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Advanced Turboprop Testbed Systems Study

I. M. Goldsmith

McDonnell Douglas Corporation
Douglas Aircraft Company
Long Beach, California 90846

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National Aeronautics and
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Lewis Research Center
Cleveland, Ohio 44135

DOUGLAS AIRCRAFT COMPANY

3855 Lakewood Boulevard Long Beach, California 90846

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The attached report, NASA CR-167895, "Advanced Turboprop Testbed Systems Study", July 1982, is transmitted to you at the request of NASA Lewis Research Center, Cleveland, Ohio. This is the Douglas Aircraft Company study report prepared under Contract NAS3-22347.

Any questions relating to the report may be directed to Irene M. Goldsmith, Douglas Aircraft Company, Long Beach, California, Telephone (213) 593-0354, or G. K. Sievers, NASA Lewis Research Center, Telephone (216) 433-4000.

Max Klotzsche

M. Klotzsche
Program Manager, ACEE

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I. M. Goldsmith
McDonnell Douglas Corporation
Long Beach, California

Prepared for
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under Contract NAS3-22347

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NASA PROP FAN RESEARCH
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FOREWORD

This document presents the results of a Contract Study (NAS3-22347), (Reference 1), for the National Aeronautics and Space Administration (NASA) by Douglas Aircraft Company, McDonnell Douglas Corporation. This work is part of the prop-fan program in the overall Aircraft Energy Efficiency (ACEE) program of which Max Klotzsche is the Douglas Program Manager. The Douglas Project Manager of the Advanced Turboprop Projects is Irene M. Goldsmith.The NASA technical monitor for the contract is Brent A. Miller, Project Engineer of the Advanced Turboprop Project Office of NASA Lewis Research Center. The overall direction and coordination of the Advanced Turboprop Program (ACEE) is provided by NASA Lewis Research Center.

The following Douglas personnel from the key engineering discipline groups have made major contributions to this study:

H. R. Welge	Unit Chief - Advanced Aircraft Design - Aerodynamics
R. W. Hahn	Section Chief - Advanced Aircraft Design - Performance
R. E. Adkisson	Section Chief - Design - Structural Advanced Design
R. E. Pearson	Dynamics Structural Mechanics
F. S. La Mar	Project Engineer - Power Plant
R. G. Sandoval	Project Engineer - Power Plant
D. E. Delaney	Acoustic Design Requirements
B. W. Kimoto	Advanced Weight Engineering
M. M. Platte	Branch Chief - Technology - Systems Analysis
R. A. Wright	Unit Chief - Technology - Configuration Design
W. E. Bachand	Director/Flight Test
S. G. Furniss	Flight Test

Subcontractors to Douglas Aircraft on the study are as follows:

<u>Prop-fan and Prop-fan Controls</u> - Hamilton Standard, Windsor Locks, Conn., Principal contacts: W. M. Adamson & B. Z. Gatzen

<u>Turboshaft Engine, Gearbox and Controls</u> - Detroit Diesel Allison, Indianapolis, Indiana
Principal contact: P. Stolp

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ADVANCED TURBOPROP TESTBED SYSTEMS STUDY

TABLE OF CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

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FIGURES

FIGURES (Continued)

TABLES

ADVANCED TURBOPROP TESTBED SYSTEMS STUDY

SUMMARY

The work performed by Douglas Aircraft Company, under Contract No. NAS3-22347, (Reference 1) with NASA Lewis Research Center is summarized herein and concerns the evaluation and recommendations of a testbed approach to the proof of concept, feasibility, and verification of the advanced prop-fan and of the integrated advanced prop-fan aircraft. All previous study work throughout the industry on the prop-fan concept has shown a definite fuel saving for the prop-fan aircraft as compared to the turbofan aircraft. These analytical comparisons show a 16 percent to 38 percent fuel savings of the prop-fan over the current turbofan engine powered aircraft; as compared to an advanced technology turbofan engine compatible with a 1990 to 1995 operation, the prop-fan shows a definite advantage of at least 15 percent fuel savings. The decreasing availability and the rapid escaltion of price of fossil fuel have made industry increasingly desirous of having this fuel economy available from the prop-fan in actual operation.

In Phase I (FY 1978 through 1980) of the NASA Advanced Turboprop (ATP) Program, a fundamental data base on small scale prop-fan models was developed and the feasibility of the high speed (Mach 0.70 to 0.80) prop-fan was established. The next follow-on step in the prop-fan development is to provide proof-of-concept by large scale testbed research and demonstration. The proof of the prop-fan itself is the key to the success of the prop-fan aircraft; therefore, proof of full scale prop-fan structural integrity, acceptable noise levels, and performance are the first priority items in the testbed program. This study reported herein provides the necessary survey, planning, and early preliminary aircraft design information associated with the initiation and continuation of a suitable large scale prop-fan testbed program. Compliance with an expedited schedule necessitates that the testbed aircraft/engine/prop-fan/controls consider existing hardware.

The facets of the overall testbed problem included in this study are the objectives and priorities of the testbed program; survey and selection of candidate propeller drive systems; selection of a satisfactory aircraft, from candidate aircraft, for the testbed; proposed testbed systems evaluation and recommendtions; conceptual design of a testbed; ROM costs; preliminary testbed flight program; and survey of wind tunnel facilities suitable for large scale prop-fan and prop-fan aircraft testing.

The Douglas study considers the DC-9-10 (or -30) as the testbed aircraft. Throughout, the Hamilton Standard SR-3 design type prop-fan is selected; the actual design of the testbed large scale prop-fan will be designated as SR-7, but is expected to have the design and performance characteristics similar to the existing SR-3. In the iniitial phase of the study, the Allison T701, the Allison T56, and the General Electric T64 turboshaft engines are compared as to the feasibility of each type as a drive system for the prop-fan testbed. One and two prop-fan nacelles are considered for the testbed arrangement. Since the unmodified DC-9 aircraft empennage is capable of satisfactory flight with the asymmetric configuration, one wing-mounted prop-fan nacelle configuration is considered as a less costly version of the testbed. However, since the two nacelle prop-fan arrangement is more desirable from the Contractor's point of view, it is considered as the primary arrangement.

For this proposed testbed aircraft concept, the major modification to the aircraft is design and mounting of the wing-mounted prop-fan nacelles. The arrangement considered in this study is a simple, primary structure, monocoque nacelle mounted at four points to the wing front and aft spar. Such an arrangement permits a well forward location of the prop-fan relative to the wing leading edge, provides ease of mainntenance (as the propulsion system components may be removed from the nacelle in a modular fashion without interference with the wing basic structure or fuel tankage) and results in an integrated prop-fan arrangement having a desired excitation factor.

General conclusions from the study are:

- A prop-fan testbed aircraft program is definitely feasible and necessary for verification of prop-fan/engine/nacelle/aircraft integration.

- The DC-9 aircraft is a particularly desirable testbed aircraft since
  - it requires no configuration modification except the addition of the wing-mounted prop-fan nacelle(s);
  - all facets of the DC-9 are known to Douglas and, thus, the installation of the prop-fan can be efficiently accomplished;
  - the aircraft is a commercial aircraft and a desirable size from the airline's point of view.

- Of the currently available turboshaft engines, the Allison T701 is most suitable as a propulsor for the prop-fan aircraft testbed.

- Modification of existing engine and propeller controls is adequate for the prop-fan testbed.

- The airframer is considered the logical systems integrator of the testbed program; full cooperation of the prop-fan manufacturer, the engine and gearbox manufacturer, and the airframer is required to accomplish a successfully expedited testbed ready for flight in 1986.

- Flight test is essential for establishing the necessary proof-of-concept, valid evaluation, and confidence in prop-fan itself and the proper integration into a prop-fan aircraft.

- Large scale wind tunnel testing will not provide adequate results for validation of the prop-fan as integrated into an aircraft.

- Sub-scale wind tunnel testing is feasible for exploration and parametric evaluation required in establishing the basic configurration assessments necessary in selecting a suitable or "near optimum" integrated testbed aircraft arrangement.

- Opposite rotation (both prop-fans rotating inboard and upward toward the fuselage) is shown to be advantageous from the performance and acoustic points of view; continued analysis and design work is warranted.

- Synchrophasing of the prop-fans is necessary for establishing satisfactory acoustic performance in the case of the two prop-fan nacelle configuration.

- The DC-9-10 testbed aircraft provides suitable configuration for measurement during flight of prop-fan near field and far field acoustic characteristics since the basic JT8D turbofan engines in the DE-9-10, operated in conjunction with the prop-fan propulsion system, do not generate background noise which will interfere with valid measurement of the prop-fan acoustic characteristics.

INTRODUCTION

ADVANCED TURBOPROP TESTBED SYSTEMS STUDY

INTRODUCTION

The ongoing reduction in fossil fuel availability and the associated rapid increase in fuel price have been prime reasons for the acceleration of research associated with development of an advanced aircraft propulsion system which is highly fuel efficient. The Advanced Turboprop Program (Prop-fan), a part of the NASA Aircraft Energy Efficient Program (ACEE), is such a research effort which has been underway for several years. The key element of the system, the prop-fan, has been under development by NASA Lewis and Hamilton Standard for quite some time (Reference 2). Results of prop-fan aircraft evaluation studies throughout the industry have consistently shown the prop-fan-powered aircraft to be definitely competitive to the turbofan powered aircraft and to provide the desired fuel savings of 16 percent to 38 percent over current medium range aircraft. The comparative results of analytical parametric studies and small scale wind tunnel tests to date have all been positive and show definite promise for the prop-fan aircraft. The logical next step in the development of a prop-fan aircraft is the ground and flight testing of a practical integrated research aircraft.

The study results of this Advanced Turboprop Testbed Systems Study, performed under NASA Lewis Contract No. NAS3-22347 by Douglas Aircraft Company, are summarized herein. These study results encompass the preliminary planning concerned with the selection of a suitable aircraft and testbed configuration for verification, demonstration, and measurement of

- structural integrity, acoustic, and performance characteristics of the prop-fan;
- integration aspects of the engine/prop-fan/nacelle/aircraft;
- prop-fan interference effects on the overall aircraft installation from the points of view of aerodynamics, structures (including sonic fatigue, flutter, and vibration), acoustics and propulsion;
- preliminary design of the suitable testbed configuration.

Wind tunnel testing and flight testing of the testbed configurations are taken into consideration; and ROM costing and preliminary scheduling are included.

The Douglas study is performed with Hamilton Standard and Detroit Diesel Allison as subcontractors, respectively, on the prop-fan characteristics (design, installation, operation, performance) and on the engine (hardware, installation, performance). Both subcontractors are highly concerned with the efficient integration of the overall propulsion system.

As this contract study progressed, the emphasis or primary direction of the study evolved in accordance with the pertinent engineering results. These changes of direction of the contracted study were done in agreement with the NASA Lewis Project Manager. The chronological variations in the study investigation are noted as follows. First, as per the original contract, the study parametrics included

- one selected testbed aircraft configuration;
- two candidate prop-fan propulsion system designs; (engine/gearbox plus prop-fan);
- one prop-fan nacelle installation.

Second, as the prop-fan propulsion systems investigation showed definite superiority of one over the other, the study emphasis changed to

- one selected testbed aircraft configuration;
- one prop-fan propulsion system design;
- one and two prop-fan nacelle installations.

Third, further investigation resulted in the evolution to the following set of configuration conditions

- one selected testbed aircraft configuration;
- one prop-fan propulsion system design;
- two prop-fan nacelle installations.

The study results summarized herein are concerned with the Douglas DC-9 aircraft modified as a prop-fan testbed by the addition of an appropriate prop-fan/engine/nacelle installation on the aircraft as shown in Figures 1 and 2. The use of the Douglas DC-9 in a flight research program provides a

FIGURE 1. DC-9-10 PROP-FAN RESEARCH AIRCRAFT
ONE PROP-FAN NACELLE CONFIGURATION

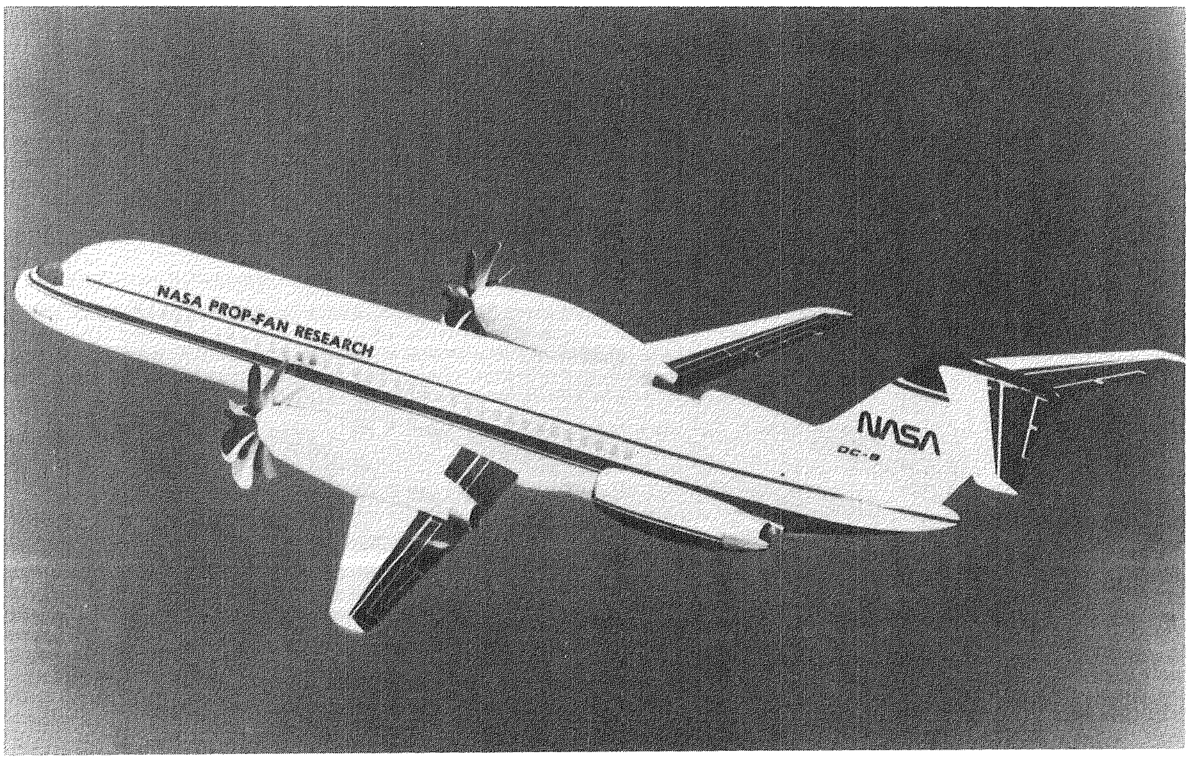

FIGURE 2. DC-9-10 PROP-FAN RESEARCH AIRCRAFT
TWO PROP-FAN NACELLE CONFIGURATION

a potential for a follow-on, powered flight research demonstration program at minimum cost. Since the existing DC-9 empennage is capable of handling the asymmetrical configuration (Figure 1) from the stability and control points of view, the single prop-fan nacelle is proposed as the initial testbed configuration in deference to a low cost. As the study progressed, the two engine prop-fan configuration is taken into account and is discussed herein. Three turboshaft engines - the Allison T56, the Allison T701, and the General Electric T64 - are considered in the earlier portion of the study. The G.E. T64, as presented by G.E. in the initial part of the study, is found to be non-competitive; the T701 with the free turbine design is shown to be advantageous for the prop-fan installation and thus is selected over the T56 single shaft turboshaft engine. At this point in time, concerted effort is spent on the T701 engine installation and on both the one prop-fan nacelle and on the two prop-fan nacelle testbed configurations.

It is to be emphasized that no detail is included in this present contract study relative to the

- o inlet (optimization, sizing, location);
- o inlet internal contours;
- o inlet boundary bleed requirements;
- o nozzle exit;
- o oil cooler inlet.

This work is very necessary for detailed definition of the well-integrated testbed configuration; however, it is beyond the scope of the present contract. The inlet/exit configuration considered in this study is an appropriate preliminary estimate; other aspects of the detail of prop-fan/engine installations will be considered as part of a follow-on testbed work.

The study results are presented in terms of the following seven technical tasks

Task I - Recommended Testbed Program Objectives and Priorities
Task II - Candidate Propeller Drive Systems

Task III - Candidate Testbed Aircraft

Task IV - Testbed System Evaluation and Recommendations

Task V - Conceptual Design of Testbed Systems

Task VI - Testbed Flight Test Program Plan

Task VII - Wind Tunnel Test Program Plan

It is to be emphasized that the above-mentioned seven tasks are not discrete but are mutually dependent. Therefore, some repetition among the tasks occurs in the discussion of these report results.

A Task VIII included in the study contract covers the reporting, summarization, and briefings of the study results.

The discussion of the results of this study is organized as per the seven tasks noted. The section on ROM costing follows the discussions of Task VII. The principal numerical results of the study are presented in English units. The associated metric units are presented as secondary values and are enclosed in parentheses, ( ).

Appendix I summarizes the characteristics of the pertinent wind tunnels. Although not a part of the contract work statement, the work breakdown structure, through the second level, for the flight test testbed program is summarized in Appendix II. Appendix III includes description of pertinent components of the Douglas Flight Test Facility.

TASK 1

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TASK I

RECOMMENDED TESTBED PROGRAM OBJECTIVES AND PRIORITIES

GENERAL

The prop-fan analysis and associated aircraft design studies which have been performed to date have shown that the prop-fan is a feasible and a viable propulsion system which should be capable of providing fuel efficient aircraft operation by 1985-1988. To date, the Advanced Turboprop Program which is a part of the Aircraft Energy Efficiency (ACEE) Program has encompassed

- design, analyses, and small scale wind tunnel testing of the prop-fan;
- low speed wind tunnel testing and analysis of critical aspects of prop-fan/aircraft integration - for instance - aerodynamic aspects of propeller slipstream effects including swirl, design procedures to aid in swirl recovery, powered semi-span model which simulates the wing/nacelle/prop-fan slipstream interaction.

Continued effort, either through wind tunnel testing or flight testing, is required in the rapid develpment of the prop-fan aircraft. The testbed program capable of verifying the prop-fan and its integration into a full scale aircraft is the next step in establishing confidence in this overall prop-fan aircraft concept. The rapidly increasing price, along with the diminishing supply, of fossil fuel has created a definite need for a fuel efficient aircraft to be introduced into the commercial and military aircraft fleets in the very near future. To meet this need for fuel efficient aircraft into the fleets, the proof of concept of the prop-fan aircraft is certainly to be expedited. Consequently, the maximum use should be made of existing suitable hardware such as an aircraft, turboshaft engine, engine and prop-fan controls. The existing prop-fan design work enhances the expediency required in this necessary validation of the prop-fan aircraft.

Throughout this prop-fan testbed research aircraft program, cooperation is required of the airframer, the prop-fan manufacturer, and the turboshaft engine manufacturer. In the resolution of all these technologies, the airframer is considered the prime integrator, with the prop-fan manufacturer cooperating closely, and the engine manufacturer a subcontractor of the airframer. This overall prop-fan testbed program is expected to be monitored by NASA Lewis.

Five specific critical objectives and their order of priority for the testbed program are considered to be

- o substantiation, by large scale testing, of the prop-fan rotor structural integrity, the acoustic characteristics of the prop-fan, and the performance capability of the full scale prop-fan;
- o overall substantiation of the integrated prop-fan/aircraft acoustic characteristics including internal and external noise levels as well as effectiveness of recommended acoustic treatments;
- o integrated prop-fan/aircraft configuration aerodynamic aspects including such as interferences, component contouring for most favorable lift and drag, stability and control, and overall performance capability;
- o integration of mechanical controls with the engine and prop-fan;
- o integration and compatibility of the prop-fan/inlet/engine for the testbed.

Another very important aspect in the development of a 1990 type prop-fan aircraft is the design study, test, and substantiation of an advanced fuel efficient turboshaft engine compatible with the timing of this future aircraft. This effort is necessarily that of the engine manufacturer in coordination with the airframer. Since the testbed itself does not consider an advanced turboshaft engine in its initial task of proof of concept of the prop-fan, discussion of this advanced turboshaft engine is not included herein as part of this testbed discussion. It is to be emphasized however that this development of the advanced turboshaft engine is particularly important to the overall prop-fan aircraft project.

Discussion follows of these above-mentioned five critical testbed program objectives. These five objectives are discussed briefly under major headings in Task I. Both large scale wind tunnel and flight testing are considered herein as means of satisfying these objectives. However, a survey of pertinent wind tunnel facilities, done during this study and reported in Task IV and Task VII, show their inadequacy to provide the concept substantiation required.

LARGE SCALE PROP-FAN ROTOR TEST OBJECTIVES

The substantiation of the structural integrity and performance of the prop-fan is basic to the continued design and development of the prop-fan aircraft. All analytical and small scale test development work on the prop-fan have shown the prop-fan to be feasible and very worthwhile for further developmental and proof of concept work. Hamilton Standard identifies and defines the following technical objectives and priorities for a testbed program in the areas associated with the prop-fan rotor. Resolution of these objectives, either through a testbed aircraft flight research program or a large scale wind tunnel test, will enhance industry acceptance of the prop-fan for commercial or military aircraft designed for cruise speeds of Mach 0.8 at altitudes greater than 30,000 feet (9144 m). As part of the NASA program, the small scale model technology already developed for the prop-fan must be extended to full scale, such that confidence of this prop-fan concept is established. Specifically, the areas of structural dynamics, acoustics and vibrations, and aerodynamic performance will be addressed, in that order of priority.

Structural Dynamics

In order to establish the most accurate test data and not precipitate additional analytical correlation studies, the large scale prop-fan should exhibit a blade diameter of approximately 8 to 10 feet (2.44 to 3.05 m). The selection of an 8 to 10 foot (2.44 to 3.05 m) diameter for the testbed stems from two considerations:

- Accurate representation of the total blade airfoil mass and stiffness distribution, in the spanwise and chordwise directions, as well as the proportioning of the mass and stiffness contributions of the elements making up any given cross section of blade airfoil;

- accurate representation of size, shape and thickness of the blade construction elements, so that a clear demonstration of full size fabrication feasibility can be made

The results of the SR-3, SR-5, and SR-6 aero-acoustic model designs have demonstrated that the thin, swept blade shape increases the degree of mass stiffness interaction due to rotation and vibration. The response of a blade to integer order excitation is related to its frequency and damping. The frequency is determined by the mass and stiffness distribution; the damping is related to the deflection amplitude and, therefore, the stiffness. The probability of non-integer order response is related to the relative magnitude of the airloads and blade inertia and to the separation of torsional and bending frequencies. The blade inertia, relative location of the blade frequencies, steady deflections of a rotating blade caused by body forces, and aerodynamic forces are all determined by the mass and stiffness distribution. The integer order response, freedom from non-integer order response (flutter),and predictable deflection characteristics are essential elements of a full scale demonstration.

The accuracy of simulation of a full scale prop-fan blade is size dependent because the full size blade will be made of several materials of different density, in order to provide a viable total weight. Since there are practical limitations on the thinness of blade parts, both from a fabrication and a durability standpoint, it is not possible to simulate full size cross sectional properties in sub-scale size. For example, in order to withstand airloads, buckling, panel flutter and FOD with a hollow blade tip cross section, the minimum required pressure side skin thickness would be .060 to .080 inches (.152 to .203 cm). If this thickness were scaled directly with prop-fan diameter from 10 feet (3.05 m) to 2 feet (.610 m), the skin thickness would be .012 to .015 inches (.034 to .038 cm). Since most composite lamina are about this thickness, multi-layer laminates, which are necessary to achieve required strength and stiffness properties, are thus ruled out. Fabricating a blade skin from such thin sheet metal would require completely different techniques than would be applied to a full scale blade.

In the retention area, similar scaling limitations are encountered. An anti-friction bearing is required for variable pitch. The area available for the retention and pitch control mechanism is fixed by the hub-to-tip diameter ratio required for aerodynamic performance. The cross section of anti-friction bearings and pitch control elements such as gears, ball screws, links, rod ends, slider blocks, etc., do not scale down well below a certain point because of fabrication and durability characteristics.

From the Hamilton Standard design work on SR-3, SR-5 and SR-6, all of which had solid metal blades without anti-friction retention bearings, Hamilton Standard judges that an accurate demonstration of dynamic behavior and fabrication feasibility could not be achieved in less than an 8 to 10 foot (2.44 to 3.05 m) diameter prop-fan.

There are two technological areas that require validation: namely,

- o the vibratory response to aerodynamic flow fields, and
- o the stall and classical flutter characteristics. This evaluation should be conducted in the order of priority indicated.

Blade Dynamic Response Validation.

Blade dynamic response is a function of the aerodynamic flow field, the blade aerodynamic characteristics, and the blade structural dynamic characteristics. The small model wind tunnel tests will give fairly good insight into the first two items, but will not simulate the structural dynamic characteristics of large, spar/shell blades. Response tests on a large scale prop-fan will provide the means for assessing the construction effects pertaining to the aerodynamic and dynamic characteristics. The object of this subject testbed program is to confirm the excitation loadings, predicted by the small model tests, in the presence of an aircraft and to assess the structural response of a large scale blade of realistic construction. Because of aeroelastic effects, it is possible that the large scale model blades may have different stress sensitivity than that shown on the small solid model blades. Although the 1P stress sensitivity can probably be better evaluated in a high speed wind tunnel under controlled conditions with better instrumentation, it is believed that a flying test bed will be the best method for evaluating the excitation effect and overall response of prop-fan blades.

In order to generate the proper flow field, the vibratory response testing must include a swept wing, a nacelle and a fuselage, at the sizes representative of a proposed full scale aircraft. Thus, the testing of the large scale prop-fan in a wind tunnel is precluded. Meaningful testing must include aircraft speeds from static to 0.8 Mach number, full variation of ground wind velocities and direction with a representative propeller thrust, full wing angle of attack variation - both with and without flaps - and a yaw variation.

In order to evaluate the effect that the structural dynamics have on blade response, the measured stresses will be analyzed with regard to magnitude and frequency. The excitations, flow field, and sensitivity will be evaluated to determine whether they are consistent with the small wind tunnel model results or whether aeroelastic effects are present. Additionally, the presence of secondary stressing due to the spar/shell blade structure will be assessed.

Blade Classical Flutter Validation

The possibility of classical flutter of prop-fan blades are of concern because of the high degree of modal coupling due to the sweep and low aspect ratio, the relatively low first torsional mode frequency, and the high operating tip speeds. The susceptability of a blade to classical flutter is dependent on both the aerodynamic and structural characteristics of the blade. Although small model blades duplicate the aerodynamic characteristics reasonably well, they do not duplicate the structural characteristics. Thus, to develop confidence that classical flutter will not be a problem, classical flutter tests should be run on large-scale model blades of typical spar/shell construction. Only in this way will the true aeroelastic effects be properly duplicated.

During classical flutter tests, the need to continuously control and measure the operating conditions and stresses accurately requires that testing be conducted in a high speed wind tunnel rather than on a flying test bed. A wind tunnel would permit running at higher MN without undue concern over safety.

For such tests there is no need for any aircraft structure, except possibly the nacelle, so that wind tunnel operation is practicable. Stress levels and frequencies will be monitored for indications of the approach of classical flutter (Random Decrement Method) over the full range of aircraft speeds from static to 0.8 MN, and must cover the full power loading (SHP/D^2) range. The results should give confidence that the full scale, spar/shell configuration prop-fan blades will be free from classical flutter, as well as the degree of margin to be expected. The results will also give an understanding of the various operating conditions on stability margin. Additionally, with a comparison of the small model results, a feel for the construction and geometry effects on classical flutter can be obtained.

Blade Stall Flutter Validation.

Prop-fan blades are highly loaded and stalled to a great degree during static, very low speed, and reverse. Consequently, they are susceptible to stall flutter, which is a function of both the aerodynamic and the structural dynamic characteristics of the blade. In order to duplicate the true aeroelastic and geometric characteristics, as well as the torsional frequency, the use of a large scale model blade is desirable. As stated previously, small solid model blades duplicate aerodynamic characteristics reasonably well, however, their structural characteristics can only be approximated. Therefore, the flutter results obtained, if this technique is utilized, would primarily be used for evaluating theoretical prediction methods.

Since stall flutter usually is most likely to occur during static, high power operations, an open test stand is the simplest and most effective way for its evaluation. However, because of the high degree of stall of the prop-fan blades, and the recent blade system flutter experience during reverse thrust on the OV10 aircraft, it appears that the best way for an overall stall flutter stability evaluation of a large scale size model prop-fan would be the flying testbed. The flying testbed allows the flexibility for evaluating not only static operation, but also reverse and forward operation at low air speeds.

Analysis indicates that for these highly stalled blades, stall flutter might occur at low forward speeds rather than statically. By monitoring the blade torsional stressing for various operating conditions (power, RPM and airspeed), it is possible to estimate the stall flutter boundary. By utilizing the Random Decrement Method, it is also possible to predict the proximity to stall flutter. This method will determine the blade torsional damping for each operating condition.

The results will provide confidence that full scale, spar/shell configuration prop-fan blades will be free from stall flutter, and will determine the degree of flutter margin. The results will also provide an understanding of how the operating conditions affect stall flutter margin. If small model tests are run, some insight can be obtained as to the effects of construction and geometry on stall flutter and the predictions can be checked out.

Since the blade structural response and stall flutter characteristics are best obtained on a flying testbed, and the classical flutter characteristics can be obtained either in a large high-speed wind tunnel or on a testbed, it is recommended that stability testing be performed on the testbed aircraft for complete validation.

Acoustics

Acoustics technology needs are described below. In general, magnitude and phase characteristics of the prop-fan noise impinging on the fuselage surface must be established on a large-scale flight vehicle during various operating conditions. Furthermore, the manner in which this noise is transmitted to the interior must be understood in order to design efficient cabin noise control treatment. An additional area in which more information is required is the definition of prop-fan far field noise for flyover noise certification and community noise evaluations.

These technology needs can be described in further detail as follows. The noise field on the fuselage surface must be identified for both ground and flight operation conditions in order to fully evaluate the cabin acoustic environment. The design condition for the cabin acoustic environment, however, will be the cruise condition. Variables that will affect acoustic loading on the fuselage include aircraft altitude, airspeeds, and angle of attack, blade loading and pitch angle, and prop-fan rotational speed. The effect of all these variables on fuselage acoustic loading must be evaluated in flight on the testbed aircraft. In addition, source noise reduction concepts such as prop-fan synchrophasing and opposite rotation should be investigated. The term "synchrophasing" refers to the ability to synchronize the propellers such that a pre-selected relative phase angle is maintained between the blades of one propeller and the blades of any other propeller on the aircraft.

Traditional propeller synchronization by mechanical governing is necessary to prevent acoustic beats in the cabin due to slight differences in rotational speeds between the various propellers. Recent advances in synchronizer technology have shown that with precision synchrophasing, not only can acoustic beats be prevented, but an overall reduction in total noise entering the cabin is possible. Synchrophasing has been demonstrated to provide noise reduction in tests conducted on existing propeller aircraft. The amount of reduction and the ability to achieve the necessary synchrophasing accuracy have not been demonstrated yet on a prop-fan aircraft, but it is considered to be a viable concept and should be evaluated on the testbed aircraft.

Prop-fan opposite rotation is another noise reduction concept which should be evaluated on the testbed aircraft. It is hypothesized (based on measurements in existing turboprop aircraft) that opposite rotation will reduce noise levels in the cabin because the blades will sweep by the fuselage on their upward path (for up-inboard rotation) where they are more lightly loaded aerodynamically. Furthermore, the area of shock impingement on the fuselage would be below the floor, as opposed to the window belt area for down-inboard rotation.

Noise transmission through the fuselage and interior panels must be understood in order to design effective noise control treatment. Analytical procedures designed to predict this transmission must be validated with experimental data in full scale using a realistic high- speed transport-type structure with appropriate acoustic treatment. Large scale (narrow-body transport size) validation is necessary because scaling from small size to full size models is important to the performance of acoustic treatment designs. Noise transmission properties of the fuselage and acoustic treatment materials cannot be scaled without the introduction of a high degree of uncertainty, which would adversely impact the accomplishment of the stated program objectives.

Initial validation of the analytical models can be accomplished in a flight test program on an existing turboprop. Such a program, with appropriate pre-test and post-test analyses, could be used to verify the predicted transmission loss of the fuselage shell as well as the performance of advanced acoustic treatment designs. Due to the cost of modifying a fuselage, this test program would probably be limited to add-on types of acoustic treatment. Presumably, several acoustic treatment designs would be initially evaluated in a laboratory test set-up before installation in the aircraft.

The definitive validation of all prediction models and acoustic treatment designs should be done on a prop-fan powered transport-type aircraft capable of cruising at 0.8 Mach. This testbed prop-fan installation should be as similar as possible to a production prop-fan installation; i.e., the prop-to-fuselage tip clearance should be approximately 0.8 prop diameters; a two prop-fan installation should be used; and a realistic inlet/nacelle/wing configuration should be utilized. Furthermore, the noise of the prop-fans should not be contaminated by extraneous noise from other propulsors on the aircraft. In other words, the aircraft layout, power requirements, and operation must be arranged in such a way as to minimize contamination of the prop-fan sound signal by turbofan noise.

In addition to measurement of near field prop-fan noise on the fuselage and interior noise, the testbed aircraft may also provide an opportunity to measure far field noise during simulated takeoff and approach conditions. These data are needed in order to make noise predictions at the FAR Part 36 measurement points. Current far field noise prediction procedures for the prop-fan require substantiation by test data. These noise measurements cannot be accomplished under static test conditions because of the present lack of understanding of the use of static test data. Although previous work has been done in permitting wind tunnel noise measurements to be used to predict far field noise, predictions obtained in this manner on a large scale propeller should be augmented by flight data.

Performance

The main objective is to confirm the performance by evaluating a prop-fan of large scale size, such as 8-10 feet (2.44-3.05 m), and shape with a realistic nacelle configuration at the critical design conditions (i.e. efficiency, pressure, velocity distribution, swirl, etc.). Altitude and Reynolds number are not considered to be an issue. Testing should be performed in a wind tunnel, over the full Mach number range with a wide variation in power loading and tip speeds.

In the field of performance, there are three technological needs that should be investigated: namely, the validation of the aerodynamic performance; the evaluation of the installation effects and; nacelle and inlet configuration definition. All of these technological needs can best be met in a wind tunnel test and in the order of priority indicated.

The last two items should be investigated in model scale rather than full scale.

Aerodynamic Performance Validation.

The prop-fan performance levels established by the small model tests conducted under the NASA Advanced Turboprop Project are expected to be achieved by the full-scale prop-fan. However, a performance test on a large scale prop-fan is important to confirm the expected performance and to provide data for designing future configurations with improved efficiency.

Since the controlled conditions in wind tunnel testing have proven to provide more accurate and repeatable measurements than is possible from flight tests, this performance confirmation test should be accomplished in a large-scale, high-speed wind tunnel. In fact, the same hardware to be used in the structural and acoustic flight test later may be used in a wind tunnel.

The performance measurements from this test with actual full scale flight test hardware, (i.e. prop-fan, nacelle without the wing) are important since these data will include such effects as surface smoothness, manufacturing tolerances, spinner-to-blade juncture, aeroelastic deflections under operating loads and full scale Reynolds number, etc. These above-mentioned shape effects are not included in the existing model test data. The complete performance spectrum of interest should be defined in this wind tunnel test. Accordingly, the test schedule should cover a tunnel Mach number range from near static through 0.8 - 0.85 for a wide range of power loading at tip speeds from 500 (152) through 900 ft/sec (274 m/sec). Reverse thrust performance, windmilling and feather drags should be investigated as part of the test program.

Installation Effects Evaluation

The effect of the prop-fan and nacelle interaction may require that the wing be modified to accommodate the prop-fan slipstream with no significant performance penalty. The basic investigation should be conducted in the wind tunnel on a small scale, semi-span model. This program is required to provide aerodynamic data for establishing the "optimum" nacelle location on the wing, the nacelle and wing interface geometry, and the wing modifications required to maintain or improve wing performance in the presence of the prop-fan slipstream.

The large-scale flight test vehicle will not be preferrred for acquiring the detailed data needed for the production design because the testbed wing is not a supercritical wing of the type anticipated for the produdction aircraft, the propeller/wing size relationship is incorrect, and the thrust minus drag data is not as accurate as can be obtained in a wind tunnel with a strain-gage balance. However, the overall aircraft performance obtained from flight test data can provide information for assessing the overall propulsive efficiency.

In this case, the performance measurements should be made on an aircraft designed for a prop-fan propulsion system rather than a flying testbed where the prop-fan engine provides a small portion of total thrust.

A more precise means of establishing propulsive efficiency would be from wind tunnel measurements on a large scale prop-fan and nacelle installed on a semi-span aircraft model . However, the tunnel size and scale effects to obtain proper wing performance becomes a question. The airframe manufacturer is best qualified to recommend the wing size and wind tunnel for this evaluation. For the best installation, the wing and fuselage forces should be measured on a balance separated from the prop-fan and nacelle forces. The prop-fan data should be obtained from thrust and torque meters installed in the nacelle and, finally, the friction drag on a nacelle should be measured on a separate nacelle balance. In this manner the effect of prop-fan slipstream on the aircraft components may be established as well as the performance of the prop-fan in the presence of the aircraft. These detailed measurements could not be made on any practical flight test vehicle.

Nacelle and Inlet Configuration Definition

The shape of the nacelle integrated with the prop-fan is important to achieving high efficiency at high flight Mach numbers. The prop-fan models tested to date have incorporated a carefully configured nacelle to minimize blade root Mach numbers thereby reducing compressibility losses. However, neither the effect of nacelle shape on aircraft performance nor the effect of engine air inlet shape on prop-fan performance and inlet pressure recovery have been investigated. This research task should be conducted in the wind tunnel on small models. When an optimum nacelle/inlet configuration has been established, a large-scale wind tunnel test should be performed to determine the efficiency, nacelle drag, and inlet pressure recovery. For the flight research program, the inlet pressure recovery should be measured, even if the nacelle and inlet shapes are not optimized configurations, in order to establish inlet pressure recovery levels actually achieved by the prop-fan inlet at high Mach numbers and Reynolds' number.

Summary of Prop-fan Testbed Program Priorities

Assessment of the priorities for the testbed program objectives is based on the relative importance of the structural integrity, acoustic environment and aircraft performance technological areas.

The areas of technological need can be summarized as indicated below:

Priority 1 - Integrity of the prop-fan structure which includes the vibratory response to aerodynamic flow fields, the prop-fan stall, and classical flutter boundaries.

Priority 2 - Passenger cabin acoustic and vibration environment. Areas of concern are:

- o evaluation of prop-fan acoustic loads on the fuselage, including the effects of prop-fan synchronization and opposite rotation, and
- o effectiveness of sidewall acoustic treatment in reducing prop-fan noise transmitted to the interior.

Priority 3 - Aircraft performance, although important, should not jeopardize satisfying the more important structural integrity and acoustic requirements. The performance areas of concern are validation of the aerodynamic performance, evaluation of the installation drag effects, and definition of the nacelle and inlet performance.

TESTBED ACOUSTIC OBJECTIVES

In order to gain acceptance of the prop-fan as a propulsor for commercial aircraft, an acceptable solution to the interior noise problem must first be demonstrated to the customer airlines. Questions that should be addressed in the area of acoustics include:

- o Can interior noise and cabin vibration levels be obtained in prop-fan aircraft that are comparable to the levels in present turbofan aircraft?

- What is the weight penalty associated with attaining low interior noise levels and how does this weight penalty affect operating costs?

- Can prop-fan aircraft meet present and future flyover noise regulations?

This study will investigate the ability of either a flying testbed aircraft or a wind tunnel test program to provide answers to these questions. It is not anticipated that either test program would completely answer all of the questions, however, the relative merits and shortcomings of each program will be discussed.

Measurement of the noise generated by a large scale prop-fan during flight conditions is necessary in order to determine acoustic levels and directivities in both the near and far field. The near field information will provide input for fuselage structural design to prevent sonic fatigue, and for acoustic treatment design to reduce interior noise. These tasks require precise definition of the external noise field acting on the fuselage in order to attain maximum design effectiveness at minimum weight penalty. Present propeller noise prediction procedures and model propfan wind tunnel test data are useful for preliminary design studies, but require verification before more detailed design work is performed. The accuracy of existing prediction procedures remains in question, as does the effect of scaling model prop-fan wind tunnel data to full scale propellers. It is anticipated that noise data from the testbed program will provide the means for verification or modification of the prediction procedures.

Measurement of far field noise is needed to show the ability of a prop-fan powered aircraft to meet present and possible future flyover noise regulations. Current procedures for prediction of prop-fan far field noise require verification before they can be used with any degree of confidence. Accurate far field noise estimates will be needed before guarantee discussions can take place with customer airlines.

The task of designing acoustic treatment to reduce interior noise requires that measurements of fuselage vibration and cabin noise be made first without any acoustic treatment, so that the noise reduction afforded by the fuselage can be determined. The difference between the cabin noise level without any acoustic treatment and the interior noise goal will be the amount of noise reduction that must be provided by the treatment.

Measurement of fuselage vibration and cabin noise will also provide a means for evaluation of the structural response analytical models that are used to predict interior noise levels. The data will show how the structure responds to the external noise field and how it radiates the noise to the interior.

The testbed aircraft will also be used to test the effectiveness of various acoustic treatment designs. The actual performance of several trim panel and sidewall cavity treatment configurations can be compared against predicted performance and the performance required to meet the interior noise goal. It is important that the ability of an acoustic treatment design to meet the interior noise goal be demonstrated to gain airline customer acceptance. These data will also provide the information necessary to compute the minimum weight penalty actually needed to attain the desired interior noise level.

As a byproduct of the testbed program, data will be available to determine the effects of scaling model prop-fan wind tunnel data to a large scale propeller. Determination of scaling effects would make existing model prop-fan data much more useful and also may enable future model prop-fan test data to be used for parametric studies of full-scale designs.

To summarize the previous discussion, the acoustic objectives of the testbed program are listed here in order of importance:

- o Measure prop-generated near field and far field noise during representative ground and flight conditions.

- Measure passenger cabin noise and fuselage vibration during cruise flight conditions.

- Determine the effectiveness of various types of noise control treatment in reducing passenger cabin noise.

- Evaluate prop-fan opposite rotation and synchronization effects.

- Determine the effects of scaling model prop-fan noise data to large scale applications at representative flight conditions.

- Obtain data to verify or modify existing theoretical prediction models.

- Obtain data to develop procedures for predicting FAR Part 36 noise levels.

Resolution of Acoustic Objectives

The resolution of acoustic objectives may be accomplished by testbed aircraft or by wind tunnel testing. The following discussion addresses these two methods.

Resolution by Testbed Aircraft.

A flying testbed aircraft will provide a highly desirable means of accomplishing most of the acoustic objectives listed above. A flying testbed will provide the direct means for verification of the various prediction procedures that are currently being relied upon rather heavily; and in addition, it will provide an opportunity for potential customer airlines to witness a large scale prop-fan installation. The ability to attain acceptable interior noise levels can also be demonstrated.

Regarding the ability of the testbed program to accomplish the stated acoustic objectives, measurement of near field noise levels and directivity can be accomplished by means of an array of external microphones flush-mounted to the fuselage skin. Precise definition of the external noise field during flight is needed to formulate detailed predictions of fuselage response. The external microphone array will be designed to measure the levels and spatial characteristics of the external noise field, including relative phase. The microphone signals will be recorded simultaneously on a multi-track recorder so that phase information can be obtained through appropriate data analysis.

It is desirable to measure prop-fan generated far field noise with the testbed aircraft. Normally, the preferred method of accomplishing this would be to conduct actual takeoffs and approaches. However, the proposed testbed aircraft is currently restricted to operation at altitudes above 15,000 feet (4572 m).

The 15,000 foot (4572 m) altitude restriction may be removed if wind tunnel testing verifies that the testbed aircraft can be operated safely at lower altitudes. Noise measurements may thus be obtained in a low-altitude level flyover, or in a low-altitude descent. These noise measurements may then be used to validate or improve the prop-fan far field noise prediction methods, which can then be used to estimate the aircraft's noise characteristics for other flight conditions.

Alternatively, far field noise data may be obtained under forward speed conditions during taxi testing. It is suggested that noise measurements during taxi tests be included in the testbed program even if it is determined that level flyovers are possible. The taxi tests will provide backup data in the event that the flyover data quality is poor. The taxi measurements also have the advantage of being uncontaminated by turbofan noise. Furthermore, the taxi data can be used for comparisons with the flyover data and ground static data to obtain a better understanding of the effects of forward speed on propeller noise.

The ability to use propeller noise measured under ground static conditions will become a necessary part of any future production program. The prop-fan testbed aircraft will provide an opportunity to obtain both ground static data and data under forward speed conditions (either during level flyovers or taxi testing, or both). As discussed later in this report, the problems associated with the interpretation of static propeller data may not be insurmountable and, therefore, these measurements should be obtained as part of the testbed program. In addition, far field noise measured during ground static runup will yield information useful for airport community noise assessment for ground operations prior to brake release.

Prop-fan near field noise will be measured using the fuselage flush- mounted microphone array during ground static, taxi, and flight operations. In addition to characterizing the prop-fan noise field on the fuselage under these conditions, the data can be combined with accelerometer and interior microphone data to identify fuselage response and transmission loss.

Passenger cabin noise will be measured using microphones located both near the sidewall and at the center of the aircraft at appropriate locations along the length of the cabin. Cabin noise will be measured for both treated and untreated (barewall) sidewall configurations. The barewall measurements will permit determination of fuselage noise reduction, when compared to the noise levels measured by the exterior microphones.

Cabin noise measurements with sidewall acoustic treatment will yield data on the noise reduction of the various treatment designs. The extent of the prop-fan noise field in the cabin and the ability of certain acoustic treatments to meet specific interior noise goals will be determined with the interior microphone system.

Fuselage shell vibration will be measured using accelerometers mounted on selected skin panels and stiffeners. These data, along with the data gathered on the external noise field from the fuselage flush mounted microphones, will permit characterization of the dynamic shell response, including amplitude, phase, skin velocity, wavespeed, and frequency response.

The inflight shell vibration data will be used with the barewall data from the interior microphones to check the ability of the structure to radiate sound energy to the interior. This property, known as radiation efficiency, is related to skin velocity, wavespeed in the structure, and wavespeed in the acoustic medium.

Additional tests that will be performed to identify the interior acoustic environment include reverberation time measurements of both the barewall and treated configurations. Reverberation times are needed in order to calculate values of cabin acoustic absorption. Calculation of cabin absorption allows conversion from noise reduction (a measured quantity) to transmission loss (an acoustic property of the material) for the fuselage structure and acoustic treatments. Assuming the inner surfaces of the various trim panel designs are not too different, one set of reverberation time measurements will be satisfactory for all trim panel configurations. In order to perform this test, multiple sound sources of pink noise will be placed in the cabin. The same set of interior microphones used for the other portions of the test program will act as receivers.

Comparison between the interior microphone measurements with and without acoustic treatment, in conjunction with the corresponding interior absorption measurements, will permit determination of the effectiveness of the various acoustic treatment designs that are tested.

There are several potentially important noise and vibration transmission paths from the prop-fan system to the aircraft interior. These include structure-borne transmission paths, which are not addressed in this study, however, this subject will be addressed in future work.

For the major portion of the testbed program, acoustic treatment designs will all be of the type known as "add-on"; i.e., not requiring modification of the primary fuselage structure. The only modifications that will be made to the basic structure will be for prevention of failure due to sonic fatigue. These necessary structural modifications will probably be accomplished by the addition of frame and longeron sections, an increase in skin gauge, or the addition of skin doublers in the vicinity of the prop plane.

Acoustic treatment designs to be included in the testbed program will be designed to be interchanged with or added to existing trim panel structure or blanket systems. Approaches that will be evaluated include increased trim panel mass and stiffness, use of honeycomb trim panels, increased skin-to-trim panel distance, damping added to skin panels, and introduction of limp mass into the blanket system. A later portion of the testbed program will involve the testing of an acoustic treatment design which requires modification of a section of the basic fuselage structure. The advanced treatment may consist of isogrid outer structure, modified standard structure, or possibly some other concept. The advanced treatment concept to be used on the testbed aircraft will be selected based on results of laboratory acoustic treatment development testing.

Determination of the effects of scaling model prop-fan near field noise data to large scale applications can be accomplished using data from the flying testbed program. It is especially desirable to scale the model prop-fan data to data acquired during flight because the effects of pressure, temperature, flow field, and forward speed will all be present in the flight data.

Acoustic objectives of this study that can be accomplished by a flying testbed program are as follows:

- Measurement of prop-fan near field and far field noise.

- Measurement of passenger cabin noise and fuselage vibration.

- Determination of the effectiveness of various types of acoustic treatment.

- Determination of the effects of scaling model prop-fan noise data to large scale applications at representative flight conditions.

The only acoustic objective of this study that cannot be accomplished in the flying testbed program is the measurement of prop-fan far field noise during takeoff and approach. In addition, measurement of far field noise during level flyovers (or descent) may not be allowed because of the previously discussed flight envelope altitude restriction.

Resolution by Wind Tunnel Testing:

Resolution of the acoustic objectives of this study by means of a wind tunnel test program is incomplete for some of the objectives and impossible for the others. At low Mach numbers measurement of near field noise generated by the prop-fan is possible in a facility such as the NASA Ames 40 x 80 foot wind tunnel. Maximum Mach number for this facility is approximately 0.45, which is far below a cruise condition Mach number of 0.80. Furthermore, the problems of ambient noise and tunnel wall acoustic reflections must be dealt with. The perimeter of the test section can be lined with sound absorbing material (this has been partially done in the past), which is expensive and relatively ineffective at the low blade passage frequency of the prop-fan. Overspeeding the prop-fan is not recommended because of problems in interpretation of the acoustic data, and also it is not compatible with other nonacoustic objectives of the test program. Acquisition of good near-field noise data inside a wind tunnel is uncertain at best, and it is not representative of cruise flight conditions.

The acquisition of far field noise data in a wind tunnel is even more uncertain than the acquisition of near field noise data. Far field noise measurements can be made in the 40 x 80 foot Ames wind tunnel for locations near the prop-fan disc plane. Depending on the location of the propeller test rig, it may be possible to place microphones up to 50 feet (15.2 m) away from the prop-fan blade tips, which is 5 prop-fan diameters away from a 10 foot (3.05 m) diameter prop-fan (the propeller far field is generally defined as beginning approximately 3 or 4 propeller diameters from the blade tips). However, high ambient noise levels and tunnel wall acoustic reflections may present severe, if not insurmountable, problems to acquisition of good acoustic data.

Far field noise may be measured under ground static conditions on an outdoor test rig such as the MDC QIAETsite engine test stand located in Quartsite, Arizona. This requires a separate installation and does not include mounting the prop-fan on a wing/fuselage section. Problems associated with the interpretation of static propeller noise data may prevent it from being useable without knowledge of proper data reduction techniques and adjustment factors. These static-to-flight adjustments have to be determined based on comparison of the static data with flight data (if they can be determined at all). Therefore, it is doubtful that the measurement of far field noise on a static test stand only will yield useable information.

Measurement of passenger cabin noise and vibration and the determination of the effectiveness of noise control treatment cannot be accomplished in a wind tunnel test program.

Assuming good near field noise data can be obtained on a 10 foot (3.05 m) diameter prop-fan in the 40 x 80 foot tunnel, effects of scaling model prop-fan data to large scale applications can be attempted. A problem that may be encountered in the determination of scaling factors is that the effect of forward speed may not be adequately represented in the 10 foot (3.05 m) diameter prop-fan data because of wind tunnel flow speed limitations. This factor leads to a great deal of uncertainty as to the validity of scale factors determined from a wind tunnel test program. Testing the 10 foot (3.05 m) diameter prop-fan in a smaller high-speed wind tunnel will not yield usable acoustic data because of the test section space limitations.

Acoustic objectives of this study that can be accomplished by a wind tunnel test program are, therefore, limited to the following:

- measurement of near field noise during low Mach number flow conditions (0.45 Mach);
- measurement of far field noise in the prop-fan disc plane during ground static conditions on an outdoor test rig (requires separate installation);
- determination of scaling effects on near field noise at low Mach number (0.45 Mach).

Acoustic objectives of this study that can not be accomplished by a wind tunnel test program include:

- o measurement of prop-fan near field noise at cruise Mach numbers;
- o determination of scaling effects on near field noise at cruise Mach numbers.
- o measurement of far field noise during formal flight;
- o measurement of passenger cabin noise and vibration;
- o determination of the effectiveness of acoustic treatment.

In view of the numerous acoustic limitations of a wind tunnel test program, it is highly recommended that the flying testbed program be undertaken. The flight testing of a large scale prop-fan installation will have a much greater ability to convince user airlines of the feasibility of operating this type of aircraft than will results of wind tunnel testing. In addition, the flight test program will provide very valuable information enabling building a more efficient and quiet aircraft.

INTEGRATED PROP-FAN/AIRCRAFT AERODYNAMICS ASPECTS

Table 1 lists the major aerodynamic objectives required to verify feasibility of the prop-fan installed on an aircraft. These are listed in order of priority for each method of test (flight and wind tunnel).

TABLE I

AERO OBJECTIVES TO VERIFY FEASIBILITY

ACCEPTANCE OF PROP-FAN

Objectives	Flight Test Large Scale	Wind Tunnel Test Large Scale Partial Span Model
Aircraft Characteristics (1)		
o Speed and fuel burned	X	--
o Flying qualities with power application		
o Stall characteristics (augmented thrust)		
o Downwash at tail with power on		
Propulsive Efficiency (1)	X	--
o Thurst minus drag		
o Nacelle/wing contouring		
o Propeller inflow velocity and angle		
Inlet/Engine Compatibility	--	X

(1) Prefer using subscale wind tunnel tests.

Aircraft Charcteristics

The most important characteristics of a prop-fan powered aircraft are speed, fuel burned, handling characteristics and flying qualities. Full span subscale wind tunnel tests at both high and low speed can be used to determine the preliminary aero characteristics and develop the details of the wing/nacelle contouring. The advantages of subscale wind tunnel testing are

- o proper engine/prop/wing size relationship;
- o accurate force measurements using a balance;
- o safe exploration of operational envelope;
- o lower cost and less time consuming geometry modifications required to optimize wing/nacelle shape.

There are several factors that subscale wind tunnel tests do not take into account. These are:

- o Reynolds number effects - low Reynolds numbers will result in unrealistic boundary layer displacement thickness modifying the effective aero external lines which will affect the drag and aero characteristics; thus premature boundary layer separations can also occur.

- o Engine inlet flow effects - the subscale tests will have propeller drive air supplied externally thus the engine inlet flow cannot be simulated. Therefore, inlet drag characteristics and interactions of the inlet with the propeller and wing cannot be measured.

- o Excrescence drag - the drag of surface roughness, cooling airflow, leakage, etc., can only be reasonably determined in large scale tests.

- o Drag due to lift - wind tunnel wall effects and low Reynolds numbers affect the induced drag.

The large scale flying testbed will closely simulate Rynolds' numbers experienced on the production aircraft. The flowing inlet will be present and, since it is flight hardware, the excrescence drag and induced drag will be properly simulated.

Propulsive Efficiency

The propulsive efficiency is defined as

$$\eta = \frac{(T-D)\ V_1}{550\ SHP}$$

(410.1 Kw)

where

T	-	prop-fan thrust - lb
D	-	drag of installation - lb
SHP	-	shaft horsepower
V	-	flight speed - ft/sec

The flight representative thrust minus drag (T-D) term can best be obtained using a flight test. Technical issues are nacelle/wing drag, propeller plane flow conditions for maximum thrust prop-fan design, and prop-fan efficiency. High Reynolds number flight hardware roughness, and the presence of the flowing inlet are required to obtain representative nacelle/wing drag and propeller thrust. This can only be done at large scale using the flying testbed.

Inlet Engine Compatibility

A test of the engine inlet and measurements to establish compatibility with the engine can be adequately performed using a partial wing span flight size model in the wind tunnel. The inflow angle and velocity errors resulting from a partial span wing (See Section VII for further discussion) are considered small enough to warrant a test of this type. Large scale is important to obtain the correct boundary layer characteristics inside the inlet duct.

INTEGRATION OF MECHANICAL CONTROLS WITH ENGINE AND PROP-FAN

The prime responsibility of selection of existing or modified controls for the engine and for the prop-fan, suitable for the testbed research aircraft, is considered that of the engine or prop-fan manufacturer in conjunction with the airframer. In the case of the prop-fan, the controls, pitchlock, and prop-fan pitch control mechanisms are designed by Hamilton Standard and are discussed herein in Task II. The engine and the associated gearbox design and/or modifications, unique to the turboshaft system, are the engine manufacturer's task. In the case of the gearbox, it is felt that realistic full scale sizes of 15,000 SHP (11,185 Kw) or under are within the present state of the art. The question of opposite rotation of the prop-fan is one which is quite feasible but will require modification of the gearbox. These are questions directed to the engine manufacturer. Discussion of this activity is included in Task II of this report.

INTEGRATION AND COMPATIBILITY OF PROP-FAN/INLET/ENGINE

The inlet design and its match to the prop-fan and engine under the required mission operating conditions is critical to the design of a "near-optimum" prop-fan aircraft. The scope of the testbed study as considered herein does not include the allowance for necessry work relative to the inlet design optimizations; this "optimization" work should be a necessary task included in any plans for follow-on testbed work. Mach number and pressure operating conditions ahead of the inlet but aft of the prop-fan are critical to the inlet design. These Mach numbers and pressures are not known at this time. Therefore, the inlet shown throughtout this study is a representation; before the testbed is flown, the inlet placement on the aircraft, the internal and the external inlet contours will have been properly substantiated. This work must be done by the airframer in close coordination with both engine and prop-fan manufacturer.

TASK 2

TASK II

CANDIDATE PROPELLER DRIVE SYSTEMS

ENGINE/GEARBOX

The turboprop testbed system study involves the assessment of feasibility of three separate engines. These engines are the General Electric T64 and the Detroit Diesel Allison T56 and T701. The role of the flight testbed on propulsion technology issues is summarized in Figure 3. Various prop-fan installation arrangements studied are shown in Figure 4.

ELEMENT	ISSUE	TESTBED ROLE
PROPELLER	STRUCTURAL INTEGRITY OF THIN-SWEPT BLADES	DEMONSTRATE STRUCTURAL INTEGRITY WITHOUT FLUTTER
GAS GENERATOR	NO ISSUE	PROVIDE DATA FOR DESIGN
GEARBOX	MAINTENANCE COSTS	PROVIDE DATA FOR DESIGN
CONTROLS	NO ISSUE	PROVIDE DATA FOR DESIGN
LOW SPOOL	OPTIMUM CONFIGURATION	DEVELOP DATA FOR DECISION
PROPULSION SYSTEM	COMMON VERSUS OPPOSITE ROTATION	DEVELOP DATA FOR DECISION
	OPTIMUM ARRANGEMENT	

80-GEN-27561A

FIGURE 3. ROLE OF FLIGHT TESTBED ON PROPULSION TECHNOLOGY ISSUES

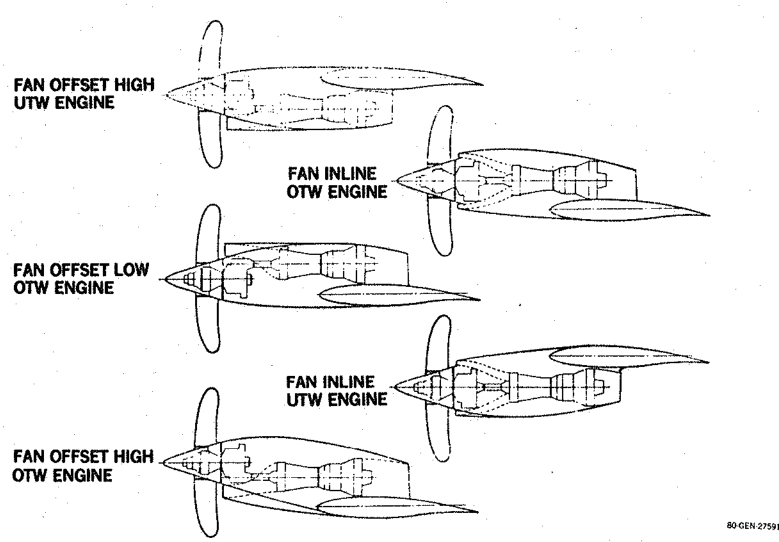

FIGURE 4. PROP-FAN INSTALLATION ARRANGEMENTS

The availability of suitable gearboxes is considered in evaluation of these engines for the DC-9 prop-fan testbed. In evaluating the engines for the DC-9 prop-fan testbed, it is determined that in each case the most appropriate gearbox orientation is pinion low. This pinion low mounting produces a favorable ground clearance and still provides for access to the engine, gearbox, and accessories in the engine compartment. In each case the engine is mounted forward and above the wing with the engine tailpipe routed over the wing and exhausting in the vicinity of the wing trailing edge.

