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MULTIPLE PURPOSE SUBSONIC NAVAL AIRCRAFT
(MPSNA)
MULTIPLE APPLICATION PROPFAN STUDY
(MAPS)

by

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PREFACE

The requirements of NASA Policy Directive NPD 2220.4 (September 14, 1970) regarding the use of SI Units have been waived in accordance with the provisions of paragraph 5d of that Directive by the Director of Lewis Research Center.

CONTENTS

CONTENTS (contd)

CONTENTS (contd)

Section Page

APPENDIX

ILLUSTRATIONS

ILLUSTRATIONS (contd)

FIGURE Page

ILLUSTRATIONS (contd)

TABLES

1 - SUMMARY

This report represents the results of the "Multiple Purpose Subsonic Naval Aircraft (MPSNA) Multiple Applications Propfan Study (MAPS)" under contract NAS3-24530. During this effort five aircraft configurations were developed: four CTOL designs meeting two sets of mission requirements, and a V/STOL design. The benefits of the propfan propulsion system relative to a turbofan system were identified. Propulsion system technology requirements for a propfan-powered MPSNA configuration were formulated and a recommended technology research and development plan was proposed.

Four CTOL design concepts were developed to compare propfan and turbofan propulsion systems. The CTOL designs are low-wing, T-tail configurations with twin engines mounted on the aft fuselage. Hamilton Standard counter-rotating pusher propfans driven by geared Pratt & Whitney engines comprise the propulsion systems for the two CTOL propfan designs. The two turbofan aircraft are powered by Pratt & Whitney high bypass ratio split flow engines. A conformal radar array providing 360 degrees of coverage is housed in the wing leading edge, horizontal tail trailing edge and both sides of the aircraft fuselage. These aircraft make extensive use of advanced composites as well as advanced aluminum and titanium alloys to produce a minimum weight aircraft using materials and manufacturing techniques representing 1990s technology.

The CTOL aircraft (MR1) meeting the most stringent set of mission requirements are in the 50,000 to 60,000 lb TOGW class, depending on payload and engine type. The propulsion systems, both propfans and turbofans, are in the 20,000 lb thrust class. The CTOL aircraft (MR2) meeting a reduced set of mission requirements are in the 40,000 lb TOGW class, with 10,000 lb thrust engines. The propfan powered aircraft are consistently 10% lighter in TOGW, burn 50% less fuel with 6% to 10% smaller thrust engines than the turbofan designs.

A brief study of a propfan-powered V/STOL design was conducted. The V/STOL concept has a high wing and coplanar H-tail. The propulsion system consists of four core engines, arranged as twin packs, installed on each side of the fuselage. These cores are cross-shafted to two propfans mounted on the outboard section of the wing. The propfan nacelle and wing outer panel rotate 90 degrees for vertical operation. This V/STOL design has a maximum TOGW of 68,000 lb and total aircraft thrust just under 90,000 lb. A derivative of this design, sized by STOVL requirements, was evaluated for potential mission performance improvements.

A propfan-powered MPSNA vehicle was found to be a viable aircraft for the year 2000 timeframe assuming the necessary propulsion technologies are developed. The major elements of the engine technology plan are:

- Engine/Propfan Cycle Optimization for Military Missions
- Engine Component Development
- Engine and Propulsor Materials Development
- Design and Test of High Horsepower Reduction Gearbox
- Propfan Pitch Change Mechanism Development.

The risks and uncertainties typical of any V/STOL system (such as dynamic response, ground effects and engine/aircraft control) would require additional research and development to successfully demonstrate a propfan powered V/STOL aircraft.

2 - INTRODUCTION

For over a decade the airframe industry has been involved in developing systems and establishing requirements for the next generation multimission support aircraft. The aircraft have gone by many names with the common goal of a single airframe to replace the E-2, S-3, EA-6B as a minimum, and possibly the C-2 and KA-6D. The designs used in this study result from many years of work on Navy contracts and Independent Research and Development (IR&D) programs.

The most notable of these efforts include the Navy-sponsored Sea-Based Aircraft Notional Studies (SEABANS), Sea-Based Air Master Studies (SEABAMS), Advanced Technology Engine Study (ATES), Multi-Application Core Engine (MACE) Study, and our conformal radar development program, the multi-mission carrier-based experimental aircraft program (MMVX), and V/STOL IR&D programs.

The conformal radar is a lightweight, multimode radar patented by Grumman. It has minimal impact on airframe design and vehicle performance, and will allow extended station-keeping time at high altitude, important considerations for an MPSNA vehicle.

The objective of our MMVX IR&D program is to develop baseline aircraft and systems concepts for a multimission carrier-based aircraft capable of countering the 21st century threat and to identify the critical technologies needed to turn these concepts into reality. During 1983, this program concentrated on the threat and airframe tradeoffs. In 1984, this program concentrated on system options. Propulsion issues were addressed in 1984 and 1985.

The long-range goal of the Tilt-Fan V/STOL IR&D Program is to acquire and analyze test and simulation data in support of the design of a Tilt-Fan V/STOL aircraft as the solution to Navy AEW/Over-the Horizon (OTH) Targeting/Surface-Launched, Air-Targeted (SLAT) missile control requirements, as well as providing ASW and EW capabilities.

Previous studies have indicated that a propfan coupled with an advanced turboprop engine could result in a 15% to 25% reduction in fuel burned when applied to commercial and military transports. The Multiple Purpose Subsonic Naval Aircraft (MPSNA), Multiple Applications Propfan Study (MAPS) addressed the potential benefit of propfan propulsion to sea-based multipurpose aircraft.

The data presented in this report reflect state-of-the-art propulsion, aerodynamic, and electronic technologies to meet a year 2000 to 2005 Initial Operating Capability (IOC). The conceptual designs meet the projected design requirements with those propulsion technologies requiring further investigation detailed. A program to bring these propfan systems to an acceptable level of readiness is outlined.

3 - DESIGN PHILOSOPHY

3.1 DESIGN OBJECTIVES & GROUNDRULES

The primary objectives of the study are threefold. The major thrust of the study is to identify the benefit of propfan systems when compared to turbofans for an MPSNA aircraft. The Figures Of Merit (FOM) used are aircraft TOGW, engine size, and fuel burned. The second objective is to identify those propulsion technologies required for the proposed configurations. The final objective is to recommend a technology and development plan to achieve these technologies in the timeframe necessary to meet the required IOC of this aircraft. The basic design groundrules were as follows:

- The use of ten design missions generated in a NADC-Grumman cooperative study
- Design two CTOL aircraft to meet all mission requirements (MR1)
- Design two lighter-weight CTOL aircraft with less multimission capability (MR2)
- Design V/STOL or STOVL propfan aircraft
- Meet basic carrier suitability requirements, including:
    - Excellent launch-and-recovery characteristics
    - Weight and size compatibility
    - Safe operation with an engine failure
- Design for a 4.5G ultimate load factor
- Technology Availability Date (TAD) of 1990, consistent with an IOC date of 2000 to 2005
- Basic payload and weapons loading as shown in Table 1
- Fuel allowances consistent with Navy procedures.

Table 1 MPSNA Payload & Weapons Summary

MISSION	PAYLOAD	WEAPONS	AVIONICS (LB)
COD	10,000 LBS. CARGO	–	1000
TANKER	23,000 LBS. TRANSFER FUEL	–	1000
ASW	(60) SONOBUOYS	(2) HARPOONS (4) ALWTs	5400
ASUW	(60) SONOBUOYS	(2) HARPOONS (4) ALWTs	5400
AAW	(3) ALQ PODS	–	5000
AEW	–	(4) AMRAAMs	8000
MIW	–	(4) MK52 MINES	5400
VAQ/VQ	(3) ALQ PODS	(2) HARMs	5000
C^3	–	(4) AMRAAMs	8000
SURVEILLANCE	(60) SONOBUOYS	(2) HARPOONS (4) ALWTs	5400

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3.2 DESIGN APPROACH

Five aircraft, four CTOL and a V/STOL alternative were designed during this study and are shown in Fig. 1 through 5. Each design was developed through the Grumman Weight Integrated Sizing Estimates (WISE) computer program utilizing propulsion and aerodynamic inputs, concurrently with three view layouts by the configuration designer. The WISE program aids in making early decisions about an airplane's optimum size and general characteristics as well as in determining the effect of major changes such as engine type. All results presented in this report are fully iterated designs developed by continuous interaction between the designer and the various technical personnel.

The propfan and turbofan aircraft that satisfy Mission Requirements 1 (MR1) were designed to meet the most critical and demanding elements of all ten design missions. These missions included:

- Carrier Onboard Delivery (COD)
- Tanker
- Mine Warfare (MIW)
- Support/Standoff Electronic Warfare (VAQ/VQ)
- Airborne Early Warning (AEW)
- Command, Communication, Control (C^3)
- Anti-Submarine Warfare (ASW)
- Anti-Surface Warfare (ASUW)
- Surveillance
- Anti-Air-Warfare (AAW).

The CTOL aircraft and the V/STOL alternative aircraft that satisfy Mission Requirements 2 (MR2) have degraded capability from MR1 aircraft without penalizing the bulk of the missions. Specific mission requirements are detailed in Section 5.

The rationale for development of the MPSNA concepts was to minimize weapon system costs and weights while maximizing aircraft performance. The preferred design approach was to develop mission variants that share a common airframe, propulsion system and core avionic systems, with modular changes to the basic MR1 or MR2 configuration. Each variant has a unique payload/ weapons/avionics suite tailored to meet specific mission requirements.

The MR2 variants are comprised of:

- An AAW variant that performs AEW and C^3 roles as an offensive and defensive weapon system
- An anti-submarine warfare variant that provides fleet protection against submarines and surface ships in addition to surveillance and mining roles
- An electronic warfare variant capable of both active jamming and passive detection.

Two additional variants are necessary to fulfill MR1 requirements:

- A COD variant for cargo and personnel transport
- A tanker variant to provide fleet in-flight refueling.

A high degree of commonality among the MPSNA variants offers several advantages over dedicated or multimission aircraft. The costs associated with development, test, production and support would be significantly less than ten

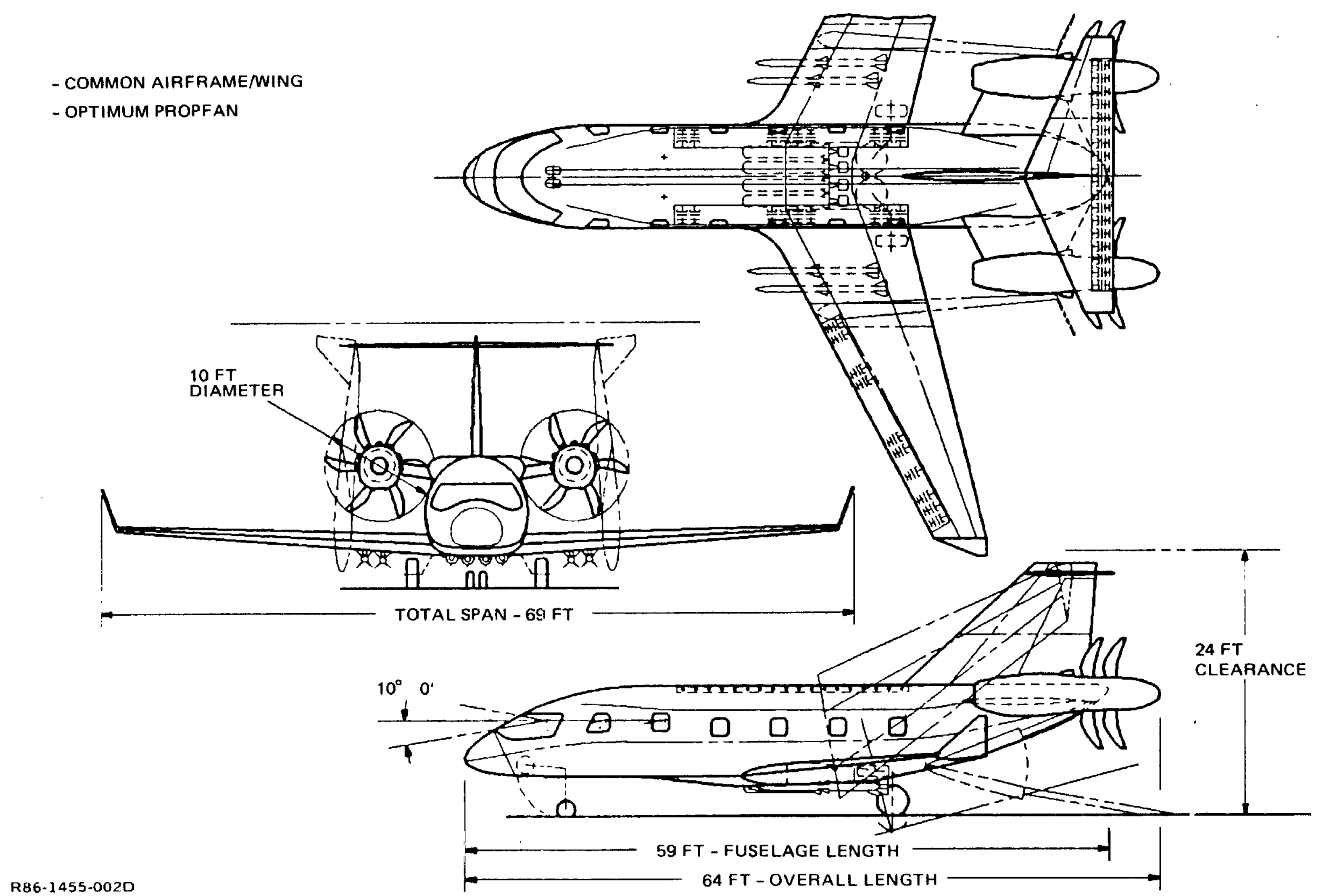


Fig. 1 MR1 Propfan Design

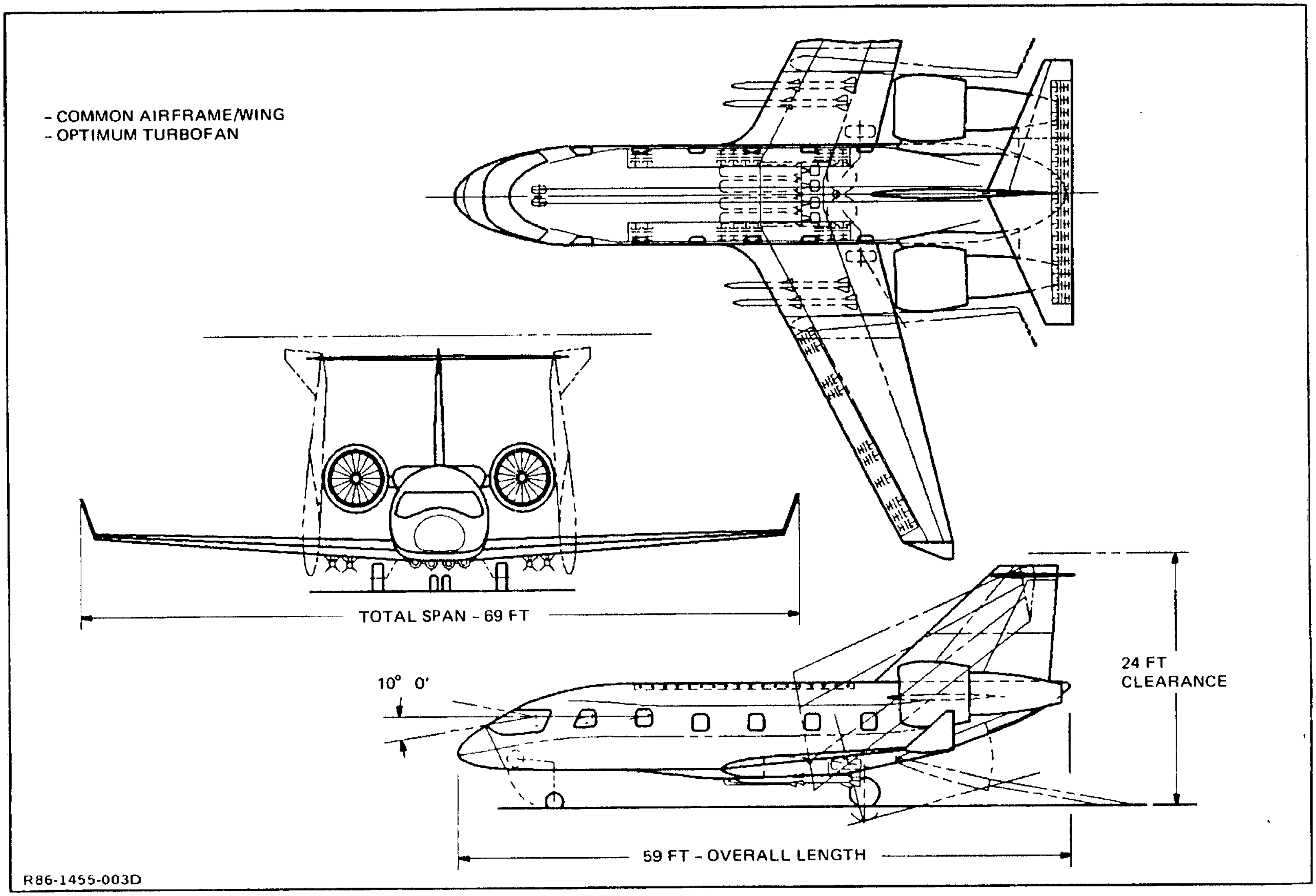


Fig. 2 MR1 Turbofan Design

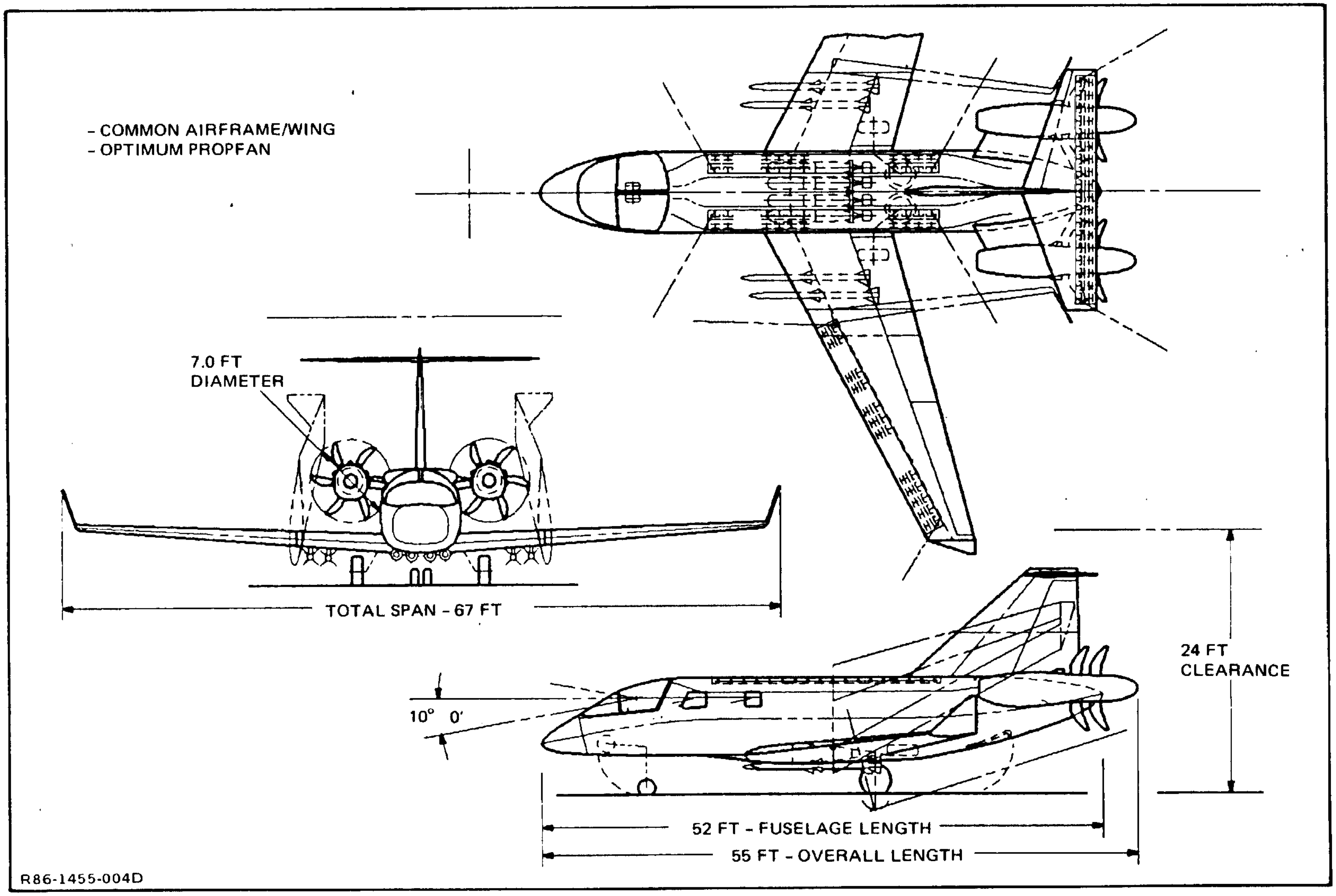


Fig. 3 MR2 Propfan Design

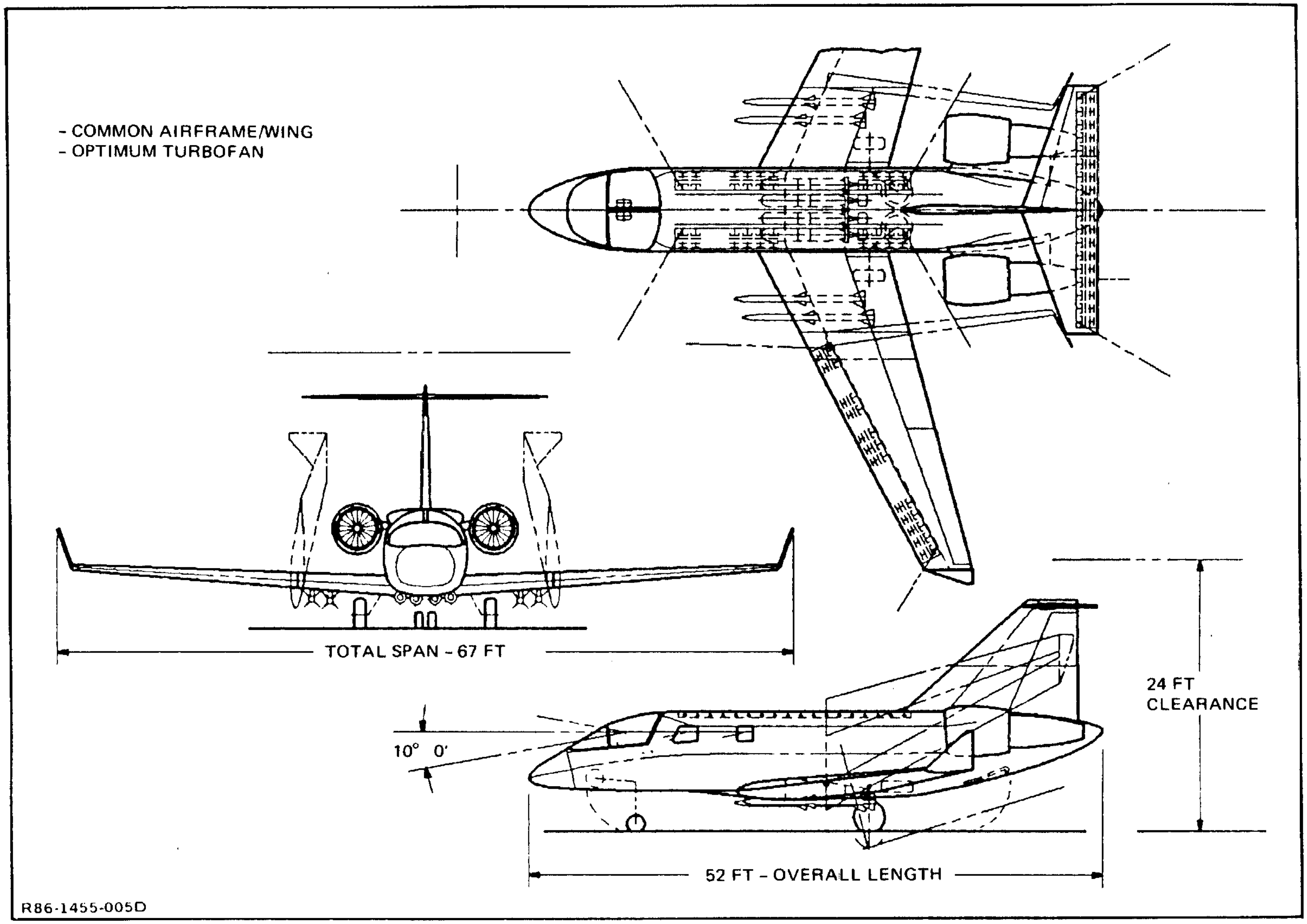


Fig. 4 MR2 Turbofan Design

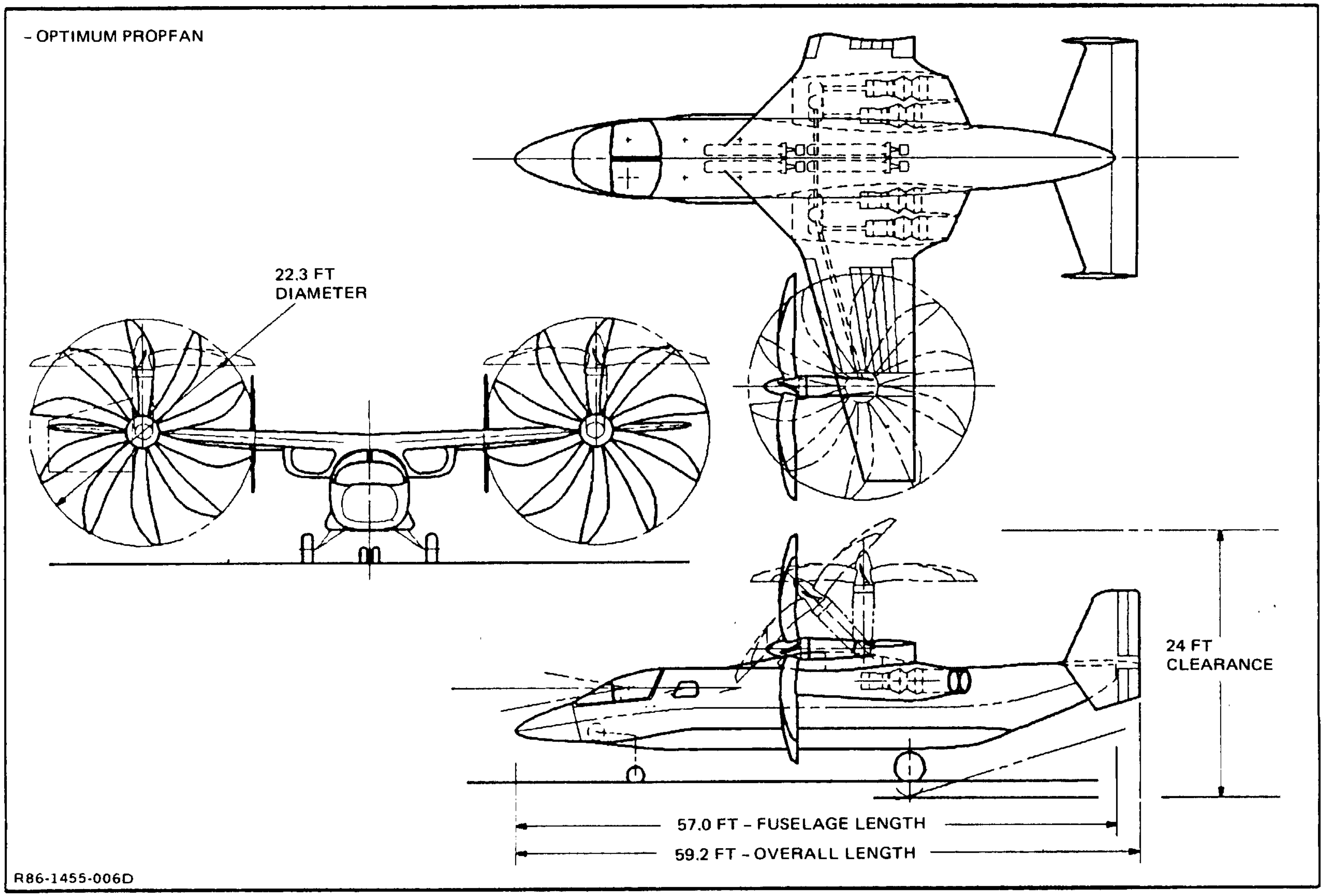


Fig. 5 V/STOL Aircraft Concept

mission-dedicated aircraft. Conversely, a single multimission aircraft possesses inherent performance and weight penalties in addition to system design restrictions that hinder its relative operational effectiveness. The variant concept of a highly-common MPSNA aircraft is most compatible with the wide range of mission requirements.

Many issues were addressed in the conceptual design process of this multipurpose support aircraft. The design philosophy was to obtain a referee configuration upon which several propfan and turbofan configurations could be judged. It was desirable to develop a configuration that would not penalize any propulsion candidate while isolating the changes in figures of merit resulting from propulsion system changes. It was also a challenge to develop a vehicle that satisfies all the mission requirements (low altitude dash, high altitude loiter, and high altitude, high speed cruise) carrying a wide variety of payloads, weapons and avionics loadings. These loadings range from 10,000 lb of cargo and 1000 lb of core avionics for the COD to 8000 lb of avionics and four air-to-air missiles for the AEW aircraft.

The engine candidates of interest in this study included propfans and high bypass turbofans. The propfans were examined both as pusher and tractor installations with single or counter-rotation propulsors mounted either on the wing or aft fuselage. A low-wing, T-tail arrangement was selected to provide maximum variability in engine installation locations.

4 - PROPULSION CHARACTERISTICS

Several propfan and turbofan propulsion systems were screened in the selection process to obtain optimum engine candidates. A detailed description of each propulsion system that was evaluated and the corresponding installation factors follow.

4.1 ENGINE DESCRIPTIONS

Three propfan systems were evaluated to determine the optimum propfan system for an MPSNA vehicle. These concepts included a counter-rotation geared pusher, a single-rotation geared tractor and an ungeared pusher Unducted Fan (UDF) configuration. The optimum propfan chosen from these candidates was compared to a point design turbofan engine concept. A family of parametric turbofans was also investigated for an engine cycle trade analysis. Each of these propulsion systems is described below.

4.1.1 Propfans

The Pratt & Whitney Aircraft (P&WA) STS743 is an advanced technology study engine driving an advanced Hamilton Standard counter-rotating propfan projected for commercial certification in the early 1990s. The STS743 drive system is a three spool geared pusher developed by P&WA, Hartford. A schematic of this engine is shown in Fig. 6. The high pressure spool consists of a four-stage

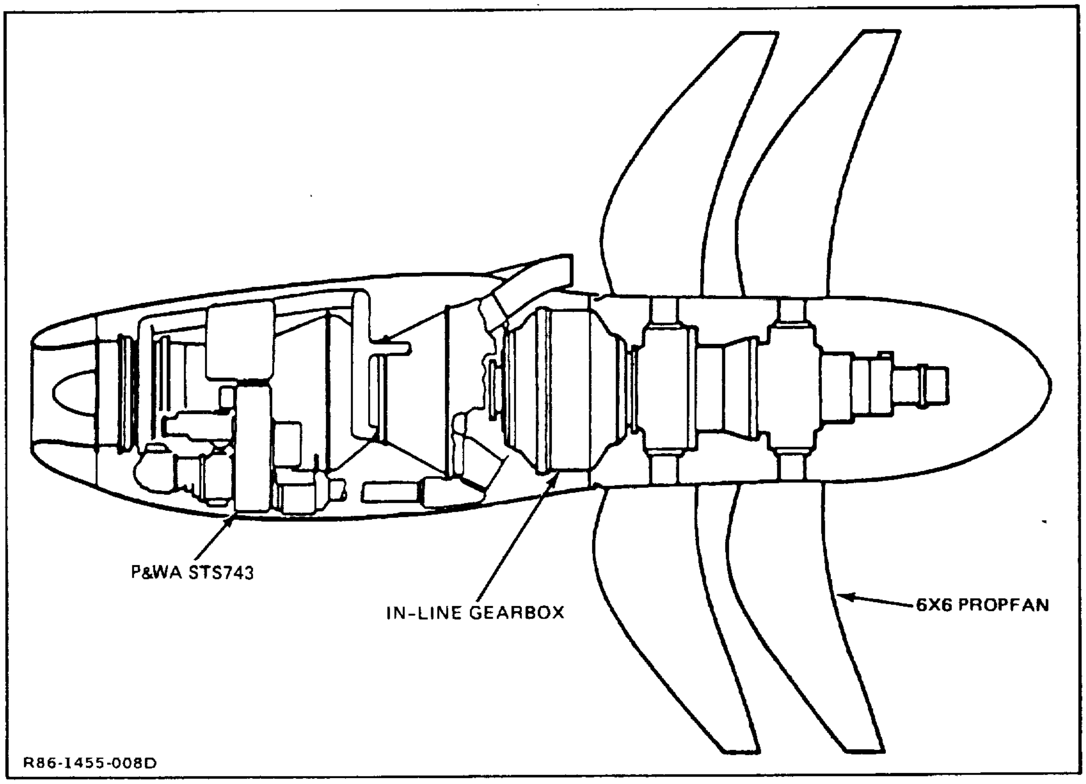


Fig. 6 Pusher Propfan System Concept – STS743

axial plus one-stage centrifugal high pressure compressor driven by a single-stage high pressure turbine. The low pressure spool incorporates a four-stage low pressure compressor driven by a single-stage low pressure turbine. Power output to the propfan is provided by a four-stage free turbine. The gas generator drives an advanced Hamilton Standard 6x6, counter-rotation propfan of hollow titanium full span spar and fiberglass outer shell construction.

Performance data for the propfan are representative of airfoils with design Mach numbers of 0.75 to 0.80. Propfan parameters and their ranges for optimization included:

- Tip speed from 700 to 750 ft/sec
- Propfan loading from 53 to 103 SHP/ft^2.

The gearbox is of the in-line differential planetary type. Results of the NASA sponsored APET Studies (Ref 1 and Ref 2) by P&WA and Allison have indicated this gearbox is the preferred configuration for use in a counter-rotation pusher system. The gearbox efficiency at cruise is 99%. The installed thrust-to-weight (T/W) of this propulsion system is 3.8 for the MR1 size and 3.6 for the MR2 size. The moderate combustor exit temperatures of this engine, 2535°F at takeoff power and 2415°F at cruise, are indicative of commercial design and life requirements. The sea level static design overall compressor pressure ratio is 28:1.

Figure 7 illustrates the tractor propfan candidate in this study, the P&WA STS679, a three spool geared engine which drives a Hamilton Standard single-rotation propfan. Operating design conditions are nearly identical to the STS743 (maximum combustor exit temperature of 2530°F, at takeoff, 2445°F at cruise, and overall design compressor pressure ratio of 28:1). The high pressure spool consists of a two-stage axial plus one-stage centrifugal, high pressure compressor driven by a single-stage high pressure turbine. The low

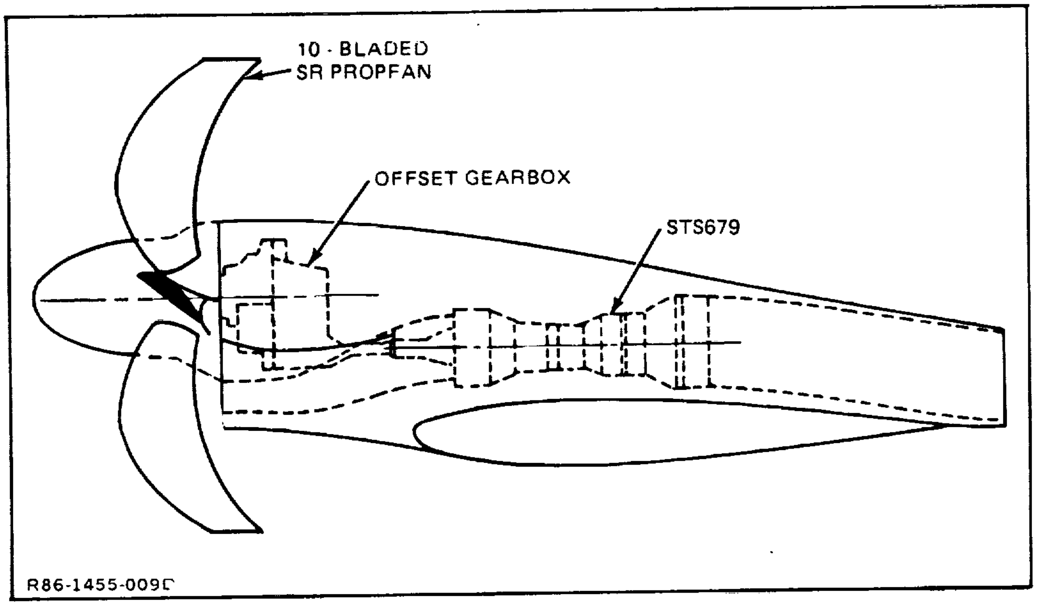


Fig. 7 Tractor Propfan System Concept - STS679

pressure spool incorporates a four-stage low pressure compressor driven by a single-stage low pressure turbine. Power output to the offset propfan reduction gearbox is provided by a three-stage free turbine. The propfan is an advanced technology single-rotation ten-bladed propfan which is conceptually similar to the Hamilton Standard SR-7 propfan designed, built and flight tested under the NASA LAP/PTA programs. These blades have the same spar-shell construction as the counter-rotation system discussed previously.

Performance data for the propfan are representative of airfoils with design Mach numbers of 0.75 to 0.80. Propfan parameters and their ranges for optimization included:

- Tip speed from 700 to 800 ft/sec
- Propfan loading from 42 to 74 SHP/ft^2.

The conventional rotation offset compound idler gearbox was chosen to take best advantage of the supercharging effect of the propfan on the engine. Other advantages when compared to an inline alternate split path gearbox include: fewer parts, longer life and simplicity of design. The efficiency of the offset gearbox at cruise is 99%, with somewhat reduced efficiencies at low power conditions.

The General Electric UDF, shown in Fig. 8, is a gearless pusher preliminary design engine based on a concept evaluated on the joint GE/NASA UDF demonstrator engine and further enhanced to incorporate early 1990s technologies being developed for the commercial market. This UDF concept is configured as a two spool gas generator aerodynamically coupled to a multistage counter-rotating free power turbine. The two spools of the power turbine directly drive the two rows of the propulsor. This fixed-cycle design employs a higher pressure ratio than the two P&WA propfan candidates with an OPR of 44:1. The design tip speed of the UDF blades is 800 ft/sec with a maximum gas generator

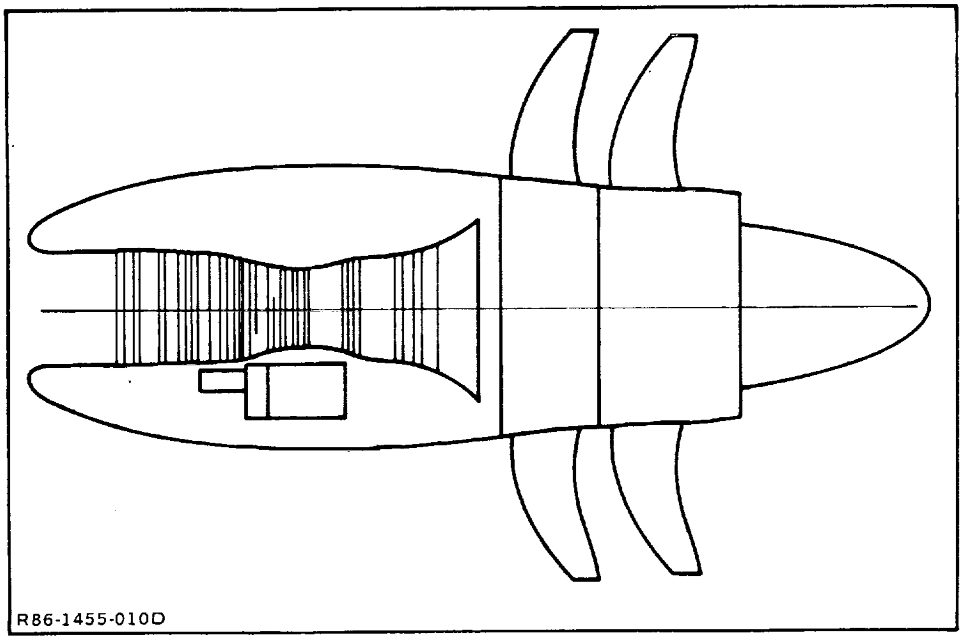


Fig. 8 UDF System Concept

turbine rotor inlet temperature of 2500°F. General Electric projects that the appropriate technology will be available to provide adequate strength and reliability using all composite UDF blades.

The counter-rotation pusher propfan candidates, both geared and ungeared, were evaluated with an aft-fuselage installation. It was preferable to locate the counter-rotation system, with increased noise levels over single-rotation propfans, behind the pressure bulkhead. This installation is also advantageous in minimizing aircraft acoustic fatigue, increasing crew and passenger comfort, providing safe carrier operation, and possibly increasing longitudinal stability. By taking advantage of the aircraft boattail, required clearance of the fuselage and propfan is maintained while reducing the spotting factor when compared to a wing-mounted system.

In an aft mount location, tractor propfan installations result in large pylons to maintain prop blade clearance. The single rotation tractor propfan candidate mounts easily on the wing in a T-tail configuration and was the installation used when evaluating this propulsion system.

4.1.2 Turbofans

The turbofan used for the propfan vs turbofan comparison was the P&WA Hartford STF686, shown in Fig. 9. The STF686 is a twin spool, split flow turbofan engine designed for commercial applications. The high pressure spool is made up of an 11-stage high pressure compressor, a low emissions combustor and a two-stage high pressure turbine. The low pressure spool consists of a single-stage shroudless fan, a three-stage low pressure compressor and a five-stage low pressure turbine. The engine has a fan pressure ratio of 1.66, a bypass ratio of 6.97, and an overall compression system pressure ratio of 37.2 at the design point. This fixed cycle turbofan operates at moderate combustor exit temperatures consistent with its commercial design, 2590°F at takeoff power and 2300°F maximum at cruise.

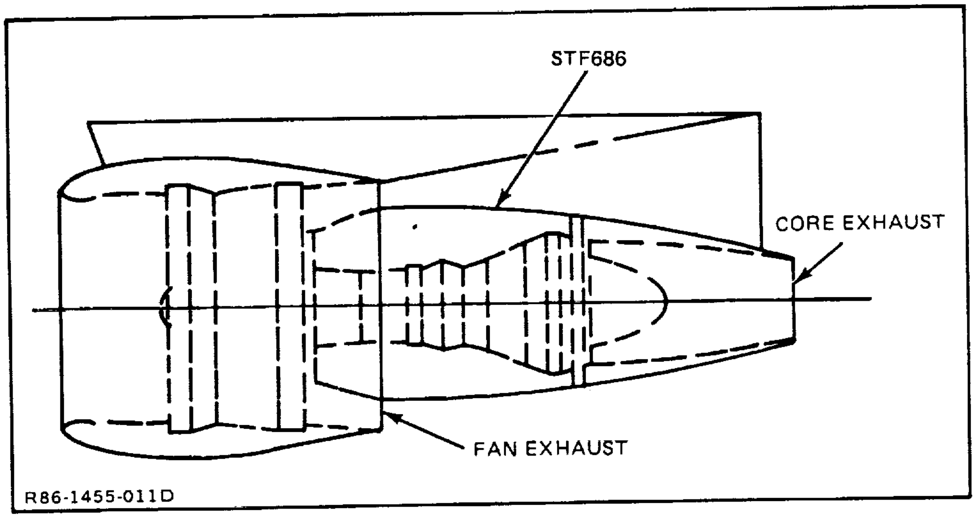


Fig. 9 Turbofan System Concept - STF686

The P&WA JT69 parametric turbofan computer simulation deck was exercised to assess the applicability of the fixed cycle STF686 engine for the MPSNA design missions. This turbofan deck was developed during the Navy-funded ATES program specifically for propulsion screening studies for military vehicles sensitive to specific fuel consumption, such as MPSNA. The technology level is consistent with an IOC of 2000 and a TAD of 1990. The JT69 computer program simulates mixed-flow, fixed turbine geometry, two-spool turbofans. The low-pressure spool is a single- or two-stage fan (a function of desired fan pressure ratio) driven by a cooled turbine. The gas generator is a single-spool compressor driven by a single- or two-stage cooled turbine.

These propulsion system data provide parametric trends. Propulsion system parameters and their ranges for optimization included:

- BPR from 2.0-7.0
- OPR from 20-35.

The design temperature was fixed as a technology item to levels representative of the commercial P&WA Hartford STS743 and STF686 engines. Results of this cycle analysis are detailed in Subsection 9.2.

The turbofan in this study for comparison to the propfans was mounted on the aft fuselage. A high bypass ratio turbofan does not mount well under a low wing due to its relatively large diameter. It does provide a good installation on the aft-fuselage, similar to the Gulfstream II/III/IV engine installation. Scrubbing drag, an important consideration in unmixed flow turbofans, is less in an aft configuration, with less area in the exhaust stream, than a wing-mounted installation.

4.2 INLET DESCRIPTIONS

Generalized performance data for the MPSNA engine air inlets are presented in Fig. 10 and 11 for the propfan and turbofan aft fuselage-mounted and the propfan wing-mounted installations, respectively. These data are given in terms of total pressure recovery and spillage drag vs specific corrected airflow for various free stream Mach numbers. They are based on experimental test data from industry and NASA sources for inlets having similar geometric features and similar installations.

4.2.1 Aft Fuselage Mounted Installations

The air induction systems for the P&WA STF686, P&WA STS743 and the GE UDF engines are scaled versions of the Gulfstream II/III inlets and the nacelles are similarly installed on the aft fuselage. Consequently, the documented wind tunnel/flight test inlet performance characteristics of the Gulfstream II (Fig. 10) were used to calculate installed performance of these engine installations. Pressure recoveries greater than 0.996 are obtainable at all flight conditions, including extreme angle-of-attack and yaw within the flight envelope.

