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Investigation of Flight Test Methods for Measuring the Performance of General Aviation Aircraft

Semi-Annual Status Report

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INTRODUCTION

This report was prepared as an informal Semi-Annual Status Report to cover work performed under NASA Grant NAG-I-3, "Investigation of Flight Test Methods for Measuring the Performance of General Aviation Aircraft." This work is being continued as Grant NAG-I-3 Supplement No. 2, commencing February 1, 1981, and therefore this report takes the form of a progress report rather than a formal final report.

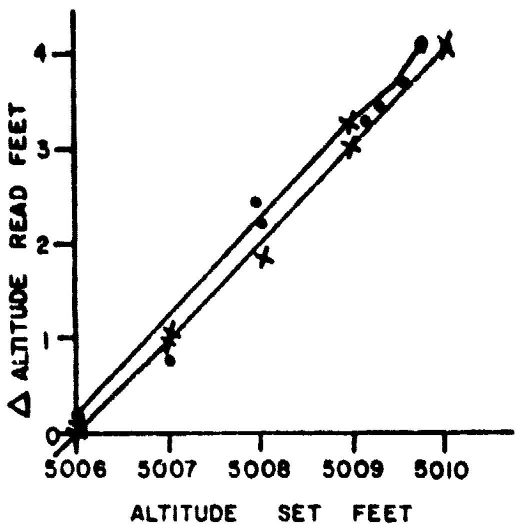
Work supported by this grant was to provide a theoretical and experimental investigation of methods for measuring the performance of general aviation airplanes, using relatively simple instrumentation which is currently available and data extraction techniques which are well established from efforts in other disciplines. The possibilities of improving flight test data by use of improved modern instrumentation and digital data recording and data analysis were to be considered.

We summarize here the work accomplished during the first year of effort under this grant, and also list topics for the effort of the current year, as we now foresee them.

HIGHLIGHTS OF RESULTS TO DATE

1. Efforts were concentrated on extracting data from the transient response in airspeed to a change in engine power while maintaining constant altitude. In addition, steady level speed-power data and steady rate of climb data from sawtooth climbs were obtained. Representative results from preliminary flight tests are included in Figure 2.

2. Airspeed and altitude instrumentation was installed which was capable of resolving indicated airspeed to within ±0.2 knots, and altitude to a fraction of a foot. Computer studies showed that this resolution would allow extraction of meaningful data from flight test records. The transducers used were high quality production units produced by Rosemount, Inc. Laboratory calibrations at MSU substantiated the manufacturer's data on resolution of the instruments. Hysteresis is important in flight test instrumentation because both airspeed and altitude can be expected to fluctuate in each direction and the laboratory tests showed that instruments had very little hysteresis. The laboratory standard used was the MSU Mensor Corporation Quartz Manometer, which has calibrations traceable to the National Bureau of Standards. A sample laboratory calibration is shown as Figure 1.



Two Runs
Rosemount Altitude Transducer
Model 1241 A5CBE Serial 111
Standard: Mensor Quartz
Manometer Quartz 856
Jan. 10, 1980

Figure 1
Hysteresis at 5000 ft.

At high altitudes the transducer provided a signal with more significant figures than could be recorded. To match the resolution of the recording system to the resolution provided by the transducer, a reference voltage source was installed which could be set in flight. The voltage produced by the transducer at the test altitude was substantially cancelled by adjustment of the reference voltage, leaving the small residual voltage proportional to altitude error to be recorded. The automatic scaling feature of the HP Data Logger allowed recording this small altitude error to the accuracy provided by the transducer. Both mean pressure altitude and altitude error from the mean were recorded.

Flight recordings of airspeed and altitude are shown in Figure 2 for the transient response in airspeed to a power change at constant altitude. Figure 3 shows a level flight speed-power run. Note the resolution to which speed and altitude error are recorded.

A NASA true airspeed "bird" was received on loan from NASA, and a wingtip boom mounting for the transducer was completed and installed.

A circuit to convert frequency to analog signal is being constructed to permit recording of the true airspeed.

Appropriate recording circuits were incorporated to record time and engine rpm.

A calibration fixture for the torquemeter was constructed and used to calibrate the torquemeter and the anticipated operating range. Results confirmed the manufacturer's specifications. In operation, a zero drift of the torque indication of about 1.5% of normal full throttle torque occurs. Cause of this is under investigation.