In working out a control system which will meet the needs of the DC-9 prop-fan testbed aircraft, and considering the control systems used by the three candidate engines, it becomes clear that a suitable control system can be devised which is not drastically different than the basic system used for each engine. Therefore, any of the control systems of the three engines under consideration for the testbed application can be suitably modified to fill the needs of the test program as visualized.

Of the three engines under consideration for the prop-fan testbed program, one, the Allison T56, is a single shaft design and the other two, the General Electric T64 and the Allison T701, are dual shaft (free turbine) designs. In the single shaft design the specified tip speeds of 800, 700 and 600 ft/sec (244, 213, and 183 m/sec) can be met by varying turbine RPM. This drastically lowers the maximum available power loading, SHP/D^2, because the shaft horsepower available is a strong function of compressor and turbine RPM. For example, if the prop-fan is sized to produce a cruise SHP/D^2 of 37.5 (301 Kw/m^2) at a tip speed of 800 ft/sec (244 m/sec) at 100 percent rated engine RPM the maximum available SHP/D^2 drops to 17 (135 Kw/m^2) when the engine speed is reduced to produce a tip speed of 600 ft/sec (183 m/sec). As the requirements of the testbed capability specifies a SHP/D^2 of 26 (209 Kw/m^2) at 600 ft/sec (183 m/sec), it is obvious that either three separate gearboxes or one gearbox with several gear changes will be required to maintain the engine at or near its rated RPM. The alternative of sizing the prop-fan for the cruise disc loading of 26 (209 Kw/m^2) results in a smaller diameter test prop-fan.

In the case of the free turbine (dual shaft) design, this speed reduction does not have such a drastic effect. Assuming, as above that the prop-fan is sized for a cruise SHP/D^2 of 37.5 (301 Kw/m^2) at a tip speed of 800 ft/sec (244 m/sec) at 100 percent engine rated RPM, the maximum SHP/D^2 would drop to 32 (181 Kw/m^2) when the power turbine is slowed to produce a tip speed of 600 ft/sec (183 m/sec).

These results are summarized in the following table:

TABLE 2

COMPARISON OF SHP/D^2 CAPABILITIES

Percent of Rated Engine RPM	Prop-Fan Tip Speed Ft/Sec,(m/sec)	Maximum Available SHP/D^2,(Kw/m^2)			Design Point SHP/D^2,(Kw/m^2)
		Single Shaft	Dual Shaft		
		T56 8 Ft (2.44 m) Propeller	T701 10 Ft (3.05 m) Propeller	T64 7 Ft (2.13 m) Propeller	
100	800 (244)	37.5 (301)	37.5 (301)	37.5 (301)	37.5 (301)
87.5	700 (213)	22.5 (181)	34.6 (278)	34.4 (276)	
75	600 (183)	17.3 (139)	32.4 (260)	31.4 (252)	

If necessary, the dual shaft engines could be equipped with gearbox changes or changes to a gearbox which would permit testing over the full range of SHP/D^2 of 37.5, 30 and 26 (301, 241 and 209 Kw/m2) at the tip speeds of 800, 700 and 600 ft/sec (244, 213, 183 m/sec). The point which must be weighed is whether it is worth the additional expense of the gearbox revisions for the dual shaft engine to obtain the full range of SHP/D^2. In the case of the single shaft engine it is obvious that, with an 8 foot (2.44 m) prop, the requirements of the prop-fan testbed program cannot be met without the gearbox modifications.

Each engine type is available for use on the prop-fan testbed program. The Allison T56 and the T701 can be bailed from one of the military services. In the case of the T701, its possible use on an Army project may necessitate that the testbed program use the commercial version (570) of the T701. This possible substitution of the commercial version of the engine for the T701 entails little change in the testbed program. The General Electric T64 engine, although somewhat small for the prop-fan diameter desired on the testbed program, may be provided by General Electric.

Each engine/gearbox combination has a somewhat different mode of cooling the oil. Each engine/gearbox oil cooler arrangement has been investigated and each are amenable to adaption to the DC-9 prop-fan research vehicle. Hardware has been identified which will suffice for the prop-fan testbed program. For opposite rotation on the prop-fans, an idler gear must be added to the gearbox system.

Since it is envisioned that the testbed aircraft will not be taking off and climbing with the prop-fan engine in operation it will be necessary to provide for a means of in-flight starting.

A typical power management schedule for the testbed aircraft, from takeoff to test altitude and speed may be such as follows:

- o begin test with feathered propeller and windmilling engine;
- o start gas generator in flight at low Mach number and altitude;
- o move from feather to test RPM with pitch schedule for zero thrust;
- o increase pitch to test value.

The prop-fan blade angle must operate from a pitch setting for zero thrust, as a function of RPM and Mach number, through a setting of positive thrust to a setting for negative thrust. Safe operating conditions must be ensured throughout the above-mentioned procedures. Two conditions in particular are of concern, namely:

- o rapid RPM changes possible from changes in blade pitch of the prop-fan or gas generator power, (low pitch lock and negative torque system), and

- o high drag resulting from flat pitch (inflight pitch lock).

Effective safety procedures or devices useful during these operating conditions may be

- o overspeed governor
- o feathering
- o pitch lock
- o propeller brake

Figure 5 presents a comparison of a current 13.5 foot (4.12 m) turboprop installation with an advanced 8.0 foot (2.44 m) diameter prop-fan installation. The drive system is identical but the diameter of the prop-fan is 40 percent smaller than the conventional propeller installation.

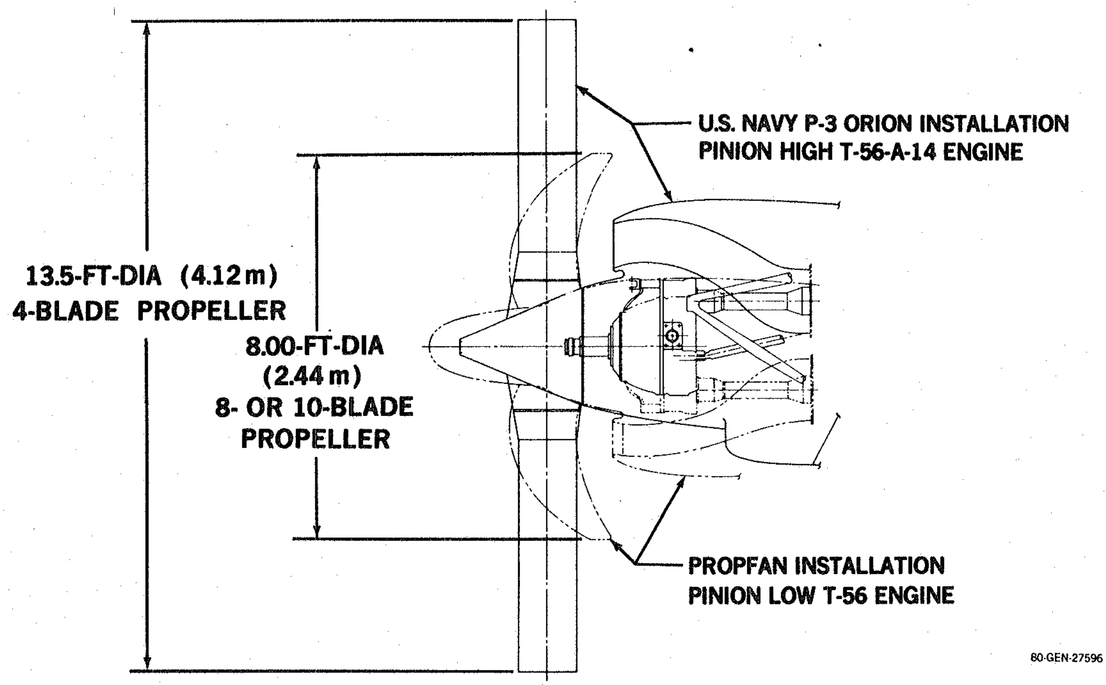

FIGURE 5. COMPARISON OF ADVANCED AND CURRENT INLET/PROPELLER RELATIONSHIP

Other critical considerations in the selection of a propulsion system include such as:

- o inline versus offset gearbox
- o common versus opposite rotation of the prop-fan, and
- o two spool versus three spool engine.
- o free turbine versus single shaft

The gearbox configuration and location not only affects the prop-fan ground clearance but is influential on the inlet design. In general, aerodynamically and acoustically the opposite rotation of wing-mounted prop-fans (both rotating upward and inboard to the fuselage) is favorable. However, considerations such as development and tooling costs, spares, noise, performance, and operational adaptability must be taken into account. Other considerations include an engine company study of the two-spool versus the three-spool engine, the use of a free turbine versus a fixed shaft design to meet off-design requirements, and the effect of these on engine size and weight.

Critical control systems required for satisfactory operation of the prop-fan/ engine propulsion system are

- prop-fan control
- engine control, and
- prop-fan/engine coordinator

Hamilton Standard recommends the modified 54H60 prop-fan control as expeditious and satisfactory for the testbed aircraft. Discussions of the necessary modifications, for the testbed or the existing 54H60 propeller control, is in subsequent paragraphs. In the case of the engine control for the testbed aircraft, Allison recommends a modification of the supervisory electronic control such as is on their T701 engine. The prop-fan/engine coordinator is a single lever which permits the pilot to readily control the two-engine testbed aircraft. This coordinator is considered a requirement for a two-engine testbed installation; it is still considered necessary to have individual engine throttle and propeller pitch levers.

<u>T701 Engine/Modified T56 Gearbox</u>

The T701 engine clearly has the advantage over the other two competing engines in that it has the highest shaft horsepower capability and is therefore capable of swinging a larger diameter prop-fan. It also has a free turbine. With the T701 cruise power available, a 9.5 foot (2.90 m) diameter prop-fan gives the maximum cruise SHP/D^2 of 37.5 (301 Kw/m^2) at M_{cruise} of 0.8 at 35,000 feet (10,668 M).

Detroit Diesel Allison (DDA) has proposed that the engine control system, which can fill the needs for the testbed aircraft, be a modification of the control system devised for controlling the T701 engine as originally planned for use in the Heavy Lift Helicopter (HLH) program. (In that HLH program, three T701 engines were connected to drive one helicopter rotor. All of the engines would have been connected to the rotor drive mechanism but each would be controlled utilizing torquemeter information so that each engine would take its proportionate share of the load.) Allison has considered the modifications necessary for the DC-9 testbed installation and an all electronic system is proposed.

Since this is a fly-by-wire control system, it is possible to vary the prop-fan tip speed by changing the prop-fan governor setting and thus controlling the output torque of the power turbine. This is much easier and less expensive than changing gearboxes or gears inside of gearboxes such as is required in the case of the fixed shaft T56 engine. If the prop-fan is sized to have a $SHP/D^2 = 37.5$ (301 Kw/m^2) at 100 percent engine RPM at 35,000 feet (10,668 m) and a Mach number of 0.80, the following maximum power loadings (SHP/D^2) are attainable with the T701 engine as a function of prop-fan tip speed at the same flight speed and attitude.

Prop-Fan Tip Speed Ft/Sec	(m/sec)	Maximum Cruise Power Loading SHP/D^2 Available	(Kw/m2)
800	(244)	37.5	(301)
700	(213)	34.6	(278)
600	(283)	32.4	(260)

The question of the use of a T56 gearbox with a T701 engine has been pursued with Allison. This combination produces a counterclockwise prop-fan rotation (looking forward) which permits the installation of the powerplant on the left wing with the tip of the prop-fan approaching the fuselage from below. Thereby the estimated benefits of lowered induced drag and prop-fan noise may be achieved. Allison indicates that the main power transmission gears of the T56 gearbox will take the larger T701 load while rotating in the opposite direction, but the accessory drive gear train rotation needs to be reversed by use of an idler gear so that the accessories which are driven by the gearbox will have the appropriate rotational direction (oil pressure and scavenge pumps). This change is required because the direction of rotation of the T701 is opposite to that of the T56.

If the T701 engine is used with the T56 gearbox, it will be necessary to restrict the engine power output to 5000 shaft horsepower (3,728 Kw) because of gearbox power limitations. Allison indicates that this power range can be used during testing on the DC-9 prop-fan testbed aircraft since these high power levels will not be required for extended time periods. Thus the amount of overall running time at high power accumulated on the gearbox will not be great. Allison also estimates that higher values of shaft power input may be possible if this level of operation is very limited in time and frequency. The shaft power capability of the T701 engine at altitudes above approximately 7,000 feet (2134 m) is less than the 5000 shaft horsepower (3728 Kw) capability of the T56 gearbox. Thus use of the T56 gearbox at altitude will not be horsepower limited and will not interfere with the collection of the specified cruise data.

The T701 engine lubricating oil system is integral with the engine, and the oil is cooled by the fuel that feeds the engine. The T56 gearbox has a separate lubricating oil system which will require provisions for cooling. The T701 engine has not been in either military or commercial service. The T64 and the T56 engine have established maintenance centers where these engines can receive required service; the T701 has none. However, for the testbed prop-fan, arrangements may possibly be made with Allison for maintenance of the T701. The T701 provides adequate horsepower for a 9.5 foot (2.90 m) diameter prop-fan, compared with an 8 foot (2.44 m) diameter prop-fan with the T56 or 7 foot (2.13 m) diameter prop-fan with the T64. The larger diameter prop-fan is a definite advantage for the testbed program.

T64 Engine/Gearbox

The T64 engine has a sea level static takeoff rating of 4,380 shaft horsepower (SHP) (3266 Kw) and a 35,000 foot (10,668 m) Mach 0.80 rating of 1,920 SHP (1431 Kw). Using the 35,000 foot (10,668 m) rating along with the maximum specified $SHP/D^2 = 37.5$ (301 Kw/m^2), the maximum prop diameter permissible is about 7 feet (2.13 m), assuming no losses. Of the three engines under consideration the T64 has the lowest available SHP and therefore must necessarily have the smallest diameter prop-fan. On the other hand, its free turbine design allows the engine to achieve the three prop-fan tip speeds required by the NASA Testbed Program without the need for three separate gearboxes or, alternatively, one gearbox with three sets of gears. General Electric states that the present T64 gearbox may be modified to a single configuration to provide the prop-fan speeds needed by the prop-fan testbed program, however, it is mandatory that assurance testing of these revised gearboxes be carried out before the gearbox is used on the prop-fan testbed program.

The T64 gearbox and engine have a common oil system. This feature can be preserved for the prop-fan testbed installation. The engine and gearbox oil are circulated through an airframe mounted and supplied oil-air heat exchanger. The T64 engine is used on the DeHavilland DHC-5 Buffalo, the Shin Meiwa Industries PS-1 ASW flying boat, US-1 SAR utility amphibian, and the Aeritalia G.222 military transport. General Electric would consider bailing an engine/gearbox combination to NASA for use on the testbed program if the engine/gearbox were to be subsequently refurbished to the "like-new" condition. The gearbox can be used in either the pinion high or pinion low configuration.

Because the T64 has a free turbine, it is possible to change the prop-fan tip speed by changing the free turbine speed without losing a large part of the available shaft horsepower. For example, at 35,000 feet (10,668 m) at Mach 0.8, the following maximum prop-fan power loading (SHP/D^2) will be available as a function of prop-fan tip speed.

Prop-Fan Tip Speed Ft/Sec (m/sec)		Maximum Cruise Power Loading SHP/D^2 Available, (Kw/m^2)	
		7 Ft (2.3 m) Prop-Fan	
800	(244)	37.5	(301)
700	(213)	34.4	(276)
600	(183)	31.4	(252)

However, the relatively small diameter prop-fan of 7 feet (2.13 m), which is compatible with the T64 engine, is quite a disadvantage to this testbed prop-fan program

T56 Engine/Gearbox

The T56 engine has the advantage of powering in-service U.S. military and commercial aircraft. It also has a long history of dependability; and its current usage in these U.S. aircraft shows it to be readily maintainable at a number of military installations. The gearbox and extension shaft also have a long history of service with the T56 engine in the C-130, P-3, C-2/E-2 and the Electra aircraft. The gearbox is used in both the pinion high and pinion low configurations. The means of maintaining these components are also relatively widespread in the U.S. and should not present serious problems in this respect if they are used in the prop-fan testbed program.

Relative to the T701, the low shaft horsepower available from the T56 engine (2,450 [557 Kw] at 35,000 feet [10,668 m] and Mach 0.80) results in a small prop-fan (about 8 foot [2.44 m] diameter assuming no losses) to achieve the specified maximum $SHP/D^2 = 37.5$ (301 Kw/m^2). Another disdvantage to the use of the T56 for the prop-fan testbed engine stems from the fact that it is a single spool engine in which engine power drops off rapidly as engine RPM is decreased. This is demonstrated in the following table:

Percent of Rated Engine RPM	Prop-Fan Tip Speed		Maximum Cruise Power Loading SHP/D^2 Available, (Kw/m^2)		Design Power Loading SHP/D^2, (Kw/m^2)	
	Ft/Sec, (m/sec)		8 Ft. (2.44 m) Diameter Prop-Fan			
100	800	(244)	37.5	(301)	37.5	(301)
87.5	700	(213)	22.5	(181)	30.0	(241)
75	600	(183)	17.3	(139)	26.0	(209

Allison has proposed that the testbed DC-9 use either three separate gearboxes or that one gearbox for the T56 installation be reworked with extra sets of gears to achieve the three prop-fan tip speeds specified in the NASA Statement of Work.

It is currently envisioned that the control system for the T56 engine and the prop-fan on the testbed DC-9 will be the same as that which is in use on the C-130. Here an air/oil heat exchanger is used to cool the engine and gearbox lubricating oil. The feasibility of using the existing C-130 overall control system will receive further study if the T56 engine is one of the two carried until the end of this prop-fan testbed systems study.

If a T56 engine/gearbox combination is used on the DC-9 testbed aircraft without change, a clockwise rotation of the prop-fan (looking forward) will result. For upward rotation of the propeller toward the fuselage, which is desired to minimize induced drag and cabin noise, installation on the right-hand wing is required. However, depending on the spanwise location of the engine, the access to the existing DC-9 fueling/defueling control panel may have to be modified.

LARGE SCALE PROP-FAN/PROP-FAN CONTROLS

As part of Task II, Hamilton Standard suggestions of candidate prop-fan control schemes for both solid shaft and free turbine engines are discussed herein.

In selecting a gas turbine drive for the large scale prop-fan, various aspects concerning the operation of the propeller control must be considered. Consequently, a study is undertaken to evaluate the feasibility of modifying an existing propeller control so that it can be adapted to a testbed drive system. The use of an all-new control is also considered. The various prop-fan configurations are based on a full scale SR-3 prop-fan configuration with 8 and 10 blades in 8 and 10 foot (2.44 and 3.05 m) diameters. At 800 feet per second (243 m/sec) tip speed, the corresponding prop-fan speeds are 1,910 and 1,528 RPM(200 and 160 radians/sec), respectively.

54H60 Propeller Control and Modifications Required

The prop-fan control selected is used with the 54H60 propeller on the Lockheed C-130 and P3 aircraft. It readily fits a 60 spline shaft such as is used on the T56 engine, and it also is the control with the highest pumping capacity. In addition to being compatible with the T56, a solid shaft engine, it is also compatible with the T701, a free turbine engine. However, with this T701 installation, additional modification to the 54H60 control will be required in order to obtain speed variability. The 54H60 control presently operates at 1020 RPM (107 radians/sec) and is designed for pump flows of about 60 quarts per minute(.946 l/sec). A whirl test was performed on a modified 54H60 control and propeller hub to determine the feasibility of operating at 1,800 RPM (188 radians/sec)(i.e., 80 percent above the design speed) and the capability of withstanding the loads imposed at this speed. It was concluded from those tests that the 54H60 control, with minor modifications, can be operated at 1,800 RPM (188 radians/sec) if adequate cooling is provided to the transfer bearing. The minor modifications include removal of items such as flyweights, low pitch stop levers, the main pump drive gear, speed bias and linkage; blockage of the standby valve, increase in the transfer bearing clearance, and insertion of a new beta feedback cam.

In order to use the 54H60 control for an 8 to 10 foot (244 to 3.05 m) prop-fan, several modifications are required. The proposed modifications are based on a preliminary study and are as follows:

- o replace standby pump drive gear;
- o increase transfer bearing clearance;
- o remove speed bias hardware;
- o redesign governor flyweights and speeder spring;
- o remove differential gear train for beta control;
- o remove or revise brushblock;
- o add external heat exchanger;

Hamilton Standard has concluded that the use of this control with modifications such as above is feasible for the prop-fan sizes mentioned. Table 2 shows estimated pitch change rates which are achievable.

TABLE 3

PROP-FAN PITCH CHANGE RATES

Diameter Ft (m)	No. Blades	PITCH CHANGE RATE Deg/Sec (radians/sec)	
		Main Pump Only	Main & Mod Standby Pumps
8 (2.44)	8	9.05 (.158)	14.5 (.253)
8 (2.44)	10	16.31 (.285)	26.2 (.457)
10 (3.05)	8	3.92 (.068)	7.8 (.136)
10 (3.05)	10	7.11 (.124)	14.2 (.248)

It can be seen that the 8 foot (2.44) diameter prop-fan with 10 blades has the highest pitch change rate of about 26 degrees per second (.457 radians/sec). This can be compared to a typical propeller blade angle pitch change rate of 20-30 deg./sec (.349-.524 radians/sec). The other configurations have pitch change rates well below rates considered acceptable for rapid transients. It is assumed that the standby pump can be resized to provide a 60 qpm (.946 l/sec) flow rate when operating with the existing main pump.

The existing standby pump cannot be utilized because the pump flows would approach 90 qpm (1.350 l/sec) and the resulting line velocities would be excessive, thus generating high friction and excessive heat. This also leads to foaming and cavitation. It is recommended that the tranfer bearing clearance be increased for cooling, and that an external heat exchanger be added. For the 60 qpm (.946 l/sec) flow rate, it is recommended that a ΔP of approximately 1,000 psi (70.32 kg/cm^2) across the piston be used instead of the 600-700 psi (42.2 - 49.2 kg/cm^2) which is typical on the existing control. This control is capable of operating at 1,000 psi (7032 kg/cm^2) since its high pressure relief setting is about 1,250 psi (87.90 kg/cm^2).

New Propeller Control

Since it has been determined that the 54H60 control with modifications is feasible for a prop-fan research vehicle in the size studied, the discussion of new controls shall be limited. First, consider why a new control might be desired. The reasons which seem plausible are:

- pitch change rates must be higher for transient tests, or
- further, more detailed, study of the 54H60 control reveals an inadequacy not currently known.

Of course, a new control can be built for the testbed, but it will look very much like a 54H60 control since it must be compatible with the T56 gearbox and its 60 spline shaft. Allison advises that there is no access through the gearbox shaft centerline or planet carrier. Therefore, a shaft mount transfer bearing is required just as presently used. A new control will require an increased flow and/or pressure system to yield higher pitch change rates. Pitch control systems such as used on the Q-Fan Demonstrator, or QCSEE, required access through the gearbox and are not applicable here. An alternate to a new shaft mounted control is a rotating pumping system where the control is mounted out on the rotating hardware. This arrangement has been previously accomplished experimentally, but does represent an all new control development program which is considered unnecessary and offers no advantage.

Free Turbine vs. Single Shaft Engine Controls

The last area investigated deals with control functions and the application of the control to a free turbine (dual shaft) versus single shaft engine. As mentioned earlier, the 54H60 control is compatible with either type of engine; it is already coupled with the T56 engine in the P-3 and C-130 aircraft. A single shaft engine requires a negative torque sensing (NTS) system which prevents gearbox decoupling during airstart but accomplishes decoupling during excessive windmilling RPM to prevent high drag. This feature may not be necessary for the prop-fan hardware if the gearbox decoupler is eliminated and an alternate means of protection against excessive drag is instituted. This latter decision may be influenced by the aircraft type being considered and the impact of high drags. The NTS is the only prop-fan control hardware difference between the two engine types.

Pitchlock

It is recommended that the prop-fan rotating hardware incorporate a pitchlock device of some type which will prevent overspeeds in case of inadvertent blade angle decreases. Use of the 54H60 type pitchlock is not feasible in the prop-fan type actuator, nor is the prop-fan pitchlock concept compatible with the 54H60 type control. The easiest way to handle the problem is with a ground adjustable stop which is set before each test to a blade angle just below the anticipated test angle. This type of stop would require numerous landings and resettings. So while it is easily accomplished, it is not convenient for testing. An alternate to this is an electrically operated in-flight adjustable stop. Such a stop is certainly feasible but requires careful use so that the stop location is always known; otherwise its protection is useless. The last and most sophisticated method of achieving pitchlock protection is an in-place type lock similar to the concept used on the commuter propellers and which is planned for the production prop-fan. This concept requires incorporation of a beta control loop in the prop-fan itself. In order to provide a rotary signal to operate the pitchlock, a hydraulic motor circuit is required to introduce the requested blade angle. A modification to the 54H60 control is required to provide a pressure to the hydraulic motor located in the hub.

Normal Governing, Feathering and Reversing

Other operations performed by the prop-fan control include normal governing, feathering and reversing. Normal governing can be handled easily by a modified or a new control for either engine type. The type of engine has no bearing. Feathering will probably be slow (low pitch change rate); and feathering out of an overspeed where higher pitch change loads exist may not be possible with a modified 54H60 control. However, with adequate overspeed protection, this may be of little consequence. Unfeathering should not be a problem with the modified control. Use of an auxiliary electrically operated hydraulic pump already on the 54H60 control will be used. Reverse operation with the 54H60 control is in a beta mode where the pilot controls the blade angle and the engine coordinator maintains a scheduled fuel flow to keep the RPM constant. This control does not govern or control RPM in reverse as it does in normal flight operations. The reversing scheme for the prop-fan will probably be fixed blade angle reversing. While this may impact solid shaft engine operation, it is not a problem for the control. The blade angle will simply be directed to decrease pitch until a stop is reached. For the multi-bladed prop-fan, a beta control system has not been designed. Such a system can probably be designed and developed if necessary; however, this system does not seem to be warranted for this propulsion testbed program.

While a modified 54H60 control, or even a new control, appears to be able to handle the desired propfan functions discussed above, there are some points concerning engine type to discuss further. Maintaining constant RPM during operations such as reverse will be difficult with a fixed blade angle. Speed control will have to be maintained by the T56 engine overspeed governor or controller; this requires further study. There is no problem of this type on a free turbine engine. Another area of concern on a solid shaft engine is with the use of a fixed pitchlock stop. For example, assume the pitchlock stop is set just below the test blade angle and then power is retarded. The blade angle will stop at the setting and the RPM will then want to decrease with further power reduction.

Assuming the test is being accomplished at 0.8 Mach and the desired test blade angle is 57 degrees (.995 radians), a 60 percent decrease in shaft horsepower requires a 4 degree (.070 radians) decrease in blade angle to maintain 100 percent RPM. If a stop is set just a few degrees below the desired test angle, then a power retardation may result in a RPM dropoff. Again, this requires further study. Lastly, the airstart procedure may be more difficult on a solid shaft engine if the pitchlock stop is set such that 100 percent speed cannot be achieved at flight idle power setting. Further coordination with the engine manufacturer is required.

Prop-Fan Control Capability

In summary, a modified propeller control is feasible for a prop-fan of 8-10 feet (2.44-3.05 m) diameter. For each size, ten blade configurations have higher pitch change rates (Table 3). In three of the four configurations considered, transient capability is quite poor. In only one case is it reasonable. All propeller control features can be provided with a modified control. There are potential problems with either a modified or new control associated with using a single shaft engine. However, none of these problems are insurmountable.

Prop-Fan/Nacelle Compatibility

Hamilton Standard will coordinate with Douglas in evaluating candidate drive systems for compatibility and suitability in meeting technical objectives. The nacelle size and shape are critical aerodynamically, since it has been determined analytically as well as in prior Hamilton Standard model design work that nacelle shape has a significant influence on inboard blade flow characteristics. In order to maintain adequate choke margins in the root area, the question of nacelle size and contour for a prop-fan rotor size of a specific engine is also important.

Utilization of an 8 foot (2.44 m) diameter prop-fan on the T56 engine and a 10 foot (3.05 m) diameter prop-fan on the T701 engine indicates that excessive blockage exists with the existing P-3 nacelle. Modification of the P-3 nacelle for use with the T56 engine requires either engine inlet resizing or a smaller overall nacelle diameter. Utilization of a new nacelle on the T701 engine results in blockage characteristics compatible with the prop-fan concept.

Figures 6 and 7 indicate that the velocity ratio V/Vo, is low and the efficiency, η, is high for the P-3 application when compared to the SR-3 prop-fan configuration. The results for the P-3 were based on measurements in a model test at M_N = .75, and extrapolated to M_N = 0.8. The SR-3 results are theoretical, and utilize a nacelle exhibiting a diameter which is 35 percent of the diameter of the prop-fan, with no inlet.

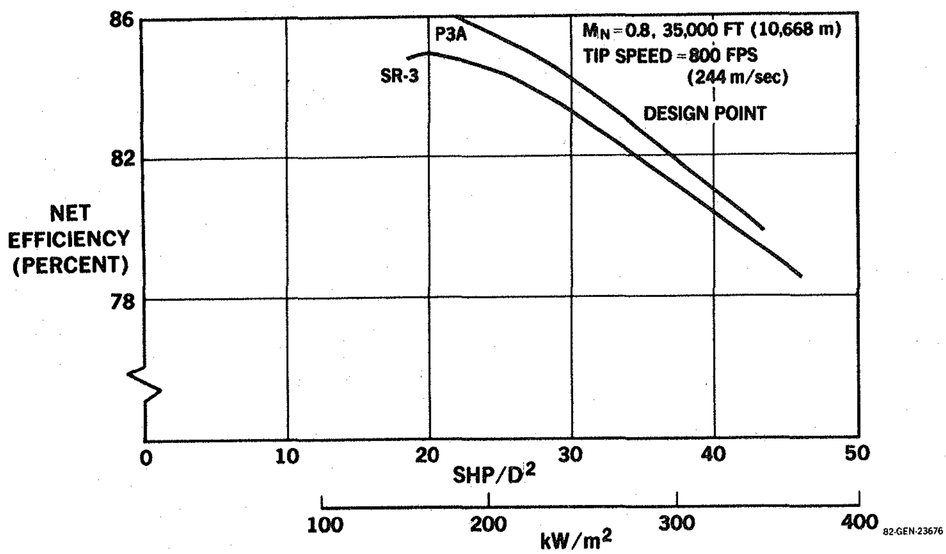

FIGURE 6. PERFORMANCE COMPARISON BETWEEN P3A VERTICAL RAKE AND SR-3 PROP-FAN WITH 35-PERCENT BODY

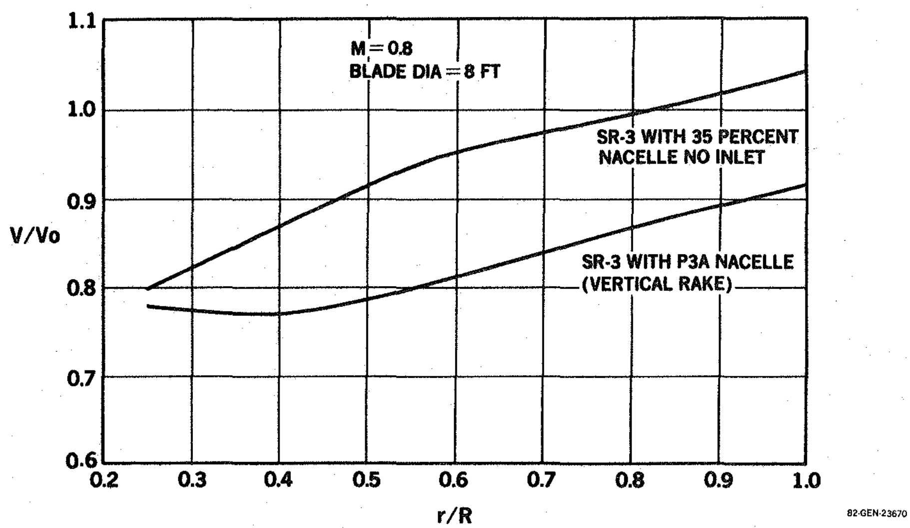

FIGURE 7. BLOCKAGE COMPARISON BETWEEN P&A VERTICAL RAKE AND SR-3 PROP-FAN WITH 35-PERCENT

COCKPIT CONTROLS AND INSTRUMENTATION

A review of the necessary constraints on available space and cockpit procedure has been made to assess the suitability of the DC-9 as a platform for the prop-fan testbed. This examination shows that the most suitable cockpit arrangement is to mount the prop-fan drive system controls on the cockpit center console, in the vicinity of the existing controls for the Pratt and Whitney JT8D, the basic propulsors for the DC-9. This arrangement will permit control of the prop-fan drive system by either the pilot or the co-pilot. In the event of an emergency one flight crew member can assume control of the DC-9 while the other member controls the prop-fan drive system. There is adequate space for these controls near the center console. The modifications to the aircraft are not extensive and will not compromise the basic safety of the DC-9 testbed aircraft.

The cockpit instrumentation will be held to a minimum yet will be adequate to allow for starting, stopping, accelerating, decelerating and otherwise controlling the prop-fan drive system. It will also allow for monitoring and setting the key prop-fan drive system operating parameters. This instrumentation will be installed closer to the co-pilot's station but will be clearly readable by the pilot. These control/ instrumentation arrangements are simplified on the DC-9 because there is such good cross-cockpit visibility and proximity which is a product of the basic two-man cockpit design of the aircraft. The cockpit instrumentation which has been preliminarily identified are concerned with the following:

- gas generator speed
- power turbine speed (or prop-fan RPM)
- power turbine inlet temperature
- engine fuel flow rate
- gearbox output torque
- gearbox and engine oil pressure and temperature.

DRIVE SYSTEM SUMMARY

The foregoing discussion of the characteristics of candidate drive systems for the prop-fan testbed aircraft is summarized in the following figures:

ITEM	ENGINE		
	T701-AD-700	T56-A-15	T64-P4D
GEARBOX	MODIFIED T 56	MODIFIED T 56	MODIFIED T644
AVAILABLE SHAFT HORSEPOWER (kW) SEA LEVEL 35,000 FT (10,668 m)	 8050 (6002) 3625 (2703)	 4591 (3423) 2450 (1826)	 4380 (3266) 1920 (1431)
GEARBOX POWER LIMIT – HP (kW)	5000 CONT (3728) 6000 SHORT (4474) TIME	5000 CONT (4728) 6000 SHORT (4474) TIME	3400 CONT (2535)
POWER-TURBINE TYPE	FREE	FIXED SHAFT	FREE
WEIGHT WITH GEARBOX – LB (kg)	1810 (821)	1843 (836)	1188 (539)
LENGTH – IN. (cm)	124.55 (316.36)	145.98 (370.78)	110.20 (279.91)
WIDTH – IN. (cm)	30.55 (77.6)	27.25 (69.2)	29.49 (74.9)
HEIGHT – IN. (cm)	46.12 (117.2)	41.38 (105.1)	45.92 (116.6)
AVAILABILITY	5 IN STORAGE BAIL FROM ARMY	IN PRODUCTION	IN PRODUCTION

FIGURE 8. CANDIDATE PROPELLER DRIVE SYSTEMS

80-GEN-27549B

		SHP/D^2, (kW/m^2)			
TIP SPEED — FT PER SECOND (m/SEC)	RPM (PERCENT)	MIN REQ	T701 10-FT (3.05 m) PROP	T56 8-FT (2.43 m) PROP	T64 7-FT (2.13 m) PROP
800 (244)	100	37.5 (301)	37.5 (301)	37.5 (301)	37.5 (301)
700 (213)	87.5	30 (241)	34.6 (278)	22.5 (181)	34.4 (276)
600 (183)	75	26 (209)	32.4 (260)	17.3 (139)	31.4 (252)

80-GEN-27560A

FIGURE 9. ESTIMATED CAPABILITY WITH FIXED RATIO GEARBOX (PROPELLER SIZED AT 800 FEET PER SECOND (344 m/SEC) AT CRUISE)

	ENGINE		
ITEM	T701-AD-700	T56-A-15	T64-P4D
MAXIMUM CRUISE SIZED PROPELLER DIAMETER — FT, (m)	9.5 (2.90)	8.1 (2.57)	7.2 (2.19)
NACELLE BLOCKAGE*	ACCEPTABLE 0.34	HIGH 0.40	UNACCEPTABLE 0.43
GEAR REDUCTION RATIO	7.5:1	7.2:1 8:1 9:1	6.2:1

* HAMILTON STANDARD CRITERIA (0.35)
(NACELLE BLOCKAGE IS A CRITERIA ESTABLISHED BY HAMILTON STANDARD AND IS THE RATIO OF THE NACALLE EQUIVALENT DIAMETER TO THE PROP-FAN DIAMETER.)

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FIGURE 10. PROPELLER DRIVE SYSTEM COMPARISON SUMMARY

As can be seen from Figures 8,9 and 10, the results of the evaluation of the three available prop-fan drive systems clearly indicates that the Allison T701 with the T56 modified gearbox is the best choice for the testbed aircraft. The primary influencing factors in this decision are that

- the T701 engine develops enough power at cruise to drive a 9.5 foot (2.90 m) diameter prop-fan at design speed and power loading; and
- the free turbine design provides the engine with the flexibility required to accommodate tip speed and power loading variations over a wide operating range without entailing gear changes.

Also, the Allison T701 engine has a commercial counterpart (570) which may be used as a back-up engine in case the T701 becomes unavailable for use on the testbed aircraft. This 570 commercial engine differs from the T701 by only a minor weight increase (15 percent) due to material substitution of some steel for titanium in the engine case.

The verification of the structural and performance integrity of the installed prop-fan is vital to the prop-fan aircraft testbed program. As stated previously, the aim of the prop-fan testbed program is to provide verification in an expeditious manner by utilizing an appropriate existing engine/gearbox hardware and an existing large scale prop-fan design. It is necessary that the diameter of the prop-fan used for the testbed be as nearly full-scale as possible so that scaling does not become a problem. Thus the T701 with its capability to swing a 9.5 foot (2.90 m) diameter prop-fan is particularly desirable.

The second choice for the drive system is the T56 engine and gearbox. This drive system is sufficient to power an 8 foot (2.74 m) diameter prop-fan, but its single shaft design requires physical changes of gears in order to meet the minimum required combination of tip speeds and power loadings. Additional hardware, flight test time, and cost are likely to be incurred with this drive system.

The T64 is the least suitable of the three engines for the testbed program because it can only accommodate a 7 foot (2.13 m) diameter prop-fan. Considering that the testbed program is primarily aimed at investigating prop-fan structural integrity for a representative blade construction, it is desirable that the prop-fan be substantially larger than 7 foot (2.13 m) diameter.

The recommended prop-fan drive system, including the selection rationale, is summarized as follows:

SELECTION	REASON
Free Turbine	Precludes need for multiple gear ratios and enables independent setting of RPM and pitch
T701	Enables largest diameter propeller tests
Modified T56 Gearbox	Low cost

TASK III

CANDIDATE TESTBED AIRCRAFT

INITIAL SURVEY OF POSSIBLE CANDIDATES

In work prior to the initiation of the study, Douglas Advanced Engineering had surveyed several candidate aircraft which might be suitable as a prop-fan testbed vehicle. The rationale and requirements for selection of a suitable aircraft are as follows:

- testbed must be capable of M_{cruise} of approximately 0.8 at 30,000 feet (9,144 m) or greater;
- test engine/prop-fan is not part of the primary propulsion system;
- testbed configuration locates the prop-fan in the proper flow environment compatible with an actual prop-fan aircraft arrangement;
- prop-fan testbed configuration must be representative of the airframe interaction to be expected in an actual aircraft design;
- testbed must be capable of providing verification of existing wind tunnel results and analytical prediction methods;
- minimum modification to the basic aircraft for the testbed is desired, therefore, the cost of the program is minimized;
- basic design data for the testbed aircraft (such as structure, aerodynamic, and fabrication) must be readily available to the Contractor;
- it is desirable that the testbed aircraft be directly oriented toward a commercial aircraft configuration;
- testbed should be compatible with a first flight of approximately 1985;
- configuration should be compatible with an approximate 10 foot (3.05 m) diameter prop-fan for the testbed; the large diameter prop-fan is a definite plus and is a desirable feature from Hamilton Standard's point of view of having the testbed prop-fan sufficiently large that extrapolation of results to the full scale case is reasonable and valid.

During the pre-study, survey the aircraft other than those of Douglas which were reviewed on a preliminary basis as potential testbed candidates included Lockheed Electra and C-141, Boeing B-52, 707, 727, 737, and C-14. These aircraft were judged inappropriate on such bases as:

- Incapable of sustained M_{cruise} of approximately 0.8 at 30,000 feet (9,144 m);
- ground clearance problems;
- inability to provide proper flow environmental conditions and thus to provide a basis for verification of existing analytical results.

Those Douglas aircraft surveyed as a possible testbed were the DC-8, C-15, A-3D, and DC-9. Possible DC-8 arrangements, utilizing the existing structural hard points, incurred low prop-fan ground clearances. Also, the DC-8 is a more expensive aircraft for a testbed than the DC-9.

The C-15 does not have a passenger interior, is not a Mach Number = 0.8 cruise aircraft, and does not provide a particularly good location of the prop-fan relative to the wing. The A-3D aircraft is capable of the M = 0.8 cruise and adequate ground clearance for a prop-fan installation of at least 13 feet (3.96 m) diameter; however, the A-3D aircraft is a military design and consequently the fuselage is not characteristic of a passenger fuselage from the pressurization aspects, the interior acoustic treatment, or from the geometric cross section.

On the basis of the above mentioned criteria, the DC-9 with a wing-mounted prop-fan installation is judged a most appropriate testbed aircraft.

ADVANTAGES OF DC-9 AIRCRAFT AS SELECTED PROP-FAN TESTBED

The DC-9 aircraft, either a -10 or a -30 version, is a particularly sound selection for the NASA prop-fan testbed research aircraft for the following reasons:

- The DC-9 is an available aircraft which is low cost from both the acquisition and operational points of view.

- The DC-9 is a Douglas aircraft, and consequently full knowledge of the aircraft detail design, flight characteristics, and modification know-how are immediately available to Douglas and to the NASA advanced turboprop project.

- The aircraft is a commercial vehicle which enjoys an enviable reputation among the airline users.

- Either the -10 or -30 aircraft may be made available for the testbed; however, the -10 is more cost-effective from the initial investment point of view. Either aircraft is efficient costwise as a testbed. The immediate availability of the specific aircraft may be dependent on the timing of the program requirement for acquisition of an airplane.

- No modification of the aircraft is required except for the wing installation of the prop-fan/engine/nacelle. The wing is not expected to require beef-up; with the possible exception of the low speed/low altitude one-engine-out condition, the existing empennage is adequate to meet the aircraft stability and control requirements for an asymmetical testbed arrangement with one prop-fan nacelle mounted on the wing.

- The prop-fan may be properly placed on the wing to acquire the practical prop-fan interactions which may be encountered in an actual design - such as nacelle/wing, prop-fan/wing, and prop-fan/fuselage interferences.

- The desired 10 foot (3.05 m) diameter prop-fan installation on the testbed is feasible.

- The general arrangement of the testbed prop-fan/ engine/nacelle/wing structural integration is representative of an actual aircraft design where maintainability is also of key importance.

- The results of a survey performed by Douglas throughout representative airlines, as part of the NASA DC-9 Prop-fan Feasibility Study Contract NAS2-10178 (Reference 3), were unanimous that the sizing of the first prop-fan commercial aircraft should have approximately 155 to 165 passengers and M_{cruise} = .80. This is typical of a Douglas DC-9-80. In all cases, the airlines' estimate the first actual commercial prop-fan aircraft should be in the size and performance category of the DC-9-30 to the DC-9-80. Therefore, the use of the DC-9-10 or -30 as the testbed aircraft affords compatibility with a practical and likely commercial aircraft.

- The DC-9-10 (or -30) prop-fan testbed aircraft is particularly amenable to measurement of prop-fan acoustic effects during flight. Valid measurement of the prop-fan near and far field acoustic characteristics can be obtained from flight test on the DC-9-10 testbed. Operation of the two basic JT8D turbofan engines, in conjunction with the prop-fan propulsion system, does not result in bacckground noise levels which will interfere with the prop-fan noise spectra for near and far field noise measurement.

  During cruise flight, the first several harmonics of the prop-fan noise signal will be easily discernible above the boundary layer noise and turbofan engine noise at near field locations of interest on the fuselage. This conclusion results from knowledge of the external acoustic environment of the production turbofan DC-9-10, gained from flight test data, compared with prop-fan noise estimates. On the production turbofan DC-9-10, engine noise impinging on the fuselage only becomes apparent in the rearmost portion of the passenger cabin, which is aft of the area of interest on the testbed aircraft.

Prop-fan far field noise can be measured using the testbed aircraft during static and taxi testing with no problems involving contamination of the prop-fan noise signal by extraneous noise sources, such as turbofan engine noise. If far field noise measurements during flyovers become a possibility, the problem of signal contamination can be avoided by limiting the turbofan thrust (this may suggest the measurements be made while the aircraft is in a slight descent).

DC-9 TESTBED CONFIGURATIONS

Three views of the prop-fan testbed DC-9-10 aircraft are presented in Figures 11 and 12 for the Allison turboshaft T701 and the T56 single engine installations. Three-views of the two prop-fan nacelle installations on the DC-9-10 and DC-9-30 are shown in Figures 13 and 14. The principle differences between the DC-9-30 and the DC-9-10 from the standpoint of a prop-fan testbed are as noted:

- o The DC-9-30 aircraft has leading edge slats which the -10 does not. In the case of the -30, these leading edge slats, or portions thereof, must be deactivated due to the prop-fan nacelle installation.

- o In order to prevent excessively high sideslip angles, the rudder deflection of the DC-9-30 has been limited to 17.2 degrees (.300 radians) at flap deflections of 15 degrees (.262 radians) and above and to 13.2 degrees (.230 radians) for flap deflections below 15 degrees (.262 radians). The rudder deflection on the DC-9-10 is not limited but utilizes the full 30 degree (.524 radians) deflection; therefore, it is probable that the -10 testbed may be safely operated at lower speeds at low altitudes than the -30 testbed.

The existing empennage of the DC-9-10 is capable of providing adequate stability and control for the asymmetric prop-fan testbed configuration; however, a small restriction on the low speed/low altitude envelope may need to be imposed in deference to the one-engine-out condition.

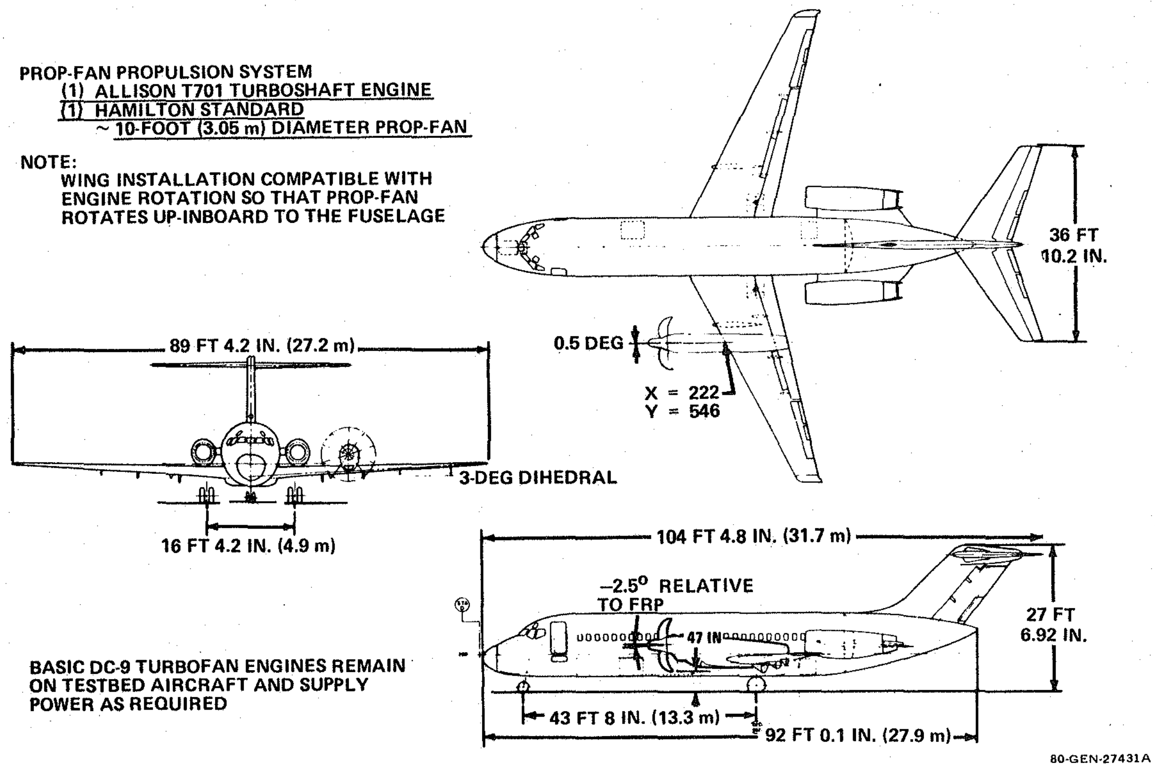

FIGURE 11. DC-9-10 PROP-FAN TESTBED – ONE ALLISON T701 ENGINE

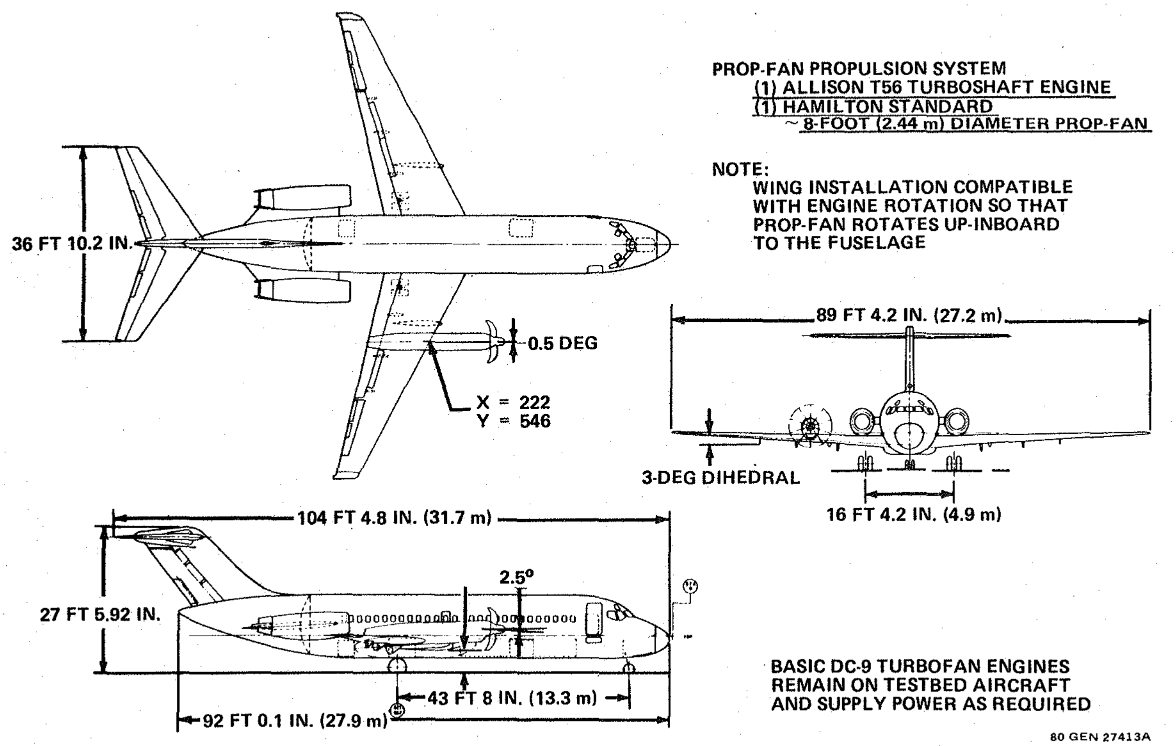

FIGURE 12. DC-9-10 PROP-FAN TESTBED – ONE ALLISON T56 ENGINE

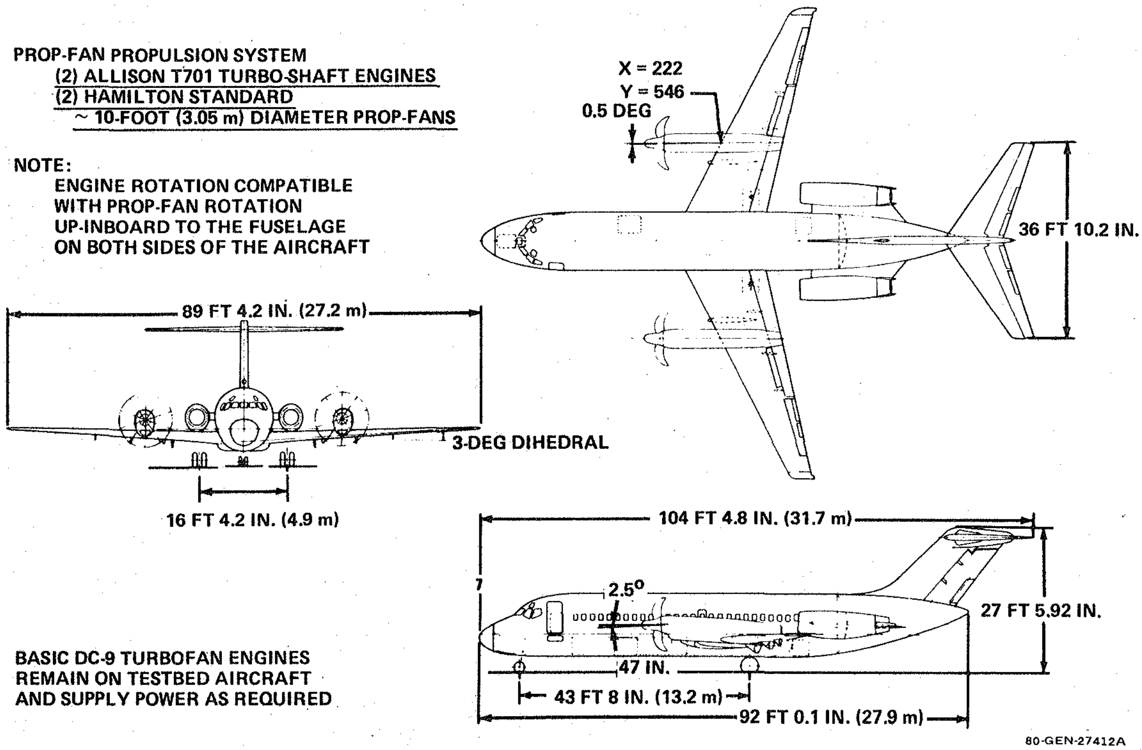

FIGURE 13. DC-9-10 PROP-FAN TESTBED – TWO ALLISON T701 ENGINES

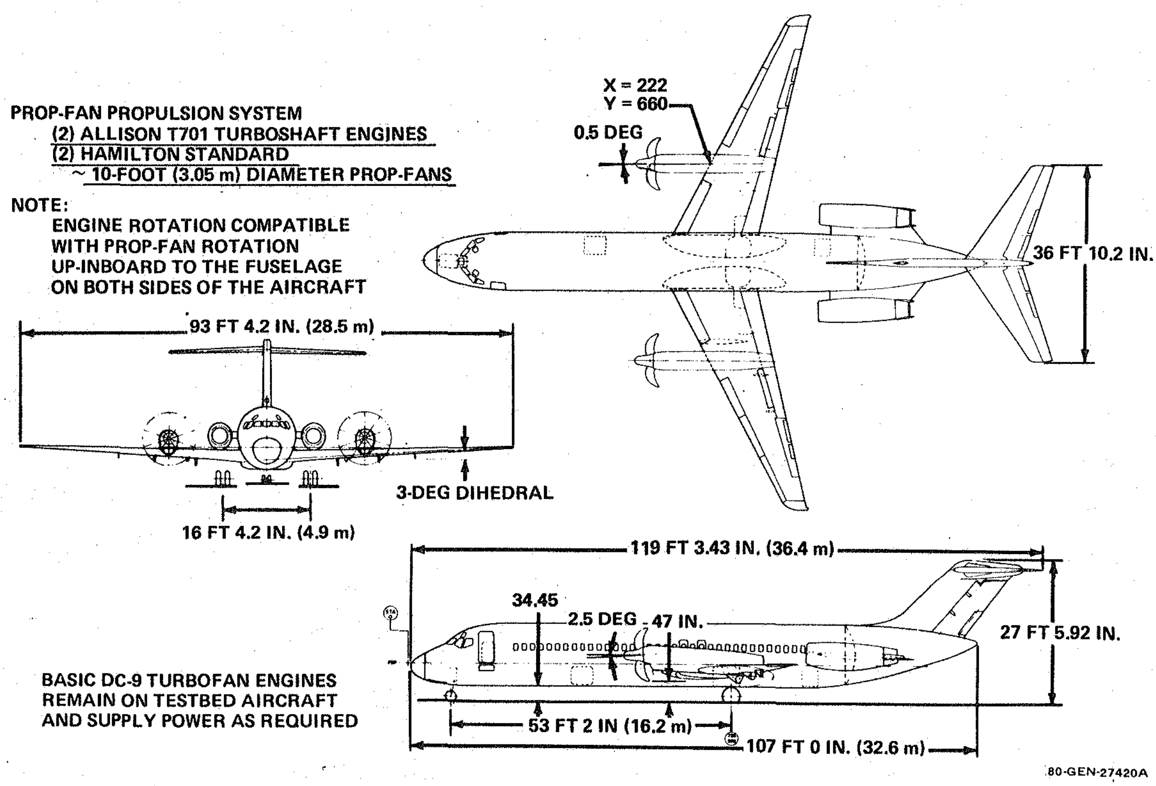

FIGURE 14. DC-9-30 PROP-FAN TESTBED – TWO ALLISON T701 ENGINES

Stability and Control Characteristics

Figure 15 presents the flight envelope showing stability and control for the DC-9-10 prop-fan testbed.

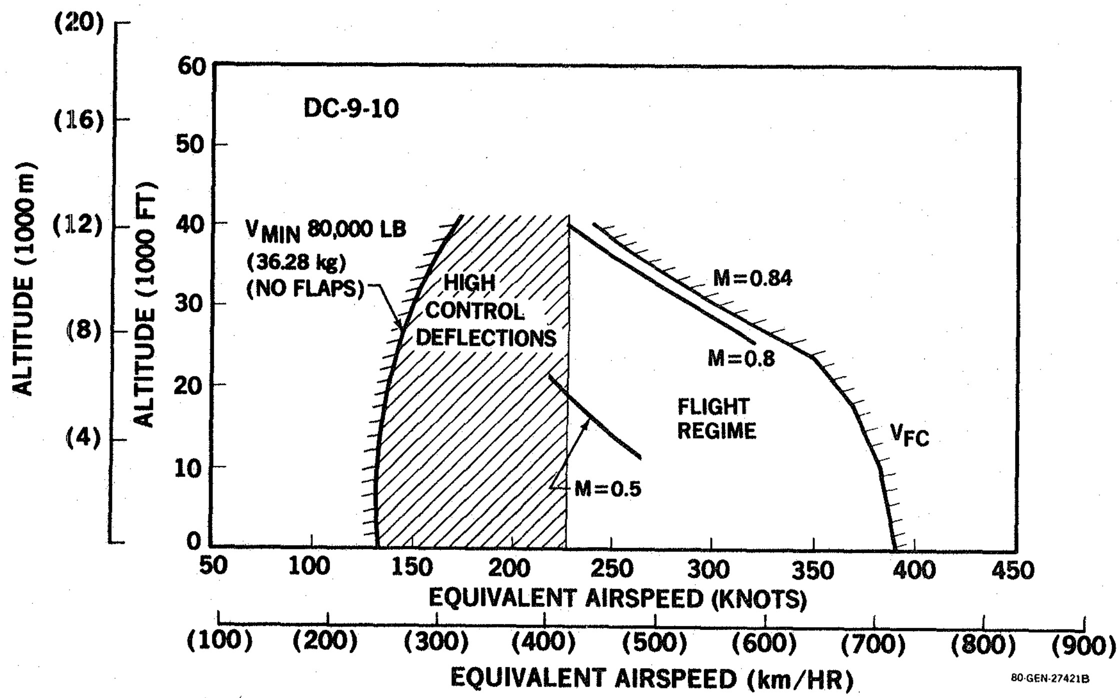

FIGURE 15. PROP-FAN TESTBED FLIGHT ENVELOPE FOR STABILITY AND CONTROL

The high-speed limits are set at M_{FC}/V_{FC} and are the same as for the basic DC-9-10. Minimum lg flight speed at 80,000 pounds (36,281 kg) gross weight with flaps up is shown as a lower limit. The gray area illustrates a region where asymmetric thrust due to operation of the turboprop will require increasingly large sideslip, bank angle, and control deflections as speed decreases. This region must be investigated in flight test to demonstrate controllability. The desired M = 0.5 and 0.8 flight conditions are indicated in the foregoing figure. The flight envelope of the DC-9-30 is nearly the same as for the DC-10-10 with only small differences in the high-speed limits. The low speed limits and flight test requirements remain the same.

