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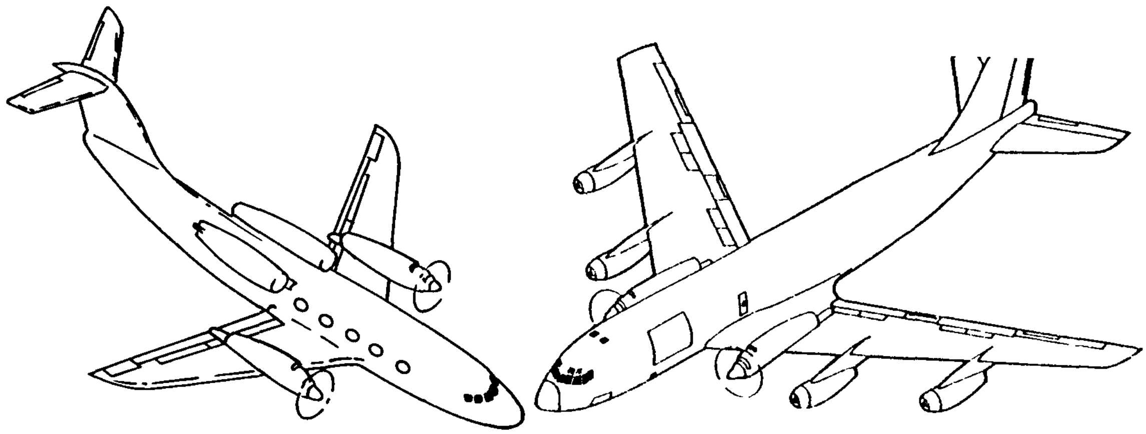

Advanced Turboprop Testbed Systems Study

Volume I

Testbed Program Objectives and Priorities, Drive System and Aircraft Design Studies, Evaluation and Recommendations and Wind Tunnel Test Plans

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16. Abstract

Program objectives and priorities to establish prop-fan technology readiness have been determined. Candidate drive systems for prop-fan application were identified and the DDA XT701/T56-A-14 combination driving a 2.89 m (9.5 ft) diameter prop-fan recommended as the drive system for testbed application. Candidate testbed aircraft were investigated for testbed aircraft suitability and four aircraft selected as possible prop-fan testbed vehicles. An evaluation of the four candidates was performed and the Boeing KC-135A and the Gulfstream American Gulfstream II recommended as the most suitable aircraft for test application. Conceptual designs of the two recommended aircraft were performed and cost and schedule data for the entire testbed program were generated. The program total cost was estimated to be in the $\$40-45 \times 10^6$ range covering a period of almost seven years.

A wind tunnel program cost and schedule was also generated in support of the testbed program.

This report is published in two volumes. Volume II is covered by limited rights legend.

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FOREWORD

This report documents the procedures and results of the Advanced Turboprop Testbed System Study performed by the Lockheed-Georgia Company for the National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.

The study was performed under Contract No. NAS3-22346 supported and augmented by the Independent Research and Development Program (IRAD) at Lockheed-Georgia. The IRAD effort was used to develop the data for Appendix B, Candidate Drive Systems - Task II; Appendix C, Candidate Testbed Aircraft - Task III; and Appendix E, Conceptual Design of Testbed Systems - Task V.

The report is presented in two volumes. The technical investigations are described in Volume I - "Testbed Program Objectives and Priorities, Drive System and Aircraft Design Studies, Evaluation and Recommendations and Wind Tunnel Test Plans." Because of the proprietary nature of the cost and schedule information these data are published separately in Volume II - "Testbed Program Costs and Schedules."

Mr. Brent A. Miller of the NASA Lewis Propeller Technology Section served as the Contract Monitor for this study.

This study was performed under the direction of Mr. E. S. Bradley of the Lockheed-Georgia Advanced Concepts Department - Manager, Mr. Roy H. Lange.

The Principal Lockheed contributors to the study were:

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The Hamilton Standard Division of the United Technologies Corporation, under a subcontract arrangement, provided data for Task I - Objectives and Priorities; Task II - Prop-Fan Control System Description; Task III - Prop-Fan Characteristics and Dynamic Load Evaluations; Task IV - Testbed Installation Evaluation; Task V - Slipstream and Acoustic Data for One Installation; and Task VI - Program Plan Data. Mr. Bernard S. Gatzen and Mr. Stanley Cohen of Hamilton Standard provided the support for the activities described above.

Detroit Diesel Allison (DDA) provided data for the gearbox modifications and for the XT701 engine, and provided support to the study on a no cost basis. Mr. P. Stolp was the DDA principal contributor.

The Gulfstream American Corporation (GAC), represented by Mr. R. Stewart, contributed to the completion of this study by making available to Lockheed-Georgia all of the technical data required to execute the Task V activities related to the "Gulfstream II" (GII) testbed configuration.

These data were loaned to Lockheed-Georgia on a no-cost basis to either Lockheed or the government. Following the completion of Task V, GAC reviewed the design and conclusions of the GII under a small subcontract.

The study was begun in February 1980 with the technical portion covering a period of nine months. Reviews were presented to the NASA LRC in September 1980 - Mid term Oral Review and the Final Oral Review in April 1981.

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SUMMARY

During the 1960s high subsonic speed cruise technology advanced rapidly. During this same period fuel was cheap and plentiful. These factors combined with the simplicity of the turbojet and turbofan were instrumental in causing propeller propulsion to almost disappear from use for commercial aircraft application.

Since that time not only have fuel prices increased significantly but occasional shortages have been experienced. These factors led to a move to reduce fuel consumption in the USA which, for the aircraft industry, was addressed through the NASA Aircraft Energy Efficient Programs (ACEE), which includes the "Advanced Turboprop Testbed Systems Study." These programs are aimed at fuel reduction through the incorporation of advanced technology into aircraft. One such technology is the advanced turboprop or prop-fan which has potential for achieving significant reductions in fuel consumption in operational areas that have been the exclusive domain of the turbofan.

Modern commercial passenger transport aircraft cruise at altitudes of 9114m (30,000 ft) and above at speeds around Mach 0.8. Analysis has shown that the prop-fan can operate efficiently at these conditions with fuel savings relative to turbofans of 20 to 35 percent. Since fuel costs have become such a significant part of Direct Operating Cost (DOC), these fuel savings can result in DOC savings of 5 to 10 percent.

All of the recent NASA experimental work related to high speed propellers has been conducted using models 0.62m (24.5 in) in diameter. Before proceeding to the design and fabrication of flight hardware, large scale tests are needed to verify structural integrity of the propeller/nacelle combination, to demonstrate manufacturing feasibility and to determine the near- and far-field acoustic characteristics of the prop-fan.

Because of the difficulty of simulating the high speed cruise environment for large scale propellers in ground-based facilities, flight test experimentation is needed. The purpose of this study has been to identify those High Speed Turboprop Technology questions and issues that are best resolved by testing a large scale propeller of advanced design in the realistic flow environment of a testbed aircraft installation and to establish propeller drive systems and aircraft combinations that best accomplish the technology objectives to establish the technology readiness of the prop-fan.

Among the results of this study are:

- Identification of the Objectives and Priorities for the Testbed Aircraft Program that would enhance the acceptance of the prop-fan and establish technology readiness. These fall in four areas: a) Integrity of the Structure - both of the prop-fan and the aircraft; b) The Acoustic Environment - both near and far-field; c) Aircraft Performance, and; d) Functional Systems operation and FOD Vulnerability.

  A total of 30 objectives have been identified and defined.

- Propeller Drive Systems consisting of reduction gearboxes, turboshaft power sections and interconnecting torque shafts suitable for testbed application were identified as the Detroit Diesel Allison (DDA) XT701/T56-A-14, DDA T56-A-7, and the General Electric GE T64/2 SDG. The DDA XT701 combination driving a 2.84m (9.5 ft) prop-fan was the drive system chosen for the Testbed Aircraft.

- Candidate aircraft from the NASA inventory were examined for Testbed Aircraft application. These were the Lockheed C-141A, the Boeing KC-135A, the Convair 990 and the Gulfstream American Corporation GII. The Boeing B-52B was considered in the role of a flying wind tunnel. The candidate aircraft were configured as single and twin prop-fans with emphasis placed on the twin prop-fan testbed.

- An evaluation of the candidate aircraft resulted in the selection of the Boeing KC-135A and the Gulfstream American Corporation GII as providing the most suitable testbed aircraft since both are capable of modification to twin prop-fan testbed aircraft within the mission and design requirements for the Testbed Aircraft.

- Conceptual designs of the KC-135A and GII were performed and the aircraft configuration, extent of structural modifications, aeroelastic characteristics, and aircraft performance defined.

- A Program Cost and Schedule was established for both recommended testbed configurations. The program schedule covers a period of 6-3/4 years from inception to the completion of the flight test documentation. The cost of the Testbed Program based on 1981 dollar values, with either of the testbed aircraft was estimated to be in the range of \$40 to \$45 x 10^6.

- A wind tunnel test plan for support of the Testbed Program addressed two areas of technological concern: a) Demonstration of the drive system operational readiness; b) Validation of the airworthiness and performance levels of the selected testbed configuration.

  Wind tunnel test of the drive system, however, is not recommended because the flight environment is difficult to simulate, the tunnel solid wall blockage limits are exceeded, and the fact that low-speed tests do not address the prop-fan design point. A limited amount of useful data would result from such tests leading to the conclusion that wind tunnel testing is not cost effective.

Reviewing the study results, it is quite evident that although considerable progress has been made in prop-fan technology since 1975 there are still areas of concern which must be addressed if this promising propulsion concept is to be accepted as a proven system. These concerns arise from the uncertainties in moving from small scale, 0.62 m (2.04 ft) diameter, prop-fan tests in a wind tunnel environment to full scale prop-fans an order of magnitude larger in a flight environment.

However, most of the areas of concern can be effectively addressed by means of the Testbed Aircraft approach. A suitable powerplant and gearbox - the DDA XT701 at 6018kW (8071 shp) @ SL and the T56-A-14 gearbox - can be assembled to drive a prop-fan of about 3.0m (9.5 ft) in diameter, and two aircraft - the Boeing KC-135A and the GAC "Gulfstream II" - are attractive as testbed vehicles.

A flight test program using the drive system defined above installed on either aircraft would provide the necessary demonstration of prop-fan propulsion for industry acceptance.

INTRODUCTION

During the 1960s the rapid advance of high subsonic speed cruise technology, the abundance of relatively inexpensive fuel together with the simplicity of the turbojet and turbofan caused a trend away from propellers in commercial aircraft service. In recent years the escalation of fuel prices and occasional fuel shortages have brought about the need for improved fuel efficiency at high subsonic speeds which, in turn, has created renewed interest in propeller technology. Modern commercial passenger transports cruise at altitudes of 9114m (30,000 ft) and above at Mach numbers in excess of 0.8. Analyses and tests of the advanced turboprop propulsion system--"Prop-fan"--have shown that, at these conditions, the prop-fan can operate efficiently with fuel savings relative to the turbofan of 20 to 35 percent. As fuel costs continue to become a more significant portion of the Direct Operating Cost (DOC), these savings can result in DOC reductions of 5 to 10 percent.

The status of the prop-fan was reviewed in detail in 1978 and then in 1980* but is summarized in the following text.

Since 1975 several wind tunnel test programs have been used to develop efficient prop-fan configurations for cruise at Mach numbers up to and including 0.8. Three eight-bladed configurations were tested in wind tunnels at United Technologies Research Center (UTRC) and at NASA Lewis Research Center (LRC). These include the SR-1 and the SR-2 prop-fans 0.62m (2.0 ft) in diameter which were designed in 1975 using methodology developed by Hamilton Standard. The two models were similar except that the SR-1 configuration had blades with 23 degrees of sweep at the tips and a conical spinner whereas the

*Dugan, James F. Jr., Gatzen, Bernard S., and Anderson, William M., "Prop-Fan Propulsion - Its Status and Potential," Society of Automotive Engineers Aerospace Meeting, Preprint 780995, November 1978.

Dugan, James F. Jr., Miller, Brent A., Graber, Edwin J., and Sagerser, David A., "The NASA High-Speed Turboprop Program," NASA TM81561, October 1980. bottom

SR-2 blade tips were unswept and the spinner was area-ruled. The experience gained from the initial tests was used to design the SR-3 prop-fan shown in Figure 1. Data from the test of the SR-3 in the NASA Lewis wind tunnel showed that at cruise Mach numbers of 0.8 at 10,668m (35,000 ft), propeller efficiency, η_p, ranged from 80 percent at a power loading of 30 shp/d^2 to 78 percent at 40 shp/d^2.

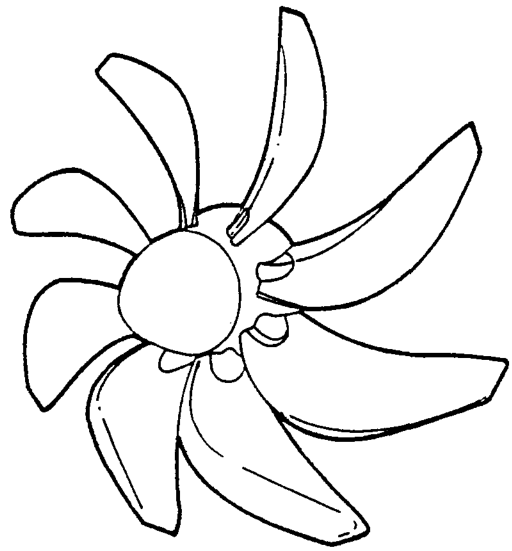


Figure 1. SR-3 Prop-Fan

One characteristic of the highly loaded prop-fan is that swirl angles up to 6 degrees are present in the slipstream. It has been estimated that propulsive efficiencies may be increased above these levels if, by proper design, the wing/nacelle integration can recover some of the swirl energy. An analytical study of this problem** was performed in an extreme case where the wing geometry was made flexible enough to cancel the swirl completely. The results of the investigation led to an impractical wing structure but did demonstrate that such an approach could be successful.

Experimentation with prop-fans continued with the development of the SR-5 and SR-6 configurations and with the testing in 1981 of an SR-3 prop-fan in a powered nacelle mounted above the fuselage of a NASA "JetStar".

The SR-5 is an aeroacoustically designed, 10-bladed prop-fan in which the blade tips are swept at 0.84 rad (48 deg). Aeroacoustic design data for a tip speed of 183 m/s (600 fps) were supplied by NASA Lewis to Hamilton Standard, who performed the mechanical design. Wind tunnel testing of this configuration was conducted early in 1981 for performance data and flutter characteristics.

**Boeing Commercial Aircraft Company, "An Analysis of Prop-Fan/Airframe Aerodynamics Integration," NASA CR152186, October 1978.

The SR-6, which is also an aeroacoustic design, has 10 blades and was designed for a tip speed of 213 m/s (700 fps). The propeller diameter is 0.70m (2.3 ft) and the blade tips are swept about 0.4 rad (23 deg). Testing of this configuration was conducted in 1980 to establish performance data. Future plans call for tests of this configuration on the NASA "JetStar" in place of the SR-3.

All of the experimentation performed so far has been conducted with small scale prop-fans between 0.62 to 0.7m (2.0 to 2.3 ft) in diameter. To enhance industry acceptance of the concept and to resolve questions and issues related to prop-fan technology readiness, large scale tests are needed before design commitment to prop-fan propulsion can be approached with confidence. Since the high speed cruise environment is difficult to simulate for large scale propellers, a flight test program using a prop-fan drive system installed on a testbed aircraft is a necessary adjunct to the existing scale model test program.

Objectives of the investigation described in this final report were to:

- o Identify those high speed turboprop questions and issues best addressed through test of large-scale prop-fans in the realistic flow field of a testbed aircraft installation and establish the testbed program objectives and priorities.

- o Identify propeller drive systems and testbed aircraft combinations that best accomplish the objectives.

- o Evaluate candidate aircraft configurations, and recommend and perform conceptual designs of two testbed aircraft systems.

- o Generate a testbed program cost and schedule for both recommended systems.

- o Establish a wind tunnel test program plan for the test of the propeller and drive system.

The study plan adopted for this investigation is shown on Figure 2 and consists of seven tasks which in summary are as follows: Task I examined the Testbed Program Objectives and Priorities; Task II investigated Candidate Propeller Drive Systems; Task III analyzed Candidate Aircraft Configurations; Task IV was the Evaluation and Recommendation of the Task III candidates and the Selection and Recommendation of two Testbed Systems; Task V was the Conceptual Design of the Recommended Systems; Task VI was the formulation of the Program Costs and Schedules; and Task VII developed the Wind Tunnel Test Plan.

Initially, the study addressed single prop-fan configurations only. However, following the submittal of the Task VI "Evaluation and Recommendations" the study was redirected by NASA to the investigation of twin prop-fan testbed configurations. Task V was, therefore, conducted for twin prop-fan configurations only.

The final report is divided into two volumes - VOLUME I, which summarizes the tasks in the main text with detailed accounts of each task presented as appendices and VOLUME II, "Testbed Program Costs and Schedules," presented as a separate entity because of the proprietary nature of the data.

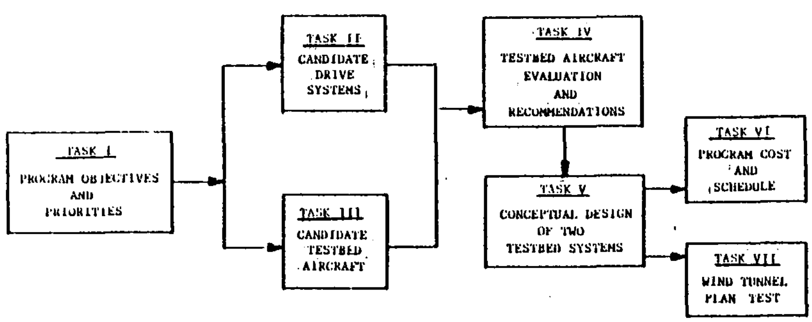


Figure 2. Advanced Turboprop Testbed System Study Plan

TECHNOLOGY CONCERNS

Although considerable progress has been made in the development of high speed propellers over the past five or six years, it must be recognized that the largest prop-fans made and operated so far have been in the diameter range of 0.62m (2.0 ft). Furthermore, these prop-fans have never been subjected to test in a realistic flight environment nor have they been tested with actual turboprop drive systems. In addition, some uncertainty exists about the noise generated by large high speed propellers and about the capability to attenuate the noise to tolerable levels both in the aircraft cabin and externally to meet community noise standards without unduly penalizing the performance of the aircraft.

Thus, before committing prop-fan propulsion to aircraft design, manufacturers and users must be convinced that:

- Large scale prop-fans can be built light enough for flight hardware and with sufficient strength and stiffness to sustain the dynamic loads to which the prop-fan blades will be subjected.

- Interior cabin noise attenuation can be achieved without incurring weight penalties that would offset the performance gains due to the prop-fan.

- Installed propulsive efficiencies commensurate with the uninstalled values can be attained. This involves:

  a) Efficient extraction of the swirl energy from the slipstream

  b) Minimization of adverse swirl in the slipstream on the wing flow, and

  c) Development of efficient inlet systems for the core engines.

These technology concerns are best addressed through a number of means which include analysis, static tests, high and low speed wind tunnel tests, and by flight test of a large scale prop-fan.

The concerns are grouped into three major technology areas as follows:

- o Integrity of the structure
- o Prop-fan acoustic environment
- o Installed performance

These areas are discussed in the following text.

INTEGRITY OF THE STRUCTURE

Propellers, whether of conventional or advanced design, when mounted in front of a wing experience cyclical loadings due to the flow field generated by the presence of the loaded wing and by other components such as the fuselage and adjacent nacelles. When mounted on a swept wing and operated at high Mach numbers the flow field becomes complex and unsymmetrical thereby including unusual dynamic loadings on the propeller and therefore on the power plant and aircraft structure. Unsteady random and periodic forces can be imposed on the propeller by the ground plane, fuselage wall, swept wing leading edge, nacelle and engine air inlets, adjacent propellers and nacelles, oblique stream due to yaw, angle-of-attack, crosswind and other factors. Unless taken into account during design and development, these factors could cause structural problems for both the propeller and airframe.

Three areas of technological concern are associated with the question of the Integrity of the Structure:

- o Propeller Structural Integrity and Dynamics
- o Propeller Induced Vibrations and Dynamics
- o Scale Effects

Propeller Structural Integrity and Dynamics

This mainly concerns the vibratory response of the propeller to the aerodynamic flow field, the stall and classical flutter characteristics of the propeller and critical speed and hub stiffness. The blade dynamic response is a function of the aerodynamic flow field and the blade aerodynamic and structural characteristics. The issues of vibratory response require that testing should be conducted in an environment that simulates actual flight conditions.

The possibility of classical flutter of prop-fan blades is of concern because of the high degree of modal coupling due to blade sweep and aspect ratio, the low torsional mode frequency and the high operating speeds. Blade classical flutter is dependent upon structural and aerodynamic characteristics and although aerodynamic characteristics can be simulated by small blades, structural characteristics can only be simulated by large blades. A similar argument holds for blade stall flutter since duplication of the aeroelastic and geometric characteristics and torsional frequency require large scale blades. The rotating blade assemblies must be examined for speed criticality since propeller blades exhibit several modes of resonant vibrations over the operating range. Prop-fans of eight or more blades could experience up to five significant excitations per revolution so that excitations up to 5P must be considered.

Propeller Induced Vibrations and Dynamics

Although the structural integrity of the prop-fan is mainly the concern of the propeller manufacturer, the influence of the flow field of the installed prop-fan propulsion system must be considered. The airframe manufacturer must therefore share responsibility in this area. A prop-fan operating at high subsonic speed introduces the possibility for the occurrence of two types of flutter problem - whirl flutter and the reduction of wing flutter stability.

The whirl and wing flutter coupling are both dependent upon propeller unsteady normal forces and moments associated with angle-of-attack changes. No steady or unsteady normal force and moment data have been measured for prop-fans but the coefficients are expected to be significantly higher than those of conventional propellers due to the higher Mach numbers at which the prop-fans operate. Sound pressures radiating from the prop-fan disk and fluctuating pressures in the prop-fan slipstream excite resonances in the airframe structures and/or drive the structure at non-resonant conditions at potentially destructive amplitudes.

A structurally safe testbed aircraft is a prime consideration for the testbed program so that test and analysis is required to ensure an airworthy testbed aircraft.

Scale Effects

Scale effects are or great importance in the development of the prop-fan propulsion system since both structural integrity and acoustic characteristics are affected. Studies of the application of prop-fans to future aircraft indicate that prop-fans from 4.26 to 6.1m (14 to 20 ft) in diameter may be required. Some concern exists on the question of what scale effects, if any, must be considered in moving to large scale from a data base developed with 0.62m (2.0 ft) diameter prop-fans. Hamilton Standard has estimated that, for good simulation of large scale structure and manufacturing feasibility, tests are needed with prop-fans not less than 2.43m (8 ft) in diameter. At this scale a blade configuration such as the SR-3 could properly represent the mass and stiffness distribution as well as demonstrate the feasibility of the spar-shell design concept. Testing prop-fans of 2.43m (8 ft) or more in diameter in a realistic flow environment presents some formidable problems. Static tests can be readily performed using one of a number of facilities in the U.S.A. Such tests, however, would not impose the same loads on the prop-fan as the actual flight environment. Testing a large propeller in a wind tunnel at a Mach number of 0.8 with proper simulation of inflow angles, support structure or other effects is difficult. Wall corrections for propeller tests are so large that even the 16-foot tunnel at the Arnold Engineering Development Center (AEDC) may not provide results sufficiently accurate for practical use. The concern over the effects of scale is, therefore, whether data from small-scale model experiments together with new data from the testbed aircraft, in combination with analytical methods will provide a data base of sufficient confidence to ensure the achievement of technical success in the design of large scale prop-fans.

Propeller noise is determined more by individual blades than by blade interactions. This is particularly true for prop-fans where the rotation tip speeds are close to sonic velocity and the addition of forward speeds produces supersonic velocities. Since no good analytical or experimental base currently exists for scaling propeller noise over a wide range of diameters, there is a need to develop accurate data for large-scale prop-fans so that designs for cabin noise attenuation treatment may be generated.

The minimum prop-fan size of 2.43m (8.0 ft) diameter, suggested for structural scaling, would also provide valuable data for acoustic scaling of sufficient accuracy to lend confidence that noise from larger diameter prop-fans may be predicted. To accomplish this it would be necessary to properly simulate the Mach 0.8 forward velocity in an anechoic environment.

PROP-FAN ACOUSTIC ENVIRONMENT

Although acoustic tests have been made on several prop-fan configurations, uncertainty about the levels and character of prop-fan noise exists. Available test facilities are inadequate to simulate the high transonic cruise speed in an anechoic environment and the conclusion that prop-fans can produce a noise level of about 136 dB SPL at the fuselage wall is based on extrapolations from low speed tests. To obtain data in a realistic environment, NASA-Dryden has conducted tests of an SR-3 prop-fan configuration, previously used for wind tunnel tests, mounted on top of the fuselage of a specially modified "JetStar". Data from these tests have not yet been published but the results are encouraging. NASA-Lewis plan more tests at the Dryden facility with the "JetStar" using 2-bladed SR-3, 8-bladed SR-2, and 10-bladed SR-6 prop-fan configurations. These near-field prop-fan noise tests are providing the first data in which forward speed effects are accurately modeled.

The prediction methodology for noise levels is inadequate in several respects. This includes the method of accounting for wave propagation over curved surfaces, cancellation and reinforcing from multiple sources, synchrophasing, effects of forward motion on surface reflections and angle-of-incidence on propagation path. The deficiencies of the theory indicates the need for more testiing to quantify the near-field noise environment as well as to validate or modify analytical methods.

The far-field noise characteristics of the prop-fan also constitute an area of technological concern. Acceptance of the prop-fan concept rests upon demonstrating that large-scale prop-fan powered aircraft can comply with current FAR Part 36 requirements for community noise levels. Current noise prediction methodology is based upon extension of propeller theory and on measurements from small-scale prop-fans operating in a low forward speed environment.

Since the "JetStar" near-field acoustic test installation is mounted on the top of the fuselage and would therefore be shielded from ground microphones, the installation would not be expected to yield good far-field noise data. As a consequence, flight tests will be needed to verify far-field noise predictions, and should be conducted using prop-fans greater than 0.62m (2.0 ft) diameter because of the need to validate prop-fan noise prediction and scaling theory.

INSTALLED PROPULSIVE EFFICIENCY

Optimizing the installation of the prop-fan propulsion system for a practical aerodynamic environment is of significant concern for at least two reasons. First, because of the high solidity and blade Mach numbers of the prop-fan, problems of some complexity are created for the core engine inlet. These problems are further compounded by the inlet duct configuration which is dictated by reduction gearbox and drive shaft location. Generally, however, the data base and experience accumulated with propeller drive systems are sufficient to permit design of inlet and internal flow systems with efficiencies approximately within 5-percent of optimum values.

The second reason for technological concern is that of the integration of the advanced propeller, nacelle, and wing into an efficient aerodynamic design. An optimistic approach to the problems associated with this task would assume that swirl energy may be extracted from the prop-fan slip-stream to offset propulsion system installation losses. At the other end of the scale, the installation will fail to recover swirl energy from the slip-stream and the swirl will degrade the wing aerodynamic performance in the slip-stream wake.

A large amount of analytical and test work is needed to develop optimum configurations.

PROP-FAN DEVELOPMENT PROGRAM OBJECTIVES AND PRIORITIES

The general areas of technological concern - structural integrity, scale effects, and installed propulsive efficiency - form the basis for the formation of a number of specific objectives for a prop-fan development program that would enhance prop-fan acceptance and demonstrate technology readiness. Four specific areas have been addressed in the formation of the objectives as follows:

- Integrity of the Structure
- Acoustic Environment
- Aircraft Performance
- Functional Systems Operation and FOD Vulnerability

The four areas, derived from the general areas of technological concern, were assigned priority levels on the basis of their importance to the demonstration of technology readiness of prop-fan propulsion.

Each specific area was further sub-divided into task-sized objective units which define the specific problem and for which the means of solution were outlined. The importance of each objective within the specific areas was also assessed and sub-priority assigned to each. The means or methods by which the objectives could be satisfied or achieved were also determined for the overall program. These methods range from analysis, static test, high and low speed wind tunnel tests to the use of a testbed aircraft for large scale flight test. A total of 30 objectives are identified on Table I in order of priority, and the techniques and type of test facility required to bring about technology readiness status indicated.

The most important objectives are those related to the Integrity of the Structure which includes not only the structural integrity of the prop-fan and airframe structure but also the effects of scale. These considerations are given first priority for program objective execution.

The second order of priority is that of the Acoustic Environment since public acceptance of prop-fan propulsion will depend upon the near-field noise

TABLE I. PROGRAM OBJECTIVES AND PRIORITIES

PRIORITY	TECHNOLOGY AREA	OBJECTIVE	SUB PRIORITY	PROBLEM SOLUTION METHOD: TESTBED AIRCRAFT	WIND TUNNEL HS	WIND TUNNEL LS	STATIC TEST	ANALYSIS
1	INTEGRITY OF THE STRUCTURE o Propeller structural integrity & dynamics	1 Blade dynamic response validation	1	(X)				
		2 Blade classical flutter validation	2	(X)	X			X
		3 Blade stall flutter validation	3	(X)		X	X	
		4 Critical speed & hub stiffness validation	4	(X)			X	
	o Propeller induced vibration & dynamics	5 Determine aerodynamic data for flutter analyses	1		(X)	(X)		X
		6 Determine structural vibration spectra magnitude	2	(X)	X	X	X	X
		7 Drive system dynamic loads & induced effects	3	(X)	X	X		X
	o Scale effects	8 Validate or develop scaling laws	1	(X)	X	X		
		9 Blade mass & stiffness distribution determination	2	(X)	X	X	X	
		10 Demonstrate full size prop-fan fabrication feasibility	3				X	
		11 Establish drive system feasibility for 15,000 SHP & above	4					X
2	ACOUSTIC ENVIRONMENT o Propeller generated near-field noise	12 Sound pressure directivity and spectra variation	1	(X)		X		X
		13 Sound pressure levels on pressurized surfaces	2	(X)				X
		14 Noise strength & directivity determination	3	(X)		X		X
		15 Fluctuating pressure spectra	4	(X)		X		X
		16 Effects of fuselage curavture	5	(X)				X
		17 Geometry of correlated sound pressure area	6	(X)				X
	o Propeller generated far-field noise	18 Verify prop-fan compliance with FAR Part 36	1	(X)				
	o Passenger cabin noise & vibration	19 Minimization of sound transmission	1	(X)				X
		20 Resonant frequency modal survey	2	(X)			X	
		21 Fuselage modes and external noise relation	3	(X)				
		22 Noise reduction & structural response minimization by synchrophasing	4	(X)				X
		23 Improvement thru optimization of shell modes	5	(X)			X	X
		24 Noise reduction thru cabin dimension changes	6	(X)			X	X
3	AIRCRAFT PERFORMANCE	25 Verify propulsive efficiency	1	X	(X)	X		
		26 Determine flow field effect on wing	2	X	(X)	X		
		27 Verify engine inlet performance	3	(X)	X	X		X
4	SYSTEMS OPERATION	28 Verify drive system control system	1	(X)		X		
		29 Verify reverser effectiveness	2	(X)		X		
		30 Determine prop-fan vulnerability to FOD	3	X			(X)	

○ PREFERRED METHOD OF SOLUTION

effects on the travelling public and upon the far-field impact on community noise environment.

Those objectives related to Aircraft Performance are considered to be third in order of priority. These objectives relate to installed propulsive efficiency and interaction effects which to a large extent can be controlled by proper design of the power plant nacelle and the nacelle/wing integration.

Functional Systems although essential to the operation of a testbed aircraft installation can be approached through developmental programs and are therefore placed fourth in order of priority.

Also indicated on Table I are the preferred methods by which the objectives may be attained.

A complete description and discussion of Program Objectives and Priorities is to be found in Appendix "A".

PROP-FAN DRIVE SYSTEMS

Typically, a prop-fan drive system consists of a power section connected to a reduction gearbox by means of connecting struts and a torque shaft and housing. The drive system configurations can be arranged so that the reduction gearbox is concentric with the power section making the use of an annular inlet duct possible, or as an offset gearbox arrangement using a scoop type inlet. So that costs can be minimized, the drive systems in this study are assembled from existing hardware modified for prop-fan application. Since none of the drive systems considered had matching gearboxes that enable concentric duct arrangements to be used, all are configured with offset gearboxes. A typical arrangement using the offset gearbox is shown on Figure 3. The drive system can be configured with the gearbox either "pinion-high" or "pinion-low" depending upon the kind of installation required for the airframe. The pinion-high configuration would generally be representative of an overwing drive system installation whereas the pinion-low arrangement would be consistent with an underwing arrangement.

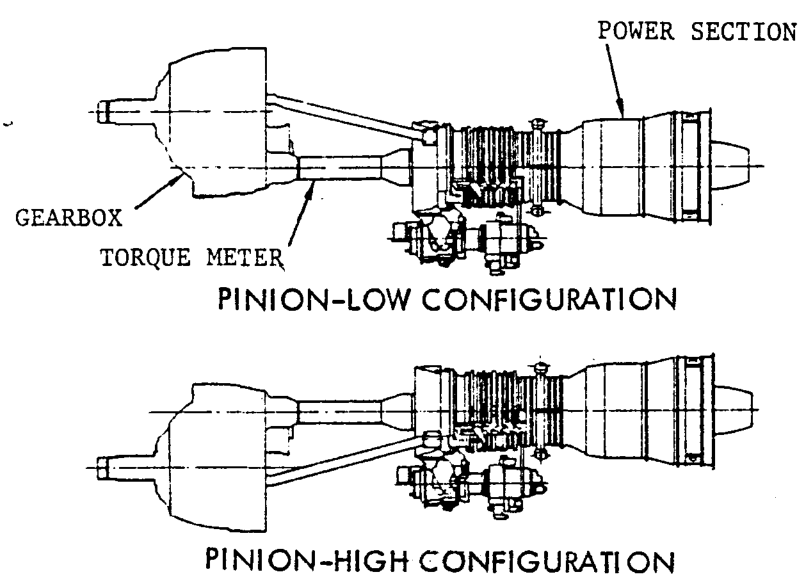


Figure 3. Typical Drive System Configuration

The design requirements for the prop-fan testbed drive system are:

Cruise Mach No.	0.8
Cruise Altitude	10.668m (35,000 ft)
Power Loading	301 kW/m^2 (37.5 shp/d^2)
Tip Speeds	183/213/244 m/s (600/700/800 fps)

Power Level-Minimum SLS 2983 kW (4000 shp)

Specifically the drive system is required to have the capability to power a given propeller at the following operating conditions:

Case 1: 209 kW/m^2 (26 shp/d^2) @ V_T = 183 m/s (600 fps)

Case 2: 241 kW/m^2 (30 shp/d^2) @ V_T = 213 m/s (700 fps)

Case 3: 244 kW/m^2 (37.5 shp/d^2) @ V_T = 244 m/s (800 fps)
where V_T is the propeller tip speed

In addition to these requirements the drive system should also be:

- o Readily available or easily derived from existing hardware which should include the core engine, gear box, nacelle, controls and accessories.

- o Configured so that the internal and external flow lines give low installation performance losses.

POWER SECTION AND GEARBOX SURVEY

A survey of domestic turboprop/turboshaft engines showed the number of engines in the desired power level and performance range to be very limited. Five power sections were identified as possible candidates as follows:

- o Detroit Diesel Allison T56 Single Shaft Turboprop o Detroit Diesel Allison XT701 Free Turbine Turboshaft

o General Electric GE T64-10-415 Free Turbine Turboshaft

o Lycoming T55-LTC4B-12 Free Turbine Turboshaft

o Pratt & Whitney JFTD12A Free Turbine Turboshaft

A review of the five power sections showed that three only would be capable of meeting the design requirements and data for the three power sections are shown on Table II.

Each of the power sections is used in combination with a gearbox which in the case of the DDA XT701 and the DDA T56 engines is a modified T56-A-14 gearbox. Since the DDA T56 engine is a single shaft fixed speed design, separate gear sets are required to provide the prop-fan tip speed variations. For the DDA XT701, however, one set of modified gears only is required. A similar modification is required for the IHI T64-2 SDG gear box should the free turbine GE T64 power section be considered.

TABLE II. CANDIDATE POWER SECTIONS

POWER SECTION	POWER AVAILABLE	
	CRUISE M = 0.8/10,668 m (35,000 ft) kW(shp)	SLS kW (shp)
*DDA XT701	2520 (3380)	6018 (8071)
DDA T56	1819 (2440)	3423 (4591)
**GE T64-10-415	1350 (1810)	3266 (4380)

*Detroit Diesel Allison
**General Electric

PROP-FAN SIZING AND CANDIDATE DRIVE SYSTEMS

The drive systems selected as candidates for testbed aircraft application based on the survey data are:

o DDA T56/T56-A-14 (Mod)

o DDA XT701/T56-A-14 (Mod)

o GE T64-10-415/1H1 T64-2 SDG (Mod)

Prop-Fan Sizing

So that proper representation of the size of prop-fans for aircraft of the future is achieved the prop-fan diameter should be as large as possible. Prop-fan diameter as a function of cruise power for a cruise Mach number and altitude of 0.8 and 10,668m (35,000 ft) is shown on Figure 4. From these data a turbo-shaft power unit for testbed application driving a prop-fan at the recommended minimum diameter of 2.43m (8.0 ft) must be capable of developing 1789kW (2400 shp) and the prop-fan size based on a power loading of 301.2 kW/m^2 (37.5 shp/d^2) from Figure 4 is shown on Table III. The requirement for a prop-fan minimum diameter of 2.43m (8.0 ft) eliminates the GE T64 from consideration as a prop-fan diameter of 2.3m (7.1 ft) only is achieveable. The selection of the drive system is, therefore, a choice between the free turbine DDA XT701/T56-A-14 (Mod) and the single shaft DDA T56/T56-A-14 (Mod). Because of the flexibility offered by the free turbine DDA XT701 and the advantages due to that feature and the fact that the DDA T56/T56A-14 (Mod) provides a marginally acceptable prop-fan diameter, the DDA XT701 drive system is the preferred drive system.

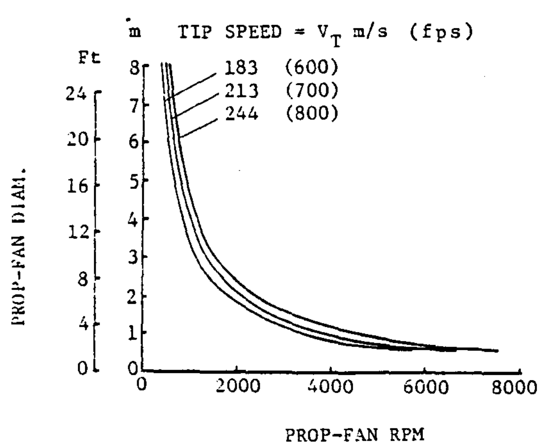


Figure 4. Prop-Fan Sizing

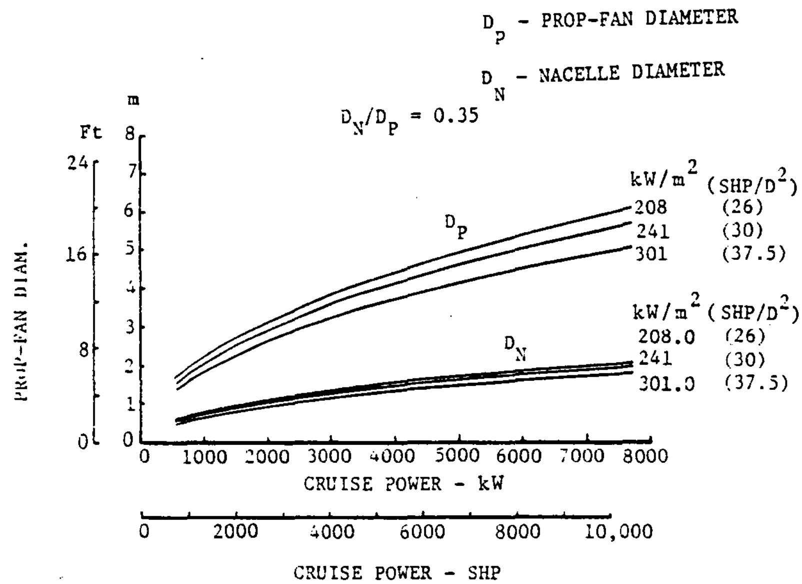


Figure 4. Prop-Fan Sizing (Cont'd)

TABLE III. DRIVE SYSTEM PROP-FAN DIAMETER

DRIVE SYSTEM	PROP-FAN DIAMETER*
DDA XT701/T56-A-14 (Mod)	2.89 m (9.5 Ft)
DDA T56/T56-A-14 (Mod)	2.47 m (8.1 Ft)
GE T64-10-415/IHI T64-2SDG (Mod)	2.13 m (7.0 Ft)

*BASED ON:

MACH = 0.8

ALT. = 10,668 m (35,000 ft)

SHP/D^2 = 301 kW/m^2 (37.5 SHP/ft^2)

V_T = 244 m/sec (800 ft/sec)

Drive System Installation

Installation of the drive system to form a Quick Engine Change (QEC) unit is accomplished by designing the nacelle contours to conform to a NASA supplied area distribution curve, Figure 5. The reason for configuring the spinner and nacelle lines to these data is so that retardation of the airflow at the surface of the spinner is achieved in order to alleviate blade root choking.

NASA AREA DISTRIBUTION

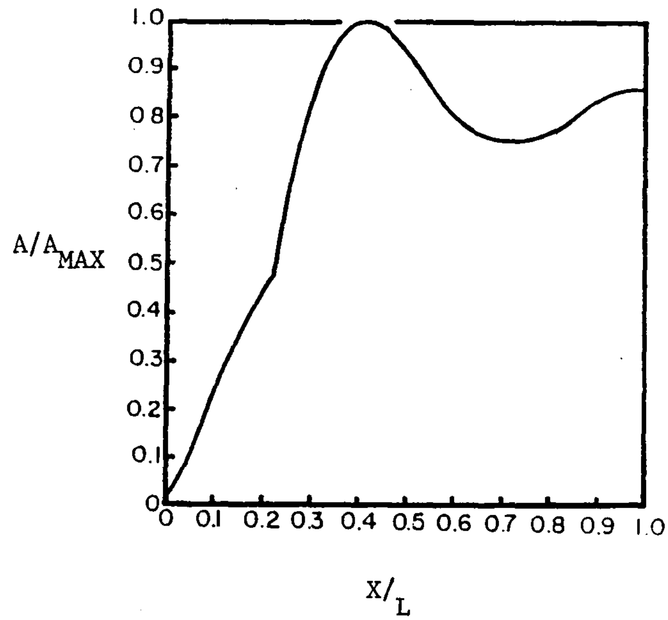


Figure 5. NASA Area Distribution

It should be noted that the data of Figure 5 relate to the installation of the test rig mounted on the "JetStar" fuselage for the near-field acoustic tests. The nacelle, which is axisymmetric, has no internal flow and is therefore not directly applicable to the offset gearbox drive systems under consideration which are unsymmetric and require internal flow for the core engines and oil coolers. The important part of Figure 5 is that portion of the curve up to the maximum cross-sectional area. Conforming to this portion of the curve is expected to keep flow velocities in the blade root region low enough to avoid locally supersonic flow. Behind the location of the maximum cross-sectional area the nacelle contours can be arranged to provide a faired body compatible with the forebody.

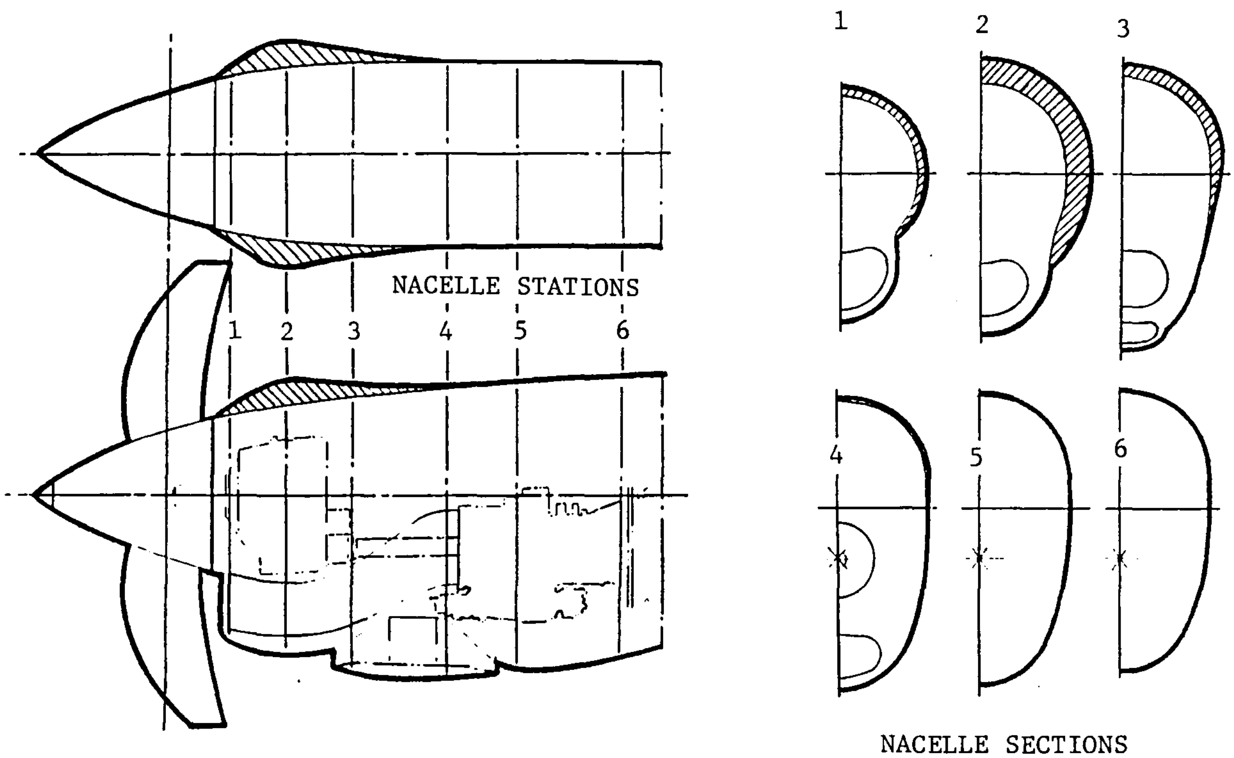
Program flexibility is assured through the QEC approach by designing the QEC installation to be independent of the subsequent receiving airframe. This would enable use of the QEC for full scale wind tunnel tests, static tests and finally for flight tests and can be adapted for installation on any suitable airframe. In the case of the XT701/T56-A-14 (Mod) combination, use of as much of the existing support structure from the Lockheed P-3C "Orion" as a cost reduction feature is considered. Development of the QEC was conducted by examining a number of nacelle installations such as modified Lockheed C-130 and P-3C nacelles as well as new installations for the GE T64, DDA T56 and DDA XT701 drive systems.

Modification of existing nacelles proved to be difficult as shown on Figure 6 for a modified C-130 nacelle and on Figure 7 for a modified P-3C nacelle. In both cases the basic distribution of cross-sectional area for the nacelles is so far removed from the ideal distribution that the best compromise is obtained by normalizing the area distribution by taking the reference area at the location of the peak area on Figure 5. The results of this approach are shown by the area distributions on Figures 7 and 8 for a P-3C and C-130 nacelle respectively and are such that modification of existing nacelles for testbed application is not practical.

Development of new nacelles for the GE T64 and the DDA T56 and XT701 drive systems was performed, first by considering separate nacelle contours for pinion-high and pinion-low configurations, followed by the generation of nacelle contours common to either pinion-high or pinion-low drive system configurations. The resulting nacelle for the DDA XT701/T56-A-14 (Mod) drive system is shown on Figure 9. In this arrangement the engine air inlet and oil cooler ducts are shown in a stacked and staggered configuration. The oil cooler duct can also be arranged to be on the opposite side of the nacelle to the engine inlet duct without changing the common contour concept.

A typical QEC, shown on Figure 10, consists of the bare drive system enveloped in a nacelle complete with mounting structures, air induction systems, exhaust systems, subsystems such as starting and electrical, prop-fan and engine controls, and the lubricating system. The unit shown is the DDA XT701/T56-A-14 (Mod) and is designed for ease of assembly/disassembly at the parting plane which is the juncture between the QEC and the fixed portion of the nacelle on the airframe.

The drive system suspension within the nacelle consists of four supports at the gear box and two adjacent to the turbine section of the power section. The nacelle structure to provide the necessary strength and stiffness utilizes modified forged support frames from the P-3C nacelle design and consists of the gearbox pick-ups and of longitudinal and diagonal members and shear panels up to



C–130 NACELLE MODIFIED FOR PROP-FAN

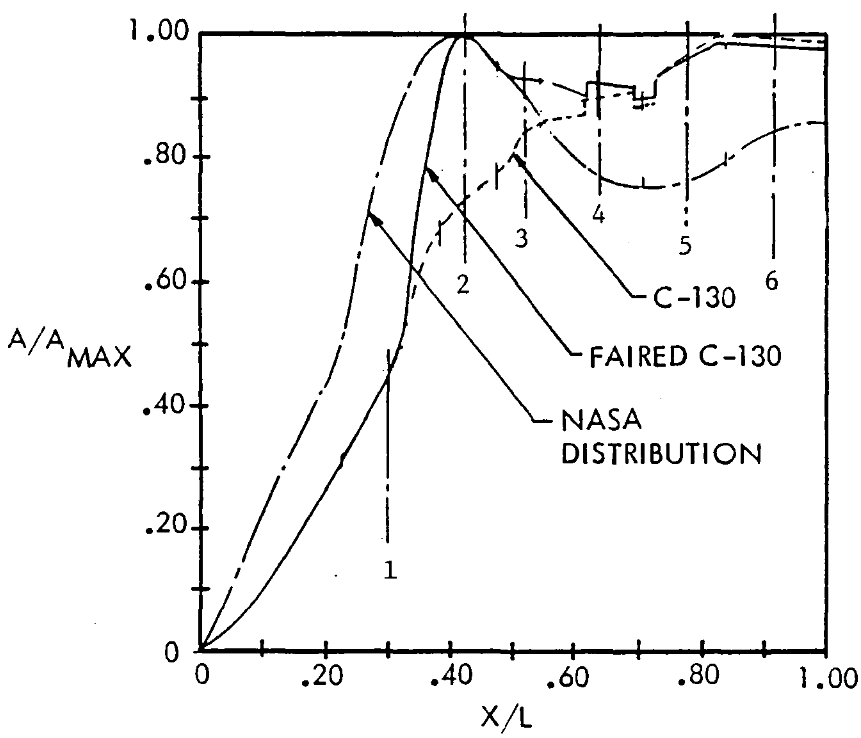
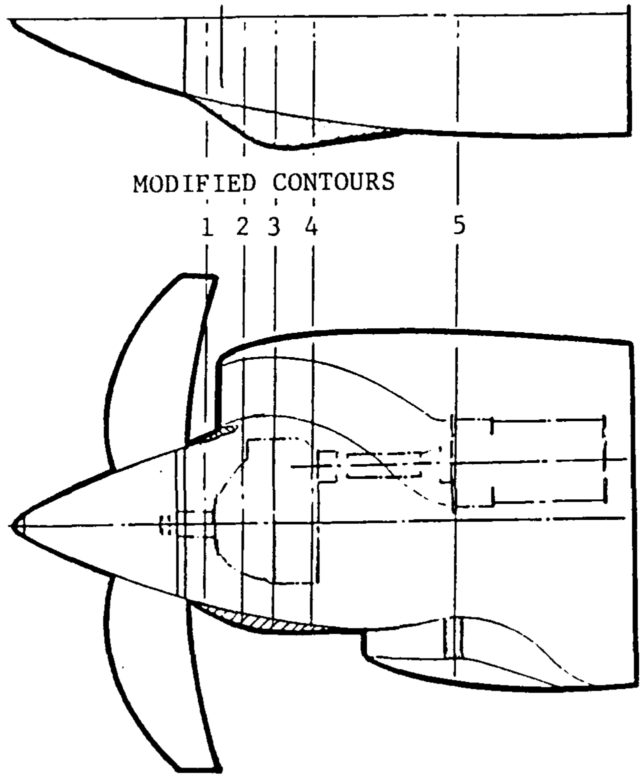
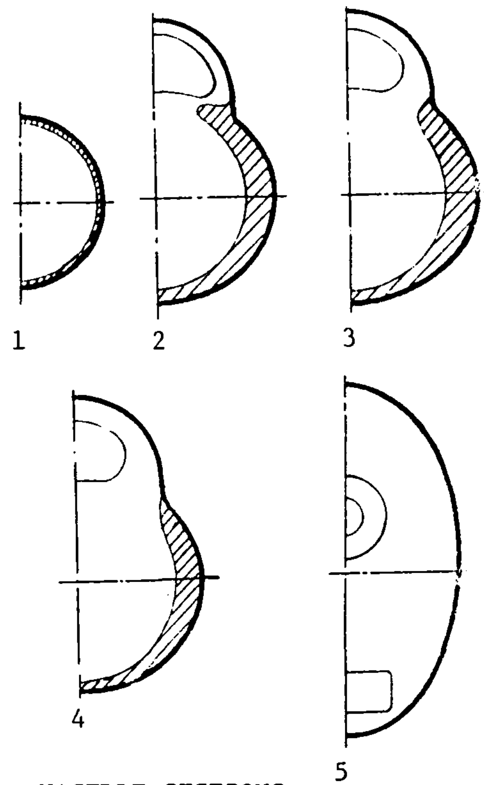


Figure 6. Lockheed C-130 Modified Nacelle



P-3C NACELLE MODIFIED FOR PROP-FAN



NACELLE SECTIONS

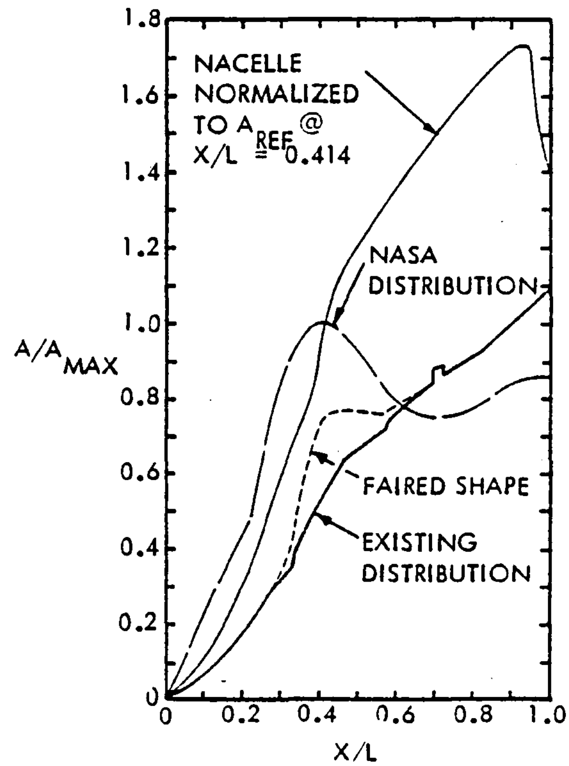


Figure 7. Lockheed P-3C Modified Nacelle Pinion-High

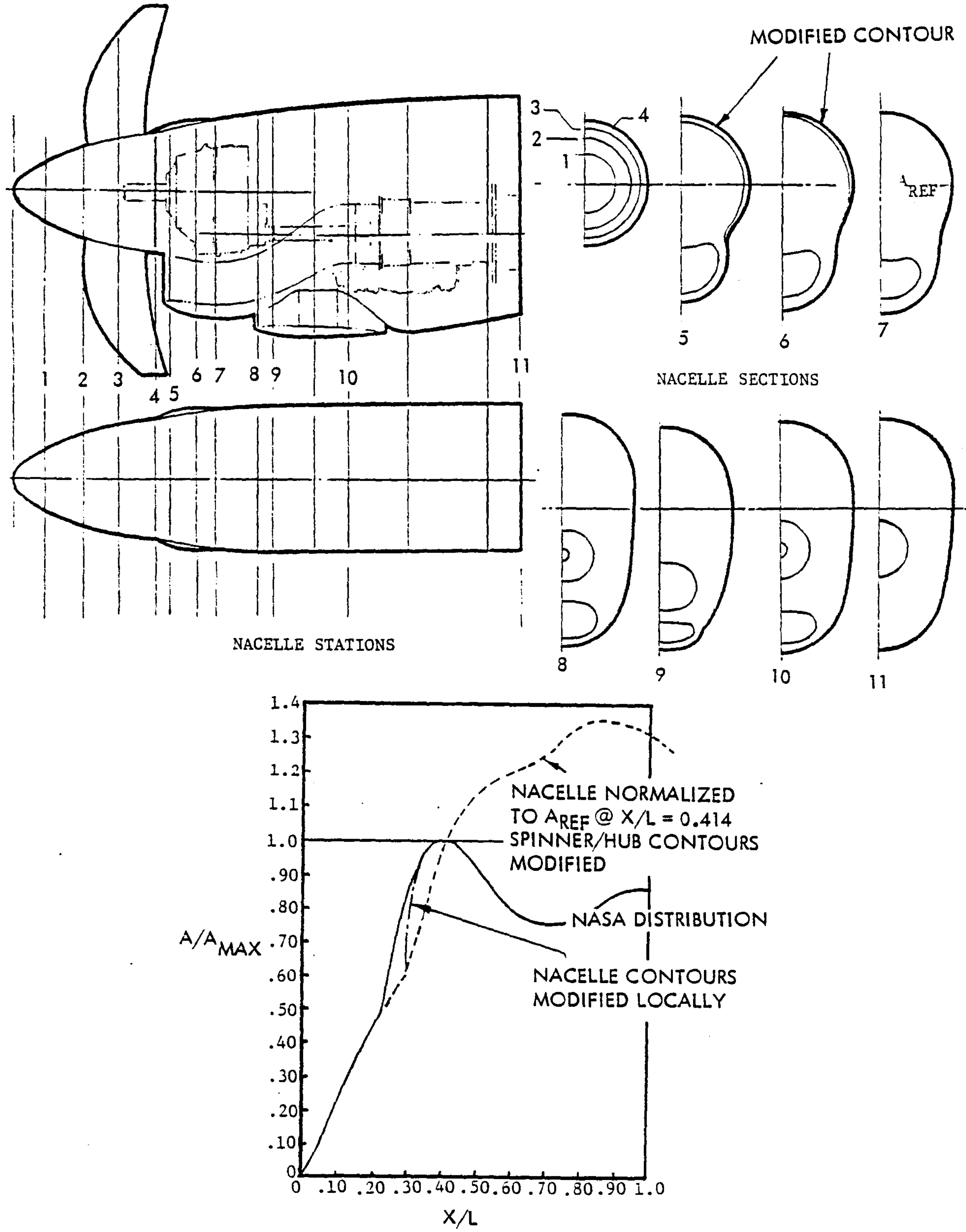


Figure 8. Lockheed C-130 Modified Nacelle Revised Reference Area

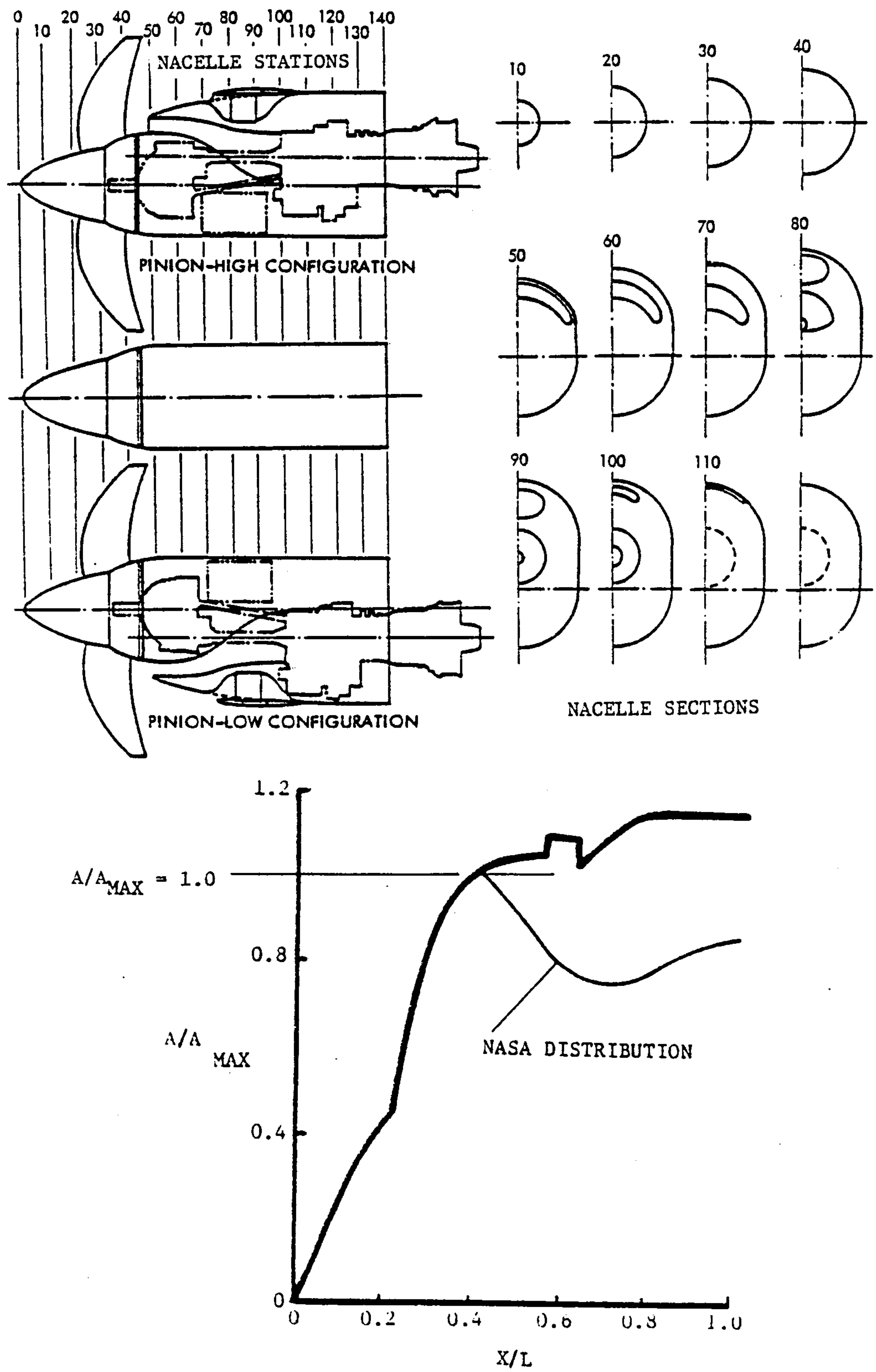
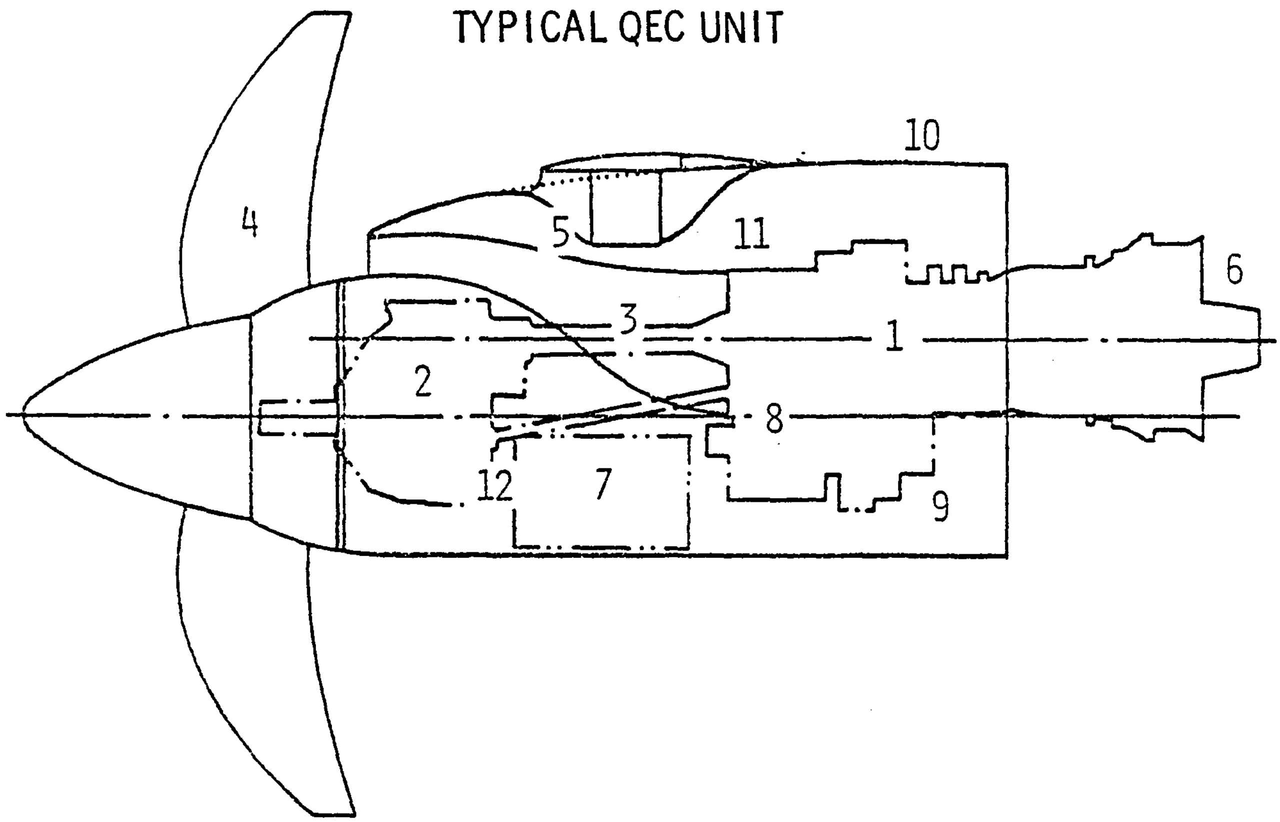


Figure 9. XT701 Nacelle Final Contours



1 POWER SECTION
2 GEAR BOX
3 TORQUE METER
4 PROPFAN
5 AIR INDUCTION SYSTEMS
6 EXHAUST SYSTEM
7 LUBRICATION SYSTEM
8 CONTROLS
9 STARTING SYSTEM
10 NACELLE STRUCTURE
11 DOORS AND PANELS
12 RESIDUAL OIL AND GREASE

Figure 10. Typical QEC

the parting plane bulkhead. Weight data for the QEC units are shown on Table IV.

Drive System Controls

A feasibility study was conducted by Hamilton Standard to determine the suitability of the 54H60 control used for the propellers of the Lockheed C-130 "Hercules" and P-3C "Orion". Compatibility of the control with the DDA XT701 has been established but some modification is required to achieve the variable-speed capability. Control functions provided include negative torque sensing (NTS), over-speed prevention, normal governing, feathering and reversing. In the case of the XT701 application NTS would not be required.

A hydro-mechanical engine control system having an electronic supervisory system from the DDA XT701 is to be used in conjunction with the 54H60 prop-fan control.

The complete description of the Task II-Candidate Propeller Drive Systems investigation is to be found in Appendix B of this report.

TABLE IV. QEC UNIT WEIGHTS

Drive System		Configuration	
		Underwing	Overwing
GE T64	kg (LB)	——	1669 (3680)
T56	kg (LB)	1827 (4030)	1980 (4366)
XT701	kg (LB)	1800 (3971)	1953 (4307)

CANDIDATE TESTBED AIRCRAFT

FLIGHT RESEARCH VEHICLE DESIGN REQUIREMENTS

The design requirements for a testbed vehicle for flight research of a prop-fan using the DDA XT701/T56-A-14(mod) drive system are as follows:

- o Speed/altitude - Mach 0.8 @ 9144m (30,000 ft)
- o Testbed aircraft to be capable of operating safely at normal flight conditions with the prop-fan powered or unpowered.
- o Take-off and landing restrictions for the prop-fan are acceptable.
- o Vehicle is to be configured initially with one prop-fan drive system.
- o Sufficient primary propulsion to be retained to permit safe operation of the vehicle.
- o Non-optimum drive system installation acceptable.

The testbed vehicle must also provide a stable platform for accurate measurement of flight test data and be able to simulate an environment in which the prop-fan can be tested to satisfy the program objectives and be large enough for the aircraft configuration geometric ratios to be representative of large-scale prop-fan propulsion. In addition the selected testbed should be capable of conversion to either a single prop-fan or a multi-prop-fan testbed.

TESTBED AIRCRAFT CONFIGURATION DEVELOPMENT

The installation of the prop-fan propulsion systems on a Testbed Aircraft falls into two categories:

a) Prop-fan Propulsion System Substitution - This type of propulsion system configuration is characterized by the removal of an existing primary propulsive unit and the substitution of a prop-fan propulsion system.

b) Prop-fan Propulsion System Addition - The existing propulsion system is retained for this propulsion system configuration and the prop-fan system added to the aircraft configuration.

The prop-fan propulsion system installation can be further identified by location on the aircraft wing, i.e., for a pinion-high drive system configuration the installation would generally be overwing whereas the pinion-low arrangement would be consistent with an underwing location.

From the structural standpoint the prop-fan substitution installation would provide the easiest modification to a testbed vehicle since the wing structures would already be designed for the attachment of a propulsion system without the need for extensive rework to accommodate the prop-fan unit. In those cases where the prop-fan unit is an addition, the wing structural changes would be much more extensive.

The location and installation of the prop-fan drive system must be such that an environment is created that will permit test of the drive system over a range of conditions from the most favorable to the most adverse and the configuration design conducted so that the testbed aircraft can achieve the program objectives of Table I.

The primary concern of the objectives is the verification of structural integrity, first of the prop-fan and secondly of the nacelle/airframe structure. Provision of this capability requires the means to change propeller excitation factor and several methods have been considered which include variable toe-in and droop angle for the nacelle and leading edge glove devices to increase leading edge and blade proximity.

The power plant nacelle non-symmetry is of particular concern because of the unsymmetric air induction systems which may affect the area distribution of the spinner/nacelle. Because the installation is to be performed on an existing aircraft the degree of nacelle/wing integration optimization is limited. However, it is expected that some account of the nacelle/wing interface can be included in the configuration design.

The near-field noise investigations can be conducted in an environment that closely simulates that of large scale prop-fan propulsion systems. With proper suppression of drive system noise, the prop-fan fundamental signal can be isolated, and the higher frequency levels made to dominate the noise spectrum so that clear signals can be obtained over the entire spectral range of frequency. Changes to the fuselage structure can be performed to determine the attenuative properties of various noise reduction concepts.

Testbed Aircraft Configurations

A technical survey of government owned aircraft resulted in seven aircraft possibilities for Testbed Aircraft suitability. The survey emphasized commercial aircraft similarity although purely military aircraft were not excluded from consideration. The initial list of suitable Testbed Aircraft consisted of:

- Lockheed JetStar -6
- Lockheed C-141A
- Boeing KC-135
- Boeing B52B
- Boeing 737-100
- Convair 990
- Gulfstream American Corporation "Gulfstream II"

In addition the following aircraft were also considered:

- McDonnell-Douglas DC9-10
- Boeing 727
- BAC 1-11

These aircraft were not pursued as Testbed Aircraft candidates because:

- DC9-10 - McDonnell-Douglas were under contract to the NASA-Lewis RC to examine this aircraft as a Testbed Aircraft.
- Boeing 727 - Omitted as a candidate since the aircraft did not appear in the NASA inventory.
- BAC 1-11 - Unable to meet speed/altitude requirements and is also a foreign aircraft.

Each of the seven aircraft in the initial list was configured as a prop-fan testbed by locating the prop-fan propulsion system on the wings either in place of or in addition to existing primary propulsion in both over and underwing configurations. A screening of the initial list was conducted to eliminate those aircraft that appeared unsatisfactory or marginal using criteria such as lack of compatibility with commercial aircraft configurations, aircraft and prop-fan scaling mismatch, adverse location of the prop-fan, marginal aircraft performance, insufficient ground or component clearances and lack of potential for modification. As a result of this, the JetStar -6 and the Boeing 737-10 were eliminated as candidate Testbed Aircraft.

Of the five remaining aircraft four were considered eligible as candidate Testbed Aircraft. The four aircraft were:

- Lockheed C-141A (L-300)
- Boeing KC-135 (707-100)
- Convair 990
- Gulfstream American Corporation "Gulfstream II"

The first two, although military aircraft, have commercial counterparts since the C-141A was certified as the Lockheed L-300 and the Boeing 707-100 series was derived from the KC-135A. The Convair 990 and the GAC "Gulfstream II" are commercial passenger transport configurations typical of commercial aircraft in their particular classes.

As far as the prop-fan installation is concerned, the overwing arrangement was considered to be more representative of commercial aircraft installations since most commercial passenger aircraft are low wing configurations which would require overwing installation of the prop-fan to provide sufficient ground clearance for the propeller. In the case of the GII which provides a matched airframe/propulsion system combination no choice is open but to install the XT701 drive system in other than the overwing location as prop-fan ground clearance becomes the limiting factor.

The Boeing B52B configuration is considered as an alternative to wind tunnel testing because it appears to have limited application as a "Flying Wind Tunnel."

Lockheed C-141A Testbed Configurations - The Lockheed C-141A, Figure 11, is shown in the testbed configuration for both pinion-high and pinion-low drive systems. In the testbed configuration an inboard primary propulsion unit is removed and the prop-fan unit substituted.

Of the two installations the pinion-low arrangement is preferred because of the reduced length of the exhaust duct nacelle and reduced effect on the wing and trailing edge device aerodynamic performance.

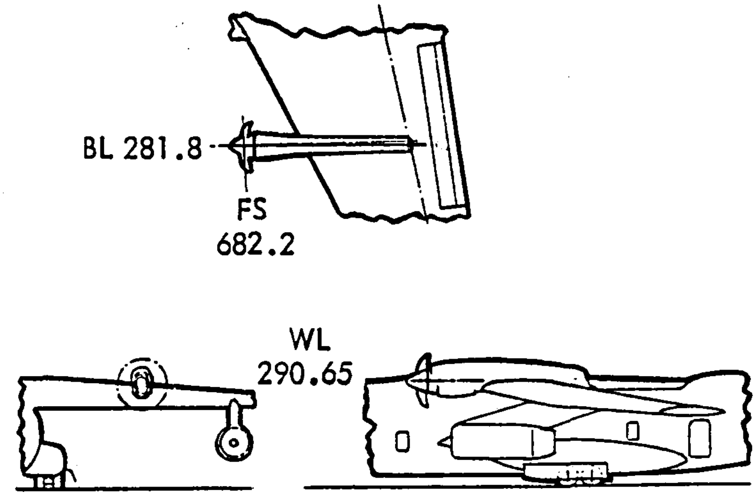
Boeing KC-135A Testbed Configurations - The KC-135A testbed arrangements shown on Figures 12 and 13 also substitute a prop-fan unit for an inboard primary engine. Although the underwing installations with the small diameter prop-fan are preferred, the overwing arrangement is considered to be a better representation of commercial configurations. Because of the length of the exhaust duct some interference with the wing upper surface and trailing devices is encountered.

Convair 990 Testbed Configurations - The Convair 990 prop-fan configurations, Figures 14 and 15, require the removal of the anti-shock bodies to enable the installation of the airframe portion of the nacelle on the wing and to prevent interference with the prop-fan/wing flow field. Some interference with the wing trailing edge device is experienced with the overwing installation.

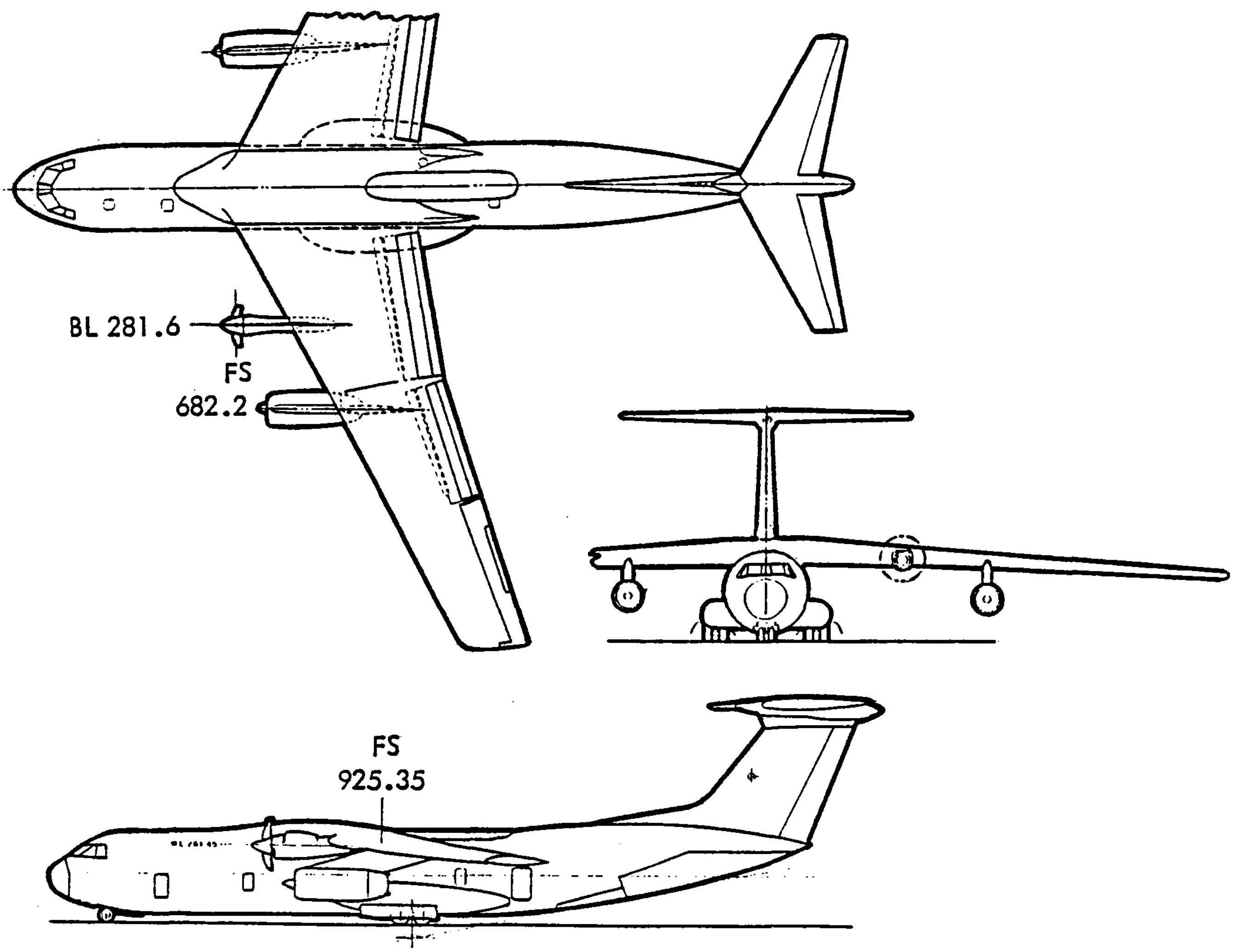
G.A.C. "Gulfstream II" Testbed Configuration - The XT701 GII testbed configuration, Figure 16, has the advantage in that the prop-fan propulsion is an addition to the configuration. Furthermore the wing is free of leading edge devices which simplifies the nacelle/wing integration. Overwing installations only are possible with this aircraft and the prop-fan is located at WS 145.0 to take advantage of the wing structure and increased thickness from this station inboard.

Potential for Modification

The three four-engined aircraft can be made into single prop-fan testbeds using the substitution concept and meet the desired requirements; further modification to twin prop-fan arrangements by substitution would result in air-



T56 OVERWING INSTALLATION



T56 UNDERWING INSTALLATION

Figure 11. C-141A Testbed Configuration

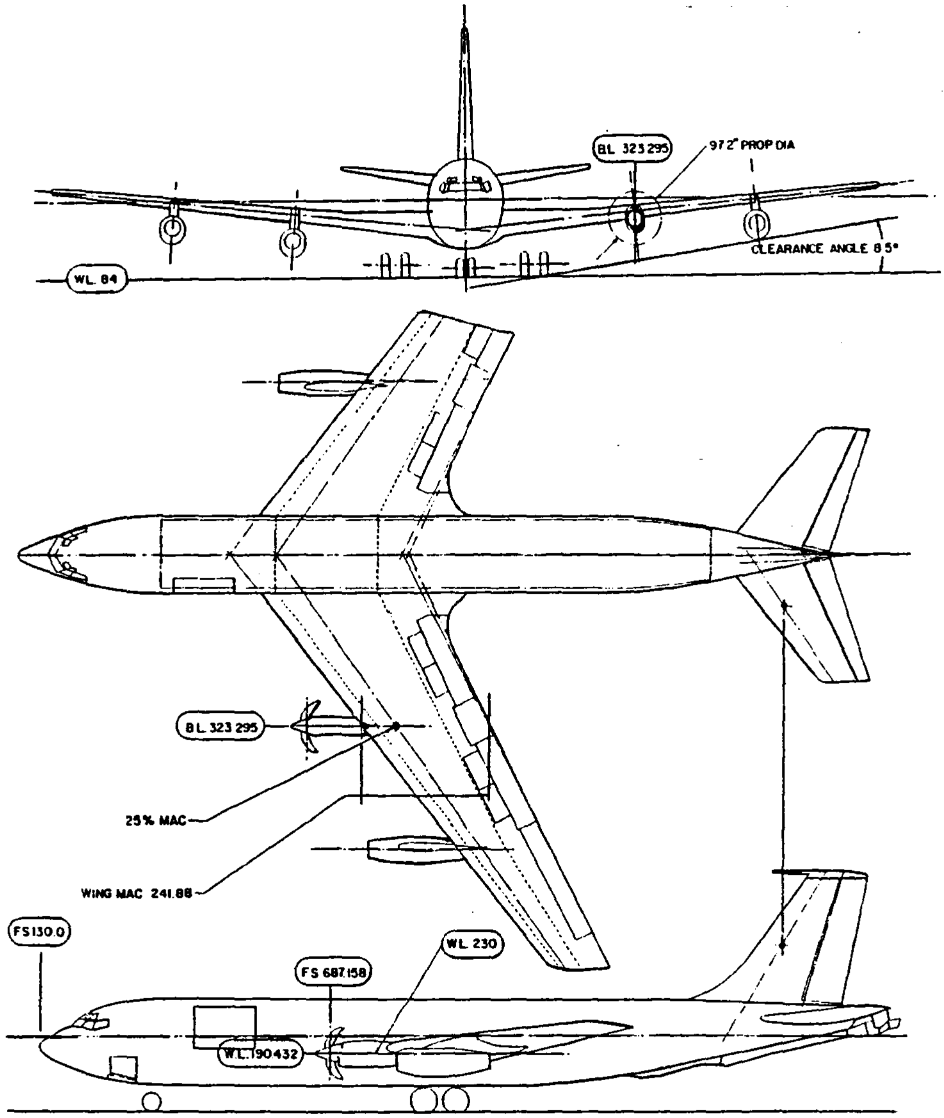


Figure 12. Boeing KC-135A Testbed Configuration XT701 Pinion-Low

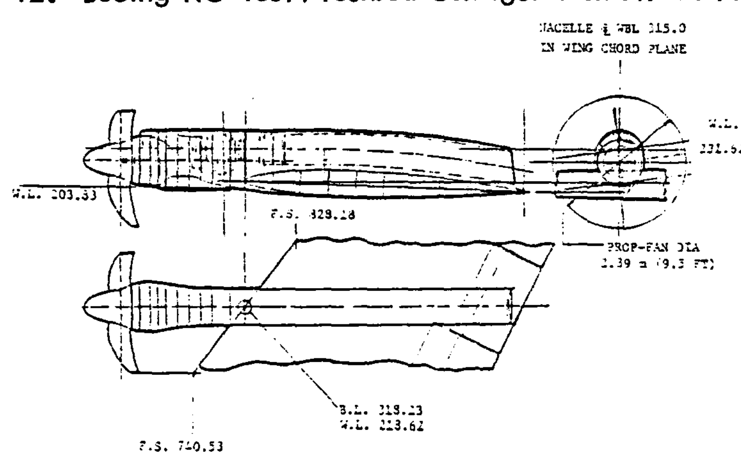


Figure 13. Boeing KC-135A XT701 Pinion-High Installation

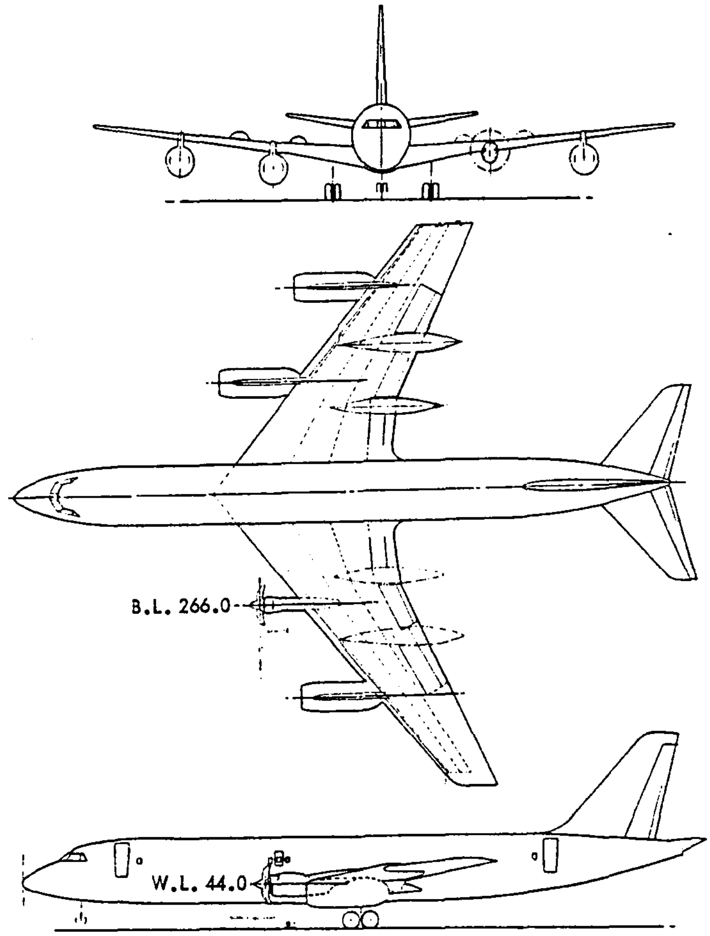


Figure 14. Convair 990 Testbed Underwing Configuration XT701 Pinion-Low

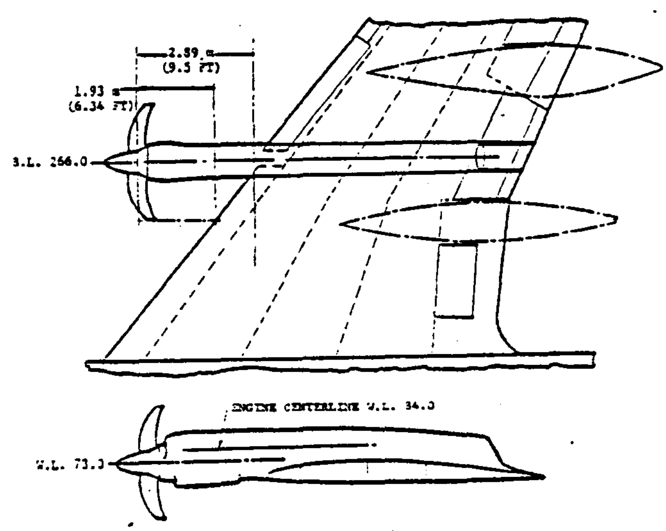


Figure 15. Convair 990 Testbed Overwing Configuration XT701 Pinion-High

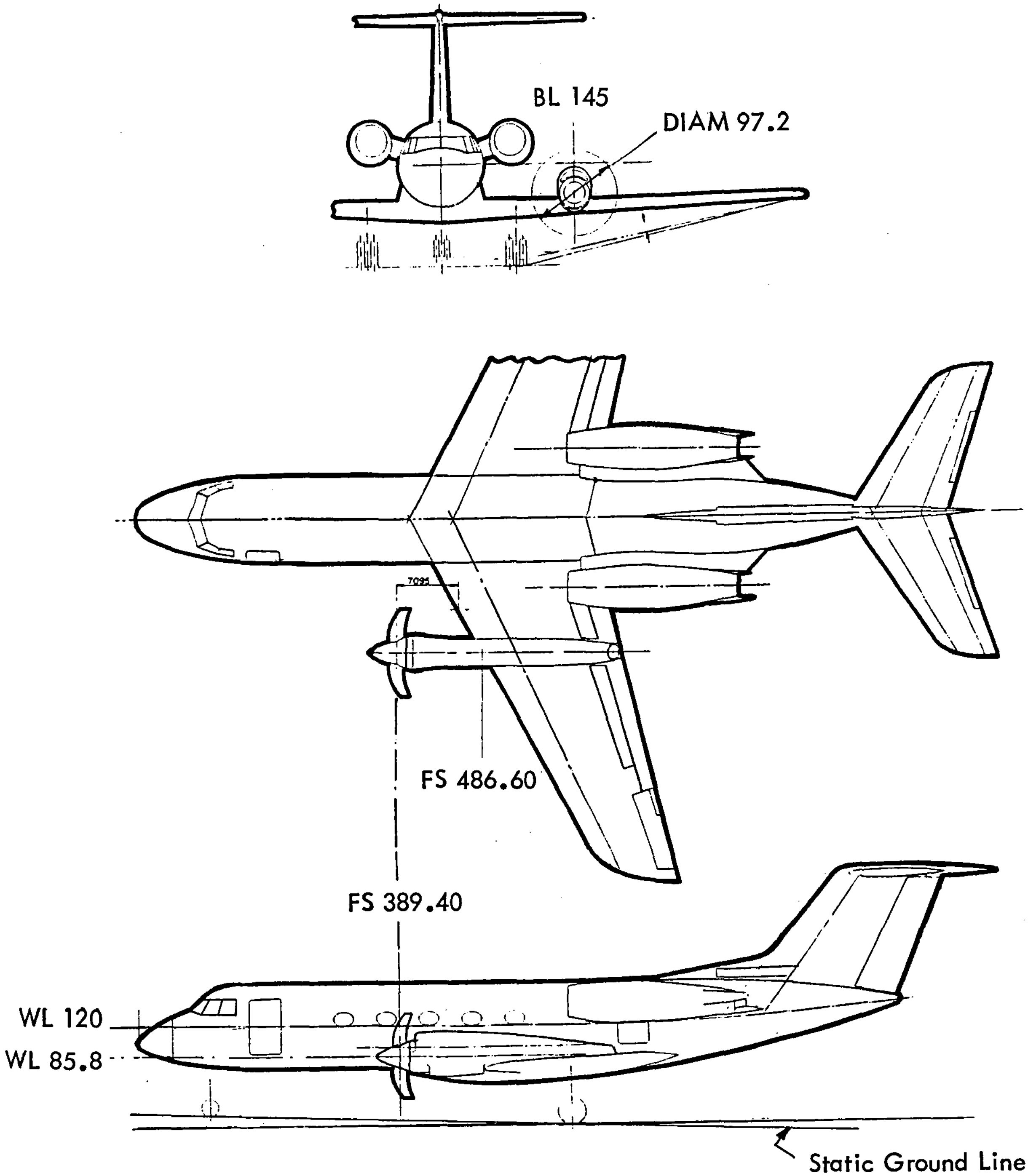


Figure 16. GAC Gulfstream II Testbed Configuration XT701 Pinion High

craft incapable of satisfying the design requirements because of the large reduction in thrust. These configurations can, however, be converted into twin prop-fan arrangements by means of the addition rather than the substitution design philosophy. This would entail placement of the prop-fan units on the wing between the fuselage and inboard primary engines, maintaining the appropriate clearances for acoustic and structural considerations. This concept can, in fact, be used for either single or twin prop-fan arrangements. There are some disadvantages to this arrangement since the prop-fan is moved inboard so that the geometric relationship of the prop-fan and wing become less favorable. Although the overall installation is non-optimum this would not prevent such a testbed aircraft from providing verification data in the principal areas of technological concern.

Analysis of the GII shows that this aircraft could be converted to a multi-prop-fan arrangement with the primary propulsion system retained. The Twin-prop fan configurations for the KC-135A and GII are shown on Figures 17 and 18 respectively.

CANDIDATE AIRCRAFT ANALYSES

Structural Characteristics

Preliminary structural analyses provided weight and balance checks for the four candidate aircraft and a preliminary assessment of the risk of encountering flutter was made. The weight summaries for the candidate aircraft are given on Table V for the XT701/T56-A-14 engine installation. The addition of the prop-fan to the three large aircraft did not affect the airplane balance characteristics. In the case of the GII, however, it was necessary to re-balance the aircraft to keep the center-of-gravity within the established boundaries for the aircraft. These data were used to determine the test mission profile for each of the testbed candidates.

Flutter appraisals for each aircraft were based primarily on the location and extent of the changes in the mass and inertial properties of the wing-engine system although in some cases flutter parametric analysis results were used.

No flutter problems are anticipated with the Lockheed C-141A, Boeing KC-135A and the Convair 990 as the weight removed exceeded the weight added by

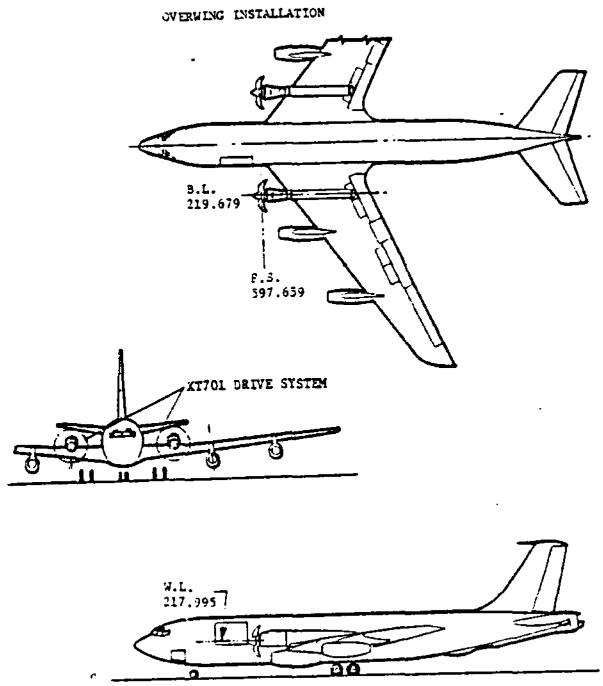


Figure 17. KC-135A Twin Engine Testbed Overwing Configuration

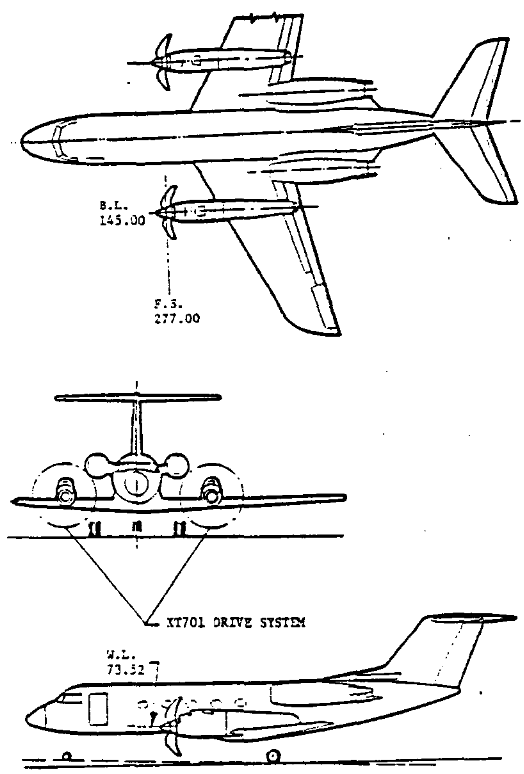


Figure 18. Gulfstream II Twin Engine Testbed Overwing Configuration

TABLE V. TESTBED AIRCRAFT WEIGHT SUMMARY

		T64 OVER WING	T56 OVER WING	T56 UNDER WING	XT701 OVER WING	XT701 UNDER WING
C-141A	ZERO FUEL WT	*		60,677 (133,770)		60,650 (133,711)
	FUEL	*		68,048 (150,020)		68,048 (150,020)
	GROSS WT	*		128,725 (283,790)		128,698 (283,731)
BOEING KC-135	ZERO FUEL WT			44,543 (98,200)		44,516 (98,141)
	FUEL			51,202 (112,880)		51,516 (112,880)
	GROSS WT			95,744 (211,080)		95,718 (211,021)
CONVAIR 990	ZERO FUEL WT			56,019 (123,500)		55,992 (123,441)
	FUEL			47,301 (104,280)		47,301 (104,280)
	GROSS WT			103,319 (227,780)		103,293 (227,721)
G II	ZERO FUEL WT		17,763 (39,160)		17,726 (39,079)	
	FUEL		10,491 (23,128)		10,491 (23,128)	
	GROSS WT		27,346 (60,288)		27,309 (60,207)	
JETSTAR	ZERO FUEL WT	11,535 (25,430)	11,902 (26,240)			
	FUEL	5,942 (13,100)	5,942 (13,100)			
	GROSS WT	17,477 (38,530)	17,844 (39,340)			
BOEING 737	ZERO FUEL WT		30,346 (66,901)	30,193 (66,565)	30,319 (66,842)	30,167 (66,506)
	FUEL		8,661 (19,095)	8,661 (19,095)	8,661 (19,095)	8,661 (19,095)
	GROSS WT		39,007 (85,997)	38,854 (85,660)	38,980 (85,937)	38,828 (85,601)

*UPPER ENTRY IS IN kg, (LOWER ENTRY IS IN LB) the substitution of a prop-fan installation. In the case of the GII where a prop-fan unit, weighing approximately twice as much as the wing semi-span, is an addition to the wing, flutter characteristics could alter drastically. The risk of encountering flutter problems with this configuration was considered to be somewhat greater than the three large candidate aircraft.

Aircraft Stability

Estimates of the stability characteristics of the candidate testbed aircraft showed that no significant changes in stability would occur with the installation of the prop-fan propulsion. The changes in the stability derivatives C_{n_β} and C_{m_α} caused by the prop-fan normal force coefficient, C_{y_β}, only were examined. The effects of the normal force are shown on Figures 19, 20, 21, and 22 for the C-141A, KC-135A, Convair 990 and the GII, respectively. These data show that the prop-fan installation causes the following:

- The change in stability derivatives decreases as Mach number increases.
- The effect of the prop-fan on the stability of the larger airplanes is small.
- The greatest change in stability derivatives occurs with the GII prop-fan installation.

Testbed Configuration Suitability for Acoustic Test

The most important consideration in the selection of a testbed aircraft subordinate only to the Integrity of the Structure is the requirement that each should possess the capability to perform as a testbed for prop-fan acoustics experimentation.

Noise level, both near-and far-field, is important from the point of view of the traveling public and to communities exposed to aircraft operations in and out of airports.

To accomplish the required acoustic experimentation a testbed vehicle should provide certain physical characteristics to enable experimentation to be performed that will lead to the development of attenuation systems and

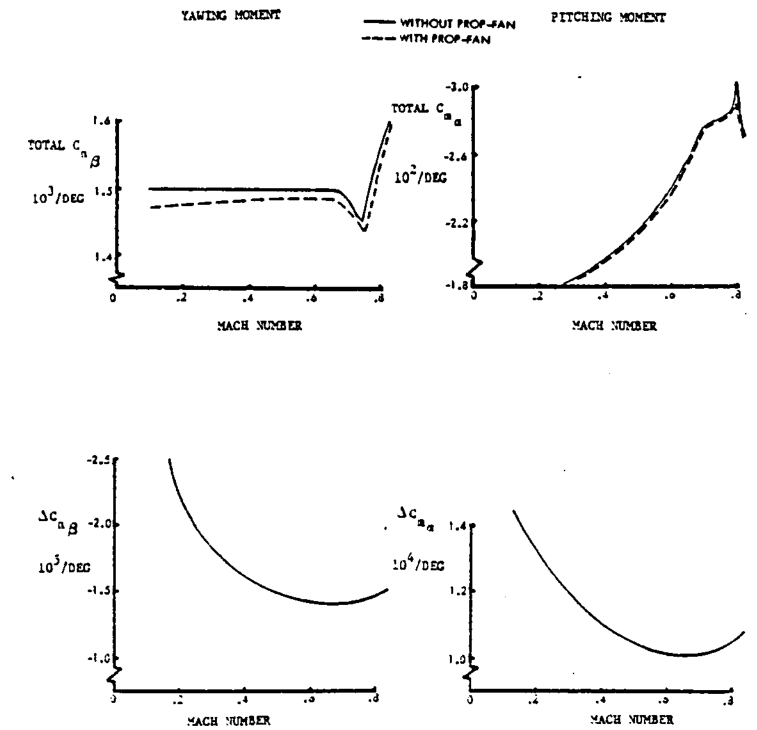


Figure 19. C-141A Prop-Fan Effect on Pitch and Yaw

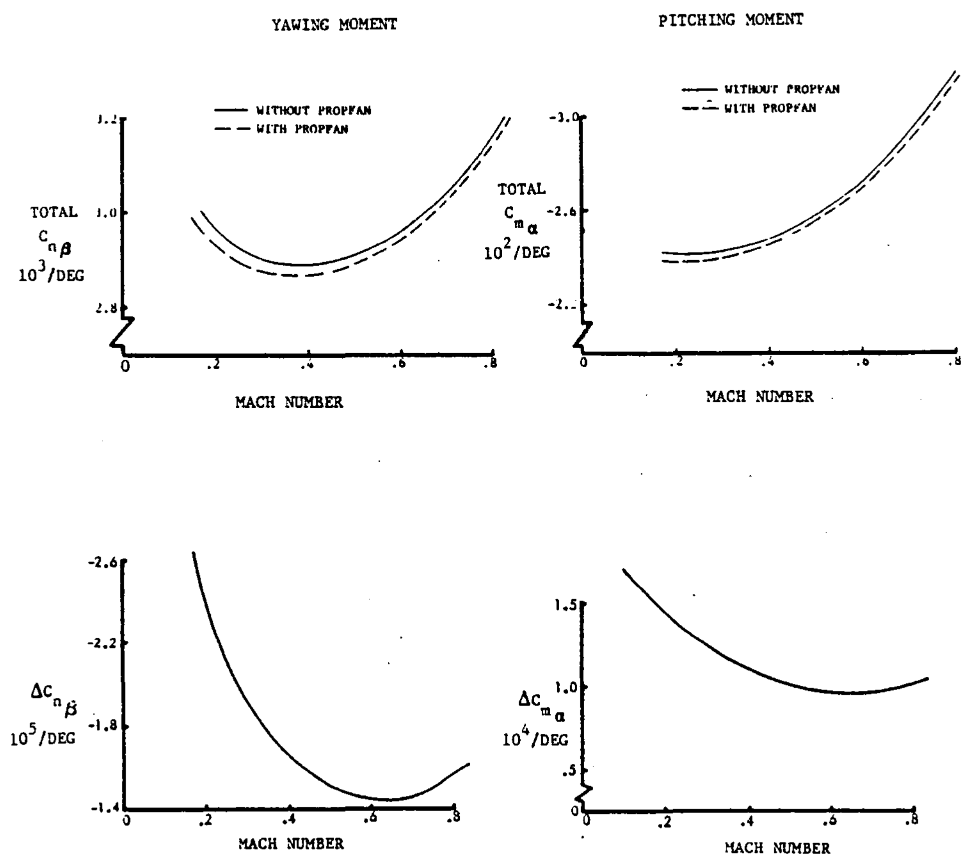


Figure 20. KC-135A Prop-Fan Effect on Pitch and Yaw

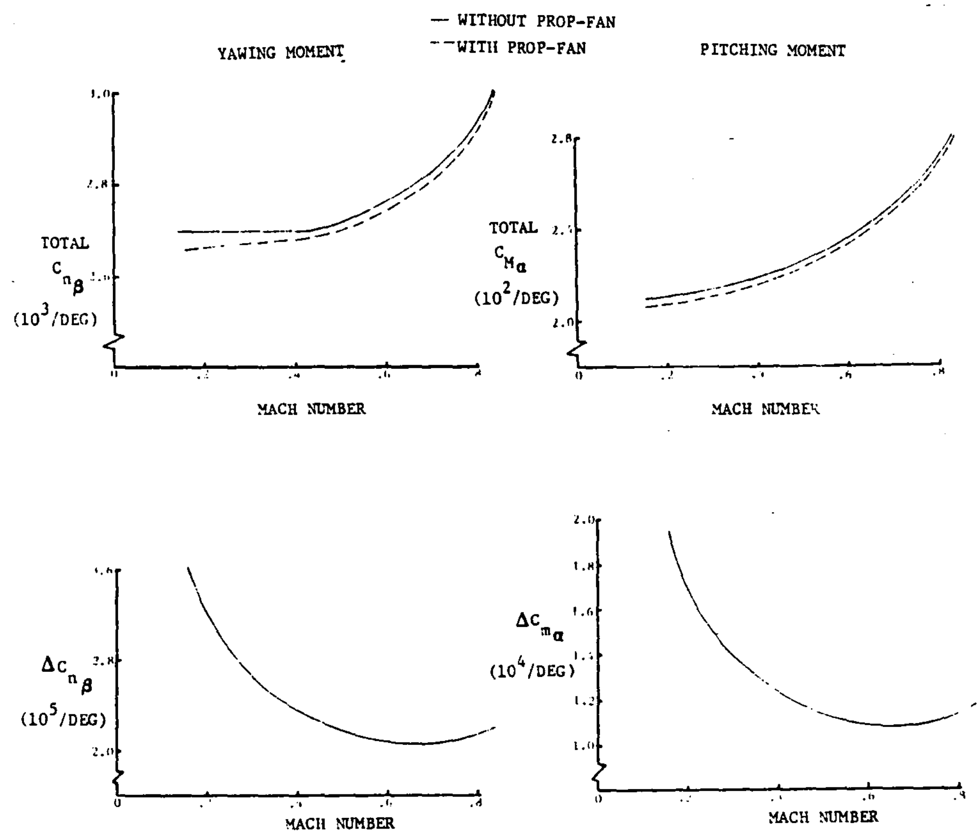


Figure 21. Convair 990 Prop-Fan Effect on Pitch and Yaw

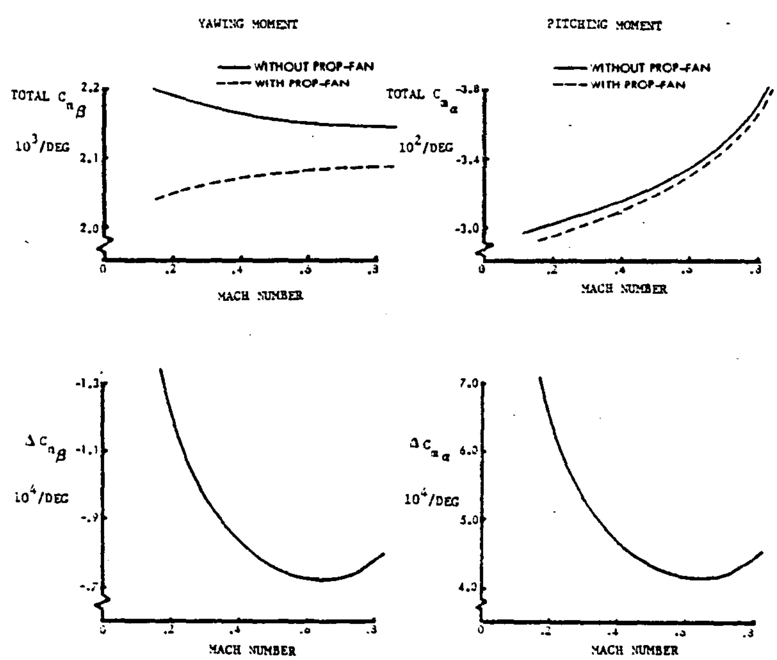


Figure 22. Gulfstream II Prop-Fan Effect on Pitch and Yaw

techniques for cabin noise reduction and provide clear prop-fan noise signals to permit the gathering of noise data from far-field noise experimentation.

Near-Field Noise - Provision of an adequate representation of a commercial passenger aircraft configuration and environment requires that, for acoustic experimentation, a number of characteristics common to the fuselage are desirable. Among these are:

- Fuselage volume should be large
- Fuselage should be pressurized
- Fuselage structural configuration should be a typical design
- Fuselage structure should be capable of modification to incorporate various noise suppressive concepts
- Fuselage should have sufficient space to house acoustic test equipment.

In addition to these characteristics the testbed candidate aircraft were examined to determine the degree to which the various physical relationships such as the prop-fan-to-fuselage and prop-fan-to-primary engine proximities, prop-fan slipstream and flap extension interaction and the effect of wing and power plants and other components acting as barriers to the prop-fan airborne noise path to the fuselage, would effect the capability of each candidate aircraft to function as an acoustic testbed configuration.

The criteria for clearances for locating the prop-fans on the aircraft are 0.8 D_p between the prop-fan tip and fuselage wall and 0.2 D_p (where D_p is the prop-fan diameter) between the prop-fan tip and adjacent components.

In general all of the configurations considered for prop-fan testbed application satisfied the near-field acoustic requirements relative to the common characteristics for the fuselage, but to a lesser degree suffer from excessive or lower than desirable clearances and from noise path obstruction when configured as single prop-fan testbeds. This situation is, improved in the case of the twin prop-fan testbed configurations, particularly in the case of the KC-135A where the clearances meet the requirements exactly.