3. Instrumentation to enable the pilot to fly the airplane at constant altitude, to the accuracy required in these tests, was constructed and installed in the T-34B test airplane. Rate of climb was provided directly by the Rosemount altitude transducer. This signal and an incremental altitude signal were displayed directly in the pilot's line of view as shown in Fig. 4. These instruments made it possible for the pilot to maintain level flight during a test run to the accuracy displayed in Fig. 2 and 3. Application of these instruments to other flight tests in which constant altitude is needed is envisioned, since they permit the pilot to reduce altitude errors by about an order of magnitude.

4. A computer analysis of the response of the airplane to a step change in power was made to investigate the effect of possible errors upon the results extracted from flight test data. The simulation used was the NASA Langley General Aviation Aircraft Simulation program coded on the Mississippi State University Univac 1100/80 computer. This program is a six degree-of-freedom simulation that represents a Cessna 172

aircraft. The program was modified so that the aircraft had a parabolic drag polar and a constant value of propeller efficiency; zero-left drag coefficient, and wing efficiency. A constant speed propeller was also added, since the T 34B flight test aircraft had a constant-speed propeller. No attempt was made at this time to change the simulation to that of a T34-B, because it was felt that the results using Cessna 172 numbers would provide the desired guidance for this stage of this program. An "autopilot" was added to the program to represent the flight test case where the pilot controlled the airplane to maintain constant altitude.

The first use of the simulation was to prove the concept. If this ideal airplane in straight and level flight was given a step input in power and constrained to hold its altitude, would the response be exponential in nature and could flight test data be extracted from this response? To determine this, the simulation was initialized in straight and level flight at 5,000 feet with a velocity of 160 feet/second. At a specified time the throttle was increased 24% (of full throttle). The simulation autopilot constrained the maximum altitude change to one foot or less. The change in velocity is shown in Figure 5. The plotted points are from the simulation, and the fitted line is a least squares type of curve fit. It can be seen that the exponential form

$$\Delta V = A(1 - e^{at})$$

provides an excellent curve fit.

The coefficients of this fit were then used to find the computed values of C_{D_0}, η_p, and e. These values, shown compared with the actual values in the first line of Table 1, show very close agreement. It is obvious that this method can yield data in an ideal case.

The second problem was to examine the limitations of this technique. The limitations included the size of the throttle change and the effect of not holding constant altitude.

The first to be examined was the size of the throttle change. Simulations were run with 5% and 10% throttle changes and the exponential curve fitted to the change in velocity. The computed values of these cases are shown in Table 1. As can be seen, the larger the throttle change, the less accurate are the calculated values. This was to be expected, since a Taylor series expansion was used to solve the differential equation of motion. This approximation becomes less accurate as one uses larger throttle changes.

For the altitude changes, the simulation autopilot was modified to produce a roller coaster motion with height deviations of 10-15 feet from the desired altitude when the throttle was increased. It was felt that this was the maximum deviation that would be seen in a flight test. The results of these runs are also shown in Table 1. Comparing the dispersed cases with those having no altitude changes, it is clear that the computed wing efficiency is the parameter most affected by the altitude dispersions, the propeller efficiency is less affected, and the computed drag coefficient is relatively insensitive to the altitude changes.

The third goal of the simulation was to examine errors in the input data to the program evaluating C_{D_0}, η_p, and e. In this instance it was assumed that the velocity and time were measured perfectly during the test flight. An exponential curve was fitted to the data to obtain the A and B coefficients. However, a wrong value of initial power, change in power, air density, or aircraft weight was used in the calculation of the unknown parameters. The errors used were representative of what could reasonably be encountered on a flight test. By examining the results of this, it would be possible to identify the accuracy requirements for measurement of these variables. The results of these errors are shown in Table 2. According to these results, the most critical measurement is the change in power. As before, the parameter most affected was the computed wing efficiency, with the computed drag coefficient affected least. To minimize these errors, it will be necessary to carefully calibrate the torque meter and to make multiple runs to average out random noise.

Further studies of the technique are now in progress. The effect of a non-parabolic drag polar, variable propulsive efficiency, and random noise, on the computed parameters will be investigated, along with other flight test techniques that will be integrated with this procedure.