Because of the destabilizing effect of the prop-fan system on static longitudinal stability, the aft center-of-gravity limit must be moved forward 3 percent MAC (mean aerodynamic chord), from the basic DC-9, for each prop-fan system used. The resulting aft center-of-gravity limits for the Series 10 and 30 DC-9 with one and two prop-fan systems will be as shown below.

DC-9 Series	No. of Prop-fans	Aft C.G. Limit %MAC
10	1	36
10	2	33
30	1	31.7
30	2	28.7

For the single prop-fan configuration the lateral control performance in the low-speed flight conditions will be degraded to some extent by virtue of the loss of flap area under the prop-fan nacelle. This flap asymmetry requires the use of 15 percent of available lateral control authority to balance when 20-degree (.349 radians) flaps are used and 20 percent of available authority when 50 degree (.873 radians) flaps are used. No lateral control is required to offset the prop-fan system weight in the single-engine configuration because ballast is added in the opposite wing to balance the airplane laterally. Thus the nuisance roll response to pitch maneuvers with laterally unbalanced airplanes is avoided. The added rolling moments of inertia created by the prop-fan system and ballast weights will cause a reduction in roll control response or roll acceleration by as much as 33 percent. Another 17 percent reduction in roll response will occur as a result of the lost spoiler area. These losses are significant in the low-speed condition and may require overspeeds of approximately 20 percent if lateral control responsiveness is to be retained.

Although the two-engine configuration does not have the asymmetry problems of the single-engine configuration, it too has the degraded roll performance resulting from increased rolling inertia and reduced spoiler area. A similar overspeed consideration is recommended for this configuration.

Stall speeds and resulting reference speeds are expected to increase with the unpowered prop-fans. Confirmation of these speeds must be obtained from wind-tunnel test data and established for the flight evaluation program. These new higher reference speeds are likely to accommodate, to some extent, the overspeeds suggested for roll performance.

A stick pusher system is designed and currently available for the DC-9. This system could be employed on the testbed airplane, if necessary, to avoid stalls by programming the pusher trigger point to whatever angle of attack schedule is appropriate.

DC-9 Prop-fan Performance Estimates

Cruise Capability

The limiting operating points assumed for the performance spectrum are those shown in Figure 16 and are representative of the boundaries of the DC-9 prop-fan aircraft flight envelope.

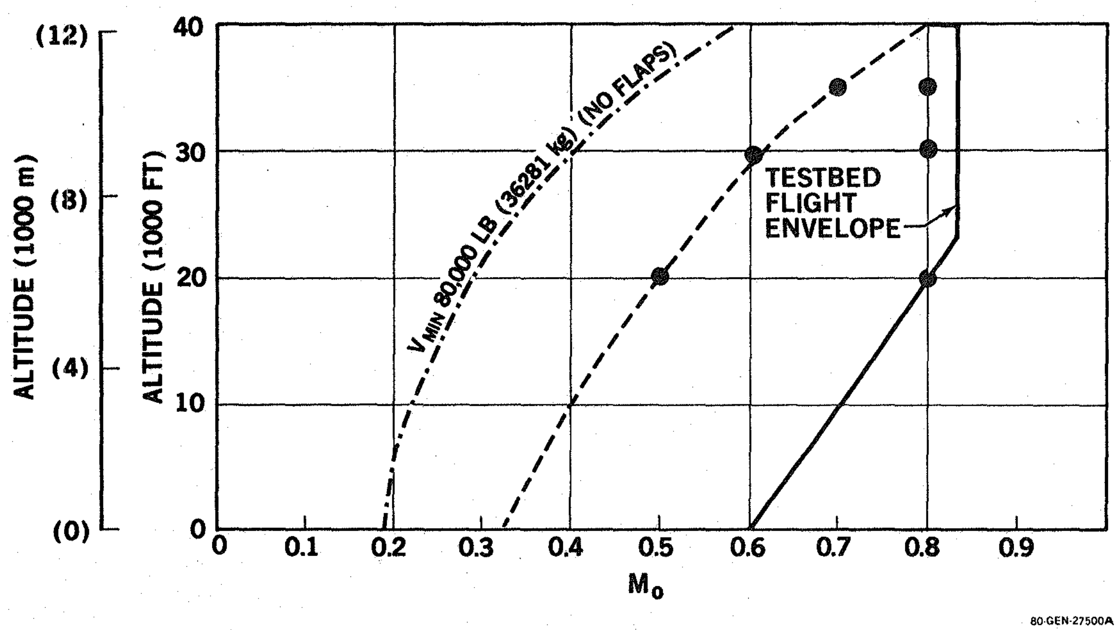

FIGURE 16. DC-9 AIRCRAFT OPERATING POINTS ASSUMED IN PERFORMANCE SPECTRUM

In order to determine the capability of the DC-9-10 prop-fan aircraft to provide adequate cruise time as a prop-fan testbed, estimates of cruise times which will be available to test prop-fan engine combinations are determined for the assumed six Mach number/altitude test conditions. The variables considered are

2 airplanes:	DC-9-10 or DC-9-30
2 test engine/prop-fan combinations:	Allison 701 engine with 9.5 foot (2.90 m) diameter prop-fan Allison T56 engine with 8.1 foot (2.46 m) diameter prop-fan
2 configurations:	One or two prop-fan engines per aircraft

Ground rules assumed for the test mission are the following:

- taxi, takeoff and approach allowances included;
- 250 KCAS (463 Km/hr) climb speed to 10,000 feet (3,048 m), and 290 KCAS (537 Km/hr) to the cruise condition unless limited by the cruise Mach number;
- 250 KCAS (463 Km/hr) descent speed;
- reserve fuel determined by a climb at 250 KCAS (463 Km/hr) to 15,000 feet (4,572 m); altitude, hold for 0.5 hour, and descent at 250 KCAS (463 Km/hr);
- prop-fan engines assumed to be windmilling, except during cruise, when full power is used;
- jet engines throttled back as required to maintain level flight;
- if the configuration had excess thrust after the main engines are throttled back to idle, this excess is assumed to be dissipated with extra drag to maintain constant speed.

Using the six operating points noted in Figure 16, estimates of the cruise time available as a function of aircraft takeoff gross weight, manufacturer's empty weight, fuel load, and flight conditions are presented in carpet plot form. The available cruise time for the DC-9-10 prop-fan testbed aircraft with either one or with two prop-fan T701 propulsion systems are cited as examples in Figures 17 and 18. As can be seen from these plots, the DC-9-10 prop-fan testbed provides more than adequate cruise test time for performing the required flight tests.

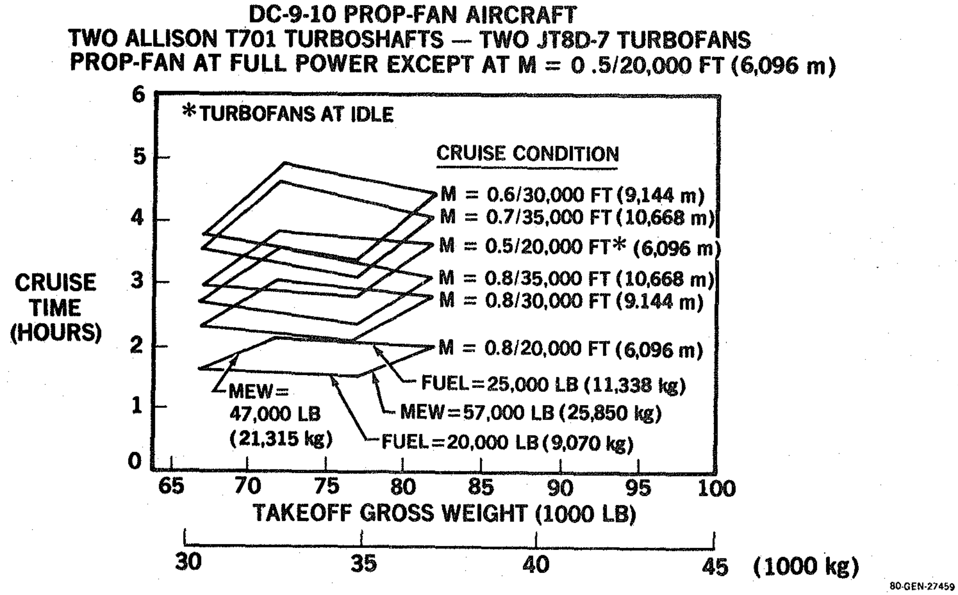

FIGURE 17. TESTBED AVAILABLE CRUISE TIME (TWO ALLISON T701 ENGINES)

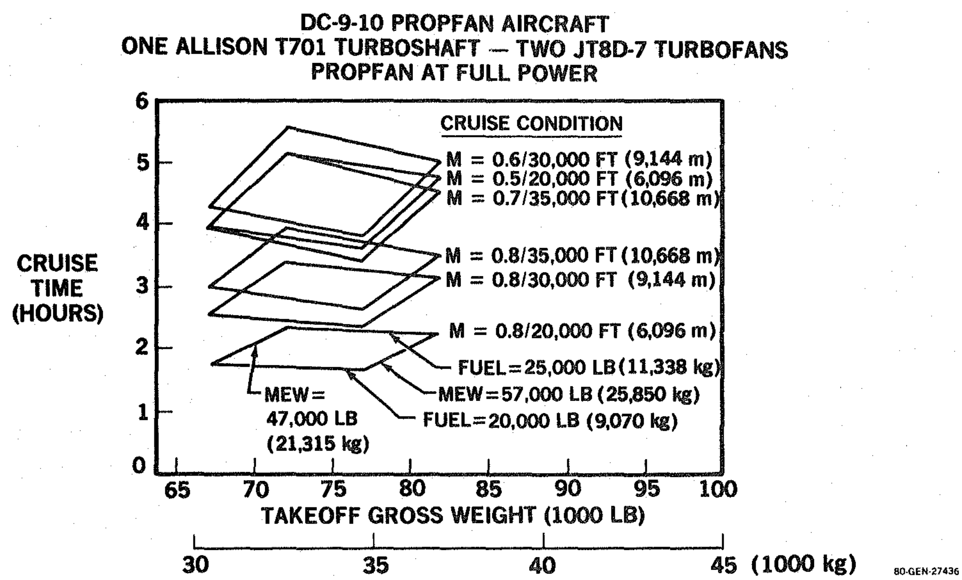

FIGURE 18. TESTBED AVAILABLE CRUISE TIME (ONE ALLISON T701 ENGINE)

The variation of cruise time with manufacturer's empty weight (MEW) and fuel carried is practically linear for the range of interest. Therefore, for each airplane, only two MEW's and two levels of fuel carried are used in the calculations. The DC-9-10 with 75 seats has a MEW of 46,742 pounds (21,198 kg) with fuel capacity of 24,743 pounds (11,221 kg); therefore, MEW's of 47,000 and 57,000 pounds (21,315 and 25,850 kg), and fuel levels of 20,000 and 25,000 pounds (9,070 and 11,338 kg) should cover the ranges of interest for a testbed aircraft.

Slightly lower cruise times are shown for the case of the two prop-fan/engine test configuration (Figure 17) than for the one prop-fan/engine configuration (Figure 18). The reason is twofold:

- the net sfc of the engine/prop-fan combination is greater than the sfc of the jet engine in the normal operating range, and
- with two prop-fans, the jet engines drop to lower thrust settings, thus increasing sfc.

As a matter of interest, the cruise times available for the DC-9-30 aircraft are shown in Figures 17A and 18A as a direct comparison to the previously discussed cruise performance of the DC-9-10 (Figures 17 and 18). The DC-9-30 with 105 seats has a MEW of 53,812 pounds (24,405 kg) and a fuel capacity of 24,649 pounds (11,179 kg), or, when a supplementary tank is added, the MEW and fuel capacity are 54,485 and 28,535 pounds (24,710 and 12,941 kg), respectively. Thus, MEW's of 55,000 and 65,000 pounds (24,943 and 29,478 kg) and fuel levels of 20,000 and 25,000 pounds (9,070 and 11,338 kg) are selected as representative for the DC-9-30 aircraft.

As is to be noted from the foregoing Figures 17, 17A, 18 and 18A, the variation in the testbed available cruise time, as a function of testbed aircraft, is relatively small. This small variation in cruise time is also to be noted when comparing the T701 and T56 turboshaft engine installations in the DC-9-10. Summary of these small differences in cruise time performance is presented in the following tabulation:

AIRCRAFT	PROP-FAN INSTALLATION	Δ TIME - HOURS (Referred to DC-9-10, Figure 18)
DC-9-30	(1) T701	- .2 to -.35
DC-9-30	(2) T701	- .25 to -.35
DC-9-10	(1) T56	- .52

DC-9-30 PROP-FAN AIRCRAFT
TWO ALLISON T701 TURBOSHAFT — TWO JT8D-7 TURBOFANS
PROP-FANS AT FULL POWER

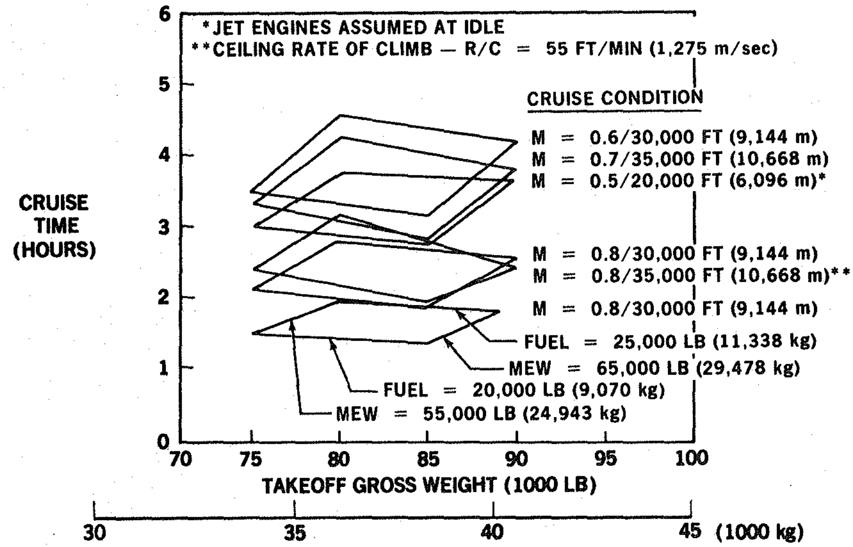

FIGURE 17a. TESTBED AVAILABLE CRUISE TIME (TWO ALLISON T701 ENGINES)

DC-9-30 PROP-FAN AIRCRAFT
ONE ALLISON T701 TURBOSHAFT — TWO JT8D-7 TURBOFANS
PROP-FAN AT FULL POWER

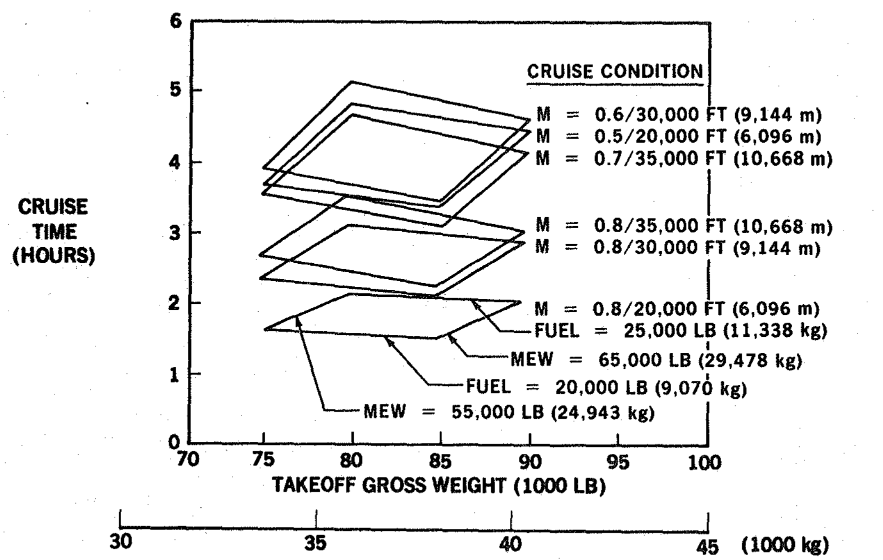

FIGURE 18a. TESTBED AVAILABLE CRUISE TIME (ONE ALLISON T701 ENGINE)

Percent Turbofan Engine Power Required

For the cruise flight conditions noted in Figure 16, the percents of power required from the turbofan engines for the prop-fan testbed cruise are noted in Figures 19, 20 and 21.

As can be seen from the negative turbofan thrust requirements, noted in Figures 19, 20 and 21, the two engine prop-fan T701 engine configurations are capable of flight on the prop-fan propulsion system alone, but at reduced gross weights and lower cruise conditions. These flight limits for sustained cruise flights, assuming power from the two T701 prop-fan propulsion units only, are summarized in Figure 22, in terms of altitude/Mach number variation. Performance shown in Figure 22 assumes the basic JT8D turbofan engines are operating at just enough thrust to overcome their own drag. Threrefore the performance shown does truly represent prop-fan-only capability. The prop-fan T56 installation on the DC-9-10 is not capable of cruise flight without the augmentation from the turbofan engines.

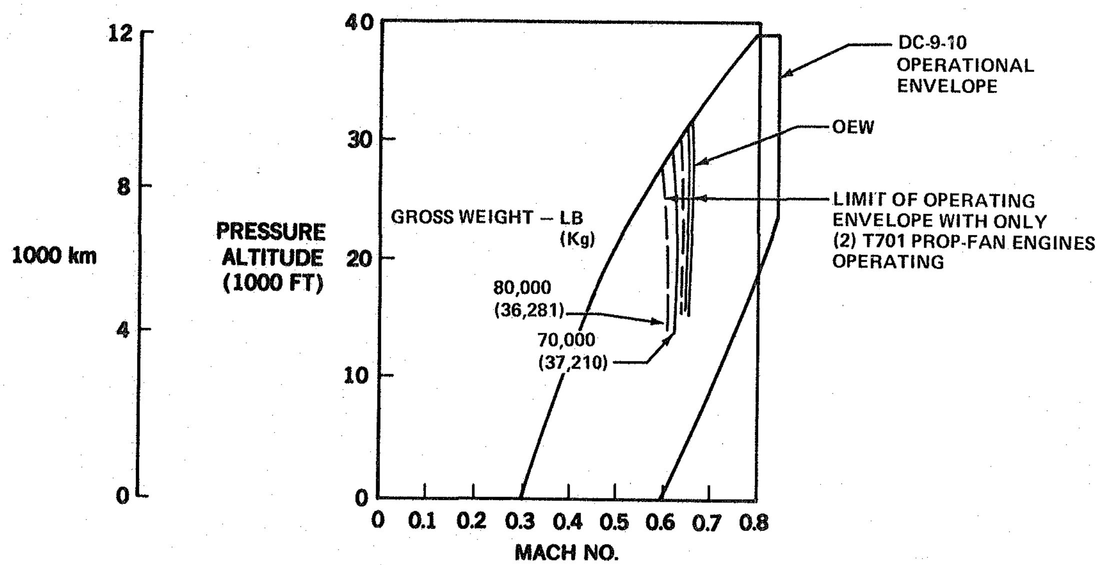

FIGURE 22. DC-9-10 PROP-FAN TESTBED FLIGHT LIMITS IN CRUISE – TWO ALLISON T701 PROP-FANS ONLY

ALLISON T701 ENGINE

ASSUMPTIONS: PROP-FAN AT FULL POWER
OEW = 57,000 LB (25,850 kg)
FUEL LOAD = 25,000 LB (11,338 kg)

FLIGHT CONDITION	ONE PROP-FAN	TWO PROP-FANS
ALTITUDE FT (m)/M_{CRUISE}	PERCENT POWER REQUIRED ON TURBOFAN	
35,000 (10,668 m)/0.8M	69 → 56	45 → 32
35,000 (10,668 m)/0.7	53 → 40	26 → 13
30,000 (9,144 m)/0.8	63 → 56	38 → 31
30,000 (9,144 m)/0.6	35 → 24	+5 → −6
20,000 (6,096 m)/0.8	66 → 63	40 → 37
20,000 (6,096 m)/0.5	15 → 7	−19 → −27

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FIGURE 19. PERCENT POWER REQUIRED FROM TURBOFAN ENGINES DURING DC-9-10 PROP-FAN CRUISE

ALLISON T56 ENGINE

ASSUMPTIONS: PROP-FAN AT FULL POWER
OEW = 57,000 LB (25,850 kg)
FUEL LOAD = 25,000 LB (11,338 kg)

FLIGHT CONDITION	ONE PROP-FAN	TWO PROP-FANS
ALTITUDE FT (m)/M_{CRUISE}	PERCENT POWER REQUIRED ON TURBOFAN	
35,000 (10,668 m)/0.8M	80 → 67	65 → 52
35,000 (10,668 m)/0.7	64 → 50	46 → 32
30,000 (9,144 m)/0.8	74 → 66	58 → 51
30,000 (9,144 m)/0.6	46 → 35	27 → 16
20,000 (6,096 m)/0.8	79 → 76	64 → 61
20,000 (6,096 m)/0.5	28 → 20	7 → −1

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FIGURE 20. PERCENT POWER REQUIRED FROM TURBOFAN ENGINES DURING DC-9-10 PROP-FAN CRUISE

ALLISON T701 ENGINE

ASSUMPTIONS: PROP-FAN AT FULL POWER
OEW = 65,000 LB (29,478 kg)
FUEL LOAD = 25,000 LB (11,338 kg)

FLIGHT CONDITION	ONE PROP-FAN	TWO PROP-FANS
ALTITUDE FT (m)/M_{CRUISE}	PERCENT POWER REQUIRED ON TURBOFAN	
35,000 (10,668 m)/0.8 M	71 → 62	46 → 39
35,000 (10,668 m)/0.7	53 → 45	26 → 18
30,000 (9,144 m)/0.8	66 → 61	42 → 37
30,000 (9,144 m)/0.6	36 → 28	+6 → −1
20,000 (6,096 m)/0.8	72 → 70	46 → 44
20,000 (6,096 m)/0.5	16 → 10	−20 → −28

80-GEN-27417A

FIGURE 21. PERCENT POWER REQUIRED FROM TURBOFAN ENGINES DURING DC-9-30 PROP-FAN CRUISE

TASK 4

TASK IV

TESTBED SYSTEM EVALUATION AND RECOMMENDATIONS

The study work delineated by the NASA Contract NAS3-22347 as Tasks II, III, IV and V are all interdependent. Before an engine prop-fan selection can be made on a sound basis, the comparative feasibility when installed on a testbed aircraft must be considered. Therefore, the work of the four tasks have been necessarily done concurrently. Although the work of integration of the propulsion system into the aircraft is performed throughout Tasks II, III, and IV, the discussion of conceptual overall testbed integration is included in Task V.

TESTBED PROGRAM RECOMMENDATIONS

As a result of the work performed in Tasks I through IV, Douglas recommends the following for the continued prop-fan testbed program:

- DC-9-10 base aircraft.
- T701 turboshaft engine.
- T56 gearbox modified as per Allison recommendation.
- Hamilton Standard 9.5 foot (2.90 m) diameter/10 blade prop-fan.
- 54H60 modified prop-fan control as per Hamilton Standard recommendation.
- Flight testing of two configurations; namely, the one wing mounted prop-fan nacelle and the two wing mounted prop-fan nacelles. In the case of the two prop-fan nacelle configuration, the prop-fans shall both rotate up and inboard toward the fuselage.
- Subscale wind tunnel testing, if required, for component design verification only.
- Large scale flight testing of the DC-9-10 testbed.

Brief discussions follow of the testbed systems evaluation from the aerodynamics, propulsion, and acoustics points of view.

ENGINE SELECTION

As per the initial contract statement of work, the two initially selected engines, T701 and T56, are to be carried in parallel throughout the study. However, in the early part of the study, the T701 engine appeared more desirable; consequently from that point on, the study effort is directed to a two prop-fan installation utilizing T701 engines. The relative merits of the T701 versus the T56 engine for the prop-fan testbed are as noted:

T701 Merits versus T56

- Flexibility of free turbine design versus single-shaft
- Variation in power loading, SHP/D^2, or tip speed efficiently accomplished without gearbox rework or change
- Larger diameter prop-fan tested - 9.5 foot (2.90) versus 8.1 foot (2.46 m)
- Less nacelle blockage to prop-fan - 34 percent versus 40 percent
- DC-9 capable of flight on two T701 prop-fans alone
- T701 engine not considered a major risk

A detailed cost comparison between the T701 and the T56 engine is not included in this study since this side-by-side comparison data are not available from the engine manufacturer. At this point, the generation of the side-by-side cost comparison was not considered warranted. Because of its long production life, the T56 is probably less costly than the T701 engine; however, this cost factor is not considered adequate to outweigh the other advantages of the T701 as the selected testbed engine.

AERODYNAMIC TESTBED PROGRAM

Subscale wind tunnel and flight tests are both required to satisfy the primary aerodynamic objective of verifying, at flight conditions, the installed propulsive efficiency of the prop-fan propulsion system. These tests are shown in the block diagram, Figure 23. Each of these tests is discussed in more detail in subsequent paragraphs.

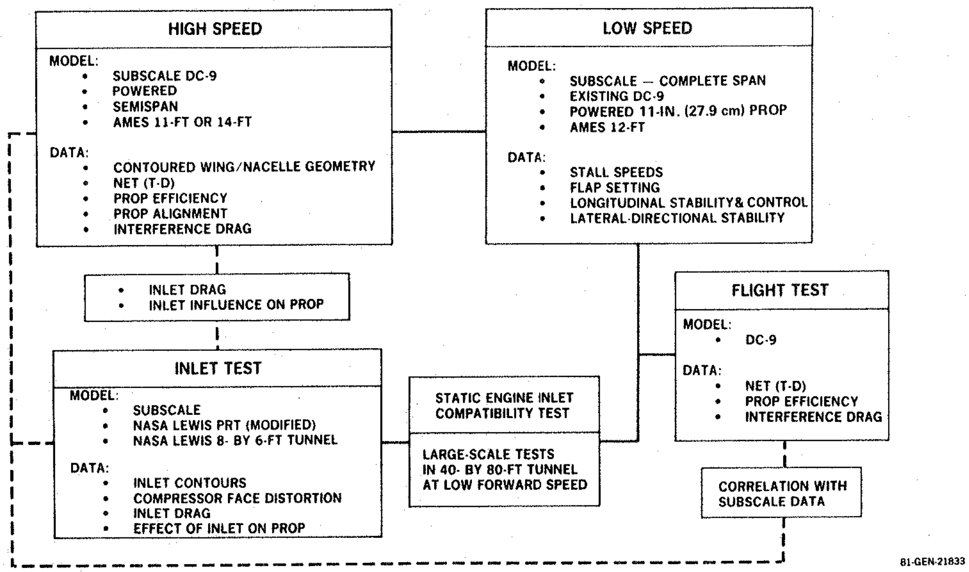
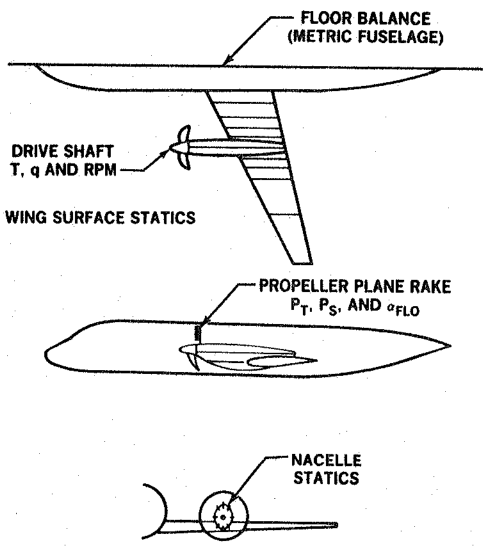


FIGURE 23. AERODYNAMIC TEST PLAN SUMMARY

High Speed Wind Tunnel Test

A high speed wind tunnel test program will be conducted using a DC-9 semi-span wing model with an air driven turbine to power the propeller. It may be possible to use the air turbine already developed at NASA Ames. The objective is to develop an efficient nacelle/wing geometry that has low drag in the presence of the propeller flow. Any transonic tunnel can be used, preferably the NASA Ames 14-foot facility. A sketch of a typical installation is shown in Figure 24.



DATA TO BE OBTAINED

- AIRCRAFT LIFT, DRAG, AND PITCHING MOMENTS
- DRAG OF DIFFERENT NACELLE/WING CONTOURED SHAPES
- PROPELLER LOADS AT DIFFERENT ORIENTATIONS RELATIVE TO AIRCRAFT
- INSTALLED PROPULSION EFFICIENCY (NET THRUST MINUS DRAG)
- PROPELLER EFFICIENCY IN PRESENCE OF AIRCRAFT
- PROPELLER INFLOW VELOCITIES AND ANGLES FOR PROPELLER DESIGN
- AIRCRAFT FLIGHT BOUNDARIES (BUFFET AND $C_{L_{MAX}}$)
- AIRLOADS (FROM SURFACE STATIC PRESSURES)

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FIGURE 24. HIGH-SPEED WIND TUNNEL MODEL

The data to be obtained are noted on Figure 24. More than one entry into the wind tunnel may be required to develop the geometry. After initial data are obtained, analysis of the data will be conducted and geometry modifications will be developed. Different nacelle contours and wing shapes will be tested.

The following configurations will be tested:

- o clean wing
- o wing plus nacelle
- o wing plus nacelle plus prop-fan

These testbed specific configurations are the same as those to be used later in the flight test program and the purpose and use for each configuration is discussed in subsequent paragraphs of Task IV relative to the flight test program. Data from these tunnel tests will be useful in defining the propulsive efficiency and drag terms as noted:

$$(T-D) = T + \text{Buoyancy} + T_{NOZ} - \text{Drag}$$

where

(T-D): net thrust minus drag of the complete configuration obtained from floor mounted balance.

T: thrust of prop-fan obtained from prop-fan drive shaft balance.

Buoyancy: the axial force obtained from an integration of nacelle surface static pressures with prop-fan operating and prop-fan off.

T_{NOZ} turbine drive nozzle thrust obtained by calibration of the nozzle.

Drag: drag of the configuration - obtained by taking the difference between the clean wing and the configuration with the propulsion system installed.

Since the turbine is powered from an external air supply source, there will not be a turboshaft engine air inlet on the nacelle as there will be for the flight installations. The effect of the inlet on the external drag, the prop-fan loads, and performance will not, therefore, be included in the high speed wind tunnel data. (The effect of the inlet on the prop-fan and inlet drag without the influence of the aircraft can be determined during the inlet development phase of the inlet tunnel test program.) This is a limitation of the high speed wind tunnel test data; and the inlet effect is therefore an item that must be evaluated during the flight test phase with the large scale hardware. The "no inlet" geometry cannot be flight tested for comparison to the wind tunnel data; therefore, the effects of the inlet and flight effects relative to the high speed wind tunnel data will have to be carefully studied. The effect of the inlet on aerodynamic performance is not anticipated to be large.

The subscale high speed wind tunnel test is the preferred method of developing an efficient shape for the wing and nacelle to be evaluated during flight. Multiple geometries can be tested in the tunnel and the appropriate diagnostic data taken much more efficiently than in flight. The fundamental questions of the installation (for instance - how large are the effects of nacelle contouring on wing pressures) can be quickly and less expensively resolved in the wind tunnel as opposed to doing the same thing in flight.

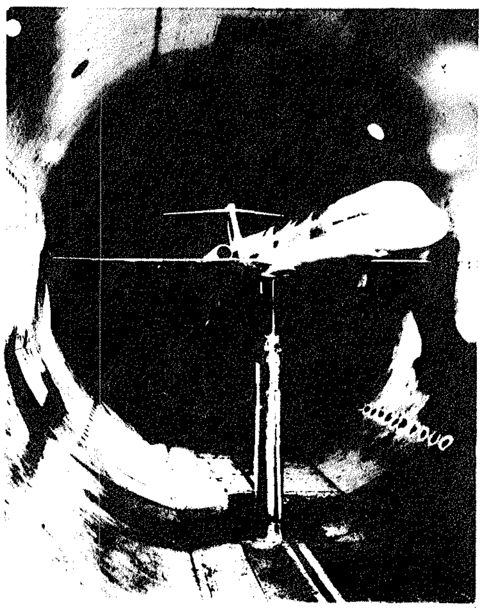
The instrumentation required for the high speed wind tunnel testing is similar to that recommended for flight test and is summarized in the following tabulation:

INSTRUMENTATION	PURPOSE
o Floor balances	o to measure configuration lift, drag, and pitching moment.
o Prop-fan drive shaft RPM thrust and torque	o prop-fan thrust and efficiency and aircraft drag.
o Nacelle surface statics	o drag analysis and buoyancy correction.
o Wing surface statics	o drag analysis.
o Prop-fan plane rake, P_{TOTAL} P_{STATIC} and flow angle	o input to prop-fan design.

Low Speed Wind Tunnel Test

Following the high speed wind tunnel test(s), the preferred high speed configuration will be tested at low speed. The objective is to determine the stall speeds and flap settings for safe operational flight during takeoff and landing.

Prop-fan windmilling conditions consistent with the flight test takeoff procedure will be tested. Effects of power at low speed will be determined by using an air-driven turbine to power the prop-fan. A new turbine with a 13 inch (3.30 cm) prop-fan will be required. An appropriate low speed facility is the Ames 12-foot tunnel. Douglas has an existing complete span DC-9 model that can be modified for use in this facility. Figure 25 presents a photograph of this Douglas DC-9 model mounted in the NASA Ames 12-foot low speed pressure tunnel along with a summary of the data to be obtained.



DATA TO BE OBTAINED

- AIRCRAFT LIFT, DRAG, AND PITCHING MOMENT WITH AND WITHOUT YAW
- STALL SPEEDS AND CHARACTERISTICS
- $C_{L_{MAX}}$
- APPROPRIATE FLAP SETTINGS
- LONGITUDINAL STABILITY AND CONTROL
- LATERAL-DIRECTIONAL STABILITY AND CONTROL

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FIGURE 25. LOW-SPEED WIND TUNNEL

These data will be used to placard the aircraft so that safe flight operation will be obtained during low speed, low altitude flight. For instance, the present conservative restriction of prop-fan operation at 15,000 feet (4,512 m) or above, noted in Figure 15, will be resolved and perhaps lowered or removed as a result of these low speed wind tunnel tests. The wind tunnel instrumentation required is not extensive. All that is needed is the six component balance data and perhaps some flow visualization equipment.

Inlet Development

The engine inlet contours will be developed concurrently with the aircraft configuration development. The objective is to develop an inlet configuration which, when operating in the presence of the rotating prop-fan, gives acceptable steady-state and time-dependent total pressure distortion at the engine compressor face. The propeller test rig (PRT) developed at NASA Lewis for use in the 8 x 6-foot transonic wind tunnel may be used for the testing. A modification to offset the drive shaft of the PRT will be required to properly scale the inlet capture area to the prop-fan and to properly model the duct offset geometry. A sketch of a typical installation is shown in Figure 26. Several inlet duct geometries will be tested until distortion levels are within satisfactory levels as established by the engine manufacturer. Following the subscale wind tunnel test, the selected inlet duct geometry will be ground tested on the engine by the engine manufacturer.

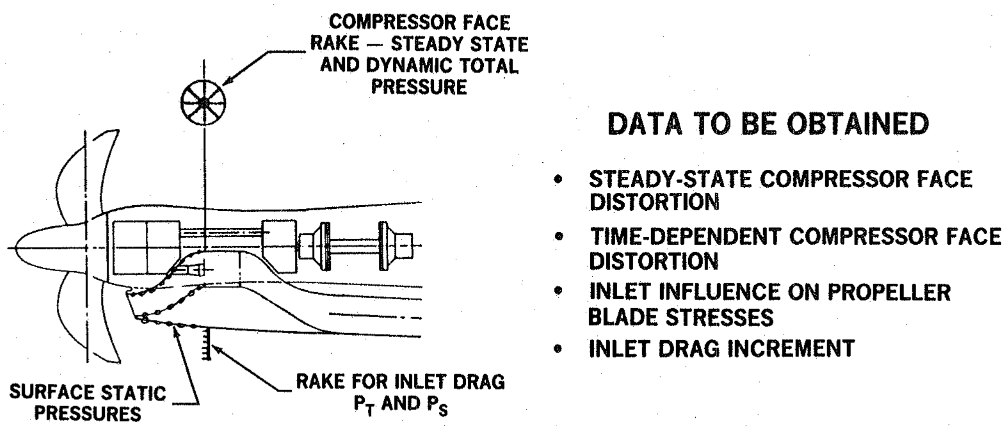

FIGURE 26. INLET TESTING

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The subscale wind tunnel test program will also establish the effects of the inlet on the prop-fan loads and the drag of the inlet. The effect on the prop-fan will be found by running with and without the inlet present and measuring the difference in blade stresses. The inlet drag will be found by placing total and static pressure instrumentation downstream of the inlet face on the external cowl surface. The estimated location of the instrumentation on the wind tunnel model is indicated in Figure 26; and the instrumentation considered for this phase of inlet testing is tabulated as follows:

INSTRUMENTATION	PURPOSE
* o Compressor face steady state total pressure rake	o steady state total pressure distortion.
* o Compressor face time dependent transducers	o time dependent (dynamic) total pressure distortion.
o Internal duct static pressures	o inlet distortion analysis.
o External static pressures	o inlet drag analysis.
o External total rakes	o inlet drag analysis.

*Location and number of probes to be defined in conjunction with engine manufacturer.

SUBSCALE WIND TUNNEL PROGRAM

Estimated Cost and Schedule

An estimated cost and schedule for the subscale wind tunnel portion of the aerodynamic development plan is presented in Figure 27. The ROM cost quoted in Figure 27 does not include any wind tunnel occupancy time.

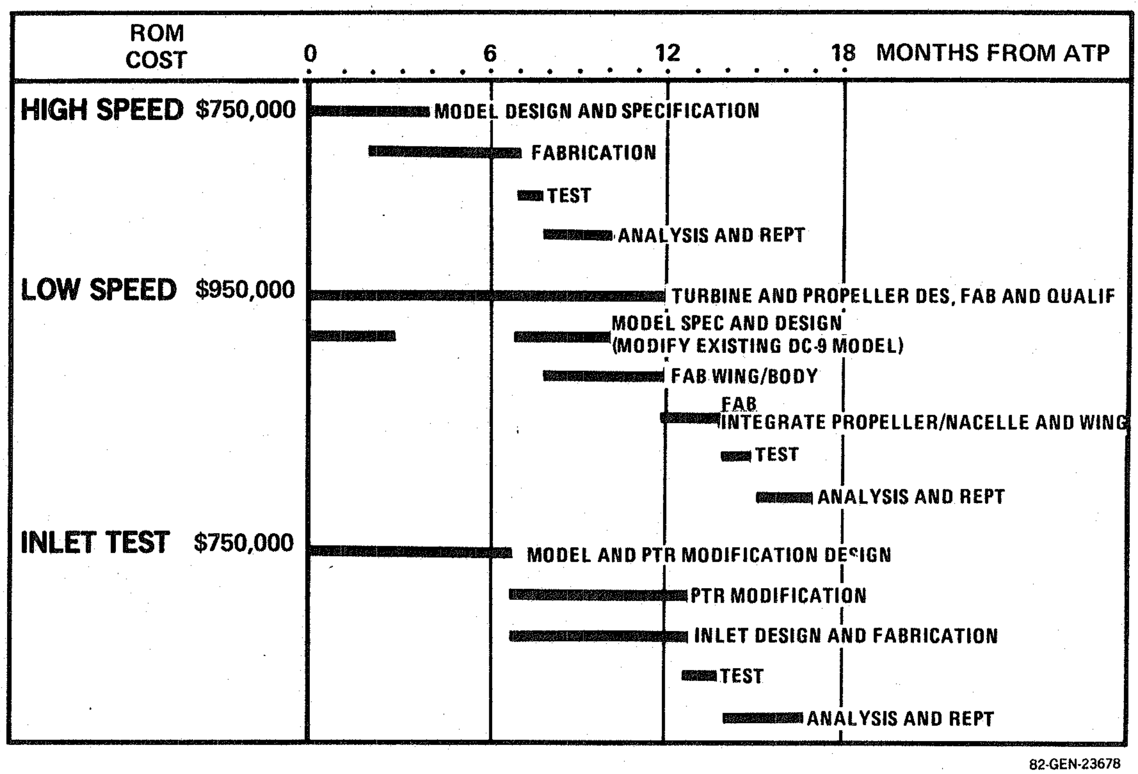

FIGURE 27. AERO DEVELOPMENT PLAN – WIND TUNNEL TEST AND SCHEDULE

Flight Test

After the high and low speed wind tunnel tests, as well as the necessary ground testing, have been conducted and the inlet/engine compatibility tests completed, the flight test phase of the program can be initiated. Figure 23 delineates the major aerodynamic aspects of the flight test program. During the high speed wind tunnel tests, the aerodynamnic effectiveness of a contoured nacelle installation under consideration will be determined. Provided structural, performance, and cost trade studies verify the overall advantages and feasibility of the contoured nacelle, the DC-9 aircraft will be modified to accept the contoured nacelle installation. Also, the minimum aircraft flight speeds will be properly placarded. Major discussions of the mechanics of the flight test program are included in Task VI, however, aerodynamic aspects of the flight testing are included herein (Task IV) as part of the aerodynamic testbed systems evaluation.

From the aerodynamic point of view, the primary purpose of the ground, wind tunnel and flight testing is to obtain the net installed thrust-minus-drag of the wing-mounted propulsion system. The appropriate aerodynamic data to be obtained during the flight testing are listed as follows:

- Speed and altitude
- DC-9 JT8D-7 turbofan engine thrust
- RPM, thrust, and torque of prop-fan drive shaft
- Surface static pressures (nacelle and wing)
- Prop-fan plane rake static and total pressures and flow angle
- Internal inlet duct static pressures
- Load factors - n_z and n_y
- Control positions - ∂_{cc}, ∂_w, ∂_r
- Airplane attitude and rate of pitch, θ & $\dot{\theta}$; roll ϕ & $\dot{\phi}$; yaw Ψ & $\dot{\Psi}$
- Airplane angle of attack - α
- Airplane sideslip - β

These data will then be used to extend the wind tunnel results and analytical estimates to actual flight conditions for the prediction of full scale prop-fan aircraft performance. The prop-fan thrust will be obtained to verify the Hamilton Standard data and to form the reference level for the Douglas thrust/drag bookkeeping system.

Basic Data Acquisition

The basic DC-9-10 engine, JT8D-7 turbofan, must be calibrated to determine the thrust characteristics at flight speeds. This calibration will be conducted in a manner acceptable to NASA, Douglas, and Pratt & Whitney.

The basic DC-9 will be flown to establish the reference drag level for the thrust-minus-drag measurements. The suggested flight envelope to be used is shown in Figure 28 and the six specific flight test points selected are shown. These six points will be flown, and the thrust of the calibrated engines will be used to determine the drag for this and all other configurations.

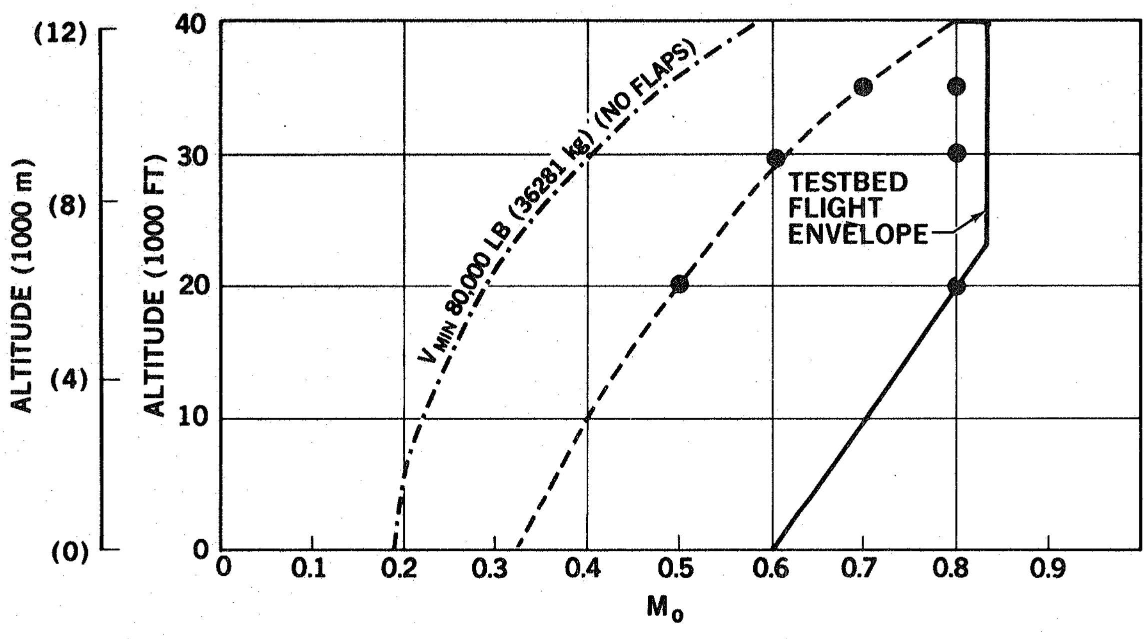

FIGURE 28. DC-9 AIRCRAFT OPERATING POINTS ASSUMED IN PERFORMANCE SPECTRUM

The nacelle installation with the prop-fan removed will then be installed in the testbed aircraft and be flown. The inlet and nozzle will be faired over to eliminate the nozzle base drag and momentum losses of the air flowing through the windmilling engine . Surface pressure data on the nacelle will be recorded in addition to the thrust (drag) data to form the baseline pressure levels for buoyany corrections to the prop-fan force data. The drag data will be used to determine the interference drag of the nacelle on the wing without the prop-fan flow effects. When compared to the prop-fan on data with power, these data will isolate the effects of power from the effects of the nacelle. The more significant effects can be isolated and, for different prop-fan or nacelle geometries, the drag interference factors of each component will be known for application to other configurations.

The inlet fairing presents a problem in that the fairing will disturb the pressures used in the buoyancy correction. The design of the fairing must be carefully tailored using 3-D surface panel potential theory to minimize differences from that of the inlet when operating with flow into the engine. Different fairing shapes will be studied until pressure distributions on the nacelle are similar to those predicted by the program with the flowing inlet represented. If pressure differences exist for the selected fairing shape, then the increments will be used to adjust the measured pressure levels to those of a flowing inlet to obtain reference levels for buoyancy corrections.

The prop-fan will then be installed on the drive system and operated at several power levels. During this phase of the testing, the JT8D-7 engine thrust, obtained from the calibration discussed previously, will be used to establish the net thrust of the prop-fan minus drag. Prop-fan thrust, torque, and RPM will be measured using prop-fan drive shaft instrumentation; and nacelle static pressures will be measured so that nacelle buoyancy corrections can be made to the prop-fan thrust.

The data will be used to define the various terms in the following equation:

$$(T\text{-}D) = T_{INST} + \text{Buoyancy} + T_{NOZ} - \text{Drag}$$

where:

(T-D)	prop-fan propulsion system installation thrust minus drag obtained using calibrated DC-9 JT8D-7 engines which is equal to the difference in the thrust required to fly a given condition with and without the prop-fan propulsion system installed.
T_{INST}	prop-fan installed thrust obtained using the drive shaft balance.
BUOYANCY	axial force correction obtained from integration of difference in nacelle surface static pressures between prop-fan on and prop-fan off.
T	prop-fan thrust corrected for buoyancy but operating in the presence of the aircraft. This thrust will be compared to the prop-fan manufacturers' data obtained on an isolated prop-fan test rig to determine the effect of installation. (This term is part of the Douglas thrust-drag bookkeeping system).
T_{NOZ}	turboshaft engine nozzle thrust obtained from calibration of nozzle and the pressure data.
DRAG	propulsion system installation drag as calculated from the basic equation; this drag term is also used in Douglas thrust-drag bookkeeping system.

The drag term will be compared to estimates made using conventional flat plate skin friction coefficients. The ratio of the measured level to the calculated level will produce an interference factor (K) that accounts for changes in induced drag due to span load distortions, local boundary layer thickening due to pressure gradients, and any other factors which could contribute to the drag. The K factors will also be compared to those obtained from the wind tunnel tests.

To obtain estimated flight performance, the following equation will be used:

$$(T\text{-}D) = T_{ISO} - K \text{ (estimated drag)}$$

where

T_{ISO} is the isolated thrust of the prop-fan propulsion system as supplied by the prop-fan and engine manufacturer.

A summary of the flight test instrumentation associated with obtaining the desired aerodynamic information is as follows:

INSTRUMENTATION	PURPOSE
o Thrust, torque, and RPM of prop-fan drive shaft	o obtain prop-fan thrust and efficiency.
o Static pressures on nacelle	o prop-fan bouyancy and interference drag analysis .
o Static pressures on wing	o drag analysis.
o Pressure rake in prop-fan plane - T_{TOTAL}, T_{STATIC}, flow direction required	o prop-fan inflow data for prop-fan design and analysis.
o Inlet-wall static pressure and P_T rake at compressor face	o inlet flow analysis
o DC-9 turbofan internal instrumentation to determine thrust	o thrust minus drag (T-D) of installed prop-fan propulsion system.
o Accelerometers	o airplane load factor tracking.
o Control position sensors	o control position tracking.
o Attitude gyros	o airplane attitude tracking.
o Angle of attack (α) vane	o angle of attack tracking.
o Sideslip (β) vane	o sideslip tracking.

A sketch of the location of the proposed instrumentation for installed propulsion system performance is given in Figure 29.

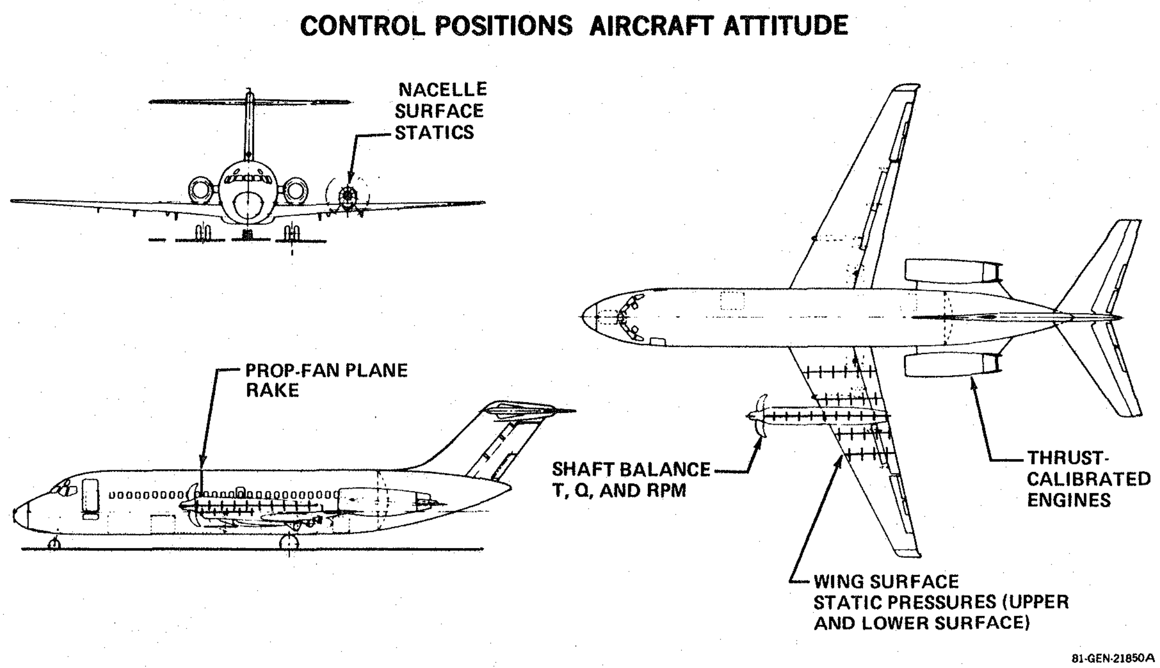

FIGURE 29. CRUISE PERFORMANCE PRESSURE SURVEY INSTRUMENTATION

PROPULSION SYSTEM - PROP-FAN/T701 ENGINE INTEGRATION

Figures 30 and 31 present preliminary sketches of the T701 engine/ prop-fan installations. The engine is installed above and forward of the wing front spar. The engine tailpipe is routed over the upper wing surface and exits at the wing trailing edge. The three section cuts (Figure 31) are through the nacelle at the forward (gearbox) mount, aft engine mount, and between the gearbox and engine proper.

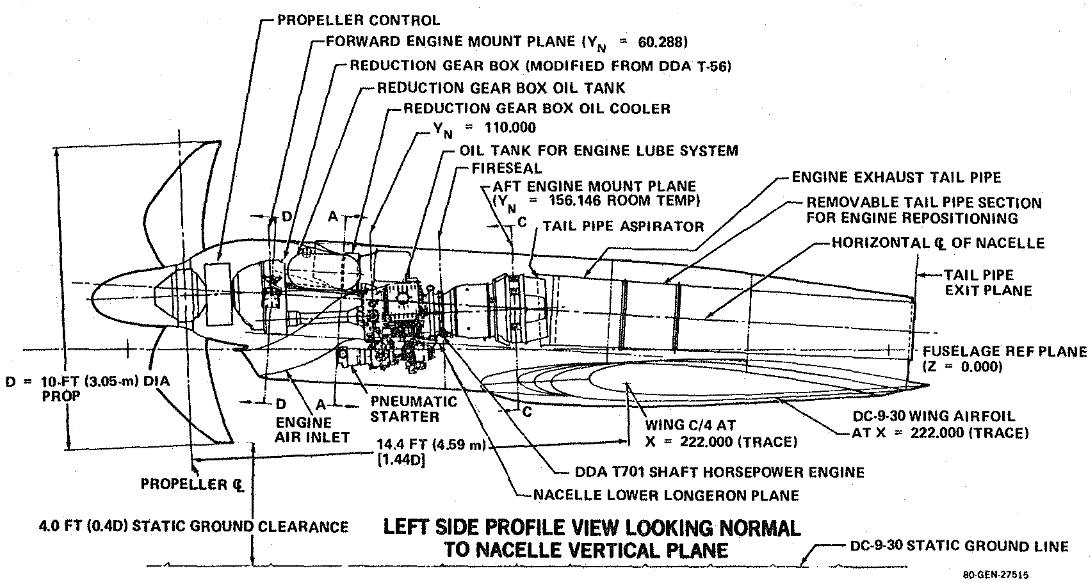

FIGURE 30. T701 ENGINE/PROP-FAN INSTALLATION

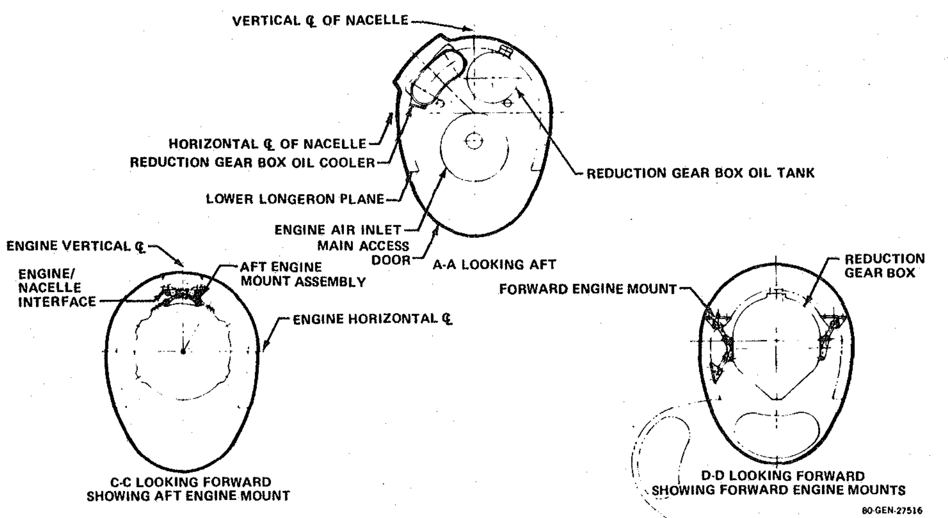

FIGURE 31. T701 ENGINE/PROP-FAN INSTALLATION (CONTINUED)

The prop-fan installation and systems characteristics are itemized as follows:

- DDA T701 SHAFT HORSEPOWER ENGINE COUPLED WITH A MODIFIED DDA T-56 GEARBOX
- GEARBOX MODIFICATION REQUIRED
  - Reverse input rotation (main gears o.k.)
  - Oil system modification (due to rotation)
  - Propeller brake (for feathered prop in flight)
- GEARBOX OIL TANK AND COOLER INDEPENDENT OF ENGINE AND MOUNTED IN FIXED STRUCTURE
- EXISTING OIL TANK AND COOLER ON ENGINE UTILIZED FOR ENGINE ONLY
- OFF-THE-SHELF PNEUMATIC STARTER USED
- HARD ENGINE MOUNTS PROVIDED, BUT SPACE AVAILABLE FOR SHOCK MOUNTS
- ENGINE MOUNTS FAIL-SAFE
- PART OF INLET SCOOP BUILT INTO LOWER DOOR
- ACCESSORY AND TURBINE COMPARTMENT SEPARATED BY FIRE SEAL
- FIRE EXTINGUISHING (TWO-SHOT) SYSTEM PROVIDED
- FIRE WARNING (FIRE DETECTORS) PROVIDED
- UPPER PORTION OF NACELLE AND WING FIRE PROTECTED
- FIREWALL FUEL SHUTOFF LOCATED CLOSE TO FUEL TANK BULKHEAD
- HOISTING PROVISIONS IN UPPER NACELLE STRUCTURE ALLOW ENGINE AND GEARBOX TO BE REMOVED OR INSTALLED AS A UNIT (STRUCTURAL BREAK AFT OF REAR MOUNT)
- SMALL ACCESS DOORS IN UPPER NACELLE FOR OIL FILLING, INSPECTION, AND BORESCOPE INSERTION
- OIL TANK SCUPPER DRAINS TERMINATE IN A DRAIN MAST
- CRITICAL OIL AND FUEL SEAL DRAINS ALSO ROUTED TO THE DRAIN MAST
- VIBRATION PICKUPS INSTALLED (PROBABLY TRACKING FILTER TYPE)
- PROVISIONS COULD BE MADE TO MOVE ENGINE AND PROP-FAN RELATIVE TO WING LEADING EDGE (REMOVABLE PLUG IN NACELLE STRUCTURE AFT OF REAR ENGINE MOUNT AND ATTACH BULKHEAD
- SYSTEMS OR COMPONENTS WHICH CAN BE DELETED IN THE INTEREST OF COST SAVING
  - Generator
  - Hydraulic pumps or system
  - Environmental bleed systems or controls
  - Anti-icing system on inlet or prop
  - Remote oil quantity indicator.

Fuel System

The fuel system connection between the basic DC-9 aircraft fuel system and the prop-fan installation is shown in Figure 32. This particular drawing represents a one prop-fan/engine installation; the same type installation on the other aircraft wing is required for the two prop-fan arrangement. As can be seen, the fuel line is connected into the basic aircraft fuel system between the two boost pumps in the main wing fuel tank. The fuel line is then routed through the front wing spar to a firewall shut-off valve and then to the fuel connection on the fuel control of the T701 engine.