Far-Field Acoustics - Investigations of far-field acoustic characteristics were conducted for the candidate, testbed aircraft over the one-third-octave-band level considering the noise sources in addition to the prop-fan to be the prop-fan drive system, and testbed primary propulsion and the testbed airframe noise. These sources generate background noise which, dependent upon level, will tend to mask the prop-fan noise signals. The investigations were conducted for a flyover altitude or 308m (1000 ft), at a speed of 72 m/s (140 KTAS) at ISA + 10^{o} and 70 percent relative humidity conditions. The noise spectra predicted by these analyses are for peak flyover noise with prop-fan drive system noise suppression and with the noise floor generated by the primary engines at idle power. The aircraft component noise levels are shown on Figures 23, 24, 25, and 26 for the Lockheed C-141A, Boeing KC-135A, Convair 990 and the GAC GII. This analysis shows the GII to be the best candidate testbed aircraft for far-field noise experimentation as the prop-fan peak signal dominates the spectrum in the 150 to 250 Hz frequency range. This investigation was conducted for a single prop-fan installation only. When a twin prop-fan arrangement is considered the power level of the primary engines is reduced causing a reduction in the level of the background noise. Since the background noise level is reduced and the prop-fan noise now radiates from two prop-fans, the two prop-fan arrangement will provide a much clearer prop-fan noise signal than that of the single prop-fan.

The complete details of this investigation, Task III - Candidate Testbed Aircraft, are to be found in Appendix "C" of this report.

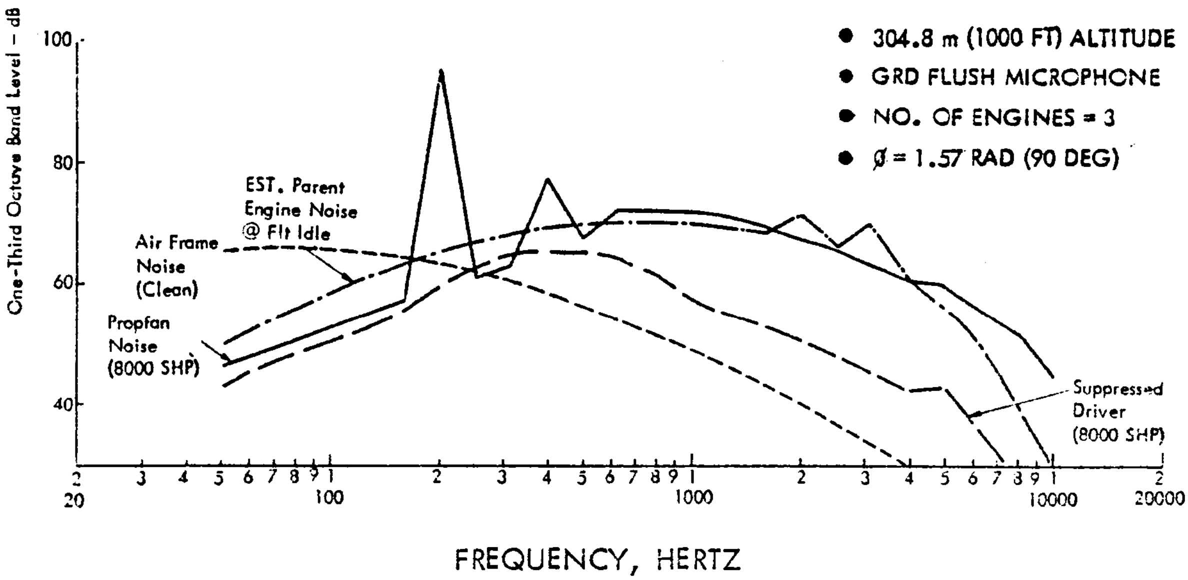


Figure 23. C-141A Component Noise Levels

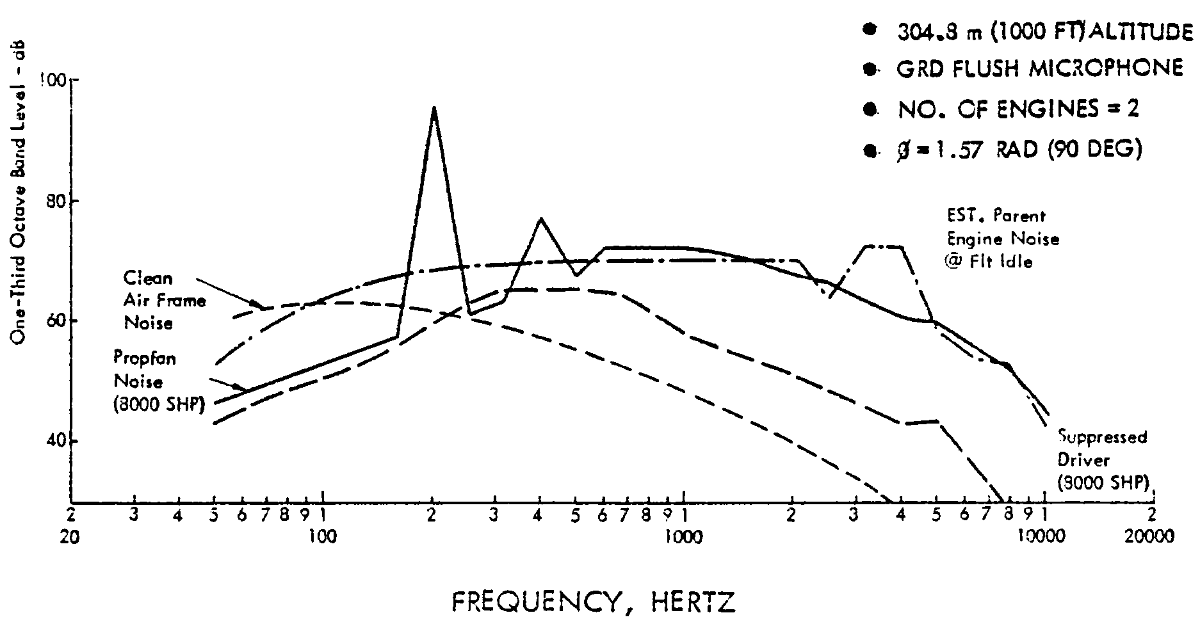


Figure 24. KC-135A Component Noise Levels

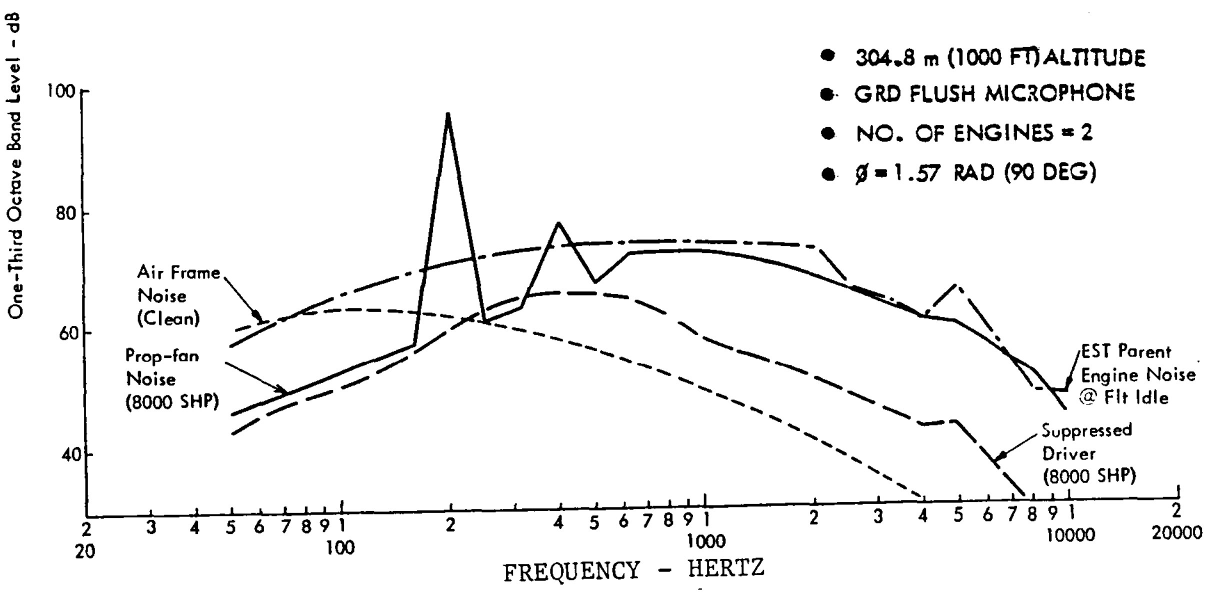


Figure 25. Convair 990 Component Noise Levels

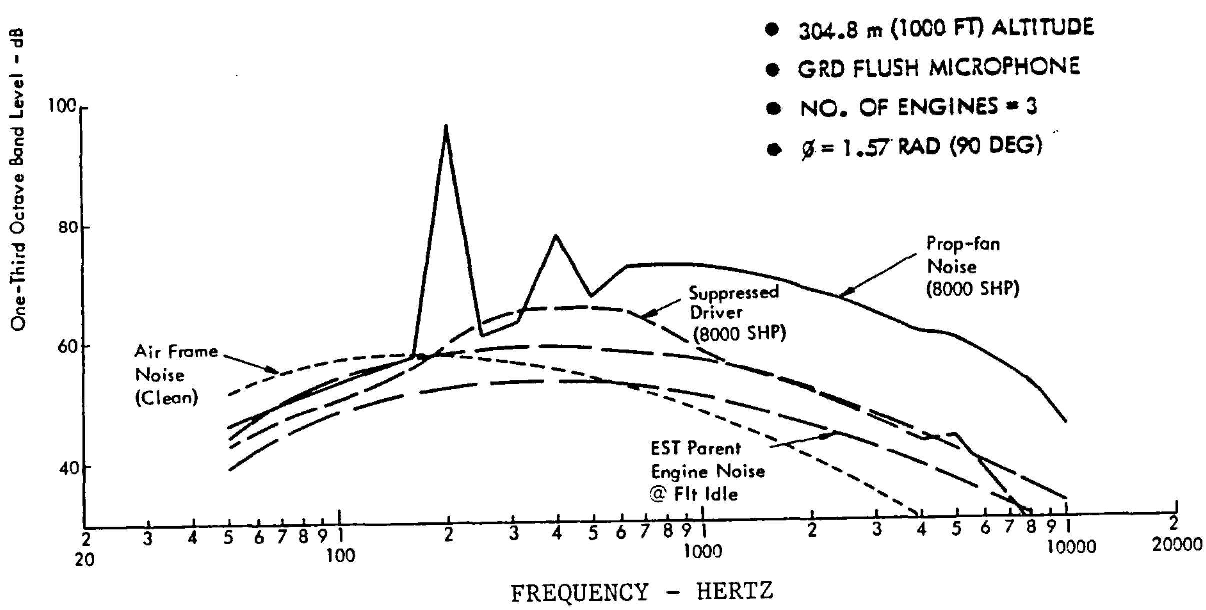


Figure 26. GII Component Noise Levels

EVALUATION AND SELECTION OF TESTBED AIRCRAFT

The Evaluation and Selection process applied to the Candidate Testbed aircraft consisted of two parts - one which addressed the evaluation and selection of the drive system and the other which considered the complete testbed aircraft. This approach was possible since the drive system studies were performed independently of the aircraft studies so that determination of the drive system for testbed aircraft application could be first accomplished. This approach simplified the second part of the process, the "Testbed Aircraft Evaluation and Selection" which was performed with a defined drive system.

Execution of the evaluation and selection process required the development of two sets of evaluation criteria - one for the drive system and a set for the testbed aircraft evaluation. These criteria, described in the following text were derived from considerations of the critical and important issues and aspects of the testbed aircraft operation such as flight safety, design and operating requirements and from the testbed program objectives requirements.

DRIVE SYSTEM EVALUATION AND SELECTION

The evaluation and selection of the drive system was performed separately based on Task II results. Initially five power sections were considered which were subsequently reduced to the three power section/gearbox combinations following:

Power Section	Gearbox
DDA T56	T56-A-14
DDA XT701	T56-A-14
GE T64-415	IHI T64-2 SDG

The drive system evaluation criteria applied to the three drive systems consisted of:

- o Drive System Operational characteristics
- o Prop-fan Size
- o Drive system modification

- Engine and gearbox availability
- Prop-fan control system requirements
- Nacelle structures
- Engine control

These items are listed on Table VI, the Drive System Evaluation Chart. Hamilton Standard indicate that for accurate demonstration of dynamic behavior and fabrication feasibility, the prop-fan diameter should not be less than 2.44 m (8 ft). In the case of the GE T64-415 drive system the prop-fan diameter at 2.16 m (7.1 ft) is less than the desired minimum and is therefore eliminated as a candidate drive system. The drive system choice was therefore narrowed to the DDA XT701 and the DDA T56.

Comparing the two drive systems the XT701 is seen to provide the largest diameter prop-fan, 2.89 m (9.5 ft) with a possibility of increasing to 3.05 m (10 ft) should higher power levels on the XT701 be demonstrated. The XT701 has the advantage over the T56 in that it provides the flexibility to change tip-speed since the power section is a free turbine. This in turn reduces the amount of gearbox modification required to a single set of gears only. No problems exist with the T56 availability, however, the XT701 is limited to five units. The industrial version of the XT701, the Model 570 is available and could be converted to a flyable unit if necessary. The drive system selection was therefore a choice between the XT701 and the T56 and is summarized on Table VII. Of the ten items listed on Table VII, the XT701 has the advantage over the T56 in five prime areas, is of equal standing in two, and is not quite as good as the T56 in three. The DDA XT701/T56-A-14 combination is therefore the drive system selected for testbed aircraft application because it:

- Provides the largest diameter prop-fan within the constraints of available power level
- Has flexibility to continuously vary prop-fan speed for test purposes
- Reduces number of gearboxes to support testbed program
- Eliminates risk present with gearbox dismantling
- Requires less control functions than T56

TABLE VI. DRIVE SYSTEM EVALUATION

		GE T64	DDA T56	DDA XT701
	GEARBOX TYPE	T64-2 SDG MODIFIED	MODIFIED T56-A-14	MODIFIED T56-A-14
OPERATIONAL CHARACTERISTICS	KW (SHP) S.L.S.	3266 (4380)	3423 (4591)	6018 (8071)
	KW (SHP) M=0.8 10.7K(35K) ALT.	1350 (1810)	1819 (2440)	2520 (3380)
	FIXED SPEED OR FREE TURBINE	FREE TURBINE	FIXED SPEED	FREE TURBINE
	TIP SPEED CONTINUOUSLY VARIABLE	YES	NO	YES
SIZING	DISK LOADING 301 KW/M² (37.5 SHP/FT²) DIA M(FT)	2.13 (6.97)	2.47 (8.1)	2.89 (9.5)
	SIZE FOR STRUCTURAL VALIDATION	UNSATISFACTORY	MARGINAL	SATISFACTORY
DRIVE SYSTEM MODS	GEARBOX	SINGLE GEAR SET	THREE GEAR SETS	SINGLE GEAR SET
	TORQUEMETER	EXISTING	EXISTING	NEW
	INTAKE CASE INTERCON. STRUTS	NOT REQUIRED	NOT REQUIRED	REQUIRED
	NORMALIZED COSTS	1.0 (2 GBOXES)	1.0 (3 GBOXES)	<1.0 (2 GBOXES)
	RISK	1.0	1.0	>1.0
ENGINE & GEARBOX AVAIL.	POWER SECTION AVAILABILITY	IN PRODUCTION	IN PRODUCTION	5 XT701 5 DEVELOPMENT UNITS
	GEARBOX AVAILABILITY	IN PRODUCTION	IN PRODUCTION	IN PRODUCTION
	SPARES AVAILABILITY	IN PRODUCTION	IN PRODUCTION	LIMITED COMMERCIAL SET AVAILABLE
PROP-FAN CONTROL SYSTEM	MODIFIED 54H60 CONTROL	NOT COMPATIBLE	COMPATIBLE	COMPATIBLE
	OVERSPEED PROTECTION	REQUIRED	REQUIRED	REQUIRED
	NTS	NOT REQUIRED	REQUIRED	NOT REQUIRED
	GOVERNING	REQUIRED	REQUIRED	REQUIRED
	FEATHERING	REQUIRED	REQUIRED (SLOW)	REQUIRED (SLOW)
	REVERSING	FIXED BLADE	FIXED BLADE	FIXED BLADE
NACELLE	STRUCTURE OVERDESIGNED	REQUIRED	REQUIRED	REQUIRED
	CONTOURS	NEW CONTOURS	NEW CONTOURS	NEW CONTOURS
ENGINE CONTROL	FUEL	REQUIRED	REQUIRED	REQUIRED

TABLE VII. DRIVE SYSTEM SELECTION

ITEM	T56	XT701
HIGHEST POWER LEVEL		●
LARGEST DIAMETER PROP-FAN		●
BEST OFF-DESIGN FLEXIBILITY		●
LOWEST MODIFIED GEAR BOXES		●
GEARBOX MOD MINIMUM	●	
POWER SECTION MOD MINIMUM	●	
DRIVE SYSTEM RELIABILITY - RISK	●	
AVAILABILITY TO SUPPORT PROGRAM	●	●
NEW NACELLE DESIGN - UNIVERSAL QEC	●	●
CONTROL SYSTEM LOWEST NO. OF FUNCTIONS		●

● = INDICATES PREFERRED DRIVE SYSTEM

- o Nacelle installation uses existing structure from the Lockheed P-3C
- o Nacelle overdesign provides independence from receiving airframe.

CANDIDATE TESTBED AIRCRAFT EVALUATION AND SELECTION

Since it appeared unlikely that any one of the candidate testbed aircraft would satisfy all of the requirements for testbed application, it was necessary to identify a number of evaluation criteria by which an assessment of the suitability of each, as an Advanced Turboprop Testbed System, could be made so that, by comparison of the testbed aircraft developed, the two aircraft arrangements most suitable for the testbed application could be selected.

The evaluation criteria were addressed to five areas of testbed characteristics as follows:

- o Aircraft safety
- o Operational characteristics
- o Testbed program objectives
- o Aircraft modification potential and data availability
- o Testbed systems relative costs

Each evaluation criterion was assigned a judgemental rating scale of 0 to 3 for acceptability but because of the diverse degree of criterion importance each of these ratings were "weighted" on a scale of 1 to 4 according to the level of priority or importance of the criterion under evaluation.

The procedure adopted for the evaluation consisted of the following:

- o A statement of conditions, concerns or requirements to be addressed was first formulated
- o Specific criteria and items for evaluation were identified and described
- o The evaluation rating on a scale of 0 to 3 was assessed and a "weighting" factor assigned
- o The "weighted" evaluation rating was then determined

The Aircraft Evaluation Chart developed using this procedure is given in Table VIII. Comparing the evaluation scores of Table VIII, the Lockheed C-141A as a single prop-fan testbed is eliminated as a candidate testbed aircraft. The

TABLE VIII. CANDIDATE TESTBED AIRCRAFT ANALYSES

AIRCRAFT EVALUATION

		EVALUATION CRITERIA CATEGORY	A AIRCRAFT SAFETY			B OPERATIONAL CHARACTERISTICS				C TESTBED PROGRAM OBJECTIVES						D DATA AVAILABILITY	E MODIFICATION POTENTIAL	F TESTBED SYSTEMS RELATIVE COST	
		EVALUATION CRITERIA (EC)	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	C4	C5	C6	D1	E1	F1	
		WEIGHTING FACTOR	2	4	4	4	3	4	4	4	4	2	4	2	2	2	3	3	
AIRCRAFT TYPE	SELECTED DRIVE SYSTEM	PROPFAN NACELLE INSTALLATION	PROP-FAN LOCATION	ENGINE-OUT SAFETY	STRUCTURAL INTEGRITY	DESIGN CRUISE CONDITION COMPLIANCE	TEST MISSION DURATION	STABILITY & CONTROL	INSTALLATION EFFECTS	DYNAMIC LOADS VALIDATION	NEAR-FIELD NOISE DATA	FAR-FIELD NOISE DATA	PROP-FAN SCALE	INSTALLED PROPULSIVE EFFICIENCY VALIDATION	INTERACTION EFFECTS	AIRCRAFT DATA AVAILABILITY	POTENTIAL FOR MOD TO RESEARCH AIRCRAFT	MODIFICATION COST DATA RANKING	WEIGHTED SCORE
			WEIGHTED RATING VALUE																
LOCKHEED C-141A	XT701	OW	6	4	12	4	9	12	6	6	4	2	12	2	2	6	2	9	98
		UW	6	4	12	4	9	12	12	6	8	2	12	2	2	6	2	9	108
BOEING KC-135A	XT701	OW	6	4	12	12	9	12	4	8	12	2	12	4	4	2	6	9	118
		UW	6	4	12	12	9	12	8	8	8	2	12	4	4	2	6	9	116
CONVAIR 990	XT701	OW	6	4	12	12	9	12	4	8	12	2	12	4	4	6	2	9	118
		UW	6	4	12	12	9	12	8	8	8	2	12	4	4	6	2	9	118
GULFSTREAM AMERICAN GULFSTREAM II	XT701	OW	3	12	8	12	9	8	4	12	8	6	12	6	6	4	6	6	122
		UW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	--
BOEING B-52B	-	OW																	
		UW								SPECIAL PURPOSE TESTBED									
		PYL																	
LOCKHEED -6 JETSTAR	-	OW								ELIMINATED ON INITIAL SCREENING									
		UW																	
BOEING 737	-	OW								ELIMINATED ON INITIAL SCREENING									
		UW																	

stacking order of the three remaining aircraft is:

Candidate Testbed A/C	Weighted Score
GAC GII	122
Boeing KC-135A	118
Convair 990	118

On the basis of these results for single prop-fan configurations only, the GAC GII is clearly the leader.

Since the KC-135A and the Convair 990 are shown to be equal it was necessary to investigate further by examining the subtotal scores of the three principal areas of evaluation, i.e., Aircraft Safety, Operational Characteristics and Program Objectives. When compared, the subtotal scores for these areas were also found to be equal for single prop-fan configurations. Extending the modification to at least two prop-fan installations, at same time keeping the primary propulsion system, produces a clear result in favor of the KC-135A. Because the inboard primary engine is located so far out on the wing it is possible to use the concept of "Propulsion System Addition" by locating the prop-fan installations between the inboard primary engines and the fuselage side without violating the clearance requirements. The situation for the CV990 is quite different. The inboard primary engines are physically closer to the fuselage than those of the KC-135A. Changing the configuration to a twin prop-fan by locating the installations between the inboard primary engine and the fuselage side results in prop-fan tip clearances below those recommended. The subtotals of the evaluation given on Table IX include the effect of the clearance considerations on the aircraft rankings. These data show the KC-135A to be slightly better than the CV990 for multi-prop-fan application.

TABLE IX. TESTBED FINAL ANALYSIS

TESTBED A/C	SUBTOTAL SCORES			SUB-TOTAL	MOD. POTENTIAL	TOTAL
	A/C SAFETY	OPERATIONAL CHARACTERISTICS	PROGRAM OBJECTIVES			
C-141A	22	31	28	81	2	83
KC-135A	22	37	42	101	6	(107)
CONVAIR 990	22	37	42	101	2	103
GII	23	33	50	105	6	(111)

○ TESTBED SELECTED A/C

The recommended testbed aircraft configurations based on the evaluation are the GAC GII and the Boeing KC-135A. Overall the GAC GII offers the most compatible aircraft/prop-fan testbed arrangement with the Boeing KC-135A as an excellent alternative.

Following the completion of the Evaluation and Selection of the Testbed Aircraft and after Lockheed-Georgia recommendations had been presented to the NASA, Lewis R.C., the NASA directed that for the remainder of the study, twin prop-fan testbed configurations only would be considered. The twin prop-fan configurations developed as part of the evaluation for the GAC GII and the KC-135A were therefore used as the basis of the conceptual design phase.

A detailed account of Task IV-Evaluation and Selection is given in Appendix "D" of this volume.

CONCEPTUAL DESIGN OF PROPFAN TESTBED SYSTEMS

Since the Boeing KC-135A and the Gulfstream American Corporation "Gulfstream II" aircraft were selected as the best candidates for a prop-fan testbed aircraft, recommendations that these two aircraft be studied further were followed in order to obtain a better design definition of each. In both cases, the designs adhered to the recommendation that the DDA XT701/T56-A-14 drive system be used to power a 2.83 m (9.5 ft) diameter prop-fan.

An overwing "pinion-high" installation was chosen as the drive system most representative of future aircraft applications, and the drive system/airframe integration was performed without attempting to optimize the arrangement aerodynamically. Gloves and fillets at the wing/nacelle intersections are, however, comtemplated to obtain an efficient installation.

Detailed conceptual designs were completed for the recommended testbed candidates to confirm the suitability and adaptability of each system to the flight test program. This design effort was aided by the loan of design and technical data to Lockheed by the Gulfstream American Corporation (GAC) and by a review of the Lockheed design by GAC for feasibility and practicality. Data for the KC-135A were obtained from the public domain through Wright-Patterson Air Force Base.

For ease of presentation, the work performed is covered in three parts. First, a description is given of the DDA XT701 Quick-Engine-Change (QEC) unit design. Second, unique features of the KC-135A testbed system design are reviewed, and finally, the GAC GII testbed system design is addressed.

QEC UNIT DESIGN

The QEC unit envisioned for the prop-fan testbed was designed primarily to contain the drive system and its associated support systems and structures. A secondary goal was to duplicate, as nearly as possible, the experimentally derived flow field through the prop-fan, in an attempt to validate the theoretical propulsive efficiencies.

Nacelle Contours

The nacelle contours were based on the NASA spinner/hub area distribution of Figure 5. They permit the use of the main forged support frames and supporting V-frames from the Lockheed P-3C T56 engine installation, modified for the DDA XT701 drive system installation. These contours, as shown in Figure 27, provide an envelope for the drive system with air induction systems for the engine and oil cooler arranged on the upper portion of the nacelle in a stacked and staggered configuration. The oil cooler inlet and ducting are designed to house the C-130 - T56 oil cooler.

Engine Air Inlet Design

A scoop type Inlet was selected for the XT701/T56-A-14 engine/gearbox arrangement, consistent with the general design philosophy that the engine should perform reliably and efficiently over the range of test conditions at the expense of drag minimization. In choosing between efficient internal or external flow performance, internal performance was considered more important.

Nacelle Structural Design

Externally applied loads for the drive system nacelle design were derived from flight envelope data for the KC-135A and for the GII. They include vertical and lateral accelerations, torque, and shear loadings. This results in a common structure in the QEC up to the mating plane. The structure on the receiving airframe, from the mating plane aft, is designed to be compatible with the QEC structure.

A finite-element analysis was performed to establish the sizes of the structural members of the nacelle, to check the capability of the Lockheed P-3C members to be used in the design, and to provide data for weight estimates of the nacelle and testbed aircraft.

The P-3C T56 suspension system is acceptable for testbed aircraft application up to a limit of 300 flight hours. A flight program beyond 300 hours will require analysis to establish mounting suitability for the suspension system locations shown on Figure 28.

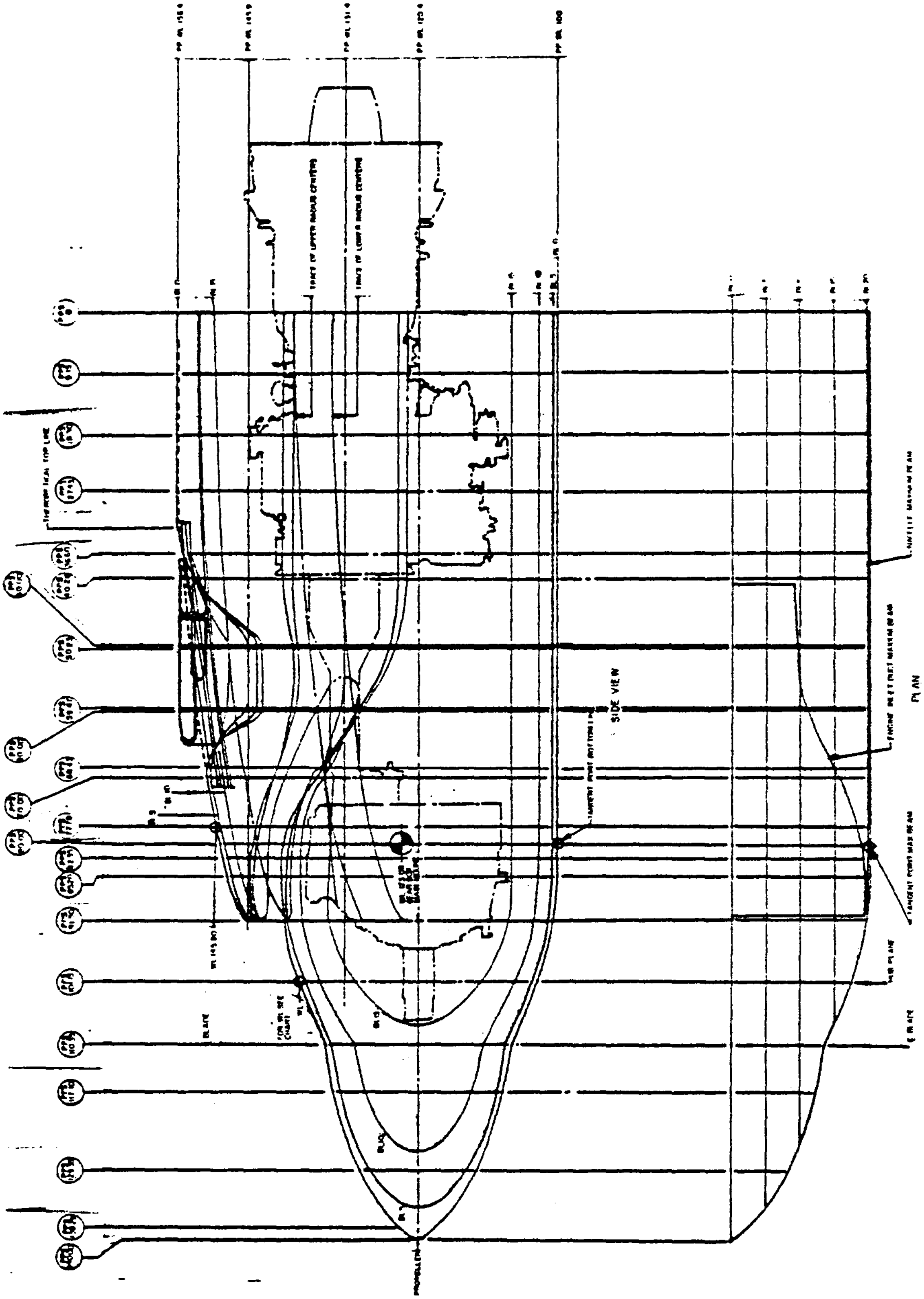
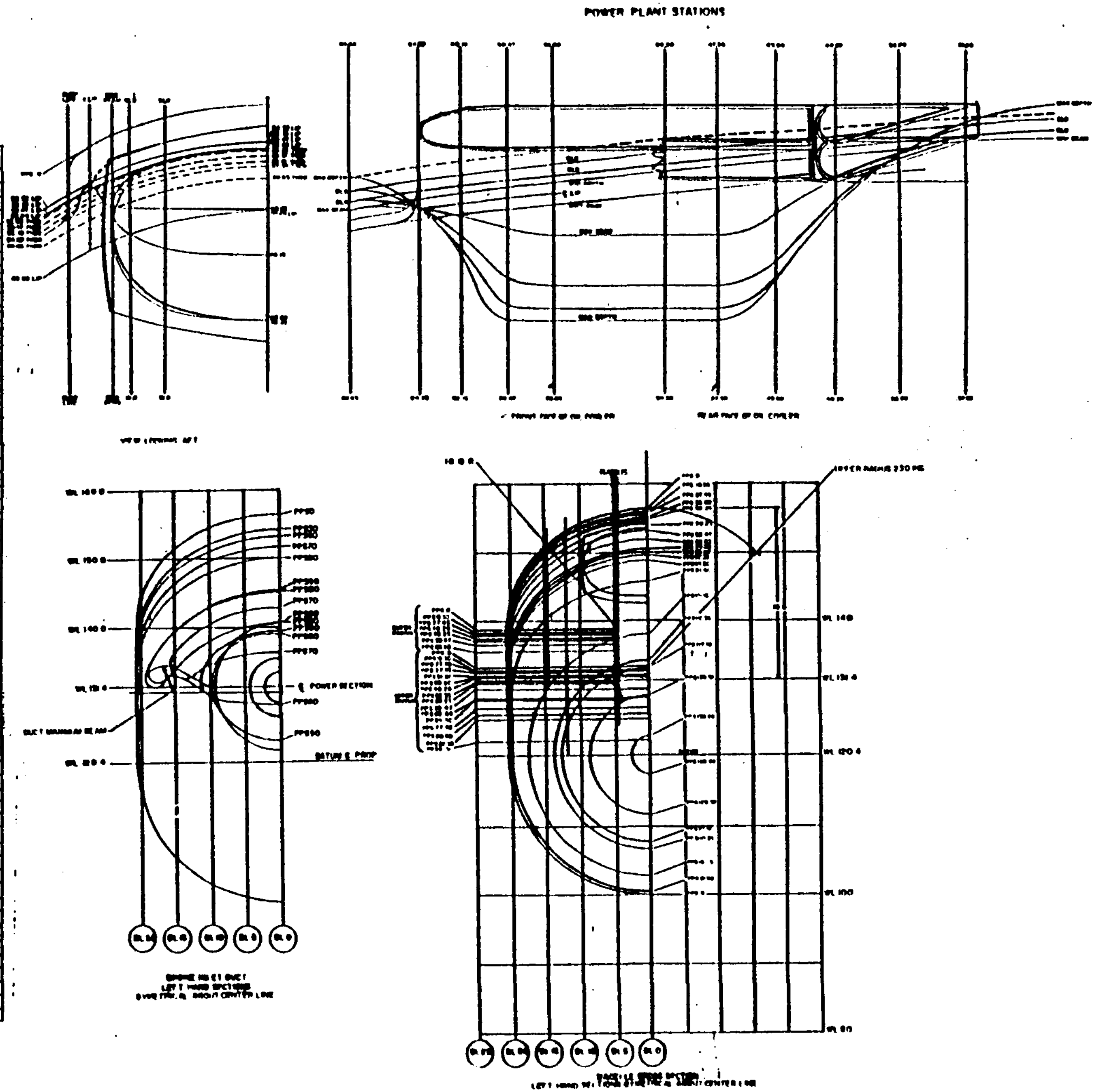


Figure E-1. XT701 QEC Nacelle Contours

Figure 27. XT701 QEC Nacelle Contours



CURVE		BOTTOM LINE		SPINNER AND HUB		TOP LINE		MAXIMUM BEAM	
	PPS		WL	RAD	WL		WL		BL
	0·		100				156 0		20 4
	3 66		100				156 392		20 4
	8 15		100				156 337		20 4
	12 81		100				156 267		20 4
	18 30		100				156 121		20 4
	21 98		100				155 996		20 4
	27 43		100				155 784		20 4
	31 11		100				155 581		20 4
	36 60		100				155 258		20 4
	40 26		100				155 006		20 4
	45 15		100				154 982		20 4
	50 32		100				154 189		20 4
	54 90		100				153 740		20 4
	59 47		100				153 250		20 4
	64 05		100				152 713		20 4
	68 629		100				152 110		20 4
	73 20		100				151 433		20 4
	77 775		100				150 656		20 4
	81 996		100	20 40	140 810		149 883		20 4
	82 35						149 994		
	84 049			20 377	140 777				
	85 095						148 994		
	86 925						148 457		
	88 100			20 189	140 389				
	89 212						147 639		
	89 670						147 445		
	90 127						147 235		
	90 768						146 879		
	90 991						146 752		
	91 134						146 596		
	91 9						159		
	92 218			19 789	140 189				
	96 304			18 991	139 791				
	97 734			18 683	139 083				
	98 112			18 589	138 989				
	98 140			18 561	138 961				
	98 304			18 529	138 929				
	98 714			18 400	138 800				
	99 120			18 264	138 664				
	99 540			18 120	138 520				
	99 946			17 971	138 371				
	100 352			17 805	138 205				
	100 762			17 657	138 057				
	101 150			17 492	137 892				
	101 178			17 492	137 892				
	104 832			15 921	138 321				
	108 920			14 304	134 704				
	110 350			13 730	134 130				
	113 008			13 036	133 436				
	115 055			12 898	133 298				
	117 100			12 661	133 061				
	121 190			11 583	131 983				
	125 278			10 128	130 828				
	129 368			8 440	128 841				
	133 457			6 329	126 729				
	135 501			5 017	125 417				
	137 472			3 426	123 826				
	139 000			2 437	122 837				
	140 000			0	120 400				

Figure 27. XT701 QEC Nacelle Contours (Cont'd)

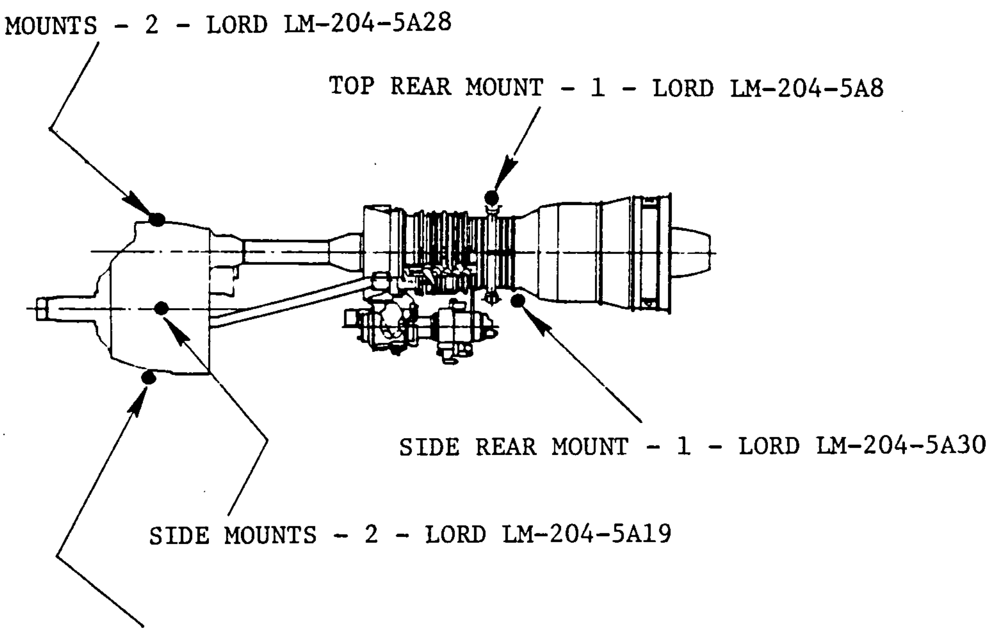


Figure 28. DDA XT701 Suspension System Mount Location

Drive System Installation

The drive system is installed in the nacelle, together with those accessories and systems necessary to operate the prop-fan unit, as shown on Figure 29. A modified 54H60 propeller control unit is used for prop-fan control and is located at the rear of the prop-fan hub. The engine fuel control is a hydro-mechanical device having an electronic supervisory system. The engine starting system uses air bled from the primary engines, conducted to an AiResearch Starter, located on the underside of the XT701 compressor case. Fuel and air line disconnects are provided on the mating bulkhead for the QEC. The oil cooling system uses the heat-exchanger from the C-130 T56 installation. A new oil tank is located below the torquemeter immediately behind the gearbox.

BOEING KC-135A TESTBED SYSTEM CONCEPTUAL DESIGN

The USAF KC-135A aircraft is a high-performance, jet propelled, low-wing aircraft from which the Boeing 707 was derived. It can, therefore, be regarded as a reasonable representation of a commercial aircraft. The KC-135A configured as a twin prop-fan testbed aircraft is shown on Figure 30.

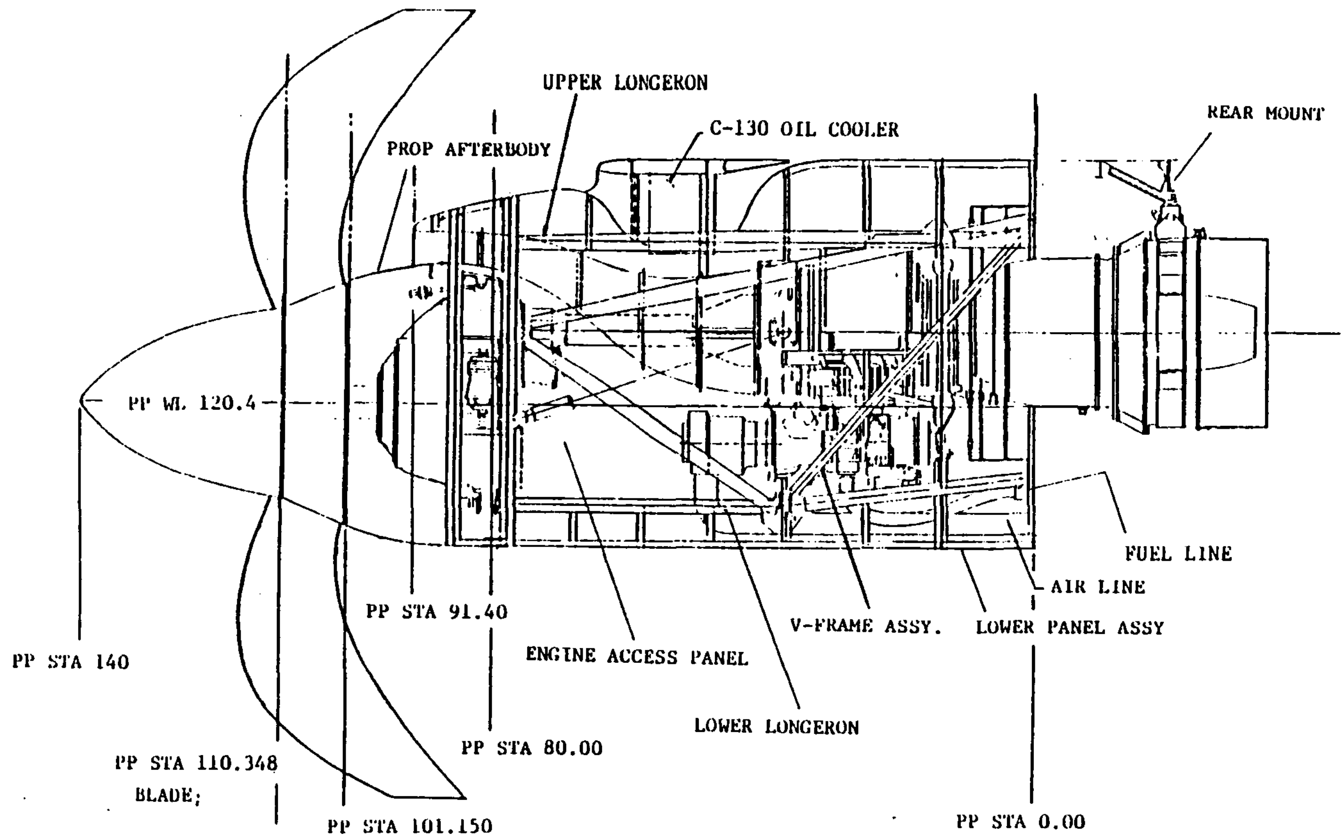


Figure 29. Drive System Installation

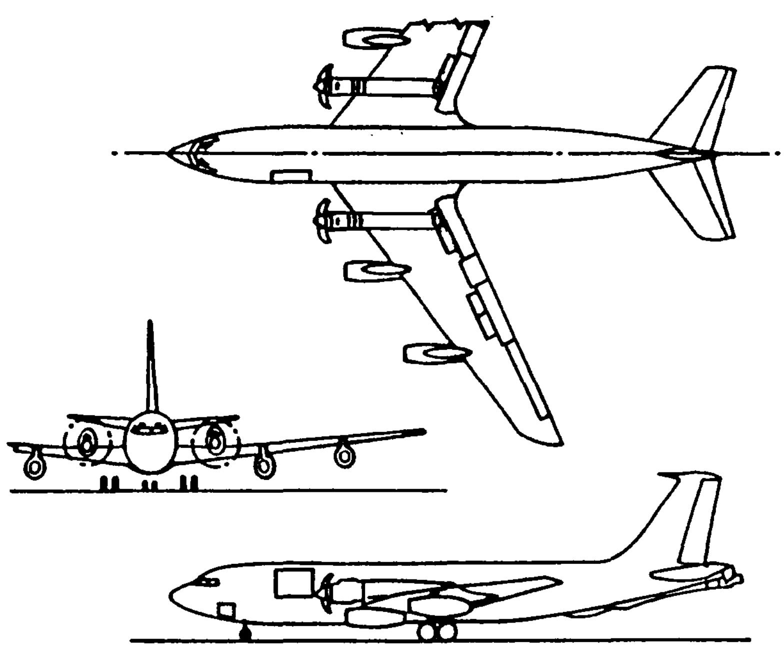


Figure 30. KC-135A Twin Prop-Fan Testbed Configuration

Drive System Location and Geometry

The drive systems are "pinion-high" overwing installations located at WBL 217 LH and RH, with the vertical plane of each installation normal to the wing chord plane. Each nacelle is placed with the prop-fan centerline located so as to provide adequate clearance between the wing upper cover and the jet exhaust pipe. The nacelle installation geometry is shown on Figure 31. Overall, the length of the installation from the spinner tip to the end of the jet pipe is 9.2 m (30.18 ft), with a maximum 1.04 m (3.4 ft) width. The height of the nacelle above the wing chord plane is 1.6 m (5.25 ft).

KC-135A Aft Nacelle Structure

The aft nacelle consists of a skin-frame-longeron structure extending aft over the wing from the nacelle mating plane, as shown on Figure 32. This

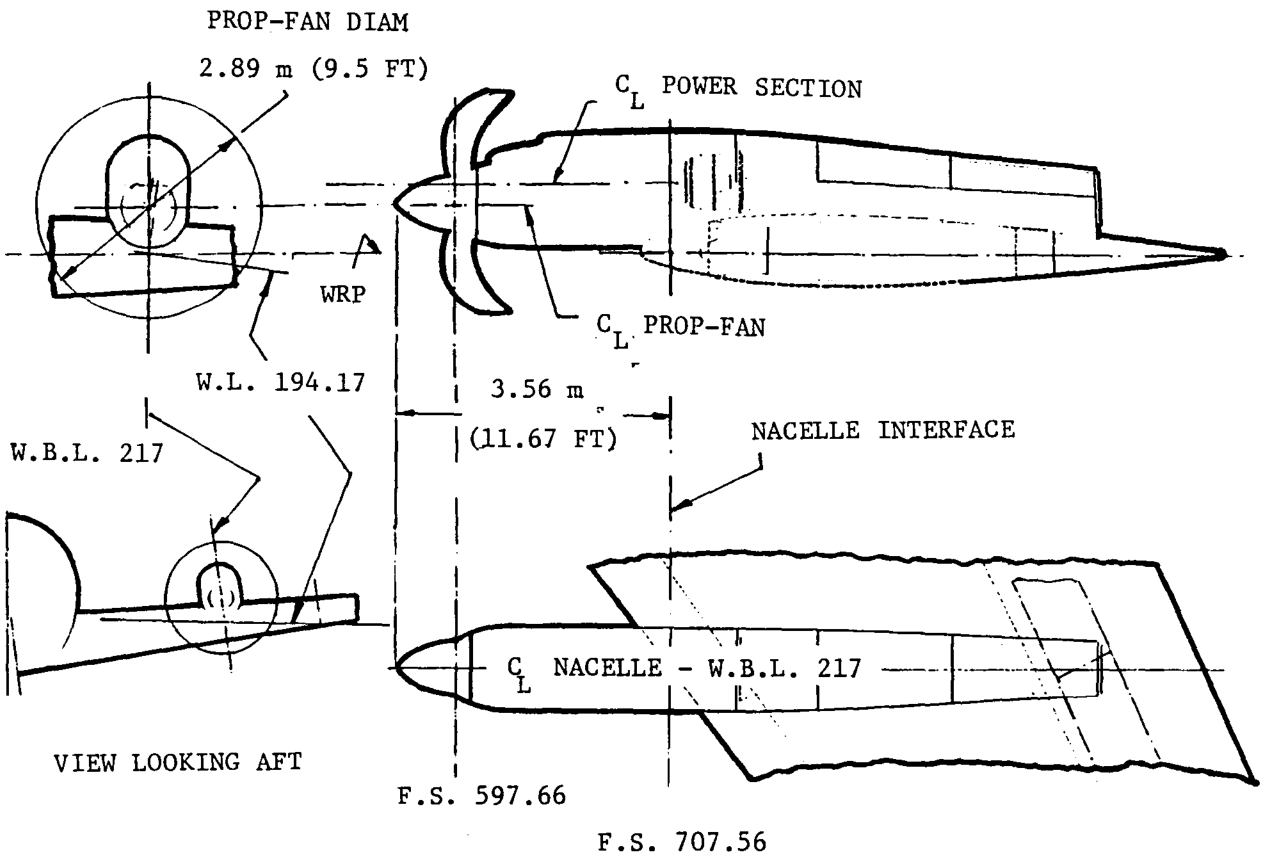


Figure 31. KC-135A Nacelle Installation Geometry

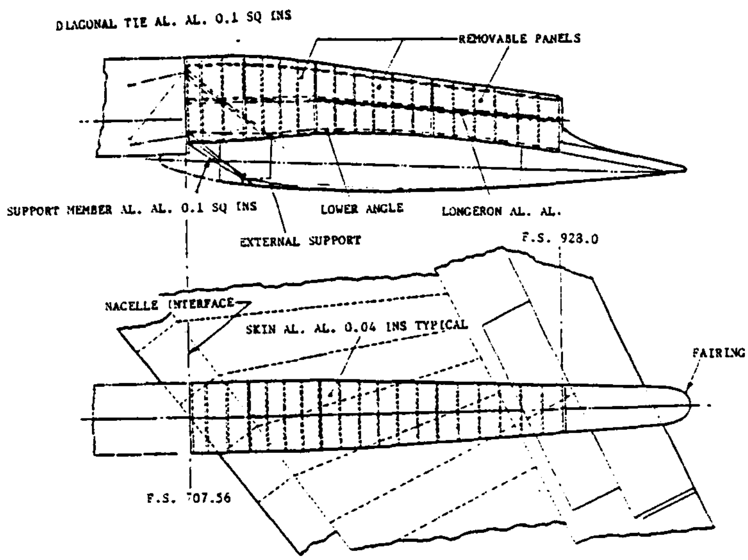


Figure 32. KC-135A Aft Nacelle Structure

portion of the nacelle is 5.6 m (18.37 ft) long and varies in height above the wing from 1.14 m (3.74 ft) to 0.9 m (2.95 ft) at the center line. As far as possible, the aft nacelle contours are designed with single curvature panels and consist of semi-circular upper sections and straight sides from the maximum beam to the intersection of the nacelle side wall with the wing upper contour. An aluminum alloy "skate" angle is attached to the wing upper surface, providing attachment for the nacelle side walls and for the lower pick-up points on the engine nacelle. Upper diagonal ties from the nacelle upper attachment are secured to the front spar, adjacent to skate angles, on the wing upper surface. Lower diagonal truss members are attached to the QEC unit lower pick-up points and extend downward and aft to an attachment located on the nacelle centerline at the front spar/lower cover junction. These members form a V-truss and transfer loads into the lower skin cover by means of an external "tee" support. Reinforcement of the covers, except for local increases in thickness to provide bearing material for nacelle structure attachment, is not required.

The aft portion of the nacelle terminates slightly forward of the trailing edge of the inboard spoilers, and a fairing is added to protect the upper surface of the flap from the jet blast. Because the nacelle covers the inboard spoilers, it is necessary to lock-down both spoilers and disconnect both from the spoiler system. Attachment of the nacelle structure is accomplished by picking up existing fastener locations in the upper cover. The addition of fasteners in excess of those already in the structure will be performed without degradation of the strength or stiffness of the wing primary structure.

Testbed Flutter Analysis

A preliminary wing flutter analysis was performed for the KC-135A testbed configuration to determine the effects of the prop-fan powerplant installation on wing flutter stability. A semi-span (half-airplane) mathematical model with the results directly applicable to a symmetrical 2-engine testbed configuration was used.

Flutter Analysis Results - The results of the flutter analysis are summarized in Figure 33. The unmodified KC-135A wing was analyzed first because Boeing data were not available to form a basis for comparison. A single weight, 86,432 kg (190,000 lb), was analyzed.* This weight includes structural reserve wing fuel of 1405 kg (3090 lb) and 37,786 kg (83,130 lb) of fuselage fuel. The critical flutter mode for the symmetric and unsymmetric conditions was found to be wing outer panel bending-torsion at a frequency of about 11 to 12 Hz. The symmetric flutter speed was lower, as shown in Figure 33, but was outside the required 1.15 V_D envelope of the unmodified KC-135A.

The addition of the prop-fan powerplant, with nominal attachment flexibilities and propeller aerodynamic and gyroscopic effects, caused the flutter speeds to change slightly. The unsymmetric flutter speed decreased slightly, and the symmetric flutter speed increased slightly as indicated by the solid square and circle symbols, respectively. Elimination of the propeller aerodynamic and gyroscopic effects and changes in the prop-fan powerplant attachment flexibilities caused negligible changes in the flutter speeds. These results suggest that the prop-fan installation will have negligible effect on the wing flutter characteristics of the KC-135A aircraft and that no changes to the wing structure will be required for flutter prevention.

KC-135A Testbed Operating Envelope

The KC-135A testbed flight envelope in Figure 34 was derived from available U.S. Air Force data. The design dive Mach number of 0.88 is sufficiently beyond the testbed design requirements of Mach 0.8 at 9118 and 10,668 m (30,000 and

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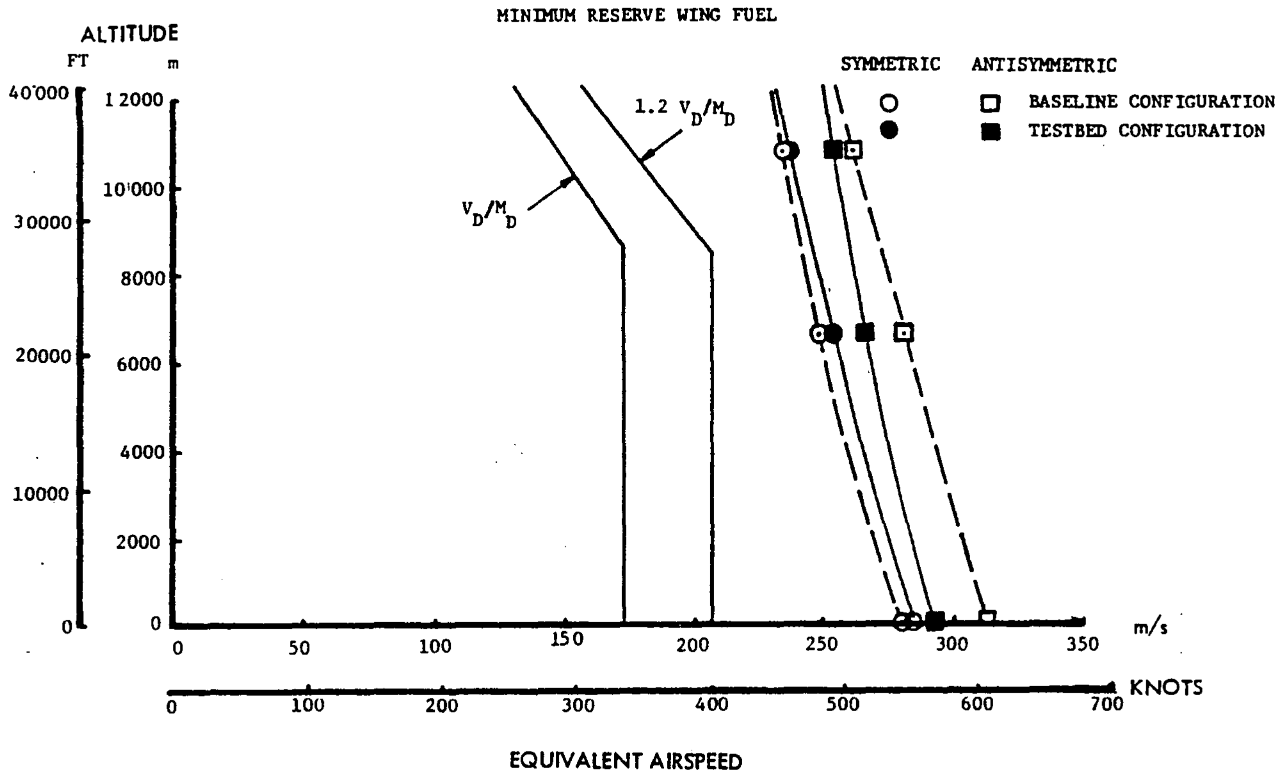
*Latz, R. N., "KC-135 Power Spectral Vertical Gust Load Analysis," AFFDL-TR-66-57, Vol. II, July 1966.

35,000 ft) to obviate the need for speed restrictions on the testbed aircraft over the full range of flight conditions.



Comparison of Predicted and Measured
Wing Vibration Modes (No Prop-fans)

Symmetric

Mode	Predicted Freq. (Hz)	Measured Freq. (Hz)	f_P/f_m
Wing 1st bending	4.31	4.40	.980
Wing 2nd bending	16.42	13.56	1.21
Wing 1st torsion	19.27	19.42	.992
Wing 2nd torsion	38.39	38.76	.990

Antisymmetric

Mode	Predicted Freq. (Hz)	Measured Freq. (Hz)	f_P/f_m
Wing 1st bending	5.15	5.12	1.06
Wing 2nd bending	12.30	9.66	1.27
Wing 1st torsion	18.18	18.32	.992
Wing 3rd bending	35.70	36.59	.976

Figure 33. KC-135A Testbed Flutter Boundaries

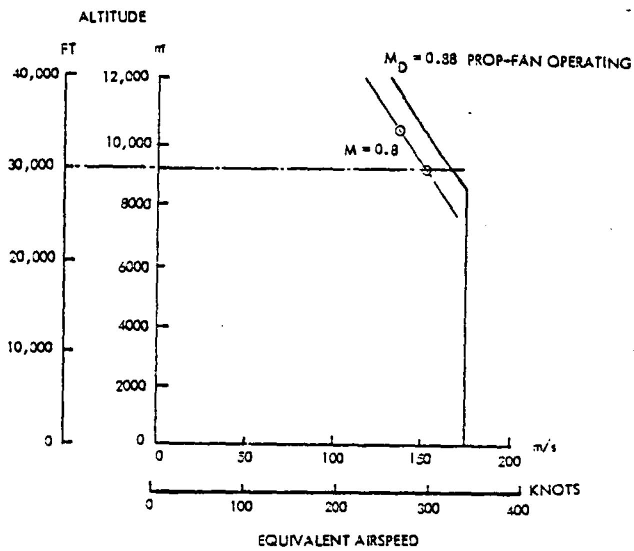


Figure 34. KC-135A Testbed Operating Envelope

KC-135A Testbed Performance

The performance of the KC-135A testbed aircraft with twin prop-fans is shown on Figure 35. Data are given for start and end cruise test weights of 81,630 kg (180,000 lb) and 54,420 kg (120,000 lb) respectively. The capability of the unmodified KC-135A is also given for the two conditions: a) three engines at normal rated thrust (NRT) and one windmilling and, b) four engines at NRT. These data demonstrate the capability of the testbed configuration to meet the design requirements. The testbed aircraft, at the true start and end cruise weights of 84,673 kg (186,280 lb) and 55,476 kg (122,047 lb) provides a test mission duration of 4.7 hours.

KC-135A Testbed Weight and Balance

The wing fuel capacity of the unmodified airplane is 49,431 kg (108,750 lb). Since the mission fuel required is less than the wing-tank capacity, all mission fuel can be carried in the wing tanks so that the center-of-gravity will move aft as fuel is loaded and forward as it is consumed. The center-of-gravity at operating weight can be maintained in any position by proper location of the test equipment. The normal range of center-of-gravity movement is from 12.5 percent MAC to 35 percent MAC. At ramp gross weight the testbed aircraft center-of-gravity at 26.4 percent MAC can operate within this range as shown in Figure 36.

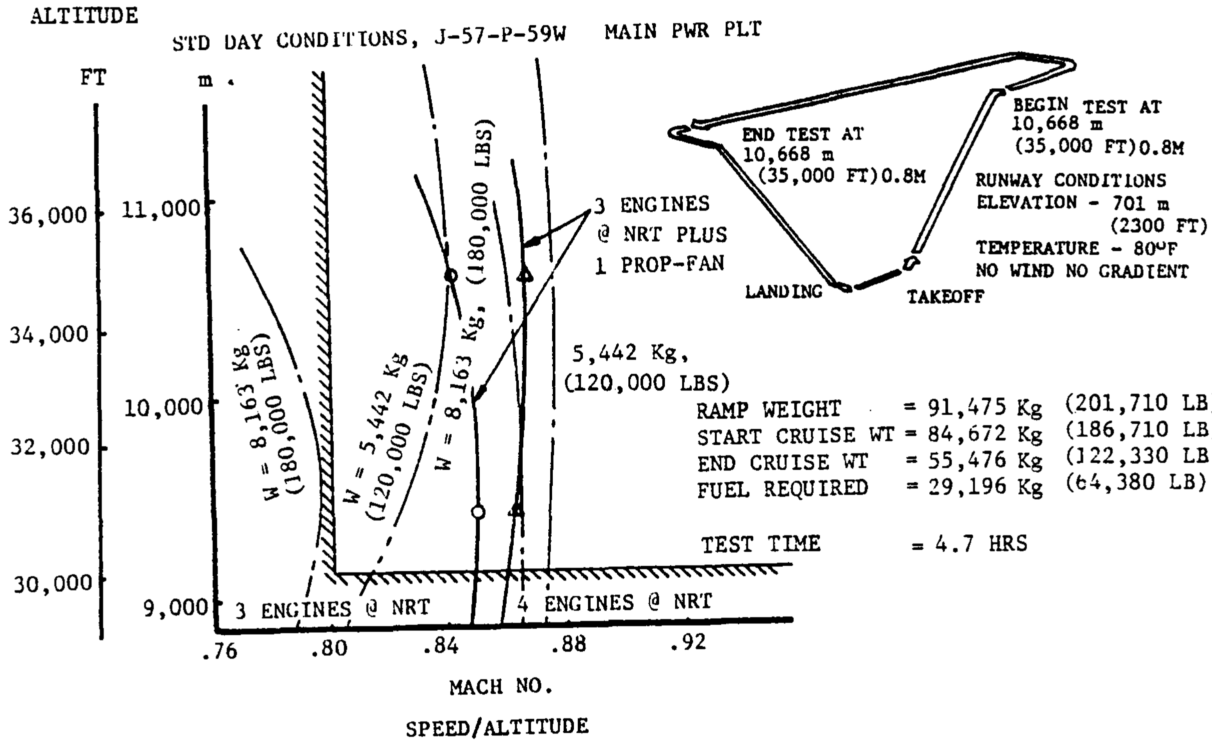


Figure 35. KC-135A Performance

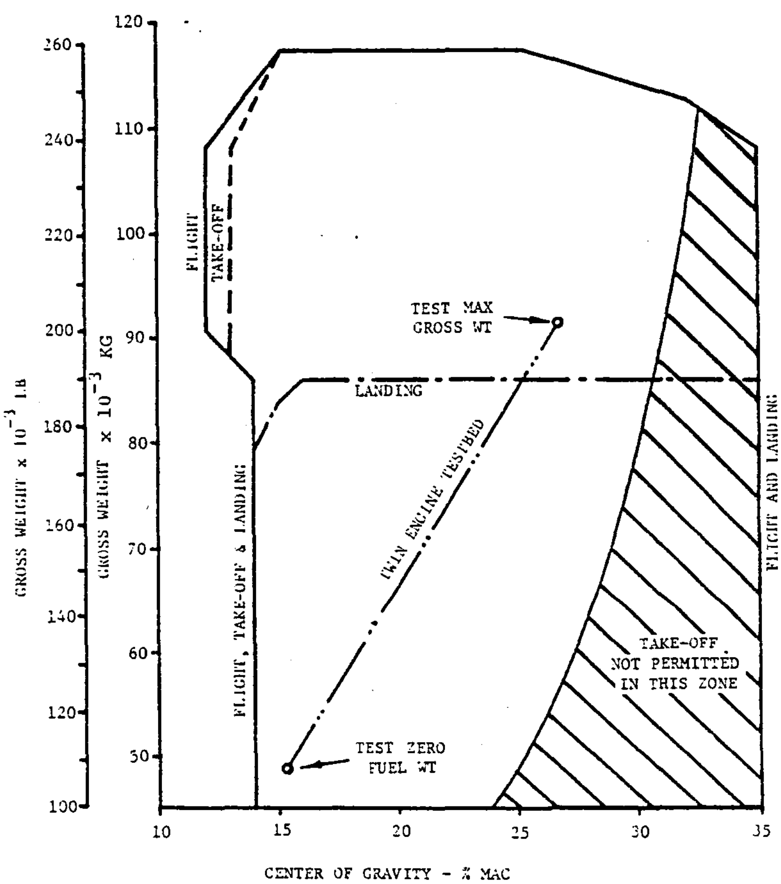


Figure 36. KC-135A Center-of-Gravity Range

GAC GII TESTBED CONCEPTUAL DESIGN

The GAC GII is a high-performance, jet propelled, low-wing, business/ executive aircraft. The modified aircraft performance, i.e., speed/altitude, is in excess of the design requirement for the testbed aircraft, and analyses have shown that the XT701 prop-fan drive system is matched to the GII airframe. The general arrangement of the GII testbed configuration is shown in Figure 37.

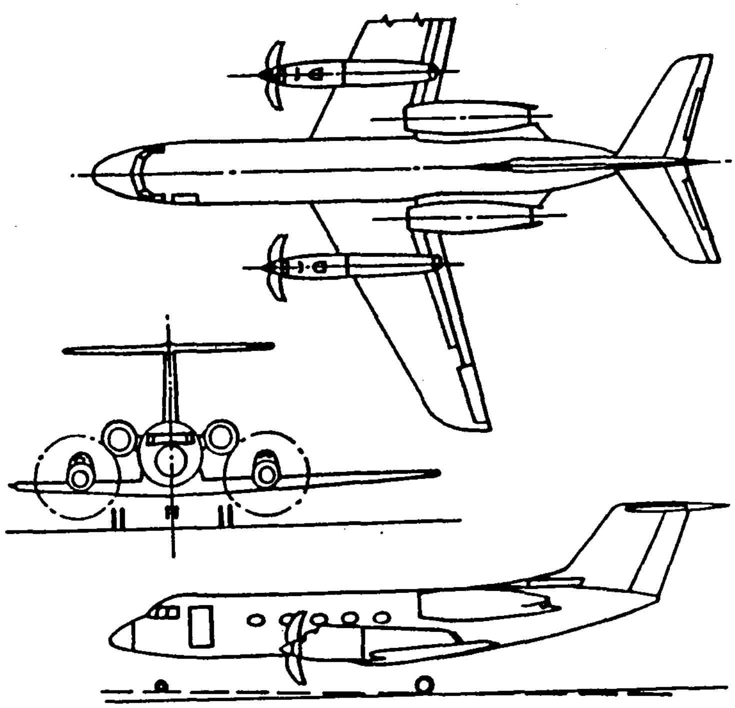


Figure 37. GII Twin Prop-Fan Testbed Configuration

Drive System Location and Geometry

Two possible locations for the drive system were selected for analysis. The first location chosen was at BL 145.0, $\eta = 0.35$, since the wing thickness increases from this location inboard and adequate back-up structure for the installation exists in the wing. This location is the limiting position inboard for the 2.89 m (9.5 ft) diameter prop-fan as far as clearance and interference with the airflow to the primary engines is concerned. In the normal ground attitude, the ground/prop tip clearance is 0.513 m (1.68 ft). Sufficient clearance is also provided between the upper surface of the wing and jet pipe. This geometry is a compromise to minimize the torque effects of the prop-fan thrust on the wing box structure and to maximize the prop-fan tip/ground clearance in the normal ground attitude.

A second location at BL 185, $\eta = 0.45$, was also investigated, because it is the limiting position on the wing at which engine-out conditions can be controlled. At this location, the prop-plane required 0.914 m (3.0 ft) of movement aft to partially satisfy flutter requirements.

GII Aft Nacelle Structure, Drive system at BL 145

The aft nacelle structure mounted on the wing upper surface at BL 145.0 is shown on Figure 38. It consists of two vertical side panels capped by a semi-circular removable cowl structure that extends from the mating plane to the end of the jet pipe near the trailing edge of the spoilers. The structure consists of an assembly of skins, frames, longerons, and stiffeners of aluminum alloy. The QEC pick-up points match similar attachment points on the aft nacelle at the mating plane, and the structure is arranged so that the upper attachments co-incide with the main diagonals which are connected to the rear spars of the wings at the lower end. The nacelle attachment angles on the upper surface of the wing pick up the QEC lower attachments and the diagonal members at the aft ends.

GII Aft Nacelle Structure, Drive system Mounted at BL 185

The aft nacelle structure in Figure 39 consists of that portion of the structure from the sloping mating plane to the trailing edge. The aft nacelle

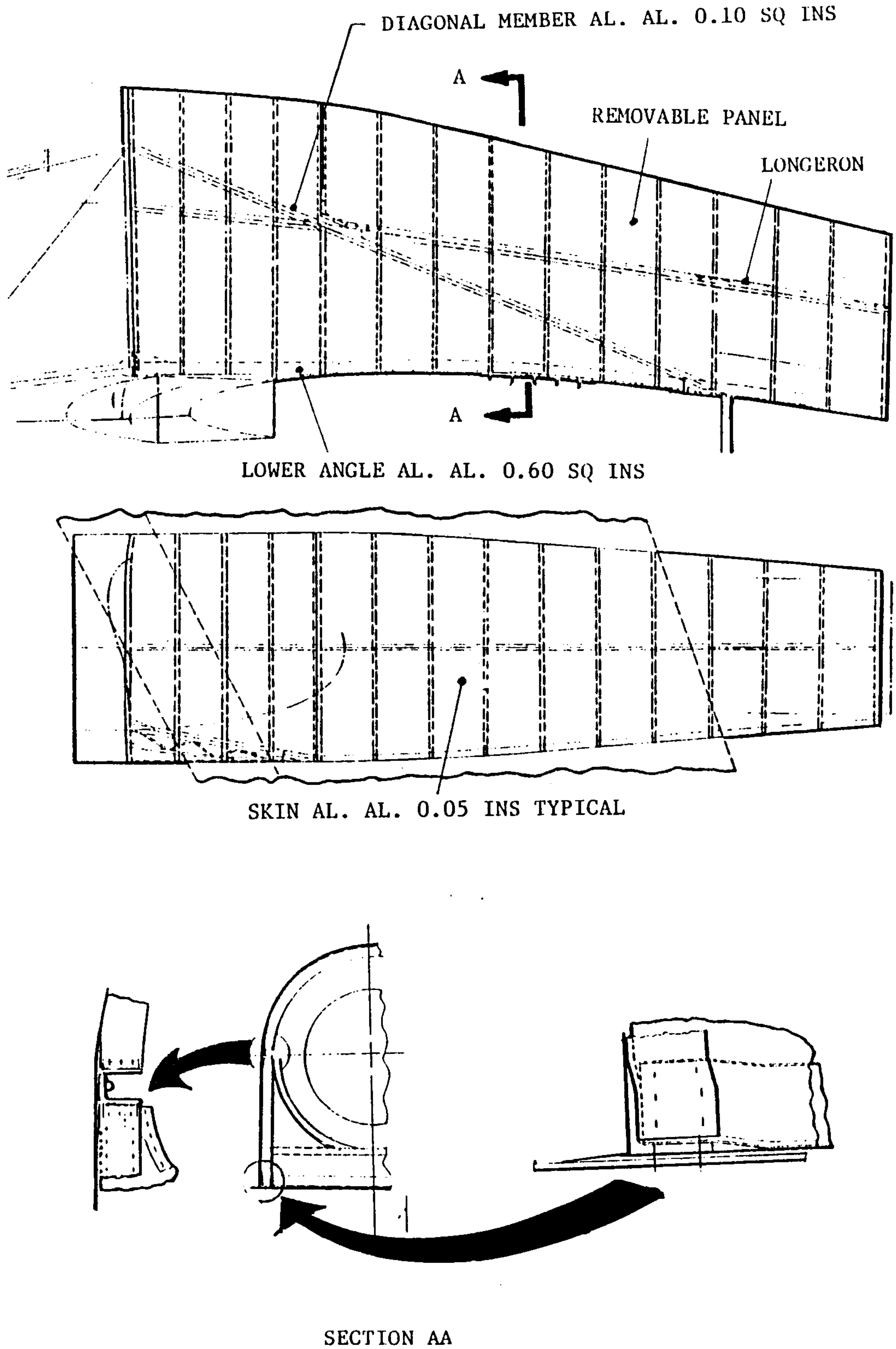


Figure 38. GII Aft Nacelle Structure B.L. 145

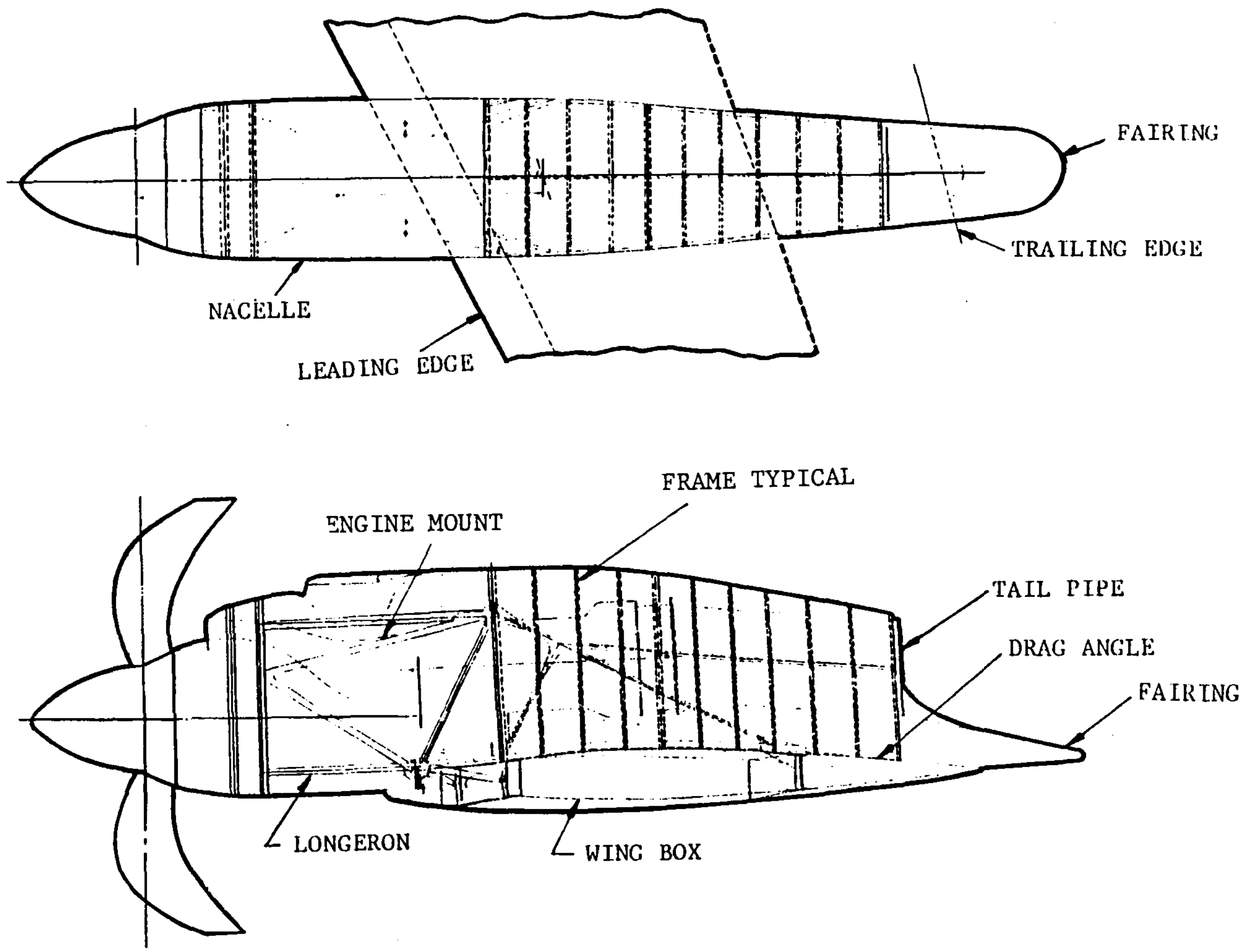


Figure 39. GII Aft Nacelle Structure B.L. 185

supports the drive system installation by means of diagonal members from the upper attachment points downward and aft to the rear spar and by skate angle and nacelle lower longeron extensions which are attached to the front spar. The nacelle structure is fabricated from aluminum-alloy skin, frames, and longerons/stiffeners. The upper, semi-circular portion of the nacelle is removable to provide access to the jet pipe installation. The main attachment of the nacelle to the wing upper surface is by means of chordwise "skate" angles. A fairing is provided at the tail pipe to protect the upper surface of the flap from the jet efflux. Because the turbine section of the power unit has moved aft to a position above the primary structure of the wing, provision for blade containment is required in this area.

GII Flutter Analysis

Preliminary wing flutter analyses were performed for the GII testbed configuration to determine the effects of the prop-fan powerplant installation at the two candidate locations. The same mathematical model was used as for the KC-135A.

Flutter Analysis Results, Drive System at BL 145.0 - The results of the wing flutter analysis are summarized in Figure 40. The unmodified GII wing was analyzed first to compare the results with the Grumman analysis and thereby validate the mathematical model. The flutter boundaries agreed within 2 percent, as indicated by the circle symbols on Figure 40, even though the Grumman mathematical model included flexible fuselage and empennage effects, which were not included in the Lockheed analysis. The flutter mode involved is a 7 to 10-Hz antisymmetric wing bending-torsion mode.

The addition of the prop-fan powerplants at BL 145 caused a 5-Hz symmetric flutter instability inside the testbed dive speed envelope, as indicated by the solid square symbol. When rotating prop-fan aerodynamic and gyroscopic couplings effects were added, the speed of this instability increased by about 23 m/s (75 ft/sec), but was still unsatisfactorily low, as shown by the open square symbol.

To increase the flutter speed to a satisfactory level, a substantial increase in the wing torsional stiffness inboard of BL 145 is required. The

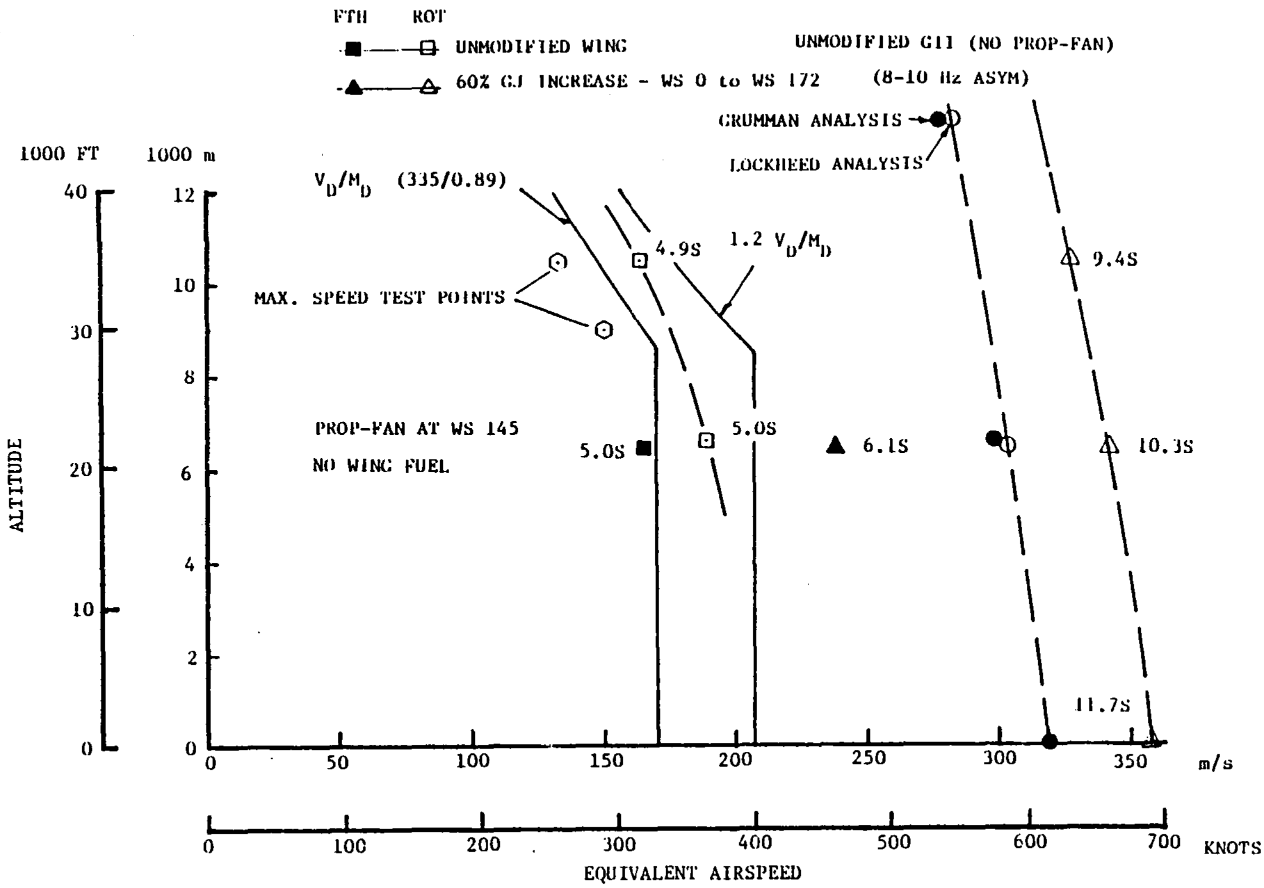


Figure 40. GII Flutter Boundaries - Prop-Fan at W.S. 145

effect of a 60 percent increase in torsional stiffness is shown by the solid and open triangular symbols for the feathered and rotating prop-fan conditions, respectively. Although a somewhat smaller stiffness increase might be satisfactory, a more elaborate and comprehensive flutter analysis will be required to determine a precise figure.

<u>Flutter Analysis Results, Drive system at BL 185.0</u> - Relocating the QEC to BL 185, and with the prop-fan plane one diameter ahead of the wing leading edge, increases the flutter speed above that with the powerpplant located at BL 145. The damping of the fundamental wing torsion modes (both symmetric and unsymmetric) is, however, unsatisfactorily low at airspeeds well within the limit-speed envelope. Attempts to stabilize the mode by increasing the wing torsional stiffness actually reduced the damping, so that it became obvious that no reasonable amount of wing stiffening would solve the problem.

Moving the prop-fan plane aft, however, 0.914 m (3.0 ft) improved the damping of these modes, which when combined with a 60 percent increase in wing stiffness out to BL 200, provided satisfactory damping within the limit speed envelope. It should be noted that the damping is marginal and is sensitive to changes in altitude, power-plant mounting stiffness, prop-fan aerodynamic characterisitics, and other parameters not investigated.

GII Wing Modification

The GII wing structure consists of integrally stiffened upper and lower skin panels and front and rear spar structures, which together form the wing box beam structure. Increasing the torsional stiffness 60 percent, for either of the drive system locations investigated, requires the addition of doublers to the upper and lower surfaces of the wing and to the front and rear spars. Because double curvature exists on the wing from BL 145 inboard, perfect matching of the doublers and skin is not possible and liquid shim would be applied to the faying surfaces.

Adding doublers to the forward face of the front spar and to the rear face of the rear spar requires removal of the leading and trailing edge structures. No problems are anticipated with the front spar reinforcement, but the doubler applied to the rear spar presents a major undertaking because removal of the landing gear support is involved. Finally, modification to the spoiler system is necessary which would eliminate the ground spoiler for the inboard location or deactivate the inboard flight spoiler for the outboard drive system location.

GII Operating Envelope

The operating envelope for the GII, Figure 41, was established by analyzing the 0.13 rad (7.5 deg) upset condition for 20 seconds to determine the dive speed. The points analyzed were those at altitudes of 9118 m (30,000 ft) and 10,668 m (35,000 ft), starting the upset at a Mach number of 0.8. The upset condition onset at 9118 m (30,000 ft) results in a Mach number increase to 0.89 at the end of 20 seconds and an end altitude of 8534 m (27,990 ft). Below this altitude the testbed aircraft speed is restricted to 172 m/s (565 ft/sec) EAS in order to minimize weight penalties arising from wing torsinal stiffness increases.

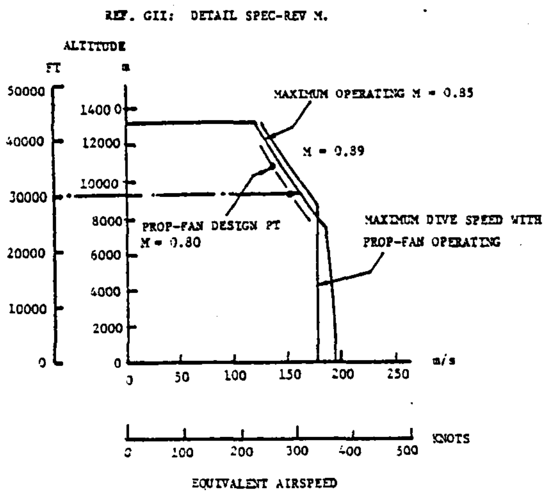
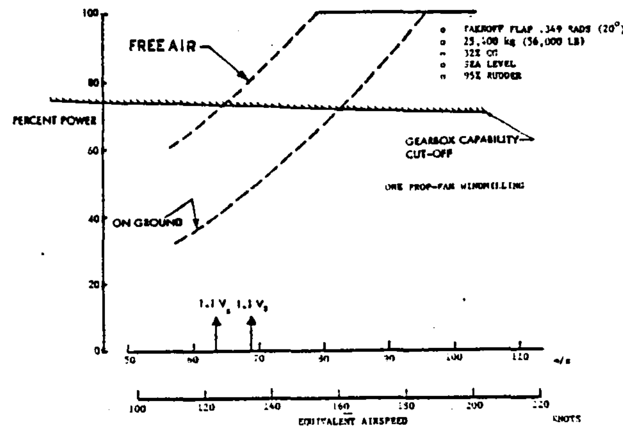


Figure 41. GII Operating Envelope



PROP FAN LOCATED AT WS 185

Figure 42. GII Trim Capability - Prop-Fan at W.S. 185

GII Prop-Fan Testbed Trim Capability

The outboard limit for locating the drive system is BL 185, $\eta = 0.45$ and is dictated by the aircraft trim capability. The data of Figure 42 show that, with one prop-fan windmilling and 100 percent power on the other, the testbed aircraft can be trimmed for engine-out conditions at 77.7 m/s (275 ft/sec) EAS in free air with 0.087 rad (5.0 deg) angle-of-bank or at 90 m/s (295 ft/sec) EAS on the ground. The use of the T56-A-14 gearbox restricts the power input to 4101 kW (5500 shp) so that, when this constraint is applied to the data of Figure 42, the power setting of the prop-fans, at the conditions indicated, is limited to approximately 75 percent of takeoff power. At this power setting, the engine-out, free-air trim capability can be achieved at a speed of 66.3 m/s (218 ft/sec) EAS and at 77.0 m/s (253 ft/sec) EAS on the ground.

GII Testbed Weight and Balance

Weight data are presented for both drive system locations in Table X. The essential difference between the weights is due to the increased doubler weight for the BL 185 drive system location. The operating weight of the unmodified aircraft is 15,464 kg (34,020 lb), which increases to 21,508 kg (47,318 lb) and 21,622 kg (47,568 lb) for BL 145 and BL 185, respectively. The difference in fuel weight for the two configurations is about 113 kg (250 lb). Balance checks of the testbed configuration show that, for either of the drive system locations, the aircraft center-of-gravity can be maintained within the envelope for the existing aircraft at all weights. Placing the test equipment in the passenger compartment eliminates center-of-gravity problems.

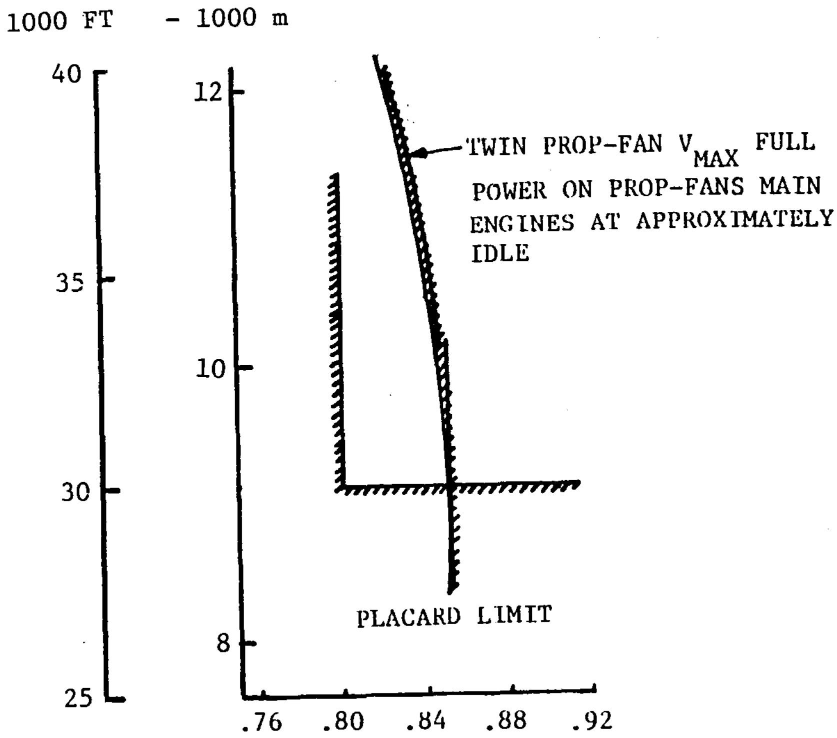
TABLE X. GII TESTBED WEIGHT AND BALANCE

DRIVE SYSTEM LOCATION	WS 145/FS 385.98*				WS 185/FS 332*			
WEIGHT COMPONENT	% MAC	WEIGHT Kg	WEIGHT LB	ARM FS	% MAC	WEIGHT Kg	WEIGHT LB	ARM FS
o OPERATING WEIGHT-UNMODIFIED	39.3	15,464	(34,100)	462.0	39.3	15,464	(34,100)	462.0
XT701 PROP-FAN PACKAGES		3,907	(8,614)	342.2		3,907	(8,614)	395.1
OVERWING NACELLE STRUCTURE		233	(514)	424.9		233	(514)	441.8
WING DOUBLERS		544	(1,200)	408.0		657	(1,450)	410.9
TEST EQUIPMENT		1,360	(3,000)	538.0		1,360	(3,000)	530.0
o ZERO FUEL WEIGHT	26.6	21,513	(47,428)	443.3	32.8	21,626	(47,678)	452.4
FUEL		6,837	(15,072)	418.5		6,723	(14,822)	418.3
o RAMP GROSS WEIGHT	22.5	28,350	(62,500)	437.5	27.3	28,350	(62,500)	444.3

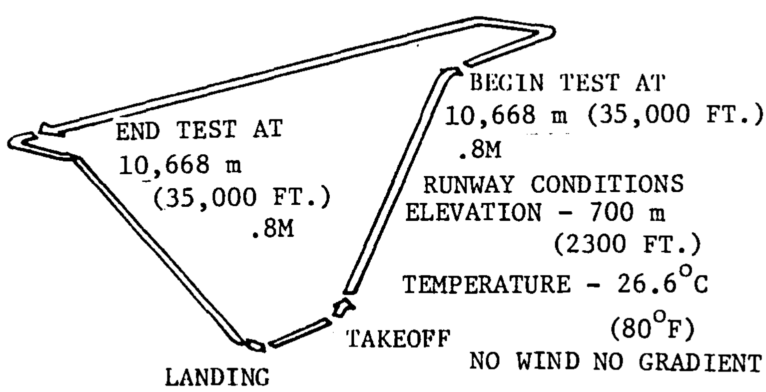
*PROP-PLANE LOCATION

GII Testbed Performance

The mission performance of the GII twin prop-fan testbed is shown in Figure 43. At a ramp weight of 28,344 kg (62,000 lb), the start cruise weight at 10,668 m (35,000 ft) is 27,317 kg (60,000 lb) and the end cruise weight is 22,109 kg (48,640 lb). Cruising at Mach 0.8 gives a test mission duration of 2.68 hours. The speed/altitude performance also shown in Figure 43, shows that a Mach number margin of 0.04 to 0.05 exists over the design conditions for the twin prop-fans operating at full power with the primary "Spey" propulsion slightly above idle power setting.



SPEED/ALTITUDE



RAMP WEIGHT	28,350 kg (62,500 LB.)
START CRUISE WEIGHT	27,322 kg (60,235 LB.)
END CRUISE WEIGHT	22,114 kg (48,752 LB.)
FUEL WEIGHT	6,837 kg (15,072 LB.)
TEST TIME	2.68 HRS

Figure 43. GII Testbed Mission Performance

GII Prop-Fan Near-Field Noise Characteristics

Free-field peak sound pressure levels and noise contours were generated for the GII fuselage for the flight conditions shown by Table XI. A peak noise level of 147.7 dB is experienced at M = 0.8 with a tip speed of 249 m/s (817 ft/sec) and a disc loading of 301 kW/m^2 (37.5 shp/d^2). The noise levels decrease as Mach number, tip speed, and disc loading decrease. Relative sound pressure levels estimated for conditions up to the tenth blade passage frequency harmonic for tip speeds of 183, 213 and 244 m/s (600, 700 and 800 ft/sec) are shown on Figures 44, 45 and 46, respectively. These data represent the explicit cruise conditions of Table XI and cannot be extrapolated for other conditions. The noise contours on the fuselage are shown on Figure 47 for the XT701 and SR3, 10 bladed prop-fan drive system at the cruise conditions of Table XI. At these conditions, the sound pressure level of blade passage frequency harmonics on the noise contour may be determined by algebraically adding the data on Figures 44, 45 and 46 to the OASPL for the appropriate tip speed of Table XI.

The complete account of Task V-Conceptual Design of Testbed Systems is to be found in Appendix E of this report.

TABLE XI. FREE FIELD PEAK OVERALL SOUND PRESSURE LEVELS

SR-3 CONFIGURATION ON GULFSTREAM II TESTBED @ 10668 m (35,000 FT.) CRUISE ALTITUDE

CASE	CRUISE M	kW/m^2	(SHP/D^2)	TIP SPEED m/s	(fps)	OASPL (dB)
1	0.8	209	(26.0)	183	(600)	142.0
2	0.8	241	(30.0)	217	(700)	146.7
3	0.8	301	(37.5)	244	(800)	147.7
4	0.8	241	(30.0)	244	(800)	146.8
5	0.8	209	(26.0)	244	(800)	147.2
6	0.7	301	(37.5)	244	(800)	145.4
7	0.7	241	(30.0)	217	(700)	137.3
8	0.7	209	(26.0)	183	(600)	129.1

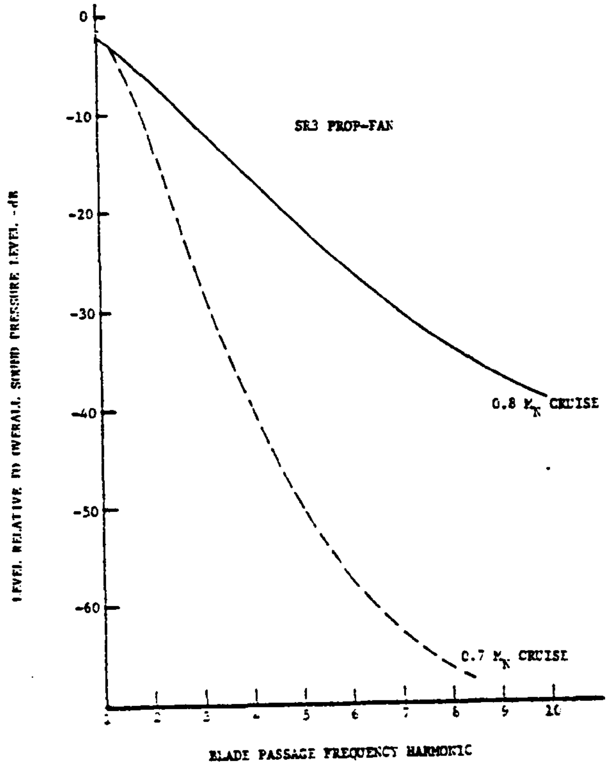


Figure 44. GII Blade Frequency Harmonics @ V_{TIP} = 183 m/s (600fps)

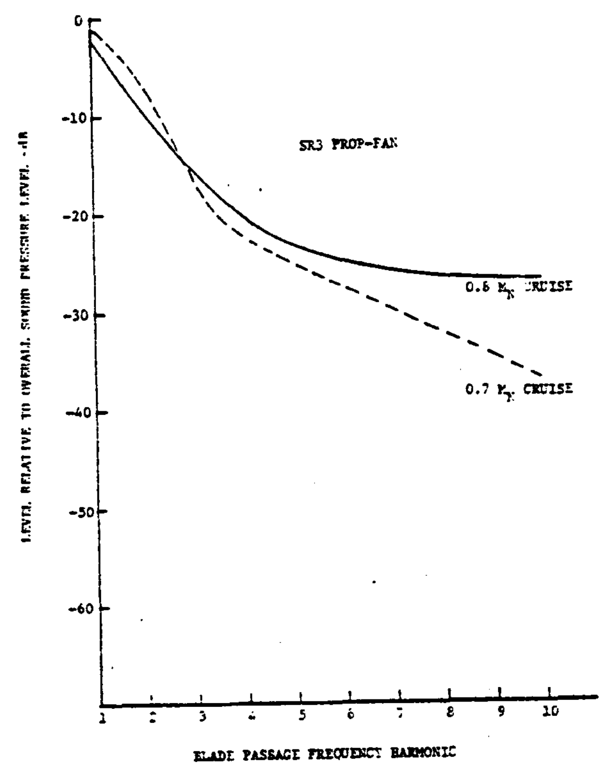


Figure 45. GII Blade Frequency Harmonics @ V_{TIP} = 217 m/s (700 fps)

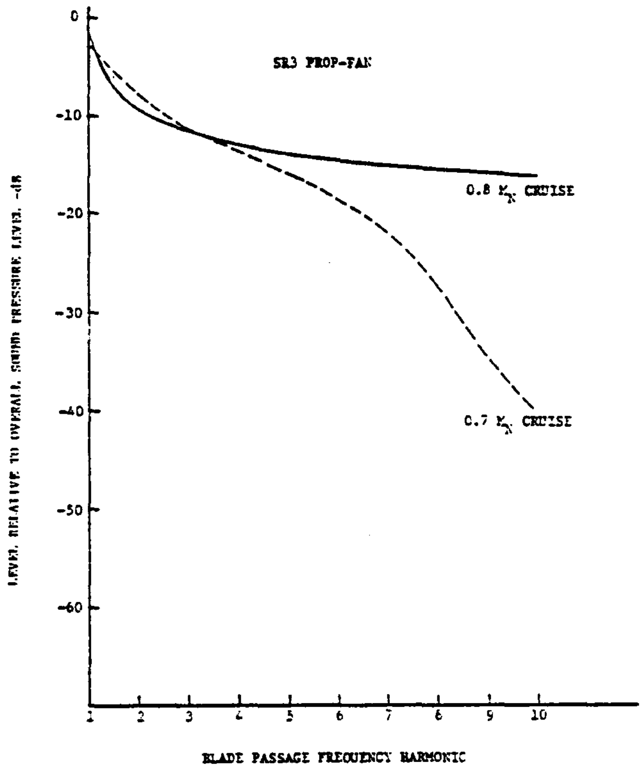


Figure 46. GII Blade Frequency Harmonics @ V_{TIP} = 244 m/s (800 fps)

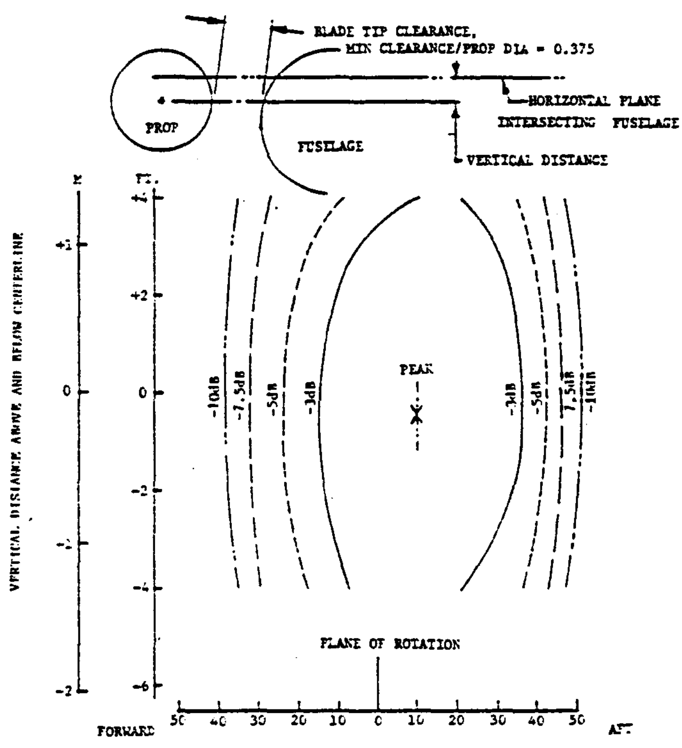


Figure 47. GII Fuselage Noise Contours

WIND TUNNEL TEST PLAN

The Wind Tunnel Test considerations structured around the Program Objectives and Priorities preferred methods of solution, shown on Table I, fall into three areas as follows:

- o Wind tunnel tests that demonstrate the operational readiness of the prop-fan and the drive system through proof testing procedures

- o Wind tunnel tests that validate and/or advance the fundamental state-of-the-art of prop-fan propulsion

- o Wind tunnel tests that validate the airworthiness and predicted performance levels of the selected testbed aircraft.

The first of these areas could be addressed by means of full scale tests in a low speed wind tunnel such as the NASA Ames 40 x 80. This tunnel is large enough to take a "Gulfstream II" complete with two prop-fan drive systems installed. In the case of the KC135A a reduced span wing with two drive systems installed and a mocked-up fuselage would be required to properly simulate the KC135A prop-fan testbed configuration. Lockheed-Georgia, however, does not recommend wind tunnel testing of the full scale drive system prior to actual flight tests for the following reasons:

- o Most of the available wind tunnels are not capable of simulating the prop-fan design flight environment in terms of dynamic pressure, Mach number and temperature.

- o Most of the available wind-tunnel flow, solid-wall blockage limits are exceeded with the full size prop-fan testbed nacelle and wing section.

- o Low speed testing does not directly address the design point of the prop-fan.

- Costs of wind tunnel testing would be high relative to the usefullness of the data obtained.

No wind tunnel testing is proposed for the second area - the development of fundamental data for the prop-fan concept - since the testbed aircraft is intended to augment test data in this area.

The third area of concern is testbed aircraft oriented and tests proposed in this area relate directly to the airworthiness and performance of the testbed vehicles.

RECOMMENDED STATIC AND WIND TUNNEL TEST PLAN

The recommended test plan consists of a static test of the drive system and high and low speed wind tunnel tests of either testbed aircraft configuration to determine performance and/or flutter characteristics.

Drive System Static Test

- Static test stand experimentation of the full scale testbed propulsion system would be conducted to demonstrate operational readiness. These tests will provide proof-of-operation of both the prop-fan and the drive system as well as some near-field acoustic environmental data for the nacelle and adjoining structure. The tests would be independent of the receiving airframe.

Wind Tunnel Test Plan

The proposed wind tunnel test plan requires both high speed and low speed wind tunnel testing.

High Speed Wind Tunnel Test Plan

- High speed tests of a semi-span 0.21 scale model of either the GAC GII or the Boeing KC135A in the AEDC 16T tunnel are proposed. These tests would provide aerodynamic data for prop-fan blade classical and stall flutter characteristics, wing/nacelle flow field characteristics data and thrust/drag relationship of the prop-fan components.

- o Test of a 0.13 scale full span dynamically simulated model of the GAC GII in the NASA Langley 16 Ft TDT facility for the purpose of investigating testbed aircraft flutter characteristics.

Low Speed Wind Tunnel Test

- o A low speed wind tunnel (LSWT) test of a 0.10 scale full span model of the GAC GII in the Lockheed-Georgia LSWT to verify handling qualities and stability and control of the GII testbed aircraft.

WIND TUNNEL AND STATIC TEST PLAN SCHEDULE AND COSTS

The schedule and costs for the recommended static and wind tunnel test plan are summarized on Table XII. The tests span a period of 3 years from the program go-ahead and the costs in terms of manhours and Material and Direct Charges (M&DC) are:

Testbed Aircraft	Test Manhours	M&DC
GAC GII	55,720	$347,560
KC135A	45,380	$158,560

The low speed and flutter tests shown for the GAC GII are felt to be unnecessary for the Boeing KC135A testbed aircraft as flight safety analysis has shown that no handling or stability and control problems exist with the addition of two prop-fan propulsion units. Furthermore, flutter testing of the KC135A is not necessary as analysis shows that no appreciable changes in flutter boundaries occur as the result of the prop-fan additions.

The detailed discussion of the Static and Wind Tunnel Test Plan is to be found in Appendix "F".

PROGRAM COSTS AND SCHEDULES

Because of the proprietary nature of the Testbed Program Costs and the associated schedules, the detailed costs and schedules are presented in Volume II of this report. A summary of the salient features of the cost determination and of the schedule is, however, provided.

PROGRAM COST ASSUMPTIONS

The program costs were developed in terms of manhours and Materials and Direct Charges for each of the conceptual twin prop-fan designs. Cost estimation methodology was based on the Lockheed-Georgia Company experience in the design and manufacture of a wide variety of aircraft. The consistency of the cost-prediction base was assured by assuming that Lockheed-Georgia would execute the total program and be supported by subcontract arrangements for those activities in direct support of Lockheed-Georgia.

The cost data also assumed that:

- o The aircraft for conversion to the testbed configuration would be GFE.
- o The modified DDA XT701 drive systems would be GFE
- o The prop-fans and modified controls would be GFE

PROGRAM ESTIMATED COST

The cost to perform the entire program for either of the recommended conceptual designs is in the range of $\$40 \times 10^6$ to $\$45 \times 10^6$ based on the value of the U.S. dollar in 1981.

PROGRAM SCHEDULE

The program schedule, Table XII covers a period of 6-3/4 years from the initiation of the program to the completion of the documentation of the flight test results. The testbed program consists of a phased arrangement of seven technical tasks and an overall management task. These tasks are as follows:

	PROGRAM PHASE/MILESTONES/EVENTS		ADVANCED TURBOPROP TESTBED PROGRAM YEAR 1 2 3 4 5 6 7 8 9 10
1	ADVANCED TURBOPROP TESTBED SYSTEM		CONTRACT
2	PHASE I	TECHNICAL ANALYSES	FLUTTER ANALYSIS GII ONLY; S&C ANALYSIS
3		PRELIMINARY DESIGN	CONFIGURATION DEFINED
4	PHASE II	TECHNICAL ANALYSES	
5		DESIGN	PDR; DDR
6		FABRICATION AND DRIVE SYSTEM INSTL.	FORGINGS REC.; DRIVE SYSTEM RECEIVED LOCKHEED; Q.E.C. FAB AND ASSY COMPLETE
7	PHASE III	TECHNICAL ANALYSES AIRCRAFT MOD.	
8		DETAIL DESIGN AIRCRAFT/MODS WING/NACELLE	PDR; DDR; ACOUSTIC MODS
9		FABRICATION AND MODIFICATION	TESTBED AIRCRAFT REC. LOCKHEED
10	PHASE IV	NACELLE PREP. AND PROP-FAN INSTL	PROP-FAN REC. LOCKHEED; DRIVE SYSTEM INSTALLED ON TESTBED
11		TEST STAND PREP.	
12		DRIVE SYSTEM STATIC TEST	DRIVE SYSTEM TESTS COMPLETE
13	PHASE V	SYSTEM FUNCTIONAL TEST	FUNCTIONAL TESTS COMPLETE
14	PHASE VI	TECHNICAL SUPPORT	
15		PLANNING INSTRUMENTATION DESIGN	
16		GROUND TESTS	GROUND TESTS COMPLETE
17		FLUTTER AND AIRWORTHINESS TESTS	AIRWORTHINESS TEST COMPLETE
18		TESTBED FLIGHT TESTS	FIRST FLIGHT TEST; FLIGHT TEST COMPLETE
19	PHASE VII	PROGRAM MANAGEMENT	ADVANCED TURBOPROP TESTBED PROGRAM COMPLETED

TABLE XII. ADVANCED TURBOPROP TESTBED SYSTEMS PROGRAM SCHEDULE

- <u>Phase I - Testbed Aircraft Definition and Development</u> - This phase is essentially the Preliminary Design Phase in which the configuration development and geometric description of the aircraft nacelle lines and scantlings will take place. A structural analysis, including a rigorous flutter analysis, if necessary, to verify nacelle location and to size structural members for design, and weight and balance checks will be conducted. A detailed performance analysis to establish drag levels to predict the mission performance of the test-bed aircraft would also be conducted. Propulsion System Analysis to provide air induction system design data, installed drive system performance and subsystems installation design data will be carried out. Stability and control analysis to determine stability and control characteristics of the testbed aircraft with the prop-fan drive systems installed will be conducted. Finally, the Aircraft Modification Design Analysis to establish the preliminary design of the QEC, wing and aft nacelle structures and aircraft subsystems will be performed.