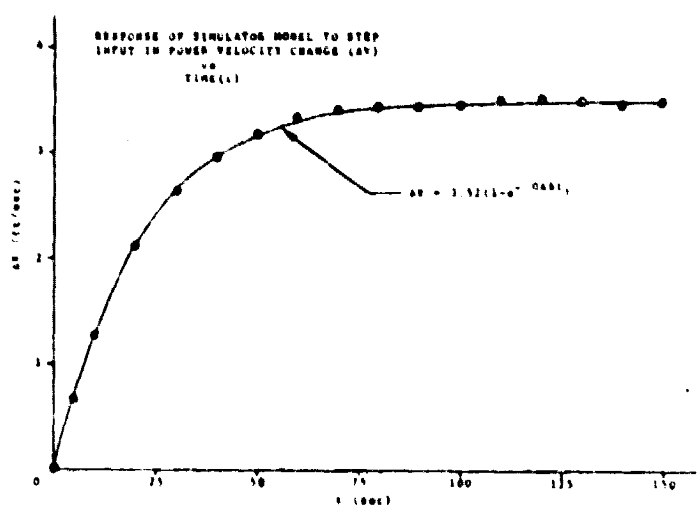


Fig. 5. Response of Simulator Model to Step Input in Power

TABLE 1

Simulation Model: $C_{D_o} = .038$, $\eta_p = 0.8$, $e = 0.67$

No Altitude Deviation

TEST CONDITION	C_{D_o}	η_p	e
2½% Throttle Increase	.0381	.7987	.6719
5 % Throttle Increase	.0393	.8265	.6422
10% Throttle Increase	.0414	.8714	.6058
±10-15 Ft. Altitude Deviation			
2½% Throttle Increase	.0394	.7906	.7550
5 % Throttle Increase	.0396	.7803	.8412
10% Throttle Increase	.0410	.8529	.6344

TABLE 2

Simulation Model: $C_{D_o} = .038$, $\eta_p = 0.8$, $e = 0.67$

2½% Throttle Increase, No Altitude Deviation

INPUT ERROR	C_{D_o}	η_p	e
Power Change 5% High	.0375	.7601	.7818
Power Change 5% Low	.0388	.8414	.5814
Initial Power 1% High	.0383	.7986	.6531
Initial Power 1% Low	.0380	.7983	.6929
Air Density 2% High	.0373	.7985	.6573
Air Density 2% Low	.0388	.7985	.6841
Aircraft Mass 1% High	.0385	.8063	.6789
Aircraft Mass 1% Low	.0378	.7907	.6658

5. Theoretical analysis of the equations describing the transient response of the airplane in level flight to a step change in power confirmed the computer studies in showing that the errors in the extracted values of propeller efficiency and drag terms would be proportional to errors in the change in horsepower. Since the change in power should be kept small to minimize errors resulting from assumptions of constant propeller efficiency and drag terms, as shown in Table 2, this finding requires a high degree of accuracy in measurement of power to provide the necessary accuracy in change of power.

Since steady speed can be related to power, the equations were developed in terms of speed, eliminating the need for measuring power. Drag data can be extracted from the data but not propulsive efficiency. However, if drag data were available propulsive efficiency could be extracted from flight test data. The equations have been developed but application to flight test data has not yet been performed.

6. Flight tests have been performed to develop the instrumentation and flight test technique, to provide data on the transient reponse to power change in level flight (Figure 2) and to provide data in steady climb, steady glide with propeller feathered, and level flight speed-power runs (Figure 3). Analysis of the latter is in progress.

7. An improved recording system applicable to the T-34B has been built and tested in the laboratory. The recording system (Figure 6) incorporates a microcomputer and cassette recorder and makes use of the transducers and Hewlett-Packard Data Logger currently installed. It will significantly reduce the time required to process flight data. This equipment will be installed in the T-34 test airplane in the near future.

The HP Data Logger incorporated in the system handles up to 20 channels of data in the form of voltages from a maximum of 1000 V to a minimum of 0.1 V full scale. Data is recorded to four significant figures and the instrument is self-scaling i.e., as the signal becomes smaller the scaling is automatically adjusted to retain four significant figures. Thus, voltages down to 1/100 MV can be resolved. Output is in BCD form, including the signal and channel identification, range and polarity.