The inlets were sized to a maximum throat Mach number of 0.64, with a capture-to-throat area ratio of 1.315. Internally, the inlet is axisymmetric with its centerline coincident with that of the engine. Elliptical 2/1 lips fair tangentially to a low-angled conical duct ($2\theta = 7°28'$) of low area diffusion ($A_{ENG}/A_{THR} = 1.20$) to provide high internal performance at all flight

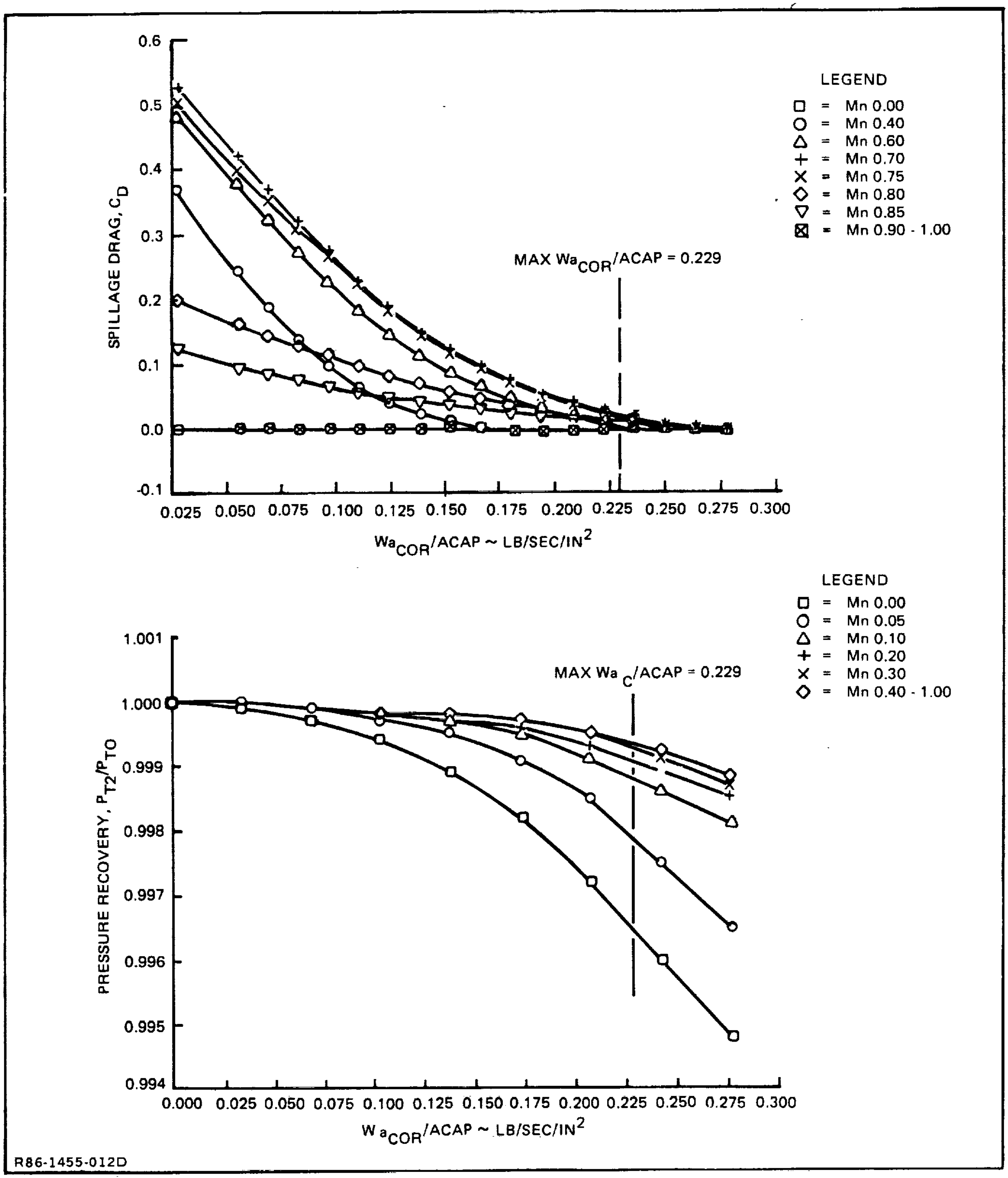


Fig. 10 Inlet Performance Characteristics: Pusher Propfan & Turbofan - Aft Mount

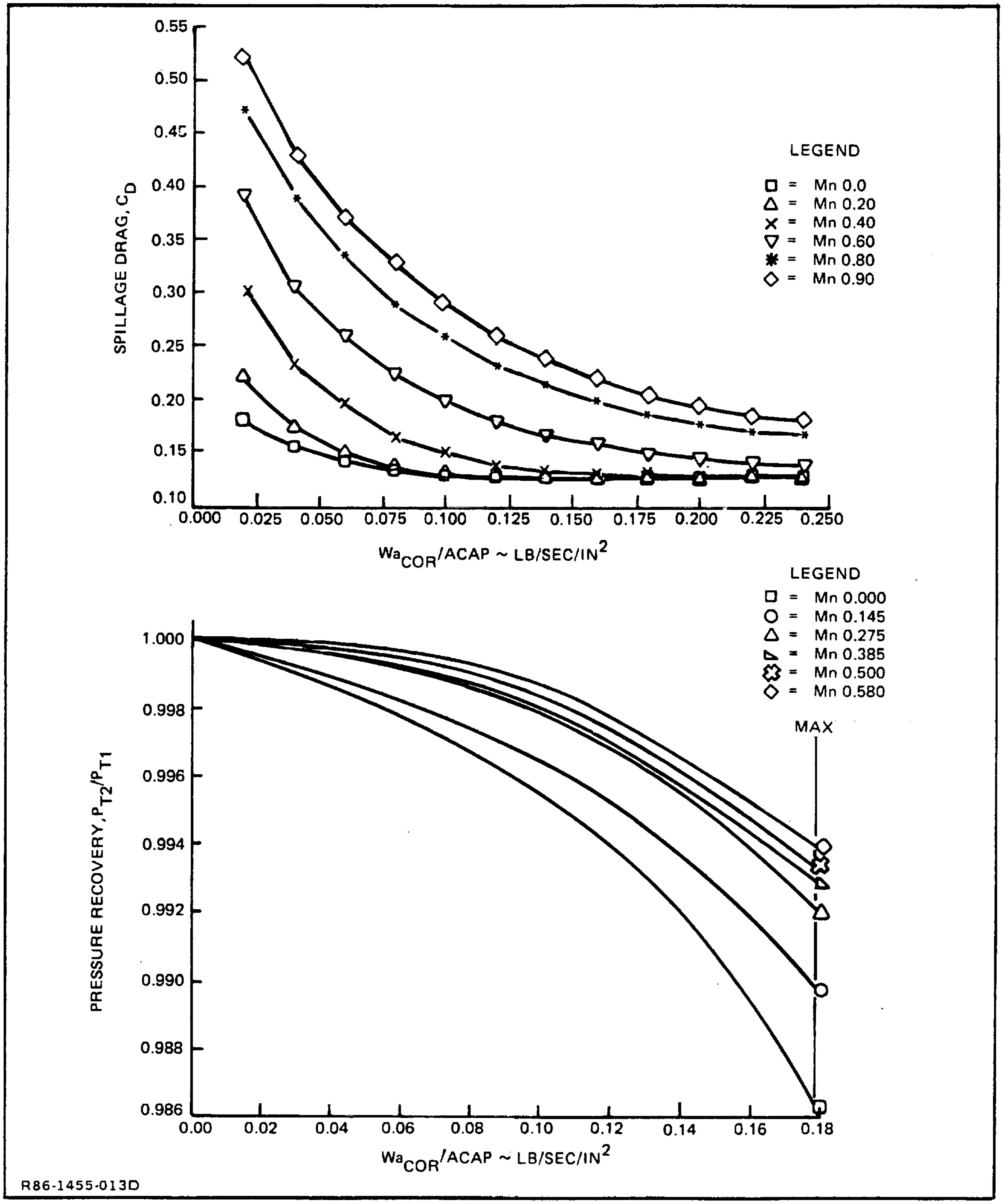


Fig. 11 Inlet Performance Characteristics: Tractor Propfan Wing Mount

conditions, including takeoff in heavy crosswind. Externally, the contours are NACA 1-70-150 designed for low drag and high critical Mach number.

4.2.2 Propfan Wing Mounted Installation

The inlet system design and performance of the P&WA STS679 engine is based on correlated experimental data from industry and NASA sources having similar geometric features and operating environment.

The entry of the chin-type inlet system, without boundary layer diverter, is designed for a maximum throat Mach number of 0.50 with a capture-to-throat area ratio, A_C/A_{TH}, of 1.45 and 2/1 elliptical lips. The duct is S-shaped with a throat-to-engine centerline offset of 0.75 engine diameters and an area ratio, duct exit-to-throat, A_{ENG}/A_{THR}, of 1.12. The maximum subtended angle between the inlet leading edge and the engine flange occurs on the top wall and is approximately 16 degrees. Within the constraints of the installation, the geometric features have been selected from test results of offset ducts and blended to insure separation-free flow with high internal performance. Externally, the contours are low drag modified NACA 1-61-50 contours with a critical Mach number higher than the aircraft maximum speed.

The inlet total pressure recovery and spillage drag characteristics are presented in Fig. 11. These data were derived from flight test results of the E-2C whose inlet system has similar offset duct parameters and similarly installed. Total pressure recoveries, not including blade pressure rise effects, at maximum engine air flow range from 0.987 at sea level static to 0.994 at maximum flight speed. The spillage drag characteristics are based on correlations of NASA and industry data for intakes which are generously contoured internally and which have a NACA 1-61-50 external profile.

4.3 EXHAUST DESCRIPTIONS

The P&WA STS743 pusher propfan uses an 11-lobe nozzle concept shown in Fig. 12 to accommodate the gearbox and propfan aft of the exhaust. The hot gas, 860°F at takeoff, is divided among the lobes and exhausts just forward of the propfan blades after mixing with cooler ambient air, providing a lower average exhaust temperature to the blades. The propfan blades were designed by Hamilton Standard to withstand average exhaust gas temperatures up to 500°F. The effect of the hot gas impingement on the propfan root characteristics was incorporated by Hamilton Standard into the P&WA computer simulation deck for the 6x6 counter-rotation pusher. The exhaust system incorporated in the P&WA STS679 tractor propfan is a simple fixed area conical exhaust nozzle.

The P&WA STF686 turbofan used in the propfan vs turbofan trade study employs split exhaust ducts for the fan and core flows. The fan flow exhausts through a short annular subsonic nozzle while the gas generator flow exhausts through a conical subsonic nozzle. Internal duct losses are calculated within the manufacturers' deck while losses for the effects of scrubbing drag on the waist cowl and pylon were included as installation effects and discussed in Subsection 4.4. The parametric turbofan engine data from P&WA Florida used for a cycle study is a mixed flow engine with a fixed area convergent axisymmetric exhaust nozzle.

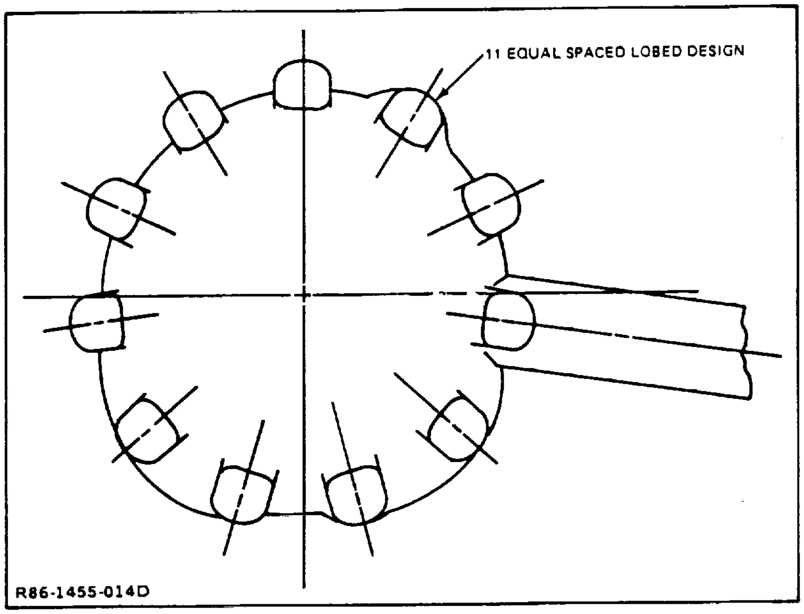


Fig. 12 STS743 Pusher Propfan Exhaust Nozzle

4.4 INSTALLATION FACTORS

Performance data supplied by the engine and propeller manufacturers were corrected to reflect installation in the MPSNA design vehicle. Installed engine performance accounts for inlet/engine matching, aircraft bleed and power extraction, exhaust scrubbing drag, propfan supercharging, and ambient temperature variations. To provide the best comparison between engines, the installation losses were consistent whenever possible. The following sections describe the levels of correction used for this study.

4.4.1 Inlet Performance

Total pressure recovery for the subsonic inlet used in the pusher propfan and turbofan applications is shown in Fig. 10. Also shown are the inlet spillage drag characteristics. These values are included in the thrust data since they vary with engine power setting. These data were derived from model tests described in Subsection 4.2.

Total pressure recovery and spillage drag for the tractor propfan configuration is shown in Fig. 11. The P&WA STS679 performance deck did not include the pressure or temperature rise through the propfan. Considering the high disk loadings of this system, this approach was thought to be too conservative. Responding to our request, Hamilton Standard provided representative values of slipstream temperature and pressure rise for a 10-bladed single rotation propfan. These data are very sensitive to the scoop design and inlet/propfan spacing and would require refinement following the completion of a detailed inlet design, installation, and test program. Spacing between the inlet and propfan was assumed to be the minimum distance possible insuring adequate clearance with the blades at feather.

From these data Grumman developed a generalized method for estimating these pressure and temperature ratios for various tip speeds at all points in the flight envelope. These values are shown in Fig. 13 through 16 for various

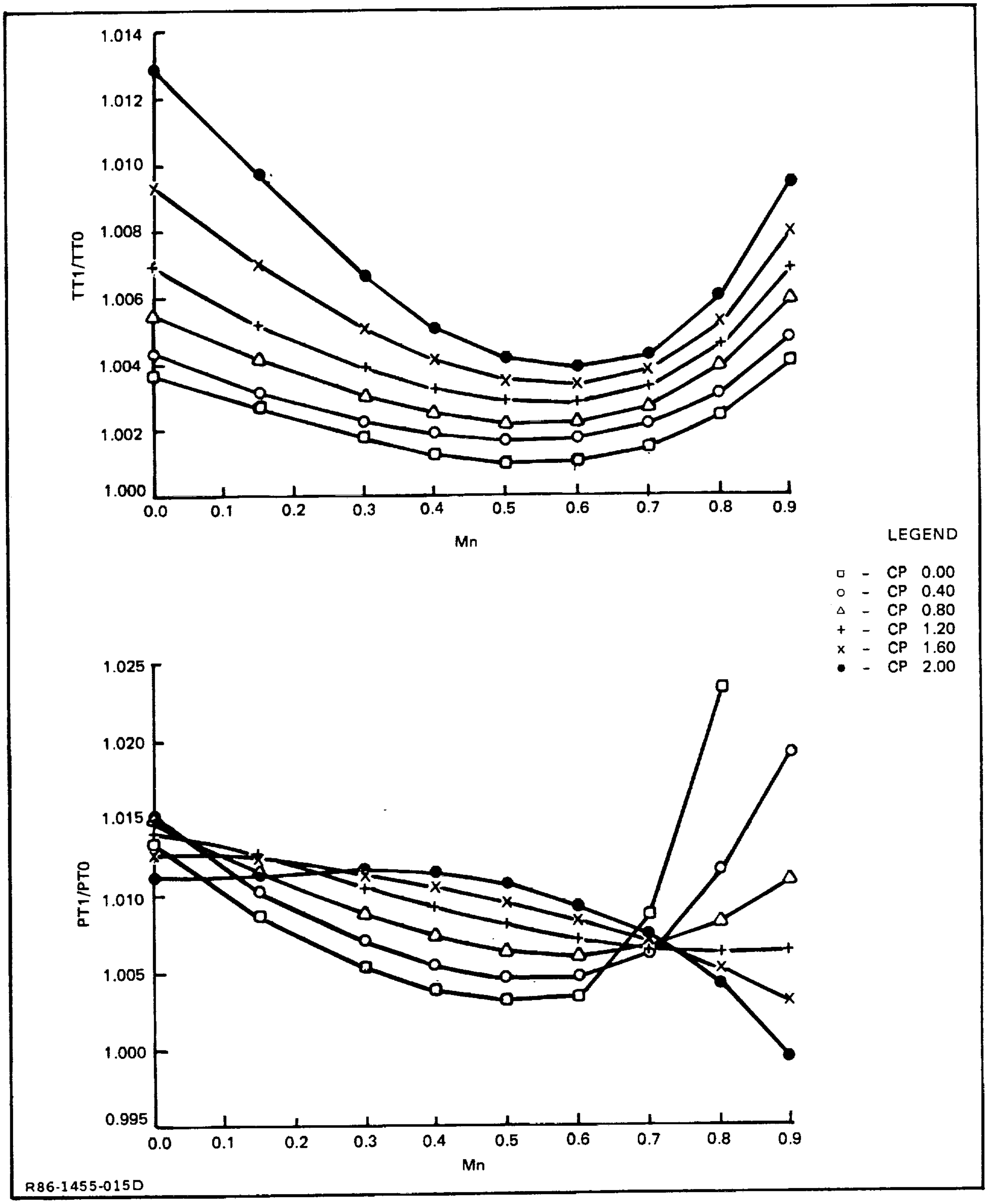


Fig. 13 Propfan Pressure & Temperature Rise: $V_{Tip}/\sqrt{\theta}$ = 600 Ft/Sec

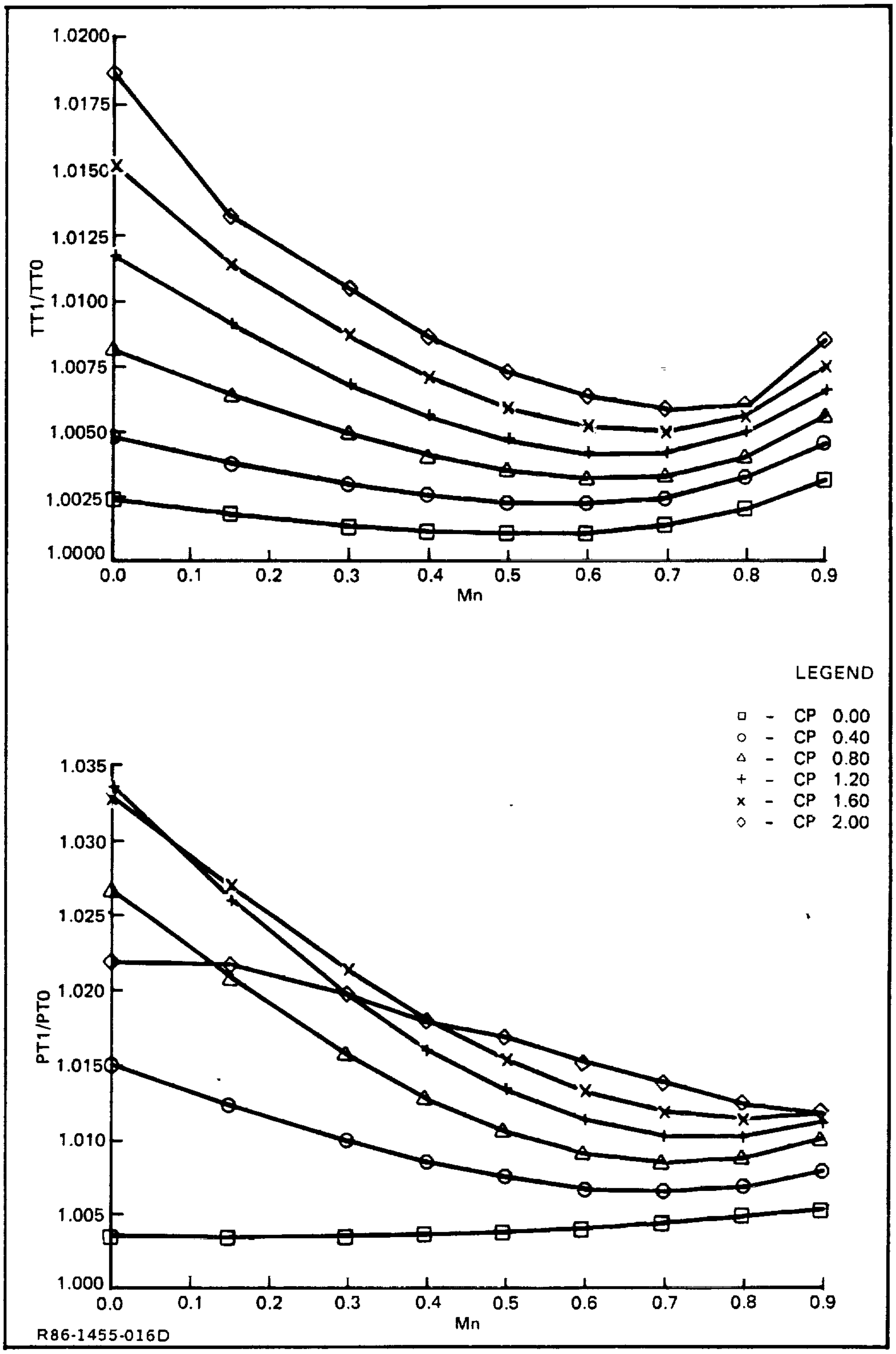


Fig. 14 Propfan Pressure & Temperature Rise: $V_{Tip}/\sqrt{\theta}$ = 750 Ft/Sec

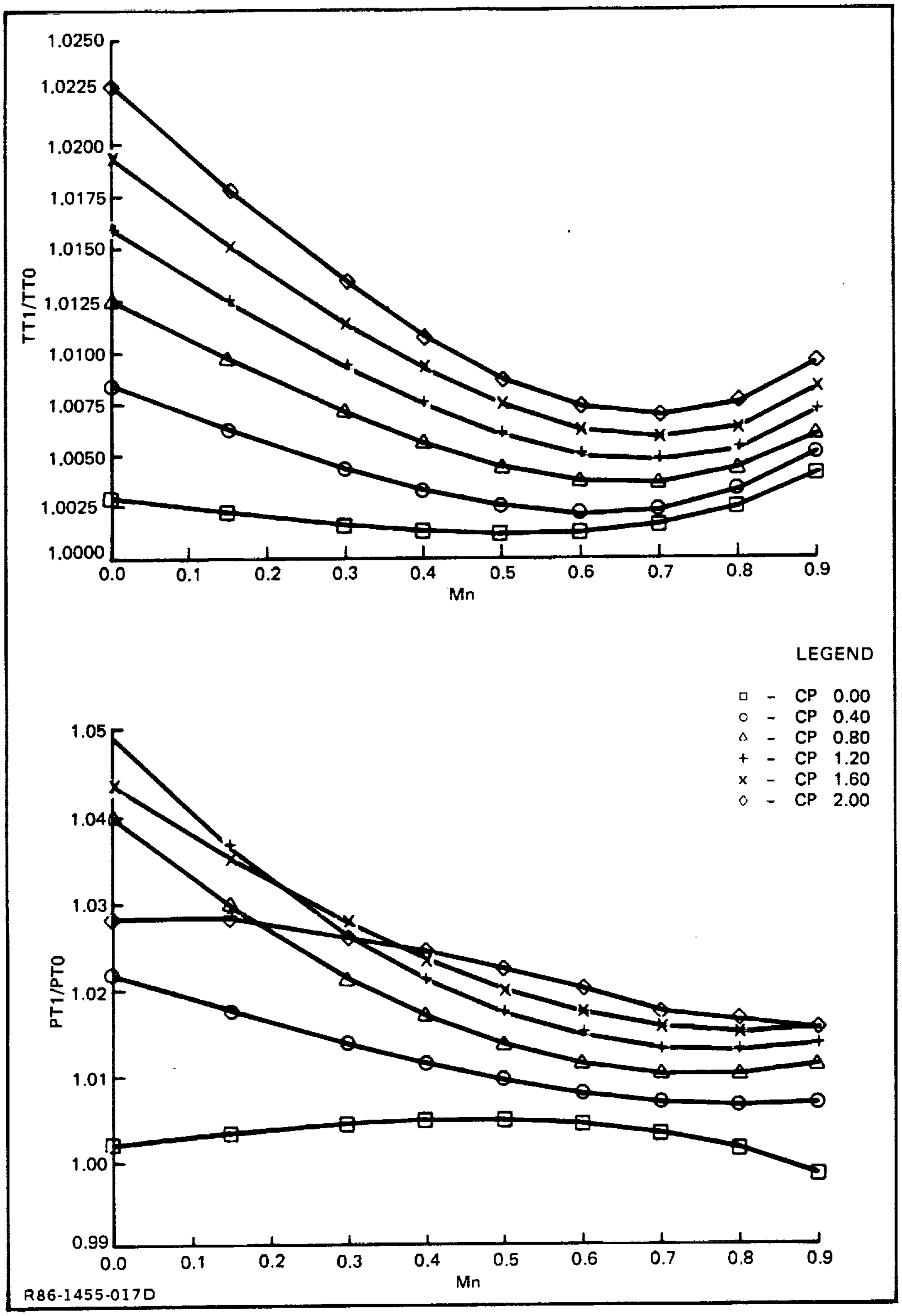


Fig. 15 Propfan Pressure & Temperature Rise:
$V_{Tip}/\sqrt{\theta} = 850$ Ft/Sec

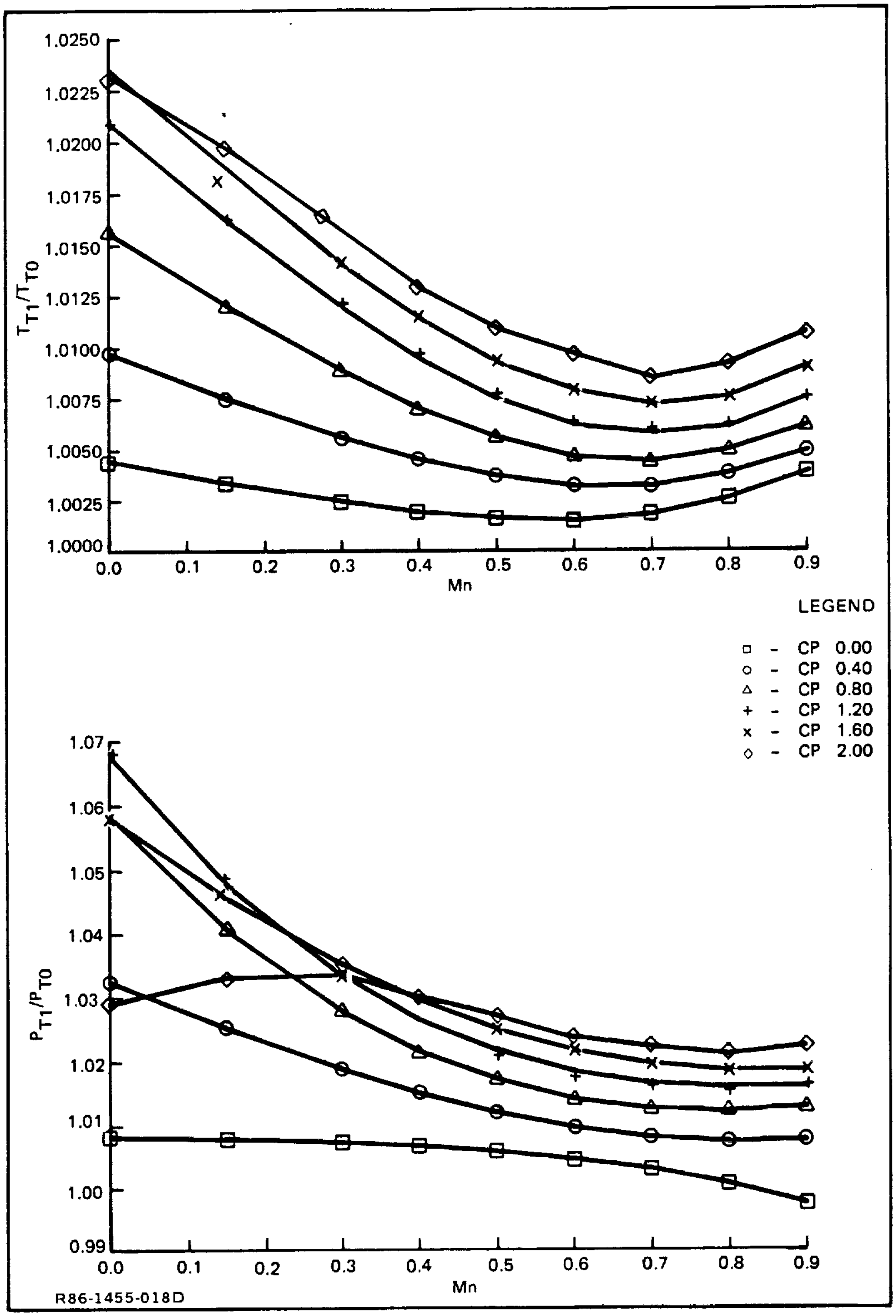


Fig. 16 Propfan Pressure & Temperature Rise
$V_{Tip}/\sqrt{\theta}$ = 950 Ft/Sec

tip speeds. Total pressure at the compressor face used for performance calculations was then corrected by the rise through the propfan (P_{T1}/P_{TO}) times the pressure loss in the inlet duct (P_{T2}/P_{T1}). This supercharging benefit is reduced by the temperature increase across the blades.

Figure 17 shows the effect of the propfan supercharging on net thrust. At cruise power and 40,000 ft, Mach number 0.75, typical cruise conditions, the isolated effect of 1.6% pressure rise is a thrust benefit of 2.3%. The isolated effect of 2.5°F increase in temperature results in a thrust penalty of 2.2%. In this case the effect on thrust is a 0.1% thrust benefit. The thrust change due to supercharging may be more or less than the sum of the isolated effects of pressure and temperature rise on thrust. This results from the interactive effect of these parameters. Results at other flight conditions at

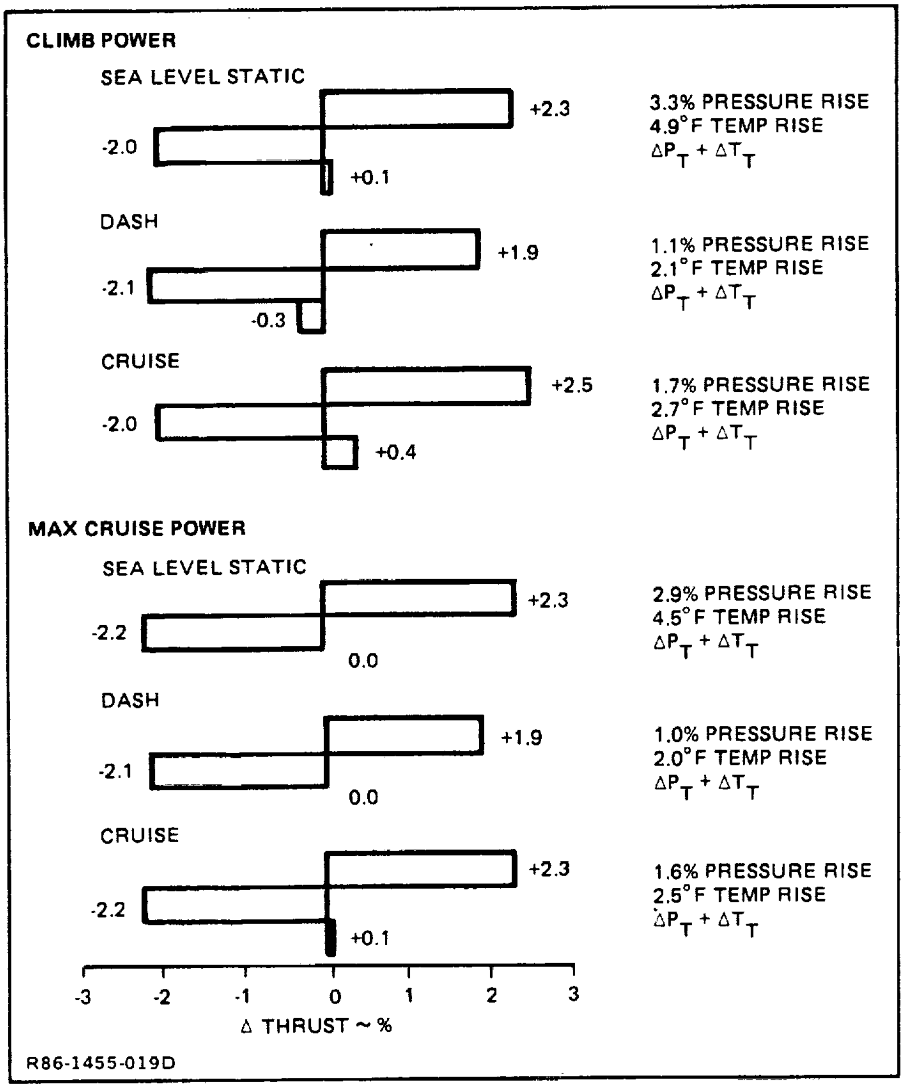


Fig. 17 Propfan Supercharging Effect on Net Thrust

cruise and climb powers show similar trends. Figure 18 shows no significant benefit in SFC results from this supercharging. The conclusion drawn is that the net effect of both pressure and temperature changes is negligible for this application and should be ignored in further preliminary studies of this type.

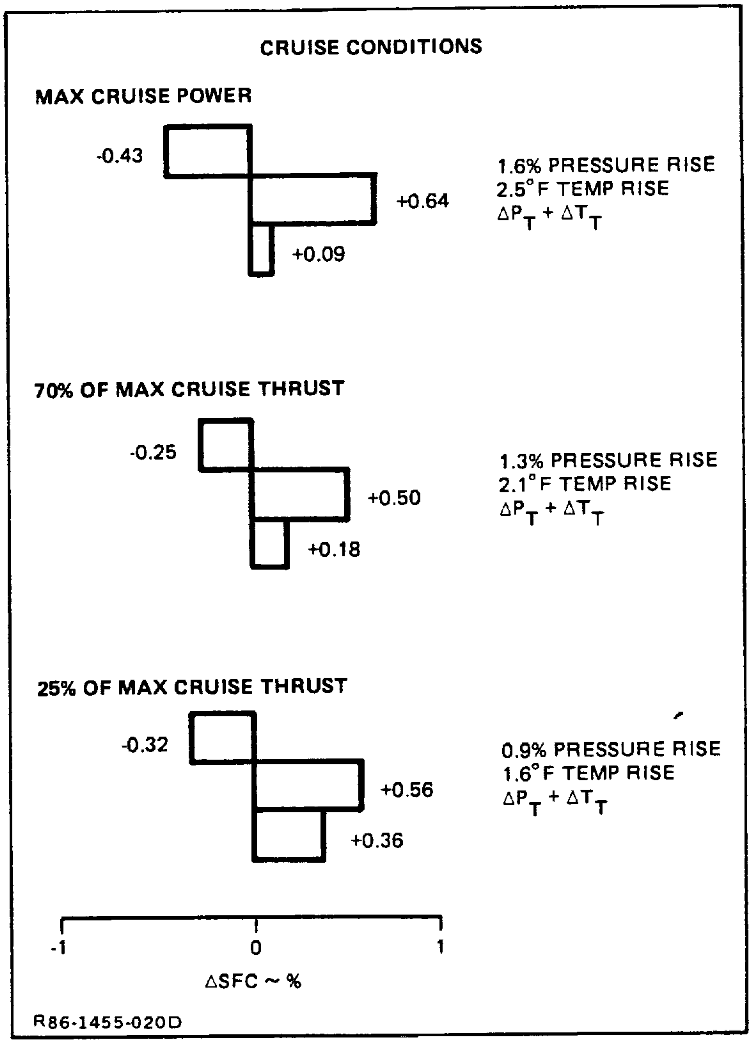


Fig. 18 Propfan Supercharging Effect on SFC

4.4.2 Bleed & Horsepower Extraction

Performance data supplied by the engine manufacturers were corrected to include 76 Horsepower (HP) extraction per engine for aircraft use. Past design experience with this type of aircraft, like the production E-2C, indicate that this level is adequate for the aircraft subsystems.

The STS743 propfan engine incorporates a "design for bleed" concept which is intended to minimize the penalty incurred when extracting customer bleed from the engine. The engine is designed with a bleed flow of 3.8% of core flow, 1.0 lb/sec at cruise. The performance data were corrected for this airbleed extraction in all engine configurations for consistency.

4.4.3 Propulsion System Drag Bookkeeping

Installed engine performance includes those drags which vary with engine power. Figure 19 schematically presents these forces, in addition to non-power dependent forces, on a typical turbofan nacelle. The inlet spillage drag, the difference between additive drag and lip suction, and the inlet duct pressure loss were discussed in Subsection 4.4.1. The bookkeeping system treats fan cowl friction and boattail drag as a function of free stream Mach number and not engine power; they are therefore accounted for in the basic aerodynamic drag polar. Force bookkeeping methodologies were carefully developed for each engine configuration. The aft-mounted pusher propfan configuration required no adjustments for power-dependent drags because of its interference-free installation. The turbofan and wing-mounted tractor propfan propulsion system drags are detailed below.

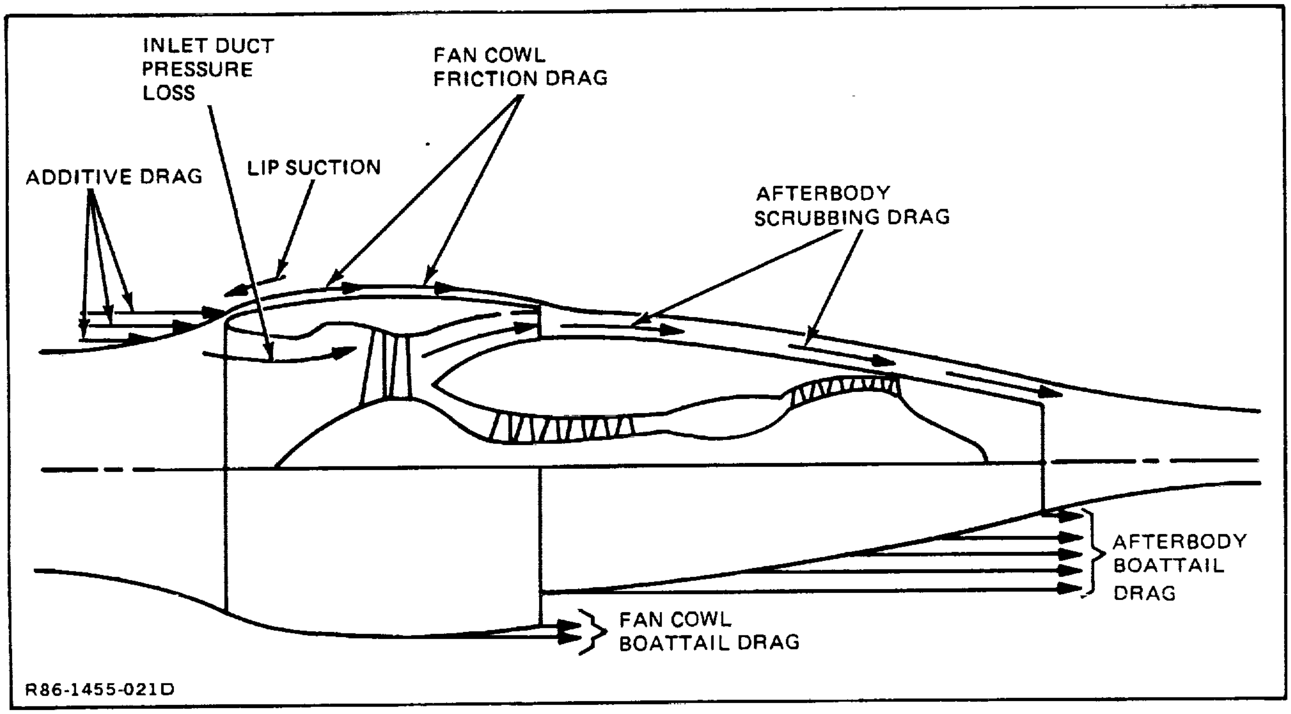


Fig. 19 Nacelle Forces

In the short fan duct configuration of the turbofan, a portion of the pylon and entire core engine cowl are immersed in the fan discharge stream. In the wing-mounted tractor propfan configuration, a portion of the wing and the entire nacelle is scrubbed by the propfan slipstream. The resulting scrubbing drag due to skin friction included in the installed performance data is defined below.

$$D_{SCRUB} = (C_f)(q_f)(A_W)(R_f): \quad \text{turbofan}$$

$$D_{SCRUB} = (C_f)(q_f-q_o)(A_W)(R_f): \quad \text{propfan}$$

where:

D_{SCRUB} = Scrubbing Drag, lb

C_f = Local Compressible Skin Friction Coefficient

$= [2 \log_{10} Re_L - 0.65]-2.3\ [1 + \frac{\gamma-1}{2} (M_n)^2]^{-.467}$

$Re_L = \rho V L / \mu$

$\rho = P_o / 32.174\ RT$

V = Fully Expanded Velocity, ft/sec

L = Characteristic Length, ft

$\mu = 2.324 \times 10^{-8}, \frac{\text{lb-sec}}{\text{ft}^2}$

$$Mn = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{P}{P_o}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

q_f = Fan Stream Dynamic Pressure, psi

q_o = Free Stream Dynamic Pressure, psi

A_W = Wetted Area, ft^2

R_f = Roughness Factor of 1.05

In the case of the turbofan, the wetted area used in this calculation includes the area of the pylon between the cowl surface and a line on the pylon from the cold stream discharge annulus height to the point on the trailing edge of the pylon where it attaches to the fuselage and the entire area of the core waist cowl aft of the fan exit plane. This area is not included in the total aircraft wetted area for drag estimation purposes. The drag is therefore book-kept in the propulsion data as a function of total or fan stream dynamic pressure. The wetted area used in the scrubbing drag calculation for the tractor propfan includes the wing area from the leading to trailing edge, the width of the propfan diameter minus the nacelle footprint, and the exposed nacelle wetted area. This area is included in the total aircraft wetted area with the drag accounted for in the basic aerodynamic drag polar as a function of free stream dynamic pressure. The installed propulsion performance accounts for only the increase in dynamic pressure in the propfan wake, $q_f - q_o$, on the wing surface.

A comparison of the scrubbing drag of the three candidates at the sizing conditions is shown in Fig. 20. As discussed earlier, there is no scrubbing drag penalty for the pusher propfan because of its configuration and aft mount location. The turbofan shows the highest penalty with the scrubbing drag equal to 2.4% of the net thrust at cruise.

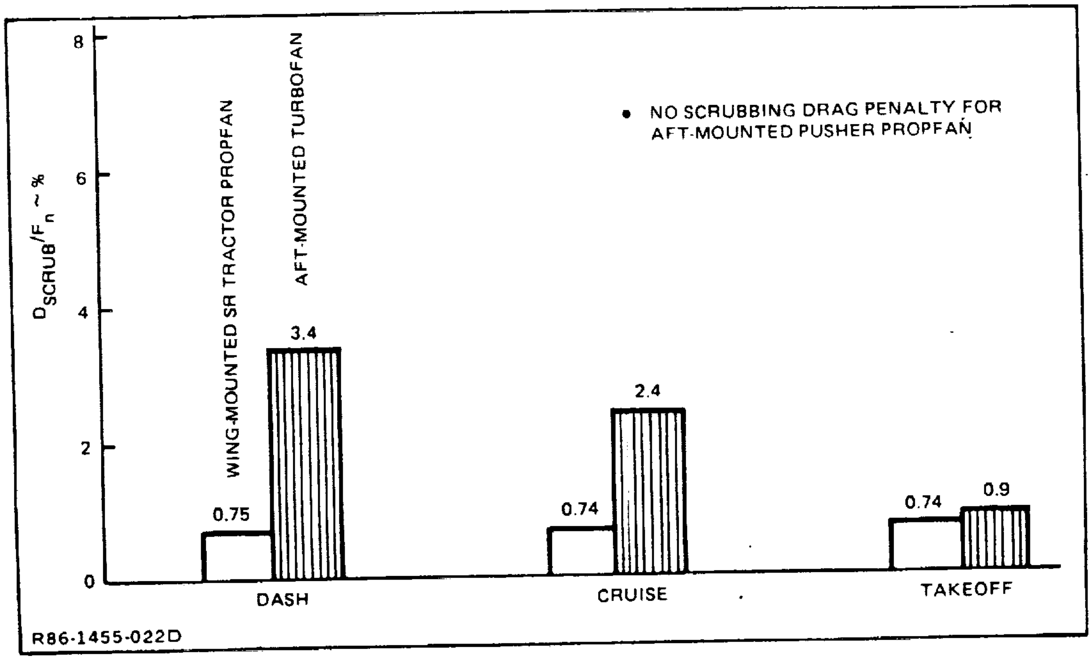


Fig. 20 Scrubbing Drag Comparison

The core engine cowl boattail drag is calculated with the following relationship:

$$D_{BOAT} = C_D \, q_f A_c$$

where:

D_{BOAT} = Boattail Drag

C_D = Drag Coefficient = 0.01

q_f = Fan Stream Dynamic Pressure, psi

A_c = Core Engine Cowl Projected Area, in.^{2}

The choice of drag coefficient equal to 0.01 is shown in Fig. 21. The radius to diameter ratio of our turbofan configuration is eight, which falls on the flat portion of the curve or $C_D = 0.01$.

Aircraft drag is conservatively computed with power off or with a nominal power setting. Propulsion thrust data could be corrected for the variation in installation drag due to throttle setting. Since back-end performance has not been experimentally verified, no interference corrections were made for this effect and the thrust data are slightly conservative.