- <u>Phase II - Drive System QEC Development Design and Fabrication</u> - This phase will produce an airworthy drive system for test-stand and test-bed application by performing analyses and design of the drive system QEC, which will include optimization of the air induction system, drive system performance predictions, flow-field analyses of the installation, stability and control checks of the effects of the QEC design, and the detailed design of the QEC nacelle and mounting structures, which will include structural analyses of the QEC nacelle structure. At the conclusion of the analyses and design, the QEC parts will be fabricated and assembled, resulting in a flyable QEC drive system.

- <u>Phase III - Design and Fabrication of Required Aircraft Modifications</u>- This phase will take the selected airframe and convert it to the testbed configuration. This will involve detailed analysis of all affected structures and systems including, not only the propulsion system and its related controls, but also the aircraft flight control system. This analysis will be conducted so that detailed design of the aircraft modification can be performed concurrently. Hardware will be fabricated as soon as design validation permits.

- <u>Phase IV - Static Test of the QEC on the Engine Test Stand</u> - This phase consists of the static test of the flyable drive system designed and assembled in Phase II to establish operational readiness of the QEC and systems before assembly to the testbed aircraft in Phase III. The test stand schedule will be arranged so that the engine tests will be concurrent with the Phase III work and will be completed to coincide with the aircraft modification for final installation on the testbed aircraft.

- <u>Phase V</u> - System functional test will be performed, following completion of the Phase III assembly, to etablish the performance of all the systems associated with the operation of the testbed aircraft, prior to conducting airworthiness tests of the modified aircraft.

- <u>Phase VI</u> - The final phase of the testbed program will be the testbed aircraft flight test program which will consist of the airworthiness flight test, followed by the Advanced Turboprop Testbed Flight Test Program.

- <u>Phase VII - Program Management</u> - This phase covers the entire time span of the testbed program.

Details of the Task VI-Testbed Program Costs and Schedules is to be found in Volume II of this report.

SUMMARY OF STUDY RESULTS AND DISCUSSION

The study results are summarized and discussed in the following text:

- o Program Objectives and Priorities necessary to enhance industry acceptance of the prop-fan for commercial aircraft and establish technology readiness have been identified and defined for a number of critical technology areas. A total of 30 objectives have been identified as crucial to the continued development of prop-fan propulsion. Furthermore examination of the objectives shows that the majority of the objectives are best approached through the medium of a test-bed aircraft.

- o The survey of drive systems reveals the scarcity in the U.S.A. of power sections at power levels of 2984 kW (4000 shp) and above. This imposed constraints on the testbed aircraft system by limiting prop-fan size to that required by the highest power level available; that of the DDA XT701 at 6018 kW (8071 shp), which imposed restrictions on the testbed aircraft configuration. A prop-fan drive system can be assembled from existing hardware suitably modified. The drive system installation design approach is based on the Quick Engine Change (QEC) concept. Use of the Lockheed P-3C nacelle structural components results in an overdesigned nacelle which renders the drive system independent of the receiving airframe. The nacelle contours and structural arrangements are simple and the nacelle contours developed apply to either a "Pinion-high" or "Pinion-low" arrangement. The drive system recommended for testbed application is a "Pinion-high" configuration consisting of the DDA XT701 in combination with a DDA T56-A-14 gearbox driving an eight-blade prop-fan 2.89 m (9.5 ft) in diameter. The "Pinion-high" configuration was selected as representative of commercial aircraft overwing nacelle installations. The study shows that the XT701 supervisory electronic control and the Hamilton Standard 54H60 propeller control can both be modified for testbed aircraft application.

- Aircraft suitable for conversion to prop-fan testbed configurations exist and of those examined the GAC GII and the Boeing KC-135A offer the best chance of achieving success. In the case of the GAC GII the airframe and the prop-fan propulsion system are very closely matched. The modification of the GII wing is, however, much greater than that required for the KC-135A. Although the GII flutter characteristics appear marginal for the two prop-fan locations examined, further analysis at other locations between the two investigated is expected to show that a location exists at which the wing flutter characteristics are acceptable. Either of the prop-fan testbeds are capable of performing to the test requirements, first to qualify the prop-fan, and secondly to establish the near- and far-field noise characteristics and the design of suitable cabin noise attenuation concepts. The design of the testbed aircraft configuration is limited by the lack of adequately sized propulsion, i.e., it is not possible to substitute a prop-fan unit capable of generating the thrust of a turbo-fan for an existing primary engine. The twin prop-fan approach adds an element of safety to testbed aircraft since the basic performance of the aircraft is not degraded. Airport operations would, therefore, be conducted using the primary propulsion.

The study further shows:

- The data base for contouring prop-fan nacelles to operate at Mach numbers up to 0.80 to be inadequate. The study nacelles were generated from data from an axi-symmetric non-flow through propeller test rig. To design a highly non-symmetric nacelle testbed nacelle for integration with a wing requires more and continued research to establish design parameters and nacelle configurations.

- A prop-fan of larger scale than the present experimental hardware is needed to demonstrate manufacturing feasibility of the spar-shell structural concept and achievement of the proper mass and stiffness distributions.

- o There is considerable doubt about the magnitude of the swirl effects and of the means by which these effects can be improved.

- o Wind tunnel testing of the full size drive system prior to flight test is not recommended because:

  - The available wind tunnels are not capable of simulating the prop-fan design point environment in terms of dynamic pressure, Mach number and temperature.

  - In most tunnels the tunnel flow solid wall blockage limits are found to be exceeded with the testbed drive system nacelle, prop-fan and a section of wing installed.

  - Low speed wind tunnel testing does not directly address the design point of the prop-fan.

  - The costs of wind tunnel tests would be high relative to the usefulness of the data obtained.

Overall, the Advance Turboprop Testbed Program described in this report is shown to be an effective means by which the Technology Readiness of Prop-Fan Propulsion can be established.

CONCLUSIONS

A number of conclusions have been reached from the results of this study, and each is presented in a single highlighted statement followed by a brief discussion of justification.

- <u>Review of the Testbed Program Objectives and Priorities shows the Testbed Aircraft as the best means of expediting problem solutions.</u>

  Thirty program objectives in four areas of technological concern require attention to establish prop-fan technology readiness and to enhance industry acceptance of the prop-fan concept. The majority of the objectives are found to be best addressed through the medium of a flying testbed aircraft.

- <u>A Suitable Powerplant and Gearbox - DDA XT701/T56-A-14 - can be assembled to drive a prop-fan about 3.0m (9.5 ft) in diameter</u>

  Three power sections in excess of 2984 kW (4000 shp) at sea level were examined for testbed application. Of the three, two were found to be unacceptable or marginal for prop-fan diameter which was fixed at a minimum of 2.42 m (8 ft). In addition to the larger prop-fan diameter attainable with the DDA XT701 combination, a further advantage is the free turbine design which allows a large measure of flexibility during flight testing. In the event that the U.S. Army owned DDA XT701 engines are not available for the testbed program, the industrial version of this engine, the DDA Model 570, could easily be converted to flightworthy status.

  The drive system integration with the testbed aircraft need not be a completely optimized design aerodynamically so that the installation could be designed as a Quick Engine Change unit. The nacelle installation can be designed to be independent of the receiving airframe which is accomplished by over-designing the drive system support structure through the use of Lockheed P-3C "Orion" V-Frame structures.

- **Two Aircraft - The Boeing KC-135A and the GAC GII - are attractive vehicles for conversion to prop-fan testbed aircraft.**

Six candidate aircraft were examined for testbed application - the Lockheed C-141A "Starlifter" and "JetStar" -6, the Boeing 737-100 and KC-135A tanker, the Convair 990 and the Gulfstream American "Gulfstream II." Of these the Boeing KC-135A and the GAC GII, the two selected aircraft, were the aircraft that best met the design conditions, provided sufficient test mission duration and a stable platform for testing, were the most suitable for acoustic investigations and easily modified to the testbed configuration. In the case of the GAC GII, a wing could be made available for modification and propulsion system installation ahead of the aircraft modification. This would reduce the time during which a GII aircraft would be out-of-service awaiting modification. The modified spare wing complete with the propulsion system would replace the wing on the aircraft to be modified. At the end of the program the original wing would replace the modified wing and the GII restored to the original configuration.

- **Program should proceed without delay if prop-fan propulsion is to be considered for inclusion on the next generation commercial passenger short/medium range transport aircraft**

The testbed aircraft program requires an elapsed time of 6-3/4 years. During this time the 2.84 m (9.5 ft) diameter prop-fan and the XT701 drive systems are to be manufactured and developed, an airframe is to be acquired and modified, the aircraft flight and acoustic tests are to be completed and the test data reduced. A new short/medium range aircraft for transporting 100/150 passengers with an IOC date of 1990 is foreseen. This would require a design commitment to prop-fan propulsion about 1987 if Advanced Turboprop Propulsion is to be considered as an alternative to turbofan propulsion. The Prop-fan Testbed Program should therefore proceed without delay. This program is of such great importance to potential users in terms of economic benefit that the schedule should in fact, be accelerated.

- **Testbed aircraft program outlined provides a cost effective means of verifying prop-fan performance**

The use of existing power plants, gearboxes, nacelle support structures and airframes and the minimization of modifications ensures a program total cost at the lowest possible level. No costly turbo-machinery or airframe development is required and both a Boeing KC-135A or a GAC GII could be made available for the program. The GAC GII is particularly attractive from the cost stand-point because of the availability of a spare wing.

- **Wind Tunnel tests of limited value**

Wind tunnel model tests of testbed aircraft configurations for airworthiness and flutter evaluation can be performed. The wider range of prop-fan experimentation is not amenable to full scale drive system tests in wind tunnels. Such tests can only be accomplished in a limited number of facilities none of which can simulate the prop-fan flight environment. These tests would be restricted by tunnel size limitations which would give rise to severe blockage problems, and by lack of proper simulation of the flight environment, i.e., M = 0.80 at an altitude of 10668 m (25,000 ft). Furthermore the lack of anechoic facilities required for near-field acoustic testing in the flight environment also precludes wind tunnel testing for noise characteristics.

The effect overall is to limit the usefulness of wind tunnel testing to performance data and provide a small amount of validation of the prop-fan structural characteristics.

APPENDICES

APPENDIX A - TESTBED PROGRAM OBJECTIVES AND PRIORITIES - TASK I

The scope of the Testbed Program Objectives and Priorities study was confined to the following four areas of technological concern:

- o Integrity of the Structure
- o Acoustic Environment
- o Aircraft Performance
- o Functional Systems Operation and FOD Vulnerability

INTEGRITY OF THE STRUCTURE

Although considerable progress has been made in the last five years it is recognized that the largest prop-fans made so far have diameters of 0.62 m (2.04 ft) and have never been tested in a realistic flight environment and, furthermore, have never been tested with an actual turboprop drive system. Before manufacturers and users can commit prop-fan propulsion systems to aircraft design the Integrity of the Structure, both of the prop-fan and of the airframe, must be verified to establish that large scale prop-fans can be built light enough for flight hardware and can be made stiff and strong enough to sustain the dynamic loads to which they will be subjected.

Propeller Structural Integrity and Dynamics

Three technological aspects that concern the propeller and need attention are: (a) the blade dynamic response to the aerodynamic flow field, (b) blade stall and classical flutter characteristics, and (c) the critical speed determination and verification of hub stiffness.

Blade Dynamic Response - Blade dynamic response is a function of the aerodynamic flow field, the blade aerodynamic characteristics and the blade structural dynamic characteristics. Wind tunnel tests of the 0.62m (2.04 ft) diameter prop-fan models should provide data on the first two considerations but would lack proper simulation of the structural dynamic characteristics of large spar/shell blades. To generate the proper flow field, the vibratory response testing must be performed in the presence of a swept wing, nacelle and fuselage combination, sized to be representative of a testbed aircraft.

OBJECTIVE 1: CONFIRM THE SMALL-SCALE TEST EXCITATION LOADINGS IN THE PRESENCE OF A REALISTIC FLOW FIELD AND MAKE AN ASSESSMENT OF THE STRUCTURAL RESPONSE OF LARGE-SCALE BLADES.

APPROACH: Perform tests using a testbed vehicle to evaluate the excitation and overall response of large-scale prop-fan blades. Testing should include a full range of speeds and altitudes from static to Mach 0.8 cruise, a full range of ground wind velocities and directions in conjunction with representative thrust levels, a full range of wing angle-of-attack with and without flaps and a range of yaw angles.

Blade Classical Flutter - The possibility of classical flutter of prop-fan blades is 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 both upon the aerodynamic and structural characteristics of the blade. Blade aerodynamic characteristics can be represented by small blades, but structural characteristics can only be accurately simulated at large scale so that flutter testing must be conducted using large scale spar/shell construction blades.

OBJECTIVE 2: CONDUCT BLADE CLASSICAL FLUTTER VALIDATION USING A TESTBED VEHICLE.

APPROACH: Perform tests at high Mach numbers over the full range of operating conditions monitoring stresses and frequencies for indications of the approach of classical flutter.

Blade Stall Flutter - During takeoff and reverse thrust operations, the highly loaded prop-fan blades are largely in a stalled condition and are, therefore, susceptible to stall flutter. Duplication of the true aeroelastic and geometric characteristics as well as torsional frequency requires the use of large-scale blades. Since stall flutter is most likely to occur at static or low speed at high power conditions, a testbed vehicle would be the best means for conducting tests.

OBJECTIVE 3: EVALUATE PROP-FAN STALL FLUTTER CHARACTERISTICS THROUGHOUT THE CRITICAL OPERATING RANGE TO ESTABLISH STALL FLUTTER BOUNDARIES.

APPROACH: Perform blade stall flutter validation using a large-scale prop-fan. Monitor blade torsional stresses for a range of operating conditions and estimate the stall flutter boundary.

Critical Speed and Hub Stiffness - Any blade rotating assembly should be examined for speed criticality, since propeller blades exhibit several modes of resonant vibration over their operating range. The range of blade frequencies of interest is determined by the number of periodic forcing functions possible and by the strength of the excitations. Prop-fans of eight or more blades may have as many as five significant excitations per revolution (5P) so that excitations beyond 5P need not be considered. The possibility of excitation at resonance within the operating range will be indicated by the intersection of blade natural frequencies of the first, second, and third modes with the integer order excitation lines.

OBJECTIVE 4: VALIDATE PROP-FAN CRITICAL SPEED AND THE HUB AND RETENTION STIFFNESS OVER THE FULL RANGE OF OPERATING RPM.

APPROACH: Perform critical speed determination using a testbed aircraft prop-fan installation by establishing the blade frequencies for excitations up to 5P. Determine hub and retention stiffness for these conditions.

Propeller-Induced Vibrations and Dynamics

All propellers, whether of conventional or advanced design, when mounted in front of a wing experience cyclical loadings due to the flow field generated by the presence of the loaded wing and of the adjacent components such as the fuselage and other nacelles. When mounted on a swept wing and operated at high subsonic Mach number, the flow field becomes complex and unsymmetrical and induces unusual dynamic loadings on the propeller and, therefore, on the powerplant and aircraft structure. Unsteady random and periodic forces can be imposed on the prop-fan by the ground plane, fuselage exterior, swept-wing leading edge, nacelle and engine air inlets, adjacent propellers and nacelles, oblique flow due to yaw, angle-of-attack, crosswind, and other factors. Unless taken into account during design and development, these forces could cause structural failure of the prop-fan and/or the airframe.

Flutter and Dynamic Loads - The use of prop-fans on high-subsonic-speed transports introduces the possibility for two types of wing flutter problems: (a) whirl flutter, and (b) a reduction of wing flutter stability. Although both these phenomena can occur on conventional propeller driven aircraft, the higher operating Mach numbers for prop-fans are expected to adversely affect the stability of these modes. Although these two flutter phenomena strictly cannot be separated, whirl flutter stability problems can be avoided by providing adequate mounting rigidity for the propulsion installation.

Propeller aerodynamic and gyroscopic forces and moments are known to reduce wing flutter speeds significantly. The degree to which this occurs is strongly dependent upon configuration, but powerplant spanwise and chordwise location relative to the wing are important parameters affecting the degree of coupling between the wing and propulsion system. Performance considerations may require the prop-fan installation to be located farther forward on the wing than existing turbofans, which would tend to increase the coupling with the flexible wing loads.

The whirl flutter and wing flutter coupling are both dependent upon propeller unsteady normal forces and moments associated with angle-of-attack changes. No steady or unsteady normal forces and moment data have been measured for prop-fans, but the coefficients are expected to be significantly higher than those of conventional propellers due to the higher Mach numbers at which the prop-fans operate.

OBJECTIVE 5: OBTAIN AERODYNAMIC DATA BY WIND TUNNEL TESTING TO EVALUATE AND PROVIDE A BASIS FOR FLUTTER, PERFORMANCE AND STABILITY AND CONTROL ANALYSES.

APPROACH: Perform wind tunnel tests using scale models to obtain side-force and moment variations with angle-of-attack. Although unsteady aerodynamic derivatives are needed for flutter analyses, the reduced frequencies associated with potential for whirl flutter and wing flutter instabilities are quite low, and a quasi-steady application of steady derivatives should provide sufficient accuracy.

Side force and moment data will be measured for a range of Mach numbers, advance ratios, and angles-of-attack sufficient to cover the predicted operating envelopes of future prop-fan aircraft, including overspeed conditions required for flutter evaluation. The instrumentation should be capable of isolating two-axis forces and moments on the prop-fan, excluding those on the nacelle and wing section, if used.

Perform flight tests of the prop-fan testbed aircraft to verify the data measured in the wind tunnel tests. Since the wind tunnel test data will be affected by wall reflections, flight test data should be measured for a few selected conditions and used to verify or adjust the wind tunnel test data. Instrumentation sufficient to measure side force and pitching moment due to aircraft sideslip would be provided.

Propeller-Induced Vibration - Sound pressures radiating from the prop-fan disc and fluctuating pressures in the prop-fan wake will excite resonances in the airframe structure, and/or drive the structure at non-resonant conditions at potentially destructive amplitudes that will require preventive design. Although the technology is available to deal with the design problem, the analytical tools for defining the environment and quantifying the vibratory strain and acceleration amplitudes are not precise enough to avoid large-scale testing.

Evidence is required to confirm that an acceptable vibratory fatigue life can be obtained for aircraft structures fabricated from state-of-the-art materials placed near a prop-fan.

OBJECTIVE 6: DETERMINATION OF THE FUSELAGE, WING, AND EMPENNAGE STRUCTURAL VIBRATION SPECTRA, AND THE SKIN AND SUBSTRUCTURE DYNAMIC STRAIN SPECTRA.

APPROACH: Analytically or empirically derive the resonant structural response amplitudes that are induced by the fluctuating pressure environment generated by the prop-fan. Validate the derivations with vibration and strain measurements from the testbed aircraft.

__Prop-fan Drive System Dynamic Loads and Induced Effects__ - A structurally safe testbed aircraft is a prime consideration in establishing the testbed aircraft program objectives. Although the structural integrity of the prop-fan is mainly the concern of the prop-fan manufacturer, the influence of the flow field of the installed testbed prop-fan propulsion system must be considered.

Unsteady random and periodic forces can be imposed on the prop-fan by the ground plane, fuselage wall, swept-wing leading edge, nacelle and engine air inlet, adjacent propellers and nacelles, oblique stream due to yaw, angle-of-attack, crosswind and other factors. Unless taken into account during design and development, these factors could cause structural failure of both the prop-fan and the airframe.

The problems associated with accurate prediction of blade and shaft stresses, correlation of analysis with measured data and of the test instrumentation and conditions must also be considered.

OBJECTIVE 7: DETERMINATION OF PROP-FAN DYNAMIC AND INDUCED LOADS TO ASSURE STRUCTURAL INTEGRITY OF THE TESTBED SYSTEM.

APPROACH: Data from high- and low-speed wind tunnel tests, static tests and from tests already completed will be used to perform analyses of the testbed installation to validate structural integrity.

The results of the analysis will be correlated with measurements from the testbed aircraft in an operational environment.

Scale Effects

One of the questions of great significance in developing the prop-fan propulsion system relates to scale effects. So far, it has been demonstrated that a prop-fan 0.62 m (2.04 ft) in diameter when tested in a wind tunnel develops sufficient thrust to lend confidence that the design goals for propulsive efficiency can be met. Other test programs, using prop-fans at the same scale, will continue to provide data on the effect of forward velocity on near-field noise and on propulsive efficiency of a representative assembly of wing, nacelle, and prop-fan when tested in a transonic wind tunnel.

Current studies of the feasibility and economics of prop-fan propulsion indicate that large-scale prop-fans will be in the size range of 3.66 to 4.87 m (12 to 16 ft) in diameter. The testbed prop-fan, on the other hand, will be constrained to a diameter of 2.44 to 3.048 m (8 to 10 ft) by the power available from available drive systems. This prop-fan size, relative to the 0.62 m (2.04 ft) diameter prop-fan previously tested, is expected to provide a good basis for the evaluation of scale effects.

Technology areas in which scaling effects are likely to be encountered in prop-fan design can be subdivided into the following general and specific areas:

1. Propeller structural integrity and dynamics scale effects
    a. Blade strength and stiffness
    b. Blade structural dynamics

2. Propeller generated near and far field noise scale effects
    a. Near- and far-field noise prediction
    b. Cabin-noise attenuation

3. Installed efficiency and interaction scale effects
    a. Prop-fan/spinner/nacelle interaction
    b. Slipstream/wing flow interaction

4. Large scale drive system scale effects.

<u>Propeller Structural Integrity and Dynamics Scale Effects</u> - To establish the most accurate test data possible and to avoid additional analytical correlation studies, the large-scale prop-fan diameter should be of the order of 2.44 to 3.048 m (8 to 10 ft). The selection of a 2.44 to 3.048 m (8 to 10 ft) diameter for the testbed aircraft arises from two considerations:

1. Accurate representation of the total blade airfoil mass and stiffness distributions 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.

2. Accurate representation of size, shape, and thickness of the blade construction elements, so that a clear verification of full-size fabrication feasibility will be made.

The results of the SR-3, SR-5, and SR-6 aeroacoustic 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, and 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, blade and mode shapes, and 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 evaluation.

The accuracy of the simulation of a large scale prop-fan blade is size-dependent, since the blade will be made of several materials of different densities to reduce weight. Since there are practical limitations on the thickness of blade parts, both from the fabrication and durability standpoints, 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 skin thickness on the pressure side would be 0.152 cm (0.060 in) to 0.203 cm (0.080 in). Scaling this thickness directly with diameter from 3.048 m (10 ft) to 0.62 m (2.04 ft), the thickness would be 0.0305 to 0.0381 cm (0.012 to 0.015 in). Since most composite laminates are about this thickness, multilayer laminates, which are necessary to achieve required strength and stiffness properties, are ruled out.

Fabricating a blade skin from thin sheet metal would require completely different techniques than would be applied to a full-scale blade.

In the area of blade retention, similar scaling limitations are encountered. In order to reverse thrust, blade pitch must be variable. An antifriction 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 antifriction bearings and pitch control elements, gears, ballscrews, links, rod ends, and slider blocks cannot be scaled down below a certain point because of fabrication and durability characteristics.

From design work on SR-3, SR-5, and SR-6 model prop-fans, all of which had solid metal blades without antifriction retention bearings, it was concluded that an accurate demonstration of the dynamic behavior and fabrication feasibility of a large scale prop-fan could not be achieved in a diameter of less than 2.44 to 3.084 m (8 to 10 ft).

Propeller-Generated Near- and Far-Field Noise Scale Effects - No data are currently available to demonstrate that propeller noise data can be accurately scaled from one diameter to another. Analytical scaling techniques have been developed, but have not been adequately validated. The testbed program will provide valuable data toward that end. The near-field noise data comparison of a nominally 2.44 m (8 ft) diameter prop-fan with data from the upcoming Jetstar testing of the 0.62 m (2.04 ft) diameter prop-fan will help to validate scaling effects methods. This validation, in turn, will permit more confident prediction of noise from full-scale prop-fans.

Installed Efficiency and Interaction Scale Effects - While it has been demonstrated that small scale prop-fans closely approach the 80-percent propulsive efficiency set as a performance goal, the same tests also show that installed propulsive efficiency is strongly dependent on the optimization of the propulsion system and the wing interaction. As will be detailed in later sections, the testbed concept does not lend itself to aerodynamic/propulsion optimization.

The aerodynamic/propulsion optimization work can best be done in the more flexible environment of a wind tunnel test program, and it is anticipated that results from such a wind tunnel test program could be scaled with a high level of confidence.

In the area of scale effects, it is therefore concluded that:

- o The basis for determining the minimum prop-fan diameter needed for the testbed aircraft is that the blades be large enough to allow the same structural design concepts as are anticipated for large-scale applications.

- o Noise data from the testbed prop-fan with a diameter in the range proposed 2.44 to 3.048 m (8 to 10 ft), will be a most valuable addition to the state-of-the-art. Correlation with the 0.62 m (2.04 ft) diameter prop-fan data and theory will provide a basis for scaling to larger diameters.

- o The aerodynamic/propulsion optimization that is needed should be obtained from wind tunnel tests. No major problems are anticipated in scaling such data to larger-scale designs.

OBJECTIVE 8: VALIDATE AND/OR DEVELOP AERODYNAMIC, ACOUSTIC AND STRUCTURAL SCALING LAWS FOR LARGE-SCALE PROP-FAN INSTALLATIONS.

APPROACH: a. Analyze aerodynamic, acoustic and structural data from all the technical investigations described in subsequent sections and correlate with data from other experimental programs and with existing analyses in order to develop the methodology for the design and characteristics of prop-fans in the diameter range of 3.66 to 4.87 m (12 to 16 ft).

b. Perform flight test of the testbed installation in an operational environment and correlate flight test data to validate scaling laws.

OBJECTIVE 9: DETERMINATION OF BLADE MASS AND STIFFNESS DISTRIBUTIONS AND AEROELASTIC CHARACTERISTICS. VALIDATE BY CONDUCTING TESTBED AIRCRAFT FLIGHT TEST.

APPROACH: Conduct design studies for a range of prop-fan diameters and obtain blade mass and stiffness distributions that satisfy the design requirements. Verify by correlating the analytical results with flight test data using a testbed aircraft.

OBJECTIVE 10: VALIDATE THE MANUFACTURING FEASIBILITY OF THE SPAR/SHELL CONCEPT FOR PROP-FAN BLADES.

APPROACH: Conduct manufacturing investigations of blade construction for various prop-fan diameters. Establish the practical size limitations and verify manufacturing feasibility by fabricating and testing the blades.

Large-Scale Drive System Scale Effects - The largest currently available propeller drive systems generate in the region of 3728 to 4473 kW (5000 to 6000 shp). Studies of the power requirements for future aircraft indicate a need for core engines developing 11,184 kW (15,000 shp) and reduction gearboxes capable of transmitting high levels of torque. The size of the core engine and configuration of drive system relative to the type of gearbox used affects the aerodynamic and structural design of the nacelle and gearbox reliability affects the economic viability of an aircraft.

OBJECTIVE 11: ESTABLISH THE FEASIBILITY OF DRIVE SYSTEMS OF 11,184 kW (15,000 SHP) AND ABOVE FOR FUTURE AIRCRAFT IN A COMMERCIAL ENVIRONMENT.

APPROACH: Perform design studies of engine cores and gearboxes to establish the feasibility of drive system design and the impact of system reliability on aircraft economics. Formulate drive system sizing laws for use in aircraft system studies.

ACOUSTIC ENVIRONMENT

In spite of the fact that acoustic tests have been made on several prop-fan configurations uncertainty still exists about prop-fan noise. Existing test facilities cannot simulate the high transonic cruise speed in an anechoic environment and the conclusion that prop-fans can operate with about 136 dB SPL at the fuselage side is based on extrapolation from low speed tests. The questions to be resolved as far as near-field noise is concerned is whether the desired cabin interior noise attentuation can be achieved without incurring weight penalties that would offset the performance gains of the prop-fan. Far-field noise characteristics are also of concern since compliance with FAR Part 36 requirements for community noise levels must be verified if the prop-fan concept is to gain acceptance.

Propeller-Generated Near-Field Noise

Since the prop-fan will be a major cause of cabin noise and vibration, a comprehensive understanding of both the noise generated by prop-fans and the relationship of this generated noise to the prop-fan principal parameters is essential.

The determination and evaluation of the prop-fan noise characteristics should use data obtained from sources such as the JetStar model tests, wind tunnel tests, and testbed model and full scale tests, in order to obtain comparisons of analytical predictions.

Near-field noise level prediction methodology is inadequate in several respects such as accounting for wave propagation over a curved surface, cancellation and reinforcing from multiple sources, synchrophasing, effects of forward motion on surface reflection, angle-of-incidence and propagation path.

The inadequacy of current theoretical and analytical prediction techniques require the use of a testbed to quantify the near-field noise environment as well as to validate or modify analytical methods. The objectives of the testbed program will therefore include consideration of the near-field noise technology.

OBJECTIVE 12: DETERMINE THE SOUND-PRESSURE DIRECTIVITY AND THE SPECTRA VARIATION AT EACH MULTIPLE OF THE BLADE PASSAGE FREQUENCY FOR EACH PROP-FAN NOISE SOURCE RADIATED LATERALLY ONTO THE FUSELAGE AND FOR FLUCTUATING PRESSURES CONVECTED REARWARD IN THE PROP-FAN SLIPSTREAM IMPINGING ON THE WINGS AND EMPENNAGE.

APPROACH: Measure the sound pressure spectra in a spatial array using a prop-fan testbed aircraft. Derive analytically, where methods exist, the variation in sound pressure spectra with blade load and thickness, number of blades, helical tip Mach number, blade stall characteristics, in-flow angle in pitch and yaw, and interference effects from wings, nacelle inlets, and adjacent components of the aircraft. Obtain the same spectra from the testbed aircraft by direct measurement and correlate the analytical and experimental results and demonstrate the adequacy of the analytical methods.

OBJECTIVE 13: DETERMINATION OF THE SOUND PRESSURE LEVELS OVER THE FUSELAGE PRESSURIZED SURFACE AREA.

APPROACH:: Measure sound pressure spectra on the testbed aircraft fuselage surface for the first 10 multiples of the blade passage frequency, while varying operating conditions such as speed, altitude, horsepower, and synchrophasing.

Correct the data to large-scale prop-fan applications using the scaling relations from Objective 8 and the parametric relations determined in Objective 12. Analytically account for multiple prop-fans rotating in a fixed optimum phase relation

OBJECTIVE 14: DETERMINATION OF THE STRENGTH AND DIRECTIVITY OF THE NOISE FROM BLADE VORTICES, SEPARATED FLOW TURBULENCE, AND BLADE THICKNESS AND LOADING AT SELECTED LOCATIONS OF THE WING AND FUSELAGE FOR DESIGN MODIFICATION TO TESTBED SIZE PROP-FANS.

APPROACH: Derive the quantities analytically, and substantiate the derivations with measurements from the testbed aircraft.

OBJECTIVE 15: DETERMINATION OF THE FULL-SCALE AIRCRAFT FLUCTUATING PRESSURE SPECTRA WHERE THE PROP-FAN SLIPSTREAM IMPINGES ON THE WINGS AND EMPENNAGE.

APPROACH: Correct the fluctuating pressure spectra obtained on the testbed aircraft in Objective 13 to full-scale aircraft conditions using the scaling relations determined in Objective 8. Quantify the variation of the fluctuating pressure spectra with forward airspeed and rearward convection distances for the prop-fan vortices, the blade thickness and loading noise, and the blade flow separation turbulence during takeoff roll.

OBJECTIVE 16: DETERMINATION OF THE EFFECTS OF FUSELAGE SURFACE CURVATURE ON THE STRENGTH OF THE SOUND PRESSURES PROPAGATING OVER THE FUSELAGE, AND ON THE PRESSURE DOUBLING AT THE SURFACE.

APPROACH: Establish the effects analytically, and obtain substantiating measurements from the testbed aircraft.

OBJECTIVE 17: FOR A FULL SCALE AIRCRAFT WITH ALL PROP-FANS OPERATING, DETERMINE THE GEOMETRY OF THE FUSELAGE SURFACE AREA WITHIN WHICH SOUND PRESSURES ARE SPATIALLY CORRELATED AT MULTIPLES OF THE BLADE PASSAGE FREQUENCY.

APPROACH: Derive the area geometries analytically for the prop-fan testbed, then measure spatial correlation at selected critical locations on the testbed and compare to the analytical derivations. Establish suitable accuracy of the analytical methods; then derive the geometries of the areas of correlated pressures for a full scale aircraft with all prop-fans

Propeller-Generated Far-Field Noise

The far-field noise characteristics of a prop-fan powered aircraft constitute an area of technological concern. Current prop-fan noise prediction methodology is based upon an extension of propeller theory and on the noise measurements from small scale prop-fans operating in a low forward speed environment.

Propeller and prop-fan noise signatures cannot be measured with accuracy on a static test rig since the blades are usually stalled at useful disk loadings and the noise emissions change drastically with forward speed.

While forward speed requirements can be simulated in large-scale wind tunnels, other constraints limit the usefulness of the noise measurements. Reflections from the walls of the tunnel interfere with noise measurement by reinforcing or cancelling the signals at certain frequencies. It is usually not feasible to line the tunnel walls with sound-absorbent material, especially if high speeds are involved. In addition, the tunnel generated noise is high in the low-frequency range which would seriously interfere with measurement of the prop-fan fundamental and low harmonic orders.

OBJECTIVE 18: VERIFY THE PROP-FAN FAR-FIELD NOISE REQUIREMENTS AS STATED IN FAR PART 36 CERTIFICATION TEST.

APPROACH: Perform measurement of the noise of a large-scale prop-fan installed on a testbed aircraft at representative flight speeds. The testbed aircraft and drive system should be such that there will be no excessive interference with the noise emitted by the prop-fan.

To ensure reliable noise measurements, the following requirements must be met:

a) The testbed aircraft should be capable of operation with the non-prop-fan engines throttled back.

b) The non-prop-fan engines should not contribute significantly to noise in the frequency range under consideration, i.e., 150 to 500 Hz. In this respect, a typical turbofan generates fan noise above 2 KHz, while low-frequency jet noise is of low magnitude.

c) The prop-fan drive system must also comply with the requirement of non-interference with the prop-fan noise signature.

Passenger Cabin Noise and Vibration

Passenger cabin noise and vibration levels are among the principal areas of concern in the application of the prop-fan to commercial passenger transport aircraft. Passenger comfort and public acceptance of the advanced turboprop require that the levels of noise and vibration in the passenger cabin of a prop-fan-powered aircraft be no greater than those in contemporary turbofan aircraft.

Cabin noise and vibration levels are strongly influenced by:

- The frequency, strength, and incidence of the propeller sound pressures.

- The degree to which the structure resonance conditions coincide with propeller excitation.

- The extent to which the structure/soundproofing/trim design has been optimized to counteract noise impinging on the exterior and to minimize the interior noise and vibration.

Evidence is required to show that passenger cabin noise can be controlled to desirable levels without incurring weight penalities that would offset the prop-fan fuel economies.

OBJECTIVE 19: DETERMINE THE MAGNITUDE OF THE NOISE REDUCTION ACHIEVABLE IN THE PASSENGER CABIN BY CREATING A "MISMATCH" BETWEEN PROPELLER BLADE PASSAGE FREQUENCIES AND THE CABIN ACOUSTIC MODE FREQUENCIES.

APPROACH: Measure the interior noise level in the testbed aircraft while varying the frequency of the exterior noise, using the same experimental setup as used for Objective 20.

OBJECTIVE 20: CONDUCT A RESONANCE FREQUENCY MODAL SURVEY AND DETERMINE THE FUSELAGE SHELL FREQUENCIES AND MODE SHAPES IN THE FREQUENCY RANGE OF 30 TO 500 HZ.

APPROACH: Use computerized transfer function analysis techniques with electroacoustically simulated prop-fan noise excitation of the testbed fuselage structure to experimentally determine the shell mode shapes for the complete fuselage. Repeat the experiments in the vicinity of the prop-fan, using actual prop-fan noise excitation of the structure, to evaluate the techniques and validate the results.

OBJECTIVE 21: DETERMINE THE RELATIONSHIP BETWEEN THE FUSELAGE SHELL RESONANCE FREQUENCIES AND MODE SHAPES AND 1) THE SPATIAL CORRELATION OF THE IMPINGING EXTERIOR NOISE, AND 2) THE INTERIOR VOLUME ACOUSTIC MODES.

APPROACH: Conduct analyses, and limited experiments on the testbed fuselage, to obtain the interior volume acoustic modes. Then use the spatial correlation data obtained in Objective 15 and the modal survey results of Objective 22 to establish the above relationships.

OBJECTIVE 22: VERIFY MINIMIZATION OF THE STRUCTURE MODAL RESPONSE BY OPTIMIZING PROP-FAN SYNCHROPHASING, AND DETERMINE THE MAGNITUDE OF THE NOISE REDUCTION OBTAINABLE BY USING SYNCHROPHASING TO "MISMATCH" AREAS OF CORRELATED EXTERIOR SOUND PRESSURES WITH SHELL MODES.

APPROACH: Using the same techniques for analysis and electroacoustic simulation of prop-fan noise as used in Objective 20, simulate four synchrophased prop-fans on the testbed airframe. Vary the phase relation of the noise sources while repeating the mode determinations so as to systematically minimize the modal response and identify the optimum phase relations.

Concurrent with these experiments, measure interior noise level in the testbed aircraft and obtain the data for relating noise level with modal response and noise source phase relations.

OBJECTIVE 23: DETERMINE THE IMPROVEMENTS ATTAINABLE BY STRUCTURAL TAILORING SO AS TO OPTIMIZE SHELL "MISMATCH" MODE SHAPE AND LOCATION RELATIVE TO AREAS OF CORRELATED EXTERIOR SOUND PRESSURE.

APPROACH: Modify the fuselage shell structure so as to use the restraint and/or stiffening effects of the floor, ceiling, and interior partitioning to alter the shape and location of the shell modes. Experimentally determine the mode shape changes; measure the interior noise level changes.

OBJECTIVE 24: OPTIMIZATION OF THE MATCHING OF THE DYNAMIC PROPERITES OF THE FUSELAGE SHELL STRUCTURE AND THE INTERIOR TRIM PANEL/AIR SPACE/INSULATION ASSEMBLY

APPROACH: Conduct analyses using existing and newly formulated theory as necessary, systematically varying the mass, stiffness, damping, absorption, and air space coupling of the structure and soundproofing/trim assembly, to perform a parametric optimization study. Install 2 variations of the soundproofing/trim design in the testbed, obtain measurements of sound transmission loss for the design variations, and evaluate the analyses methods. Demonstrate the effectiveness of an optimized fuselage shell/trim/insulation design.

AIRCRAFT PERFORMANCE

Optimum installation of the prop-fan propulsion system into a practical aerodynamic environment represents concern for at least two reasons. First, the high solidity and blade Mach number of the prop-fan creates core engine inlet problems which are compounded by the configuration of the engine air duct which must be arranged to account for the gearbox and drive shaft. Secondly, the integration of the prop-fan, nacelle, and wing into an efficient aerodynamic design must be arranged to minimize losses due to swirl and scrubbing effects which would tend to reduce the benefits of prop-fan propulsion.

Installed Propulsive Efficiency

Wind tunnel studies of small-scale prop-fans indicate that prop-fan net efficiency will reach the 80-percent goal at a cruise Mach number of 0.8. One objective of the technology development program will be to demonstrate that this goal can be achieved for a large-scale installation. This may, however, be very difficult to do on the testbed aircraft. Although flight test measurements of propulsion system thrust can be obtained under proper conditions, the accuracy of the thrust from the test installation determined by conventional flight test techniques may be low for a testbed aircraft powered by more than one type of engine. Some consideration has been given to the measurement of the thrust from the test engine by strain-gaging the engine support system. This has been done for pylon-mounted engines but would be very difficult, if not impossible, for the type of wing-mounted installation anticipated for the testbed.

Among other things, engine inlet performance can be significantly affected by the shape of the prop-fan spinner and hub and by the nacelle immediately behind the prop-fan. Engine inlet performance will, therefore, require verification both in wind tunnel tests and by flight tests to ensure that the propulsive efficiency is not impaired by duct design and lip location.

OBJECTIVE 25: PERFORM HIGH-SPEED SMALL-SCALE WIND TUNNEL TESTS TO OBTAIN DATA TO VERIFY PROPULSIVE EFFICIENCY.

APPROACH: Expand NASA-Ames prop-fan/nacelle/wing test program to include more realistic nacelles. Augment with tests from core inlet test rig.

Interaction Effects: Aerodynamic/Propulsion Integration and Optimization

Two important aspects are associated with the integration and optimization of the prop-fan/nacelle/wing installation: 1) the need to maintain the aerodynamic efficiency of a high-speed airfoil immersed in the prop-fan slipstream, and 2) the need to recover the propulsive thrust from the slipstream swirl. Reference 1 reports a wind tunnel study of a supercritical wing immersed in a simulated prop-fan slipstream. Swirl was found to effect wing drag, and the slipstream power additions affected wing shock location, but generally, these effects were less than anticipated. Some anomalies in these data, however, raise questions about the test techniques employed and the need for further study has been recognized. Upcoming tests of the 0.62 m (2.04 ft) diameter prop-fan in the NASA Ames 11-ft Transonic tunnel should provide additional verification data.

The wing can also significantly affect propulsive efficiency. Recovering residual swirl from the prop-fan slipstream, more than any other single factor, has the potential for providing large gains in efficiency. This swirl might be recovered by proper local tailoring of the wing as shown in the analytical study of Reference 1, but complete swirl removal could result in an impractical wing structure with sheared front and rear spars. More work is certainly needed in the area of optimizing the prop-fan/nacelle/wing interaction region. Although test data will be needed to validate and augment such analytical work, the testbed aircraft will not be the proper source for such data because the test wing will not be supercritical. Even if gloves are used to simulate a supercritical wing section locally, the installation and modifications together with any subsequent modifications would be very expensive.

It is, therefore, recommended that aerodynamic/propulsion integration and optimization studies should be a major part of a wind tunnel test program. This does not imply that the testbed aircraft will not contribute to solutions to this problem area. With proper instrumentation, e.g., wake and swirl rakes, distributed static pressure orifices, a large amount of useful data can be obtained which will aid the optimization of the prop-fan installation.

OBJECTIVE 26: PERFORM HIGH- AND LOW-SPEED WIND TUNNEL TESTS OF SCALED TESTBED (SPECIFICALLY PROP-FAN, NACELLE AND WING) THROUGH A RANGE OF FLIGHT AND PROPULSION SYSTEM VARIABLES TO OBTAIN DATA ON THE FLOW FIELD CHARACTERISTICS.

APPROACH: These data will be obtained by placing rakes in several azimuthal chordwise positions behind the prop-fan. The wing upper and lower surfaces will also be fitted with several chordwise rows of static pressure orifices. The flow field characteristics for the wing alone, prop-fan alone, and for the wing/prop-fan with both metric and non-metric nacelles/prop-fans, will be obtained. Definition of the flow characteristics will include swirl angles, axial velocity increments, surface pressure distributions, effect of local contouring, and effects of blockage.

Although the testbed aircraft will not be equipped with a supercritical airfoil section, the wind tunnel results will be analytically applied to such sections. Tailoring of the nacelle can then be accomplished and the results verified.

OBJECTIVE 27: DETERMINE ENGINE INLET PERFORMANCE FOR THE TESTBED PROP-FAN INSTALLATION THROUGH A RANGE OF FLIGHT CONDITIONS.

APPROACH: Install pressure rakes in the scaled testbed installation inlet and perform high-speed wind tunnel tests to obtain data.

Verify by flight test of the large scale propulsion system over a range of conditions.

FUNCTIONAL SYSTEMS OPERATION AND FOD VULNERABILITY

A number of propulsion subsystems also present areas of concern. Among these are the prop-fan pitch control system and the effectiveness of the thrust reverser, and the prop-fan blades vulnerability to foreign-object damage.

Prop-Fan Pitch Control System

Although the prop-fan pitch control system is expected to require only the normal functions of a conventional turboprop system, the testbed installation will provide verification of the assumptions that state-of-the-art systems are adequate.

OBJECTIVE 28: DETERMINE THE CHARACTERISTICS OF THE TESTBED PROP-FAN INSTALLATION CONTROL SYSTEM.

APPROACH: Perform flight tests in an operational environment to obtain data on the transient behaviour of the control system.

Thrust-Reversing Effectiveness

Application of prop-fans to transport aircraft will require knowledge of the thrust-reverser effectiveness. Measurement of reverse thrust, although presenting difficulties, has the advantage that the prop-fan propulsion system would be operated in a flight or taxi condition in which other propulsion units on the testbed aircraft would be shut down or at idle conditions.

OBJECTIVE 29: DEMONSTRATE THE EFFECTIVENESS OF THE PROP-FAN IN THE REVERSE THRUST MODE.

APPROACH: Perform measurements of reversed thrust in a flight or taxi condition with engines other than the prop-fan unit at flight idle or shutdown. Measurement of reversed thrust will be obtained in a manner similar to that for obtaining flight thrust.

Vulnerability to Foreign-Object Damage

Foreign-object damage (FOD) analytical methods have been correlated with fan-blade development test data. No tests have been performed using prop-fan blades constructed using the spar/shell concept, but analysis of the blades using the available methods shows that the blades can sustain large-bird strikes without affecting the structural integrity of the blades. No criteria exist that specifically relate to prop-fan FOD tolerance. The ability of the prop-fan to sustain foreign-object impacts is found to be in excess of a criteria established for turbofans (FAA Advisory Circular 33-1B). However, tests on large-scale blades are needed to verify impact resistance.

OBJECTIVE 30: VERIFY FOD TOLERANCE FOR ADVANCED LARGE-SCALE PROP-FAN BLADES FABRICATED USING THE SPAR/SHELL CONCEPT TO ESTABLISH VULNERABILITY.

APPROACH: Perform FOD tests on large-scale swept prop-fan blades in static tests simulating bird-strike and other objects such as nuts, bolts, small pieces of metal, and other materials such as dirt and sand that might cause blade erosion.

TESTBED PROGRAM PRIORITIES

Priorities for the testbed program objectives are based upon the relative importance of the integrity of the structure, acoustic environment, aircraft performance, and systems operation. Areas of technological concern are ranked according to priority as outlined below.

Program Priority 1 - Integrity of the Structure

The most important objectives are those related to the integrity of the structure, which includes both the prop-fan and the airframe, as well as scale effects.

Three areas of concern fall into this category:

a) Propeller structural integrity and dynamics
b) Propeller induced vibrations and static and dynamics loads
c) Scale effects

Program Priority 2 - Acoustic Environment

Public acceptance of the prop-fan will be dependent upon the far-field impact on community noise environment and of the near-field effect on the traveling public. Two acoustic areas must, therefore, be given second priority for testbed program objectives:

a) Propeller-generated near- and far-field noise
b) Passenger cabin noise and vibration

Program Priority 3 - Aircraft Performance

Those technological concerns that affect aircraft performance are placed third in order of priority. These objectives concern installed propulsive efficiency and the interaction effects that, to some extent, can be controlled by proper design of the powerplant nacelle and nacelle/wing integration.

Two technology areas fall into this category:

a) Installed propulsive efficiency and interaction effects
b) Engine inlet performance

Program Priority 4 - Functional Systems Operation and FOD Vulnerability

Those items that are essential to the operation of the testbed, but which are related to the functional systems of the testbed installation and which can be approached by functional test and development, are ranked lowest in order of priority. Three items fall into this category:

a) Prop-fan control system
b) Thrust-reversing system
c) FOD vulnerability

Program Objectives Categorization

The program objectives are subdivided into task size units within each level of program priority and are further ranked in importance on a subpriority basis.

A review of the technology concerns, objectives, and priorities is given in Table A-I. Also shown is the identification of the subpriorities within each technological area and the methods of solution available to satisfy each objective.

Although more than one method may be necessary to obtain the required solutions, the preferred methods are indicated by the circles in Table A-I.

TABLE A-1. PROGRAM OBJECTIVES AND PRIORITIES

PRIORITY	TECHNOLOGY AREA	OBJECTIVE	SUB PRIORITY	PROBLEM SOLUTION METHOD: TESTBED AIRCRAFT	WIND TUNNEL HS	WIND TUNNEL LS	STATIC TEST	ANALYSIS
1	INTEGRITY OF THE STRUCTURE o Propeller structural integrity & dynamics	1 Blade dynamic response validation	1	(X)				
		2 Blade classical flutter validation	2	(X)	X			X
		3 Blade stall flutter validation	3	(X)		X	X	
		4 Critical speed & hub stiffness validation	4	(X)			X	
	o Propeller induced vibration & dynamics	5 Determine aerodynamic data for flutter analyses	1		(X)	(X)		X
		6 Determine structural vibration spectra magnitude	2	(X)	X	X	X	X
		7 Drive system dynamic loads & induced effects	3	(X)	X	X		X
	o Scale effects	8 Validate or develop scaling laws	1	(X)	X	X		
		9 Blade mass & stiffness distribution determination	2	(X)	X	X	X	
		10 Demonstrate full size prop-fan fabrication feasibility	3				X	
		11 Establish drive system feasibility for 15,000 SHP & above	4					X
2	ACOUSTIC ENVIRONMENT o Propeller generated near-field noise	12 Sound pressure directivity and spectra variation	1	(X)		X		X
		13 Sound pressure levels on pressurized surfaces	2	(X)				X
		14 Noise strength & directivity determination	3	(X)		X		X
		15 Fluctuating pressure spectra	4	(X)		X		X
		16 Effects of fuselage curavture	5	(X)				X
		17 Geometry of correlated sound pressure area	6	(X)				X
	o Propeller generated far-field noise	18 Verify prop-fan compliance with FAR Part 36	1	(X)				
	o Passenger cabin noise & vibration	19 Minimization of sound transmission	1	(X)				X
		20 Resonant frequency modal survey	2	(X)			X	
		21 Fuselage modes and external noise relation	3	(X)				
		22 Noise reduction & structural response minimization by synchrophasing	4	(X)				X
		23 Improvement thru optimization of shell modes	5	(X)			X	X
		24 Noise reduction thru cabin dimension changes	6	(X)			X	X
3	AIRCRAFT PERFORMANCE	25 Verify propulsive efficiency	1	X	(X)	X		
		26 Determine flow field effect on wing	2	X	(X)	X		
		27 Verify engine inlet performance	3	(X)	X	X		X
4	SYSTEMS OPERATION	28 Verify drive system control system	1	(X)		X		
		29 Verify reverser effectiveness	2	(X)		X		
		30 Determine prop-fan vulnerability to FOD	3	X			(X)	

○ PREFERRED METHOD OF SOLUTION

APPENDIX B - CANDIDATE PROPELLER DRIVE SYSTEMS - TASK II

The rapid advance of turbofan technology for high-speed cruise during the 1950/60s resulted in a reduction in the demand for turboshaft engine cores for propeller-driven aircraft application. Turboshaft engine development was, therefore, reduced to a level consistent with the requirements for rotary wing aircraft.

A survey of the available turboshaft core engines was conducted without regard for the purpose for which the engines were developed, i.e., either for propeller application or for rotary-wing use. Available gearboxes suitable for the drive system application were also investigated. A prime consideration in the selection of a drive system was to avoid costly turbo-machinery and gearbox development.

Typically, the bare drive system consists of a core or power section, a torquemeter, interconnecting struts, and a reduction gearbox. The drive systems utilize available gearboxes which have offset power input pinion gears, and can be configured with the gearbox either in the "pinion-high" or "pinion-low" arrangement, as shown in Figure B-1. The choice depends on the type of installation required for the airframe. The "pinion-high" configuration would generally be representative of an engine nacelle over-the-wing drive system installation, whereas the "pinion-low" arrangement would be consistent with the engine nacelle under-the-wing arrangement.

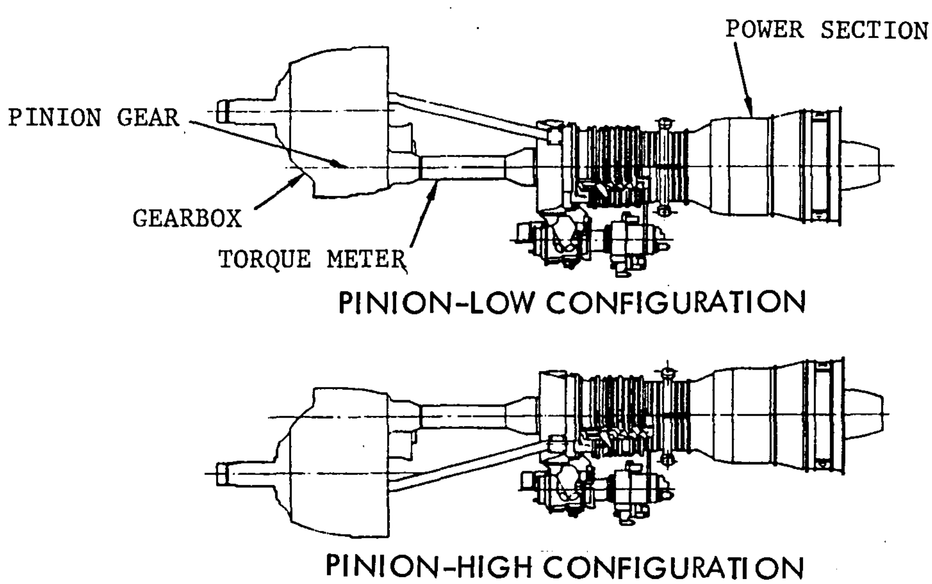


Figure B-1. Typical Drive System Configuration

DRIVE SYSTEM DESIGN REQUIREMENTS

The drive system for the testbed aircraft, as a minimum, should have the capability to satisfy the following design requirements:

- Power an advanced propeller for flight research from static sea-level conditions to Mach 0.8 at altitudes of 10,668m (35,000 ft) or higher.
- At the design cruise conditions of Mach 0.8 at 10,668m (35,000 ft), the drive system should be capable of powering an advanced propeller over a range of conditions given by:

  - Power loading - 209 to 301 kW/m^2 (26 to 37.5 shp/d^2)
  - Propeller tip speeds - 183 to 244 m/s (600 to 800 fps)

Specifically, the drive system should have the capability of powering a given propeller at design cruise conditions in each of the following three operating combinations:

Case 1: 209 kW/m^2 (26 shp/d^2) @ V_T = 183m/s (600 fps)
Case 2: 241 kW/m^2 (30 shp/d^2) @ V_T = 213m/s (700 fps)
Case 3: 301 kW/m^2 (37.5 shp/d^2) @ V_T = 244m/s (800 fps)

where V_T is the prop-fan tip speed.

- Drive system minimum power level at sea level to be 2983 kW (4000 shp)

In addition to these design requirements, the drive system should be:

- Readily available or easily derivable from existing hardware and should include the core engine, gearbox, nacelle, controls, and accessories.
- Configured so that the internal and external flow lines give low installation performance losses.
- Capable of providing acceptable operation of all components throughout the flight envelope.

POWER SECTION AND GEARBOX SURVEY

Power Section Survey

A survey of domestic turboprop/turboshaft engines showed the number of engines in the approximate power level and performance range to be very limited, to the extent that only five were identified as capable of satisfying the minimum power level requirement. The power sections identified were:

- Detroit Diesel Allison T56 Single Shaft Turboprop
- Detroit Diesel Allison XT701 Free Turbine Turboshaft
- General Electric GE T64-10-415 Free Turbine Turboshaft
- Lycoming T55-LTC4B-12 Free Turbine Turboshaft
- Pratt Whitney JFTD12A Free Turbine Turboshaft

Following closer examination of the characteristics of each of the engines, the P&W JFTD12A was found to be unsuitable for testbed aircraft application because the drive shaft was arranged to extend rearward yielding an engine intake and gearbox configuration unsuitable for a tractor-type propeller application.

The Lycoming T55-LTC4B-12 turboshaft engine data indicated a capability of operation up to an altitude of 7,620m (25,000 ft). No data were available for higher altitudes or for changes required to increase the altitude capability.

The P&W JFTD12A and the Lycoming T55-LTC4B-12 were, therefore, eliminated as candidate power sections for testbed aircraft application.

The performance characteristics of the remaining power sections are given in Table B-I.

TABLE B-1. CANDIDATE POWER SECTIONS

POWER SECTION	POWER AVAILABLE	
	CRUISE M = 0.8/10,668 m (35,000 ft) kW(shp)	SLS kW (shp)
*DDA XT701	2520 (3380)	6018 (8071)
DDA T56	1819 (2440)	3423 (4591)
**GE T64-10-415	1350 (1810)	3266 (4380)

*Detroit Diesel Allison
**General Electric

Gearbox Survey

Examination of the available gearboxes indicated that the following units possessed the capability of matching the output of the candidate power sections:

- o Detroit Diesel Allison T56-A-14
- o Detroit Diesel Allison T56-A-15
- o Ishikarapima-Harim Heavy Industries IHI T64-2 SDG

DDA T56-A-14 Gearbox - This gearbox is a "pinion-high" configuration as used on the Lockheed P-3C "Orion" aircraft but can be adapted for prop-fan application using either the XT701 or T56 power sections. The modification required to match the XT701 is complicated by the fact that the rotation of this engine is opposite to that of the T56 power section, and by the significantly lower RPM of the XT701. The clockwise rotation and the 11,500 RPM of the XT701 require changes to the main drive sun gear and pinion and to the accessory drive train to provide correct rotation for the oil pump and tachometer speed.

DDA T56-A-15 Gearbox - This is a "pinion-low" gearbox used for the Lockheed C-130 drive system. Because of the design of the gearbox lubrication system, which requires baffles located adjacent to the pinion and which cannot be relocated, the maximum diameter of the pinion is restricted. This in turn would cause a small reduction in the diameter of a prop-fan used for a "pinion-low" arrangement to reach a tip speed of 244m/s (800 fps).

IHI T64-2 SDG Reduction Gear - This gearbox is rated at 2535 kW (3400 shp) and has a reduction ratio of 14.31. The gearbox could be used by modifying the pinion and bullgear in the same way that the T56 gearbox is altered.

DRIVE SYSTEM ASSEMBLY

The bare drive systems are assembled by combining the power sections and the appropriate gearboxes by means of a connecting torquemeter. The drive system assemblies can be configured as either "pinion-high" or "pinion-low", depending upon installation requirements. The length of the torquemeter is, to some extent, dictated by the engine intake requirements if scoop-type inlet short-coupling with abrupt duct curvature is to be avoided.

GE T64-10-415

The assembly of this drive system for "pinion-high" and "pinion-low" configurations is shown in Figure B-2, together with the principal dimensions and characteristics.

DDA T56

The "pinion-high" and "pinion-low" assemblies are given on Figure B-3. This assembly is based upon that of the Lockheed C-130. The principal dimensions and data are also included in Figure B-3.

DDA XT701

The XT701 drive system assembly for "pinion-high" and "pinion-low" are illustrated in Figure B-4. Also included are the dimensional data and the principal characteristics.

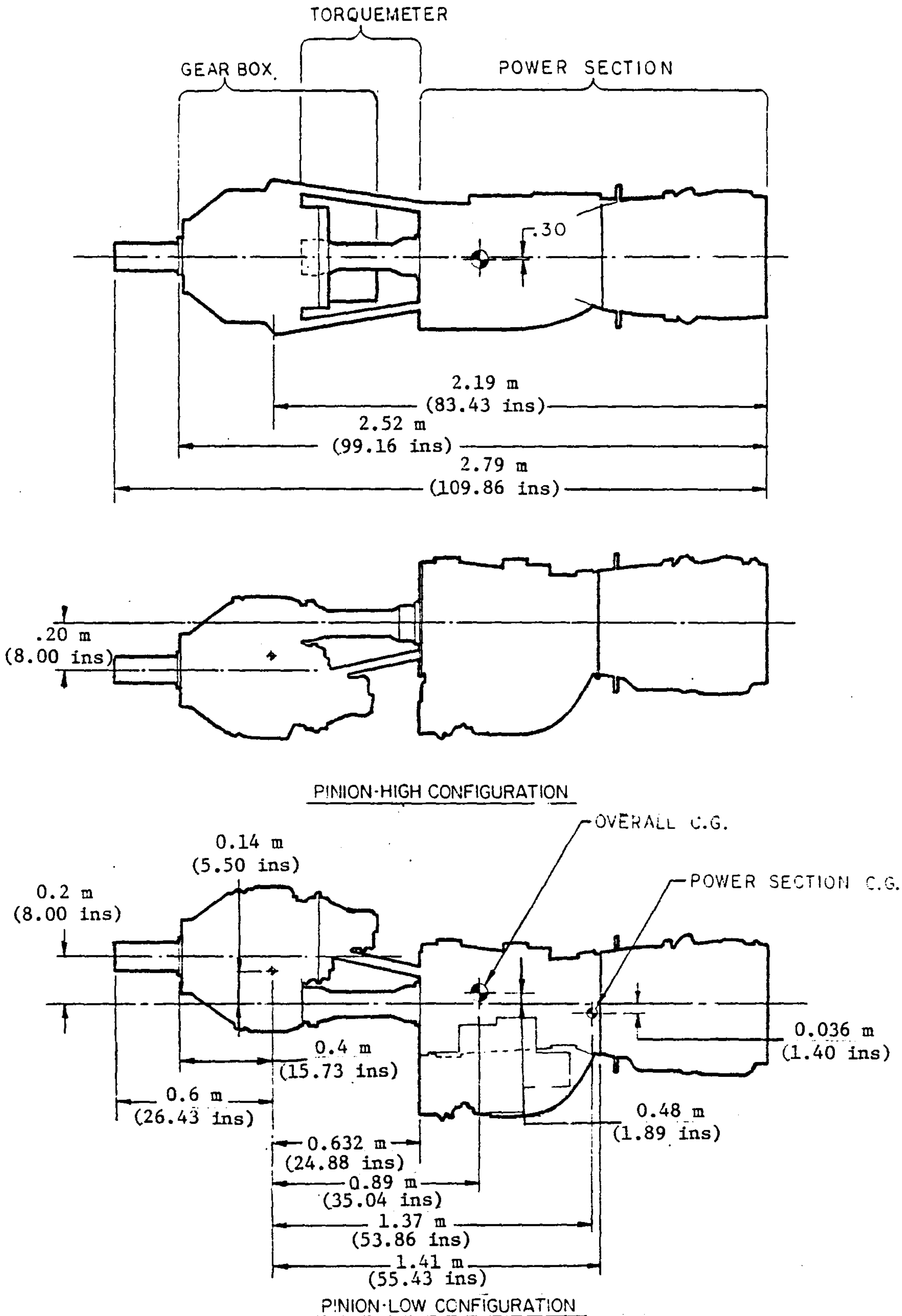


Figure B-2. T64 Drive System Assembly

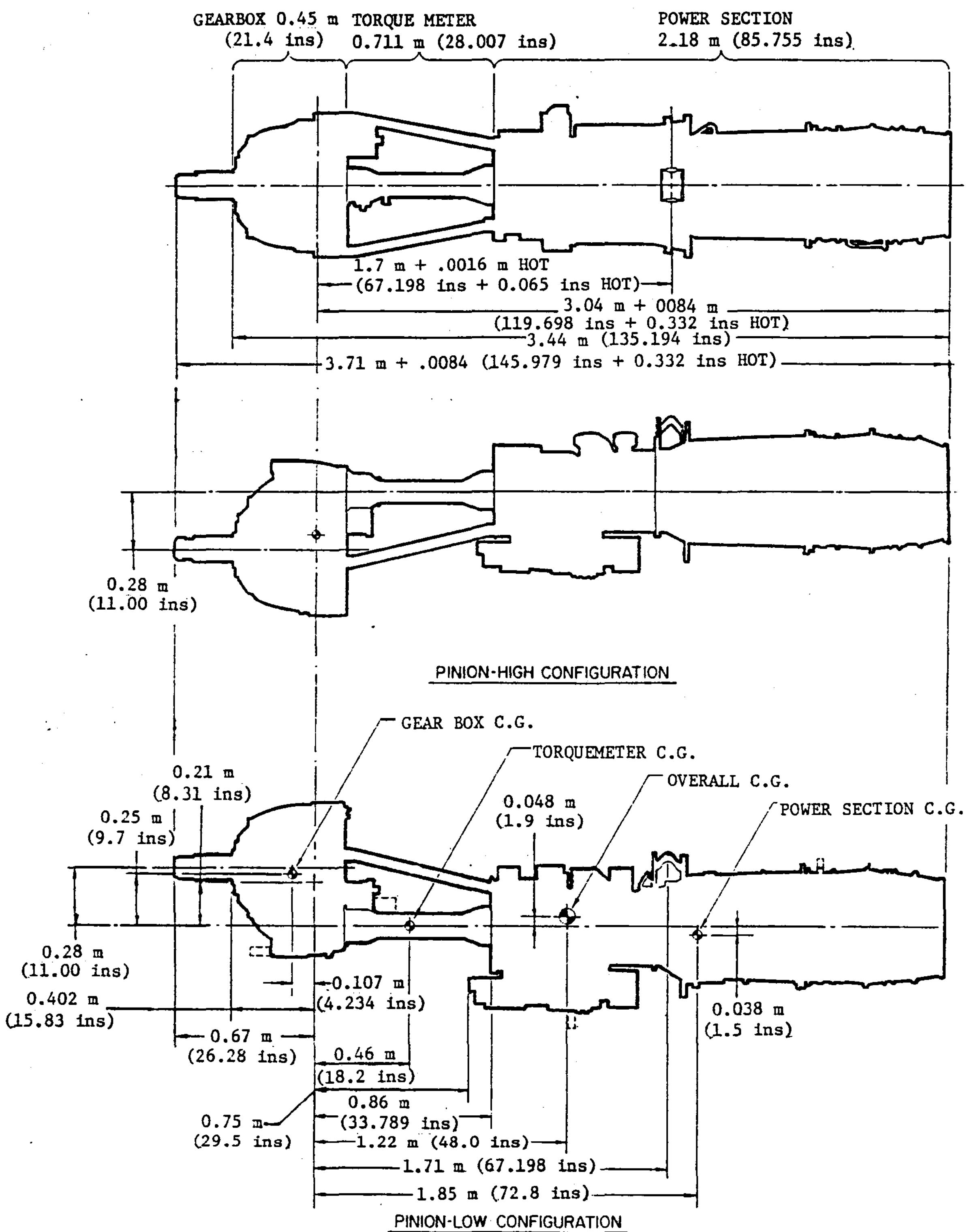


Figure B-3. T56 Drive System Assembly

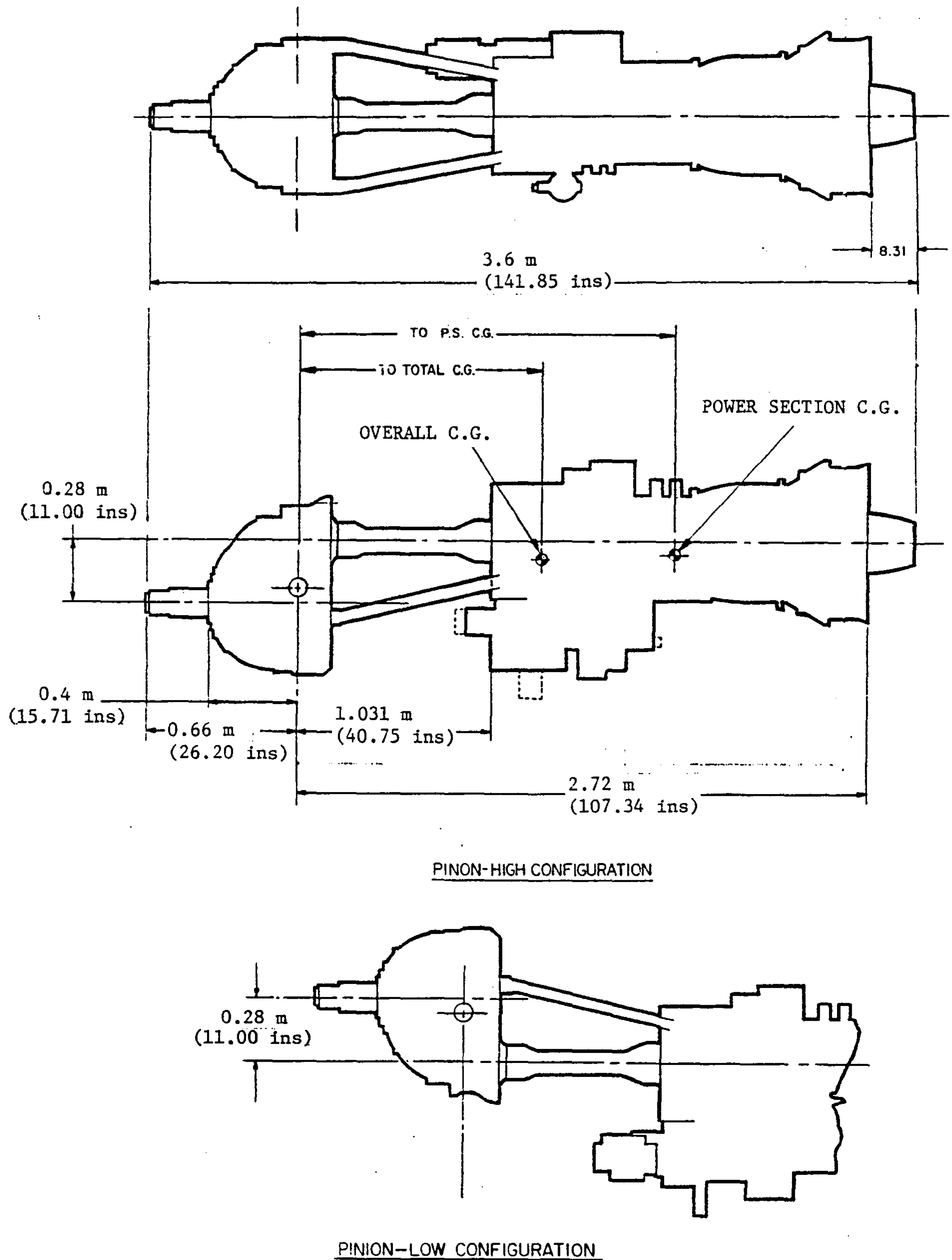


Figure B-4. XT701 Drive System Assembly

PROP-FAN SIZING AND DRIVE SYSTEM CHARACTERISTICS

The prop-fan diameter for testbed application should be as large as possible if the size of prop-fans for aircraft of the future is to be properly represented. Prop-fan and nacelle diameters as a function of cruise power and prop-fan RPM at an altitude of 10,668m (35,000 ft) are shown in Figure B-5. A turboshaft drive system for testbed application at the minimum acceptable diameter of 2.43m (8 ft) must be capable of generating 1789 kW (2400 shp). The design point for the prop-fan at cruise conditions, i.e., M=0.8 at 10,668m (35,000 ft), is a disk loading of 301 kW/m^2 (37.5 shp/d^2) and a tip speed of 244m/s (800 fps). These data together with the data for disc loading of 241 and 209 kW/m^2 (30 and 26 shp/d^2) are also shown in Figure B-5.

Prop-fan diameter for each candidate drive system is also shown in Table B-II and the principal characteristics of the propeller drive systems are shown in Table B-III.

The requirement for a minimum diameter of 2.43m (8 ft) would tend to eliminate the GE T64 drive system from consideration. Drive system availability is, however, an important factor so that it is considered expedient to carry the GE T64 drive system as a candidate until availability of all candidate drive systems is verified.

The principal candidates for the drive system are the free turbine DDA XT701/T56-A-14 and the fixed-speed single shaft DDA T56-A-14. Because of drive shaft RPM flexibility offered by the free turbine power sections, and the advantages arising from that feature in flight research activities, a drive system utilizing either the DDA XT701 or the GE T64 would be desirable.

DRIVE SYSTEM/NACELLE INSTALLATION

The drive system installation to form a Quick Engine Change (QEC) unit was accomplished by designing the nacelle contours to a NASA supplied area distribution curve, Figure B-6. The spinner and nacelle shapes were configured to retard the airflow to alleviate blade-root choking. The data of Figure B-6 were derived from NASA tests of axisymmetric nacelles without air inlets. They can, therefore, only be considered as guidelines in the design of configurations that are highly unsymmetrical and require internal flows for the engine

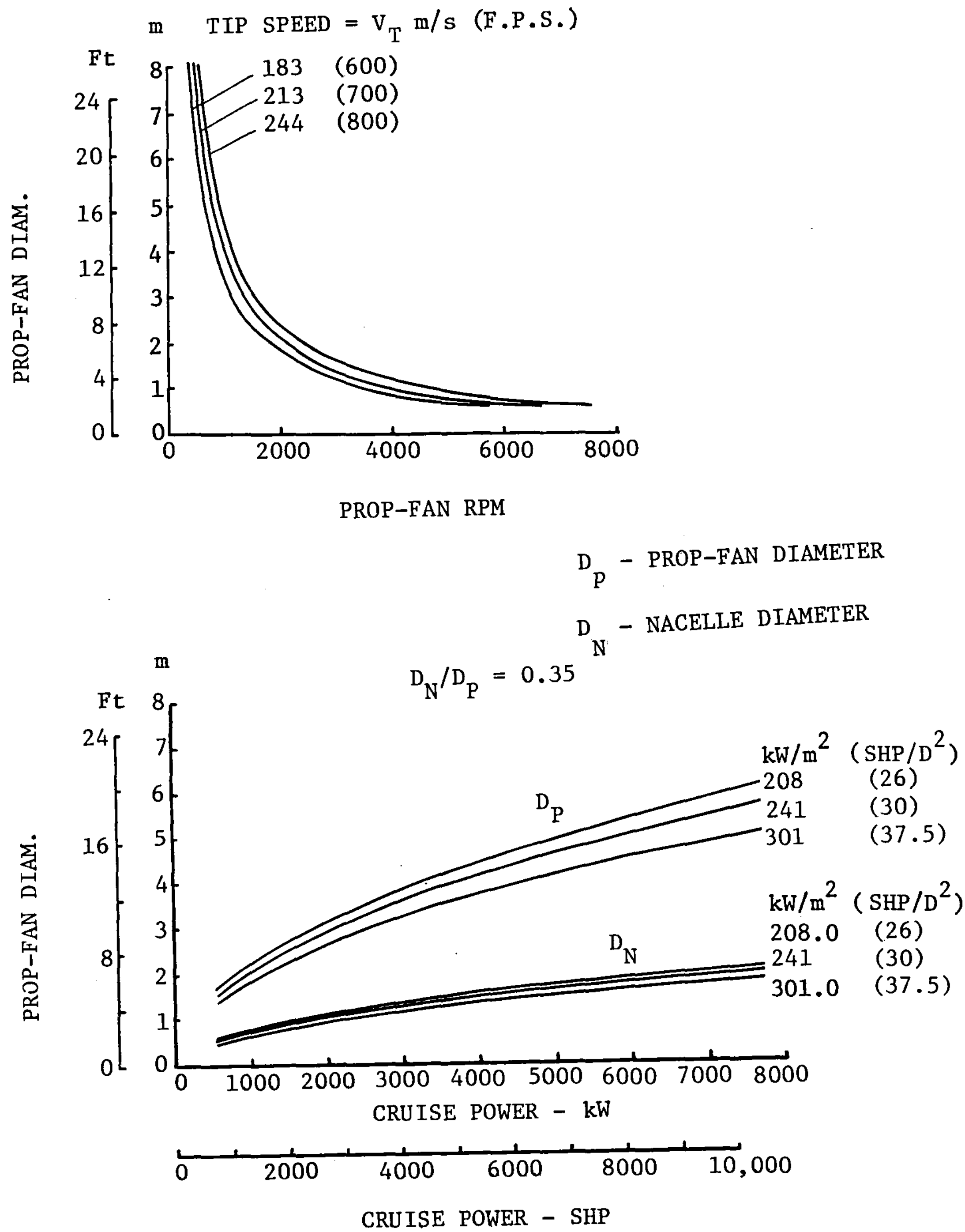


Figure B-5. Prop-Fan Sizing - 10,668m (35,000 ft) Altitude

TABLE B-II. DRIVE SYSTEM PROP-FAN DIAMETER

DRIVE SYSTEM	PROP-FAN DIAMETER*
DDA XT701/T56-A-14 (Mod)	2.89 m (9.5 Ft)
DDA T56/T56-A-14 (Mod)	2.47 m (8.1 Ft)
GE T64-10-415/IHI T64-2SDG (Mod)	2.13 m (7.0 Ft)

*BASED ON:

MACH = 0.8

ALT. = 10,668 m (35,000 ft)

SHP/D^2 = 301 kW/m^2 (37.5 SHP/ft^2)

V_T = 244 m/sec (800 ft/sec)

TABLE B-III. CANDIDATE DRIVE SYSTEM SUMMARY

ITEM / ENGINE TYPE / ROTATION -ALF* \ ENGINE	GE T64 FREE TURBINE COUNTERCLOCKWISE			DDA T56 FIXED SPEED COUNTERCLOCKWISE			DDA XT701 FREE TURBINE CLOCKWISE		
PERFORMANCE									
POWER SLS kW (SHP)	3266 (4380)			3423 (4591)			6018 (8071)		
10688 m (35,000 FT) M = 0.8	1350 (1810)			1819 (2440)			2520 (3380)		
RPM MAX CONTINUOUS	13600			13820			11500		
PROP-FAN SIZING									
DISK LOADING kW/m^2 - (SHP/D^2)	301 (37.5)	301 (37.5)	301 (37.5)	301 (37.5)	301 (37.5)	301 (37.5)	301 (37.5)	301 (37.5)	(37.5)
V_{TP} m/s (fps)	244 (800)	213 (700)	183 (600)	244 (800)	215 (700)	183 (600)	244 (800)	213 (700)	185 (600)
RPM	2140	1870	1600	1900	1660	1430	1610	1410	1210
PROP-FAN DIAMETER m (FT)	←	2.13 (6.97)	→	←	2.47 (8.1)	→	←	2.89 (9.5)	→
REDUCTION GEAR	1			1	2	3	1		
V_{TP} m/SEC (FT/SEC)	244 (800)	213 (700)	183 (600)	244 (800)	213 (700)	183 (600)	244 (800)	213 (700)	183 (600)
PINION GEAR	← N/A →			68T/8P	63T/8P	56T/8P	← 68T/8P →		
MAIN DRIVE GEAR	← N/A →			108T/8P	113T/8P	120/8P	← 108T/8P →		
ALTERNATOR GEAR	← N/A →			← N/A →			61T/10P		
OIL PUMP DRIVE GEAR	← N/A →			← N/A →			78T/10P		
OIL PUMP DRIVEN GEAR	← N/A →			← N/A →			33T/10P		
MASS PROPERTIES WEIGHTS									
REDUCTION GEAR kg (LB)	194.1 (428)			249.6 (550.5)			249.6 (550.5)		
TORQUEMETER kg (LB)	18.14 (40)			27.21 (60)			27.21 (60)		
POWER SECTION kg (LB)	326.5 (700)			550.7 (1214.5)			534.7 (1179)		
TOTAL kg (LB)	538.74 (1188)			827.51 (1825)			811.48 (1789.5)		
	ROLL	YAW	PITCH	ROLL	YAW	PITCH	ROLL	YAW	PITCH
MOMENT OF INERTIA kg/m^2 LB/FT^2	130.7 (638)	—	—	—	—	—	—	—	—
CG LOCATION PINION LOW m (Ins)	W.L. 102.2 BL 95.7			.048 (1.9) ABOVE POWER SECTION ℄ 1.62 (63.83) AFT OF THRUST NUT			← N/A →		

*ALF - AFT LOOKING FORWARD

NASA AREA DISTRIBUTION

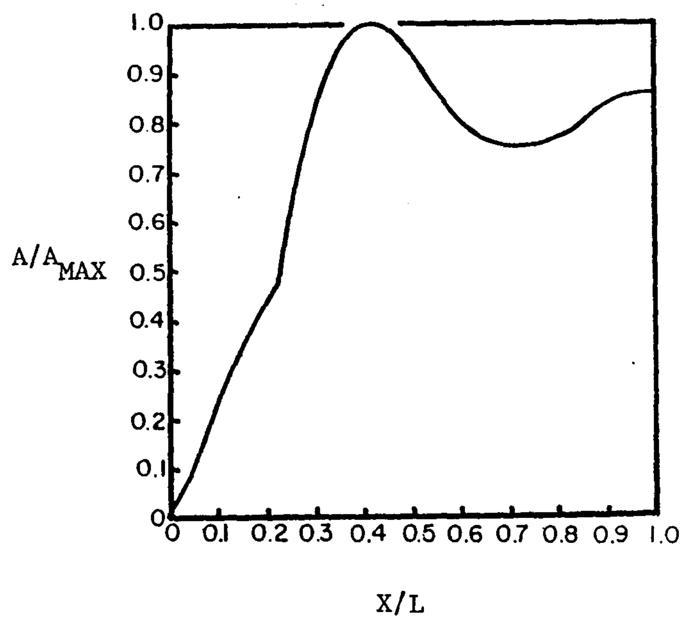


Figure B-6. NASA Nacelle Area Distribution Curve

and oil coolers. The significant part of Figure B-6 for nacelle design is the portion up to the location of the maximum area.

DRIVE SYSTEM NACELLE DEVELOPMENT

Development of the nacelle designs for the various drive systems was based upon Hamilton Standard recommendations, Reference 2. The principal design conditions were:

- Nacelle Length - 1.0 Propeller Diameter from the Wing Quarter Chord to the Prop-Plane.
- Nacelle Diameter/Propeller Diameter D_N/D_P = 0.35.

When applied to practical designs, the nacelle length (prop-plane to wing C/4 @ 1.0 D_P) was found to place the rear portion of the power section in such a position, relative to the wing, that the propeller thrust line/wing reference plane separation was unnecessarily increased and fairing between the nacelle and wing leading edge rendered difficult. By changing this dimension to 1.0 D_P from the prop-plane to the wing leading edge, the turbine portion of the power section could be moved forward away from the wing maximum thickness, permitting minimization of the thrust line offset and improved integration of the nacelle and wing.

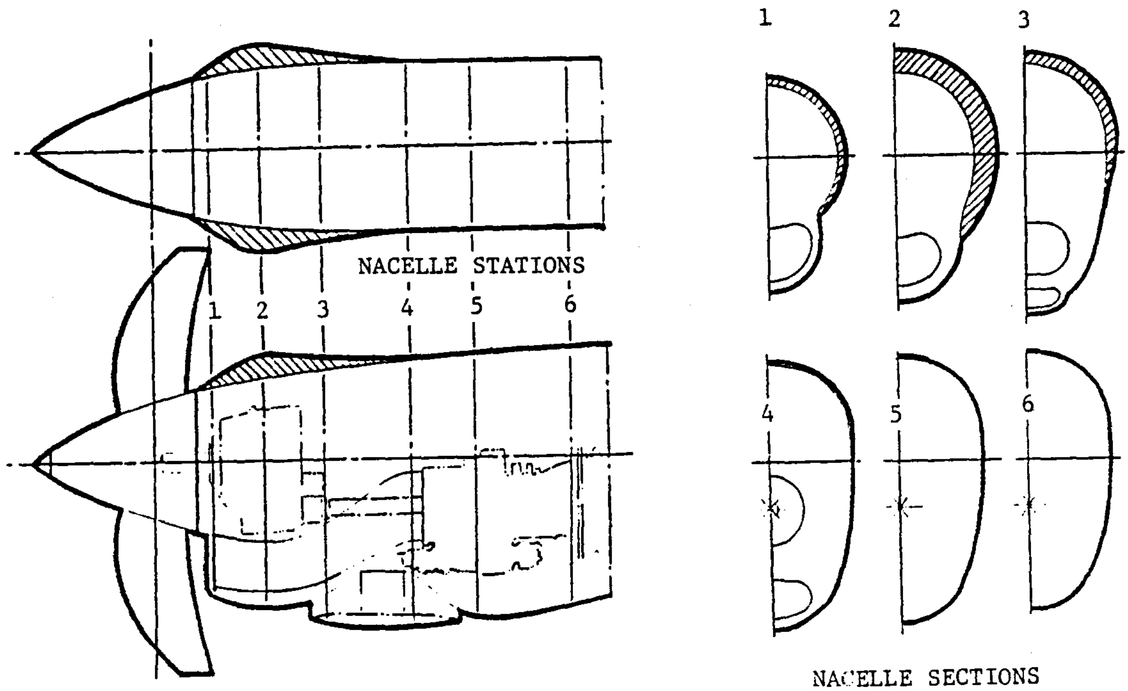
Nacelle layouts and contours were developed for the three selected engines for "pinion-high" and "pinion-low" configurations. Initially, the similarities between the T56 and the XT701 were thought to be such that a set of common contours could be used for either engine. The possiblity of using an existing nacelle such as the C-130 and P-3C was also investigated. The nacelle development investigation considered the following cases:

- Modified C-130 and P-3C T56 nacelles.
- Common T56/XT701 nacelle "pinion-high" and "pinion-low" configurations.
- T64 nacelle contours for "pinion-high" and "pinion-low" configurations.
- T56 nacelle common contours for both "pinion-high" and "pinion-low".
- XT701 nacelle contours for "pinion-high" and "pinion-low" configurations.
- Revised XT701 nacelle common contours for "pinion-high" and "pinion-low" configurations.

Modification of Existing Nacelles

As a low-cost approach to nacelle design, the nacelle contours for two existing designs, the Lockheed C-130 T56 and the Lockheed P-3C T56 nacelles, were investigated for conformance to the NASA area distribution curve, Figure B-6.

Lockheed C-130 Modified Nacelle - Modification of the area distribution and the modified contours for the Lockheed C-130 "pinion-low" nacelle are shown in Figure B-7. Improvement of the distribution would require a prop-fan hub of greater diameter than that of the C-130 propeller. This would require relocation of the engine intake downward. It is possible to add area to conform to the NASA distribution in the region of the maximum cross-sectional area, but the actual and modified distributions forward of the maximum area are so far removed from the NASA curve that the modified nacelle would not present a satisfactory representation of the true conditions for the prop-fan.



C-130 NACELLE MODIFIED FOR PROP-FAN

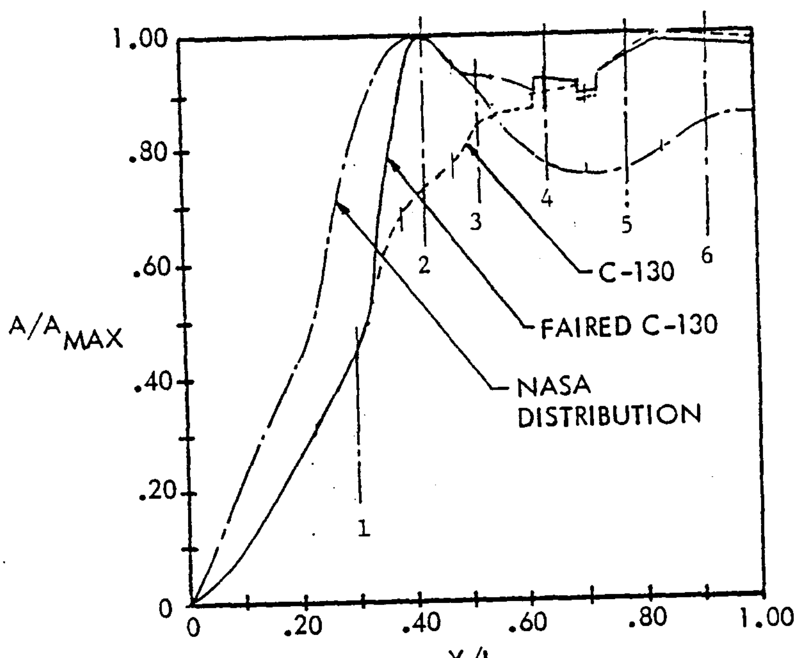


Figure B-7. Lockheed C-130 Modified Nacelle

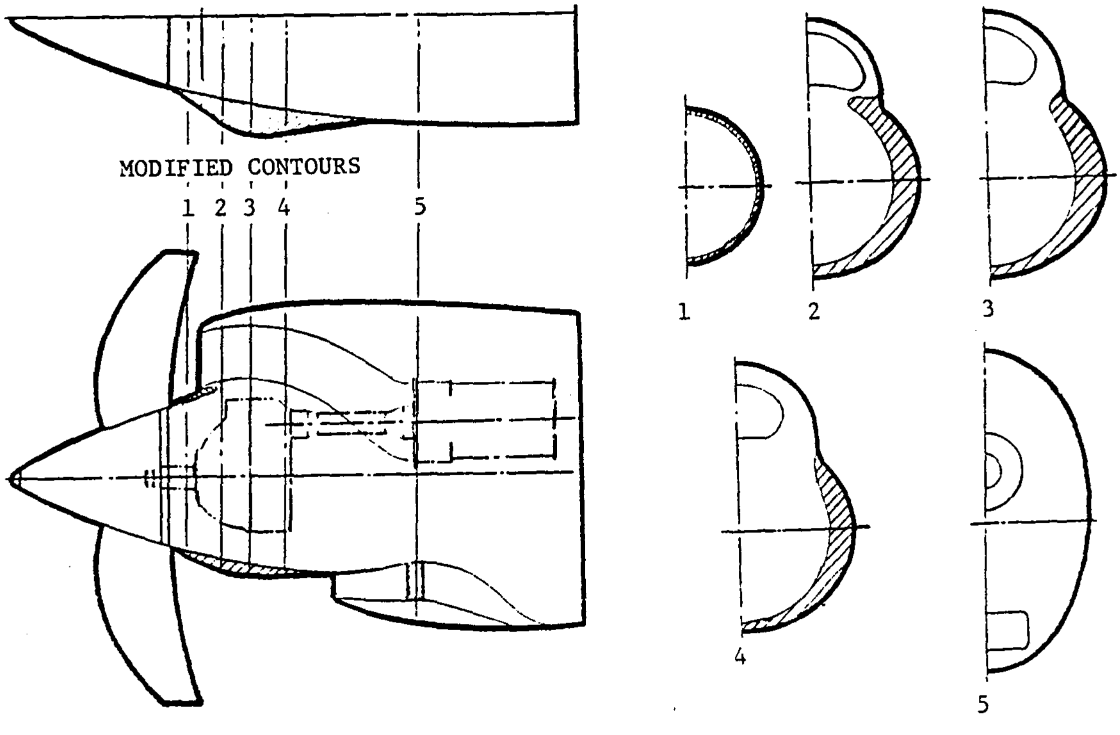
Lockheed P-3C Modified Nacelle - A situation similar to that of the C-130 exists when the modification of the Lockheed P-3C nacelle is considered. This nacelle, shown in Figure B-8, is configured for a "pinion-high" arrangement. When the actual and NASA area distributions, Figure B-8, are compared, the mismatch can be seen to be far greater than that of the C-130 nacelle due primarily to the larger base area of the P-3C nacelle. In this case, adding area to the nacelle at the location of the maximum cross-sectional area of the NASA distribution does not change the actual distribution enough to provide an adequate representation of a prop-fan nacelle. As in the case of the C-130, the area distribution modification is constrained by the location of the engine and oil cooler inlets.

Revised T56 Nacelle Contours - The T56 nacelles, described in the preceding text, were contoured by normalizing on the base area at an X/L = 1.00 and deriving the maximum cross-sectional area, A_{MAX}, at X/L = 0.414 for the nacelle. The resulting nacelles produced values of nacelle equivalent diameter to propeller diameter of 0.49 for the C-130 and 0.62 for the P-3C, with the actual distribution having little correspondence to the NASA curve.

In an effort to improve the area distribution of the existing C-130 T56 nacelle, the reference cross-sectional area used for normalizing was changed from that at X/L = 1.0 to that at X/L = 0.414. The resulting nacelle and corresponding area distribution, shown in Figure B-9, conform closely to the NASA curve over the spinner and prop-fan hub, and can be achieved without changing the nacelle lines behind the hub. The effect of adding a slight nacelle build-up behind the hub is also shown in Figure B-9. Using this technique, the C-130 T56 nacelle with or without contour build-up could provide a minimum modification arrangement.

Applying the same technique to the P-3C nacelle does improve the area distribution, as shown in Figure B-8, but would require contour build-up to match the NASA curve over the hub/intake region. Since the base area of the nacelle at the propeller hub is fixed by the dimensions of the existing propeller, any increase in cross-sectional area by contour build-up would affect the engine intake region of the nacelle. This would require a considerable reconfiguration of the nacelle shapes amounting to a new nacelle.

T56/XT701 "Pinion-High" Nacelle - The nacelle layout, contours and area distribution for the "pinion-high" configuration T56/XT701 common nacelle are shown in Figure B-10. The nacelle contours follow the desired area distribu-



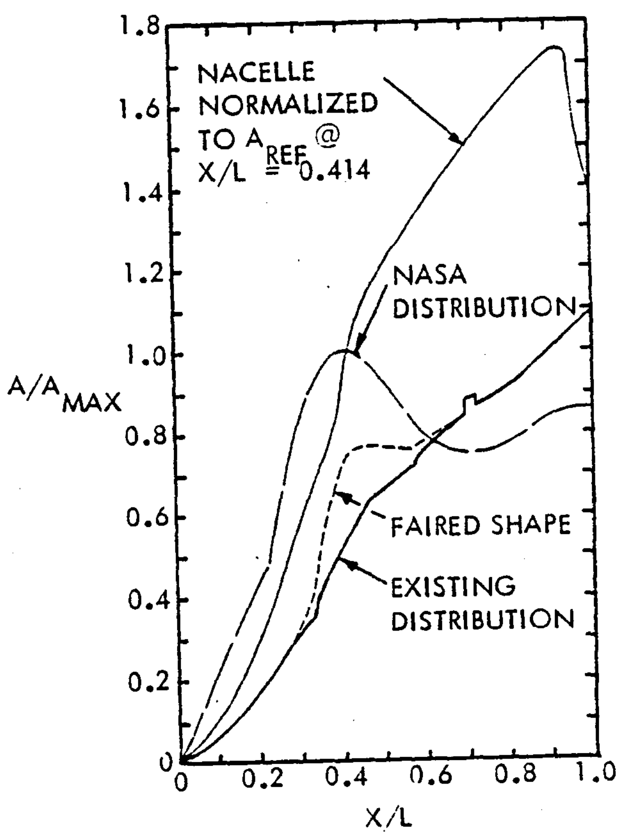
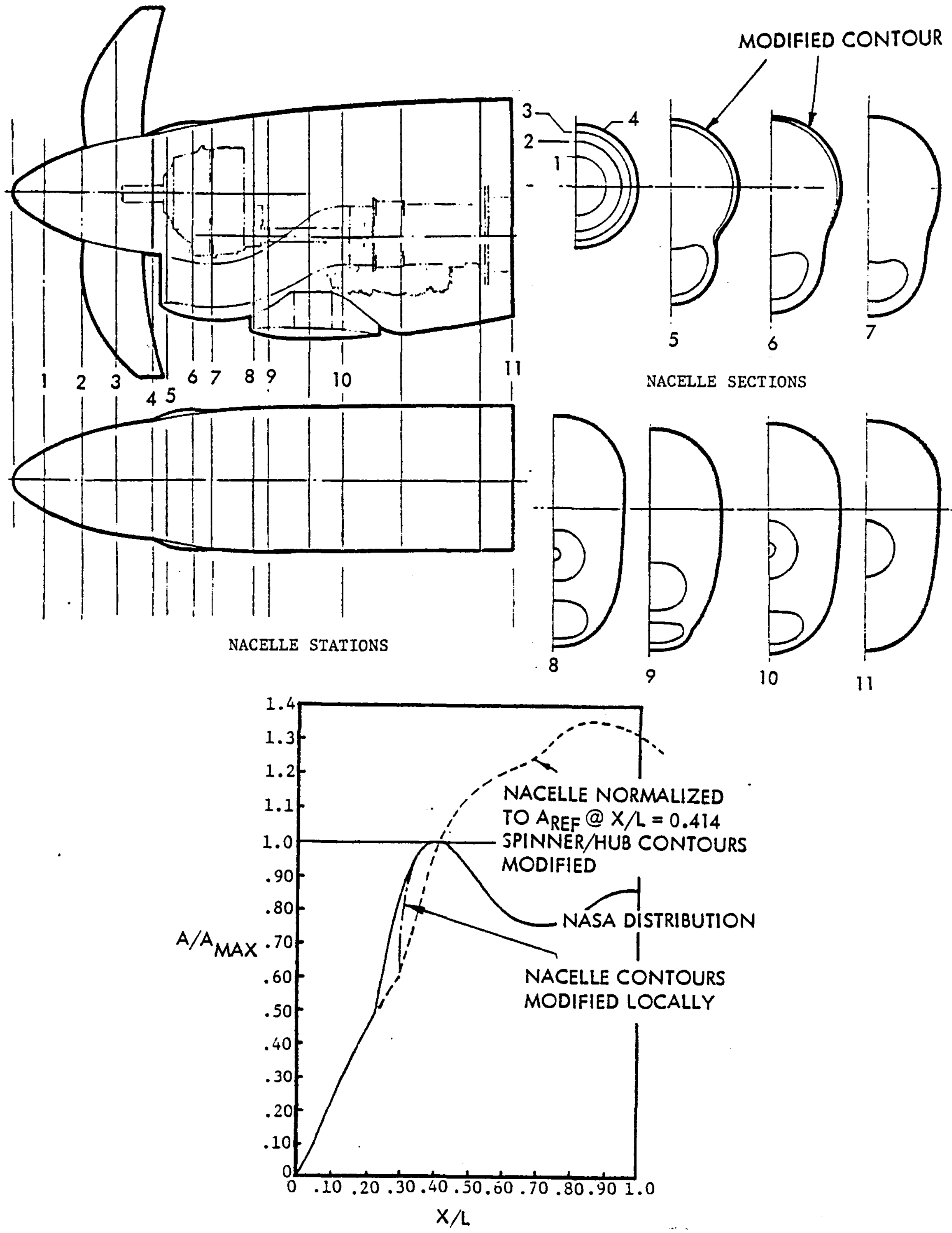


Figure B-8. Lockheed P-3C Modified Nacelle, Pinion-High



Fibure B-9. Lockheed C-130 Modified Nacelle Revised Reference Area

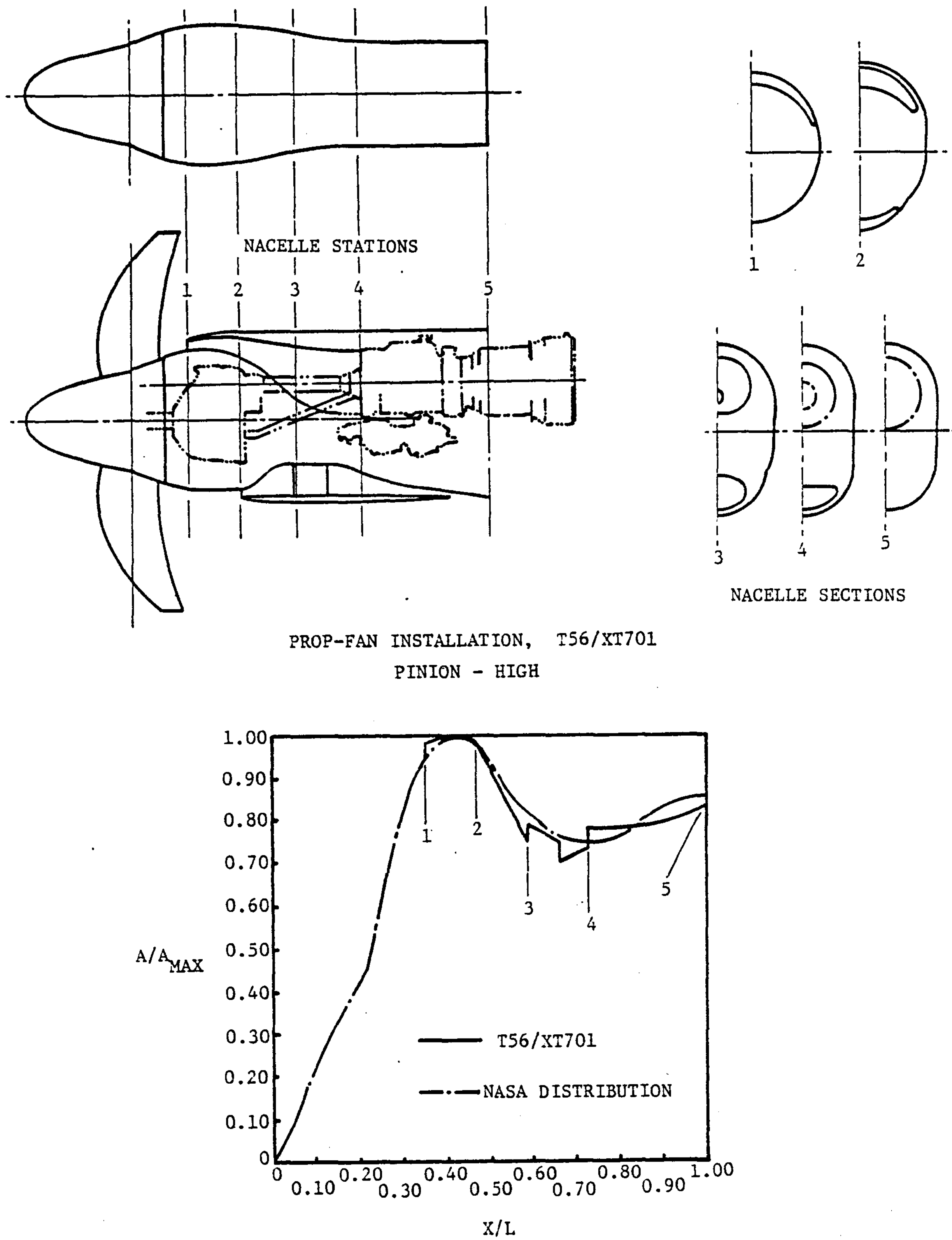
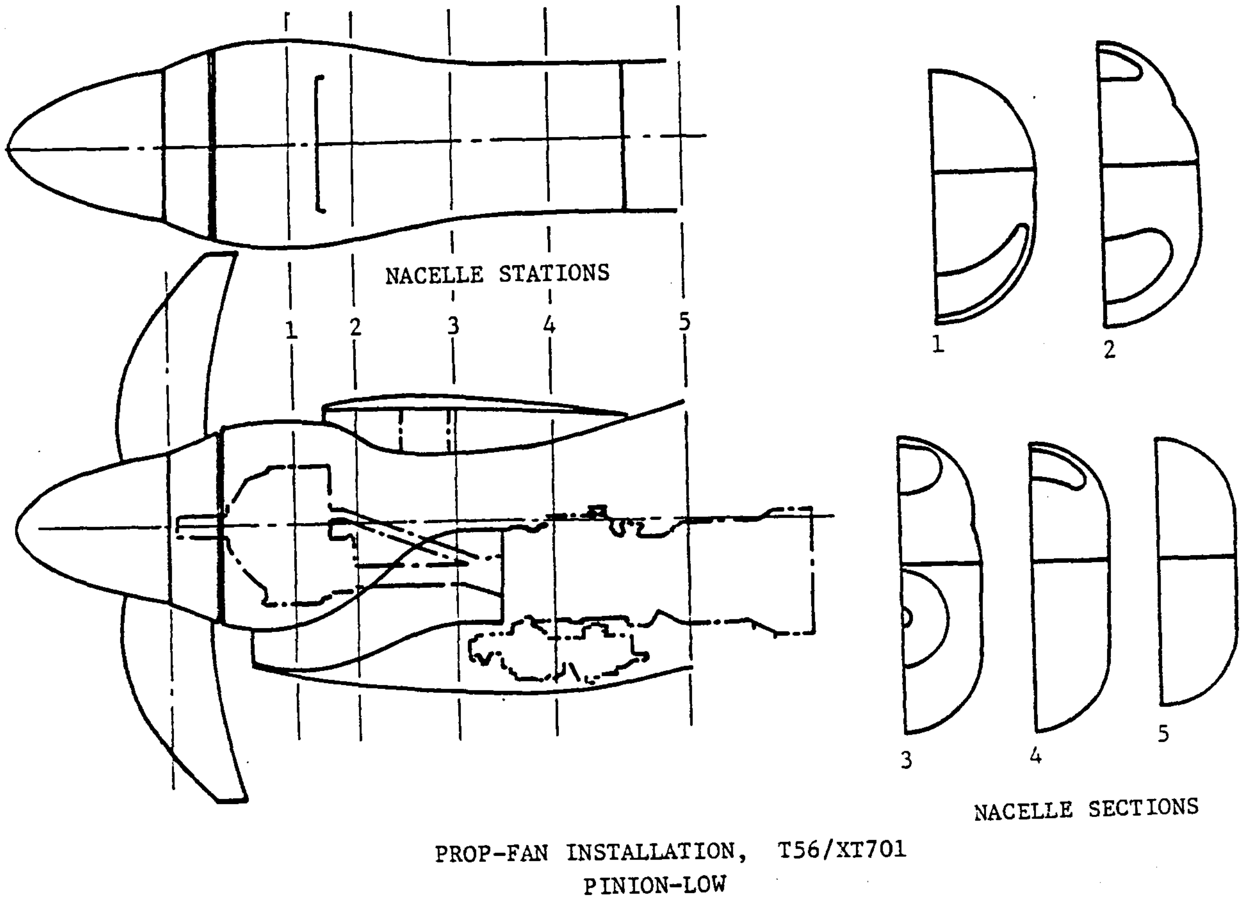


Figure B-10. T56/XT701 Common Nacelle, Pinion-High tion and are highly unsymmetric. The arrangement of the scoop-type air intake above the engine and the oil cooler inlet below gives essentially parallel top and bottom lines for the nacelle, a result of the offset between the propeller shaft and the power section centerline. Adherence to the area distribution curve, as shown in the plan view of Figure B-10, produces a pronounced bulge in the nacelle shape at the maximum cross-sectional area.

Since the T56 engine is slightly smaller in diameter than the XT701, although longer, the T56 power section fits into the contours configured for the XT701. The nacelle shapes are based on the prop-fan diameter of 2.90m (9.5 ft) for the XT701 and the maximum cross-sectional area is determined by the ratio $D_N/D_P = 0.35$. Changing from the XT701 to the T56 engine at a disc loading of 301 kW/m^2 (37.5 shp/d^2) would reduce the prop-fan diameter to 2.5m (8.1 ft) and would require recontouring of the nacelle to satisfy the $D_N/D_P = 0.35$ ratio. To maintain the same contours for both drive systems would, therefore, require a constant diameter for the prop-fan. This, in effect, means that the XT701 drive system would represent a maximum cruise disc loading of 301 kW/m^2 (37.5 shp/d^2) while the T56 would operate at approximately 217 kW/m^2 (27.0 shp/d^2). Downstream of the maximum cross-sectional area, the nacelle contours can be modified for particular airframe installations without compromising the overall area distribution.

T56/XT701 "Pinion-Low" Nacelle - The nacelle layout, contours, and area distribution for the T56/XT701 "pinion-low" configuration common nacelle are shown in Figure B-11. The nacelle bottom line is controlled by the depth of the drive system power section accessories, which are mounted at the front of and below the XT701 engine intake. The same considerations relative to the nacelle size, prop-fan size, and disc loading as discussed in the preceding text for the "pinion-high" configuration apply to the "pinion-low" nacelle. Because the XT701 accessories control the depth of the nacelle, when using the T56 power section, the bottom line could be raised slightly relative to the position shown in Figure B-11. In general, the "pinion-low" nacelle with a "chin" type of air intake on the underside of the nacelle and with the oil cooler ducting arranged on the upper portion increases the cross-sectional area, as can be seen from the comparison of the NASA and actual area distributions shown in Figure B-11.



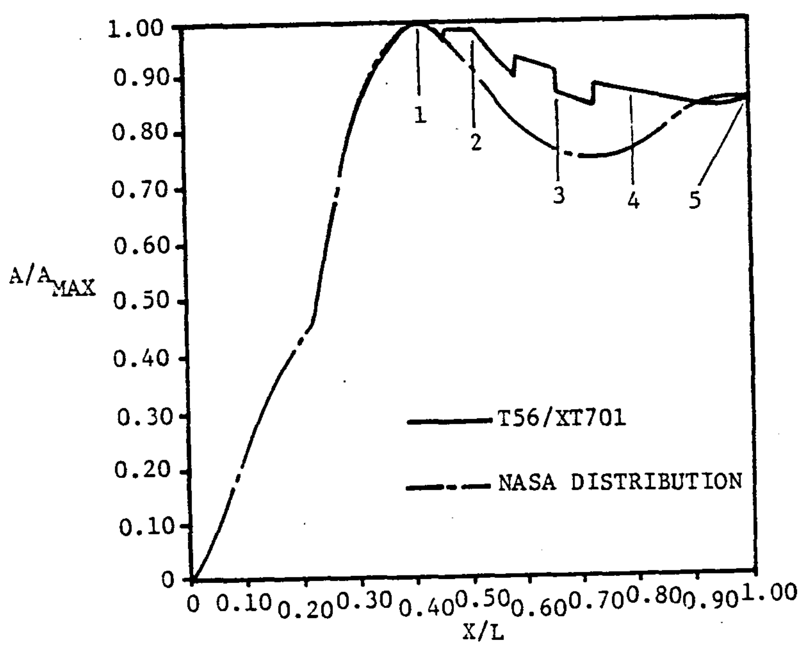


Figure B-11. T56/XT701 Common Nacelle, Pinion-Low

<u>GE T64 Nacelle Contours</u> - The nacelle contours and layout developed for the GE T64 drive system and the corresponding area distribution data are shown on Figure B-12 for the "pinion-high" configuration.