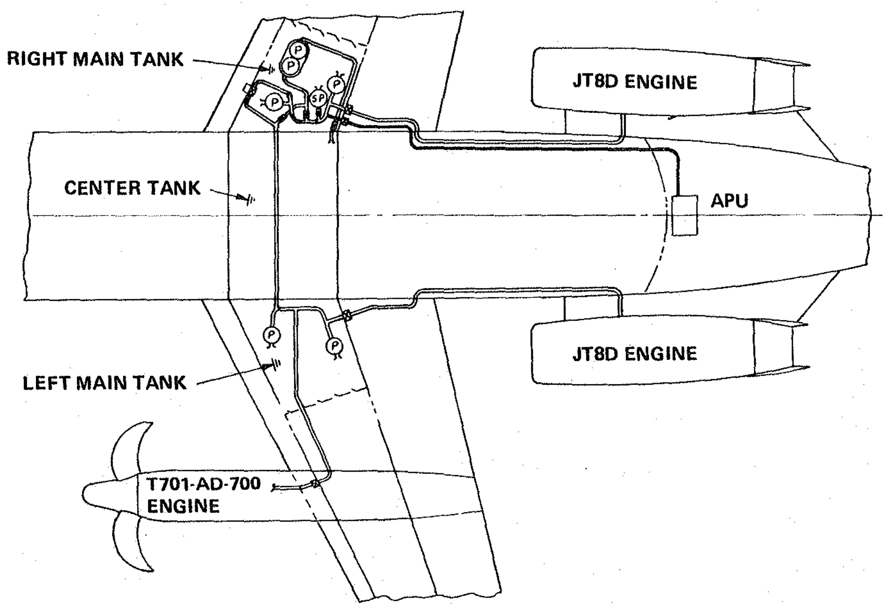

FIGURE 32. DC-9 PROP-FAN FLIGHT TESTBED FUEL SYSTEM

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Opposite Rotation

Investigation of the gains, both aerodynamically and acoustically, of installing both the prop-fans to rotate up and inboard to the fuselage also entails a trade study of the engine manufacturer to evaluate the complexity and cost of providing the engine gearbox with capability to permit opposite prop-fan rotation. In general, such an arrangement is felt to be quite feasible; a detailed study of such opposite rotation is currently underway by Allison.

Other operational considerations associated with the prop-fan opposite rotation include the

- o clockwise and counter-clockwise swirl from the prop-fan, and
- o cyclic prop-fan frequency dynamic distortion.

Consequences of these operational results may entail such as

- o one inlet design for a "worst case" or separate inlets for right and left hand installations,
- o different left and right hand engine operation from the points of view of performance or transient operations,
- o inlet guide vane tailoring for each engine.

These operational considerations warrant further investigation before testbed flight.

Key Characteristics of Prop-fan Propulsion System

The key characteristics of the testbed prop-fan propulsion system, based on the work performed during Task I through V are summarized as follows:

- o T701 with modified T56 gearbox is the most suitable prop-fan drive for the NASA testbed.
- o The largest diameter prop-fan available (T701 engine capaility of swinging a 9.5 foot [2.90 m] diameter prop-fan) is compatible with Hamilton Standard recommendations.
- o Hamilton Standard recommends use of a modified 54H60 prop-fan control.
- o Allison recommends use of a modified T701 engine control.
- o The prop-fan drive can be installed on a DC-9 wing.
- o An inlet testing must be developed before proceeding with the testbed flights
- o A prop-fan/engine control coordinator may be required for flight test particularly on the two-engine prop-fan installation).

ACOUSTIC TESTBED PROGRAM

The acoustic technology objectives identified in Task I are listed here for convenience in order of priority:

- o Primary Objectives
  - o Determine prop-fan near field and far field noise characteristics during representative ground and flight conditions.
  - o Determine passenger cabin noise characteristics and fuselage vibration transmission during cruise flight.
  - o Determine the effectiveness of various cabin noise control treatments.

- o Secondary Objectives
  - o Evaluate effects of prop-fan opposite rotation and synchronization on noise characteristics.
  - o Determine effects of scaling model prop-fan acoustic data to large scale applications with flight effects.
  - o Obtain acoustic data to verify or modify existing theoretical prediction models.
  - o Obtain acoustic data to develop and verify procedures for predicting FAR Part 36 noise levels.

The production DC-9 turbofan fuselage sidewall acoustic treatment is shown in Figure 33. This sidewall configuration will not provide sufficient attenuation to meet the selected interior noise goal on the testbed aircraft. Therefore, treatment modifications must be identified that will meet this goal. A laboratory test program to identify promising treatment designs is described in a subsequent section.

Resolution of Acoustic Technology Objectives

The possibility of accomplishing the acoustic technology objectives by a program which includes high and low speed wind tunnel and static test stand work is discussed in Task I and is summarized in Figure 34.

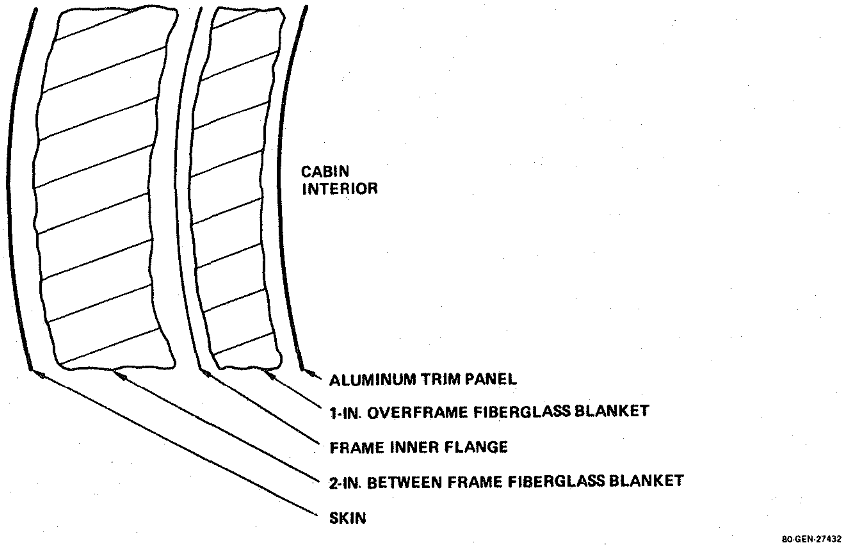

FIGURE 33. PRODUCTION DC-9 SIDEWALL ACOUSTIC TREATMENT

	RESOLUTION BY:	
	TESTBED AIRCRAFT	WIND TUNNEL*
MEASURE NEAR- AND FAR-FIELD NOISE DURING GROUND AND FLIGHT CONDITIONS	YES	PARTIAL
MEASURE CABIN NOISE AND VIBRATION DURING CRUISE	YES	NO
DETERMINE EFFECTIVENESS OF ACOUSTIC TREATMENT	YES (ADD-ON TYPES)	NO
EVALUATE OPPOSITE ROTATION AND SYNCHRONIZATION	YES (2-PROP-FAN NACELLE PROGRAM)	NO
OBTAIN FLYOVER DATA FOR FAR PART 36 PREDICTIONS	TBD	POSSIBLE
OBTAIN FUSELAGE RESPONSE DATA FOR MODEL VERIFICATION	YES	NO
OBTAIN FUSELAGE LOAD DATA TO DETERMINE SCALING EFFECTS	YES	PARTIAL

* CONSIDERING HSWT, LSWT, AND STATIC TEST PROGRAM

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FIGURE 34. RESOLUTION OF ACOUSTIC TECHNOLOGY OBJECTIVES

It is concluded that the wind tunnel program alone will not provide a means for accomplishing most of the acoustic objectives. The measurement of near field noise may be partially accomplished by performing acoustic tests in the Ames 40 x 80 low speed wind tunnel. Acoustic measurements in a non-acoustic wind tunnel (like the 40 x 80) present problems with the background and reverberant noise levels, in addition to the Mach number limitation. Existing acoustic wind tunnels are too small to accommodate a half span test using a 9.5 foot (2.90 m) diameter prop-fan. Size limitations present a problem even in the Ames 40 x 80 foot tunnel if one proposes to include a simulated fuselage surface as part of the test fixture.

However, measurement of near field noise during half span testing in the 40 x 80 foot wind tunnel without a simulated fuselage surface is a possibility, although the data quality will probably be marginal. Absolute levels of prop-fan noise measured in this manner will be unreliable; but the data will be useful for examining noise trends with variations in measurement location, installation geometry, and operating conditions. Static test stand acoustic measurements on an open propeller rotor have been shown to give unpredictable results because the flow field of a static propeller or fan greatly modifies the structure of turbulence present in the atmosphere. Spurious random sources are then created when blades encounter the turbulence. Some sophisticated data analysis techniques, designed to separate random and periodic noise, have been used on static propeller noise (Reference 4). The utility of the methods has not been established, however, since no direct comparison of data so reduced has ever been made with flight data. Test stand measurements are also incomplete because they do not include local flow field modification by the presence of the aircraft, have incorrect relative velocities between the airstream and the blades, and have different convective amplification effects than the free flight case.

Other acoustic objectives which have some possibility of resolution by a static test stand and wind tunnel program alone are the determination of scaling effects and the measurement of far field noise for development of FAR Part 36 predictions. However, these objectives would suffer from the same problems mentioned above. The remaining objectives have no possibility of being accomplished with a wind tunnel program. Subsequent discussion will, therefore, be confined to resolution of acoustic objectives by a testbed aircraft flight program. Resolution of all acoustic technology objectives could be accomplished with a program which includes laboratory testing of acoustic treatment designs, and ground static testing, taxi testing, and flight testing with a two prop-fan system mounted on a testbed aircraft. The elements of this program are shown in Figure 35. In the case of the outdoor test stand, the measurement of near and far field noise is dependent upon the facility selected for the static testing.

Level flyovers at $\leq 2,000$ feet (610 m) altitude are desired; however, these flyovers are contingent upon the flight envelope restriction discusssed in Task III and in the aerodynamic testing of this Task IV.

LABORATORY TESTING
- IDENTIFY BASELINE SIDEWALL ACOUSTIC TREATMENT
- IDENTIFY ADDITIONAL PROMISING TREATMENT DESIGNS

OUTDOOR TEST STAND
- PROP-FAN/ENGINE/GEARBOX/NACELLE SYSTEM
- MEASURE NEAR- AND FAR-FIELD NOISE

GROUND RUNUP AND TAXI TESTING
- TWO PROP-FAN SYSTEMS INSTALLED ON AIRCRAFT
- MEASURE NEAR-FIELD, FAR-FIELD, AND INTERIOR NOISE

FUSELAGE EXTERNAL ACOUSTIC LOADS
- ALTITUDE
- MACH NUMBER
- TIP SPEED
- BLADE PASSAGE FREQUENCY
- PROP-FAN POWER LOADING
- BLADE ANGLE

INTERIOR NOISE
- BASELINE ACOUSTIC TREATMENT
- ADDITIONAL TREATMENT DESIGNS (ALSO BARE WALL)
- VARIOUS OPERATING CONDITIONS
- OPPOSITE ROTATION
- SYNCROPHASER EVALUATION
- SELECTED FLIGHT CONDITION

CABIN ABSORPTION
- MEASURE REVERBERATION TIMES FOR BARE-WALL AND TREATED CONFIGURATIONS

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FIGURE 35. ACOUSTIC TEST REQUIREMENTS

Laboratory Testing

Laboratory testing will be performed in an acoustic facility and will be used to identify a baseline acoustic treatment design. The baseline treatment will be of the add-on type (no changes to aircraft fuselage structure) and will be the most efficient sidewall design identified in the test program; this program will provide the transmission loss predicted to be necessary to achieve a selected interior noise goal on the testbed aircraft. Additional promising treatment designs will also be identified in the lab test program; a design incorporating change to the outer fuselage structure will be included. Some of the acoustic treatment changes that will be investigated during the laboratory test program are shown in Figure 36 and 37.

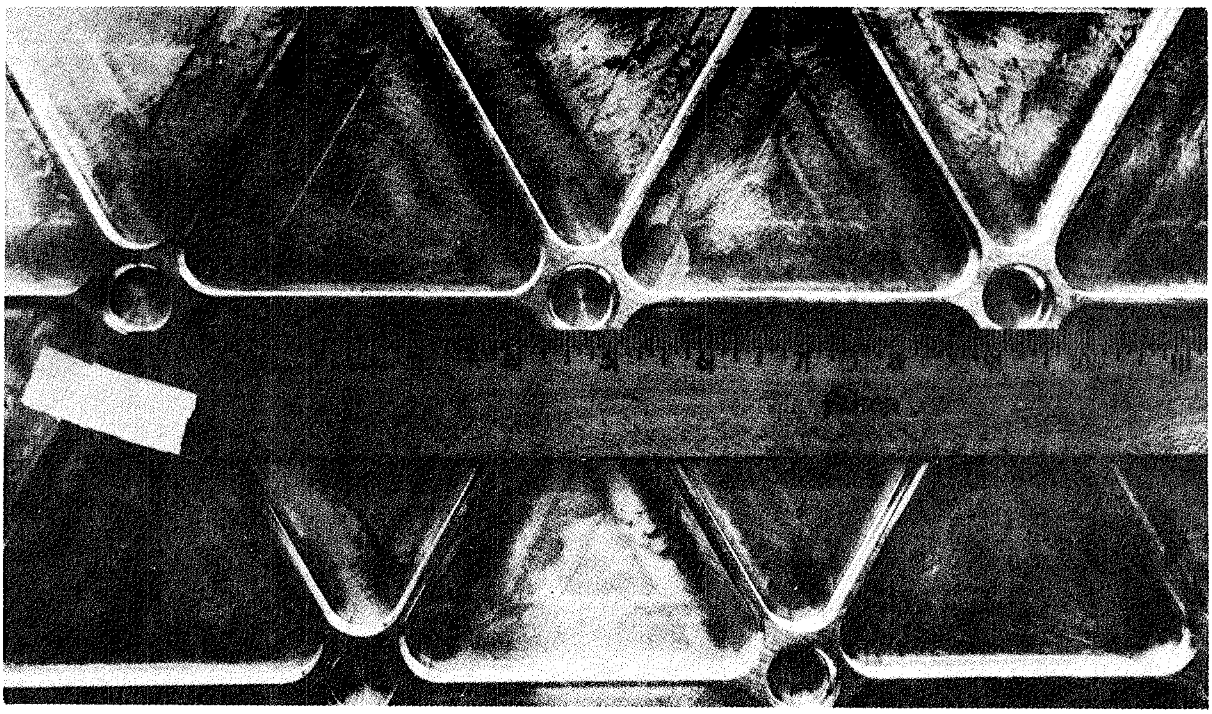

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FIGURE 36. ISOGRID STRUCTURE

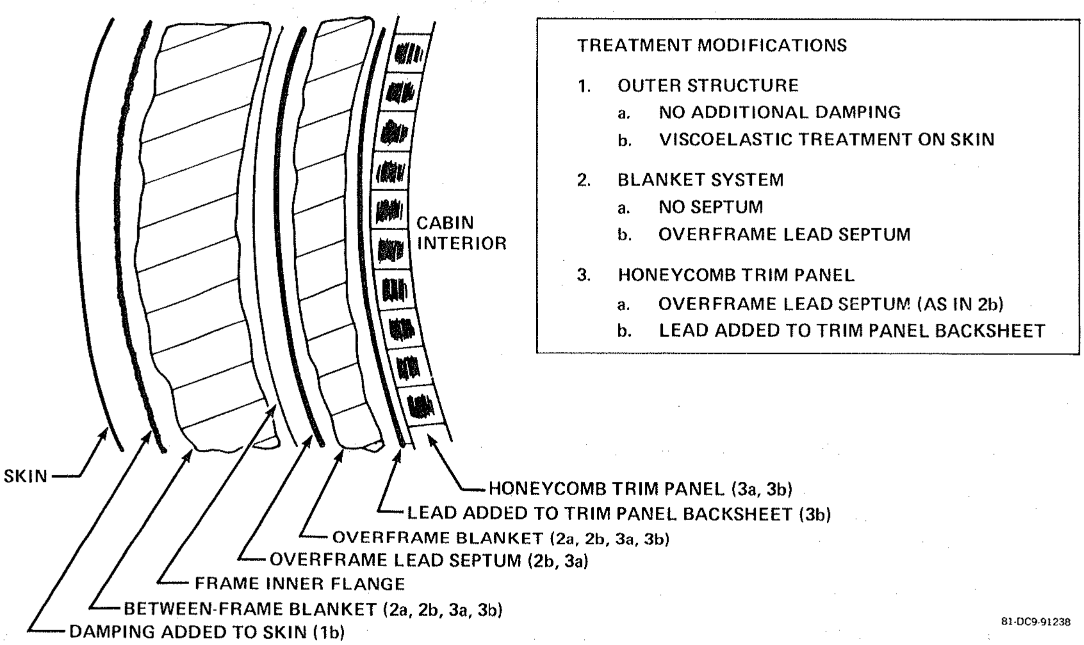


FIGURE 37. MODIFIED SIDEWALL ACOUSTIC TREATMENT

Outdoor Test Stand

Outdoor test stand acoustic measurements on an open rotor have significant problems as mentioned previously. However, assuming the prop-fan/engine/gearbox/nacelle system will be run on a test stand with acoustic measurement capability, it is proposed to obtain near field and far field acoustic data at the same time as the other static testing, Figure 38.

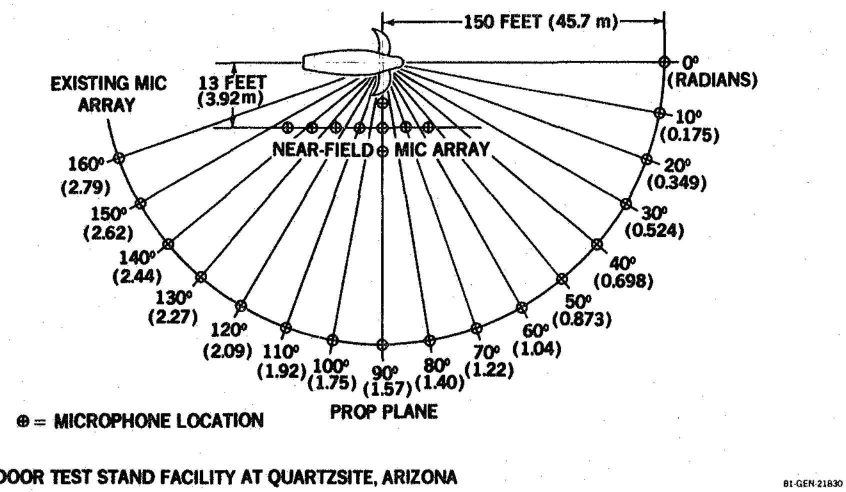


FIGURE 38. MEASUREMENT OF NEAR- AND FAR-FIELD NOISE ON OUTDOOR TEST STAND

This test will be useful for two reasons. The data may provide advance information of fuselage acoustic loading and community noise representative of conditions at brake release. The static test stand measurements may also provide a valuable data base for future investigations which rely on static acoustic data to predict in-flight noise. The ability to use static data may become important when the prop-fan system achieves production status because the airframer must understand the situation with regard to noise certification of the aircraft prior to construction. The alternative to using static acoustic data is the use of purely theoretical techniques, which may not inspire the same level of confidence as test data. It is felt that the non-periodic effects of turbulent inflow to the prop-fan can be analyzed and may not pose an insurmountable problem.

Ground Static Runup

Acoustic measurements will be performed with the testbed aircraft operating on the ground during static runup. The acoustic tests will consist of near field, far field, and interior noise measurements during prop-fan engine operation at power settings typical of idle/warm-up, taxi and takeoff. Fuselage and cabin vibration levels will also be measured during this part of the testing. The near field and interior noise measurements will identify fuselage loads, fuselage/sidewall noise reduction, and interior noise levels in the ground runup environment. The measurements will be performed with the baseline acoustic treatment installed. The far field measurements , Figure 39, may provide information for predicting community noise during ground static operations. In the event that far field noise cannot be measured during the test stand engine runs, an attempt will be made to relate the far field noise measured during ground static and taxi tests with the data measured during level flyovers. It is felt that the capability of predicting in-flight levels from static data may be a necessary ingredient in any future production program.

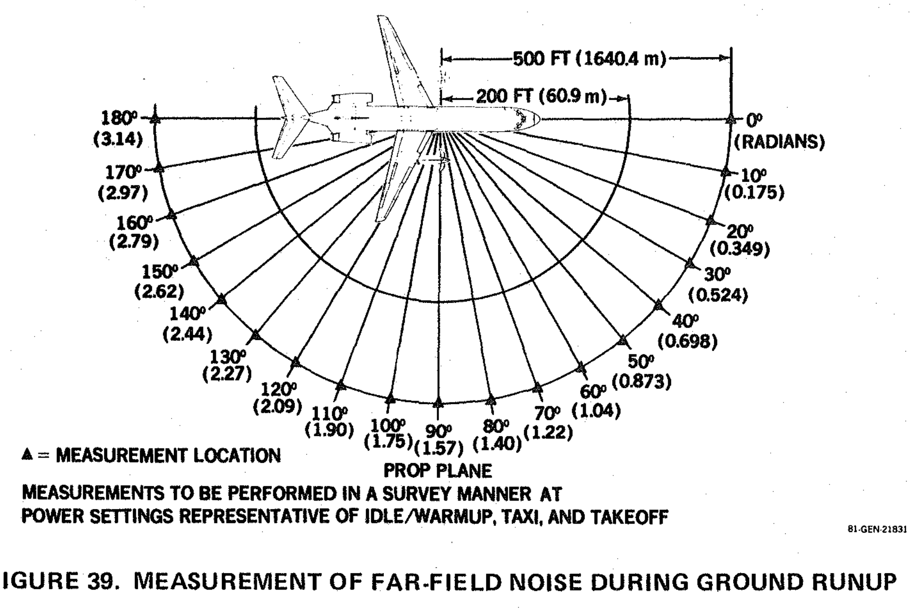


FIGURE 39. MEASUREMENT OF FAR-FIELD NOISE DURING GROUND RUNUP

In order to complete the data necessary for the interior noise evaluation, it is proposed to measure cabin absorption coefficients. This will be done during ground testing by performing reverberation time measurements using an internally-mounted random noise source. Reverberation times will be measured in the area of acoustic treatment modification while on the ground, using the same microphones as for the interior noise measurements. Reverberation times will be measured for the sidewall configurations that vary significantly in absorption (i.e., barewall, barewall damped, baseline).

Flight Test

The flight test program will include measurement of near field noise as well as interior noise and vibration during various cruise conditions throughout the flight envelope. The conditions will be selected to investigate the effects of the following operating parameters: altitude, airspeed, prop-fan tip speed, blade passage frequency, prop-fan disc loading and blade angle. These measurements will be performed with the baseline acoustic treatment installed. The tests will measure fuselage acoustic loading, fuselage/sidewall noise reduction, fuselage response, interior noise, and vibration levels at the selected operating conditions. The fuselage load data will also allow determination of the effects of scaling model prop-fan data to large installations with flight effects; and the fuselage response data will provide the means for verification of existing theoretical prediction models.

Another portion of the flight test program will consist of measurements of external load, fuselage response, and interior noise with alternate acoustic treatment designs installed. The alternate designs to be tested will have been identified in the laboratory test program. Two barewall configurations will be included, one with damping and one without damping, in order to identify the absolute noise reductions of the fuselage structure and the sidewall teatments separately. Acoustic and vibration measurements will be made in the barewall configuration with constrained layer viscoelastic damping treatment applied to the skin panels (in addition to the undamped barewall measurements). The alternate sidewall designs will be evaluated at one of the flight conditions selected for the baseline treatment in order to minimize the number of variables involved and to provide a readily discernible basis for comparison.

In addition, it is planned to test a treatment configuration that includes changes to a section of the basic fuselage structure. The change may include the use of isogrid structure, which preliminary laboratory testing shows to have good attenuation characteristics in the low and mid frequency range. The modified fuselage structure will be tested at the same flight condition as the other treatment designs, preferrably in the barewall configuration.

Other acoustic objectives which can be accomplished during this phase of the test program include the evaluation of prop-fan opposite rotation and synchronizing (assuming a two-prop-fan testbed). Presumably, if opposite rotation is selected for the testbed program, the testbed aircraft will be flown primarily with the opposite-rotating systems installed. A comparative evaluation can be conducted by installing same-rotating systems (perhaps using one of the prop-fan/gearbox spares sets) and measuring external load, fuselage response, interior noise, and vibration during cruise at the flight conditions previously selected for testing the acoustic treatment designs. The opposite rotation evaluation can be run with any of the sidewall treatments installed, but it is preferable to use the baseline treatment as it will have a broader data base. Therefore, it may be advisable to perform this evaluation before the baseline treatment is removed. Prop-fan synchronization can be evaluated simply by disconnecting the synchronizer and allowing the relative phase of the prop-fans to change. It is desirable to be able to monitor the relative phase angle of the prop-fans and record it simultaneously with the acoustic and vibration data. Data to be measured during the synchronization evaluation includes external loading, fuselage response, interior noise, and vibration.

It may be possible to measure far field noise levels using the testbed aircraft by performing a series of level flyovers at low altitudes of $\leq$ 2,000 feet (610 m). However, at the present time, there is an approximate lower altitude limit of 15,000 feet (4,572 m) imposed on the testbed flight envelope for safety reasons. It is predicted that a one-engine-out condition below 15,000 feet (4,572 m) may introduce stability and control problems (discussed in aerodynamics section). Therefore, the level flyovers at low altitude may be contingent upon relaxation of this restriction.

Testbed instrumentation includes an exterior flush-mounted microphone array in the area of high prop-fan acoustic loading of the fuselage. A fairly extensive array will be mounted on one side of the fuselage with a smaller array on the other side (for the two-prop-fan testbed). The large microphone array is used to determine relative phase contours and magnitude of the prop-fan noise field on the fuselage, while the smaller array is used primarily to acquire magnitude information. Additional microphones may be placed on nacelle and wing surfaces to measure the strength of the acoustic field for sonic fatigue analyses. For the evaluation of prop-fan opposite rotation, the prop-fan installation to be changed should, preferrably, be on the side with the more extensive microphone array. Instrumentation includes interior microphones located near both sidewalls and on the fuselage centerline. These microphones are hard-mounted and located in the area of high prop-fan loading. There will also be a portable recording system on board to investigate problems which may arise. In addition, it is planned to install a number of accelerometers to measure fuselage and cabin vibration in key locations such as skin panels, frames, trim panels, floor, etc. A sketch of the testbed aircraft acoustic and vibration data acquisition system is shown in Figure 40.

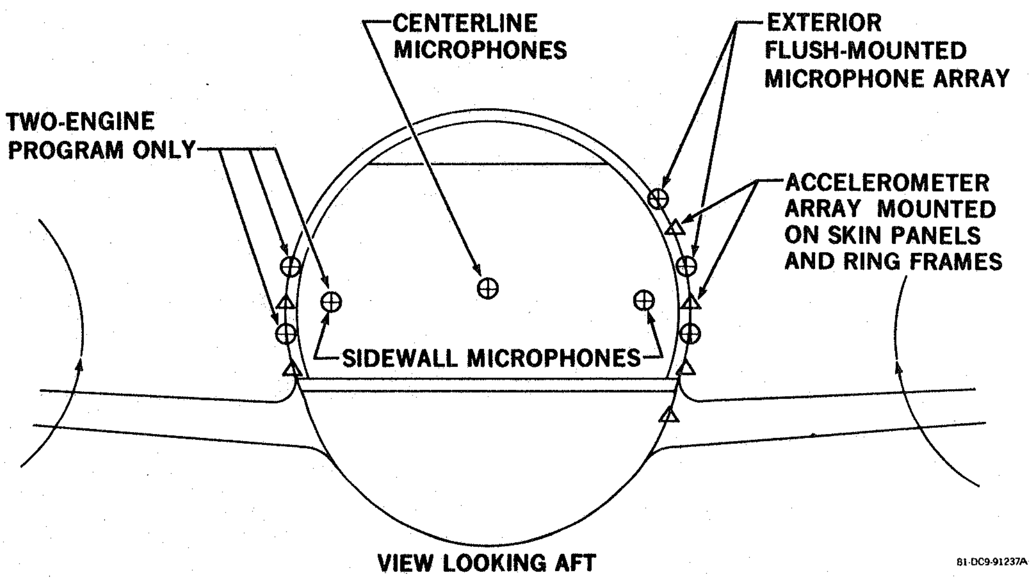


FIGURE 40. MEASUREMENT OF EXTERIOR/INTERIOR NOISE AND FUSELAGE VIBRATION

The testbed aircraft will have a representative passenger interior in the area of prop-fan loading including seats, carpet, and interior panels. The data recording equipment will be located away from this area, probably in the rear of the aircraft. All necessary data reduction equipment and techniques are available at the Douglas Long Beach facility as discussed in the flight test portion of this report, Task VI.

TASK 5

TASK V

CONCEPTUAL DESIGN OF TESTBED SYSTEMS

The principal design changes to the basic DC-9 aircraft for the DC-9 prop-fan testbed are encompassed in the integration of the prop-fan/engine/nacelle into the basic DC-9 aircraft. With this propulsion system change, minor modification to the fuel supply system, controls, and the installation of necessary flight test instrumentation and recording equipment, the basic DC-9 may be converted to an appropriate prop-fan testbed airplane.

To properly orient the prop-fan/engine/nacelle on the aircraft wing, the aircraft characteristics and propulsion system local onset flow field are evaluataed. For the DC-9, the aircraft angle-of-attack as a function of lift coefficient (C_L) is shown in Figure 41. The aircraft angle-of-attack is referenced to the fuselage reference plane. Using these data and the flow field data similar to that shown in Figure 42, the excitation factors for several fore and aft locations of the prop-fan are evaluated at critical flight points. The results of this work provide the prop-fan orientation angles such as are shown in Figure 13.

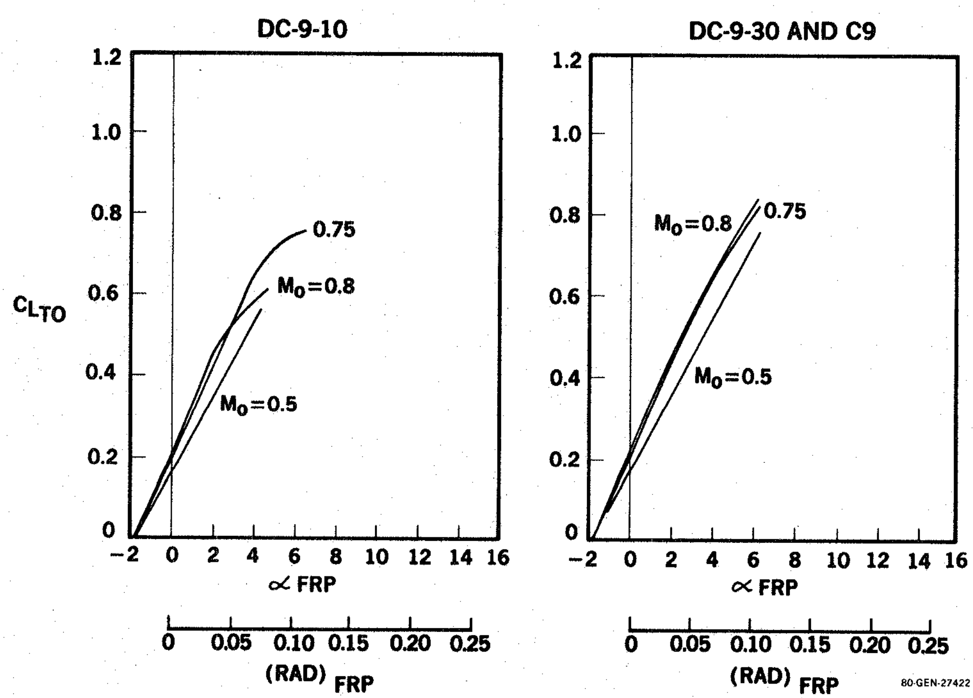


FIGURE 41. DC-9 LIFT VARIATION WITH ANGLE OF ATTACK

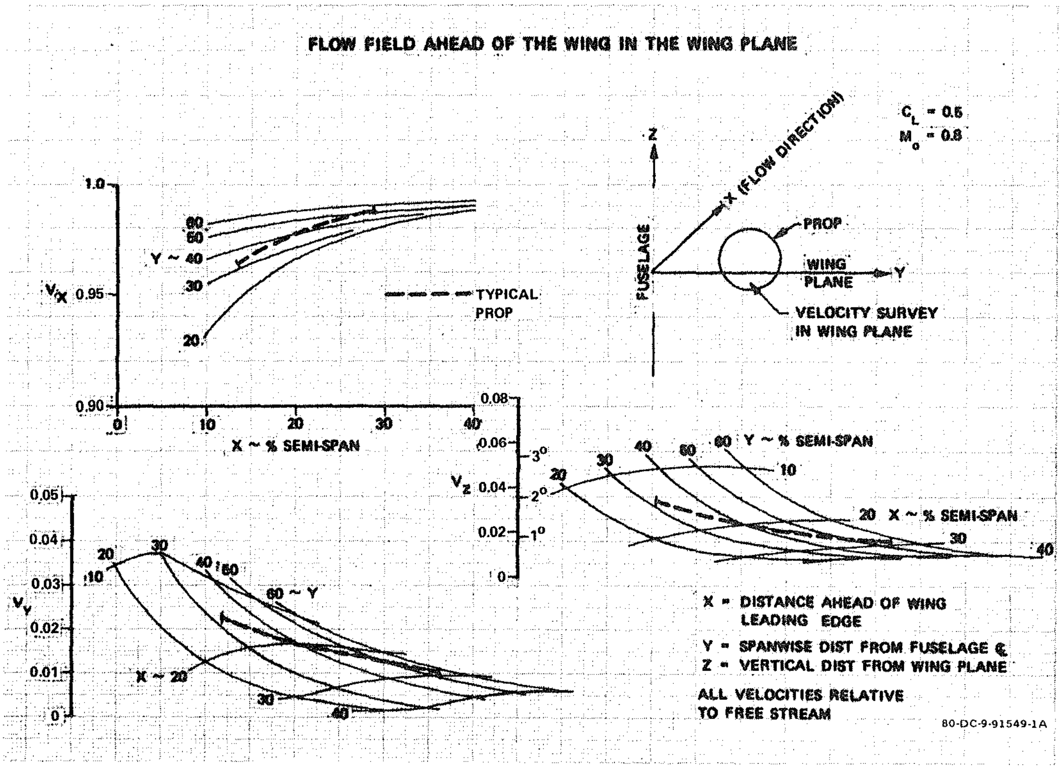


FIGURE 42. DC-9 WING BODY FLOW FIELDS

The nacelle external lines for the finalized DC-9 flight testbed may be contoured in such a manner as to minimize the local disturbances to the wing flow. Analytical methods will be used to determine the local flow streamlines and the nacelle will be accordingly shaped, within practical structural and mechanical constraints, to these streamlines.

The final prop-fan/engine/nacelle installation on the wing, from the aerodynamic point of view, will be evaluated by taking into account the pressure distributions calculated for the proposed flight test geometry.

NACELLE AND WING STRUCTURAL INTEGRATION

The installation of a prop-fan on the wing of a DC-9 testbed aircraft is a simple arrangement within minimum rework required to the existing structure. The aircraft is to be refurbished, upon completion of the test program, to its original configuration. The location of the prop-fan in relation to the wing is critical, requiring a long nacelle which extends well forward of the wing leading edge.

Previous turboprop installations have been mounted to a metal tube truss arrangement as the propellers were generally a short distance forward of the wing leading edge. These original structural arrangements utilizing tubular members were not fail-safe due to a single strut configuration. Fixes incorporated into this type of arrangement added weight to both the gearbox mount and to the supporting nacelle structure. Consequently, with the long nacelle necessary for the satisfactory prop-fan installation, consideration is given to an integrated structural design. This has proven to be a feasible arrangement.

Two different turboshaft engines, the Allison T701 and T56, are considered for use as the power source for the prop-fans. Each utilizes the same gearbox with some slight modifications.

Preliminary sketches of the T701 and the T56 engine installations on the DC-9-10 wing are shown in Figures 43 and 44, respectively. The T701 arrangement is more compact and the nacelle size meets the preliminary requirements for blockage limitations set forth by Hamilton Standard for an approximate ten foot (3.05 m) diameter prop-fan.

The length of the nacelle supporting the T701 engine package is 169 inches (429 cm), or 14.08 feet (4.29 m). This is measured from the wing quarter chord to the prop-fan plane. The T56 installation is 179 inches (455 cm), or 14.91 feet (4.55 m), based on the same ground rules. Based on Hamilton Standard data,(Reference 2) shown in Figure 45, the minimum length for the T701 nacelle designed for $M_{cruise} = .8$, with the ten foot (3.05 m) diameter prop-fan, is 147 inches (373 cm or 12.2 feet (3.73 m).

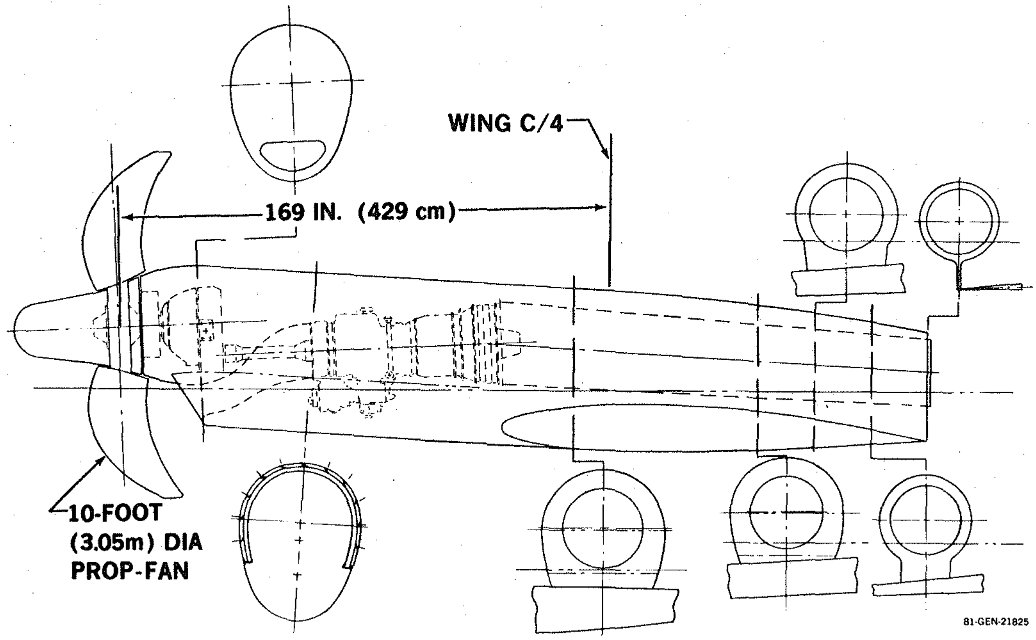


FIGURE 43. INSTALLATION OF ALLISON T701 ENGINE AND PROP-FAN ASSEMBLY ON DC-9-10 AIRCRAFT WING

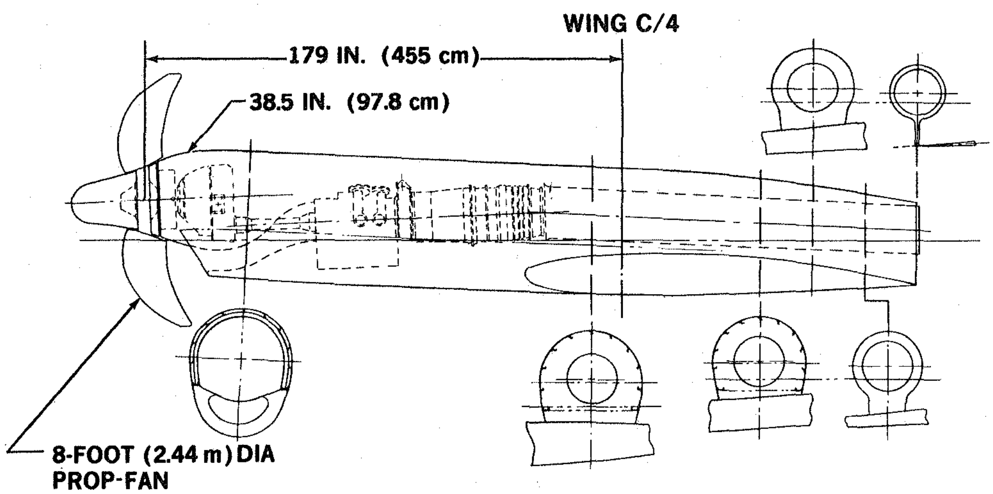


FIGURE 44. INSTALLATION OF ALLISON T56 ENGINE AND PROP-FAN ASSEMBLY ON DC-9-10 AIRCRAFT WING

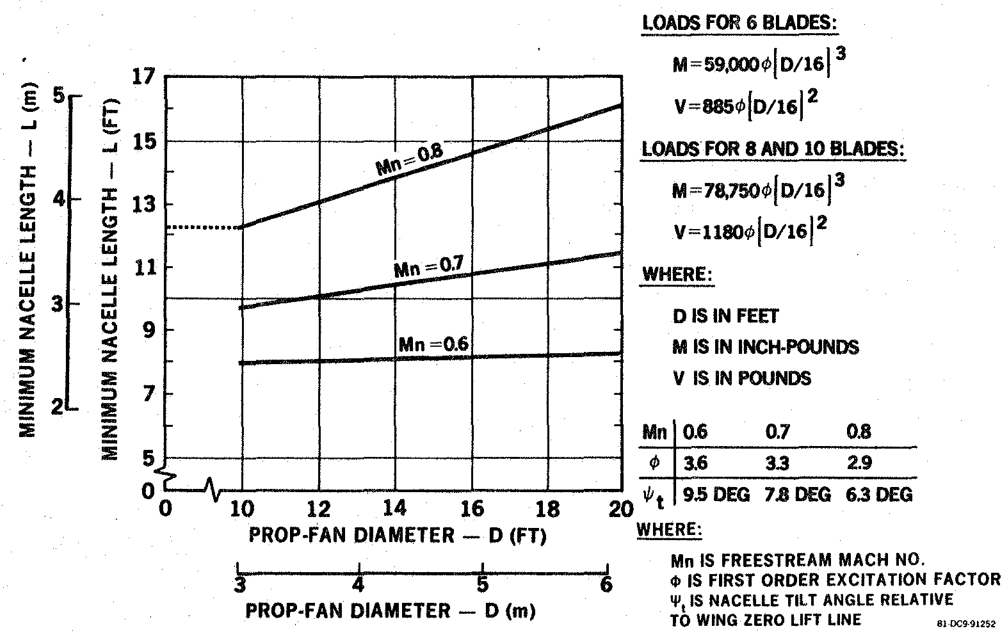


FIGURE 45. MINIMUM PROP-FAN NACELLE LENGTH AND LOAD DATA (REF 2)

The minimum length of the T56 nacelle, with an 8 foot (2.44 m) prop-fan, is not quoted on Figure 45. The T56 nacelle is longer than the T701 nacelle and is, therefore, assumed to exceed the minimum length. The nacelle lengths are determined by positioning the engines completely forward of the wing front spar. This positioning allows easy access to, and removal of, the engine without removing the nacelle.

The basic diameter of the nacelle for the T701 installation is 42 inches (107 cm) which corresponds to 35 percent of the 120 inches (305 cm) prop-fan diameter. This is compatible with the Hamilton Standard recommendations as noted on Figure 46.

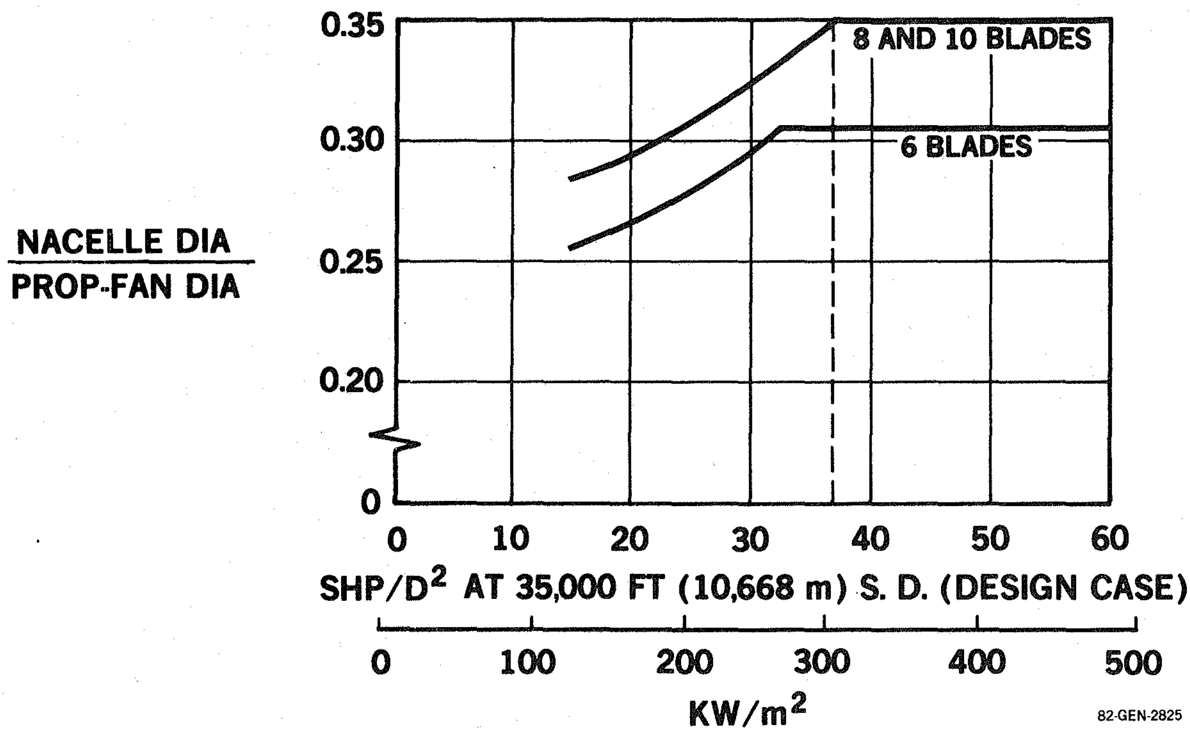


FIGURE 46. RECOMMENDED NACELLE/PROP-FAN DIAMETER RATIO

The T56 installation has the same gearbox; therefore, the nacelle can only be reduced to a minimum of 38.5 inches (97.8 cm) diameter, thus the nacelle to prop-fan diameter ratio becomes 40 percent which is in excess of the Hamilton Standard recommendation.

Guidelines were established by Hamilton Standard for the design of the prop-fan spinner and hub. The shape of the system is plotted in Figure 47. The T701 engine installation is able to conform to these lines. The T56 nacelle requires a larger hub than the 35 percent recommended.

As noted in previous sections, the Allison T701 engine package is selected for the DC-9-10 testbed installation. The structural configuration will be described for this system in the following paragraphs.

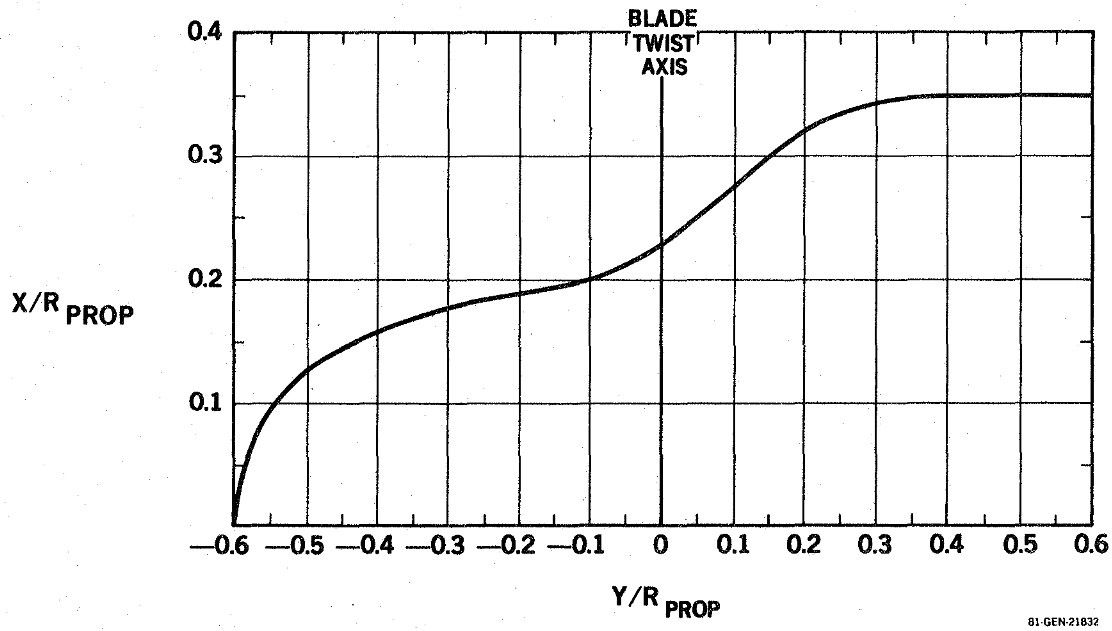


FIGURE 47. RECOMMENDED PROP-FAN SPINNER AND HUB DESIGN

Structural Configuration

The structural arrangement of the T701 nacelle is a horseshoe shaped semi-monocoque aluminum configuration consisting of frames, stiffeners and skin, as shown in Figure 48.

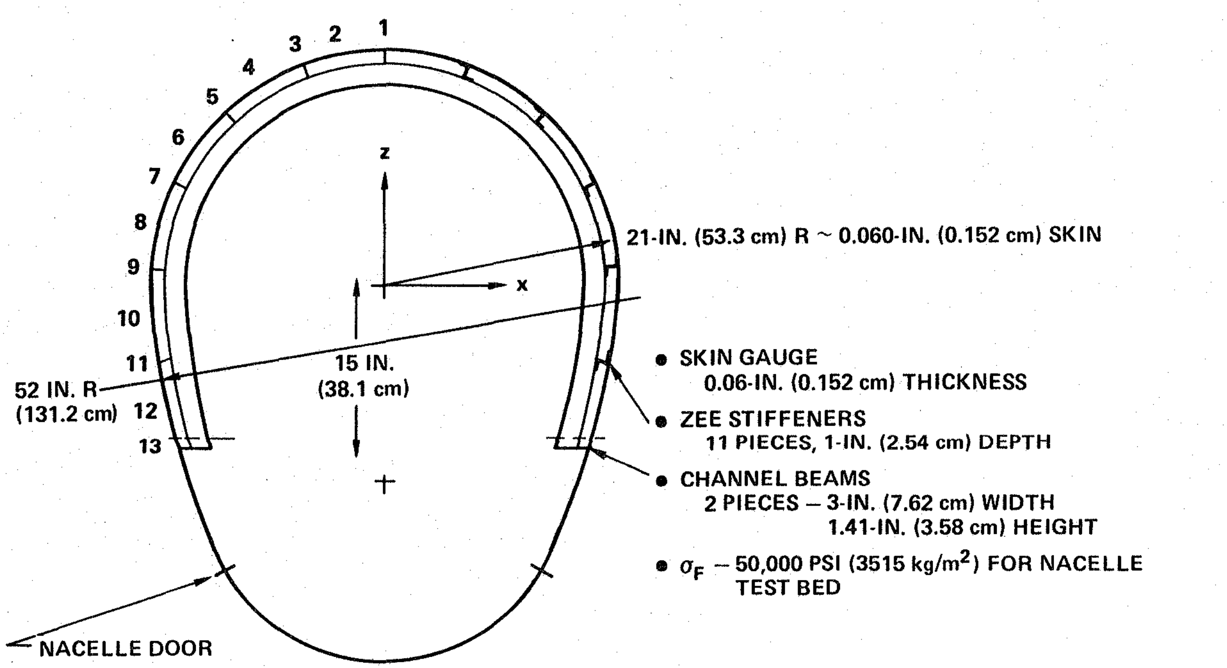


FIGURE 48. DC-9 PROP-FAN NACELLE STRUCTURE

A modified T56 gearbox and a T701 engine are secured together as a single unit; therefore, their structural support is at the gearbox centerline and the aft mount of the engine. Fail-safe supports can be designed at each attach point and the shell structure is a fail-safe member between them.

Access to the engine section is through an access door covering the entire lower portion of the nacelle. The door opening is from the back face of the gearbox to midway between the wing leading edge and front spar. The door is hinged on the outboard side and when closed and latched will provide a torque path for the balance of the structure. The door structure is an aluminum inner and outer skin arrangement stiffened with aluminum ribs.

The engine and gearbox assembly is positioned at an angle to the centerline of the nacelle, in the profile view, in order to provide adequate prop-fan ground clearance and to keep the nacelle close to the wing upper surface. The engine tail pipe is positioned so that any raw fuel from engine starts will drain aft, away from wing structure.

Nacelle Attachment to Existing Wing Structure

Two aircraft have been considered for the flying testbed. They are the -10 and -30 series of the DC-9 airplane. The two wing structural boxes are similar. The -30 is more difficult to rework because of the leading edge slat system. The proposed structural integration of the prop-fan nacelle is such that a minimum of rework is necessary to the wing box. Two machined fittings are mounted to the forward side of the front spar. Straps are installed on the upper and lower skins to introduce the loads into the wing box.

Two machined fittings are attached on the aft side of the rear spar with straps from the fittings to both skins. The forward set of attachments resist vertical, thrust, and side loads. The aft set has vertical and side loads. A pictorial view is shown in Figure 49.

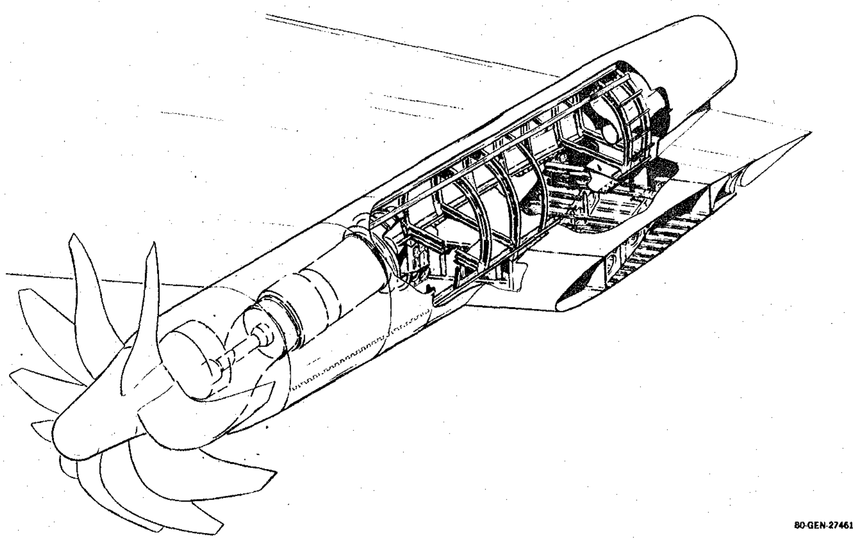


FIGURE 49. SCHEMATIC OF NACELLE/WING STRUCTURAL INTERSECTION

The nacelle extends aft over one spoiler and the flap system. Therefore, this spoiler and the opposite wing spoiler section must be deactivated. The nacelle support fittings on the rear spar do not encroach upon the spoiler structure; therefore, no structural rework is required. The nacelle is cantilevered from the rear spar aft; consequently, operation of the flap system is not affected.

The wing leading edge structure is removed in the area of the nacelle and will have to be replaced for refurbishing. The -10 series aircraft has only the fixed leading edge. The -30 series has a slat system that must be deactivated on the opposite wing for flight tests. The rework of the slatted wing is more extensive than for the fixed structure of the -10 aircraft.

Preliminary Load Criteria

The DC-9 aircraft design speeds are plotted in Figure 50 for both the -10 and -30 series. Each has an 0.84 Mach number cruise capability at altitude, from 23,500 to 35,000 feet (7,163 to 10,668 m).

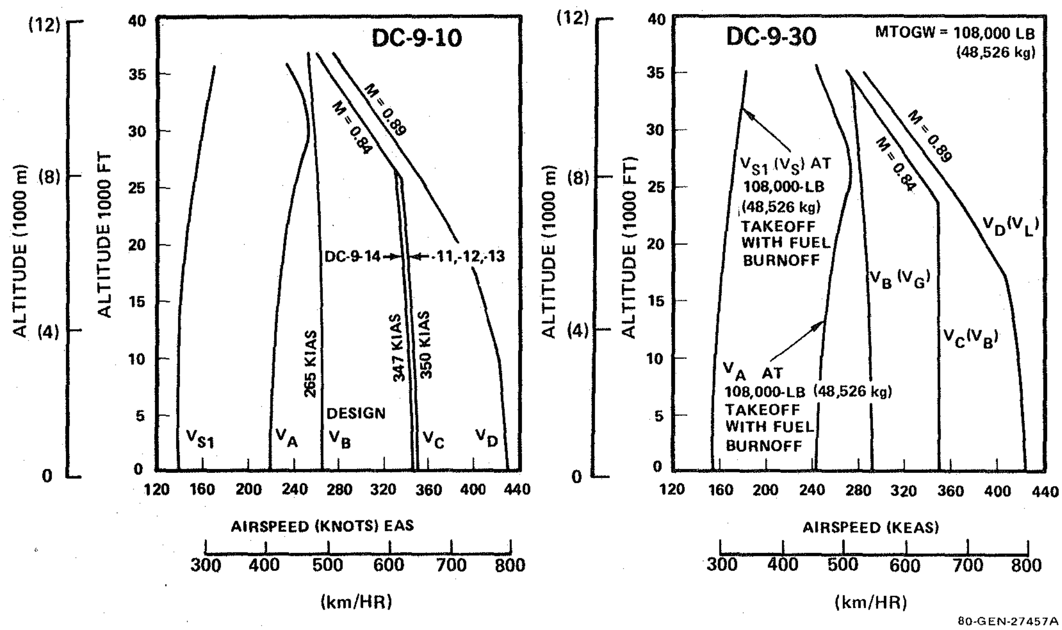
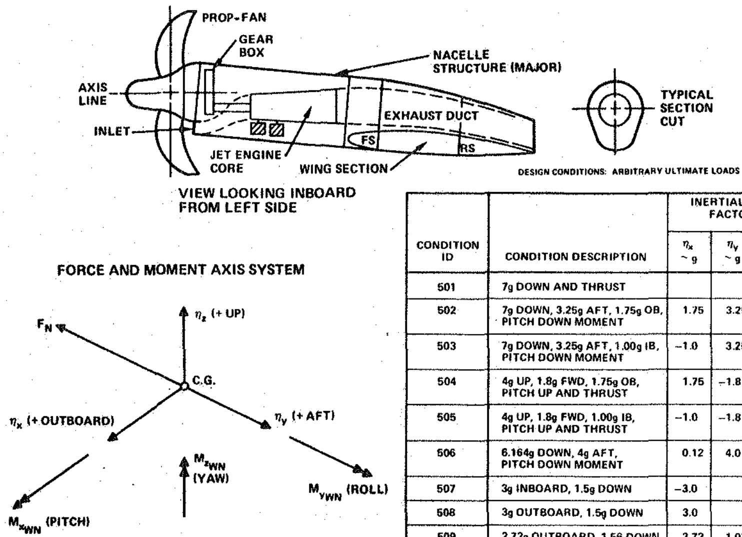


FIGURE 50. AIRCRAFT DESIGN SPEEDS

The prop-fan/gearbox system strength will be assumed to be safe life, thus precluding fail-safe design for any remote possibility of a seizure of the rotating elements. However, engine seizure of the gas generator, resulting in decoupling between itself and the gearbox, will be considered. Spool-down time will be one (1) second for any single spool seizure. The spool-down time for any two spool seizures will be two (2) seconds. This follows DC-10 fan jet criteria.

Structural integrity involves safe flight throughout the expected flight regime for the prop-fan testbed. Structural placards related to possible restrictions such as gross weight, maneuvers, placard speeds and touchdown sink rate will be determined in the design phase.

The loads used to define the preliminary structural member sizes are based on typical wing mounted nacelle load factors from the DC-10 criteria. The noted load factors and thrust loads are listed in Figure 51. The preliminary analysis gives values for wing-to-nacelle attach loads that can be tolerated by this structural arrangement without a major wing rework program. The loads are noted in Figure 52. The final nacelle-wing attach loads will be determined in the testbed design phase.