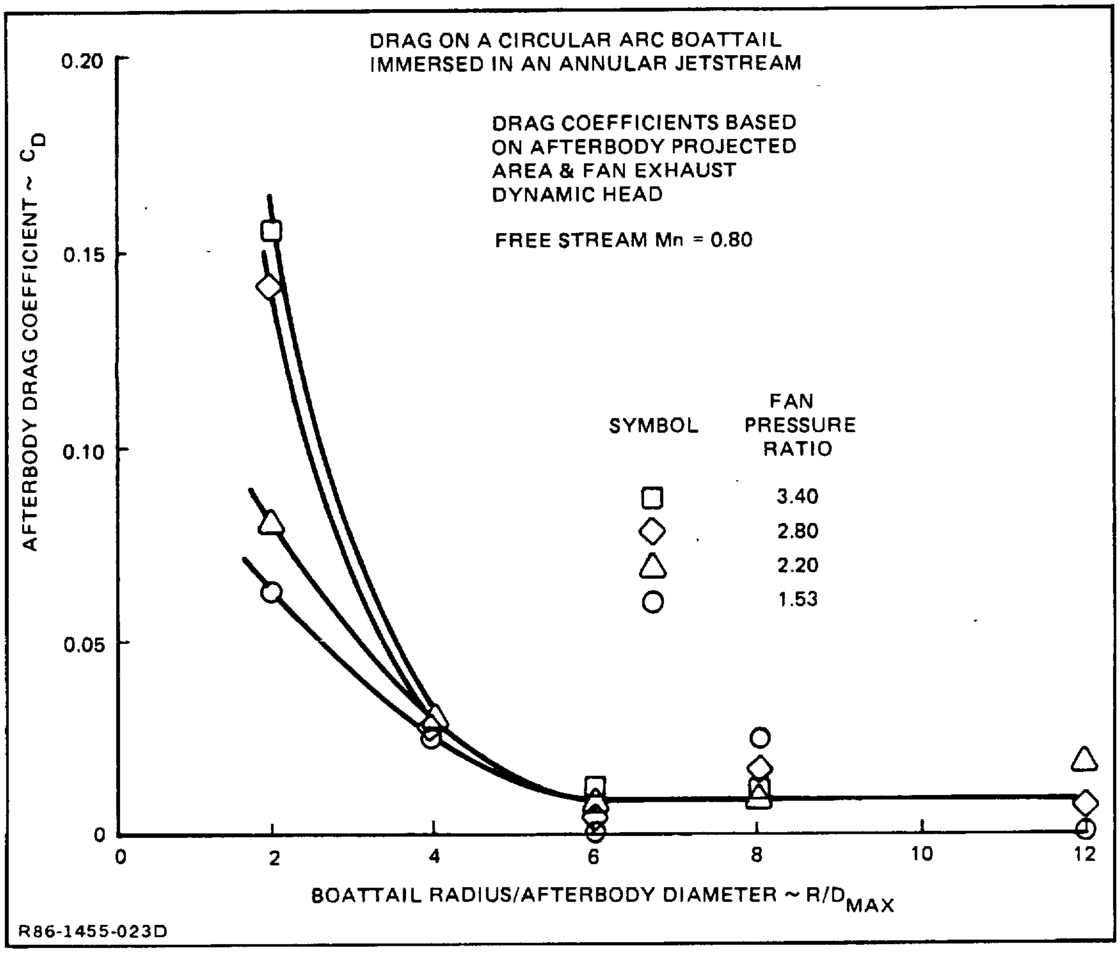


Fig. 21 Boattail Drag Coefficient

5 - CONCEPT DEVELOPMENT

5.1 DESIGN MISSIONS

The missions utilized during the MPSNA study were the result of numerous studies conducted for the U.S. Navy as well as over 50 years of Grumman experience as builders of Navy aircraft. Ten missions were developed based on the following operational and analytical factors:

- The current missions flown by existing Naval support aircraft
- Anticipated requirement increases for the year 2000 based on the projected threat
- In-house studies conducted for the U.S. Navy to establish operational requirements for future aircraft
- In-house design studies conducted under IR&D and government contract of Mission Support Aircraft.

Compiling this information, Grumman has established the following ten mission scenarios, each adhering to the groundrules established in Section 3.

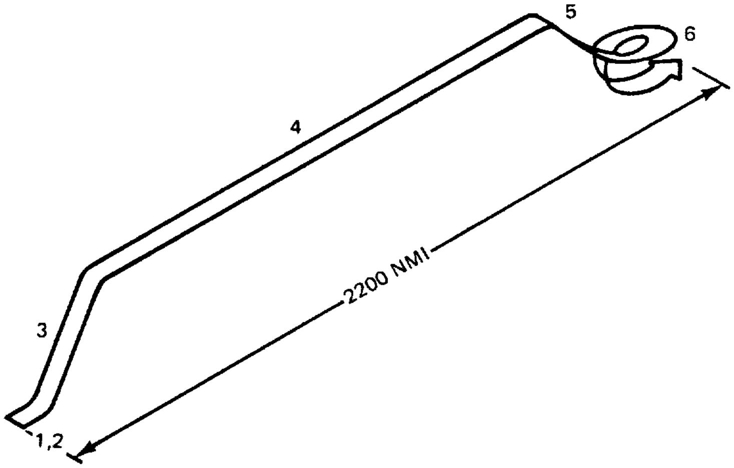
In summary, most missions require faster transit speeds, higher loiter altitudes, longer loiter times and greater distances to their station than any of the current aircraft that MPSNA is intended to replace. In addition, payloads will be greater due to the required increased capability and multiplicity of sensor systems within any one aircraft.

5.1.1 Carrier On-board Delivery (COD)

The COD mission (Fig. 22) is basically a transport-type profile in which personnel and cargo are delivered over long distances. This design would replace the C-2A. The 2200 nmi range is indicative of the longest range necessary for military application. A unique requirement over commercial transports is the ability to land and take off from a carrier, thus requiring special cargo restraints and 463L pallets. This reduces the available volume for deliverable cargo. During the MR1 development, this cargo volume requirement dictated the fuselage size. Vehicle sizing drivers for this mission are long range with a payload of 10,000 lb. A crew of three and an installed avionics weight of 1000 lb are required.

5.1.2 Tanker

This mission (Fig. 23) is currently the same as that performed by carrier-based tankers, like the KA-6D. The 23,000 lb transfer fuel exceeds current tanker capability. The design entails a short range, high payload-fraction aircraft with a cruise speed of 400 kt. A crew of two and 1000 lb of avionics are required.



1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB AT INTERMEDIATE THRUST TO BEST ALTITUDE (NOT TO EXCEED CRUISE CEILING)
4. CRUISE OUT AT BEST CRUISE ALITITUDE AND SPEED. (CRUISE SPEED MUST NOT BE LESS THAN 350 KTAS) FOR 2200 NMI
5. DESCEND TO SEA LEVEL NO FUEL USED, NO TIME OR DISTANCE CREDIT
6. LANDING ALLOWANCE AND RESERVE
   - DESIRED RANGE - 2200 NMI
   - PAYLOAD - 10,000 LB (CARGO DENSITY = 8.57 LB/FT^3)
   - AVIONIC - 1000 LB INSTALLED
   - CREW (3) - 750 LB
   - PROVISIONS FOR 18 PASSENGERS OR ABOVE PAYLOAD
   - ULTIMATE LOAD FACTOR - 4.5G (MAY BE GUST CRITICAL)

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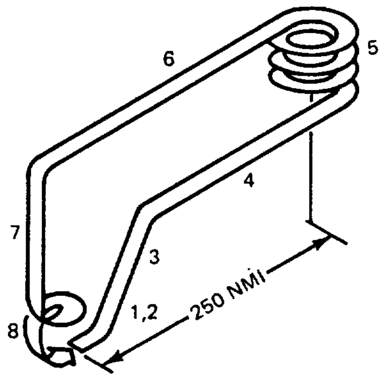
Fig. 22 COD Mission



1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB AT INTERMEDIATE POWER TO BEST CRUISE ALTITUDE (NOT TO EXCEED CRUISE CEILING)
4. CRUISE OUT TO 250 NMI AT BEST CRUISE ALTITUDE AND SPEED (CRUISE SPEED TO BE 400 KTAS)
5. TRANSFER FUEL - FUEL ALLOWANCE - 20 MIN AT CRUISE ALTITUDE, MAX ENDURANCE SPEED, DROGUE DEPLOYED - NO DISTANCE GAINED
6. CRUISE BACK AT BEST CRUISE ALTITUDE AND MACH NUMBER
7. DESCENT TO SEA LEVEL - NO FUEL USED, NO TIME OR DISTANCE CREDIT
8. LANDING ALLOWANCE AND RESERVE
   - FUEL TRANSFER - 23,000 LB
   - AVIONICS - 1000 LB INSTALLED
   - MISSION PAYLOAD - 2000 LB
   - CREW (2) - 500 LB
   - ULTIMATE LOAD FACTOR - 4.5G (MAY BE GUST CRITICAL)

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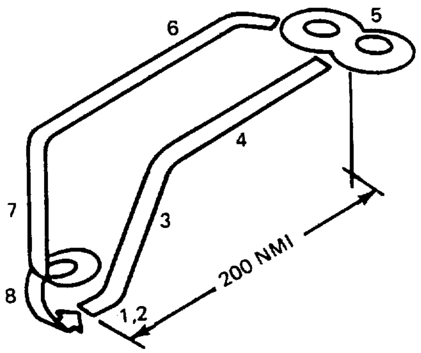
Fig. 23 Tanker Mission

5.1.3 Anti-Air-Warfare (AAW)

The AAW mission, shown in Fig. 24, is used for fleet defense by providing electronic counter-measure support using three externally-mounted jamming pods. This role is currently filled by the EA-6B. The primary aircraft sizing drivers are high cruise speed (425 kt) and a loiter time of four hours at 35,000 ft. A crew of four and an installed avionics weight of 5000 lb are required.



1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB - CLIMB AT INTERMEDIATE THRUST TO BEST ALTITUDE (NOT TO EXCEED CRUISE CEILING)
4. CRUISE OUT - CRUISE OUT AT BEST ALTITUDE AND SPEED (CRUISE SPEED MUST BE AT LEAST 425 KTAS TO 200 NMI)
5. LOITER AT 200 NMI, 35,000 FT ALTITUDE FOR 2 TO 4 HRS
6. CRUISE BACK AT BEST CRUISE ALTITUDE AND MACH NUMBER
7. DESCEND TO SEA LEVEL, NO FUEL USED, NO TIME OR DISTANCE CREDIT
8. LANDING ALLOWANCE AND RESERVE

- DESIRED RANGE - 200 NMI
- PAYLOAD - 3 ECM PODS
- CREW (4) - 1000 LB
- ULTIMATE LOAD FACTOR - 4.5G (MAY BE GUST CRITICAL)
- AVIONICS - 5000 LB INSTALLED (INCLUDING PODS)

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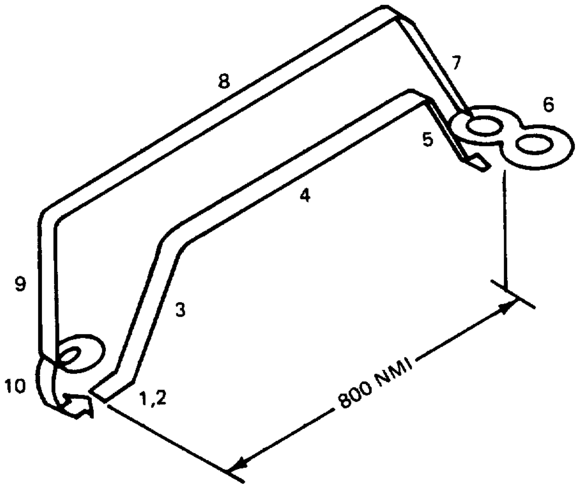
Fig. 24 AAW Mission

5.1.4 Support/Standoff Electronic Warfare (VAQ/VQ)

The VAQ/VQ mission (Fig. 25) is an EA-6B type surveillance mission. The aircraft is primarily for passive detection (SIGINT and ELINT) but has the capability to provide jamming as well as carry weapons for targets of opportunity. The vehicle sizing drivers are high cruise speed (425 kt) as well as a one hour loiter at 30,000 ft. A crew of three and 5000 lb of avionics are required. Two HARMs are carried externally.



1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB AT INTERMEDIATE THRUST TO BEST CRUISE ALTITUDE
4. CRUISE OUT - AT BEST CRUISE ALTITUDE AND SPEED (CRUISE SPEED MUST BE AT LEAST 425 KTAS TO 800 NMI)
5. DESCEND TO A NOMINAL 30,000 FT (25,000 TO 35,000 FT) NO FUEL USED, NO TIME OR DISTANCE CREDIT
6. LOITER AT 30,000 FT FOR 1 HR TOS
7. CLIMB BACK TO BEST CRUISE ALTITUDE
8. CRUISE BACK AT BEST CRUISE ALTITUDE AND MACH NUMBER
9. DESCEND TO SEA LEVEL, NO FUEL USED, NO TIME OR DISTANCE CREDIT
10. LANDING ALLOWANCE AND RESERVE
    - RANGE - 800 NMI
    - PAYLOAD - 3 ECM PODS
    - CREW (4) - 1000 LB
    - WEAPONS - 2 HARM
    - ULTIMATE LOAD FACTOR - 4.5G (MAY BE GUST CRITICAL)
    - AVIONICS - 5000 LB INSTALLED (INCLUDES POD)

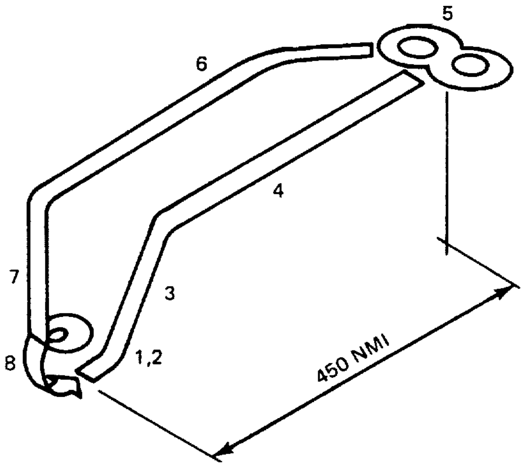
R86-1455-027D

Fig. 25 VAQ/VQ Mission

5.1.5 Airborne Early Warning (AEW) & Command, Communication, Control (C^3)

These two missions (Fig. 26) are flown simultaneously, one used defensively and the other offensively. AEW relies on an extended sensor capability to provide early detection of attacking forces for fleet defense, like the E-2C.

The C^3 aircraft is used to orchestrate the battle by directing friendly forces to counter-attacking enemy forces. The vehicle sizing drivers in both cases are high cruise speed (450 kt) and long endurance, high altitude loiter (four hours at 40,000 ft). A six-man crew and 8000 lb of installed avionics are required, with a weapons load of four AMRAAMs.



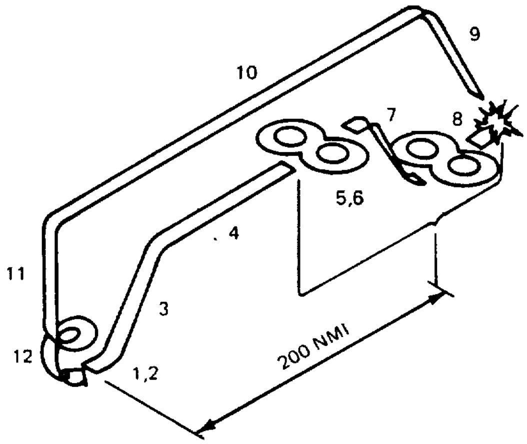
1. TAKEOFF ALLOWANCE
2. TAKEOFF
2. CLIMB - CLIMB AT INTERMEDIATE THRUST TO BEST ALTITUDE (NOT TO EXCEED CRUISE CEILING)
4. CRUISE OUT - AT BEST CRUISE ALTITUDE AND SPEED (CRUISE SPEED MUST NOT BE LESS THAN 450 KTAS FOR 450 NMI)
5. LOITER AT 40,000 FT FOR 4 HRS
6. CRUISE BACK AT BEST CRUISE ALTITUDE AND MACH NUMBER
7. DESCEND TO SEA LEVEL, NO FUEL USED, NO TIME OR DISTANCE CREDIT
8. LANDING ALLOWANCE AND RESERVE
   - AVIONICS - 8000 LB INSTALLED
   - CREW (6) - 1500 LB
   - SELF DEFENSE WEAPONS OR DECM - 1200 LB
   - ULTIMATE LOAD FACTOR - 4.5G (MAY BE GUST CRITICAL)

R86-1455-028D

Fig. 26 AEW, C^3 Mission

5.1.6 Anti-Submarine Warfare (ASW)

The requirements of ASW involve four distinct missions. Figure 27 depicts the basic ASW mission. The aircraft travels to its station, sows a sonobuoy field, then loiters and monitors the field for any activity. Once a contact is made, the aircraft descends to sea level and proceeds to prosecute the target and finally drops weapons, in wartime. The S-3A/B currently performs this role. The ability to efficiently loiter at 25,000 ft and sea level while carrying a wide variety of weapons influences the vehicle design. A crew of



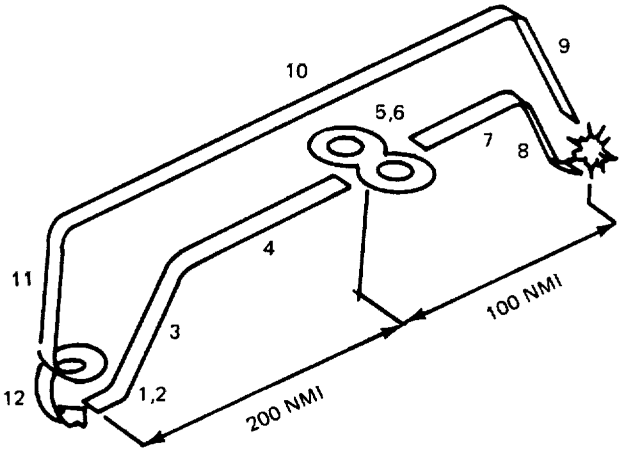
1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB - CLIMB AT INTERMEDIATE THRUST TO BEST ALTITUDE (NOT TO EXCEED CRUISE CEILING)
4. CRUISE OUT - AT BEST CRUISE ALTITUDE AND SPEED FOR 200 NMI
5. DEPLOY SONOBUOY FIELD FOR 1 HR AT 25,000 FT
6. LOITER AT 25,000 FT FOR 2¼ HR AT BEST LOITER CONDITION
7. DESCEND TO SEA LEVEL NO FUEL USED, NO TIME OR DISTANCE CREDIT
8. CONTACT INVESTIGATION AND LOCALIZATION AT SEA LEVEL FOR 1 HR BEST LOITER SPEED - LAUNCH 2 TORPEDOES
9. CLIMB TO BEST CRUISE ALTITUDE
10. CRUISE BACK AT BEST ALTITUDE AND MACH NUMBER
11. DESCEND TO SEA LEVEL, NO FUEL USED, NO TIME OR DISTANCE CREDIT
12. LANDING ALLOWANCE AND RESERVE
    - AVIONICS - 5400 LB INSTALLED
    - CREW (3) - 750 LB
    - WEAPONS - 5670 LB (4 ALWT AND 2 HARPOONS)
    - SONOBUOYS (60) - 1430 LB
    - FLARES AND MARKERS - 52 LB
    - ULTIMATE LOAD FACTOR 4.5G (MAY BE GUST CRITICAL)

R86-1455-029D

Fig. 27 ASW Mission

three and 5400 lb of avionics are required, with a weapons load of 60 sonobuoys, four torpedos and two Harpoons.

Anti-Surface Warfare (ASUW) is another role performed by the S-3. It is similar to the basic ASW mission except that the contact is a surface target (Fig. 28). The aircraft dashes to the target and releases weapons, then returns to base. The critical vehicle drivers for this mission are high-speed



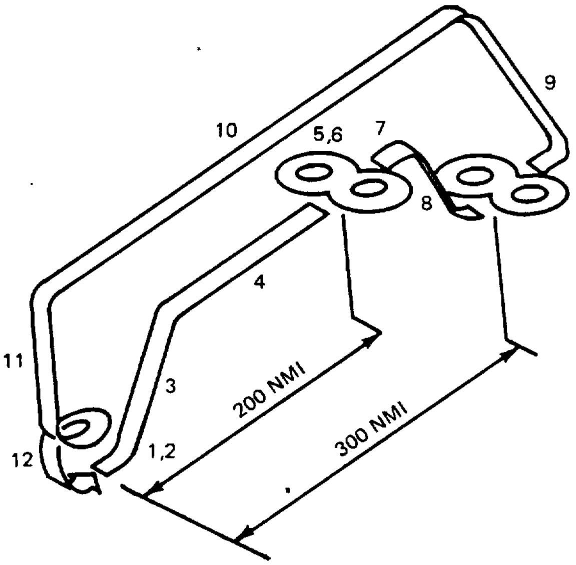
1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB AT INTERMEDIATE POWER TO BEST ALTITUDE (NOT TO EXCEED CRUISE CEILING)
4. CRUISE OUT - AT BEST CRUISE ALTITUDE AND SPEED (CRUISE SPEED NOT TO BE LESS THAN 450 KTAS) FOR 200 NMI
5. SOW SONOBUOY FIELD AND BEGIN LOITER AT 25,000 FT
6. LOITER FOR 3¼ HRS AT 25,000 FT ALTITUDE - BEST SPEED AND MACH NUMBER
7. DASH AT 450 KTAS MINIMUM TO 300 NMI
8. DESCEND TO SEA LEVEL AND RELEASE HARPOONS - NO TIME OR DISTANCE OR FUEL USED
9. CLIMB TO BEST CRUISE ALTITUDE
10. CRUISE BACK AT BEST ALTITUDE AND MACH NUMBER
11. DESCEND TO SEA LEVEL NO FUEL USED, NO TIME OR DISTANCE CREDIT
12. LANDING ALLOWANCE AND RESERVE
    - AVIONICS - 5400 LB INSTALLED
    - CREW (3) - 750 LB
    - WEAPONS - 5670 LB (4 ALWT & 2 HARPOONS)
    - SONOBUOY (60) - 1430 LB
    - FLARES AND MARKERS - 52 LB
    - ULTIMATE LOAD FACTOR 4.5G (MAY BE GUST CRITICAL)

R86-1455-030D

Fig. 28 ASUW Mission

cruise and dash (450 kt) and extended loiter capability at 25,000 ft. Crew size, avionics suite and weapons load are the same as the ASW mission.

The Surveillance mission (Fig. 29) is the most common ASW mission flown during peacetime operation. A high altitude contact investigation is conducted



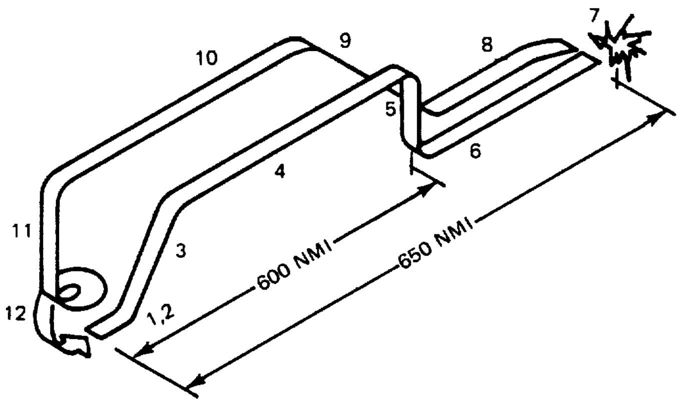
1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB - CLIMB AT INTERMEDIATE THRUST TO BEST ALTITUDE (NOT TO EXCEED CRUISE CEILING)
4. CRUISE OUT - AT BEST CRUISE ALTITUDE AND SPEED (CRUISE SPEED NOT TO BE LESS THAN 450 KTAS FOR 200 NMI)
5. SOW SONOBOUY FIELD AND BEGIN LOITER AT 25,000 FT
6. LOITER FOR 3¼ HOURS AT 25,000 FT ALTITUDE - BEST SPEED AND MACH NUMBER
7. DASH AT 450 KTAS MINIMUM TO 300 NMI
8. DESCEND TO SEA LEVEL AND RUN A PHOTOGRAPHIC MISSION TO RIG TARGET - ½ HOUR AT SEA LEVEL
9. CLIMB TO BEST CRUISE ALTITUDE
10. CRUISE BACK AT BEST ALTITUDE AND MACH NUMBER
11. DESCEND TO SEA LEVEL, NO FUEL USED, NO TIME OR DISTANCE CREDIT
12. LANDING ALLOWANCE AND RESERVE
    - AVIONICS - 5400 LB INSTALLED
    - CREW (3) - 750 LB
    - WEAPONS - 5670 LB (4 ALWT AND 2 HARPOONS)
    - SONOBUOY (60) - 1430 LB
    - FLARES & MARKERS - 52 LB
    - ULTIMATE LOAD FACTOR - 4.5G (MAY BE GUST CRITICAL)

R86-1455-031D

Fig. 29 Surveillance Mission

followed by a dash to sea level where the ship or submarine is photographed for identification. The mission profile is similar to the ASUW profile with an additional loiter segment of 30 minutes at sea level. The crew, avionics and weapons are the same as the ASW mission.

The final ASW-related operation is Mine Warfare (MIW). Figure 30 illustrates this mission, which is currently shared by the S-3 and A-6 aircraft. The aircraft cruises at high altitude to within 50 miles of the target, then drops below the radar horizon and dashes in at high speed (500 KTAS) to mine a harbor and deny access, for example. The critical design drivers in addition to the 500 KTAS, sea level dash are an extended radius and 425 KTAS cruise speeds. The same crew and avionics are carried as the ASW mission. The weapons load is four Faired MK52 mines.



1. TAKEOFF ALLOWANCE
2. TAKEOFF
3. CLIMB - AT INTERMEDIATE THRUST TO BEST CRUISE ALTITUDE
4. CRUISE OUT - AT BEST CRUISE ALTITUDE AND SPEED (CRUISE SPEED MUST BE AT LEAST 425 KTAS TO 600 NMI)
5. DESCEND TO 500 FT ALTITUDE, NO FUEL USED, NO TIME OR DISTANCE CREDIT
6. DASH FOR 50 NMI AT 500 FT, MACH NUMBER NO LESS THAN 0.75 (500 KTAS)
7. DROP WEAPONS
8. RETURN AT 5000 FT FOR 50 NMI, MACH NUMBER NO LESS THAN 0.75 (500 KTAS)
9. CLIMB TO BEST CRUISE ALTITUDE
10. CRUISE BACK AT BEST ALTITUDE AND MACH NUMBER
11. DESCEND TO SEA LEVEL, NO FUEL USED, NO TIME OR DISTANCE CREDIT
12. LAND ALLOWANCE AND RESERVE
    - AVIONICS - 5400 LB INSTALLED
    - CREW (3) - 750 LB
    - WEAPONS - 5614 LB ((4) MK52 MINES OR (2) MK56 MINES)
    - ULTIMATE LOAD FACTOR - 4.5G (MAY BE GUST CRITICAL)

R86-1455-032D

Fig. 30 MIW Mission

5.1.7 Mission Requirements Summary

It can be seen from the preceding ten missions that the MPSNA aircraft is required to carry a multitude of weapons and payloads while providing good loiter endurance at both high and low altitudes. The aircraft must also have high speed capability at altitude to minimize transit time, and high speed capability at sea level to minimize its exposure time and provide some degree of survivability.

5.2 Point Designs

An important step in developing a multipurpose aircraft concept is to establish individual design solutions for each particular mission. This process gives insight into design requirements and sensitivities, providing guidance to the synthesis of a common airframe/engine system.

A point design was determined for each of the ten MPSNA missions for both turbofan and propfan engines. Extensive parametric analyses identified the combination of vehicle characteristics (e.g., wing geometry, wing and thrust loading) that resulted in minimum takeoff gross weight. The point-designed aircraft also serve as a benchmark for assessing the commonality penalties associated with the MR1 and MR2 multipurpose aircraft.

5.2.1 Wing Planform Optimization

Table 2 lists the mission elements that are critical to wing geometry selection. In general, high-speed dash capability and loiter endurance call for opposing types of wing planforms. Long loiter endurance demands the lift-to-drag efficiency of a high aspect ratio wing, such as the E-2 (AR = 9.27) and S-3 (AR = 7.89) aircraft. Conversely, low aspect ratio wings are preferable for low-altitude, high-speed dash capability due to the considerable structural loads encountered during flight at high dynamic pressure. Also, loiter at altitudes of 40,000 ft call for relatively low wing loadings, whereas low-altitude dash capability is best satisfied with high wing loadings.

Table 2 Critical Mission Elements to Wing Design

MISSION	SPEED REQUIREMENT	LOITER ENDURANCE
COD	X	X
TANKER	X	20 MIN AT 25K FT
MIW	500 KTAS AT SEA LEVEL 425 KTAS AT CRUISE ALT	X
SURV	450 KTAS AT CRUISE ALT	3.25 HR AT 25K FT 30 MIN AT SEA LEVEL
AEW, C^3	450 KTAS AT CRUISE ALT	4 HR AT 40K FT
ASUW	450 KTAS AT CRUISE ALT	3.25 HR AT 25K FT
ASW	X	3.25 HR AT 25K FT 1 HR AT SEA LEVEL
VAQ/VQ	425 KTAS AT CRUISE ALT	1 HR AT 30K FT
AAW	425 KTAS AT CRUISE ALT	4 HR AT 35K FT
R86-1455-033D		

Figure 31 depicts the optimum wing geometric characteristics of the individually-sized aircraft with the baseline propfan system (P&WA STS743) mounted on the aft fuselage. The missions without any cruise speed specifications (COD, Tanker, ASW) tend toward thick, unswept wings. As the specified cruise speed increases, the trend is to thinner, more swept wings. The MIW design necessitates a sturdy airframe to withstand flight loads at the structural placard of 950 lb/ft^2 (0.8 Mach at sea level). A root airfoil thickness of 15% provides this extra strength with a drag divergence of 0.75 Mach, equal to the dash speed requirement.

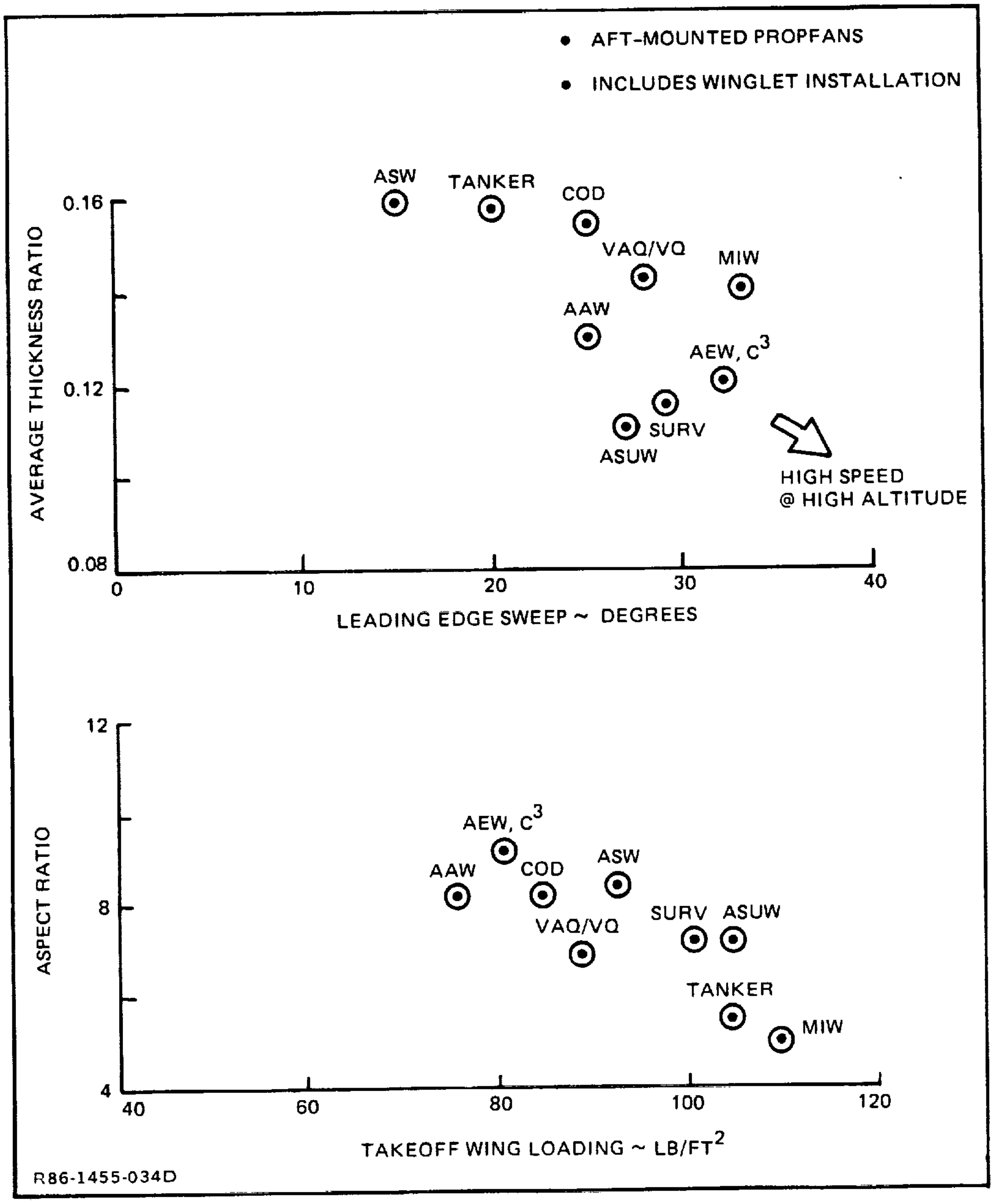


Fig. 31 Mission-Optimized Wing Geometries, Propfan Configuration

The high-altitude, long loiter segments of the AEW, C^3 and AAW profiles drive the optimum wing geometries to high aspect ratios and low wing loadings. The MIW wing design is dominated by the 500 kt dash leg at sea level, driving the planform to low aspect ratio and high wing loading. The Tanker design is driven to a similar combination of AR and W/S, due to the structural demands of 4.5G ultimate load factor with a payload fraction nearly 50% of the TOGW.

Figure 32 summarizes the optimum wing geometries of the individually sized aircraft with the baseline turbofan system (P&WA STF686) mounted on the aft fuselage. The wing sweep and thickness values are similar to the propfan aircraft results. Somewhat different aspect ratio and wing loading characteristics are evident between the turbofan and propfan designs. These results are attributed to the engines' dissimilar lapse rate, fuel consumption and thrust-to-weight characteristics which influence the optimal aero/structural configurations.

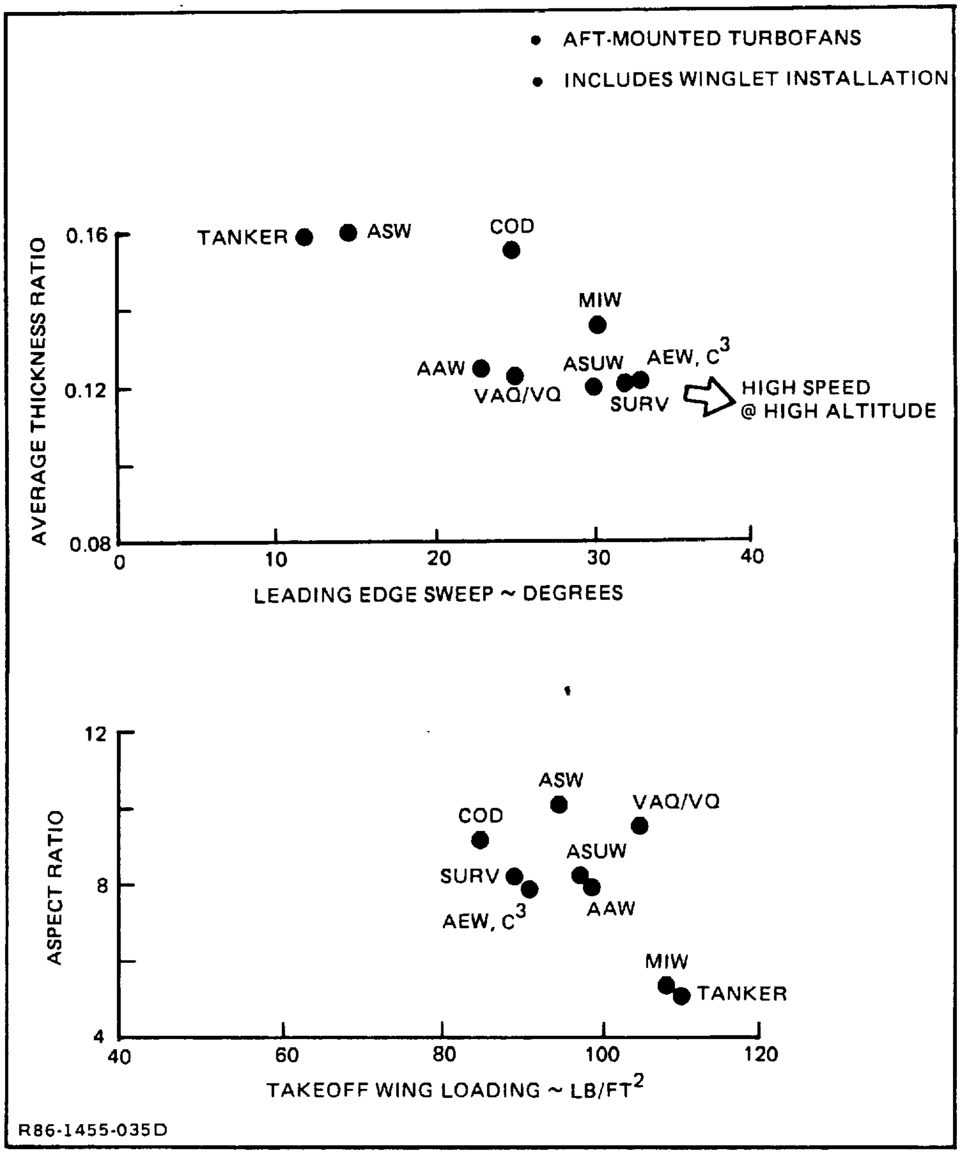


Fig. 32 Mission-Optimized Wing Geometries, Turbofan Configuration

5.2.2 Vehicle Design Characteristics

Each point-design aircraft was sized to its corresponding set of mission requirements (see Subsection 5.1), including fuel volume, weapons/avionics suite, and crew size with associated furnishings, subsystems and equipment. Thrust loading was based on satisfying cruise/dash speed requirements, or if not specified, a thrust-to-weight ratio of 0.4 was used to meet minimum engine-out rate-of-climb performance levels. Wing planform characteristics were individually optimized, as discussed in the preceding section. Fuselage length and volume were determined by the size of the crew station, installed avionics suite, side-looking UHF radar arrays, fuel tankage, and in the case of the COD design, by the cargo load. The point designated aircraft are unique to each mission with the only common feature a generic low wing/T-tail arrangement.

Figure 33 presents the TOGW characteristics of the mission-optimized point designs. The propfan aircraft weigh 10% less than their turbofan counterparts, except for the Tanker design. The large payload (23,000 lb of transfer fuel) of the Tanker coupled with a relatively benign mission (20 minutes refueling, 250 nmi from carrier) requiring a small fuel load results in the most unique

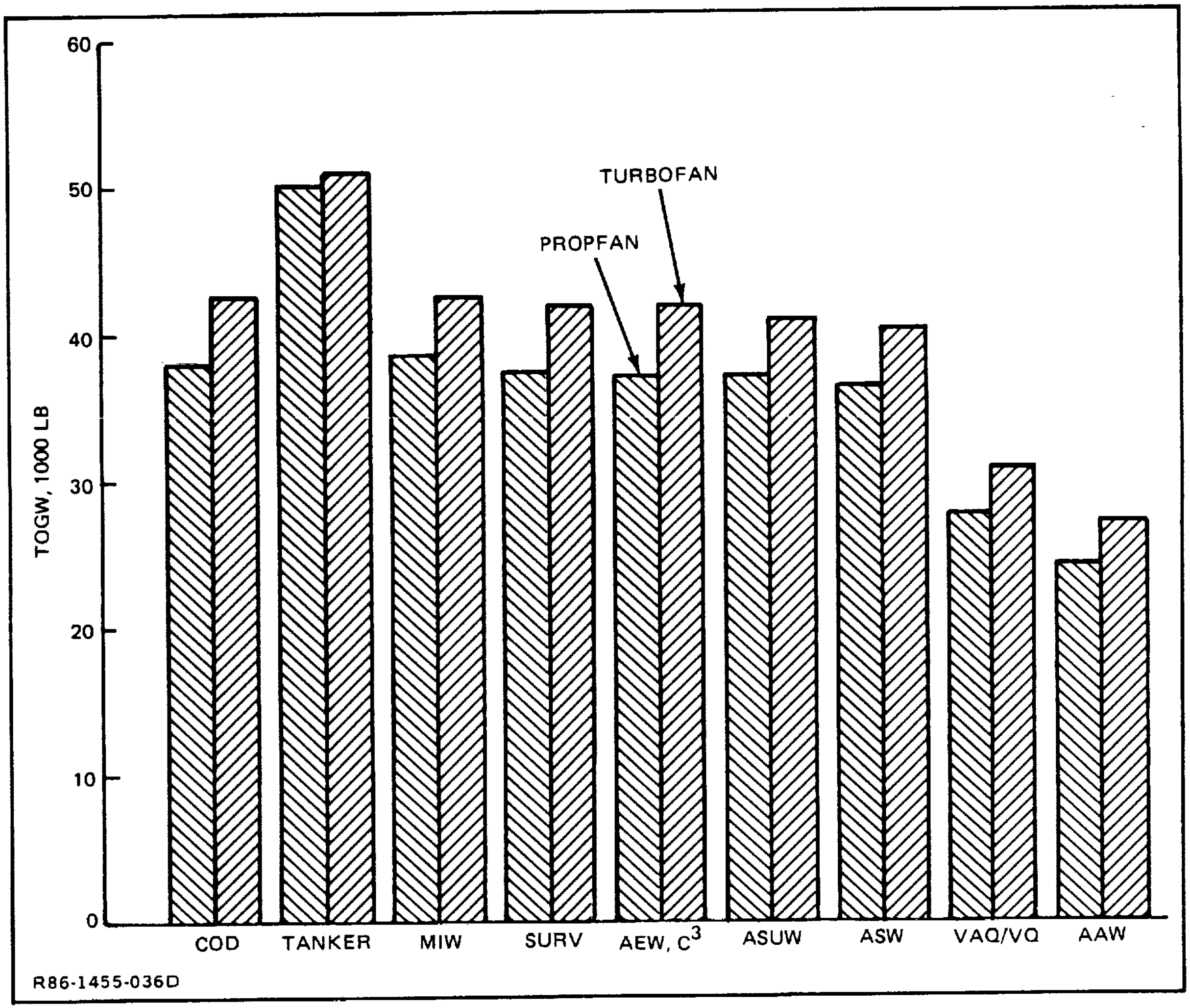


Fig. 33 TOGW Characteristics of Point-Designed Aircraft

(and heaviest) MPSNA point design with little improvement resulting from the reduced propfan specific fuel consumption characteristics. The VAQ/VQ and AAW point designs are substantially lighter than the remaining mission concepts, an indication that these operational requirements could be made more demanding (i.e., greater range or time on station).

The individual mission-optimized aircraft serve as a stepping-off point in the development of highly-common, multimission designs. A TOGW benchmark is available for quantifying the penalties and compromises associated with commonality. The missions that drive the sizing of major vehicle components (wing, engines, fuselage) can also be identified. For the point-designed propfan configurations, the Tanker design possessed the largest wing, as indicated in Fig. 34. The wing area of a "fully-capable" multipurpose concept (MR1 aircraft) would therefore be expected to be driven by the Tanker role. In a

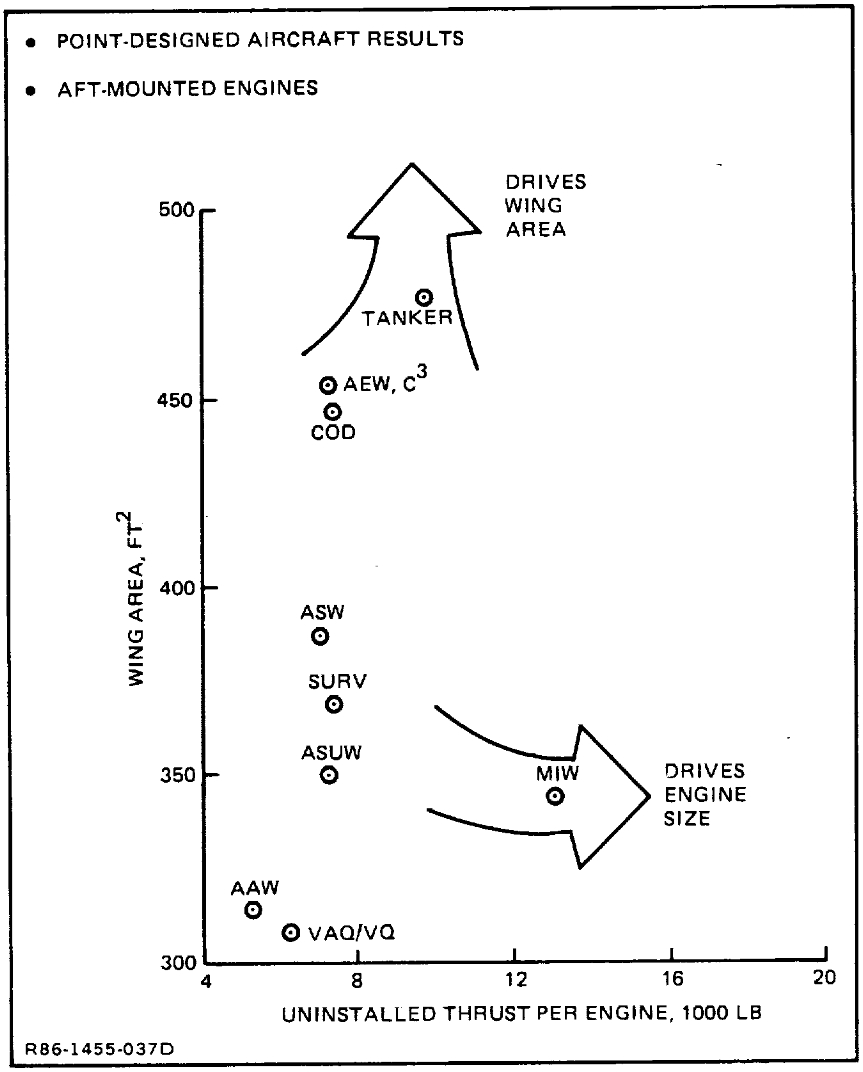


Fig. 34 Common Wing/Engine Sizing Drivers, Propfan Configuration

similar manner Fig. 35 shows that the COD mission would drive the wing area for a "fully-capable" turbofan configuration. The engine size (i.e. uninstalled static thrust level) is decided by the 500 KTAS sea level dash leg of the MIW mission for both propfan and turbofan configurations. The wing area of an MR2 multimission concept (which eliminates the Tanker and COD roles) is sized by the AEW mission for the propfan design and the Surveillance mission for the turbofan design. This information helps to focus the efforts of defining and refining the MPSNA concepts.