The recording system is based upon a SYM-1 microprocessor and a cassette recorder. The microprocessor has 16 K memory, easily expandable to approximately 40 K. The existing memory of 16 K permits 4000 readings, at 4 bytes per channel, before the data must be loaded into the cassette to permit further recording. Thus, 10 channels recorded at one second intervals would permit approximately 6 1/2 minutes of recording of any one test run. The system is capable of a data recording rate of one channel per 100 microseconds. Data can be loaded into the cassette in flight in approximately four minutes and the system is then ready for the next data run.

In the MSU system, flight data is played back through the same SYM-1 microprocessor that is used in flight through an RS 232 serial output port into an HP 1000 mini computer which stores the data and performs the analysis. Output is printed or plotted on an HP 7245 A plotter-printer. This recording system was assembled for $1000 for parts and about 5 man weeks of labor.

8. Results of the project at this stage were presented as a progress report to the industry in the form of a paper presented to the Society

of Flight Test Engineers 11th Annual Symposium at Atlanta, August 27-29, 1980. The paper was entitled "Determining Performance Parameters of General Aviation Aircraft," Gifford Bull and Philip D. Bridges.

9. Data from steady climb, steady glide, and level speed-power runs are being used in preparation of a masters thesis at MSU.

TOPICS FOR SUCCEEDING YEAR

1. Investigation of use of incremental drag as an input to increase the resolution with which input data can be measured.
2. Investigation of use of speed data only in the transient response to a power change to obtain drag data without the requirement for high accuracy in measurement of engine power.
3. Demonstration of the capability to measure accurately and repeatedly the effect on speed of small drag changes, such as are made in efforts to improve the fuel efficiency of airplanes.
4. Investigation of the use of a NASA true airspeed transducer in the performance flight tests.
5. Investigation of extraction of performance information from data provided by a matrix of different suitable flight test maneuvers.
6. Continuation of analytical and theoretical studies of the performance problem as a guide to design of instrumentation and development of data analysis techniques.
7. Implementation of an improved microprocessor-based digital recording system, developed and built at MSU, to provide improved and more rapid extraction of data from flight tests.
8. Investigation of motion of the atmosphere, using instrumentation and techniques developed in this grant.