DESIGN CONDITIONS: ARBITRARY ULTIMATE LOADS

CONDITION ID	CONDITION DESCRIPTION	INERTIAL LOAD FACTORS			F_N $\times 10^{-3}$ LB	$M_{X_{WN}}$ $\times 10^{-6}$ IN-LB	$M_{Y_{WN}}$ $\times 10^{-6}$ IN-LB	$M_{Z_{WN}}$ $\times 10^{-6}$ IN-LB
		η_x ~ g	η_y ~ g	η_z ~ g				
501	7g DOWN AND THRUST			−7.0	9			
502	7g DOWN, 3.25g AFT, 1.75g OB, PITCH DOWN MOMENT	1.75	3.25	−7.0				
503	7g DOWN, 3.25g AFT, 1.00g IB, PITCH DOWN MOMENT	−1.0	3.25	−7.0				
504	4g UP, 1.8g FWD, 1.75g OB, PITCH UP AND THRUST	1.75	−1.8	4.0				
505	4g UP, 1.8g FWD, 1.00g IB, PITCH UP AND THRUST	−1.0	−1.8	4.0				
506	6.164g DOWN, 4g AFT, PITCH DOWN MOMENT	0.12	4.0	−6.164				
507	3g INBOARD, 1.5g DOWN	−3.0		−1.5				
508	3g OUTBOARD, 1.5g DOWN	3.0		−1.5				
509	2.72g OUTBOARD, 1.56 DOWN, PITCH DOWN AND YAW OB MOMENTS	2.72	−1.07	−1.56				
510	MAX. YAW MOMENT AND 1.5g DOWN			−1.5				
511	LIMIT THRUST x 2.25				18			
512	MAX. REVERSE THRUST AND 1.5g DOWN			−1.5				
513	MAX. SEIZURE TORQUE AND 1.5g DOWN			−1.5				

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FIGURE 51. NACELLE STRUCTURAL LOADS

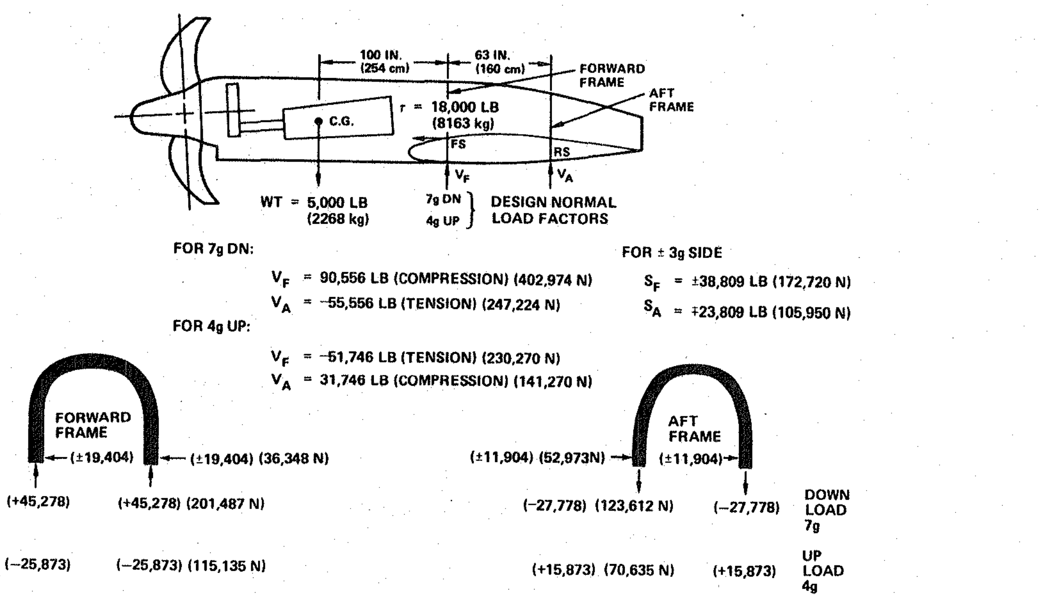

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FIGURE 52. NACELLE/WING FRAME SUPPORT LOADS

Preliminary Whirl Mode Analysis

Hamilton Standard has determined the minimum structural stiffness required to prevent the prop-fan whirl mode and it is replotted as a "carpet" plot, Figure 53. The stiffness of the nacellee is shown in Figure 54.

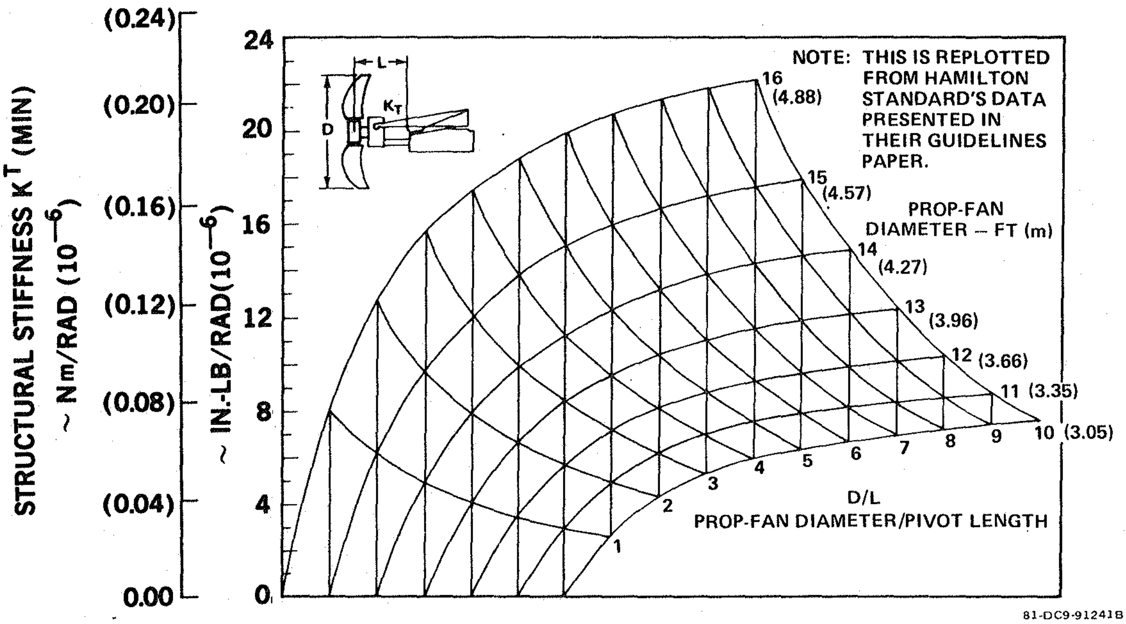
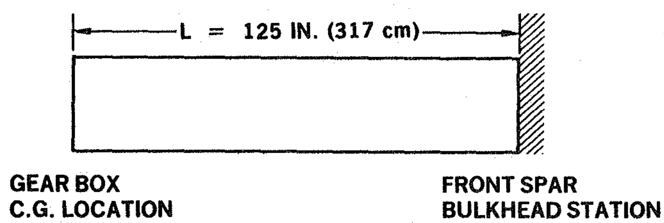


FIGURE 53. NACELLE STIFFNESS REQUIRED TO PREVENT WHIRL FLUTTER VERSUS PROP-FAN-DIAMETER-TO-NACELLE-LENGTH RATIO



DOWNWARD DEFLECTION

(FROM TIE-IN OF NACELLE TO WING TO CENTER OF GEAR BOX)

0.0361 INCHES PER 1000-LB LOAD (0.0917 cm/453 kg)

LATERAL DEFLECTION

(APPLIED AT ATTACHMENT OF GEAR BOX ON NACELLE)

0.0231 INCHES PER 1000-LB LOAD (0.0587 cm/453 kg)

FIGURE 54. STIFFNESS OF PROP-FAN NACELLE

Definition of terminology shown in the preceding Figures 51 and 52 is as follows:

K_T - minimum effective torsional stiffness of wing/nacelle mount system (pitching)

L - distance from the wing C/4 station to the prop-fan plan of rotation

D - prop-fan diameter

A preliminary flutter/whirl mode analysis is performed to determine the feasibility of installing the prop-fan assembly as far forward of the wing as required with the stiffened monocoque structure as developed. This analysis is performed using the Allison T701 engine with a 10 foot (3.05 m) diameter 10 blade prop-fan with a tip speed of 800 feet per second (244 m/sec).

The results are shown in Figure 55. The total installation is predicted to be flutter-free and stable in a whirl mode up to 1.2 V_D (475 KEAS) [475 km/kg] of the DC-9 airplane. These conceptual analyses will be expanded prior to design release.

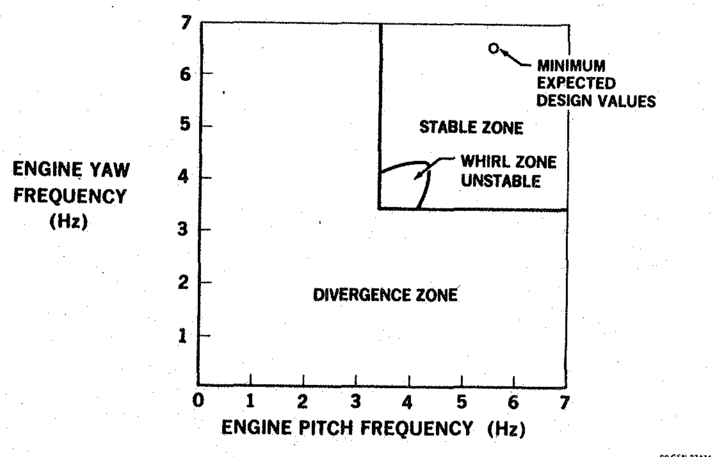


FIGURE 55. WHIRL FLUTTER BOUNDARY

Prop-fan Excitation Factors

Hamilton Standard performed several analyses to determine the effect on prop-fan excitation factors of length of nacelle, wing sweep, and direction of rotation near the fuselage for the DC-9-10 aircraft. The lowest factors for the T701 and T56 installations occurred for a prop-fan rotation where the tips rotate up near the fuselage (up inboard).

The effect of prop-fan rotation on excitation factors are compared to design values formulated by Hamilton Standard and are presented in Figure 56. As shown in Figure 56, the excitation factors are lower for the up-inboard rotation case. The prop-fan excitation factors are calculated for the T701 engine installation on both the -10 and -30 series of the DC-9. The results are compared to each other and to the established design values shown on Figure 57. For this comparison the prop-fan rotation considered in this figure is down-inboard. The series -30 arrangement has the lowest calculated values for the excitation factor.

DC-9-10

PROP-FAN DIAMETER 9.5 FT (2.90 m) T-701
8.1 FT (2.47 m) T-56

NACELLE DOWNTILT — 4.3 DEG (0.075 rad)
PROP PLANE DISTANCE TO WING C/4 = 14.08 FT (4.29 m)
MAXIMUM WEIGHT CLIMB

PROP-FAN ROTATION		HAM STD DESIGN VALUE	UP INBOARD		DOWN INBOARD	
TURBOSHAFT ENGINE			T-701	T-56	T-701	T-56
EQUIVALENT DES 1P EF		4.5	3.756	3.670	4.753	4.617
BASIC 1P ONLY		3.3	3.329	3.255	3.329	3.253
RELATIVE	1P	1.0	1.0	1.0	1.0	1.0
	2P	0.375	0.062	0.058	0.312	0.308
	3P	0.111	0.054	0.052	0.085	0.082
	4P	0.048	0.011	0.010	0.023	0.023
	5P	0.024	0.003	0.002	0.007	0.006

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FIGURE 56. EFFECT OF DIRECTION OF PROP-FAN ROTATION AND EXCITATION FACTORS (EF) OF PROP-FAN INSTALLATION

MAXIMUM WEIGHT CLIMB
PROP-FAN DIAMETER — 9.5 FT (2.90 m)
PROP-FAN ROTATION — DOWN INBOARD

		HS DESIGN VALUES	DC-9-10	DC-9-30
			T-701	T-701
EQUIVALENT DES 1P EF		4.5	4.753	2.940
BASIC 1P ONLY		3.3	3.329	2.736
RELATIVE	1P	1.0	1.0	1.0
	2P	0.375	0.312	0.072
	3P	0.111	0.085	0.004
	4P	0.048	0.023	0.008
	5P	0.024	0.007	0.003

80-GEN-27453A

FIGURE 57. DC-9-10 AND DC-9-30 PROP-FAN EXCITATION FACTORS

Sensitivity of the prop-fan excitation factor to nacelle installation geometry is calculated for the T701 engine on the DC-9-30 airplane. Parametric variation of down tilt angle and nacelle length (Figures 56 through 58) are considered. The down tilt angle refers to the orientation of the prop-fan relative to the wing zero lift line such that the inflow to the prop-fan is at or near zero degrees. The down tilt angle for the prop-fan is varied from 0 degrees to -6 degrees (.105 radians). The 6 degree (.105 radians) down tilt position has the smallest excitation factor. As can be seen from Figure 58, the shorter nacelle length, 9.0 feet (2.74 m), results in considerably higher excitation factors over those associated with the basic design length of 14.08 feet (4.29 m).

DC-9-30

T-701 TURBOSHAFT ENGINE
MAXIMUM WEIGHT CLIMB
PROP PLANE TO C/4 = 14.08 FT (4.29 m), DOWNTILT = 4.3 DEGREES (0.075* rad)
PROP-FAN ROTATION — DOWN INBOARD

	BASIC CONDITION	NACELLE LENGTH = 9.0 FT (2.74 m)	DOWNTILT = 6 DEG (0.105 rad)	DOWNTILT = 2 DEG (0.035 rad)	DOWNTILT = 0 DEG
EQUIVALENT DES 1P EF	2.940	4.682	2.139	4.0811	5.130
BASIC 1P ONLY	2.736	3.619	2.031	3.682	4.500
RELATIVE 1P	1.0	1.0	1.0	1.0	1.0
RELATIVE 2P	0.072	0.135	0.044	0.108	0.138
RELATIVE 3P	0.004	0.043	0.007	0.002	0.004
RELATIVE 4P	0.008	0.005	0.010	0.006	0.005
RELATIVE 5P	0.003	0.0009	0.004	0.003	0.002

*[REFERENCE CASE]

80-GEN-27450A

FIGURE 58. SENSITIVITY OF PROP-FAN EXCITATION FACTOR TO NACELLE INSTALLATION GEOMETRY

Alternate Testbed Structural Arrangement

The basic installation of the prop-fan nacelle on the wing is shown in Figure 43. The excitation factor is influenced by the nacelle length as measured from the wing quarter chord and by the angle the prop-fan plane makes with the wing zero lift line. Therefore, a proposed testbed structural arrangement to determine flight test data for various nacelle lengths and prop-plane tilts is developed during this phase of the study. A schematic is shown in Figure 59.

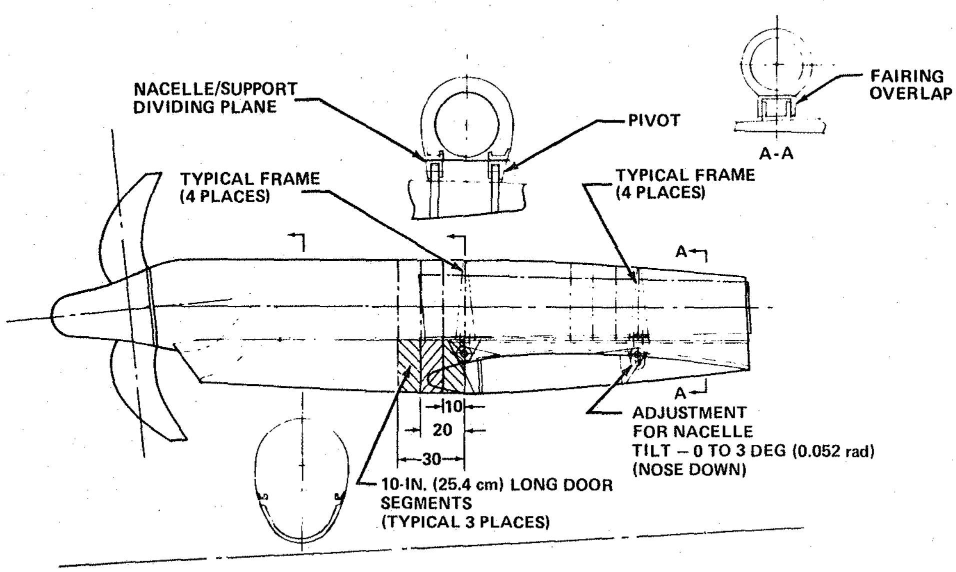


FIGURE 59. PROPOSED NACELLE TESTBED ARRANGEMENT FOR VARIOUS PROP LOCATIONS AND TILT RELATIVE TO THE WING

The nacelle is attached to a mounting plate with eight tension bolts. There are three additional nacelle frames each at the wing front and rear spar attachment locations. Thus the nacelle may be moved as much as 30 inches (76.2 cm) aft from the initial installation. The lower access door has three 10 inch (25.4 cm) long segments that may be removed separately as needed when moving the nacelle aft.

The mounting plate is arranged such that it may be tilted nose down by pivoting at the wing front spar location. The wing rear spar connection controls the amount of tilt. The simple mechanical adjustment could be made on the ground.

PREFERRED NACELLE/WING INSTALLATION

Preliminary layouts and conceptual analyses have shown the feasibility of installing a semi-monocoque structure nacelle, by means of four-point attachment, to a DC-9 wing for flight testing. The resulting structural stiffness is adequate to prevent whirl flutter. Provision is made for easy engine removal. Rework of the wing box structure is minimized as an aid to refurbishment after the test program. Summary of the advantages of this engine/prop-fan structural mounting concept is given in Figure 60.

SIMPLE, STRAIGHTFORWARD MOUNT

STIFF MOUNT EFFECTIVE IN FLUTTER AND/OR WHIRL FLUTTER REDUCTION

EASE OF MAINTENANCE

- **ENGINE REMOVAL FREE OF WING INTERFERENCE**
- **ACCESS TO NACELLE**
- **MODULAR ENGINE/PROP-FAN/GEAR BOX/ACCESSORY MAINTENANCE**

80-GEN-27440

FIGURE 60. ENGINE/PROP-FAN STRUCTURAL MOUNTING CONCEPT ADVANTAGES

It is recommended that a testbed article should be built and flown utilizing the alternate configuration to obtain data for the various nacelle lengths and tilts possible. Consideration should be given to the possibility of changing the tilt during flight since various stages of a flight mission profile could impose large excitation factors when the prop-fan is not aligned correctly with the wing flow field.

PROP-FAN CONFIGURATION WEIGHTS

Three testbed prop-fan propulsion system installation concepts are evaluated utilizing DC-9-10 weights and geometry (shown in Table 4) as the baseline airplane. The three wing-mounted prop-fan propulsion systems considered are one Allison T701 turboshaft engine, one Allison T56 turboshaft engine, and the two Allison T701 turboshaft engines shown in Figures 11, 12, and 13, respectively.

One T701 Prop-fan Configuration

A group weight summary of the one engine T701 prop-fan installation, Figure 11, is presented in Table 5. Description of the component systems follows.

The wing geometry and weight is like the DC-9-10 aircraft, except for a minimal rework which is required for the integration of the prop-fan nacelle to the wing. The rework includes the installation of four attach points (two fittings located forward of the front spar and two fittings located aft of the rear spar). The wing weight includes a weight penalty for the eight local straps, located on the upper and lower skin panel and at each attach point, which distribute the prop-fan installation loads into the wing box structure.

The horizontal and vertical stabilizer, fuselage, landing gear design and weights are identical to the DC-9-10 airplane.

The flight control system weight is identical to the DC-9-10. The inboard spoiler panel and actuation mechanism on both sides of the wing is deactivated. The weight penalty required to deactivate the mechanism is negligible.

The turbofan nacelle, pylon, engine, and engine system weight of the basic prop-fan testbed airplane is identical to the DC-9-10 aircraft.

The fuel system weight is increased over the base DC-9-10 weight to reflect the additional plumbing required to supply fuel from the existing DC-9 fuel system to the prop-fan engine.

TABLE 4

WEIGHTS AND GEOMETRY
BASELINE DC-9-10 AIRCRAFT

	English Units	Metric Units
Maximum Ramp Gross Weight	87,100 lb	39,501 Kg
Maximum Takeoff Gross Weight	86,300	39,138
Maximum Landing Gross Weight	81,700	37,052
Maximum Zero Fuel Gross Weight	71,800	32,562
Operational Empty Weight	50,213*	22,772
Manufacturer's Empty Weight	47,602*	21,588
Trapezoidal Wing Area (Planform Area)	834 ft^2	77.5 m^2
Theoretical Horizontal Tail Area	276 ft^2	35.65 m^2
Theoretical Vertical Tail Area	161 ft^2	14.96 m^2
Total Fuselage Length	1,105 in	28.07 m
Total Number of Passengers	72	
(12) First Class		
(60) Tourist		

Two (2) Aft Fuselage Side-Mounted JT8D-7

* Derived from Air Canada DC-9-14 (DTS 3506)** and averaged actual MEW of six aircraft at time of original delivery.

** Air Canada Series 14 (Series 10 Standard airplane plus Specification Change Notices) defined in Detailed Type Specification 3506.

TABLE 5A

DC-9-10 PROPFAN TESTBED GROUP WEIGHT SUMMARY

ONE WING MOUNTED ALLISON T701 PROPFAN

English Units

Maximum Ramp Gross Weight		87,100 lb
Maximum Takeoff Gross Weight		86,300
Maximum Landing Gross Weight		81,700
Maximum Zero Fuel Gross Weight		71,800
Wing		9,290
Horizontal Tail		1,527
Vertical Tail		1,092
Fuselage		9,336
Landing Gear		3,640
Flight Controls		1,276
Nacelle and Pylon - Basic Airplane		1,418
Engine and Systems - Basic Airplane		7,119
Propfan Propulsion System		3,925*
Turboshaft Engine	1,152 lb	
Propeller and Controls	857	
Gearbox and Struts	658	
Engine Systems	321	
Nacelle, Exhaust, and Mount Structure	892	
Nacelle to Wing Attach	45	
Fuel Systems		534*
Instruments and Warning		665
Auxiliary Power Units		805
Hydraulic System		418
Pneumatic System		283
Electrical System		1,275
Avionics		671
Furnishings		6,825
Air Conditioning		1,016
Ice Protection		472
Handling Gear		19
Ballast Lateral		2,030*
Testbed Manufacturer's Empty Weight		53,617 lb
Testbed Operator Items (Table 6)		1,020*
Testbed Operational Empty Weight		54,637 lb

*Changed or added weight

TABLE 5B

DC-9-10 PROPFAN TESTBED GROUP WEIGHT SUMMARY

ONE WING MOUNTED ALLISON T701 PROPFAN

Metric Units

Maximum Ramp Gross Weight		39,501 Kg
Maximum Takeoff Gross Weight		39,138
Maximum Landing Gross Weight		37,052
Maximum Zero Fuel Gross Weight		32,562
Wing		4,204
Horizontal Tail		692
Vertical Tail		495
Fuselage		4,234
Landing Gear		1,650
Flight Controls		574
Nacelle and Pylon - Basic Airplane		643
Engine and Systems - Basic Airplane		3,228
Propfan Propulsion System		1,780*
Turboshaft Engine	522 Kg	
Propeller and Controls	389	
Gearbox and Struts	298	
Engine Systems	146	
Nacelle, Exhaust, and Mount Structure	405	
Nacelle to Wing Attach	20	
Fuel Systems		242
Instruments and Warning		302
Auxiliary Power Units		365
Hydraulic System		190
Pneumatic System		128
Electrical System		578
Avionics		304
Furnishings		3,095
Air Conditioning		461
Ice Protection		214
Handling Gear		9
Ballast Lateral		921*
Testbed Manufacturer's Empty Weight		24,316 Kg
Testbed Operator Items (Table 6)		463*
Testbed Operational Empty Weight		24,779 Kg

*Changed or added weight

The prop-fan propulsion system weight includes a T701 turboshaft engine, a 10 blade Hamilton Standard prop-fan and prop-fan controls, a modified T56 gearbox, engine related systems, nacelle and mounting structure, and nacelle to wing attach structure. The T701 engine weight is based on information dated August 1980 from Detroit Diesel Allison. The prop-fan weight represents a 10 blade, 9.5 foot (2.90 m) diameter, 800 feet per second (244 m/sec) tip speed, Hamilton Standard prop-fan. The prop-fan weight is based on Hamilton Standard's weight estimate which accounts for non-production processing methods and the use of current technology. The gearbox is a modified T56 gearbox; the modification provides compatibility between the T701 engine, prop-fan, and T56 gearbox. The gearbox weight is based on information from Allison and includes the gearbox, shaft, struts, and oil. The prop-fan engine-related systems weight is based on the P-3A Allison T56-A-10 systems weight which includes the lubrication system (oil tank installation, cooling system, ducting, and plumbing), engine controls, fire warning and extinguishing system, and the start system.

The nacelle structure weight is based on a preliminary design layout shown in Figure 43. The metal fabricated upper nacelle structure is a semi-monocoque design, constructed from skins, zee stiffeners, intermediate frames, engine and nacelle mounts and frames, machined bulkheads, shear clips, lower keel beam members, and attachments. The lower access door panel installation weights include skins, doublers, frames, latching, and hinges. The weights for the upper nacelle structure and lower access doors are estimated from preliminary structural member sizing calculations. The engine air inlet installation weight is based on preliminary estimates and includes skins, frames, intake duct, lip assembly, seals, and attachments. The engine exhaust tailpipe and aft fairing installation weights are based on statistical data of similar designs. The weight includes the inner tailpipe installation, which starts at the turbine rear flange and terminates at the exhaust nozzle plane, and the aft outer fairing installations, which begins at the rear spar plane and ends at the exhaust nozzle plane. The nacelle weight also includes the lower nacelle to wing fairing and a titanium fireshield located between the wing leading edge and the rear spar. The nacelle to wing attach structure weight is based on preliminary estimates and does account for the attach structure and attachments required to secure the prop-fan installation to the four attach points located on the wing. The group weights for the instruments and warning system, auxiliary power unit, hydraulic system, electrical system, avionics, air conditioning system, ice protection system, and handling gear are identical to the base DC-9-10 weights.

The furnishings group weight is also identical to the base DC-9-10 which includes seats and passenger accommodations for twelve (12) first class passengers and sixty (60) coach passengers. The production DC-9-10 cabin sidewall panels and acoustic treatment, shown in Figure 33, are used for the baseline testbed weight. The weight penalties associated with the various acoustic treatments required for the acoustic test are assumed part of the payload weight.

The base DC-9-10 pneumatic system weight is increased to reflect additional ducting, valves, and controls necessary to supply bleed air to start the prop-fan engine. The weight penalty for the modification is based on preliminary estimates.

The lateral imbalance caused by the single prop-fan installation on one side of the wing is corrected by installing ballast on the opposite side of the wing; thus the testbed airplane lateral flying qualities are made similar to the basic DC-9. Lead weights are installed in the wing between the front and rear spar at the most practical outboard spanwise location.

The operator items weight for the testbed airplane is based on the ACA (DTS 3506) DC-9-14 weights and modified to represent weight consisting of items most likely to be considered in a testbed program. The modification includes the removal of two cabin crew members and their baggage, food, liquids, commissary equipment, cabin supplies, galley inserts, and twenty gallons of potable water. The remaining weight, with the addition of the prop-fan engine oil and unusable fuel weight is shown in Table 6.

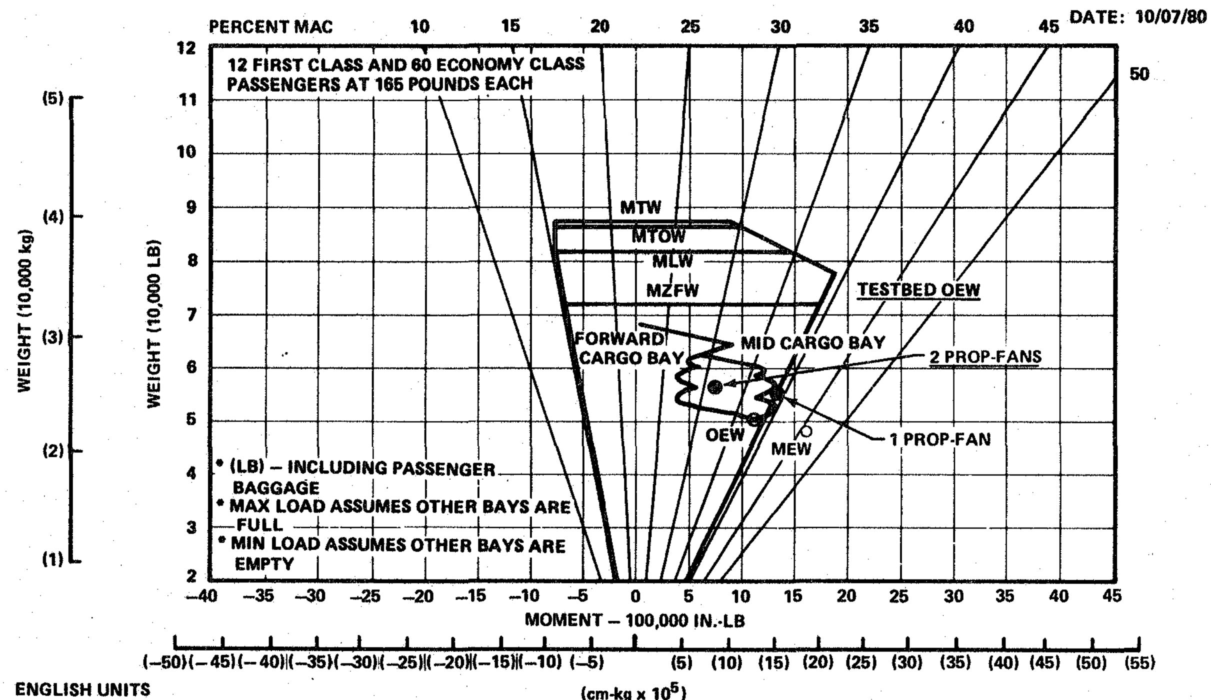
TABLE 6

TESTBED OPERATIONAL ITEMS WEIGHT

ONE ALLISON T701 PROPFAN

	English Units	Metric Units
Unusable Fuel	249 lb	113 Kg
Unusable Oil (Base Engine, APU < & CSD)	46	21
Toilet Chemicals and Water	45	20
Crew Compartment Manuals	10	5
Emergency Escape Chute	48	22
Flight Crew - 2 @ 170 lb (77.5 Kg) each	340	154
Briefcases	15	7
Oil (Basic Engine and APU)	89	40
Potable Water	85	39
Oil and Unusable Fuel - Turboshaft Engine	93	42
Total Testbed Operational Items Weight	1,020 lb	462 Kg

The balance diagram, shown in Figure 61, represents the loading features of the base DC-9-10 airplane. The operational empty weight center-of-gravity (c.g.) of the one engine prop-fan configuration and the two engine prop-fan configuration are superimposed over the DC-9-10 to show that all of the prop-fan configurations are within the DC-9-10 c.g. limits. The test equipment (payload) should be placed in the forward section of the passenger cabin to insure that the airplane c.g. is always forward of the aft balance limit.



ENGLISH UNITS

MAX TAXI WEIGHT (MTW) (LB):	97100
MAX TAKEOFF WEIGHT (MTOW) (LB):	86300
MAX LANDING WEIGHT (MLW) (LB):	81720
MAX ZERO FUEL WEIGHT (MZFW) (LB):	71800
OPERATORS EMPTY WEIGHT (OEW) (LB):	58213

INTERIOR ARRANGEMENT PER OW5 5900540

MEAN AERODYNAMIC CHORD (MAC) (IN.):	141.500
LEADING EDGE MAC (5TH):	543.130
QUARTER CHORD (C/4) (STA):	580.000
REFERENCE STATION (STA):	580.000
DEW CENTER OF GRAVITY (STA):	502.800

METRIC UNITS

MAX TAXI WEIGHT (MTW) (kg)	44036
MAX TAKEOFF WEIGHT (MTOW) (kg):	39138
MAX LANDING WEIGHT (MLW) (kg)	37061
MAX ZERO FUEL WEIGHT (MZFW) (kg):	32562
OPERATORS EMPTY WEIGHT (OEW) (kg):	26400

MEAN AERODYNAMIC CHORD (MAC) (m):	359.4
LEADING EDGE MAC (5TH)	1379
QUARTER CHORD (C/4) (STA):	1473
REFERENCE STATION (STA):	1473
DEW CENTER OF GRAVITY (STA):	1277

80-GEN-27458B

FIGURE 61. DC-9-10 CG DIAGRAM

Two T701 Prop-fan Configuration

A group weight summary of the two engine T701 prop-fan DC-9-10 configuration (Figure 13) is shown in Table 7.

The wing weight is similar to the one engine prop-fan configuration shown in Table 5, except the rework weight penalty for the integration of the prop-fan nacelles to the wing is twice as much as the one engine prop-fan configuration. The horizontal stabilizer, vertical stabilizer, fuselage, landing gear, flight control system, and the basic airplane nacelle, pylon, engine, and engine system weights are identical to the one engine prop-fan configuration.

The fuel system weight is like the one engine prop-fan fuel system weight, except the prop-fan engine fuel supply plumbing weight penalty is twice as much.

The two engine prop-fan propulsion system consists of two Allison T701 prop-fan installations (one on each side of the fuselage). The geometry is like the one engine T701 prop-fan installation with the engine, propeller and controls, engine systems, nacelle, engine mounting structure, and nacelle to wing attach structure. The total propulsion system weight is twice as heavy as the one engine prop-fan installation. A weight penalty is added to one modified T56 gearbox to reflect an idler gear and housing installation required for the opposite rotation prop-fan.

The group weights for the instruments, auxiliary power unit, hydraulic system, electrical system, avionics, furnishings group, air conditioning group, ice protection group, and handling gear are identical to the one engine prop-fan configuration.

The pneumatic system weight is like that of the one engine T701 prop-fan configuration, except the prop-fan engine start system ducting, valve, and control weight penalty is twice as heavy as the one engine prop-fan penalty.

TABLE 7A

DC-9-10 PROPFAN TESTBED GROUP WEIGHT SUMMARY

TWO WING MOUNTED ALLISON T701 PROPFAN

English Units

Maximum Ramp Gross Weight		87,100 lb
Maximum Takeoff Gross Weight		86,300
Maximum Landing Gross Weight		81,700
Maximum Zero Fuel Gross Weight		71,800
Wing		9,290
Horizontal Tail		1,527
Vertical Tail		1,092
Fuselage		9,336
Landing Gear		3,640
Flight Controls		1,276
Nacelle and Pylon - Basic Airplane		1,418
Engine and Systems - Basic Airplane		7,119
Propfan Propulsion System		7,850*
Turboshaft Engine	2,304 lb	
Propeller and Controls	1,714	
Gearbox and Struts	1,316	
Engine Systems	642	
Nacelle, Exhaust, and Mount Structure	1,784	
Nacelle to Wing Attach	90	
Fuel Systems		554*
Instruments and Warning		665
Auxiliary Power Units		805
Hydraulic System		418
Pneumatic System		404*
Electrical System		1,275
Avionics		671
Furnishings		6,826
Air Conditioning		1,016
Ice Protection		472
Handling Gear		19
Ballast Lateral		0
Testbed Manufacturer's Empty Weight		55,572 lb
Testbed Operator Items (Table 8)		1,113*
Testbed Operational Empty Weight		56,685 lb

*Changed or added weight

TABLE 7B

DC-9-10 PROPFAN TESTBED GROUP WEIGHT SUMMARY

TWO WING MOUNTED ALLISON T701 PROPFAN

Metric Units

Maximum Ramp Gross Weight		39,501 Kg
Maximum Takeoff Gross Weight		39,138
Maximum Landing Gross Weight		37,052
Maximum Zero Fuel Gross Weight		32,562
Wing		4,213
Horizontal Tail		693
Vertical Tail		495
Fuselage		4,234
Landing Gear		1,651
Flight Controls		579
Nacelle and Pylon - Basic Airplane		643
Engine and Systems - Basic Airplane		3,229
Propfan Propulsion System		3,560*
Turboshaft Engine	1,045 Kg	
Propeller and Controls	777	
Gearbox and Struts	597	
Engine Systems	291	
Nacelle, Exhaust, and Mount Structure	809	
Nacelle to Wing Attach	41	
Fuel Systems		251*
Instruments and Warning		302
Auxiliary Power Units		365
Hydraulic System		190
Pneumatic System		183
Electrical System		578
Avionics		304
Furnishings		3,096
Air Conditioning		461
Ice Protection		214
Handling Gear		9
Ballast Lateral		0
Testbed Manufacturer's Empty Weight		25,202 Kg
Testbed Operator Items (Table 8)		505 *
Testbed Operational Empty Weight		25,707 Kg

*Changed or added weight

The operator items weight for the two engine prop-fan configuration is similar to the one engine prop-fan weight, except additional engine oil and trapped fuel weight is added to account for the second prop-fan installation as shown in Table 8.

TABLE 8

TESTBED OPERATIONAL ITEMS WEIGHT
TWO ALLISON T701 PROPFAN

	English Units	Metric Units
Unusable Fuel	249 lb	113 Kg
Unusable Oil (Base Engine, APU < & CSD)	46	21
Toilet Chemicals and Water	45	20
Crew Compartment Manuals	10	5
Emergency Escape Chute	48	22
Flight Crew - 2 @ 170 lb (77.5 Kg) each	340	154
Briefcases	15	7
Oil (Basic Engine and APU)	89	40
Potable Water	85	39
Oil and Unusable Fuel - Turboshaft Engine	186	89
Total Testbed Operational Items Weight	1,113 lb	505 Kg

One T56 Prop-fan Configuration

A group weight summary of the one engine T56 prop-fan DC-9-10 configuration (Figure 12) is shown in Table 9.

The airplane configuration and group weights are identical to the one engine T701 prop-fan airplane, except for the prop-fan propulsion system, lateral ballast, and operator items weights.

The prop-fan propulsion system weight includes a T56 turboshaft engine, a 10 blade Hamilton Standard prop-fan and prop-fan controls, a modified T56 gearbox, engine related systems, nacelle and mounting structure, and nacelle to wing attach structure. The T56 engine and gearbox weights are quoted from the Allison T56-A-15 engine installation drawing No. 6829700. The gearbox modification includes a change in gear ratio to provide the proper engine and prop-fan RPM combination. The gearbox weight includes the gearbox, struts, shaft, and oil and also accounts for the weight penalty for the gearbox modification which is assessed as being negligible. The prop-fan represents a 10 blade, 8.1 foot (2.47 m) diameter, 800 feet per second (244 m/sec) tip speed Hamilton Standard prop-fan. The prop-fan weight is based on Hamilton Standard's weight information which accounts for non-production processing methods and the use of current technology.

The prop-fan engine related systems weight is identical to a single P-3A engine systems weight, except the P-3A water injection system weight is removed. The engine systems weight also includes the fire warning and extinguishing system weight.

The nacelle structure weight is based on a preliminary design layout shown in Figure 44. The design, construction, and weight estimating methods of the upper nacelle structure, lower access doors, engine air inlet, engine exhaust tailpipe and aft fairing, firesheilds, and attach structure and attachments are similar to the one engine T701 prop-fan installation.

TABLE 9A

DC-9-10 PROPFAN TESTBED GROUP WEIGHT SUMMARY

ONE WING MOUNTED ALLISON T56 PROPFAN

English Units

Maximum Ramp Gross Weight		87,100 lb
Maximum Takeoff Gross Weight		86,300
Maximum Landing Gross Weight		81,700
Maximum Zero Fuel Gross Weight		71,800
Wing		9,270
Horizontal Tail		1,527
Vertical Tail		1,092
Fuselage		9,336
Landing Gear		3,640
Flight Controls		1,276
Nacelle and Pylon - Basic Airplane		1,418
Engine and Systems - Basic Airplane		7,119
Propfan Propulsion System		3,504*
Turboshaft Engine	1,209 lb	
Propeller and Controls	619	
Gearbox and Struts	614	
Engine Systems	257	
Nacelle, Exhaust, and Mount Structure	762	
Nacelle to Wing Attach	43	
Fuel Systems		534*
Instruments and Warning		665
Auxiliary Power Units		805
Hydraulic System		418
Pneumatic System		283*
Electrical System		1,275
Avionics		671
Furnishings		6,826
Air Conditioning		1,016
Ice Protection		472
Handling Gear		19
Ballast Lateral		1,825*
Testbed Manufacturer's Empty Weight		52,991 lb
Testbed Operator Items (Table 10)		1,024*
Testbed Operational Empty Weight		54,015 lb

*Changed or added weight

TABLE 9B

DC-9-10 PROPFAN TESTBED GROUP WEIGHT SUMMARY

ONE WING MOUNTED ALLISON T56 PROPFAN

Metric Units

Maximum Ramp Gross Weight		39,501 Kg
Maximum Takeoff Gross Weight		39,138
Maximum Landing Gross Weight		37,052
Maximum Zero Fuel Gross Weight		32,562
Wing		4,204
Horizontal Tail		693
Vertical Tail		495
Fuselage		4,234
Landing Gear		1,651
Flight Controls		579
Nacelle and Pylon - Basic Airplane		643
Engine and Systems - Basic Airplane		3,229
Propfan Propulsion System		1,589*
Turboshaft Engine	548 Kg	
Propeller and Controls	281	
Gearbox and Struts	278	
Engine Systems	117	
Nacelle, Exhaust, and Mount Structure	346	
Nacelle to Wing Attach	20	
Fuel Systems		242*
Instruments and Warning		302
Auxiliary Power Units		365
Hydraulic System		190
Pneumatic System		128*
Electrical System		578
Avionics		304
Furnishings		3,096
Air Conditioning		461
Ice Protection		214
Handling Gear		9
Ballast Lateral		828*
Testbed Manufacturer's Empty Weight		24,032 Kg
Testbed Operator Items (Table 10)		464*
Testbed Operational Empty Weight		24,496 Kg

*Changed or added weight

The lateral imbalance on this aircraft is similar to the one engine T701 prop-fan configuration. The lighter T56 prop-fan propulsion system weight requires approximately 10 percent less ballast weight than the T701 configuration to correct the lateral imbalance condition.

The operator items weight, Table 10, is similar to the one engine T701 configuration, except the T56 engine oil weight is slightly heavier.

TABLE 10

TESTBED OPERATIONAL ITEMS WEIGHT
ONE ALLISON T56 PROPFAN

	English Units	Metric Units
Unusable Fuel	249 lb	113 Kg
Unusable Oil (Base Engine, APU < & CSD)	46	2
Toilet Chemicals and Water	45	20
Crew Compartment Manuals	10	5
Emergency Escape Chute	48	22
Flight Crew - 2 @ 170 lb (77.5 Kg) each	340	154
Briefcases	15	7
Oil (Basic Engine and APU)	89	40
Potable Water	85	39
Oil and Unusable Fuel - Turboshaft Engine	97	44
Total Testbed Operational Items Weight	1,024 lb	465 Kg

Weight Comparison Summary

Side-by-side comparisons of the group weight summaries for the one and two prop-fan installations using the T701 and the T56 turboshaft engines are presented in Figure 62. As noted throughout the foregoing discussion, the T701 engine and a 9.5 foot (2.90 m) prop-fan are compatible. The T56 engine is capable of swinging an 8.1 foot (2.47 m) prop-fan.

ENGLISH UNITS

		ONE PROP-FAN WING MOUNT		TWO PROP-FAN WING MOUNT	
		T701	T56	T701	T56
MAXIMUM RAMP GROSS WEIGHT	87,100 lb				
MAXIMUM TAKEOFF GROSS WEIGHT	86,300				
MAXIMUM LANDING GROSS WEIGHT	81,700				
MAXIMUM ZERO FUEL GROSS WEIGHT	71,800				
INTERIOR ARRANGEMENT 12/60 = 72 MIXED CLASS PASSENGERS					
ENGINE TYPE – BASIC AIRCRAFT	JT8D-5				
F_N (LB/ENGINE)	12,250				
WING	9,290				
HORIZONTAL TAIL	1,527				
VERTICAL TAIL	1,092				
FUSELAGE	9,336				
LANDING GEAR	3,640				
FLIGHT CONTROLS	1,276				
NACELLE AND PYLON – BASIC AIRCRAFT	1,418				
ENGINE AND SYSTEMS – BASIC AIRCRAFT	7,119				
PROP-FAN PROPULSION SYSTEM		3,925	3,504	7,850	7,008
ENGINE		1,152	1,209	2,304	2,418
PROPELLER		857	619	1,714	1,238
GEARBOX		658	614	1,316	1,228
ENGINE SYSTEMS		321	257	642	514
NACELLE (INCL INLET, LWR ACC DOORS, TAILPIPE, AFT FAIRING, FIRESHIELD AND MOUNTS)		937	805	1,874	1,610
FUEL SYSTEM	554				
INSTRUMENTS AND WARNING	665				
AUXILIARY POWER UNIT	805				
HYDRAULIC SYSTEM	418				
PNEUMATIC SYSTEM	404				
ELECTRICAL SYSTEM	1,275				
AVIONICS	671				
FURNISHINGS	6,826				
AIR CONDITIONING	1,016				
ICE PROTECTION	472				
HANDLING GEAR	19				
BALLAST – LATERAL		2,030	1,825	0	0
MANUFACTURER'S EMPTY WEIGHT		53,617	52,091	55,572	54,831
OPERATOR ITEMS		1,020	1,024	1,113	1,131
OPERATIONAL EMPTY WEIGHT		54,637	54,015	56,685	55,962

DERIVED FROM ACA DC-9-14 (DTS 3506) – AVERAGE ACTUAL MEW OF SIX AIRCRAFT AT TIME OF ORIGINAL DELIVERY

80-GEN 27435A

METRIC UNITS

		ONE PROP-FAN WING MOUNT		TWO PROP-FAN WING MOUNT	
		T701	T56	T701	T56
MAXIMUM RAMP GROSS WEIGHT	39,501 kg				
MAXIMUM TAKEOFF GROSS WEIGHT	39,738				
MAXIMUM LANDING GROSS WEIGHT	37,052				
MAXIMUM ZERO FUEL GROSS WEIGHT	32,562				
INTERIOR ARRANGEMENT 12/60 = 72 MIXED CLASS PASSENGERS					
ENGINE TYPE – BASIC AIRCRAFT	JT8D-5				
F_N (LB/ENGINE)	12,250				
WING	4,213				
HORIZONTAL TAIL	693				
VERTICAL TAIL	405				
FUSELAGE	4,234				
LANDING GEAR	1,654				
FLIGHT CONTROLS	578				
NACELLE AND PYLON – BASIC AIRCRAFT	643				
ENGINE AND SYSTEMS – BASIC AIRCRAFT	3,228				
PROP-FAN PROPULSION SYSTEM		1,780	1,589	3,560	3,178
ENGINE		522	548	1,045	1,097
PROPELLER		388	281	777	561
GEARBOX		298	278	596	556
ENGINE SYSTEMS		146	116	291	233
NACELLE (INCL INLET, LWR ACC DOORS, TAILPIPE, AFT FAIRING, FIRESHIELD AND MOUNTS)		425	365	849	730
FUEL SYSTEM	251				
INSTRUMENTS AND WARNING	302				
AUXILIARY POWER UNIT	365				
HYDRAULIC SYSTEM	190				
PNEUMATIC SYSTEM	183				
ELECTRICAL SYSTEM	578				
AVIONICS	304				
FURNISHINGS	3,096				
AIR CONDITIONING	461				
ICE PROTECTION	214				
HANDLING GEAR	9				
BALLAST – LATERAL		921	828	0	0
MANUFACTURER'S EMPTY WEIGHT		24,316	23,624	25,203	24,867
OPERATOR ITEMS		463	464	505	513
OPERATIONAL EMPTY WEIGHT		24,779	24,498	25,708	25,380

DERIVED FROM ACA DC-9-14 (DTS 3506) – AVERAGE ACTUAL MEW OF SIX AIRCRAFT AT TIME OF ORIGINAL DELIVERY

80-GEN 37435-1

FIGURE 62. DC-9-10 PROP-FAN TEST-BED GROUP WEIGHT SUMMARY

TASK 6

TASK VI

TESTBED TEST PROGRAM PLAN

As described in the Introduction, the emphasis of the contract work relative to the prop-fan propulsion system(s) changed as the study progressed. Consequently, both the one prop-fan nacelle and the two prop-fan nacelle configurations are considered throughout the study. Initially, the one prop-fan nacelle configuration was submitted in deference to a lower cost program. However, the two prop-fan nacelle arrangement permits the acquisition of additional acoustic data and thus a more complete evaluation of the prop-fan testbed. The flight test evaluation and data to be obtained differ somewhat between the two configurations. Since the two prop-fan nacelle configuration is the one of most interest to NASA, the testbed program discussed in this Task VI considers the two nacelle prop-fan testbed first, with the differences for the one nacelle prop-fan arrangement described secondly. The two prop-fan testbed does permit the

- o acquisition of realistic internal aircraft acoustic and vibration data,
  well as vibration data;
- o evaluation of effectiveness of opposite prop-fan rotation on the aerodynamic interferences, performance, and acoustics, and
- o evaluation of synchrophasing in the testbed program.

The initial goals of this prop-fan testbed flight test program to be performed by Douglas Aircraft Company are to open the flight envelope and to prove the airworthiness of the testbed vehicle. It is this portion of the flight test program that is described herein. Continuation of the prop-fan flight test program, utilizing the fully instrumented DC-9-10 flight testbed, entails the prop-fan structural integrity, overall performance, and acoustic testing. Whether these latter phases of the flight test program will be perfomed by Douglas or by NASA Dryden will be resolved as the total testbed program evolves. Douglas has the facilities and capability of doing the complete flight test program; however, the relative cost-effectivness of completing the flight testing at Douglas or at Dryden needs to be taken into account. It is to be noted that the data acquisition and recording system to be used by Douglas is compatible with that at Dryden Data Center, Edwards AFB.

DATA MONITORING, PROCESSING FACILITIES AND SYSTEMS

Facilities

Douglas Aircraft Company maintains flight test facilities at the Long Beach Municipal Airport, Long Beach, California, and at Yuma International Airport, Yuma, Arizona. The initial ground testing of the complete aircraft and systems prior to first flight will be accomplished at Long Beach. The first flight of the aircraft with the prop-fan engine installed will terminate at Yuma. The aircraft will be based at the Yuma test site for all of the prop-fan tests up through completion of structural airworthiness, then NASA may continue testing at Dryden Flight Research Center.

Appendix III includes brief excerpts from the Douglas Engineering Research Technical Facility Description Handbook which describes pertinent component facilities associated with the Advanced Prop-fan Test Program.

Performance Data Systems

The Douglas Teledyne Remote Multiplexer Data Units (RMDU) Data System will be used for the flight test program. The system consists of an airborne data system, telemetry microwave link and a ground data center. This affords excellent real time coverage for almost all test areas in Southern California, Nevada, Arizona, and Northern Baja. The data system is designed to provide real-time monitoring in engineering units in the air, reduction of a large number of parameters simultaneously on the ground, and reduction of the remaining data within hours of each flight. This system is compatible with the Dryden Data Center at Edwards AFB.

The airborne tape recorder Interrange Instrumentation Group-B (IRIG-B) records time and the serial Pulse Code Modulation (PCM) data simultaneously with signal transmission to the Ground Data Center at Long Beach. Data is recorded at five selectable sample rates from 12,500 bits per second to 500,000 bits per second with a packing density of 8,333 bits per inch. The recorder has direct and FM capability with capacity of 14 tracks on 1 inch tape with 12-1/2 inch reel.

Tape speed is changed at the time the bit rate is selected so that the packing density is maintained constant. The aircraft is equipped with a telemetry transmitter for transmitting all PCM data to the ground station for real-time processing.

The Flight Control and Ground Data Center at Long Beach serves as both a data reduction center and flight control monitor station. It provides the equipment and environment to allow flight data processing and monitoring, both in graphical and tabular forms. The data is available in real-time through telemetry or from flight recorded tape in engineering units on Cathode Ray Tube (CRT) displays, hard copy, microfilm, line printer or magnetic tape (which can be formatted to be suitable for other equipment). Strip charts are available for selected monitoring and provide redundancy independent of the computer.

The ground data system includes five independent CRT's, a large random access disc file used for temporary raw data storage, and two computer modules which permit post-flight analysis on two separate flights (or a combination of post-flight analysis in conjunction with real-time flight monitoring). Calibrations for all channels for every flight of the test aircraft are stored on the Rapic Access Disc (RAD). The Data Center also includes a complete communications system, operating through the microwave relay station, that permits direct aircraft communications for the Test Director and/or the individual CRT users.

Experience has shown that high priority data can be processed in 24 hours with routine data following within a few days. When telemetry data coverage is provided, the most significant data are returned to the test site within hours. Duplicate engineering unit computer tapes can be provided within one to three days following a flight.

Transmittal of flight tapes from Yuma to Long Beach is accomplished by courier or shuttle aircraft and processed data returned via same or telephone facimile equipment. Data may also be transmitted via the Yuma Microwave System to the Long Beach Data Center for immediate processing.

Acoustics and Vibration Facility and Systems

Acoustics and vibration data processing will be conducted using the facilities of the Acoustics and Vibration Data Center at Long Beach . The Data Center is equipped with a number of multiple-channel and single-channel magnetic tape systems and a variety of data processing systems. Data systems include: (1) Computer-controlled audio filter system with 1/3-octave-band parallel outputs onto digital tape for subsequent large-scale computer processing; (2) narrow-band spectrum analyzers with variable averaging; (3) computer-controlled processing system for paired-signal analysis in both time and frequency domains using Fourier Transform methods with graphical and tabular output capabilities; and (4) statistical processors with probability and correction output modes. In addition, multi-channel strip chart recorders and necessary peripheral equipment such as time code, signal conditioning and audio output subsystems are incorporated.

TWO NACELLE PROP-FAN CONFIGURATION

This preliminary flight test plan assumes a DC-9-10 as a flying testbed utilizing two Allison T701-AD-700 engines with modified T56 gearboxes and Hamilton Standard 9.5 foot (2.90 m) diameter prop-fans (Figure 13, Task III). The primary objectives of this flight test program are as follows:

- o definition of wing, fan blade, gearbox, nacelle, engine mount, prop-fan hub stress and loads data;
- o measurement of noise data inside and outside the fuselage;
- o measurement of airframe and engine environmental vibration;
- o obtain engine mount and fuselage acoustic stress data;
- o investigation of the prop-fan, nacelle and swept wing aerodynamic integration;
- o determination of the net installed thrust-minus-drag (cruise performance) of the wing-mounted propulsion system;
- o engine performance measurement;
- o measurement of acoustic far-field engine noise (ground only).

The operation of the prop-fan propulsion system on the DC-9-10 testbed aircraft will be restricted to the flight envelope presented in Figure 63. The low speed/low altitude limits may vary somewhat from that shown in Figure 15, depending on the results of stability and control subscale wind tunnel tests.

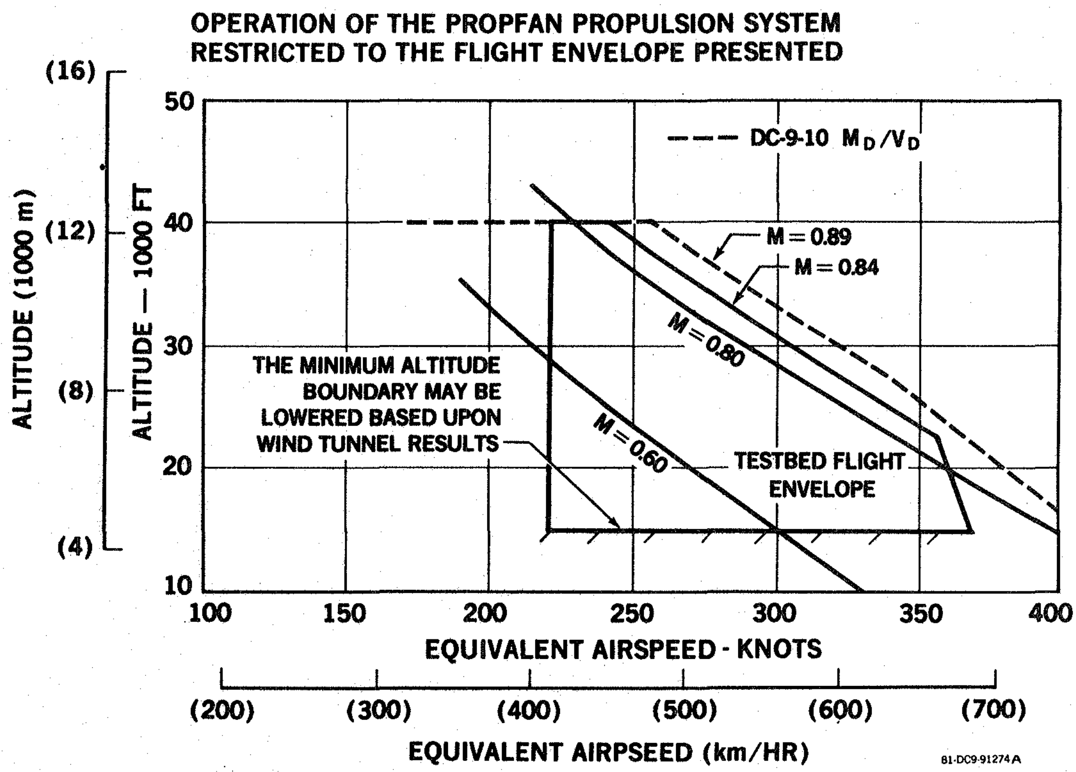


FIGURE 63. DC-9-10 TESTBED AIRCRAFT OPERATING ENVELOPE

Tests will be conducted with both prop-fans rotating in the same direction and with the direction of rotation reversed on one engine so that both prop-fans rotate up and inboard to the fuselage. Synchrophase testing will also be included in the testing.

Throughout the flight testing, the airspeeds will be such that a conservative margin of safety will be provided; no testing such as minimum unstick speed (V_{mu}), ground minimum control speed (V_m c.g.), and air minimum control speed (Vm_{ca}). will be done.

TESTING

Initial Ground Tests

Prior to any flight testing, the engine, the prop-fan, the engine/prop-fan gearbox, and the complete engine prop-fan package including the gearbox and engine prop-fan controls will be checked out on ground test stands. These ground tests are performed as component testing with the propulsion system separate from the aircraft.

The initial testing of the large scale prop-fan and the T701-AD-700 engine with modified T56 gearbox will be performed independently but probably concurrently by the respective manufacturers. Hamilton Standard and Allison will establish the manufacturers' performance data. During this testing, calibration of flightworthy blade pitch position instrumentation will be obtained. Strain gages will be installed on the prop-fan and a slip ring system will be used to collect blade strain gage data.

Prop-fan structural integrity will be investigated during static rotor tests, static propulsion system tests, and wind tunnel tests of the propulsion system. Compatibility of the T701 engine and modified T56 gearbox will be verified during component and drive system tests. In the same manner as the components of the propulsion system are built up and tested, the compatibility of the overall propulsion system will be demonstrated. The individual systems reliability will be established. Flightworthy instrumentation required during this ground testing phase is listed below:

- strain gages on prop-fan blades;
- prop-fan shaft torque and thrust
- negative torque sensor light and test switch
- auto prop-fan feather arming light
- prop-fan feather light
- temperatures for engine and gearbox oil inlet and discharge;
- pressure for engine and gearbox oil;
- exhaust gas temperature and pressure;
- high and low spool RPM;
- fuel flow rate
- engine vibration accelerometers
- pitch control hydraulic oil temperature and pressure
- gearbox and pitch lube chip detector.

The first integration of the large scale components into a complete system with all instrumentation installed will be performed on an engine test stand at Hamilton Standard, Allison, or the Douglas QIAETsite facility at Quartzsite, Arizona. Photographs of these three facilities are shown in Figures 64, 65 and 66. Selection of the specific facility or facilities for this integration test work will be made during the final formulation and scheduling of the required ground tests.

Testing will be performed to determine the compatibility of the prop-fan systems throughout the entire prop-fan power spectrum. Evaluation and qualifiction of subsystems such as the modified engine control system, gearbox, prop-fan control system, and prop-fan will be made. The engine and gearbox oil systems, the prop-fan pitch control system, the engine mount and related structural hardware will be included. All engine safety systems will be checked.

Dynamic prop-fan blade loads will be measured for evaluating the fatigue life of the blades and to ensure that the blade design meets the structural requirements for extensive testing. Dynamic pressure and strain gage data will be acquired on magnetic tape for stabilized operation at several representative combinations of blade pitch angle and prop-fan speed to define the basic sustained loads. In addition, prop-fan speed scans at various blade pitch angles will be conducted from idle to maximum power (including overspeed) to reveal any transient load problems.

Combined prop-fan and exhaust nozzle thrust will be determined for the two prime and one spare prop-fan engines at various combinations of prop-fan pitch speeds. The T701 exhaust nozzle thrust will be analytically determined using inputs from internal nozzle instrumentation.

A pressure rake will be installed immediately behind the left prop-fan rotor to determine performance levels at various blade pitch angles and RPM settings.

