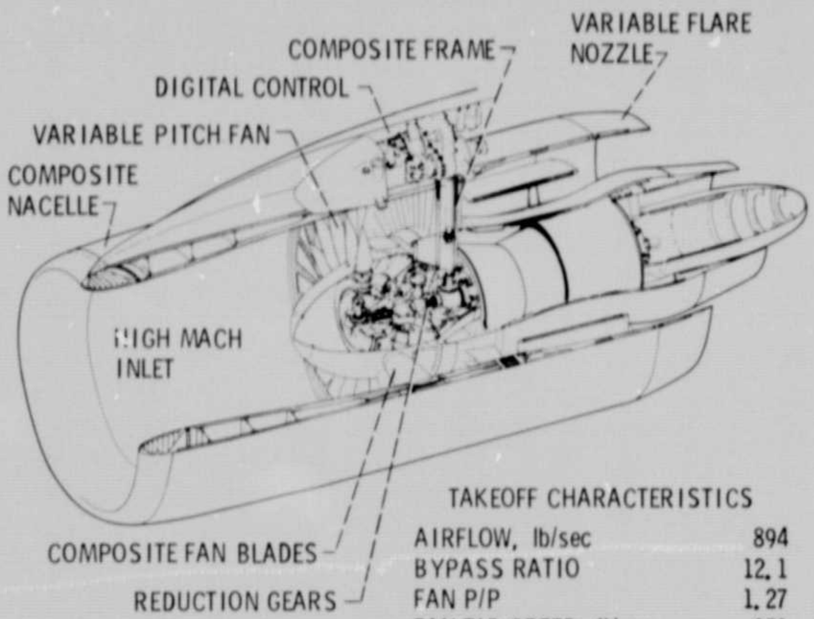


Figure 19. - Conceptual UTW short-haul aircraft.



TAKEOFF CHARACTERISTICS

AIRFLOW, lb/sec	894
BYPASS RATIO	12.1
FAN P/P	1.27
FAN TIP SPEED, ft/sec	950
OVERALL P/P	14.3
THRUST, lb	17 400

Figure 20. - QCSEE UTW engine.

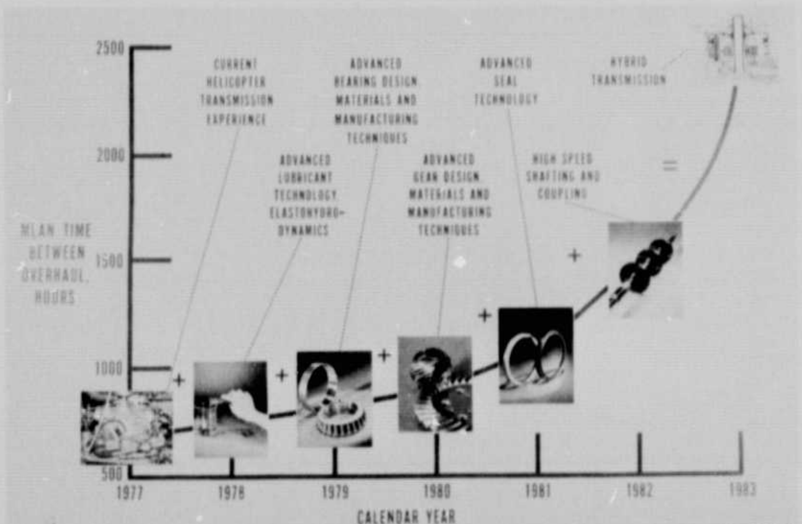


Figure 21. - Goals of NASA advanced mechanical components and transmission technology.

Figure 22. - High-speed commercial helicopter.

E-7373

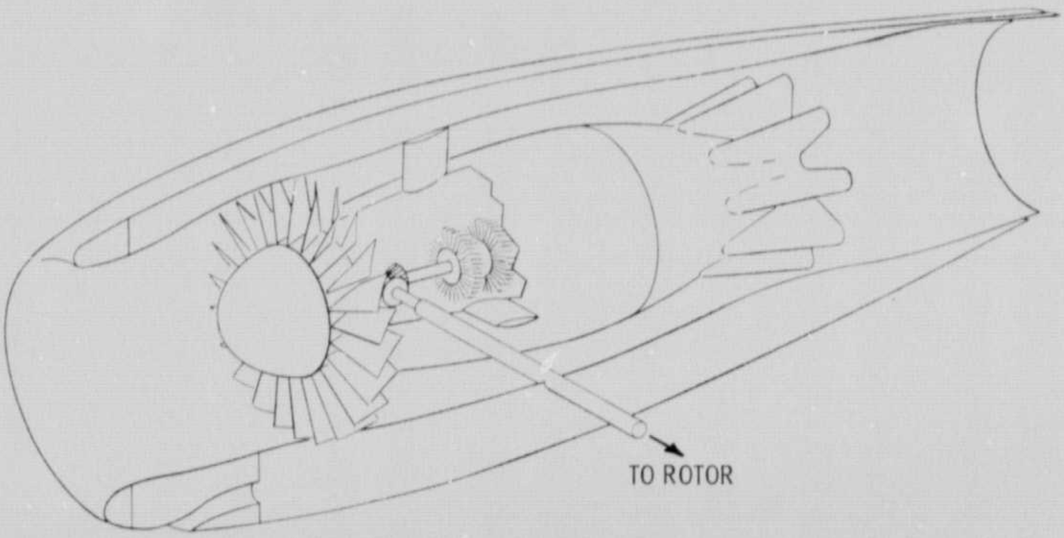


Figure 23. - Helicopter convertible propulsion system.