The nacelle area distribution shown in Figure B-12 corresponds to the NASA curve up to X/L = 0.50. Although the curve is slightly atypical beyond X/L = 0.50 due to the various inlets, generally the curve is smooth. The nacelle configuration shown in Figure B-12 has the scoop inlet located on the upper part of the nacelle and the oil cooler below the engine.

In the case of a "pinion-low" configuration, the base cross-sectional area at X/L = 1.0 is the same as that of the "pinion-high" configuration so that the area distribution of Figure B-12 applies to both configurations. The portion of the spinner/hub/nacelle up to Nacelle Station 7 is circular in cross-section.

The T64 nacelle was further refined to provide a D_N/D_P = 0.35. The refined nacelles were contoured by reducing the maximum cross-sectional area, A_{MAX}, to the value required to give D_N/D_P = 0.35 at X/L = 0.414. The actual base area at X/L = 1.0 was not changed in the revised nacelles and although the spinner/hub/nacelle contours follow the ideal distribution up to values of X/L = 0.50, beyond that point the contours are allowed to depart from the curve. Since the testbed installation is not an aerodynamically optimized nacelle/wing integration, the departure behind X/L = 0.50 is not expected to adversely affect aerodynamic performance. The refined "pinion-high" nacelle layout, contours, and area distribution are shown on Figure B-13.

The "pinion-low" arrangement, Figure B-14, is also reduced in size from that illustrated on Figure B-12. The actual area distribution follows the NASA curve closely up to X/L = 0.70. Beyond that point, the area is permitted to vary to provide a faired nacelle.

In both refined nacelles the important regions of the hub-spinner/nacelle contours conform to the NASA distribution. Because the base area at X/L = 1.0 is likely to vary from one installation to another, some variation in the area distribution can be expected in the region of the nacelle from X/L = 0.50 to X/L = 1.0.

<u>T56 Nacelle Contours</u> - The original T56 nacelle contours were generated on the assumption that a single nacelle could be designed for both the XT701 and T56. Since nacelle size is a function of the prop-fan diameter, the nacelle envelope for T56 application was too large. The T56 nacelle "pinion-high" and "pinion-low" variants were, therefore, revised to accommodate the T56 based on

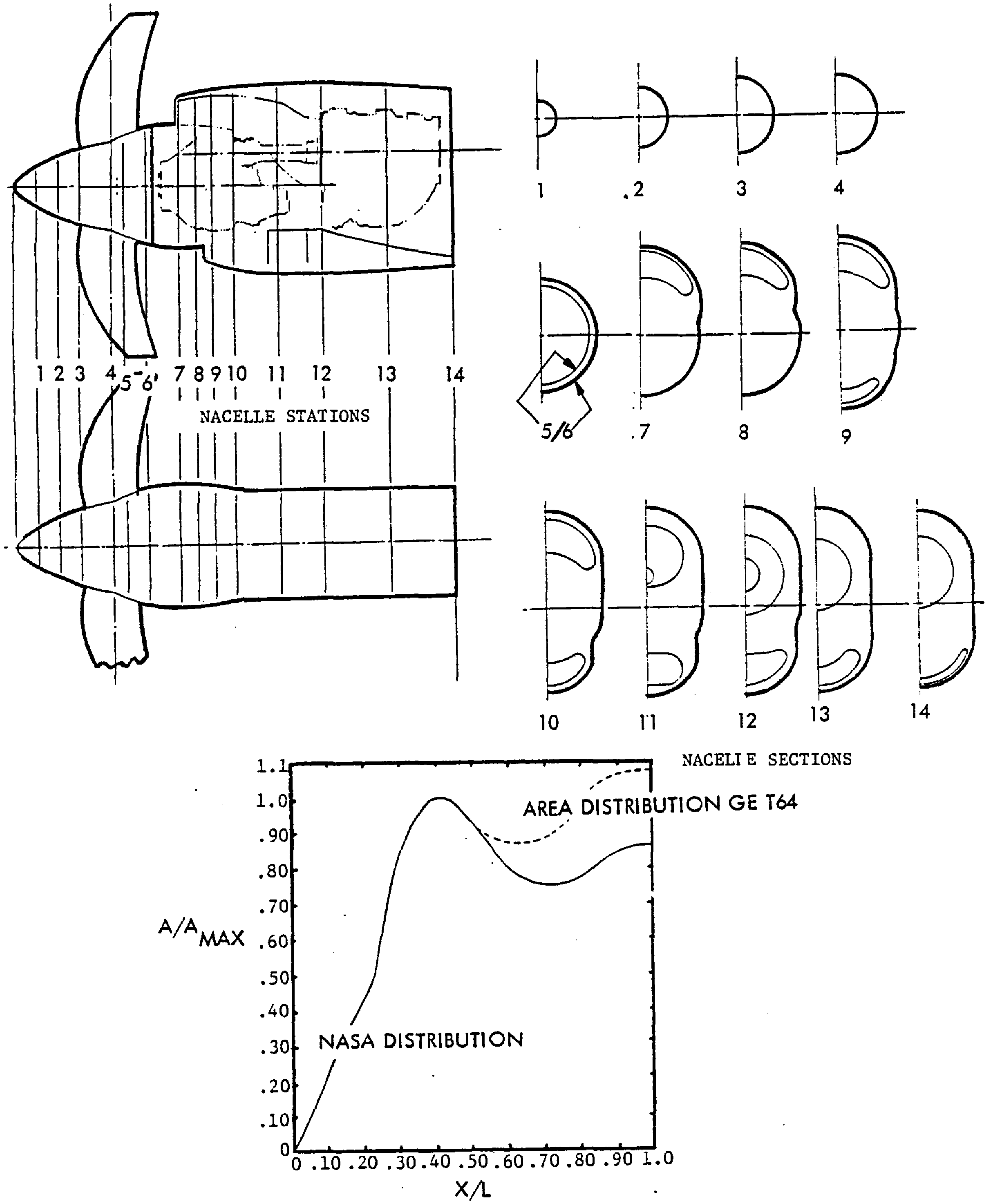
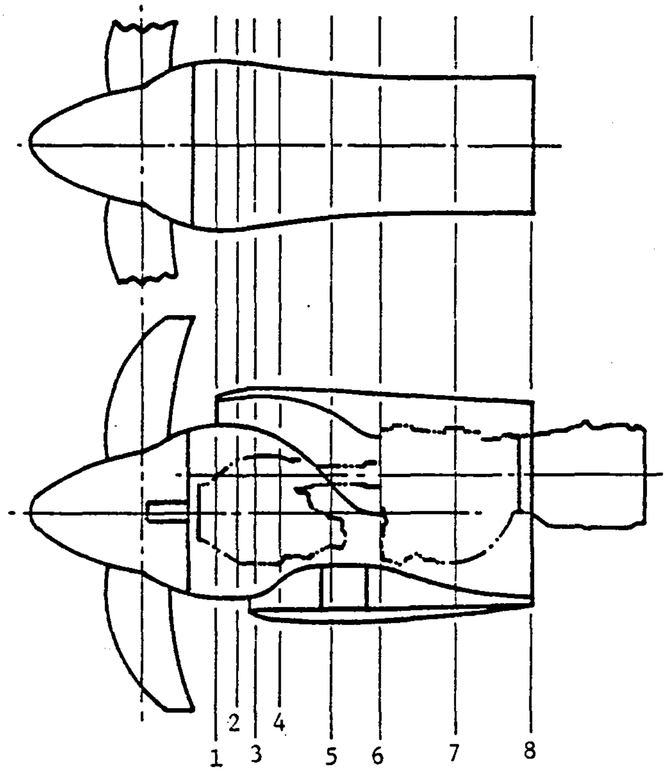
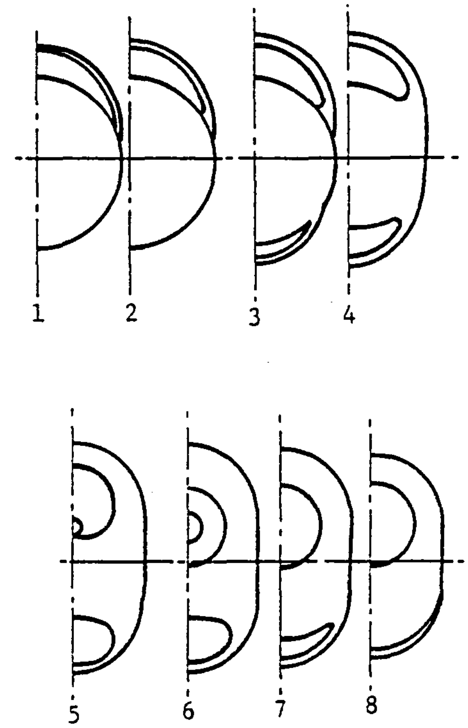


Figure B-12. T64 Pinion-High Nacelle



NACELLE STATIONS



NACELLE SECTIONS

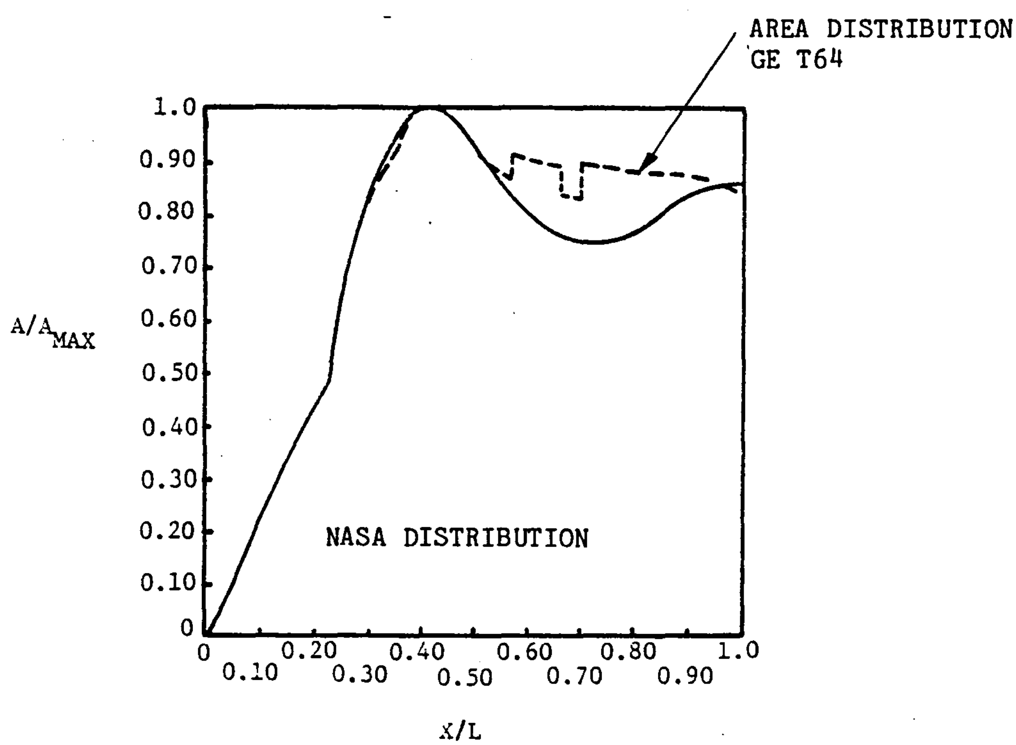
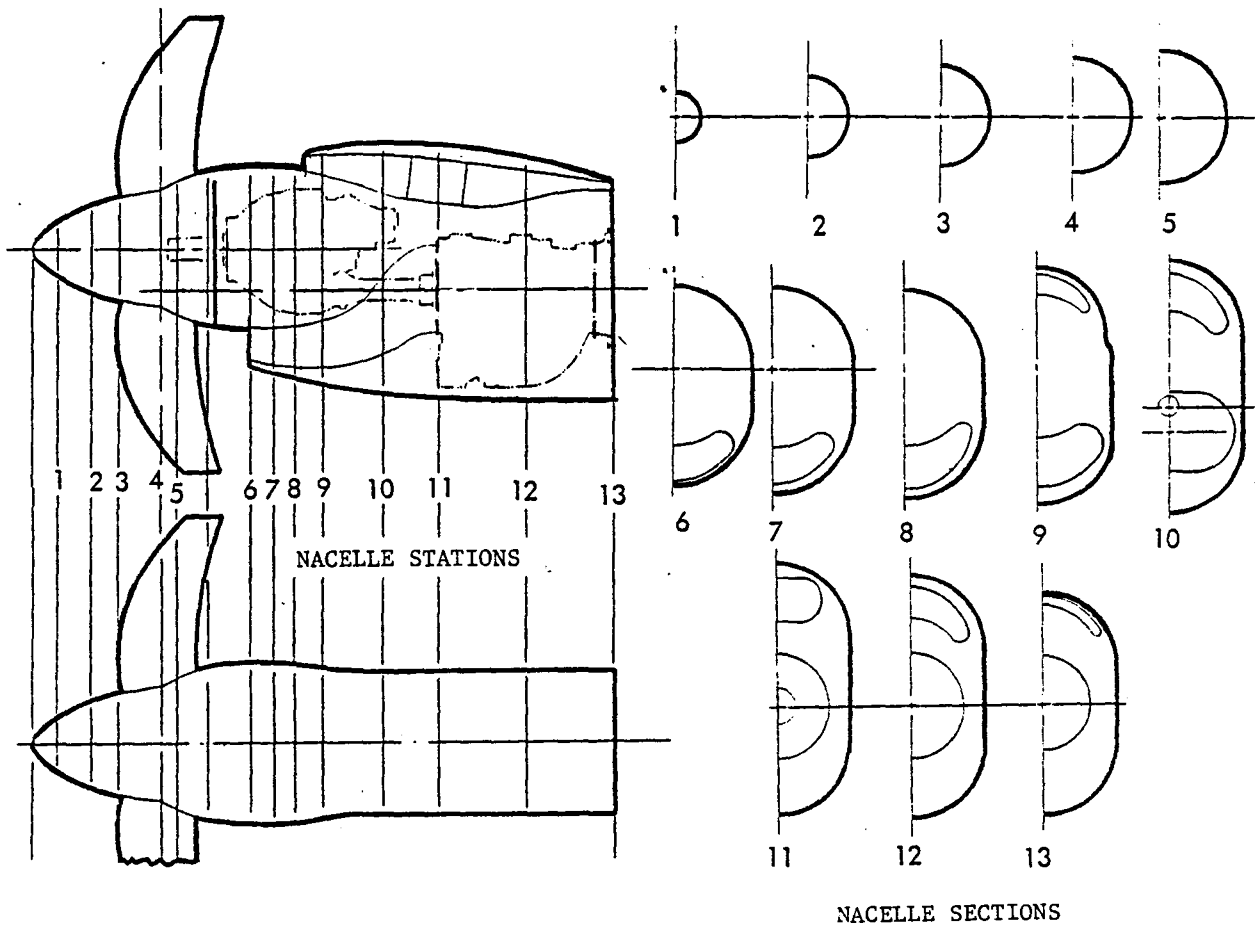


Figure B-13. T64 Pinion-High Refined Nacelle



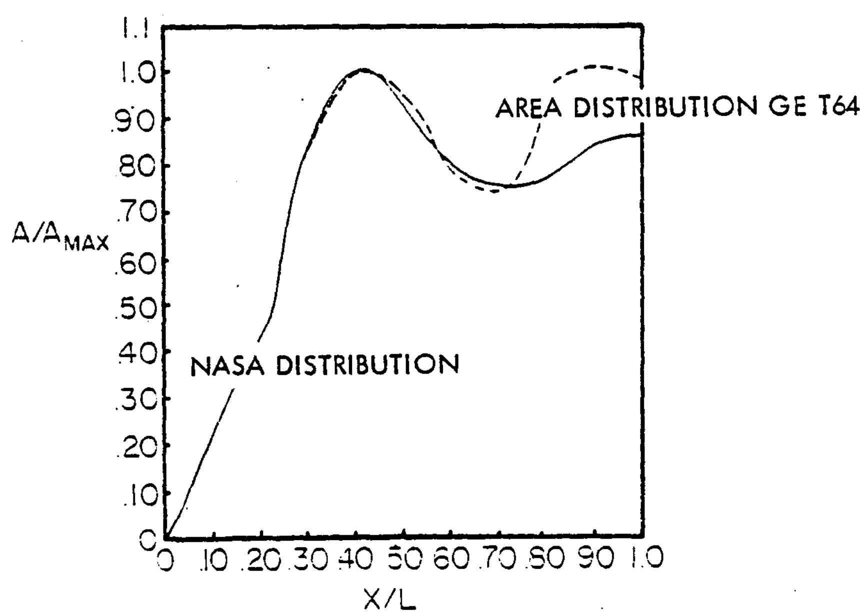


Figure B-14. T64 Pinion-Low Refined Nacelle a prop-fan diameter of 2.5m (8.1 ft). The nacelle maximum cross-sectional area located at X/L = 0.414 was determined using the ratio D_N/D_P = 0.35, with D_P = 2.5m (8.1 ft). During the investigation of the nacelle contours, it was found that a common set of contours could be used for the "pinion-high" and "pinion-low" configurations. The nacelle layout and contours are shown in Figure B-15. The contours shown are for the "pinion-low" arrangement. Rotation of the contours 3.14 radians (180 degrees) gives the arrangement for the "pinion-high" configuration. Although the envelopes are the same, the mounting and structural arrangement for the "pinion-high" and "pinion-low" arrangements would be different.

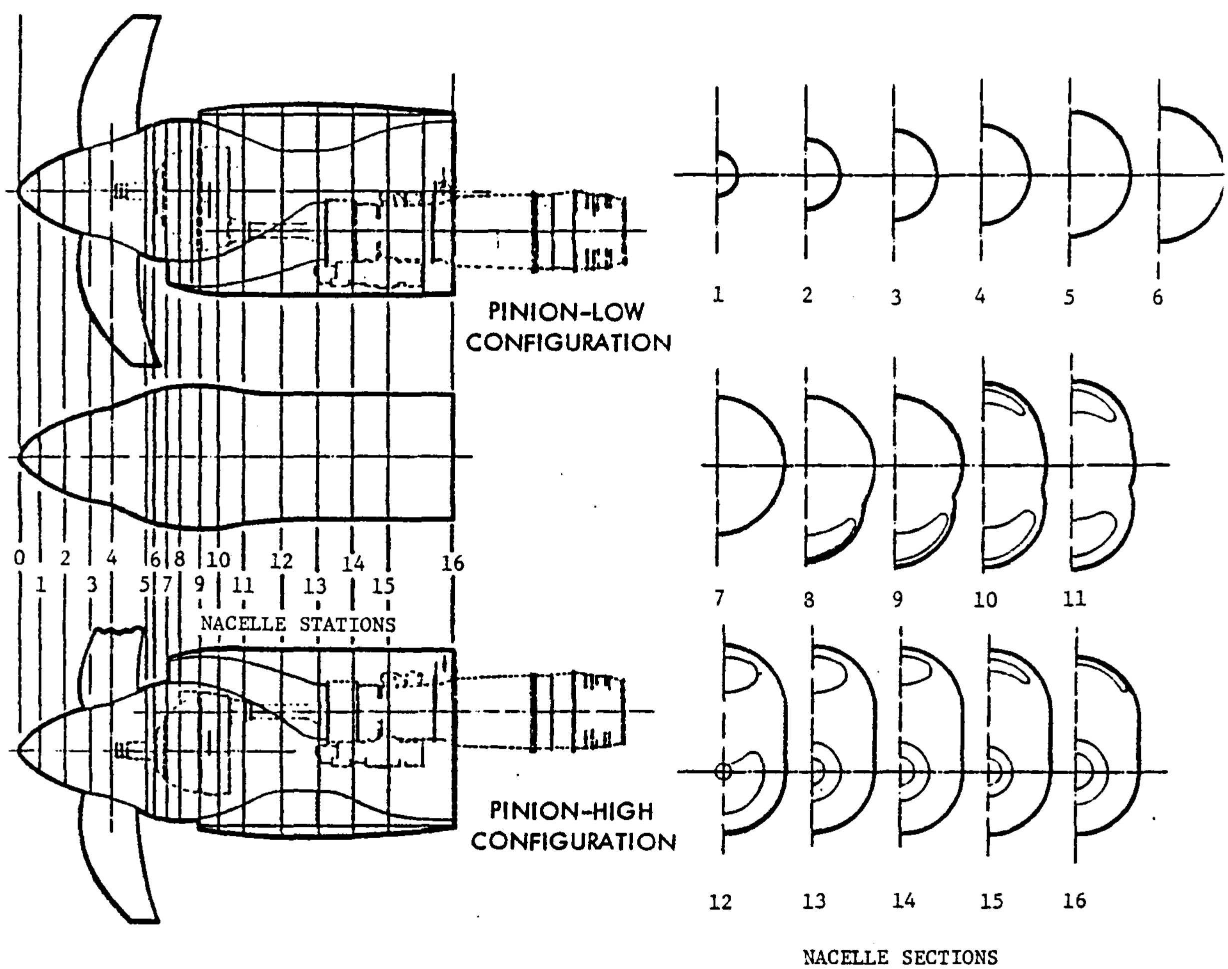


Figure B-15. T56 Pinion-High and Pinion-Low Common Contours

XT701 Nacelle Contours - The departure from a universal T56/XT701 nacelle and the development of common contours for the T56 "pinion-high" and "low" nacelle led to the development of a similar set of contours for the XT701 drive system. A number of important differences in the nacelle arrangement occurred as the result of the contour refinement. First, because the nacelle/ wing integration was not an optimized arrangement, the shaping of the maximum beam of the nacelle beyond the location of the maximum cross-sectional area was changed to allow the maximum beam dimension to remain constant over the aft portion of the nacelle. Second, in the previous designs, the engine and oil cooler ducts were arranged to be opposite each other; in the revised design, the ducts are arranged in a stacked and staggered configuration to best use the available space within the nacelle envelope. The nacelle layout, contours, and area distribution are shown in Figure B-16. Further refinement of this nacelle was performed to change the shapes for structural and manufacturing simplicity. The major change was the slight increase in nacelle diameter to permit the use of major structural elements from the Lockheed P-3C nacelle and the introduction of a constant shape for the upper portion of the nacelle, allowing straight sides on the nacelle. The final design for the XT701 contours and area distribution are shown in Figure B-17.

Prop-Fan and Nacelle Ratios - The nacelle/prop-fan diameter ratios are shown in Table B-IV. The nacelle diameter, D_N, is the equivalent diameter based on the maximum cross-section area, or reference area occurring at X/L = 0.414. These data show that new nacelles can be configured with the desired diameter ratio but that some compromise is necessary if existing nacelles are to be used.

CANDIDATE PROPELLER DRIVE SYSTEM INSTALLED PERFORMANCE

Installed performance for the prop-fan drive systems using eight bladed prop-fan data are provided in Figure B-18 for takeoff conditions and at altitudes of 4572m (15,000 ft), 7620m (25,000 ft), 10,668m (35,000 ft) for the XT701 and GE T64 drive systems and 4572m (15,000 ft), 7620m (25,000 ft), 11,000m (36,089 ft) for the T56 drive system. Jet thrust data are also given.

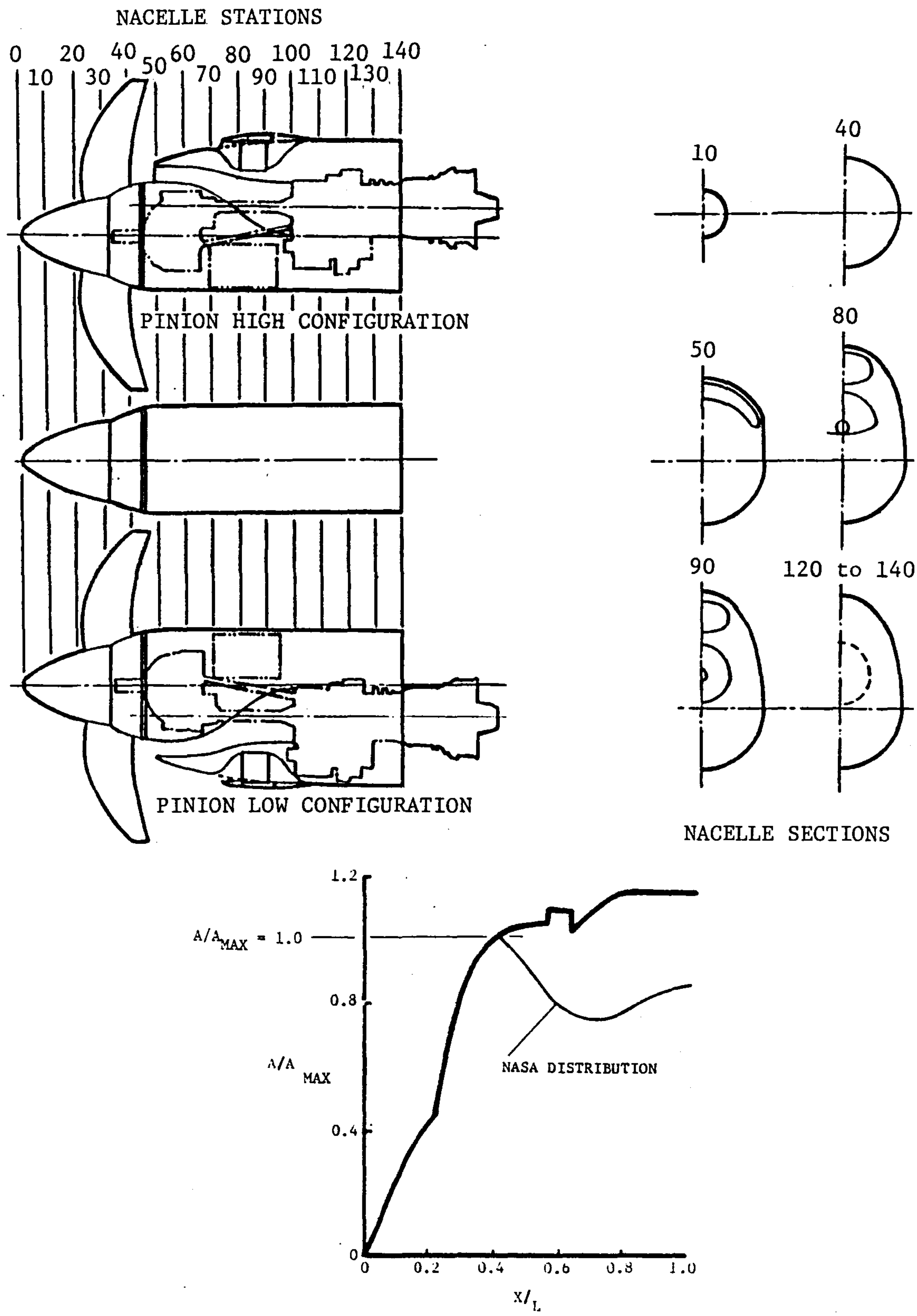


Figure B-16. XT701 Nacelle Common Contours

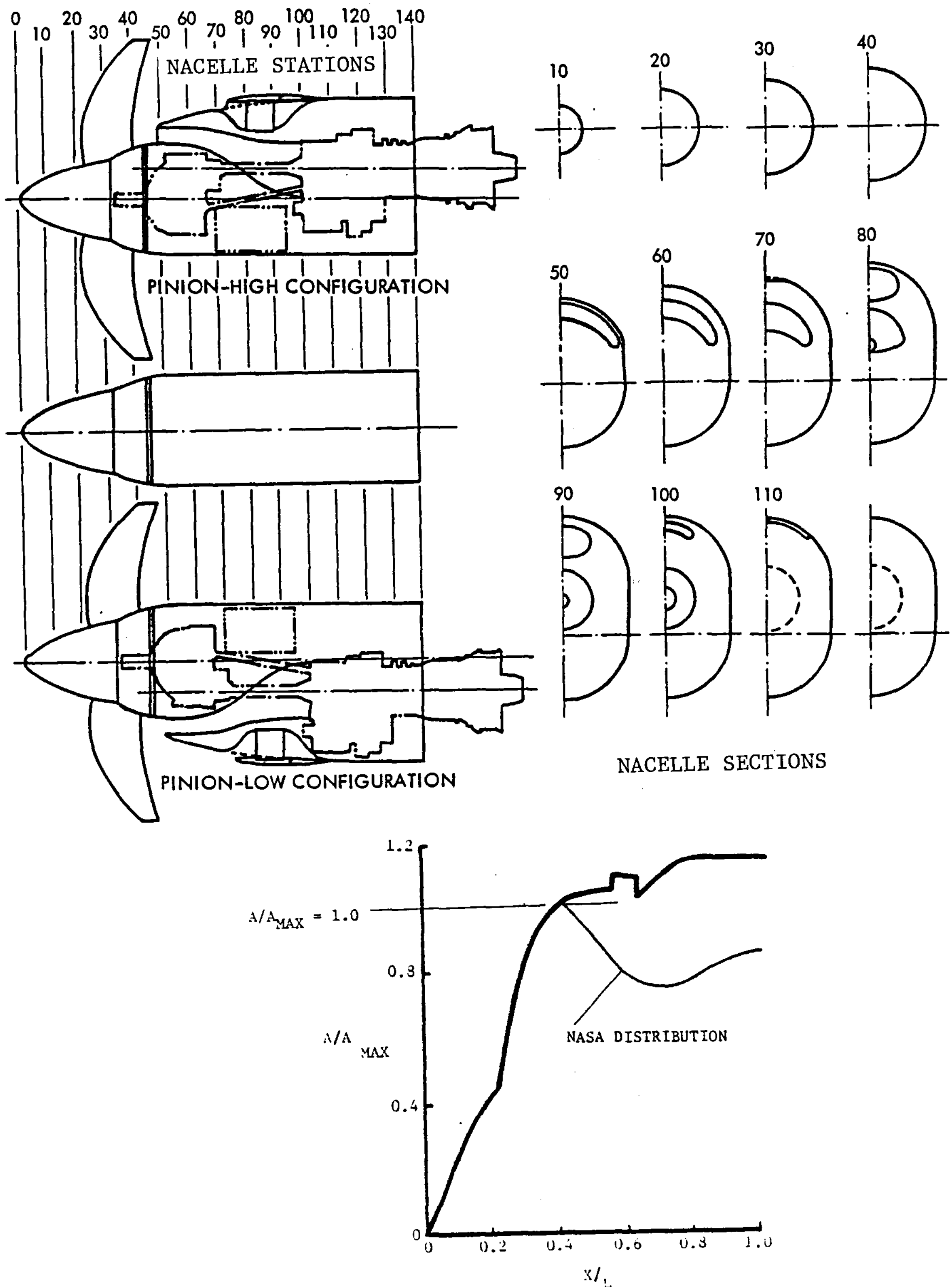


Figure B-17. XT701 Nacelle Final Contours

TABLE B-IV. SUMMARY OF NACELLE/PROP-FAN RATIOS

NACELLE		A_{MAX} m^2	(FT^2)	D_P m	(FT)	D_N m	(FT)	D_N/D_P
X701	Pinion-Low	1.00	(10.77)	2.89	(9.5)	1.13	(3.70)	0.388
*T56	Pinion-Low	1.00	(10.77)	2.47	(8.1)	1.13	(3.70)	0.45
XT701	Pinion-High	0.922	(9.93)	2.89	(9.5)	1.08	(3.56)	0.358
*T56	Pinion-High	0.922	(9.93)	2.47	(8.1)	1.08	(3.56)	0.44
T64	Pinion-Low	0.515	(5.55)	2.12	(6.97)	0.81	(2.66)	0.38
T64	Pinion-High	0.515	(5.55)	2.12	(6.97)	0.31	(2.66)	0.38
C-130 - T56	Pinion-Low	1.15	(12.40)	2.47	(8.1)	1.21	(3.97)	0.49
C-130 - T56	Pinion-Low (Revised)	0.87	(9.37)	2.47	(8.1)	1.05	(3.45)	0.42
P3C - T56	Pinion-High	1.88	(20.20)	2.47	(3.1)	1.56	(5.071)	0.62
P3C - T56	Pinion-High (Revised)	1.07	(11.51)	2.47	(8.1)	1.17	(3.53)	0.47
XT701	Pinion-High/Low	0.345	(9.1)	2.89	(9.5)	1.04	(3.41)	0.35

A_{MAX} = Reference Cross Sectional Area at X/L = 0.414

D_P = Prop-Fan Diameter

D_N = Nacelle Equivalent Diameter @ X/L = 0.414

*These nacelle configurations were assumed to be the same as the XT701 because of the similarities of the XT701 and T56 engines. The T56 nacelles can be refined to give D_N/D_P = 0.35 consistent with the 2.47 m (8.1 FT) diameter prop-fan.

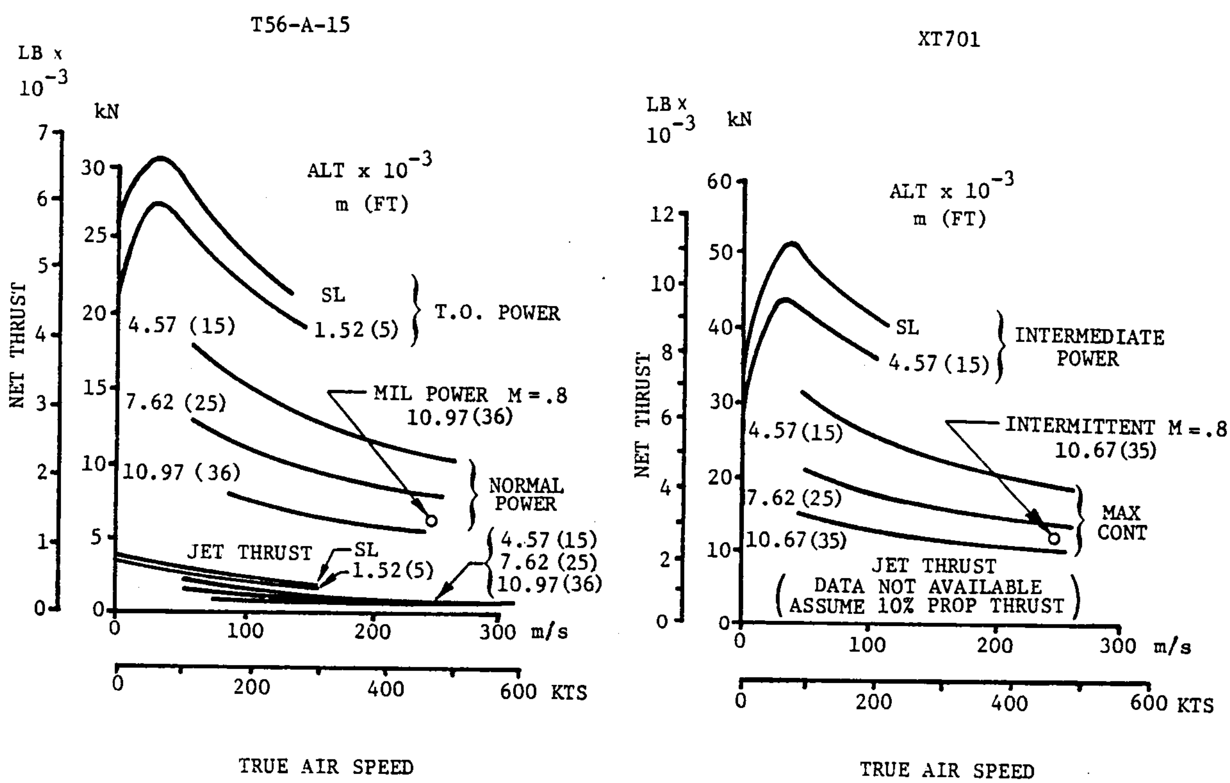


Figure B-18. Drive System Installed Performance

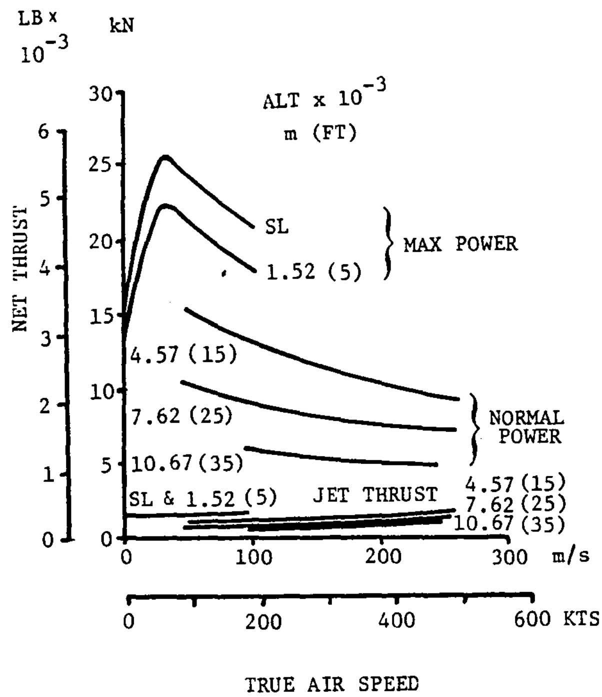


Figure B-18. Drive System Installed Performance (Cont'd)

REDUCTION GEARBOX MODIFICATIONS FOR PROP-FAN APPLICATION

Application of the available gearboxes to the prop-fan drive systems requires modification of the gearboxes to match the power-section performance, direction of rotation, and the sizing requirements for the prop-fans. Free turbine power sections have an advantage over fixed-speed, single-shaft cores through the ability to vary engine speed and power level to change prop-fan tip speed. Only one modified gearbox is required for the free turbine units, whereas a separate gearbox would be required for each tip speed for the single-shaft, fixed-speed engine.

T64-2 SDG Reduction Gearbox

The gearbox, shown in Figure B-19, consists of a planetary section and an offset section. Conversion to prop-fan application requires modification of the offset section only. The current planetary gearbox, rated at 2535 kW (3400

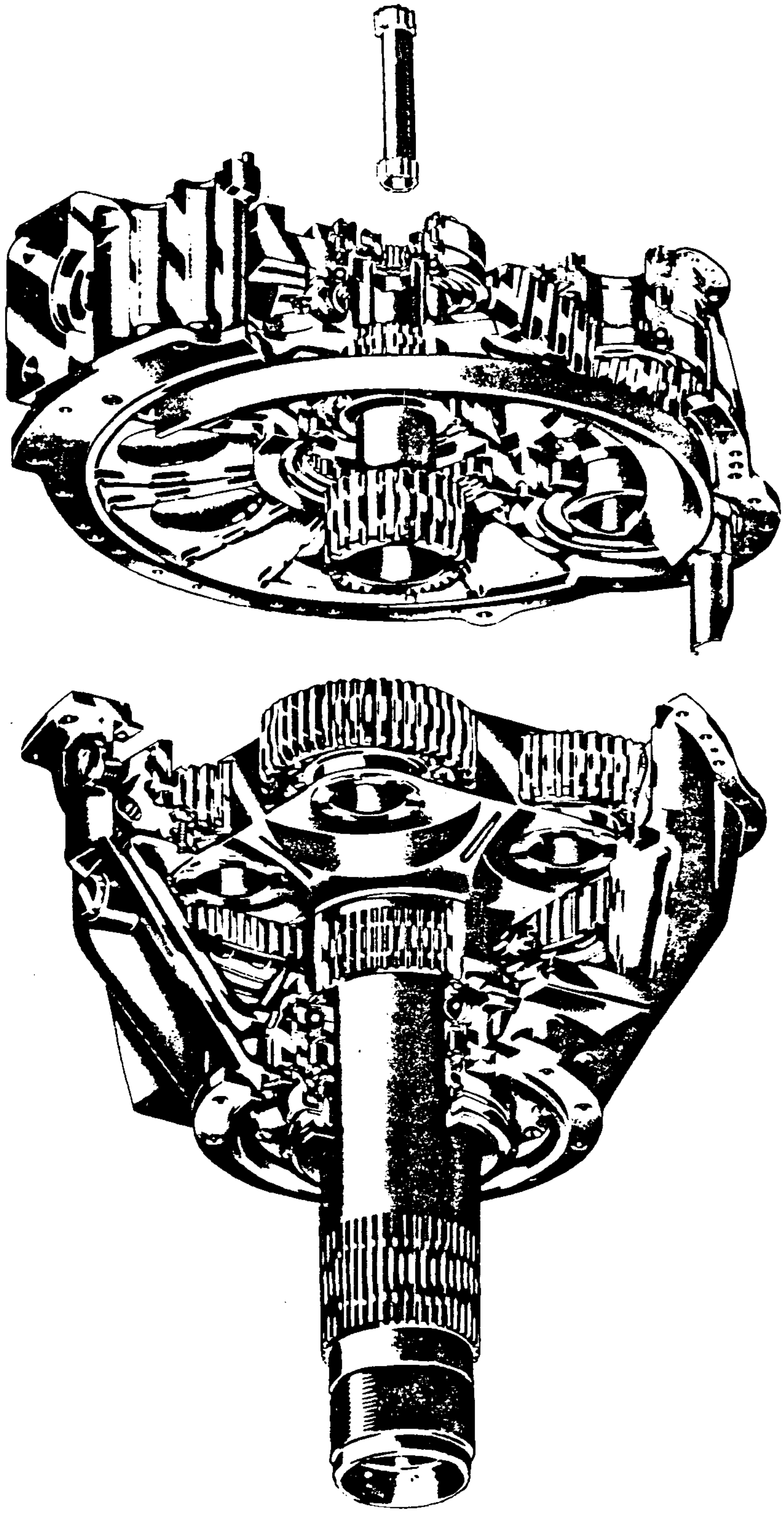


Figure B-19. T64-2 SDG Gearbox

shp), could be used with a modified offset gearbox to give the required tip speed. Modifications to the offset section do not require major changes to the housing castings but do need:

- o Minor modification to the offset section castings
- o New offset gears
- o Modified gear mesh lube
- o New lube tube/seal/spider

The gearbox can be used either in the "pinion-high" or "pinion-low" configuration without changing output.

The gearbox for reverse rotation would require a completely new design for the offset section.

DDA T56-A-14 Gearbox

This gearbox is a "pinion-high" configuration as used in the Lockheed P-3C "Orion"; it can be adapted for prop-fan application using either the T56 or XT701 power sections, although the modifications required to match the XT701 to the prop-fan are complicated by the rotation of the XT701, which is opposite to that of the T56 and by the significantly lower RPM of the XT701.

<u>Gearbox Modification for the DDA T56</u> - The following modifications are required to match the T56 power section for tip speeds of 183, 213, and 244 m/s (600, 700, and 800 fps):

Rework Required—

- o Machine rear housing for larger pinion gear
- o Reroute oil supply to pinion bearing externally
- o Machine main diaphragm to reroute oil supply

New Parts Required: Operation of the prop-fan at tip speeds of 183, 213, and 244 m/s (600, 700, and 800 fps) will require three gearset configurations:

o 68T, 8P Pinion Gear	244 m/s (800 fps)
o 108T, 8P Main Drive Gear	

- 63T, 8P Pinion Gear
- 113T, 8P Main Drive Gear

} 213 m/s (700 fps)

- 56T, 8P Pinion Gear
- 120T, 8P Main Drive Gear

} 183 m/s (600 fps)

- Offset Pinion Gear Lube Nozzle

<u>Gearbox Modifications for the DDA XT701</u> - Since the XT701 is a free turbine power section, only one set of gears is required. The modifications to the gearbox for use with the DDA XT701 are as follows:

Rework Required:

- Machine rear housing for larger pinion gear
- Machine rear housing for added idler gear spindle
- Reroute oil supply to pinion bearing externally
- Machine main diaphragm to reroute oil supply
- Machine nose bearing plate for nose oil pump
- Machine clearance on inner diaphragm for idler gear

New Parts Required:

- 68T, 8P Pinion Gear
- 108T, 8P Main Drive Gear
- Offset Pinion Gear Lube Nozzle
- 61T, 10P Alternator Gear
- 78T, 10P Nose Oil Pump Drive Gear
- 33T, 10P Nose Oil Pump Driven Gear
- Idler Gear Spindle
- NTS Helical Spline Coupling
- Lockout Spacer in Prop-Fan Brake

In addition, the XT701/T56-A-14 combination would also require:

- o New torquemeter and housing
- o New compressor inlet adapter ring for interconnecting strut attachment
- o New interconnecting struts

The modified T56 gearbox is illustrated on Figure B-20.

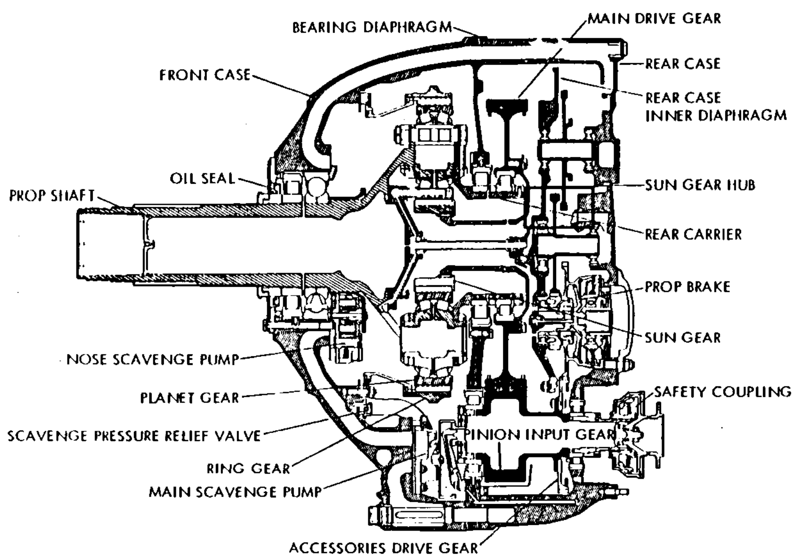


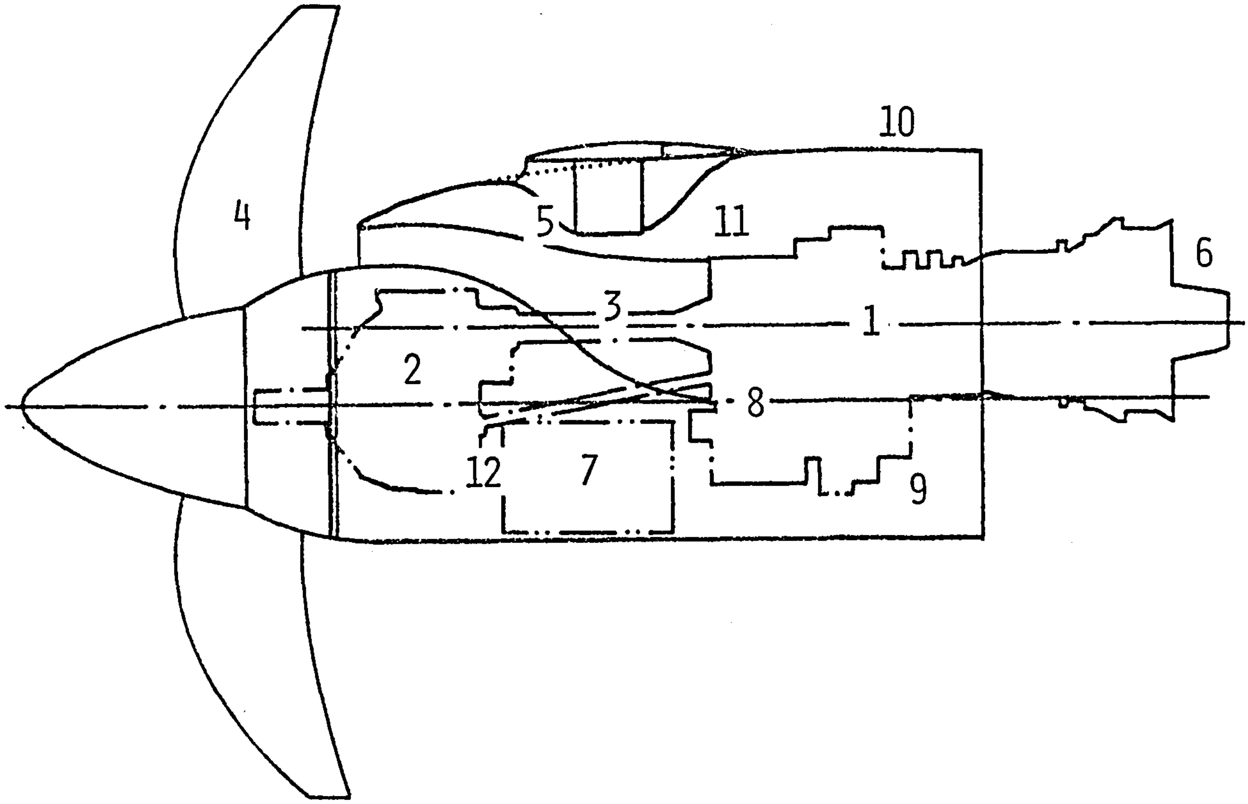
Figure B-20. T56 Gearbox Modifications

DRIVE SYSTEM QUICK ENGINE CHANGE (QEC) UNIT

The design approach to the drive system was to consider the drive system as an independent unit and, therefore, independent of the subsequent receiving airframe. Since QEC unit weight was not a critical item, the design approach included over-design of the drive system mounting structure to permit universal application of the unit.

In the case of the DDA T56/XT701 drive systems, the QECs would use support structure from the C-130 "pinion-low" nacelle and P-3C "pinion-high" nacelle.

A typical QEC unit, shown on Figure B-21, consists of the bare drive system housed in a nacelle complete with mounting structures, air induction systems, exhaust systems, subsystems such as starting and electrical, the prop-fan and engine controls, and the lubrication system. The unit is designed for ease of assembly/disassembly at the parting plane, which is the juncture between the



1 POWER SECTION
2 GEAR BOX
3 TORQUE METER
4 PROPFAN
5 AIR INDUCTION SYSTEMS
6 EXHAUST SYSTEM
7 LUBRICATION SYSTEM
8 CONTROLS
9 STARTING SYSTEM
10 NACELLE STRUCTURE
11 DOORS AND PANELS
12 RESIDUAL OIL AND GREASE

Figure B-21. Typical QEC

QEC and the fixed portion of the nacelle on the airframe. The QEC design can be varied for either an underwing or an overwing installation. Investigation of an overwing arrangement shows that the nacelle structure can be assembled from P-3C nacelle parts as follows:

P-3C Parts Used in QEC

P-3C Part No.	Quantity	Name
918468	1	Machined Forging
839475-1	1	U-Frame Assembly
839475-2	1	U-Frame Assembly
632238-7	2	Mount
632238-9	2	Mount
632238-51	1	Mount
918611-3	2	Mount
918611-1	2	Mount

The lubrication system can be designed to use the oil cooler from the C-130 identified as part No. 697226.

Drive System QEC Weights - The weights for each QEC unit for the three candidate drive systems are shown on Table B-V.

TABLE B-V. QEC UNIT WEIGHTS

QEC UNIT WEIGHTS

Drive System		Configuration	
		Underwing	Overwing
GE T64	kg (LB)	———	1669 (3680)
T56	kg (LB)	1827 (4030)	1980 (4366)
XT701	kg (LB)	1800 (3971)	1953 (4307)

Drive System Controls

<u>Prop-Fan Control System Description, T56 and XT701</u> - A feasibility study was conducted by Hamilton Standard to determine the suitability of the control used for 54H60 propellers on the Lockheed C-130 and P-3C aircraft. This control readily fits a 60-spline shaft such as that of the T-56 engine (a fixed-speed engine) and also has a high pumping capacity. Compatibility of the control has also been established for the DDA XT701 free turbine power section, but some modification is necessary to achieve variable-speed capability. The control, which currently operates at 1020 RPM is designed for pump flows of $0.057 m^3/min$ (60 quarts/min). Following a whirl test on a modified 54H60 control and propeller hub at 1800 rpm, it was concluded that the control could operate at this speed and was capable of withstanding the loads imposed if minor modifications were performed. These modifications would consist of:

- Replacement of standby pump drive gear
- Increased clearance for the transfer bearing
- Speed bias and linkage removal
- Redesign of governor flyweights and speeder spring
- Removal of Beta control differential gear train
- Brushlock removal or revision
- Addition of a heat exchanger for transfer bearing cooling

In the study, prop-fans having diameters of 2.47 and 3.05m (8 and 10 ft) with eight or ten blades were examined. Although it is feasible to use the control for these conditions, it was found that the pitch change rates for 2.44m (8ft) 8 blade and for the 3.05m (10 ft) 8- and 10-blade combinations were slow and well below the rates considered acceptable for rapid transients.

Control functions examined include negative torque sensing (NTS), overspeed prevention, normal governing, feathering, and reversing.

It has already been established that the control is compatible with either the T-56 or the XT701; in the case of the T-56, however, a negative torque sensing system is required and is the only control hardware difference between the two engines.

Normal governing can be accomplished with the modified control and is independent of the type of engine.

Feathering is likely to be slow because of the low pitch change rates, as shown in Table B-VI and feathering out of an overspeeed condition where higher pitch change loads exist may not be possible with the modified 54H60 control. With the provision of adequate overspeed protection, however, this may be inconsequential.

Unfeathering using the modified control does not appear to present problems since an electrically driven auxiliary pump already on the control will be used.

Since the use of the 54H60 pitch-lock is not feasible in the prop-fan actuator, and conversely, the prop-fan pitch-lock concept is not compatible with the 54H60 control, some form of pitch-lock device should be incorporated into the prop-fan rotating hardware to prevent overspeeding in cases of inadvertent decrease in blade angle. A number of arrangements have been considered, and an electrically operated in-flight stop is considered to be feasible. This device would provide testing flexibility, although it would be necessary to be certain of the stop location at all times if overspeed protection is to be provided.

Engine Control -- T56 and XT701

A hydro-mechanical engine control system having an electronic supervisory system will be used in conjunction with the 54H60 prop-fan control.

TABLE B-VI. PROP-FAN PITCH CHANGE RATES

DIAM. m (FT)	NO. BLADES	PITCH CHANGE RATE RADS/SEC (DEG/SEC)	
		MAIN PUMP ONLY	MAIN & MOD STANDBY PUMPS
2.44 (8)	8	0.158 (9.05)	0.253 (14.5)
2.44 (8)	10	0.285 (16.31)	0.457 (26.2)
3.05 (10)	8	0.069 (3.92)	0.136 (7.8)
3.05 (10)	10	0.124 (7.11)	0.248 (14.2)

APPENDIX C - CANDIDATE TESTBED AIRCRAFT - TASK III

The procedure adopted for the identification and selection of the candidate testbed aircraft consisted of a two-level screening process. A survey of all NASA aircraft was conducted, and a list of those aircraft capable of meeting the specific design requirements was compiled. In addition, aircraft not in the NASA inventory were also included where suitability was established.

An initial screening of the list of these aircraft was conducted, and those that appeared unsatisfactory or marginal were eliminated. Such criteria as lack of compatibility with commercial passenger transport configurations, aircraft and prop-fan scaling mismatch, adverse location of the prop-fan, marginal aircraft performance, insufficient ground or component clearances, and lack of potential for modification, provided the basis for elimination. Following the initial screening, the aircraft remaining consituted the list of candidate testbed aircraft and were subjected to further and more detailed analysis.

CANDIDATE TESTBED AIRCRAFT DESIGN REQUIREMENTS

The design requirements for a testbed vehicle for flight research testing of a propeller of advanced design were as follows:

- Speed/Altitude - Mach 0.8 @ 9144m (30,000 ft) and above
- Capable of operating safely at normal flight conditions with the prop-fan powered or unpowered
- Takeoff and landing restrictions for the prop-fan operation acceptable
- Vehicle to be configured with one prop-fan drive system
- Sufficient primary propulsion to be retained to permit operation of the vehicle with the prop-fan powered or unpowered
- Non-optimum drive system installation acceptable

In addition, the testbed vehicle was required to provide a stable platform for accurate measurement of flight test data and proper simulation of the environment in which the prop-fan could be tested to satisfy the program objectives, and be large enough so that the aircraft geometric ratios would be representative of large-scale propulsion. The selected vehicles should also be capable of modification to multi-prop-fan testbed configurations.

AIRCRAFT SURVEY

A preliminary list of suitable aircraft was compiled from the approximately 110 aircraft in the NASA inventory, consisting of:

Lockheed C-141A (L-300)
Lockheed JetStar -6
Convair 990
Gulfstream American Corporation "Gulfstream II"
Boeing 737
Boeing KC135A (707 - 100)
Boeing B52H

Other aircraft considered included:

McDonnell-Douglas DC9-10
Boeing 727
BAC 111

These three aircraft were not pursued as testbed configurations for the following reasons:

- o DC9-10 - McDonnell-Douglas were under contract to the NASA-Lewis Research Center to examine the aircraft as a testbed vehicle. Inclusion in the study would have resulted in some duplication of effort.

- o Boeing 727 - Omitted as a candidate since this aircraft does not appear in the NASA inventory.

o BAC 1-11 - Does not meet speed/altitude design requirements and is a foreign aircraft.

These three aircraft (as are the JetStar and GII) are all aft-mounted propulsion configurations each presenting a clean wing for prop-fan application.

The survey included the physical location of each aircraft, the current or planned configuration, and the availability. This information is given in Table C-I.

TABLE C-I. AIRCRAFT SURVEY

AIRCRAFT	MODEL NO.	LOCATION	CURRENT OR PLANNED CONFIGURATION	AVAILABILITY	COMMENTS
Lockheed C-141A	C-141A	Ames RC	Telescope Program	Not Avail.	
Lockheed JetStar	-6 No. 3	Dryden FRC	Prop-Fan Acoustic Tests LFC Program	Mid '81 '83	Slipper Tanks Will be Removed
Convair 990 (1) (2)	10-37 11-29	Ames RC Ames RC	Airborne Instrument Lab AF Program	Not Avail.	High Operating Costs
Gulfstream II (1) (2)		Johnson RC	Shuttle Simulator Trainers	Not Avail.	
Boeing 737	-100 19437	Langley RC	Terminal Area Configured Vehicle Program	Not Avail.	
Boeing KC-135 (1) (2)		Edwards AFB Johnson RC	On Loan - Winglet Program Zero G	Returns to AF at End of Phase I Not Avail. Service Life Expended In '85	High Operating Costs
Boeing B-52	B	Edwards AFB	X-15, RPV Hymet Joint Program AF F III	Available	

TESTBED AIRCRAFT/PROPULSION SYSTEM CONFIGURATION

The installation of the prop-fan drive systems on the testbed aircraft falls into two categories:

- o Prop-Fan Propulsion System Substitution - This type of propulsion system arrangement requires the removal of an existing primary propulsive unit and the substitution of a prop-fan propulsion system at the same location.

- o Prop-Fan Propulsion System Addition - All existing primary propulsion is retained and the prop-fan propulsion system is added to the aircraft configuration.

The prop-fan propulsion system installation can be further defined by the location on the aircraft wing, i.e., for a "pinion-high" drive system configuration, the installation would generally be an overwing configuration, whereas the "pinion-low" arrangement would usually correspond to an underwing location. The prop-fan substitution arrangement, from the structural standpoint, would provide the best potential for modification, since wing structure to support the power plant would already be available to accommodate any candidate drive system with minimum modification. In those cases where the prop-fan installation would be an addition to a wing, the structural changes would probably be much more extensive.

The location of the prop-fan on the aircraft should be selected such that an environment exists that would permit testing the system throughout the full range of operating conditions. The configuration design must, therefore, be conducted so that the testbed aircraft will achieve the testbed program objectives.

The primary objective of the testbed is the verification of structural integrity, first of the prop-fan and second of the nacelle/airframe structure. It is, therefore, desirable that some means of changing excitation factor should be included in the design, and several means of accomplishing this have been considered, including variable toe-in and droop angle for the nacelle and leading-edge extensions to increase blade proximity. The non-symmetry of the nacelle due to the presence of unsymmetric air induction systems is also of concern, since the area distribution of the spinner/hub/nacelle may be affected.

Because the prop-fan system is to be installed on an existing aircraft, the degree of nacelle/wing integration optimization is limited. It is expected, however, that some contouring of the nacelle/wing interface can be included in the configuration design.

Investigation of near-field noise can be conducted in an environment that closely simulates that of a large-scale propulsion system with proper suppression of the prop-fan drive system noise. The prop-fan fundamental signal can be isolated and the higher frequencies made to dominate the noise spectrum so that clear signals can be obtained over the entire spectral range of frequencies. Provision must also be made to include testing of various noise attenuation concepts in the fuselage.

Testbed Aircraft Configurations

Testbed aircraft configurations were developed for the following aircraft and drive system combinations:

Aircraft	Drive System
Lockheed C-141A (L300)	XT701 pinion-high and low T56 pinion-high and low
Lockheed JetStar -6	T56 pinion-high T64 pinion-high
Boeing 737-10	XT701 pinion-low T56 pinion-low T64 pinion-high and low
Boeing KC-135A (707-100)	XT701 pinion-high and low T56 pinion-high and low
Boeing B52B	XT701 pinion-high and low T56 pinion-high and low
Convair 990	XT701 pinion-high and low T56 pinion-high and low T64 pinion-high and low

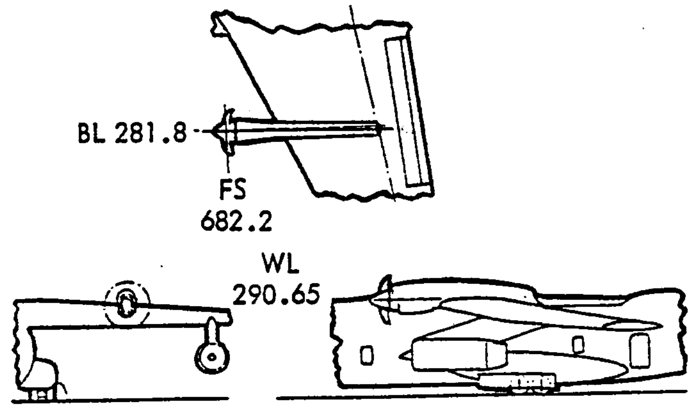
GAC "Gulfstream II"	XT701 pinion-high
	T56 pinion-high

C-141A Testbed Configurations - The C-141A configured as a testbed using the T56 drive system is shown in Figure C-1. This testbed configuration requires the removal of the left-hand inboard turbojet engine and the substitution of the prop-fan drive system. Two arrangements are shown for the T56; three views show the installation for the "pinion-low" gear box arrangement, and the auxilliary views illustrate the "pinion-high" overwing installation. The arrangements for the XT701 drive systems are similar, except that the installation would be substituted for the right-hand inboard turbojet. Of the two installations, i.e., "pinion-high or low," the "pinion-low" arrangement leading to an underwing configuration is preferred because of the reduced length of the exhaust duct nacelle, no interference with the trailing-edge flaps or spoilers, and because this installation is more favorable for conducting acoustic tests.

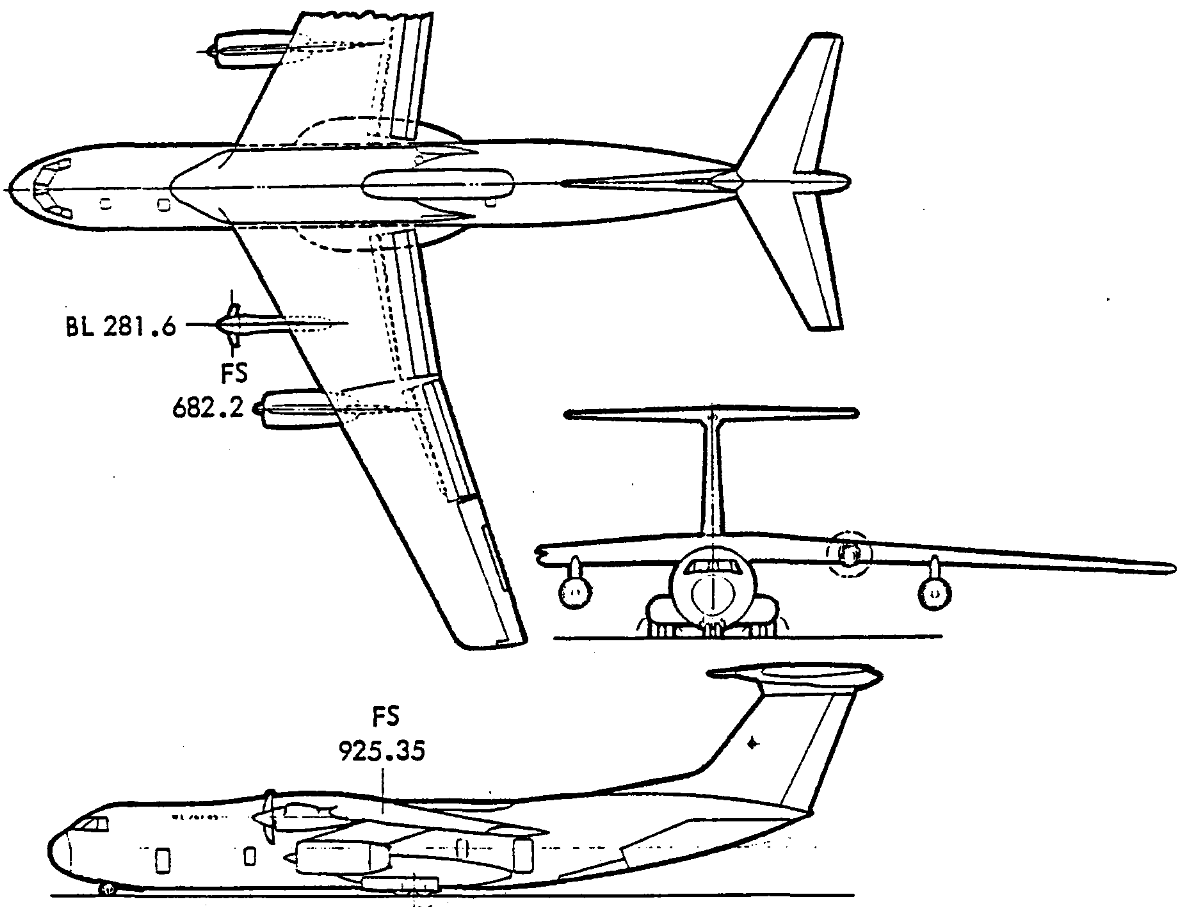
JetStar Testbed Configuration - JetStar -6 testbed configurations were generated by adding the prop-fan installation to the left-hand wing at the location of the external fuel tank, which is removed. The T64 "pinion-high" testbed configuration is shown in Figure C-2. In this configuration, sufficient ground clearance exists for the 2.13m (7 ft) diameter prop-fan and the prop-fan sweep does not overlap the main aft mounted propulsion system. Ground clearance in the normal attitude is marginal for the T56 mounted at the same location, Figure C-3. In the rolled attitude, however, a tip/ground interference occurs.

The XT701 installation was not included in the JetStar studies, as the 2.89m (9.5 ft) prop-fan diameter would result in a ground interference condition.

Boeing 737 Testbed Configuration - The Boeing 737 configured as a prop-fan testbed is shown in Figure C-4 for the T56 "pinion-low" drive system configuration. Since the prop-fan drive system is an addition to the configuration, it is located outboard of the left-hand turbofan at BL 293 LH. In the case of the XT701, the "pinion-low" drive system arrangement, Figure C-5, would be located on the right-hand wing at BL 293 RH. Both the T56 and the XT701 "pinion-high" installations could be located above the wing at the same but opposite spanwise location. The T64 installations for both "pinion-low" and "pinion-high" at BL



T56 OVERWING INSTALLATION



T56 UNDERWING INSTALLATION

Figure C-1. C-141A Testbed Configuration

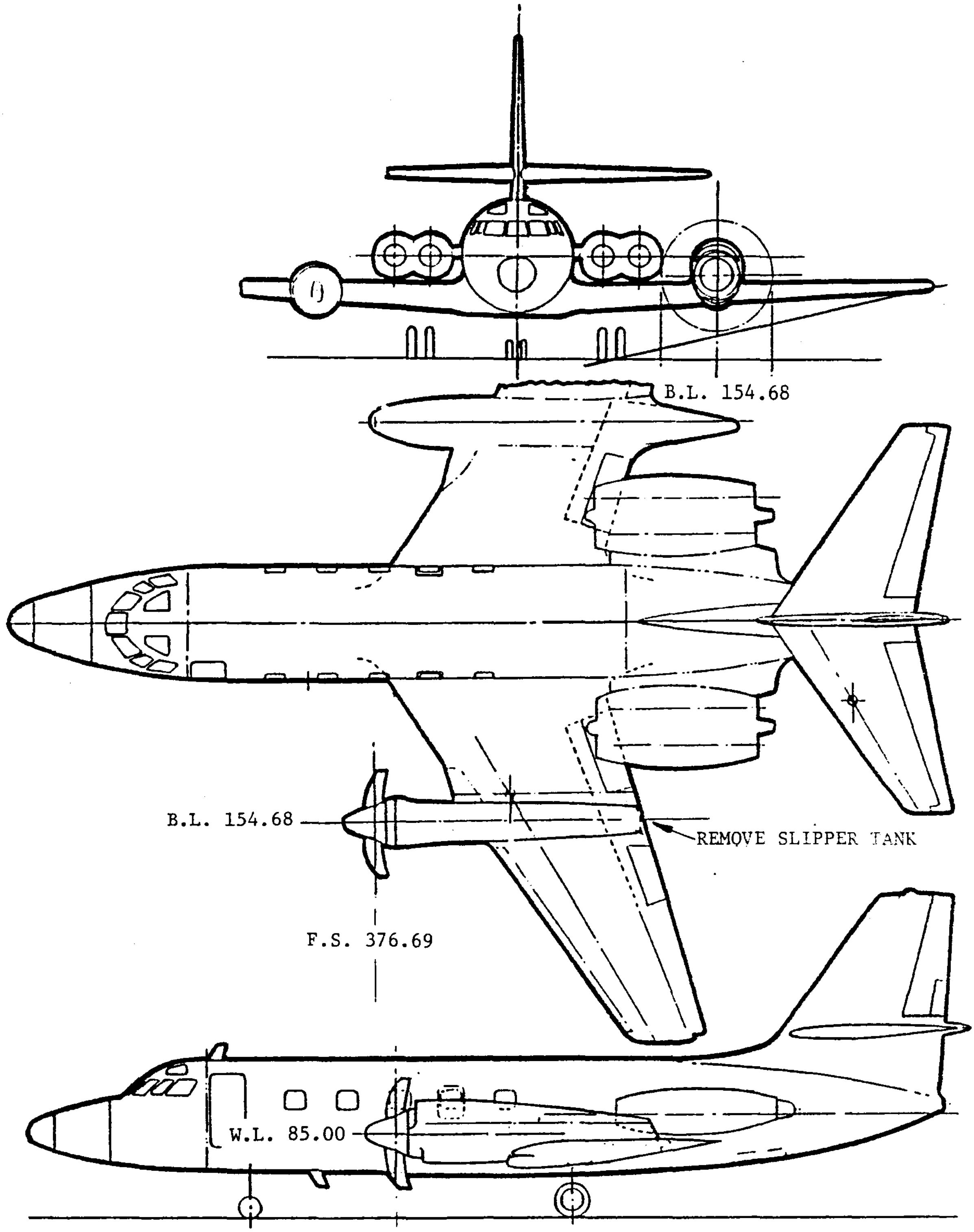


Figure C-2. JetStar -6, T64 Testbed Configuration

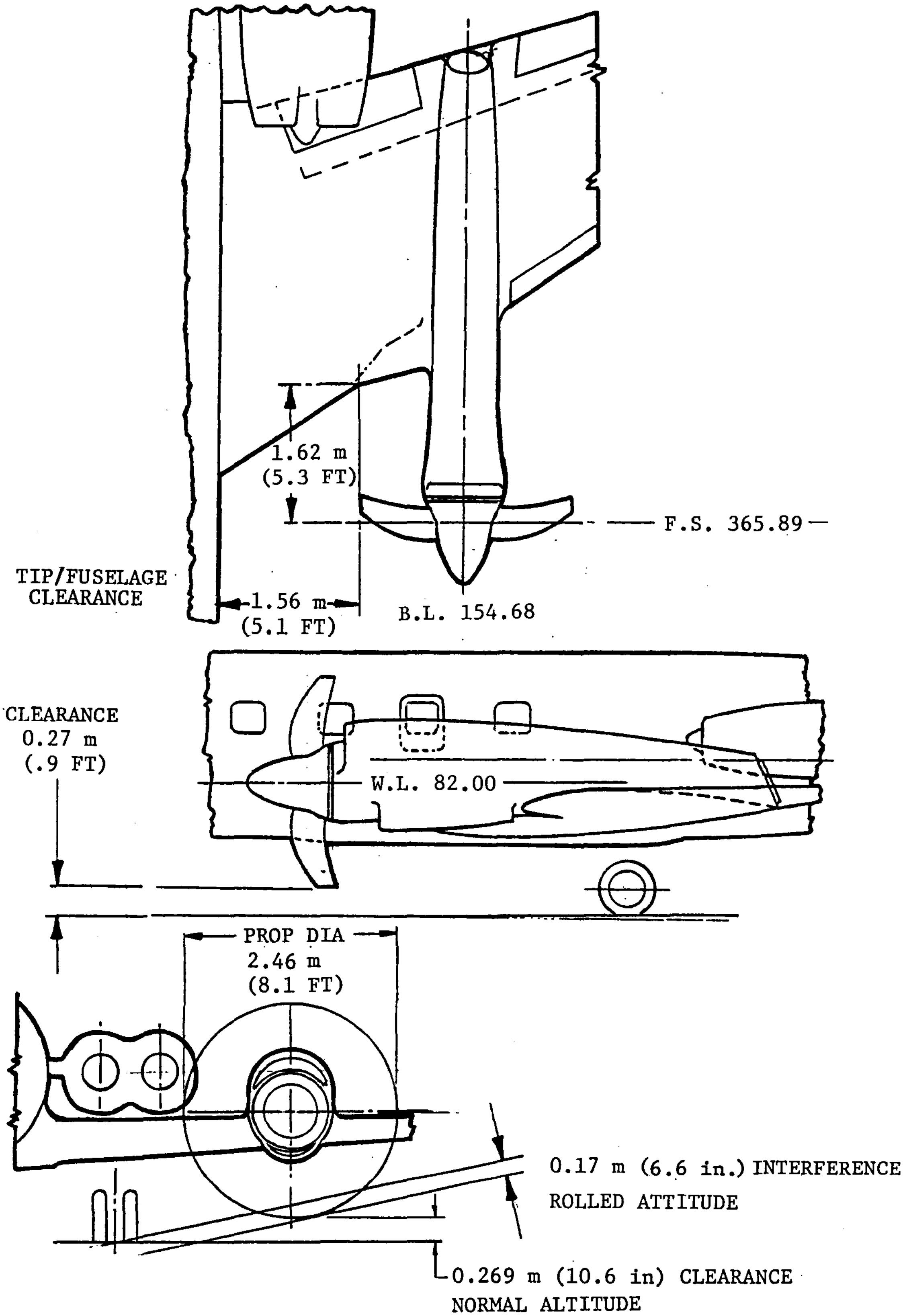


Figure C-3. JetStar -6, T56 Testbed Configuration

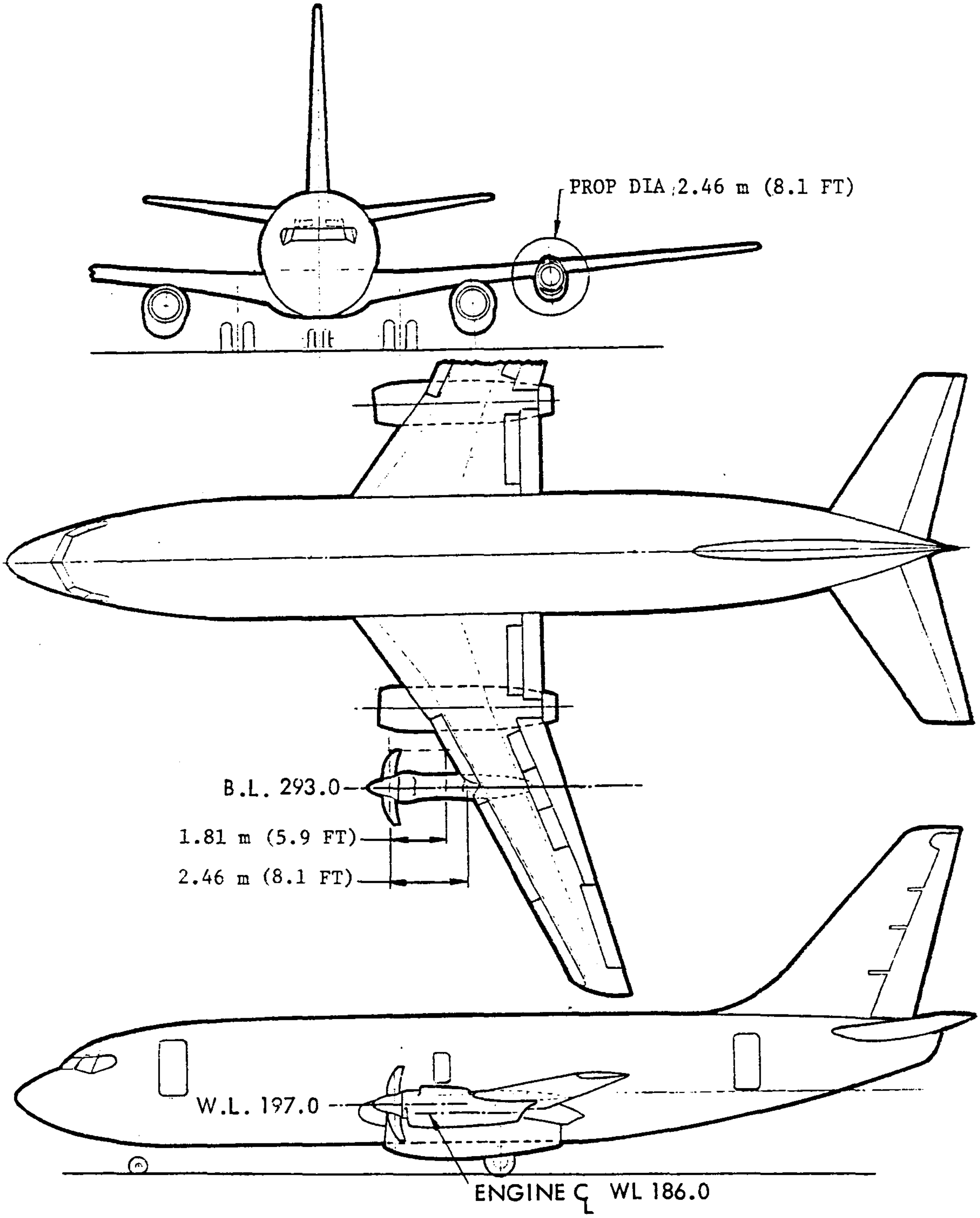


Figure C-4. Boeing 737-10, T56 Testbed Configuration

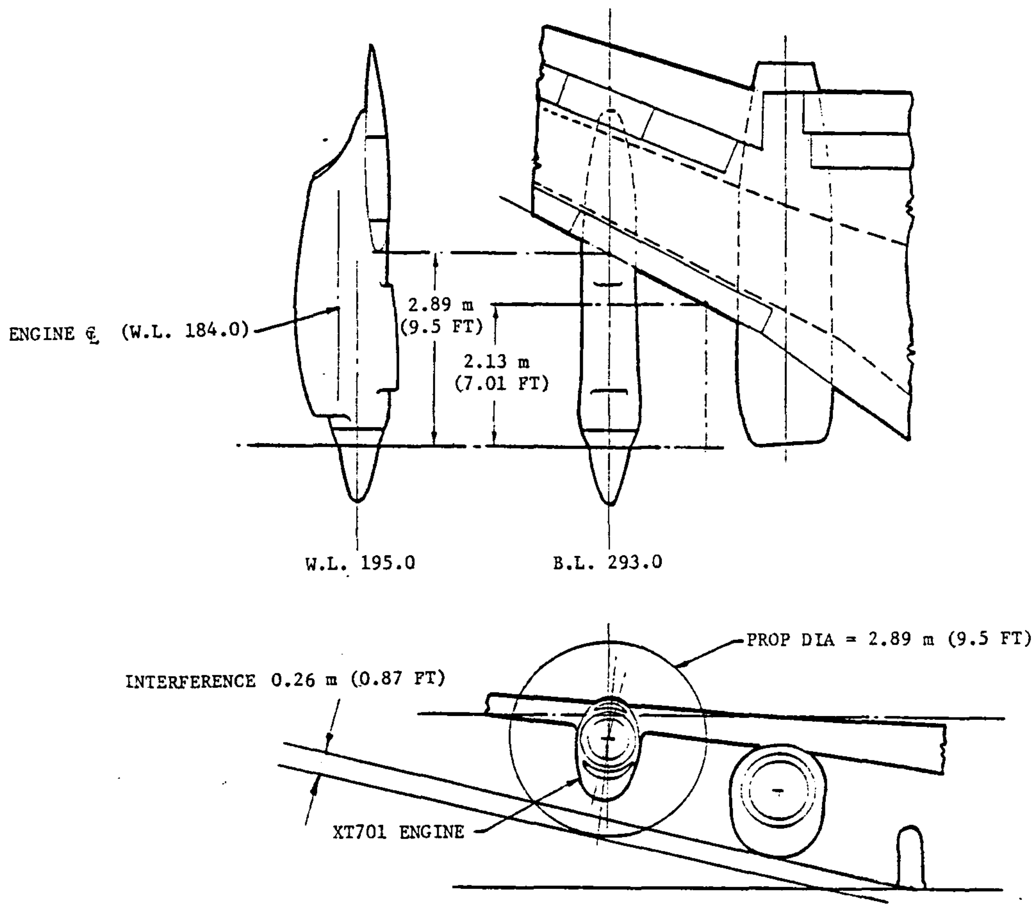


Figure C-5. Boeing 737-10 Testbed Configuration XT701 Pinion-Low

293 are shown in Figures C-6 and C-7. The "pinion-low" installation, Figure C-6, is slung beneath the wing and does not interfere with the trailing-edge devices as is the case with the "pinion-high" installation, Figure C-7.

KC-135A Testbed Configuration - The KC-135A configured as a prop-fan testbed aircraft is shown in Figures C-8 and C-9 for the T56 underwing installation, and in Figure C-10 for the overwing.

The corresponding installation of the XT701 on the right-hand wing is shown in Figures C-11 and C-12 for the underwing installation and in Figure C-13 for the overwing installation.

Ground clearance is not a problem with any of the installations, since the lateral clearance angle is determined by outer engine ground contact.

Variation in prop-fan size, however, would be constrained with the underwing installations to 3.72m (12.2 ft) and to 5.18m (17 ft) for the overwing installations.

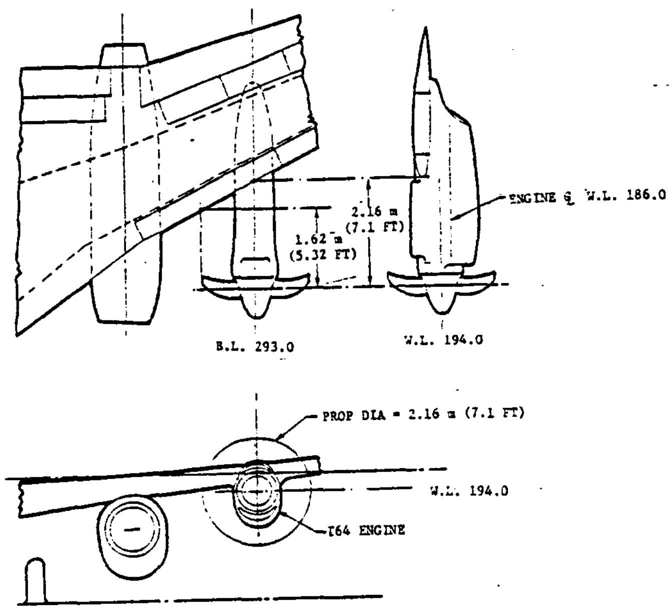


Figure C-6. Boeing 737-10 Testbed Configuration T64 Pinion-Low

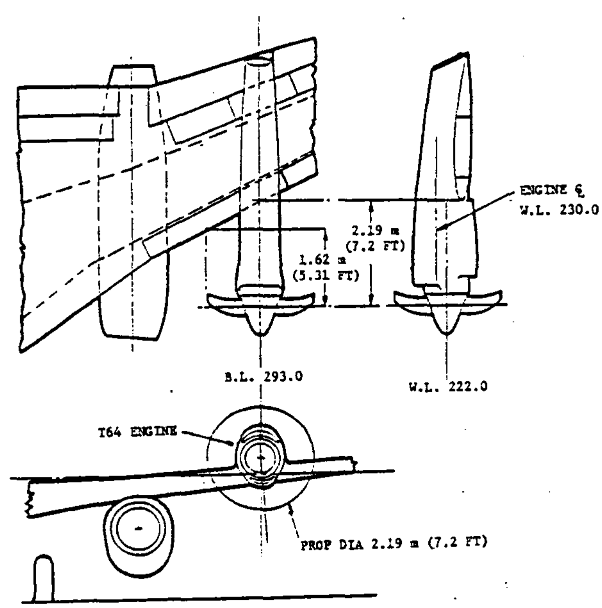


Figure C-7. Boeing 737-10 Testbed Configuration T64 Pinion-High

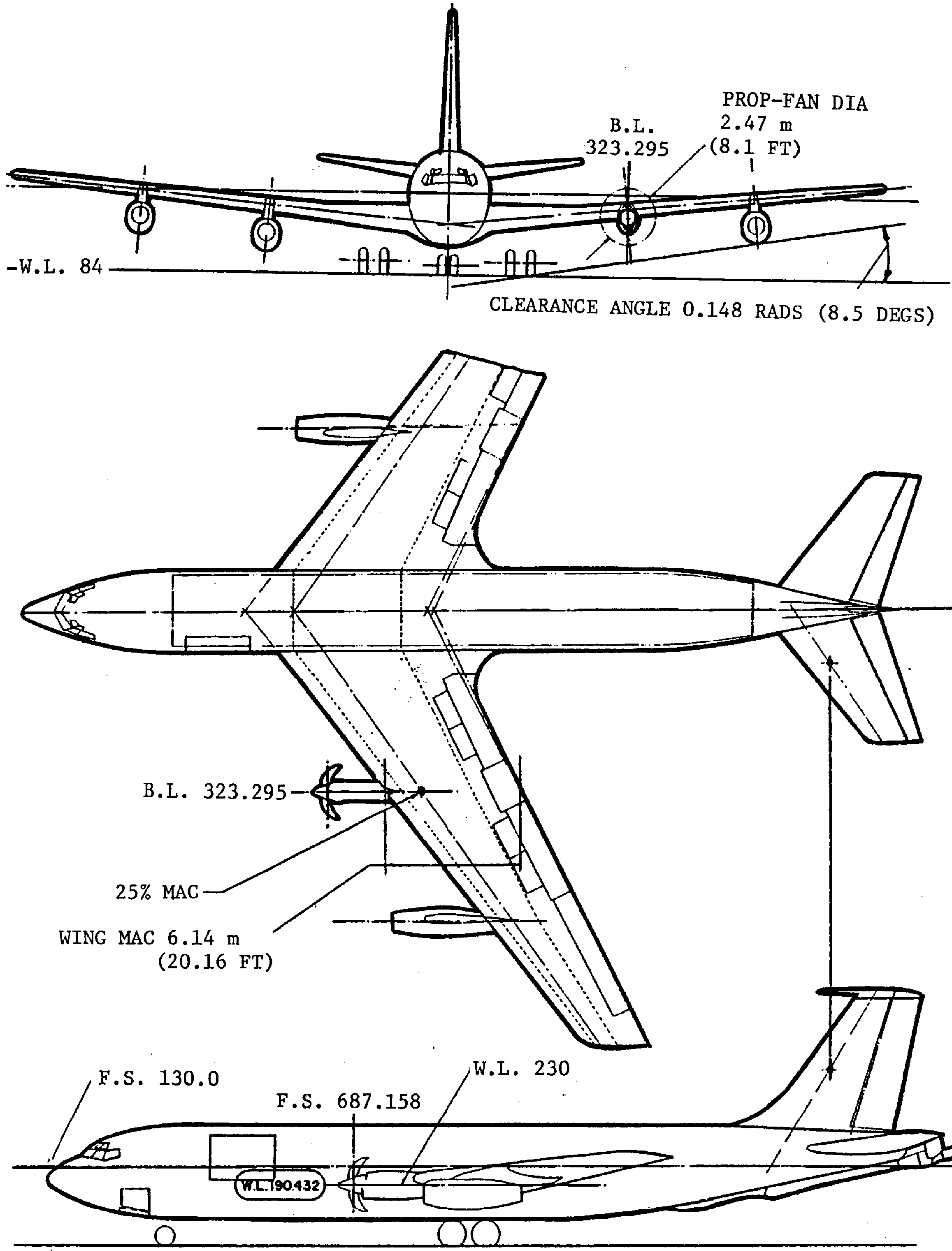


Figure C-8. Boeing KC-135A Testbed Configuration T56 Pinion-Low

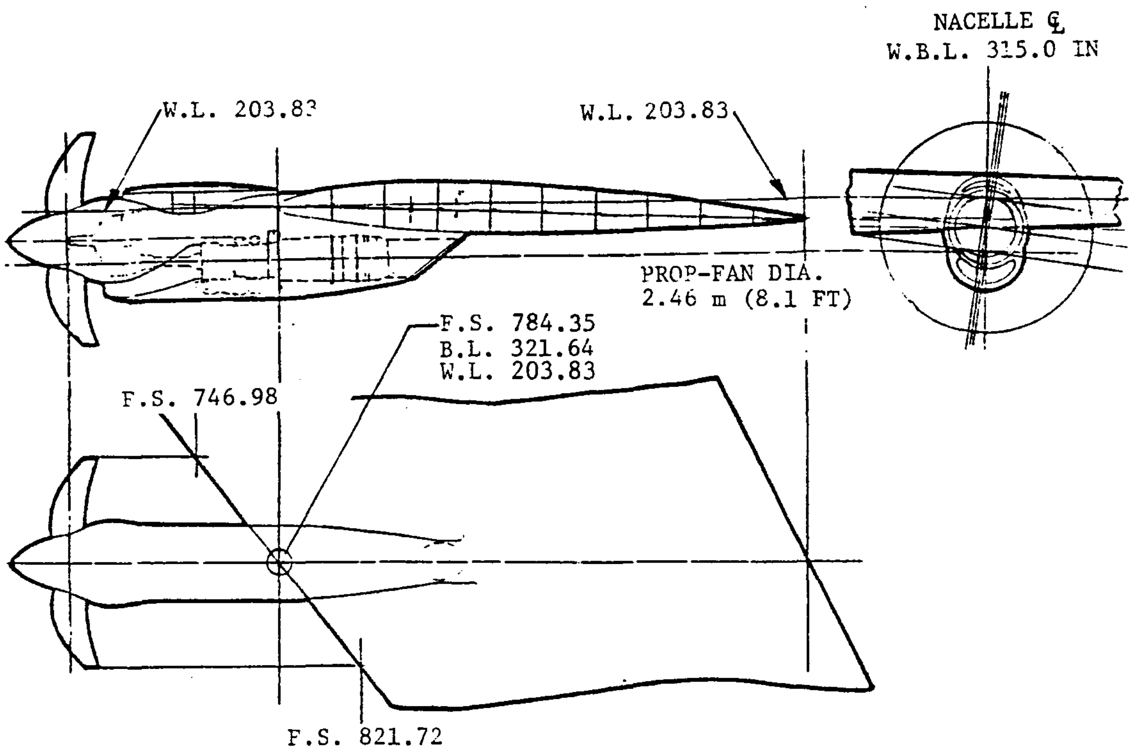


Figure C-9. Boeing KC-135A T56 Pinion-Low Installation

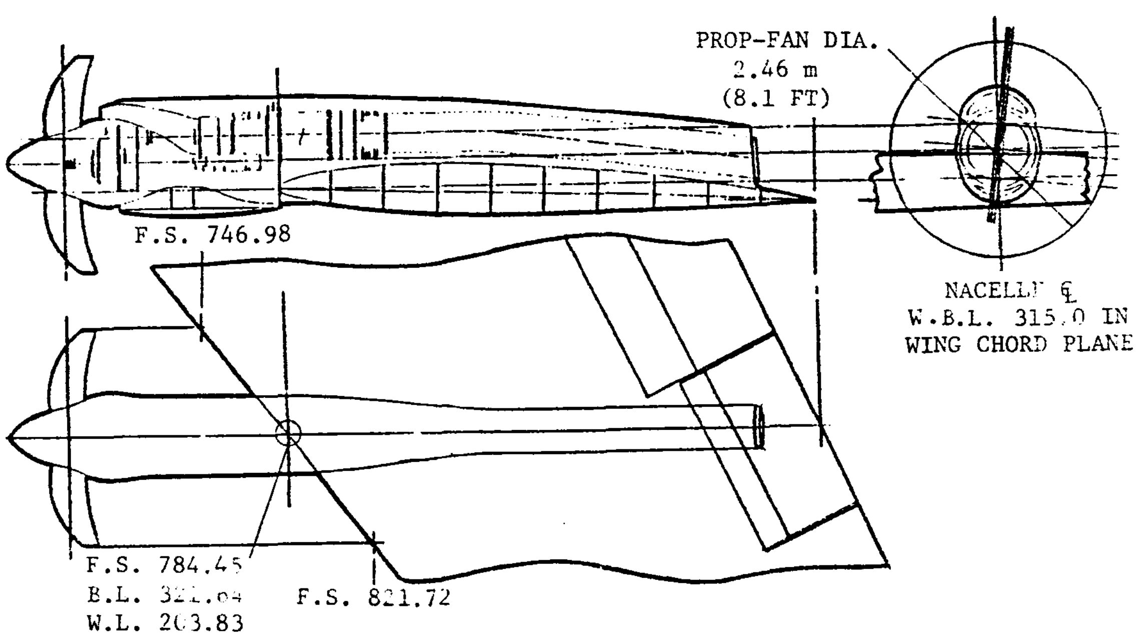


Figure C-10. Boeing KC-135A T56 Pinion-High Installation

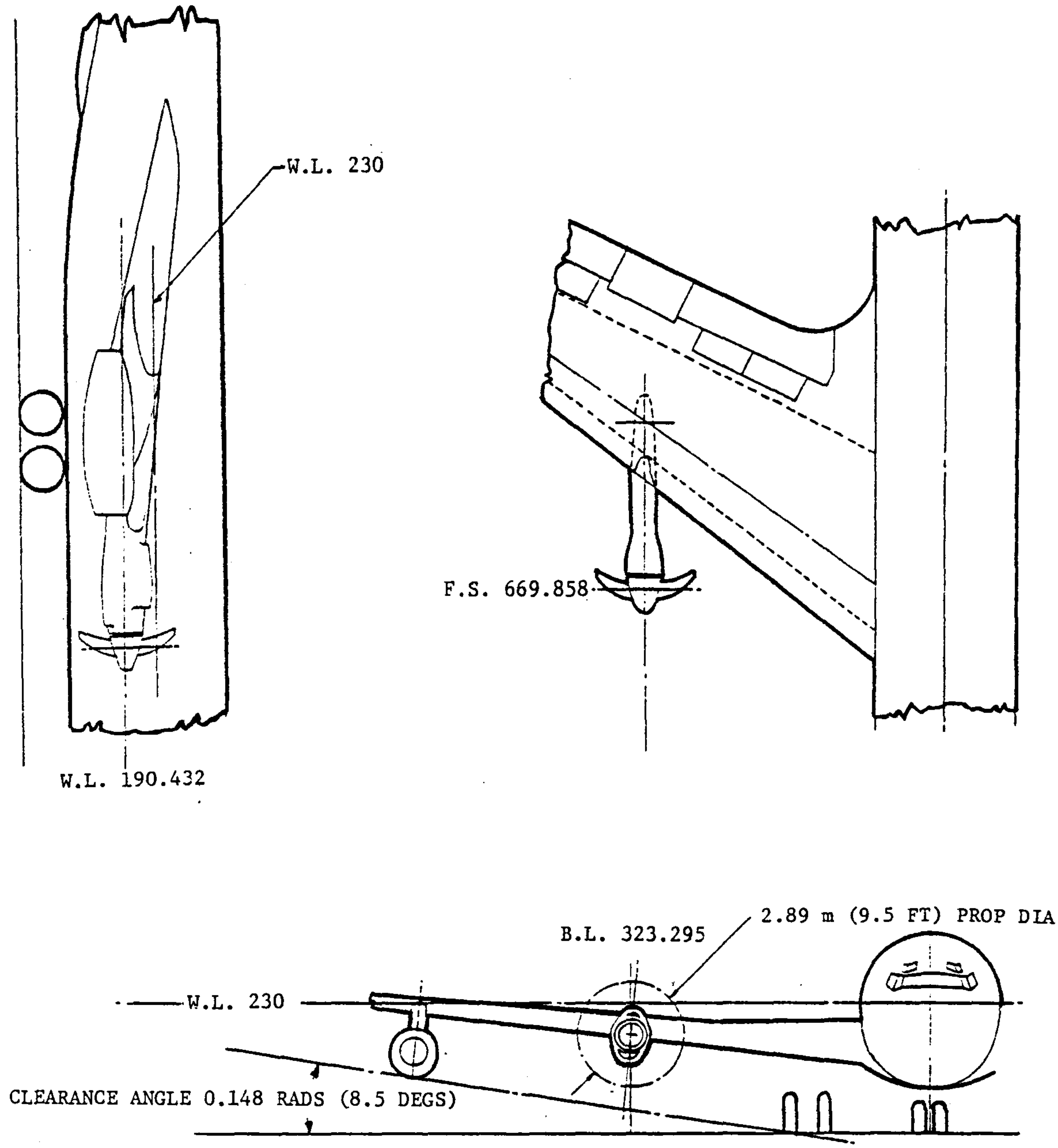


Figure C-11. Boeing KC-135A Testbed Configuration XT701 Pinion-Low

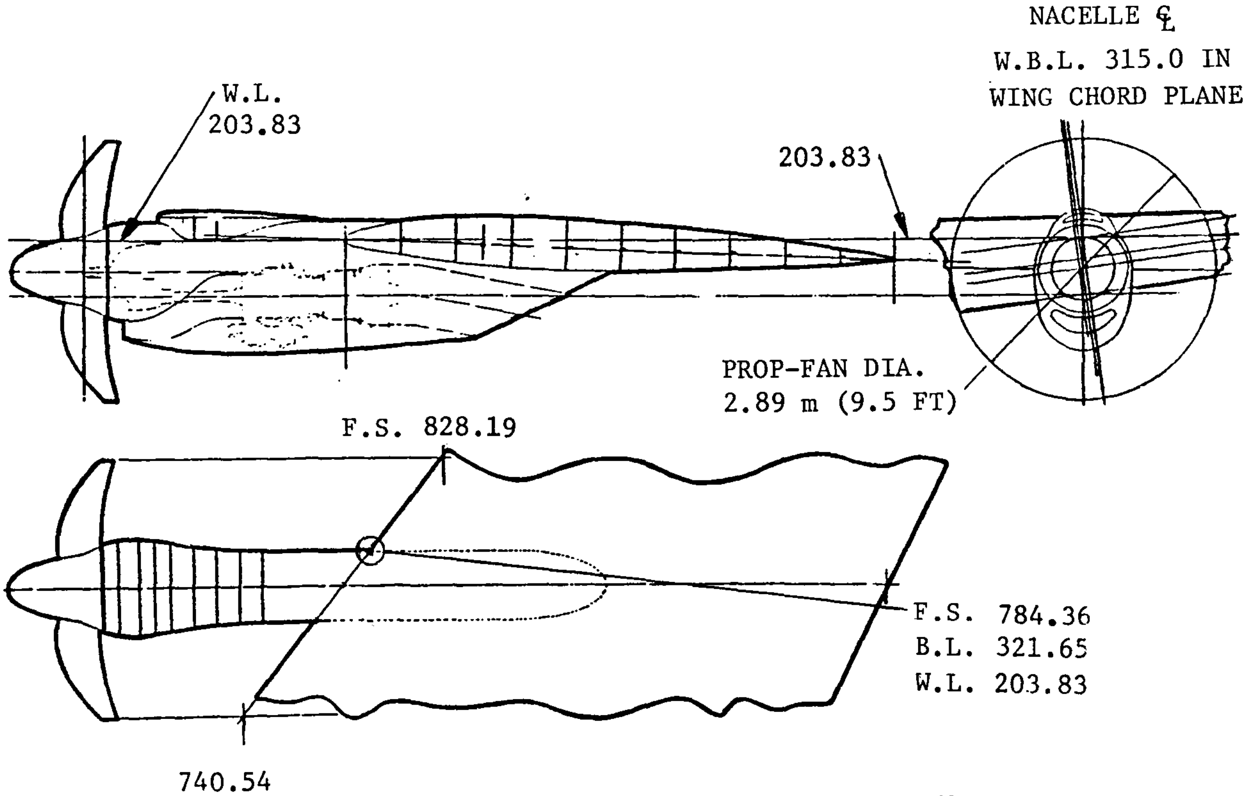


Figure C-12. Boeing KC-135A XT701 Pinion-Low Installation

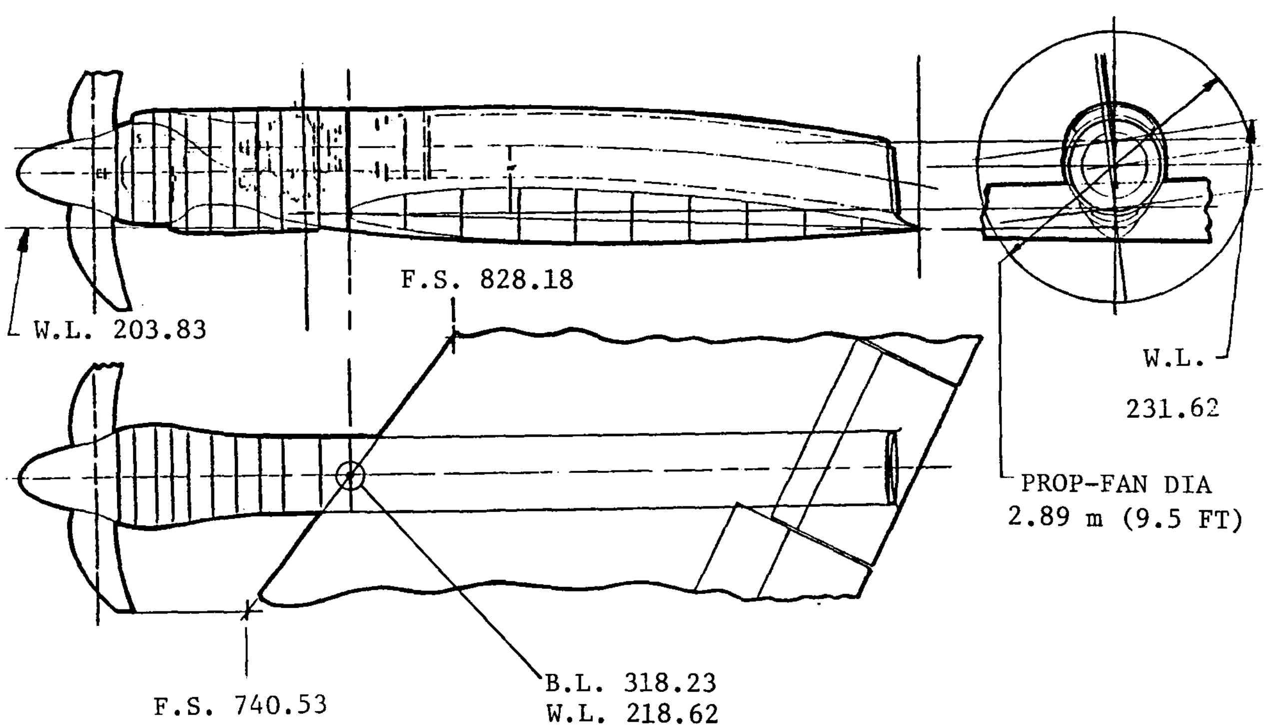


Figure C-13. Boeing KC-135A XT701 Pinion-High Installation

In the case of the overwing nacelles, the nacelle interferes with the high-speed aileron to the extent that this control would be eliminated if a long jet pipe is required. Lateral control at high speed may, therefore, be a problem for this configuration.

Boeing B-52B Testbed Configuration - The Boeing B-52B Testbed Configuration featuring the T56 underwing installation is shown on Figures C-14 and C-15, and the corresponding overwing installations on Figures C-16 and C-17. These installations are located on the wing at BL 217, which is the existing pylon mount for equipment test purposes.

The installations illustrated on Figure C-18 and C-19 are for the XT701 underwing, and on Figures C-20 and C-21 for the overwing installation.

These installations suffer from the following disadvantages:

- In all cases, the depth of the nacelle is approximately the same as the depth of the wing. This, in conjunction with the high incidence angle and leading-edge sweep of the wing, complicates the integration of the wing and nacelle and the arrangement of the engine support structure. An additional 0.3m (12 in) was added to the nacelle behind the QEC parting line to simplify nacelle/support structure/wing integration.

- The magnitude of the wing chord at the pylon mount is very large compared with the diameter of the prop-fan, with the result that the scale effect will be such that the prop-fan will not significantly affect the wing flow field and would, therefore, not present a realistic situation for assessing the aerodynamic influence of the prop-fan on nacelle/wing combinations. Furthermore, the wing blockage particularly for the underwing installations almost obscures the prop-fan swept area.

  One other effect of the large chord is the inordinately long jet pipe required for the overwing installations leading to increases in installed weight and additional losses in jet thrust.