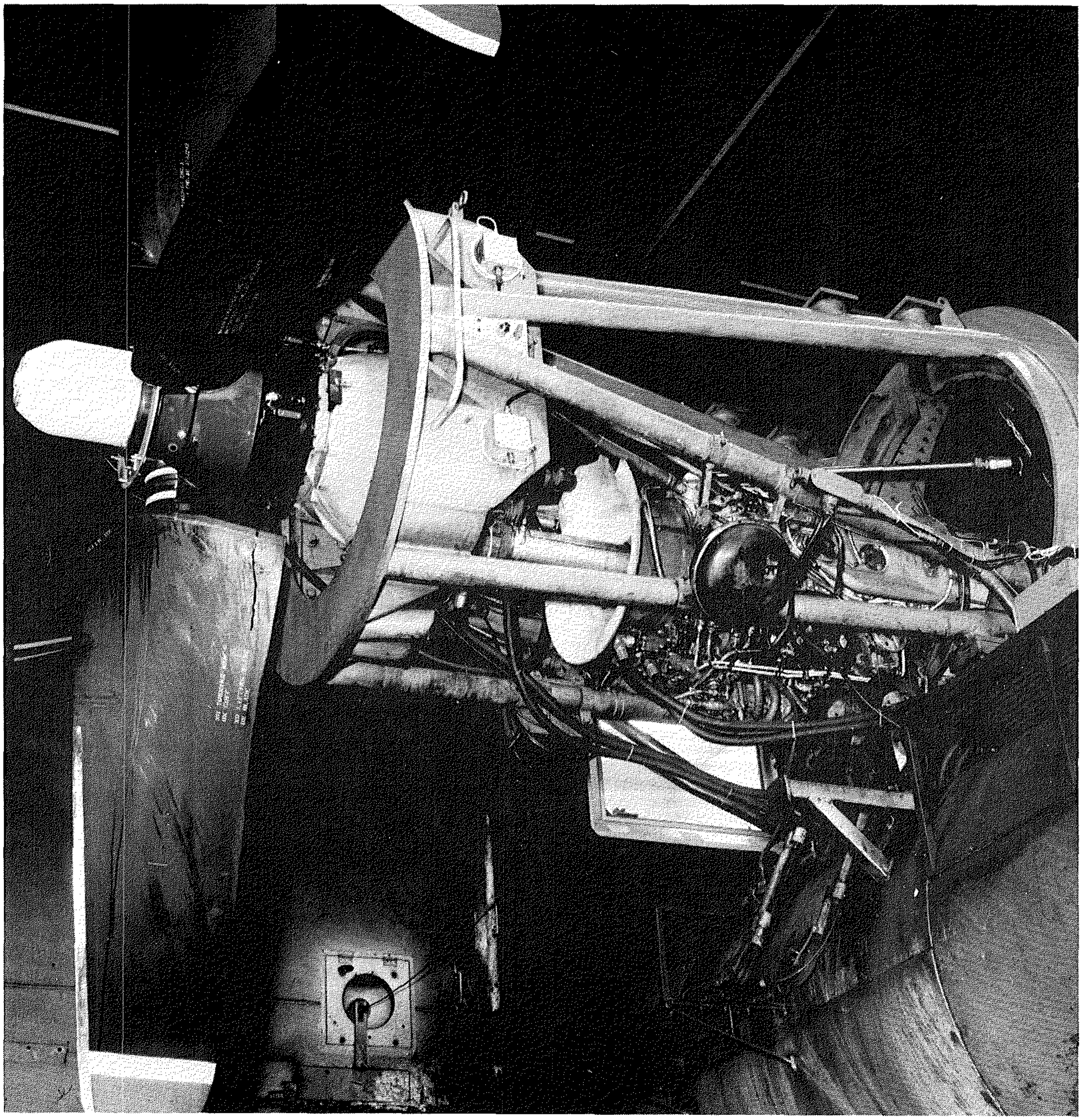


FIGURE 64. HAMILTON STANDARD PROPELLER TEST FACILITY – WINDSOR LOCKS, CONNECTICUT

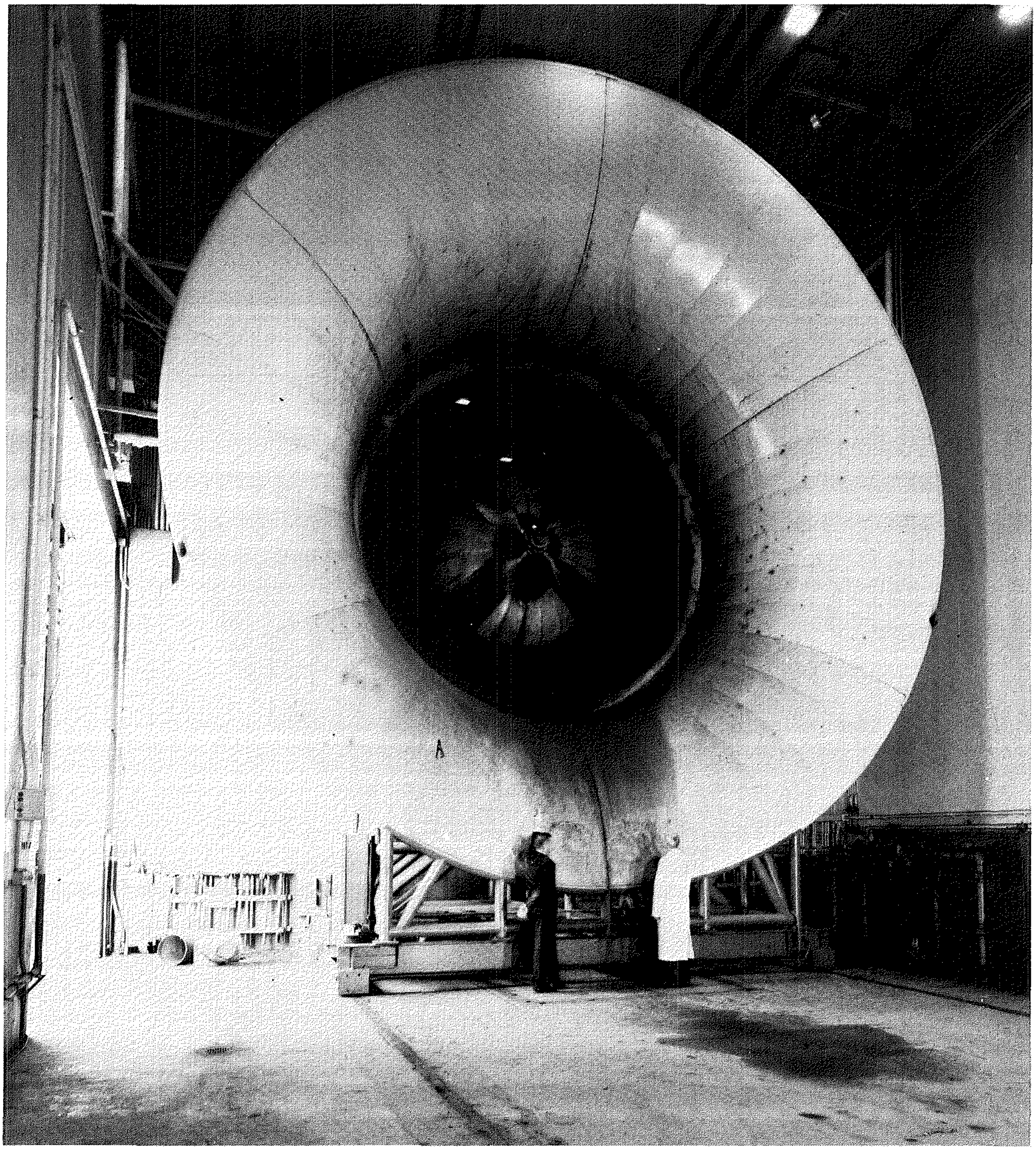


FIGURE 65. DETROIT-DIESEL-ALLISON ENGINE TEST FACILITY – INDIANAPOLIS, INDIANA

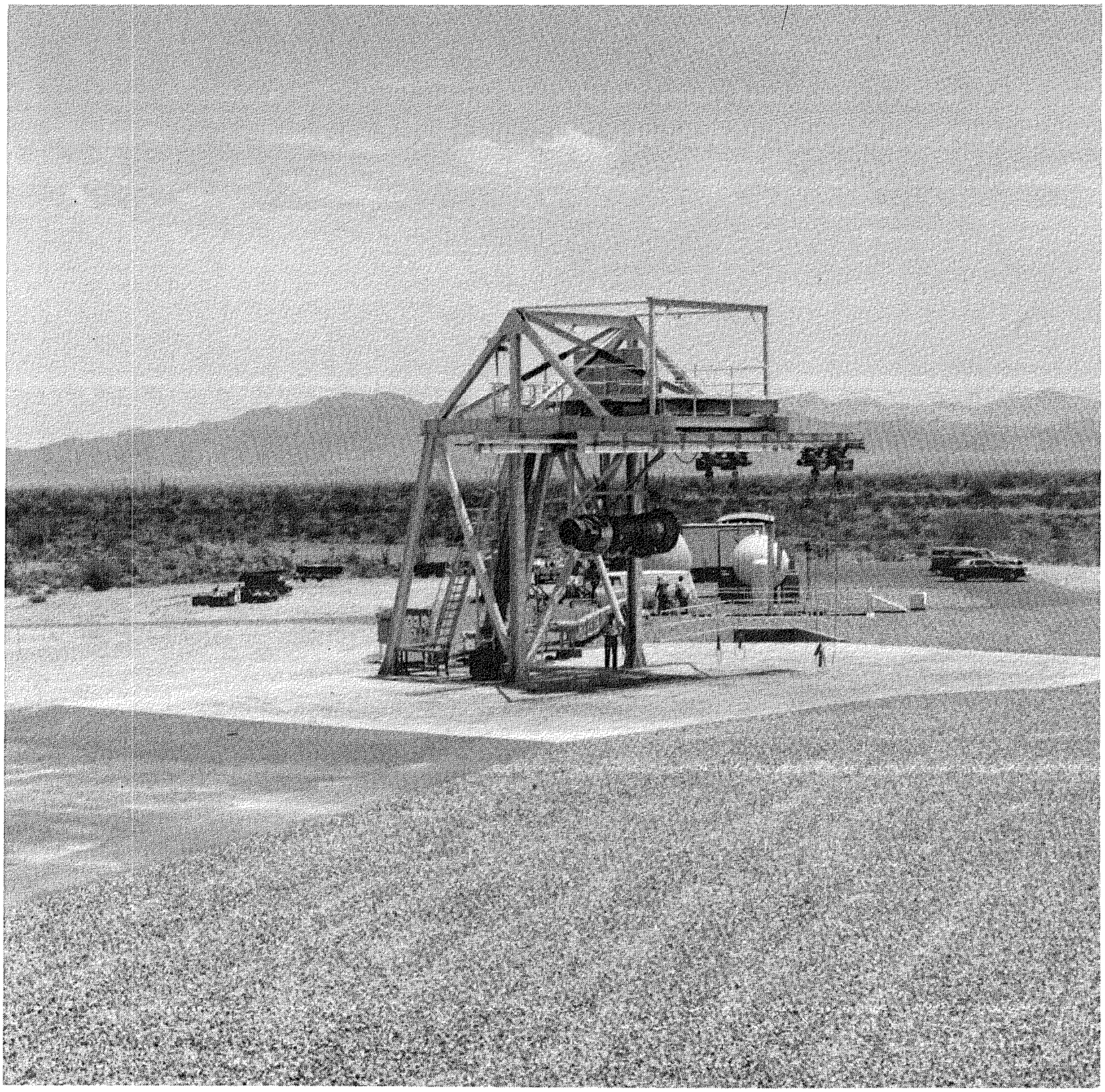


FIGURE 66. DOUGLAS OUTDOOR ENGINE TEST – QUARTZSITE, ARIZONA

The peak prop-fan loading and overspeed performance will be monitored and the data will be compared to that obtained in the initial ground tests.

Prior to the prop-fan/engine being installed on the aircraft, minimum duty cycle will be performed to establish reliability of the overall system.

Engine vibration will be monitored and compared to the engine manufactuer's limits. Vibration measurements will be made on the gearbox and at the manufacturer's standard Engine Vibration Monitoring locations at stable power settings during such tests as thrust detemination and duty cycle evaluation.

A more detailed discussion of the acoustic measurements and data desired is presented in the Acoustics section of Task IV. Brief description is included here of the acoustic data to be obtained during the ground testing phase of the flight program. To define the directivity and amplitudes of acoustic pressures imposed on the fuselage, vertical and horizontal arrays of microphones in the acoustic near field (within 10 feet [3.05 m] of the prop plane) will be used to make measurements that are free of the effects of the airplane. This will allow the subsequent measurements in the presence of the airplane and the ground surface to be adjusted to other airplane geometries. The engine conditions to be tested will be the same as those for prop-fan load testing as described above. Measurements will be made over a range of approach and takeoff power setting (about 12 stable engine conditions). It is hypothesized that both the near-field acoustic pressures and the far-field noise will be adversely affected by reingestion of eddies produced by the prop-fan. More detailed discussion of the acoustic test program is included in Task IV - Acoustics.

Airplane Modification

The DC-9 Series 10 airplane, with the instrumented JT8D-7 engines used for the baseline tests, will be modified to allow the installation of the two calibrated T701-AD-700 engines on the wing, the prop-fan controls, and associated data acquisition instrumentation. Flight safety features such as an escape chute will also be installed as part of this aircraft modification phase. Both cabin sidewalls will be strengthened in the prop-fan plane to ensure structural integrity for the test program. As the testing proceeds, this baseline acoustic treatment will then be replaced with at least one other treatment material in an effort to determine an "optimum" acoustic configuration.

Complete Aircraft Ground Tests

Prior to first flight, ground testing will be accomplished to verify that structural design requirements have been satisfied. Checkout of prop-fan/engine and prop-fan/control systems will be accomplished plus determination of static acoustic and structural loads. The following additional tests will be performed:

- o wing and engine mount structural integrity proof test; structural integrity;
- o complete ground vibration testing to establish the aircraft modal characteristics;
- o engine runs to ensure that all prop-fan controls and instrumentation is properly integrated with on-board aircraft controls. (The critical prop-fan dynamic and static load strain gages will be monitored during this test phase to define safety limits.)
- o Prop-fan wake measurements to assess the possible effects on wing surfaces and JT8D engine inlet

Discussion of acoustic results from the aircraft ground testing is included in Task IV.

Low and high speed taxi runs will be performed initially, without the prop-fan engines operating, to assess the aircraft's handling characteristics and to ensure that all instrumentation is functioning correctly. Engine mount and wing oscillatory loads are to be monitored.

High-speed taxi runs will then be conducted to determine the effects of prop-fan-induced eddies on aircraft acoustic characteristics. Pass-by noise will be recorded with ground level microphones located in arrays both perpendicular and parallel to the runway. This will enhance the development of testing and/or analysis techniques to estimate flyover noise based on static noise. Due to prop-fan engine power limitations, only one or two pitch angles will likely be tested during the high-speed taxi tests.

Flight Tests

The flight testing program is divided into three phases:

Phase 1 DC-9-10 baseline testing including JT8D-7 engine calibration and wing pressure surveys; aircraft will be operated out of the Long Beach facility.

Phase 2 DC-9-10 prop-fan testbed aircraft demonstration and minimum tests required to prove airworthiness, structural integrity, performance and acoustic characteristics of the prop-fan propulsion system. Tests to be performed during this Phase 2 are discussed in subsequent paragraphs. Unless otherwise stated, the testbed aircraft will be based at Yuma, Arizona.

Phase 3 Accomplish any additional NASA required testing such as evaluation of an alternate fuselage structure; this is undefined at this stage and will not be discussed further.

Stability and Control

The aircraft will be instrumented to provide control surface positions and forces, aircraft attitude, center of gravity, and normal, lateral and longitudinal accelerations. These tests will be performed with both prop-fan engines furthest forward on each wing (Figure 67) as this represents the worst case condition. These tests are to be performed to establish satsifactory handling characteristics; and the tests must be performed before the objectives can be safely investigated.

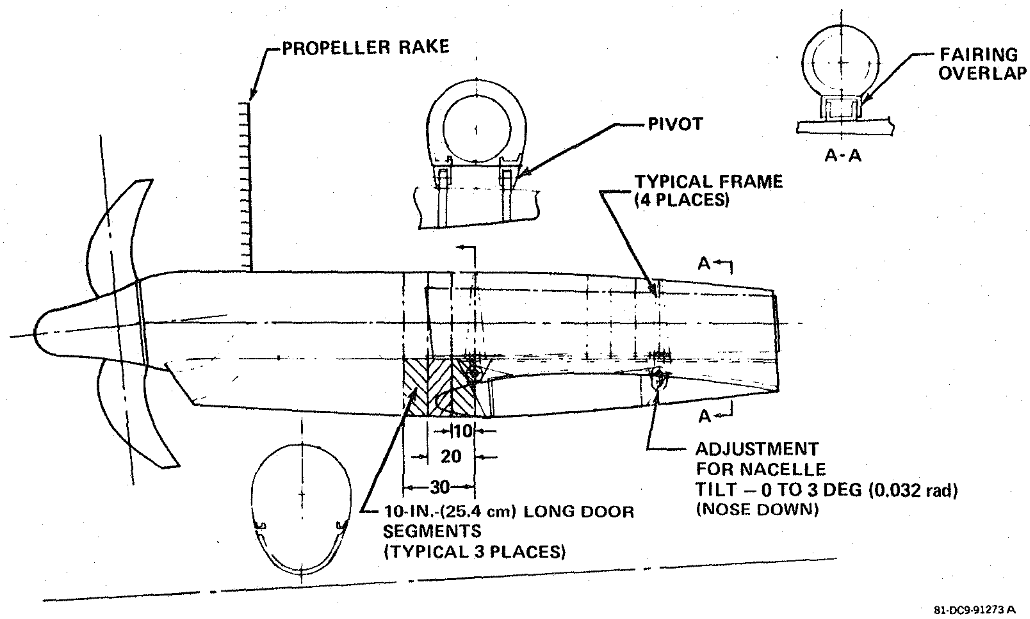


FIGURE 67. EFFECT OF PROP-FAN LOCATION RELATIVE TO WING

Directional Stability and Rudder Effectiveness - Directional stability will be assessed for takeoff and landing configurations with both JT8D engines operating and then with one engine at idle and the prop-fan feathered. Further assessment will be made in the cruise configuration at various power settings with both prop-fans rotating in the same direction and with both rotating up and inboard to the fuselage.

Lateral Control and Aileron Effectiveness - Lateral control during rolling maneuvers will be assessed in takeoff and landing configurations with both JT8D engines operating and then with one engine at idle and the prop-fan feathered. Further assessment will be made in the cruise configuration at various power settings with both prop-fans rotating in the same direction and with both rotating up and inboard to the fuselage.

Static Longitudinal Stability - Static longitudinal stability will be assessed in takeoff, landing and cruise configurations with the prop-fans feathered. A limited assessment will be made for the cruise operation with both prop-fans operating.

Dynamic Longitudinal Stability - Dynamic longitudinal stability will be assessed in takeoff, landing and cruise configurations with the prop-fans feathered. A limited assessment will be made in the cruise configuration with the prop-fans operating.

Dynamic Lateral-Directional Stability (Dutch Roll Mode) - Dynamic lateral-directional stability will be evaluated in both cruise and landing configurations with the prop-fans feathered, and in the cruise configuration only with the prop-fans operating at various power settings. Checks will be made with both prop-fans rotating in the same direction and with both rotating up and inboard to the fuselage. Dutch roll oscillations will be produced using pilot inputs, and the damping will be recorded after the controls have been released.

Approach to Stall - The aircraft handling qualities down to a speed of 1.3 V_S will be assessed with the prop-fan engine off and with prop-fan feathered in the landing, takeoff, and cruise configurations.

Structural and Aerodynamic Damping

Flutter characteristics will be investigated at 24,000 feet and 30,000 feet (7,315 and 9,144 m) with the prop-fan engines operating, and at 24,000 feet (7,315 m) with the prop-fan engines off and prop-fans feathered. The case of fuel in one wing and the prop-fan engines in the forward position will be tested. The whirl mode flutter characteristics will be assessed during this testing.

Excitation of the critical flutter mode will be provided by pilot inputs to the aircraft control surfaces. Both control surface pulses and oscillations will be input into the aircraft. As illustrated in Figure 68, approximately sixteen accelerometers (located on the wing, prop-fan engine, vertical and horizontal stabilizer and fuselage) a number of strain gages (located on the hub support structure and wing) and ten surface positions will be used to monitor these tests.

All flutter flights will be monitored on the ground via real time telemetry and will be observed from a safety chase airplane.

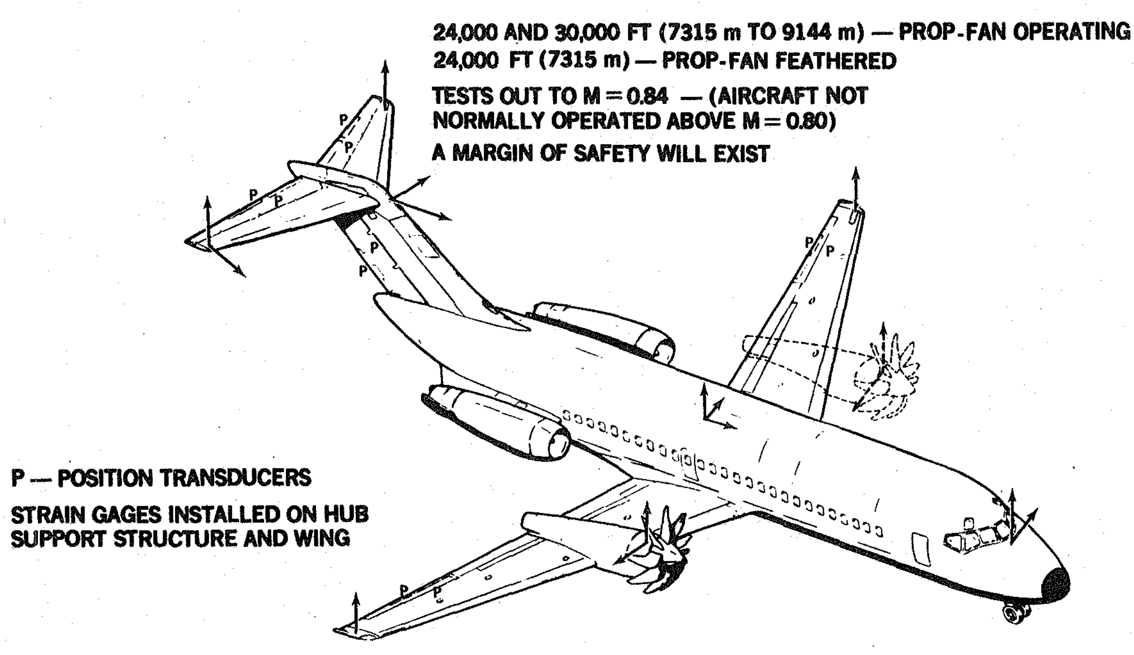


FIGURE 68. STRUCTURAL AND AERODYNAMIC DAMPING

Loads Monitoring

During the envelope expansion, the prop-fan assessment, and the takeoff and landing tests, critical load parameters will be monitored to assess the static and oscillatory load environment. Components included in the monitoring are horizontal and vertical stabilizer, wing and pylon, engine mounts, prop-fan blades, and the prop-fan engine.

The effect of variation in prop-fan engine tilt and location relative to the wing on the prop-fan blade stress will be assessed. The prop-fan engine tilt can be varied from 0 degrees to 3 degrees (0 to .052 radians), and three engine locations aft relative to the wing are possible. The method of achieving this variation is presented in Figure 59 and a description is given in Task V.

Loads measurements will be made at several engine power settings and prop-fan blade pitch angles. Maneuvers to 80 percent aircraft normal 'g' capability will be performed at a TBD engine configuration with and without the prop-fan engines operating. A high speed motion camera will be positioned to film the prop-fan. Loads will be recorded during all phases of testing. Specific tests will be performed at the speeds and altitudes indicated in Figure 69.

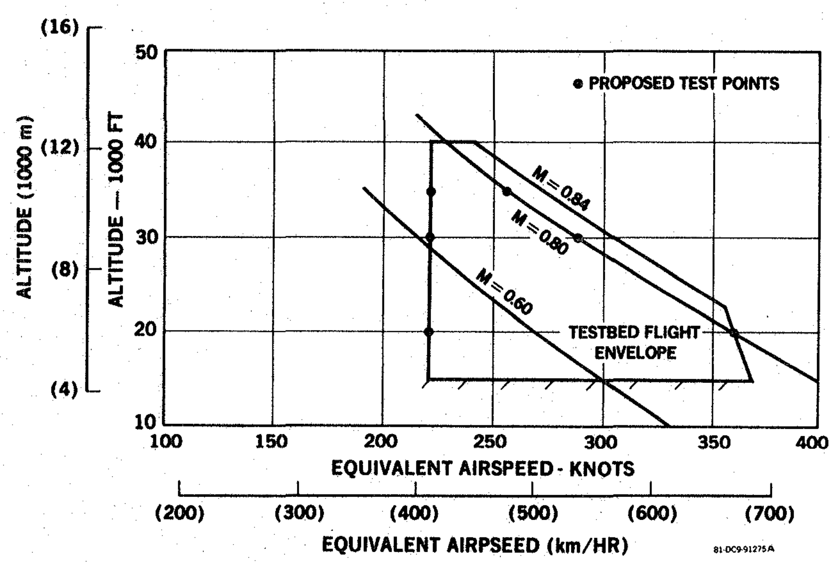


FIGURE 69. PROPOSED LOADS TEST POINTS

Propulsion

Throughout the prop-fan engine testing, critical parameters will be monitored. An anti-icing system for the inlet or prop-fan is not provided, and so the prop-fan will not be operated in icing conditions. All safety critical flights will be monitored on telemetry and observed from a chase aircraft. The initial start of one and then both prop-fan engines will also be observed from a chase aircraft. The gas generator will be initially started at low Mach number and altitude with feathered prop-fans and windmilling engines. The prop-fan will then be accelerated from feather to test RPM with pitch schedule for zero thrust. Prop-fan pitch angle will then be increased. The initial engine operating envelope expansion will be performed with the engine at one location relative to the wing and one pitch attitude.

Variations of engine location and pitch attitude are discussed in a subsequent paragraph under Loads Monitoring.

<u>Airstart Envelope</u> - An acceptable airstart envelope for the prop-fan operation, within approximate 15,000 feet to 30,000 feet (4,572 to 9,144 m), will be defined. As mentioned previously, this lower limit for the safe operation of the prop-fan system is dependent on results of subscale wind tunnel stability and control tests.

<u>Engine Characteristics</u> - Tests will be performed throughout the aircraft operating envelope. Demonstration that the prop-fan feathers correctly will be included. The check out of the engine and gearbox oil systems, the prop-fan pitch control system, the engine mount and related structural loading will be included. The engine safety systems and instrumentation will also be checked.

The effect of the prop-fan propulsion system on DC-9 aerodynamics, structural loading, and acoustics characteristics will be assessed. The operation of the DC-9-10 testbed on the two prop-fan engines only requires that the aircraft flys at a reduced speed and weight.

Prop-fan Overspeed - Prop-fan overspeed tests will be conducted at various altitudes and airspeeds.

Prop-fan Performance - A pressure rake located just behind the left prop-fan engine rotor will provide a pressure survey to define the local flow field ahead of the engine inlet and to determine prop-fan efficiency (see Figure 29). Data will be taken at various blade pitch angles and RPM settings. Tests will also be conducted to assess the impact of nacelle location, engine pitch attitude (variations described in the Loads Monitoring paragraph), and prop-fans rotating conventionally or in opposite directions.

Acoustic and Vibration

The desired acoustic testing, both ground and flight, for the testbed is discussed in detail in Task IV. Reference to this discussion on the relative value of subscale tunnel testing, ground testing, and large scale flight testing, as well as required instrumentation and location of data recording equipment, is apropos for this acoustic flight test program.

Cruise Performance/Wing and Nacelle Pressure Survey

If the testbed flight testing is turned over to NASA Dryden upon the completion of the Douglas flight testing, which encompasses the basic component testing and proof of airworthiness, then NASA Dryden would perform the prop-fan aircraft cruise performance, including the wing and nacelle pressure data, installed prop-fan characteristics, and further acoustic data. If the prop-fan testbed is not turned over to Dryden at this point, Douglas will continue with the flight testing.

Cruise performance will be determined at two W/δ's (weight/atmospheric pressure ratios) at the selected Mach/altitude operating points noted in Figure 70.

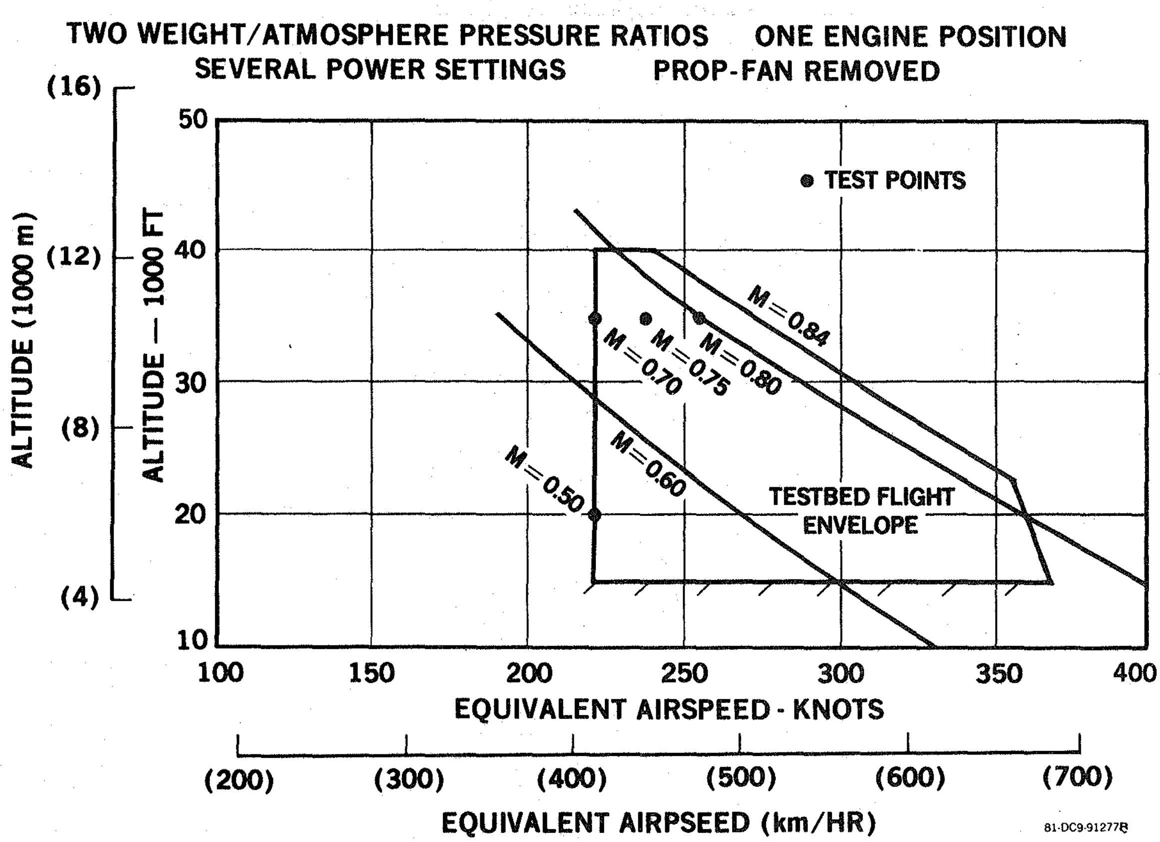


FIGURE 70. CRUISE PERFORMANCE/WING AND NACELLE PRESSURE SURVEY

The flight tests will be performed with both prop-fans operating and with the prop-fans removed. From these tests, the net installed thrust-minus-drag of the prop-fan propulsion system will be obtained using the calibrated JT8D engines and the previously described DC-9 baseline flight test data.

Testing with both prop-fans operating include:

- varying power settings;
- optimum nacelle tilt and location relative to the wing (as previously defined by flight test);
- prop-fans rotating conventionally (in the same direction) and with opposite rotation so both prop-fans rotate up and inboard to the fuselage.

T701 nozzle thrust will be removed analytically using nozzle exhaust pressure and temperature data. Prop-fan thrust and efficiency will be obtained using calibrated thrust strain gage and shaft balance data.

To isolate the effects of power from the effects of the nacelle and to obtain reference pressure data on the nacelle for buoyancy corrections, the prop-fans will be removed and the same flight test points flown. For this case the inlet and nozzle will be faired over to remove momentum losses.

Wing and nacelle pressure data will be obtained during cruise performance testing; these data will provide the diagnostic information to interpret the force results. Necessary pressure survey instrumentation locations on the aircraft are illustrated in Figure 29.

Preliminary Test Schedule

Figure 71 presents an estimated schedule of the flight test effort which involves the opening of the DC-9-10 prop-fan flight envelope and airworthiness testing. Further flight testing which may be done at either Dryden or at Douglas is not included in this figure.

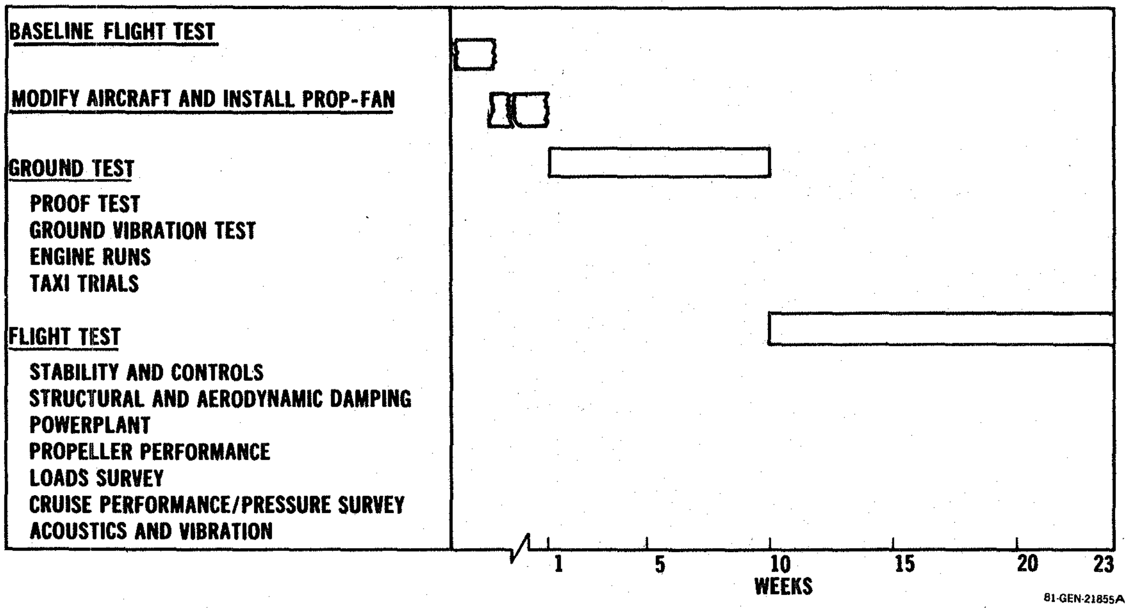


FIGURE 71. PRELIMINARY FLIGHT TEST SCHEDULE

ONE NACELLE PROP-FAN CONFIGURATION

The foregoing discussion of the flight testing has assumed a two nacell prop-fan configuration. As per the contract Statement of Work, the one nacelle prop-fan configuration is also considered. The flight testing procedures for the two configurations are the same with the exceptions noted below which are not compatible with the one prop-fan configuration:

- o effects due to opposite prop-fan rotation;
- o synchronization;
- o proper evaluation of representative acoustic loads, interior noise, and vibration.

The acoustic and vibration data obtained from the one nacelle prop-fan configuration requires considerable adjustment to remove the asymmetric effects so that these acoustic results may be properly projected to a realistic prop-fan DC-9-10 configuration.

TASK 7

TASK VII

LARGE SCALE WIND TUNNEL PROGRAM PLAN

COMPATIBILITY OF LARGE SCALE FLIGHT HARDWARE AND WIND TUNNEL TEST MODEL

As part of the overall program development, the possibility of using the flight hardware in a wind tunnel test to satisfy program objectives is investigated. The prop-fan/engine/nacelle/wing integration system, described in Task V, to be installed on the testbed aircraft does lend itself particularly well as a large scale wind tunnel model. As can be seen in Figure 72, the nacelle parting line from the flight testbed installation is behind the engine installation and ahead of the wing front spar.

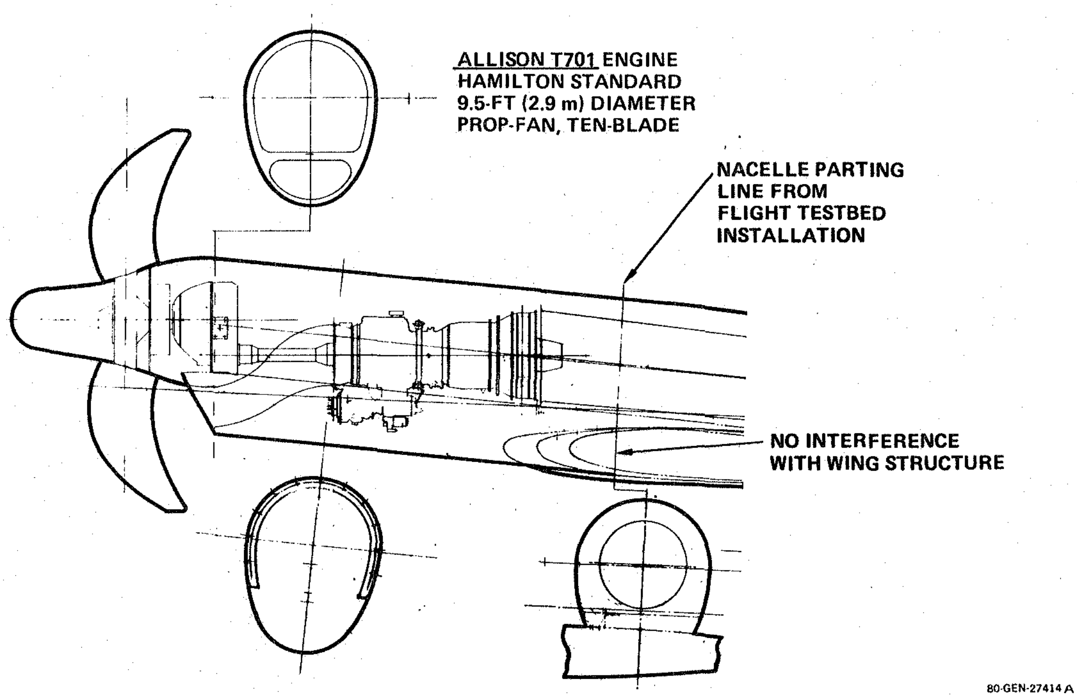


FIGURE 72. COMPATIBILITY OF PROP-FAN/ENGINE/NACELLE FLIGHT TEST INSTALLATION WITH WIND TUNNEL TEST MODEL

Such an arrangement permits the testbed installation of the prop-fan/engine/nacelle/inlet to be utilized as the large scale wind tunnel test model. The problems of availability of adequate sized wind tunnel facilities for the total large scale tests or the strength requirements suitable for a wind tunnel model are discussed in the subsequent paragraphs.

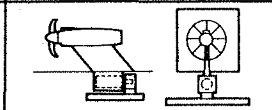
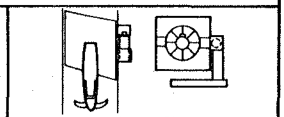
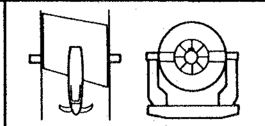
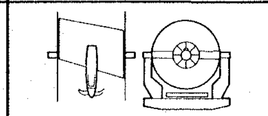
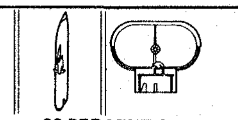
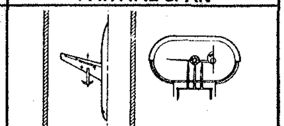
These facilities and hardware are different from the Aerodynamics development plan described in Task IV where subscale models are used to establish flight safety boundaries and efficient wing/nacelle external contours. Throughout discussions in this Task VII, the term "large scale" refers to the prop-fan diameter of 8 foot (2.44 m) or greater. For the program considered here, it is required that the same prop-fan and fuel burning engine hardware used in flight be tested in the tunnel. Static, low speed, and high speed conditions are considered. At high speed conditions, it is necessary to simulate flight conditions at $M_0 = 0.8$ and 30,000 feet (9,144 m). The objectives of the tests are to evaluate the prop-fan blade loads, thrust minus drag, surface pressures and inlet characteristics.

LARGE SCALE WIND TUNNEL CHARACTERISTICS

A survey is made of available wind tunnels; and those facilities that may be useful to fulfill these requirements are:

Ames 40 x 80 (low speed only)
AEDC 16 foot
Lewis Altitude Facility
ONERA S1 8 meter

A summary of the characteristics of these four wind tunnels is given in Figure 73. The wind tunnel capabilities and limitations are presented in Figure 74. A proposed installation for each facility, together with a more detailed description of the capabilities, limitations, and tunnel interference effects, is presented in Appendix I. The tunnel interference effects are evaluated by calculating the solid blockage and comparing it to accepted testing practice and by calculating the incremental solid wall tunnel velocity errors produced by the prop-fan. The latter correction is based on the work of Glauert (Reference 5) using the ratio of the prop-fan to tunnel cross-sectional area and the ratio of the prop-fan thrust to tunnel dynamic pressure.

WIND TUNNEL/AVAILABILITY	MACH NUMBER	ALTITUDE FT (m)	MODEL INSTALLATION	
CURRENT AEDC 16 FT TULLAHOMA, TENNESSEE	0.2 → 0.8	SL → 30K* (9144)	 STRUT SUPPORT NO WING	 PARTIAL SPAN
~ 1985 LEWIS ALTITUDE – 20 FT OR 45 FT NASA LEWIS RESEARCH CENTER CLEVELAND, OHIO	0.2 → 0.8	SL → 30K (9144)		 PARTIAL SPAN
CURRENT ONERA SI – 26 FT MODANE, FRANCE	0.2 → 0.8	SL → 11K (3353)		 PARTIAL SPAN
~ 1982 AMES 40 FT BY 80 FT NASA AMES RESEARCH CENTER MOUNTAIN VIEW, CALIFORNIA	0.45	STATIC	 90-PERCENT SPAN PLUS FUSELAGE	 FULL SPAN PLUS FUSELAGE

*PRESSURE SIMULATION ONLY. TEMPERATURE IN ERROR

80-GEN-27434A

FIGURE 73. SURVEY OF PROBABLE WIND TUNNEL FACILITIES FOR PROP-FAN TESTBED TESTING

		SOLID BLOCKAGE*	$\Delta V/V_{POWER}$*	BALANCE AXIAL FORCE	BALANCE NORMAL FORCE(C_ℓ OR C_L)	α CAPABILITY	EXISTING MODEL SUPPORT	AVAILABILITY
AEDC 16-FOOT STRUT SUPPORT	$M_0 = 0.2$ $M_0 = 0.8$	3% ↓	8% <1%				MUST BE ADAPTED	
PARTIAL SPAN WING SUPPORT	$M_0 = 0.2$ $M_0 = 0.8$	9.8%	↓		1.1 0.2		↓	
LEWIS ALTITUDE TUNNEL	$M_0 = 0.2$ (45 FT) $M_0 = 0.8$ (20 FT)	4% 9.7%	1% <1%	?	?	?	?	1985
ONERA S1 8 METER	$M_0 = 0.2$ $M_0 = 0.8$	7.2% ↓	4% <1%		0.8 0.07			
AMES 40 BY 80 FLOOR MOUNT STRUTS MOUNT	$M_0 = 0.45$	5.5%	1%		0.55 3.4			1982

*T701 INSTALLATION

80-GEN-27575A

FIGURE 74. WIND TUNNEL CAPABILITIES AND LIMITATIONS SUMMARY

Wind Tunnel Model Strength Requirements

As a matter of safety precaution for protection of wind tunnel facilities, equipment, and associated personnel, strength requirements of the models to be tested in wind tunnel facilities are imposed. Generally, all hardware tested in wind tunnels must meet one of the following strength criteria:

- o Analytically demonstrate that predicted loads of any structural component do not exceed -
  - one-fifth the ultimate tensile strength, or
  - one-third the yield strength.

- o Static proof test critical model components to three times the maximum predicted load.

- o Static proof test critical model components to two times the maximum predicted load if the aerodynamic load is directly or continuously monitored.

Plots of deflection as a function of load for a complete loading cycle shall show no permanent set.

When considering the use of flight hardware as a wind tunnel test model, the structural integrity of the test item must meet with the tunnel specifications for strength requirements. In general, these requirements are greater than that necessary to satisfy the structural integrity of the flight hardware component.

LOW SPEED WIND TUNNEL TESTBED INSTALLATION

The largest wind tunnel that will accommodate tests requiring fossil fuel burning engines is the NASA Ames 40 x 80 foot tunnel. This tunnel operates at sea level total pressure at speeds up to 0.45 Mach number. The tunnel size will allow testing of a complete semi-span wing and fuselage if the airplane is mounted horizontally on three tunnel support struts (Figure 73d). These struts will allow both pitch and sideslip angle variation. Lift coefficients up to 3.4 are within the capability of the tunnel balance, and the balance drag link is sufficiently strong to allow testing of the prop-fan engine at full power when the thrust is approximately 7,500 pounds (3,104 kg).

If the airplane is split at the plane of symmetry and mounted on the balance turntable in the tunnel floor with the wing vertical, the wing must be clipped at 90 percent semi-span, as referred to the DC-9 (Figure 73d). The balance load capacity limits the lift coefficient to 0.55 for this mounting arrangement and the model cannot be tested in sideslip. The tunnel interference effects are assessed by evaluating the tunnel solid blockage and the incremental velocities produced by the prop-fan thrust. The solid blockage, in either case, is about 5.5 percent which is high but acceptable for low speed testing. The tunnel velocity correction due to power is small, less than 1 percent.

HIGH SPEED WIND TUNNEL TESTBED INSTALLATION

The large wind tunnels which will accommodate fossil fuel burning engines and provide test Mach numbers of 0.8 are the AEDC 16-foot Transonic Tunnel, the ONERA S1 (26-foot diameter) Tunnel in Modane, France, and the NASA Lewis Altitude Tunnel with the proposed improvements. Of these, only the Lewis Altitude Tunnel with the proposed improvements provides proper simulation of both the temperature and pressure at 30,000 feet (9,144 m) altitude. However, this facility will probably not be available for four or five years, too far downstream to aid this phase of the prop-fan program. The AEDC 16-foot Tunnel will allow simulation of the pressure at 30,000 feet (9,144 m); however, the tunnel heat exchangers do not have the capacity to cool the tunnel air to 412 degrees Rankine, the standard temperature at 30,000 feet (9,144 m). The ONERA S1 Tunnel operates at an ambient total pressure, therefore, at a Mach numer of 0.8 the test section static pressure is approximately equal to the pressure at 11,000 feet (3,352 m).

Because of the limited size of the test sections of these facilities, only partial span wings can be tested with the prop-fan engine and nacelle. Figures 73a, 73b and 73c depict the installation considered for each facility. As shown in Figure 73a, the stub wing is to be supported in the AEDC 16-foot tunnel with a trunion system. The airloads and engine thrust are measured with the largest existing six component strain-gage balance available. However, because of the large area of the wing, the balance normal force limitations of 16,000 pounds (7,256 kg) limits the lift coefficient to approximately 0.2 at a Mach number of 0.8. In addition, the solid blockage of the installation studied is 9.8 percent, well above the acceptale level of 0.5 percent. Similar installations were studied for the ONERA S1 tunnel, Figure 73c, and for the NASA Lewis Altitude Tunnel, Figure 73b. The available ONERA balance limits the lift coefficients to an unacceptably low value; the balance for the Lewis Altitude Tunnel is undefined. The solid blockage in these facilities, 7.2 and 9.7 percent, respectively, will result in erroneous force data.

In addition, since the size of available tunnels limits testing to a partial span wing, the wing tip is not present which means that the downwash, sidewash, and spanwise lift distribution of the wing in the propeller/nacelle region are not properly simulated. The missing wingtip and the distortion of the loading caused by the wind tunnel walls, will modify the vortex wake downstream of the wing, thereby modifying the downwash in the wing plane which is the cause of induced drag. Prop-fan power effects on the span loading are not properly represented because of the interaction of the prop-fan wake and wing trailing vortex wake are also not properly simulated. The local flow fields in the region of the propeller nacelle is also incorrect. The factors discussed above lead to the conclusion that the proper thrust and drag cannot be obtained in the tunnel using flight size hardware.

Since the use of a partial span wing is not satisfactory, the most promising test installation appears to consist of the engine nacelle mounted on a blade strut support with no wing (Figure 73a). This installation permits evaluation of the engine thrust at static, takeoff, and cruise conditions. The angle of the airflow in the plane of the prop-fan can be approximated by adjusting the angle of incidence of the engine and nacelle. Because of the pressure altitude simulation capability and the availability, the AEDC 16-foot transonic tunnel would be the preferred facility in which to conduct the isolated strut mount prop-fan engine test.

Although the strut mounted engine test in the AEDC 16-foot tunnel will yield the most meaningful data, the results will not satisfactorily fulfill all of the test requirements. Since the engine is to be tested without the influence of the wing, the upwash and sidewash caused by the wing flow field are not present and the proper levels of engine thrust-minus-installed-drag cannot be measured.

A rough order of magnitude estimate indicates that the cost of preparing an engine for test on a blade strut in the AEDC 16-foot tunnel, designing and fabricating the support system and balance mounts, conducting the test, and preparing pre-test and post-test reports are approximately $450K, in 1981 dollars, and requires approximately eight months to complete. The cost estimate assumes that the tunnel is to be furnished at no expense to DAC.

LARGE SCALE WIND TUNNEL RECOMMENDATIONS

The results of the study of the feasibility of testing the prop-fan flight hardware in a wind tunnel, summarized in Figure 74, clearly indicate that all the desired test data cannot be obtained. Using the only reasonable installation, the isolated-strut mounted nacelle in the AEDC 16-foot tunnel, the approximate engine thrust can be obtained; however, because of the large diameter of the prop-fan relative to the tunnel size, the data will be questionable. Since there is no wing in the tunnel, the installed thrust minus drag cannot be determined. The prop-fan loads may be approximated by setting the engine angle of attack at values derived from a three dimensional analysis of the wing flow field; however, the variation of flow field angles across the prop-fan disc cannot be simulated.

An overall evaluation of the wind tunnel as a means of obtaining proper large scale prop-fan/engine/nacelle data results in the following conclusions:

Flow Simulation

- o None of the tunnels will accommodate a complete span model at $M_o = 0.8$.
- o Upwash and sidewash cannot be simulated.
- o All tunnels have balance normal force limitations with a partial span wing at $M_o = 0.8$ and 30,000 feet (9,144 m) simulation.
- o Lewis Altitude Tunnel will not be available until at least 1985.

Thrust Minus Drag

- o Cannot measure because of partial span wing.
- o Proper airfoil section drag cannot be obtained due to balance normal force limits.

For test conditions at $M \sim 0.45$, the prop-fan loads, thrust-drag, and isolated prop-fan efficiency are obtainable from appropriate wind tunnel tests. However, for the test conditions of M_{cruise} of 0.80, these prop-fan loads and thrust-drag data are not obtainable; even the results for prop-fan efficiency are questionable. Because of the inadequacy of the wind tunnel test results, it is recommended that the DC-9-10 prop-fan flying testbed be used to obtain the aerodynamic data for the prop-fan configuration at large scale. Reliable acoustic data must also be obtained from flying testbed results.

ROM COSTS OF TWO-NACELLE PROP-FAN TESTBED PROGRAM

BACKGROUND

The estimated costs for the two-nacelle prop-fan testbed are based on a detailed evaluation of the WBS elements identified in Appendix II. Wherever possible, the buildup of manhour estimates were made from very similar effort accomplished in the recent past. There were several NASA sponsored programs that involved flight tests on a DC-8 and a DC-9 aircraft that were specifically related to the propulsion system on the aircraft. The DC-8 "Quiet Engine Program" consisted of modifications and special acoustic treatment designs on all four nacelles. The DC-9 "Refan Program" consisted of design, wind tunnel testing, fabrication of new nacelles, and pylon support structure for a rebuilt JT8D-9 engine that was converted to a larger diameter JT8D-209 engine. In addition, a recently completed program for the Air Force called PABST (Primary Adhesively Bonded Structure Test) involved the design and fabrication of tools and components for a single major test assembly. A very recent program that involved a considerable number of high and low speed and flutter wind tunnel models, as well as the design and construction of one set of flight test parts, was the DC-10 Winglet Flight Evaluation Program. All of the above programs have very similar work efforts that are identified in this prop-fan program. It is noteworthy to indicate that all of the above-mentioned programs were accomplished on schedule and within budget.

MAJOR ELEMENT DESCRIPTION

Preliminary Design Through PDR

All major functions that are to participate on the program are to be assigned and co-located in one area and to work together in establishing the design of the nacelle installation on the wing in a most cost effective manner considering design, tooling, fabrication, assembly, and installation which will result in a preliminary manufacturing plan. In parallel with this effort the specific definition of all the model programs is to be drafted into preliminary planning documents. In conjunction with the engine/gearbox subcontractor and propeller supplier, a draft plan for large scale ground testing, taxi testing and flight testing is to be prepared. All the preliminary planning documents are to be provided at the Preliminary Design Review (PDR). In addition, at PDR the layout drawings for the flight test nacelle, aircraft modification and test installation will be provided for approval.

Development Testing

Immediately after the PDR approval, the detail definition of all model wind tunnel testing is initiated. Both high and low speed wind tunnel models of the test aircraft are considered to be tested in the NASA Ames Research Center 11-foot and 12-foot wind tunnels provided at no Contractor expense. Model modifications consider nacelles off and on, both powered and unpowered, with the primary objective of stability and control required to define minimum operational speeds considering one prop-fan system failure and one test aircraft primary propulsion system failure. A basic low speed flutter model is considered essential to the program for methods validation for both the nacelles on and off. A test aircraft full scale inlet is also considered as part of this program. The acoustic development tests are in two parts. One deals with the development of treatment that can be added to the current structural arrangement of the test aircraft fuselage. The second part of the acoustic development effort will be the definition and specimen tests of a newly designed segment of structure optimized for minimum acoustic transmission. The layout of this section would be suitable for rework into the test aircraft.

Detail Design

The selection of the flight test nacelle and installation configuration will have been made as a result of PDR. Upon NASA concurrence, the detail design is to be initiated for the nacelle and for aircraft modification. The structural detail design will be established in conjunction with manufacturing tooling in order to "optimize" for a least cost prop-fan effort. The final design for all major components will be completed at the Critical Design Review (CDR). At the time of CDR, the high speed wind tunnel model stability and control, inlet, and acoustic tests should be completed. The low speed tests can be completed after CDR. At CDR both engine and prop-fan subcontractors will participate to identify their interface requirements, how they have been satisfied in the program to date, as well as how the future schedule and interface requirements are being satisfied. Tooling design and tool fabrication will be nearly complete at CDR with some component fabrication of parts in progress. At CDR the flight program instrumentation plan will have been completely definitized.

Ground Tests

The ground test programs will consist of a test stand run of the complete flight test propulsion assembly. Included will be the test engines, gearbox, and first set of flightworthy prop-fan blades. Runs to full allowable gearbox horsepower will be made for systems check-out and operation. The complete flight test propulsion unit will than be installed in the flight nacelle on the aircraft. A ground vibration test on the nacelle and aircraft will previously have been conducted which included represenntative mass and inertia of the propulsion system. There may be some question regarding the propulsion system representation during these ground vibration tests; if serious, the ground vibration test would be accomplished with the full flight hardware installed. Engine runs will be accomplished on the aircraft in a tie-down condiction. In conjunction with the installation check-out, a series of acoustic tests on the fuselage sidewall will be accomplished. After successful completion of all static ground runs, the aircraft will undergo a series of taxi tests, up to 100 knots, to measure all structural, acoustic, engine performance, and operational data. For the purpose of this program, the 40 x 80 wind tunnel testing and alternate fuselage sidewall are not included in the cost estimates and are considered options to the basic flight program.

Flight Tests

Flight tests will be initiated after satisfactory completion of all ground tests and analyses of all key data items. The aircraft flight handling characteristics will be evaluated without power on the test engines. Included will be flutter checks for envelope expansion. The test engines will then be air started and operated at increasing horsepower and speed as the aircraft operational characteristics are determined to be satisfactory. Propeller performance (aerodynamic, structural, and acoustic) as well as fuselage acoustic data and nacelle/wing aerodynamic data will be obtained throughout the prescribed test envelope.

Baseline Flight Tests

The test aircraft, prior to entering modification for nacelle installation, will be instrumented and a series of flights will be conducted to obtain basic flight handling and performance data. These basic data will then be a reference for all prop-fan data to be gathered.

Major Subcontracting

At initiation of the basic or prime contract, a definition of the engine/ gearbox subcontract will be made. For purposes of ROM estimates, information has been provided by Detroit Diesel Allison (DDA), a Division of General Motors, for gearbox manufacture and shaft engine preparation in a configuration suitable for flight test. During preliminary design, DDA will be given a purchase order to present their role in the program at PDR. For purposes of this contract effort, the DDA estimate used in the summary cost figures include engine runs of 50 hours on the dynamometer. The first buildup with a propeller will be on the Douglas test stand. For the ROM estimates presented, the prop-fan subcontrct with Hamilton Standard would commence upon receipt of the flight hardware. All previous effort PDR and CDR would be covered under a Prop-fan Development Contract with Hamilton Standard. A subcontract with Hamilton Standard is considered in effect during all ground and flight tests that included the prop-fan. For ROM estimating purposes, it is assumed that the two companies identified above will be the only major subcontractors. Consideration was given to soliciting estimates from a nacelle design and/or fabricator, but for purposes of the estimates shown in this report, the nacelle design and manufacture is accomplished by the airframe company.

Program Management

The estimates made in this element consider the direct charge Project Management which includes a Task Manager from Engineering, Manufacturing and Flight Test. These personnel are not necessarily full time for the duration of the program. The Administrative business function for budget and schedule planning and tracking is also included in this element. Costs for all estimated reports (monthly, quarterly, planning, test results, etc.) are included in this section. Oral report preparation and travel are also considered in this section of the estimates.

Costs

The estimated total program costs, Rough Order of Magnitude (ROM), for a prop-fan program outlined in the previous paragraphs and outlined more specifically in WBS format in Appendix II is provided in Figure 75. These ROM estimates are costs which include all normal burden charges except fee.

Program Schedule

The program schedule from which all the cost estimates were generated was developed in mid-contract period. The two major subcontractors supplied their schedule based on the definition of the prop-fan testbed program at that time (late 1980). The program overall schedule is shown in Figure 76, which identifies first flight occurring at 44 months from program go-ahead. The program schedule considers that the first flight prop-fan delivery occurs at 33 months from go-ahead. This schedule coincides with a schedule developed by Hamilton Standard based on their ability to deliver the flight prop-fan in the 33 month time period (Figure 77). The engine gearbox delivery from DDA is identified as available in 15 months from go-ahead. DDA go-ahead could occur as part of the CDR release schedule. The program does consider an earlier start for DDA so that engine/gearbox fit checks in the test stand and aircraft can be made well ahead of receipt of the flight rated prop-fan assembly. The DDA schedule is provided in Figure 78. Also shown on the DDA schedule are Option 1 and Option 2, which are not considered in this particular program since the first full propulsion system run with the flight hardware is identified as a Douglas test stand ground run element.

ESTIMATED TOTAL PROGRAM COSTS

ROUGH ORDER MAGNITUDE (ROM)

DC-9-10 TESTBED

(Two Allison T701 Engines)

WBS Element*		$K 1981 (Mid-Year)
1000	Preliminary Design thru PDR	1,200
2000	Development Testing	4,560
3000	Detailed Design thru CDR	2,800
4000	Manufacturing	6,340
5000	Ground Tests	5,635
6000	Flight Tests	7,410
7000	Baseline Flight Tests	2,225
8000	Major Subcontracting	6,500**
9000	Program Management	4,100
Test Aircraft Cost (DC-9-10)		2,500
TOTAL		43,000

*Appendix II for detailed definition of effort considered in each element.