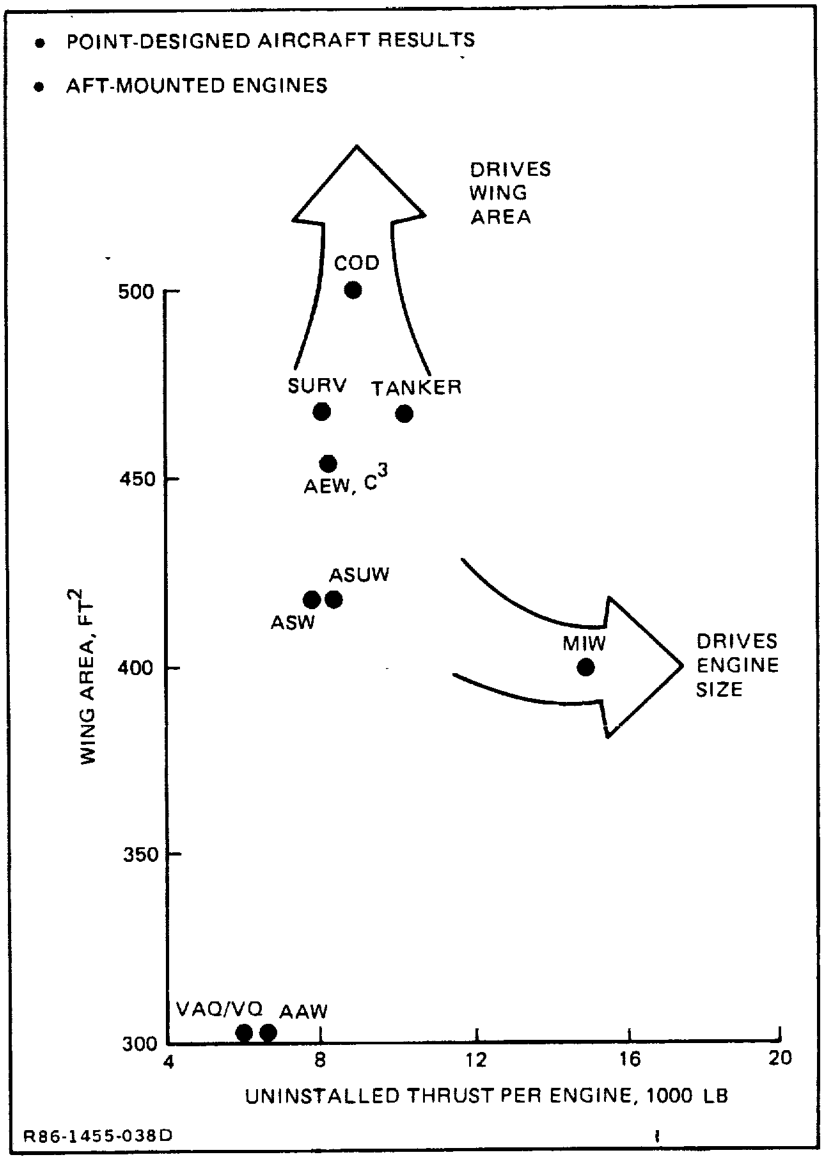


Fig. 35 Common Wing/Engine Sizing Drivers, Turbofan Configuration

5.3 MR1 AIRCRAFT DESIGN

This section describes the MR1 configuration. This concept is capable of performing all ten MPSNA design missions, with a high degree of commonality between variants. The MR1 configuration is a 60,000 lb class aircraft powered by twin, aft-mounted engines, either propfans or turbofans, and is compatible with operations from CV59 and subsequent carriers.

5.3.1 Vehicle Description

The MR1 configuration (Fig. 36) blends a COD fuselage, optimized low wing/T-tail, and various weapon/avionic provisions. Conformal array radar capability is incorporated into the fuselage, wing leading edge and horizontal tail trailing edge surfaces. Fuselage and wing mounted pylons are provided for weapons carriage.

The wing design was selected as a balance between high-subsonic speed capability, good loiter performance and low carrier takeoff and landing speeds. A leading edge sweep of 28 degrees and an average thickness ratio of 13% provide the best overall mission capability. Wing span and volume are sufficient to house the conformal radar arrays, transmitters and receivers. The selection of wing aspect ratio (7.0) and area (620 ft^2) are described in the next section. The high-lift system consists of inboard, double-slotted flaps and outboard single-slotted flaperons. No leading edge device is required for low carrier launch-and-recovery speeds, simplifying conformal radar installation.

An all-moving stabilizer serves as the primary pitch control effector. The "T-tail" arrangement permits unobstructed radar coverage to the rear, in addition to the other advantages discussed in Subsection 6.3. A continuous span for uninterrupted linear antennas is also provided. The vertical fin/rudder is of conventional design. It was sized for engine-out operation at low speeds with a 30 kt crosswind and allows for a wide range of CG travels.

The MR1 design, shown in Fig. 37, provides maximum commonality between variants. It can be reconfigured as needed to support various mission requirements. The airframe can support COD, ASUW, ASW, Surveillance and Tanker missions requiring only secondary structural modifications.

The fuselage volume is dictated by the required COD cargo loading capability of 10,000 lb, at a density of 8.57 lb/ft^3. This requirement sizes the fuselage width, and combined with crew accommodation requirements, sizes the fuselage length, with consideration given to required conformal array length. The crew configuration is mission dependent, ranging from two (Tanker) to six place (AEW) layouts. The fuselage design incorporates provisions which minimize crew reconfiguration modifications to structure, avionics and ECS systems. A summary of the crew arrangements required by each mission profile is shown in Fig. 38. The wide body of the COD design provides extra room for crew comfort, allowing for an aisle and room to stand. Emergency egress is through a hatch located in front of the wing leading edge root.

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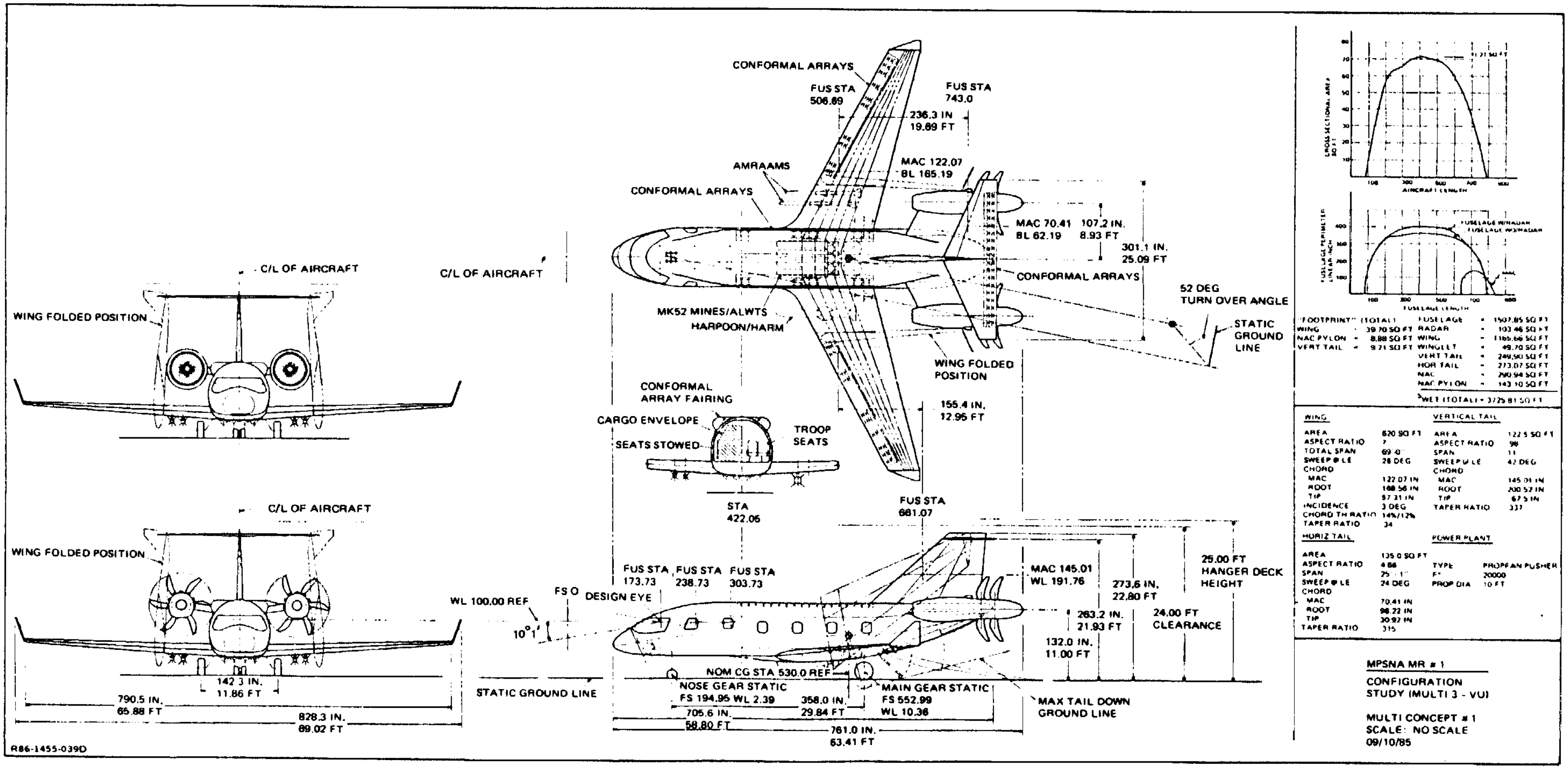

"FOOTPRINT" (TOTAL)			
WING = 39.70 SQ FT		FUSELAGE	= 1507.85 SQ FT
NAC PYLON = 8.88 SQ FT		RADAR	= 103.46 SQ FT
VERT TAIL = 9.71 SQ FT		WING	= 1165.66 SQ FT
		WINGLET	= 49.70 SQ FT
		VERT TAIL	= 249.50 SQ FT
		HOR TAIL	= 273.07 SQ FT
		NAC	= 290.94 SQ FT
		NAC PYLON	= 143.10 SQ FT

S_{WET} (TOTAL) = 3725.81 SQ FT

WING		VERTICAL TAIL	
AREA	620 SQ FT	AREA	122.5 SQ FT
ASPECT RATIO	7	ASPECT RATIO	.98
TOTAL SPAN	69'0"	SPAN	11
SWEEP @ LE	28 DEG	SWEEP @ LE	42 DEG
CHORD		CHORD	
MAC	122.07 IN	MAC	145.01 IN
ROOT	168.56 IN	ROOT	200.57 IN
TIP	57.31 IN	TIP	67.5 IN
INCIDENCE	3 DEG	TAPER RATIO	.337
CHORD TH RATIO	14%/12%		
TAPER RATIO	.34		

HORIZ TAIL		POWER PLANT	
AREA	135.0 SQ FT		
ASPECT RATIO	4.66	TYPE	PROPFAN PUSHER
SPAN	25'-1"	F*	20000
SWEEP @ LE	24 DEG	PROP DIA	10 FT
CHORD			
MAC	70.41 IN		
ROOT	98.22 IN		
TIP	30.92 IN		
TAPER RATIO	.315		

MPSNA MR # 1

CONFIGURATION
STUDY (MULTI 3 - VU)

MULTI CONCEPT # 1
SCALE: NO SCALE
09/10/85

Fig. 36 MR1 Aircraft General Arrangement

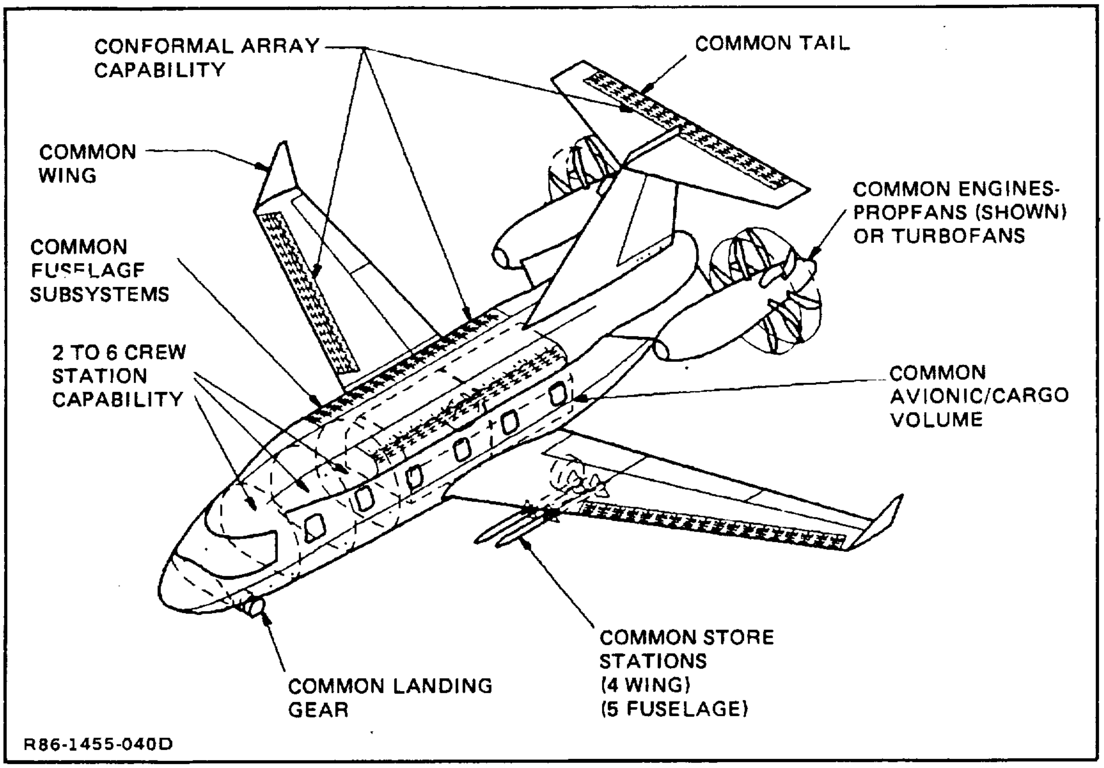

Fig. 37 MR1 Airframe/Engine Commonality

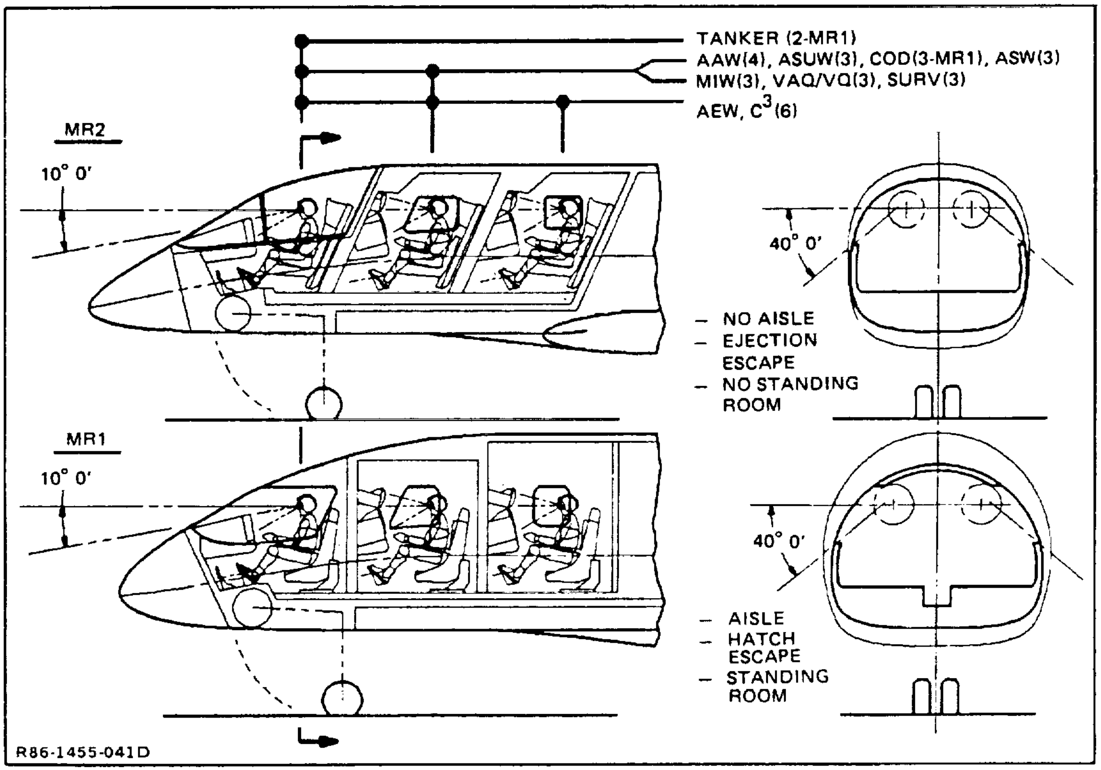

Fig. 38 Crew Station Mission Requirements

A conformal array radar system is incorporated into the fuselage design as shown in Fig. 39. The antenna modules are positioned to provide maximum coverage in azimuth, to minimize any potential interference with structure or propulsion systems and to minimize additional cross-sectional area required for installation. A fiberglass or Kevlar covering is required to enclose the antennas due to incompatibility between radar operation and metallic materials.

The aft fuselage is configured to allow incorporation of various mission dependent packages as shown in Fig. 40. The COD variant has a loading ramp for cargo handling. This area is ideal for incorporation of sonobuoys, required for ASUW, ASW and Surveillance missions, and refueling equipment for the Tanker mission. The sonobuoy and refueling equipment, palletized and installed in place of the COD loading ramp, locks into supporting structure designed to accommodate all palletized equipment.

A retractable Infrared (IR) sensor turret is mounted in the lower nose. A second IR turret is mounted on top of the fuselage. In-flight refueling capability is provided by a probe that retracts into the nose cap. Modular avionic components are mounted internally in integrated racks.

Figure 41 illustrates the store loadings for all variants of MR1. Judicious placement of weapons payload resulted in CG trends within the design limits for take-off, landing, and flight conditions. Weapons are located near the CG and when expended do not result in travel beyond the tolerances of the flight control system, a result of sequencing store release with fuel management. A total of nine stations are provided for carriage of a variety of weapons and pods. The fuselage has five semi-submerged stations, the wing has four pylon mounts inboard of the wing fold, and sonobuoys are carried internally.

5.3.2 Configuration Definition

The MR1 configuration was developed as a flexible, highly-capable, carrier-based support aircraft for the purpose of evaluating the benefits of propfan engines relative to comparable-technology turbofans. The installation of the engines off the aft fuselage was the preferred arrangement for several reasons:

- Wing-mounted propfans cause considerable concern in the areas of carrier deck handling and safety, noise at crew station, conformal radar interference and weapons carriage and launch
- Aft-mounted propfans (and turbofans) lead to lower aircraft spot size over wing mounting.

Although a wing-mounted turbofan design is viable (e.g., S-3), a common aft-mounted engine installation was used for comparing propfans and turbofans. A low wing/T-tail configuration was selected as the preferred airframe for aft-mounted powerplants. The approach of a common wing-body-tail-engine arrangement allowed for the clear identification of propfan/turbofan advantages without introducing myriad airframe variables, such as:

- High wing vs low wing
- Low tail vs T-tail
- Landing gear location and weight
- Weapons carriage
- Side-looking/rear-looking radar array location.

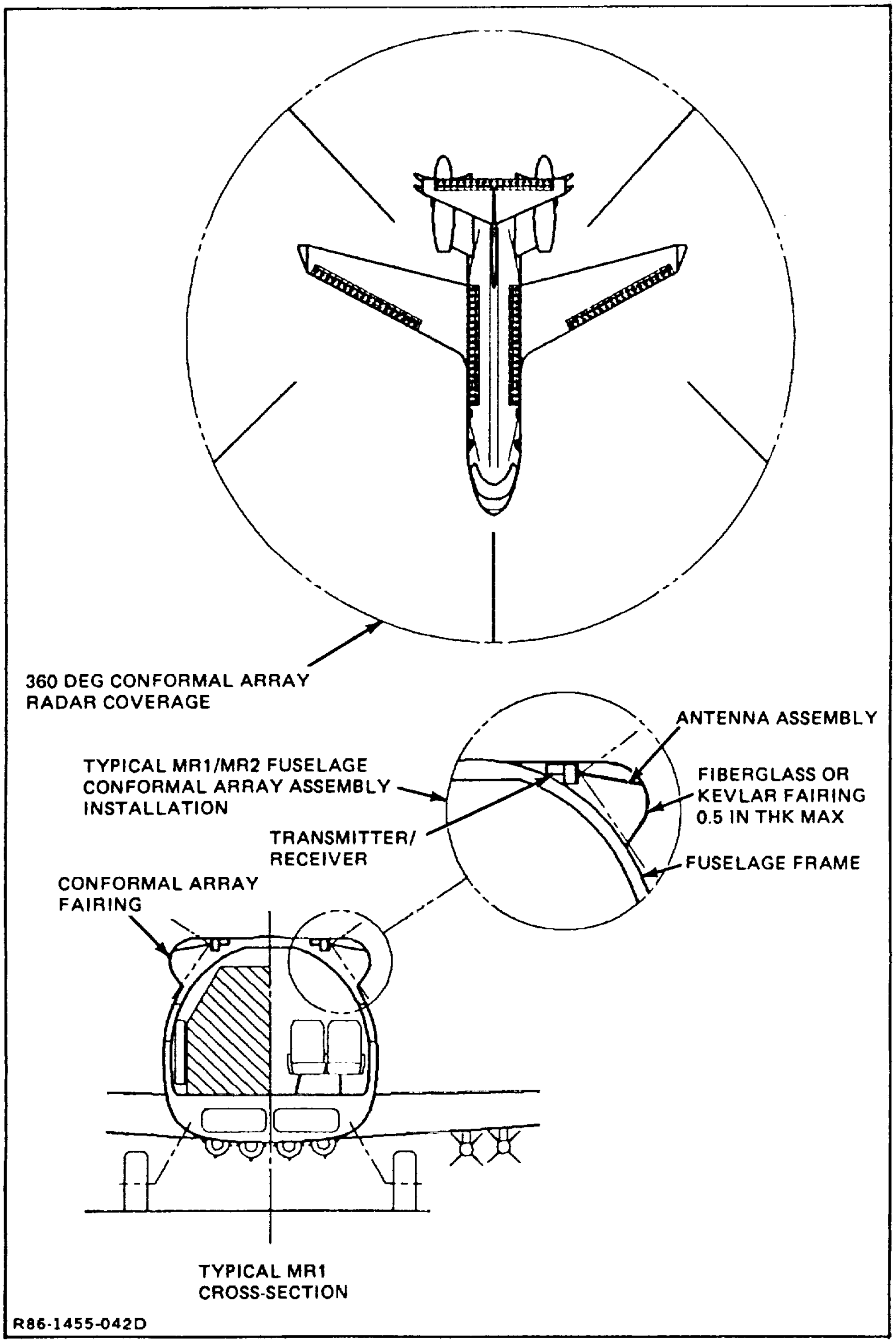

Fig. 39 MR1 Conformal Radar Array Integration

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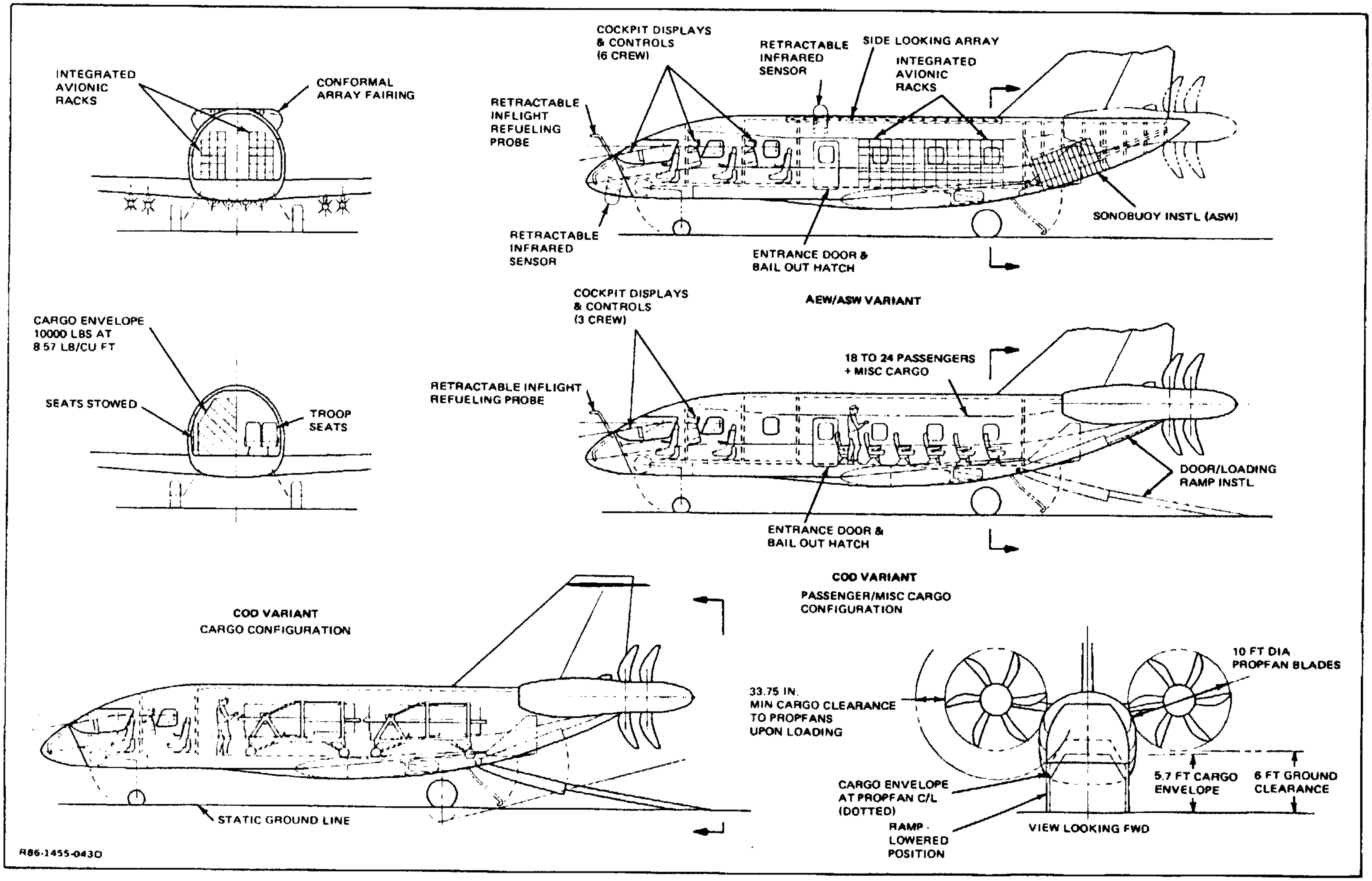

Fig. 40 MR1 Aircraft Inboard Profile

1 FOLDOUT FRAME

2 FOLDOUT FRAME

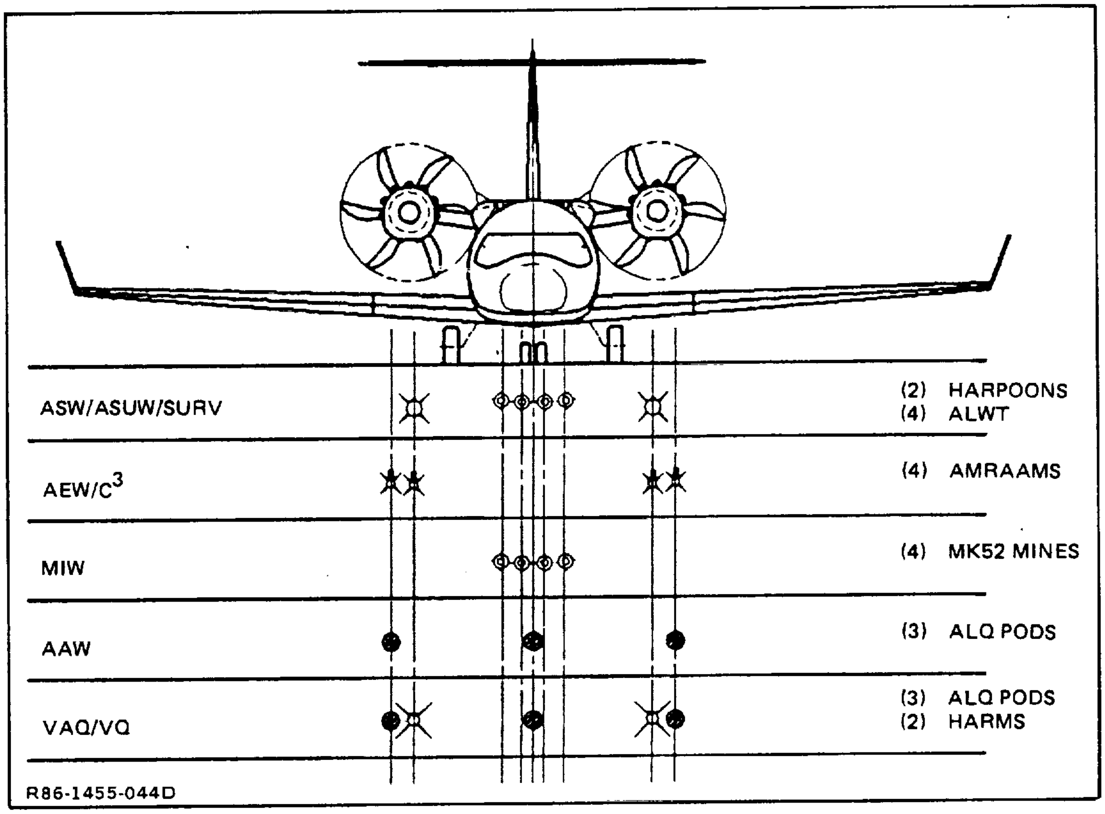

Fig. 41 Weapons/Store Installation

The thrust requirements for MR1 were based on the ability to dash at 500 KTAS at sea level. The propfans for the fully iterated MR1 designs are each rated at 20,000 lb thrust, whereas the turbofans are 21,100 lb thrust per engine. The high thrust loading of MR1 (T/W=0.66) results in excellent climb performance with one engine inoperative.

A wing leading edge sweep of 28 degrees and an average thickness ratio of 13% were selected for a good balance between high-subsonic speed capability and low-speed, high-lift generation. Extensive parametric analyses were conducted (see Subsection 5.2.1) to find the most appropriate common wing geometry for MR1. Wing area and aspect ratio were also derived from these analyses. In addition, consideration was given to available exposed wing span for conformal radar installation, wing fold and weapons carriage. The minimum exposed span is 56.5 ft, plus a 9.4 ft wide body, which leads to a total span requirement of 65.9 ft. This necessitates a trade-off between a high AR/small wing or a lower AR/larger wing, as shown in Fig. 42.

The selected aspect ratio and wing area for MR1 are 7.0 and 620 ft^2. The value of AR = 7.0 was found to be optimum following parametric analyses. Figure 43 depicts the TOGW and engine size sensitivities to wing area variation with AR = 7.0. A 620 ft^2 wing results in TOGW which is 3% to 4% above the theoretical minimum TOGW level for the turbofan and propfan designs. Note that these results are for the missions which dominate the wing sizing, as discussed in Subsection 5.2.2. The selected 620 ft^2 wing improves the approach speed,

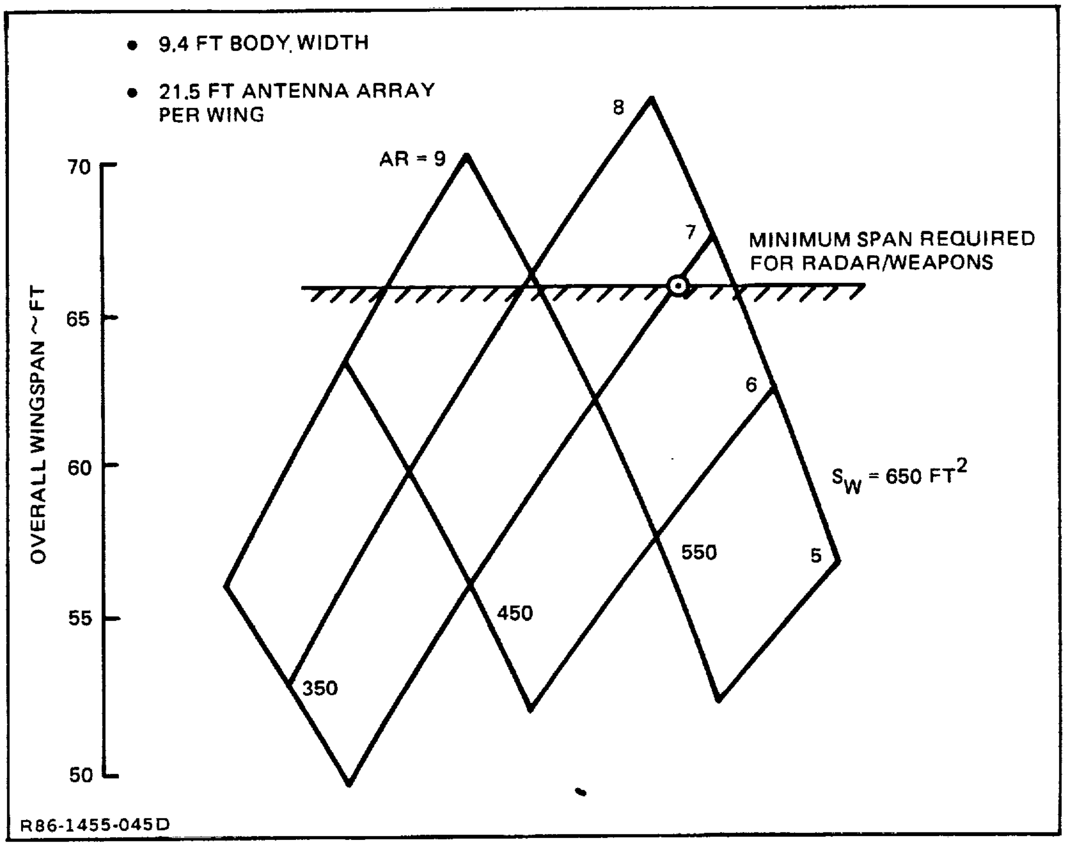

Fig. 42 MR1 Minimum Exposed Wing Span Requirement

loiter speed and engine-out performance, as compared to the smaller "minimum-TOGW" wing area. Alternately, it offers a design margin to compensate for the historical growth of aircraft weight.

5.4 MR2 AIRCRAFT DESIGN

This section describes the MR2 configuration. This concept was designed to a relaxed level of multimission capability compared to the "fully-capable" MR1 concept. Specifically, it does not perform the roles of COD or Tanker, and its low-altitude dash speed capability is a fallout. The resulting MR2 operational capabilities are well matched with a highly-common vehicle. It is a 40,000 lb class aircraft that would replace the Navy's E-2, S-3 and EA-6 aircraft. The MR2 design would be able to perform some Tanker duties through the use of the Advanced Aerial Refueling Store, and provide priority cargo/passenger delivery service similar to the US-3. The MR2 aircraft is powered by twin, aft-mounted engines, either propfans or turbofans, and is compatible with operations from CV59 and subsequent carriers.

5.4.1 Requirements Evolution

The aircraft that satisfy MR2 have degraded capability from MR1 aircraft without penalizing the bulk of the missions. Evaluation of drivers in the MR1 design led to changes in mission requirements for the MR2 aircraft. These changes include elimination of the COD as part of a common aircraft, reducing structural weight and aircraft drag. This follows current Navy thinking where

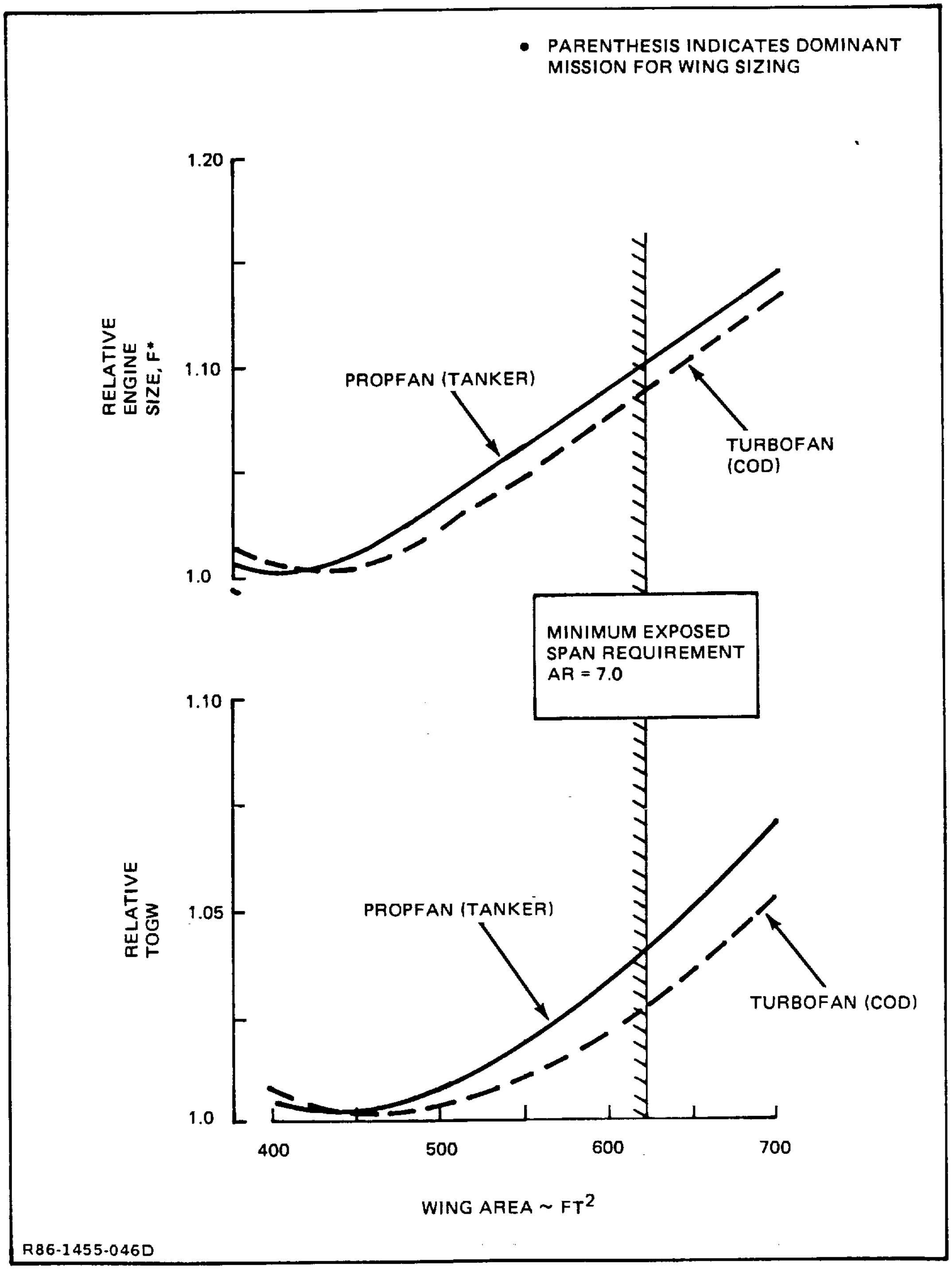

Fig. 43 Design Sensitivity to Wing Area, MR1 Aircraft

the COD would be a derivative of a multimission vehicle. To make all aircraft capable of doing the Tanker role the Advanced Aerial Refueling Store and drop tanks are used. Some resulting benefits to a common MR2 design are reduced structural weights and lighter landing gear because of the lower design weight.

The last change in mission requirements was to reduce the dash speed in the MIW role in an attempt to obtain a compatible engine size for a common aircraft. Figures 44 and 45 show that an engine sized for the MIW low level dash is oversized compared to the other roles. Using the high altitude cruise speed in the Surveillance mission (the next most critical requirement) as the engine sizing constraint a more compatible thrust size is achieved. Figure 44 shows that the thrust required for the remaining MR2 missions are then closely matched. The fallout MIW dash Mach number of the MR2 aircraft with an engine

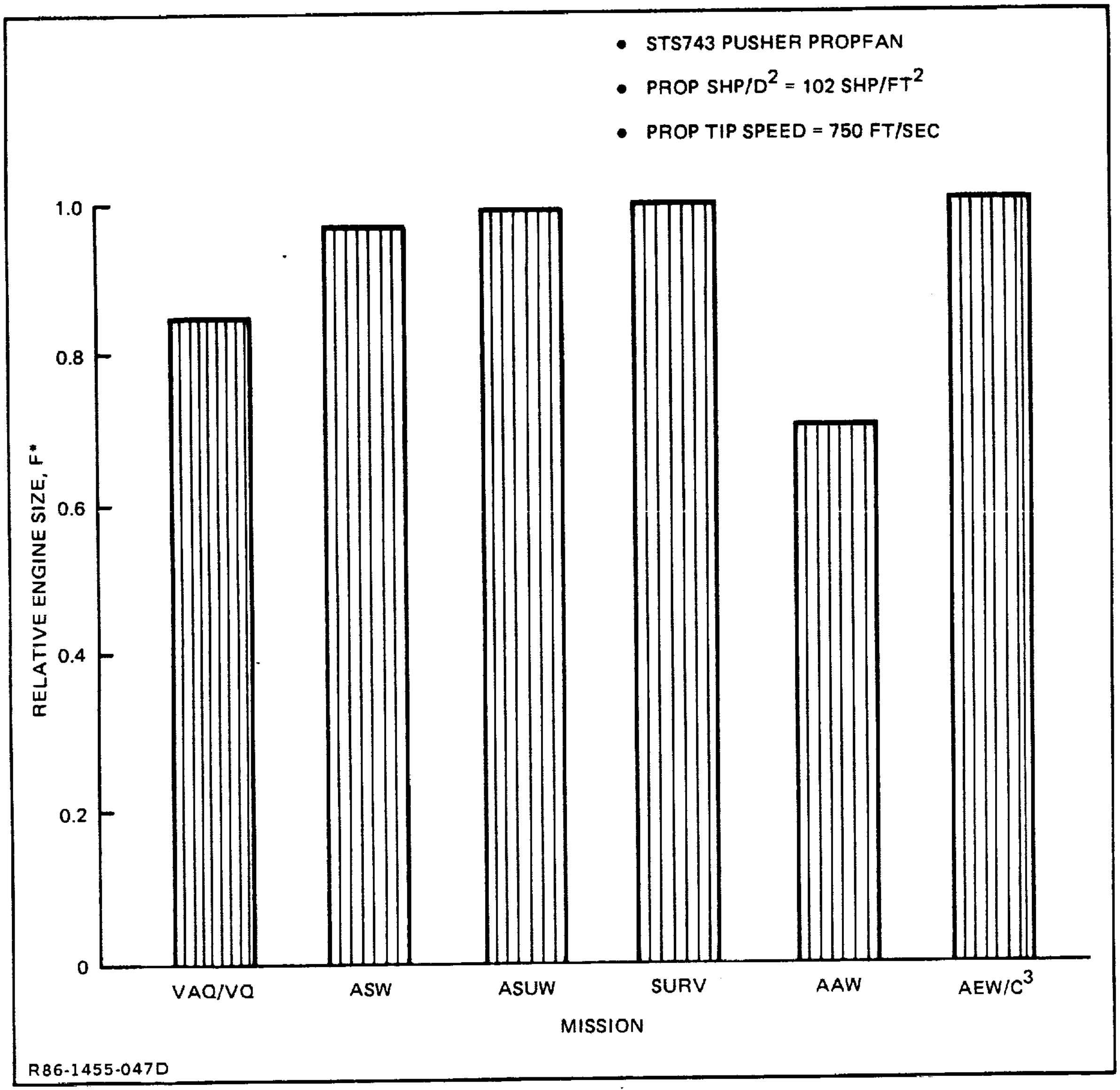

Fig. 44 MR2 Engine Sizing Requirements

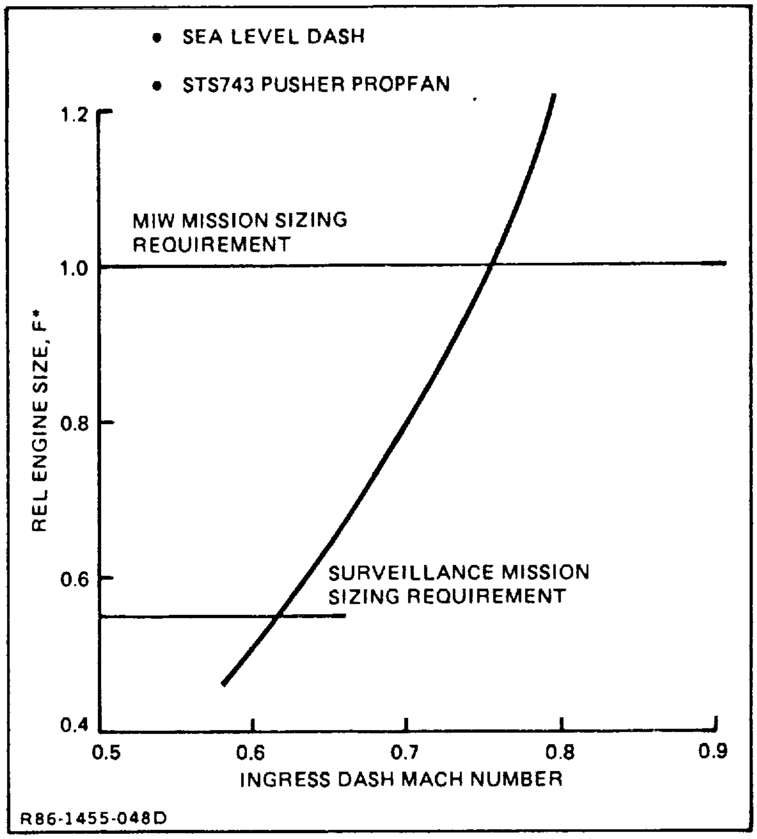

Fig. 45 MIW Dash Speed Effect On Engine Size

sized by Surveillance requirements is 0.61 ingress and 0.72 egress. Figure 45 shows the sensitivity of engine size to MIW dash speed. Backing off in Mach number from 0.75 to 0.61 reduces the required thrust by about one half.

5.4.2 Vehicle Description

The MR2 configuration (Fig. 46) combines a common fuselage for all variants, optimized low-wing/T-tail and various weapon and avionic provisions, as in the MR1 configuration design. Conformal array radar system capability is incorporated within fuselage, wing and horizontal tail surfaces. Fuselage and wing pylons are provided for various store combinations.

The wing design was selected as a balance between high-subsonic speed capability, good loiter performance, and low carrier takeoff and landing speed. The wing leading edge sweep (28 degrees) and average thickness (13%) are the same as MR1. Wing aspect ratio (7.5) is slightly higher than MR1, and the wing area (550 ft^2) results in a lower wing loading. The selection of AR and S_W are discussed in Section 5.4.3. The high-lift system consists of full-span, single-slotted flaps. No leading edge device is required for low carrier launch-and-recovery speed, simplifying conformal radar installation.