Since the wing section data for the B-52B were not available, a representative section, NACA 0012-64 base thickness form, was scaled to the appropriate thickness for the wing. Because of the high incidence angle of the wing

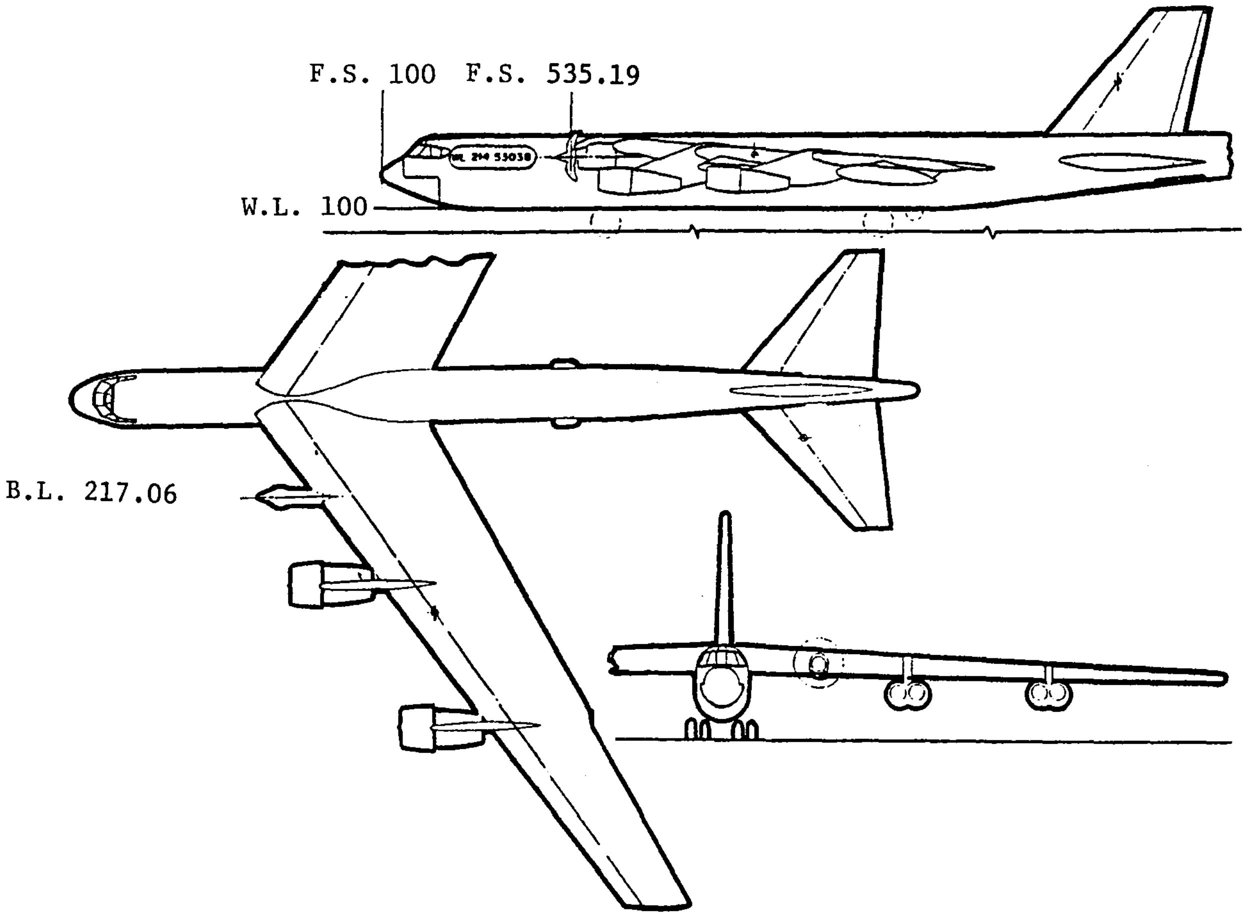


Figure C-14. Boeing B-52B Testbed Configuration T56 Pinion-Low

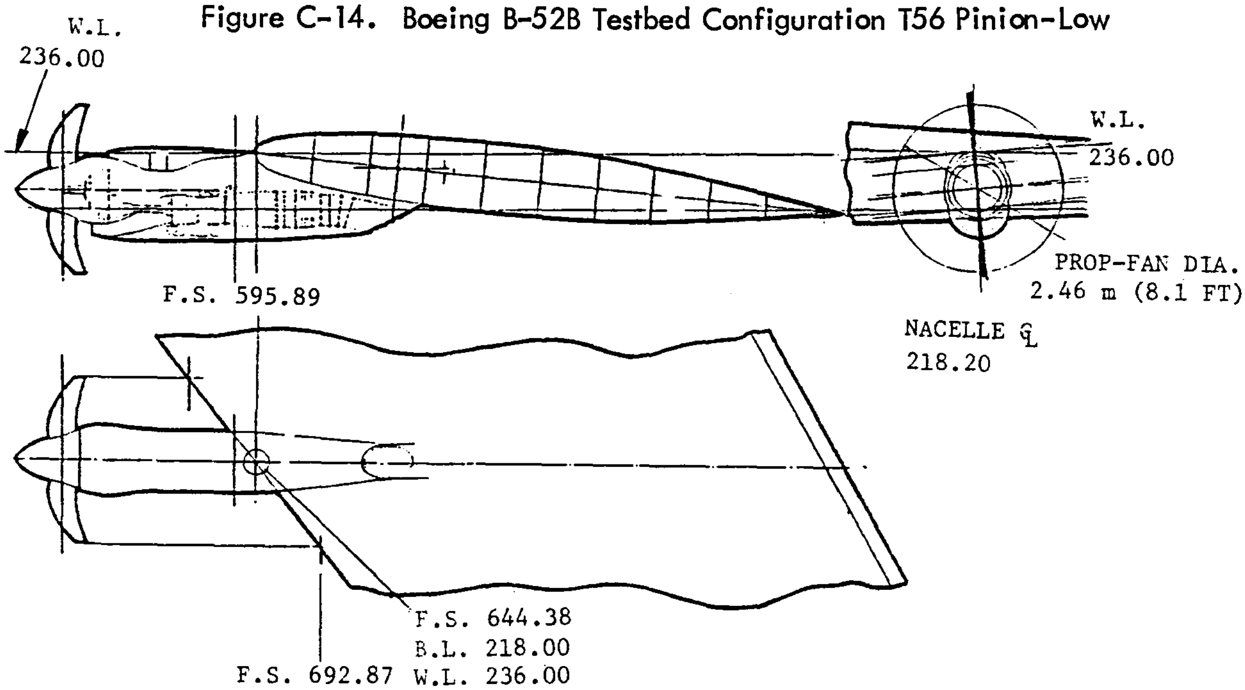


Figure C-15. Boeing B-52B T56 Pinion-Low Installation

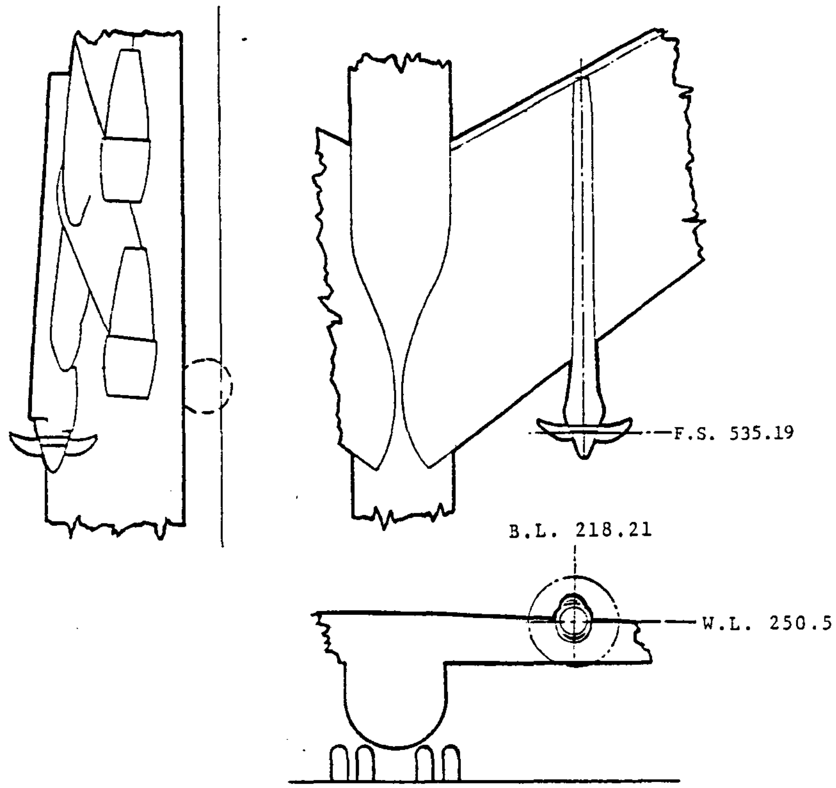


Figure C-16. Boeing B-52B Testbed Configuration T56 Pinion-High

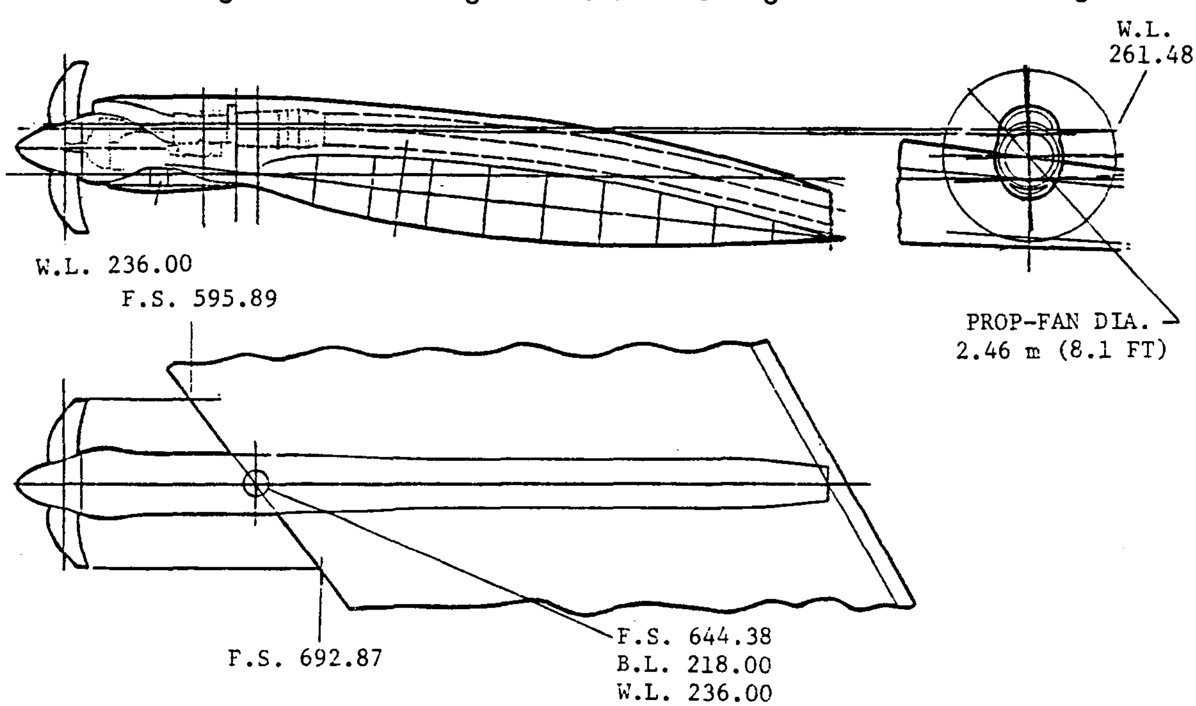


Figure C-17. Boeing B-52B T56 Pinion-High Installation

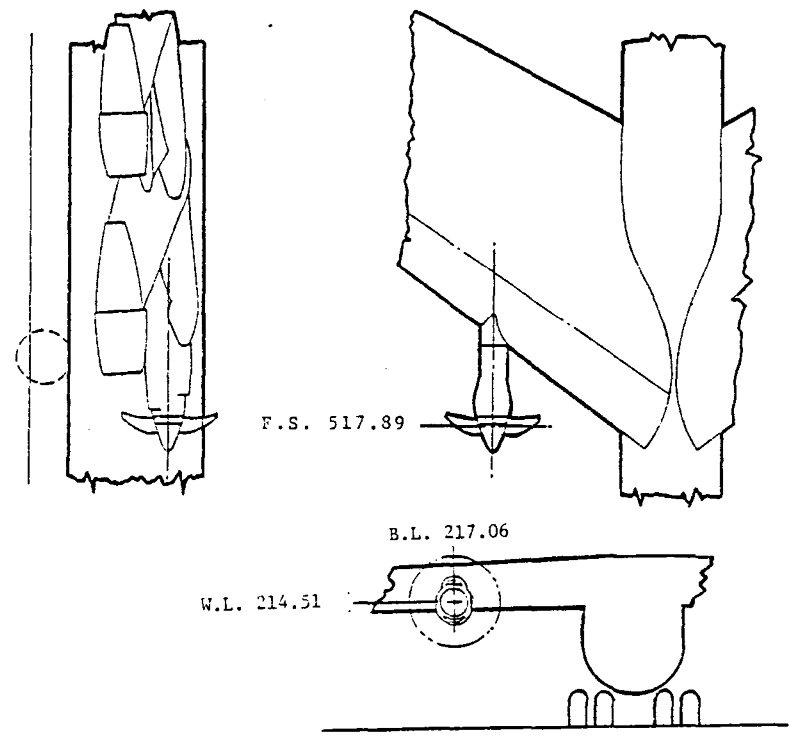


Figure C-18. Boeing B-52B Testbed Configuration XT701 Pinion-Low

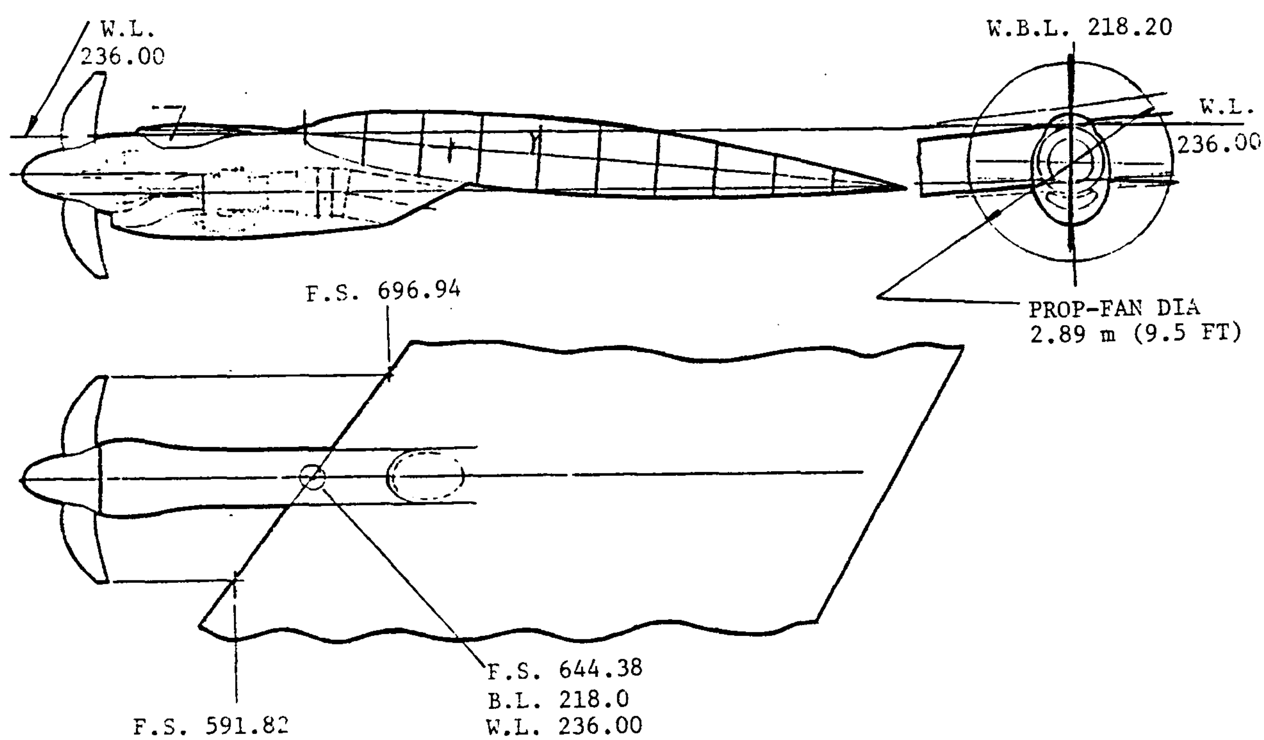


Figure C-19. Boeing B-52B XT701 Pinion-Low Installation

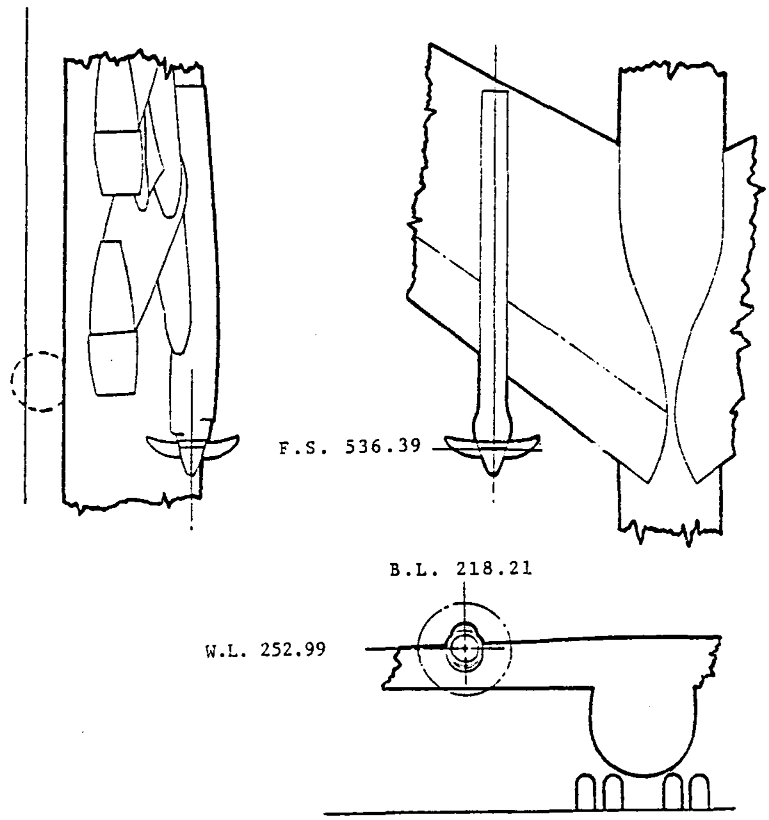


Figure C-20. Boeing B-52B Testbed Configuration XT701 Pinion-High

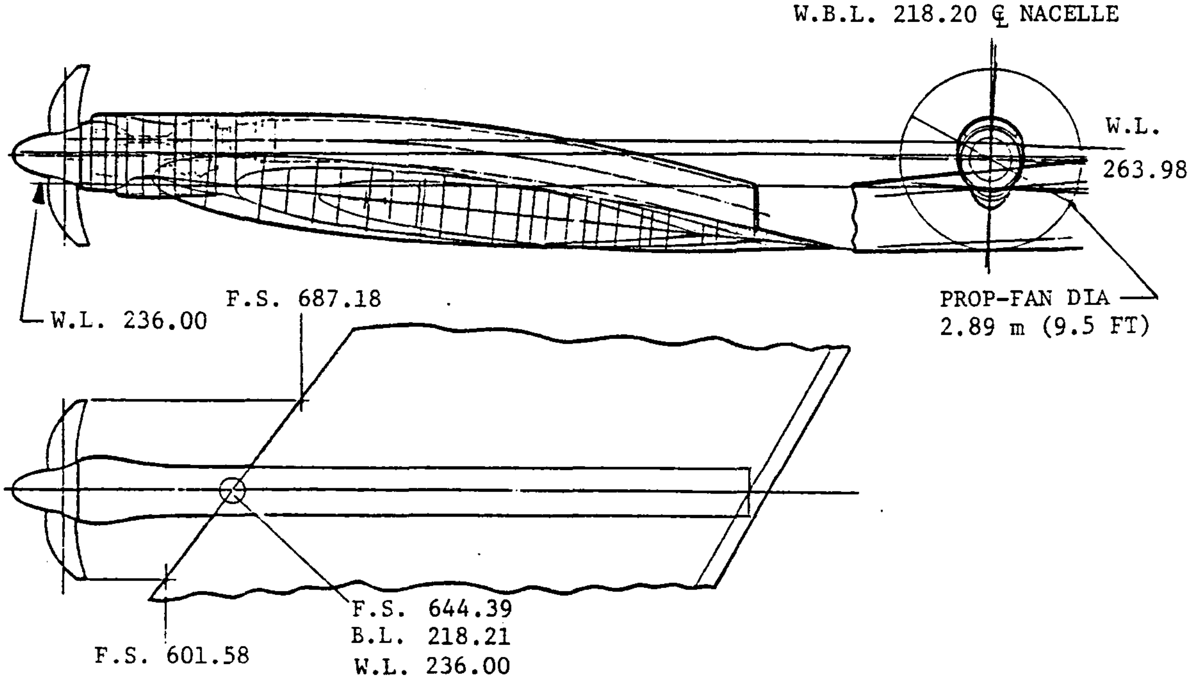


Figure C-21. Boeing B-52B XT701 Pinion-High Installation and the high-speed capability of the aircraft, the section was assumed symmetrical.

Convair 990 Testbed Configuration - The Convair 990 configured as a testbed is shown in Figure C-22 for the DDA T56 engine underwing installation. As a

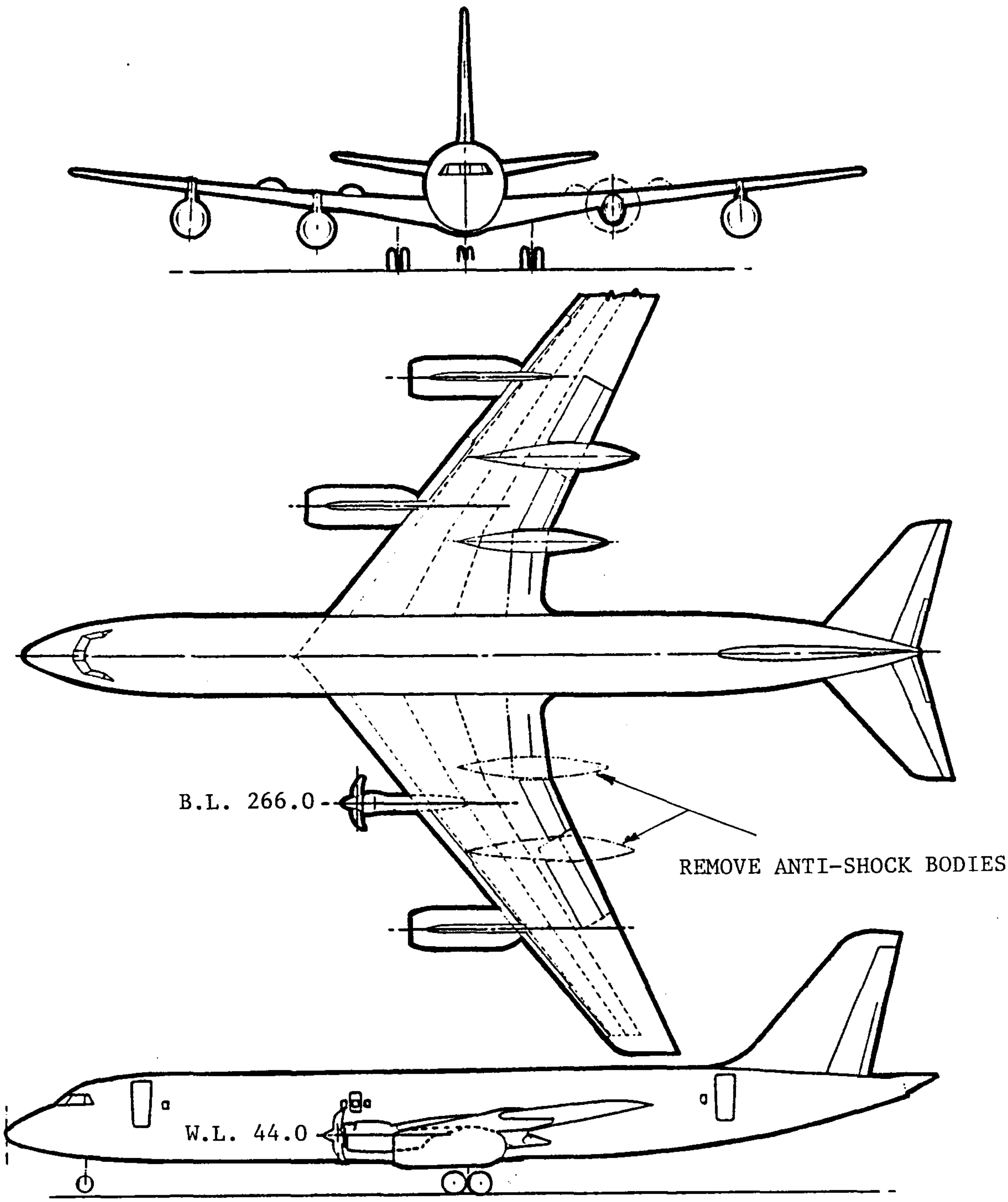


Figure C-22. Convair 990 Testbed Underwing Configuration T56 Pinion-Low prop-fan testbed using the T56 engine, the inboard left-hand primary engine is removed, and the T56 nacelle is substituted either as an underwing pinion-high installation, Figure C-22, or an overwing pinion-low arrangement, Figure C-23. This configuration also requires removal of the anti-shock bodies so that test equipment, i.e., pressure rakes, can be fitted to the wing and to ensure that the prop-fan wake over the wing is not influenced by existing components of the aircraft.

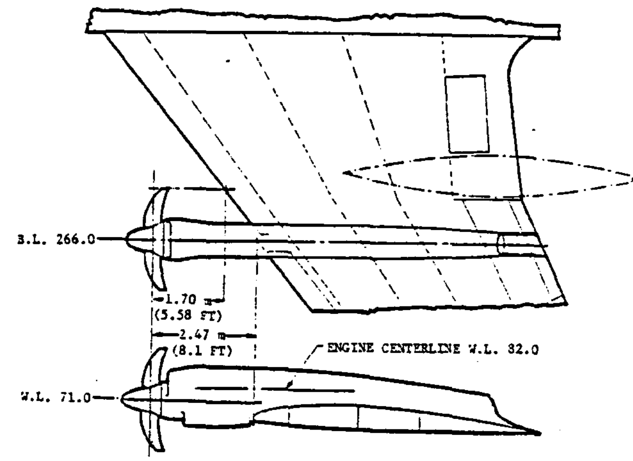


Figure C-23. Convair 990 Testbed Overwing Configuration T56 Pinion-High

Similarly, in the case of the XT701 testbed configuration, the right-hand inboard engine is removed and the prop-fan is substituted either as an underwing installation, Figure C-24, or an overwing installation, Figure C-25.

Of the two principal configurations the underwing arrangements are preferred since there is no effect upon the trailing edge devices.

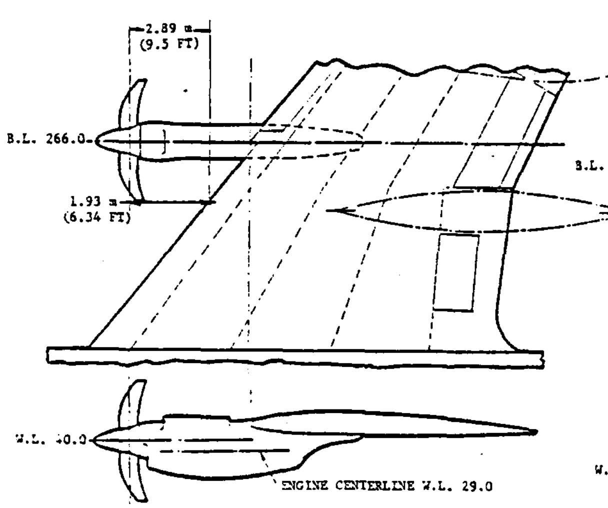


Figure C-24. Convair 990 Testbed Underwing Configuration XT701 Pinion-Low

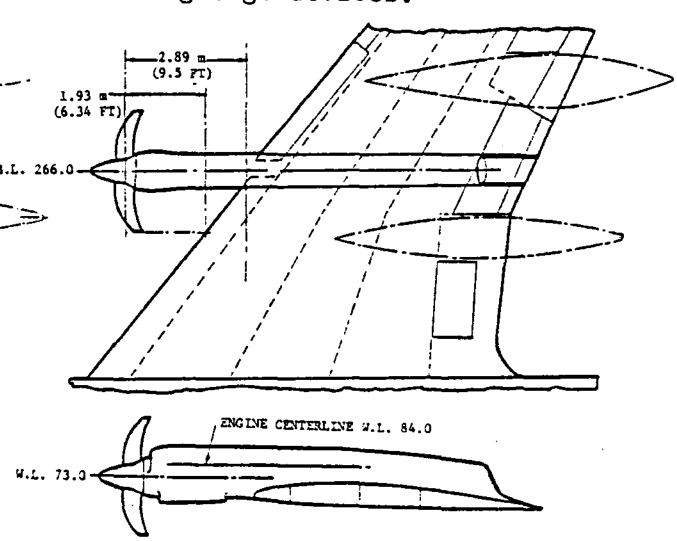


Figure C-25. Convair 990 Testbed Overwing Configuration XT701 Pinion-High

GAC Gulfstream II (GII) Testbed Configuration - The T56 GII testbed is shown in Figure C-26. This aircraft has the advantage that the prop-fan propulsion unit is an addition to the configuration rather than a substitution. Furthermore, the wing leading edge has no high-lift devices, which simplifies the nacelle/wing integration.

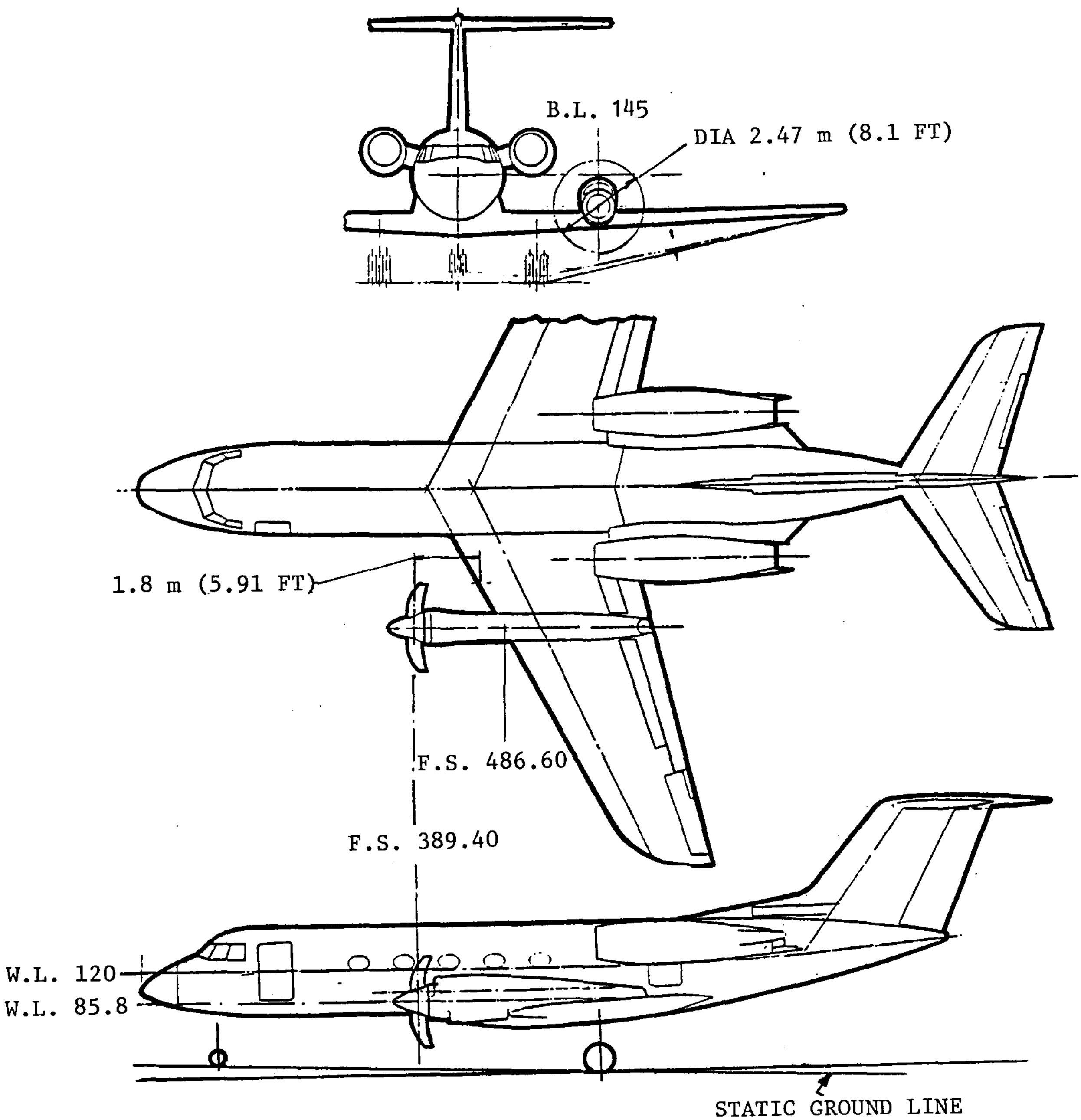


Figure C-26. GAC "Gulfstream II" Testbed Configuration T56 Pinion-High

Because of the size of the aircraft, overwing installations only are possible and are shown on the left-hand side of the aircraft for the T56, Figure C-26, and for the XT701 on the right-hand side of the aircraft, Figure C-27. Since the wing thickness increases from BL 145 to the center, the engines are located at BL 145 to take advantage of the structural characteristics of the inboard wing.

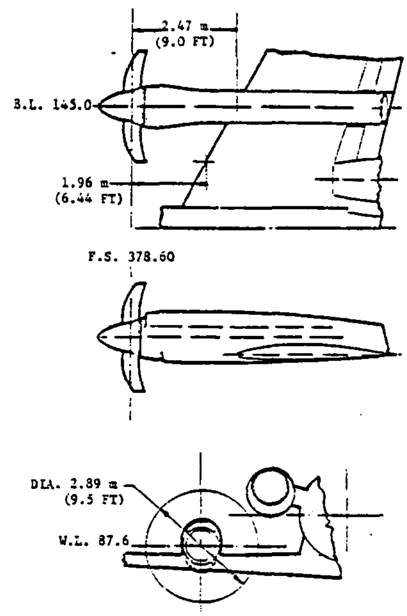


Figure C-27. GAC Gulfstream II Testbed Configuration XT701 Pinion-High

Testbed Aircraft Performance

Testbed mission analysis is based upon the design requirements of a flight Mach number of 0.80 at an altitude of 10,668m (35,000 ft), at standard atmosphere conditions.

For purposes of comparison, the following assumptions have been made:

- o The prop-fan operates at zero net thrust except during test operations.
- o For those aircraft where substitution of an original engine with a prop-fan occurs takeoff distance is computed using three-engine ferry rules.

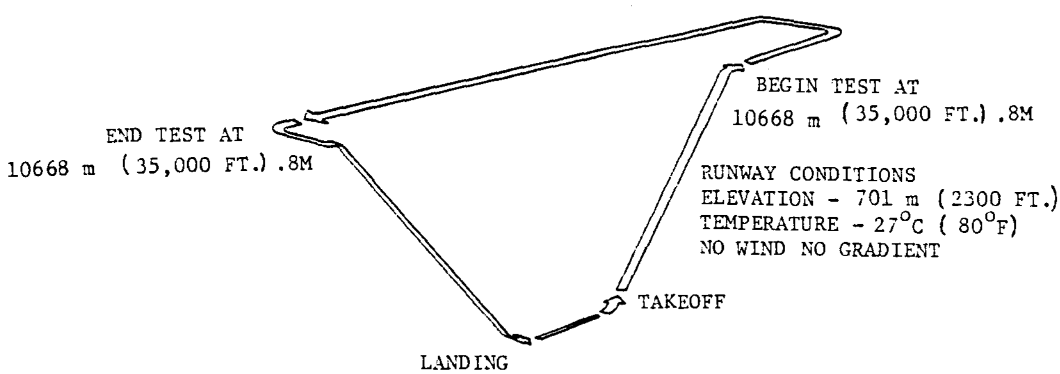
o For large aircraft, e.g., C-141A, KC-135, Convair 990, a fuel allowance of 453 kg/hr (1000 lb/hr) has been included for operating the prop-fan, regardless of the drive system type.

o Although the test mission profiles have not been defined, it has been assumed that it will be necessary to obtain data over a wide range of prop-fan thrust values. The start test weight has, therefore, been limited to that which will provide the capability of achieving a Mach number of 0.8 at 10,668m (35,000 ft) with zero net thrust from the prop-fan.

o Reserve fuel allowance is sufficient for approximately one hour of flight time at low speed and low altitude.

o For the smaller aircraft, e.g., JetStar -6, and the GII, ballast to correct the lateral imbalance is included in the zero fuel weight, ZFW.

Time to complete a flight test at a Mach number of 0.8 at 10,668m (35,000 ft) with several testbed aircraft/drive system configurations is presented in Figure C-28. The corresponding test mission profile is also shown in the figure.



AIRCRAFT	RAMP WT Kg (LB)	START TEST WT Kg (LB)	ENG TEST WT Kg (LB)	DURATION (HRS)	DRIVE SYSTEM
C-141A	99,271 (218,900)	95,254 (210,000)	66,224 (146,000)	4.33	XT701
GII	27,341 (60,288)	26,303 (58,000)	19,484 (42,960)	3.38	XT701
KC-135A	82,990 (183,000)	75,734 (167,000)	48,615 (107,200)	4.69	T56
CV-990	87,072 (192,000)	82,537 (182,000)	60,769 (134,000)	4.2	T56
B-52H	114,452 (252,376)	111,777 (246,476)	81,982 (180,770)	4.5	XT701
JETSTAR-6	18,367 (40,500)	16,779 (37,000)	15,372 (33,900)	0.65	T64
B-737	33,407 (73,500)	31,818 (70,000)	ZFW30,339 (66,900)	—	T56

Figure C-28. Testbed Aircraft/Drive System Configuration Performance

C-141A Testbed Configuration Performance - Capability of the C-141A testbed configuration to meet the design conditions is shown on Figure C-28. A start test weight of 95254 kg (210,000 lb) was selected for the testbed configuration. At takeoff the ramp weight is 99271 kg (218,900 lb) and the takeoff distance is 1890m (6200 ft) at an airport elevation of 701m (2300 ft) and at temperature of 300°K (80°F). Test mission duration is 4.33 hours.

JetStar -6 Testbed Configuration Performance - Capability of the JetStar -6 configured as a testbed is shown in Figure C-28, for the GE T64-powered prop-fan. Starting at a ramp weight of 18,367 kg (40,500 lb) and climbing to test altitude, the start test weight is 16,779 kg (37,000 lb). At a zero fuel weight of 13,741 kg (30,300 lb), which includes 1315 kg (2900 lb) of ballast for lateral balance, and adding 1632 kg (3600 lb) of reserve fuel gives an end test weight of 15,373 kg (33,900 lb). The test duration for 1406 kg (3100 lb) of fuel is 0.65 hours.

The installation with the T56 engine results in a further decrease in the flight duration due to the increase of the zero fuel weight to 14104 kg (31,100 lb) leaving 1038 kg (2290 lb) of fuel for the test mission. This amounts to 0.48 hours of test time.

Boeing 737-10 Testbed Configuration Performance - Investigation of the Boeing 737-10 performance, also shown on Figure C-28, indicated that an unmodified aircraft at an altitude of 10668m (35,000 ft) would be capable of a speed of Mach 0.802 at a weight of 31,751 kg (70,000 lb). The ramp weight corresponding to this start test weight is 33,409 kg (73,500 lb). Modifying the aircraft to a testbed configuration with one prop-fan unit on the wing and the addition of pressure rakes would produce increases in drag that would reduce the Mach number below that set by the testbed design requirements.

Boeing KC-135A Testbed Configuration Performance - The T56 powered KC-135A testbed configuration performance is shown on Figure C-28. At a ramp weight of 82990 kg (183,000 lb), the 3-engined ferry take-off distance is 2774m (9100 ft) over a 15m (50 ft) obstacle. Start test weight following a climb to 10668m (35,000 ft) is 75734 kg (167,000 lb) and the end test weight is 48615 kg (107,200 lb). Test duration at these weights is 4.7 hours. The zero fuel weight for this configuration is 44542 kg (98,200 lb) which includes the weight of the test equipment.

The configuration with the XT701 drive system has slightly reduced zero fuel weight, which together with the improved specific fuel consumption (SFC) for the XT701, would give slightly more test duration time than the T-56 configuration.

Boeing B-52 Testbed Configuration Performance - The B-52 testbed performance is shown in Figure C-28. Since performance data for the B-52B were not available, the testbed performance was generated using available B-52H data. The B-52H, which is powered with P&W TF33 turbofans provides improved performance over the J57 powered B-52B version.

At a ramp weight of 114452 kg (252,376 lb), the takeoff distance is 1033m (3390 ft) over the 15m (50 ft) obstacle. Climbing to test altitude reduces the weight to 111777 kg (246,476 lb) the start test weight, and at an end test weight of 81982 kg (180,776 lb) the test mission duration is 4.5 hours. Because of the large speed margin above the test cruise Mach number, higher ramp and start test weights can be achieved with large increases in test duration. The ramp weight selected provided a test duration compatible with other candidate testbed aircraft.

Convair 990 Testbed Configuration Performance - The capability of the Convair 990 configured as a testbed aircraft, shown in Figure C-28, is for the T56 powered prop-fan. Ramp weight in this configuration is 87,072 kg (192,000 lb) and the start test weight following climb to test altitude is 82,537 kg (182,000 lb). At a zero fuel weight of 56,000 kg (123,500 lb), which accounts for the removal of the anti-shock bodies on the wing, the addition of test equipment and adding reserve fuel of 4761 kg (10,500 lb), gives an end test weight of 60,769 kg (134,000 lb). The test duration for 21,768 kg (48,000 lb) of fuel is 4.2 hours.

The installation of the XT701 engine decreases the zero fuel weight to 55,980 kg (123,441 lb) and the lower specific fuel consumption of the XT701 would increase the test duration over that of the T56-engined configuration.

GAC GII Testbed Configuration Performance - The performance of the GII as a prop-fan testbed powered by an XT701 engine over the test mission profile is given on Figure C-28. Beginning at a ramp weight of 27341 kg (60,288 lb) the start test weight at 10668m (35,000 ft) altitude is 26303 kg (58,000 lb). The zero fuel weight is 17722 kg (39,079 lb), including 680 kg (1500 lb) ballast for lateral balance, and the end test weight is 19484 kg (42,964 lb). Mission test time is 3.38 hours.

The lower powered DDA T56 engine will produce slightly less test time at altitude because the zero fuel weight is slightly greater than that of the XT701 configured testbed.

CANDIDATE TESTBED AIRCRAFT - INITIAL SCREENING AND SELECTION

An initial screening was conducted using criteria such as mission performance, clearances, scale mismatch, acoustic test suitability, and commercial passenger transport configuration compatibility to establish testbed suitability. As the result of this screening, the Lockheed -6 JetStar and the Boeing 737 were eliminated from the list of candidates for the following reasons:

o Lockheed -6 JetStar

One testbed configuration only - that with the GE T64 engine provided an aircraft configuration with sufficient prop-fan tip/ground clearance, as shown in Figure C-29, with the aircraft in a rolled attitude. Minimum clearance would also exist for the combined condition of two flat tires and a landing gear strut fully compressed.

The installation with the T56, Figure C-30, has a tip clearance in the normal ground attitude of 10.8 inches; in the rolled attitude, however, a tip/ground interference of 6.6 inches occurs.

The mission test time available, 0.65 hour, is unacceptable from a flight test standpoint, since very little data could be accumulated in such a short test time and the cost of acquiring such data would be high. In addition, this configuration is considered to present a moderate risk as far as wing flutter is concerned.

o Boeing 737-10

The Boeing 737-10, Figure C-31, was eliminated as a testbed candidate because the unmodified aircraft performance at a weight of 31,751 kg (70,000 lb) and an altitude of 10668m (35,000 ft) has a Mach number capability of only 0.801. When in the testbed configuration with the

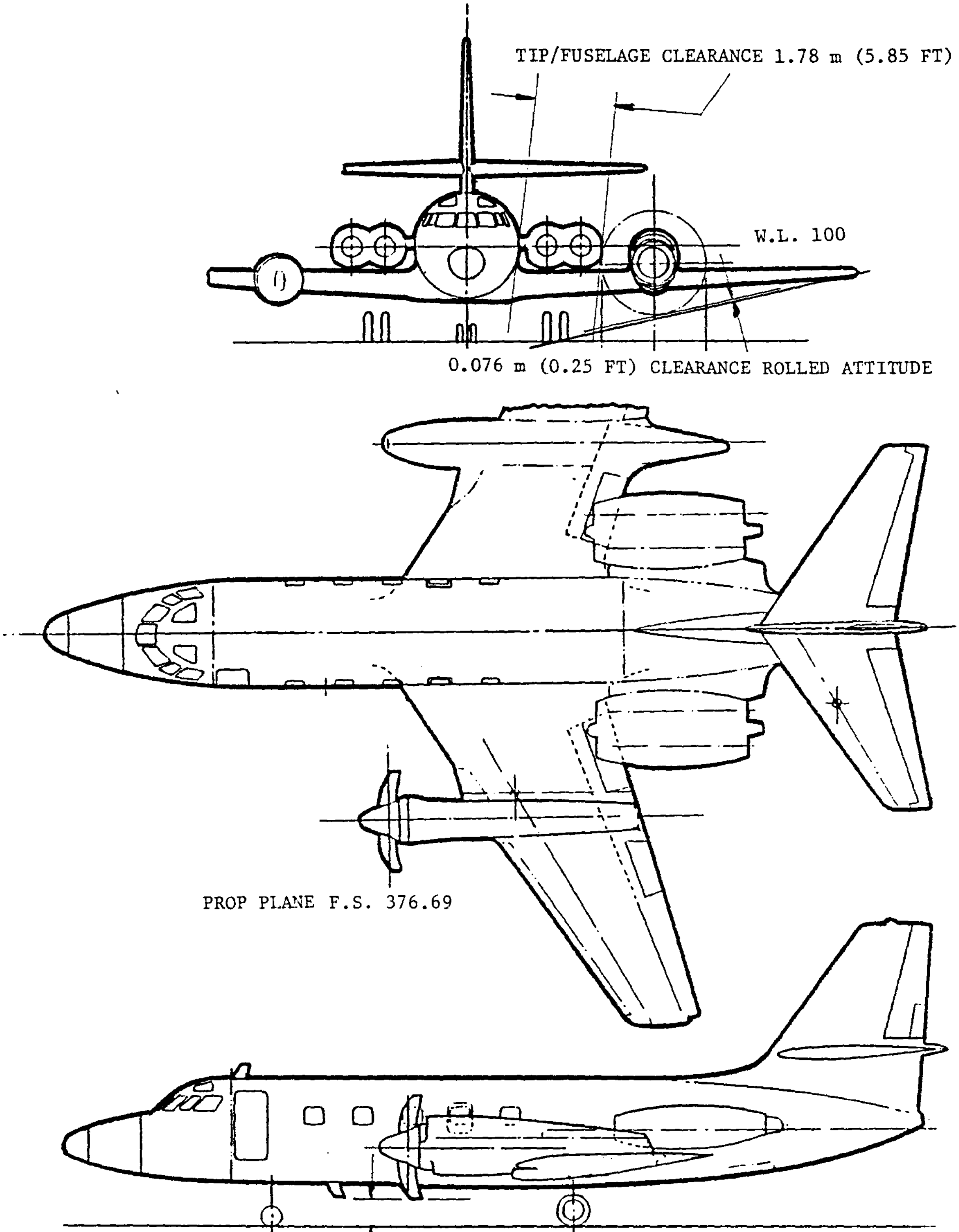


Figure C-29. JetStar -6 T64 Testbed Clearances

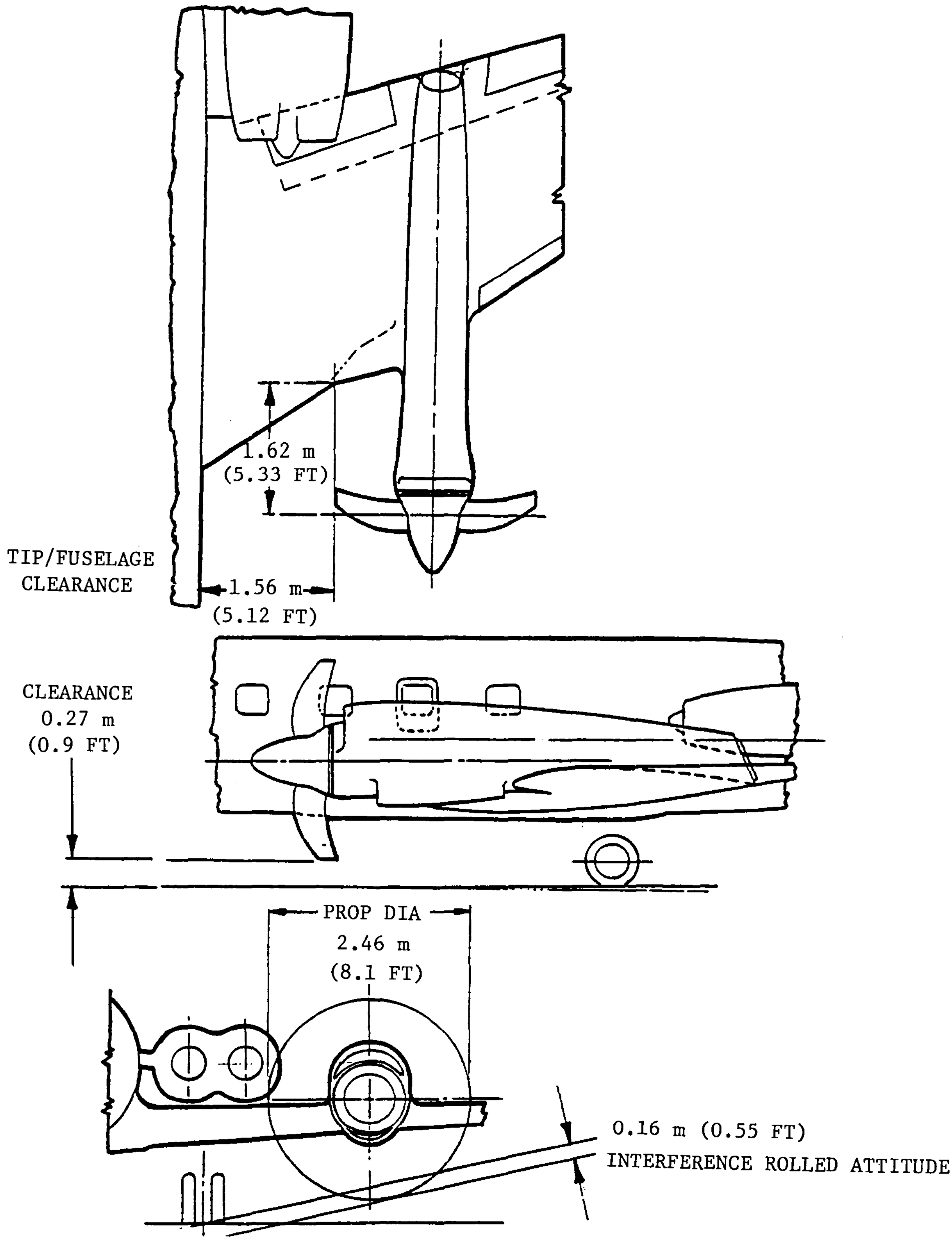


Figure C-30. JetStar -6 T56 Testbed Clearances

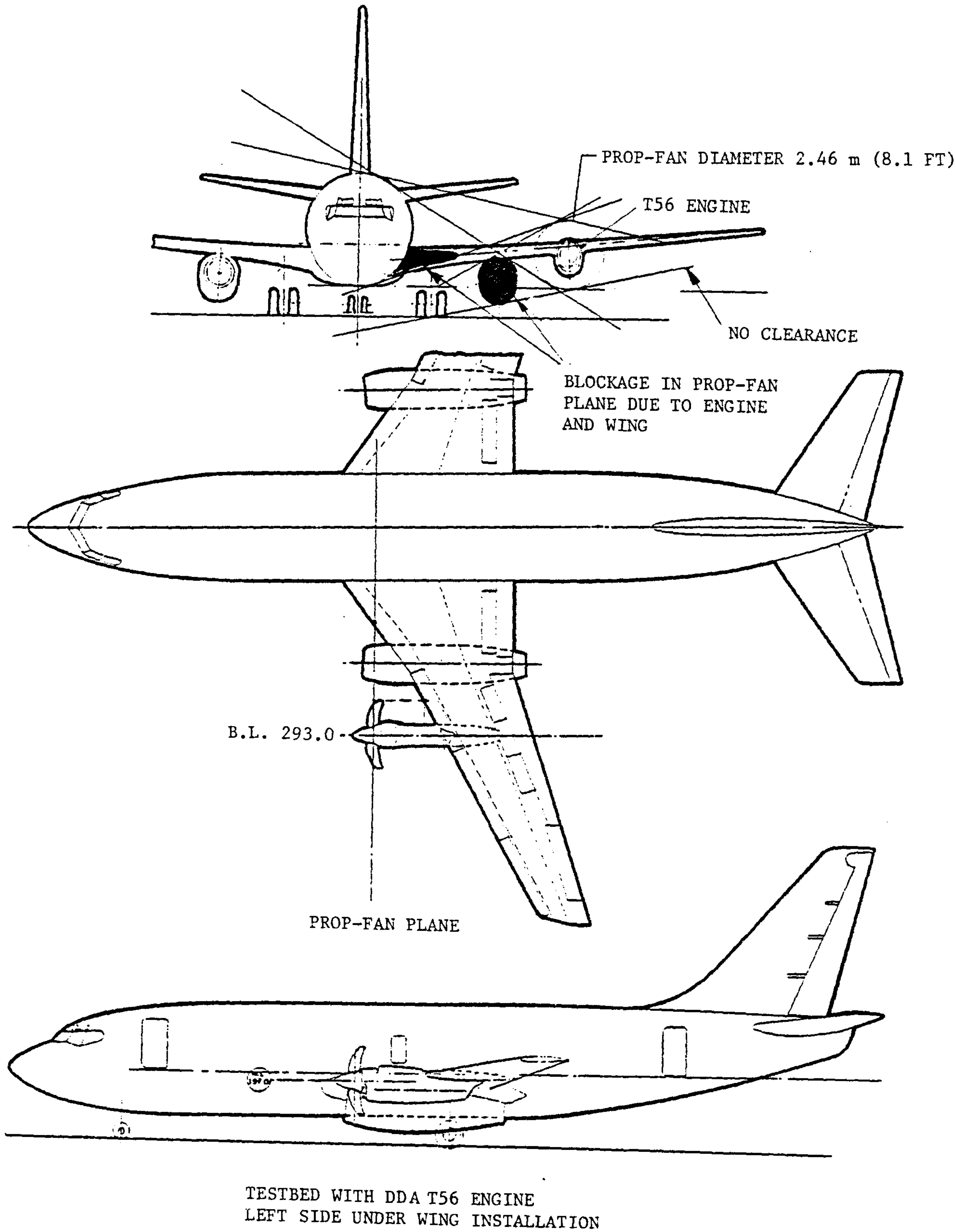


Figure C-31. Boeing 737-10 Prop-Fan Testbed addition of trim and test equipment drag, the speed/altitude performance will fall short of the M=0.8/10,668m (35,000 ft) desired for the testbed aircraft.

The location of the prop-fan propulsion system on the wing, Figure C-31, is such that a moderate element risk would be incurred from the wing flutter standpoint.

As a vehicle for gathering acoustic data, the configuration is unsuitable because of the proximity of the basic aircraft jet engine and of the shielding effect of the engine nacelle and inboard portion of the wing as shown in Figure C-31. Ground clearance would be inadequate with the 2.89m (9.5 ft) prop-fan of the XT701 underwing installation, since tip/ground interference would occur in the rolled attitude as indicated on Figure C-32.

The following aircraft remain as candidate aircraft subsequent to the application of the inital screening criteria:

- o Lockheed C-141A
- o Boeing KC-135A
- o Convair 990
- o Gulfstream American Corporation "Gulfstream II"

The Boeing B-52B, although a purely military aircraft and therefore not representative of commercial transport aircraft, was also retained as a special class of testbed vehicle with limited potential as a prop-fan testbed vehicle.

Candidate Testbed Aircraft Analyses

Testbed Aircraft Performance and Buffet Limits - The performance and buffet limits as a function of Mach number of each candidate testbed aircraft with XT701 engines are shown in Figure C-33. These data show the relationship of the weight/altitude curves at start and end test weights at the design conditions of Mach 0.8 at altitudes above 9144m (30,000 ft). The 1g buffet limit is superimposed on each plot.

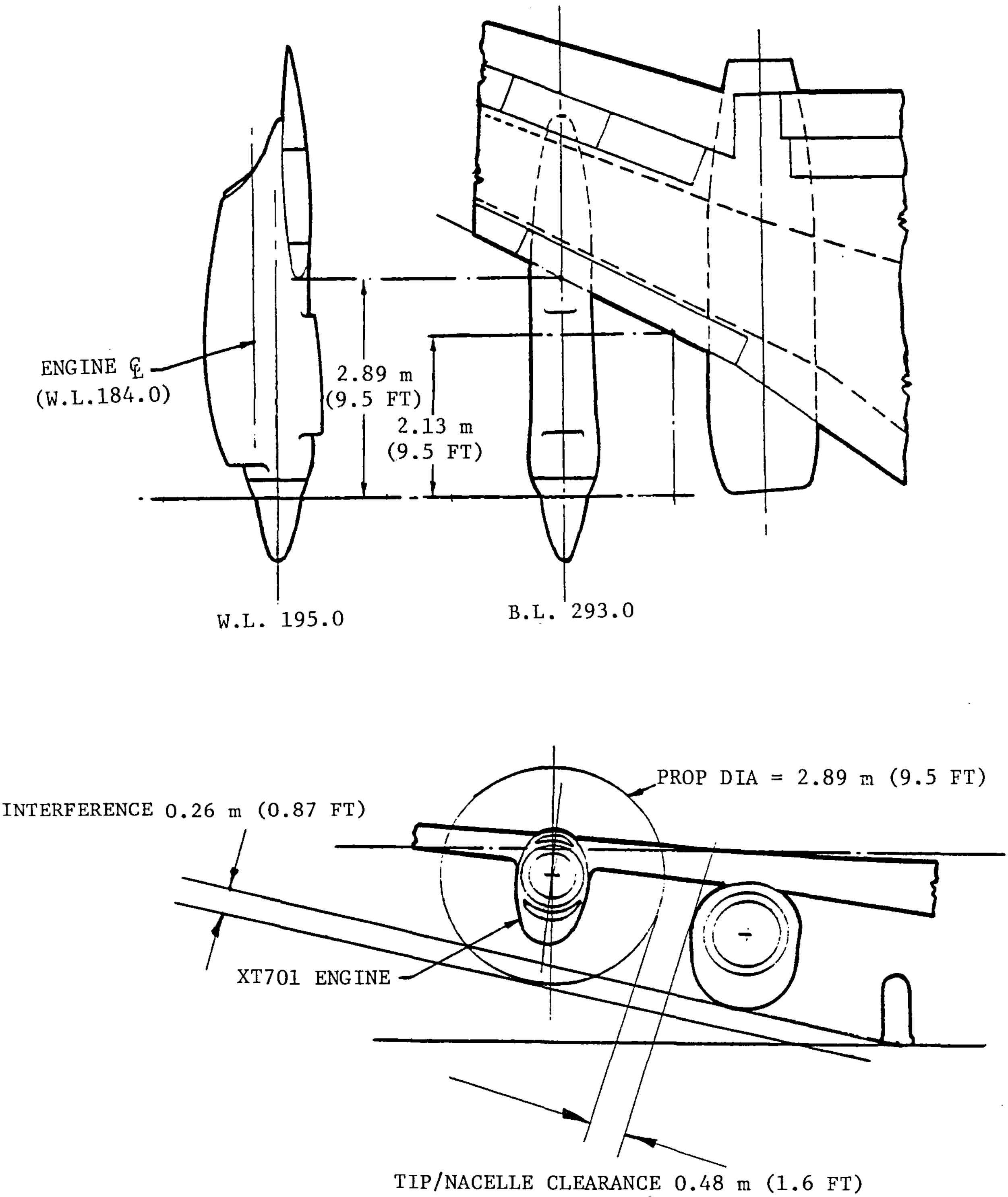


Figure C-32. Boeing 737-10 XT701 Underwing Configuration Interference

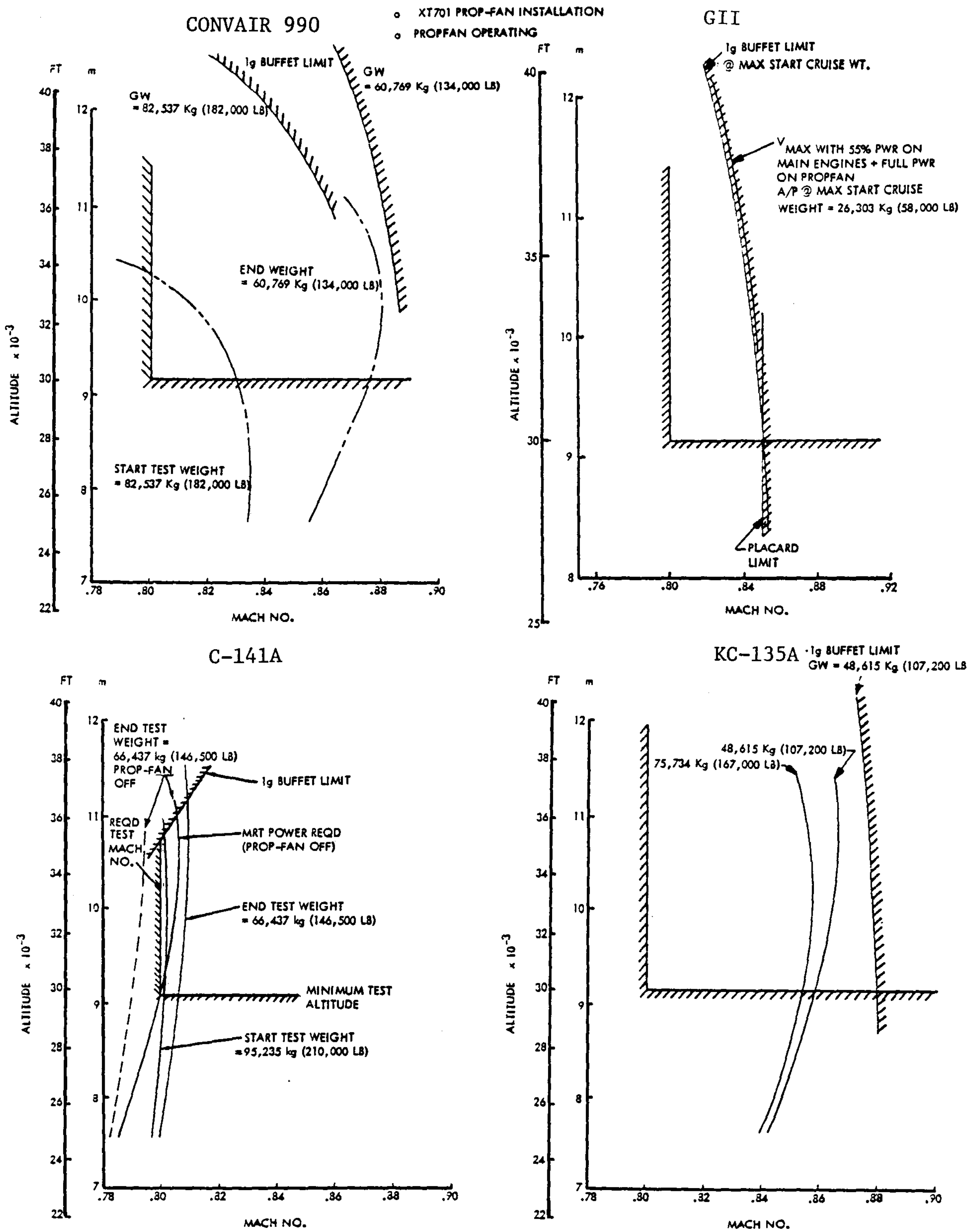


Figure C-33. Testbed Aircraft Performance and Buffet Limits

These data are required for the Task IV Evaluation, Appendix D, to compare the design capability and to rank the aircraft/drive system combinations.

Data for the Lockheed C-141A are shown in Figure C-33 and indicate a small speed margin over Mach 0.8 and a buffet cut-off in the region of 10668-11277m (35,000 - 37,000 ft).

The Boeing KC-135A data, of Figure C-33, show that the speed margin at the start and end test weights and the altitude range are large and not constrained by the 1g buffet limit.

In the case of the Convair 990, Figure C-33, a wide speed margin is achievable over the range of test weights, although the altitude range is restricted to a maximum value in the region of 10668m (36,500 ft). The speed/altitude capability falls inside the 1g buffet limit.

Figure C-33 also presents similar data for the GAC GII, which indicates a substantial speed and altitude margin over the desired conditions. The onset of buffet, however, is the limiting condition and causes a very slight reduction in the maximum achievable Mach number.

Testbed Configuration Weight Summary - The weight summary for the six aircraft comprising the initial list of possible testbed aircraft is shown on Table C-II. These weight data were used to establish test mission profile data with various drive systems.

Preliminary Appraisal of Candidate Testbed Flutter Characteristics

Preliminary appraisals were made of the candidate testbed aircraft relative to the risk of encountering wing flutter problems that might place the testbed program in jeopardy. The appraisals that follow were primarily based on the location and on the extent of the changes in the mass and inertial properties of the wing-engine system. In some cases, flutter parametric analysis results were also used. Since the appraisals were not based on specific flutter analysis, they are qualitative in nature and are intended only for use in the Task III screening to establish the suitability of candidate testbed aircraft.

C-141A Testbed Configuration Flutter Appraisal - No flutter problems are anticipated with the C-141A testbed configuration. The substitution of a prop-fan powerplant in place of an existing inboard P&W TF33 powerplant results in a weight reduction of approximately 1451 kg (3200 lb), which is almost equivalent to a weight reduction for the existing powerplant of 43 percent.

TABLE C-II. TESTBED AIRCRAFT WEIGHT SUMMARY WITH VARIOUS DRIVE SYSTEMS

		T64 OVER WING	T56 OVER WING	T56 UNDER WING	XT701 OVER WING	XT701 UNDER WING
C-141A	ZERO FUEL WT	*		60,677 (133,770)		60,650 (133,711)
	FUEL	*		68,048 (150,020)		68,048 (150,020)
	GROSS WT	*		128,725 (283,790)		128,698 (283,731)
BOEING KC-135	ZERO FUEL WT			44,543 (98,200)		44,516 (98,141)
	FUEL			51,202 (112,880)		51,516 (112,880)
	GROSS WT			95,744 (211,080)		95,718 (211,021)
CONVAIR 990	ZERO FUEL WT			56,019 (123,500)		55,992 (123,441)
	FUEL			47,301 (104,280)		47,301 (104,280)
	GROSS WT			103,319 (227,780)		103,293 (227,721)
G II	ZERO FUEL WT		17,763 (39,160)		17,726 (39,079)	
	FUEL		10,491 (23,128)		10,491 (23,128)	
	GROSS WT		27,346 (60,288)		27,309 (60,207)	
JETSTAR	ZERO FUEL WT	11,535 (25,430)	11,902 (26,240)			
	FUEL	5,942 (13,100)	5,942 (13,100)			
	GROSS WT	17,477 (38,530)	17,844 (39,340)			
BOEING 737	ZERO FUEL WT		30,346 (66,901)	30,193 (66,565)	30,319 (66,842)	30,167 (66,506)
	FUEL		8,661 (19,095)	8,661 (19,095)	8,661 (19,095)	8,661 (19,095)
	GROSS WT		39,007 (85,997)	38,854 (85,660)	38,980 (85,937)	38,828 (85,601)

*UPPER ENTRY IS IN kg, (LOWER ENTRY IS IN LB)

Because of the inboard location, at 30 percent of the wing semi-span, this change is not expected to affect wing flutter speed adversely.

Convair 990 Testbed Configuration Flutter Appraisal - The substitution of prop-fan propulsion system in place of an existing inboard engine is approximately equivalent to a weight reduction of 907 kg (2,000 lb) or 33 percent over the weight of the original powerplant. It is considered that this change is not likely to alter the wing flutter characteristics unless the flutter speed is unusually sensititve to the weight of the inboard engines. The removal of the two adjacent anti-shock bodies is considered of little consequence from a flutter standpoint. This configuration is not likely, therefore, to encounter flutter problems.

GII Testbed Configuration Flutter Appraisal - Addition of a prop-fan propulsion system weighing roughly twice as much as the wing semi-span will drastically alter the wing flutter characteristics.

Parametric studies of wing flutter of wings of similar planform indicate that the addition of a large concentrated mass located at 36.3 percent of the semispan may increase the flutter speed over that of the base wing.

Since these studies do not account for variations in wing fuel, flexibility of attachment structure, and other variables that may be important on the testbed aircraft, they can be used only as a preliminary indication that the prop-fan installation may not cause flutter problems. The proposed installation of 680 kg (1500 lb) of ballast on the wingtip of the side opposite the prop-fan installation, to provide lateral balance, is not expected to cause flutter problems, since the weight is approximately equivalent to one of the 0.95m^3 (250 gal) wingtip tanks with which this aircraft has been certified.

The risk of encountering a serious flutter problem with the testbed configuration is considered to be low, but flutter analyses will be required to verify this position.

KC-135A Testbed Configuration Flutter Appraisal - The replacement of an inboard nacelle with a prop-fan propulsion system results in a net weight change of 635 kg (1400 lb) or 26 percent of the weight of the existing P&W J57 powerplant. This weight change, located at 41 percent of the wing semi-span is not sufficient to change the flexible wing fundamental modes significantly and is, therefore, not expected to adversely affect the wing flutter characteristics.

Boeing B-52B Testbed Configuration Flutter Appraisal - It is considered very unlikely that this configuration will encounter flutter problems as a prop-fan testbed system. The inboard location of the prop-fan installation, together with the small inertia properties compared with those of the wing--engine system, should not change the dynamic and flutter characteristics of the wing. Since the location has already been used to carry a variety of pylon-mounted stores and equipment, many of which had greater weight and inertia properties than the proposed prop-fan installation, the risk of flutter problems arising with this testbed installation is estimated to the lowest of any of the candidate testbed aircraft.

Stability and Control Analyses

Estimates of the stability and control changes due to prop-fan application have been made for the four candidate testbed aircraft. The analyses show that there are no significant changes in stability when the XT701 drive system is installed on any of the testbed aircraft.

The stability changes analyzed were those considered to be of greatest importance, and consisted of the pitching and yawing moments caused by the installation of the prop-fan. The changes in the control derivatives C_{m_α} and C_{n_β} are caused by the prop-fan normal force, and an estimate of this force provided by Hamilton Standard is shown on Figure C-34. The effects of the prop-fan on total yawing and pitching moment are shown in Figures C-35, C-36, C-37 and C-38 for the C-141A, KC-135A, Convair 990 and the GII, respectively. Yawing and pitching moment data for the C-141A were obtained from Lockheed-Georgia data files and estimates of the KC-135A, Convair 990 and GII were obtained by the use of DATCOM.

The changes in stability are also shown on Figures C-35, C-36, C-37 and C-38 for the C-141A, KC-135A, Convair 990, and GII, respectively.

These data show the following trends due to prop-fan installation:

1) The change in the stability derivatives decreases as Mach number increases.

2) The effect of the prop-fan on the large airplanes, C-141A, KC-135A, and Convair 990, is small.

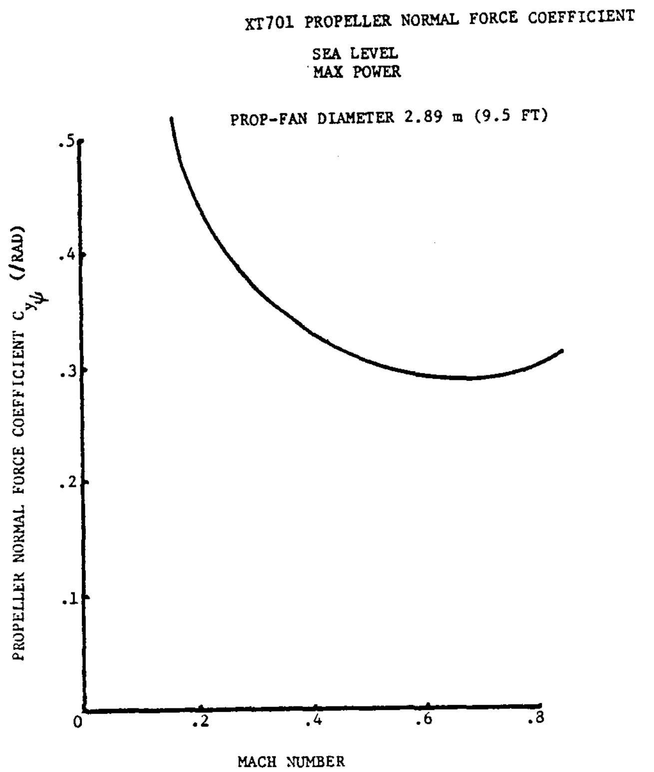


Figure C-34. XT701 Prop-Fan Normal Force

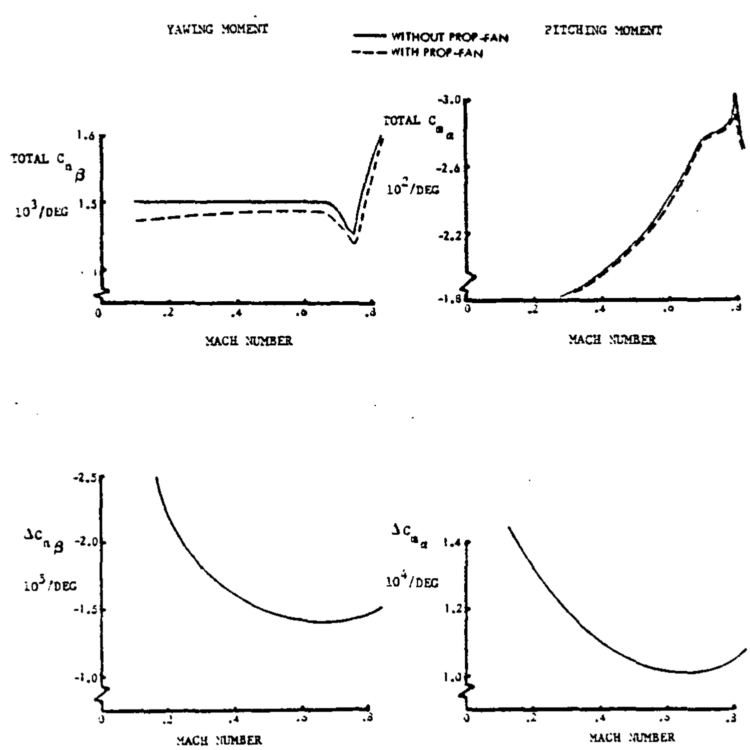


Figure C-35. C-141A Prop-Fan Effect on Pitch and Yaw

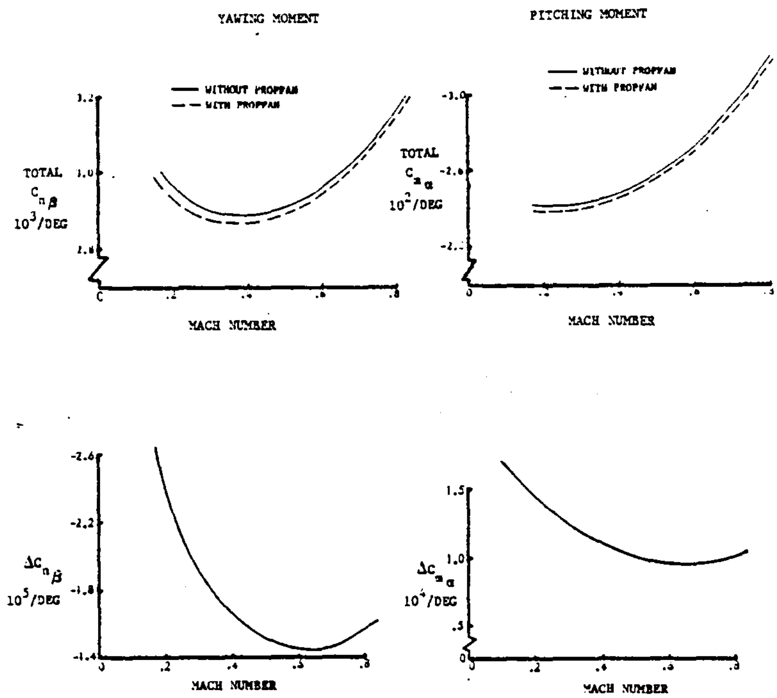


Figure C-36. KC-135A Prop-Fan Effect on Pitch and Yaw

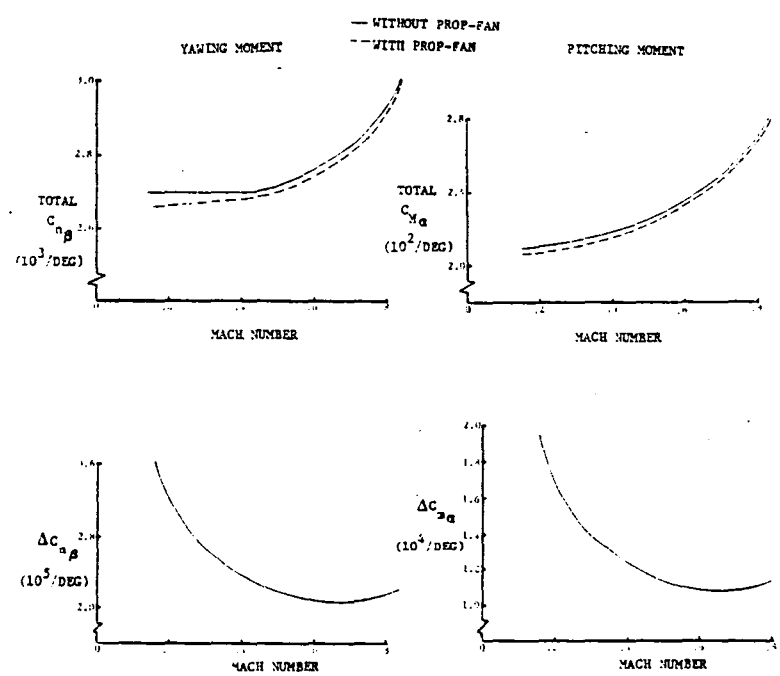


Figure C-37. Convair 990 Prop-Fan Effect on Pitch and Yaw

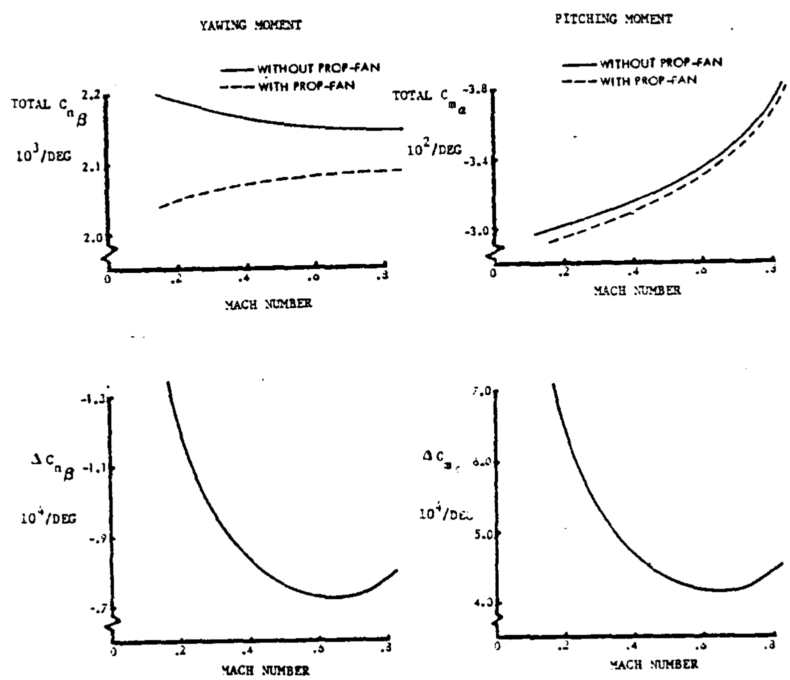


Figure C-38. Gulfstream II Prop-Fan Effect on Pitch and Yaw

3) The GII exhibits the greatest change in stability due to the prop-fan. At low Mach number C_{n_β} changes by seven percent. Although not significant, some minor degradation of the flying qualities may occur.

Testbed Aircraft Suitability for Acoustic Test

Near-Field Acoustic Analyses - The four testbed configurations were reviewed for suitability as acoustic test and data gathering vehicles by considering the common features as far as near-field acoustics are concerned, as described below.

It was determined that all of the configurations have:

- Sufficient fuselage volume
- Cabin pressurization
- Representative fuselage structural configurations

- Potential for modification for test of acoustic suppressive concepts

- Space for acoustic test equipment

In addition, each configuration has a number of advantages and disadvantages, as follows:

Testbed	Advantages	Disadvantages
Lockheed C-141A (L300)	High position of prop-fan relative to the fuselage center line.	Large powerplant on same side as prop-fan, with lower noise frequencies from large discharge which may interfere with prop-fan noise measurements
	Large ratio of fuselage diameter to prop-fan diameter	
	Large separation of prop-fan, fuselage and wing leading edge	
	Separation of adjacent nacelle - different water line location	
Boeing KC-135A (707-100)	Prop-fan height relative to fuselage centerline compatible	Fuselage separation/ prop-fan diameter ratio too large
	Fuselage diameter/prop-fan diameter ratio indicates a good match	Portion of the inboard wing obstructs prop-fan noise passage to fuselage
Convair 990	Prop-fan height relative to fuselage centerline compatible	Wing obstructs noise passage to fuselage

Convair 990 (cont'd)		Fuselage separation/ prop-fan diameter ratio larger than would occur in actual design
GII	Prop-fan height relative to fuselage centerline compatible	Fuselage is small relative to the prop-fan diameter
	Wing blockage is well aft of the prop-fan plane	

<u>Far-Field Noise Analysis</u> - The prop-fan testbed aircraft will have noise sources other than the prop-fan as follows:

- o Prop-fan Drive System
- o Testbed Primary Engine
- o Testbed Airframe Noise

These additional sources generate the background noise for which an acoustic analysis was performed to identify all of the noise characteristics. The airplane reference conditions chosen for the analysis were:

Level Flyover, Altitude	308m (1000 ft)
Speed	72m/sTAS (140 KTAS)
ISA + 10°C Conditions	
70% Relative Humidity	

The acoustic comparisons for all sources were made for the following conditions:

- For the aircraft directly over the microphone (which is very close to the peak noise from the prop-fan).
- With atmospheric attenuation effects included.
- For a microphone mounted with its diaphragm close to the ground (the noise levels thus include a 6dB increase over free-field noise levels).
- In one-third octave band levels.

Noise Source Characteristics

Prop-Fan Alone - The noise levels were predicted for a single prop-fan with the following characteristics:

Prop-fan Diameter	2.89m (9.5 ft)
Number of Blades	8
V_T, Rotational Tip Speed	244m/s (800 ft/sec)
Power	1491/2982/4474/5965 kW (2000/4000/6000/8000 shp)

The predicted one-third octave band spectra are shown in Figure C-39.

Prop-Fan Drive System - The drive system data are based on test cell measurements of the DDA XT701. The noise data are shown on Figure C-40 for power levels of 1491/2982/4474/5965 kW (2000/4000/6000/8000 shp).

Aircraft Flyover Noise - Measured flyover noise data from the Lockheed C-141A, Boeing KC-135A, Convair 990, and the GAC GII with hardwall nacelle and "Hush" kit, are shown on Figures C-41, C-42, C-43, C-44 and C-45 for the indicated power settings.

The primary engine noise dominates the spectra for these aircraft.

Testbed Airframe - The predicted "clean" airframe noise levels with the gear and flaps up for the Lockheed C-141A, Boeing KC135A, Convair 990, and the GAC GII are shown in Figures C-46 through C-49.

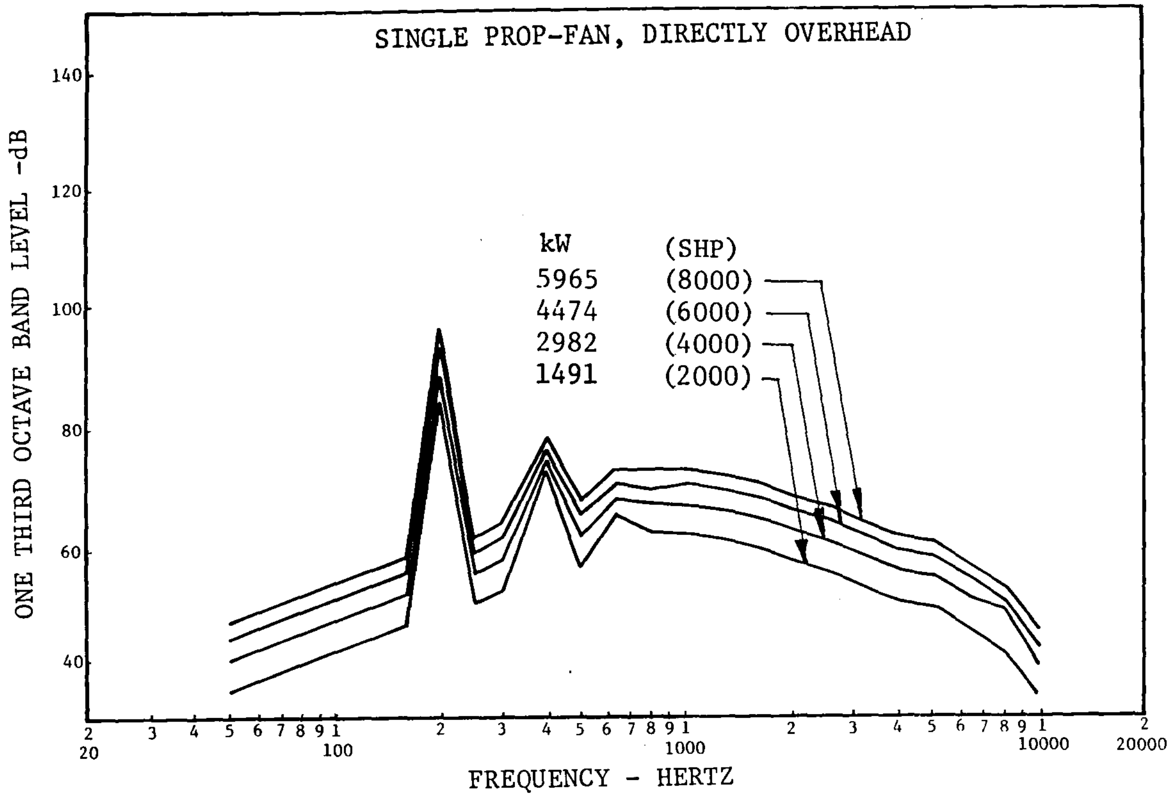


Figure C-39. Prop-Fan Alone Noise

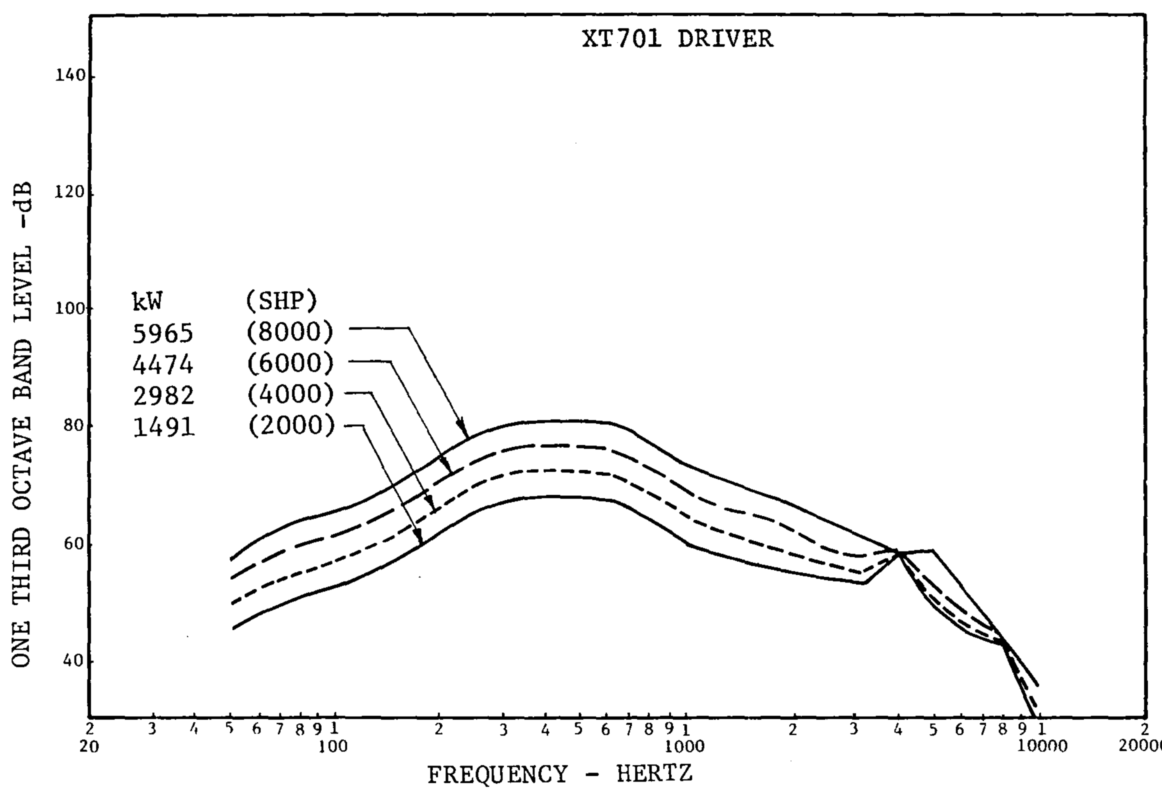


Figure C-40. XT701 Prop-Fan Drive System Noise

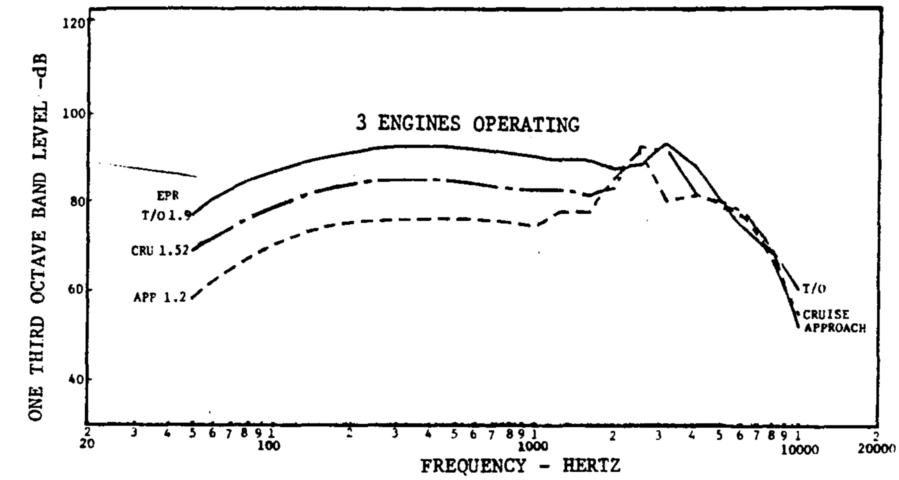


Figure C-41. Lockheed C-141A Flyover Noise

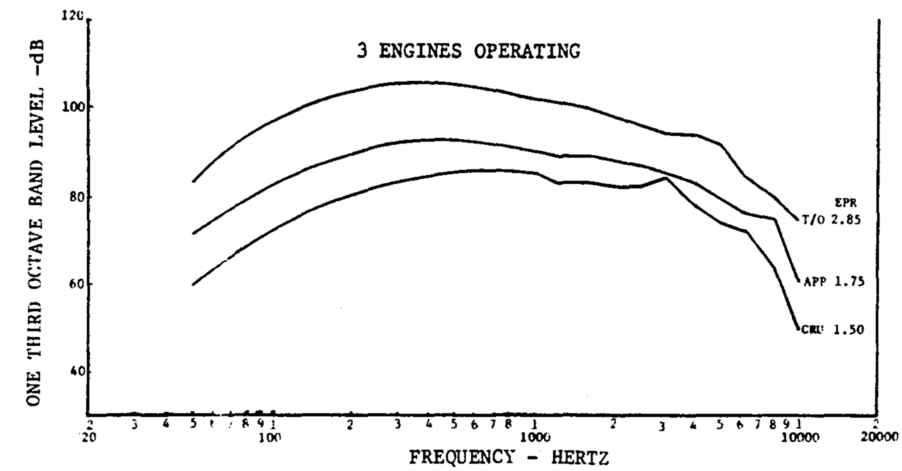


Figure C-42. KC-135A Flyover Noise

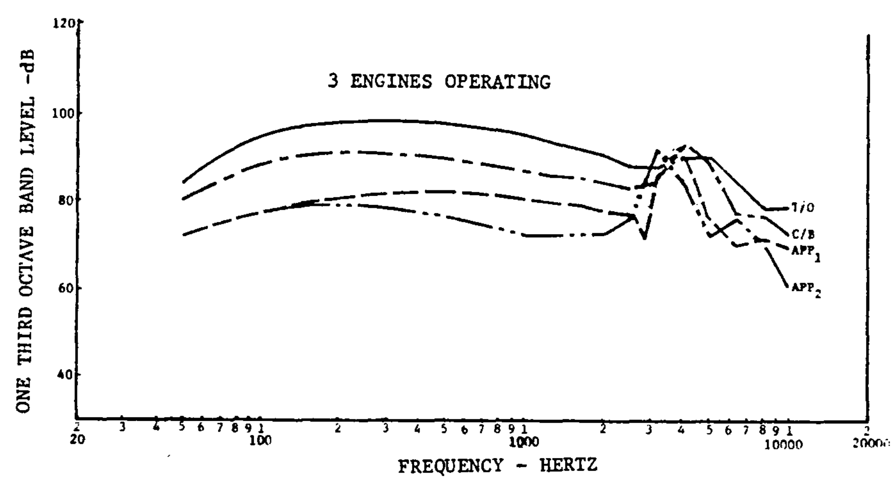


Figure C-43. Convair 990 Flyover Noise

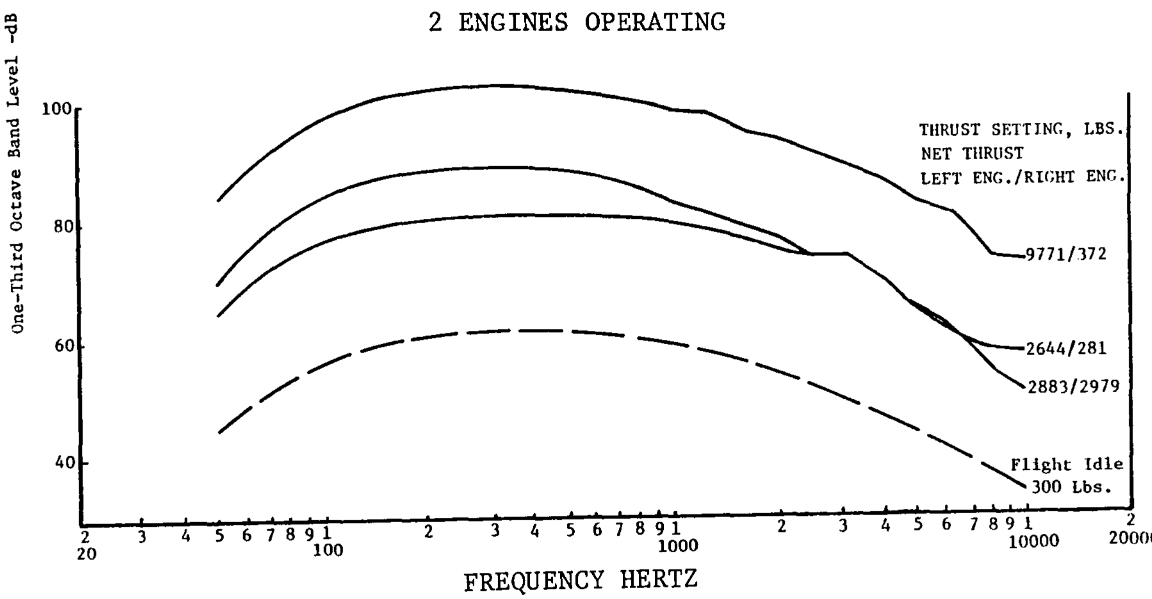


Figure C-44. GAC Gulfstream II Flyover Noise - Hardwall Nacelle

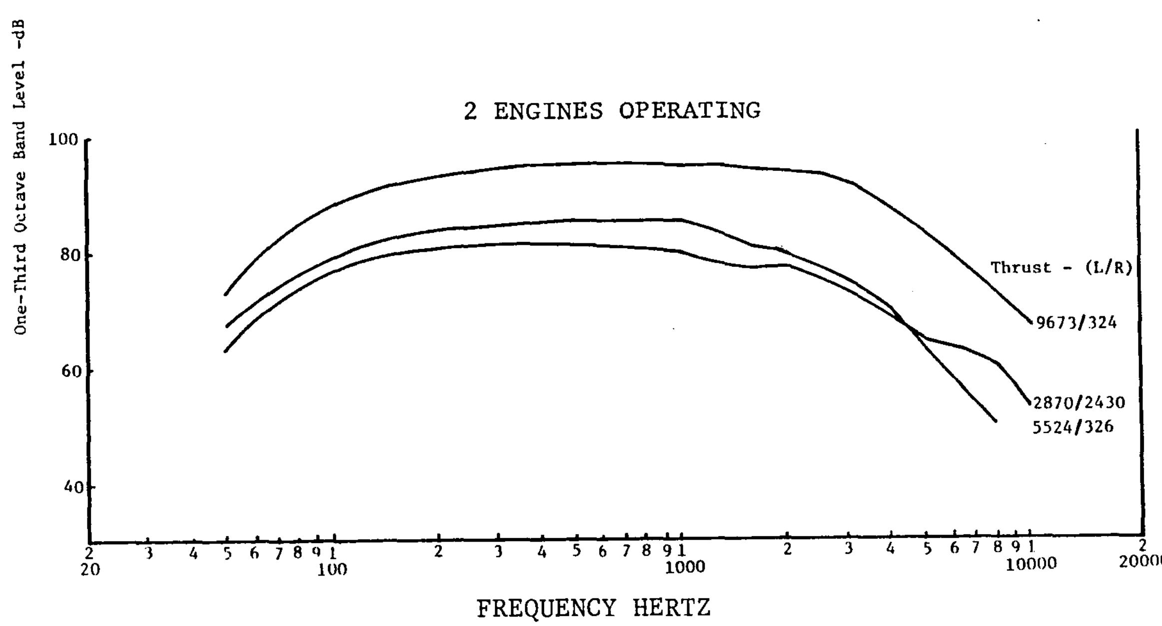


Figure C-45. GAC Gulfstream II Flyover Noise - Hush Kit Nacelle

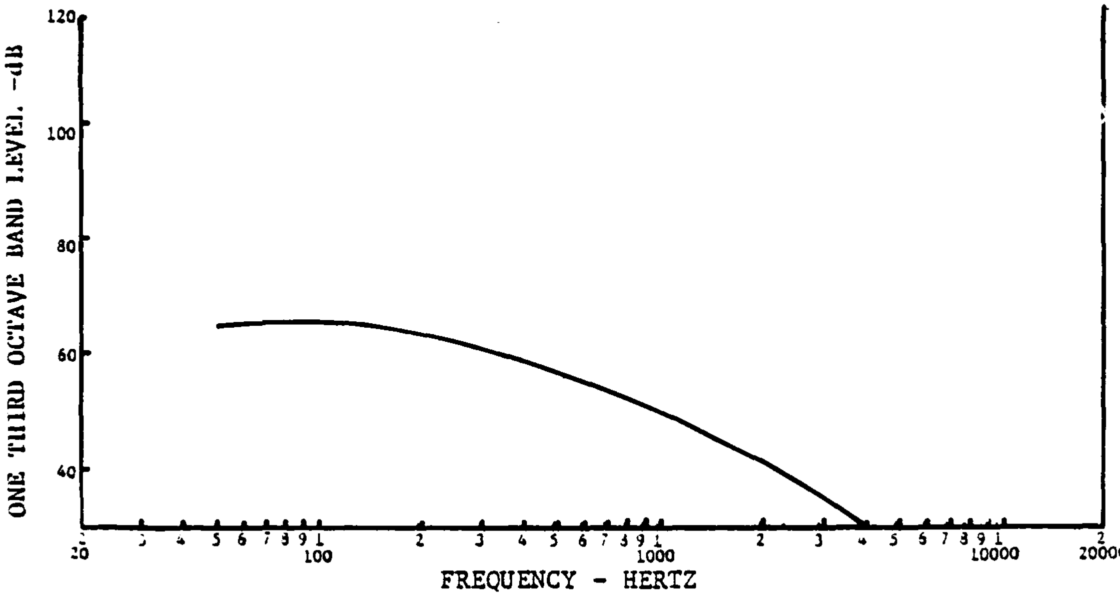


Figure C-46. Lockheed C-141A Airframe Noise

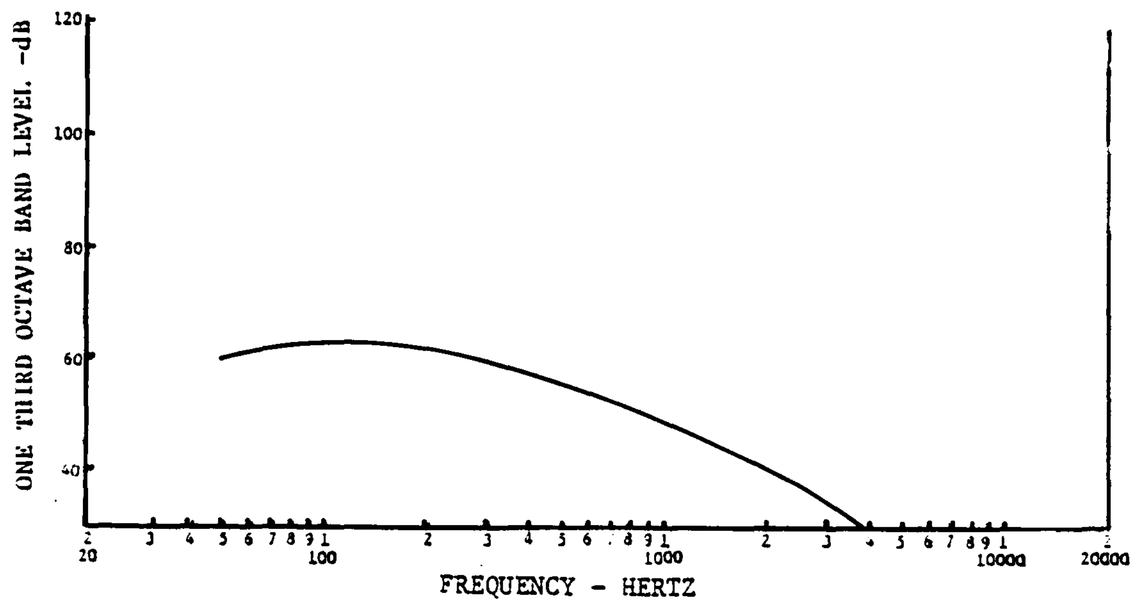


Figure C-47. Boeing KC-135A Airframe Noise

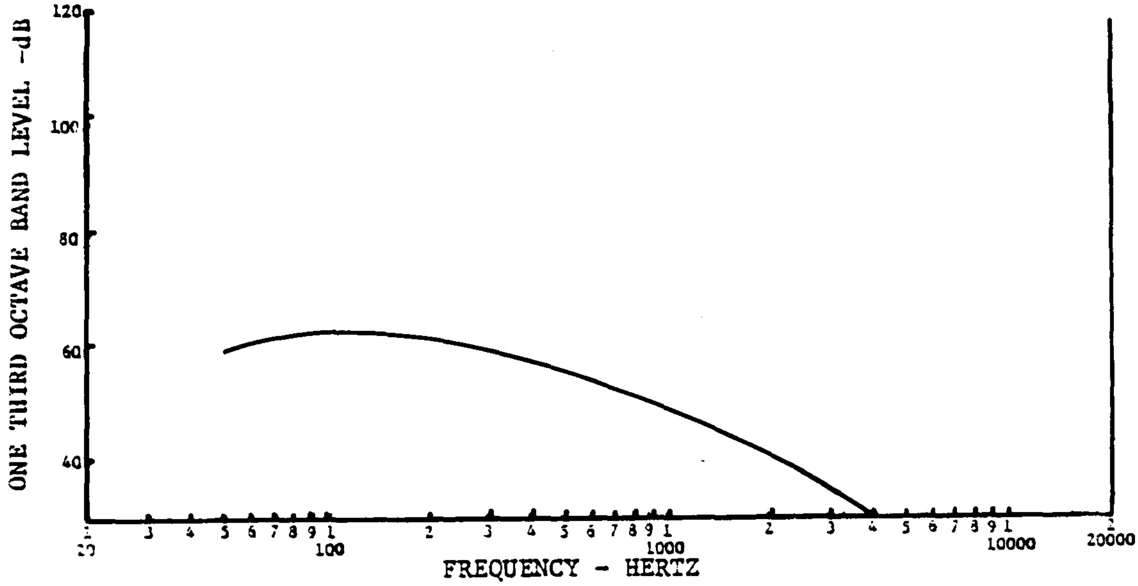


Figure C-48. Convair 990 Airframe Noise

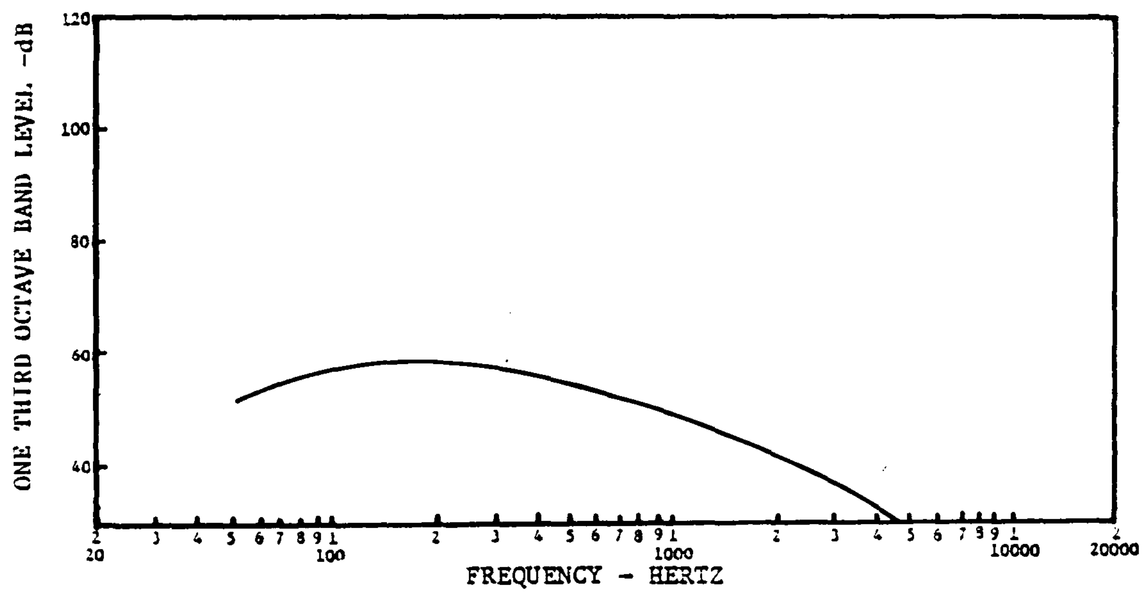


Figure C-49. GAC Gulfstream II Airframe Noise

<u>Prop-Fan Drive System Muffler</u> - The data of Figure C-50 shows that the prop-fan noise is subject to considerable masking from the noise radiated by the XT701 drive system, principally from the exhaust.

Achievement of a cleaner noise signal from the prop-fan requires reduction of the drive system exhaust noise. This could be done by either locating the drive system exhaust over the wing well upstream of the trailing edge to take advantage of wing shielding or by adding a larger muffler to the exhaust.

Figure C-50 also shows the drive system noise with 15db suppression throughout the spectrum.

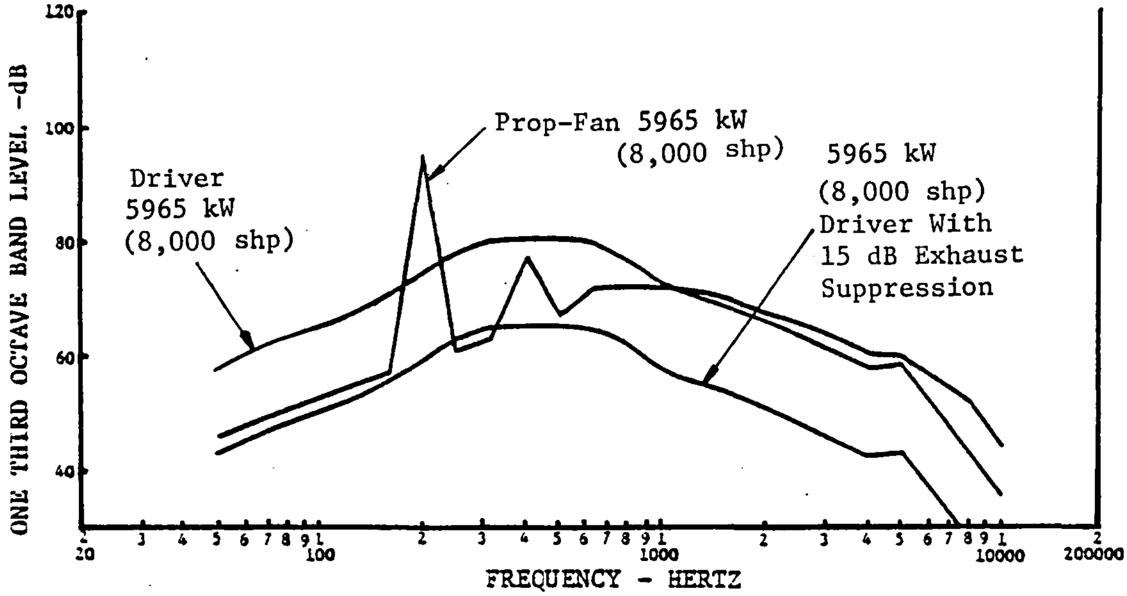


Figure C-50. Prop-Fan Driver Suppression Requirement

The need for this amount of suppression is applicable to all the candidate aircraft and is shown on the aircraft component noise spectra.

Aircraft Component Noise Spectra - Component noise spectra are shown on Figures C-51, C-52, C-53, and C-54 for the Lockheed C-141A, Boeing KC-135A, Convair 990 and the GAC GII. These spectra are predicted for peak flyover noise with drive system suppression and with the noise generated by the primary engines at flight idle power. Although the latter predictions are based on flyover noise measurements, some degree of uncertainty does exist as to their actual value. The flight test for an Acoustic Test Program, however, could be planned to better define these noise levels. In the case of the GAC GII, a "Hush kit" is available which could further reduce the noise level of the "Spey" engines. The data show that the cleanest prop-fan noise signal is that from the GAC GII testbed.