**DDA engine and gearbox plus program support
Hamilton Standard program support.

FIGURE 75. ESTIMATED TOTAL COSTS FOR PROP-FAN TESTBED PROGRAM

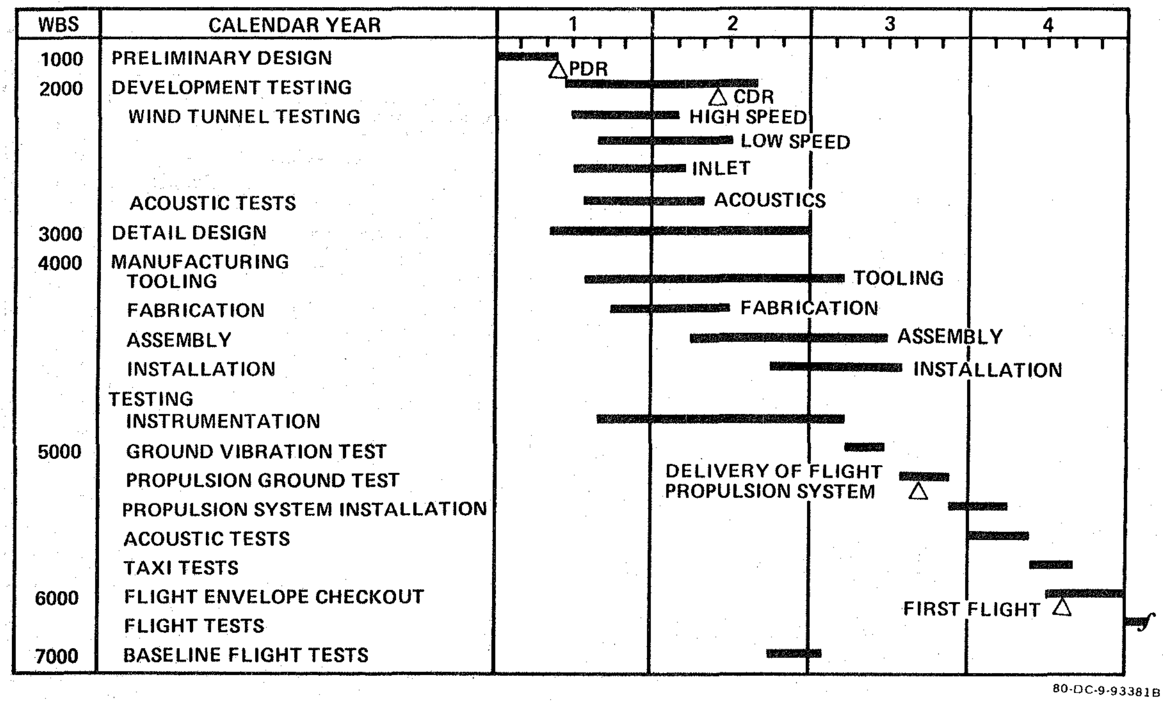


FIGURE 76. DOUGLAS AIRCRAFT PROP-FAN TESTBED PROGRAM SCHEDULE

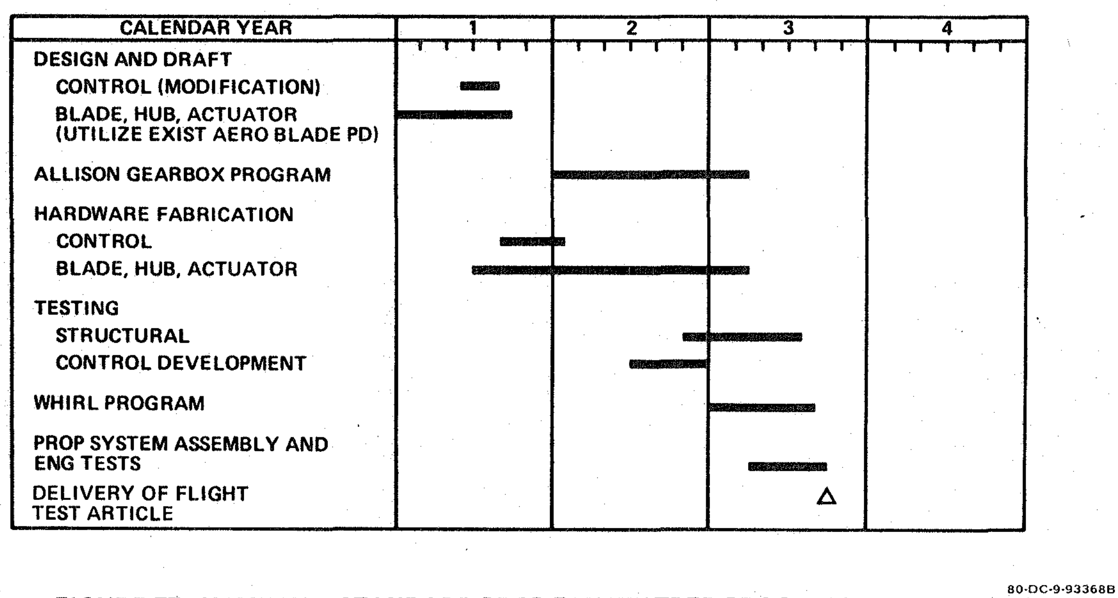
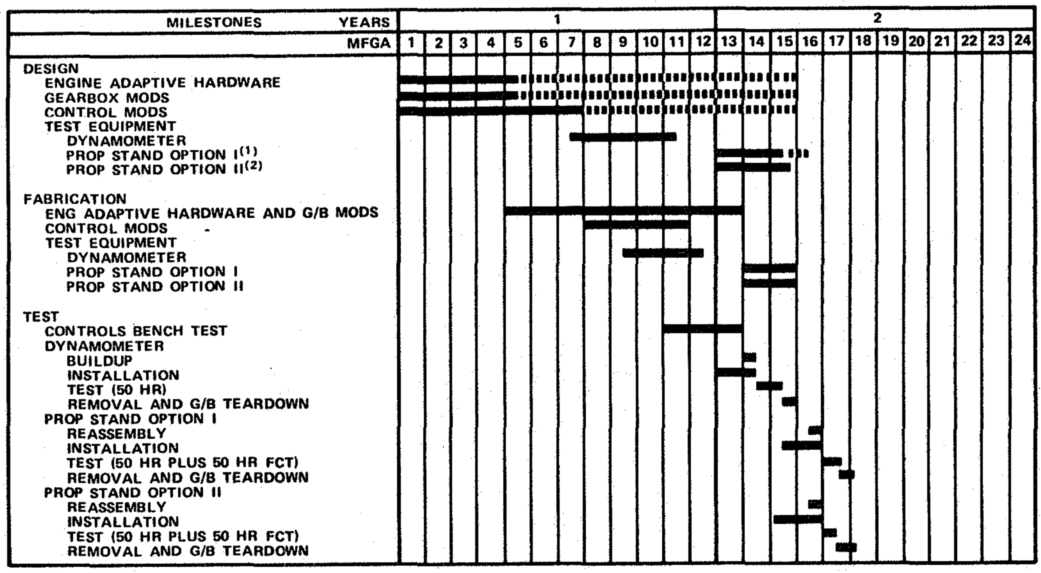


FIGURE 77. HAMILTON STANDARD PROP-FAN TESTBED PROGRAM SCHEDULE



(1) TEST STAND 861 INSTALLATION – MOD OF STAND CURRENTLY IN USE
(2) TEST STAND 862 INSTALLATION – MOD OF IDLE STAND FOR QEC INSTALLATION

80-DC-9-93370A

FIGURE 78. DETROIT-DIESEL ALLISON PROP-FAN TESTBED PROGRAM SCHEDULE

REFERENCES

1. Advanced Turboprop Testbed Systems Study, NASA Lewis Research Center, Contract NAS3-22437, January 22, 1980.

2. "Prop-fan Data Support Study Technical Report," Hamilton Standard Report prepared under Contract No. NAS2-9750, NASA Contractor Report 152141, February 28, 1978.

3. Goldsmith, I. M., "A Study to Define the Research and Technology Requirements for Advanced Turbo/Prop-fan Transport Aircraft," Contract NAS2-10178. NASA Contractor Report 166138, February 1981.

4. Magliozzi, B., "The Influence of Forward Flight on Propeller Noise," NASA Contractor Report 145105, February 1977.

5. Pope, A. and Harper, J. J., "Low Speed Wind Tunnel Testing," John Wiley & Sons, New York, 1966.

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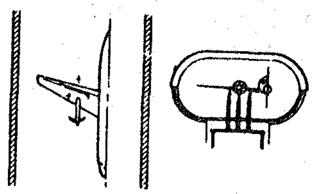
APPENDIX I

APPENDIX I

CAPABILITIES OF WIND TUNNELS SUITABLE FOR
PROP-FAN TESTBED LARGE SCALE TESTING

Test Facility: NASA Ames 40 x 80 foot wind tunnel, Moffett Field, Calif.



FULL SPAN PLUS FUSELAGE

Capabilities:

- o Speed range: Mach No. $0 \sim 0.45$
- o Pressure: Atmospheric total pressure
- o Force measuring: External balance with
  - Normal force limit = 102,000 lb (46,258 kg)
  - Axial force limit = 18,000 lb (8,163 kg)
- o Axial force limit-to-force required = 18,000/7,500 (8,163/3,401 kg)
- o C_L limit ≈ 3.4
- o Angle of attack range: Ample
- o Allows testing of complete half-span configuration
- o Utilizes existing tunnel supports

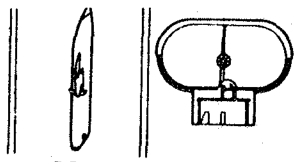
Limitations:

- o Not available until July 1982
- o Low speed only

Tunnel Interference:

- o Solid blockage = 5.5 percent
- o A_{prop}/A_{tunnel} = 2.8 percent
- o $\Delta V/V)_{PWR}$ = <1 percent

Test Facility: NASA Ames 40 x 80 foot wind tunnel, Moffett Field, Calif.



Capabilities:

- o Speed range: Mach No. 0 ~ 0.45
- o Pressure: Atmospheric total pressure
- o Force measuring: External balance with
  Normal force limit = 16,400 (7,437 kg)
  Axial force limit = 18,000 (8,163 kg)
- o Axial force limit-to-force required = 18,000/7,500 (8,163/3,401 kg)
- o Angle of attack range: Ample
- o Allows testing with 90 percent of the model span and half the fuselage
- o Utilizes existing tunnel supports

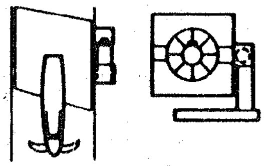
Limitations:

- o Not available until July 1982
- o Tip effects not simulated
- o Low speeds only
- o C_L limit $\approx$ 0.55 (16,400 lb [7,437 kg] normal force limit)

Tunnel Interference:

- o Solid blockage = 5.5 percent
- o Aprop/Atunnel = 2.8 percent
- o $\Delta V/V)_{PWR}$ = <1 percent

Test Facility: AEDC 16 foot transonic wind tunnel, Tullahoma, Tennessee


PARTIAL SPAN

Capabilities:

- o Speed range: Mach No. 0 → 1.6
- o Pressure: 180 → 4,000 psfa (12.7 → 281.2 kg/sq m)
- o Force measuring: 6 component strain gage balance with
  Normal force limit = 16,000 lb (7,256 kg)
  Axial force limit = 8,000 lb (3,628 kg)
- o Axial force limit-to-force required
  = 8,000/7,500 (3,628/3,401 kg) at M = .2
  = 8,000/2,250 (3,628/1,020 kg) at M = .8
- o Angle of attack: Ample
- o Can simulate 30,000 feet (9,144 m) pressure at M = 0.8 but not temperature
- o Perforated test section walls

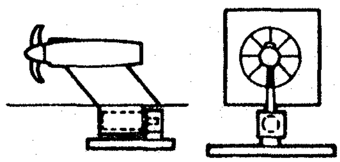
Limitations:

- o Partial wing span
- o Support system must be adapted

Tunnel Interference:

- o Solid blockage = 9.8 percent
- o A_{prop}/A_{tunnel} = 30 percent
- o $V/V)_{PWR}$ = 8 percent at M = 0.2
  = 1 percent at M = 0.8

Test Facility: AEDC 16 foot transonic wind tunnel, Tullahoma, Tennessee



STRUT SUPPORT NO WING

Capabilities:

- o Speed range: Mach No. 0 → 1.6
- o Pressure: 180 → 4,000 psfa (12.7 → 281.2 kg/sq m)
- o Force measuring: 6 component strain gage balance with
  Normal force limit = 16,000 lb (7,256 kg)
  Axial force limit = 8,000 lb (3,628 kg)
- o Axial force limit-to-force required
  = 8,000/7,500 (3,628/3,401 kg) at M = .2
  = 8,000/2,250 (3,628/1,020 kg) at M = .8
- o Angle of attack: Undefined
- o Can simulate 30,000 feet (9,144 m) pressure at M = 0.8 but not temperature
- o Perforated test section walls

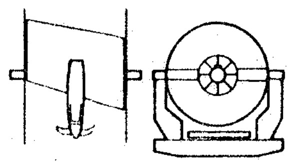
Limitations:

- o Wing not simulated
- o Support system must be adapted

Tunnel Interference:

- o Solid blockage = 3.0 percent
- o A_{prop}/A_{tunnel} = 30 percent
- o $V/V)_{PWR}$ = 8 percent at M = 0.2
  = 1 percent at M = 0.8

Test Facility: ONERA S1, subsonic-transonic wind tunnel, Modane, France
8 meter (26.2 ft.) diameter



PARTIAL SPAN

Capabilities:

- o Speed range: Mach No. 0 — 1.03
- o Pressure: Atmospheric total pressure
- o Force measuring: External balance with
  Normal force limit = 18,000 lb (8,163 kg)
  Axial force limit = 22,500 lb (10,204 kg)
- o Axial force limit-to-force required
  = 22,500/7,500 (10,204/3,401 kg) at M = 0.2
  = 22,500/4,400 (10,204/1,995 kg) at M = 0.8
- o Angle of attack range: Ample
- o Utilizes existing tunnel supports
- o Full range of required Mach No. can be tested with one installation
- o Minimally slotted test section walls

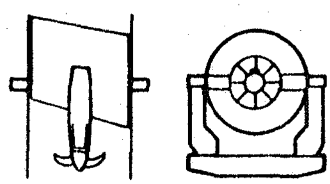
Limitations:

- o Partial wing span
- o Altitude simulation at M = 0.8 is 11,000 ft (3,352 m)
- o C_L limit = 0.8 at M = 0.2
  = 0.07 at M = 0.8

Tunnel Interference:

- o Solid blockage = 7.2 percent
- o Aprop/Atunnel = 14 percent
- o $\Delta V/V)_{PWR}$ = 4 percent at M = 0.2
  = 1 percent at M = 0.8

Test Facility: NASA Lewis altitude wind tunnel, Cleveland, Ohio



PARTIAL SPAN

Capabilities:

- Speed range: Mach No. 0 – 0.8
- Pressure: 1.32 psia (.93 kg/sq m^2) → atmospheric
- Test section diameters: Low speed 45 ft (13.7 m)
  High speed 20 ft (6.10 m)
- Force measuring: Undefined
- Angle of attack range: Undefined
- Revisions to tunnel can be designed to the test and model requirements
- Proper temperature and pressure simulation for M = 0.8 at 30,000 ft (9,144 m) altitude
- Slotted test section walls
- Support system exists

Limitations:

- Tunnel not available earlier than 1985
- Partial wing span

Tunnel Interference:

o Solid blockage	=	4.0 percent (45 ft [13.7 m] diameter)
	=	9.7 percent (20 ft [6.1 m] diameter)
o A_{prop}/A_{tunnel}	=	5 percent (45 ft [13.7 m] diameter)
	=	25 percent (20 ft [6.1 m] diameter)
o $V/V)_{PWR}$	=	1 percent (45 ft [13.7 m] diam. at M = 0.2)
	=	1 percent (20 ft [6.1 m] diam. at M = 0.8)

APPENDIX II

APPENDIX II

PROP-FAN FLIGHT RESEARCH PROGRAM
WORK BREAKDOWN STRUCTURE (WBS)

Although not a part of the contractual Statement of Work (NAS3-22347), a work breakdown structure (WBS) through the second level, appropriate to the Prop-fan Flight Research Program, is included here as Appendix II. This WBS has previously been submitted to NASA Lewis as ACEE Report 27-PL-1480A, dated May 1981. Further expansion of this WBS is considered apropos as a part of the response to the upcoming RFP on prop-fan testbed program.

SUMMARY

MAJOR WBS ELEMENTS

001 FLIGHT RESEARCH PROGRAM

- 1000 PRELIMINARY DESIGN
- 2000 DEVELOPMENT TESTING
- 3000 DETAIL DESIGN
- 4000 MANUFACTURING
- 5000 GROUND TESTS
- 6000 FLIGHT TESTS
- 7000 BASELINE FLIGHT TEST
- 8000 MAJOR SUBCONTRACTING
- 9000 PROGRAM MANAGEMENT

WBS WORKSHEET

1000 PRELIMINARY DESIGN

- 1100 AERO INSTALLATION DESIGN
- 1200 STRUCTURAL LAYOUT
- 1300 INSTALLATION LAYOUT
- 1400 DEVELOPMENT TEST (PLAN)
- 1500 MANUFACTURING (PLAN)
- 1600 GROUND TEST (PLAN)
- 1700 FLIGHT TEST (PLAN)
- 1800 PRELIMINARY DESIGN REVIEW
- 1900 ALTERNATE PROGRAM

WBS WORKSHEET

2000 DEVELOPMENT TESTING

- 2100 HIGH SPEED WIND TUNNEL MODEL TEST
- 2200 LOW SPEED WIND TUNNEL MODEL TEST
- 2300 INLET WIND TUNNEL MODEL TEST
- 2400 LOW SPEED FLUTTER MODEL TEST
- 2500 ACOUSTIC TREATMENT DEVELOPMENT TESTS
- 2600 ALTERNATE FUSELAGE STRUCTURE DEVELOPMENT TESTS

WBS WORKSHEET

3000 DETAIL DESIGN

- 3100 AERODYNAMIC CONFIGURATION
- 3200 STRUCTURE
- 3300 INSTALLATION
- 3400 AIRCRAFT MODIFICATION
- 3500 CRITICAL DESIGN REVIEW

WBS WORKSHEET

4000 MANUFACTURING

- 4100 PLANNING
- 4200 TOOLING
- 4300 FABRICATION
- 4400 ASSEMBLY
- 4500 AIRCRAFT MODIFICATION
- 4600 INSTALLATION
- 4700 SUSTAINING ENGINEERING

WBS WORKSHEET

5000 GROUND TESTS

- 5100 INSTRUMENTATION
- 5200 TEST STAND
- 5300 GROUND VIBRATION TEST
- 5400 STATIC ENGINE RUN - INSTALLED
- 5500 TAXI TESTS
- 5600 ALTERNATE FUSELAGE SIDEWALL
- 5700 SUSTAINING ENGINEERING
- 5800 FORWARD NACELLE 40 x 80 WIND TUNNEL
- 5900 NACELLE/WING 40 x 80 WIND TUNNEL

WBS WORKSHEET

6000 FLIGHT TESTS

- 6100 TEST PLAN
- 6200 INSTRUMENTATION CHECKOUT
- 6300 AIRCRAFT ENVELOPE EVALUATION
- 6400 TEST ENGINE OPERATION
- 6500 ENGINE TEST ENVELOPE EVALUATION
- 6600 PERFORMANCE TESTS
- 6700 ACOUSTIC TESTS
- 6800 ENVELOPE EXPANSION
- 6900 FLIGHT TEST DATA

WBS WORKSHEET

7000 BASELINE FLIGHT TESTS

- 7100 TEST PLAN
- 7200 CALIBRATE ENGINES
- 7300 INSTRUMENTATION
- 7400 WING PRESSURE SURVEY
- 7500 CRUISE PERFORMANCE
- 7600 FLIGHT TEST DATA

<u>WBS WORKSHEET</u>

8000	MAJOR SUBCONTRACTS	
9000	PROGRAM MANAGEMENT	
	9100	PROJECT MANAGEMENT
	9200	ADMINISTRATION BUDGET/SCHEDULE
	9300	REPORTS - PERIODIC
	9400	ORAL REPORTS
	9500	INTERIM REPORTS
	9600	FINAL & SUMMARY REPORTS
	9700	TRAVEL

WBS WORKSHEET

1000 PRELIMINARY DESIGN

- 1100 AERO INSTALLATION DESIGN
  - 1101 FORWARD NACELLE
  - 1102 AFT NACELLE
  - 1103 ENGINE INLET
  - 1104 OIL COOLER INLET
  - 1105 WING LEADING EDGE
  - 1106 TAILPIPE
  - 1107 AIRCRAFT
- 1200 STRUCTURAL LAYOUT
  - 1201 FORWARD NACELLE
  - 1202 AFT NACELLE
  - 1203 WING ATTACH
  - 1204 AIRCRAFT MODIFICATION
- 1300 INSTALLATION LAYOUT
  - 1310 MOUNTING SYSTEM POWER/TRAIN
  - 1320 CONTROLS
  - 1330 FUEL SYSTEMS
  - 1340 OIL COOLING SYSTEM
  - 1350 ACCESSORIES
  - 1360 INLET/EXHAUST
  - 1370 SYNCHROPHASING SYSTEM
  - 1380 EMERGENCY/SAFETY SYSTEMS
  - 1390 PRELIMINARY INSTALLATION SPECIFICATION

WBS WORKSHEET

1000 PRELIMINARY DESIGN (CONTINUED)

1400 DEVELOPMENT TESTS (PLAN)

1410 HIGH SPEED WIND TUNNEL MODEL

1420 LOW SPEED WIND TUNNEL MODEL

1430 INLET WIND TUNNEL MODEL

1440 LOW SPEED FLUTTER MODEL

1450 ACOUSTIC TREATMENT DEVELOPMENT

1460 ALTERNATE FUSELAGE STRUCTURE

1470 PRELIMINARY DEVELOPMENT TEST PLAN

1500 MANUFACTURING (PLAN)

1510 PLANNING

1520 TOOLING

1530 FABRICATION

1540 ASSEMBLY

1550 PRELIMINARY MANUFACTURING PLAN

1600 GROUND TESTS (PLAN)

1610 INSTRUMENTATION DEFINITION

1620 FORWARD NACELLE - QUARTZSITE

1630 AIRCRAFT INSTALLATION - PROOF TEST

1640 AIRCRAFT INSTALLATION - GVT

1650 STATIC & TAXI RUNS - ACOUSTIC

1660 DATA REDUCTION AND ANALYSIS

WBS WORKSHEET

1000 PRELIMINARY DESIGN (CONTINUED)

1600 GROUND TESTS (PLAN) (CONTINUED)

1670 PRELIMINARY GROUND TEST PLAN

1680 FORWARD NACELLE - 40 x 80 WIND TUNNEL

1690 INSTALLATION & WING SECTION - 40 x 80 WIND TUNNEL

1700 FLIGHT TESTS (PLAN)

1710 INSTRUMENTATION DEFINITION

1720 AIRCRAFT ENVELOPE EVALUATION

1730 TEST ENGINE OPERATION

1740 ENGINE TEST ENVELOPE EVALUATION

1750 ACOUSTIC CONDITION

1760 ENVELOPE EXPANSION

1770 FLYOVER NOISE

1780 DATA REDUCTION AND ANALYSIS

1790 PRELIMINARY FLIGHT TEST PLAN

1800 PRELIMINARY DESIGN REVIEW

1810 NASA APPROVAL

WBS WORKSHEET

2000 DEVELOPMENT TESTING

2100 HIGH SPEED WIND TUNNEL MODEL TEST

2110 MODEL CONFIGURATION

2120 MODEL DESIGN

2130 MODEL FABRICATION

2140 MODEL INSTRUMENTATION

2150 TEST PLAN

2160 MODEL TESTS

2170 DATA REDUCTION

2180 DATA ANALYSIS

2190 TEST REPORTING

2200 LOW SPEED WIND TUNNEL MODEL TEST

2210 MODEL CONFIGURATION

2220 MODEL DESIGN

2230 MODEL FABRICATION

2240 MODEL INSTRUMENTATION

2250 TEST PLAN

2260 MODEL TESTS

2270 DATA REDUCTION

2280 DATA ANALYSIS

2290 TEST REPORTING

WBS WORKSHEET

2000 DEVELOPMENT TESTING (CONTINUED)

- 2300 INLET WIND TUNNEL MODEL TEST
  - 2310 MODEL CONFIGURATION
  - 2320 MODEL DESIGN
  - 2330 MODEL FABRICATION
  - 2340 MODEL INSTRUMENTATION
  - 2350 TEST PLAN
  - 2360 MODEL TESTS
  - 2370 DATA REDUCTION
  - 2380 DATA ANALYSIS
  - 2390 TEST REPORTING
- 2400 LOW SPEED FLUTTER MODEL TEST
  - 2410 MODEL CONFIGURATION
  - 2420 MODEL DESIGN
  - 2430 MODEL FABRICATION
  - 2440 MODEL INSTRUMENTATION
  - 2450 TEST PLAN
  - 2460 MODEL TESTS
  - 2470 DATA REDUCTION
  - 2480 DATA ANALYSIS
  - 2490 TEST REPORTING

WBS WORKSHEET

2000 DEVELOPMENT TESTING (CONTINUED)

- 2500 ACOUSTIC TREATMENT DEVELOPMENT TESTS
  - 2510 BASIC STRUCTURE ANALYSIS
  - 2520 TREATMENT A DESIGN
  - 2530 TEST PLAN
  - 2540 TREATMENT FABRICATION
  - 2550 TREATMENT TESTING
  - 2560 DATA REDUCTION
  - 2570 DATA ANALYSIS
  - 2580 RECOMMENDATION REPORT

- 2600 ALTERNATE FUSELAGE STRUCTURE DEVELOPMENT TEST
  - 2610 CONFIGURATION ANALYSIS
  - 2620 TEST SELECTION DESIGN
  - 2630 TEST PLAN
  - 2640 COMPONENT FABRICATION
  - 2650 COMPONENT TESTING
  - 2660 DATA REDUCTION
  - 2670 DATA ANALYSIS
  - 2680 DESIGN RECOMMENDATION

WBS WORKSHEET

3000 DETAIL DESIGN

- 3100 AERODYNAMIC CONFIGURATION
  - 3110 FORWARD NACELLE
  - 3120 AFT NACELLE
  - 3130 ENGINE INLET
  - 3140 OIL COOLER INLET
  - 3150 WING LEADING EDGE
- 3200 STRUCTURAL
  - 3210 FORWARD NACELLE
  - 3220 AFT NACELLE
  - 3230 WING ATTACH
  - 3240 WING LEADING EDGE
- 3300 INSTALLATION
  - 3310 MOUNTING SYSTEMS POWER TRAIN
  - 3320 CONTROLS
  - 3330 FUEL SYSTEM
  - 3340 OIL COOLING SYSTEM
  - 3350 ACCESSORIES
  - 3360 INLET/EXHAUST
  - 3370 SYNCHROPHASING SYSTEMS
  - 3380 EMERGENCY/SAFETY SYSTEMS
  - 3390 INSTALLATION SPECIFICATION

WBS WORKSHEET

3000 DETAIL DESIGN (CONTINUED)

3400 AIRCRAFT MODIFICATION

3410 WING

3411 SPAR & SKIN PANELS

3412 LEADING EDGE

3413 TRAILING EDGE

3414 SPOILER SYSTEM

3420 FUSELAGE

3421 ACOUSTIC TREATMENT

3422 ALTERNATE SIDEWALL

3430 CONTROLS & DISPLAYS

3431 COCKPIT

3432 TEST CONSOLE

3433 WING/FUSELAGE

3500 CRITICAL DESIGN REVIEW

3510 NASA APPROVAL

WBS WORKSHEET

4000 MANUFACTURING

- 4100 PLANNING
  - 4110 FORWARD NACELLE
  - 4120 AFT NACELLE
  - 4130 WING MODIFICATION
  - 4140 CONTROL SYSTEMS
  - 4150 FUEL & OIL COOLING SYSTEM
  - 4160 FUSELAGE TREATMENT
  - 4170 INLET/EXHAUST
  - 4180 ACCESSORIES INSTALLATION
  - 4190 ALTERNATE FUSELAGE SIDEWALL
- 4200 TOOLING
  - 4210 FORWARD NACELLE
  - 4220 AFT NACELLE
  - 4230 WING MODIFICATION
  - 4240 CONTROL SYSTEMS
  - 4250 FUEL & OIL COOLING SYSTEM
  - 4260 FUSELAGE TREATMENT
  - 4270 INLET/EXHAUST
  - 4280 ACCESSORIES INSTALLATION
  - 4290 ALTERNATE FUSELAGE SIDEWALL

WBS WORKSHEET

4000 MANUFACTURING (CONTINUED)

- 4300 FABRICATION
  - 4310 FORWARD NACELLE
  - 4320 AFT NACELLE
  - 4330 WING MODIFICATION
  - 4340 CONTROL SYSTEM
  - 4350 FUEL & OIL COOLING SYSTEM
  - 4360 FUSELAGE TREATMENT
  - 4370 INLET EXHAUST
  - 4380 ACCESSORIES INSTALLATION
  - 4390 ALTERNATE FUSELAGE SIDEWALL

- 4400 ASSEMBLY
  - 4410 FORWARD NACELLE
  - 4420 AFT NACELLE

- 4500 AIRCRAFT MODIFICATION
  - 4501 AIRCRAFT AVAILABILITY
  - 4510 WING STRUCTURE
  - 4520 FUEL SYSTEM
  - 4530 SPOILER CONTROL SYSTEMS
  - 4540 WING LEADING EDGE

WBS WORKSHEET

4000 MANUFACTURING (CONTINUED)

- 4600 INSTALLATION
  - 4610 AFT NACELLE
  - 4620 FORWARD NACELLE
  - 4630 PROPULSION SYSTEM
  - 4640 FUEL SYSTEM
  - 4650 CONTROL SYSTEMS
  - 4660 FUSELAGE TREATMENT
  - 4670 INLET/EXHAUST
  - 4680 ACCESSORIES
  - 4690 ALTERNATE FUSELAGE SIDEWALL
- 4700 SUSTAINING ENGINEERING

WBS WORKSHEET

5000 GROUND TESTS

- 5100 INSTRUMENTATION
  - 5110 DESIGN
    - 5111 FORWARD NACELLE
    - 5112 AFT NACELLE
    - 5113 WING/FUSELAGE
  - 5120 FABRICATION
    - 5121 FORWARD NACELLE
    - 5122 AFT NACELLE
    - 5123 WING/FUSELAGE
  - 5130 INSTALLATION
    - 5131 FORWARD NACELLE
    - 5132 AFT NACELLE
    - 5133 WING/FUSELAGE
- 5200 TEST STAND
  - 5210 TEST PLAN
  - 5220 INSTALLATION - SUPPORT FIXTURE FORWARD NACELLE
    - 5221 DESIGN
      - 522101 TEST STRUCTURE
      - 522102 CONTROLS
      - 522103 FUEL SYSTEM
    - 5222 FABRICATION
      - 522201 TEST STRUCTURE
      - 522202 CONTROLS
      - 522203 FUEL SYSTEM
    - 5223 ASSEMBLY TEST STRUCTURE
      - 522301 TEST STRUCTURE
      - 522302 CONTROLS
      - 522303 FUEL SYSTEM

WBS WORKSHEET

5000 GROUND TESTS (CONTINUED)

- 5200 TEST STANDS (CONTINUED)
  - 5224 TEST STAND INSTALLATION
    - 522401 TEST STRUCTURE
    - 522402 CONTROLS
    - 522403 FUEL SYSTEM
  - 5230 INSTRUMENTATION
    - 5231 DESIGN
    - 5232 FABRICATION
    - 5233 INSTALLATION
  - 5240 NACELLE INSTALLATION
  - 5250 EQUIPMENT INSTALLATION
    - 5251 ENGINE - GB - PROP
    - 5252 CONTROLS
    - 5253 FUEL SYSTEM
    - 5254 ACCESSORIES
  - 5260 STARTUP & CHECKOUT
  - 5270 TEST RUNS
  - 5280 DATA REDUCTION & ANALYSIS
  - 5290 TEST REPORT
- 5300 GROUND VIBRATION TEST
  - 5310 TEST PLAN
  - 5320 TEST SETUP
    - 5321 DESIGN
    - 5322 FABRICATION
    - 5323 ASSEMBLY

WBS WORKSHEET

5000 GROUND TESTS (CONTINUED)

5300 GROUND VIBRATION TEST (CONTINUED)

5330 INSTRUMENTATION

5331 DESIGN

5332 FABRICATION

5333 INSTRUMENTATION INSTALLATION

5340 AIRCRAFT SETUP

5350 TESTING

5360 DATA REDUCTION & ANALYSIS

5370 TEST REPORT

5400 STATIC ENGINE RUN - INSTALLED

5410 TEST PLAN

5420 ENGINE STARTUP & CHECKOUT

5430 ENGINE TEST RUNS

5440 ACOUSTIC TEST RUNS

5441 ENGINE RUNUP ACOUSTIC TESTS

5442 CABIN REVERBERATION TESTS

5450 DATA REDUCTION & ANALYSIS

5460 TEST REPORT

5500 TAXI TESTS

5510 TEST PLAN

5520 ENGINE TEST TAXI RUNS

5530 ACOUSTIC TEST TAXI RUNS

5540 DATA REDUCTION

5550 TEST REPORT

WBS WORKSHEET

5000 GROUND TESTS (CONTINUED)

5600 ALTERNATE FUSELAGE SIDEWALL

5610 TEST PLAN

5620 INSTRUMENTATION

5621 DESIGN

5622 FABRICATION

5623 INSTALLATION

5630 GROUND TESTS

5631 STATIC ENGINE RUNS

5632 TAXI RUNS

5640 DATA REDUCTION & ANALYSIS

5650 TEST REPORT

5700 SUSTAINING ENGINEERING

WBS WORKSHEET

OPTION PROGRAM

5800 FORWARD NACELLE 40 x 80

- 5810 TEST PLAN
- 5820 INSTRUMENTATION
  - 5821 DESIGN
  - 5822 FABRICATION
  - 5823 INSTALLATION
- 5830 TEST INSTALLATION
  - 5831 DESIGN
  - 5832 FABRICATION
  - 5833 INSTALLATION
- 5840 NACELLE INSTALLATION
  - 5841 STRUCTURAL
  - 5842 POWER SYSTEM
  - 5843 CONTROLS
  - 5844 FUEL SYSTEM
- 5850 CHECKOUT & STARTUP
  - 5851 STATIC STARTUP
  - 5852 TUNNEL RUN
  - 5853 CHECKOUT RUN
- 5860 TEST RUNS
- 5870 DATA REDUCTION & ANALYSIS
- 5880 TEST REPORT

5900 NACELLE/WING 40 x 80

- 5910 TEST PLAN

WBS WORKSHEET

OPTION PROGRAM

5900 NACELLE/WING 40 x 80 (CONTINUED)

- 5920 INSTRUMENTATION
  - 5921 DESIGN
  - 5922 FABRICATION
  - 5923 INSTALLATION
- 5930 TEST INSTALLATION
  - 5931 DESIGN
  - 5932 FABRICATION
  - 5933 INSTALLATION
- 5940 TEST WING INSTALLATION
  - 5941 MODIFICATION DESIGN
  - 5942 FABRICATION
  - 5943 WING MODIFICATION
  - 5944 INSTALLATION
  - 5945 AFT NACELLE INSTALLATION
- 5950 NACELLE INSTALLATION
  - 5951 STRUCTURAL
  - 5952 POWER SYSTEM
  - 5953 CONTROLS
  - 5954 FUEL SYSTEM
- 5960 CHECKOUT & STARTUP
  - 5961 STATIC STARTUP
  - 5962 TUNNEL RUN
  - 5963 CHECKOUT RUN
- 5970 TEST RUNS
- 5980 DATA REDUCTION & ANALYSIS
- 5990 TEST REPORT

WBS WORKSHEET

6000 FLIGHT TESTS

- 6100 TEST PLAN
  - 6110 FLIGHT SAFETY REVIEW BOARD
  - 6120 FIRST FLIGHT
- 6200 INSTRUMENTATION CHECKOUT
- 6300 AIRCRAFT ENVELOPE EVALUATION
  - 6310 FLUTTER CHECKS
  - 6320 STABILITY & CONTROL
  - 6330 BUFFET BOUNDARY
- 6400 TEST ENGINE OPERATION
  - 6410 INFLIGHT STARTUP
  - 6420 POWER VARIATIONS
- 6500 ENGINE TEST ENVELOPE EVALUATION
  - 6510 HIGH SPEED
  - 6520 LOW SPEED
  - 6530 APPROACH CONFIGURATION
- 6600 PERFORMANCE TESTS
  - 6610 DISK LOADING VARIATION
  - 6620 SPEED VARIATIONS
- 6700 ACOUSTIC TESTS
  - 6710 CRUISE CONDITION
  - 6720 LOW SPEED
  - 6730 APPROACH CONFIGURATION

WBS WORKSHEET

6000 FLIGHT TESTS (CONTINUED)

- 6700 ACOUSTIC TESTS (CONTINUED)
  - 6740 FUSELAGE TREATMENT
    - 6741 AIRCRAFT INSTALLATION
    - 6742 INSTRUMENTATION INSTALLATION
    - 6743 GROUND TEST CONDITIONS
    - 6744 FLIGHT TEST CONDITIONS
  - 6750 FLYOVER NOISE MEASUREMENT
  - 6760 ALTERNATE FUSELAGE SIDEWALL
- 6800 ENVELOPE EXPANSION
  - 6810 ALTITUDE REDUCTION
  - 6820 SPEED VARIATION
  - 6830 POWER VARIATION
- 6900 FLIGHT TEST DATA
  - 6910 DATA REDUCTION
    - 6911 PROPELLER
    - 6912 POWER TRAIN
    - 6913 AIRCRAFT PERFORMANCE
    - 6914 ACOUSTICS
  - 6920 DATA ANALYSIS
    - 6921 PROPELLER
    - 6922 POWER TRAIN
    - 6923 AIRCRAFT PERFORMANCE
    - 6924 ACOUSTICS

WBS WORKSHEET

6000 FLIGHT TESTS (CONTINUED)

- 6900 FLIGHT TEST DATA (CONTINUED)
  - 6930 TEST REPORTS
    - 6931 PROPELLER
    - 6932 POWER TRAIN
    - 6933 AIRCRAFT PERFORMANCE
    - 6934 ACOUSTICS
  - 6940 ALTERNATE FUSELAGE SIDEWALL
    - 6941 DATA REDUCTION
    - 6942 DATA ANALYSIS
    - 6943 TEST REPORT

7000 BASELINE FLIGHT TESTS

- 7100 TEST PLAN
- 7200 CALIBRATE ENGINES
- 7300 INSTRUMENTATION (DATA SYSTEM)
  - 7310 DESIGN
  - 7320 FABRICATION
  - 7330 INSTALLATION
- 7400 WING PRESSURE SURVEY
- 7500 CRUISE PERFORMANCE
- 7600 FLIGHT TEST DATA
  - 7610 DATA REDUCTION
  - 7620 DATA ANALYSIS
  - 7630 TEST REPORT

WBS WORKSHEET

8000 MAJOR SUBCONTRACTS

DETROIT DIESEL ALLISON - ENGINE

- GEARBOX

HAMILTON STANDARD - PROPELLER

- NACELLE

9000 PROGRAM MANAGEMENT

9100 PROJECT MANAGEMENT

9200 ADMINSTRATION BUDGET/SCHEDULE

9300 REPORTING - PERIODIC

9400 ORAL BRIEFINGS

9401 NO. 1 ANNUAL

9402 NO. 2 ANNUAL

9403 NO. 3 ANNUAL

9404 NO. 4 ANNUAL

9405 FINAL ORAL

9500 INTERIM REPORT

9600 FINAL & SUMMARY REPORT

9700 TRAVEL

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APPENDIX III

APPENDIX III

BRIEF DESCRIPTION OF DOUGLAS FLIGHT TEST FACILITIES PERTINENT TO THE ADVANCED PROP-FAN FLIGHT TEST PROGRAM

Brief excerpts from the Douglas Engineering and Research Technical Facility Description Handbook are included in Appendix III. Those general sections pertinent to the Douglas Advanced Prop-fan Flight Test Program which are included in Appendix III are:

- Advanced Test Data System
- Flight Crew Training Center
- Yuma Flight Test Facility
- Instrument Landing System - Yuma, Arizona
- Precision Aircraft Tracking System - Yuma, Arizona
- Flight Safety and Parachute Loft Facility
- Ground Support Facilities, Flight and Laboratory Development
- Support Shops, Flight and Laboratory Testing
- Acoustic Test Facilities
- Radiation Test Facilities
- Automated Graphics System

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ADVANCED TEST DATA SYSTEM

The Douglas Flight Test Data System was designed to provide a new approach to data acquisition, communications, and processing. To ensure success for the DC-10 Program, these three elements were developed and integrated simultaneously to obtain maximum compatibility. The resulting system has performed very well and according to design specifications. It has been successfully utilized in the development and certification of the DC-10 (Series 10, 30, and 40), DC-9 and DC-8 commercial aircraft, the A-4N military attack aircraft and the YC-15 advanced medium STOL transport development and demonstration programs, and many miscellaneous laboratory programs, including seat ejection development tests and fuselage decompression tests.

Operational Characteristics:

Airborne Data Acquisition System

The airborne data acquisition system was procured in 1968 and 10 of these systems are in use today. The system uses Pulse Code Modulation (PCM) encoding techniques and contains 400 data channels, 90 channels recorded at prime sampling rates, 290 channels recorded at a 10:1 subcom rate, and 20 channels 20:1 at a subcom rate. The prime and subcom allocations are made up of 320 analog, 60 digital, and 20 frequency input channels. This prime channel sampling srate can be controlled in flight from 400 to 10 samples per second in 6 stages.

Test information is resolved into a 10-bit data word for a ±511-count range. The maximum data stream rate is 500,000 bits per second. Recording is in a manchester 1 code (serial) with a maximum tape packing density of 8333 bits per inch. Telemetry transmission uses Non Return to Zero (NRZ) –M code. An IRIG time code generator is integrated in the system to provide system clock, remote time displays for the flight-test engineer, clocking pulses to drive auxiliary equipment, group binary time in the data stream, and serial Binary Coded Decimal (BCD) time with a 1–kHz carrier on a separate tape search track.

The system is given wide flexibility for recording instrumentation inputs through the use of a signal conditioning subsystem. This subsystem consists of an identical processing network for 320 analog input channels packaged in two 160-channel modules. Each one provides amplification (gain), zero adjustment, active filtering, common mode isolation, shunt calibration, and standard instrumentation excitation power distribution. All elements except amplifiers may be bypassed if desired. Transducer bridge, thermocouple, or other electrical signal inputs of 5 millivolts to 30 volts full-scale can be accepted on any of these universal analog channels. In addition, the system will accept pure parallel digital inputs on both prime and subcom channels.

In the testing of the relatively small A-4N military aircraft, a special small airborne data acquisition system was developed. This Mini System (125 channels) is a subset of the larger 400 Channel System and was installed in a 150-gallon external store for the A-4N test project.

Multiplexer Airborne System

This is an advanced airborne acquisition system using a central programmable controller for the selection and formatting of the PCM data stream from small remotely located acquisition units. These remote multiplexer units are mounted in various areas of the test aircraft, such as in the wing, engines, the avionics compartment, the tail section, etc., and connected to the central controller by a single cable from each unit. Each remote unit uses large-scale integrated (LSI) solid-state electronics to produce a very small size, but reliable package. The cost of installing miles of wiring and the associated man-hours in a standard instrumented aircraft are eliminated by this decentralized remote multiplexer acquisition system.

All airborne data systems have a 14-track tape recorder with 2-MHz bandwidth response at a tape speed of 120 inches per second. The recorders operate at any one of six run speeds to match the selected digital data sampling rates. The PCM data are recorded on one track and the IRIG B on another. The magnetic tape, which is 1 inch wide, has 12 other tracks for FM or other data recording (Figure 1).

FACILITY LOCATION	DEPT. NO. 257	BLDG NO. 41A
CITY Long Beach	STATE California	

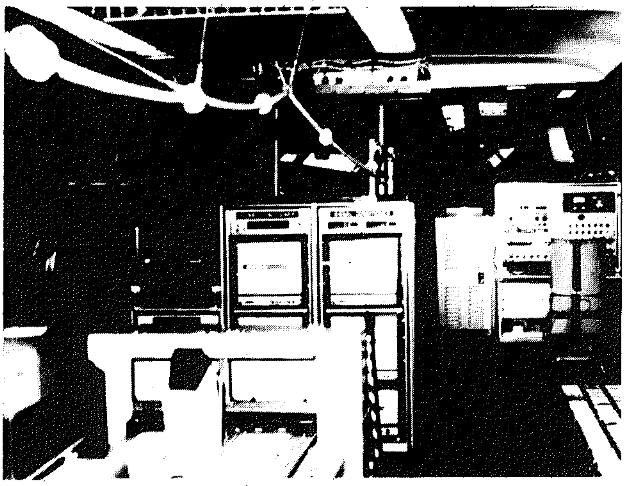

FIGURE 1. FLIGHT RECORDER ONBOARD

Data Transmission/Communications

Developed and procured at the same time as the airborne acquisition systems was the baseline telemetry and microwave link that provides real-time data and voice communications for Douglas flight test operations in Southern California. The telemetry section originally utilized dual, 10-watt, L-band transmitters in the aircraft operating on different frequencies in the 1435- to 1485-MHz band. An automated ground tracking antenna is located atop the 8400-foot Blue Ridge Electronics Site, Figure 2 (42 air miles from Long Beach) and provides a test radius of up to 250 miles at 30,000-foot altitude. The mountain-top facility uses four receivers for frequency and polarization diversity monitoring of signals to minimize signal dropout during aircraft maneuvering. The entire data stream and IRIG time of day is received and relayed to Long Beach via the microwave link and also provides active radio communication on several bands between test aircraft and the Long Beach facility. Automatic microwave fault isolation monitoring is also carried on the link (Figure 2).

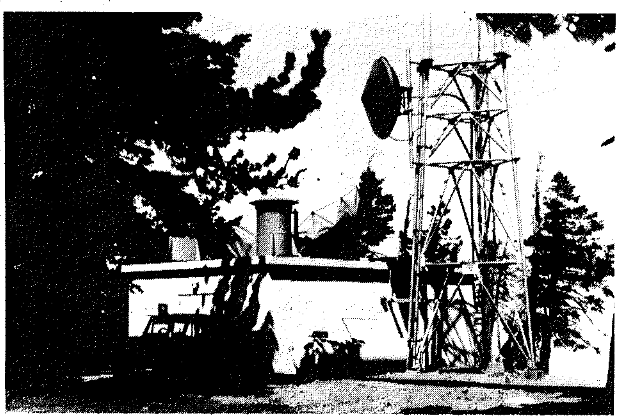

FIGURE 2. BLUE RIDGE TELEMETRY STATION

New Facilities and Capabilities

The following improvements have been made in the T/M microwave link: (1) Telemetry Transmission – One of the earliest updates to the telemetry section was to improve the reliability and bandwidth capabilities of the airborne transmitter; 20-watt transmitters have replaced the 10-watt units and have improved the overall operation considerably. (2) Yuma Remote Terminal – Shortly after the start of the DC-10 test program the bulk of the test operation was moved to Yuma, Arizona, which is 190 air miles from Long Beach. Initially, test flights from this facility were monitored with telemetry from the Blue Ridge antenna only after the aircraft had reached an altitude of 20,000 feet. Today the operation is quite different. The Yuma facility has its own telemetry tracking system and is connected to Long Beach by a separate microwave system, using four automatic relay stations. This greatly extended system now covers airspace from above Fresno, California, into Baja, California where the Mexican Government has given Douglas Aircraft permission to operate (Figure 3). (3) Data Dump – Operating from

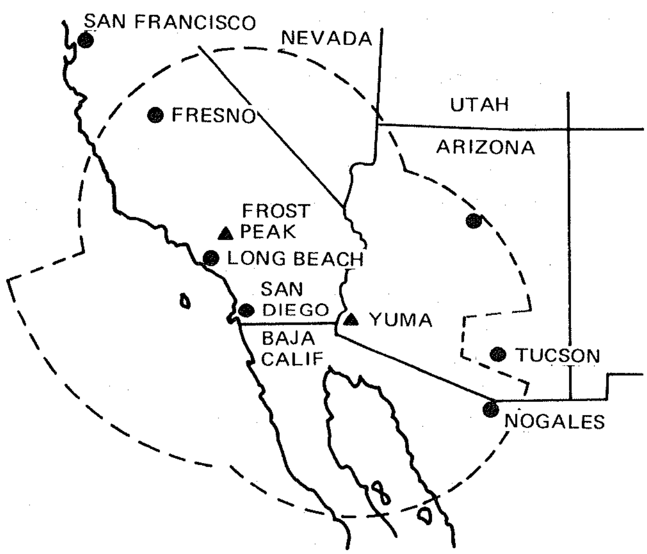

FIGURE 3. DATA TRANSMISSION LINKAGE

Yuma necessitated an improvement in the transportation of high-priority airborne recorded tapes to the Long Beach facility. Instead of waiting for air or ground shipment of these tapes they are now dumped via the microwave link to Long Beach and duplicated on similar tape equipment. Playback rates of up to 1 MHz are used to expedite this transmittal providing a speed up to 2 to 64 times the real-time record rate. (4) Closed Circuit TV – The Yuma microwave link provides 24 channels of telephone lines in addition to the data transmittal. Management and engineering personnel at Long Beach and their counterpart at Yuma now communicate (pre- and post-flight meetings, etc.) from conference rooms and offices equipped with camera and monitors using the two-way TV system and telephone channels. (5) Laser Modem – Although not a basic part of the flight test data system, the mobile laser tracking system must communicate with the Long Beach facility to expedite data processing. This is accomplished by transmitting the laser data via a dual modem and the microwave link to the Long Beach facility. The microwave link eliminates many problems associated with commercial telephone networks.

EAFB Microwave Link

The Blue Ridge/Long Beach Microwave Link is being implemented for the KC-10 test program to include Edwards Air Force Base for telemetry, radio telephone, and data monitoring.

Flight Control and Data Center

The Flight Control and Data Center serves as both a data reduction center and a flight control monitor station for flight test aircraft. It provides the equipment and environment to allow multiple test vehicle data processing and monitoring of test data, both in graphical and tabular forms, with strip chart backup for redundancy independent of the computer (Figures 4 and 5). The data processing consists of handling the multiple, high-rate input data, making engineering unit displays of selected test data, and obtaining hardcopy and/or high-quality microfilm outputs of the finished display.

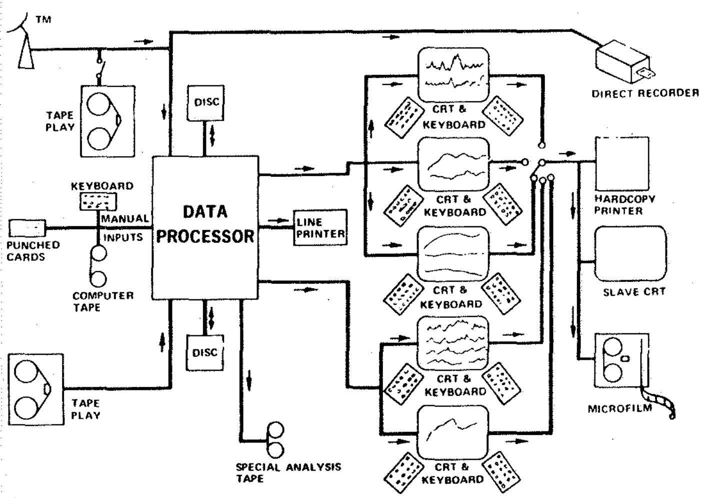

FIGURE 4. DATA PROCESSING SYSTEM OPERATIONAL SCHEMATIC

The heart of the flight control and data center is a Sigma 9 computer with 192K words of memory. The computer receives test information either from the telemetry microwave link or from the tape recorded onboard for postflight analysis, converts the raw data into engineering units and displays the results in corrected time history or tabular form on cathode ray tubes (CRT). Through a special function keyboard

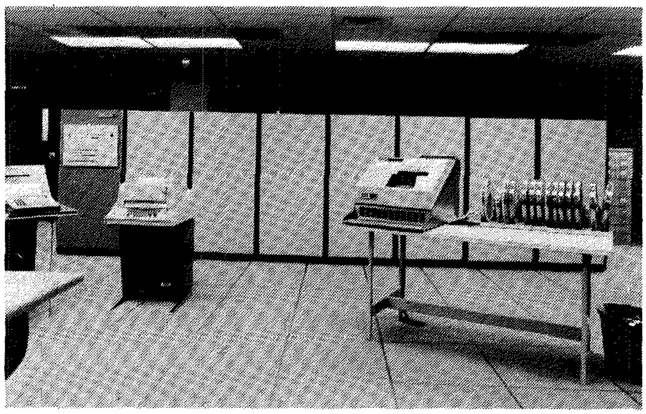

FIGURE 5. SIGMA 9 MACHINE ROOM

designed specifically for Flight Development and a standard alphanumeric keyboard, a CRT operator (flight test engineer) is able to call for any parameter over any time span. Through these keyboards and a light pen, the operator is capable of adding, deleting or replacing parameters, changing scales in both X and Y axes, adding notes and titles, and producing on the CRT a final annotated engineering unit tabulation, or time history plot. This can be accomplished during the flight or after the flight. When the operator is satisfied with the results, he can make a hardcopy or microfilm copy, or both, by actuating a key on the special function keyboard. The hardcopy is available in approximately 10 seconds.

The ground system includes five active CRTs, each completely independent of the others, a large random access disc file used primarily for temporary raw data storage, and two PCM decommutators which permit postflight analysis on two separate flights or a combination of postflight analysis in conjunction with real-time flight monitoring. For easy access and fast data processing, all calibrations for all parameters and all flights for each test aircraft are also stored on the random-access disc. A standard line printer and a 1/2-inch magnetic tape output are also available for analysis and for standard batch programs not requiring the graphic display output. The data center also includes a complete communications system, operating through the microwave relay station, that permits direct aircraft communication for the flight director and/or the individual CRT users.

For processing of FM recorded data the system contains a constant bandwidth (CBW) FM demodulation system for up to 20 channels per FM data track. These data can be input to the computer via a 24-channel multiplexer at sampling rates up to 8,000 samples per second, providing high-frequency data analysis.

Associated Equipment: (Figures 4, 5, and 6)

Sigma 9 computer (192K memory bank)
PCM decommutators
24-channel multiplexer
Constant bandwidth discriminator rack
3 Sigma 2 computers (32K memory bank)
Card readers
Card punch
Five 9-track computer tape units — 800 BPI
Four 9-track computer tape units — 800/1600 BPI
Three 14-track tape recorders
Fourteen rapid access discs (RADS), 6.2 million bytes each
Two teletype writers
Three line printers
Five display generators
Six Sanders CRT display units
Two hardcopy units
Microfilm unit
Telemetry input rack
Laser receiver modem rack
Radio communications console

FIGURE 6. FLIGHT TEST CONTROL ROOM

DOUGLAS AIRCRAFT COMPANY MCDONNELL DOUGLAS CORPORATION	ENGINEERING AND RESEARCH TECHNICAL FACILITY DESCRIPTION

Flight Crew Training Center

A modern Flight Crew Training Center (Figure 1) has enabled the Douglas Flight Training Department to consolidate all its ground and training activities at one location and provides one of the most carefully designed "real work" training environments available. This facility, known as Building 71, is located at 4330 Donald Douglas Drive, Long Beach, California, 90808. This location is on the Long Beach Airport property, just west of Lakewood Boulevard.

The Training Center encompasses an area of approximately 19,000 square feet and consolidates Douglas flight crew training departments, ground and flight training activities under one roof. The facility houses four specially designed classrooms, a Cockpit Procedures Trainer (CPT), computer room, DC-9 and DC-10 flight simulators, briefing rooms, student lounge, staff offices and office spaces available to airline personnel.

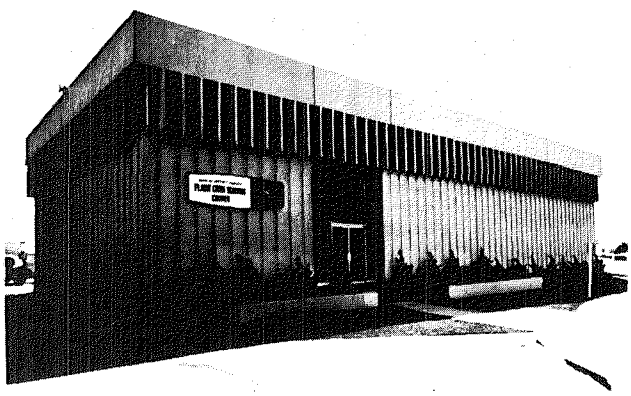

FIGURE 1. FLIGHT CREW TRAINING CENTER

Operational Characteristics:

The Flight Crew Training Program is a completely integrated instructional system to prepare flight crews, flight crew instructors, and cabin attendants, as well as operations management, to effectively perform their duties under normal, abnormal and emergency operating conditions. This program falls into three divisions:

Ground school courses
Flight transition training and line qualifications
After-delivery services.

The Flight Transition Training may be presented at the Flight Crew Training Center, or it may be presented at any other location in the world where adequate facilities are available.

Associated Equipment:

Advanced training devices employed in the classrooms include:

- Rear-lighted projection screens for 35mm slide presentations
- Color TV monitors for closed-circuit television or video tape presentations
- Viewgraph projection
- 16mm movie projection
- Electronic response monitors
- Instructor's centralized remote console
- DC-9 and DC-10 Cockpit Procedures Trainers (Figure 2).

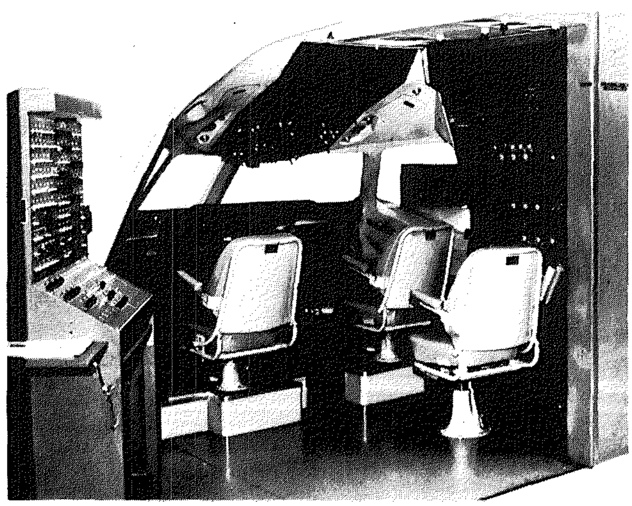

FIGURE 2. DC-10 COCKPIT PROCEDURES TRAINER

FACILITY LOCATION	DEPT NO. 270	BLDG NO. 71
CITY Long Beach	STATE California	

220-004

These trainers are an exact replica of the crew stations on a fixed base. All aircraft systems are operational with the exception of navigation, flight and air data instruments. The aural and visual warnings, cautions, annunciators and associated logic are operational, as well as sound simulation for engine operation. An instructor's failure panel is included so that all normal, abnormal and emergency procedures may be introduced. Design flexibility permits partial reconfiguration capability.

o **Vital III Visual Simulator**

The DC-10 Flight Simulator (Figure 3) provides visual as well as motion cues. The Vital III visual simulator provides a realistic and responsive night scene with a textured runway, runway markings and numerals, horizon glow, runway lighting (including VASI's) and thousands of light points representing surrounding city lights. This is a computer generated scene providing unlimited maneuverability over a large volume of air space and the flexibility of program central to reconfigure the visual scene.

o DC-10 Flight Simulator

This flight simulator has the capability of providing advanced six-degrees-of-motion. This movement provides roll, pitch, yaw, heave, slip and longitudinal motion simulation for realistic pilot training in response to motion cues. One design feature is a simplified instructor's malfunction projection layout (SIMPL). This is a projection system with backlighted slides that will depict 24 of the DC-10's major systems. Through a keyboard mounted at the instructor's station, the instructor may introduce up to 53 separate problems into each of these major systems. Through the simulator's integral computer system, a record and playback feature allows the training crew to recall any part of an exercise for review and study.

The Flight Crew Training Center has an ample inventory of tools and electronic equipment to perform any maintenance that may be required.

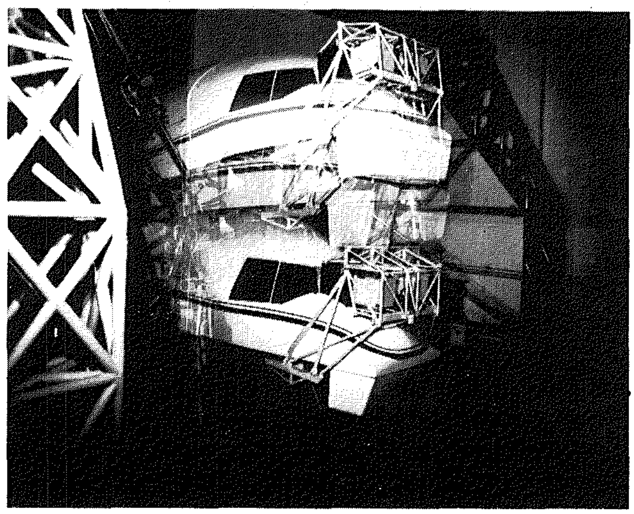

FIGURE 3. DC-10 FLIGHT SIMULATOR

Yuma Flight Test Facility

The Douglas Aircraft Company operates a modern Flight Test Facility (C3) (Figure 1), located adjacent to the Yuma International Airport, Yuma, Arizona, which is specifically designated to support Douglas Aircraft Development Programs. This facility has direct access to the airport proper. The main runway (3L-21R) is 13,300 feet long by 200 feet wide. The test facility encompasses a total area of 46.2 acres, of which approximately 22 acres have been developed. The entire area is on a 20-year leasehold contracted with the Yuma Airport Authority beginning in 1969. The advantages of the Yuma Test Facility became obvious during the first phase of the DC-10 Test Program. Good flying weather, uncongested airspace, ready access to the Mexican corridor, and close proximity to the city of Yuma combined to permit unprecedented efficiency in testing operations.