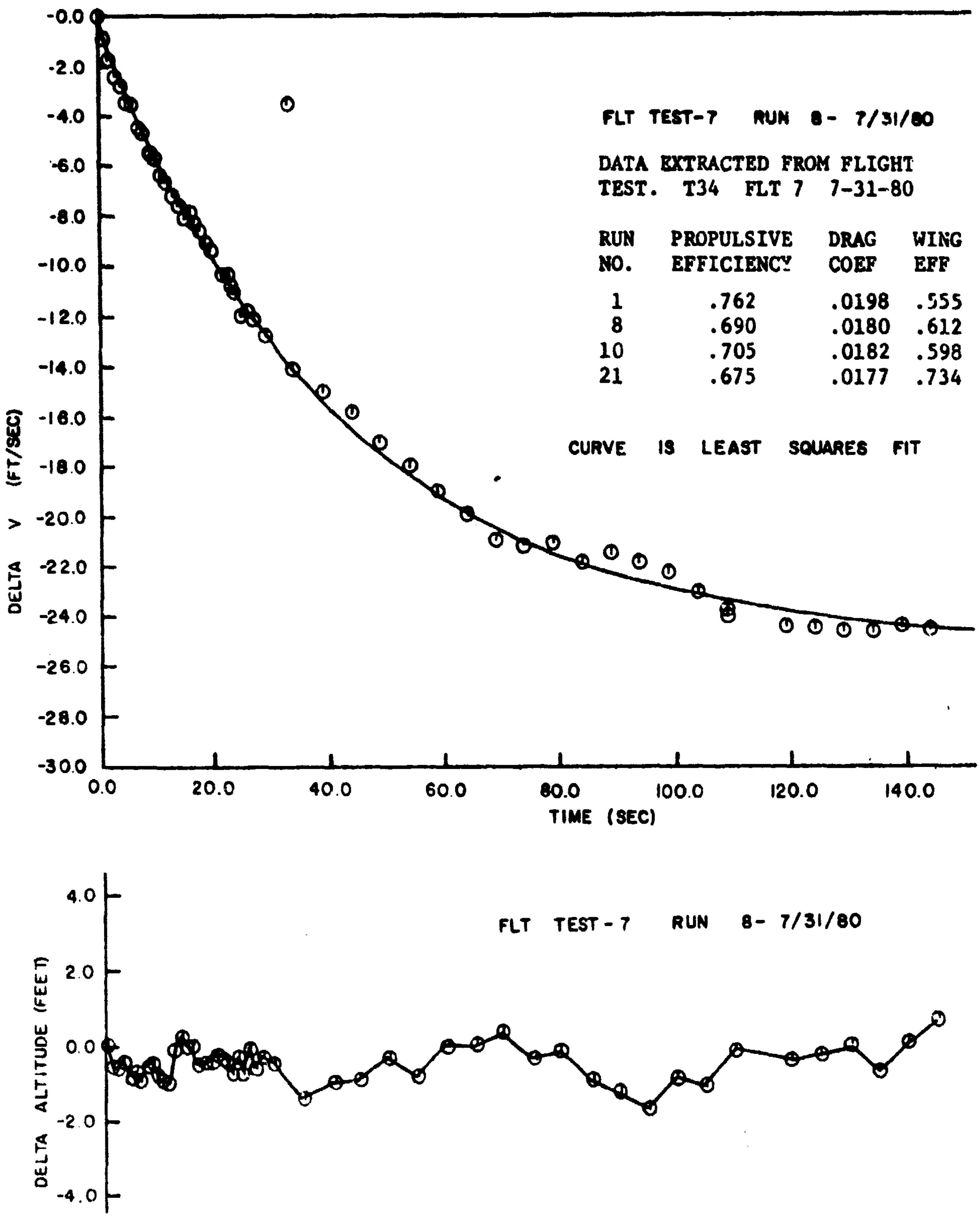


Figure 2. Flight Data. Response to Transient in Power in Level Flight.