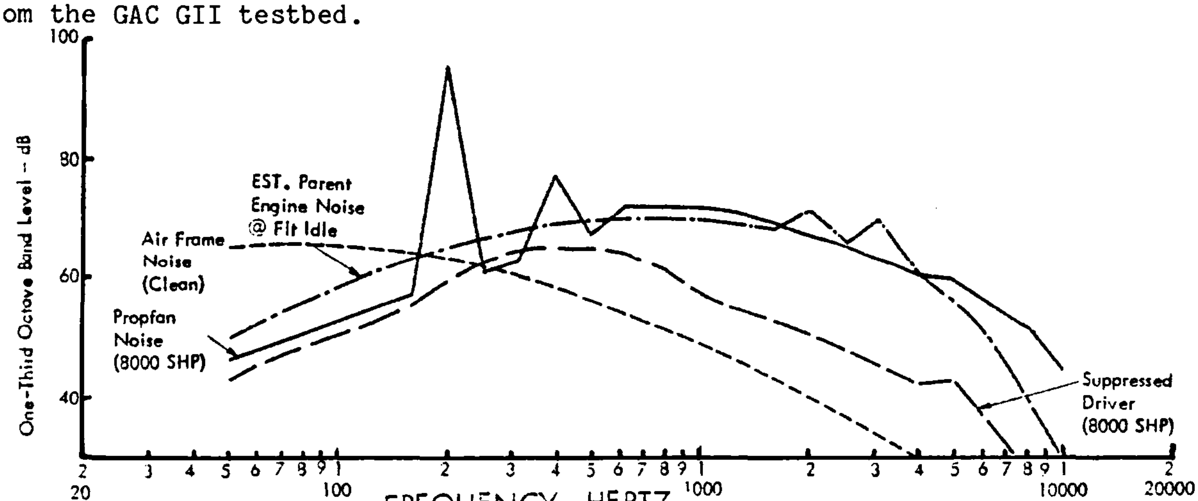


Figure C-51. C-141A Component Noise Levels

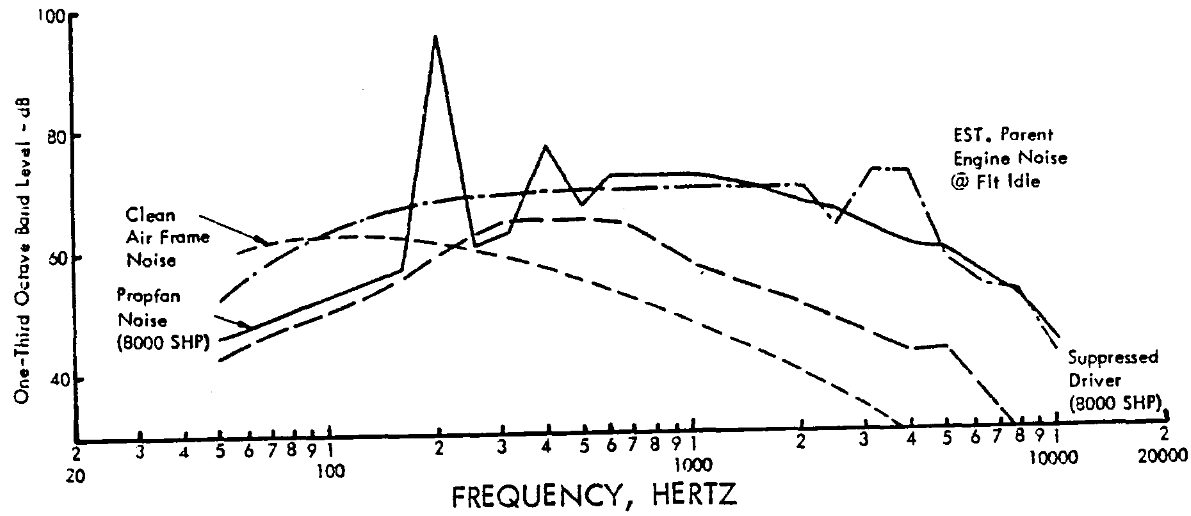


Figure C-52. KC-135A Component Noise Levels

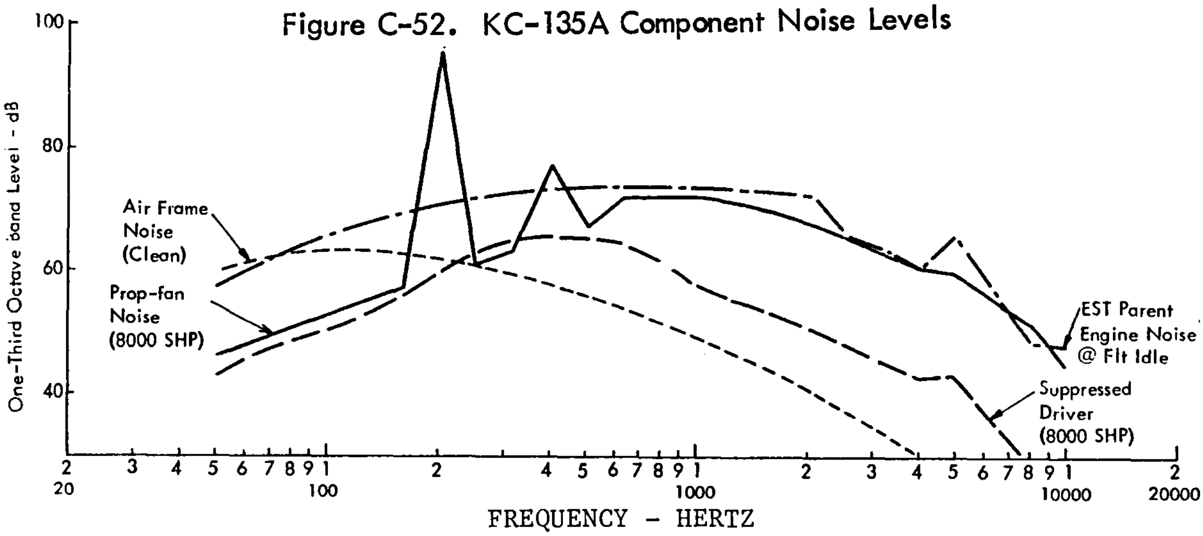


Figure C-53. Convair 990 Component Noise Levels

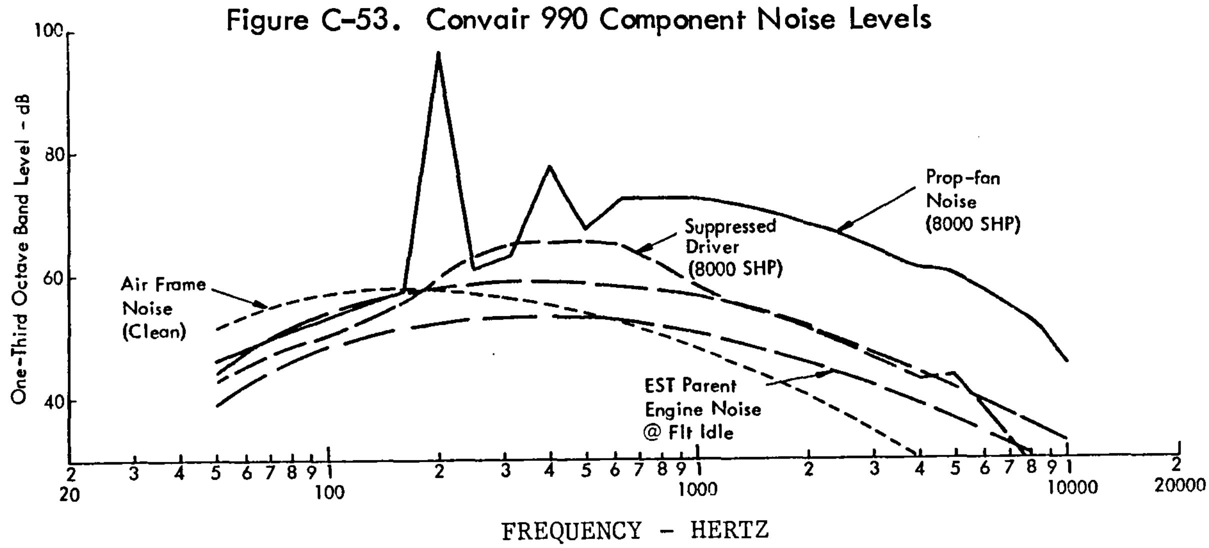


Figure C-54. GII Component Noise Levels

Testbed Aircraft Alternate Configurations

The single engine testbed aircraft were examined for possible conversion to multi-prop-fan configurations. It was found that the large aircraft - C-141A, KC-135A, and the Convair 990, which in the single prop-fan configuration were propulsion substitutions - would require a change to propulsion addition to achieve a multi-prop-fan testbed. In the case of these aircraft, the prop-fan propulsion units would be located on the wings inboard of the existing inboard primary propulsion. As far as possible, the units would be located to provide the desired clearances for structural and acoustic considerations. The three configurations are shown on Figures C-55, C-56, and C-57.

The multi-prop-fan GAC GII is achieved by adding a second wing-mounted prop-fan drive system as shown in Figure C-58.

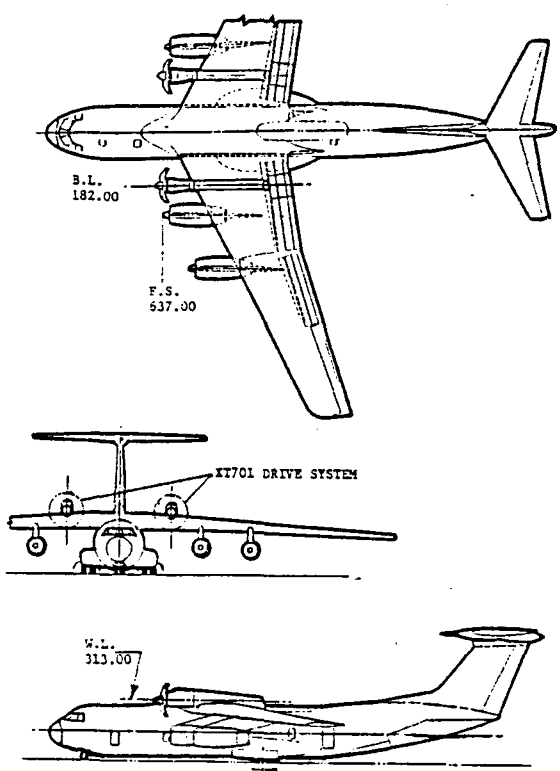


Figure C-55. C-141A Twin Engine Testbed Overwing Configuration

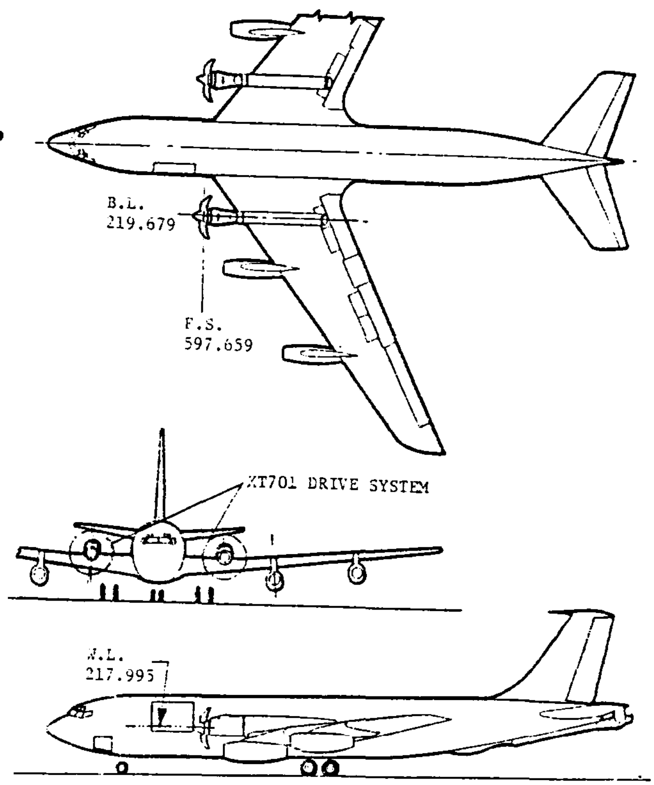


Figure C-56. KC-135A Twin Engine Testbed Overwing Configuration

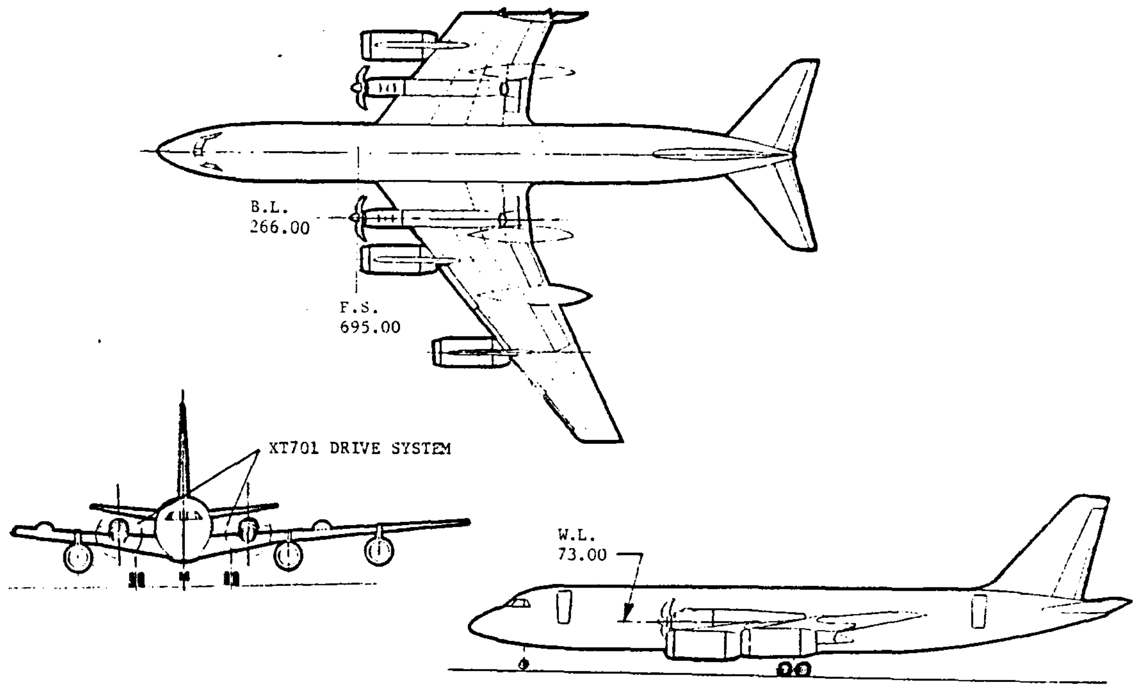


Figure C-57. Convair 990 Twin Engine Testbed Overwing Configuration

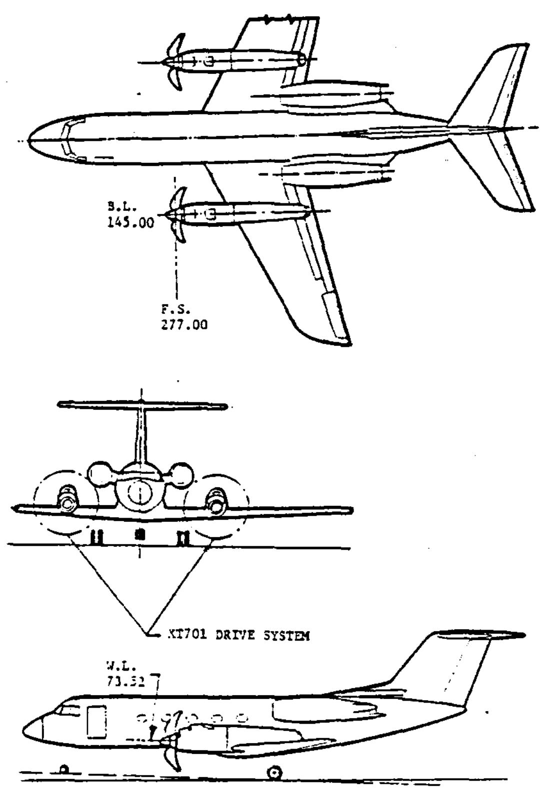


Figure C-58. Gulfstream II Twin Engine Testbed Overwing Configuration

APPENDIX D - TESTBED SYSTEM EVALUATION AND RECOMMENDATIONS - TASK IV

A list of evaluation factors developed in accordance with the NASA Statement of Work and approved by NASA was used to perform the Advanced Turboprop Testbed System Evaluation from which recommendations were made to the NASA Lewis Research Center regarding equipment requirements for the Testbed Program and for the Program Plan. To simplify the process, the evaluation was divided into a "Drive System Evaluation and Selection" based on Task II results, and an "Aircraft Evaluation and Selection" based on Task III results. This enabled the selection of the Drive System to be made before proceeding with the Aircraft Evaluation, thereby eliminating the Drive System as a variable in the Aircraft Evaluation process. The doubt surrounding the availability of the aircraft considered in the study was also sufficient cause to remove aircraft availability from the evaluation. This came about when a survey of the list of NASA aircraft revealed that none of the aircraft suitable for Testbed application would be available in the near or far terms for the Testbed Program. Aircraft availability was, therefore, made a separate consideration addressed following to the evaluation. This survey indicated that acquisition of an airframe for the testbed aircraft may be possible only by purchasing a suitable vehicle. This is particularly true if the prop-fan testbed program is to be accelerated.

CANDIDATE DRIVE SYSTEM EVALUATION AND SELECTION

Five propeller drive systems were investigated in Task II and three engine/gearbox combinations emerged as candidates for the testbed aircraft drive system as listed below:

Power Section	Gearbox
DDA T56	T56-A-14
DDA XT701	T56-A-14
GE T64-415	IHI T64-2 SDG

Of the three drive systems two, the T56/T56-A-14 and the GE T64-415/IHI T64-2 SDG, are in production, whereas the third, the DDA XT701, exists in sufficient quantity to support a testbed aircraft program.

Drive System Evaluation

Evaluation criteria for the drive system were grouped into the following categories:

Operational Characteristics

- Shaft horsepower at design condition
- Fixed speed or free turbine

Prop-Fan Sizing

- Disc loading
- Structural validation constraints

Drive System Modification

- Gearbox modification
- Power section modification
- Normalized cost
- Risk

Engine and Gearbox Availability

- Power section availability
- Gearbox availability
- Spares availability

Prop-Fan Control System Requirements

- Modified 54H60 control compatibility
- Control functions required

Nacelle Structure

- Overdesigned structure
- New contours

Engine Controls

- Fuel control

These items are listed on Table D-I, where the relative merits are addressed. Hamilton Standard has determined that an accurate demonstration of dynamic behavior and fabrication feasibility cannot be achieved with prop-fan diameters of less than 2.44m (8 ft). Since the prop-fan diameter for the General Electric GE T64-415 was only 2.16m (7.1 ft), this drive system was eliminated from consideration. The selection of the drive system for the testbed aircraft, therefore, became a choice between the DDA T56 and the DDA XT701.

Comparing the two drive systems, it is readily apparent that the XT701 provides the largest diameter prop-fan 2.89m (9.5 ft) with a possibility of increasing to 3.05m (10 ft) when higher power levels on the XT701 have been demonstrated. This is about 17 percent greater in diameter than the nearest rival, the T56-sized prop-fan 2.47m (8.1 ft) in diameter. The gearbox power limitation at sea level for the XT701/T56 3729 kW (5000 shp) and the T64 2237 kW (3000 shp) will affect ground operations.

The XT701, which has a free turbine power section, has another advantage over the T56, a fixed-speed unit, in that the prop-fan tip speeds can be varied continuously over a wide range. This speed range provides test condition flexibility of great value in a flight test program. In addition, the fixed-speed T56 requires a negative torque-sensing system, which is one more control function than is required by the XT701.

Drive system modifications of significance are those required to match the T56-A-14 gearbox to the drive system test requirements. The modification to the gearbox for speed compatibility with the XT701 requires only one set of new gears, whereas the T56 requires three sets of new gears, one for each tip speed. Because the XT701 rotates counterclockwise and the T56 gearbox is designed for clockwise rotation, additional gearing modifications are also required to rotate

TABLE D-1. DRIVE SYSTEM EVALUATION

		GE T64	DDA T56	DDA XT701
	GEARBOX TYPE	T64-2 SDG MODIFIED	MODIFIED T56-A-14	MODIFIED T56-A-14
OPERATIONAL CHARACTERISTICS	KW (SHP) S.L.S.	3266 (4380)	3423 (4591)	6018 (8071)
	KW (SHP) M=0.8 10.7K(35K) ALT.	1350 (1810)	1819 (2440)	2520 (3380)
	FIXED SPEED OR FREE TURBINE	FREE TURBINE	FIXED SPEED	FREE TURBINE
	TIP SPEED CONTINUOUSLY VARIABLE	YES	NO	YES
SIZING	DISK LOADING 301 KW/M^2 (37.5 SHP/FT^2) DIA M(FT)	2.13 (6.97)	2.47 (8.1)	2.89 (9.5)
	SIZE FOR STRUCTURAL VALIDATION	UNSATISFACTORY	MARGINAL	SATISFACTORY
DRIVE SYSTEM MODS	GEARBOX	SINGLE GEAR SET	THREE GEAR SETS	SINGLE GEAR SET
	TORQUEMETER	EXISTING	EXISTING	NEW
	INTAKE CASE INTERCON. STRUTS	NOT REQUIRED	NOT REQUIRED	REQUIRED
	NORMALIZED COSTS	1.0 (2 GBOXES)	1.0 (3 GBOXES)	<1.0 (2 GBOXES)
	RISK	1.0	1.0	>1.0
ENGINE & GEARBOX AVAIL.	POWER SECTION AVAILABILITY	IN PRODUCTION	IN PRODUCTION	5 XT701 5 DEVELOPMENT UNITS
	GEARBOX AVAILABILITY	IN PRODUCTION	IN PRODUCTION	IN PRODUCTION
	SPARES AVAILABILITY	IN PRODUCTION	IN PRODUCTION	LIMITED COMMERCIAL SET AVAILABLE
PROP-FAN CONTROL SYSTEM	MODIFIED 54H60 CONTROL	NOT COMPATIBLE	COMPATIBLE	COMPATIBLE
	OVERSPEED PROTECTION	REQUIRED	REQUIRED	REQUIRED
	NTS	NOT REQUIRED	REQUIRED	NOT REQUIRED
	GOVERNING	REQUIRED	REQUIRED	REQUIRED
	FEATHERING	REQUIRED	REQUIRED (SLOW)	REQUIRED (SLOW)
	REVERSING	FIXED BLADE	FIXED BLADE	FIXED BLADE
NACELLE	STRUCTURE OVERDESIGNED	REQUIRED	REQUIRED	REQUIRED
	CONTOURS	NEW CONTOURS	NEW CONTOURS	NEW CONTOURS
ENGINE CONTROL	FUEL	REQUIRED	REQUIRED	REQUIRED

the accessory drives in the proper direction. The testbed program with a single prop-fan configuration could be operated with two modified gearboxes for the XT701 drive system, but utilizing a T56 drive system would require at least three gearboxes to minimize "down time" interference with the testbed program when changing prop-fan tip speeds. However, there is a slightly higher risk associated with the XT701/T56-A-14 gearbox because of the high power level of the XT701, which could place restrictions on operating at high power conditions (low altitude).

No problems are associated with availability of the T56 for the testbed program, since the engine is in production. In the case of the XT701, five engines exist with another five at various stages of development. In addition, an industrial engine, the Model 570, has a large degree of commonality with the XT701, the principal difference is in the compressor case material which is titanium for the flight weight XT701 and steel for the Model 570. Reliability and availability of spare parts are not expected to present problems for the XT701. Furthermore, it is considered that the number of Preliminary Flight Rating Test and developmental engines is sufficient to support the testbed program.

The Drive System Selection is summarized in Table D-II. Of the ten items listed, the XT701/T56-A-14 combination is superior to the T56/T56-A-14 in 5, of equal standing in 2 and is not as good as the T56/T56-A-14 in 3 items.

TABLE D-II. DRIVE SYSTEM SELECTION

ITEM	T56	XT701
HIGHEST POWER LEVEL		●
LARGEST DIAMETER PROP-FAN		●
BEST OFF-DESIGN FLEXIBILITY		●
LOWEST MODIFIED GEAR BOXES		●
GEARBOX MOD MINIMUM	●	
POWER SECTION MOD MINIMUM	●	
DRIVE SYSTEM RELIABILITY - RISK	●	
AVAILABILITY TO SUPPORT PROGRAM	●	●
NEW NACELLE DESIGN - UNIVERSAL GEC	●	●
CONTROL SYSTEM LOWEST NO. OF FUNCTIONS		●

The XT701/T56-A-14 Drive System, based on this analysis, is the selected Drive System for the Advanced Turboprop Testbed Aircraft because it: (a) provides the largest diameter prop-fan within the constraints of the available power level, (b) has the flexibility to continuously vary prop-fan speed for test purposes, (c) reduces the number of gearboxes required for this program and eliminates the reliability risk associated with gearbox dismantling and reassembly to change gear sets, and (d) requires less control functions to operate the drive system than the T56.

Because of the uncertainty surrounding the availability of an airframe for the testbed program, the drive system will be designed as a universal QEC unit with structural margins high enough to permit installation on any of the candidate testbed aircraft. Over-design of the nacelle structure does not involve a weight increment of great significance.

CANDIDATE AIRCRAFT EVALUATION AND SELECTION

Aircraft selected for consideration as Advanced Turboprop Testbeds in Task III were confined to those known to be in the NASA inventory or available to NASA through loan arrangements with the Military services. The candidate aircraft evaluated were:

- o Lockheed C-141A
- o Boeing KC-135A
- o Convair 990
- o Gulfstream American Corporation "Gulfstream II"
- o Boeing B-52B

These candidate aircraft fall into three types for which two classes of propulsion system application are possible and for which two variations of prop-fan installation can be identified.

Candidate Testbed Aircraft Categories

The candidate testbed aircraft fall into three categories as follows:

- o Commercial passenger transports

- Military transports representative of commercial aircraft designed for FAA certification

- Military aircraft non-representative of commercial aircraft but having limited potential for advanced turboprop testbed application by virtue of previous usage as a test vehicle

Candidate Testbed Aircraft Propulsion System Configurations

The propulsion system configurations of the candidate testbed aircraft were divided into two classes:

- Prop-fan propulsion system substitution: This class of propulsion system configuration was characterized by the removal of an existing propulsive unit and the substitution of a prop-fan propulsion system.

- Prop-fan Propulsion System Addition: The existing propulsion system was retained for this propulsion configuration and the prop-fan system was added to the aircraft configuration

Candidate Testbed Aircraft Prop-Fan Installation Variants

Two variations of prop-fan propulsion unit installations were identified as follows:

- Pinion-high overwing installation

- Pinion-low underwing installation

Evaluation Criteria

The evaluation criteria categorized according to function are as follows:

A. Aircraft Safety Requirements

- Ground Operational Safety
- Flight Operational Safety

- o Aircraft Structural Integrity

B. Operational Characteristics Requirements

- o Compliance with Design Conditions
- o Test Mission Duration
- o Aircraft Stability and Control
- o Installation Effects

C. Testbed Program Objectives Achievement

- o Realistic Environment for Dynamic Loads Validation
- o Acoustic Data Acquisition
- o Prop-fan Scale
- o Installed Propulsive Efficiency and Interaction Effects

D. Data Availability

- o Contractor Access to Aircraft Data

E. Potential for Modification to Research Aircraft Configuration

- o Performance with Existing and Projected Drive Systems

F. Relative Costs of Testbed Systems

- o Comparison of Testbed Systems ROM Costs

Evaluation Criteria Ratings and Procedures

Since it is unlikely that any one of the selected testbed aircraft will have all of the features desired for the testbed aircraft, a number of evaluation criteria ratings have been identified to assist in the selection process. Each evaluation criterion is rated on a scale of 0 to 3 for acceptability, but because of the diversity of the evaluation criteria and their equally diverse degrees of importance, each rating is "weighted" on a scale of 1 to 4 according to the level of priority or importance of the criterion under evaluation.

The ratings used in the evaluation are as follows:

Acceptability	Rating
Unacceptable	0
Marginal	1
Satisfactory	2
Good	3

The weighting factors applied to each of the evaluation criteria listed on Table D-III cover a scale of 1 to 4, with the higher levels of weighting factor indicating higher levels of criterion priority.

A total score is produced for each candidate testbed aircraft by the summation of the products of the Evaluation Criterion Rating (ECR) and the Weighting Factor (WF) as follows:

$$\text{Total Score} = \sum \text{ECR} \times \text{WF}$$

The candidate testbed aircraft are then ranked according to the weighted score for which the higher scores indicate those aircraft suitable for the Advanced Turboprop Testbed System Application.

Testbed Aircraft Evaluation

The evaluation process was conducted by dividing the procedure into a number of components and subcomponents:

- A statement identifying the major concerns or conditions to be satisfied was first formulated.

- This was followed by the identification of specific evaluation criteria and a description of each item evaluated.

TABLE D-III. EVALUATION CRITERIA IDENTIFICATION

EVALUATION CRITERIA AND WEIGHTING FACTORS

EVALUATION CRITERIA		WEIGHTING FACTOR
A - AIRCRAFT SAFETY		
A-1	PROP-FAN LOCATION	2
A-2	ENGINE-OUT SAFETY	4
A-3	STRUCTURAL INTEGRITY	4
B - OPERATIONAL CHARACTERISTICS		
B-1	DESIGN CRUISE CONDITIONS COMPLIANCE	4
B-2	TEST MISSION DURATION	3
B-3	AIRCRAFT STABILITY AND CONTROL	4
B-4	INSTALLATION EFFECTS	4
C - TESTBED PROGRAM OBJECTIVES ACHIEVEMENT		
C-1	DYNAMIC LOADS VALIDATION	4
C-2	NEAR-FIELD NOISE DATA ACQUISITION	4
C-3	FAR-FIELD NOISE DATA ACQUISITION	2
C-4	PROP-FAN SCALE	4
C-5	INSTALLED PROPULSIVE EFFICIENCY VALIDATION	2
C-6	INTERACTION EFFECTS VALIDATION	2
D - DATA AVAILABILITY		
D-1	AIRCRAFT DATA AVAILABILITY	2
E - POTENTIAL FOR MODIFICATION TO RESEARCH AIRCRAFT CONFIGURATION		
E-1	POTENTIAL FOR MODIFICATION TO A RESEARCH AIRCRAFT	2
F - RELATIVE COST OF TESTBED SYSTEMS		
F-1	MODIFICATION COST DATA RANKING	3

- The evaluation rating for each item was then developed and the weighting factor applied.

- The weighted evaluation rating for the testbed evaluation was then determined. Averaging was used when more than one item was involved in the process.

Each of the Evaluation Criteria (EC), identified alphanumerically, is shown on Table D-III, together with the appropriate weighting factors.

AIRCRAFT SAFETY REQUIREMENTS

The aircraft must be capable of operation on the ground and in the air without damage to the prop-fan, the installation and the aircraft and without danger to the crew. Requirements include ground operational safety, flight operational safety and structural integrity.

Ground Operational Safety

EC A-1 Prop-fan Location

The prop-fan location must be such that:

- Sufficient ground clearance will exist to permit operation of the prop-fan installation without damage under normal operating conditions.
- Sufficient ground clearance will exist following the deflation of a tire or tires in combination with full contraction of a landing gear strut.
- Sufficient clearance will exist between the prop-fan and adjacent components to permit operation of the prop-fan without damage and interference.

The criteria for clearances recommended by Hamilton Standard are:

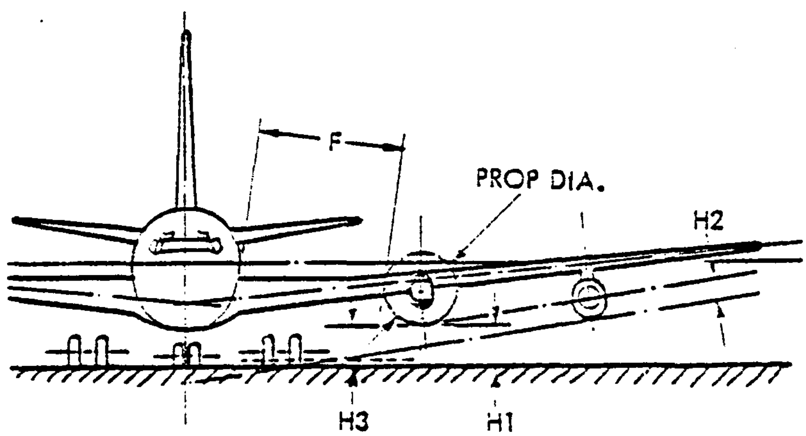
Prop-fan Tip/Ground-Normal Attitude-H 1.8m (6 ft)

Prop-fan Tip/Fuselage-F $0.8D_p$ For Acoustics

$0.2D_p$ For Excitation

where D_p is the prop-fan diameter

Additional prop-fan clearance nomenclature is identified in Figure D-1.



H_1 - GROUND CLEARANCE NORMAL ATTITUDE

H_2 - GROUND CLEARANCE ROLLED ATTITUDE

H_3 - GROUND CLEARANCE COMPRESSED STRUT AND FLAT TIRE

F - FUSELAGE/PROP-FAN TIP CLEARANCE

Figure D-1. Prop-Fan Location and Clearance Definition

The data for the evaluation criteria development are given in Tables D-IV, D-V, D-VI and D-VII for the Lockheed C-141A, Boeing KC-135A, Convair 990, and the Gulfstream American GII over- and under-wing configurations, respectively.

Flight Operational Safety

Engine-out Safety - The testbed aircraft must be capable of safe operation following an engine failure.

TABLE D-IV. EC A-1 PROP-FAN LOCATION EVALUATION - C-141A

WEIGHTING FACTOR = 2

C-141 TESTBED AIRCRAFT OVERWING

CRITERIA	PROPUL SYS	HEIGHT/DIST m (in)	$H = f(D_p)$	RATING VALUE	CRITERION SCORE	LIMIT
GROUND CLEARANCE NORMAL H1	T64	NA	NA	NA	NA	
	T56	4.94 (194.65)	$2.0D_p$	3	6	
	XT701	5.06 (199.15)	$1.75D_p$	3	6	
GROUND CLEARANCE ROLLED ATTITUDE H2	T64	NA	NA	NA	NA	OUTBD. ENGINE FIRST CONTACT
	T56	3.00 (118.0)	$1.21D_p$	3	6	
	XT701	2.79 (110.0)	$.96D_p$	3	6	
GROUND CLEARANCE DEFLATED TIRES & CONTRACTED STRUT H3	T64	NA	NA	NA	NA	
	T56	4.79 (188.65)	$1.94D_p$	3	6	
	XT701	4.91 (193.15)	$1.69D_p$	3	6	
PROP-FAN/FUSELAGE CLEARANCE F	T64	NA	NA	NA	NA	
	T56	4.06 (160.0)	$1.64D_p$	3	6	
	XT701	3.91 (154.0)	$1.35D_p$	3	6	

C-141A TESTBED AIRCRAFT UNDERWING

CRITERIA	PROPUL SYS	HEIGHT/DIST m (ins)	$H = f(D_p)$	RATING VALUE	CRITERION SCORE	LIMIT
GROUND CLEARANCE NORMAL H1	T64	NA	NA	NA	NA	
	T56	2.97 (116.85)	$1.20D_p$	3	6	
	XT701	3.71 (146.05)	$1.28D_p$	3	6	
GROUND CLEARANCE ROLLED ATTITUDE H2	T64	NA	NA	NA	NA	OUTBD ENGINE FIRST CONTACT
	T56	2.44 (96.0)	$.98D_p$	3	6	
	XT701	1.98 (78.0)	$.68D_p$	3	6	
GROUND CLEARANCE DEFLATED TIRES & CONTRACTED STRUT H3	T64	NA	NA	NA	NA	
	T56	2.71 (106.85)	$1.09D_p$	3	6	
	XT701	3.56 (140.0)	$1.23D_p$	3	6	
PROP-FAN/FUSELAGE CLEARANCE F	T64	NA	NA	NA	NA	
	T56	3.94 (155.0)	$1.59D_p$	3	6	
	XT701	3.61 (142.0)	$1.24D_p$	3	6	

TABLE D-V. EC A-1 PROP-FAN LOCATION EVALUATION - KC-135A

WEIGHTING FACTOR = 2

KC-135A TESTBED AIRCRAFT OVERWING

CRITERIA	PROPUL SYS	HEIGHT/DIST m (in)	$H = f(D_p)$	RATING VALUE	CRITERION SCORE	LIMIT
GROUND CLEARANCE NORMAL H1	T64	NA	NA	NA	NA	
	T56	2.14 (84.13)	$0.87 D_p$	3	6	
	XT701	1.92 (75.73)	$0.66 D_p$	3	6	
GROUND CLEARANCE ROLLED ATTITUDE H2	T64	NA	NA	NA	NA	OUTBD. ENGINE FIRST CONTACT
	T56	1.45 (57.00)	$0.59 D_p$	3	6	
	XT701	1.33 (52.41)	$0.46 D_p$	3	6	
GROUND CLEARANCE DEFLATED TIRES & CONTRACTED STRUT H3	T64	NA	NA	NA	NA	OUTBD. ENGINE FIRST CONTACT
	T56	1.07 (42.0)	$0.43D_p$	3	6	
	XT701	0.96 (37.6)	$0.33D_p$	3	6	
PROP-FAN/FUSELAGE CLEARANCE F	T64	NA	NA	NA	NA	
	T56	5.07 (199.46)	$2.06D_p$	3	6	
	XT701	4.83 (190.00)	$1.66D_p$	3	6	

KC-135A TESTBED AIRCRAFT UNDERWING

CRITERIA	PROPUL SYS	HEIGHT/DIST m (ins)	$H = f(D_p)$	RATING VALUE	CRITERION SCORE	LIMIT
GROUND CLEARANCE NORMAL H1	T64	NA	NA	NA	NA	
	T56	1.52 (59.82)	$0.61D_p$	3	6	
	XT701	1.26 (49.42)	$0.43D_p$	3	6	
GROUND CLEARANCE ROLLED ATTITUDE H2	T64	NA	NA	NA	NA	OUTBD ENGINE FIRST CONTACT
	T56	0.78 (30.59)	$0.31D_p$	3	6	
	XT701	0.56 (22.19)	$0.19D_p$	3	6	
GROUND CLEARANCE DEFLATED TIRES & CONTRACTED STRUT H3	T64	NA	NA	NA	NA	OUTBD. ENGINE FIRST CONTACT
	T56	1.27 (50.00)	$0.51D_p$	3	6	
	XT701	1.04 (41.00)	$0.36D_p$	3	6	
PROP-FAN/FUSELAGE CLEARANCE F	T64	NA	NA	NA	NA	
	T56	5.08 (200.00)	$2.00D_p$	3	6	
	XT701	4.89 (192.40)	$1.70D_p$	3	6	

TABLE D-VI. EC A-1 PROP-FAN LOCATION EVALUATION - CONVAIR 990

WEIGHTING FACTOR = 2

CONVAIR 990 TESTBED AIRCRAFT OVERWING

CRITERIA	PROPUL SYS	HEIGHT/DIST m (in)	$H = f(D_p)$	RATING VALUE	CRI-TERION SCORE	LIMIT
GROUND CLEARANCE NORMAL H1	T64	NA	NA	NA	NA	
	T56	2.12 (83.5)	$0.86D_p$	3	6	
	XT701	2.06 (81.1)	$0.71D_p$	3	6	
GROUND CLEARANCE ROLLED ATTITUDE H2	T64	NA	NA	NA	NA	OUTBD. ENGINE FIRST CONTACT
	T56	1.84 (72.5)	$0.75D_p$	3	6	
	XT701	1.59 (62.5)	$0.55D_p$	3	6	
GROUND CLEARANCE DEFLATED TIRES & CONTRACTED STRUT H3	T64	NA	NA	NA	NA	OUTBD. ENGINE FIRST CONTACT
	T56	1.52 (60.0)	$0.62D_p$	3	6	
	XT701	1.32 (52.0)	$0.46D_p$	3	6	
PROP-FAN/FUSELAGE CLEARANCE F	T64	NA	NA	NA	NA	
	T56	3.71 (146.0)	$1.50D_p$	3	6	
	XT701	3.49 (137.5)	$1.21D_p$	3	6	

CONVAIR 990 TESTBED AIRCRAFT UNDERWING

CRITERIA	PROPUL SYS	HEIGHT/DIST m (ins)	$H = f(D_p)$	RATING VALUE	CRI-TERION SCORE	LIMIT
GROUND CLEARANCE NORMAL H1	T64	NA	NA	NA	NA	
	T56	1.44 (56.5)	$0.58D_p$	3	6	
	XT701	1.22 (48.1)	$0.42D_p$	3	6	
GROUND CLEARANCE ROLLED ATTITUDE H2	T64	NA	NA	NA	NA	OUTBD ENGINE FIRST CONTACT
	T56	1.08 (42.5)	$0.44D_p$	3	6	
	XT701	0.76 (30.0)	$0.26D_p$	3	6	
GROUND CLEARANCE DEFLATED TIRES & CONTRACTED STRUT H3	T64	NA	NA	NA	NA	OUTBD. ENGINE FIRST CONTACT
	T56	0.76 (30.0)	$0.31D_p$	3	6	
	XT701	0.44 (17.5)	$0.15D_p$	3	6	
PROP-FAN/FUSELAGE CLEARANCE F	T64	NA	NA	NA	NA	
	T56	3.81 (150.0)	$1.54D_p$	3	6	
	XT701	3.58 (141.0)	$1.23D_p$	3	6	

TABLE D-VII. EC A-1 PROP-FAN LOCATION EVALUATION - GII

WEIGHTING FACTOR = 2

GULFSTREAM II TESTBED AIRCRAFT OVERWING*

CRITERIA	PROPUL SYS	HEIGHT/DIST m (in)	$H = f(D_p)$	RATING VALUE	CRI-TERION SCORE	LIMIT
GROUND CLEARANCE NORMAL H1	T64	NA	NA	NA	NA	
	T56	0.61 (24.0)	$0.25D_p$	3	6	
	XT701	0.44 (17.4)	$0.15D_p$	2	4	
GROUND CLEARANCE ROLLED ATTITUDE H2	T64	NA	NA	NA	NA	PROP-FAN TIP FIRST CONTACT
	T56	0.27 (10.8)	$0.11D_p$	2	4	
	XT701	0.11 (4.5)	$0.04D_p$	1	2	
GROUND CLEARANCE DEFLATED TIRES & CONTRACTED STRUT H3	T64	NA	NA	NA	NA	PROP-FAN TIP FIRST CONTACT
	T56	0.18 (7.2)	$0.70D_p$	2	4	
	XT701	0.03 (1.2)	$0.01D_p$	0	0	
PROP-FAN/FUSELAGE CLEARANCE F	T64	NA	NA	NA	NA	
	T56	1.48 (58.3)	$0.60D_p$	3	6	
	XT701	1.26 (49.46)	$0.44D_p$	3	6	

<u>EC A-2</u> Engine-out Safety

- Primary Engine-out Operation
- Prop-Fan Engine-out Operation

The testbed aircraft must be capable of takeoff and landing with a primary engine failed and with the prop-fan at flight idle or full power. This criterion is particularly important where primary engine substitution has been made. The C-141A, the KC-135A, and the Convair 990 fall into this category of aircraft.

Data for the KC-135A and Convair 990 are not available for an assessment of the two-engine operation. However, the data for the C-141A two-engine operation have been analyzed and are presented in Figures D-2 and D-3. The most critical case, that of takeoff with Air Force hot-day conditions prevailing is shown. The thrust available and thrust required, and the drag increment due to two failed engines are shown in Figure D-2.

Drag at L/D_{MAX} and the thrust at normal rated and military rated thrusts are shown Figure D-3 for two engine operation. The corresponding climb

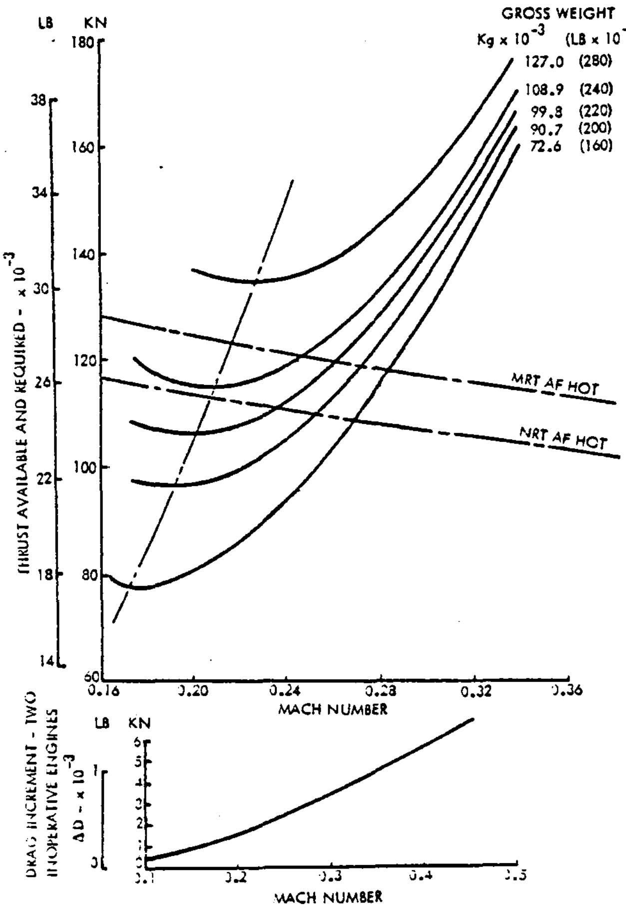


Figure D-2. C-141A
Thrust Available and Required -
Two Engine Operation

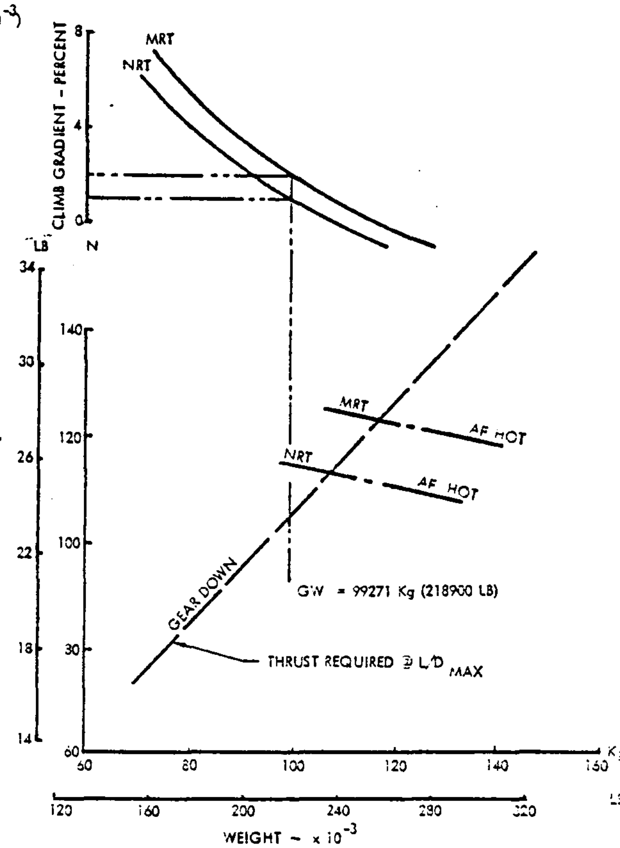


Figure D-3.
C-141A Two-Engine Operation

gradients are also shown on Figure D-3.

The air minimum control speed for two engine operation of the C-141A covers a band of speed of 69.4 to 74.6m/s (135 to 145 knots) true airspeed. These data show that a positive climb gradient of about 1 percent is available for two engine operation.

No data are available for the KC-135A and Convair 990; however, assuming that similar conditions exist for these aircraft, at testbed weights, two-engine performance should be available to provide a measure of safety.

In the case of the Gulfstream II, the propulsion system is an addition to the existing primary propulsion system so that normal operation is possible and FAR Part 25 performance with one primary engine failed is satisfied.

The data for this evaluation are shown in Table D-VIII.

TABLE D-VIII. EC A-2 ENGINE-OUT SAFETY EVALUATION

WEIGHTING FACTOR = 4

TESTBED A/C	PROPULSION SYSTEM	RAMP WEIGHT Kg (LB)	CLIMB GRAD 2-ENG AF HOT DAY GEAR DOWN	RISK	RATING VALUE	CRI-TERION SCORE
C-141A	SUBSTITUTION	99271 (218,900)	1% @ NRT	HIGH	1	4
KC-135A	SUBSTITUTION	82990 (183,000)	NO DATA SIMILAR TO C-141A	HIGH	1	4
CONVAIR 990	SUBSTITUTION	87072 (192,000)	NO DATA SIMILAR TO C-141A	HIGH	1	4
GULFSTREAM II	ADDITION	27210 (60,000)	NO REDUCTION IN CLIMB GRADIENT	LOW	3	12

Aircraft Structural Integrity

The prop-fan must be installed without incurring problems which could affect the structural integrity of the testbed aircraft. The risk of encountering wing flutter problems and severe changes in balance must be evaluated.

EC A-3 Structural Integrity
- Wing Flutter Appraisal
- Aircraft Balance Check

Modification of the candidate testbed aircraft must be achieved without adversely affecting the airframe structural integrity. The two principal concerns in this area are wing flutter and changes in the aircraft balance characteristics.

Wing Flutter - Appraisals of the candidate testbed aircraft have been made relative to the risk of encountering wing flutter problems which could jeopardize the testbed program. The candidate testbed aircraft have been appraised based upon flutter parametric analyses, where available, and on the basis of location and extent of changes in the mass and inertial properties of the wing-engine systems.

The propulsion system/wing configurations are shown on Figures D-4, D-5, D-6 and D-7 for the Lockheed C-141A, Boeing KC-135A, Convair 990, and Gulfstream II and the data for the evaluation are shown on Table D-IX.

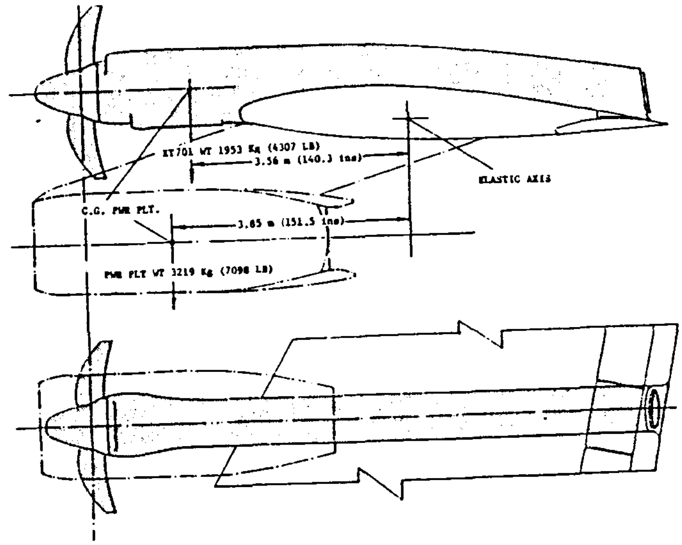


Figure D-4. C-141A Propulsion System Changes

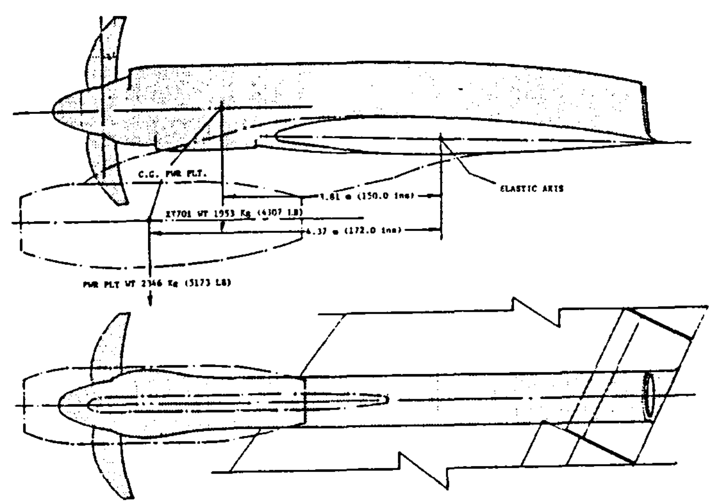


Figure D-5. KC-135A Propulsion System Changes

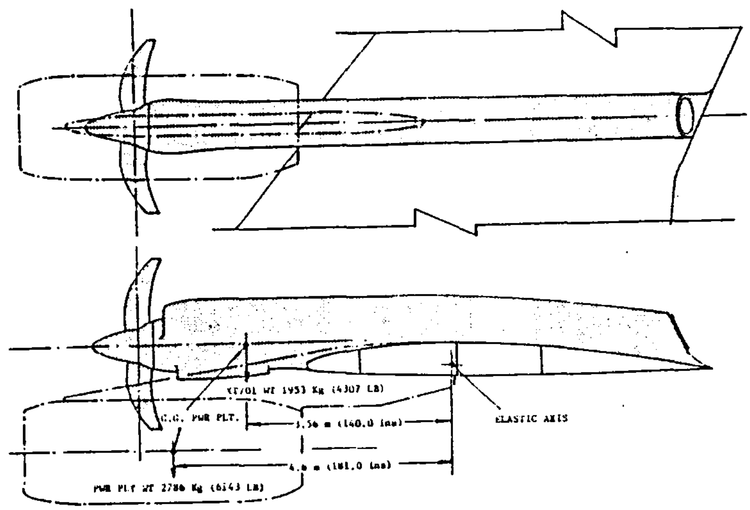


Figure D-6. Convair 990 Propulsion System Changes

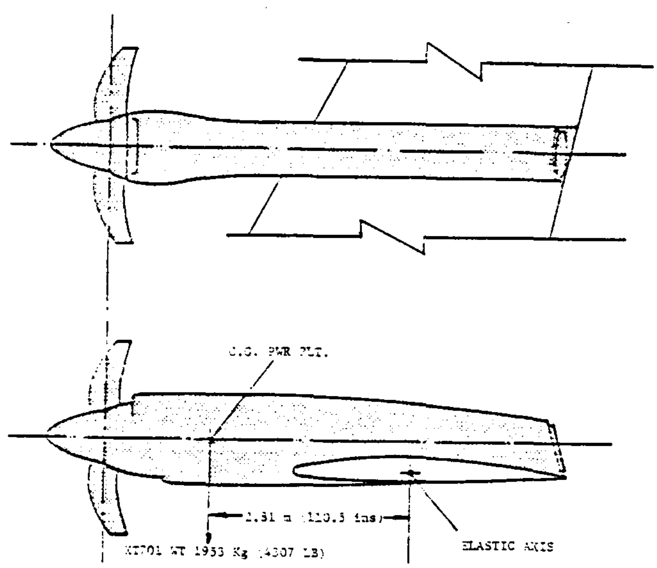


Figure D-7. GII Propulsion System Arrangement

Aircraft Balance - Modification of the aircraft to the testbed configuration must not cause undue restriction of the useable range of center-of-gravity location or cause the center-of-gravity to move beyond the existing boundaries of the aircraft center-of-gravity envelopes.

Center-of-gravity changes must not cause aircraft flight restriction within the existing structural envelope. Longitudinal imbalance may be corrected by the addition of ballast, which may include a fixed amount of fuel. Lateral imbalance may be corrected by fuel management procedures and by the addition of ballast where necessary.

TABLE D-IX. EC A-3 STRUCTURAL INTEGRITY EVALUATION

WEIGHTING FACTOR = 4

TESTBED A/C	FLUTTER	RATING VALUE	A/C BALANCE	RATING VALUE	CRI. SCORE AVG.	CRI-TERICN SCORE
C-141A	Low Risk	3	Within Current Envelope	3	3	12
KC-135A	Low Risk	3	Within Current Envelope	3	3	12
CONVAIR 990	Low Risk	3	Within Current Envelope	3	3	12
GULFSTREAM II	Moderate Risk	2	Lateral and Longitudinal Balance Affected. Ballast Required	2	2	8

C-141A Balance - The C-141A aircraft as a prop-fan testbed has no problems from the standpoint of aircraft balance. The substitution of the prop-fan propulsion system for the inboard TF33-P-7 engine and nacelle group results in negligible change in the balance characteristics of the aircraft.

There is no significant difference in the overwing versus the underwing installation of the prop-fan propulsion system from the standpoint of aircraft balance.

KC-135A Balance - The balance characteristics of the KC-135A aircraft as a prop-fan testbed vehicle are not significantly changed by the prop-fan installation, since the location of the horizontal axis of the testbed propulsion system is very close to that of the inboard nacelle. No detailed balance data are available for the KC-135A, but it is unlikely that the aircraft balance will be adversely affected by the substitution of the prop-fan propulsion system. There will be no significant difference in the longitudinal balance effects for the overwing or underwing prop-fan installations.

Convair 990 Balance - The Convair 990 aircraft as a prop-fan testbed has excellent balance characteristics. The prop-fan installation, which is lighter than the CJ805 engine installation it replaces, is mounted so that the center of gravity of the total installation is behind that of the CJ805 installation. The total change in aircraft longitudinal moment is negligible. There is no significant difference, from the standpoint of aircraft horizontal balance, between the overwing and the underwing installation.

Gulfstream II Balance - The Gulfstream II encounters some balance problems as a prop-fan testbed because of the small size and geometry of the aircraft so that the installation of the prop-fan has a greater influence than occurs on the other, larger candidate airplanes. Since the prop-fan propulsion system is an add-on rather than a substitution, the total zero fuel weight is increased rather than decreased, and since the prop-fan installation is mounted on the wing, the balance characteristics of the aircraft are affected both laterally and longitudinally. The lateral unbalance can be corrected by the addition of lead wingtip ballast on the side opposite the prop-fan engine installation. The Gulfstream II has the structural capability for wingtip tanks, and since the testbed aircraft will not require these tanks and the wingtip ballast required for lateral balance weighs less than the tank and fuel, no additional structural changes should be required.

The wing tip ballast will also be of benefit to the longitudinal balance, since the ballast center-of-gravity will be considerably aft of the wing mean aerodynamic quarter-chord-point. This will tend to offset the effects of locating the prop-fan installation forward of the MAC quarter chord. The aircraft, although limited in payload capability, will still be able to accommodate the testbed propulsion system as well as the required ballast, within the zero fuel weight envelopes of the basic aircraft. The balance characteristics will, therefore, be maintained.

The flutter appraisal and balance characteristics and evaluations are shown on Table D-IX.

AIRCRAFT OPERATIONAL CHARACTERISTICS REQUIREMENTS

The operational characteristics requirements for the aircraft must include compliance with design cruise conditions, a practical test mission duration, and acceptable aircraft stability and control and prop-fan installation effects.

Compliance With Design Requirements

The testbed aircraft must comply with the required design cruise conditions of a cruise Mach No. of 0.8 at 9144m (30,000 ft) altitude and above and the proximity of the testbed aircraft cruise conditions to the high Mach number buffet limits which may impose constraints on the useable range of weight and lift coefficients at a Mach number of 0.8 must be determined.

<u>EC B-1</u> Design Cruise Conditions Compliance
- Aircraft Speed/Altitude Capability
- High Speed Buffet Constraints

Each testbed aircraft must be capable of performing the test mission at a Mach No. of 0.8 at altitudes of 9144m (30,000 ft) and above. Furthermore, the cruise capability should not be impaired by high-speed buffet constraints over the range of weights for the test-mission profile. A reduced buffet limit with the prop-fan installed has been determined for each aircraft. The combined data for cruise performance and buffet boundaries are shown in Figures D-8, D-9, D-10, and D-11 for Lockheed C-141A, Boeing KC-135A, Convair 990 and Gulfstream II, respectively. These data show the speed/altitude capability at start and

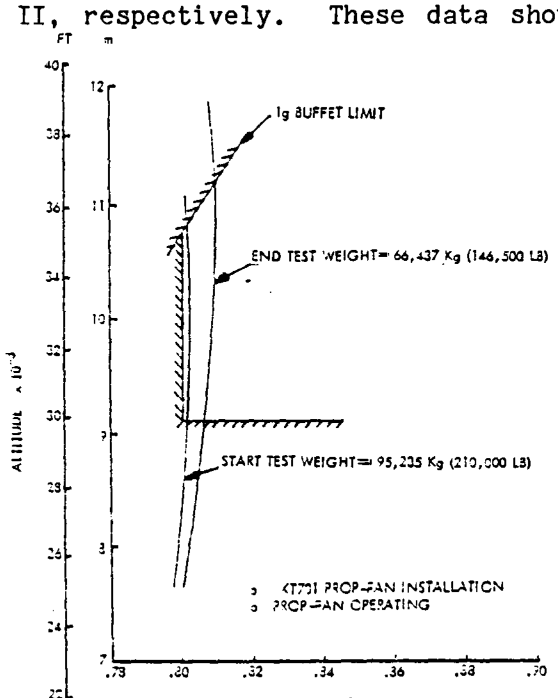


Figure D-8. C-141A Speed/Atltitude Performance and Buffet Boundaries

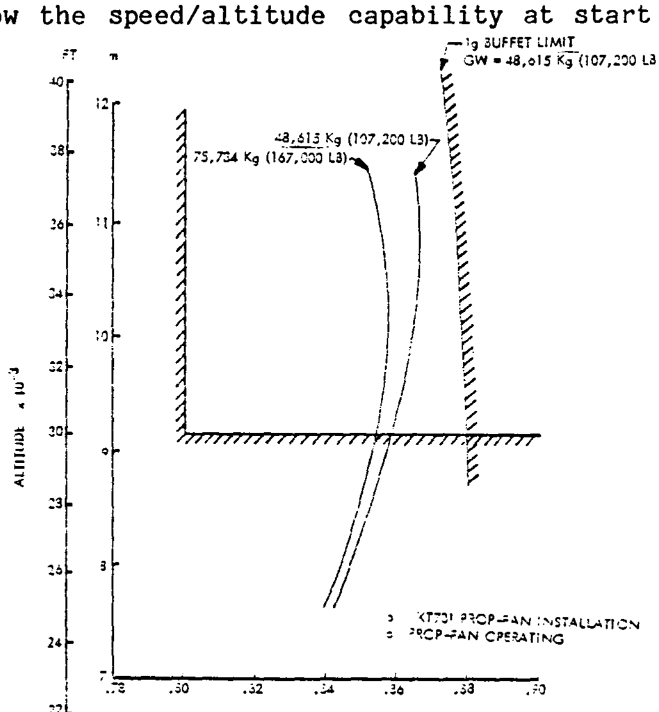


Figure D-9. KC-135A Speed/Altitude Performance and Buffet Boundaries

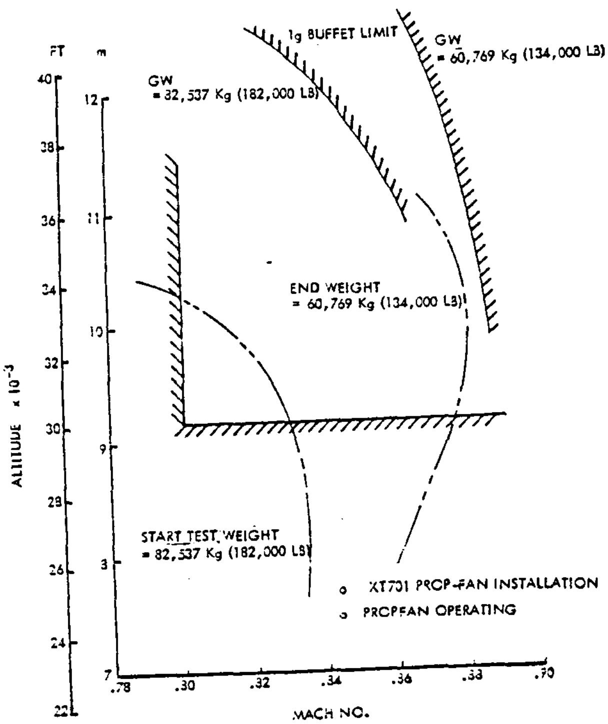


Figure D-10. Convair 990 Speed/Altitude Performance and Buffet Boundaries

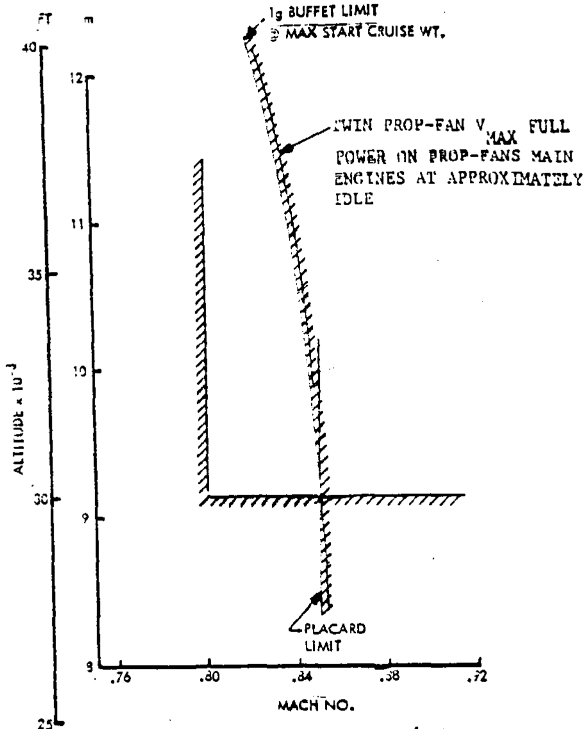


Figure D-11. GII Speed/Altitude Performance and Buffet Boundary

end cruise weights, together with the high-speed buffet limits and the boundaries imposed by the design requirements.

The rating considerations are shown in Table D-X.

Test Mission Duration

The test mission duration must be long enough to permit the acquisition of good test data economically.

EC B-2 Test Mission Duration
- Testbed aircraft will be ranked according to test mission duration.

The mission profile and the test duration for the Lockheed C-141A, Boeing KC-135A, Convair 990, and Gulfstream American Gulfstream II are shown in Figure D-12. All testbed configurations have acceptable test-mission duration.

TABLE D-X. EC B-1 DESIGN CRUISE CONDITIONS COMPLIANCE EVALUATION

REQUIREMENT - MACH 0.8 AT 9144 m (30,000 FT) AND ABOVE
WEIGHTING FACTOR = 4.0

TESTBED A/C	MIN WT-Kg/ALT-m (MIN WT-LB/ALT-FT)	MAX WT-Kg/ALT-m (MAX WT-LB/ALT-FT)	ΔM	RATING VALUE	CRI. SCORE (PF OFF)
C-141A	66,438/10,668 (146,500/35,000)	95,235/10,668 (210,000/35,000)	.006/.002	1	4
KC-135A	4,852/10,688 (107,200/35,000)	75,734/10,058 (167,000/33,000)	.048/.01	3	12
	** 4,852/11,277 (107,200/37,000)	** 75,734/10,058 (167,000/33,000)	.066/.057	** 3	
CONVAIR 990	60,769/9,753 (134,000/32,000)	82,537/9,144 (182,000/30,000)	.08/.03	3	12
GULFSTREAM II	19,500/9,144 (43,000/30,000)	26,303/9,144 (58,000/30,000)	.05/.04	3	12
	** 19,500/9,144 (43,000/30,000)	** 26,303/10,668 (58,000/35,000)	.05*	**3	

*PLACARD LIMITED
**PROP-FAN ON

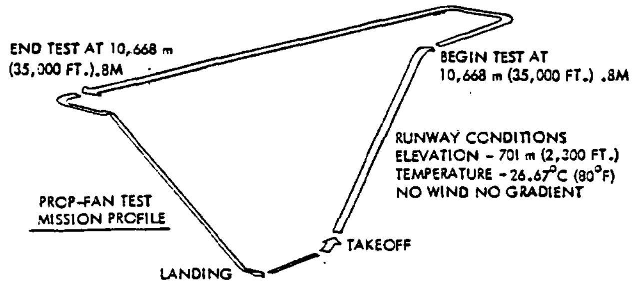
HIGH SPEED BUFFET CONSTRAINTS
WEIGHTING FACTOR = 4

TESTBED A/C	WT-Kg/ALT-m (WT-LB/ALT-FT)	$\Delta M_{TOT} / \Delta M_{MARGIN}$	RATING	CRITERION SCORE
C-141A	66,438/10,668 (146,500/35,000)	.01/0	1	4
	95,235/10,668 (210,000/35,000)	.002/0		
KC-135A	48,615 (107,200)	.08/.01	3	12
CONVAIR 990	60,769 (134,000)	.08/.005	3	12
GULFSTREAM II	26,303 (58,000)	.04/0	3*	12

*GULFSTREAM II IS BUFFET LIMITED WITH PROP-FAN ON.
ALL OTHER AIRCRAFT ARE THRUST LIMITED

EC B-1 DESIGN CRUISE COMPLIANCE OVERALL RATING

AIRCRAFT	CRUISE	BUFFET	OVERALL
C-141A	4	4	4
KC-135A	12	12	12
CONVAIR 990	12	12	12
GULFSTREAM II	12	12	12



WEIGHTING FACTOR = 3

TESTBED A/C	START CRUISE WT. END CRUISE WT. kg (LB)	MISSION DURATION HRS	RATING	CRITERION SCORE
LOCKHEED C-141	95,235 (210,000) 66,437 (146,500)	4.33	3	9
BOEING KC-135A	75,734 (167,000) 48,615 (107,200)	4.69	3	9
CONVAIR 990	82,537 (182,000) 60,769 (134,000)	4.2	3	9
GULFSTREAM II	26,303 (58,000) 19,484 (42,964)	3.38	3	9

Figure D-12. EC B-2 Test Mission Duration

Aircraft Stability and Control

The testbed aircraft must be capable of operating as a stable platform to permit the acquisition of good test data.

EC B-3 Aircraft Stability and Control

- The prop-fan has a destablizing effect on both longitudinal and lateral-directional control, and this effect is more pronounced on the smaller aircraft. Each testbed aircraft must exhibit good stability characteristics over the full range of prop-fan power settings and test conditions.
- Each testbed aircraft must be able to achieve trimmed flight attitudes without large incidence and yaw angles on the prop-fan and be able to trim at various angles of incidence when desired.

Estimates of the normal force caused by the installation of the prop-fan were used to determine the changes in stability derivatives C_{n_β} and C_{m_α}, the yawing and pitching moment derivatives, respectively. These data are shown in Figures D-13, D-14, D-15 and D-16 for the aircraft with and without the prop-fan installation.

C-141A - The aircraft total C_{n_β} and C_{m_α} were obtained from C-141A data and are shown in Figure D-13. These data indicate very little change in the levels of aircraft stability due to the prop-fan. The greatest reduction in the level of yawing moment derivative occurs at the low speed end of the Mach number band and amounts to a loss of 1.86 percent. The loss in pitch stability is almost constant over the entire speed range and amounts to 1 percent.

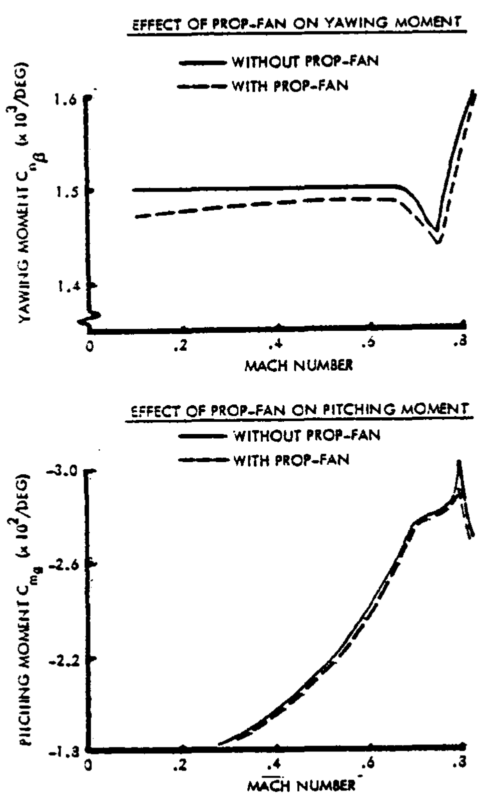


Figure D-13. C-141A Effect of Prop-Fan on Yawing and Pitching Moments

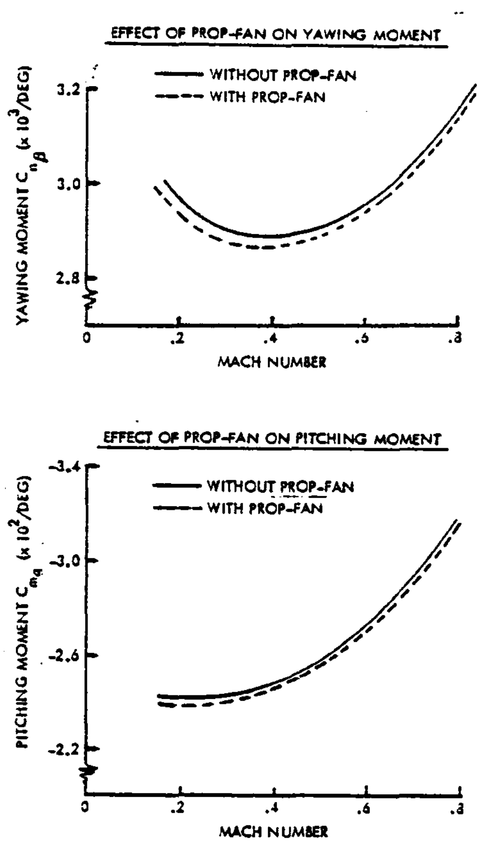


Figure D-14. KC-135A Effect of Prop-Fan on Yawing and Pitching Moments

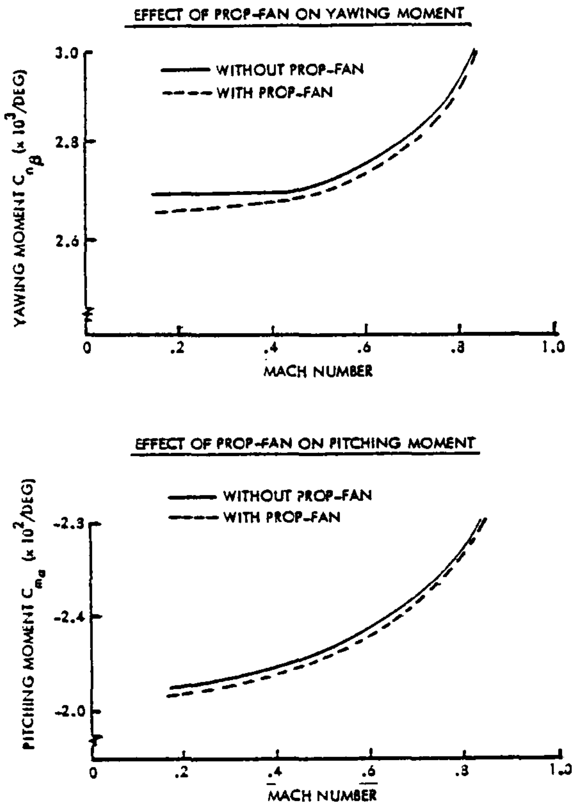


Figure D-15. Convair 990 Effect of Prop-Fan on Yawing and Pitching Moments

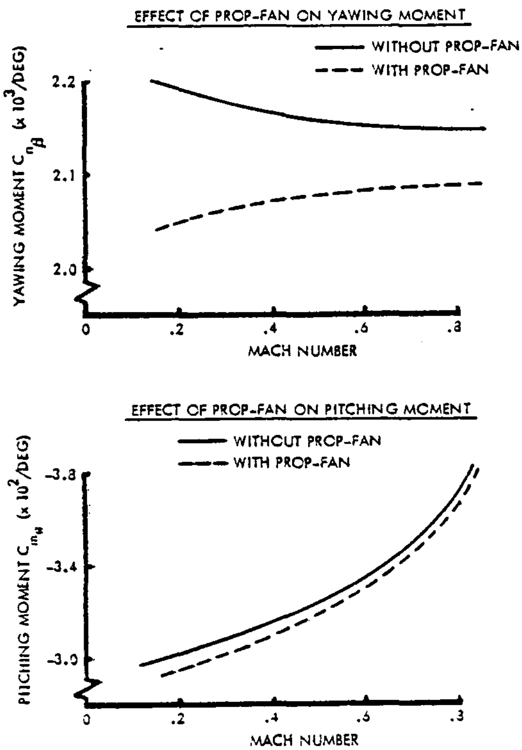


Figure D-16. GII Effect of Prop-Fan on Yawing and Pitching Moments

KC-135A - The derivatives for the KC-135A were generated using DATCOM to determine the effect of the prop-fan installation on stability. The data, shown in Figure D-14 indicate a loss of C_{n_β} of 1 percent at low Mach numbers and less than 1 percent at high speeds. Similarly, the loss in C_{m_α} is 1.6 percent at low Mach numbers and 1 percent at high Mach numbers. No significant loss in stability, therefore, occurs with the installation of the prop-fan.

Convair 990 - The stability derivative data for the Convair 990 shown in Figure D-15 were also derived by means of DATCOM. The greatest loss in the yawing moment derivative occurs at low Mach numbers and amounts to 1 percent with the prop-fan installed. At high Mach numbers, the loss in C_{n_β} is less than 1 percent. The losses in C_{m_α} amount to 1.4 percent at low Mach numbers, reducing to 0.7 percent at high Mach numbers.

Gulfstream II - The derivatives for the Gulfstream II, also obtained by using DATCOM to determine the effect on stability with and without the prop-fan, are shown in Figure D-16. The data indicate that the prop-fan has a greater effect on the stability of the smaller aircraft than on the much larger candidates. The greatest change occurs to C_{n_β} at low speeds for which the prop-fan changes the level by almost 8 percent. The decrease in stability, although not apparently dangerous, is significant in that it does highlight areas having potential for problems such as engine-out characteristics and high-altitude dutch roll/dynamic stability.

The changes in the stability derivatives are shown in Figures D-17, D-18, D-19, and D-20 for the C-141A, KC-135A, Convair 990, and Gulfstream II, respectively. All the candidate testbed aircraft exhibit similar characteristics over the range of Mach numbers considered.

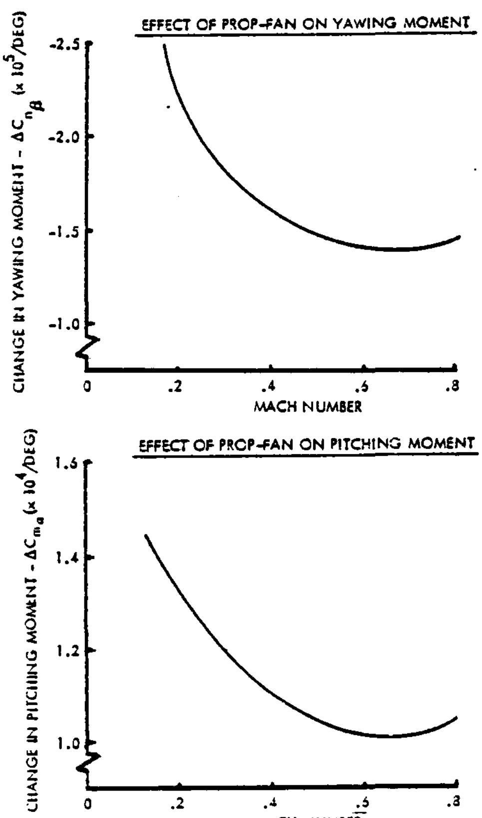


Figure D-17. C-141A
Change in Yawing and Pitching
Moments Due to Prop-Fan

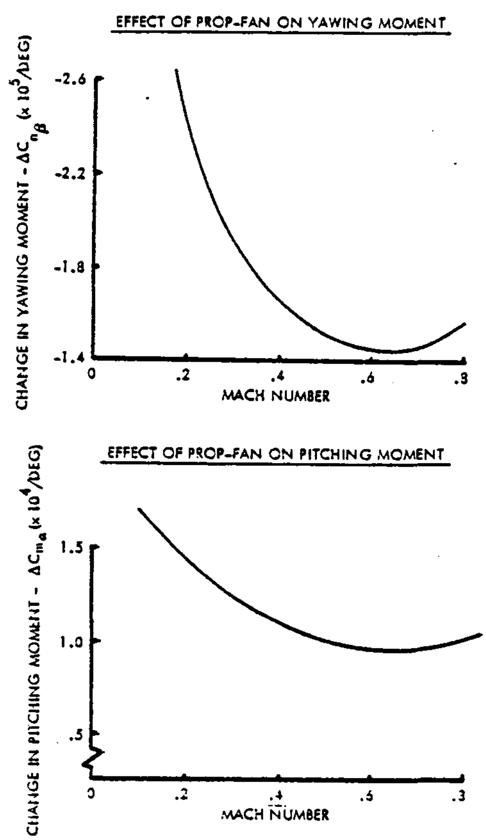


Figure D-18. KC-135A
Change in Yawing and Pitching
Moments Due to Prop-Fan

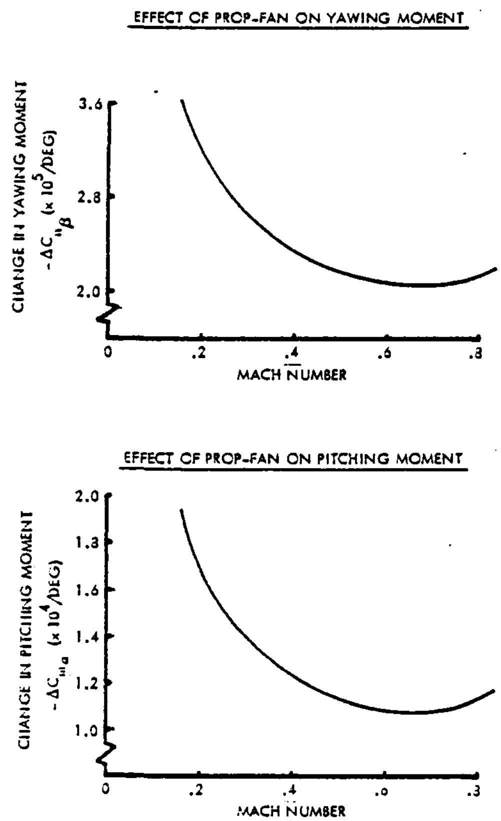


Figure D-19. Convair 990
Change in Yawing and Pitching
Moments Due to Prop-Fan

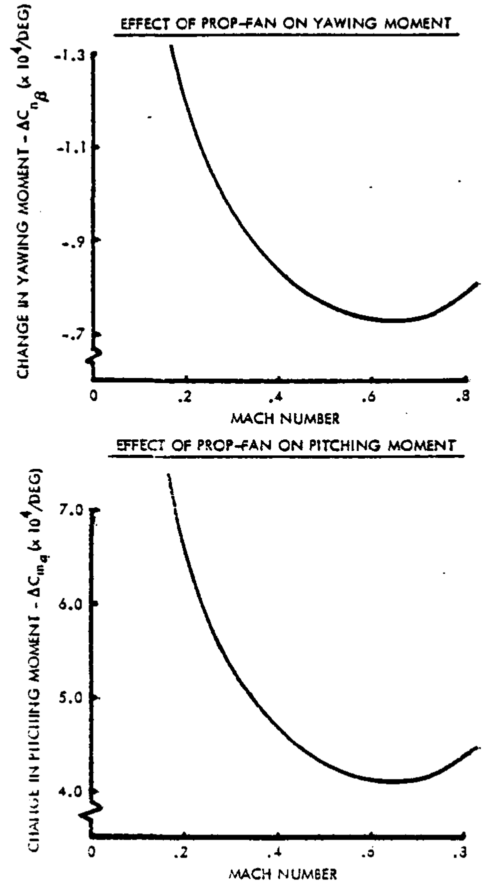


Figure D-20. GII
Change in Yawing and Pitching
Moments Due to Prop-Fan

In general, no significant losses in stability and control have occurred as the result of the prop-fan installation.

The evaluation of the candidate testbed aircraft stability and control is shown on Table D-XI.

TABLE D-XI. EC B-3 AIRCRAFT STABILITY AND CONTROL EVALUATION

WEIGHTING FACTOR = 4

TESTBED A/C	% CHANGE C_{n_β}	% CHANGE C_{m_α}	PROBLEM AREAS	RATING VALUE	CRITERION SCORE
C-141A	≏ -2	<-1	NONE	3	12
KC-135A	≏ -1	<-2	NONE	3	12
CONVAIR 990	≏ -1	<-2	NONE	3	12
GULFSTREAM II	-3 TO -5	-1.3 TO -7.8	DUTCH ROLL /DYNAMIC STABILITY HIGH ALT.	2	8

EC B-4 Prop-Fan Installation Effects

- The installation of the prop-fan propulsion system will affect the high-lift devices and flight controls systems to the extent that the operational characteristics of the testbed aircraft could be changed. The degree of interference caused by the prop-fan will be assessed and rated based on the magnitude of the problems.

The installation effects of the various propulsion systems are due to the interference of the prop-fan installation on essential devices such as high lift and flight control systems.

The principal effects on the C-141A, KC-135A, Convair 990 and Gulfstream II are shown on Figures D-21, D-22, D-23 and D-24, respectively, for the overwing installations.

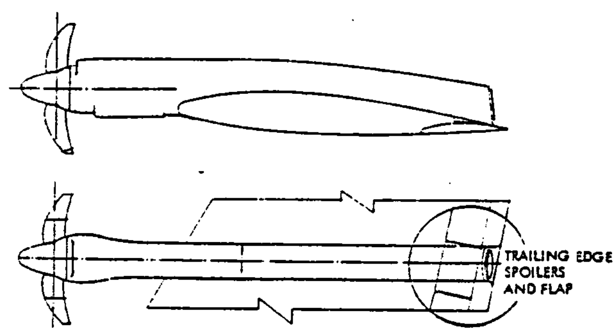


Figure D-21. C-141A
Prop-Fan Installation Interference

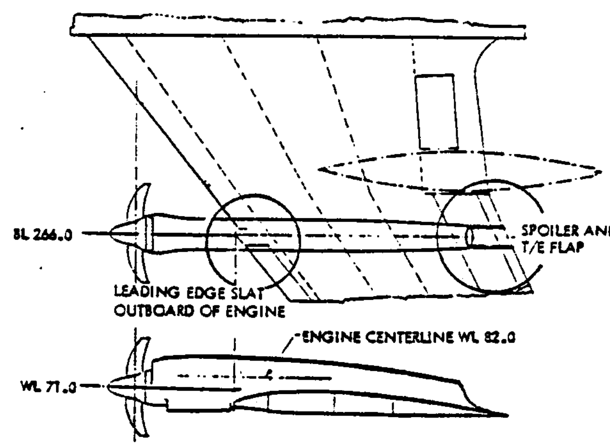


Figure D-23. Convair 990
Prop-Fan Installation Interference

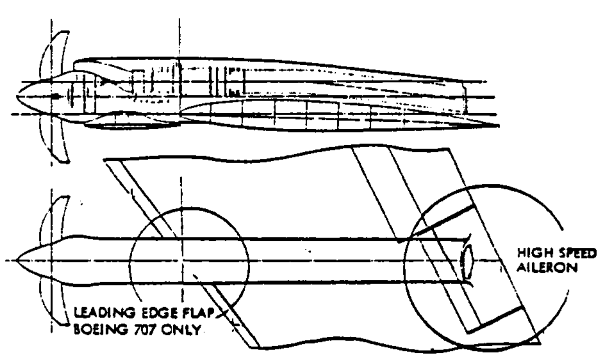


Figure D-22. KC-135A
Prop-Fan Installation Interference

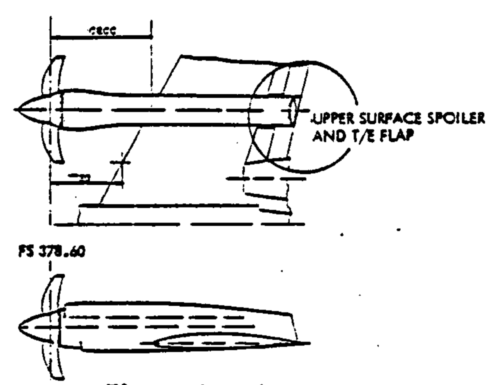


Figure D-24. GII
Installation Interference

In the case of the underwing installations, interference occurs only at the leading edge.

The ratings of the interference effects are based upon the magnitude of the problems caused, such as loss of maximum lift coefficient at takeoff and loss of control power for flight, and on the difficulty of rectifying such deficiencies where such appear mandatory. The ratings are shown in Table D-XII.

TABLE D-XII. EC B-4 INSTALLATION EFFECTS

WEIGHTING FACTOR = 4

TESTBED A/C		INTERFERENCE LEADING EDGE DEVICE	TRAILING EDGE DEVICE	FLIGHT CONTROL	RATING VALUE	CRITERION SCORE
C-141A	UW	NONE	NONE	NONE	3	12
	OW	NONE	FLAP	SPOILER	1.5	6
KC-135A	UW	SLAT	NONE	NONE	2.0	
	OW	SLAT	NONE	HIGH SPEED AILERON	1.0	4
CONVAIR 990	UW	SLAT OUTBD	NONE	NONE	2.0	8
	CW	SLAT OUTBD	FLAP	SPOILER	1.0	4
GULFSTREAM II	OW	NONE	FLAP	SPOILER	1.0	4

TESTBED PROGRAM OBJECTIVES ACHIEVEMENT

The Testbed Program Objectives, established in Task I, form the basis for the evaluation criteria ratings that measure the suitability of each candidate as a testbed aircraft. The Task I order of priority for these objectives is followed in the listing of the Evaluation Criteria.

Realistic Environment for Dynamic Loads Validation

An important objective of the testbed program is the determination of the prop-fan cyclical loading to validate the structural integrity of the prop-fan structure.

EC C-1 Dynamic Loads Validiation Environment

- The assessment of each testbed installation will consider the degree to which each provides a representative environment for the validation of prop-fan structural characteristics and induced effects upon the aircraft structure. This will include consideration of the engine nacelle overhang, toe-in and the proximity of the wing leading edge, fuselage and other aircraft components.

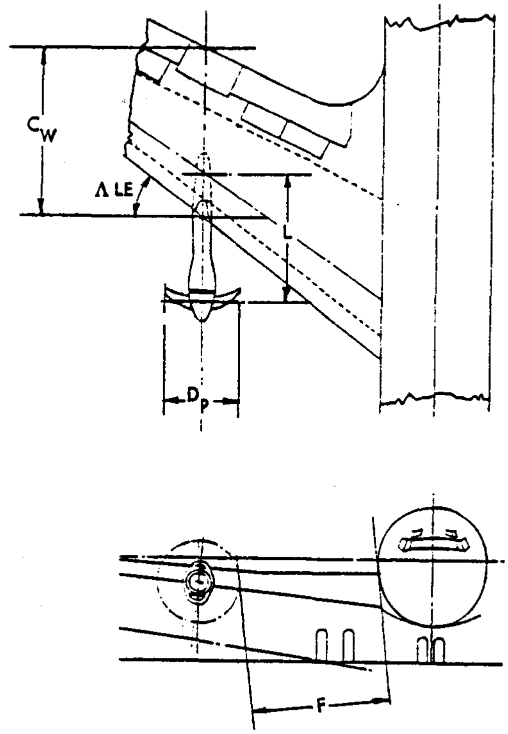
The prop-fan blade dynamic response is a function of the blade aerodynamic and structural dynamic characteristics and of the aerodynamic flow field in which the prop-fan operates. One drive system was selected for the four candidate testbed aircraft, the 2.89m (9.5 ft) diameter prop-fan/XT701/T56-A-14 combination, thus eliminating prop-fan blade aerodynamic and structural characteristics as design variables.

Prop-fan flow field variations, which induce blade dynamic loads, are caused primarily by configuration geometry, i.e., proximity of the wing and, to a lesser extent, the fuselage. Typically, a commercial passenger aircraft configuration would be a low-wing arrangement having approximately 0.523 rad (30 deg) of leading-edge sweep and two or four prop-fan propulsion units mounted over the wing to provide sufficient ground clearance for the large-diameter prop-fans.

On this basis, the testbed aircraft configuration for proper representation of the prop-fan environment should be a low wing. The prop-fan located for adequate demonstration of blade characteristics should be one prop-fan diameter from the wing aerodynamic center (assumed to be at the wing quarter-chord for this study). For proper representation of the equivalent full-power prop-fan propulsion installation, the ratio of wing chord, C_w, to prop-fan diameter, D_p, should be in the region of 1.0 for inboard engines and 1.5 for outboard engines. The prop-fan tip/fuselage clearance, F, should be a minimum of $0.2D_p$ for acceptable excitation and $0.8D_p$ for acceptable acoustic environment characteristics. The geometric parameters are shown in Figure D-25, and the rating values, showing the degree to which each candidate simulates the dynamic loads environment, are given in Table D-XIII.

Acoustic Data Acquisition

The ability of each testbed aircraft as an instrument for obtaining near- and far-field noise data will be evaluated.



Cw - CHORD LENGTH AT NACELLE CENTERLINE

Λ_{LE} - LEADING EDGE SWEEP

D_p - PROP-FAN DIAMETER

Figure D-25.

Geometric Parameters for Dynamic Loads Validation

TABLE D-XIII.

EC C-1 DYNAMIC LOADS ENVIRONMENT VALIDATION EVALUATION

WEIGHTING FACTOR = 4

	PARAMETER	WING LOCATION	Λ_{LE}^{0} RAD(DEG)	C_W/D_p	FUS/TIP CLEARANCE F	ENGINE INSTALLATION	RATING	CRITERION
	DESIRED VALUE	LOW	.523 (30°)	1.0 INBD 1.5 OUTBD	0.2 D_p STRUCT 0.8 D_p AC	OVERWING	VALUE	SCORE
TESTBED A/C	C-141A	HIGH	.488 (28°)	2.54	1.35 D_p	OVER/UNDER	1.5	6
TESTBED A/C	KC135A (707-120)	LOW	.663 (38°)	2.15	1.66 D_p	OVER	2	8
TESTBED A/C	CONVAIR 990	LOW	.698 (40°)	2.34	1.21 D_p	OVER	2	8
TESTBED A/C	GULFSTREAM II	LOW	.488 (28°)	1.36	0.44 D_p	OVER	3	12

C_w = WING CHORD

D_p = PROP-FAN DIAMETER

EC C-2 Near-Field Noise Data Acquisition

- The effects of configuration geometry on near-field noise include prop-fan to fuselage clearance, propfan centerline to fuselage centerline relation, prop-fan/wing leading edge clearance, prop-fan/fuselage diameter ratio, prop-fan shielding by existing components and proximity of other powerplants. Other considerations include flap and control surface immersion in prop-fan wash and the effect of testbed attitude characteristics on near-field noise measurement.

Since one of the major objectives of the testbed aircraft is to investigate near-field acoustic characteristics, it is important that the prop-fan be properly located so that clear noise signals can be obtained inside and outside of the fuselage. In addition, the fuselage structure and interior trim and furnishings should be representative of the commercial aircraft environment. Furthermore, the fuselage structure in the region of the prop-fan plane should be capable of modification to test various noise-attenuation concepts.

This evaluation criterion includes all these considerations as shown in Table D-XIV. The interiors of fuselage for the C-141A and KC-135A are configured for military use and are, therefore, not representative of commercial configurations. Some modification of the basic aircraft would be necessary in the prop-fan plane region to simulate a passenger aircraft configuration. In the case of the KC-135A, this deficiency could be overcome by using the 707-120 series aircraft.

TABLE D-XIV. EC C-2 NEAR-FIELD NOISE DATA ACQUISITION EVALUATION

WEIGHTING FACTOR = 4

TESTBED A/C		FUSELAGE WINDOWS	INSULATION	INTERIOR TRIM	AC & PRESS. DUCTING	COMMERCIAL REPRESENT	ACOUSTIC MODS	RATING VALUE	CRITERION SCORE
C-141A	UW OW	NONE	INTERNAL BLANKETS	NONE MILITARY INTERIOR	√	NONE REP	√	1 2	4 8
KC135A	UW	NONE	INTERNAL BLANKETS	NONE MILIT. INT.	√	NONE REP	√	2	8
(707-120)	OW	(√)	(√)	(√)	(√)	(REP)	(√)	3	12
CONVAIR 990	UW OW	√	√	PASSENGER CONFIG	√	REP	√	2 3	8 12
GULFSTREAM II	OW	√	√	PASSENGER CONFIG	√	REP	√	2	8

EC C-3 Far-field Noise Data Acquisition

- The capability of the testbed aircraft to provide prop-fan noise detectability above the levels of the basic aircraft and engines will be evaluated by comparing the noise signature of the basic aircraft and engines with the predicted noise of the testbed prop-fan over a range of frequencies wide enough to provide useful data.

The acquisition of a good, clean, prop-fan noise signal depends on the ability to reduce background noise, generated by other noise sources, on the candidate testbed aircraft. This can be accomplished by:

- o Operating the prop-fan at the highest power setting (loudest)
- o Providing noise suppression for the prop-fan driver
- o Operating the primary engines at the lowest possible power setting (flight idle)
- o Operating the airframe in a "clean" configuration

It is considered that prop-fan noise of good quality can be obtained by the above means, which could be used to validate prop-fan noise prediction methodologies.

The predicted noise characteristics for the prop-fan and driver are shown in Figure D-26. These data clearly indicate the need for suppressing the XT701 driver noise to allow the prop-fan signal to dominate the noise spectrum. The aircraft component noise spectra for the Lockheed C-141A, Boeing KC-135A, Convair 990, and the GII are shown in Figures D-27, D-28, D-29 and D-30.

The ranking of the candidate testbed aircraft for far-field noise prediction methodology validation is shown in Table D-XV. The ranking is based on how well the prop-fan signal, S, is separated from the background noise, N, in one-third octave band level decibels. The S/N factor is presented for the prop-fan fundamental tone and high frequency noise e.g. >1,000 Hz.

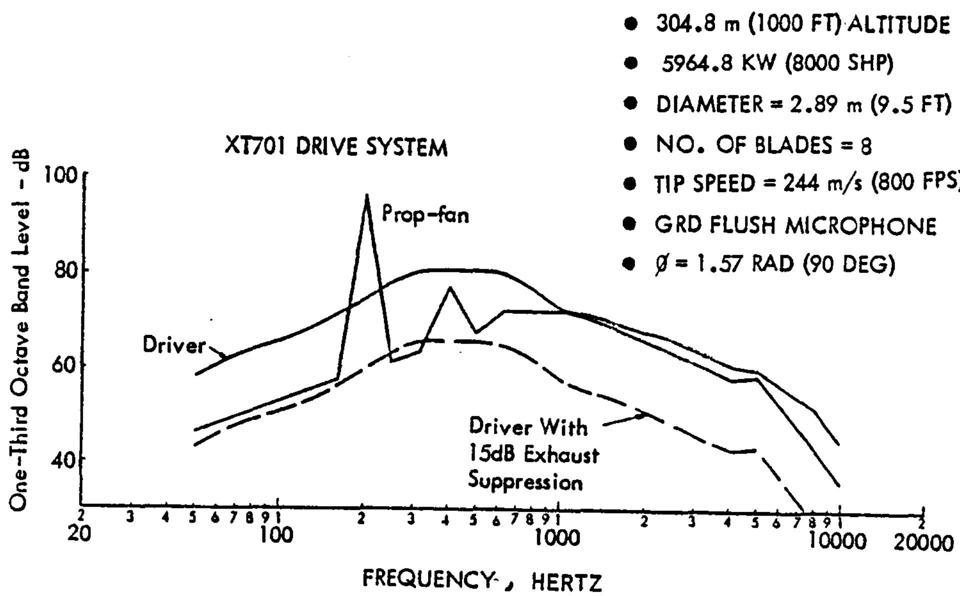


Figure D-26. Prop-Fan Driver Suppression

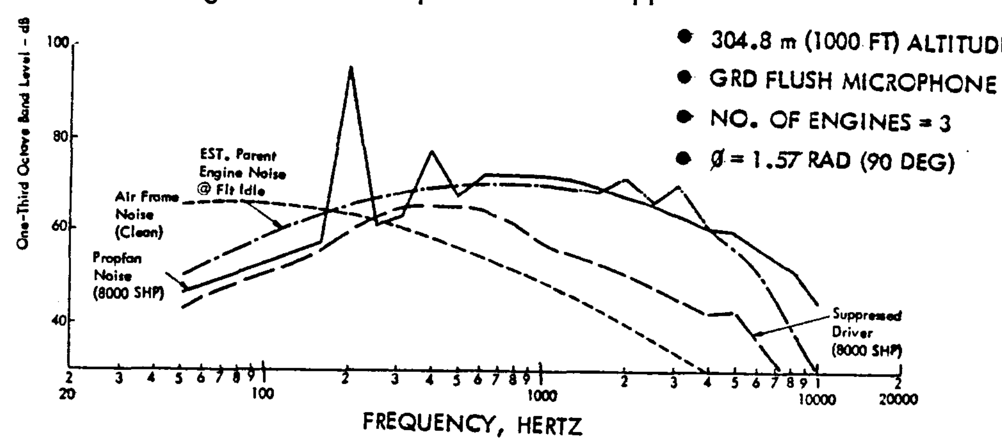


Figure D-27. C-141A Component Noise Levels

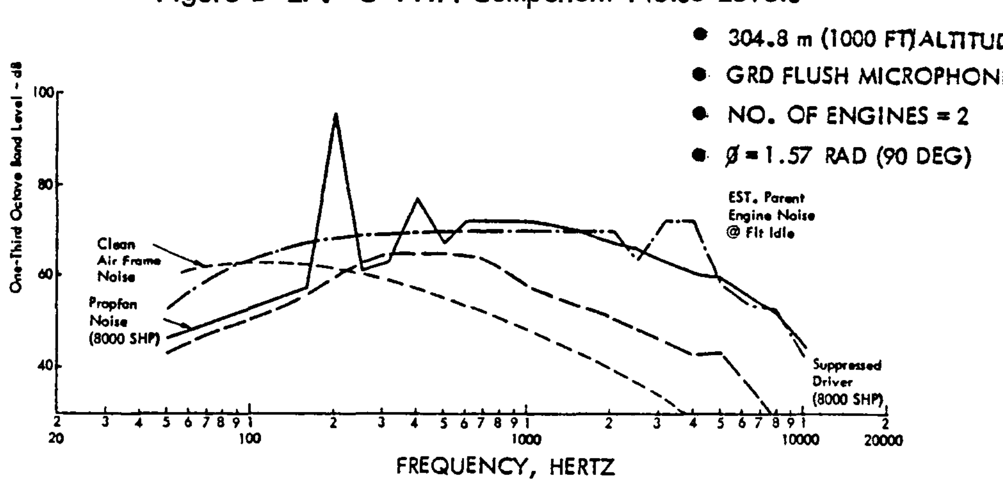


Figure D-28. KC-135A Component Noise Levels

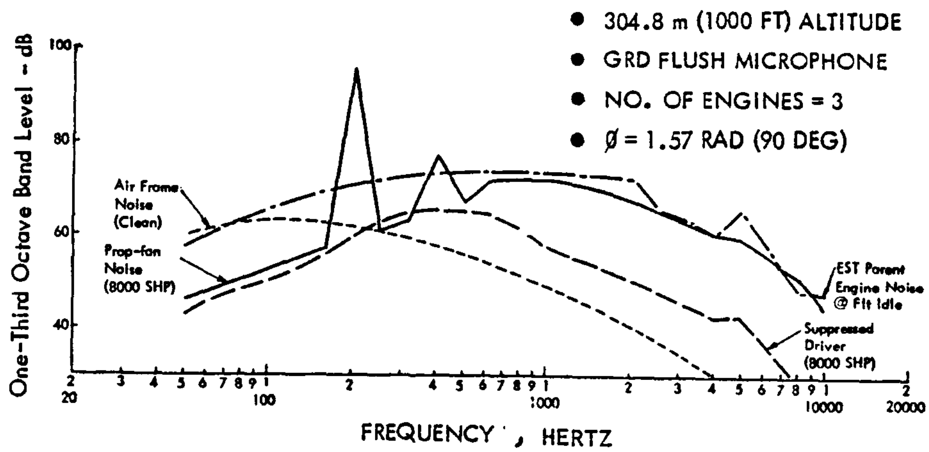


Figure D-29. Convair 990 Component Noise Levels

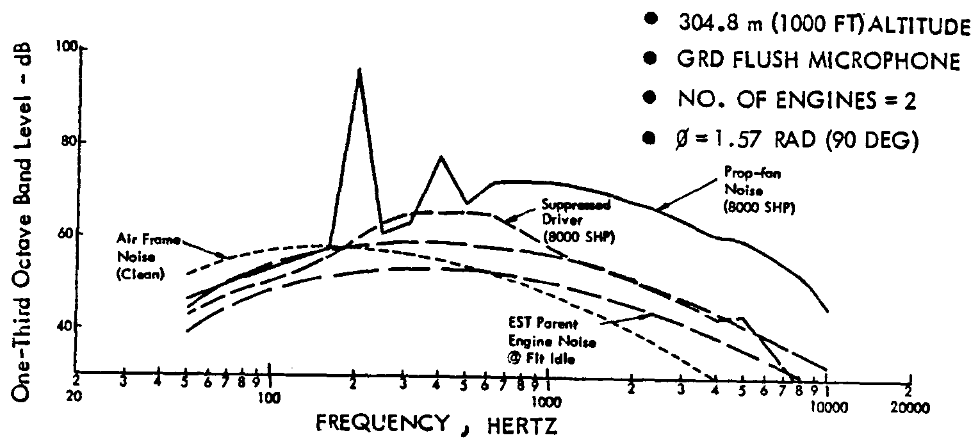


Figure D-30. GII Component Noise Levels

TABLE D-XV. EC C-3 FAR-FIELD NOISE DATA ACQUISITION EVALUATION

WEIGHT FACTOR - 2

TESTBED A/C	FUNDAMENTAL S/N dB	HIGH FREQUENCY S/N dB	RATING VALUE	CRITERION SCORE:
C-141A	25	0	1	2
KC135A	25	0	1	2
CONVAIR 990	25	0	1	2
GULFSTREAM II	30	10-15	3	6

S/N Signal to Noise Ratio

Prop-Fan Scale

<u>EC C-4</u> Prop-Fan Scale Effects

- The diameter of the prop-fan is important in confirming manufacturing and fabrication feasibility and for scaling laws validation.
- Hamilton Standard recommends that the minimum diameter for the prop-fan, to ensure a representative structural configuration and characteristics, should be in the range of 2.44 to 3.05m (8 to 10 ft). The XT701 propulsion system is capable of driving a prop-fan having a diameter of 2.89m (9.5 ft) at current power levels and disk loadings.

Prop-fan scale should be consistent with the Hamilton Standard recommendations for demonstrating the manufacturing and fabrication feasibility of the prop-fan. The recommended minimum value is 2.44m (8 ft). The XT701 drive system is capable of powering a prop-fan diameter of 2.89m (9.5 ft) and satisfies this requirement. The rating values and criterion score are shown in Table D-XVI.

TABLE D-XVI. EC C-4 PROP-FAN SCALE EVALUATION

WEIGHTING FACTOR - 4

TESTBED A/C		PROPFAN DIAM-FT	SATISFY REQMT	RATING VALUE	CRITERION SCORE
C-141A	UW OW	9.5	YES	3	12
KC135A	UW OW	9.5	YES	3	12
CONVAIR 990	UW OW	9.5	YES	3	12
GULFSTREAM II	OW	9.5	YES	3	12

Installed Propulsive Efficiency and Interaction Effects

An objective of the testbed program is to demonstrate that the prop-fan net efficiency of 80 percent can be achieved at a cruise Mach number of 0.8. The evaluation will consider the degree to which this may be accomplished on the various configurations.

EC C-5 Installed Propulsive Efficiency Validation

- Each testbed configuration will be evaluated for suitability to obtain the data necessary for propulsive efficiency validation. This will include consideration of the test equipment required and the accuracy of the data obtained.
- The aerodynamic/propulsion system integration will be concerned with the need to maintain the aerodynamic efficiency of a modern, high speed airfoil immersed in the slipstream of a prop-fan. Also of concern, will be the need to recover some of the propulsive thrust from the slipstream swirl.

Two methods of establishing installed propulsive efficiency are by:

1. Evaluation of flight test performance data
2. Conducting wake surveys by means of pressure rakes

The first method is indirect. Unless the candidate testbed aircraft can fly on prop-fan power alone at the cruise point, at which measurement of the propulsive efficiency is to be performed, the speed-altitude conditions must be attained through a combination of prop-fan and primary engine thrust. The thrust of the primary engines must, therefore, be separated from the total thrust to obtain the performance of the prop-fan. This procedure necessitates accurate determination of the thrust of all of the propulsive units contributing to the total thrust and may suffer somewhat in accuracy.

The second method, which is also the preferred method, determines propulsive efficiency by conducting wake surveys with pressure rakes located behind the prop-fan and behind the wing to measure the average momentum of the prop-fan wash and wing wake. Instrumentation of the wings of the candidate testbed aircraft can be accomplished with varying degrees of difficulty. The C-141A and KC-135A do not present problems, the Convair 990 requires removal of the anti-shock bodies behind the prop-fan unit. Finally, the GII instrumentation installation requires care to minimize flow distortion to the aft mounted primary engines. Although the candidate testbed aircraft differ, the ability to obtain accurate test data by this method is not significantly affected by the variations. The configurations are ranked equally for the evaluation, but no account of this feature will appear in the evaluation score.

It is important that the configurations on which installed propulsive efficiency is measured represent realistic geometric conditions, to remove uncertainties due to the size or scale of the prop-fan propulsion unit. Representative values of geometric relationships, such as prop-fan diameter/fuselage diameter, prop-fan diameter/wing chord, effective disc area, and slipstream affected area/total wing area, are important if a realistic environment for propulsive efficiency validation is to be provided. Wind tunnel tests have shown that the propulsive efficiency of the uninstalled prop-fan may be increased as much as 5 to 6 percent if the energy locked in the swirling component of the propwash can be extracted. It is possible that, by properly contouring the wing and nacelle in the propwash, some of this thrust loss may be recovered. Therefore, if the prop-fan size relative to the wing size is not realistic, the possibility of verifying thrust recovery techniques diminishes. Realism in the proportionate scale of the prop-fan and aircraft is thus of primary importance.

It has been analytically determined, Reference 3, that optimizing aircraft, on the basis of takeoff noise footprint, results in a ratio of prop-fan diameter/fuselage diameter of 1.5. It has, therefore, been concluded that the ratio of D_p/D_f for the testbed aircraft should be as close to 1.5 as practicable to yield representative data.

The data from Reference 3 also showed the ratio of prop-fan diameter/wing chord, D_p/C_w, to be in the range of 0.95 to 1.5, depending upon the location and number of propulsion units. Furthermore, the scale effect of slipstream-washed wing area/total wing area and power loading ratio will be realistic if the ratio for $S_{w_{slip}}/S_{w_{total}}$ is 0.17, and the power loading ratio is 0.4.

The effective disc area, which is a measure of the nacelle blockage, is based on a ratio of $D_n/D_p = 0.35$, where D_n is the equivalent diameter of the nacelle. In the case of the XT701 nacelle, this value is 0.39, which although slightly larger than optimum, can be reduced by further refinement of the nacelle.

The values of the various ratios and the evaluation to determine the suitability of each candidate testbed aircraft as a vehicle for installed propulsive efficiency validation are shown in Table D-XVII.