Operational Characteristics:

Operations

The test site operations are housed in a block wall constructed building 60 by 70 feet comprising the facility management offices, flight test engineering office, flight dispatch radio room, photography/oscillograph darkroom, conference rooms, and the necessary restrooms. In addition, there is a 40- by 60-foot trailer for additional office space use.

Support Building

This is a 6,000-square-foot (60- by 100-foot) metal constructed building that houses the operations support offices and shop area. The entire building is environmentally controlled.

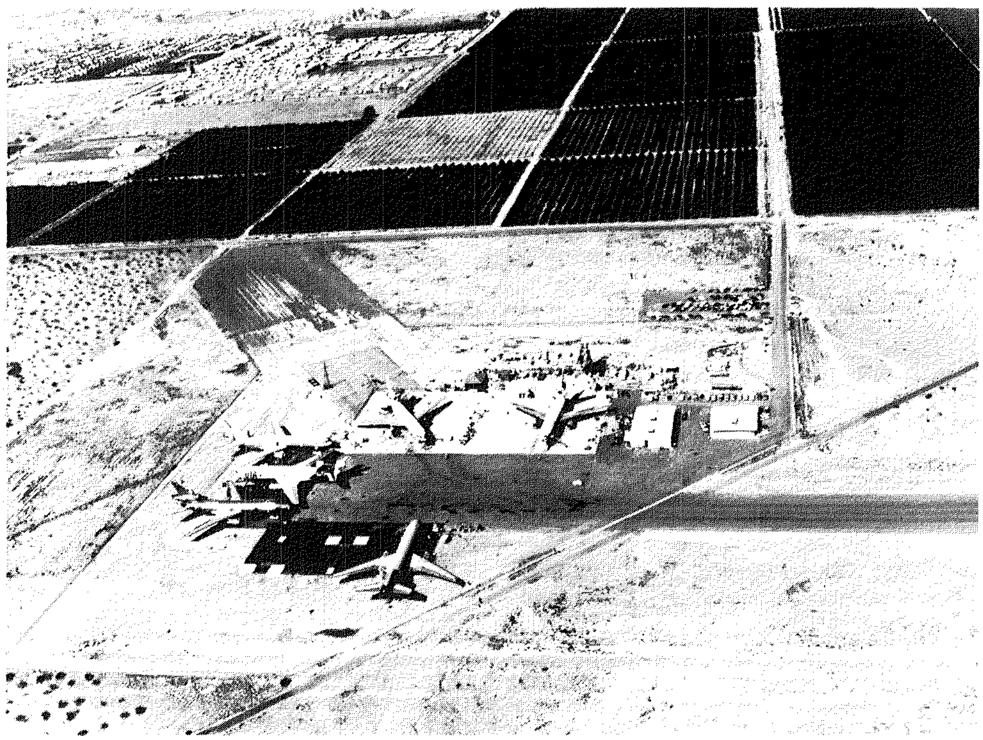

FIGURE 1. AERIAL VIEW – DAC FLIGHT TEST FACILITY AT YUMA, ARIZONA

FACILITY LOCATION	DEPT NO. 270	BLDG NO. 300,301
CITY Yuma	STATE Arizona	

The office area is divided into three separate areas: supervisor's office, Quality Assurance, and Reprographics/Reproduction offices.

The Shop/Storage area consists of a 400-square-foot (20- by 20-foot) wheel, brake and tire storage area, a 240-square-foot (12- by 20-foot) avionics area, a 480-square-foot (16- by 30-foot) electronics storage, and a 400-square-foot (20- by 20-foot) secured stockroom. The balance of this area is for the storage of miscellaneous parts. The operations support area consists of an 800-square-foot office area with 11 QA and F&LD personnel work stations. The remaining area is used by shipping and receiving, outfitted with a Xerox 7000 copy machine and a Datafax unit.

Aircraft Accommodations

This facility has the capability of accommodating simultaneously eight DC-10s (4 operational/4 stored), and A-4 and the business fleet. These facilities include a concrete parking ramp, an asphalt ramp area, and a single taxiway.

Ramp: A 256,940-square-foot area, with 94,300 square feet constructed of 15-inch-thick reinforced concerete and 162,640 square feet constructed of asphalt concrete. The ramp contains scale pits for weighing DC-10s.

Taxiway: A single 75-foot-wide taxiway from the Yuma International Airport runway to the MDC flight test facility ramp. The taxiway is constructed of 4-inch-thick asphalt and is capable of supporting DC-10 size aircraft.

Ground Support Equipment (GSE) Storage Area and Equipment

A 6-inch-thick concrete pad (28,000 square feet) is located adjacent to the ramp for storage of GSE necessary to support the ramp operations.

Associated Equipment:

This facility is equipped with the Douglas-designed DC-10 empennage access workstand (Figure 2). This stand comprises three individual stands — right- and left-hand horizontal, and a 60-foot-tall, 5-level vertical stand. This equipment provides access to all areas and of the DC-10 empennage.

A Telemetry/Microwave/Communications (TCM) trailer is located in the southwest corner of the leased property and is used to provide real-time flight data between Yuma and the Long Beach Center (Figure 3).

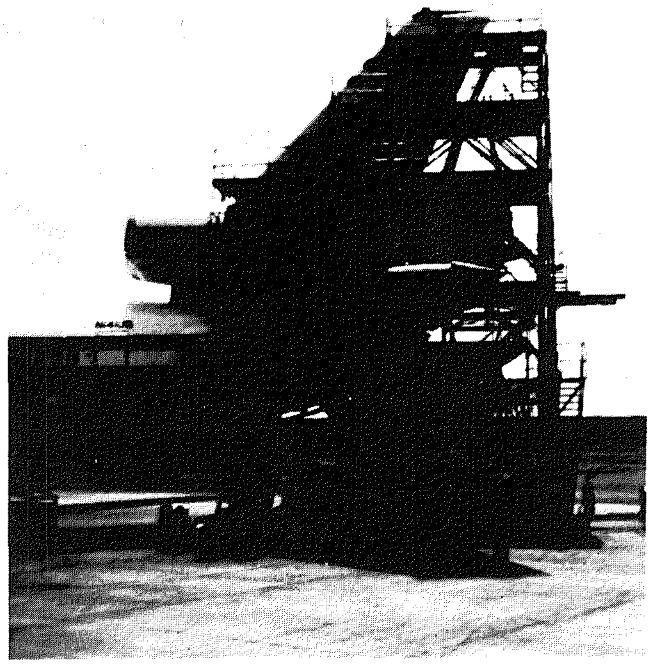

FIGURE 2. DC-10 EMPENNAGE WORKSTAND

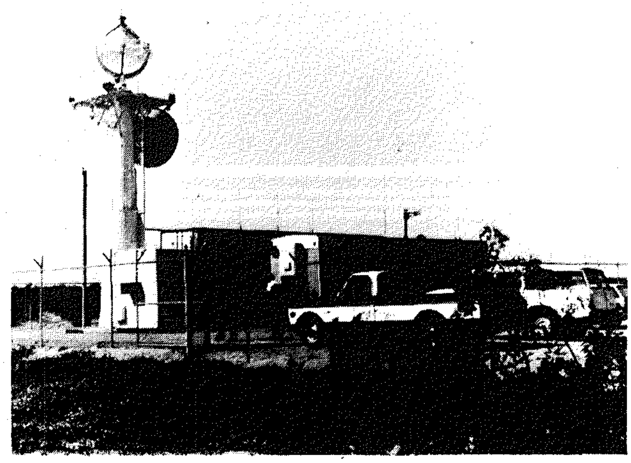

FIGURE 3. TELEMETRY/MICROWAVE/ COMMUNICATION TRAILER

Instrument Landing System, CAT II (refer to 220-013)
Precision Aircraft Tracking System (refer to 220-014)
Weighing Truck, electronic
Waste Fuel Cart, 500-gallon
Boost Cart, nitrogen
Air Compressor, Deager
Trailer, Airstream 16
Respirator, AirPak
Shear, Niagra
Scale, FM — 31-ton capacity
Truck, Chevrolet Blazer

Two Skydrol Test Stands, 30-gpm Sprague
Two workstands, Skywitch
Two power unit 99-kva tractors
Clarktor tug, 6-wheel, outfitted with rigging level sensor
Four Skydrol test stands, 50-gpm Sprague
Two aircraft movers
Two axle jacks, 60-ton, Malabar
Two axle jacks, 60-ton, Sangor
Cryostart unit, for aircraft starting
Trailer data – 40-foot
Trailer, American photo
Testok, air data
Truck, Ford Skyworker
Four workstands, Ballymore
Power unit, 60-kva diesel
Two Ground Starter Units, air portable (MAIA)
Water waste cart
Level Sensor Readout Module, Kearfott
A/C unit, 3-ton
A/C unit, 30-ton
Cargo loader
Aerostand, 24-foot

In addition, the ground support operations has ample shop and electronic equipment to support the everyday operations.

Support Facilities

Two 20,000-gallon fuel tanks
Two 1,500-gallon sewage disposal units
Deionized water, 36,000-gallon capacity
1,000-kva minimum, 1,700-kva at 2,000 amperes, electrical transformer to supply the existing facilities
Liquid nitrogen storage area
1,500-gallon gasoline supply for ground support vehicles
Power islands, 440 volts

Telephone Communications

Direct dial tielines on the voice network have been provided to give direct access to and from telephone stations at the Yuma Facility via the DAC Microwave Link.

Instrument Landing System — Yuma, Arizona

A Douglas-owned, single-channel, solid-state Airborne Instruments Laboratory (Cutler-Hammer) Type 55L Instrument Landing System (ILS) is installed at the Yuma, Arizona, airport on Runway 3L. There are three transmitters: the glideslope, localizer, and the middle marker. The glideslope antenna is 40 feet west and 1250 feet from the end of the runway (Figure 1).

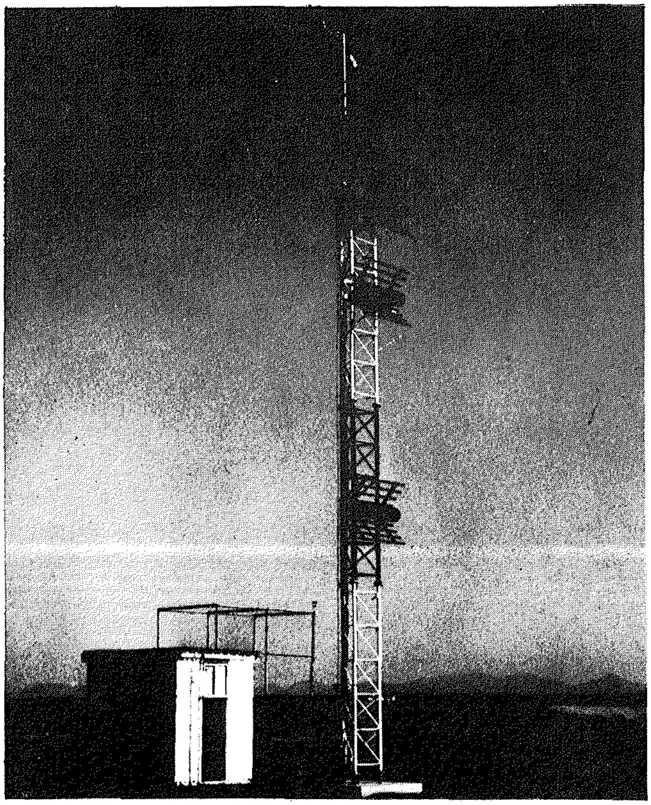

FIGURE 1. ILS GLIDESLOPE TRANSMITTER

The localizer antenna is 10 feet high and is located 900 feet off the runway on a runway centerline (Figure 2).

Applications:

The ILS system was purchased and installed by Douglas to support DC-10 CAT II, III Autoland development, DC-9/10 production acceptance and test flight checks, and customer flight training activities at Yuma. Figure 3 illustrates the physical location of the localizer and glideslope transmitters. Figure 4 illustrates the beam geometry of the Category II Instrument Landing System.

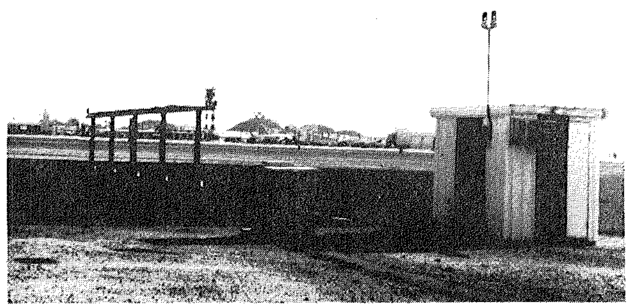

FIGURE 2. ILS LOCALIZER TRANSMITTER

FACILITY LOCATION	DEPT NO. 270	BLDG NO. Yuma Int'l Airport
CITY Yuma		STATE Arizona

DOUGLAS AIRCRAFT COMPANY MCDONNELL DOUGLAS CORPORATION	ENGINEERING AND RESEARCH TECHNICAL FACILITY DESCRIPTION

Precision Aircraft Tracking System, Yuma, Arizona

Douglas has introduced a Precision Aircraft Tracking System (PATS) or optical radar. It was developed primarily for aircraft instrument landing system tests, flyover noise tests, and other tasks which require very accurate flight path determination.

Operational Characteristics:

During normal operation, the Tracker determines the azimuth, elevation, and range of the target at a sample rate of 100 measurements per second. These data are time-correlated via a precision time-code generator, periodically checked against a time standard. These measurements plus time of day are available as binary words for data recording on magnetic tape and are directly displayed for immediate reference. The magnetic tape is processed in the F&LD Data Center to yield final data. This system eliminates the need for reduction of data from photographic or radio theodolite systems.

A single operator is required for the acquisition function, and tracking is automatically initiated when the target is positioned in the acquisition field. An infrared vidicon is used for acquisition and provides haze penetration and sensitivity to the infrared laser radiation.

The Precision Laser Tracker consists of an infrared laser transmitter, a laser pulse receiver, an infrared television camera and TV monitor for the operator and a servo-controlled mirror mount. A retroreflector is mounted on the aircraft to provide adequate return signal to the Tracker, and to define the tracking point precisely. The transmitter consists of a Q-switched, flash-pumped Nd: Yag Laser operating at 100 pps. The 1.06-microradiation is not visible or hazardous to the test aircraft crew.

The Tracker is mounted in a van, as shown in Figure 1, and the laser beam is transmitted and received through the servo-controlled mirror. The television camera receives an ambient image of the target and the surrounding field of view.

The laser pulse receiver generates range data and angle errors for the servo-controlled mirror. The return of a pulse by the retroreflector automatically initiates tracking. The system then tracks automatically and no further manual control is required (Figure 2).

System Features:

Self-contained mobile system (auxiliary power unit required)
Infrared TV used for initial acquisition
Autotrack from 1000 to 60,000 feet
Azimuth, elevation, range, and time recorded at 1, 10, or 100 samples/second
Data recorded on computer-compatible magnetic tape
Precision time code referenced to WWV
Solid state 1060 Angstrom laser (Neodynium-Doped Yttrium Aluminum Garnet)
Automatic control of laser power for eye safety
System performance

FIGURE 1. LASER VAN

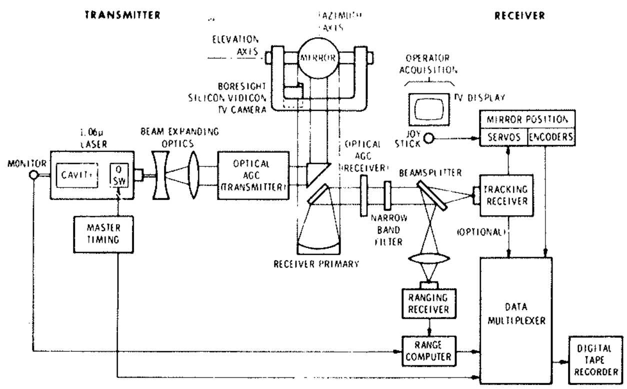

FIGURE 2. SYSTEM BLOCK DIAGRAM

	Resolution	Estimated Accuracy Target Range 10,000 Ft
Range	±0.5 Ft	X = ±3 Ft
Azimuth	±0.1 Milliradian	Y = ±2 Ft
Elevation	±0.2 Milliradian	Z = ±3 Ft
Time	±0.1 Millisec	

FACILITY LOCATION	DEPT NO. 270	BLDG NO. Ramp
CITY Yuma		STATE Arizona

Flight Safety and Parachute Loft Facility

The Flight and Laboratory Development Division (F&LD) of the Douglas Aircraft Company maintains a facility which is made up of the flight safety group, FAA Repair Station (No. 4108) and a flight equipment issue room. The flight safety group and FAA Repair Station are located in the parachute loft (Figure 1) which has about 1900 square feet of floor space and provides housing and space for maintenance and storage of survival equipment associated with commercial and military flight.

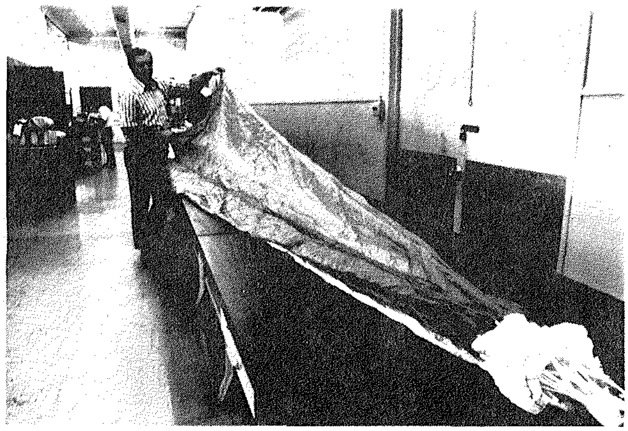

FIGURE 1. PARACHUTE LOFT

Operational Characteristics:

The parachute loft is responsible for all inspection and certification of production and development work performed within the Douglas Aircraft Company on the following listed equipment:

- Parachutes
- Life Rafts
- Life Vests
- Escape Slides
- Survival Kits
- Helmets
- Flight Clothing

In addition, the personnel staffing this facility and the FAA Repair Station are certified as master parachute riggers and repairmen of emergency equipment.

Associated Equipment:

A room 10 by 10 feet with a ceiling 60 feet high used for airing and drying parachute canopies.

Parachute packing table 50 feet long, used for inspection, repair, and repacking of personnel parachutes, and drag and spin chutes.

A carpeted area approximately 17 by 25 feet used for inflation test inspection and repacking of life rafts and escape slides.

Four sewing machines used in the repair and maintenance of all types of survival equipment and flight clothing.

A table 12 by 12 feet used for inspection and repair of survival kits, life vest and fabric layout and cutting.

A complete technical library on. Navy, Air Force and commercial safety and survival equipment.

All small tools required to repair and test safety equipment.

The Issue Room is located on the ground floor of F&LD Flight Operations and has approximately 1400 square feet of floor space. Included in this facility are the following items:

A locker room with 96 flight crew members' lockers.

Lounge area for crew members.

Flight equipment issue room with storage space for 60 parachutes, a supply of flight clothing (flight suits, jackets, boots, life vests and helmets).

FACILITY LOCATION	DEPT.NO. 270	BLDG NO. 15
CITY Long Beach		STATE California

Ground Support Facilities, Flight and Laboratory Development

Flight and Laboratory Development, C1-270, maintains facilities in and adjacent to the Flight Test Hangar, Building 41, to support F&LD test functions in conjunction with providing all the ground support equipment, such as aircraft tow tractors, portable aircraft air conditioners, engine air starters, sky-workers, workstands, etc., to support all the Douglas test aircraft (both military and commercial) and all west ramp production aircraft. The maintenance facilities include an administration and storage building (Building 45), Oxygen Service Laboratory, a Wheel and Tire Shop, a Ground Support Equipment Repair Shop and an Engine Shop.

Operational Characteristics:

Building 45

This building, containing 6480 square feet, is staffed to perform all the administrative functions required to carry out the ground support activities. In addition, it is a storage area for tools and electronic equipment also needed for ground support activities (Figure 1).

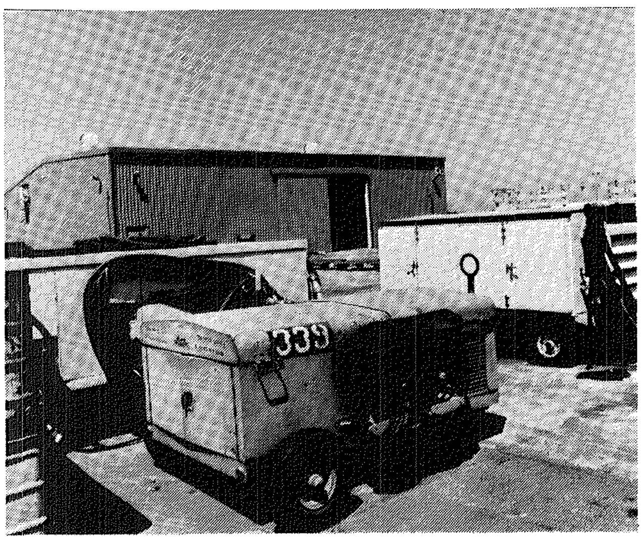

FIGURE 1. BUILDING 45

Oxygen Service Laboratory

This laboratory is 363 square feet in size and its primary function is to obtain laboratory samples for chemical analyses on all liquid oxygen received in Long Beach (C1) and perform the certification testing on all onboard oxygen bottles to meet both military and commercial (FAA) specifications. In addition, the laboratory performs the following maintenance: oxygen system purging, certification of onboard bottles, filling of all onboard aircraft bottles and maintaining storage area for these bottles.

Wheel and Tire Shop

The Wheel and Tire Shop is located adjacent to the west ramp and is housed in a shed of 1500 square feet. The shop is equipped with the following equipment:

Electric forklift, 1500-pound capacity.

Manual cargo haulster, 1000 pounds.

Nitrogen manifold regulator system, high pressure (2500 psi).

Two liquid nitrogen Cry-O-Carts, low pressure (400 pounds).

Ground Support Equipment Repair Shop

This shop is housed in the same shed building adjacent to the Wheel and Tire Shop and comprises an area of 750 square feet. The primary function in this shop is to perform preventative maintenance on all ground support equipment such as portable air conditioners, engine starters, generators, hydraulic stands, pneumatic stands, air compressors, aerostands, jacks, etc. No major repair is performed in this shop.

Engine Shop and Storage Area

The Engine Shop and Storage area is located in the northwest corner of Building 41. The primary function of this shop is to control, store, maintain and repair various types of aircraft engines that are in F&LD custody. The basic assignment of this facility is to assist the engine manufacturer in accomplishing various service changes and instruction such as the following:

FACILITY LOCATION	DEPT NO. 270	BLDG NO. Ramp Area
CITY Long Beach	STATE California	

Installation of test equipment.

Quick engine change build-up and replacement.

Installation and replacement of the auxiliary power unit (APU).

Installation and maintenance of nose cowl inlets.

Perform internal inspection of engines (Boroscope).

Maintenance of thrust reversers.

Preservation of engines.

Receiving and shipping of all F&LD engines and engine components.

Maintain current inventory and status of engines.

DOUGLAS AIRCRAFT COMPANY MCDONNELL DOUGLAS CORPORATION	ENGINEERING AND RESEARCH TECHNICAL FACILITY DESCRIPTION

SUPPORT SHOPS, FLIGHT AND LABORATORY TESTING

Several mechanical fabrication shops support Engineering Flight and Laboratory Testing. These shops have been combined into one facility so that maximum utilization of equipment and manpower can be achieved. With their diversified capability, a wide variety of unique products can be produced from many materials to support engineering tests.

Typical products which are routine for this facility are precision models for wind tunnel and display, mockups of both plastic and wood, machined parts, sheet metal assemblies, and fabricated test fixtures.

Operational Characteristics:

Model Shop (Figures 1 and 2)

A completely equipped and staffed model shop can produce highly accurate metal scale models fully instrumented for wind tunnel testing. Also, aesthetic display scale models are created by skilled personnel for various purposes. The shops are nearly self-supporting except for special processing such as plating, heat treat, etc.

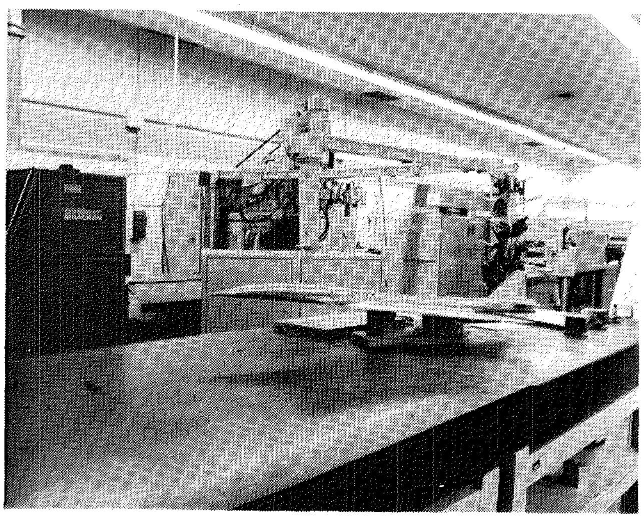

FIGURE 1. WIND TUNNEL MODEL

Machine Shop (Figure 3)

The Machine Shop consists of converntional machine tools and is staffed with a group of highly skilled personnel. This group specializes in developing new machining and fabricating techniques, machining parts from new alloys for test purposes and providing unique and special parts in support of test programs.

FIGURE 2. MODEL SHOP

The equipment consists of eight precision lathes ranging from tool room lathes to machines with a swing of 22 inches in diameter by 102 inches in length. One 22-inch lathe is equipped with a full-length tracing attachment which has a 6-inch radial travel. There are ten milling machines: five universal, two horizontal and three vertical. These machines are of various sizes having maximum table length of 60 inches. All equipment is completely tooled with supporting equipment so that any machining operation can be accomplished. A horizontal boring mill, with a horizontal and vertical travel of 60 inches is available and completely tooled. Supporting tools such as cylindrical and surface grinders, drill presses (radial, multiple and single spindle), cutoff saws, etc., all complement this shop (Figure 3).

Associated Machine Shop Equipment Includes:

Numerically-controlled 3-axis mill 24- by 96-inch bed with an acramatic scanner with its own minicomputer. The scanner can be used as a conventional tracer or it can produce its own tapes by scanning a part that needs to be duplicated. Another advantage of the scanner, as weighed against a tracer-controlled

REVISED NOVEMBER 1979

FACILITY LOCATION	DEPT NO. 257	BLDG NO. 26, 32, 41A
CITY Long Beach	STATE California	

220-007

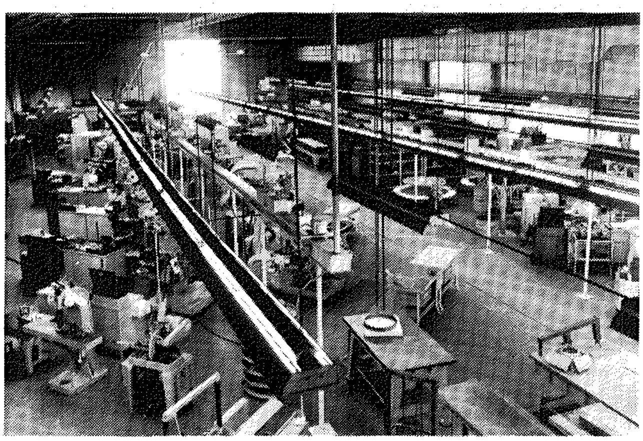

FIGURE 3. MACHINE SHOP

machine, is that one can utilize the full working surface of the machine while producing a punched tape. A tracer-controlled machine can only utilize the amount that is between the cutter and tracer head.

Numerically-controlled machining center vertical 3-axis milling machine with acramatic CNC control, part program edit, and extended storage 26- by 80-inch bed. Head position will repeat within ±0.0005 inch.

Vertical hone for precision honing of wind tunnel model components or test specimens.

Glass bead vapor hone for finishing detailed parts.

Horizontal surface grinder with a cylindrical attachment.

Vertical jig bore.

Horizontal boring mill with a vertical and horizontal travel of 60 inches.

Tracer lathe with a 3-D attachment.

Tracer lathe 72-inch bed, 20-inch swing.

Electrical discharge machine with a 200-ampere power supply.

The bench area consists of 30 benches for a two-shift operation. Precision surface plates and precision measuring equipment to set up and rig models. Shop is air-conditioned to hold a temperature of 72 ± 2°F.

Sheet Metal Shop

The Sheet Metal Shop has the capability for fabricating special sheet metal parts or assemblies to support any test or program. Typical assemblies fabricated in this shop are antenna test pattern models, special fabricated test specimens, and modifications to structural test assemblies.

General sheet metal equipment includes shears and brakes with a maximum length of 96 inches. Other equipment includes rolls, bandsaws, punches, and a complete welding facility to support this shop.

Plastic Shop (Figure 4)

The Plastic Shop provides various nonmetallic components for F&LT programs and special tests. Many large, complex assemblies such as radome covers, engine inlet cowlings, and interior test panels are routinely fabricated in this shop. Three large ovens provide a curing capability of up to 12 by 12 by 15 feet deep at a temperature of 350°F and are equipped with vacuum capability inside the ovens. Other equipment includes a 350-ton hot platen press (48 by 48 inches), saws, a large paint booth (12 by 12 by 40 feet deep), cold storage capability, metal spray-on plastic and other supporting equipment.

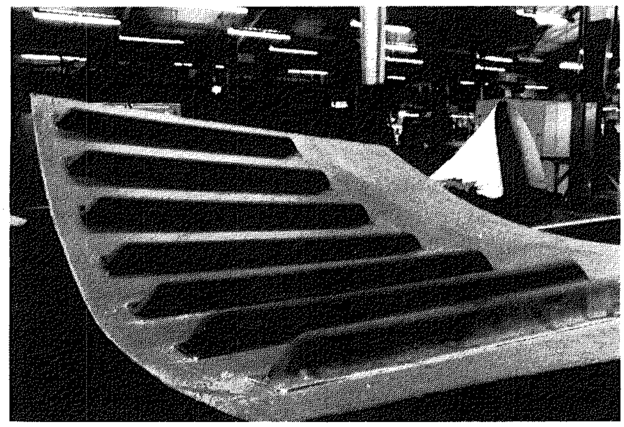

FIGURE 4. PLASTICS SHOP

Fabrication Shop (Figure 5)

The prime function of the Fabrication Shop, located in Building 26, is to build large fixtures which will

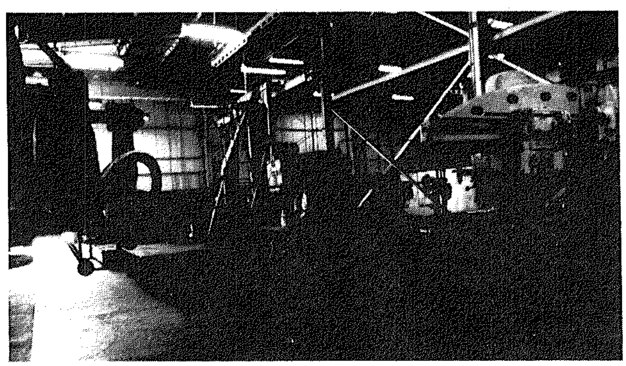

FIGURE 5. FABRICATION SHOP

hold test specimens and to fabricate other miscellaneous components. Heavy-duty equipment, such as shear, brake, drill press, saws, and automatic feed welding machines, are available in this shop.

Electrical/Electronic Shop

The Electrical/Electronic Shop, located in the Engineering Development Center, Building 41A (Figure 6), performs various degrees of maintenance on electrical/electronic systems, e.g., microwave systems, radios, telemetry, and airborne digital data systems associated with flight test aircraft. In addition, the shop is equipped and staffed to: (1) manage the complete fabrication of flight test and support instrumentation, (2) fabricate instrumentation racks and consoles, (3) stamp identification numbers on wires and sleeves, (4) wire wrap printed circuit boards, and (5) assemble cables and wire runs.

The shop personnel also install strain gages and foil-type temperature pickups on test aircraft. However, to ensure proper installation and eliminate the possibilities of receiving irrelevant data, trial or mockup installations are made on test models, aircraft components, and airframe structures. This procedure is used to satisfy all types of environmental test prerequisites such as high and low temperatures, long-term stability, and temperature compensation.

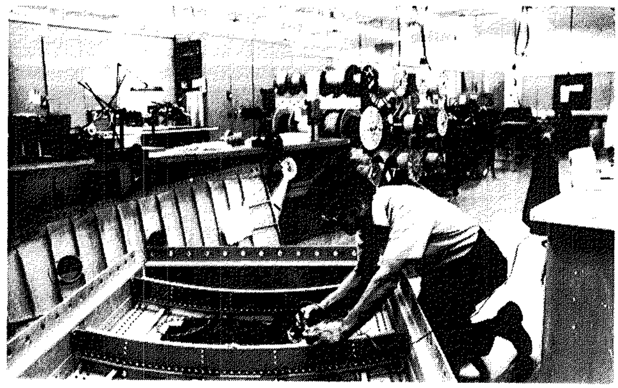

FIGURE 6. F&LT ELECTRICAL FABRICATION SHOP

Associated Electrical Equipment Includes:

Blue Line Oven, Model FC-812
Delta Design Environmental Chamber, Model 2850L
Delta Design Environmental Chamber, Model MK3900
Conrad/Missemer Freezer
Coded Communication, Model ECO-3
John Fluke Voltage Calibrator, Model 313
Hallcross Resistance Box
Two Kingsley Wire Stamp Machines, Model KWE-7-B
American Pacific Trojan Wire Marker
Gardner Denver Company Wire Wrap Machine, Model 144A-1
SLI Photoelectric Reader, Model PER-300.

ACOUSTIC TEST FACILITIES

The Acoustic Test Facilities provide for the investigation of materials, assemblies and subsystems primarily related to acoustical duct linings, aircraft equipment noise, and resistance of aircraft structures to sonic fatigue, and specialized facilities for studying the generation and suppression of noise. A major test facility for acoustics, the Anechoic Acoustic Test Facility at El Segundo, is described in a separate section.

The absorptive characteristics of acoustically treated test panels in acoustic and aerodynamic environments (like those in jet engine inlet and exhaust ducts) are measured in the Duct Transmission Loss Facility shown in Figure 1. A rectangular test duct is mounted between two reverberant chambers. The length of the test panels (L) mounted in the sidewalls of this duct and the duct width (H) can be selected to attain various L/H ratios. The direction of one of the chambers can be either with or against a specified airflow (up to Mach 0.7) to simulate engine exhaust ducts or inlets. Sound pressure levels in each chamber are analyzed to determine the transmission loss due to the presence of the test panels.

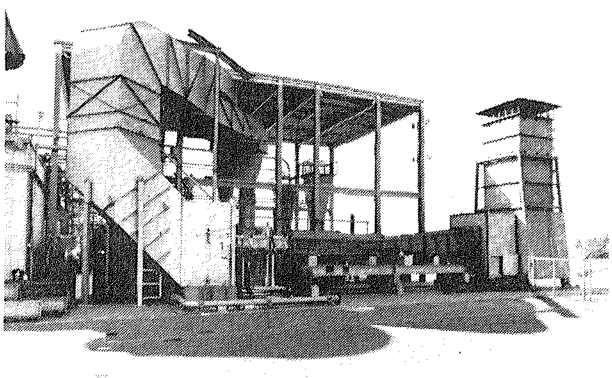

FIGURE 1. DUCT TRANSMISSION LOSS FACILITY

The resistance of aircraft structures to fatigue induced by high-intensity acoustical environments is determined in the Sonic Fatigue Facility (Figure 2). A noise generator with an exponential horn is attached to a rectangular Progressive Wave Tube (PWT) containing a test section and an absorptive termination section. As the acoustic waves travel the length of the tube, they graze the test panel which is mounted to one side of the PWT, exciting it at a specified

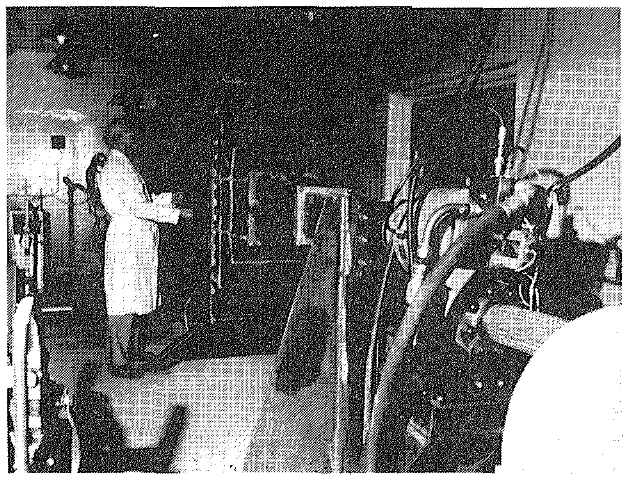

FIGURE 2. SONIC FATIGUE FACILITY

noise spectrum and level. Discrete frequency, broadband random, and combinations of these excitations can be produced. Testing at sound pressure levels substantially greater than those encountered in service can uncover structural deficiencies in a relatively short period of time.

Resistance to normal flow (the fundamental parameter describing porous, acoustically absorptive lining materials used to suppress noise in many aircraft installations) is measured at various velocities in the Flow Resistance Facility shown in Figure 3. The equipment consists of

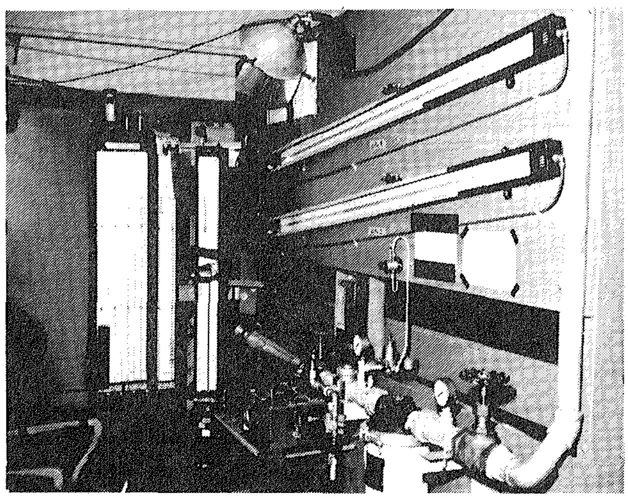

FIGURE 3. FLOW RESISTANCE FACILITY

FACILITY LOCATION	DEPT NO. 257	BLDG NO. 29/41A
CITY Long Beach	STATE California	

airflow controls, metering, and pressure-drop/temperature instruments. Although small samples are usually tested, flow resistance can be measured for specification compliance checks of larger sheets to be used in fabricating full-size parts.

The impedance and absorption of acoustical materials are determined in the Standing Wave Apparatus (Figure 4) which consists of a selection of tubes, loud-speakers with horn attachments, and a probe microphone which traverses the length of the tube axis. The characteristics of the standing wave pattern (i.e., relative to sound pressure levels and acoustic mode/antinode locations) produced from normally incident sounds at selected discrete frequency and sound pressure level are determined from probe microphone data.

These data are input to a digital computer to calculate the real and reactive components of the complex acoustic impedance and the normal incidence absorption coefficient.

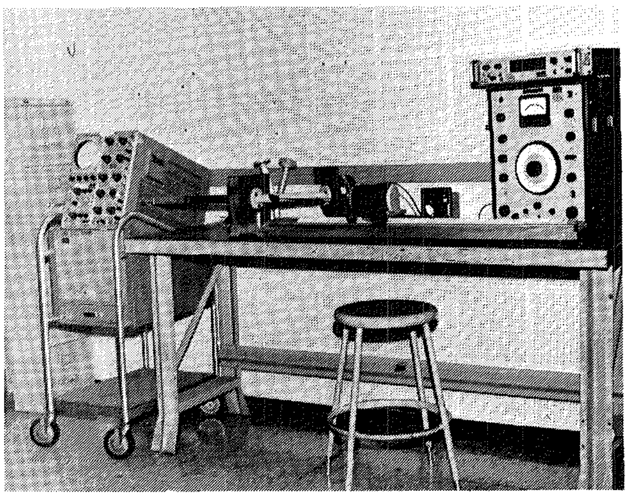

FIGURE 4. STANDING WAVE APPARATUS

For flyover noise recording and other tests at remote locations, the Acoustics and Vibration Van (Figure 5) has been equipped with multichannel recording capability. A self-contained electrical power system supplies a complete complement of test and support equipment including signal conditioning and monitoring systems. In addition, there is a very high frequency (VHF) transceiver, a receiver for time code signals, radio telephone, long-line remote microphone systems, calibration equipment, and a graphic level recorder. As currently configured, the van carries up to 11 long-line microphone stations which can be deployed to distances of 10,000 feet or more. In addition, for remote locations where the use of long cables is impractical, self-contained remotely-controlled noise-recording systems are available.

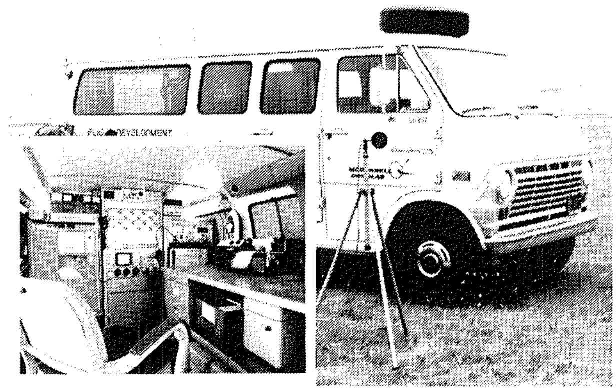

FIGURE 5. ACOUSTICS AND VIBRATION VAN

Noise data processing is conducted using the facilities of the Acoustics and Vibration Data Center (Figure 6). The Data Center is equipped with a number of multiple-channel and single-channel magnetic tape systems and a variety of data processing systems. Data systems include: (1) computer-controlled audio filter system with 1/3-octave-band parallel outputs onto digital tape for subsequent large-scale computer processing; (2) narrow-band spectrum analyzers with variable averaging; (3) computer-controlled processing system for paired-signal analysis in both time and frequency domains using Fourier Transform methods with graphical and tabular output capabilities; and (4) statistical processors with probability and correlation output modes. In addition, multichannel strip chart recorders and necessary peripheral equipment such as time code, signal conditioning and audio output subsystems are incorporated.

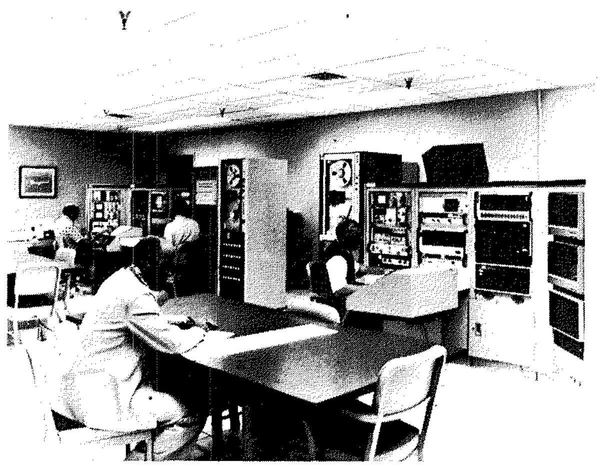

FIGURE 6. ACOUSTICS AND VIBRATION DATA CENTER

Systems developed by Douglas for acoustical data acquisition include those for specialized flyover noise testing to the standards of Part 36 of the U.S. Federal Aviation Regulations and Annex 16 of the International Civil Aviation Organization.

Operational Characteristics:

Duct Transmission Loss Facility

Maximum Specimen Size:
- Width – 8 inches
- Length – 48 inches
- Thickness – 4 inches

Duct Cross Section:
- Height – 10.375 inches
- Width variable from 2 to 17 inches
- L/H Ratio: 0 to 24
- Mach Number: 0 to 0.7

Reverberation Chambers (inlet and exhaust):
4.2 by 5.2 by 6.5 feet high with 35- by 40-inch-high access door

Noise Source: Ling EPT-200 and Airjets (see Noise Generators)

Sonic Fatigue Facility

Maximum Specimen Size:
- 20.25 by 27.00 inches long (small window)
- 50.0 by 60.0 inches long (large window)
- 60.0 by 70.0 inches long (door)

Progressive Wave Tube, Cross Section:
12.45 by 62.25 inches high
Noise Source: Noraircoustic MK VII and Ling EPT-200 (see Noise Generators)

Flow Resistance Facility

Maximum Specimen Size: 1.2 by 2.4 meters; 0.8 meter thick
Velocity: 0.70 to 10.0 meters/second through a 0.1-meter-diameter test area
Flow Resistance: 50 to 10,000 mks Rayls

Standing Wave Apparatus

Maximum Specimen Size:
- 10 cm diameter for 90 to 1,800 Hz
- 3 cm diameter for 800 to 6,500 Hz
- 1.5 cm diameter for 5,000 to 10,000 Hz

Normally Incident Sound:
90- to 155-dB sound pressure level at 1/3-octave-band center frequencies of 400 to 10,000 Hz

Standing Wave Ratio: 45 dB

Noise Generators:

Noraircoustic MK VII:
- Electrohydraulic
- 200,000 acoustic watts
- Random frequency range: 40 to 10,000 Hz
- Up to 172 dB in Sonic Fatigue Facility

Ling EPT-200:
- Electropneumatic
- 10,000 acoustic watts
- Sinusoidal frequency range: 40 to 1,250 Hz
- Random frequency range: 40 to 10,000 Hz
- Up to 158 dB in Sonic Fatigue Facility

Maximum air supply: 7,100 scfm (9 pounds/second)
Combined 250 and 300 psig systems
Reference Pneumatic Test Facilities, Section 217-003

Applications:

The Acoustic Test Facilities are actively utilized in experimental research on sources and effects of sound as related to the products produced by Douglas.

The following are some of the more specific programs that are being investigated:

Fan duct noise propagation and absorption
APU inlet/exhaust muffler
Fan duct design
Sidewall transmission loss
Environmental control system and component noise
Aircraft equipment noise control
Psychoacoustics studies
Jet noise suppression
Propulsive lift system noise
Panel absorption
Fan noise source definition and suppression
Panel acoustic loads and stress
Near-Field noise measurements
Airport noise surveys
Factory noise surveys
Community noise surveys
Flyover noise surveys

Instrumentation:

A large assortment of condenser microphones of 1-, 1/2-, 1/4-, and 1/8-inch diameters, both pressure and free-field types, are maintainted, In addition, high-frequency-response pressure transducers with pressure rakes are available for airflow velocity and turbulence measurements for correlation with acoustical data.

Suitable types and quantities of microphone preamplifiers, field-effect-transistor-type cathode followers, power supplies, and multichannel magnetic tape recorders with a variety of recording electronics are availlable to meet the needs of several laboratory, field, and flight tests concurrently.

In addition, several portable single-channel sound-recording systems of the system shown in Figure 7 are maintained as primary test recording systems and to supplement facility systems.

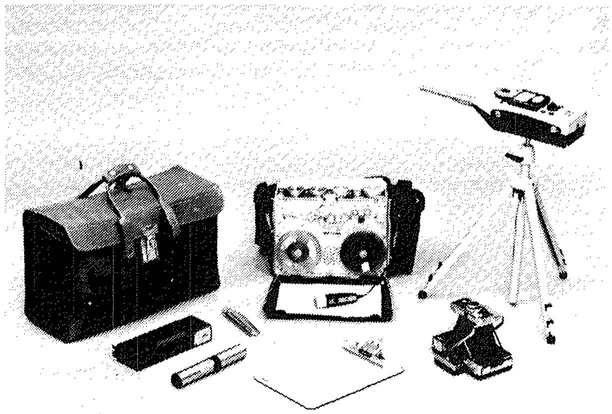

FIGURE 7. PORTABLE FLIGHT AND FIELD SOUND RECORDING SYSTEM

RADIATION TEST FACILITIES

The radiation test facilities (antenna ranges) are used to conduct tests of various antennas used onboard commercial and military aircraft. The test facilities consist of one outdoor range and an indoor microwave anechoic chamber. The outdoor range (Figure 1) is located on the roof of Building 36. It is used for general radiation pattern measurement in the frequency range of 200 MHz to 30 GHz. It is equipped with an azimuth/elevation positioner with maximum bending moment of 10,000 foot-pounds and a 17-foot model tower capability of handling maximum static weight of 750 pounds.

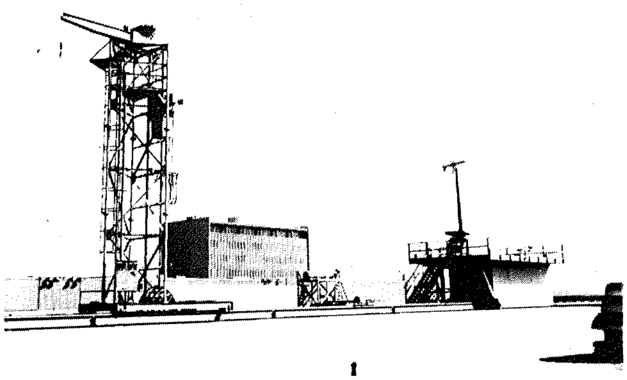

FIGURE 1. ANTENNA TEST RANGE

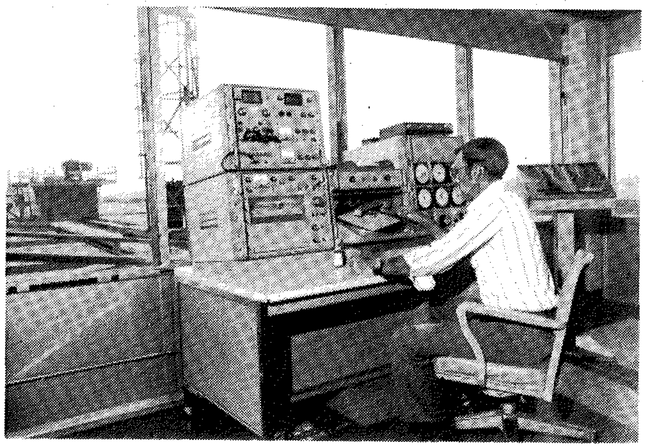

FIGURE 2. ANTENNA RANGE EQUIPMENT

The tramistting antennas are standard horns, L-band through K-band, and 6-foot- and 10-foot-diameter parabolas with interchangeable feed antennas.

The range is equipped with a full complement of Scientific-Atlanta antenna range equipment and the necessary supporting equipment (Figure 2).

FACILITY LOCATION	DEPT NO. 250	BLDG NO. 36
CITY Long Beach	STATE California	

AUTOMATED GRAPHICS SYSTEM

The Automated Graphics System is a computing facility (Figure 1) for producing graphics from digital data, or converting graphics to digital data, using a Gerber Flatbed Plotter (an X-Y coordinate positioning device) or a Versatec Electrostatic Plotter connected to a minicomputer controller. These systems operate from on-line telecommunications with an IBM 3033 system.

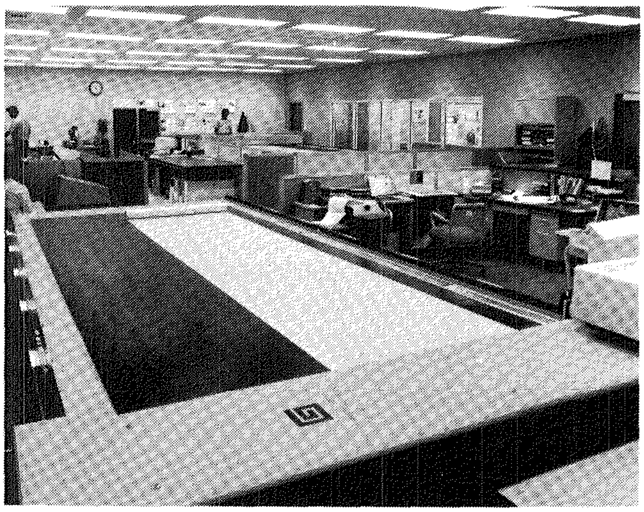

FIGURE 1. AUTOMATIC GRAPHICS PLOTTING ROOM

The Gerber Data Management System (DMS) is an element of a distributed processing system that provides data storage, communications, and processing services to system networks. Other elements in the network may be program-controlled digitizing or drafting systems (such as the Gerber 2075 and 4477), remote large-scale computing systems, or additional DMS systems.

Graphics (Engineering drawings, patterns and geometric designs for stencils or artwork, data plots, etc.) up to 5 by 16 feet are created by designers using computer programs or cathode ray tubes. This information is then transmitted to the Gerber or Versatec for plotting, Figure 2 and 3.

Digital data (area and weight calculations, trace for drawing configurations, numerical/control (N/C) tape, flight path studies, or any application requiring numeric data from Graphics) are obtained by utilization of the automatic line follower to convert graphics to digital format.

The facility consists of three systems which provide support for Acoustics, Aerodynamics, Flight Test, Interiors, Mechanical, Power Plant, Structural Mechanics and Structures, while having the capability to provide support or interface with Tooling and Manufacturing.

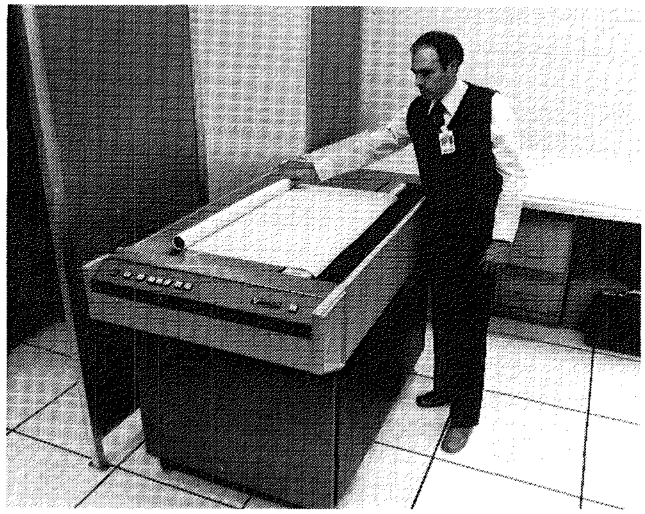

FIGURE 2. VERSATEC PLOTTER

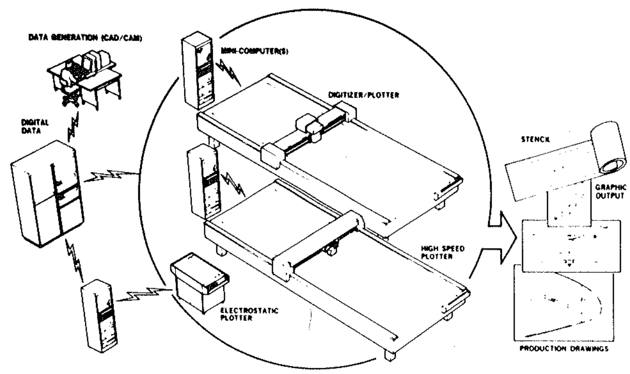

FIGURE 3. SYSTEM ILLUSTRATION

Operational Characteristics

Gerber Flatbed

Table Size (Usable area)
- 5 by 16 Feet (With Vertical Tilting Capability)
- 5 by 16 Feet (High-Speed Nontilting)

FACILITY LOCATION	DEPT NO. 250	BLDG NO. 35
CITY Long Beach	STATE California	

Maximum Drafting Speed
500 Inches/Minute (2075 System)
2800 Inches/Minute (4477 System)

Maximum Digitizing Speed
180 Inches/Minute (2075 System)

Output Head
Wet Pen, Ballpoint Pen, Fibertip Pen, Scribe, Stencil Cutter

Plotting Media
Paper, Vellum, Mylar, Scribecoat, Rubylith, Stencil Material

Accuracy (Drafting)
(±) 0.004 Inch (Overall)

Resolution (Drafting)
(±) 0.0005 Inch

Repeatability (Drafting)
(±) 0.002 Inch

Telecommunication Speed
4800/9600 Baud

Paper Tape Reader Speed
300 CPS

Paper Tape Punch Speed
120 CPS

Versatec Electrostatic

Plot Size (Usable Area)
35.19*
*Limited only by size of paper roll (500 feet)

Plotting Speed
1584 Square Inches/Minute

Plotting Media
Bond or translucent paper

Accuracy
(±) 0.2 percent of 0.015 maximum accumulated error (adjustable in X axis by software)

Resolution
(±) 0.005

Applications

The Automated Graphics System provides graphics or digital data output for the following:

Engineering layouts and production drawings are created or modified using computer-aided design drafting (CADD), Data Coded Geometrical Operation (DACGO) program subroutines, automatic programmed tool (APT), Fortran or Gerber language and transmitted via telecommunication lines to the plotting systems.

Area and weight calculations, flight path studies, or any application where numeric data are required from Graphics and are obtained by operating the Gerber plotters in the digitizing mode. Also, by utilizing a cutter offset routine, the digitizing program will provide, in N/C machine tool format, data for use in preparation of N/C tapes.

Producing paint stencils for exterior aircraft markings is accomplished by programming in Gerber or taking marking artwork (customer-furnished or Douglas-designed) and photographing to desired scale, utilizing opti-copy camera. The shape defined on photoprint is digitized for digital data moved to a CADD access data storage area where additional shape definition is added and a hardcopy file is produced which can be plotted on stencil stock.

Aerodynamic and Power Plant performance graphs and Acoustic contour curves are derived from theoretical, wind tunnel test models, flight test aircraft, etc., and processed by programs for data to be transmitted via telecommunication lines to the Gerber or Versatec for plotting.

N/C tape verifications.

Stress analysis diagrams.

Mechanism motion study drawings.

Geodetic survey (tract, topographical, etc.).

Geometric patterns for interior ceiling and side panels.

N/C tapes for automatic drilling and wire wrapping machine.

Associated Equipment

Gerber Optical line following with line lock-on capability to allow operator to digitize "hands off" mode.

Camera and TV monitor to allow the operator a "follower's eye view" of the graphics being digitized.

ASR-33 teletype unit for machine control and I/O operation.

Adds 520 console for machine control I/O operation and data manipulation.

High-speed paper tape punch for output of EIA (Electronic Industries Association) or ASCII (American Standard Code for Information Interchange) data on punched paper tape.

Tektronix 4014 CRT storage tube for previewing data prior to plot.

Tektronix 4631 hard copy unit.

4954 graphics tablet for fast-digitizing or free-hand graphics (34 by 42 inches).

DTC 382 time-sharing terminal for data management.

Minicomputer Controllers

Honeywell DDP-516 Eight K Memory
Hewlett-Packard 2108 Sixteen K Memory
Hewlett-Packard 2112 Eighty K Memory
Interdata 180-4 Sixty-Four K Memory

Disk Drives

Hewlett-Packard 7900A Five Megabytes
CDC 9762 Eighty Megabytes

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Technical Monitor: Brent A. Miller, MS 301-2
NASA Lewis Research Center
2100 Brookpark Road
Cleveland, Ohio 44135

16. Abstract The work performed by Douglas Aircraft Company, with Hamilton Standard and Detroit Diesel Allison as subcontractors, provides a recommended NASA program for establishing the proof of concept, feasibility, and verification of the advanced prop-fan and of the integrated advanced prop-fan aircraft. The use of existing hardware is compatible with having a successfully expedited testbed ready for flight in 1986. The study considers the DC-9-10 (or -30) as the testbed aircraft; Hamilton Standard SR-3 design type prop-fan; the Allison T701, the Allison T56, and the General Electric T64 turboshaft engine; one and two prop-fan nacelles with the two nacelle prop-fan as the primary arrangement. An approximate 10 foot diameter prop-fan is considered necessary for the flight test to provide adequate scaling which may arise in the application of test results to full scale aircraft.

The facets of the overall testbed program included in this study are the program objectives and priorities; survey and selection of candidate propeller drive systems; selection of a satisfactory aircraft; proposed testbed systems evaluation and recommendations; conceptual design of testbed; ROM costs; preliminary testbed flight program; and survey of suitable wind tunnel facilities.

Major conclusions are: A prop-fan testbed aircraft is definitely feasible and necessary for verification of prop-fan/prop-fan aircraft integrity. The DC-9 aircraft is a particularly desirable testbed aircraft. The Allison T701 is most suitable as a propulsor and modification of existing engine and propeller controls are adequate for the testbed. The airframer is considered the logical overall systems integrator of the testbed program. Large scale wind tunnel testing is not adequate for validation of the prop-fan aircraft.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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