A T-tail empennage similar to MR1 is used, as discussed in Subsection 6.3.

The MR2 fuselage volume was defined by the required AEW avionics suite

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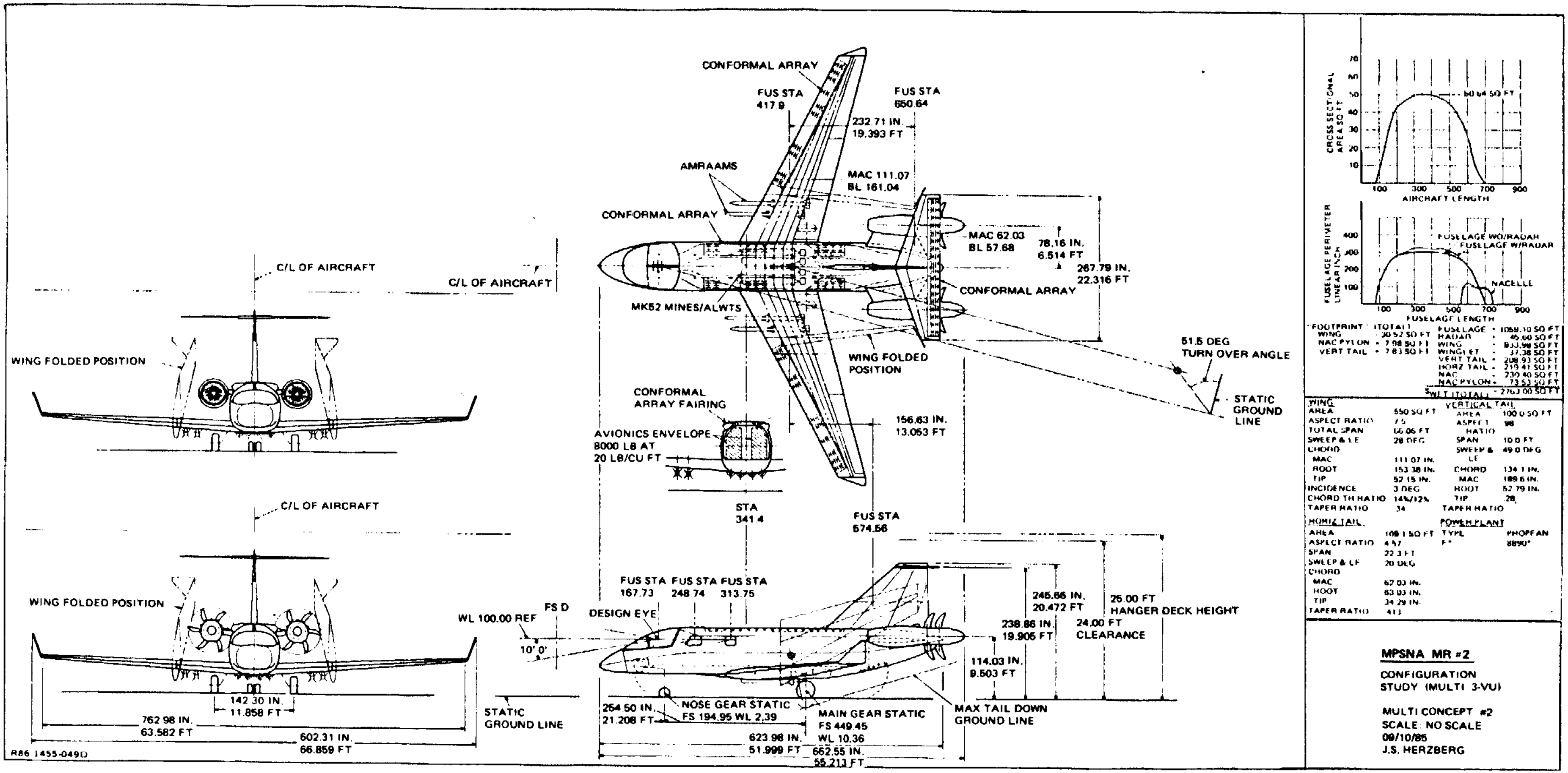

Fig. 46 MR2 Aircraft General Arrangement

FOLDOUT FRAME

2 FOLDOUT FRAME

(8000 lb at 20 lb/ft^3), and accommodations for a crew of six. Consideration was also given to the requisite length of the side-looking UHF radar array which is incorporated into the fuselage as shown in Fig. 47. The airframe can support all MR2 requirements with minimum changes to secondary structure among variants.

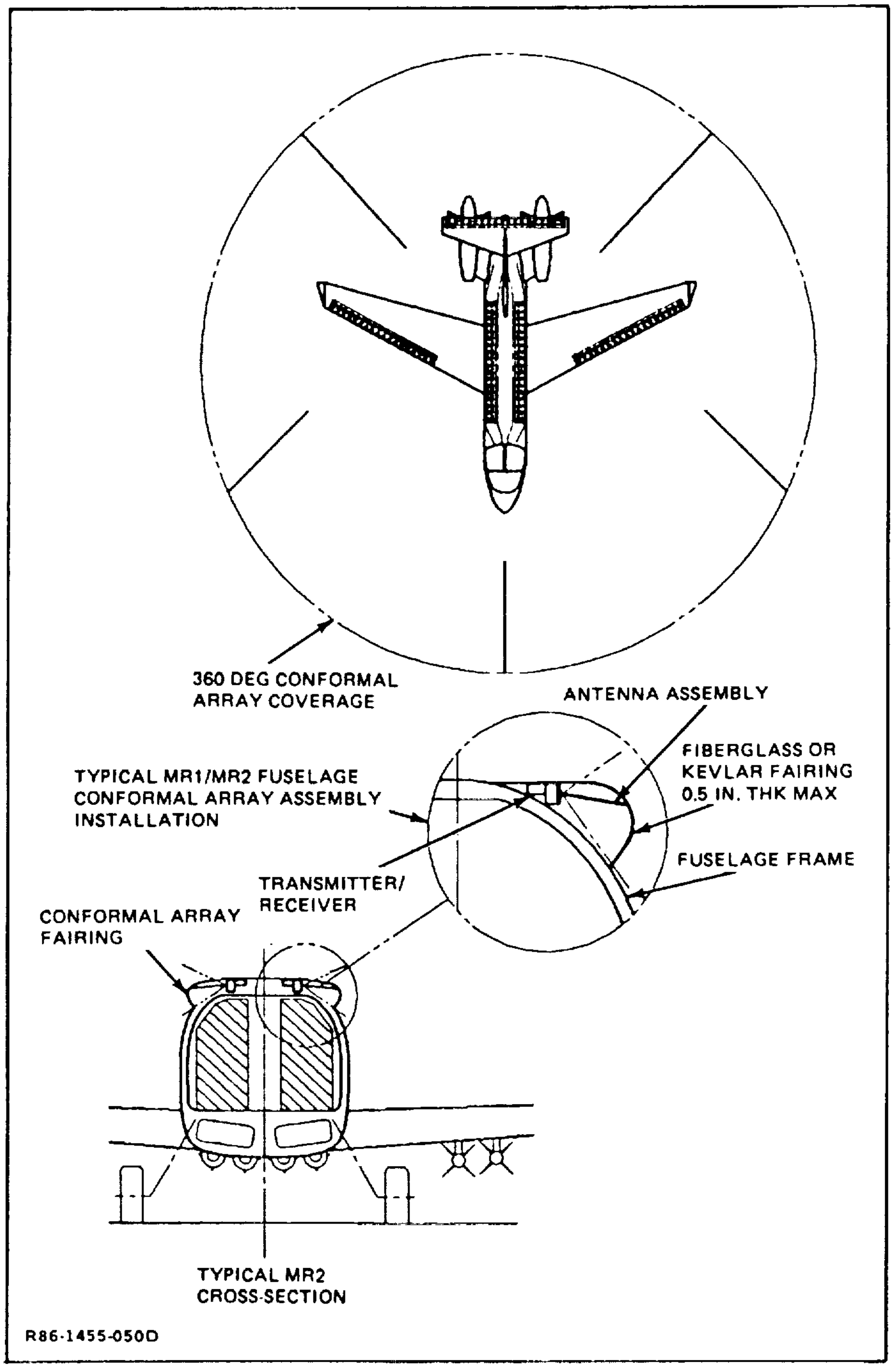

Fig. 47 MR2 Conformal Radar Array Integration

The aft fuselage includes a utility bay for sonobuoys, antenna/avionic cooling equipment and future avionics growth. Figure 48 depicts the MR2

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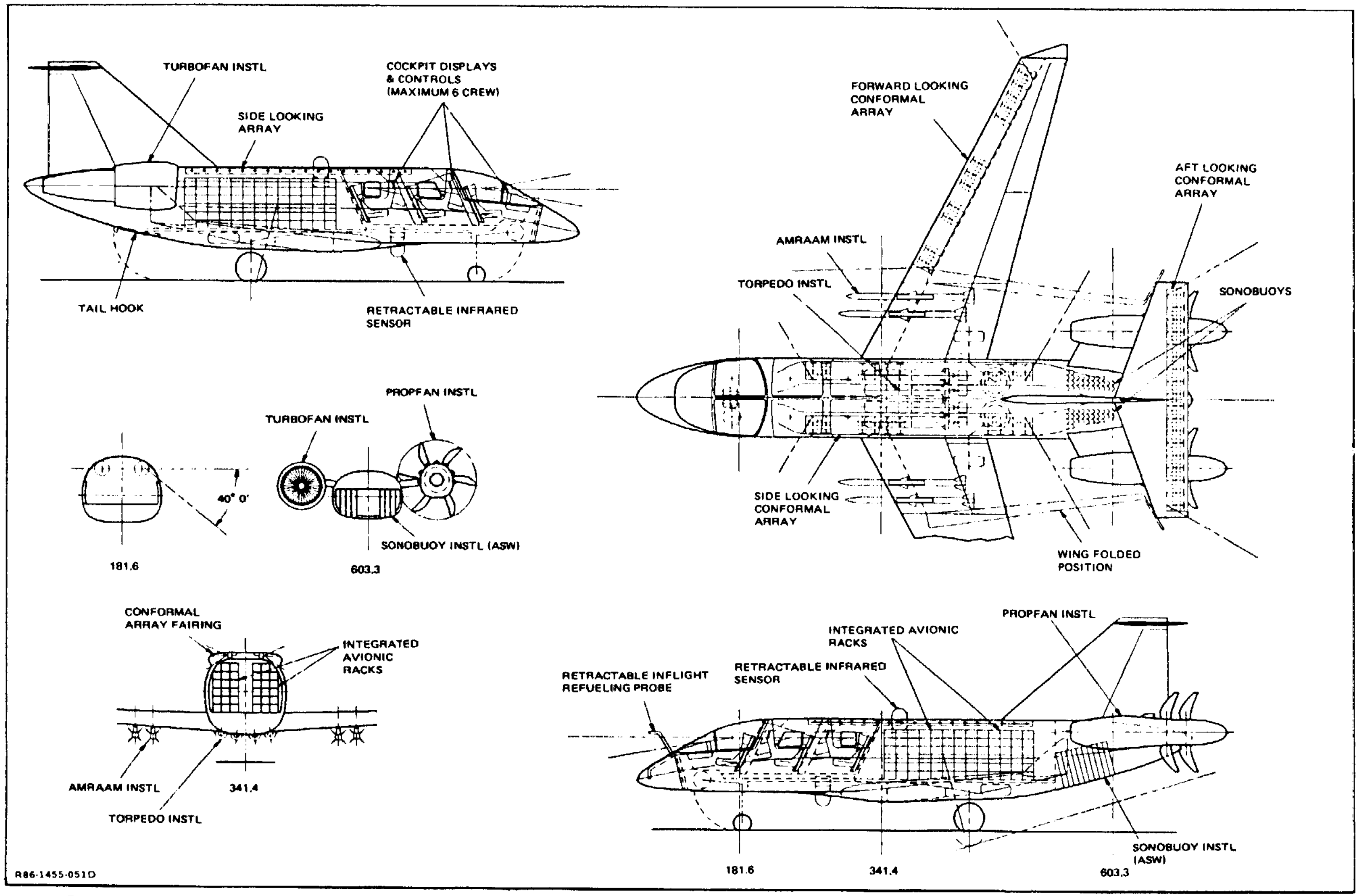

Fig. 48 MR2 Aircraft Inboard Profile

1 FOLDOUT FRAME

2 FOLDOUT FRAME

inboard profile. Entry and egress is via centerline-hinged canopies. Emergency escape is provided by ejection seats. Two retractable IR sensor turrets are included, similar to MR1. In-flight refueling is by way of a retractable nose probe. Modular avionics components are mounted in integrated racks.

MR2 is capable of carrying the same wide variety of stores as MR1 (see Subsection 5.3.2). The fuselage has five semi-submerged stations, and the wing has four pylon mounts.

5.4.3 Configuration Definition

The MR2 configuration has the same generic features as MR1: low wing, T-tail and twin, aft-mounted engines. This common wing-body-tail-engine arrangement was selected to help focus the study of propfans vs turbofans.

The MR2 fuselage geometry was determined by the AEW avionics suite, six-member crew station and length needed for side-looking UHF radar. The empennage sizing was based on safe operations at low speeds (with one engine inoperative) over a wide CG range (see Subsection 6.3).

The thrust requirements for MR2 were derived from the ability to cruise at speeds no less than 450 kt in the AEW, ASUW and Surveillance roles. The MR2 propfans are 8888 lb thrust engines, and each MR2 turbofan is 9900 lb of thrust. The resulting thrust availability is sufficient to meet satisfactory climb margins with an inoperative engine.

Extensive parametric analyses (see Subsection 5.2.1) led to the wing design characteristics shown in Fig. 46. The wing area and aspect ratio were additionally influenced by the need for adequate exposed wing span (56.5 ft) for conformal radar, wing fold and weapon stations. An overall span of 64.1 ft is required with the MR2 body width of 7.6 ft. A value of AR = 7.5 was found through parametric analyses to best meet MR2 requirements. The increase from MR1's value of 7.0 reflects the elimination of the Tanker and MIW roles (see Fig. 31) which called for lower aspect ratios. With an aspect ratio of 7.5, an area of 550 ft^2 satisfies the minimum exposed span requirement of Fig. 49. This wing size results in a TOGW about 2½% above the theoretical minimum TOGW, as indicated in Fig. 50.

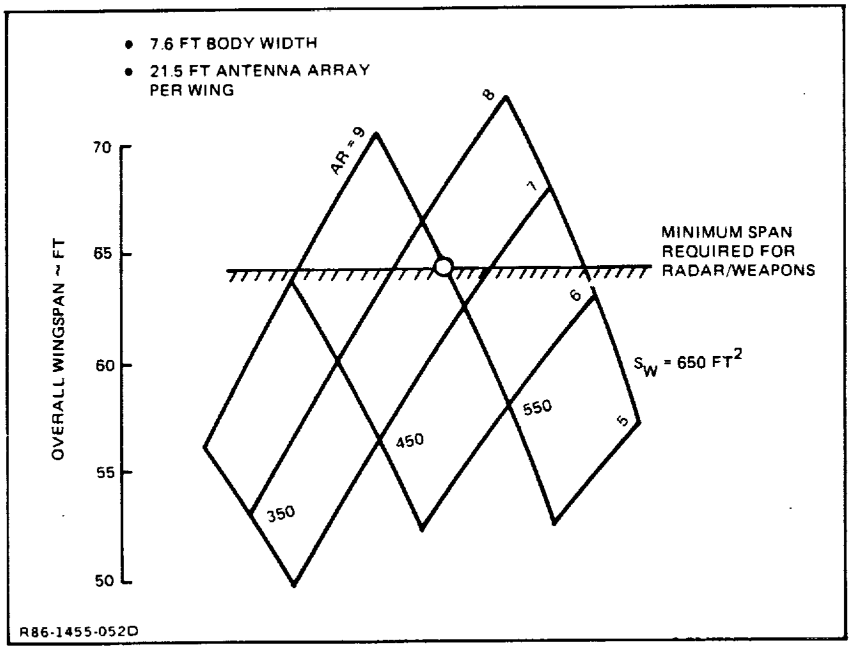

Fig. 49 MR2 Minimum Exposed Wing Span Requirement

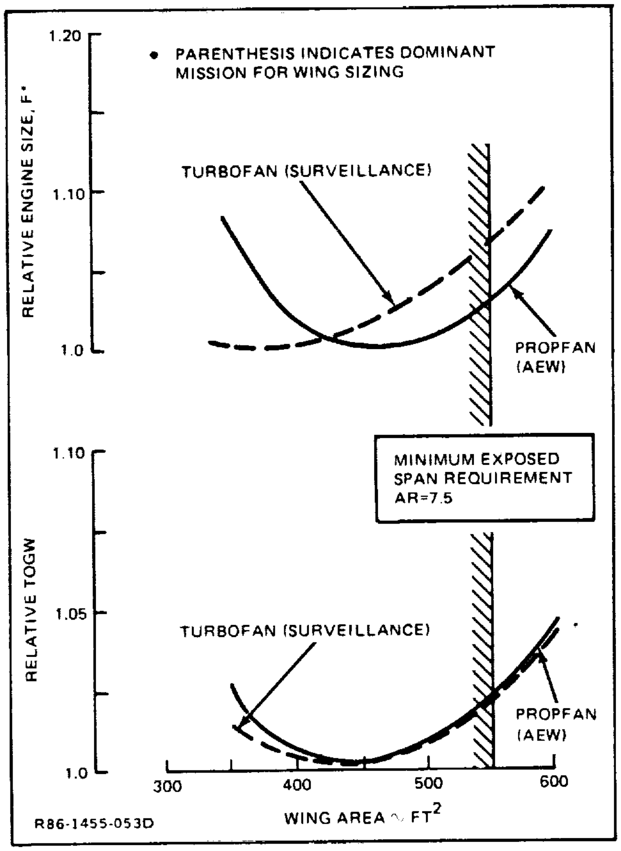

Fig. 50 Design Sensitivity to Wing Area, MR2 Aircraft

6 - AERODYNAMICS

6.1 TECHNOLOGY APPLICATION

The aerodynamic technologies employed in the design of the MPSNA concepts are listed in Table 3. All of the selected technology items are consistent with a 1990 Technology Availability Date (TAD). Many of these have been (or are currently being) validated through flight demonstration. The Grumman X-29A incorporates many of these technologies, including advanced airfoil/wing design, variable trailing edge camber and relaxed static stability. Advanced high-lift systems designed with Computational Fluid Dynamics (CFD) methods are being incorporated on new aircraft designs. Further advances in low-speed and transonic wing design are possible with the advent of more sophisticated computational tools. Special design challenges such as wing/winglet, wing/engine or fuselage/engine integration will also be greatly aided by advances in CFD.

Table 3 Aerodynamic Technology Suite

AERO TECHNOLOGY	IMPLEMENTATION	PAYOFF
ADVANCED AIRFOIL/WING DESIGN	SMART CFD TOOLS (2-D/3-D TRANSONIC OPTIMIZATION)	MULTI-REGIME L/D EFFICIENCY (CRUISE, LOITER, DASH)
ADVANCED MECH HI-LIFT SYSTEM	MULTI-ELEMENT CFD TOOLS W/CONFLUENT BOUNDARY LAYER EFFECTS	EXCELLENT HI-LIFT GENERATION WITH SUPERIOR STALL CHARACTERISTICS & MAXIMUM L/D
VARIABLE TRAILING EDGE CAMBER	ADVANCED FLIGHT CONTROL SYSTEM (FCS)	MULTI-REGIME L/D EFFICIENCY
RELAXED STATIC STABILITY	ADVANCED FCS	MINIMAL TRIM DRAG; FULL UTILITY OF VARIABLE TRAILING EDGE
AIRFRAME/ENGINE INTEGRATION	ADVANCED CFD TOOLS W/PROPULSION MODELING	INTERFERENCE-FREE INSTALLATION
WING/WINGLET INTEGRATION	ADVANCED CFD TOOLS	FULL INDUCED DRAG BENEFITS
FLIGHT MANAGEMENT SYSTEM	ADVANCED FCS & AI	OPTIMAL FLIGHT PROFILES; MINIMUM FUEL CONSUMPTION

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Technology improvements in automated Flight Control System (FCS) hardware and software should prove invaluable to MPSNA concepts. Relaxed static stability, fuel management systems and optimized wing camber control contribute to increases in range, endurance and speed. A smart flight management system coupled to the FCS allows full realization of the aircraft's performance capability via optimization of flight profiles (speed, altitude, heading) and integration with aero-surfaces and engine monitoring. Long duration flights with monotonous searching and tracking over vast oceans characterize the tasks of an MPSNA pilot; an automated flight management system will yield significant improvements to actual fuel consumption by eliminating pilot variability.

An important technology area not applied in this study is Natural Laminar Flow (NLF), Laminar Flow Control (LFC) and related viscous drag reduction schemes, such as riblets and large eddy break-up devices. The payoffs of this technology could be substantial, especially to range/endurance intensive designs like MPSNA. However, there are many practical concerns yet to be resolved, including wing surface contamination (insects, dirt, salt) and aircraft instabilities (pitch and roll) near stall due to asymmetric laminar-to-turbulent transition shifting. In-house design investigations of NLF airfoils have found they exhibit low $C_{L\ max}$ capability because of premature stall at the leading edge. Slats or Krueger flaps are not viable design solutions when conformal radar arrays are installed in the wing leading edge, as is the case with MPSNA. LFC concepts typically incorporate porous surfaces with suction systems, and often inject cleansing fluids to avoid clogging. This type of LFC system would also be difficult to integrate with a conformal radar system, as would any hot-film or other electromagnetic means of maintaining laminar wing flow. Viscous drag reduction technology appears promising, but was judged not to be consistent with a TAD of 1990.

6.2 WING/WINGLET DESIGN

The MR1 and MR2 concepts employ an advanced, supercritical wing with an average thickness-to-chord ratio of 13%. This wing design provides a higher drag rise Mach number capability for a given level of low-speed, high-lift performance, as compared to conventional, 1960 technology designs. The trade of wing sweep with differing levels of airfoil technology is illustrated in Fig. 51. As previously discussed, a leading edge sweep of 28 degrees was

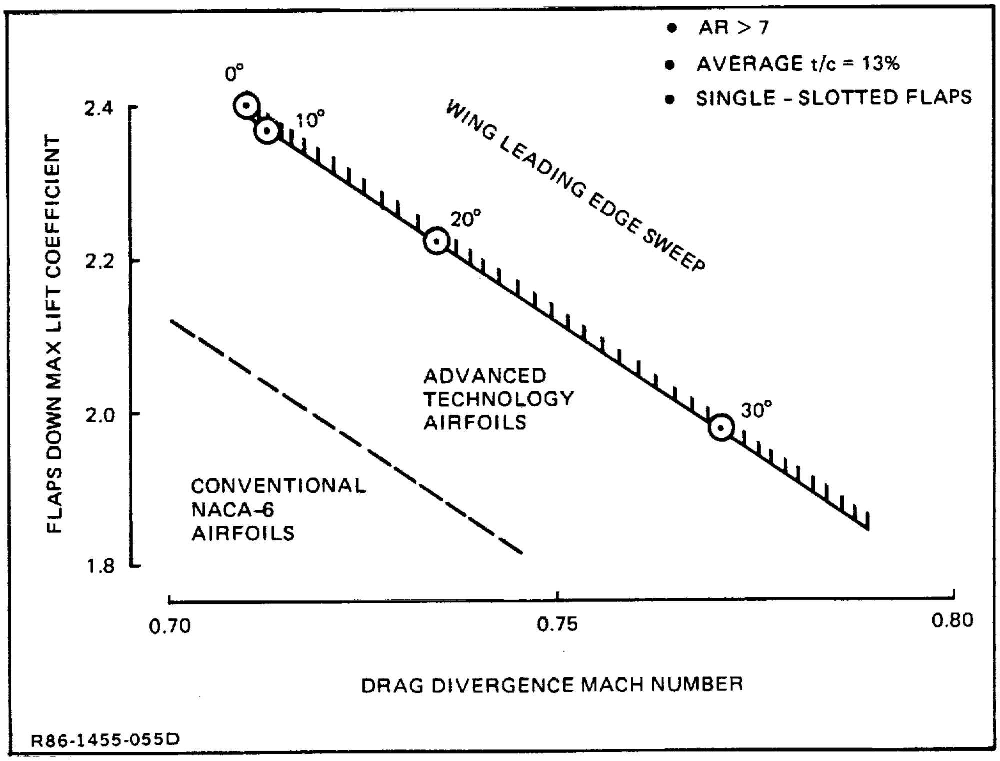


Fig. 51 Aerodynamic Trade of Wing Sweep

selected for a good balance between high speed cruise, loiter efficiency, and takeoff and landing performance.

Figure 52 shows the drag improvements offered by winglets. During mission cruise and loiter legs, drag is reduced on the order of 2% to 8% of total aircraft levels. Greater rate-of-climb performance is also provided by winglets, adding an extra safety margin during single-engine operations. For aircraft sized to missions where minimum engine-out climb rates determine the engine thrust requirements, this drag advantage allows for smaller engines and lower iterated TOGW.

An investigation was made of the iterative weight impact of winglet installation. The MR1 propfan design was evaluated over the eight dominant MPSNA missions (AAW and VAQ/VQ not examined). The iterated weight changes include structural effects, engine size variations and fuel required. MR1's geometric characteristics (wing, empennage, fuselage) were held constant.

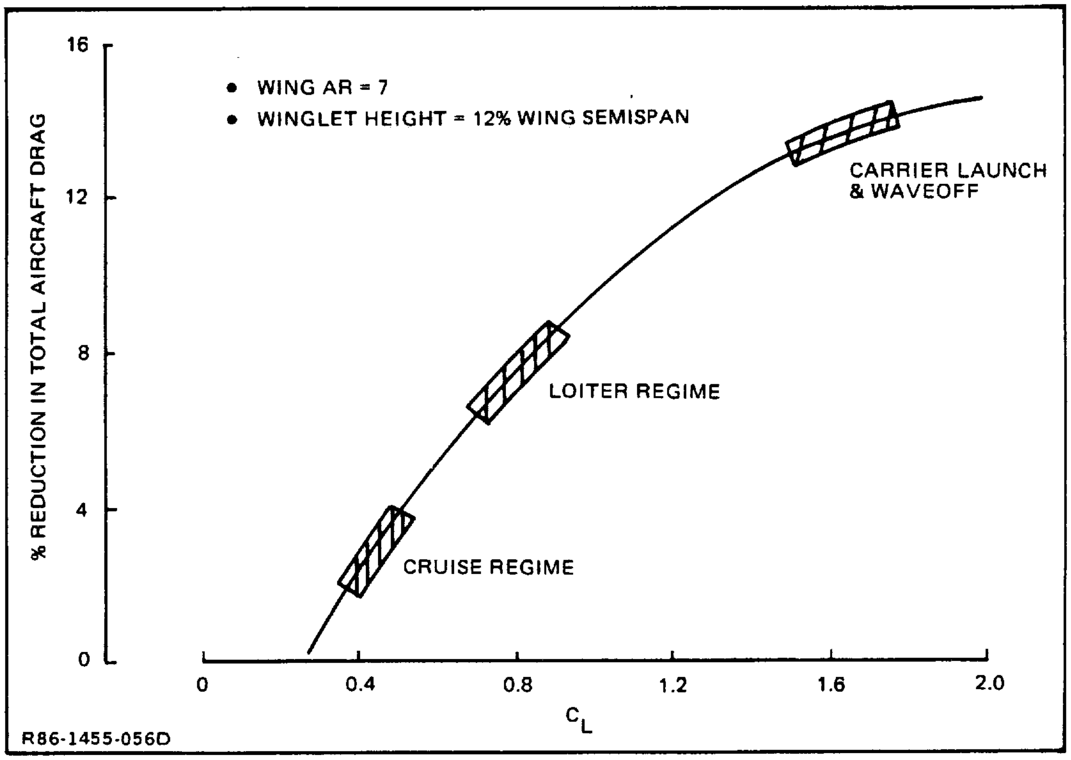


Fig. 52 Drag Reduction from Winglet Installation

Figure 53 shows that winglets provide TOGW savings dependent on the amount of time in the design mission. A dedicated AEW concept realizes the greatest (2½%) TOGW reduction because of its long endurance (four hours at 40,000 ft) requirement. Equivalent wing-tip extensions (i.e., equal induced drag benefits) follow a similar trend with mission loiter time, but they lead to a weight penalty for missions with high payloads or fuel fractions that operate at low altitudes over extended periods. An interesting finding is that for the range-intensive COD mission, winglets and wing-tip extensions result in equally small weight savings. This conclusion is consistent with studies conducted for commercial transports.

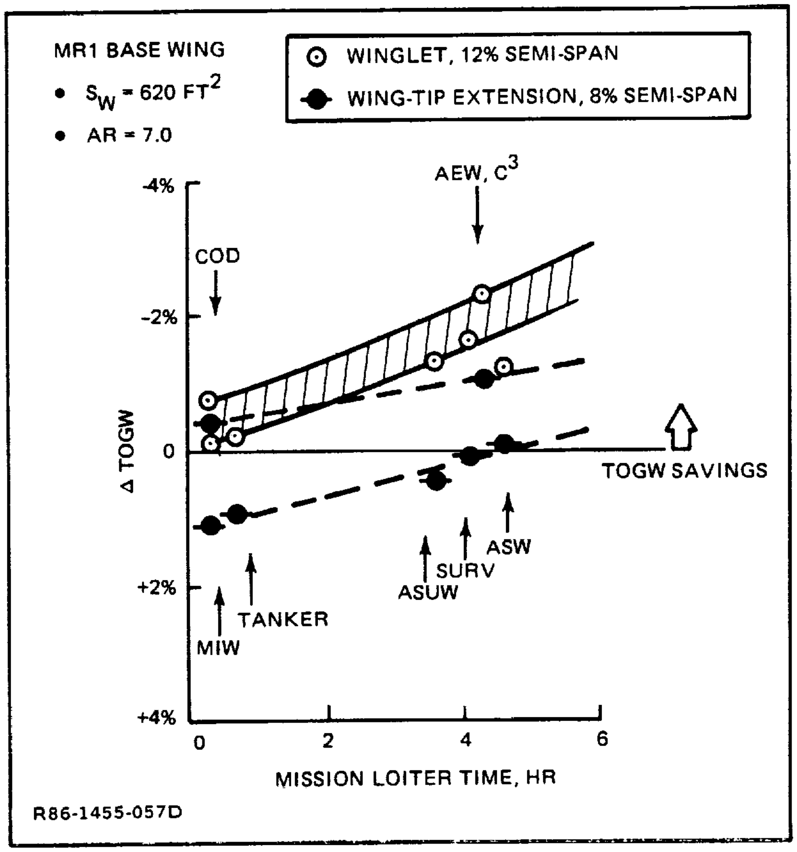
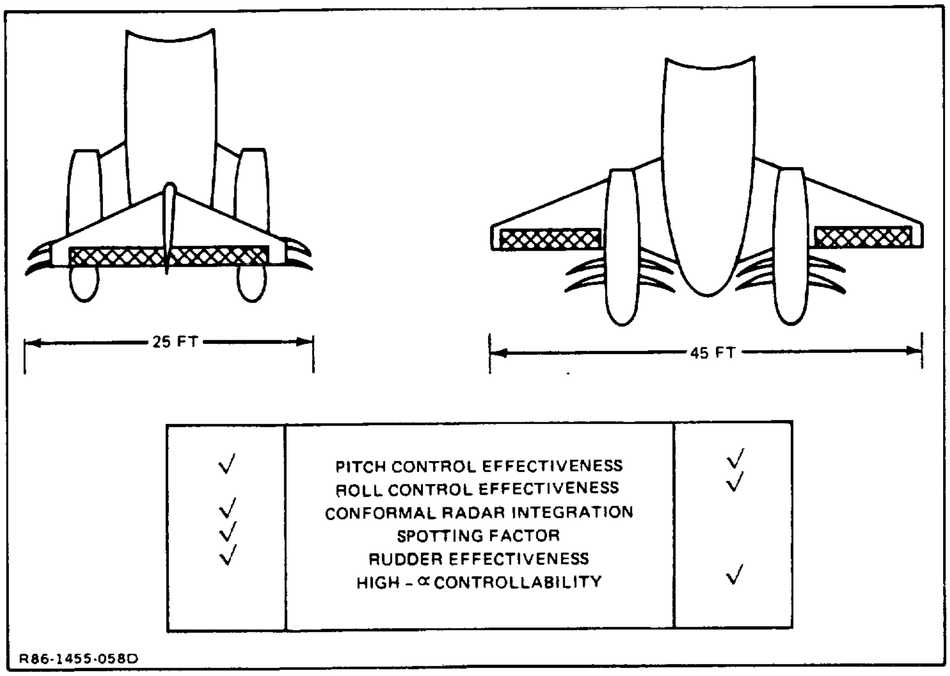


Fig. 53 Winglets Compared to Wing-Tip Extensions

6.3 EMPENNAGE DESIGN

The MR1 and MR2 designs are distinguished by their "T-tail" empennage. This configuration provides several advantages as indicated in Fig. 54. It becomes a feasible option given the 25 ft hangar deck clearances available on Forrestal-class (CV59) carriers and superior. The basic difference in exposed span (for equal pitch control effectivenss) compared to a low tail arrangement has obvious benefits to aircraft spotting size. The superior high angle-of-attack characteristics of a low tail are not particularly relevant to a support aircraft like MPSNA.

The tail area was determined by the need to control a large center of gravity location envelope. An all-moving stabilizer is utilized to provide sufficient pitch authority at low airspeeds. Figure 55 shows it has greater control power than an equal area, fixed-stabilizer with elevator.



✓	PITCH CONTROL EFFECTIVENESS	✓
	ROLL CONTROL EFFECTIVENESS	✓
✓	CONFORMAL RADAR INTEGRATION	
✓	SPOTTING FACTOR	
✓	RUDDER EFFECTIVENESS	
	HIGH - α CONTROLLABILITY	✓

Fig. 54 Horizontal Tail Location Trades

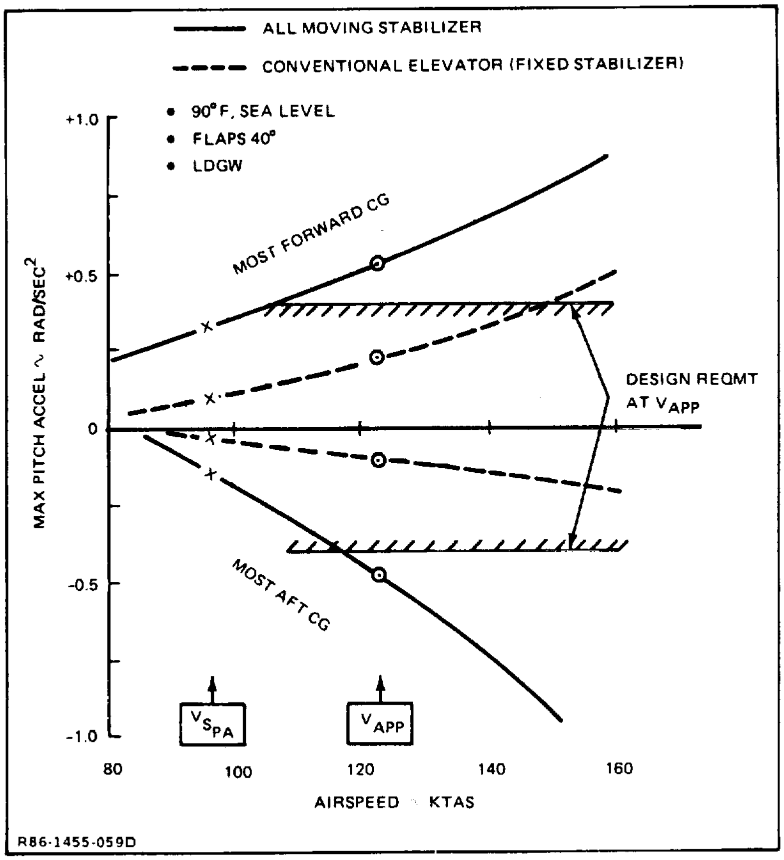


Fig. 55 Low-Speed Pitch Control Authority

Figure 56 depicts the beneficial end-plate effect of the T-tail configuration on rudder authority. This results in a smaller vertical tail (or shorter fuselage) than with the stabilizer in the low position.

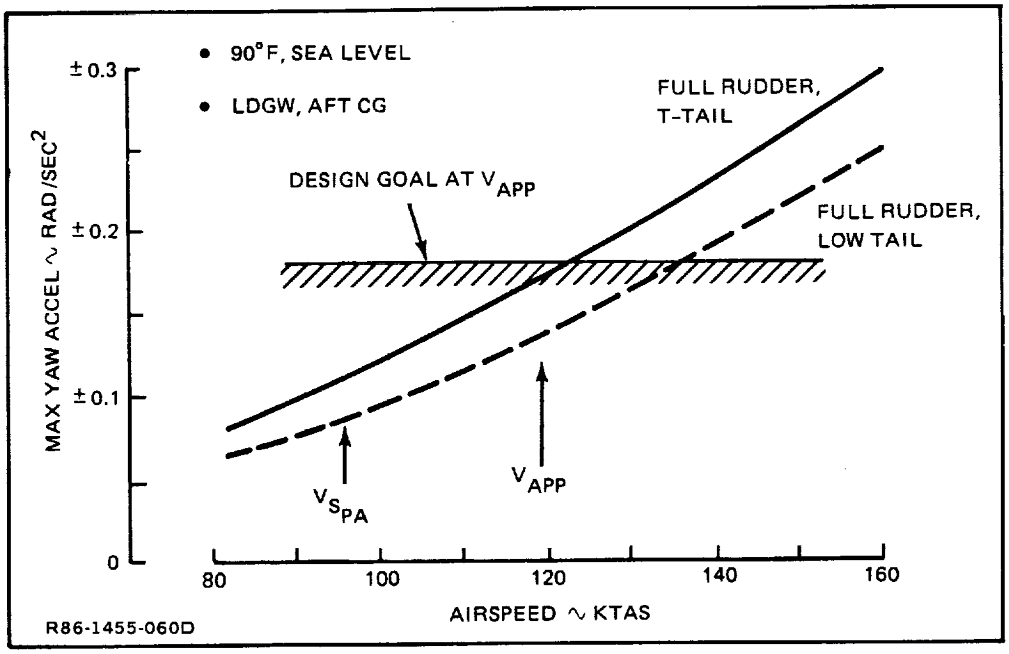


Fig. 56 Low-Speed Yaw Control Authority

6.4 HIGH-LIFT CHARACTERISTICS

Figures 57 and 58 present the trimmed lift characteristics of MR1 and MR2, respectively. MR1 is equipped with a double-slotted flap system on the inboard wing, with the outboard flaperons drooped and slotted in the landing configuration. MR2 suffices with a full-span single-slotted flap system due to its lower wing loading. Figures 59 and 60 show the high-lift drag characteristics used in calculations of post-launch and waveoff performance.

6.5 DRAG CHARACTERISTICS

The component wetted areas and characteristic lengths of MR1 and MR2, and the buildup of minimum drag are presented in Tables 4 and 5 for the propfan configurations. Figures 61 and 62 depict the drag-due-to-lift efficiency factors of MR1 and MR2. The resulting polar ($C_{D_{min}} + C_{D_{LIFT}}$) was used in the mission performance calculations.

6.5.1 Cruise Drag

The cruise drag characteristics of MR1 and MR2 are shown in Fig. 63 and 64. Both wings are designed to a drag divergence of 0.76 Mach. The component drag buildup of MR2 agrees well with the initial sizing estimate of minimum (zero-lift) drag. This lends confidence to the ability of the aircraft as sized to meet the design requirements. Analysis of the minimum drag level of MR1 found the initial sizing estimate was too low. This is attributed to the significant afterbody drag of the upswept COD fuselage, which was not fully accounted for in the early parametric design process.