TABLE D-XVII. EC C-5 INSTALLED PROPULSIVE EFFICIENCY VALIDATION EVALUATION

WEIGHTING FACTOR = 2

	ITEM	D_p/D_{Fuse}	C_w/D_p	D_n/D_p	D_{Fuse}/C_w	DISC LOADING/ WING LOADING	Sw_{Slip}/Sw	RATING VALUE	CRITERION SCORE
	DESIRED VALUE	1.0 to 1.5	1 TO 1.5	0.35	1.0	0.4	0.17		
TESTBED A/C	C-141A UW OW	0.67	2.54	0.39	0.59	0.423	0.082	1	2
TESTBED A/C	KC-135A UW OW	0.80	2.15	0.39	0.59	0.432	0.0896	1	2
TESTBED A/C	CONVAIR 990 UW OW	0.80	2.34	0.39	0.54	0.370	0.1116	2	4
TESTBED A/C	GULF-STREAM II OW	1.21	1.36	0.39	0.60	0.493	0.1553	3	6

D_p = PROP-FAN DIAM

D_{Fuse} = FUSELAGE DIAM

D_n = NACELLE EQUIV. DIAM

$S_{w_{Slip}}$ = SLIPSTREAM WASHED AREA

S_w = WING TOTAL AREA

C_w = WING CHORD LENGTH

EC C-6 Interaction Effects Validation

- The effects of slipstream supervelocity and swirl can be reduced by local tailoring and contouring of the wing. Each configuration will be evaluated by considering testbed installations with regard to their relative sizing of the prop-fan, nacelle, and wing reflecting the ability of each to render representative aerodynamic data.

EC C-6 Interaction Effects Validation - The ability of the candidate testbed aircraft to yield valuable data on interaction effects is strongly reflected by the evaluation for propulsive efficiency validation. In the case of interaction effects, the principal considerations for a realistic environment were dependent upon geometric relationships. In the case of installed propulsive efficiency, however, the important considerations for a realistic environment depend upon the position of the nacelle relative to the wing and on the wing section sensitivity to swirl and supervelocity effects. For the first of these considerations - the position of the nacelle on the wing - only two configurations are of interest: (a) the nacelle placed on top of the wing, and (b) the nacelle placed under the wing. In the general application, both locations are likely to be encountered and will depend on aircraft type.

It has been speculated that the underwing location, which is typical for high-wing cargo aircraft configurations, may have less adverse effect on wing flow. This, however, has yet to be proved. Commercial passenger aircraft are generally low-wing configurations, which for prop-fan dedicated aircraft, would require an overwing nacelle installation. Because of the lack of data, comparison of the two nacelle locations cannot be featured in the evaluation from the point-of-view of establishing interaction effects.

Proper evaluation of the interaction effects requires that the testbed aircraft wings should be representative of the wings of future prop-fan-powered aircraft. This means that the wings should have an advanced, transonic airfoil section with the thickness and sweep associated with cruise at the appropriate Mach number. Because all of the candidate testbed aircraft are configured from existing aircraft of varying age, this criteria cannot be met so that some compromise is necessary. This suggests that the nacelle/wing relationship be such that some local reshaping to approximate a realistic aerodynamic environment would be desirable. The geometric characteristics for propulsive efficiency validation apply to the evaluation of the interaction effects. However, two additional geometric parameters are considered in the interaction effects validation: nacelle overhang and leading-edge sweep. The position of the nacelle on each of the testbed aircraft configurations is arranged so that the prop-fan plane is one prop-fan diameter from the wing leading edge at the center line of the nacelle. Although this arrangement produces low excitation factors for the prop-fan, sufficient clearance is provided to enable filleting and contouring of the nacelle/leading edge to be performed in order to investigate interaction effects.

Where propulsion system substitution has been performed, the amount of modification permissible is somewhat limited. For the case of propulsion system addition, where more extensive modification to the wing is required, the opportunity to extensively contour the wing/nacelle intersection is much greater. This evaluation is, therefore, based on the degree to which a realistic environment for interaction effects can be simulated on each testbed aircraft.

The data for the evaluation are shown in Table D-XVIII.

TABLE D-XVIII. EC C-6 INTERACTION EFFECTS VALIDATION EVALUATION

WEIGHTING FACTOR = 2

TESTBED A/C	A/C TYPE SIMULATION	BASIC A/C TYPE	NACELLE OVERHANG	LE SWEEP Λ_{LE} RAD (DEG)	IP EFF EXC. FACTOR	WING CONTOURING	RATING VALUE	CRITERION SCORE
C-141A UW OW	MIL/CARGO COMM/PASS	MILITARY	1.0 D_p	.489 (28°)	– –	LIMITED FWD OF F/S	1	2
KC-135A UW OW	COMM/PASS	MILITARY	1.0 D_p	.663 (38°)	CLIMB 2.81 CRUISE 1.89	LIMITED FWD OF F/S	2	4
CONVAIR 990 UW OW	COMM/PASS	COMM	1.0 D_p	.680 (39°)	–	LIMITED FWD OF F/S	2	4
GULF STREAM II OW	COMM/PASS	COMM	1.0 D_p	.506 (29°)	CLIMB 2.75 CRUISE 2.47	EXTENSIVE IN REBUILT WING	3	6

AIRCRAFT, HARDWARE AND DATA AVAILABILITY AND MODIFICATION POTENTIAL

This category of evaluation criteria relates to the ability to assemble the components for the testbed aircraft in the early to mid-1980 time frame.

Aircraft Survey

A survey of aircraft in the NASA inventory was made in conjunction with the Aircraft Office at NASA Headquarters, Washington, D.C. Out of a total of 110 aircraft, either belonging to, or on loan to the NASA, only 7 were found to be compatible with the design requirements for the Advanced Turboprop Testbed Aircraft. The 7 aircraft are:

- Lockheed C-141A
- Lockheed -6 JetStar
- Boeing KC-135A
- Boeing 737
- Boeing B-52B
- Convair 990
- Gulfstream American Corporation Gulfstream II

These aircraft were subjected to an initial screening to establish testbed suitability. As the result of this screening, the Lockheed -6 JetStar and the Boeing 737 were eliminated. The data relating to the survey are shown in Table C-I and include the the location of each aircraft, the current or planned configuration, and availability.

Aircraft Availability

The availability of each aircraft for testbed service in the mid 1980's was examined as part of the survey. Except for the Boeing B-52B, which has limited application for testbed use, all of the aircraft considered are either engaged in long-term programs or are returning to their parent organizations on completion of the current activities.

Aircraft in the NASA inventory are, therefore, not likely to be available for this program. The Boeing KC-135A and the Gulfstream American Gulfstream II, could be obtained from the USAF and on the used-aircraft market, respectively. Alternatively, a Boeing 707-120 could be substituted for the KC-135A.

Checks of the used aircraft market indicate that early models of the Boeing 707 aircraft are available in the price range of $\$1.0 \times 10^6$ to $\$1.4 \times 10^6$. It is clear from the survey that, unless NASA priorities change, none of the desired aircraft will be available for the Advanced Turboprop Testbed.

Data Availability

The modification of the base aircraft to the testbed configuration will require detailed knowledge of the structural and systems design of the selected testbed aircraft. There is concern that, because of the age of many of the aircraft designs, the data to perform the required modification may be difficult to acquire. During the lifetime of some of the aircraft, changes have occurred which further complicate data acquisition. These changes include change of manufacturing organization, termination of manufacture, extensive modification to later models and type serialization.

EC D-1 Aircraft Data Availability

- The Candidate Testbed Aircraft will be evaluated for data availability by establishing the degree to which the data are available, degree of cooperation extended to contractor by the appropriate manufacturer, arrangement by which data may be acquired and, in the case that the necessary data are not currently available, the ease with which the data required may be reconstructed.

Data such as basic aerodynamic, propulsion, structural, and aircraft performance as well as control system characteristics and aircraft subsystems information would be required to perform the aircraft modification.

The position, as far as data availability is concerned, ranges from the immediately accessible contractor data for the C-141A to doubtful acquisition of such information in the case of the oldest of the aircraft under consideration, the Boeing KC-135A. The prototype for this aircraft, the 360-80, first flew in May 1954.

Airframe manufacturers are reluctant to share proprietary information with competitors, however, avenues such as U.S. Air Force channels may provide access to the necessary data for the Boeing KC-135A.

In the case of the Convair 990, General Dynamics and the Lockheed-Georgia Company have an agreement of mutual assistance for providing information required for the aircraft modification. General Dynamics has already supplied data for Task III of this study, and further assistance either by data purchase or subcontract participation has been pledged.

The Gulfstream II, originally manufactured by Grumman, is now a product of Gulfstream American Corporation, Savannah, Georgia. Some contact has been made with Gulfstream American and information obtained. There is every indication that further information may be obtained by subcontract or through data purchase.

The availability of data may influence the selection of the testbed aircraft for further study. However, this factor, although important, will not be an overriding element in the evaluation process. The weighting factor for this evaluation criterion has been set at 2 to prevent the criterion from unduly influencing the final choice of testbed aircraft. This evaluation is shown in Table D-XIX.

TABLE D-XIX. EC D-1 CONTRACTOR ACCESS TO AIRCRAFT DATA EVALUATION

WEIGHTING VALUE = 2

TESTBED A/C	CONTRACTOR DATA ACCESS	SUBCONTRACT OR DATA PURCHASE	U.S. AIR FORCE OR OTHER CHANNELS	RATING VALUE	CRITERION SCORE
C-141A	✓	NA	NA	3	6
KC-135A	X	✓	✓	1	2
CONVAIR 990	X	✓	NA	3	6
GULFSTREAM II	X	✓	NA	2	4

The evaluation assumes that the Lockheed-Georgia Company performs the testbed aircraft modification.

Potential for Modification to Research Aircraft Configuration

The performance of each testbed aircraft will be evaluated with the available and projected drive systems for potential for modification of the testbed to a research aircraft configuration where all or most of the propulsive thrust is obtained from prop-fan propulsion, since this is an important long-range consideration.

EC E-1 Potential for Modification to Research Aircraft

- This evaluation is based on the possibility of achieving research aircraft status, with the selected drive system.

The possibility of the candidate testbed aircraft undergoing further modification to a research aircraft configuration, where two or more prop-fan propulsion units provide all or most of the propulsive thrust, is limited by the power of the XT701 drive system. The thrust available from two and four XT701 units and the thrusts required by the candidate testbed aircraft are shown in Figure D-31. These data indicate that the choice of a twin engined research aircraft is limited to the GII. The GII also has the advantage of having the prop-fan units as additions so that the aircraft could meet the design speed/altitude requirement with power from the primary engines at the maximum takeoff gross weight of 27210 kgs (60,000 lb). Alternatively, the primary engines could be removed and the speed/altitude requirement could be satisfied at a maximum weight of 25396 kgs (56,000 lb). At 27210 Kgs (60,000 lb), the prop-fan-dedicated GII could achieve a Mach number of 0.783. The configuration is shown in Figures D-32.

The C-141A, KC-135A and the Convair 990 would fall short of Mach 0.8 at 10668m (35,000 ft) if the two inboard engines were replaced by XT701 prop-fan drive systems. Conversion to a dedicated prop-fan for these candidate testbed aircraft is also out of the question, as the data of Figure D-31 show. Four XT701 drive systems would produce 39,142N (8800 lb) of thrust, and at the lowest flight weights for the test mission, the C-141A, KC-135A, and Convair 990 all require greater thrust to satisfy the design requirement.

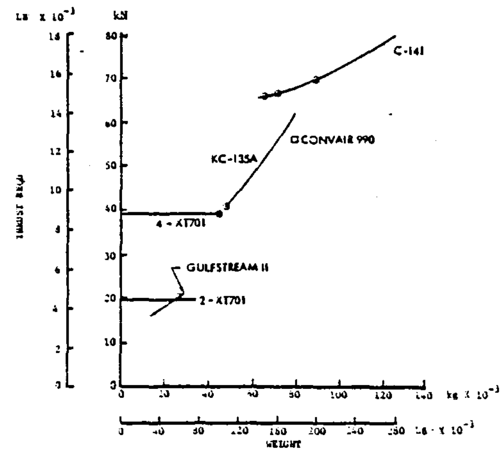


Figure D-31. Potential for Modification to Research Aircraft

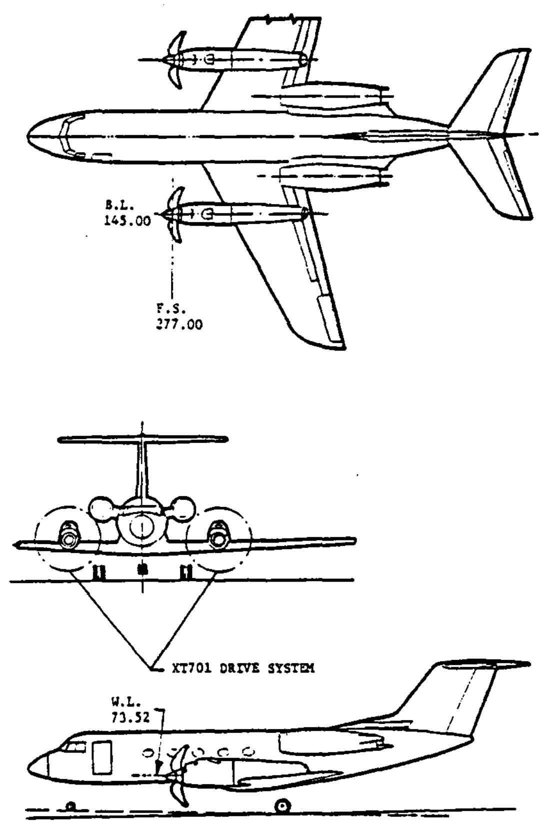


Figure D-32. Gulfstream II Twin-Engine Testbed Overwing Configuration

To achieve the performance level required for a four prop-fan propulsion system arrangement, the power level required would be as shown in Table D-XX.

An improvement in the modification potential of the three aircraft listed in Table D-XX could result if the design philosophy is changed from that of propulsion system substitution to one of addition as in the case of the GII. This has the advantage that the primary propulsion is retained and therefore the aircraft, when modified for the addition of one or two prop-fan units located on the wing between the fuselage and the inboard engine, do not suffer significant performance degradation.

TABLE D-XX. POWER LEVEL REQUIRED

TESTBED A/C	XT701 kW (SHP)	GROWTH FACTOR	XT7XX kW	(SHP)	PROP-FAN DIA. m	(FT)
C-141A	6019 (8071)	1.80	10,835	(14,530)	4.08	(13.4)
KC-135A	6019 (8071)	1.47	8,844	(11,860)	3.69	(12.1)
CONVAIR 990	6019 (8071)	1.40	8,426	(11,300)	3.60	(11.8)

The twin-engined testbed configurations for the C-141A, KC-135A, and Convair 990 are shown on Figures D-33, D-34, and D-35. All are overwing installations so that clearances are maximum. Of the three arrangements, the KC-135A appears to be the best since the inboard engine is so far out on the wing, $\eta = 0.41$, that ample clearance between the prop-fan and the fuselage and engine nacelles exists. These twin-engine testbed configurations do not fulfill the previously defined "research aircraft configuration" role in that the prop-fan units do not provide a significant portion of the total required propulsive thrust. However, they would provide additional valuable accoustic data relating to multiple sources and their interactions. Therefore, a twin-engine testbed of this form might prove highly desirable.

The potential for modification evaluation takes into account the change in design philosophy which is reflected in the rating values of Table D-XXI.

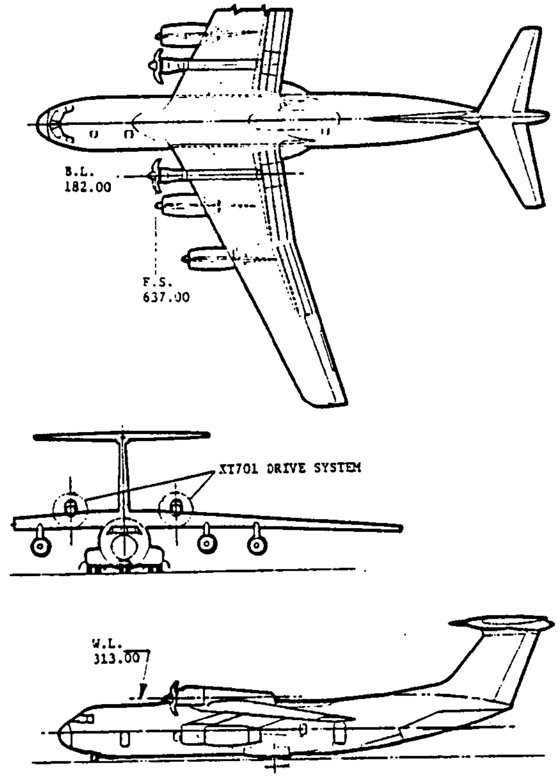


Figure D-33. C-141A Twin-Engine Testbed Overwing Configuration

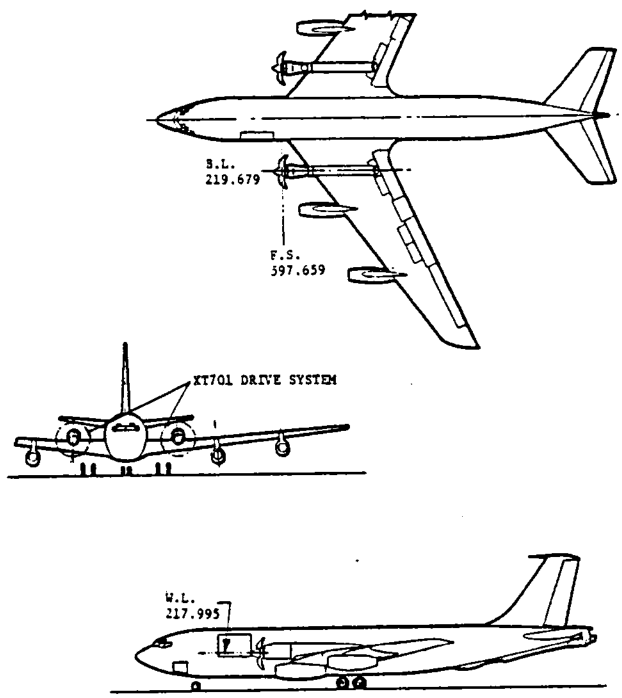


Figure D-34. KC-135A Twin-Engine Testbed Overwing Configuration

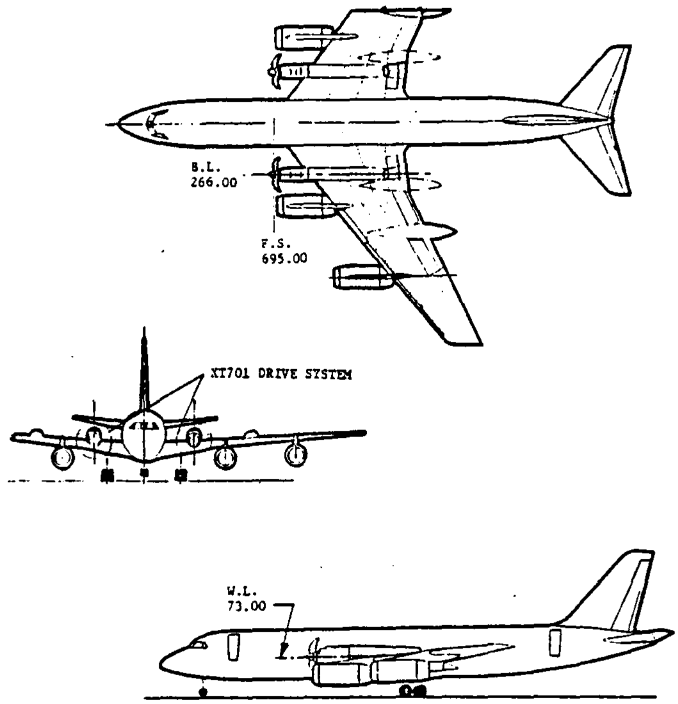


Figure D-35. Convair 990 Twin-Engine Testbed Overwing Configuration

TABLE D-XXI.

EC E-1 POTENTIAL FOR MODIFICATION TO RESEARCH AIRCRAFT EVALUATION

WEIGHTING FACTOR = 2

TESTBED A/C	RATING VALUE	CRITERION SCORE
C-141A	1	2
KC-135A	3	6
CONVAIR 990	1	2
GULFSTREAM II	3	6

RELATIVE COST OF TESTBED SYSTEMS

The ROM cost data for modification to the testbed configuration derived for Task III will be reviewed and will form the basis for cost comparison of the candidate testbed aircraft.

EC F-1 Modification Cost Data Ranking

- This evaluation will be based on the comparison of the ROM costs to modify each testbed aircraft and will include identification of the cost drivers.

ROM cost data estimates have been prepared for each candidate testbed aircraft. These data include the following:

Structure and Systems

- o New nacelle structure
- o Engine/prop-fan controls modification
- o Surface controls modification
- o Fuel system changes
- o Flap and spoiler modification for prop-fan loads and temperature effects
- o Wing Structure changes for engine QEC pick-up and resulting spar, cover and rib changes
- o System changes for hydraulic electric and aircraft systems affected by the deletion of a primary engine

Engineering and Test

- o Design of structure and systems
- o Design support, i.e., structures, aerodynamics, propulsion, flutter, and vibration
- o Ground test of components and installation on aircraft
- o Modification of the aircraft to the testbed aircraft configuration

The ranking of the cost data is shown in Table D-XXII. The data for the C-141A, KC-135A, and Convair 990 are all of the same order. Aircraft size and amount of modification required are similar. Extensive structural modification for the wings is not required, since the prop-fan installation is located in the same place as the primary engine. The modification to the GII is, however, much greater, since the prop-fan installation is added to the wing. This necessitates extensive rework of the structure of the wing inboard of the prop-fan installation. This fact is reflected in the ROM cost for the GII, which has the highest cost of the four testbed configurations.

The cost data of Table D-XXII do not include the cost of modifying the drive system gearbox. DDA estimates this cost to be in excess of $400,000.

The cost data have been estimated on the basis that the power section and unmodified gearbox are government-furnished equipment.

All dollar values are in 1980 dollars.

TABLE D-XXII. EC F-1 MODIFICATION COST DATA RANKING

WEIGHTING FACTOR = 3

TESTBED AIRCRAFT	ROM COST ESTIMATE $ X 10^{-6}	RATING VALUE	CRITERIA SCORE
C-141A	11.7	3	9
KC-135A	11.7	3	9
CONVAIR 990	11.8	3	9
GULFSTREAM II	12.5	2	6

CANDIDATE TESTBED AIRCRAFT EVALUATION AND RECOMMENDATIONS

The data from each of the evaluation criteria have been consolidated in Table D-XXIII and the total weighted score computed. This evaluation shows that the C-141A is not a suitable candidate for the advanced turboprop system, mainly because of the marginal performance at the design conditions. The speed and altitude increments beyond Mach 0.8 and at 9144m (30,000 ft) do not provide sufficient flexibility for test purposes or to accommodate increases in aircraft drag should more refined analyses show this to be the case.

TABLE D-XXIII. CANDIDATE TESTBED AIRCRAFT EVALUATION

AIRCRAFT EVALUATION

			EVALUATION CRITERIA CATEGORY	A AIRCRAFT SAFETY			B OPERATIONAL CHARACTERISTICS				C TESTBED PROGRAM OBJECTIVES						D DATA AVAILABILITY	E MODIFICATION POTENTIAL	F TESTBED SYSTEMS RELATIVE COST	
			EVALUATION CRITERIA (EC)	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	C4	C5	C6	D1	E1	F1	
			WEIGHTING FACTOR	2	4	4	4	3	4	4	4	4	2	4	2	2	2	3	3	
AIRCRAFT TYPE	SELECTED DRIVE SYSTEM	PROPFAN NACELLE INSTALLATION	WEIGHTED RATING VALUE	PROP-FAN LOCATION	ENGINE-OUT SAFETY	STRUCTURAL INTEGRITY	DESIGN CRUISE CONDITION COMPLIANCE	TEST MISSION DURATION	STABILITY & CONTROL	INSTALLATION EFFECTS	DYNAMIC LOADS VALIDATION	NEAR-FIELD NOISE DATA	FAR-FIELD NOISE DATA	PROP-FAN SCALE	INSTALLED PROPULSIVE EFFICIENCY VALIDATION	INTERACTION EFFECTS	AIRCRAFT DATA AVAILABILITY	POTENTIAL FOR MCD TO RESEARCH AIRCRAFT	MODIFICATION COST DATA BANKING	WEIGHTED SCORE
LOCKHEED C-141A	XT701	OW		6	4	12	4	9	12	6	6	4	2	12	2	2	6	2	9	98
		UW		6	4	12	4	9	12	12	6	8	2	12	2	2	6	2	9	108
BOEING KC-135A	XT701	OW		6	4	12	12	9	12	4	8	12	2	12	4	4	2	6	9	118
		UW		6	4	12	12	9	12	8	8	8	2	12	4	4	2	6	9	118
CONVAIR 990	XT701	OW		6	4	12	12	9	12	4	8	12	2	12	4	4	6	2	9	118
		UW		6	4	12	12	9	12	8	8	8	2	12	4	4	6	2	9	118
GULFSTREAM AMERICAN GULFSTREAM II	XT701	OW		3	12	8	12	9	8	4	12	8	6	12	6	6	4	6	6	122
		UW		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BOEING B-52B	-	OW																		
		UW								SPECIAL PURPOSE TESTBED										
		PYL																		
LOCKHEED -6 JETSTAR	-	OW								ELIMINATED ON INITIAL SCREENING										
		UW																		
BOEING 737	-	OW								ELIMINATED ON INITIAL SCREENING										
		UW																		

The possible candidate testbed aircraft are, therefore, as follows:

Gulfstream II	Weighted Score		122
Boeing KC-135A	Weighted Score	OW	118
		UW	118
Convair 990	Weighted Score	OW	118
		UW	118

Estimation of the score subtotals for these aircraft in the categories of Aircraft Safety, Operational Characteristics, and Testbed Program Objectives Achievements show some interesting results, shown on Table D-XXIV. The scores shown are for overwing installations, since these are considered to be most representative of commercial aircraft application.

From the testbed aircraft safety standpoint, there is a little difference between the four candidates; all can be operated safely as testbed aircraft. On the basis of operational characteristics as testbed vehicles, the KC-135A and Convair 990 are best, offering the most stable platforms with greatest performance margins. The GII is not quite as good, primarily because of the requirement for ballasting to maintain balance.

In the area of meeting testbed objectives, however, the GII clearly emerges as the best candidate aircraft with a score in that category high enough to make it the best overall candidate.

The second choice is between the KC-135A and the Convair 990 for which the evaluation total scores are identical. The weighted score subtotals for the evaluation criteria of categories A, B and C of the evaluation are also identical as shown on Table D-XXIV, Testbed Final Selection. These scores relate to single prop-fan testbed configurations only. If, however, the potential for modification to a multi-prop fan arrangement is a consideration, any inherent advantage in one configuration may be of significance. This is shown to be the case, since scrutiny of the configurations, Figures D-34 and D-35, shows that conversion can be accomplished on the KC-135A without infringing on the important clearance parameters, since the inboard engine is located at 41 percent of the wing semi-span against 36 percent for the Convair 990. When the weighted score for this criteria is considered as shown on Table D-XXIV a clear choice is possible for the second testbed aircraft, since the KC-135A has a total of 107 against the 103 for the Convair 990. It should be noted that the GII continues to have the highest score.

TABLE D-XXIV. TESTBED FINAL SELECTION

TESTBED A/C	SUBTOTAL SCORES			SUB-TOTAL	MOD. POTENTIAL	TOTAL
	A/C SAFETY	OPERATIONAL CHARACTERISTICS	PROGRAM OBJECTIVES			
C-141A	22	31	28	81	2	83
KC-135A	22	37	42	101	6	(107)
CONVAIR 990	22	37	42	101	2	103
GII	23	33	50	105	6	(111)

◯ TESTBED SELECTED A/C

The following are the recommendations for the testbed aircraft and for the study Task V activities:

(1) Recommended Drive System

- o Detroit Diesel Allison XT701/T56-A-14 Gearbox

(2) Propulsion System Configuration

- o Overwing Installation
- o Universal QEC Design

(3) Recommended Testbed Aircraft

- o Boeing KC-135A
- o Gulfstream American Gulfstream II

TEST PLAN AND INSTRUMENTATION RECOMMENDATIONS

This recommended test plan is submitted in response to Task IV of the Statement of Work for the "Advanced Turboprop Testbed Systems Study." The test plan will be expanded and/or modified as required in Task VII.

Test Article

The test article will be fitted with the recommended drive system: Detroit Diesel Allison XT701/T56-A-14 gearbox with a universal, QEC-type, overwing installation. The recommended testbed aircraft, either the Gulfstream American Gulfstream II or the Boeing KC-135A, is considered as the vehicle for the test program.

Approach

Contractor flight test personnel will conduct the instrumentation system installation during the modification span for powerplant installation. The instrumentation system design and installation will be supplied by the

Lockheed-Georgia Company to include the recording system, wiring, transducers, and support equipment for all measurements except those required by Hamilton Standard for the test propeller and DDA for the propeller drive system. The Hamilton Standard recording system will be installed by the Contractor and necessary wiring incorporated from the propeller to the recording system. The associated slip rings and engine wiring for the propeller and propeller shaft instrumentation will be supplied by Hamilton Standard/DDA.

All instrumentation recording systems will be installed in the passenger/cargo compartment of the test vehicle. The test instrumentation will be maintained by Contractor personnel, except for the propeller and propeller shaft instrumentation systems.

It is assumed that the test engine(s)/gearbox will be fully qualified and will be received as calibrated units for test purposes.

Objectives

The objectives of the flight test program are to assure the airworthiness of the installed prop-fan test system and to provide data to verify the goals of the program. Tests will be conducted for data acquisition to:

- Verify the test system/airframe airworthiness
- Evaluate prop-fan control system function
- Evaluate propeller and propeller shaft structural integrity and dynamics
- Determine airframe dynamic and vibratory characteristics induced by the propeller
- Evaluate cabin noise levels and the benefit of additional cabin acoustic treatments
- Evaluate near- and far-field noise levels
- Evaluate engine inlet performance

o Substantiate scale effects

Test Program

After instrumenting the aircraft and the test drive system, the testbed will be prepared for flight and enter a ground test phase.

Ground Tests

The ground tests to be conducted will include the ground vibration tests of the airframe structure, propeller shaft and blade stress testing, noise evaluation, propeller control tests, and aircraft ground control tests.

Flight Tests

The flight test phase will involve evaluation of propeller shaft and blade structural dynamics characteristics, airframe flutter characteristics, airframe/test system airworthiness, near- and far-field noise, engine inlet performance, and propeller control system operation.

Instrumentation Requirements

The recommended instrumentation requirements will be developed to support the program objectives. The following instrumentation groupings are estimated to provide the data required to support the test program.

Parameter/Instrumentation	Quantity (est)	Location
o Noise (Microphones)	200	Fuselage, Wing, Empennage
o Accelerometers	30	Wing, Empennage, Nacelle
o Surface Pressures	40	Wing
o Pressure Rake	2	Wing
o Wake Rake	1	Wing
o Engine Inlet Rake	1	Engine Inlet
o Basic Engine Parameters	6	Engine

o Basic Aircraft Parameters	16	Motion, control position, airspeed/altitude, accelerations
o Propeller Strains		Propeller
o Propeller Shaft Strains		Propeller Shaft
o Engine Acceleration		Engine
o Engine Pressures and Temperatures		Engine

Typical instrumentation is shown in Figure D-36.

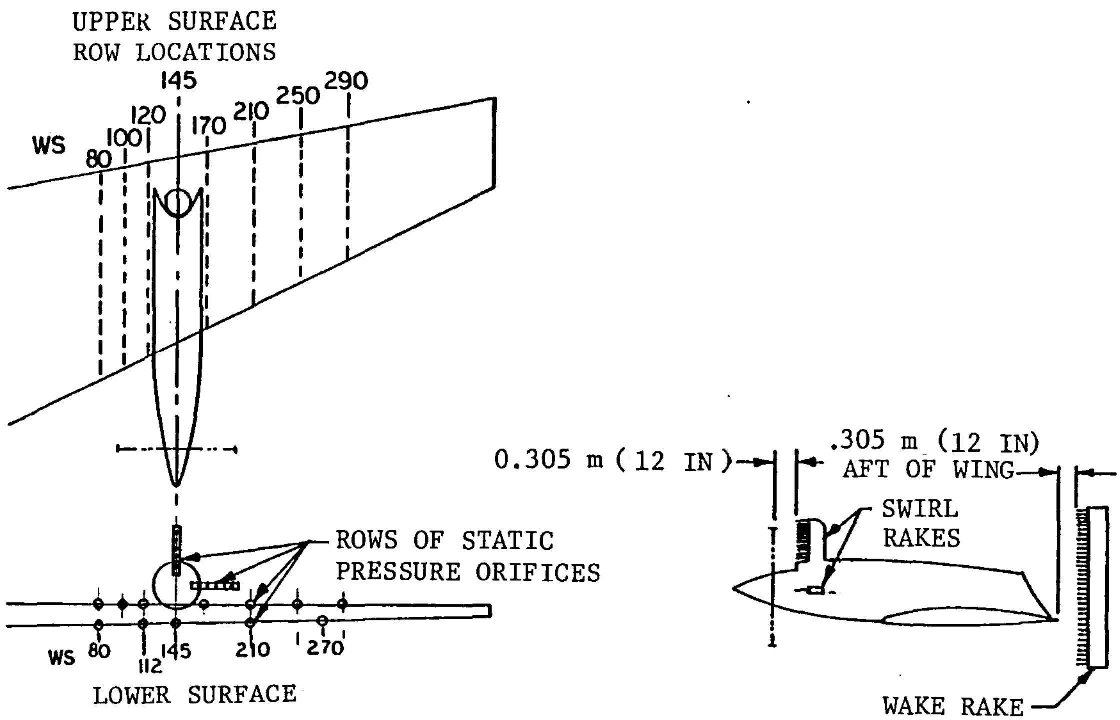


Figure D-36. Instrumentation for GII Testbed Aircraft

APPENDIX E - CONCEPTUAL DESIGN OF TESTBED SYSTEMS - TASK V

At the conclusion of Task IV, the evaluation showed the candidate testbed aircraft configurations to be the Boeing KC-135A, the GAC GII, and the Convair 990. The two testbed systems recommended for further study were selected from the three candidate systems and identified as the Boeing KC-135A and the GAC GII. Although the KC-135A is a military aircraft configuration, the commercial counterpart is the Boeing 707-100 series, which was derived from the KC-135A. The Boeing 707-100 can, therefore, be substituted without changing any of the findings of the evaluation and without change to the recommendations. These testbed aircraft systems were recommended in conjunction with the DDA XT701 drive system powering a 2.89 m (9.5 ft) diameter prop-fan. Following the Task IV "Evaluation and Recommendations," the NASA Lewis Research Center directed that single prop-fan aircraft designs should be discontinued and that the Task V "Conceptual Design of Testbed Systems" should proceed with twin prop-fan configurations.

The overwing "Pinion-High" installation was chosen as the drive system most representative of future aircraft applications, and the drive system/airframe integration was performed without attempting to optimize the arrangement aerodynamically. Gloves and fillets at the wing/nacelle intersections are contemplated, however, to obtain an efficient installation.

The change to the twin prop-fan design did not affect the choice of candidate testbed aircraft, as the potential for modification to multi-prop-fan arrangements was an evaluation criterion in Task IV. Selection of the candidates, therefore, included this consideration. The effect on the GII was to add a second prop-fan QEC unit to the left-hand wing of the aircraft. In the case of the KC-135A, however, the effect was to change the design approach from a prop-fan substitution to a prop-fan addition. Since the inboard primary engine is located at 43 percent of the semi-span, no difficulty was encountered in positioning the prop-fan units on the wings, between the inboard engines and the fuselage, to give the recommended 0.8 D_p from prop-fan tip to fuselage wall, and 0.2 D_p from prop-fan tip to engine nacelle clearances.

Detailed conceptual designs were completed for each of the recommended testbed candidates to further confirm the suitability and adaptability of each system to the flight test program. This design effort was aided by the loan of design and technical data to the Lockheed-Georgia Company by GAC and by a review of the Lockheed design by GAC for feasibility and practicality. Data for the KC-135A were obtained from the public domain through Wright-Patterson Air Force Base.

The following text describes this design process which is divided into three distinct sections. First, a description of the quick engine change (QEC) nacelle design, including rationale for the selection of the basic nacelle contours, engine air inlet design, nacelle structural design, and drive system installation is given. Second, the KC-135A testbed system design is reviewed covering the drive system location and geometry, the aft nacelle structure, a flutter analysis, the testbed operating envelope, the testbed performance, and a summary of the KC-135A testbed weights and balance. Finally, the testbed system design utilizing the GAC GII is covered including the same design details as for the KC-135A system, and additional details concerning trim capability, required wing modifications, estimates of the prop-fan slipstream characteristics, and estimates on near-field noise characteristics.

QEC NACELLE DESIGN CONSIDERATIONS

The QEC nacelle envisioned for the prop-fan testbed was designed to contain the drive system and its associated support systems and structures, and to duplicate, as nearly as possible, the experimentally derived flow field through the prop-fan, in an attempt to validate propulsive efficiency gains theoretically possible from this propulsion system.

Nacelle Contours

The XT701 nacelle contours were designed to provide the same envelope for "pinion-high" and "pinion-low" drive system configurations. Since the overwing installation was chosen for both conceptual designs, the development of the nacelle envelope for the "pinion-high" arrangement only will be addressed.

The nacelle contours were based on the NASA spinner/hub area distribution, Figure B-6, and are arranged to permit the use of the main forged support frames and supporting V-frames from the Lockheed P-3C T56 engine installation, modified for the DDA XT701 drive system installation.

The nacelle contours, Figure E-1 are arranged to provide an envelope for the drive system with air induction systems for the engine and oil cooler arranged on the upper portion of the nacelle in a stacked and staggered configuration. The oil cooler inlet and ducting are designed to house the C-130 - T56 oil cooler.

Engine Air Inlet Design

A scoop type inlet was selected for the XT701/T56A-14 engine/gearbox arrangement, as shown in Figure E-1. The general design philosophy adopted was that the engine should perform reliably and efficiently over the range of test conditions at the expense of drag minimization. Thus, in choosing between efficient internal or external flow performance, internal performance was considered more important.

Turboprop-powered aircraft have not heretofore been designed to cruise at Mach numbers higher than 0.6. Consequently, large inlet areas have been used, resulting in a contraction in the duct between inlet and engine compressor face. At Mach 0.5 or 0.6, this results in moderate flow spillage around the inlet lips, and insignificant spillage drag. However, at Mach 0.8, spillage drag may be significant. From the drag standpoint, therefore, it is desirable to keep the inlet area as small as possible. A small inlet, however, may result in excessive internal flow pressure losses and flow distortion at the engine compressor face. For the testbed nacelle, the inlet area was selected to be equal to the compressor face area - a compromise intended to provide good internal flow without excessive drag.

The shape of the engine air inlet, as shown in the front view of Figure E-1, was selected to minimize departures from symmetry about the nacelle axis. This results in a high-aspect-ratio inlet shape or one in which the inlet encircles a large portion of the upper half of the nacelle. Use of this arrangement was based on: (1) knowledge that large obstructions behind the prop-fan would induce 1-P dynamic loads on the prop-fan, and (2) the premise that since the forebody design criteria were based on tests of bodies-of-revolution, the design risk is minimized by using nacelle shapes which approach symmetry as closely as possible.

A third inlet design consideration concerned the fore-and-aft location of the inlet. In the case of the testbed, the inlet was located farther aft than

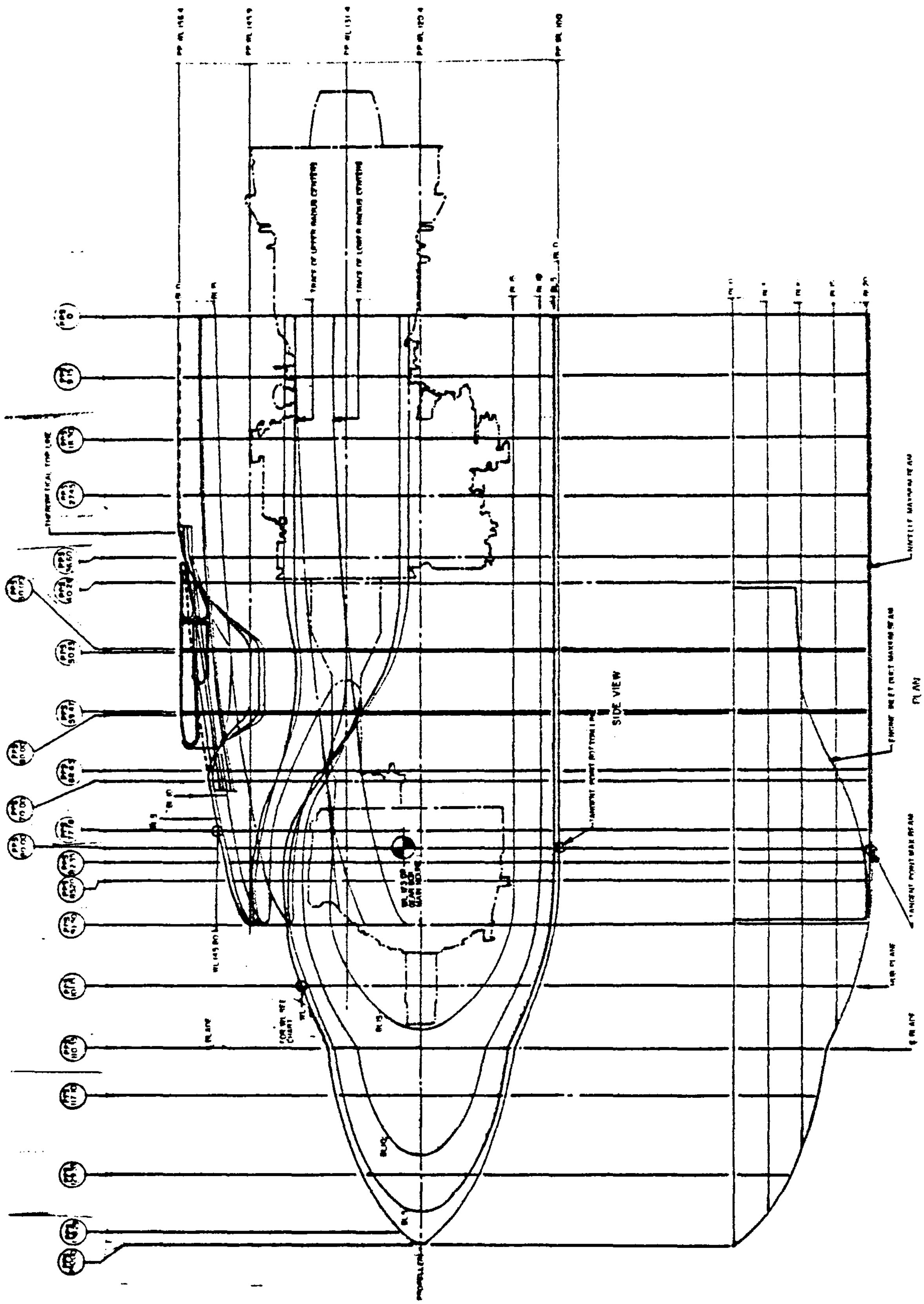


Figure E-1. XT701 QEC Nacelle Contours

CURVE		BOTTOM LINE		SPINNER AND HUB		TOP LINE		MAXIMUM BEAM	
	PPS		WL	RAD	WL		WL		BL
	0		100				156.4		20.4
	3.66		100				156.392		20.4
	9.15		100				156.337		20.4
	12.81		100				156.267		20.4
	18.30		100				156.121		20.4
	21.96		100				156.996		20.4
	27.45		100				155.764		20.4
	31.11		100				155.581		20.4
	36.60		100				155.256		20.4
	40.26		100				155.006		20.4
	45.75		100				154.582		20.4
	50.32		100				154.189		20.4
	54.90		100				153.748		20.4
	59.47		100				153.258		20.4
	64.05		100				152.713		20.4
	68.625		100				152.110		20.4
	73.20		100				151.433		20.4
	77.775		100				150.656		20.4
	81.998		100	20.40	140.800		149.693		20.4
	82.35						148.994		
	84.042			20.377	140.777				
	85.095						148.994		
	86.925						148.457		
	88.130			20.189	140.589				
	89.212						147.639		
	89.670						147.445		
	90.127						147.235		
	90.768						146.879		
	90.951						146.752		
	91.134						146.596		
	91.5						115.9		
	92.218			19.789	140.189				
	96.304			18.991	139.391				
	97.734			18.663	139.063				
	98.112			18.589	138.989				
	98.140			18.561	138.961				
	98.306			18.529	138.929				
	98.714			18.400	138.800				
	99.120			18.264	138.664				
	99.540			18.120	138.520				
	99.946			17.971	138.371				
	100.352			17.803	138.203				
	100.762			17.657	138.057				
	101.150			17.492	137.892				
	101.178			17.492	137.892				
	104.832			15.991	136.391				
	108.920			14.304	134.704				
	110.350			13.730	134.130				
	113.008			13.036	133.436				
	115.055			12.896	133.296				
	117.101			12.661	133.061				
	121.190			11.583	131.983				
	125.278			10.128	130.628				
	129.368			8.441	128.841				
	133.457			6.329	126.729				
	135.501			5.017	125.417				
	137.472			3.426	123.826				
	138.000			2.437	122.837				
	140.000			0	120.400				

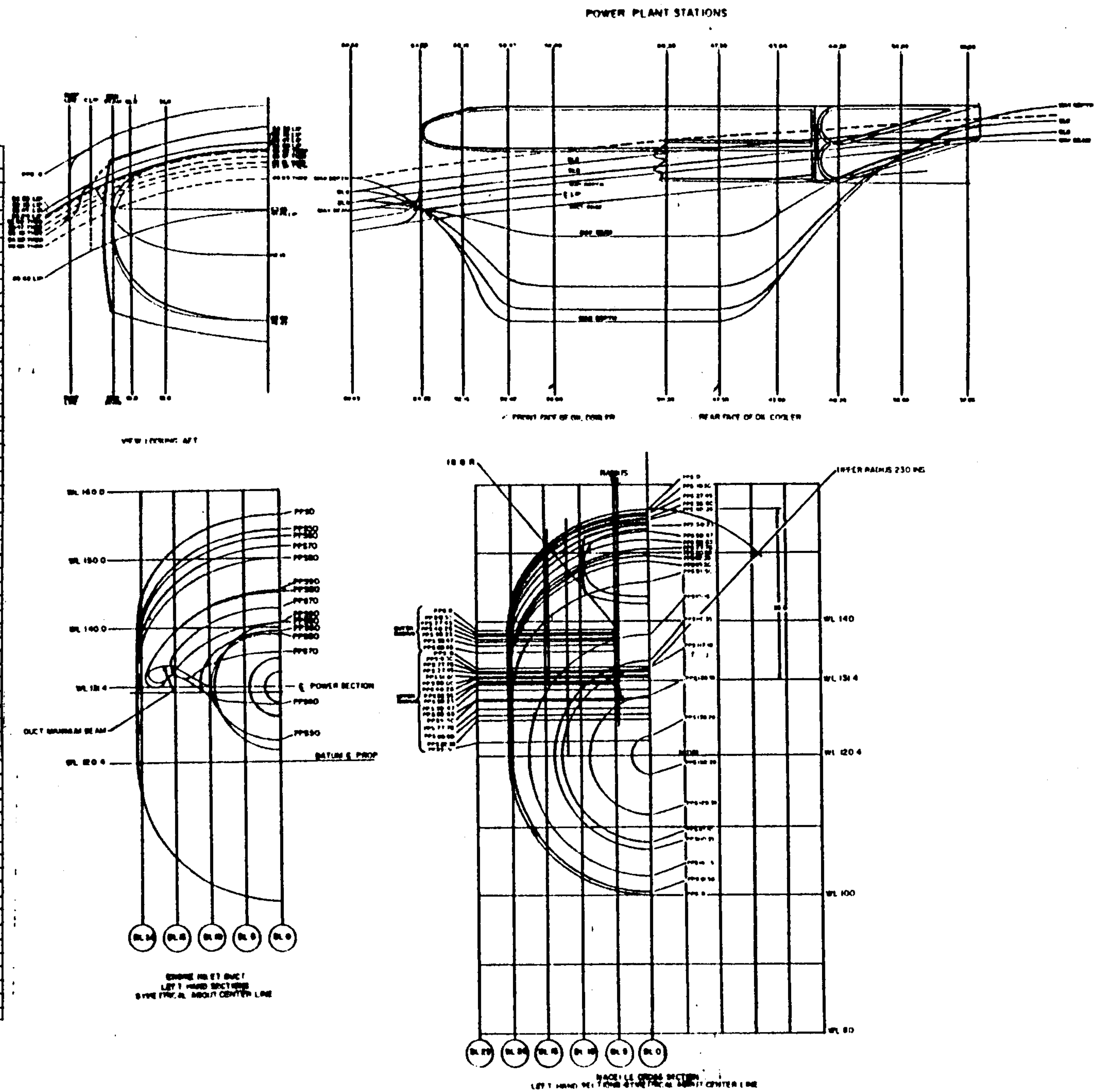


Figure E-1. XT701 QEC Nacelle Contours (Cont'd) on existing turboprop installations in order to maintain adequate airflow over a wide range of prop-fan blade angles.

As shown in Figure E-1 the oil cooler for the testbed is located in a stacked and staggered position relative to the engine inlet S-duct. The configuration selected uses a fixed lip inlet and variable geometry (flapped) exhaust for the cooling air flow. If necessary, the air flow can be augmented at low forward speeds, ground idle, and other critical conditions by an engine-bleed-powered ejector pump downstream of the heat exchanger.

NACELLE STRUCTURAL DESIGN

The externally applied loads for the drive system nacelle design were derived from flight envelope data for the KC-135A and for the GII. The external limit loads data, Table E-I, include positive and negative vertical accelerations, positive and negative lateral accelerations, torque, and shear loadings. Since the external loads, Table E-I, are common to both testbed configurations, the internal loads and sizes of structural members are independent of the receiving airframe. This results in a common structure in the QEC up to the mating plane. The structure on the receiving airframe, from the mating plane aft, is designed to be compatible with the QEC structure. The nacelle shapes are arranged to facilitate manufacture and consist of a body-of-revolution for the spinner/hub region, changing to an upper and lower radius joined by straight sides over the remaining portion of the nacelle. The nacelle is 3.56m (140.0 in) long, 1.43m (56.4 in) deep, and 1.01m (40.0 in.) wide. The cross-sectional area is 1.32 sq m (14.2 sq ft) and the wetted area is 11 sq m (122 sq ft).

A finite-element analysis was performed to establish the sizes of the structural members of the nacelle, to check the capability of the P-3C members to be used in the design and to provide data for weight estimates of the nacelle and testbed aircraft. The respresentations of the nacelle structure are given in Figure E-2, which is the engine facsimile; Figure E-3 the representation of the longerons and truss members; Figure E-4, which shows the nacelle structure shear panels; and Figures E-5 and E-6, the representations of the main support and mating plane frames, respectively. The results of the analysis are shown in Tables E-II and E-III for the axial elements and shear panels, respectively.

TABLE E-1. NACELLE - EXTERNAL LIMIT LOADS

LOAD CASE = 1 N_z = -5.0g (LIMIT)

NODE NO	FX	FY	FZ
74	.0000	.0000	-30750.0000

LOAD CASE = 2 N_z = +3.0g (LIMIT)

NODE NO	FX	FY	FZ
74	.0000	.0000	18450.0000

LOAD CASE = 3 N_y = +2.0g (LIMIT)

NODE NO	FX	FY	FZ
74	.0000	12300.0000	.0000

LOAD CASE = 4 N_y = -2.0g (LIMIT)

NODE NO	FX	FY	FZ
74	.0000	-12300.0000	.0000

LOAD CASE = 5 M_x = +200,000 IN.-LB. (LIMIT)

NODE NO	FX	FY	FZ
69	.0000	.0000	-9960.1600
70	.0000	.0000	9960.1600

LOAD CASE = 6 M_x = -200,000 IN.-LB. (LIMIT)

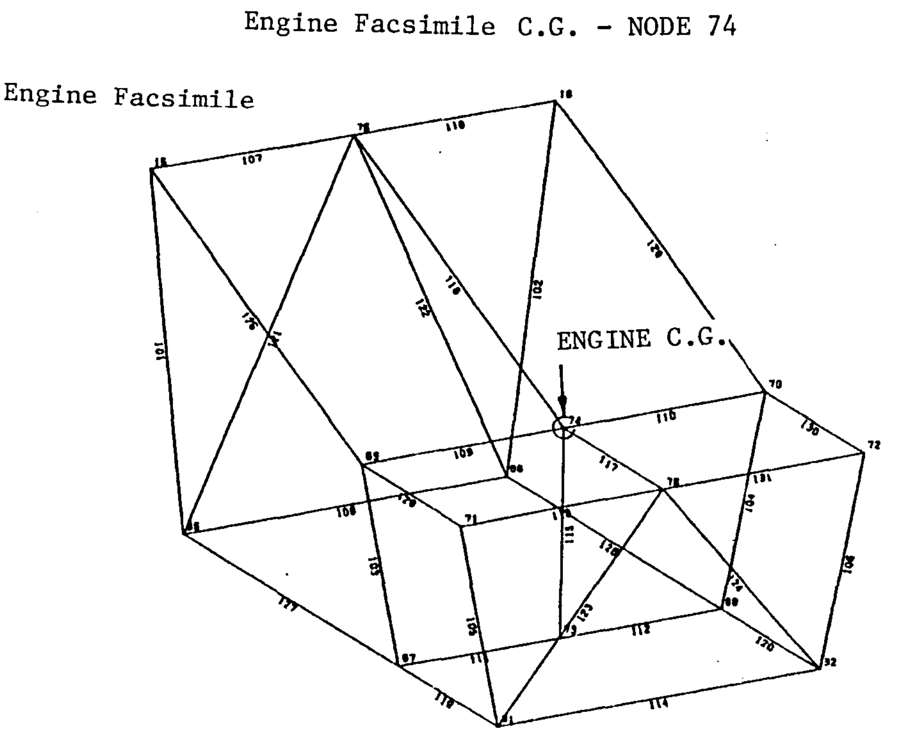
NODE NO	FX	FY	FZ
69	.0000	.0000	9960.1600
70	.0000	.0000	-9960.1600

LOAD CASE = 7 N_z = -1.5g M_x = +400,000 IN.-LB. (LIMIT)

NODE NO	FX	FY	FZ
74	.0000	.0000	-6150.0000
69	.0000	.0000	-19920.3201
70	.0000	.0000	19920.3201

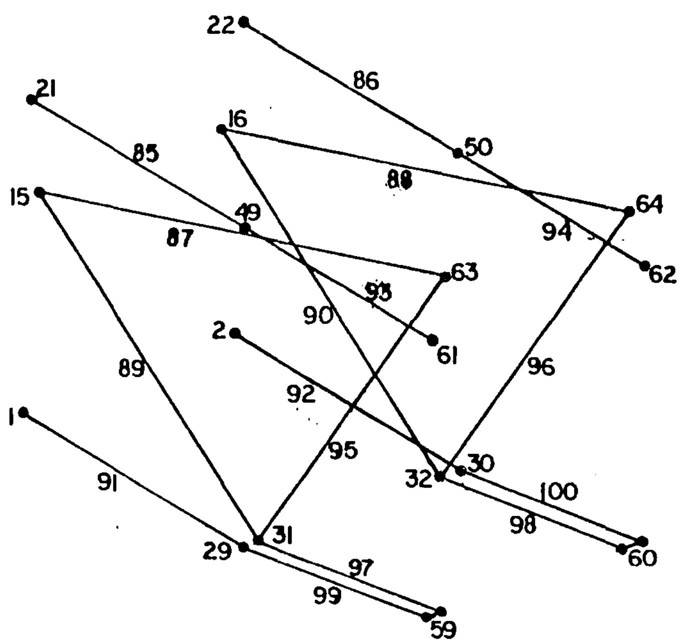
LOAD CASE = 8 N_z = -1.5g M_x = -400,000 IN.-LB. (LIMIT)

NODE NO	FX	FY	FZ
74	.0000	.0000	-6150.0000
69	.0000	.0000	19920.3201
70	.0000	.0000	-19920.3201



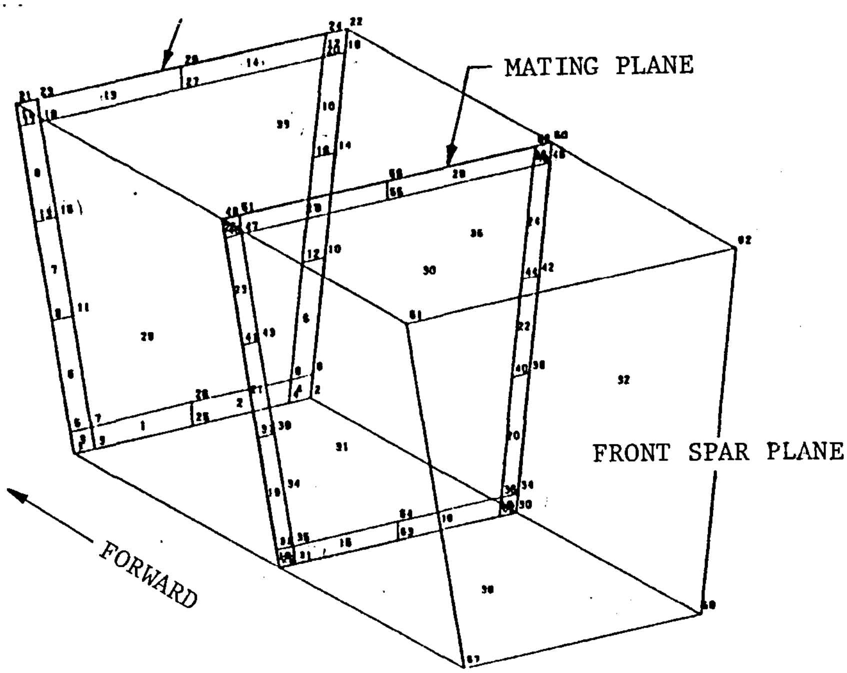
AXIAL ELEMENT	NODE 1	NODE 2	AREA
101	15	65	.1308
103	67	69	.8730
105	31	71	.6760
107	15	75	.1159
108	65	66	.1000
109	69	74	.4607
119	67	31	.2517
121	75	65	.1000
126	16	70	.3926
127	65	67	.2521
129	69	71	.3644

Figure E-2. FEA Engine Facsimile



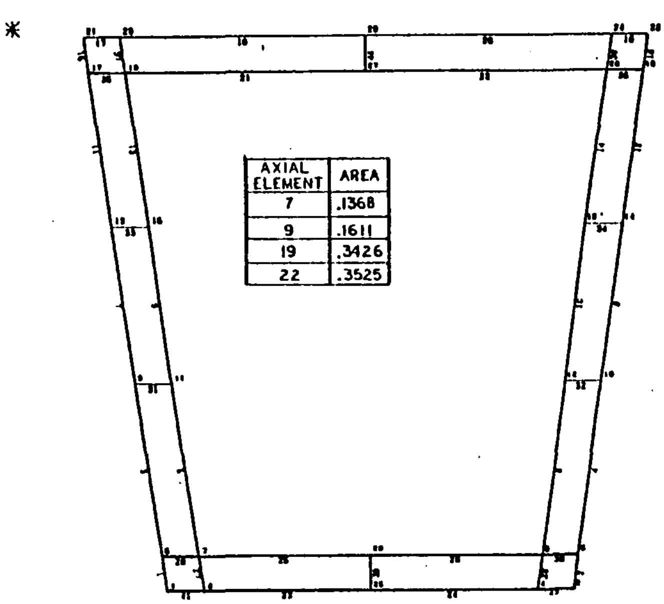
AXIAL ELEMENT	NODE 1	NODE 2	AREA
85	21	49	.2027
93	49	61	.4227
87	15	63	.6000
95	63	31	.5000
89	15	31	.6000
91	1	29	.1109
99	29	59	.3765
97	31	59	.1933

Figure E-3. FEA Longerons and Truss Members



SHEAR PANEL	THICKNESS
29	.0400
30	
31	
32	
33	.0400

Figure E-4. FEA Shear Panels



AXIAL ELEMENT	AREA
7	.1368
9	.1611
19	.3426
22	.3525

Figure E-5. FEA Main Support Frames

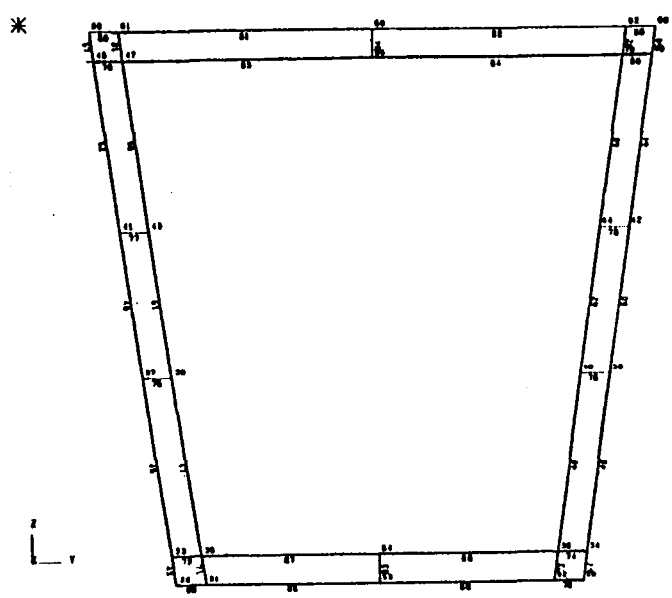


Figure E-6. FEA Mating Plane Frame

TABLE E-II. FEA AXIAL ELEMENTS

MEMBER	NODE1	NODE2	LENGTH	AREA	WEIGHT
1	1	5	2.427	.1000	.025
2	2	6	2.427	.1000	.025
3	5	9	12.123	.1000	.125
4	6	10	12.123	.1000	.125
5	7	11	12.123	.1000	.125
6	8	12	12.123	.1019	.127
7	9	13	10.861	.1368	.153
8	10	14	10.861	.1410	.158
9	11	15	10.851	.1611	.180
10	12	16	10.851	.1701	.190
11	13	17	10.609	.2336	.255
12	14	18	10.609	.2320	.253
13	15	19	10.618	.3133	.339
14	16	20	10.618	.3143	.344
15	17	21	2.526	.2336	.061
16	18	22	2.526	.2320	.060
17	21	23	2.500	.3423	.088
18	22	24	2.500	.3436	.088
19	23	27	17.000	.3423	.599
20	24	28	17.000	.3436	.602
21	19	27	16.640	.3474	.595
22	20	27	16.640	.3525	.604
23	3	25	11.500	.1000	.116
24	4	25	11.500	.1000	.116
25	7	26	11.860	.1000	.122
26	8	26	11.860	.1000	.122
27	3	7	2.427	.1000	.025
28	4	8	2.427	.1000	.025
29	5	7	2.500	.1000	.026
30	6	8	2.500	.1000	.026
31	9	11	2.500	.1000	.026
32	10	12	2.500	.1000	.026
33	13	15	2.566	.1007	.027
34	14	16	2.566	.1027	.027
35	17	19	2.500	.3494	.090
36	18	20	2.500	.3545	.091
37	19	23	2.526	.3100	.081
38	20	24	2.526	.3140	.082
39	25	26	2.500	.1000	.026
40	27	28	2.500	.1000	.026
41	1	3	2.500	.1000	.026
42	2	4	2.500	.1000	.026
43	29	33	2.021	.1000	.021
44	30	34	2.021	.1000	.021
45	33	37	12.528	.1000	.129
46	34	38	12.528	.1000	.129
47	35	39	12.528	.1000	.129
48	36	40	12.528	.1000	.129
49	37	41	10.103	.1000	.104
50	38	42	10.103	.1000	.104
51	39	43	10.103	.1000	.104
52	40	44	10.103	.1000	.104
53	41	45	11.871	.1000	.122
54	42	46	11.871	.1000	.122

TABLE E-II. FEA AXIAL ELEMENTS (CONT'D)

55	43	47	11.871	.1000	.122
56	44	48	11.871	.1000	.122
57	45	49	2.021	.1000	.021
58	46	50	2.021	.1000	.021
59	49	51	2.000	.1000	.021
60	50	52	2.000	.1000	.021
61	51	56	17.500	.1000	.180
62	52	56	17.500	.1000	.180
63	47	55	17.212	.1000	.177
64	48	55	17.212	.1000	.177
65	31	53	12.000	.1086	.134
66	32	53	12.000	.1191	.147
67	35	54	12.288	.1231	.156
68	36	54	12.288	.1214	.154
69	29	31	2.000	.1302	.027
70	30	32	2.000	.3459	.071
71	31	35	2.021	.1666	.035
72	32	36	2.021	.1645	.034
73	33	35	2.000	.1231	.025
74	34	36	2.000	.1214	.025
75	37	39	2.000	.1000	.021
76	38	40	2.000	.1000	.021
77	41	43	2.000	.1000	.021
78	42	44	2.000	.1000	.021
79	45	47	2.000	.1000	.021
80	46	48	2.000	.1000	.021
81	47	51	2.021	.1000	.021
82	48	52	2.021	.1000	.021
83	53	54	2.000	.1000	.021
84	55	56	2.000	.1000	.021
85	21	49	41.000	.2027	.856
86	22	50	41.000	.1991	.841
87	15	63	79.738	.6000	13.874
88	16	64	79.738	.6000	13.874
89	15	31	48.196	.6000	8.386
90	16	32	48.196	.6000	8.386
91	1	29	41.000	.1109	.468
92	2	30	41.000	.1198	.506
93	49	61	37.000	.4227	1.611
94	50	62	37.000	.3864	1.473
95	31	63	55.811	.5000	8.093
96	32	64	55.811	.5000	8.093
97	31	59	37.226	.1933	.741
98	32	60	37.226	.1950	.748
99	29	59	37.280	.3765	1.446
100	30	60	37.280	.4602	1.767
101	15	65	25.335	.1328	.346
102	16	66	25.335	.1344	.351
103	67	69	14.722	.8707	1.320
104	68	70	14.722	.8647	1.311
105	31	71	14.722	.6497	.985
106	32	72	14.722	.6539	.992
107	15	75	15.060	.1306	.203
108	65	66	24.000	.1000	.247
109	69	74	15.060	.4583	.711
110	70	74	15.060	.4583	.711
111	67	73	12.000	.3864	.478
112	68	73	12.000	.3864	.478

TABLE E-II. FEA AXIAL ELEMENTS (CONT'D)

113	71	76	15.060	.1984	.308
114	31	32	24.000	.2763	.683
115	73	74	14.400	1.2142	1.831
116	74	75	30.086	.1000	.310
117	74	76	12.900	.1000	.133
118	16	75	15.060	.1325	.206
119	67	31	12.900	.2700	.359
120	68	32	12.900	.2641	.351
121	75	65	27.866	.1000	.287
122	75	66	27.866	.1000	.287
123	76	31	18.745	.1000	.193
124	76	32	18.745	.1000	.193
125	15	69	30.086	.3812	1.181
126	16	70	30.086	.3844	1.191
127	65	67	28.100	.2576	.745
128	66	68	28.100	.2566	.743
129	69	71	12.900	.3564	.474
130	70	72	12.900	.3594	.477
131	72	76	15.060	.1981	.307
132	64	78	37.108	.1000	.382
133	63	77	37.108	.1000	.382
134	78	80	75.308	.1000	.776
135	77	79	75.308	.1000	.776
136	60	81	19.950	.1000	.205
137	59	81	18.708	.1000	.193
138	79	84	1.000	.1000	.010
139	77	85	1.000	.1000	.010
140	78	82	1.000	.1000	.010
141	77	83	1.000	.1000	.010
142	80	90	1.000	.1000	.010
143	79	87	1.000	.1000	.010
144	80	86	1.000	.1000	.010
145	79	87	1.000	.1000	.010
146	80	88	1.000	.1000	.010
147	79	89	1.000	.1000	.010
148	79	91	1.000	.1000	.010
149	61	93	1.000	.1000	.010
150	61	92	1.000	.1000	.010
151	81	94	1.000	.1000	.010
152	59	60	24.000	.1000	.247
153	60	96	8.246	.1000	.085
154	59	95	42.048	.1000	.433
155	96	97	1.000	.1000	.010
156	95	98	1.000	.1000	.010
157	96	101	1.000	.1000	.010
158	95	102	1.000	.1000	.010
159	96	99	1.000	.1000	.010
160	95	100	1.000	.1000	.010
161	60	64	37.693	.1000	.388
162	59	63	37.693	.1000	.388
163	61	62	39.000	.1000	.402

TOTAL WEIGHT OF AXIAL ELEMENTS .... 103.920 POUNDS

TABLE E-III. FEA SHEAR PANELS

MEMBER	NODE1	NODE2	NODE3	NODE4	AREA	THICKNESS	WEIGHT
1	3	7	26	25	28.625	.0400	.118
2	4	8	26	25	28.625	.0400	.118
3	1	3	7	5	6.000	.0400	.025
4	2	4	8	6	6.000	.0400	.025
5	5	7	11	9	30.000	.0400	.124
6	6	8	12	10	30.000	.0400	.124
7	9	11	15	13	27.230	.0400	.112
8	10	12	16	14	27.230	.0400	.112
9	13	15	19	17	26.596	.0625	.171
10	14	16	20	18	26.596	.0634	.174
11	17	19	23	21	6.250	.1733	.112
12	18	20	24	22	6.250	.1743	.112
13	19	27	29	23	42.050	.0400	.173
14	20	27	28	24	42.050	.0400	.173
15	31	53	54	35	24.288	.0400	.100
16	32	53	54	36	24.288	.0400	.100
17	29	31	35	33	4.000	.1043	.043
18	30	32	36	34	4.000	.1029	.042
19	33	35	39	37	24.800	.0400	.102
20	34	36	40	38	24.800	.0400	.102
21	37	39	43	41	20.000	.0400	.082
22	38	40	44	42	20.000	.0400	.082
23	41	43	47	45	23.500	.0400	.097
24	42	44	48	46	23.500	.0400	.097
25	45	47	51	49	4.000	.0400	.016
26	46	48	52	50	4.000	.0400	.016
27	47	55	56	51	34.712	.0400	.143
28	48	55	56	52	34.712	.0400	.143
29	1	21	49	29	1580.321	.0400	6.511
30	2	22	50	30	1580.321	.0400	6.511
31	29	49	61	59	1358.079	.0400	5.595
32	30	50	62	60	1358.079	.0400	5.595
33	21	22	50	49	1599.000	.0400	6.588
34	1	2	30	29	1148.000	.0400	4.730
35	49	50	62	61	1443.000	.0400	5.945
36	29	30	59	59	521.171	10.0000	536.806
37	15	65	67	69	562.531	.0418	2.425
38	16	66	68	70	562.531	.0420	2.431
39	67	69	71	31	189.908	.0460	.900
40	68	70	72	32	189.908	.0465	.910
41	15	75	74	69	453.096	.0400	1.867
42	65	66	68	67	674.400	.0400	2.779
43	69	74	76	71	194.274	.0400	.800
44	67	68	32	31	309.600	.0400	1.276
45	15	16	66	65	680.559	.0400	2.804
46	31	32	72	71	389.664	.0400	1.605
47	67	69	74	73	194.832	.0443	.884
48	68	70	74	73	194.832	.0883	1.771
49	67	69	74	73	194.832	.0440	.884
50	70	72	76	74	194.274	.0400	.800
51	16	75	74	70	453.096	.0400	1.867
52	70	74	76	72	194.274	.0400	.800

TOTAL WEIGHT OF SHEAR PANEL ELEMENTS ..... 605.923 POUNDS

Nacelle Structural Details

The nacelle structure, Figure E-7, consists of a drive system suspension and mounting, and an aluminum-alloy envelope supported by frames and longerons.

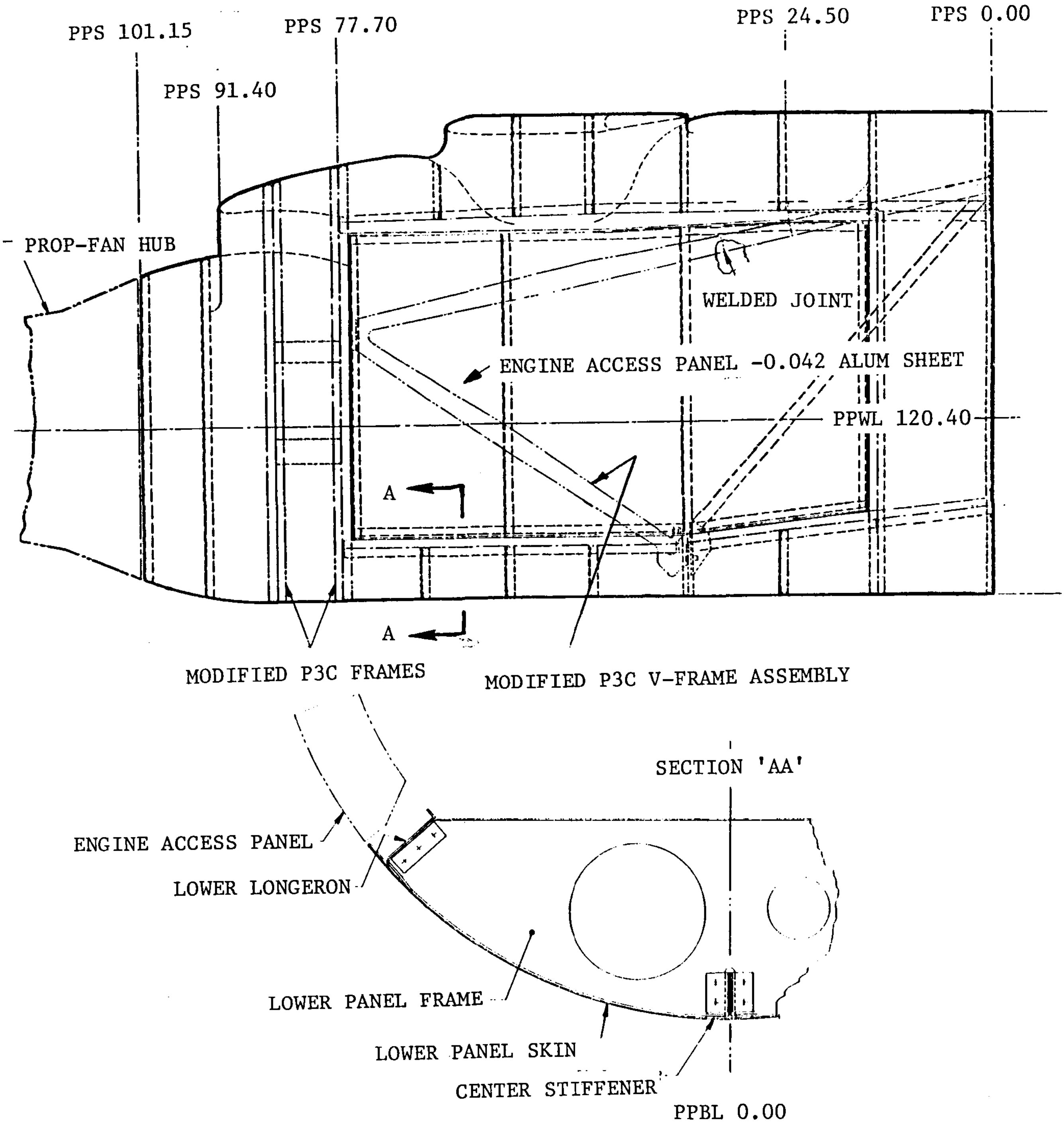


Figure E-7. Nacelle Structure

XT701 Mounting System - The mounting system for the XT701 is similar to that of the T56 installation in the Lockheed P-3C and consists of a suspension system and the supporting truss, longeron, and frame members.

The suspension system consists of seven mountings located and identified as follows:

Two (2) side front mountings, Lord P/N LM-204-5A19
Two (2) top front mountings, Lord P/N LM-204-5A28
One (1) bottom front mounting, Lord P/N LM-204-5A21
One (1) top rear mounting, Lord P/N LM-204-5A8
One (1) side rear mounting, Lord P/N LM-204-5A30

These mountings provide restraint in pitch, yaw, and torque and have been analyzed using the XT701/T56-A-14 limitations of 4175 kW (5600 shp) at 1600 rpm and a maximum torque of 2540 m-kg (220,500 in.-lb).

The analysis shows the P-3C suspension system to be acceptable for testbed aircraft application with a limit of 300 flight hours. A flight program beyond 300 hours will require further analysis to establish mounting suitability. The suspension system locations are shown on Figure E-8. The main mounts on each

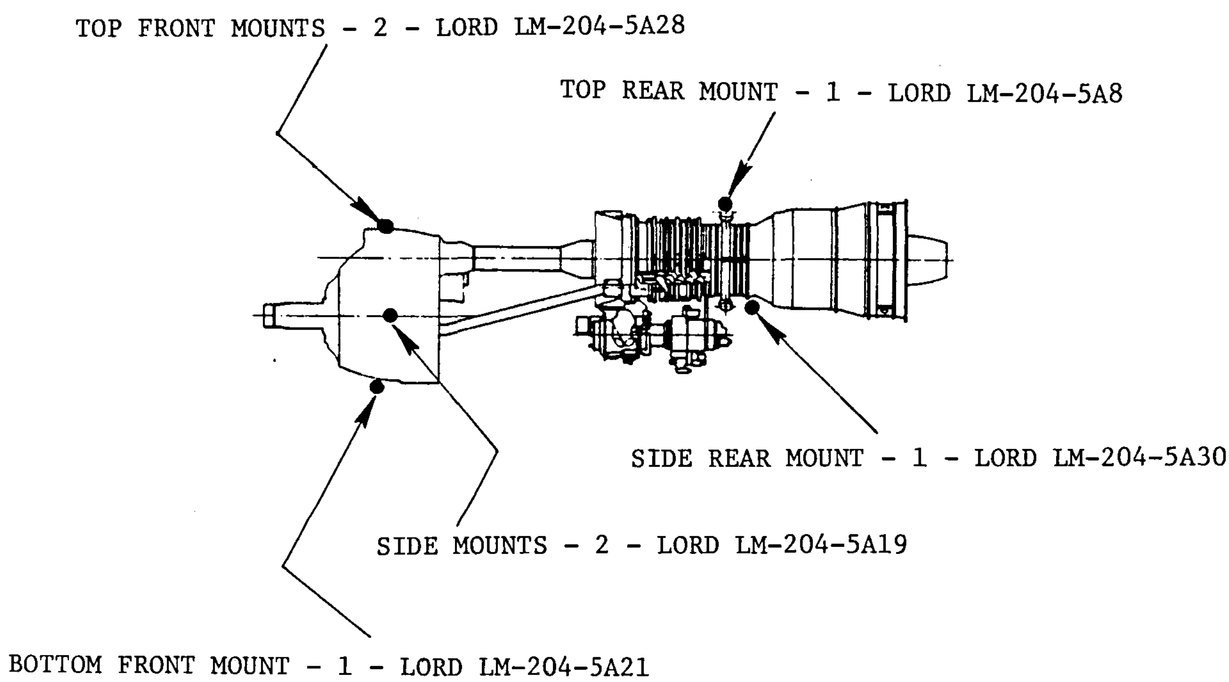


Figure E-8. DDA XT701 Suspension System Mount Location side of the gearbox react loads in all three directions. The top and bottom front mountings react fore and aft loads. The bottom mount is also designed to react vertical load in the event of a main mount failure. The aft upper mount and the side mount on the rear casing of the engine are designed for vertical and lateral loads respectively. The mounting structure consists of two forged frame members adjacent to the gear-box mounts, fore and aft V-frames, aft diagonals, and upper and lower longerons as shown in Figure E-7.

The V-frame members are fabricated from the P-3C nacelle V-frame part number 918829-1, parts as follows:

The upper tube Part No. 839477, made from 8630 steel tubing heat treated to 862,000kPa - 655,000 kPa at the flashwelds (125,000 psi - 95,000 psi at the flashwelds), is extended at the aft end by flash welding a similar piece of 8630 steel to form the lengthened upper tube of the truss. The aft upper fitting is a new part fabricated from 4340 steel welded to the upper tube. The new part is required because of the change in the angle of the faying surfaces at the mating plane. The forward fittings, also flashwelded to the upper tube, require new parts for the same reason.

The lower diagonal of the V-Frame, part number 839428, is used directly from the P-3C structure. This part is fabricated from 8630 steel tubing, heat-treated to 862,000 kPa - 655,000 kPa at the flashwelds (125,000 psi - 95,000 psi at the flashwelds) and is tapered from each end toward the center, with areas of 3.2 sq cm (0.495 sq in) at the ends and 3.32 sq cm (0.515 sq in) at the center. The lower attachment is a new part fabricated from 4340 steel.

Aluminum alloy, built-up aft diagonal members are connected to the V-Frame at the upper and lower ends. The outer flanges of these members are also attached to the nacelle outer skin. The lower longeron extension is also connected to the rear fitting of the lower diagonal and to the nacelle skin.

The forward support frames are manufactured from the P-3C forgings used for part numbers 918459-1 and 918468-1. The upper portion of each frame is modified to accommodate the engine air inlet for the

XT701 engine, and the lower portion requires changes in the flange bevel angles for compatibility with the "area ruled" spinner/hub.

The nacelle structure extends forward from PPS 0.0, the mating plane location, to PPS 101, the hub plane. The nacelle forebody consists of a formed, aluminum alloy upper portion, 1.0 mm (0.04 in) thick between PPS 77.7 and PPS 101.15 and includes the engine inlet lip. The lower portion is also a formed aluminum alloy structure 1.0 mm (0.04 in) thick. Channel-section frames are located at intermediate stations to support the forebody structure. Between PPS 0.0 and PPS 77.70, the nacelle structure is an arrangement of shear panels, longerons and frames. Frames are located at approximately 25.4 cm (10.0 in) spacing and consist of aluminum alloy channel sections which, with the upper and lower longerons, form the basic skeletal structure of the nacelle. The upper and lower shear panel skins are aluminum alloy 1.0 mm (0.04 in) and 2.54 mm (0.10 in) thick. The longerons are built-up from aluminum alloy extrusions and sheet and have cross-sectional areas of 0.65 sq cm (0.10 sq in) for the upper and 0.8 sq cm (0.12 sq in) for the lower. The lower longeron extension, from the aft portion of the V-Frame lower diagonal, is reduced to an area of 3.7 sq cm. (0.57 sq in) and is also fabricated from aluminum alloy. The aluminum alloy diagonal member, extending upward from the lower fitting of the V-frame lower diagonal to the V-frame upper tube joint, at the mating plane bulkhead, is a built-up structure having a total cross-sectional area of 3.22 sq cm (0.5 sq in).

The side panels between PPS 0.0 and PPS 77.70 and the upper and lower longerons are aluminum alloy 1.0 mm (0.04 in) thick. Portions of the side panels are removable for access to the engine. An S-duct, located between PPS 77.7 and the engine compressor casing, is fabricated from stainless steel sheet supported by external rings.

The upper shear panel is configured to accommodate the ducting for the oil cooler and its inlet and exhaust. A controllable flap is provided on the exit duct to control the cooling air mass flow as required.

The mating plane bulkhead located at PPS 0.0 also serves as the fire barrier and is fabricated from 1.0 mm (0.04 in) thick titanium sheet, for the web, and aluminum alloy extruded sections at the inner and outer boundaries. The main attachment points for the engine nacelle to the airframe aft nacelle are located on the bulkhead at the ends of the upper tubes and lower longeron extensions.

DRIVE SYSTEM INSTALLATION

The drive system is installed in the nacelle, together with those accessories and systems necessary to operate the prop-fan unit, as shown on Figure E-9. A modified 54H60 control unit is used for prop-fan control and is located at the rear of the prop-fan hub. The engine fuel control is a hydro-mechanical device having an electronic supervisory system. The engine starting system uses air bled from the primary engines, conducted to an AiResearch Starter No. ATS100-397, located on the underside of the XT701 compressor case. Fuel and air line disconnects are provided on the mating bulkhead for the QEC. The oil cooling system uses the heat-exchanger from the C-130 T56 installation. A new oil tank is located below the torquemeter immediately behind the gearbox.

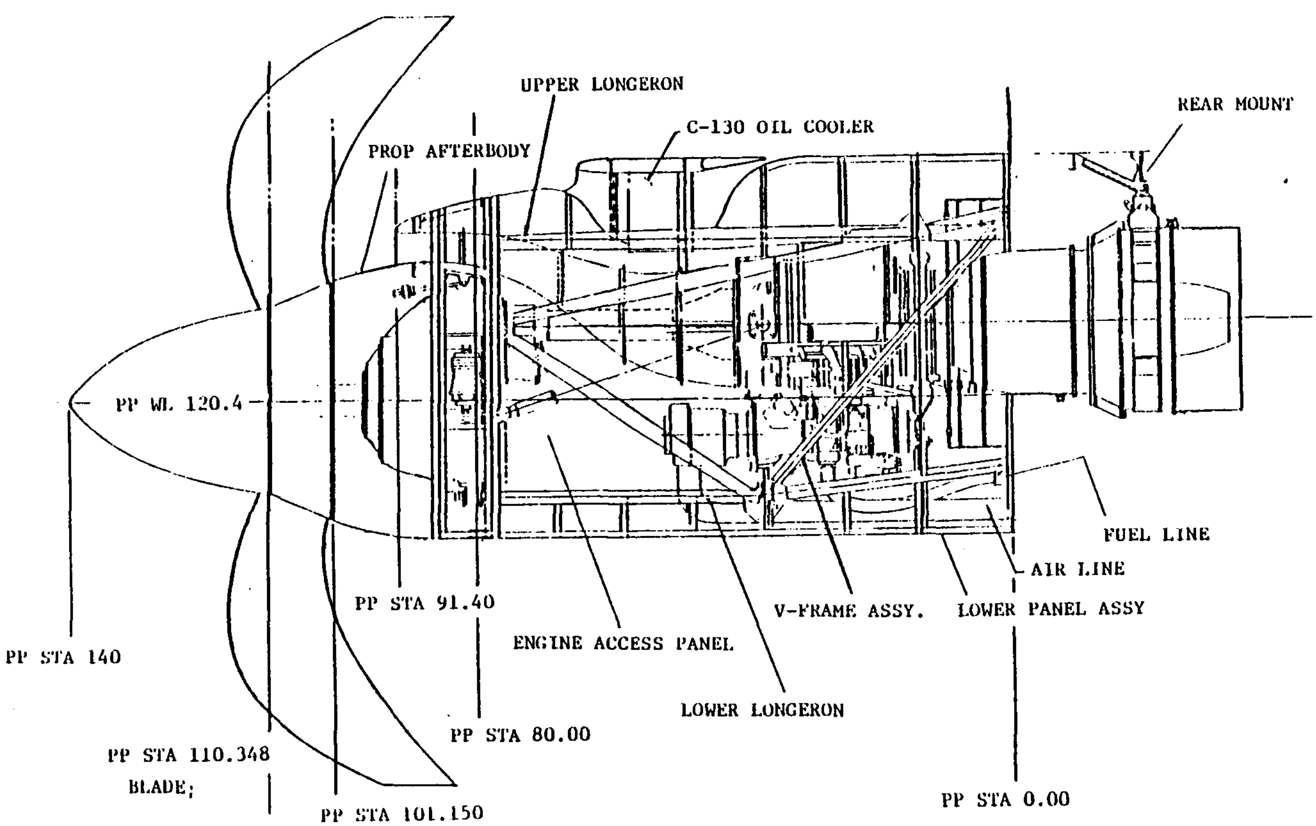


Figure E-9. Drive System Installation

BOEING KC-135A TESTBED SYSTEM CONCEPTUAL DESIGN

The USAF series KC-135A aircraft is a high-performance, jet-propelled, tanker-transport, low-wing aircraft. The C-135A and the Boeing 707-100 series are outwardly identical to the KC-135A, except for the removal of the aerial refueling boom. The KC-135A can, therefore, be regarded as a reasonable representation of a commercial aircraft configuration for the purpose of the conceptual design. The main differences between the military tanker-transport and commercial versions are the lack of windows, cargo stressed floor, side cargo door, and the lack of commercial cabin furnishings and trim. These are not, however, considered to significantly affect the KC-135A suitability as a vehicle for the test of acoustic attenuation concepts for near-field acoustic tests. The principal dimensions and characteristics for the C-135A, KC-135A and 707-100 series airplanes are given on Table E-IV. The KC-135A configured as a twin prop-fan testbed aircraft is shown on Figure E-10 for the "Pinion-high" overwing installation.

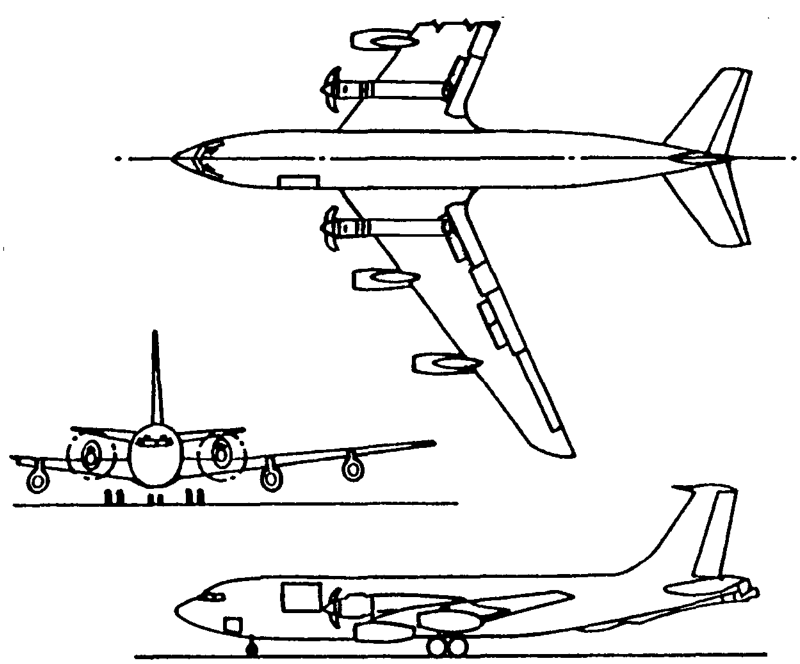


Figure E-10. KC-135A Twin Prop-Fan Testbed Configuration

Drive System Location and Geometry

The inboard wing scantlings and sections of Figure E-11 were used to locate the prop-fan drive system installation and for the development of the wing sections adjacent to the installation. The drive systems are "pinion-high" overwing installations located at WBL 217 LH and RH, with each installation vertical plane normal to the wing chord plane. Each nacelle is placed with the prop-fan centerline located at WL 217.995, which provides adequate clearance between the wing upper cover and the jet exhaust pipe. The nacelle installation geometry is shown on Figure E-12. Overall, the length of the installation from the spinner tip to the end of the jet pipe is 9.2 m (362 in) and is a maximum of 1.6 m (62 in) wide. The height of the nacelle above the wing chord plane is 1.04 m (40.8 in).

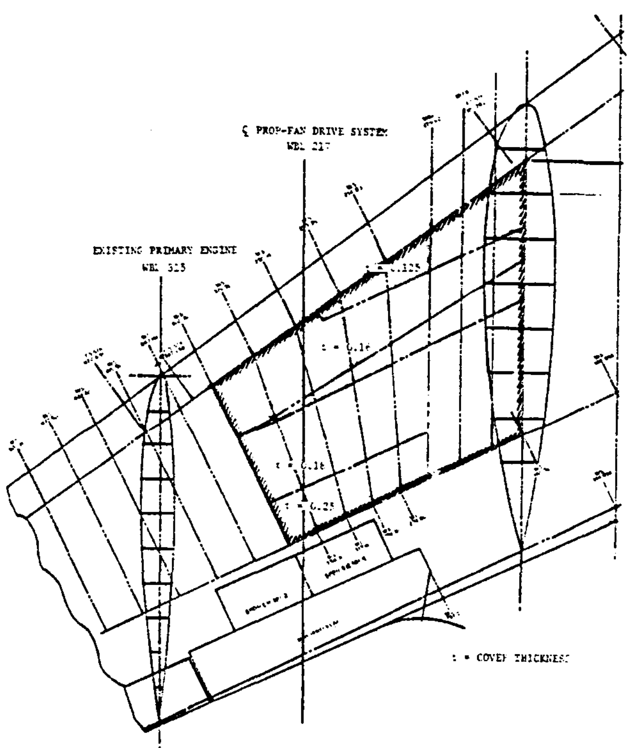


Figure E-11. KC-135A Inboard Wing Scantlings

KC-135A Aft Nacelle Structure

The aft nacelle structure consists of a skin-frame-longeron structure extending aft from the nacelle mating plane at FS 707.56 to approximately FS

TABLE E-IV. KC-135A PRINCIPAL DIMENSIONS AND CHARACTERISTICS

	KC-135A	C-135A	707-100
RAMP WEIGHT Kg (LB)	136,926 (301,600)	126,893 (279,500)	117,132 (258,000)
OPERATING WEIGHT Kg (LB)	117,132 (258,000)	65,494 (99,359)	49,801 (109,695)
FUEL WEIGHT Kg (LB)	92,071 (202,800)	85,656 (188,670)	40,996 (90,300)
WING SPAN M (FT)	39.87 (130.83)	39.87 (130.83)	39.87 (130.83)
OVERALL LENGTH M (FT)	41.56 (136.25)	41.02 (134.5)	41.20 (135.083)
HEIGHT M (FT)	12.7 (41.67)	12.7 (4167)	12.7 (41.67)
WING			
AREA SQ M (SQ FT)	226 (2433)	226 (2433)	226 (2433)
ROOT CHORD M (INS)	8.58 (337.98)	8.58 (337.98)	(337.98)
TIP CHORD M (INS)	2.84 (112)	2.84 (112)	2.84 (112)
MAC M (INS)	6.14 (241.88)	6.14 (241.85)	6.14 (241.88)
t/c @ WBL 70.5	15.6%	15.6%	15.6%
t/c @ WBL 360	9%	9%	9%
t/c @ WBL 780	9%	9%	9%
INCIDENCE RADS (DEGS)	0.035 (2)	0.035 (2)	0.035 (2)
DIHEDRAL RADS (DEGS)	0.122 (7)	0.122 (7)	0.122 (7)
SWEEP ¼ C RADS (DEGS)	0.61 (35)	0.61 (35)	0.61 (35)
ASPECT RATIO	7.065	7.065	7.065
HORIZONTAL STABILIZER			
AREA SQ M (SQ FT)	46.51 (500)	46.51 (500)	46.51 (500)
SPAN M (FT)	12.11 (39.7)	12.11 (39.7)	11.50 (37.7)
ROOT CHORD M (INS)	5.28 (208)	5.28 (208)	5.28 (208)
TIP CHORD M (INS)	2.41 (95.05)	2.41 (95.05)	2.41 (95.05)
MAC M (INS)	3.99 (157)	3.99 (157)	3.99 (157)
ASPECT RATIO	3.2	3.2	3.2
VOLUME COEFF V_H	.62	.62	.62
VERTICAL STABILIZER			
AREA SQ M (SQ FT)	30.5 (328.3)	30.5 (328.3)	30.5 (328.3)
SPAN M (FT)	7.53 (24.7)	7.53 (24.7)	7.53 (24.7)
ROOT CHORD M (INS)	6.15 (242)	6.15 (242)	6.15 (242)
TIP CHORD M (INS)	2.21 (86.92)	2.21 (86.92)	2.21 (86.92)
MAC M (INS)	4.44 (174.6)	4.44 (174.6)	4.44 (174.6)
ASPECT RATIO	(1.8)		
VOLUME COEFF V_V	.064	.064	.064
FUSELAGE			
MAX WIDTH M (FT)	3.66 (12)	3.66 (12)	3.66 (12)
MAX HEIGHT M (FT)	5.44 (17.83)	5.44 (17.83)	5.44 (17.83)
OVERALL LENGTH M (FT)	39.27 (128.83)	39.27 (128.83)	42.3 (138.83)
PROPULSION SYSTEM			
TYPE	P&W J57	P&W J57	P&W JT3C-6
INBOARD LOCATION	WBL 315 $\eta = 0.402$	WBL 315 $\eta = 0.402$	WBL 315 $\eta = 0.402$
OUTBOARD LOCATION	WBL 545 $\eta = 0.694$	WBL 545 $\eta = 0.694$	WBL 545 $\eta = 0.694$
MAX TAKEOFF THRUST (NET) N (LB)	49,840 (11,200)	49,840 (11,200)	60,075 (13,500)

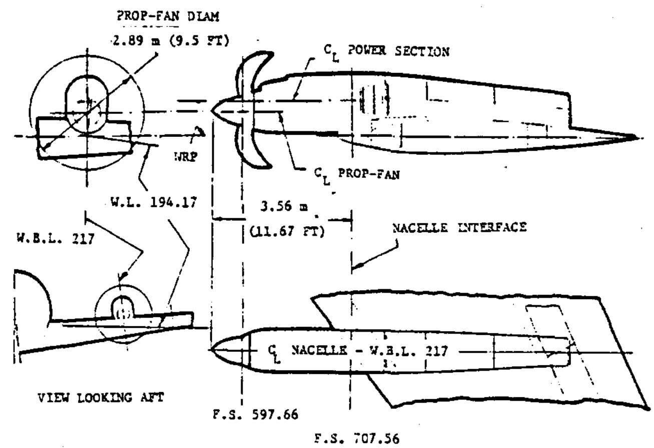


Figure E-12. Nacelle Installation Geometry

928, as shown on Figure E-13. This portion of the nacelle is 5.6 m (221 in) long and varies in height above the wing from 1.14 m (45 in) to 0.9 m (35 in) at the center line. As far as possible, the aft nacelle contours are designed with single curvature panels and consist of a semi-circular upper section and straight sides from the maximum beam to the intersection of the nacelle side wall with the wing upper contour. An aluminum alloy "skate" angle is attached to the wing upper surface, providing attachment for the nacelle side walls and for lower pick-up points on the engine nacelle. Upper diagonal ties from the upper attachment are secured to the front spar, adjacent to the skate angles, on the wing upper surface. Lower diagonal truss members are attached to the lower QEC unit pick-up points and extend downward and aft to an attachment located on the nacelle centerline at the front spar/lower cover junction. These members form a V-truss and transfer load into the lower skin cover by means of an external "tee" support. Reinforcement of the covers, except for local increases in thickness to provide bearing material for nacelle structure attachment, is not required. The aft nacelle structure frames are spaced approximately at 30.5 cm (12.0 in) intervals. The frames are formed aluminum alloy channel sections 1.0 mm (0.04 in) thick. Extruded aluminum-alloy longerons, at the maximum beam of the nacelle, form the boundary between the straight-sided walls of the nacelle and the semi-circular upper covers. Access to the jet pipe is provided by three removable panels. In general, the nacelle skins are aluminum alloy 1.0 mm (0.04 in) thick supported by longitudinal "tee"-section aluminum alloy extruded stiffeners. The aft portion of the nacelle terminates slightly forward of the trailing edge of the inboard spoilers, and a fairing is added to protect

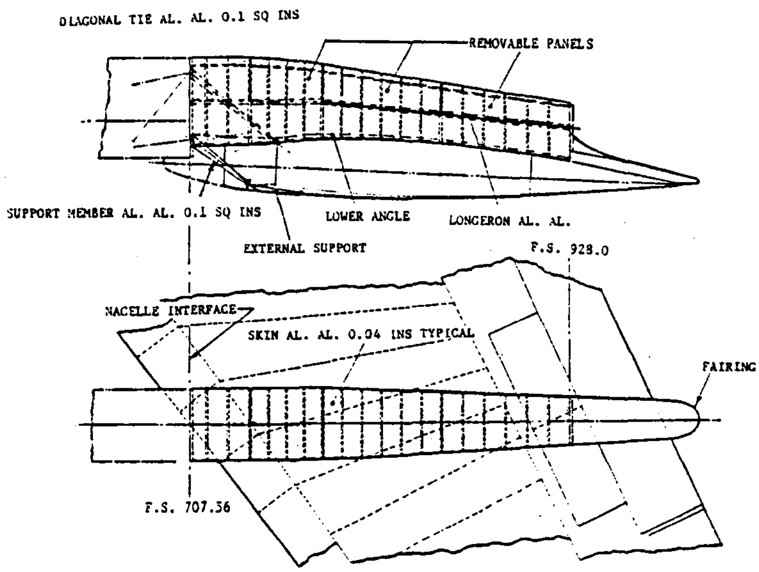


Figure E-13. KC-135A Aft Nacelle Structure

the upper surface of the flap from the jet blast. Because the nacelle covers the inboard spoilers, it is necessary to lock-down both spoilers and disconnect both from the spoiler system. The KC-135A wing is a two-spar distributed structure consisting of constant-thickness, roll-tapered or machined, aluminum-alloy skins and of extruded "Z"-section stiffeners. In general, the stiffeners are 6.35 cm (2.5 in) deep and vary in thickness from 2.39 mm to 7.62 mm (0.094 in to 0.30 in). The upper cover thicknesses in the area of the prop-fan installation vary from 3.18 mm to 6.35 mm (0.125 in to 0.25 in). Cover and stiffener material is aluminum alloy 7178-T6. The front spar in the region of the prop-fan installation has a web 2.29 mm (0.09 in) thick and extruded aluminum-alloy "tee" section caps. Where possible, attachment of the nacelle structure will be accomplished by picking up existing fastener locations in the upper cover. The addition of fasteners in excess of those already in the structure will be performed without degradation of the strength or stiffness of the wing primary structure.

KC-135A Testbed Flutter Analysis

A preliminary wing flutter analysis was performed for the KC-135A testbed configuration to determine the effects of the prop-fan powerplant installation on the wing flutter stability. A semi-span (half-airplane) mathematical model, which implies structural and aerodynamic symmetry about BL 0.0, was used. The results of the analysis are, therefore, directly applicable to a symmetrical 2-engine testbed configuration.

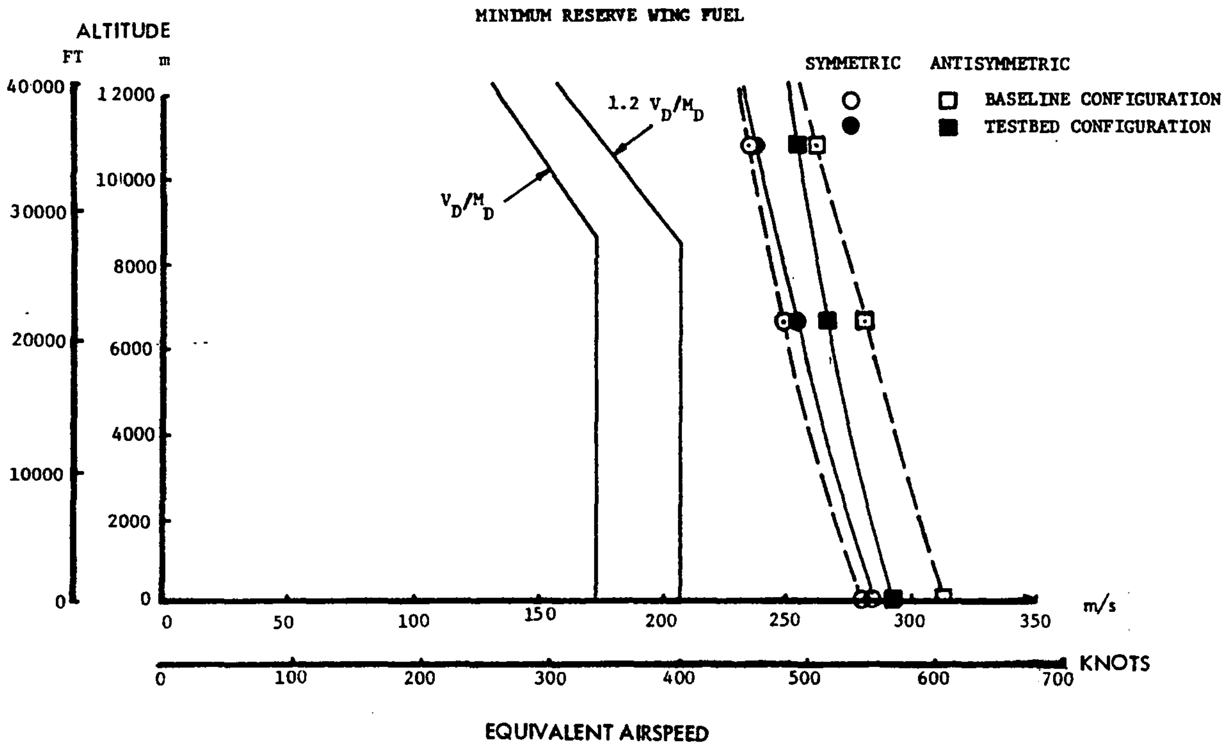
Structural Representation - The structural representation used in the analysis consisted of a flexible wing with flexibly mounted turbojet and prop-fan powerplants and a rigid fuselage-empennage. The flexible wing was represented as a 10-lumped mass system with freedom in vertical and fore-and-aft bending, and torsion. The pylon flexibilities for the primary turbojet engines were each represented by one vertical and one side bending mode. All mass and stiffness data for the basic airplane were taken from the Reference 4.

The prop-fan powerplants were represented as additional sprung and unsprung mass lumps located at BL 217. The sprung mass of 1378 kg (3040 lb) represented the propeller, gearbox, and engine and had uncoupled mode frequencies of 5.72 Hz (lateral), 7.51 Hz (vertical), 8.68 Hz (yaw), and 9.93 Hz (pitch). The unsprung mass of 703kg (1550 lb) represented the fixed nacelle structure and wing local strengthening.

Aerodynamic Representation - The unsteady aerodynamic forces on the wing were computed by the Theodorsen strip theory. Finite span and compressibility effects were accounted for approximately by local lift-curve slope and aerodynamic-center modifications, which were based on vortex lattice calculations for a speed of M = 0.85. The wing aerodynamic forces were computed for 10 strips which coincided with the 10 mass panels. No unsteady aerodynamic forces were applied to the fuselage or empennage surfaces.

Aerodynamic forces on the prop-fan were computed by quasi-steady strip theory, modified for lift lag due to unsteady flow. The prop-fan blade lift-curve slope distribution data were calculated by Hamilton Standard for the 8-blade SR-3 prop-fan operating at M = 0.8.

Flutter Analysis Results - The results of the flutter analysis are summarized in Figure E-14. The unmodified KC-135A wing was analyzed first, since Boeing data were not available to form a basis for comparison. A single weight condition of 86,432 kg (190,590 lb), condition "C" of Reference 4, was analyzed. This weight condition includes structural reserve wing fuel of 1405 kg (3100 lb) and 37,786 kg (83,323 lb) of fuselage fuel. The critical flutter mode for the symmetric and unsymmetric conditions was characterized by wing outer panel bending-torsion at a frequency of about 11 to 12 Hz. The symmetric flutter



Comparison of Predicted and Measured
Wing Vibration Modes (No Prop-fans)

Symmetric

Mode	Predicted Freq. (Hz)	Measured Freq. (Hz)	fp/fm
Wing 1st bending	4.31	4.40	.980
Wing 2nd bending	16.42	13.56	1.21
Wing 1st torsion	19.27	19.42	.992
Wing 2nd torsion	38.39	38.76	.990
Antisymmetric			
Wing 1st bending	5.15	5.12	1.06
Wing 2nd bending	12.30	9.66	1.27
Wing 1st torsion	18.18	18.32	.992
Wing 3rd bending	35.70	36.59	.976

Figure E-14. KC-135A Testbed Flutter Boundaries speed was lower, as shown in Figure E-14, but was outside the required 1.15 V_D envelope of the unmodified KC-135A.

The addition of the prop-fan powerplant, with nominal attachment flexibilities and propeller aerodynamic and gyroscopic effects, caused the flutter speeds to change slightly, as the flutter mode involved mainly outer wing motion. The unsymmetric flutter speed decreased slightly, and the symmetric flutter speed increased slightly as indicated by the solid square and circle symbols, respectively. Elimination of the propeller aerodynamic and gyroscopic effects and changes in the prop-fan powerplant attachment flexibilities caused negligible changes in the flutter speeds. It was concluded from these results that the prop-fan installation will have negligible effect on the wing flutter characteristics of the KC-135A aircraft and that no changes to the wing structure will be required for flutter prevention.

KC-135A Testbed Operating Envelope

The KC-135A testbed flight envelope, Figure E-15, was derived from KC-135A data. The design dive Mach number, 0.88, is sufficiently beyond the testbed design requirements of Mach 0.8 at 9118 and 10,668 m (30,000 and 35,000 ft) to obviate the need for speed restrictions on the testbed aircraft over the full range of flight conditions.