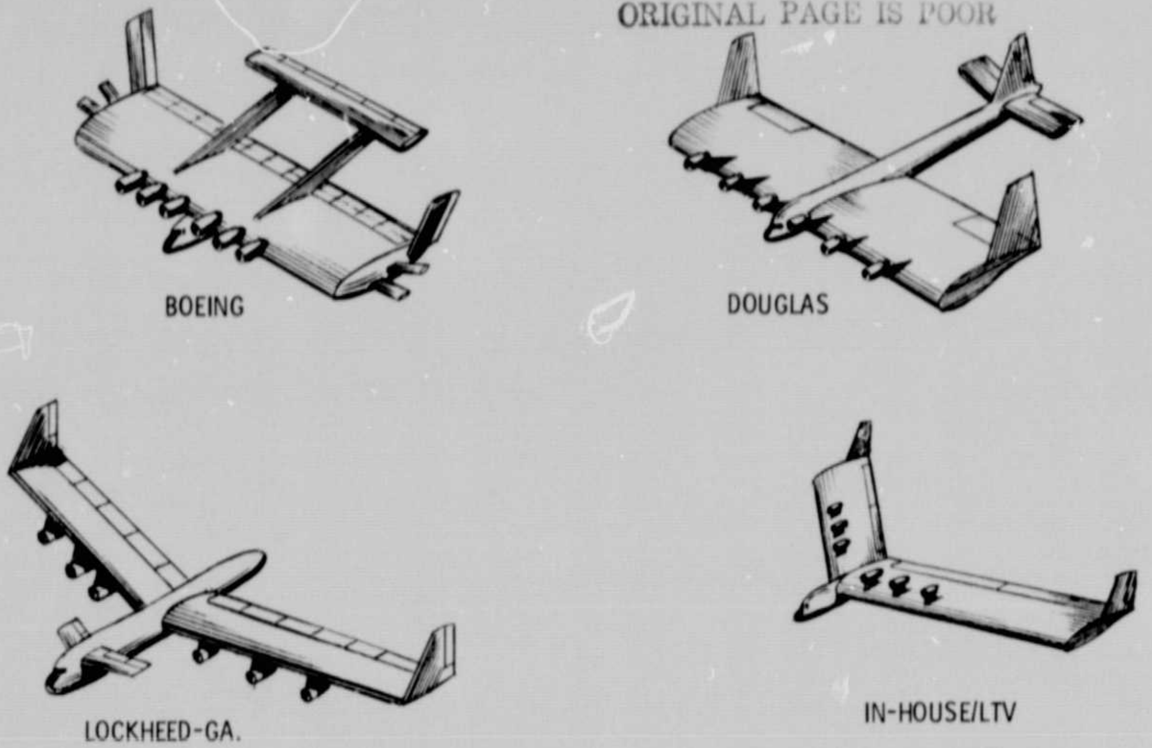


Figure 24. - Span-distributed load, cargo aircraft concepts.

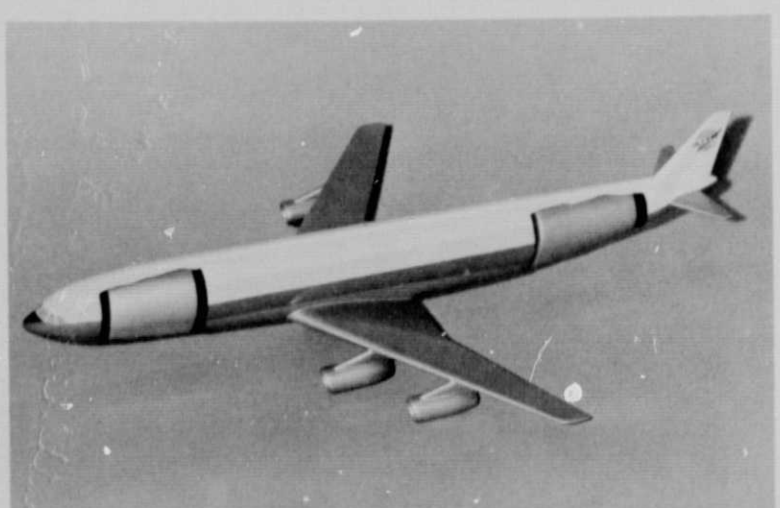


Figure 25. - Hydrogen-fueled transport.

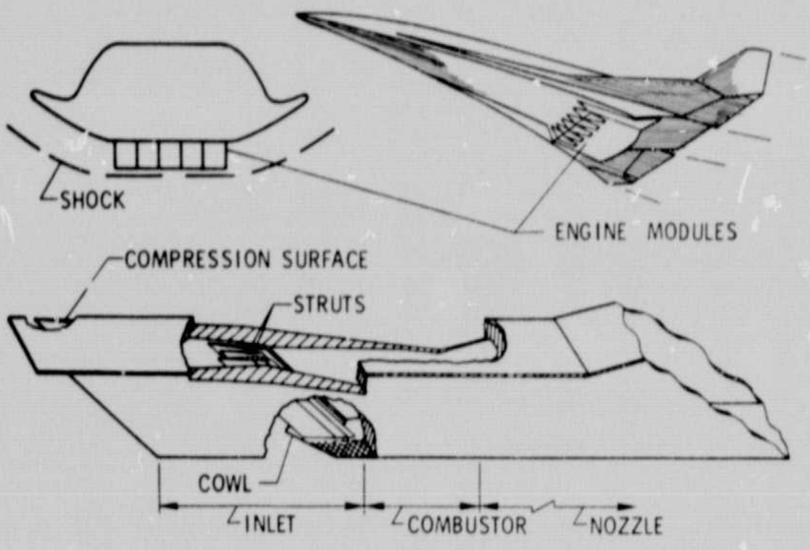


Figure 26. - Hypersonic propulsion.

E-9373