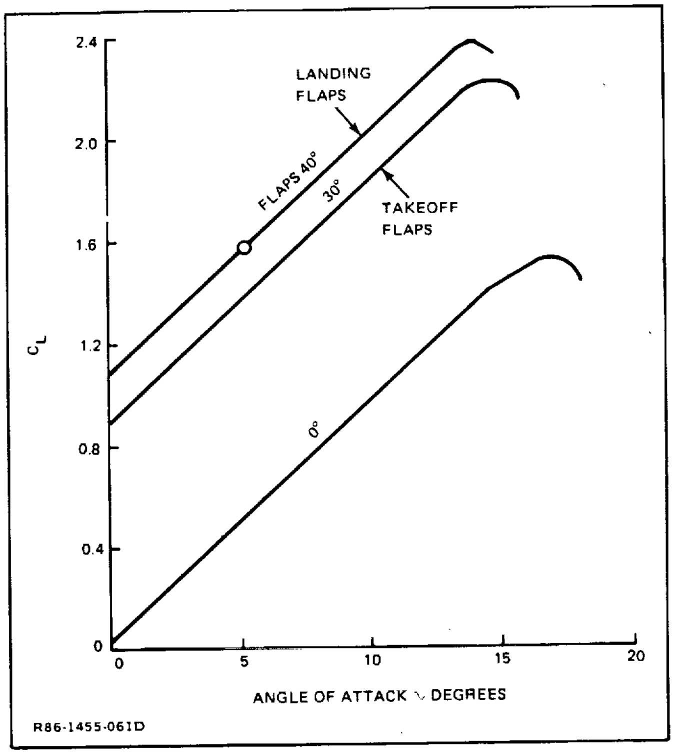


Fig. 57 MR1 Trimmed Lift Characteristics

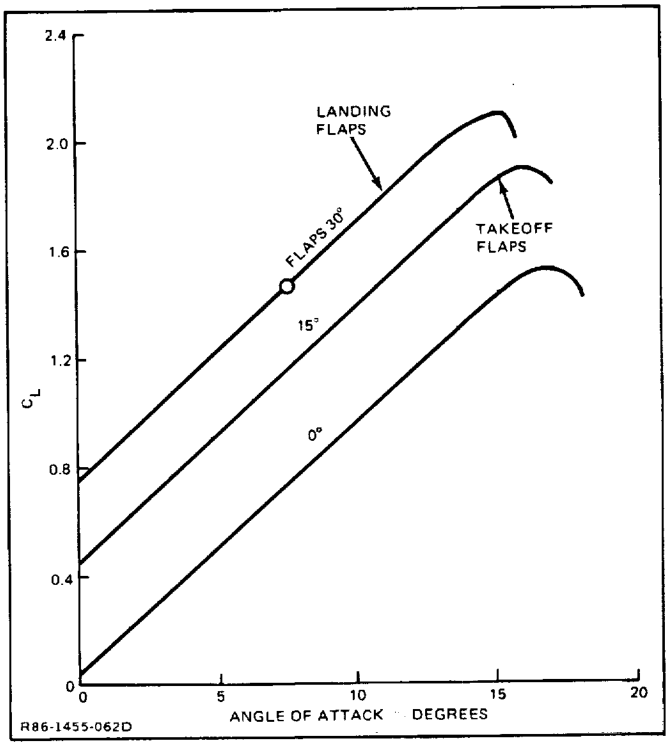


Fig. 58 MR2 Trimmed Lift Characteristics

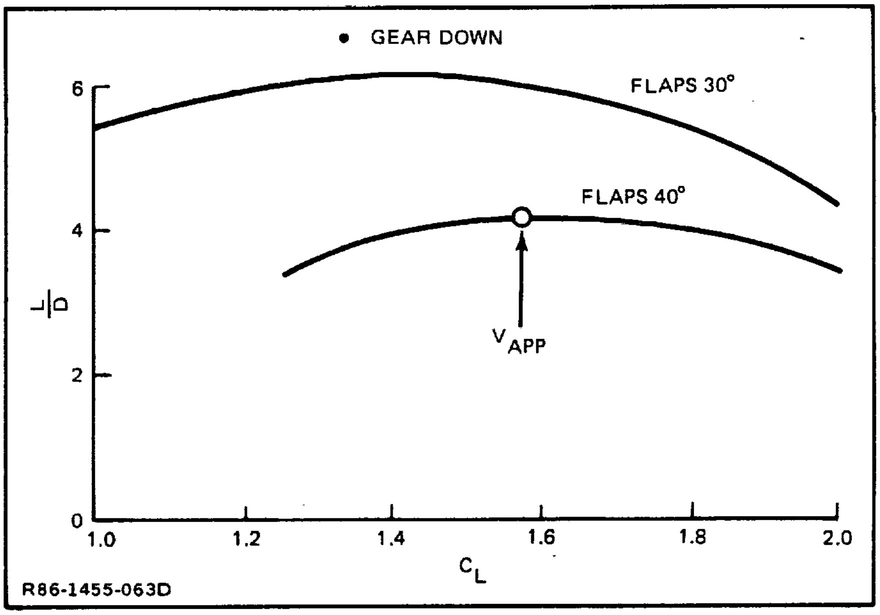


Fig. 59 MR1 Drag at High-Lift Conditions

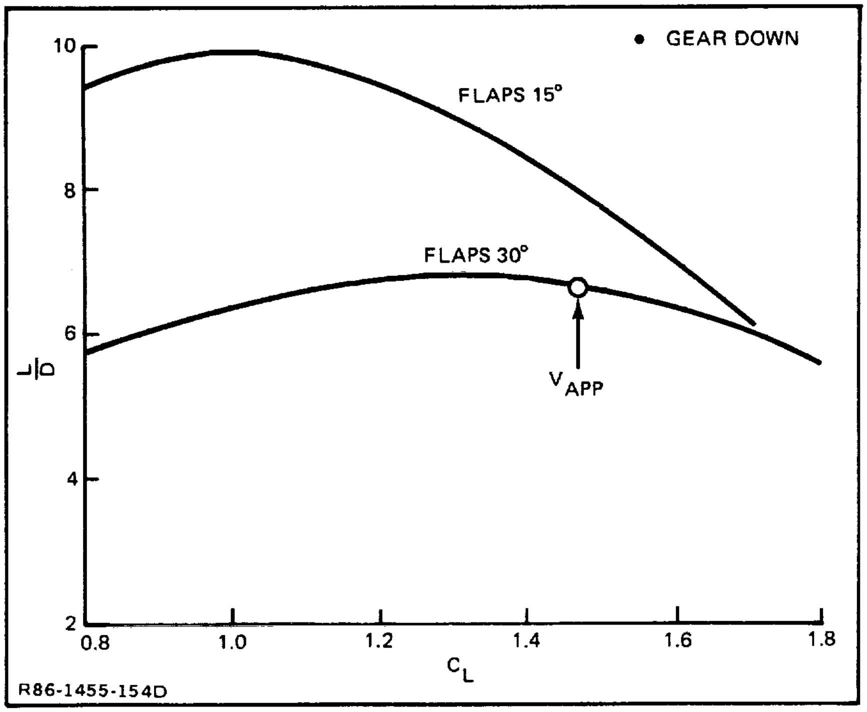


Fig. 60 MR2 Drag at High-Lift Conditions

Table 4 MR1 Minimun Drag Buildup

COMPONENT	CHARACTERISTIC LENGTH, FT	S_{WET}, FT^2	$C_{D_{P\,MIN}}$
FUSELAGE	58.8	1243	0.00857
SIDE-LOOKING RADAR	39.0	310	0.00131
INBOARD WING	11.5	538	0.00388
OUTBOARD WING	7.1	394	0.00248
NACELLE	16.5	217	0.00115
NACELLE PYLON	9.4	143	0.00068
HORIZONTAL TAIL	5.6	273	0.00141
VERTICAL TAIL	11.2	250	0.00107
WINGLET	3.0	50	0.00027

- Re No AT 0.6Mn, 36K FT
- S_{REF} = 620 FT^2
- S_{WET} = 3517 FT^2
- AFT-MOUNTED PUSHER PROPFANS

MIN PARASITE DRAG	0.02082
COOLING/VENTILATING	0.00082
EXCRESCENCE/ROUGHNESS	0.00188
$C_{D_{MIN}}$	0.02352

R86-1455-064D

Table 5 MR2 Minimum Drag Buildup

COMPONENT	CHARACTERISTIC LENGTH, FT	S_{WET}, FT^2	$C_{D_{P\,MIN}}$
FUSELAGE	52.0	922	0.00566
SIDE-LOOKING RADAR	25.0	137	0.00070
INBOARD WING	10.0	589	0.00422
OUTBOARD WING	6.2	363	0.00271
NACELLE	14.5	141	0.00090
NACELLE PYLON	7.7	83	0.00053
HORIZONTAL TAIL	5.0	219	0.00148
VERTICAL TAIL	10.2	208	0.00117
WINGLET	2.4	37	0.00028

- Re No AT 0.6 Mn, 36K FT
- S_{REF} = 550 FT^2
- S_{WET} = 2699 FT^2
- AFT - MOUNTED PUSHER PROFANS

MIN PARASITE DRAG	0.01765
COOLING/VENTILATING	0.00068
EXCRESCENCE/ROUGHNESS	0.00159
$C_{D_{MIN}}$	0.01992

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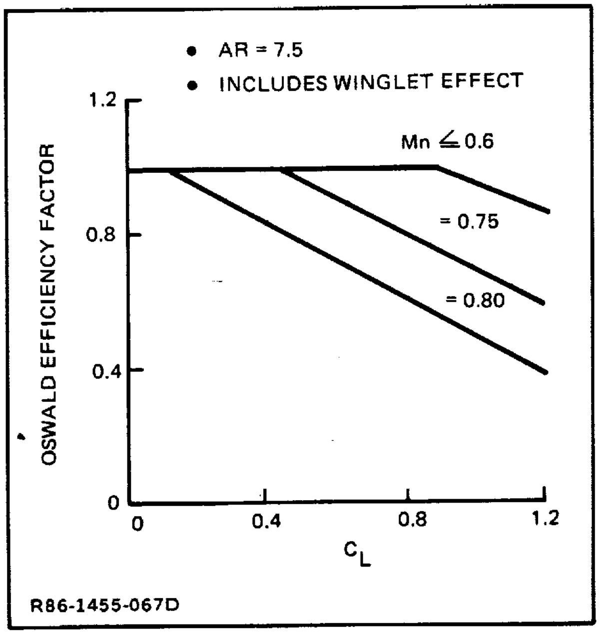

Fig. 62 MR2 Drag Due to Lift Efficiency Factors

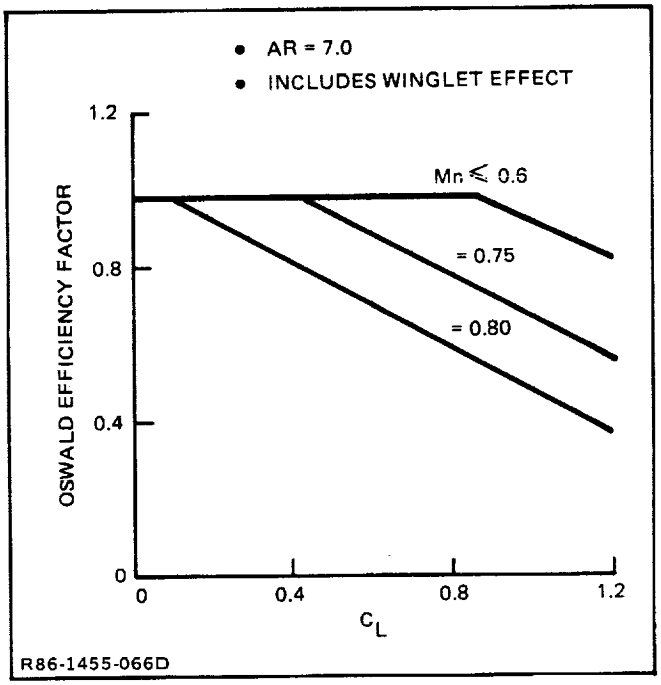

Fig. 61 MR1 Drag Due to Lift Efficiency Factors

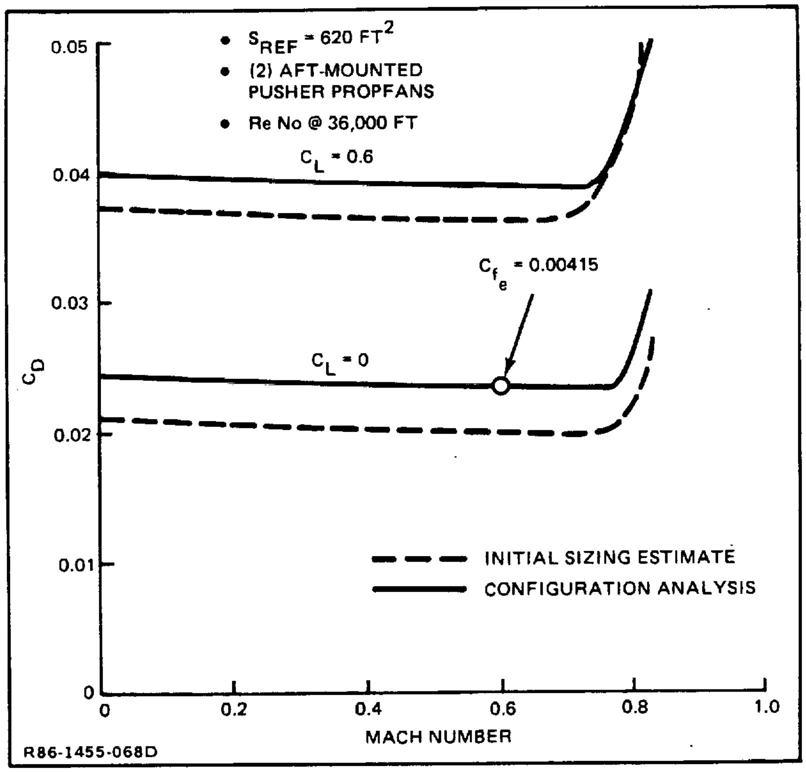

Fig. 63 MR1 Cruise Drag Characterisitcs

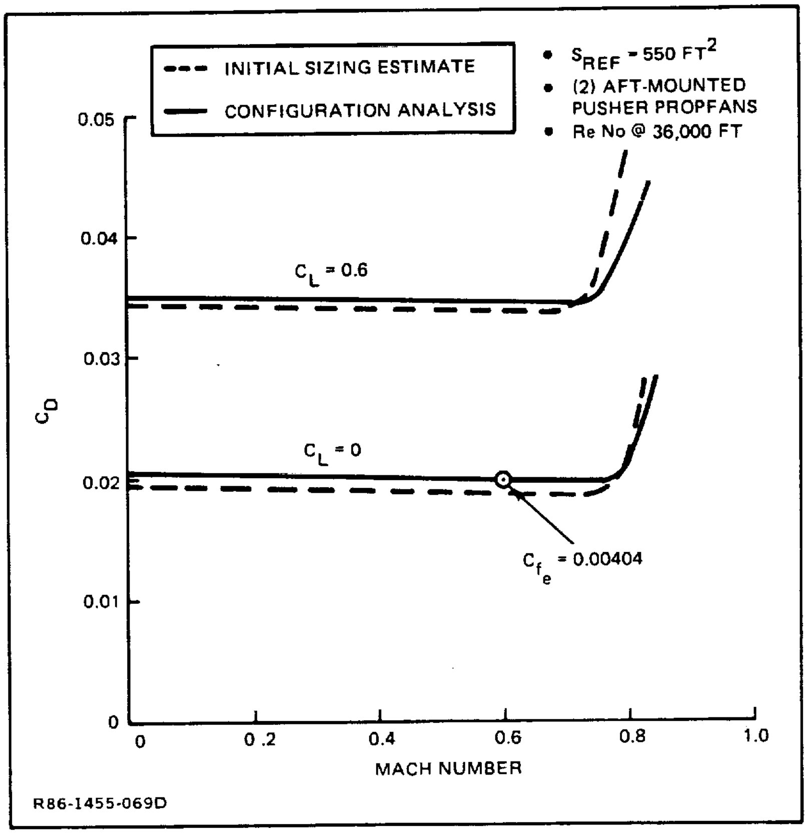

Fig. 64 MR2 Cruise Drag Characteristics

6.5.2 Loiter Drag

Figure 65 shows the lift-to-drag ratio of MR1 and MR2 at loiter conditions. Note that the higher aspect ratio of MR2 yields better aerodynamic efficiency. A slight reduction in aspect ratio for the MR1 design was necessary because of the influence of the Tanker and MIW roles.

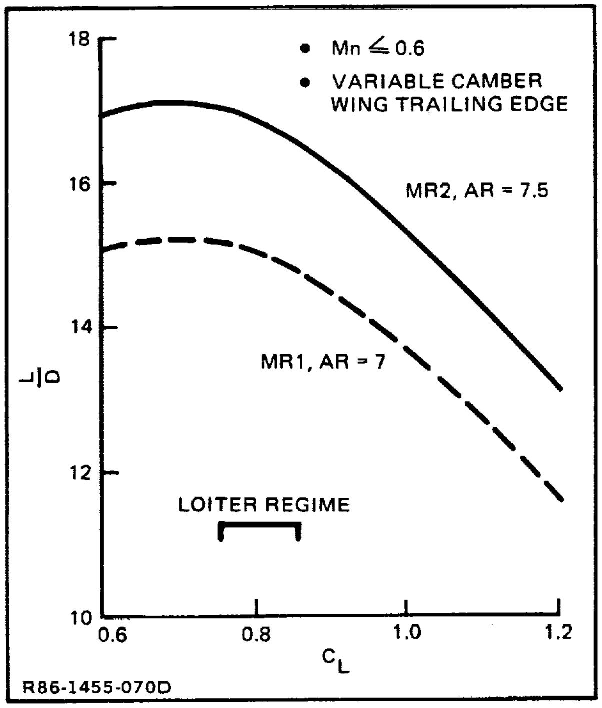

Fig. 65 Lift-to-Drag Ratio in Loiter

6.5.3 Engine Installation Effects

The basic polars were generated for the MR1 and MR2 aircraft with aft-fuselage mounted pusher propfans. Drag increments were added to account for different engine installations; i.e., aft-fuselage mounted turbofans and wing-mounted tractor propfans.

Figure 66 shows the drag associated with propfans and turbofans installed on the aft-fuselage. The turbofan configuration has a lower drag level due to less wetted area (core cowl scrubbing drag bookkept by propulsion data) but its greater cross-sectional area causes an earlier drag rise.

Figure 67 compares the drag increments of the wing-mounted tractor propfan, a single-rotation system (STS679), with the baseline, fuselage-mounted, counter-rotating STS743 engine. At nominal cruise conditions, the wing-mounted SR tractor incurs a 3% penalty relative to total drag. During loiter, this penalty increases to about 8% of total drag. The interference drag of the wing-mounted SR tractor is primarily due to an asymmetric wing span loading caused by the identical, co-rotating direction of the propulsors, chosen for logistic support of carrier based aircraft. Careful design integration including local wing treatments has been assumed to keep the propfan/wing interference drag to a minimum. Note that at low lift coefficients, the wing-mounted system has lower drag because of less nacelle wetted area than the fuselage-mounted nacelle and pylon.

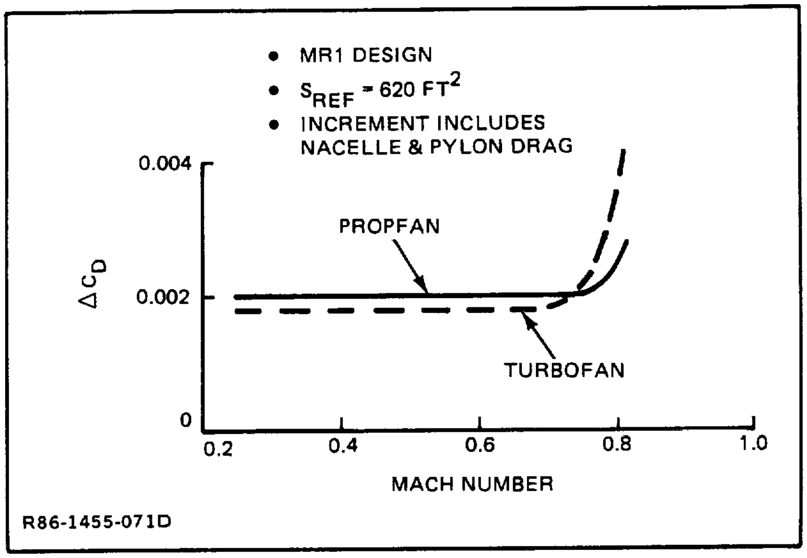

Fig. 66 Aft-Mounted Engine Installation Drag

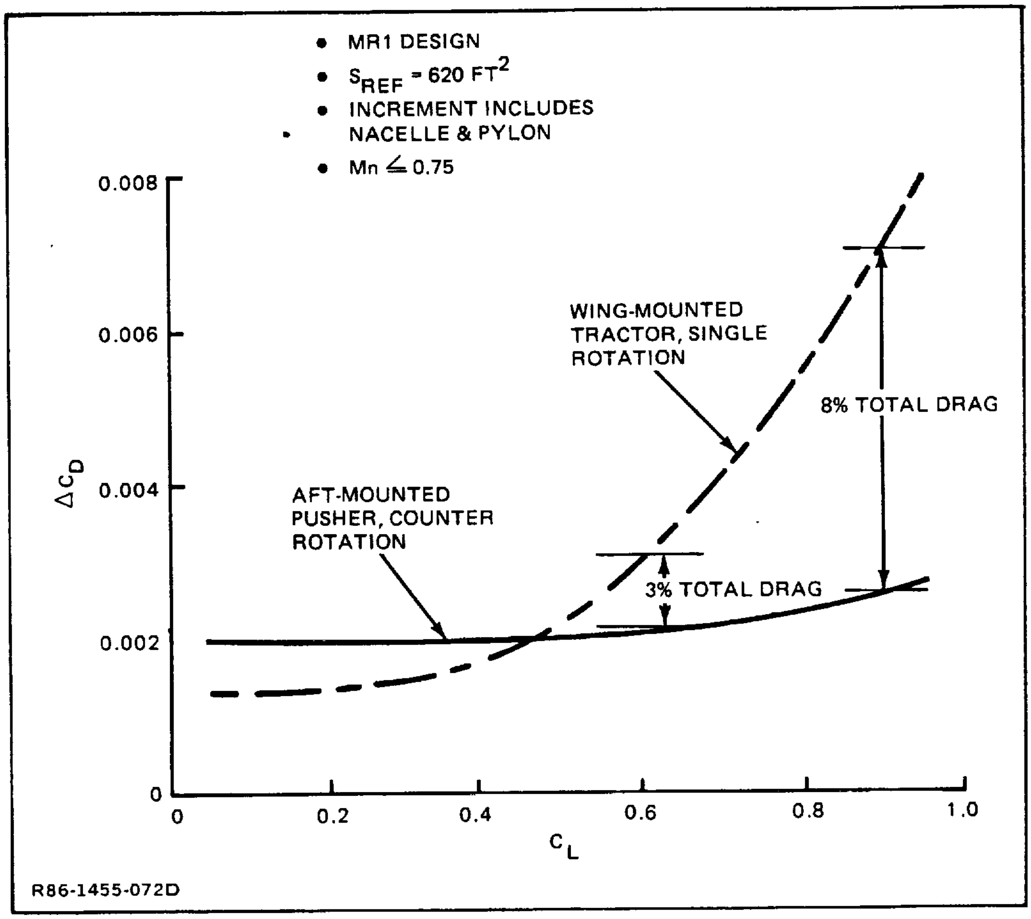

Fig. 67 Drag Effect of Wing-Mounted Propfans

6.6 LONGITUDINAL STABILITY/CG ENVELOPE

Figures 68 and 69 present the neutral point location and allowable CG range for MR1 and MR2. The definition of CG limits was based on analysis of nose-up control authority at low airspeeds with flaps down (forward limit) and avoidance of high angle-of-attack hung stalls (aft limit).

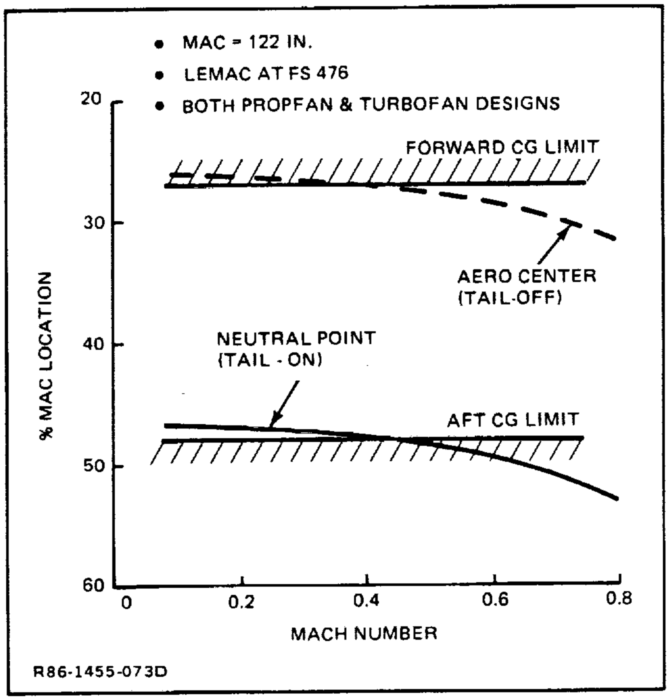

Fig. 68 MR1 Longitudinal Characteristics & CG Limits

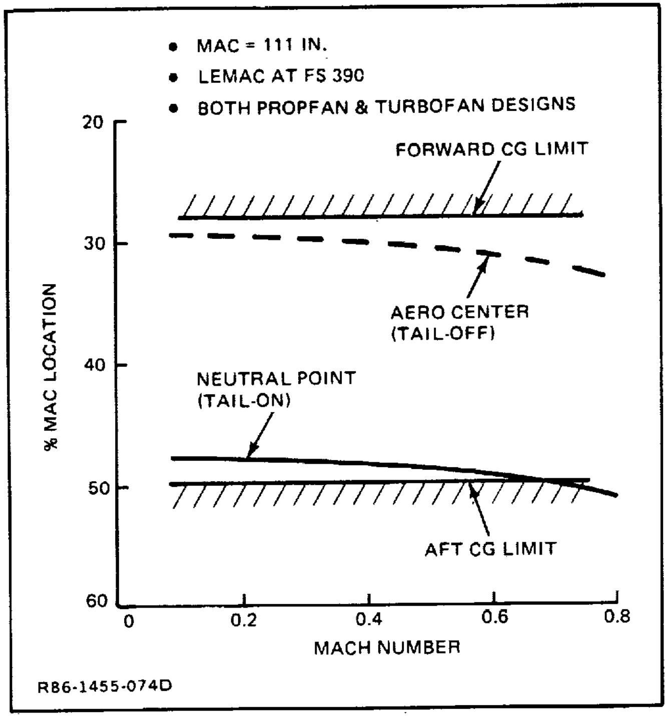

Fig. 69 MR2 Longitudinal Characteristics & CG Limits

7 - ADVANCED STRUCTURES/MATERIALS TECHNOLOGY

The criteria used to evaluate and select advanced structures/materials technologies emphasize the potential for reduced airframe structure weight, vehicle take-off gross weight, and life cycle cost. Those technologies exhibiting the greatest potential for meeting these criteria, consistent with the needed 1995 technology availability date, were identified and consist of:

- Advanced composites (epoxy and thermoplastic matricies)
- Advanced metallics
- Hybrid material systems.

The optimum material selection for each MPSNA candidate, as for any complex weapon system, is predicated upon recognizing that the structural system is made up of numerous components, each of which is designed to fulfill a specific function in a specific environment. Thus, each component has specific design requirements which must be satisfied. No single material or even one material category satisfies all of the requirements for all the components within the airframe in an optimum manner. The net result is an airframe structure optimized for static and cyclic loading, stiffness, damage tolerance, temperature, moisture, acoustics, durability, reliability, maintainability, and cost (production, operation, and support).

Candidate advanced material systems are selected in an iterative process involving:

- Identification of the basic components by function, primary loading, and service environment
- Selection of material categories and specific materials within those categories
- Selection of processes available to the material and part geometry
- Optimization of the selected materials mix to assure compatibility within the system and the environment
- Evaluation of the payoff from various combinations.

The projected MPSNA material distribution with the resultant component weight savings, is shown in Table 6. This distribution represents the combined application of advanced materials technologies and results in a weight savings of 22% over an all aluminum base.

7.1 ADVANCED COMPOSITES

The best prospect for significantly decreasing airframe weight is through the maximum effective utilization of advanced composite materials. The use of advanced composite materials offers the greatest technological improvement over historical airframe weight and has demonstrated, even in first generation applications (on a component basis), weight reductions of 15% to 30%.

Table 6 MPSNA Materials Use & Savings

COMPONENT	MATERIAL COMPONENT WEIGHT, %								WEIGHT REDUCTION, %(1)
	GRAPHITE	KEVLAR	TITANIUM	ALUMINUM	ALUMINUM LITHIUM	MMC	STEEL	MISC	
WING	56	9	13		12		5	5	29
VERTICAL TAIL	47	13	10		20			10	25
HORIZONTAL TAIL	35	11	22		22		5	5	29
FUSELAGE	25	5	13	19	19	4	7	8	18
LANDING GEAR			22	1		23	29	25	15
AIR INDUCTION	47	3	14	10	13		1	12	23
TOTAL STRUCTURE	35	6	15	7	13	5	9	10	22

(1) FROM ALL ALUMINUM BASE

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The major composite material employed on the MPSNA aircraft is the intermediate modulus graphite epoxy, (Gr/Ep), representing 35% of total structural weight. Gr/Ep exhibits high specific strength, high specific stiffness, and resistance to crack propagation compared to other materials such as aluminum. Materials used to obtain a graphite/epoxy hybrid are Kevlars, fiberglass, and boron, totaling 6% of structural weight.

The technology that can lead to improved composite wing structures and associated structural efficiency is increasing design ultimate strain levels beyond the current ultimate level of 3500 to 4000 μin./in., to 6000 μin./in. or greater, without sacrificing fatigue life, damage tolerance, survivability, or repairability. This technology has progressed to the point where it is ready for full-scale development and is, therefore, consistent with the MPSNA 1990 TAD.

Recently, a number of new polymer matrix composites with improved fibers and resin systems have been introduced by material suppliers. These fibers offer higher strain-to-failure and/or increased modulus while the resin systems have increased toughness and improved elevated temperature-wet properties compared to material systems currently being used in operational aircraft.

The structural and performance benefits that can be realized by using advanced composites, however, are often constrained by labor intensive manufacturing processes. The key to timely realization of the benefits lies in part in the development of new, mechanized, low-cost fabrication techniques optimized for composite structures. An example is an automated integrated laminating center developed by Grumman. This system is in operation today at the Grumman Composite Manufacturing Plant in Milledgeville, GA. Additional composite materials, manufacturing and assembly technologies requiring further development are summarized in Subsection 12.2.

7.2 ADVANCED METALLIC MATERIALS

Advanced metallic materials are particularly attractive for those airframe components that experience elevated temperatures (in excess of 350°F) or where isotropic properties are desirable (components with lugs, for example). Advanced metallic materials currently being considered are advanced titanium, advanced aluminum (including aluminum-lithium), and advanced steel. In recent years, the attention on metallics has been focused on such things as fracture toughness, reduced crack growth rate, and resistance to corrosion. Currently, reduced weight and acquisition/certification cost advantages of advanced metallics have started to make significant gains.

The emergence of new high strength titanium alloys coupled with the emphasis on new developments in lower cost titanium manufacturing technology, such as Superplastic Forming/Diffusion Bonding (SPF/DB) and net shape technology (in which Grumman has been concentrating), offers the potential for significant cost-effective weight savings and increased structural reliability. Alloy development for titanium has produced materials with static allowables 30% over conventional titanium while still retaining comparable dynamic properties. Fifteen percent of total structure weight is comprised of these advanced titanium alloys.

Projected alloy development for aluminum includes the emergence of a class of powder alloys exhibiting 25% to 30% higher strength. Development of an aluminum-lithium based alloy offers the potential for a high-modulus, low-density material retaining relatively high strength and excellent corrosion resistance. Specific stiffness properties 25% higher than conventional aluminum have been demonstrated.

Primary interest in the development of these alloys lies in their potential for weight savings. Studies have shown the capability for 10% to 15% weight savings in compression designed structure when compared to the commonly used 2024 alloy. Similarly, lightly-loaded, minimum gauge structure benefits from the projected reduction in material density. The significance of various material properties on structural weight have been determined and is illustrated in Fig. 70. The structural weight reduction for increases in strength and stiffness are approximately equal. However, structural weight reduction is directly proportional to decreases in density.

Steel has a limited application of only 9% of structure weight, compared to aluminum and titanium. Use of AF1410, because of its high fracture toughness and high strength levels, can provide some structural weight savings.

7.3 HYBRID MATERIAL SYSTEM

The most common hybrid material system is the selective reinforcement of metals. In selective reinforcement, high strength, high modulus fibers embedded in a metal matrix are used to selectively enhance the properties of the metal structure.

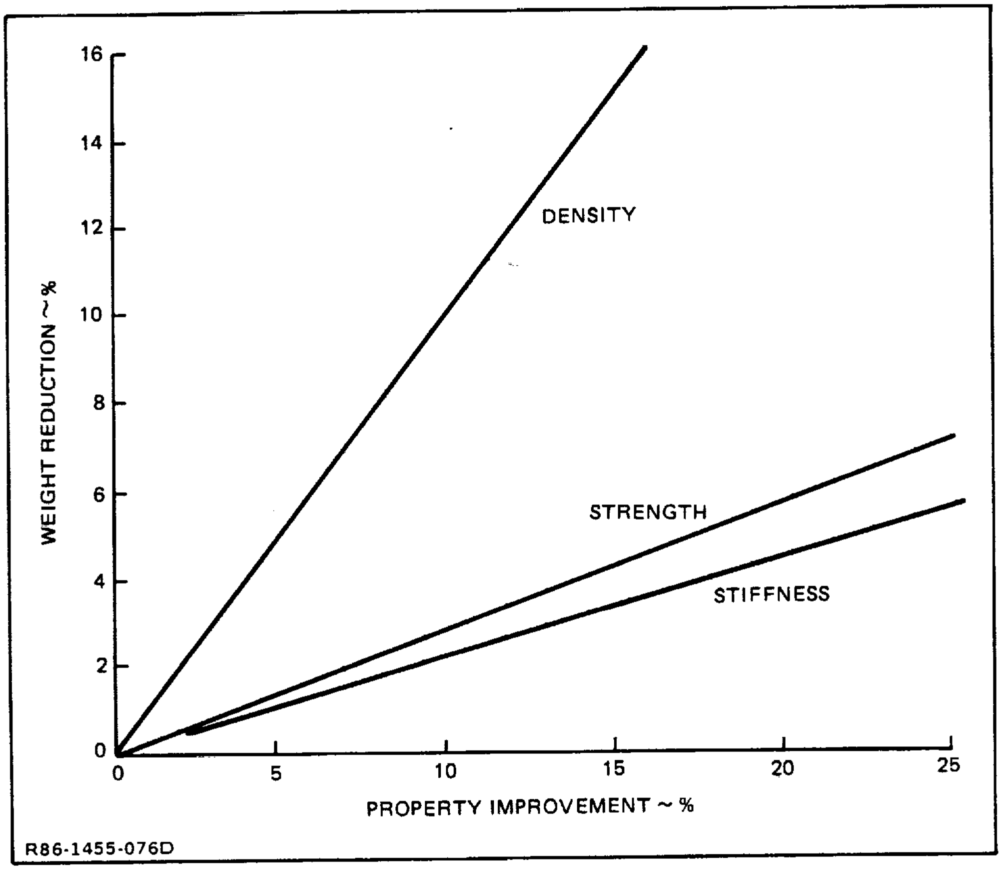

Fig. 70 Effect of Property Changes on Structural Weight

Recent developments in fiber-reinforced titanium offer the potential for enhanced strength and stiffness properties compared to conventional titanium, as well as the capability to tailor properties locally for specific applications. The resulting potential weight savings are comparable to organic matrix composites, at the higher operating temperature ranges.

Selectively reinforced titanium structures should result in several performance benefits at a slight cost increase over SPF/DB or Hot Isostatic Pressing (HIP). They are:

- Tailoring of material/directional properties to enhance strength and stiffness
- Higher service temperature.

8 - CARRIER SUITABILITY

MR1 and MR2 aircraft are fully compatible with operations from CV59 and superior carriers. Their landing gear and arresting hooks are compatible with both above-deck and flush-deck catapult hardware and the Mark 7 Mod 2 and Mod 3 arresting engines. The aircraft have self-start capability which minimizes the need for yellow gear on the flight deck. The MPSNA designs are compatible with the MD3A tractor and NT-4 tow bar as well as with the SD-10 spotting dolly.

8.1 LAUNCH & RECOVERY PERFORMANCE

Minimum launch airspeeds for a maximum sink-off-bow of 5 ft are presented for the MR1 and MR2 aircraft in Fig. 71 and 72, respectively. The difference between the launch airspeed and catapult endspeed determines the Wind-Over-Deck (WOD) requirements. The takeoff WOD characteristics of MR1 and MR2 are also shown in Fig. 71 and 72, for the older C7 catapult (CV59-CV62) and the latest C13-1 catapult (CV66-CVN71). At maximum TOGW of MR1 turbofan design

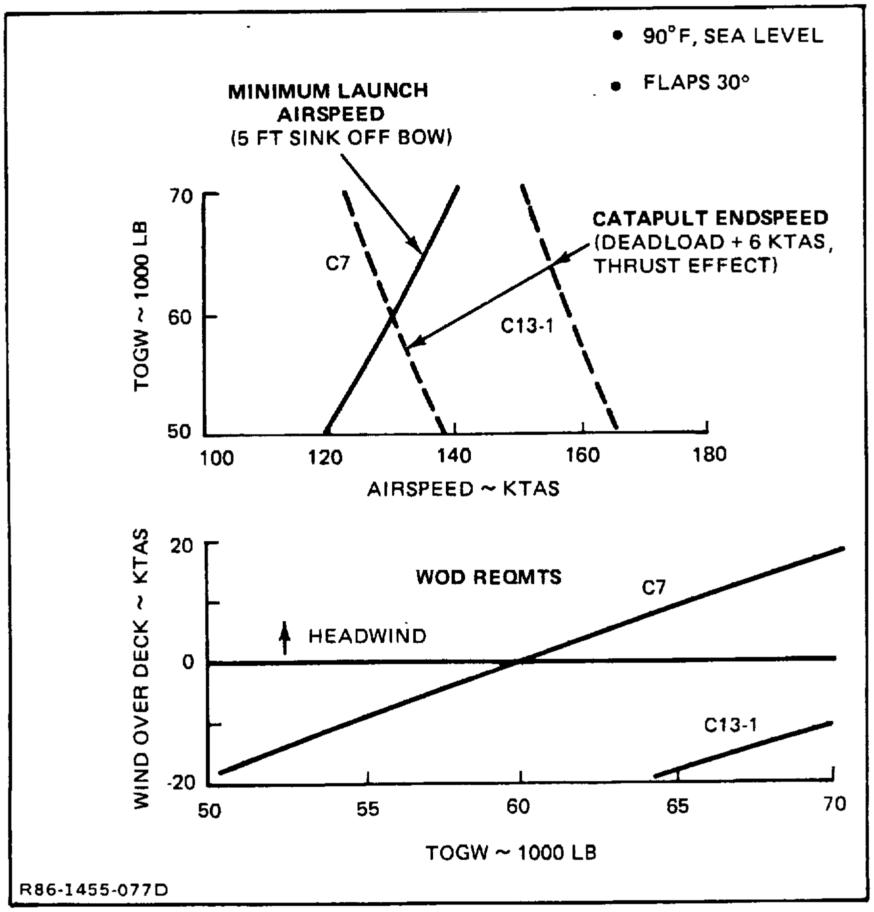

Fig. 71 MR1 Catapult Takeoff Wind-Over-Deck Requirements

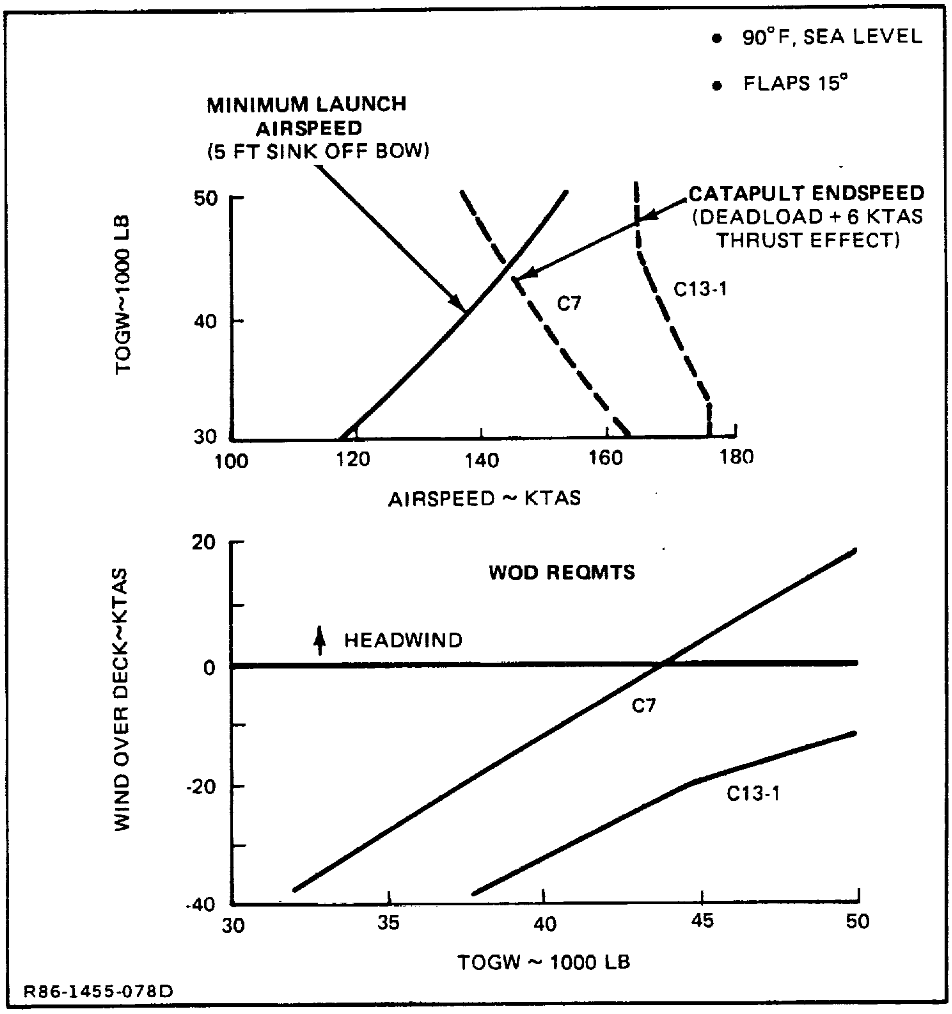

Fig. 72 MR2 Catapult Takeoff Wind-Over-Deck Requirements

(63,534 lb), a WOD of 10 KTAS is required for takeoff from the C7 catapult. At the MR2 turbofan's maximum TOGW (44,149 lb), a C7 catapult takeoff requires no WOD.

The post-launch longitudinal acceleration capability of MR1 (Fig. 73) significantly exceeds minimum requirements, even with an inoperative engine. This results from the high thrust loading necessitated by the MIW dash requirement. The MR2 design has satisfactory engine-out and twin-engine post-launch performance, as shown in Fig. 74. MR2 utilizes a moderate flap setting (15 degrees) during carrier takeoffs for a greater lift-to-drag ratio. The MR1 concept (with a higher wing loading than MR2) uses 30 degree flap deflection on takeoff to minimize WOD requirements. The excess thrust availability of MR1 compensates for the reduced lift-to-drag efficiency of 30 degree flaps.

MR1 has a carrier approach speed of 120 KTAS at its landing design weight of 45,500 lb, as shown in Fig. 75. MR2 has an approach speed of 116 KTAS at LDGW of 35,800 lb, as shown in Fig. 76. These nominal approach speeds are 1.29

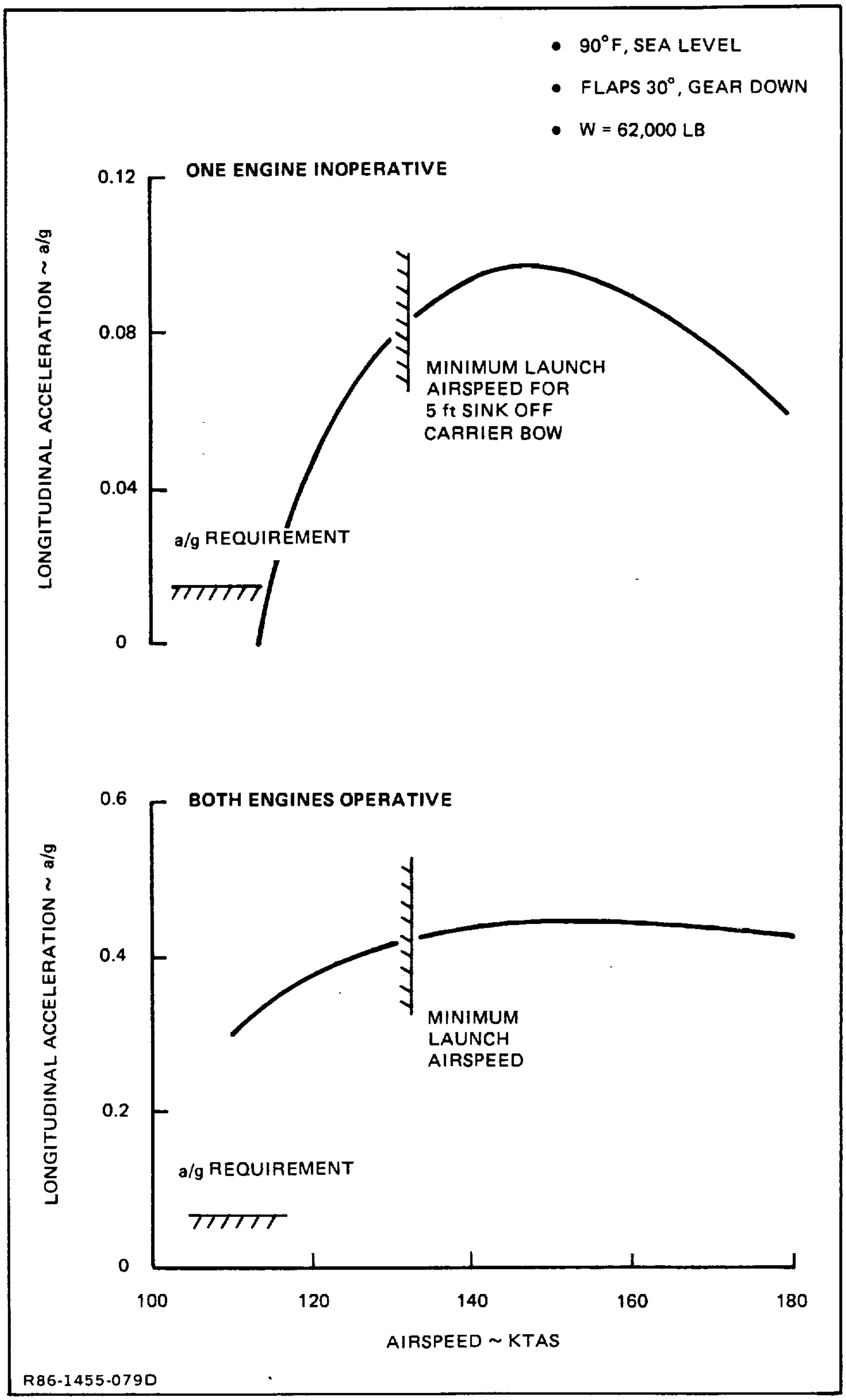

Fig. 73 MR1 Post-Launch Longitudinal Acceleration

C-2

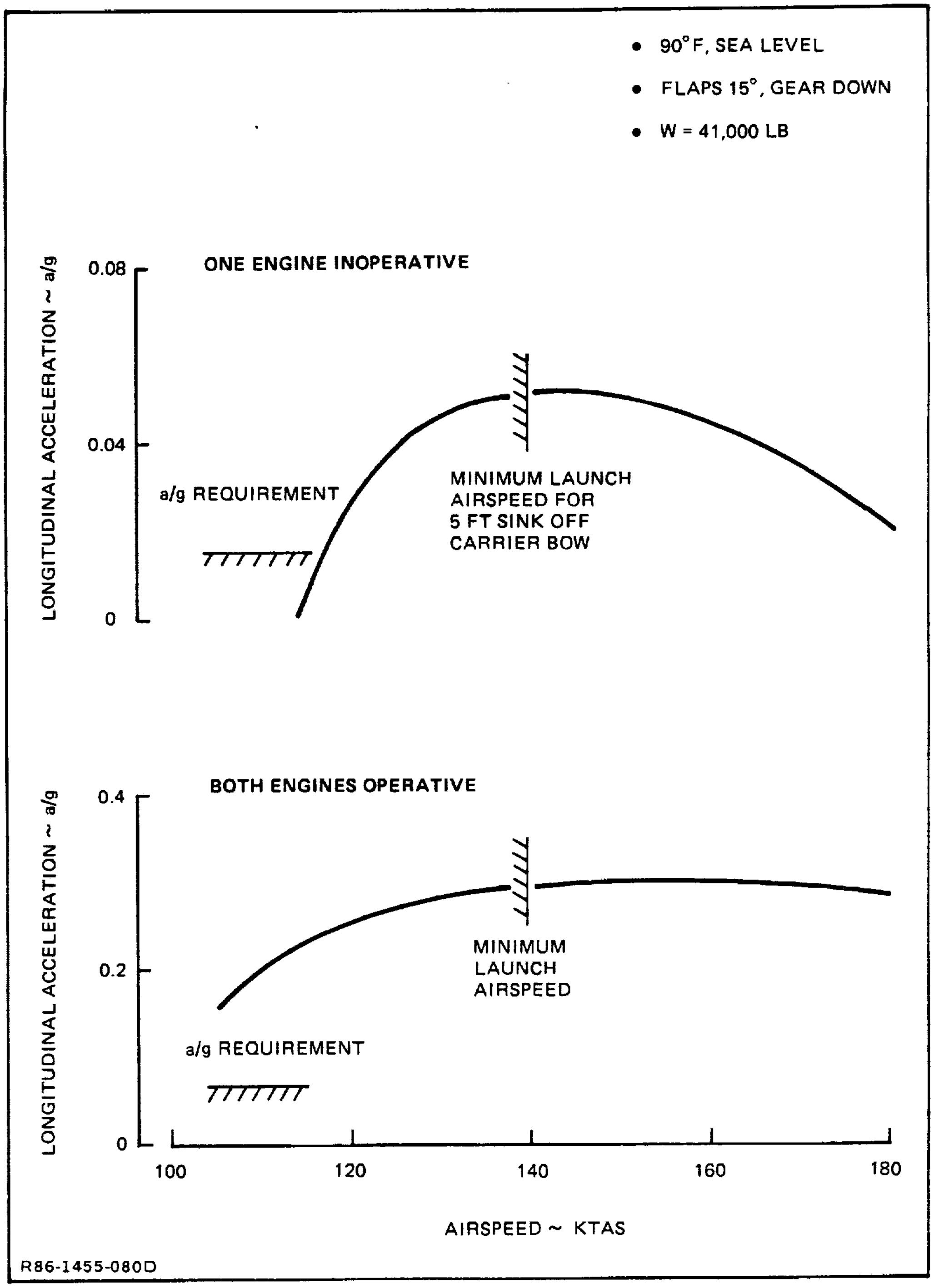

Fig. 74 MR2 Post-Launch Longitudinal Acceleration

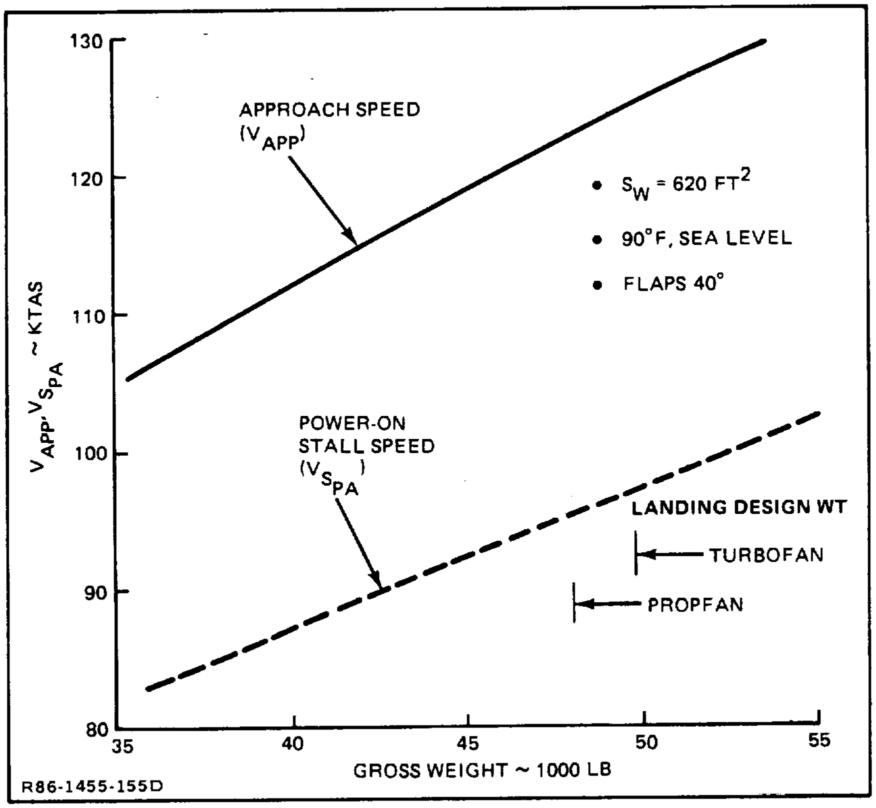

Fig. 75 MR1 Approach Speed Performance

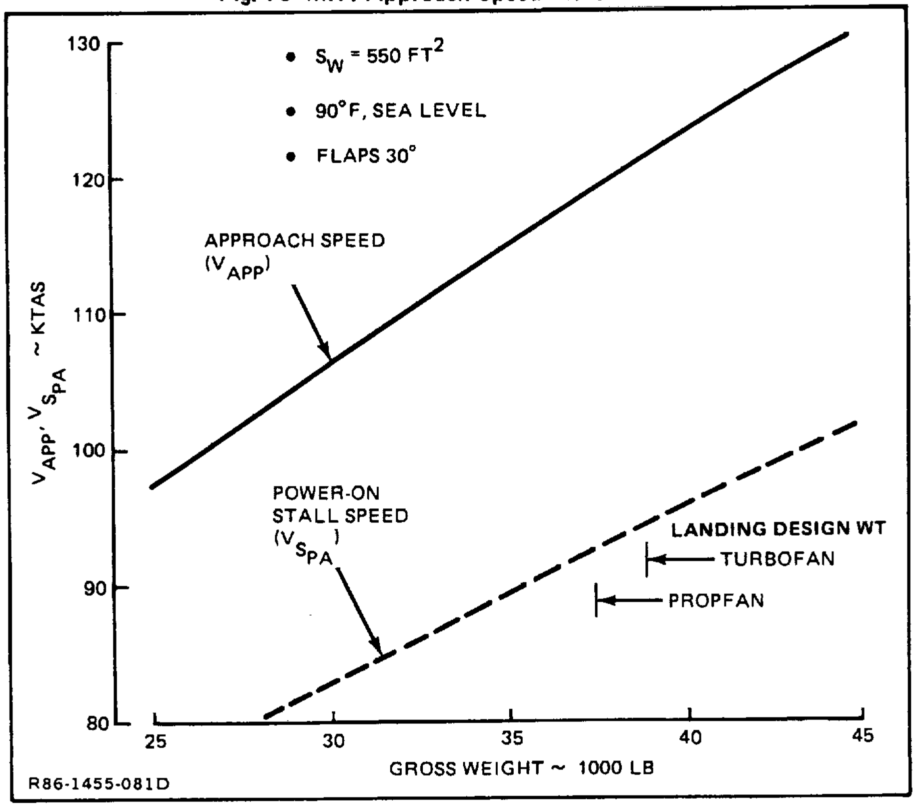

Fig. 76 MR2 Approach Speed Performance

times the power-on stall speed ($V_{S_{PA}}$) to ensure that the aircraft meet standard Navy specifications concerning pop-up maneuvers, acceleration margins, engine transients and flying qualities.