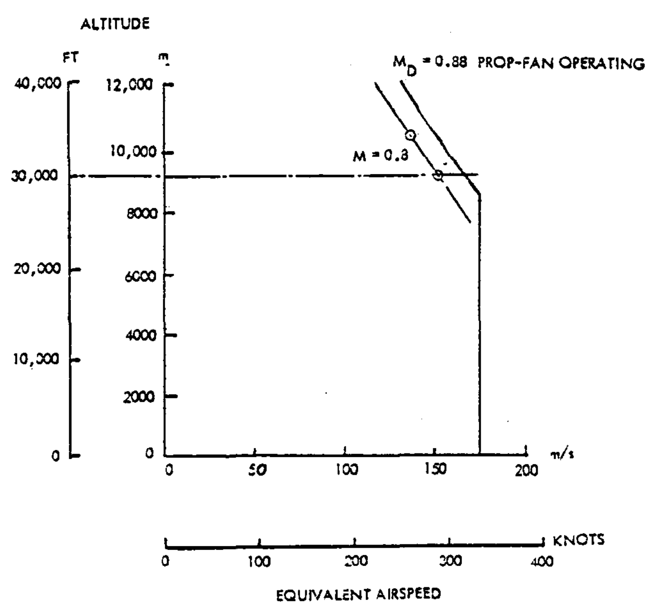


Figure E-15. KC-135A Testbed Operating Envelope

KC-135A Testbed Performance

The performance of the KC-135A testbed aircraft with twin prop-fans is shown on Figure E-16. Data are given for two weight conditions representing start and end cruise test weights of 81,630 kg (180,000 lb) and 54,420 kg (120,000 lb), respectively. The capability of the KC-135A is given for the unmodified aircraft for two conditions: three engines at normal rated thrust (NRT) and one windmilling and with four engines at NRT. These data show the capability of the basic aircraft to satisfy the testbed aircraft design requirements. The remaining data demonstrates the capability of the testbed configuration to meet the design requirements. Operating three primary engines at NRT and the two prop-fans at a power equivalent to the thrust output of a primary engine at NRT provides a speed margin of ΔM = 0.05 to ΔM = 0.07 over the altitude range 9144 m to 12,192 m (30,000 to 40,000 ft). The testbed aircraft, at the true start and end cruise weights of 84,673 kg (186,710 lb) and 55,476 kg (122,330 lb), provides a test mission duration of 4.7 hours. This test mission duration will provide adequate time to set up test conditions and to accumulate test data.

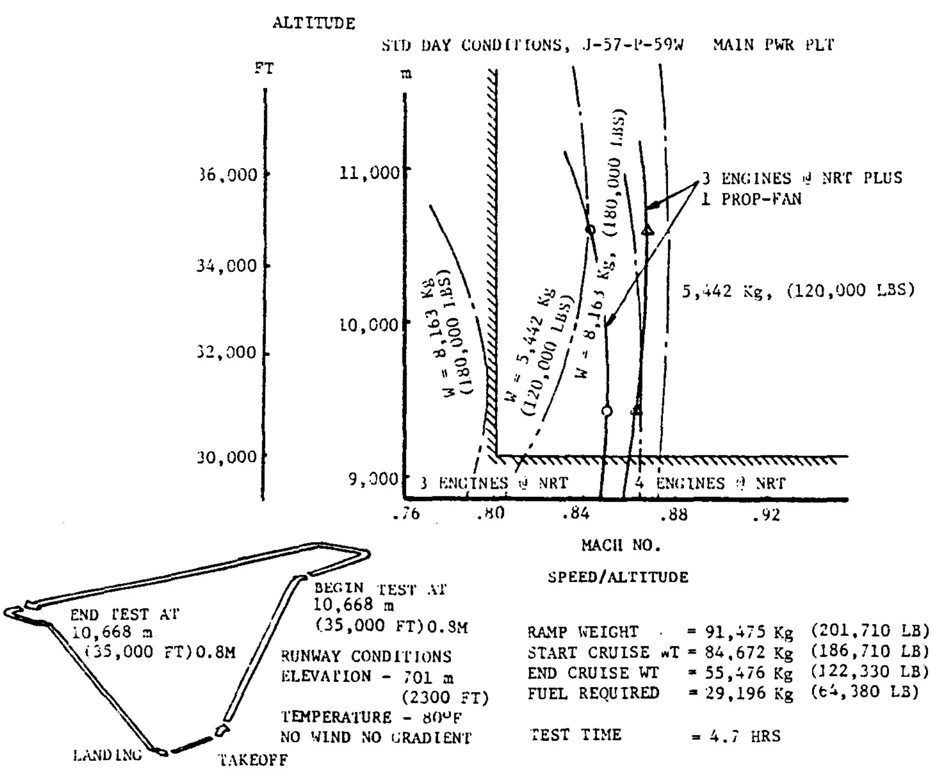


Figure E-16. KC-135A Performance

KC-135A Testbed Weight and Balance

Weight and balance data for the testbed aircraft are shown on Table E-V. The wing fuel capacity of the unmodified airplane is 49,431 kg (109,500 lb). Since the mission fuel required is less than the wing-tank capacity, all mission fuel can be carried in the wing tanks so that the center-of-gravity will move aft as fuel is loaded and forward as it is consumed. The center-of-gravity at operating weight can be maintained in any position for the modified aircraft by proper location of the test equipment. The normal range of center-of-gravity movement is from 12.5 percent MAC to 35 percent MAC. At ramp gross weight the testbed aircraft center-of-gravity at 26.4 percent MAC can operate within this range as shown in Figure E-17.

TABLE E-V.
KC-135A WEIGHT AND BALANCE

WEIGHT COMPONENT	LOCATION % MAC	WEIGHT KG	WEIGHT LB	ARM FS
• OPERATING WEIGHT UNMODIFIED	30	41117	(90,666)	850.6
2-XT701 PROP-FAN PACKAGES		3906	(8614)	662.9
OVERWING NACELLE STRUCTURE		296	(654)	798.0
TEST EQUIPMENT		1360	(3000)	964.1
• ZERO FUEL WEIGHT	25	49129	(108,334)	838.5
FUEL		42346	(93,376)	
• RAMP GROSS WEIGHT		91475	(201,710)	

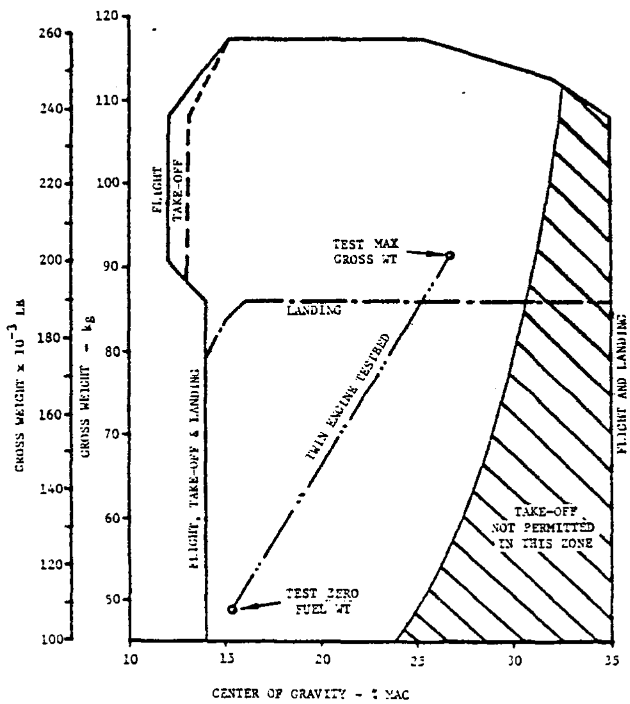


Figure E-17.

KC-135A Center-of-Gravity Range

GAC GII TESTBED CONCEPTUAL DESIGN

The GAC GII is a high-performance, jet propelled, low-wing, business/executive aircraft. The GII has sufficient volume in the passenger area to seat a maximum of 19 passengers and can fly cruise missions at M = 0.80 and M = 0.85 of 4723 to 5648 km (2550 to 3050 nm) and 3389 to 4000 km (1830 to 2160 nm) respectively. The unmodified aircraft performance, i.e., speed/altitude, has been shown to be in excess of the design requirement for the testbed aircraft, and previous analyses have shown that the XT701 power/aircraft/prop-fan scale to be compatible with a GII powered by the DDA XT701/T56-A-14 drive system. The principal dimensions and characteristics for the GII are given in Table E-VI. Two testbed configurations were investigated; that shown in Figure E-18 is the testbed with the drive systems located at BL 145 left and right, $\eta = 0.35$, for which Figure E-19 shows the corresponding nacelle geometry. Figure E-20 illustrates the drive systems located at BL 185, $\eta = 0.45$, the limiting outboard location.

GII Drive System Location and Geometry

The GII wing scantlings and sections, Figure E-21 were obtained from data supplied by GAC and were used to locate the drive systems on the wings. Two locations were investigated, as indicated above. The first location chosen, shown on Figure E-18, was at BL 145.0 $\eta = 0.35$, because a change in wing thickness occurs from this location inboard and adequate back-up structure for the prop-fan installation exists in the wing. This location is the limiting position inboard for the 2.89 m (9.5 ft) diameter prop-fan as far as clearance and interference with the airflow to the primary engines is concerned. Mounting the drive system at BL 145.0 places the mating plane for the nacelle/airframe at FS 385.98, the location of the wing leading edge at BL 145.0. In keeping with the recommendations of Hamilton Standard for minimizing excitation factors, the mating plane is inclined forward 0.0174 rad (1 deg) from the vertical plane through FS 385.98. In the normal ground attitude, the ground/prop tip clearance is 0.513 m (20.2 in). The prop-fan shaft centerline, located at WL 73.52 and FS 386.98 at the mating plane, positions the power section centerline so that

TABLE E-VI. GULFSTREAM II PRINCIPAL DIMENSIONS AND CHARACTERISTICS

RAMP WEIGHT Kg (LB)	28,375 (62,500)
OPERATING WEIGHT Kg (LB)	15,481 (34,100)
FUEL WEIGHT MAX Kg (LB)	10,578 (23,300)
WING SPAN M (FT)	21.0 (68.83)
OVERALL LENGTH M (FT)	24.4 (79.92)
OVERALL HEIGHT M (FT)	7.5 (24.5)
WING	
AREA SQ M (SQ FT)	73.7 (793.5)
ROOT CHORD M (FT)	5.08 (16.67)
TIP CHORD M (FT)	1.93 (6.34)
MAC M (FT)	3.75 (12.28)
t/c ROOT	12.05%
t/c TIP	8.42%
DIHEDRAL RADS (DEGS)	0.052 (3°)
SWEEP C/4 RADS (DEGS)	0.436 (25°)
ASPECT RATIO	6.0
HORIZONTAL STABILIZER	
AREA SQ M (SQ FT)	16.93 (182.25)
SPAN M (FT)	8.23 (27)
ROOT CHORD M (FT)	2.74 (9)
TIP CHORD M (FT)	1.37 (4.5)
MAC M (FT)	2.13 (7)
ASPECT RATIO	4.0
VOLUME COEFF V_H	0.677
DIHEDRAL	0
VERTICAL STABILIZER	
AREA SQ M (SQ FT)	14.38 (154.7)
SPAN M (FT)	3.75 (12.3)
ROOT CHORD M (FT)	4.65 (15.25)
TIP CHORD M (FT)	3.022 (9.92)
MAC M (FT)	3.89 (12.77)
ASPECT RATIO	1.0
VOLUME COEFF	0.073
FUSELAGE	
MAX WIDTH M (FT)	2.39 (7.84)
MAX HEIGHT M (FT)	2.39 (7.84)
LENGTH M (FT)	21.74 (71.33)
PROPULSION SYSTEM	
TYPE	RR "SPEY" KK511-8 (RB 163-25)
LOCATION	AFT FUSELAGE
MAX TAKEOFF THRUST N (LB)	50707 (11400)

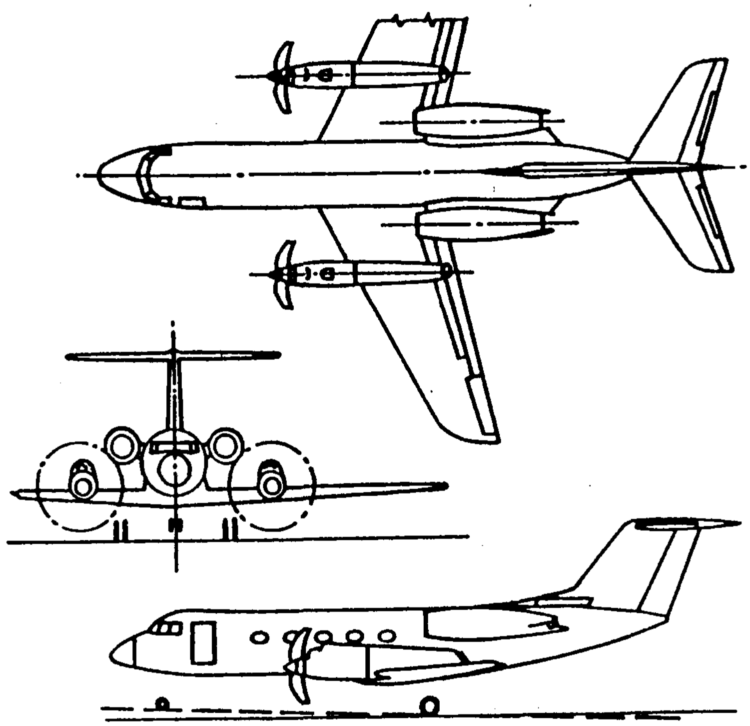


Figure E-18. GII Twin Prop-Fan Testbed Configuration

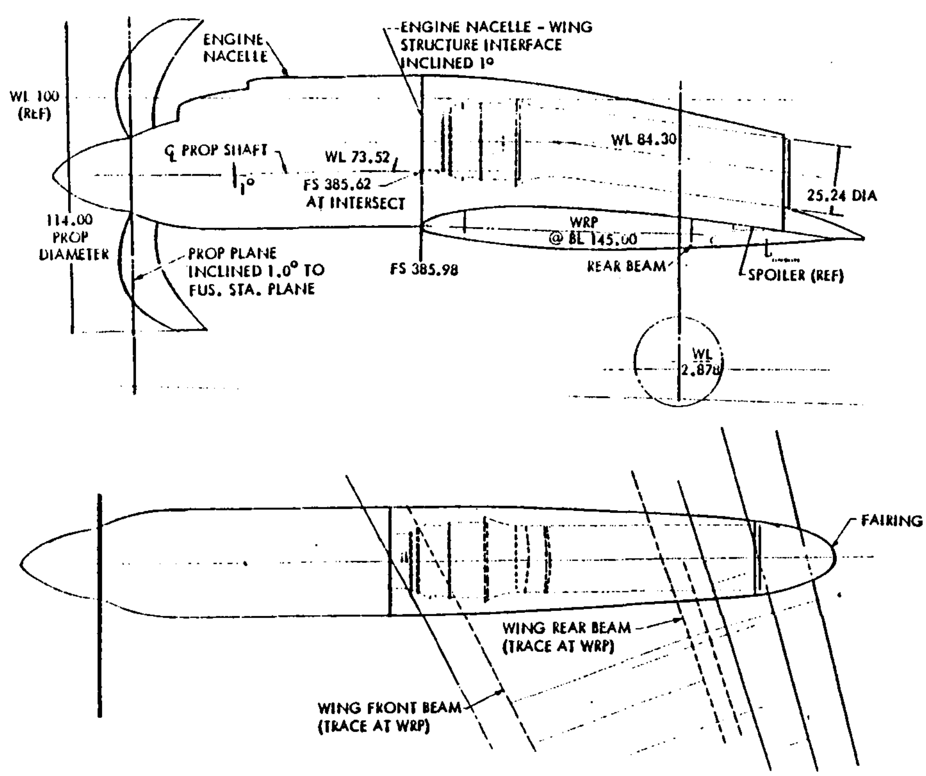


Figure E-19. GII XT701 Nacelle Geometry

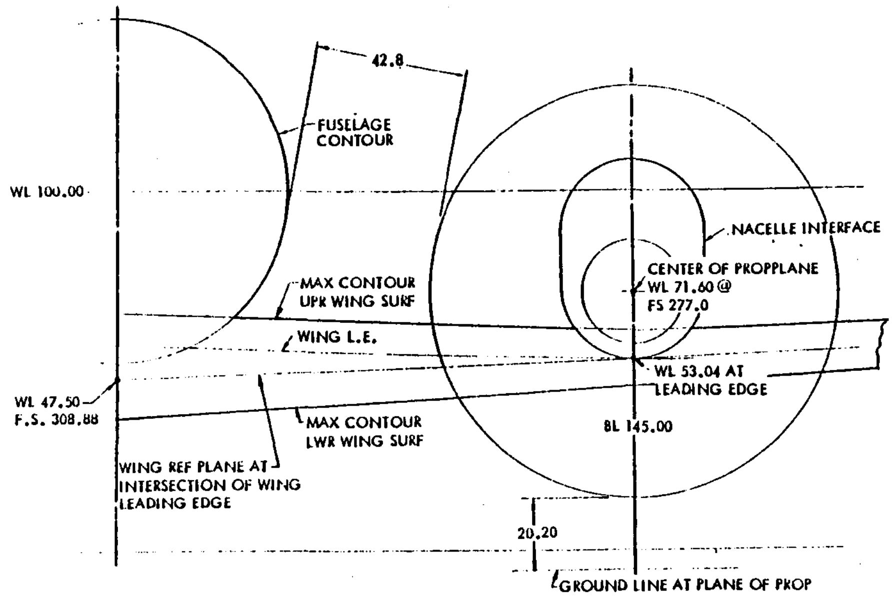


Figure E-19. GII Testbed Nacelle Geometry B.L. 185 (Cont'd)

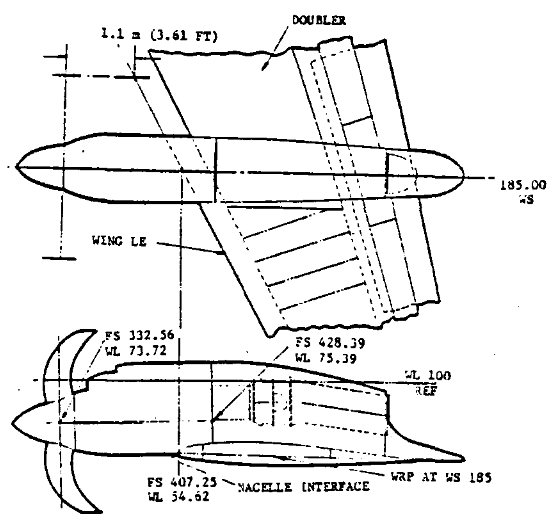


Figure E-20. GII Testbed Nacelle Geometry B.L. 185

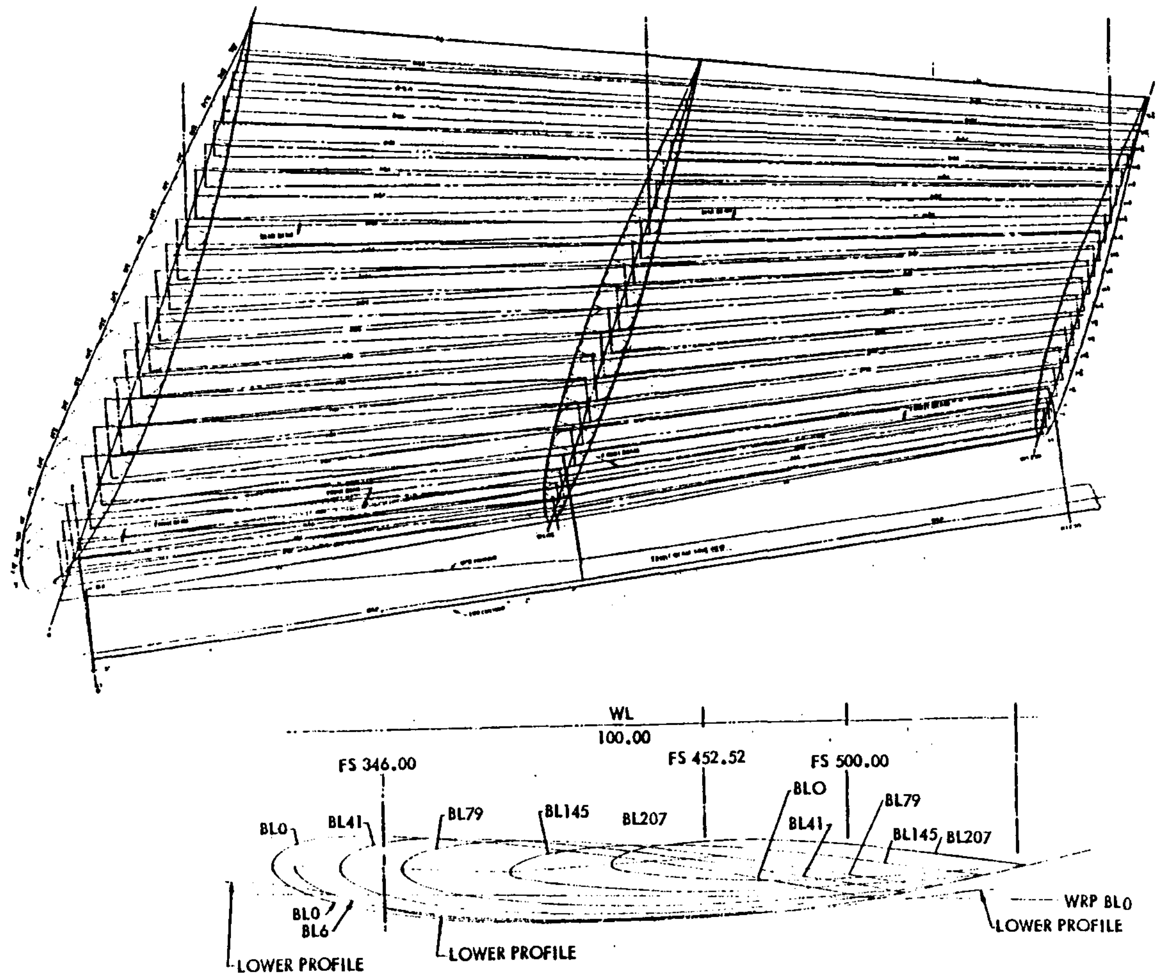


Figure E-21. GII Wing Scantlings

sufficient clearance is provided between the upper surface of the wing and jet pipe. This geometry is a compromise location to minimize the torque effects of the prop-fan thrust on the wing box structure and to maximize the prop-fan tip/ground clearance in the normal ground attitude.

A second location at BL 185, $\eta = 0.45$ Figure E-19, was also investigated, since this position represented the limiting position outboard on the wing, at which engine-out conditions could be controlled. At this location the prop-plane required 0.914 m (36 in) of movement aft to partially satisfy flutter requirements.

The nacelle/airframe interface plane is located at FS 407.25 and WL 54.62, the wing leading edge at BL 185, and is inclined 0.017 rads (1 deg) forward from the vertical plane through this location. The intersection of the prop-fan plane and shaft center line is at FS 332.56 and WL 73.72 and the prop-fan shaft center line through this point is normal to the interface plane.

The data for the two locations, which represent the limits of inboard and outboard movement for the drive system, were generated to establish the clearances between prop-fan tip and fuselage external surface. Near-field acoustic considerations, relative to cabin noise attenuation, recommended a minimum clearance of 0.8 D_p (where D_p is the prop-fan diameter). At the BL 145 location the clearance is 1.087 m (3.57 ft) or 0.375 D_p. At BL 185 the clearance increases to 2.062 m (6.77 ft) or 0.71 D_p. Although less than the recommended clearance these clearances should not prevent the use of the GII a vehicle for acoustic tests.

GII Aft Nacelle Structure, Drive System at BL 145

The aft nacelle structure mounted on the wing upper surface at BL 145.0 is shown on Figure E-22. The nacelle structure consists of two vertical side panels capped by a semi-circular removable cowl structure. The aft nacelle extends from the mating plane to the end of the jet pipe located approximately at the trailing edge of the spoilers. The structure consists of an assembly of skins, frames, longerons, and stiffeners of aluminum alloy. The engine QEC pick-up points match similar attachment points on the aft nacelle at the mating plane, and the structure is arranged so that the upper attachments coincide with the main diagonals which are connected to the rear spars of the wings at the lower end. The nacelle attachment angles on the upper surface of the wing pick-up the QEC lower attachments and the diagonal members at the aft ends. The skins, which are 1.0 mm (0.04 in) thick are supported every 25.4 cm (10 in) by 10 cm (4.0 in) deep channel section frames. Longerons on each of the nacelle walls located on the maximum beam of the envelope also serve as boundary members for the removable semi-circular panels. Frame thickness is 1.0 mm (0.04 in) and the areas of the longerons, main diagonals and attachment angles are approximately 4.0 sq cm (0.6 sq in).

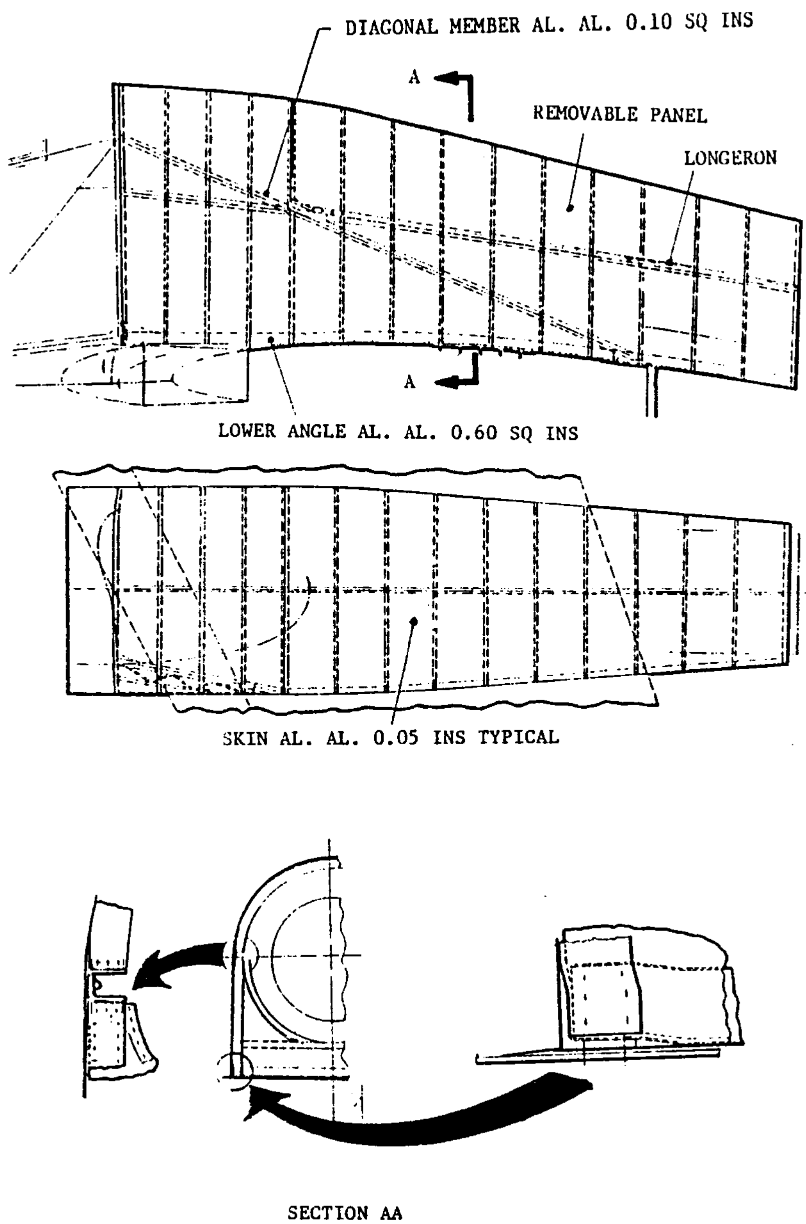


Figure E-22. GII Aft Nacelle Structure B.L. 145

GII Aft Nacelle Structure, Drive System at BL 185

The flutter analysis with the QEC mounted at BL 185 indicated an unacceptable condition, as far as damping modes were concerned, so that mounting the QEC, Figure E-9, at this location was not practical. Further analysis with the propeller plane moved aft, toward the leading edge, 9.15 cm (36 in) produced a marginal condition. The geometry for this location is shown in Figure E-19. The lines and contours for the shortened nacelle were developed from those of the QEC unit by removing 35.6 cm (14.0 in) from the aft portion of the nacelle. Due to the relocation of the prop-plane, the mating plane is reconfigured to a sloping bulkhead between the nacelle attachment points. Above and below the attachments points, the mating plane bulkhead segments are normal to the nacelle center line. The nacelle mounting consists of the Lockheed P-3C V-frame members, with the appropriate changes in the attachment fitting angles at the mating plane. The aft nacelle structure, Figure E-23, consists of that portion of the structure from the sloped mating plane to the trailing edge. The aft nacelle supports the drive system installation by means of diagonal members from the upper attachment points downward and aft to the rear spar and by "skate" angle and nacelle lower longeron extensions which are attached to the front spar. The nacelle structure is fabricated from aluminum-alloy skin, frames, and longerons/ stiffeners. Skin thickness is 1.0 mm (0.04 in) and frames are 10 cm (4.0 in)-deep channel sections. The upper, semi-circular portion of the nacelle

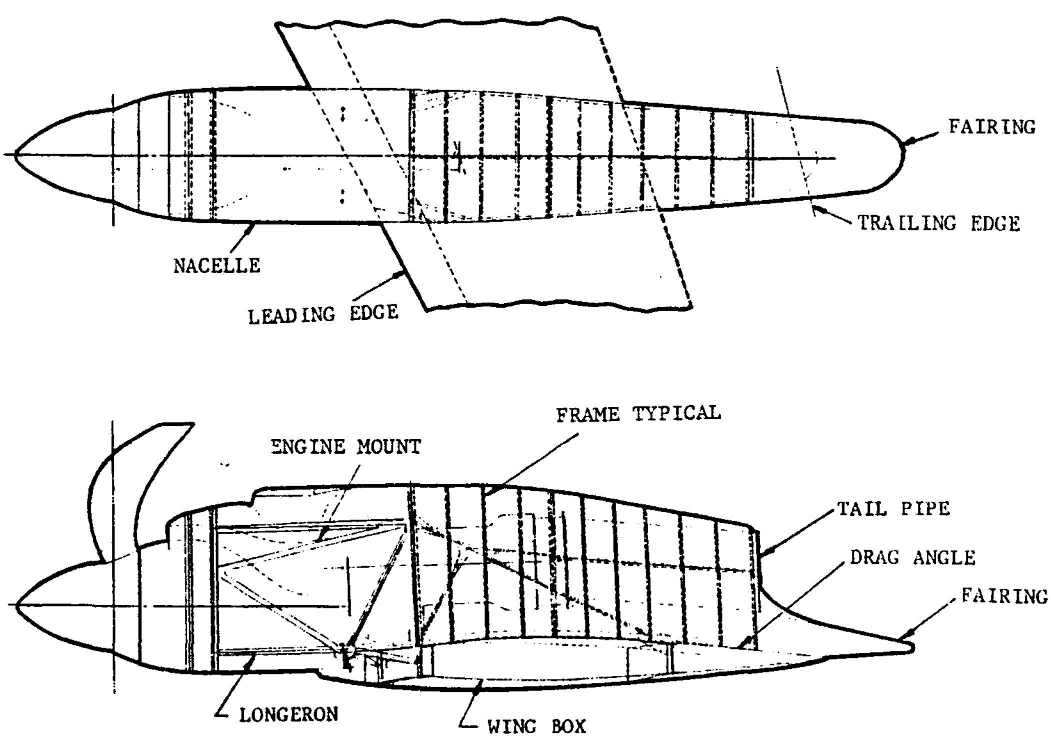


Figure E-23. GII Aft Nacelle Structure B.L. 185

is removable to provide access to the jet pipe installation. The main attachment of the nacelle to the wing upper surface is by means of chordwise "skate" angles. A fairing is provided at the tail pipe to protect the upper surface of the flap from the jet efflux. Because the turbine section of the power unit has moved aft to a position above the wing upper surface primary structure, provision for blade turbine containment is required in this area.

GII Wing Modification

The GII wing structure consists of integrally stiffened machined upper and lower skin panels and front and rear spar structures, which together form the wing box beam structure. The upper surface of the wing has approximately 26 circular or elliptical access panels on each side, and changes of curvature occur at BL 145 inboard to the center lines. Increasing the torsional stiffness 60 percent, for either of the drive system locations investigated, requires the addition of doublers to the upper and lower surfaces of the wing and to the front and rear spars. Aluminum-alloy doublers, Figure E-24, 1.9 to 2.1 mm (0.075 to 0.084 in) thick are required for the upper and lower surfaces, respectively. These doublers would be attached to the existing skins with mechanical fasteners and would be arranged to accommodate new covers at each access panel location.

Because double curvature exists on the wing from BL 145 inboard, perfect matching of the doublers and skin is not possible and liquid shim would be applied to the faying surfaces. Machined plate, aluminum alloy doublers approximately 2.54 mm (0.1 in) thick, would be added to the forward face of the front spar and to the rear face of the rear spar. Addition of the doublers would require removal of the leading and trailing edge structures. No problems are anticipated with the front spar reinforcement, but the doubler applied to the rear spar presents a major undertaking since the removal of the landing gear support is involved. The wing reinforcement would extend from BL 172 L to BL 172 R for the drive system located at BL 145 and from BL 220 L to BL 220 R for the BL 185 location. Finally, modifications to the spoiler system are necessary. These would consist of eliminating the ground spoiler for the inboard location or deactivating the inboard flight spoiler for the outboard drive system location.

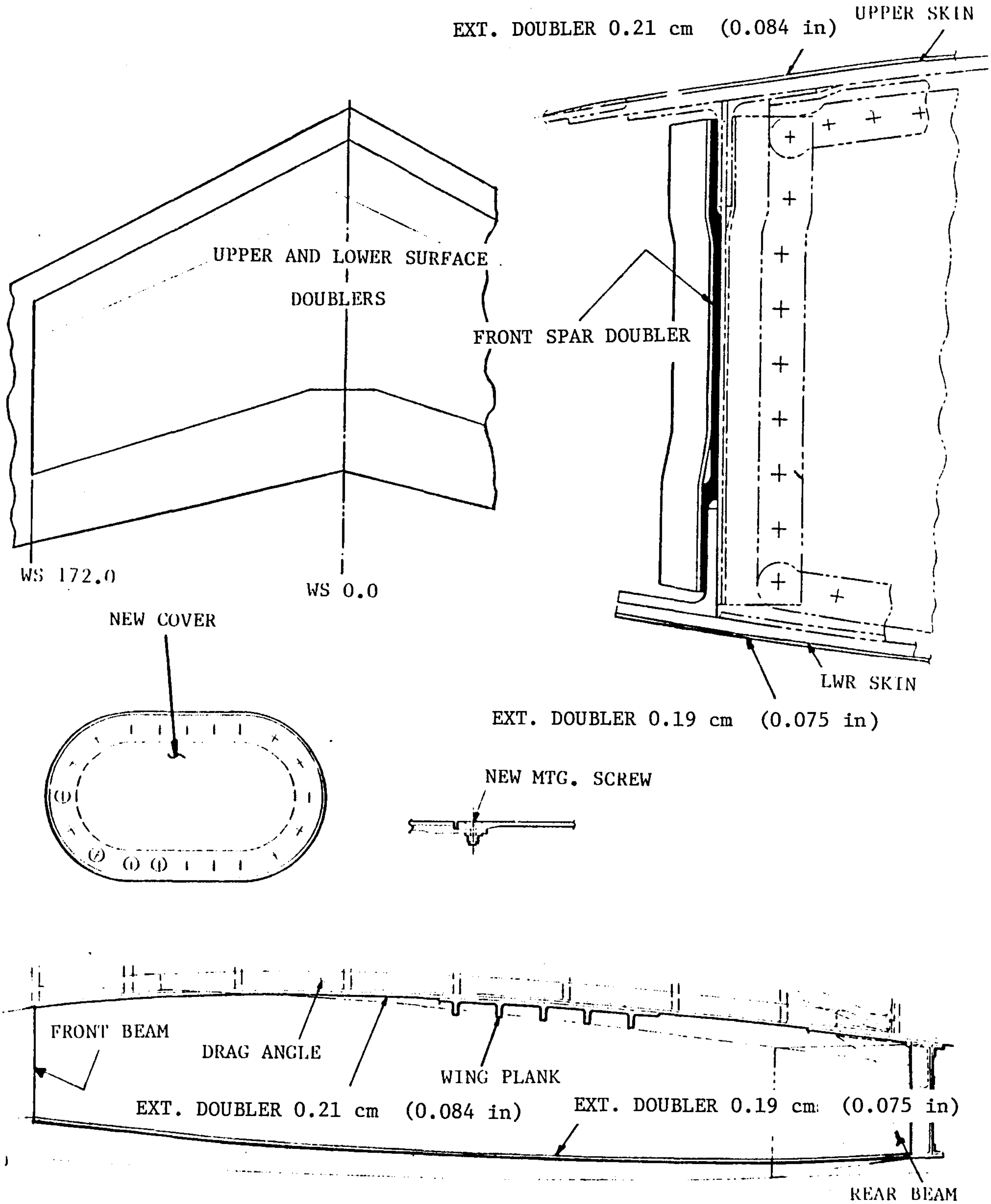


Figure E-24. GII Wing Modification

GII Flutter Analysis

As previously noted, preliminary wing flutter analyses were performed for the GII testbed configuration to determine the effects of the prop-fan powerplant installation at BL 145 and BL 185. A semi-span (half aircraft) mathematical model was used, implying structural and aerodynamic symmetry about BL 0.0. The results are, therefore, directly applicable to a symmetrical 2-engine testbed configuration.

Structural Representation - The structural representation used in the analysis consisted of a flexible wing with a flexibly mounted prop-fan powerplant and a rigid fuselage-empennage. The flexible wing was represented as a 10-lumped mass system with beam vertical bending and torsion degrees of freedom. The wing mass data were taken from Table IV of Reference 5, and stiffness data from Figures VIII-3 and VIII-4 of Reference 6. The torsional stiffness was increased by 12 percent to obtain better correlation with the vibration test results of Reference 7. For the unsymmetric case only, a wing-to-fuselage flexibility in roll was added for the same reason.

A comparison of the predicted and measured wing vibration mode frequencies for the unmodified GII, without prop-fan powerplants, is shown in Figure E-25. The comparison is very close for both the symmetric and unsymmetric cases, with the exception of the second bending mode frequencies, which were overpredicted by 21 and 27 percent for the symmetric and antisymmetric cases, respectively. It was concluded that these differences were caused primarily by engine pod flexible mode coupling, which was not represented in this analysis.

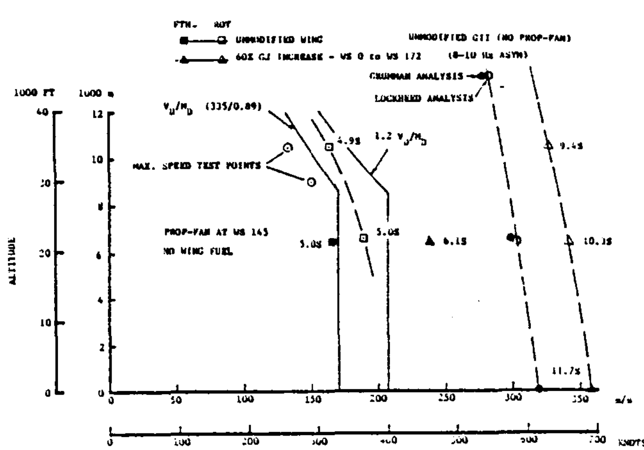


Figure E-25. GII Flutter Boundaries - Prop-Fan at W.S. 145

The prop-fan powerplants were represented structurally as additional sprung and unsprung mass lumps located at BL 145 and BL 185. The sprung mass of 1378 kg (3040 lb) represented the prop-fan, gearbox and engine and had uncoupled mode frequencies of 5.72 Hz (lateral), 7.51 Hz (vertical), 8.68 Hz (yaw) and 9.93 Hz (pitch), which were derived from Lockheed "Electra" nacelle and engine mount stiffness data. The unsprung mass of 474.8 kg (1047 lb) represented the fixed nacelle structure and wing local reinforcement.

Aerodynamic Representation - The unsteady aerodynamic forces on the wing were computed by Theodorsen strip theory. Finite span and compressibility effects were approximately accounted for by local lift-curve-slope and aerodynamic-center modifications, which were based on data from Table VI of Reference 5. The wing aerodynamic forces were computed for 10 strips, which coincided with the 10 mass panels, as shown in Figure 2 of Reference 5. No unsteady aerodynamic forces were applied to the fuselage or empennage surfaces, since previous experience has shown that these are relatively unimportant for wing flutter predictions.

Aerodynamic forces on the prop-fan were computed by quasi-steady strip theory, modified for lift lag due to unsteady flow. The prop-fan blade lift-curve-slope distribution data were supplied by Hamilton Standard and were for the 8-blade SR-3 prop-fan operating at M = 0.8.

Flutter Analysis Results, Drive System at BL 145.0 - The results of the wing flutter analysis are summarized in Figure E-25. The unmodified GII wing was analyzed first and compared with the results of the Grumman analysis to validate the mathematical model. The flutter boundaries agreed within 2 percent, as indicated by the circle symbols in Figure E-25, even though the Grumman mathematical model included flexible fuselage and empennage effects, which were not included in the Lockheed analysis. The flutter mode involved is a 7 to 10-Hz antisymmetric wing bending-torsion mode.

The addition of the prop-fan powerplants at BL 145 caused a 5-Hz symmetric flutter instability inside the testbed dive speed envelope, as indicated by the solid square symbol. When rotating prop-fan aerodynamic and gyroscopic couplings effects were added, the speed of this instability increased by about 23 m/s (45 knots), but was still unsatisfactoriily low, as shown by the open square symbol.

To increase the flutter speed to a satiisfactory level, a substantial increase in the wing torsional stiffness inboard of BL 145 is required. The effect of a 60 percent increase is shown by the solid and open triangle symbols for the feathered and rotating prop-fan conditions, respectively. Although a somewhat smaller stiffness increase might be satisfactory, a more elaborate and comprehensive flutter analysis will be required to determine a precise figure.

Flutter Analysis Results, Drive System at BL 185 - Relocating the QEC to BL 185, and with the prop-fan plane one diameter ahead of the wing leading edge, increases the flutter speed above that for the powerplant at BL 145. The damping of the fundamental wing torsion modes (both symmetric and unsymmetric) is, however, unsatisfactorily low at airspeeds well within the limit-speed envelope. Attempts to stabilize the mode by increasing the wing torsional stiffness actually reduced the damping, so that it became obvious that no reasonable amount of wing stiffening would solve the problem.

It was found, however, that moving the prop-fan plane aft 91.4 cm (36 in) improved the damping of these modes, which when combined with a 60 percent increase in wing stiffness out to BL 200, provided satisfactory damping, within the limit speed envelope. It should be noted that the damping is only marginal, as indicated in the Figure E-26, and is sensitive to changes in altitude, powerplant mounting stiffness, prop-fan aerodynamic characteristics, and other parameters not investigated. Additional investigation is required to verify the damping characteristics at this powerplant location and to determine, more precisely, the wing and powerplant design requirements for flutter prevention.

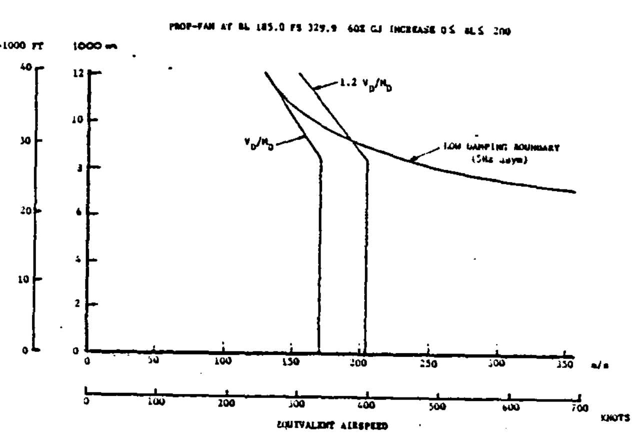


Figure E-26. GII Flutter Boundaries - Prop-Fan at W.S. 185

GII Operating Envelope

The operating envelope for the GII, Figure E-27, was established by analyzing the 0.13 rad (7.5 deg) upset condition for 20 seconds to determine the dive speed. The points analyzed were those at altitudes of 9118 m (30,000 ft) and 10,668 m (35,000 ft), starting the upset at a Mach number of 0.8. The upset condition onset at 9144 m (30,000 ft) results in a Mach number increase to 0.89 at the end of 20 seconds and an end altitude of 8534 m (28,000 ft). Below this altitude the testbed aircraft speed is restricted to 172 m/s EAS (335 KEAS) in order to minimize weight penalties arising from wing torsional stiffness increases.

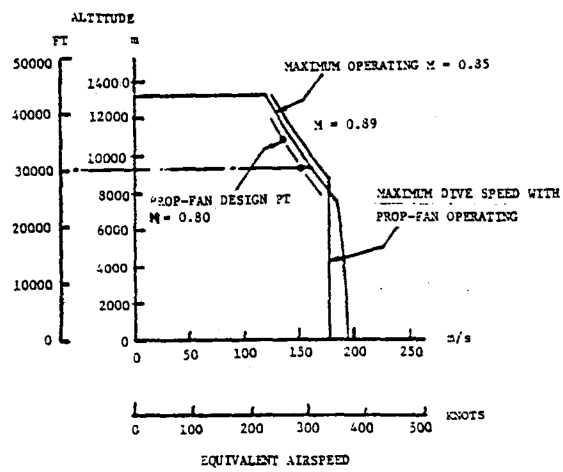
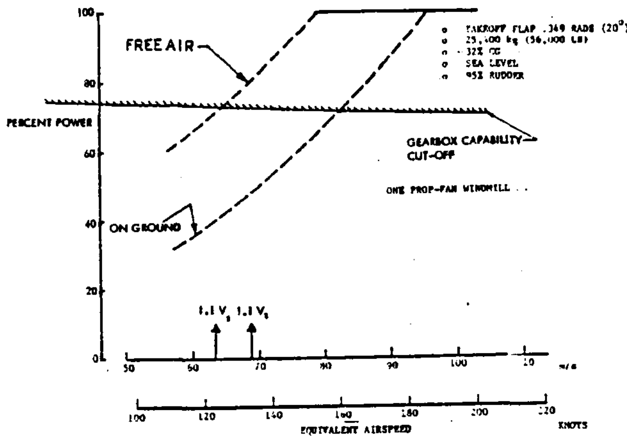


Figure E-27. GII Operating Envelope

GII Prop-Fan Testbed Trim Capability

The outboard limit for locating the drive system is BL 185, $\eta = 0.45$, which is dictated by the aircraft trim capability. The data of Figure E-28 show that, with one prop-fan windmilling and 100 percent power on the other, the testbed aircraft can be trimmed for engine-out conditions at 77.7 m/s EAS (151 KEAS) in free air with a 0.087 rad (5 deg) angle-of-bank or at 90 m/s EAS (175 KEAS) on the ground. The use of the T56-A-14 gearbox restricts the power input to 4101 kW (5500 shp) so that, when this constraint is applied to the data of Figure E-28, the power setting of the prop-fans, at the conditions indicated, is limited to approximately 75 percent of takeoff power. At this power setting,



PROP FAN LOCATED AT WS 185

Figure E-28. GII Trim Capability - Prop-Fan at W.S. 185

the engine-out, free-air trim capability can be achieved at a speed of 66.3 m/s EAS (129 KEAS) and 77.0 m/s EAS (150 KEAS) on the ground.

The data of Figure E-28 apply to takeoff conditions at sea level standard day, with a flap setting of 0.35 rads (20 degs), at a weight of 25396 Kg (56,000 lb), with center-of-gravity located at 32 percent of the MAC. The trim capability is shown for 95 percent rudder movement.

GII Testbed Weight and Balance

Weight data are presented for both drive system locations in Table E-VII. The essential difference between the weights is due to the increased doubler weight for the BL 185 drive system location. The operating weight of the unmodified aircraft is 15,464 kg (34,100 lb), which increases to 21,508 kg (47,428 lb) and 21,622 kg (47,678 lb) for BL 145 and BL 185, respectively. The difference in fuel weight for the two configurations is about 113 kg (250 lb). The take-off weight of 28,344 kg (62,500 lb) is based on the maximum ramp weight of aircraft serialized from 101 to 216, inclusive. The small size of the testbed configuration, and the large weight increment percentage needed to convert the basic aircraft to the testbed vehicle, requires careful control of the center-of-gravity. Balance checks of the testbed configuration show that, for either of the drive system locations, the aircraft center-of-gravity can be maintained within the envelope for the existing aircraft at all weights, by

TABLE E-VII. GII TESTBED WEIGHT AND BALANCE

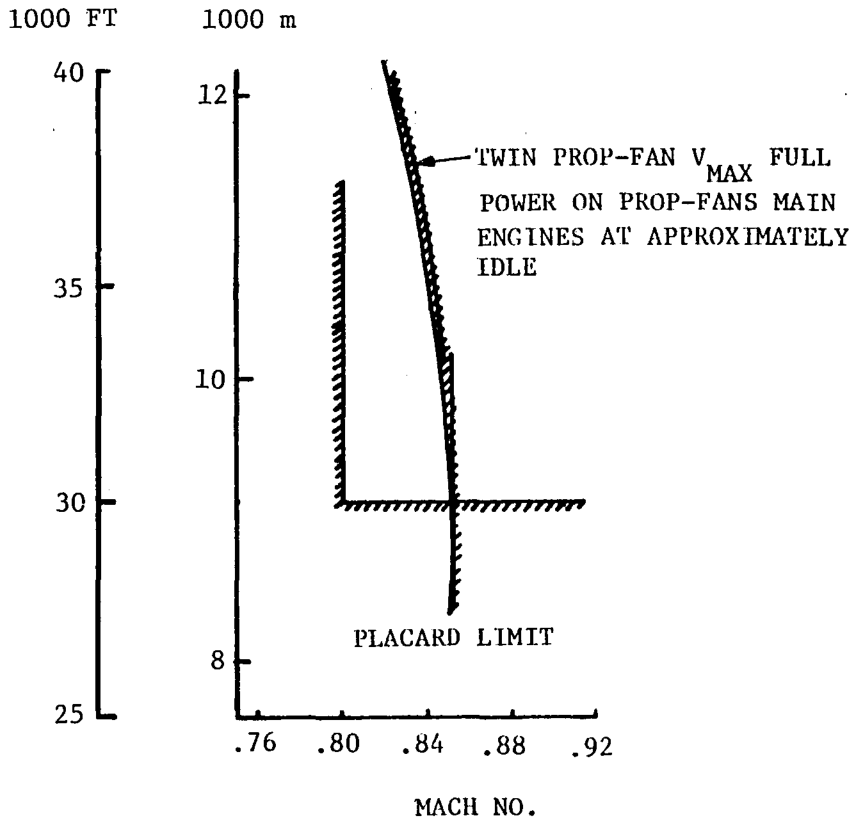
DRIVE SYSTEM LOCATION	WS 145/FS 385.98*				WS 185/FS 332*			
WEIGHT COMPONENT	% MAC	WEIGHT		ARM FS	% MAC	WEIGHT		ARM FS
		Kg	LB			Kg	LB	
o OPERATING WEIGHT-UNMODIFIED	39.3	15,464	(34,100)	462.0	39.3	15,464	(34,100)	462.0
XT-701 PROP-FAN PACKAGES		3,907	(8,614)	342.2		3,907	(8,614)	395.1
OVERWING NACELLE STRUCTURE		233	(514)	424.9		233	(514)	441.8
WING DOUBLERS		544	(1,200)	408.0		657	(1,450)	410.9
TEST EQUIPMENT		1,360	(3,000)	538.0		1,360	(3,000)	530.0
o ZERO FUEL WEIGHT	26.6	21,513	(47,428)	443.3	32.8	21,626	(47,678)	452.4
FUEL		6,837	(15,072)	418.5		6,723	(14,822)	418.3
o RAMP GROSS WEIGHT	22.5	28,350	(62,500)	437.5	27.3	28,350	(62,500)	444.3

*PROP-PLANE LOCATION

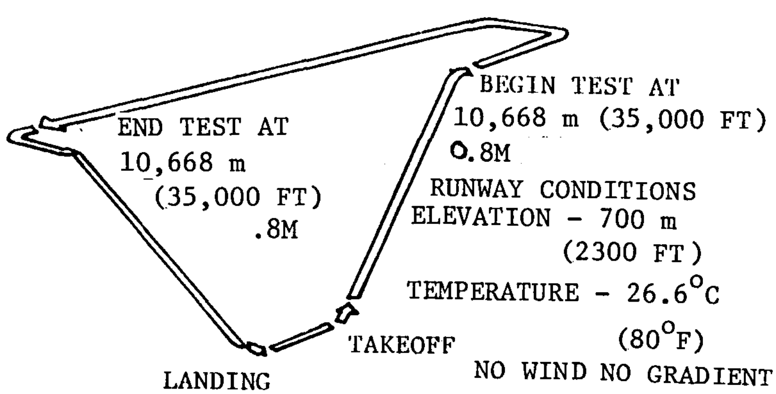
placing the test equipment in the passenger compartment, the center-of-gravity problems are eliminated.

GII Testbed Performance

The mission performance of the GII twin prop-fan testbed is shown in Figure E-29. At a ramp weight of 28,344 kg (62,500 lb), the start cruise weight at 10,668 m (35,000 ft) is 27,317 kg (60,235 lb), and the end cruise weight is 22,109 kg (48,752 lb). Cruising at Mach 0.8 gives a test mission duration of 2.68 hours. The speed/altitude performance, also shown in Figure E-29, shows that a Mach number margin of $\Delta M = 0.04$ to 0.05 exists over the design conditions for the twin prop-fans operating at full power with the primary "Spey" propulsion slightly above idle power setting. Because of the gearbox power absorption limitation and the design of the basic aircraft flap and spoiler systems for operation without propeller slipstream effects, the use of the prop-fans on takeoff and landing would be restricted to a condition of zero net thrust.



SPEED/ALTITUDE



RAMP WEIGHT	28,350 kg (62,500 LB)
START CRUISE WEIGHT	27,322 kg (60,235 LB)
END CRUISE WEIGHT	22,114 kg (48,752 LB)
FUEL WEIGHT	6,837 kg (15,072 LB)
TEST TIME	2.68 HRS

Figure E-29. GII Testbed Mission Performance

GII Estimates of the Prop-Fan Slipstream Characteristics

Slipstream characteristics were calculated for the GII, in terms of velocity and swirl angle, using an SR3, 10-bladed prop-fan configuration. The data shown in Table E-VIII are consistent with values used to determine slipstream effects for the estimation of the GII testbed mission performance.

TABLE E-VIII. GII SLIPSTREAM CHARACTERISTICS

CONDITION								% RADIUS									
CASE	kW/m^2 (SHP/D^2)	V_T m/s (fps)	MN	ALT m (FT)	C_p	J		.249	.291	.361	.455	.563	.676	.785	.878	.949	.990
1	209 (26)	183 (600)	0.8	10668 (35000)	2.789	4.08	$\Delta v/v$	.006	.0079	.0107	.0139	.0162	.0179	.0195	.0234	.0186	.0191
							ψ	4.58	5.19	5.50	5.47	4.98	4.53	4.20	4.60	3.29	3.27
2	241 (30)	217 (700)	0.8		2.027	3.497	$\Delta v/v$	.0077	.0102	.0138	.0178	.021	.0239	.0270	.0298	.0216	.0247
							ψ	4.37	5.02	5.49	5.61	5.34	5.07	4.94	4.91	3.20	3.57
3	301 (37.5)	244 (800)	0.8		1.697	3.06	$\Delta v/v$	.0092	.0123	.0170	.0223	.0273	.0326	.0383	.0330	.0281	.0338
							ψ	4.23	4.96	5.67	5.98	6.03	6.06	6.18	4.67	3.65	4.29
4	241 (30)	244 (800)	0.8		1.3579	3.06	$\Delta v/v$	.0085	.0113	.0155	.0198	.0237	.0279	.0325	.0254	.0206	.0246
							ψ	3.76	4.39	4.99	5.16	5.06	5.05	5.11	3.51	2.61	3.05
5	209 (26)	244 (800)	0.8		1.1769	3.06	$\Delta v/v$	.008	.0106	.0146	.0184	.0215	.0252	.029	.0211	.0163	.0194
							ψ	3.50	4.08	4.61	4.69	4.52	4.49	4.51	2.87	2.04	2.37
6	301 (37.5)	244 (800)	0.7		1.697	2.677	$\Delta v/v$	.0118	.0157	.0219	.0293	.0368	.0449	.0534	.0629	.0519	.0593
							ψ	4.67	5.45	6.27	6.85	7.10	7.34	7.60	8.15	6.07	6.78
7	241 (30)	217 (700)	0.7		2.027	3.06	$\Delta v/v$	.0101	.0132	.0179	.0234	.0286	.0341	.0396	.0497	.0471	.0483
							ψ	4.85	5.50	6.10	6.38	6.37	6.40	6.43	7.42	6.45	6.37
8	209 (26)	183 (600)	0.7	10668 (35000)	2.789	3.57	$\Delta v/v$	.0082	.0106	.0144	.0188	.0228	.0267	.0303	.0364	.0428	.0459
							ψ	5.26	5.83	6.28	6.36	6.16	6.00	5.84	6.40	7.15	7.43

GII Prop-Fan Near-Field Noise Characteristics

Free-field peak sound pressure levels and noise contours were generated for the GII fuselage at the flight conditions shown in Table E-IX with the BL 145 drive system location. A peak noise level of 147.7 dB occurs at M = 0.8 with a tip speed of 249 m/s (800 fps) and a disc loading of 301 kW/m^2 (37.5 shp/ft^2). The noise levels decrease as Mach number, tip speed and disc loading decrease. Relative sound pressure levels estimated for conditions up to the tenth blade passage frequency harmonic, for tip speeds of 183, 213, and 244 m/s (600, 700 and 800 fps), respectively, are shown on Figures E-30, E-31, and E-32. These data represent the explicit cruise conditions of Table E-IX and should not be extrapolated to other conditions. The noise contours on the fuselage are shown on Figure E-33 for the XT701 and SR3, 10-bladed prop-fan drive system at the cruise conditions of Table E-IX. At these conditions, the sound pressure level of blade passage frequency harmonics on the noise contour may be determined by algebraically adding the data for each tip speed from Figures E-30, E-31 and E-32 to the OASPL of Table E-IX.

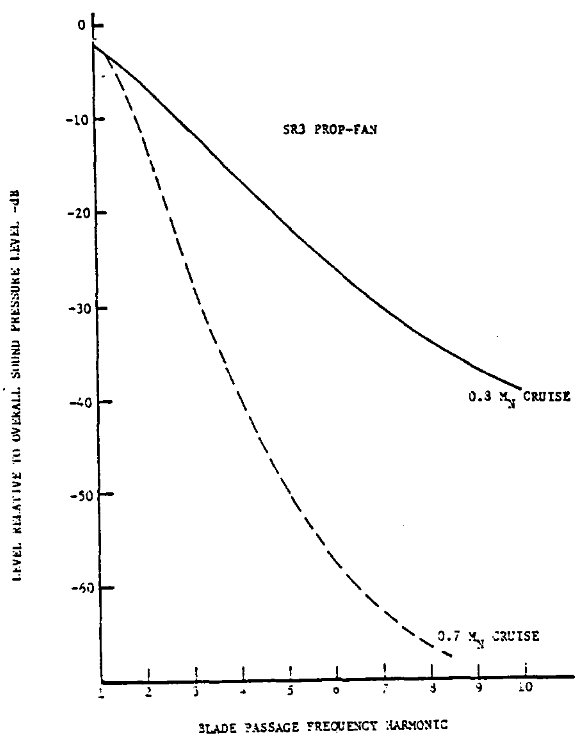


Figure E-30.

GII Blade Frequency Harmonics

@ V_{TIP} = 183 m/s (600 fps)

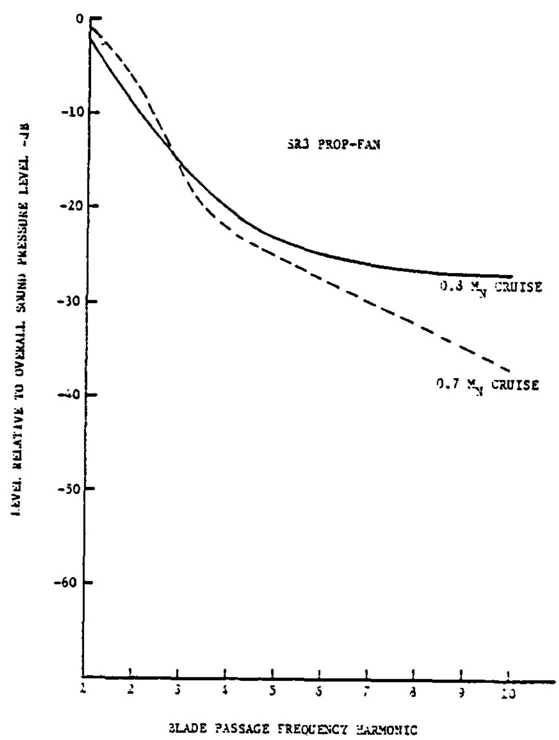


Figure E-31.

GII Blade Frequency Harmonics

@ V_{TIP} = 217 m/s (700 fps)

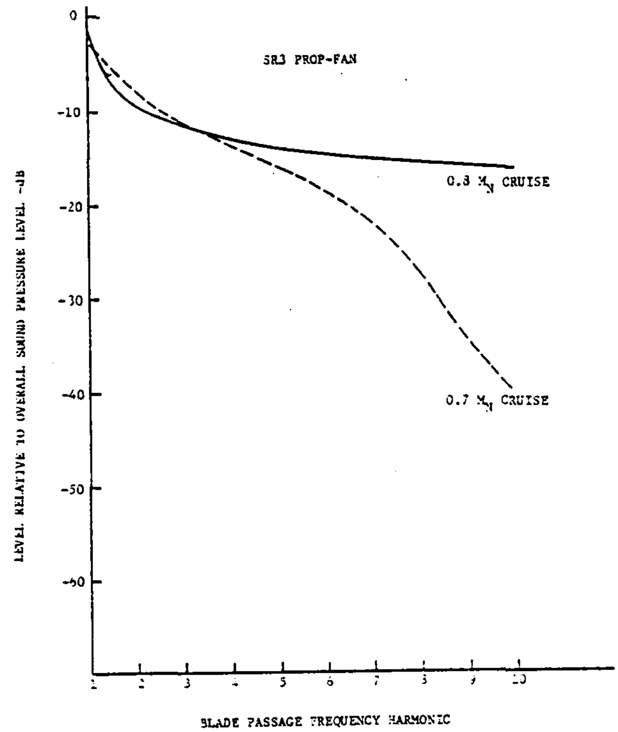


Figure E-32. GII Blade Frequency Harmonics @ V_{TIP} = 244 m/s (800 fps)

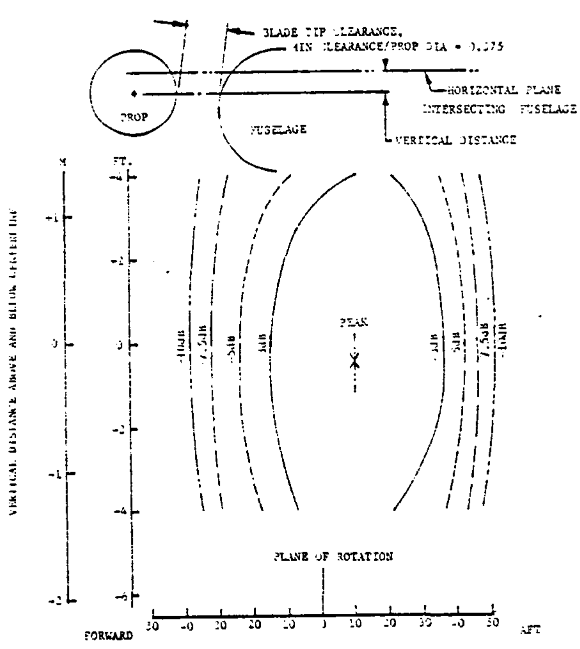


Figure E-33. GII Fuselage Noise Contours

TABLE E-IX. FREE FIELD PEAK OVERALL SOUND PRESSURE LEVELS

SR-3 CONFIGURATION ON GULFSTREAM II TESTBED

@ 10668 m (35,000 FT.) CRUISE ALTITUDE

CASE	CRUISE M	kW/m^2	(SHP/D^2)	TIP SPEED m/s	(fps)	OASPL (dB)
1	0.8	209	(26.0)	183	(600)	142.0
2	0.8	241	(30.0)	217	(700)	146.7
3	0.8	301	(37.5)	244	(800)	147.7
4	0.8	241	(30.0)	244	(800)	146.8
5	0.8	209	(26.0)	244	(800)	147.2
6	0.7	301	(37.5)	244	(800)	145.4
7	0.7	241	(30.0)	217	(700)	137.3
8	0.7	209	(26.0)	183	(600)	129.1

<u>GII Twin Prop-Fans at BL 185 Stability Derivatives</u>

The stability derivatives; yawing moment coefficient due to sideslip, C_{n_β}, rolling moment coefficient due to sideslip, C_{l_β} and the sideforce coefficient due to sideslip, C_{y_β} were estimated for the GII with the prop-fans located at BL 185. These coefficients were then compared with those for the unmodified aircraft at takeoff and cruise conditions. As indicated in Table E-X, the coefficients change very little as a result of adding the prop-fan. There is, however, a loss in roll control effectiveness due to the elimination of the inboard flight spoiler. It is estimated that the roll control effectiveness would be reduced to 69 percent of that of the unmodified aircraft.

TABLE E-X. STABILITY DERIVATIVES FOR GII - PROP-FAN LOCATED AT W.S. 185

CONDITION	DERIVATIVE	UNMODIFIED GII	TWIN PROP-FAN GII
TAKEOFF	C_{n_β} (yaw)	0.0024	0.00202
	C_{l_β} (roll)	-0.00295	-0.00295
	C_{y_β} (side-force)	-0.0150	-0.0164
CRUISE	C_{n_β} (yaw)	0.0023	0.00206
	C_{l_β} (roll)	-0.00170	-0.00170
	C_{y_β} (side-force)	-0.0144	-0.0153

ROLL CONTROL EFFECTIVENESS WITHOUT INBOARD SPOILER REDUCED TO 69% OF UNMODIFIED GII VALUE

APPENDIX F - WIND TUNNEL TEST PLAN - TASK VII

The Wind Tunnel Test Plan developed in Task VII is directly related to the Testbed Program Objectives outlined in Task I, Appendix A, where four technological areas are identified as follows:

- o Integrity of the Structure
- o Acoustic Environment
- o Aircraft Performance
- o Systems Operation

The objectives, within each technology area, were also identified and assigned priority, as shown on Table F-I which is essentially a repeat of Table A-I, but with the addition of NASA-sponsored programs providing useful data concerning the specific technology objectives. Several methods of solution to satisfy the objectives are presented, and the preferred methods identified. The preferred methods of solution, identified by the circles, are not absolute or singular methods, but are merely recommendations. It is, therefore, recognized that the same or similar data for specific objectives can be obtained by alternative approaches.

Wind tunnel investigation was identified as the preferred method of solution for three objectives:

- o Propeller Aerodynamic Data for Flutter Analysis
- o Verification of Propulsive Efficiency
- o Effect of Propeller Flow Field on the Wing

As a result of this preferrential selection for wind tunnel testing, a Wind Tunnel Test Plan has been developed to augment the Testbed Objectives and to provide answers to technology questions that are uniquely testbed configuration dependent.

The Wind Tunnel Test considerations, structured around the Program Objectives and Priorities, preferred methods of solution fall into three areas as follows:

TABLE F-1. PROGRAM OBJECTIVES AND PRIORITIES

PRIORITY	TECHNOLOGY AREA	OBJECTIVE	SUB PRIORITY	PROBLEM SOLUTION METHOD					TYPE OF TES	TEST STATUS
				TESTBED AIRCRAFT	WIND TUNNEL HS	WIND TUNNEL LS	STATIC TEST	ANALYSIS		
1	INTEGRITY OF THE STRUCTURE o Propeller structural integrity & dynamics	1 Blade dynamic response validation	1	(X)						
		2 Blade classical flutter validation	2	(X)	X			X		
		3 Blade stall flutter validation	3	(X)		X	X			
		4 Critical speed & hub stiffness validation	4	(X)			X			
	o Propeller induced vibration & dynamics	5 Determine aerodynamic data for flutter analyses	1		(X)	(X)		X		
		6 Determine structural vibration spectra magnitude	2	(X)	X	X	X	X		
		7 Drive system dynamic loads & induced effects	3	(X)	X	X		X		
	o Scale effects	8 Validate or develop scaling laws	1	(X)	X	X				
		9 Blade mass & stiffness distribution determination	2	(X)	X	X	X			
		10 Demonstrate full size prop-fan fabrication feasibility	3				X			
		11 Establish drive system feasibility for 15,000 SHP & above	4					X		
2	ACOUSTIC ENVIRONMENT o Propeller generated near-field noise	12 Sound pressure directivity and spectra variation	1	(X)		X		X		
		13 Sound pressure levels on pressurized surfaces	2	(X)				X		
		14 Noise strength & directivity determination	3	(X)		X		X		
		15 Fluctuating pressure spectra	4	(X)		X		X		
		16 Effects of fuselage curvature	5	(X)				X		
		17 Geometry of correlated sound pressure area	6	(X)				X		
	o Propeller generated far-field noise	18 Verify prop-fan compliance with FAR Part 36	1	(X)						
	o Passenger cabin noise & vibration	19 Minimization of sound transmission	1	(X)				X		
		20 Resonant frequency modal survey	2	(X)			X			
		21 Fuselage modes and external noise relation	3	(X)						
		22 Noise reduction & structural response minimization by synchrophasing	4	(X)				X		
		23 Improvement thru optimization of shell modes	5	(X)			X	X		
		24 Noise reduction thru cabin dimension changes	6	(X)			X	X		
3	AIRCRAFT PERFORMANCE	25 Verify propulsive efficiency	1	X	(X)	X			Fundamental Prop-Fan Technology	*See Note Below
		26 Determine flow field effect on wing	2	X	(X)	X				
		27 Verify engine inlet performance	3	(X)	X	X		X		
4	SYSTEMS OPERATION	28 Verify drive system control system	1	(X)		X				
		29 Verify reverser effectiveness	2	(X)		X				
		30 Determine prop-fan vulnerability to FOD	3	X			(X)			

(X) = PREFERRED METHOD OF SOLUTION

* Swirl Simulator	ARC 14'	Completed
Semi-Span, Powered	ARC 14'	Completed
Semi-Span, Unpowered	ARC 11' x 11'	Completed
Semi-Span, Powered	ARC 11' x 11'	To be tested
2D Wing & Unpowered Nacelle	LRC	To be tested
2D Wing & Powered Nacelle	LRC	To be tested
Prop-Fan & Non-Symmetric AAC	LeRC	To be tested
Prop-Fan & Flow-thru Nacelle		To be tested

- Wind tunnel tests that demonstrate the operational readiness of the prop-fan drive system through proof testing procedures.

- Wind tunnel tests that validate and/or advance the fundamental prop-fan design state-of-the-art.

- Wind tunnel tests that validate the airworthiness and the predicted performance levels of the selected testbed configuration.

The first of these technological areas is not aircraft-dependent, but relates to the selected drive system for the testbed aircraft. The second area of concern relates to the development of fundamental data that contribute to a better understanding of the technologies associated with the prop-fan concept. Present NASA programs are also directed toward providing answers to prop-fan concept problems such as prop-fan/nacelle/wing interaction and improved propulsive efficiency through propeller swirl recovery. The third area of technological concern is testbed aircraft-oriented, such that tests in this area will relate directly to the airworthiness of the testbed vehicle, to the preflight prediction and determination of the testbed aerodynamic characteristics, and to the development of a wing/nacelle installation final design. Furthermore, these tests will provide technology-related data uniquely associated with the testbed aircraft.

Recommendations concerning the Wind Tunnel Test Plan are arranged to satisfy the Testbed Program Objectives and to demonstrate airworthiness of the Flight Research Vehicle, and are outlined in the following text. The Schedule of Testing presented in Figure F-1 should provide answers to the first and third areas of technological concern listed above. Because the testbed concept is intended to augment test data in the second area of concern, no wind tunnel tests are recommended for this area.

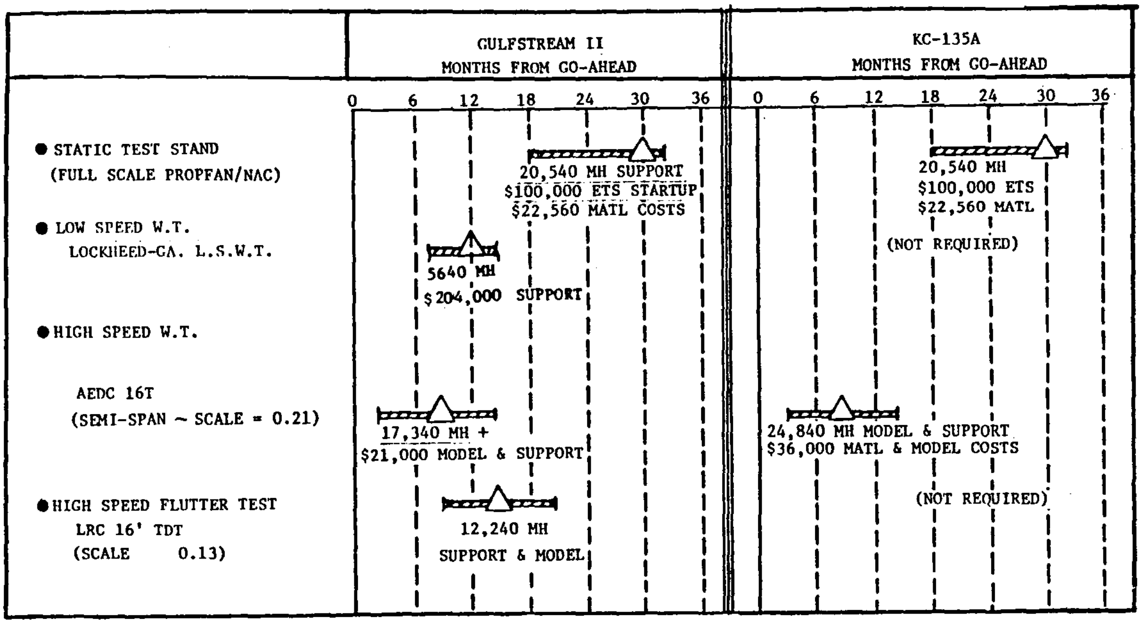


Figure F-1. Wind Tunnel Test Program Schedule

DRIVE SYSTEM OPERATIONAL READINESS DEMONSTRATION

Operational Readiness Test Plan Recommendation

The recommended Test Plan to demonstrate operational readiness, preceding actual flight test of the Advanced Turboprop Testbed System, involves static test stand experimentation only. These tests will provide proof of operation of the prop-fan and the drive system, as well as some near-field acoustic environmental data for the nacelle and adjoining structure. These tests would be applicable to either of the selected testbed systems, i.e., the GII or the KC-135A. A suggested test program, including test site and manhour/cost estimates, will be presented subsequently in this section.

Lockheed-Georgia decided not to recommend wind tunnel testing of the propeller drive system prior to actual flight test for the following reasons:

- o Most of the available wind tunnels are not capable of simulating the prop-fan design flight environment in terms of dynamic pressure, Mach number, and temperature.

- o Most of the available wind-tunnel-flow, solid-wall blockage limits are exceeded with the selected full-size nacelle, prop-fan, and wing-section installation.

- o Low-speed testing does not directly address the design point of the prop-fan.

- o Costs of wind-tunnel testing are high relative to the usefulness of the data obtained.

These reasons are justified in the following discussions.

Wind Tunnel Simulation of Prop-Fan Flight Conditions Inadequate

With the selection of the 2.89 m (9.5 ft) diameter prop-fan, several wind-tunnel facilities are eliminated from consideration, leaving the Ames 14-foot Transonic Wind Tunnel, the AECD 16T wind tunnel, and the Modane, France, S-1 wind tunnel as candidate facilities. The Ames 14-foot and the Modane S-1 wind tunnels are both atmospheric and are not capable of simulating the Mach number/altitude (M = 0.8/10688 m (35,000 ft)) environment of the prop-fan design point. To test at Modane, the largest of the available wind tunnels, the Mach number would have to be reduced to about 0.41, so that the operational design point dynamic pressure of the prop-fan would not be exceeded. Testing at the Modane facility would require a strengthened test article, which would not be representative of the flight article. The AEDC 16T, although capable of testing operational gas turbine powerplants in the test section, has not been used for a propeller test in over 20 years. The AECD 16T is, however, a pressure tunnel and is capable of simulating near-design flight conditions of Mach number and pressure altitude with a slight mismatch of $33^{o}C - 39^{o}C$ ($60^{o} - 70^{o}F$) in stagnation temperature. This mismatch could be reduced to approximately $17^{o}C$ ($30^{o}F$) with additional tunnel cooling. Other test constraints, such as wind-tunnel blockage and model size, limit the use of the 16T for full-size nacelle testing.

Wind Tunnel Blockage Limits

A criterion to be considered in selecting a suitable wind tunnel is the model blockage in the test section, as measured by the ratio of the test article maximum cross-sectional area to wind-tunnel test-section area, A_M/A_{WT}. The proposed prop-fan test article cross-sectional area would include a wing section. No contribution due to the prop-fan blades would be included. Table F-II identifies the estimated area ratio of the test article for each wind tunnel/ test candidate combination and compares it with the chocking limit of a solid-wall wind tunnel at M = 0.8.

TABLE F-II. WIND TUNNEL BLOCKAGE

WIND TUNNEL BLOCKAGE

Tunnel	Solid Wall Choking Limit @ M = 0.8	Area Ratio A_M/A_{WT}		
		KC-135	GII	Nacelle Only
Modane S-1	.037	0.122	0.089	0.026
AEDC	.037	0.180	0.136	0.055
Ames 14-FT	.037	0.215	0.165	0.072

The lowest nacelle cross-sectional area ratio, 0.026, shows that the only tunnel to meet the solid-wall choking limit is the Modane facility. This ratio, based on a nacelle cross-sectional area of 1.32 m (14.2 sq ft), does not include model support contributions, which would further increase the area ratio toward the choking limit for a solid-wall tunnel. Recommendations of 2/3 or, preferably, 1/2 of the choking limit are usual for solid-wall tunnels such as Modane. Testing of the nacelle/prop-fan on a vertical type of support, therefore, becomes critical because the area ratio approaches the choking limit. Wall effects and blockage interference corrections would be significant for these tests, thereby introducing further questions concerning proper data reduction and analysis.

The Ames 14-foot wind tunnel, which as a slotted-wall test section, would alleviate the solid-wall blockage limit; however, the blockage ratio is excessive for the nacelle alone. The AEDC 16T wind tunnel, which has a porous-wall test section, may be able to accommodate the nacelle-alone test article. Wall effect and blockage interference in a porous wall test section are presently unknown quantities. Currently, three-dimensional blockage analysis procedures are being developed, but are, as yet, uncorrelated. A significant amount of additional, time-consuming, costly testing would be required to fully develop and understand the blockage effects. The blockage interference problem is neither unique to the testbed development, which could be completed without this information, nor is it deemed critical enough to encumber the program with the additional costs necessary to provide its solution.

The chief purpose of wind tunnel testing of the prop-fan installation would be to obtain valid data for correlation with flight-test data. The use of the testbed full-size nacelle, with its associated blockage problems, would place such serious doubt on the validity of data obtained from wind tunnel testing, this type of test is not justifiable.

Low-Speed Wind-Tunnel Testing Validity

A full-scale, low-speed wind tunnel test of the operational prop-fan installation is not recommended. A limited amount of data only can be obtained from such tests due to the physical size of the testbed drive system nacelle. A possible installation of the GII testbed in the AMES 40x80 foot wind tunnel is shown in Figure F-2. The 18.3 m (60 ft) span of the GII fits snugly into the test section with no apparent problems in adapting the aircraft to the Ames strut-type mounting system. Based on NASA experience with other full-scale aircraft installations in the 40x80 tunnel, ARC personnel suggest that component data only can be expected to be valid. Total balance data would not be valid, in part, due to wind tunnel wall interference with the aircraft. The KC-135A testbed article would present an even more serious problem. Because of its size, only a segment of the fuselage and wing span can be accommodated in the tunnel as shown in Figure F-3. This type of arrangement negates the possibility of obtaining data directly applicable to the total aircraft configuration.

Although the acquisition of basic aerodynamic data on the testbed configurations appears unlikely from these types of installations, the acquisition of some valid component information, such as pressure data over the wing and nacelle, should be possible. Total pressure data in the wake of the wing/nacelle would also be valid. Strain-gage information on the propeller blades, propeller shaft, wing/nacelle structure, flaps, and other components should also be valid. Angle-of-attack excursions of the installation will provide useful information for flutter analysis of the prop-fan blades.

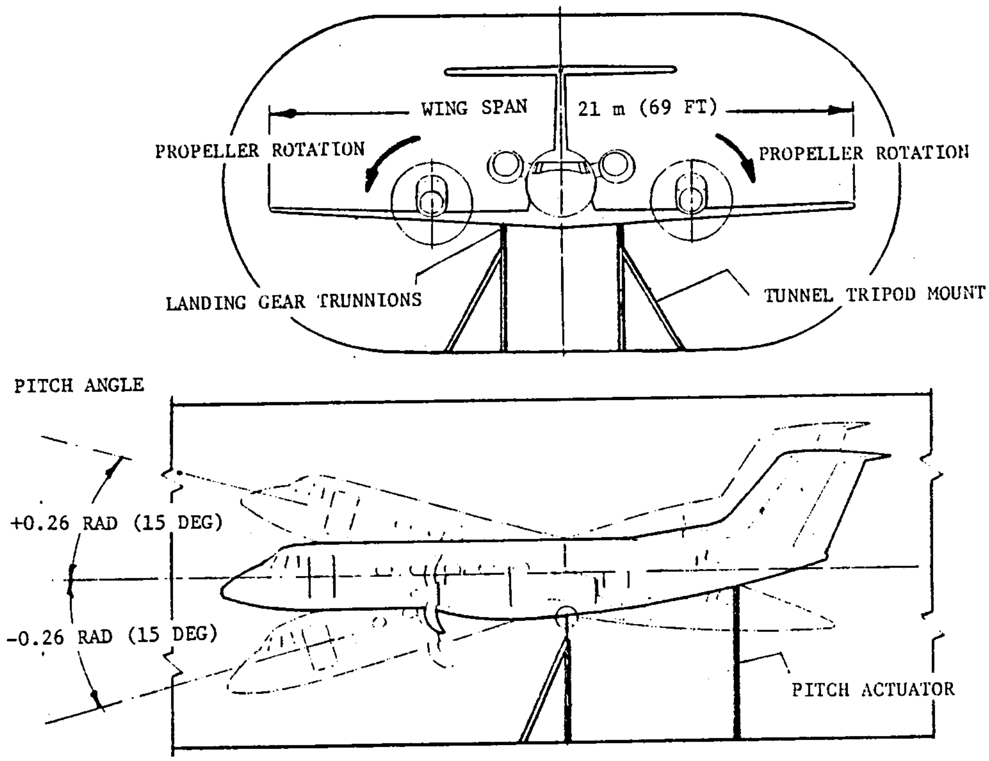


Figure F-2. GII Installation in Ames 40X80 Tunnel

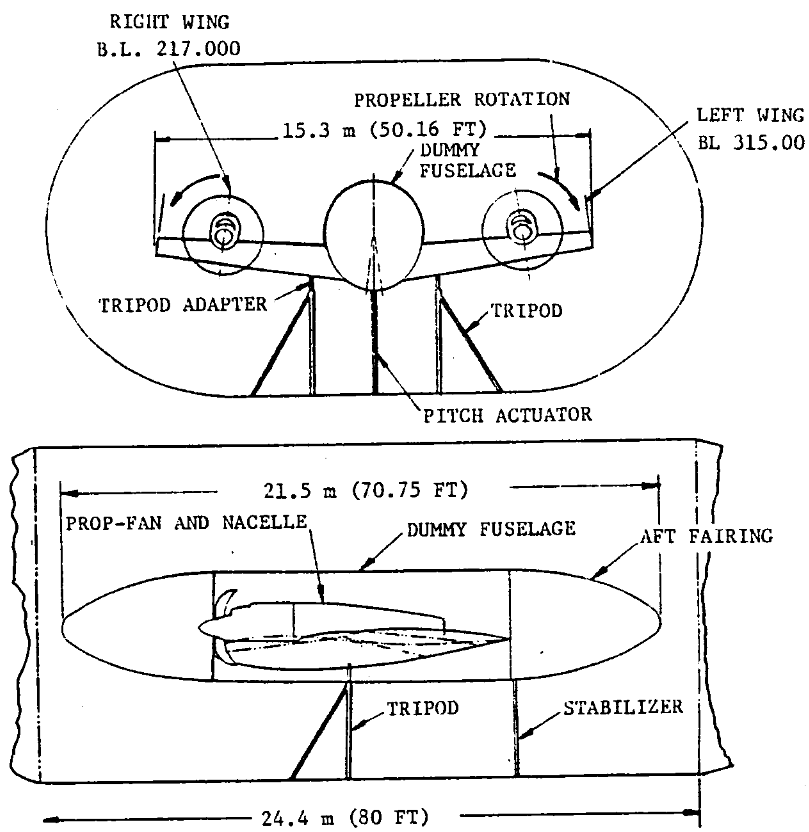


Figure F-3. KC-135A Installation in Ames 40x80 Tunnel

The necessity for low-speed testing in the development of any aircraft, particularly for flight safety, and to identify the aircraft takeoff, landing, and low-speed flight characteristics, is recognized. This type of information is more readily available through testing of scale models of the testbed configurations and will be addressed later in this section.

Testing Costs Relative to Necessary Test Requirements

Because costs for wind-tunnel model design, development, fabrication, and operation have escalated in recent years, the requirements for testing have become more stringent. Wind tunnel testing requirements for the testbed development should, therefore, be based on absolute need, rather than on a desire to increase the prop-fan technology data base.

OPERATIONAL READINESS STATIC TEST STAND TEST PLAN

The Testbed Program Objectives that can benefit by the test stand static tests are: (1) the investigation of propeller generated near and far-field noise, and (2) the proof testing of the operational aspects of the prop-fan/gearbox/drive train assembly and systems operation.

The static test, as presented in Figure F-1, would be the initial test of the complete prop-fan/powerplant/nacelle assembly in the QEC configuration. At the conclusion of this testing, the QEC assembly would be removed from the test stand and installed on the flight-research aircraft.

A recommended facility for the drive system static test is the Lockheed-Georgia non-metric engine test stand shown in Figure F-4. Assuming that Lockheed-Georgia would modify the testbed aircraft and install the prop-fan assembly, it would be advantageous to conduct the static test with the same personnel as would be involved in the flight testing of the testbed aircraft.

Instrumentation for the static test stand would include, but not be limited to, equipment to measure nacelle surface pressures, wake pressures at several longitudinal positions aft of the prop-fan plane, pressure rakes for inlet investigations, blade strain gage, acoustic transducers for near- and far-field noise measurements, prop-fan blade position, and power plant parameters.

Measured data requirements would include information to verify the structural integrity of the prop-fan installation, i.e., prop-fan blade, gearbox, drive train and attachments, and acoustic environment parameters to identify prop-fan sonic pressure intensity and direction. Also, propulsive data that would include pressure profiles for compressor and oil cooler inlets and the powerplant exhaust, as well as conventional power-plant parameters, would be required.

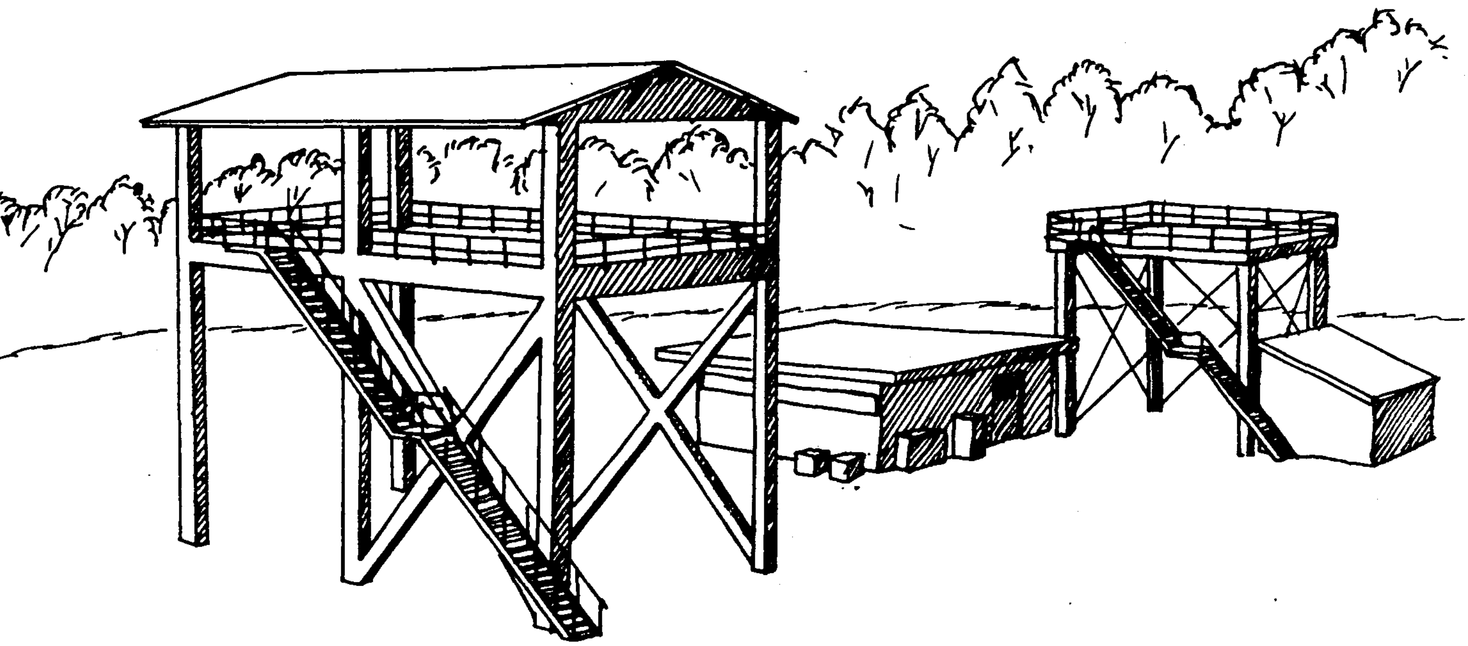


Figure F-4. Static Test Stand

The manhour/cost estimates for the static test, given in Table F-III, include the cost of the engine test stand start-up phase.

TESTBED AIRWORTHINESS AND TECHNOLOGY VALIDATION TESTS

The prop-fan operational environment encompasses both high- and low-speed flight regimes. It is possible that some testbed design features will be compromises between the high- and low-speed design point performance considerations and high- and low-speed safety-of-flight considerations. To investigate these areas of concern, and to provide supportive and validation data to the testbed aircraft prior to flight, low- and high-speed model wind-tunnel tests are recommended. These tests are summarized in Figure F-1.

Table F-III. Wind Tunnel and Static Test Estimated Manhours and Direct Charges

	GULFSTREAM II								KC-135A			
	GELAC ETS		AEDC 16T-HSWT		NASA LRC 16TDT		GELAC LSWT		GELAC ETS		AEDC 16T-HSWT	
ELAPSED TIME:												
TEST PREPARATION AND SET-UP	50 WEEKS		26 WEEKS		18 WEEKS		18 WEEKS		50 WEEKS		26 WEEKS	
TEST DURATION	4 WEEKS		4 WEEKS		3 WEEKS		4 WEEKS		4 WEEKS		4 WEEKS	
DATA ANALYSIS	8 WEEKS		26 WEEKS		26 WEEKS		4 WEEKS		8 WEEKS		26 WEEKS	
TEST SUPPORT - MANHOURS AND CHARGES:	M/H	$	M/H	$	M/H	$	M/H	$	M/H	$	M/H	$
AERODYNAMICS	400		2,000		480		440		400		2,000	
WIND TUNNEL SUPPORT			1,600				200				1,600	
PROPULSION	1,000		2,520				200		1,000		2,520	
ADVANCED STRUCTURES	1,680		720		2,800				1,680		720	
STABILITY AND CONTROL	80		360		360		880		80		360	
MODEL DESIGN			2,320		1,900		800				2,320	
EXPERIMENTAL SHOP (FABRICATION)			7,820		6,700		3,120				15,320	
ENGINEERING FLIGHT TEST	1,600								1,600			
START-UP ENGINE TEST STAND	4,500								4,500			
DIRECT CHARGES		$100,000								$100,000		
ENGINE INSTALLATION ON ETS	11,280	$22,560							11,280	$22,560		
WIND TUNNEL DIRECT CHARGES												
MATERIAL COSTS				$15,000				$4,000				$30,000
DIRECT CHARGES				$6,000				$200,000				$6,000
TOTALS:	20,540	$122,560	17,340	$21,000	12,240		5,640	$204,000	20,540	$122,560	24,840	$36,000
TOTAL MANHOURS	55,760								45,380			
DIRECT CHARGES	$347,560								$158,560			

High-Speed Model Wind-Tunnel Testing

The high-speed wind tunnel test plan will contribute to the satisfaction of the Objectives of the Advanced Turboprop Testbed Program Plan by the following:

(1) Validation of prop-fan blade classical and stall flutter characteristics.

(2) Provision of the necessary aerodynamic and structural data required for a testbed airplane flutter analysis.

(3) Verification of the propulsive efficiency of the prop-fan installation for the individual testbed candidates.

(4) Investigation of the wing/nacelle/prop-fan interactions through flow-field studies.

Semi-Span High Speed Wind Tunnel Test - NASA has previously conducted wind-tunnel tests to investigate the uninstalled performance of several prop-fan configurations. Prop-fan swirl effects and interactions on a supercritical wing were investigated at the Ames 14-foot wind tunnel with the use of a slipstream simulator. Recently, a powered semi-span model using a 0.62 m (2.0 ft) prop-fan and a supercritical wing was tested at the Ames 11 x 14-foot wind tunnel to investigate the installed effects and interactions of the nacelle and wing. These tests, and others already planned, will provide a substantial data base for analytical studies of the prop-fan testbed interaction question.

A possible alternative to the recommended high-speed wind-tunnel model would be the adaptation of an existing 1/8.8-scale semi-span GII model. To scale the prop-fan correctly a 0.33 m (1.08 ft) diameter propeller would be required.

The selection of model scale and test site are inseparable. The critical dimension for establishing model scale is the prop-fan diameter. The use of existing prop-fans with a 0.62 m (2.0 ft) diameter would result in a scale, relative to the 2.89 m (9.5 ft) prop-fan of approximately 0.21. NASA already has a drive system for the 0.62 m (2.0 ft) prop-fan, however, the prop-fan diameter could be increased to 1.24 m (4.0 ft) with this drive system, and the model scale doubled; i.e., the scale would be 0.42. Table F-IV shows the estimated characteristic dimensions and the estimated cross-sectional area of a semi-span model for each testbed candidate, and Figures F-5 and F-6 illustrate a possible installation of a model for each candidate testbed aircraft.

TABLE F-IV. WIND TUNNEL MODEL CHARACTERISTICS

Wind Tunnel Model Characteristics

Characteristic Dimension	Gulfstream II	KC-135A
Prop-Fan Diameter - m (ft)	0.62 (2.0)	0.62 (2.0)
Model Length - m (ft)	5.1 (16.78)	11.55 (28.6)
Wing Semi-Span - m (ft)	2.2 (7.22)	4.19 (13.74)
Cross-sectional Area (est.) - m^2 (ft^2)	0.309 (3.32)	0.552 (5.94)
Prop-Fan Diameter - m (ft)	1.24 (4.0)	1.24 (4.0)
Model Length - m (ft)	10.23 (33.56)	17.43 (57.2)
Wing Semi-Span - m (ft)	4.4. (14.44)	8.37 (27.48)
Cross-Sectional Area (est.) - m^2 (ft^2)	1.23 (13.26)	2.21 (23.76)

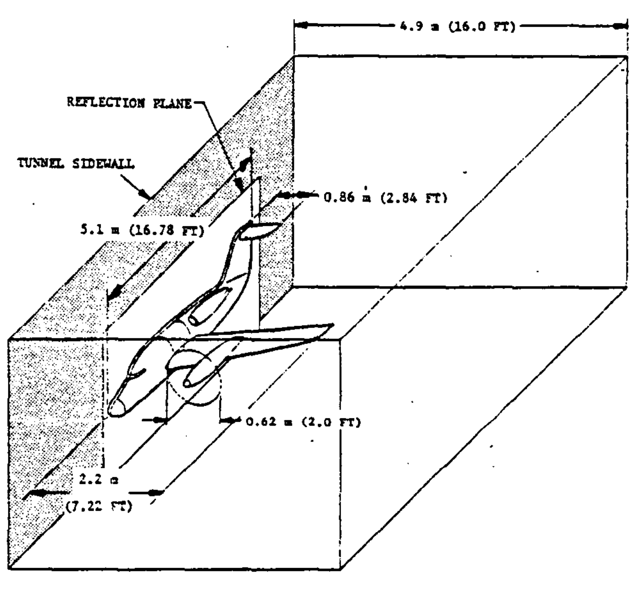


Figure F-5. GII in AEDC 16T Tunnel

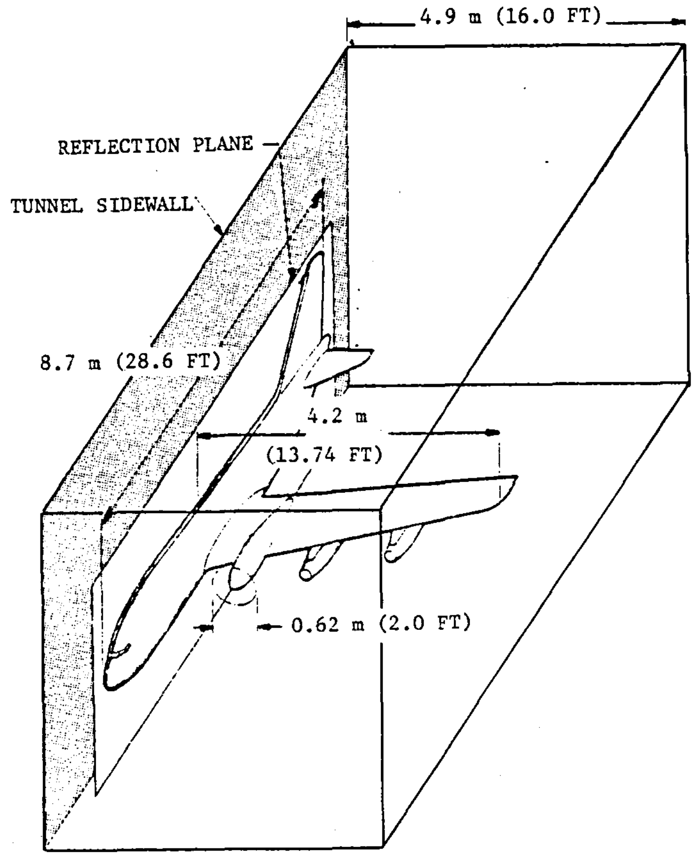


Figure F-6. KC-135A in AEDC 16T Tunnel

Figure F-7 compares the model-to-test-sectional area ratio for three different wind tunnels using the solid-wall choking as the limit. The NASA-Ames 14-Foot and 11-Foot Tunnels have slotted test sections, while the AFDC 16T has a porous wall test section. The model-to-test-section area ratio for both tunnel types may be permitted to exceed the solid-wall choking limit of Figure F-7. It is generally accepted that an area ratio of 0.05 is the limit for models in vented test sections, however, this depends on the tunnel and its porosity.

The data of Figure F-7 show that a model at a scale of 0.21 could meet the area ratio requirement of the Ames 11-Foot Tunnel, but would be marginal for the KC-135A. The limiting factor is model length and/or wing span. The 0.42 scale can be used only for the GII and only in the AEDC 16T. The KC-135A can be tested only at the AEDC 16T at a scale of 0.21. If the GII is the selected testbed configuration, a 0.42-scale model would require the development of new prop-fan models and some adaptation of the existing drive system. Although this would provide new data for use in determining scale effects, development of this model would incur high costs in model construction, testing, and correlation with previous testing. Based on these considerations, Lockheed recommends the 0.21-scale, 0.62 m (2.0 ft) prop-fan diameter for the testbed wind tunnel model with testing performed in the AEDC 16T tunnel, where wind-tunnel wall interference would be at a minimum level.

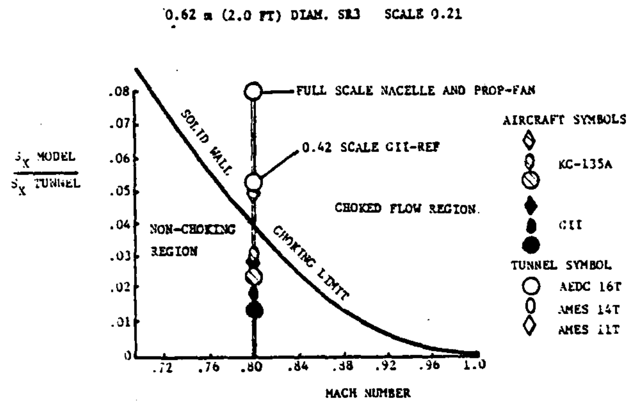


Figure F-7. Tunnel Blockage

An additional consideration in the selection of the AEDC 16T is the lower Mach number capability. This would provide data in the low-speed flight regime that is not currently planned.

Instrumentation requirements would include force balance for prop-fan, surface pressure taps for wing and nacelle, flow-field rakes for measuring surface pressures and flow angularity, strain-gages for blades, and wind-tunnel wall pressures.

Force and pressure data at several Mach number and Reynolds number combinations are needed; prop-fan blade angle is of prime importance so that a feathered flight position and thrusting positions from flight idle to maximum power can be tested. Since the proposed model would be a semi-span configuration, only longitudinal data will be measured. Although the recommended drive system for the prop-fan testbed would be the DDA XT701, a free turbine design which operates at near constant RPM, the wind tunnel test can be structured to test with RPM as a variable in order to investigate excursions from the desired value.

The manhour/cost estimates for the high-speed wind tunnel test of the Test Program Plan are presented in Table F-III.

High-Speed Flutter Test - One problem area identified with the selection of the GII as the test-bed vehicle is a possible reduction in the testbed aircraft flutter speed. Preliminary flutter analyses have shown that this problem would not affect the prop-fan testbed design point, but has been identified at off-design conditions (high speed at low altitude), and modifications to the wing structure have been suggested to overcome this problem.

The high-speed flutter considerations apply only to the GII and are not anticipated for the KC-135A testbed.

A preliminary flutter analysis of the GII indicates that the installation of prop-fan powerplants at WS 145 reduces the wing flutter speed to an unsatisfactory level, and that a 60-percent increase in torsional stiffness from WS 145 inboard is required to restore the flutter speed to a satisfactory level.

In addition to the flutter analysis, a minimum-risk testbed program would also include a high-speed flutter model test to verify the transonic wing and whirl flutter stability of the aircraft. A dynamically scaled model of the complete aircraft, including windmilling prop-fans, would be tested in Freon in the NASA Langley 16-foot Transonic Dynamic Tunnel (TDT). The test would reduce the uncertainty in the analytical results, due primarily to inaccurate representation of the transonic, unsteady, aerodynamic forces in the wing and prop-fan.

The flutter model scale would be approximately 0.13 and would be compatible with the recommended test site: Langely Research Center's 16-foot TDT. The model would require a scaled prop-fan capable of windmilling operation.

Instrumentation for this model would include wing, nacelle and empennage accelerometers, wing spar strain gages, and high-speed motion pictures.

Test parameters would include wing variable fuel distributions, atmospheric density and dynamic pressure, and Mach number. Data output would provide flutter speed and frequency and sub-critical damping.

The manhours/cost estimates for the flutter test and model development are presented in Table F-III.

Low Speed Wind Tunnel Testing

The purpose of the recommended low-speed wind-tunnel test is the airworthiness verification of the testbed aircraft. Preliminary examination of critical engine failure during takeoff on the KC-135A indicates the availability of adequate control power to overcome the addition of the prop-fan thrust so that low-speed wind tunnel test of the KC-135A is not required. As a more definitive prop-fan design is developed, control power for the KC-135A would be continually monitored to ensure the airworthiness of the testbed aircraft. The prop-fan tip clearances between the fuselage and inboard primary engines do not significantly affect the operation of the high-lift system. Longitudinal control effectiveness could be determined at the low Mach number spectrum of the recommended semi-span test. While some change in effectiveness of flaps and horizontal tail is expected, estimates have not indicated a critical situation.

The GII thrust requirements are more nearly matched to the thrust available from the prop-fan than is the case for the KC-135A, and to ensure that the GII testbed vehicle will be completely airworthy, Lockheed recommends a low-speed wind-tunnel test to examine the low-speed longitudinal, lateral, and directional aerodynamic characteristics. GAC advises that a 1/10-scale, low-speed model of the GII is available that could be tested in the Lockheed-Georgia Low Speed Wind Tunnel, which has a test section 4.9 m x 7.0 m (16 ft x 23 ft). Lockheed-Georgia also has 50 hp electric motors available that could be used to drive the prop-fan to simulate thrust and slipstream effects on the testbed aircraft. Testing requirements would include:

- Basic longitudinal stability and control characteristics with and without prop-fan power.
- Basic lateral-directional stability levels with and without prop-fan power.
- Rudder effectiveness with and without prop-fan power.
- Lateral control effectiveness with and without prop-fan power.

Model requirements would include multiple elevator, aileron, rudder, spoiler and flap positions, static pressure measurement capability, and the operating prop-fans capable of simulating variable thrust levels.

Instrumentation requirements would include the basic tunnel balance system, a force balance for the prop-fan, surface pressure taps on the wing and nacelles, and flow-field rakes for measuring wake pressures and flow angularity.

Manhour/cost estimates for this low-speed test are presented in Table F-III. These costs include the estimate for fabrication of a new wing designed to accommodate the prop-fan drive train adapters required on the prop-fan installations.

APPENDIX G - LIST OF SYMBOLS AND ABBREVIATIONS

A/A_{MAX}	-	Cross-sectional Area-to-Maximum Cross-sectional Area Ratio
A_{REF}	-	Reference Area
A_{WT}	-	Wind Tunnel Test Section Area
A/C	-	Aircraft
AEDC	-	Arnold Engineering Development Center
ARC	-	Ames Research Center
BAC	-	British Aerospace Corporation
BL	-	Buttock Line
^{o}C	-	Degrees Centigrade (Temperature)
$C_{l\beta}$	-	Rolling Moment Coefficient Due to Sideslip
$C_{m\alpha}$	-	Pitching Moment Coefficient Due To Angle-of-Attack
$C_{n\beta}$	-	Yawing Moment Coefficient Due to Sideslip
C_{w}	-	Wing Chord
$C_{Y\beta}$	-	Side-force Coefficient Due to Sideslip
$C_{Y\psi}$	-	Propeller Normal Force
CG	-	Center-of-Gravity
cm	-	Centimeter
D_{F}	-	Fuselage Diameter
D_{N}	-	Nacelle Diameter
D_{P}	-	Prop-Fan Diameter
D_{n}/D_{P}	-	Nacelle Diameter-to-Prop-fan Diameter Ratio
dB	-	Decibels
DDA	-	Detroit Diesel Allison
deg	-	Degrees (Angle)
DOC	-	Direct Operating Cost
EAS	-	Equivalent Air Speed
EC	-	Evaluation Criteria
ECR	-	Evaluation Criteria Ranking
F	-	Prop-fan Tip-to-Fuselage Clearance
^{o}F	-	Degrees Fahrenheit (Temperature)
FAA	-	Federal Aviation Administration
FAR	-	Federal Air Regulations
FOD	-	Foreign Object Damage

fps	-	Feet per Second
FS	-	Fuselage Station
FT	-	Feet
GAC	-	Gulfstream American Corporation
gal	-	Gallon
GFE	-	Government Furnished Equipment
GW	-	Gross Weight
Hz	-	Hertz
in	-	Inch
ISA	-	International Standard Atmosphere
^oK	-	Degrees Kelvin (Temperature)
kg	-	Kilograms
kN	-	Kilonewton
KPa	-	Kilopascal
KTAS	-	Knots True air Speed
KTS	-	Knots
kW	-	Kilowatts
LB	-	Pound
L/D	-	Lift-to-Drag Ratio
L/D_{MAX}	-	Maximum Lift-to-Drag Ratio
LeRC	-	Lewis Research Center
LH	-	Left Hand
LRC	-	Langley Research Center
LSWT	-	Low Speed wind Tunnel
m	-	Meter
M	-	Mach Number
M_D	-	Design Dive Mach Number
MAC	-	Mean Aerodynamic Chord
M&DC	-	Material and Direct Charges
mm	-	Millimeter
MRT	-	Maximum Rated Thrust
m/s	-	Meters per Second
N	-	Newtons or Background Noise
NRT	-	Normal Rated Thrust
NTS	-	Negative Torque Sensing

OSPL	-	Overall Sound Pressure Level
OW	-	Overwing
PPS	-	Power Plant Station
P&W	-	Pratt & Whitney
QEC	-	Quick Engine Change
rad	-	Radians
RH	-	Right Hand
ROM	-	Rough Order of Magnitude
RPM	-	Revolutions per Minute
S	-	Prop-fan Signal
S/N	-	Signal-to-Noise Ratio
Sw_{SLIP}/Sw_{TOTAL}	-	Slipstream-wetted Wing Area-to-Total Wing Area Ratio
SHP	-	Shaft Horsepower
SHP/D^2	-	Power (Disk) Loading
SL	-	Sea Level
SLS	-	Sea Level Static
SPL	-	Sound Pressure Level
TDT	-	Transonic Dynamic Tunnel
UW	-	Underwing
V_D	-	Design Dive Speed
V_S	-	Stall Speed
V_T	-	Propeller Tip Speed
WL	-	Water Line
WRP	-	Wing Reference Plane
WS	-	Wing Station
X/L	-	Location as a Fraction of Total Length
ZFW	-	Zero Fuel Weight
Δ	-	Increment
η	-	Location as a Fraction of Wing Semi-span
η_p	-	Propeller Efficiency
Λ_{LE}	-	Wing Leading Edge Sweep

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