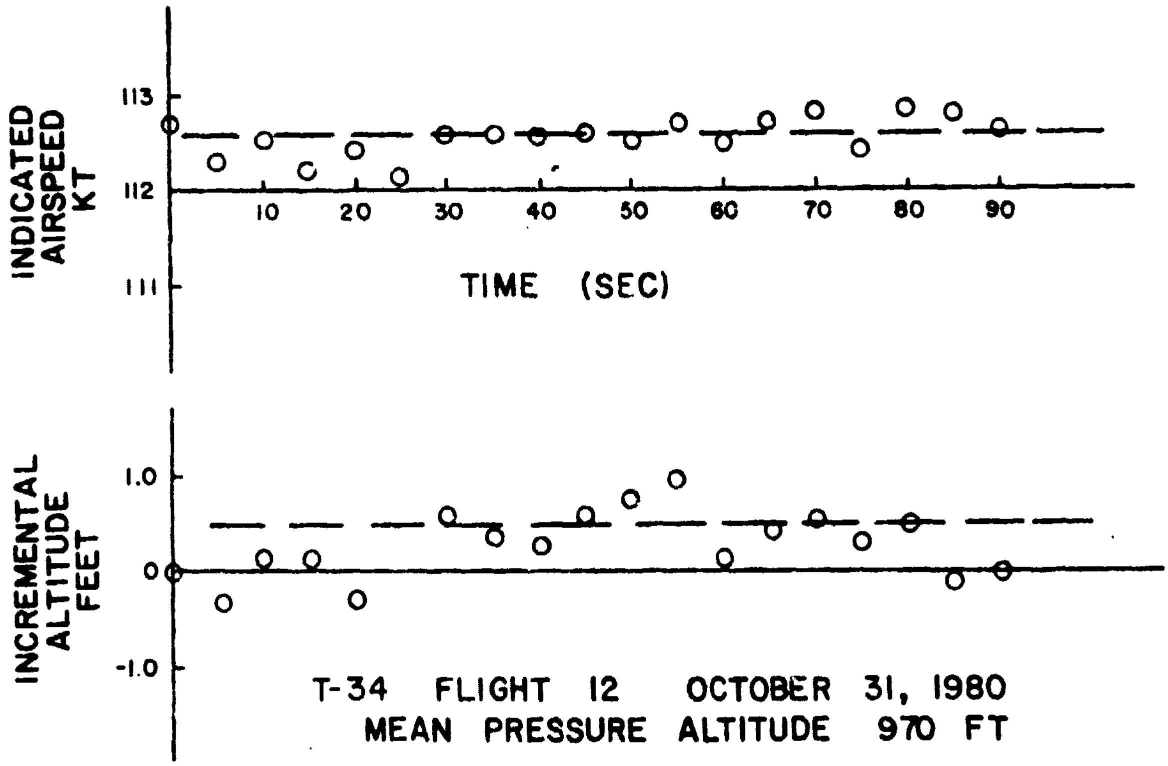


Figure 3. Airspeed and Altitude Variation.
Level Speed-Power Run

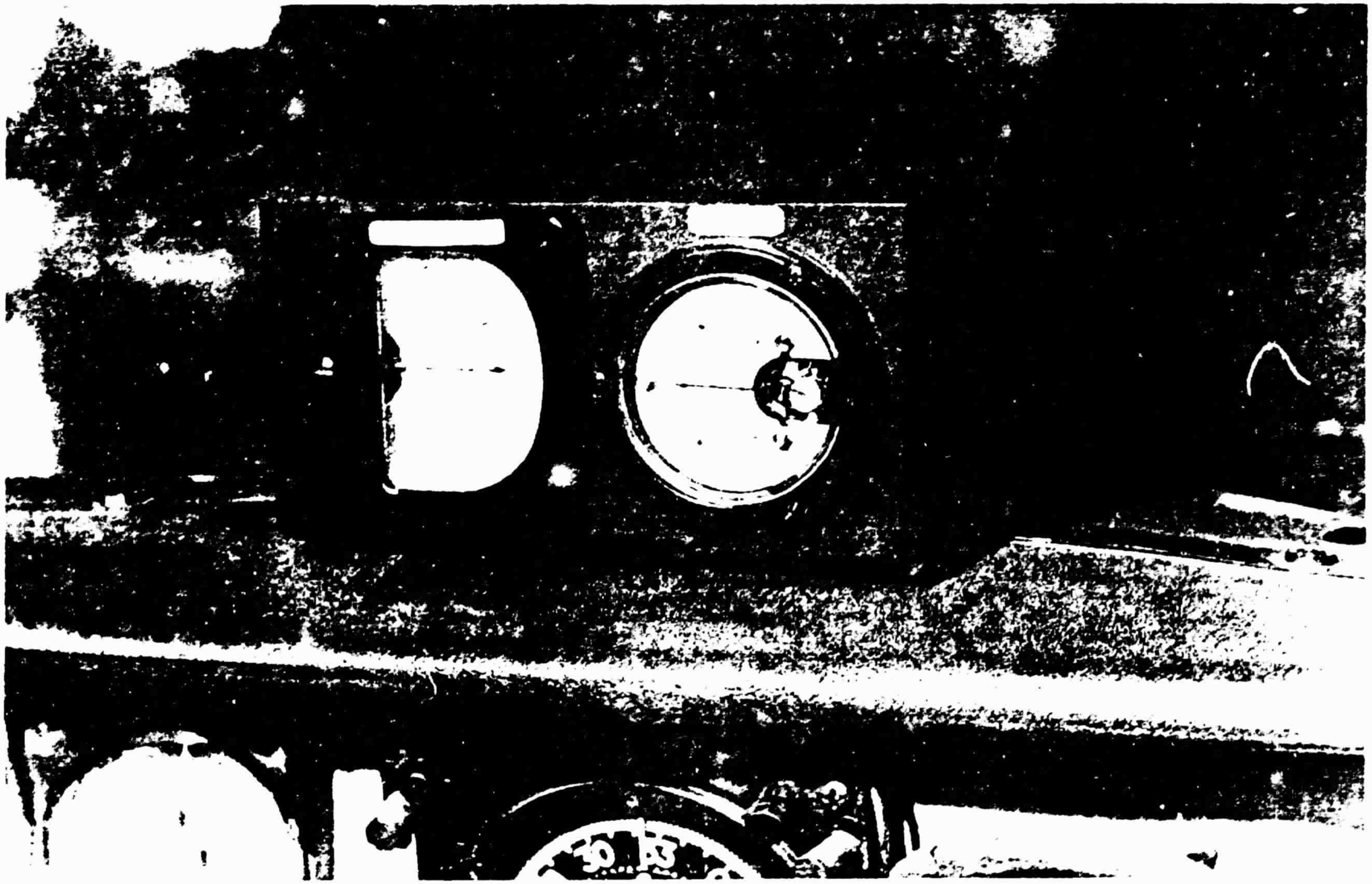