An engine-out waveoff climb rate of almost 2000 ft/min is available at nominal approach conditions for MR1 (see Fig. 77). A minimum engine-out rate-of-climb of 500 ft/min is provided for the MR2 over the range of landing weights (see Fig. 78). These calculations assume the inoperative engine is a windmilling turbofan. An inoperative propfan would have less drag when feathered.

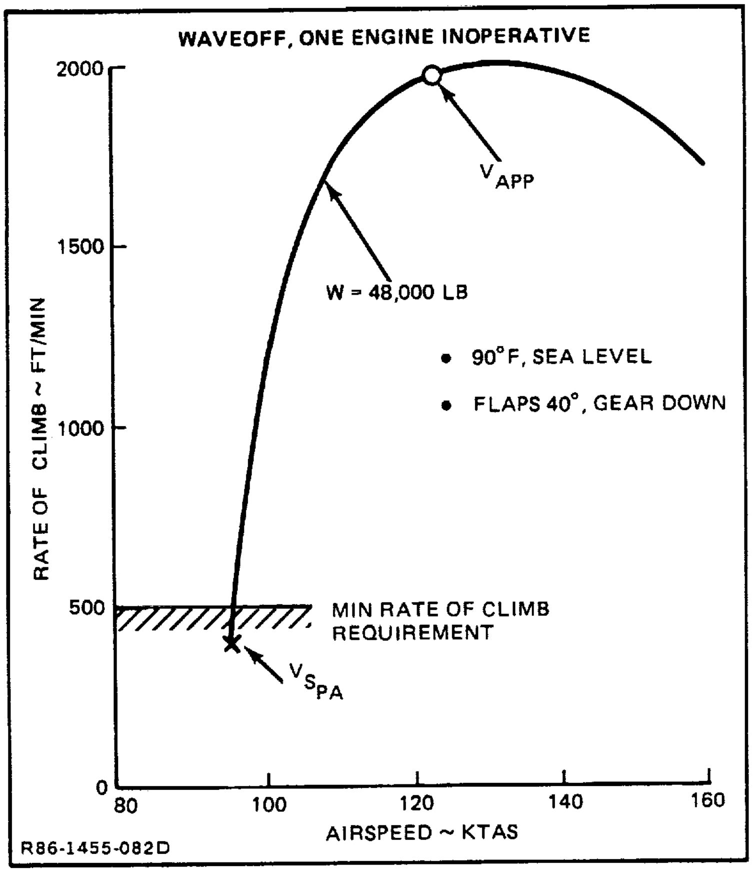

Fig. 77 MR1 Engine-Out Waveoff Performance

Minimum WOD requirements for arrested landings are shown in Fig. 79 and 80. MR1 does not need any WOD at a landing weight of 45,500 lb with the Mark 7 Mod 2 or Mod 3 engines. Similarly, MR2 can land at a weight of 35,800 lb without any WOD.

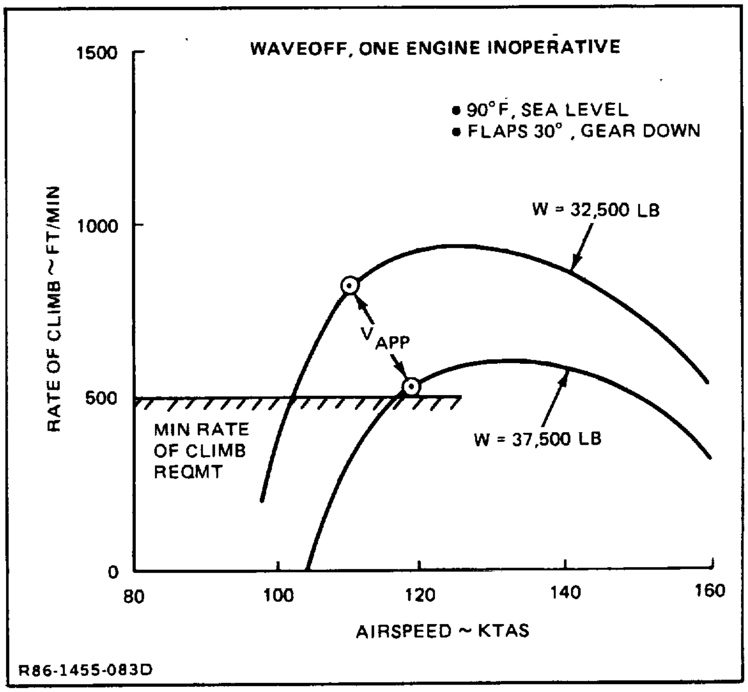

Fig. 78 MR2 Engine-Out Waveoff Performance

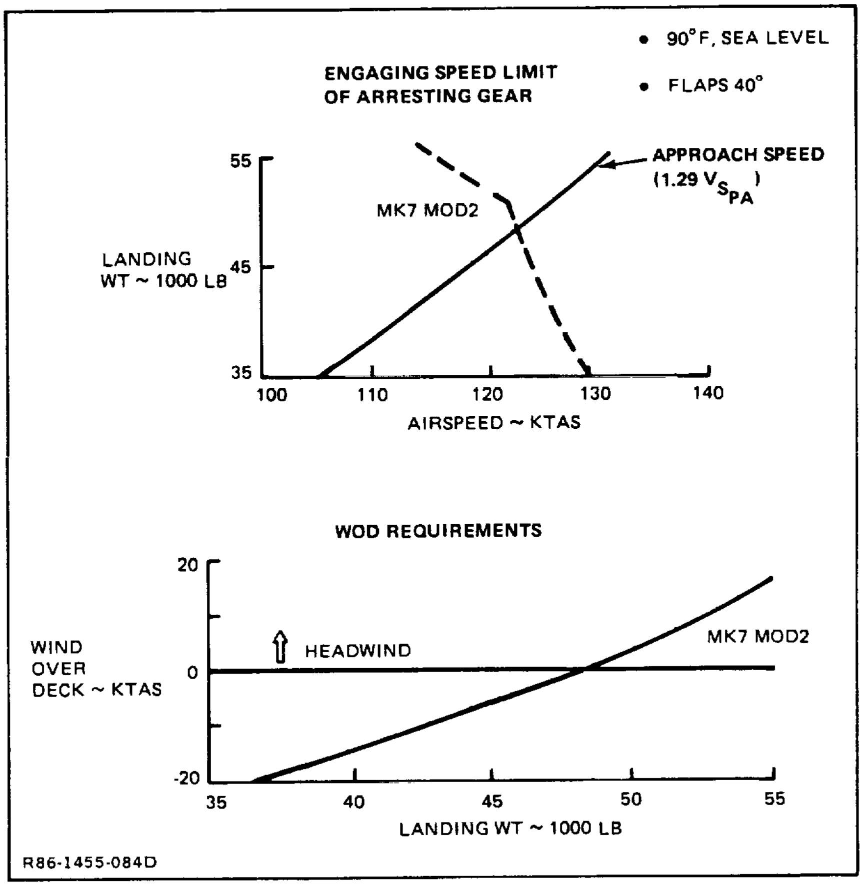

Fig. 79 MR1 Arrested Landing WOD Requirements

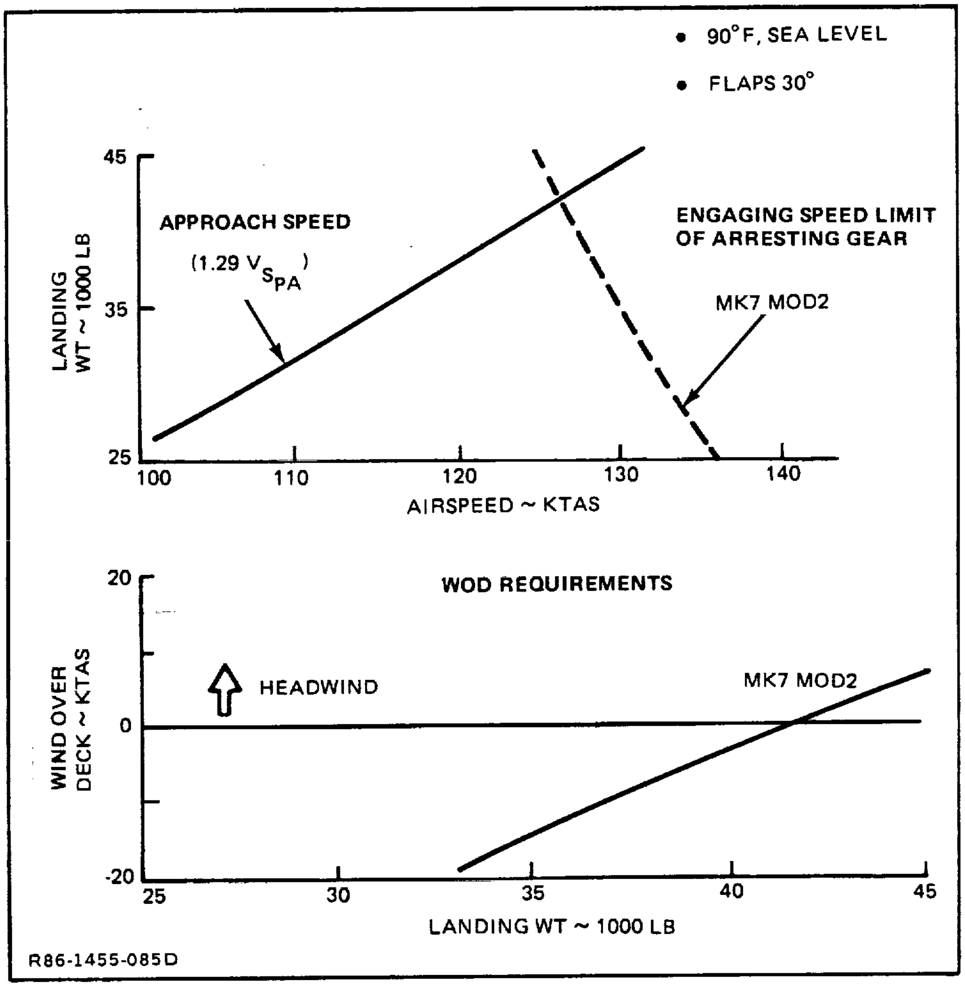

Fig. 80 MR2 Arrested Landing WOD Requirements

8.2 SPOT SIZE

When determining the spot size of a carrier-based aircraft, 18 in. of clearance is required between adjacent aircraft and between the landing gear and deck edge. The spot sizes of the MR1 and MR2 aircraft are shown in Fig. 81 relative to the E-2C and S-3A aircraft, respectively. This comparison provides a realistic assessment of carrier operations using MR1 and MR2 aircraft relative to current aircraft size.

An E-2C type wing fold design is incorporated into both MR1 and MR2 aircraft. This fold arrangement allows for minimum spot size while maintaining the capability to fold/unfold the wings at the hangar deck level. This allows easy access to critical wing components such as the conformal radar arrays and associated transmitters, receivers and other equipment.

8.3 GEOMETRIC & WEIGHT LIMITATIONS

When operating on CV59-CV62 elevators, the maximum permissible aircraft weight is 66,750 lb, plus 12,000 lb for the tow tractor (MD-3A) and 1,250 lb for associated personnel and gear. This total weight limit of 80,000 lb is increased to 130,000 lb for CV63 carriers and superior. Figure 82 depicts the

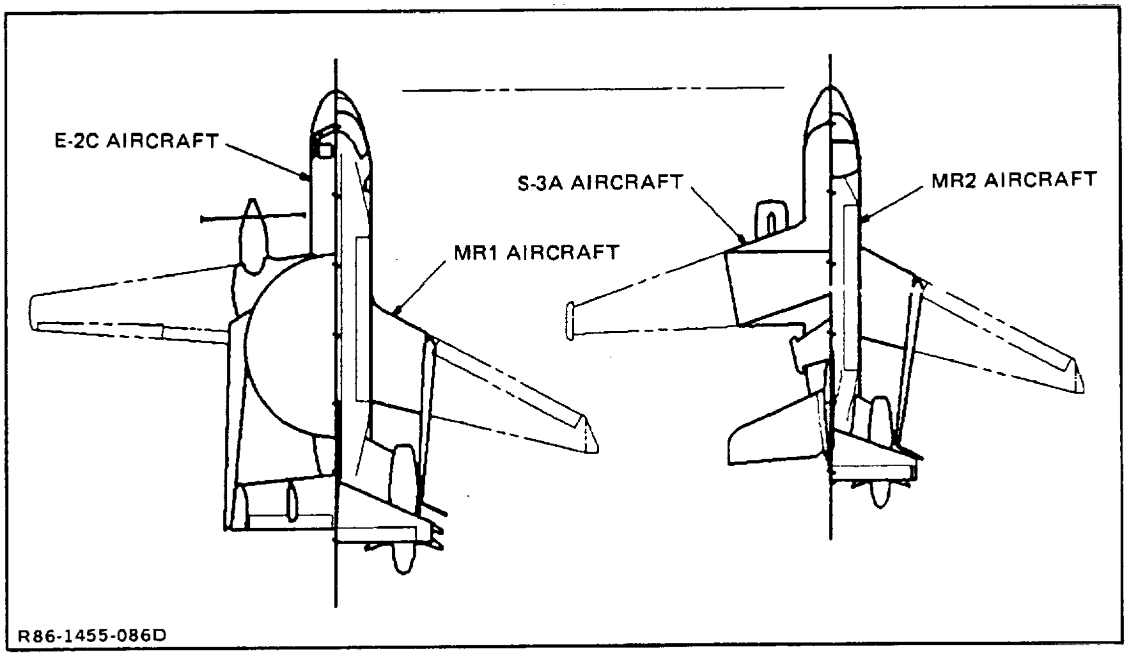

Fig. 81 Spot Size Comparisons with E-2C & S-3A

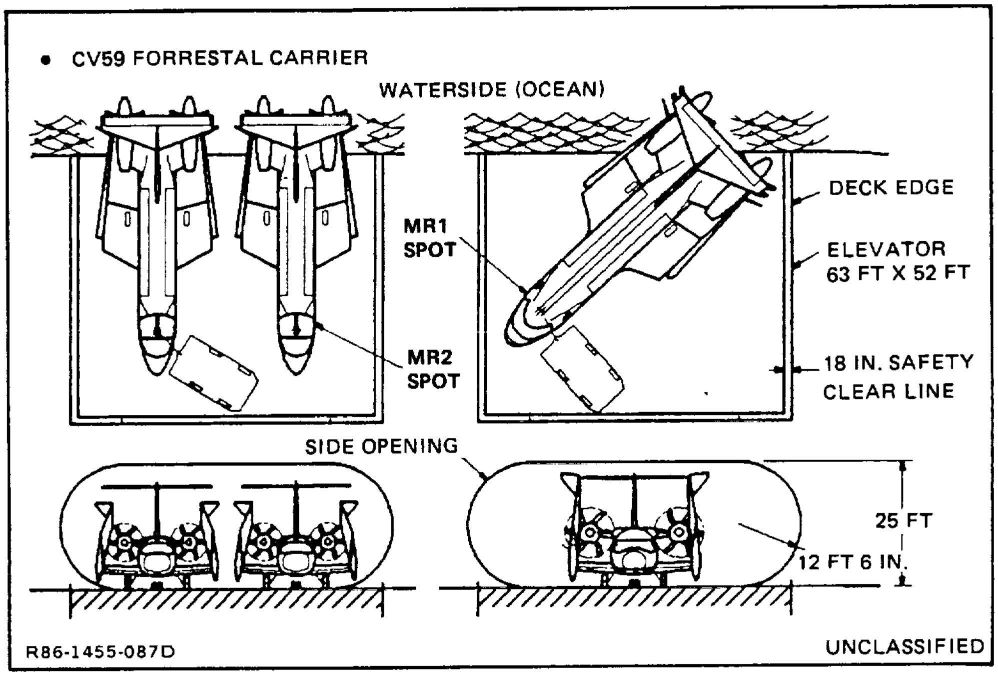

Fig. 82 Elevator & Hangar Deck Clearances

hangar deck entrance geometry and the elevator size. Both MR1 and MR2 designs meet the 25 ft height limit. Two MR2 aircraft may be elevated simultaneously (without a full fuel load) while only one MR1 aircraft may be elevated. The two MR2 aircraft would be subsequently "topped-off" upon reaching the flight deck. The 18 in. clearance requirement to all structure is achieved but may require the aircraft to hang over the elevator edge.

9 - ENGINE SELECTION

The primary objective of this study was to identify the benefits of a propfan propulsion system when compared to a turbofan engine for an MPSNA vehicle. The engine concepts were optimized to provide the best comparison. Installed propulsion data were generated with consistent installation factors for each of the concepts of interest for a MPSNA application. The preferred installation and configuration were selected for a propfan and a turbofan during this propulsion screening process.

9.1 PROPFAN TRADE STUDIES

Propfan engines from P&WA, Hartford, were used to ensure a consistent design philosophy with regard to performance, weight and technology levels. The one exception was inclusion of the GE UDF in this study. As this power plant is to be flight-tested as early as 1987, with possible commercial production, it is a technology that should be studied as a candidate for a subsonic Navy vehicle.

Engine data from the manufacturer were used to perform a sequence of propfan optimization, configuration, and installation trades. During this phase of analysis, both the single and counter-rotating configurations were optimized for diameter and tip speed. The configuration with the best figures of merit were carried to the pusher vs tractor trade.

9.1.1 Optimum Geared Propfan Configuration Selection

Proper sizing of the counter-rotation pusher propfan engine and MR1 aircraft resulted from optimization of this propulsion system in the critical MIW role. Optimization parameters included prop tip speeds of 700 to 750 ft/sec and diameters of 10.1 to 13.6 ft at the baseline engine class of 10,000 horsepower. This corresponds to a sea level static power loading range of 103 to 53 SHP/d^2.

Figure 83 shows the effect of variations in tip speed and diameter on the Figures of Merit (FOM), in percent of TOGW, engine size, and fuel burned. The FOM were relatively insensitive to variations in tip speed but highly sensitive to diameter, essentially power loading.

The classical inverse relationship between static thrust per input horsepower and power loading is reflected by the trend of increasing F^* (sea level, static, uninstalled maximum thrust) with decreasing power loading. High static thrust is secondary to high thrust at the MIW engine sizing condition off 500 KTAS at sea level. Figure 84 shows that large diameter, lower loaded propfans, though they develop high static thrust, have poorer thrust lapse characteristics with airspeed than smaller diameter propfans. This results in a higher thrust loaded aircraft (total aircraft thrust to aircraft TOGW ratio) to meet the

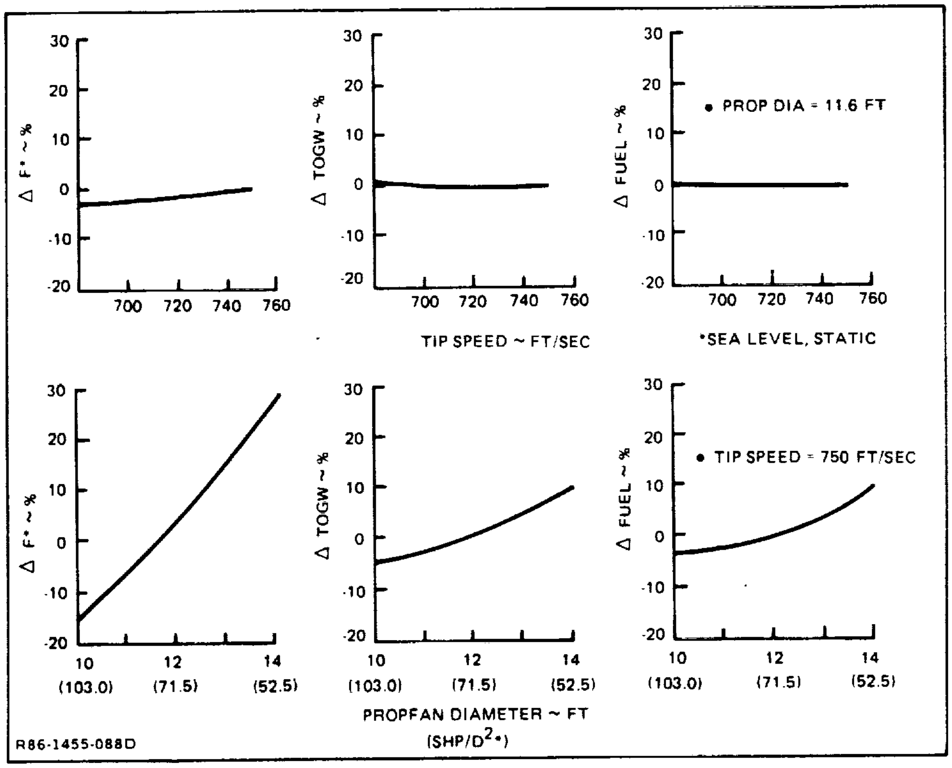

Fig. 83 Counter Rotation Pusher Optimization – MIW Role

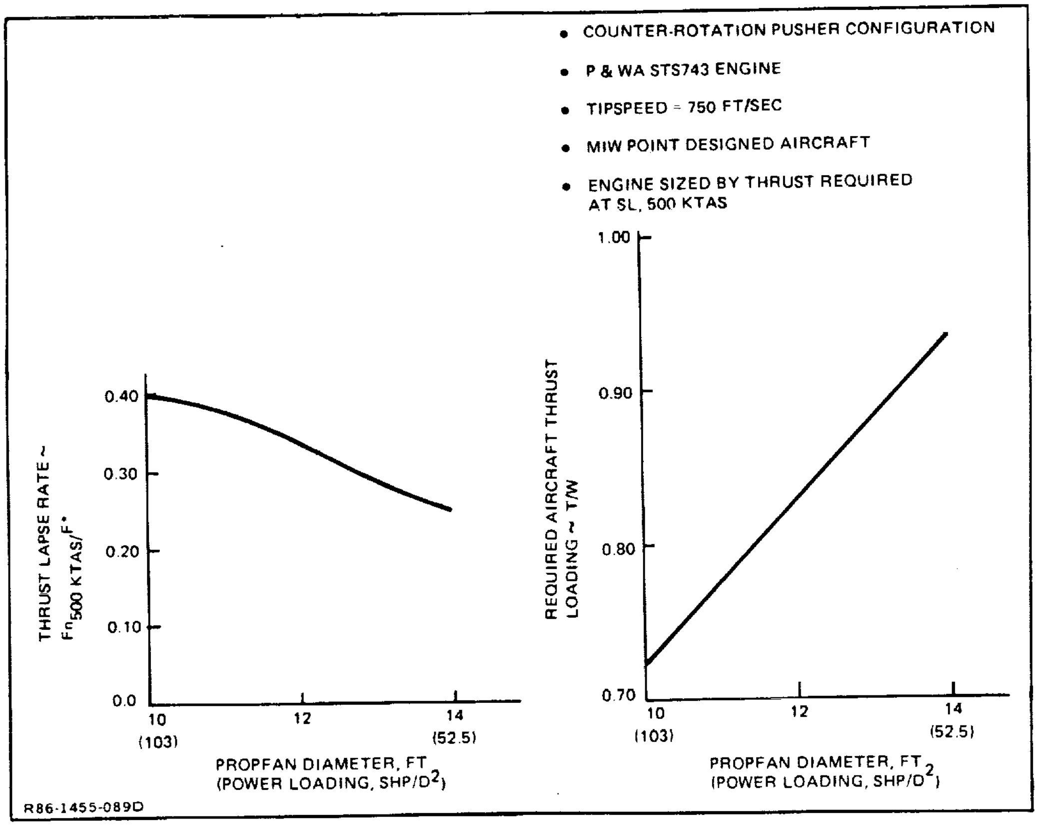

Fig. 84 Effect of Thrust Lapse Rate on Required Engine Size – MIW Role

design requirement for high diameter propfans. This required engine upsizing results in a trend of increasing iterated aircraft weight and fuel burned with increasing prop diameter. The optimum configuration shown is a highly loaded propfan, 102 SHP/d^2, with a tip speed of 750 ft/sec.

A similar optimization was done for the MR1 single-rotation tractor propfan configuration. The optimization variables used were tip speeds of 700 to 800 ft/sec and diameters of 12 to 15 ft or power loadings of 74 to 42. Trends with tip speed for the single-rotation system in the MIW role, shown in Fig. 85, are similar to the counter-rotation system. A high power loading (74 SHP/d^2) minimizes the FOM, with tip speed having little effect. A tip speed of 800 ft/sec was chosen for further study.

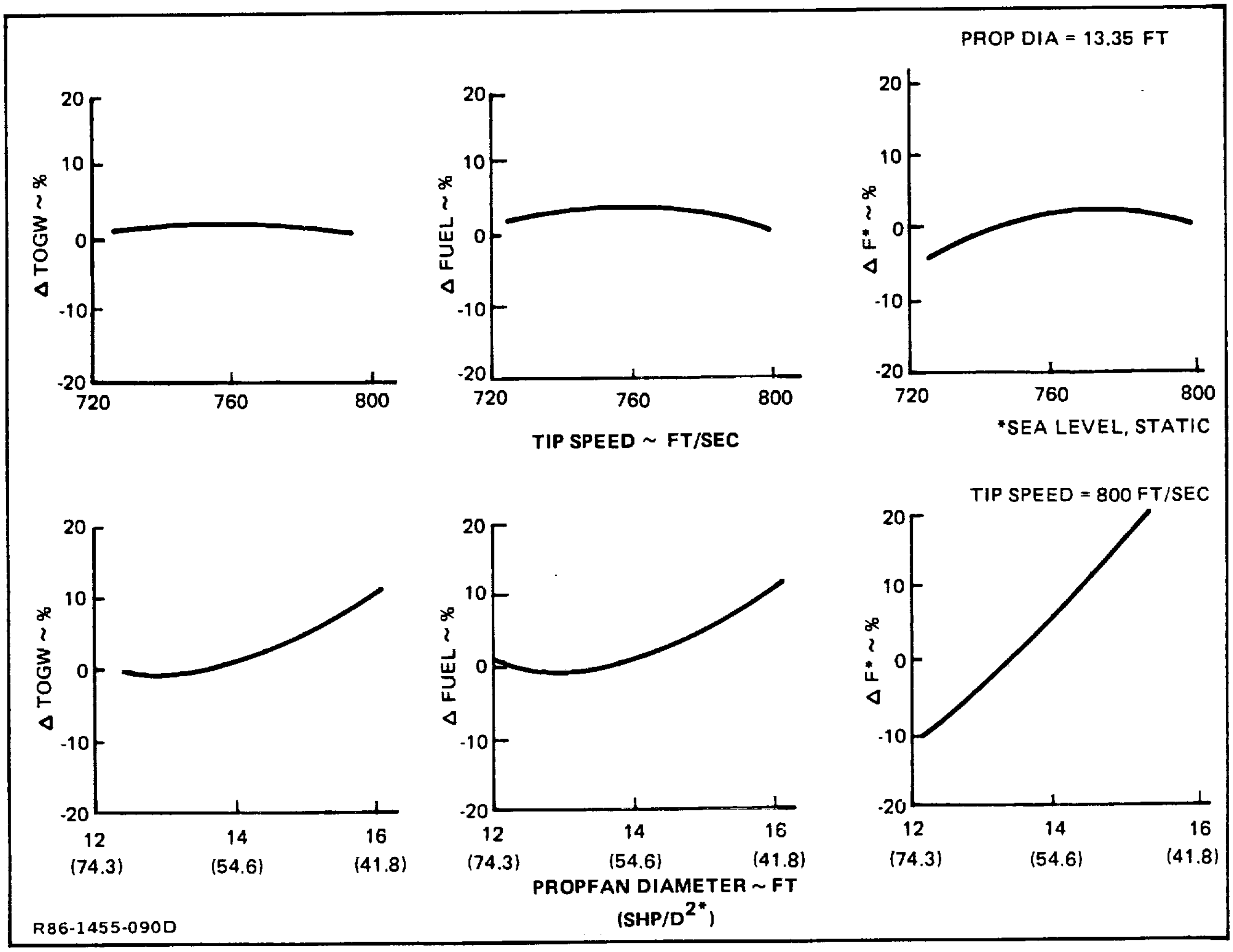

Fig. 85 Single Rotation Tractor Optimization — MIW Role

The engine for the MR2 vehicle is sized by requirements of the Surveillance mission as discussed in Subsection 5.4.1. To minimize the thrust required in the common vehicle, the power plant was optimized in the sizing role. The results (Fig. 86) are similar to the MR1 optimization where high power loadings are preferred and tip speed is insensitive. Single-rotation trends, shown in Fig. 87, follow those of the counter-rotation system in the Surveillance role.

Figure 88 reflects the comparison of an optimized single-rotation, wing-mounted tractor and an optimized counter-rotation, aft-mounted pusher. Shown is the penalty in the three FOM due to the single-rotation system using the counter-rotation propfan as the baseline. It is clear that the counter-rotation pusher is a more appropriate concept for an MPSNA application using fuel burned and engine thrust size as FOM. TOGW is not as clear a discriminator in this comparison.

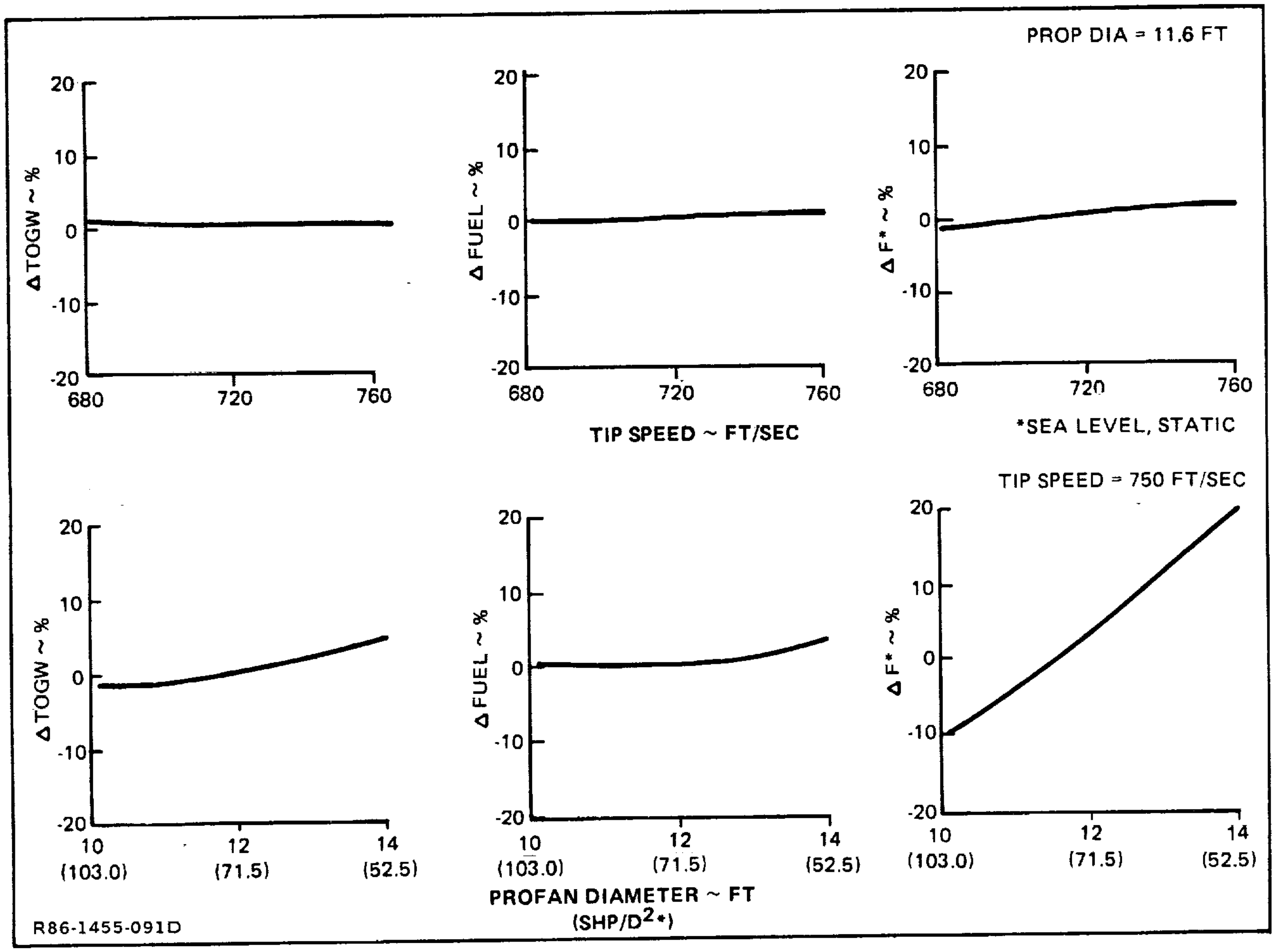

Fig. 86 Counter Rotation Pusher Optimization – Surveillance Role

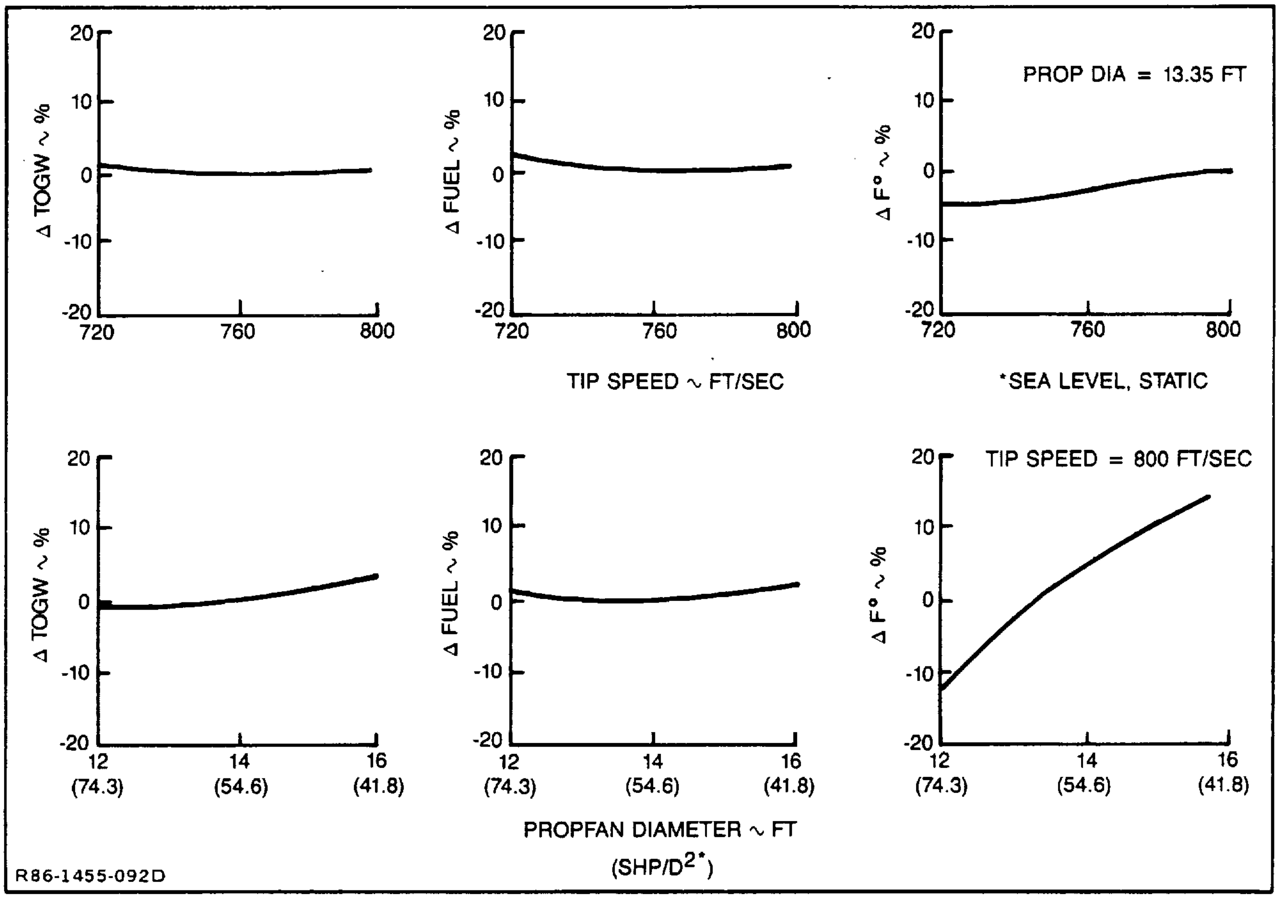

Fig. 87 Single Rotation Tractor Optimization - Surveillance Role

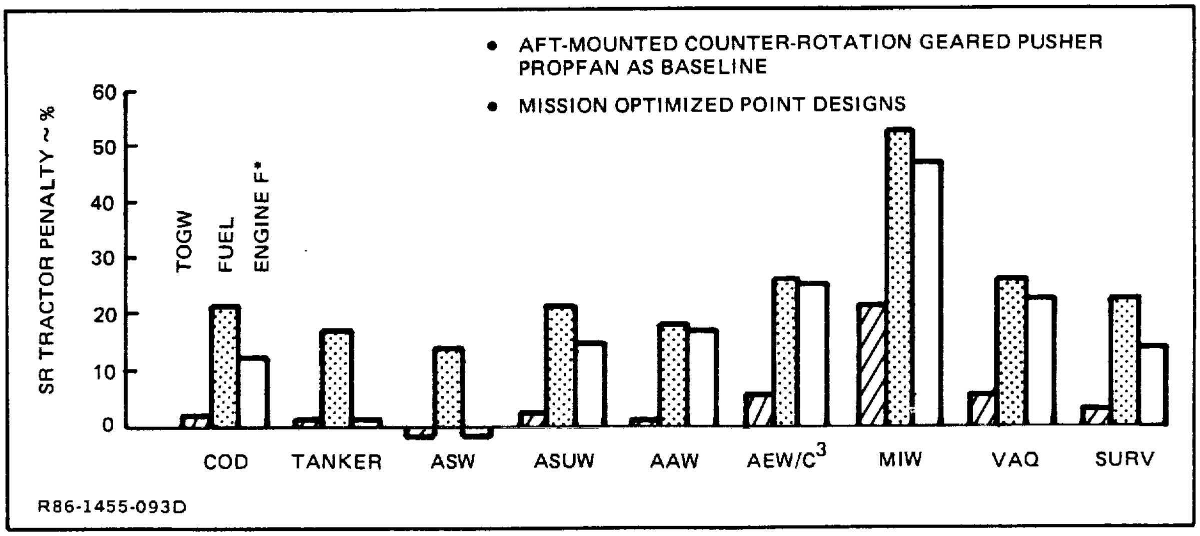

Fig. 88 Counter Rotation Pusher vs Single Rotation Tractor

The penalty incurred by the tractor aircraft can be attributed to four parameters. These parameters in the AEW role are shown in Fig. 89 and 90. The better SFC characteristics of the counter-rotation propfan are due primarily to the swirl recovery of the second row of blades. The 12% increased SFC results in a 26% increase in fuel burned for the tractor system. The pusher system has

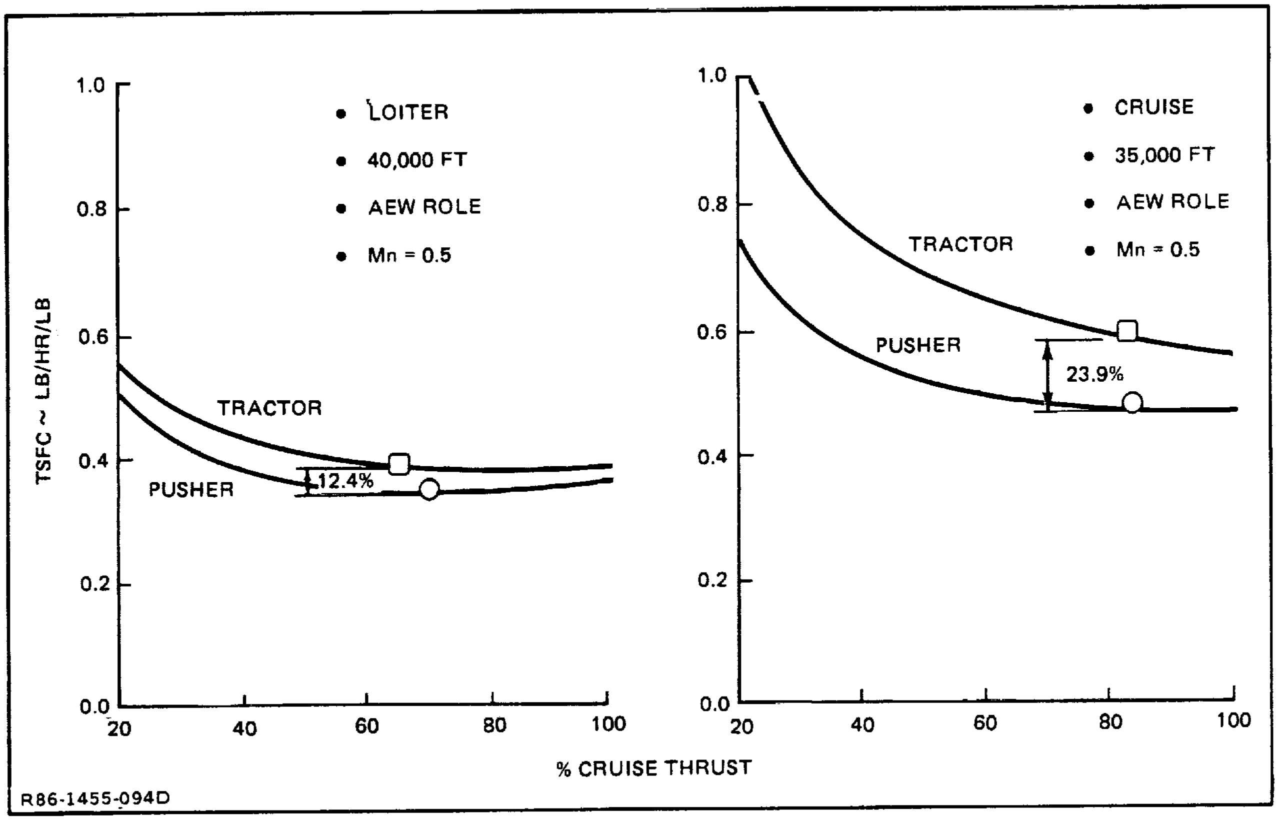

Fig. 89 Pusher & Tractor SFC Comparison

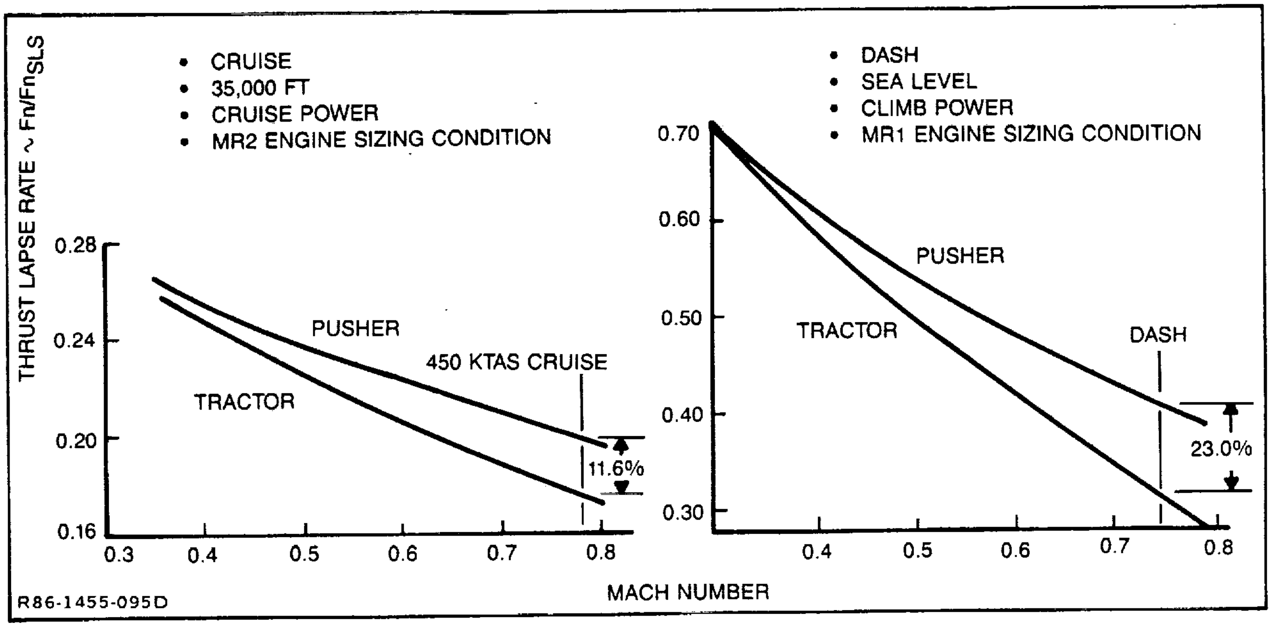

Fig. 90 Pusher & Tractor Thrust Lapse Rate Comparison

more thrust available at the engine sizing condition and a better lapse rate, resulting in an engine thrust size 25% smaller than the tractor. Counterbalancing the better SFC and lapse rate of the pusher is the 17% higher thrust-to-weight ratio of the single-rotation system. In addition, the wing-mounted tractor benefits from some wing load alleviation, greater in high aspect ratio configurations like AEW, resulting in an incremental structural weight decrease over an aft-mounted engine. These two characteristics, higher T/W and wing load alleviation, lessen the impact of fuel and engine size on TOGW resulting in a 5% weight growth of the tractor over the pusher for the AEW configuration, as seen in Fig. 87. The study continued to the geared vs ungeared systems with the counter-rotation pusher as the preferred geared propfan configuration.