Figure 6. Cockpit Indications of Altitude and Rate of Climb

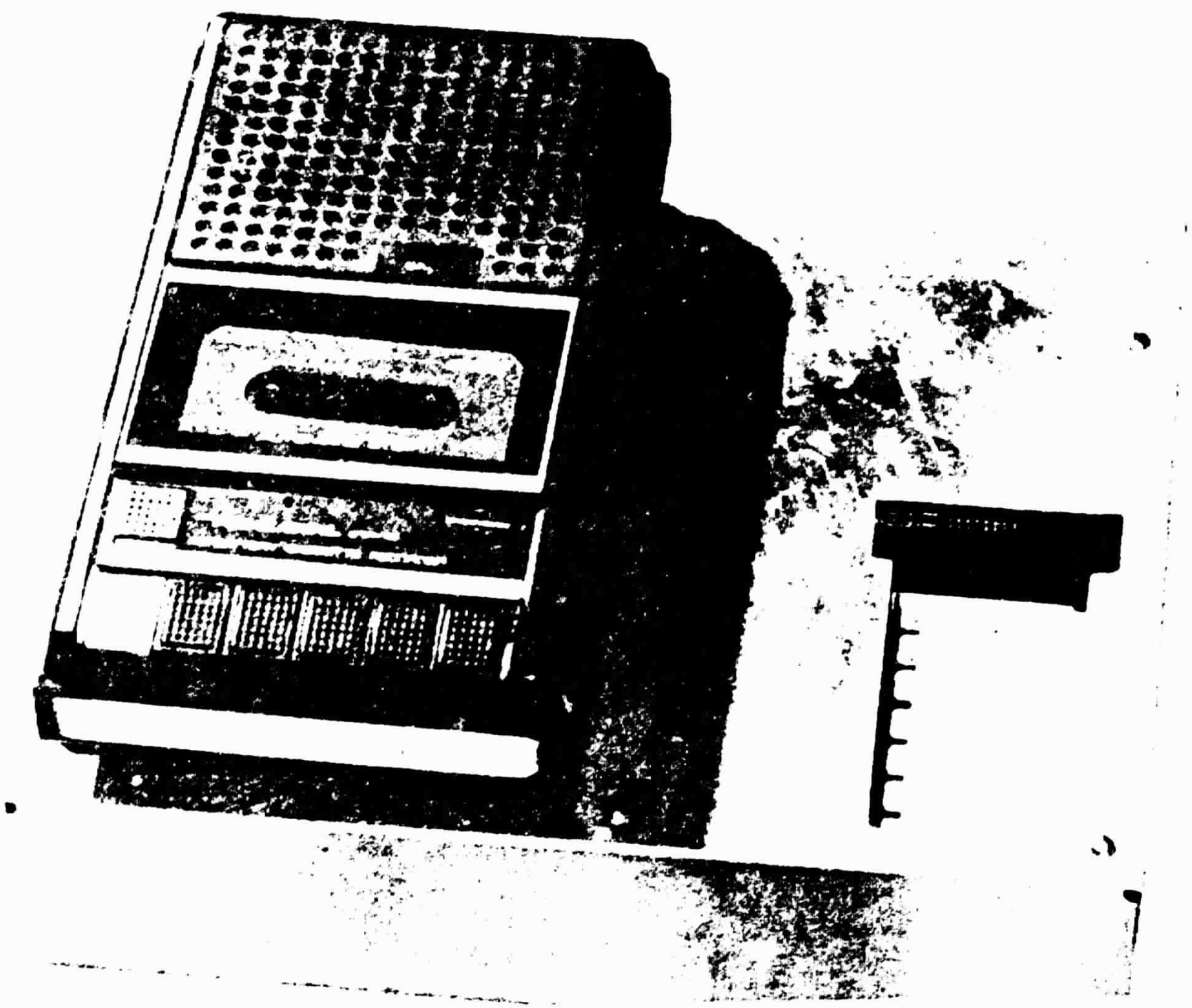


Figure 6. Preliminary Photo of
Digital Recording System