9.1.2 Geared vs Ungeared Propfans

P&WA Hartford engines were used in this study for consistency. Their engine candidates did not include an ungeared system, which is of interest. A trade study was conducted using the P&WA optimum geared propfan and the GE UDF engine, even though it is always difficult to compare results using different engine manufacturers' data.

Several adjustments were made to the GE-provided UDF engine data for comparison to the P&WA engine data. These adjustments included:

- Addition of Grumman estimated spillage drag, (GE assumed spillage drag was equal to zero)
- Addition of losses for horsepower extraction (76 HP per engine) and customer bleed (3.8% of core flow)
- Development of geometric and weight scaling laws based on three discrete UDF engine sizes (P&WA provided scaling curves). Geometric scaling relationships are necessary to accurately calculate nacelle-wetted area for drag estimation. Determination of weight scalers resulted from a detailed accounting of geometrically scalable (inlet anti-ice, hydraulic pump and lines, mounts, etc) and non-scalable (generator, pneumatic starter, fuel lines, etc) engine components. These engine scaling laws ensured accurate weight and drag estimates at the iterated aircraft design sizes.

The UDF shows some penalty in fuel burned when compared to the P&WA geared system, as seen in Fig. 91. With the exception of the MIW role, no significant conclusion can be drawn on the basis of TOGW or engine size. The high OPR of the UDF (design OPR=44) results in a burner pressure limit cutback at the MIW design condition which in turn oversizes the engine to meet this requirement. A lower OPR engine (OPR=28) like the P&WA propfan configuration is more suitable for this low level dash mission. The study continued to the propfan vs turbofan comparison with the counter-rotation pusher as the optimum propfan configuration.

9.2 TURBOFAN TRADE STUDIES

The turbofan candidate received from Pratt & Whitney, Hartford was used in this study for consistency. This point design engine has a fixed cycle with a Bypass Ratio (BPR) of 7:1 and an Overall Pressure Ratio (OPR) of 37:1. A Pratt & Whitney parametric deck from the military division in Florida was utilized to determine the applicability of this engine cycle for MPSNA. Both BPR and OPR

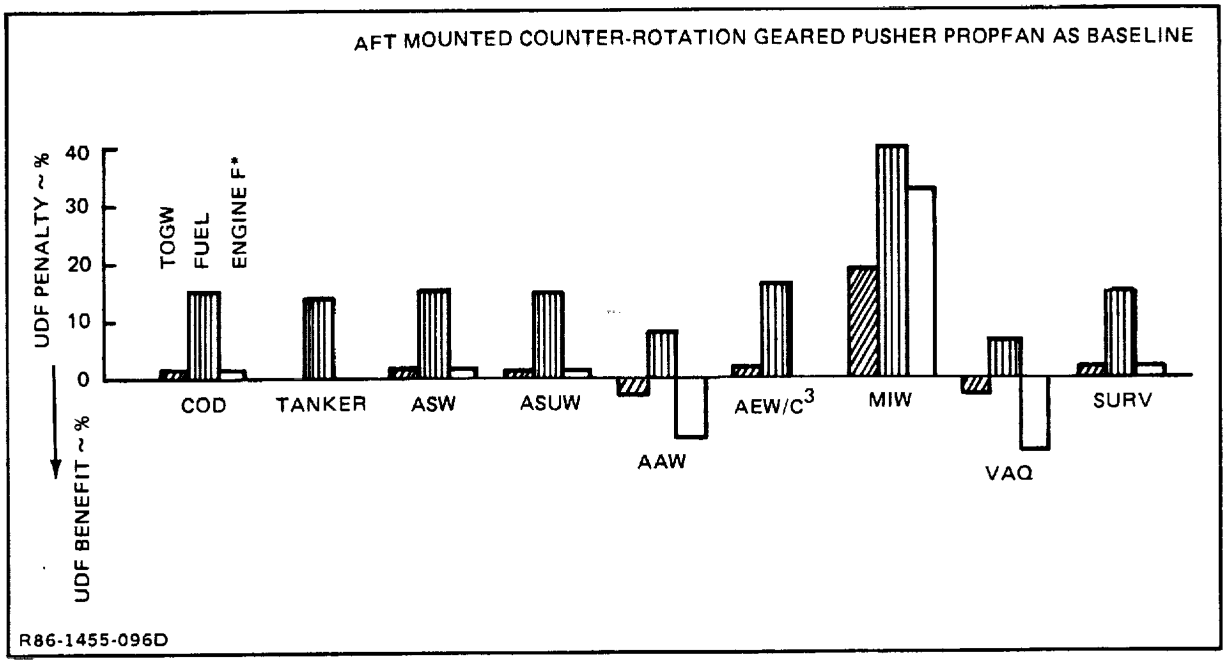

Fig. 91 Geared Propfan vs UDF

were investigated with engine operating temperature held at the Hartford deck levels as a measure of technology. In addition, an analysis using this parametric deck indicated that rescheduling of the Hartford engines could result in a better requirements/propulsion system match.

9.2.1 Cycle Analysis

The design missions were broken into three groups determined by engine sizing condition. The engine sizing conditions and missions associated with each are summarized in Fig. 92. The cycle trends with the FOM are shown in

CONDITION	MISSIONS
• SEA LEVEL DASH • HIGH SPEED CRUISE	MIW AEW SURV ASUW AAW VAQ C^3
• SINGLE ENGINE RATE OF CLIMB	COD TANKER ASW

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Fig. 92 Engine Sizing Conditions

Fig. 93 through 95. In missions with no speed requirement (COD, Tanker, and ASW), the FOM are insensitive to BPR variations between 4:1 and 7:1, with a high OPR of 35 minimizing TOGW, engine size and fuel burned. The lower SFC of a 7 BPR engine is countered by its increased drag causing the flattening of the curve between BPRs 4 and 7. Six of the ten design missions contain a high speed cruise requirement. The same insensitivity to BPR is seen in this group of missions with the speed requirement driving the OPR bucket to lower values,

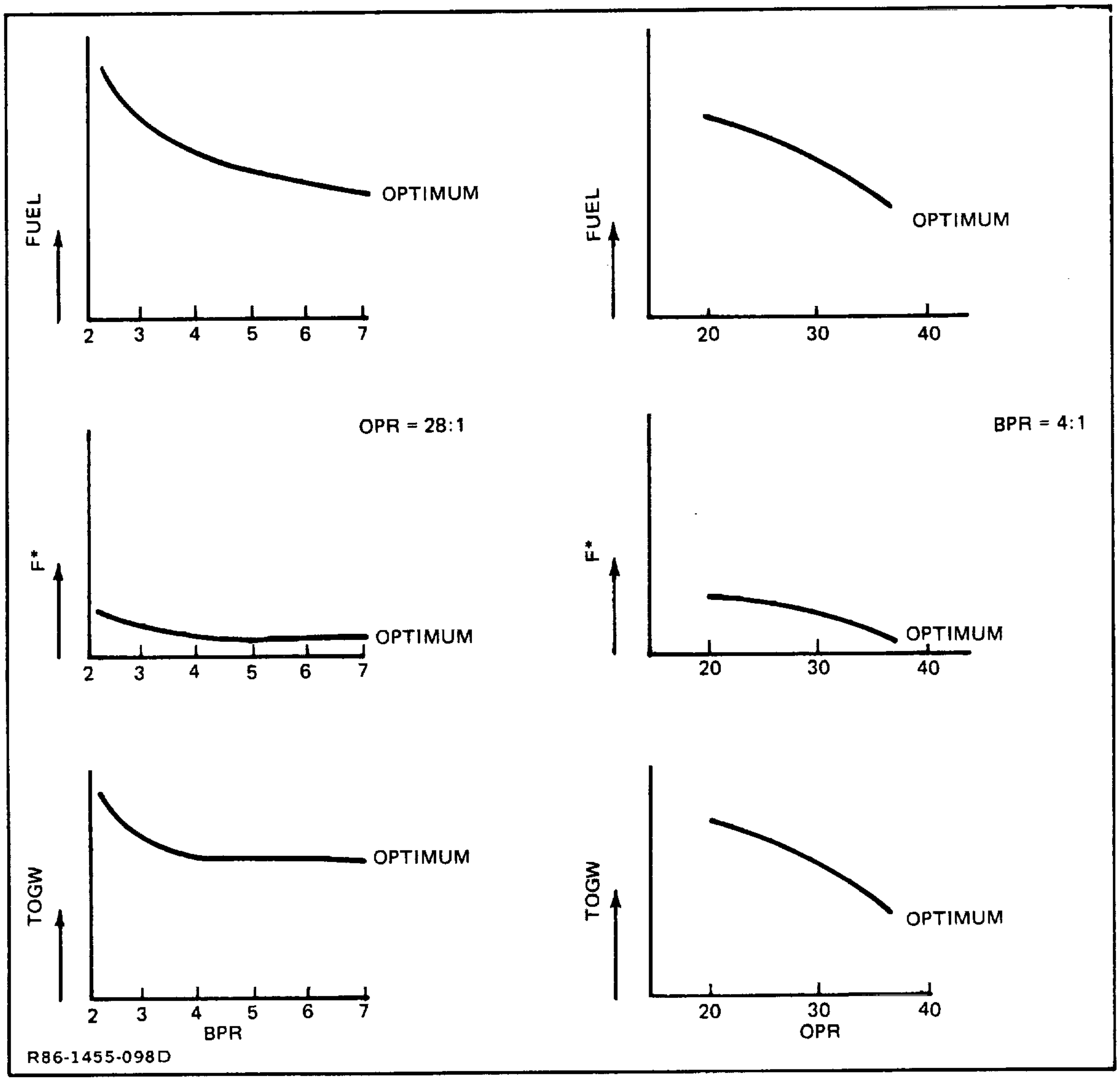

Fig. 93 Turbofan Cycle Optimization: No Speed Requirement Missions

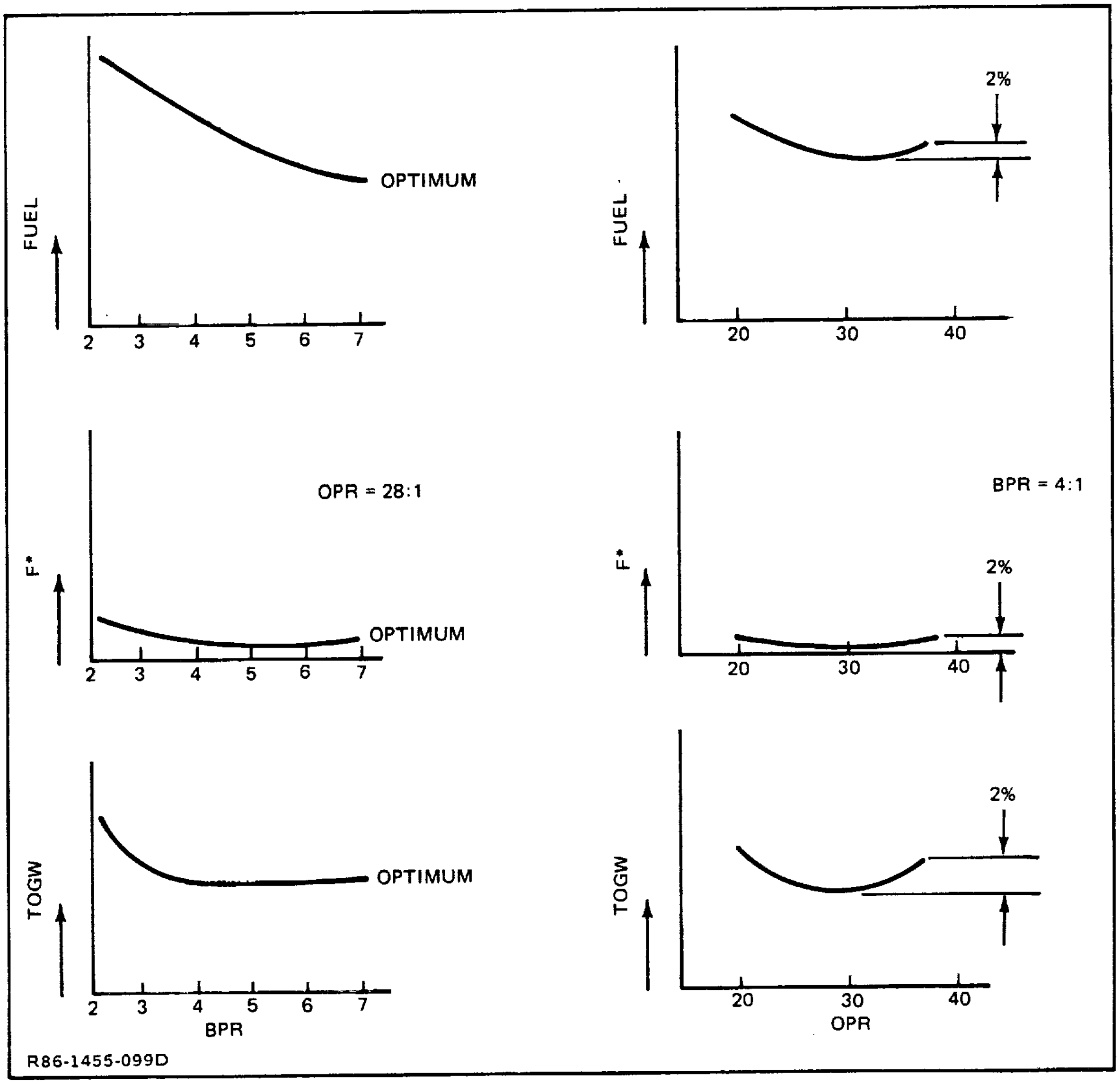

Fig. 94 Turbofan Cycle Optimization: Cruise Speed Requirement Missions

between 28:1 and 30:1. The MIW mission, with its 500 KTAS, sea level dash requirement, has cycle trends significantly different than the others. In this case a minimum BPR between 2 and 4 is preferred, along with a moderate OPR between 20:1 and 25:1. High BPR engines, although fuel efficient, have high drag at high speed and lapse faster with Mach number than do lower BPR turbofans. High OPR engines require a cutback to maintain acceptable levels of burner pressure in the high q environment and engine oversizing ensues. This cutback occurs at higher Mach numbers with engines of moderate OPR.

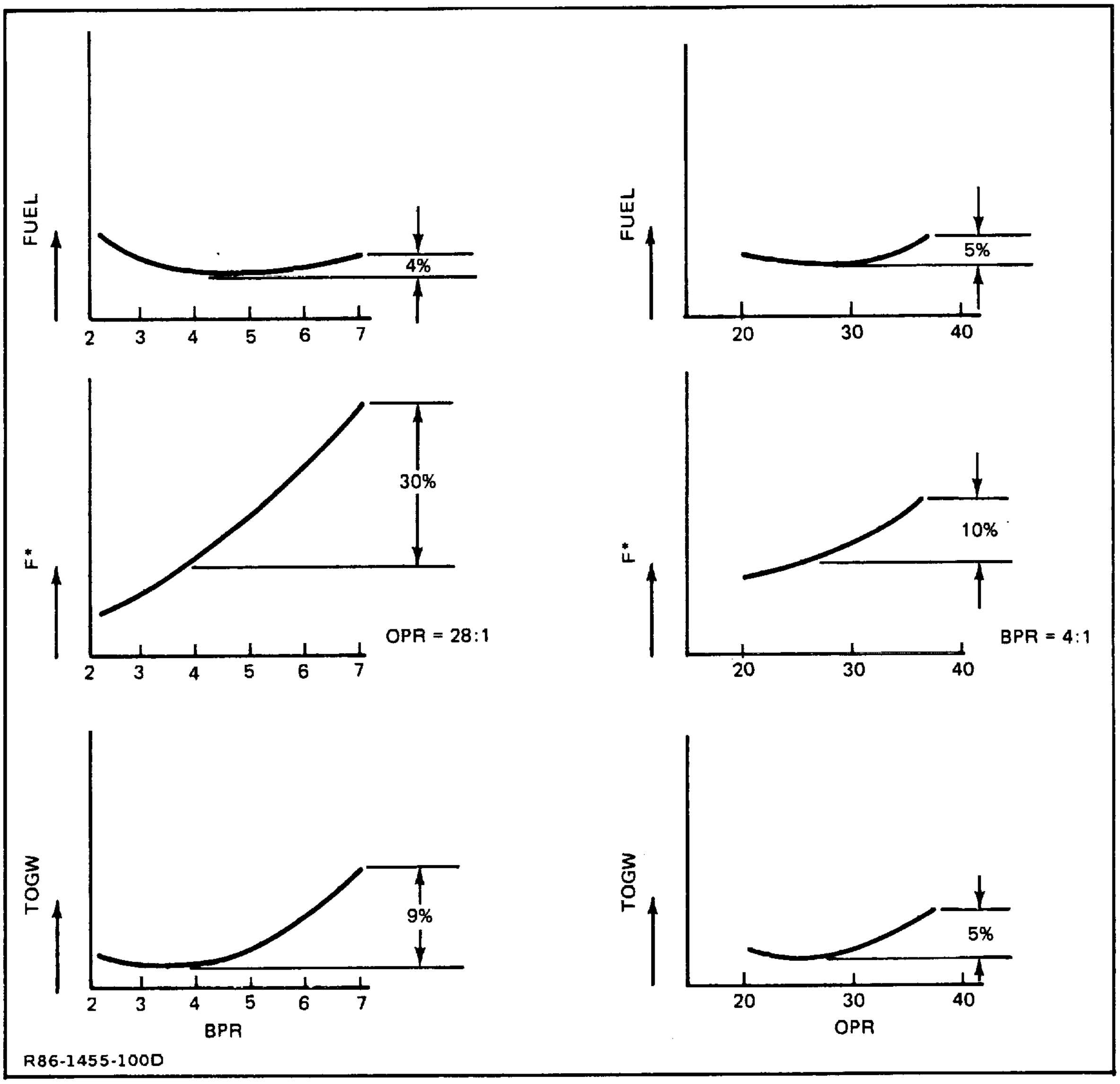

Fig. 95 Turbofan Cycle Optimization: Low Altitude Dash Mission

The optimum cycle parameters for the ten MPSNA design missions are shown in Fig. 96. The point design turbofan with a BPR of 7:1 and OPR of 37 is an appropriate cycle for nine of the ten design missions. The optimum BPR for the MR1 aircraft, where MIW requirements size the engine, is 4:1 or less. The resulting penalty of the off-optimum BPR point design on TOGW is 9% and on engine size is 30%. The high OPR of this fixed cycle turbofan penalizes the engine size by 10% and aircraft TOGW by 5%. Propfan aircraft were found to be 10% lighter than turbofan aircraft in MR1 designs. Results of this cycle analysis suggest that optimization of the turbofan cycle parameters could improve performance and reduce TOGWs by as much as 10%. This indicates that a fair MR1 comparison would show little difference in the FOM between propfans and turbofans. This comparison could be done when additional turbofan data becomes

MIW DASH REQUIREMENT	LONG LOITER & CRUISE REQUIREMENTS
• MODERATE BPR 2-4	• HIGH BPR 4-7
• MODERATE OPR 20-25	• HIGH OPR 30-35
• 1 MISSION	• 9 MISSIONS

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Fig. 96 Point Design Turbofan Evaluation

available with optimization of power loading and tip speed available with the current propfan decks. As the MIW dash speed is not a MR2 constraint, but rather a fallout, selection of this fixed-cycle turbofan design does not affect the validity of MR2 study conclusions.

9.2.2 Engine Scheduling Analysis

A result of cycle investigations using the Florida parametric deck was that the rating, scheduling and design philosophies of this Pratt & Whitney turbofan engine are different from those of the Hartford point design turbofan. Hartford propfan and turbofan engines were used for consistency throughout the study. The Florida-generated deck has some characteristics that could be used in further studies of this nature to better match MPSNA type mission requirements.

The ten design missions were broken into three groups by engine sizing condition. The MIW sizing condition is the 500 KTAS sea level dash. The engine control parameters, corrected engine speed $(N/\ \theta)$, corrected airflow $(W_a\ \sqrt{\theta/\delta})$, and engine temperature, and the resulting thrust are shown in Fig. 97 and 98 for the Hartford and Florida engines respectively. The Hartford engine is derated in operating temperature on a standard day, where mission performance is estimated, resulting in flat-rated thrust. The Florida turbofan develops full temperature and power on a standard day resulting in a smaller engine than one that is derated at the engine design point. It should be noted that this operating condition in the MIW role sizes the power plant for all MR1 designs.

Six of the ten design missions have high speed cruise as their engine sizing criteria. The lapse with Mach number of both turbofans at cruise altitude is shown in Fig. 99 and 100. The Hartford engine is scheduled with corrected temperature with θ_{TAMB}, a constant value at any altitude. This results in a constant control temperature across the Mach range and a thrust lapse with increasing cruise speed follows. In the case of the Florida-designed turbofan, engine control temperature is held at constant corrected temperature with θ_{T2}, not ambient. This results in increased temperature and thrust available with Mach number. This engine has its design point closely matched to the aircraft design point requiring a minimum size propulsion system to satisfy mission requirements. If the Hartford engine was rescheduled with θ_{T2}, like the Florida engine, an increase in thrust at the design point is possible. This operating condition in the surveillance role sizes the power plant for all MR2 designs.

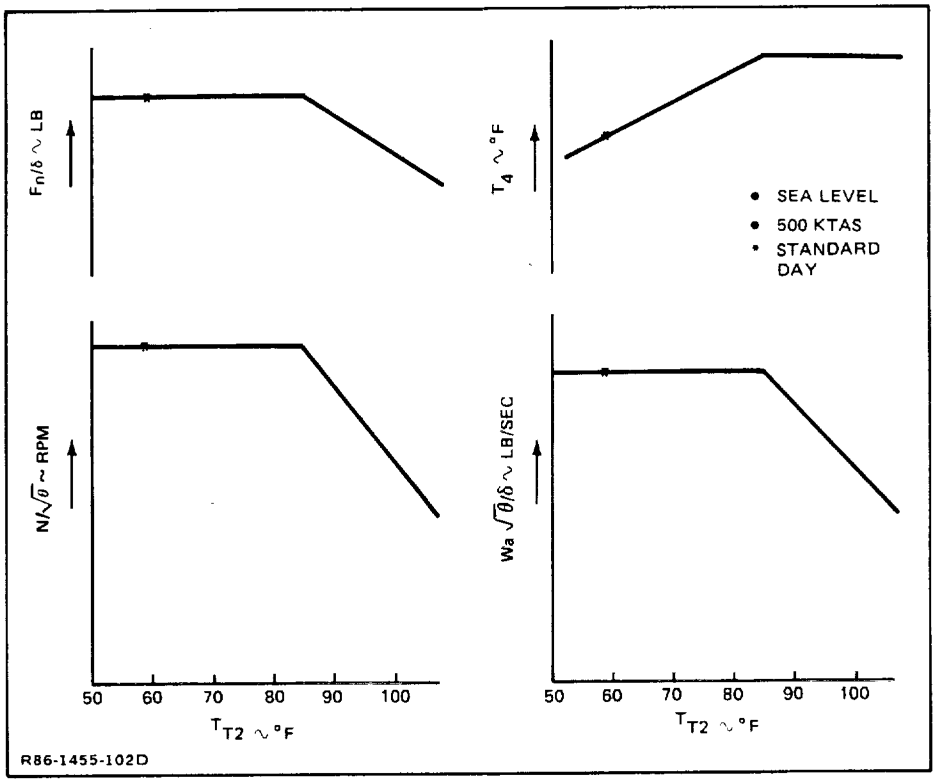

Fig. 97 Hartford Turbofan: MIW Engine Sizing Condition

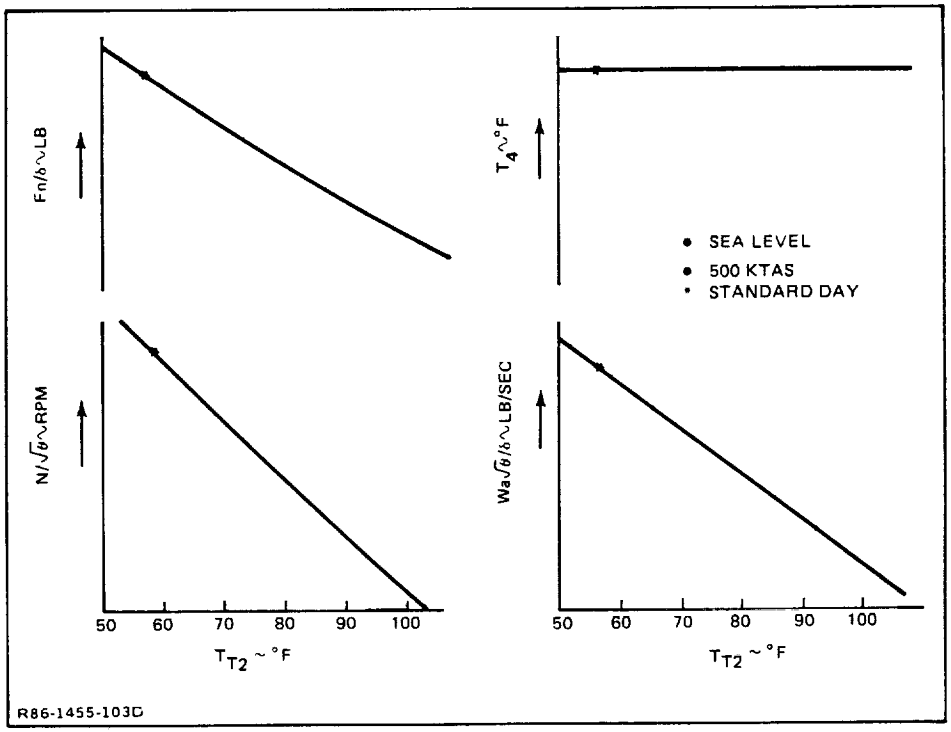

Fig. 98 Florida Turbofan: MIW Engine Sizing Condition

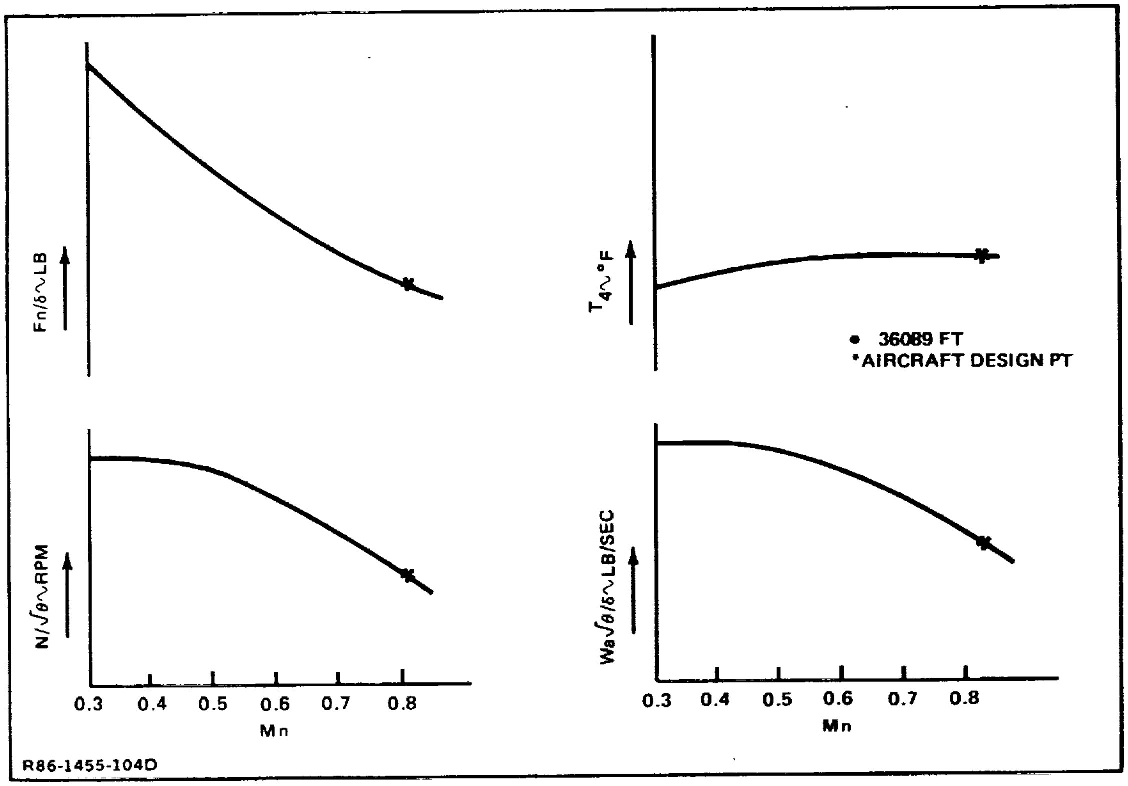

Fig. 99 Hartford Turbofan: High Speed Cruise Sizing Condition

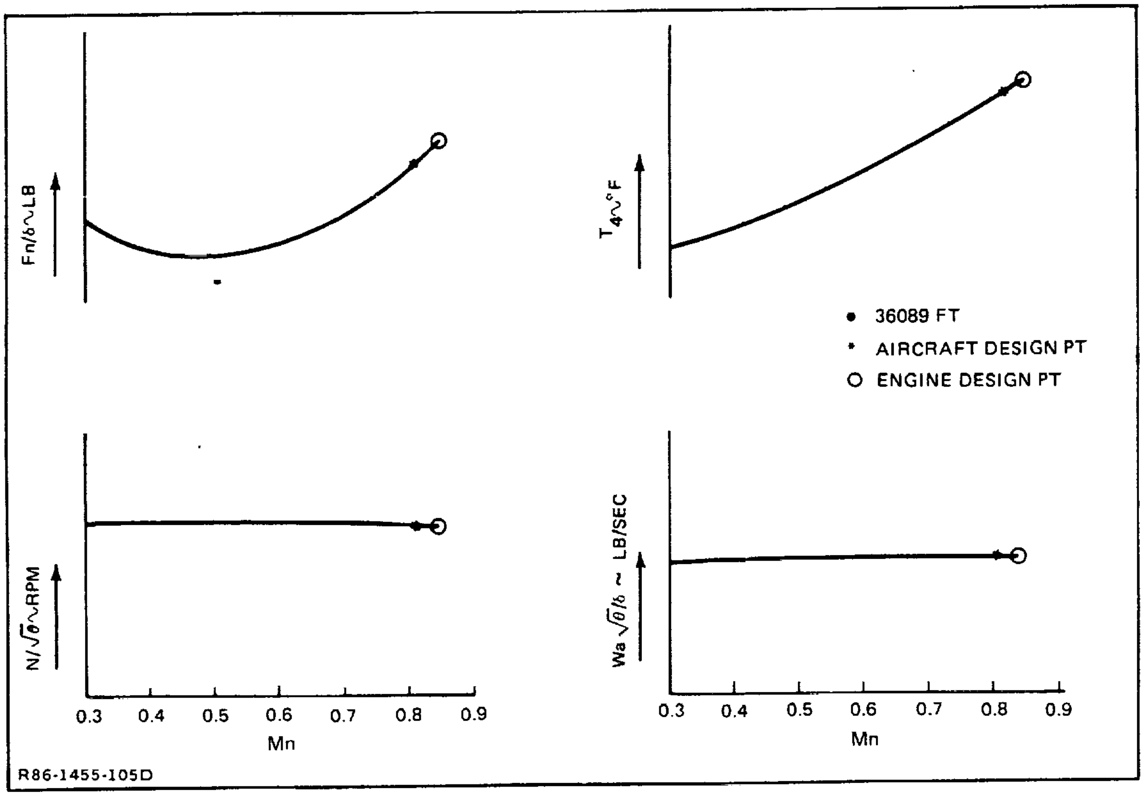

Fig. 100 Florida Turbofan: High Speed Cruise Sizing Condition

The three missions with no speed requirements are sized to meet Single Engine Rate-of-Climb (SERC). Figures 101 and 102 show the engine characteristics at this condition. The Hartford engine has its design point at sea level static on an off-standard day, (86°F), with flat-rated thrust at lower temperatures. The Florida engine develops maximum allowable combustor exit temperature on a standard day with no flat rating and normal thrust lapse with ambient temperature. The waveoff SERC requirement of 500 ft/min at tropical day conditions (90°F) may best be satisfied with flat-rated, sea level, static thrust.

The result of this analysis is a set of engine design requirements for an aircraft with MPSNA missions. A summary of these requirements and the characteristics of the P&WA Hartford engines is shown in Fig. 103. All scheduling requirements may not be met simultaneously; however, the engines could be redesigned to be more compatible with the requirements resulting in a better

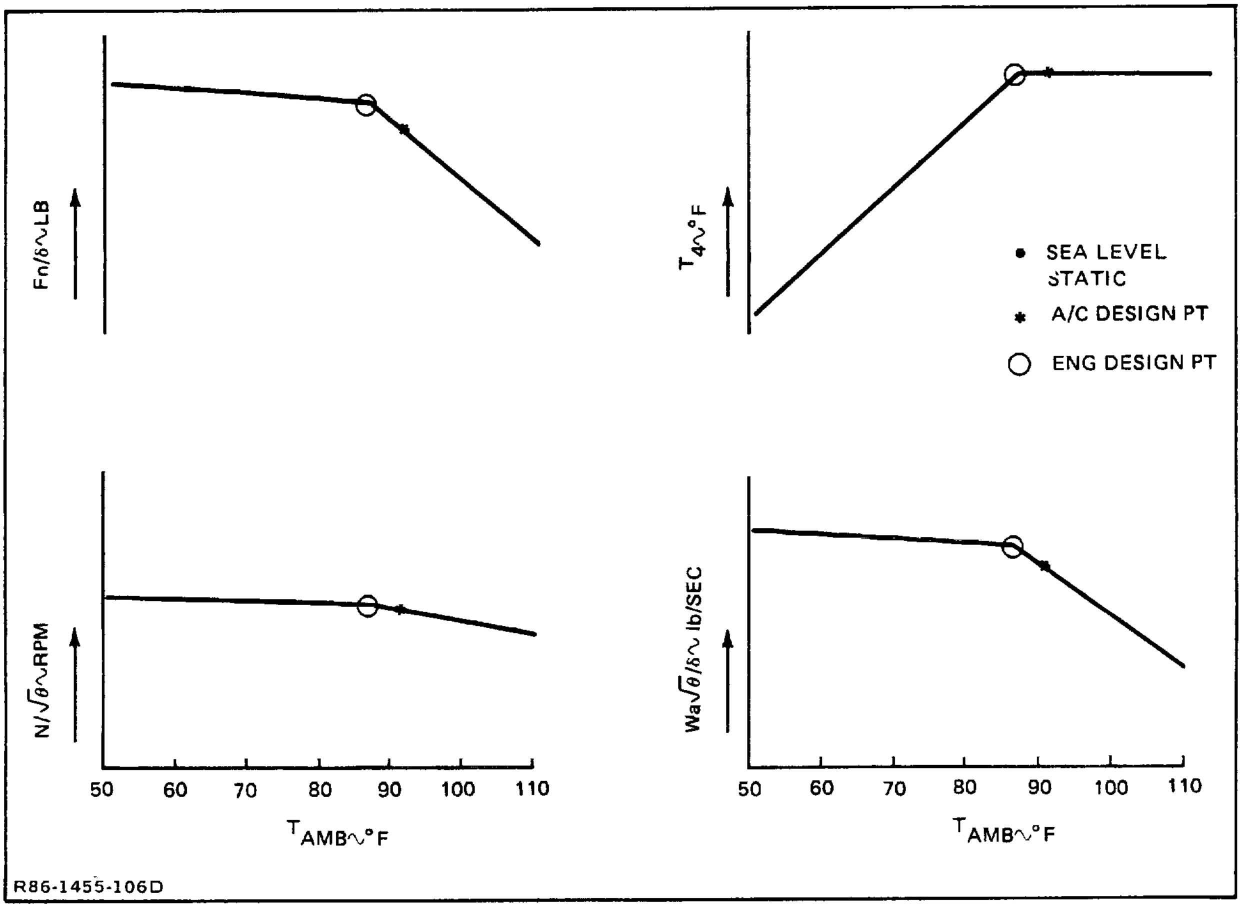

Fig. 101 Hartford Turbofan: SERC Sizing Condition

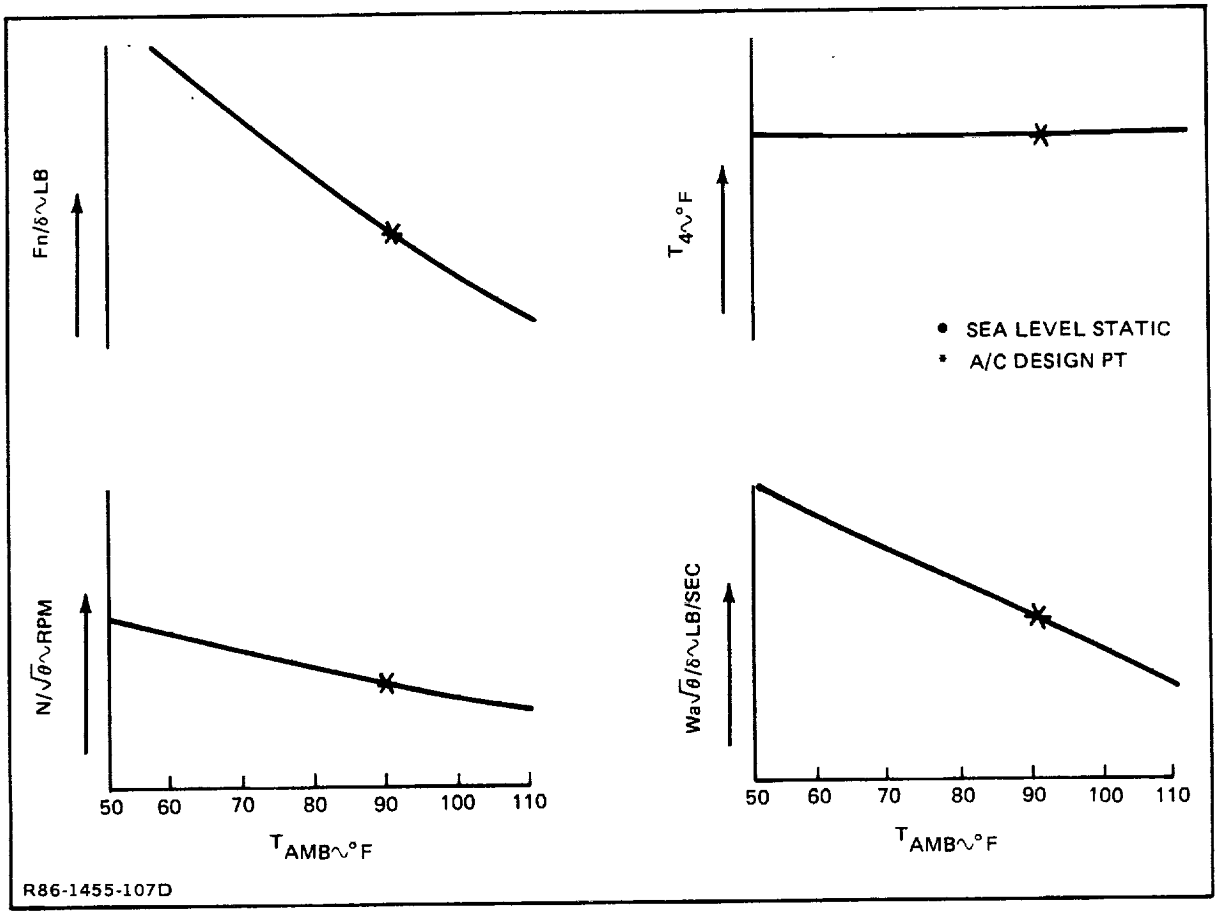

Fig. 102 Florida Turbofan: SERC Sizing Condition

REQUIREMENTS	P& WA HARTFORD ENGINES
• HIGH STANDARD DAY Fn AT SEA LEVEL DASH	• FLAT RATED Fn AT SEA LEVEL DASH
• DESIGN POINT AT CRUISE CONDITIONS	• DESIGN POINT AT SEA LEVEL TAKEOFF ON TROPICAL DAY
• MACH NUMBER BIAS AT CRUISE ALTITUDE	• DECREASING Fn WITH MACH NUMBER AT CRUISE ALTITUDE
• FLAT RATED Fn AT TAKEOFF	• FLAT RATED Fn AT TAKEOFF

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Fig. 103 MPSNA Engine Design Requirements engine/airframe match with the smallest power plant and vehicle possible. An example of a potential benefit of this rescheduling is shown in Fig. 104. If the Hartford engines, turbofans or propfans, were rescheduled and the design point was moved to high speed cruise, the engine size required could be 3% to 30% less with a resulting 3% to 14% decrease in aircraft size, depending on mission role. The three aircraft sized by SERC show the least benefit, as this constraint most closely matches the Hartford design.

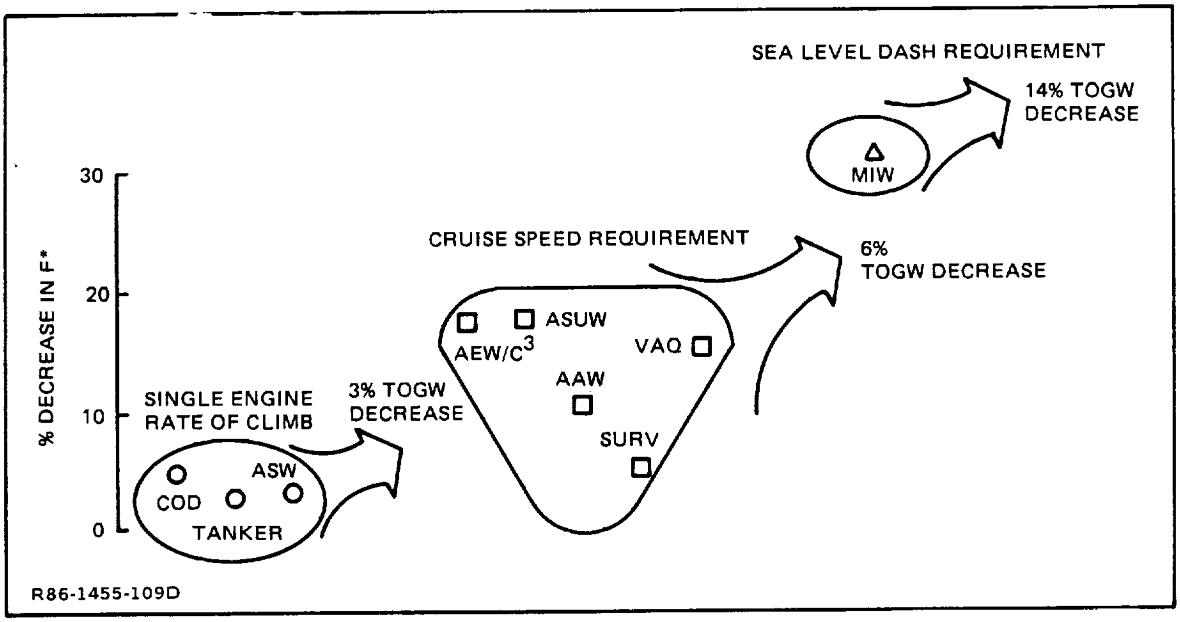

Fig. 104 Benefit of Design Point Rescheduling

10 - CTOL DESIGN RESULTS

10.1 PROPULSION RESULTS

Propfan MR1 and MR2 designs require 6% to 11% smaller engines than the turbofan designs. The better thrust lapse rate and higher thrust-to-weight ratio of the turbofan engines for both MR1 and MR2 are overridden by their higher SFC characteristics.

10.1.1 Selection Drivers

Several engine characteristics affect mission fuel required, thrust required, and resultant aircraft size to meet the mission requirements. These characteristics include SFC thrust lapse rate and engine thrust-to-weight ratio.

Figure 105 shows a comparison of SFC for the MR1 and MR2 propfan and turbofan aircraft during typically high fuel burn mission legs, cruise and loiter. The SFC of the turbofan engine is 40% to 45% higher than the propfan engine for both MR1 and MR2. This is reflected in a 50% to 60% higher fuel load for the turbofan MR1 and MR2 aircraft.

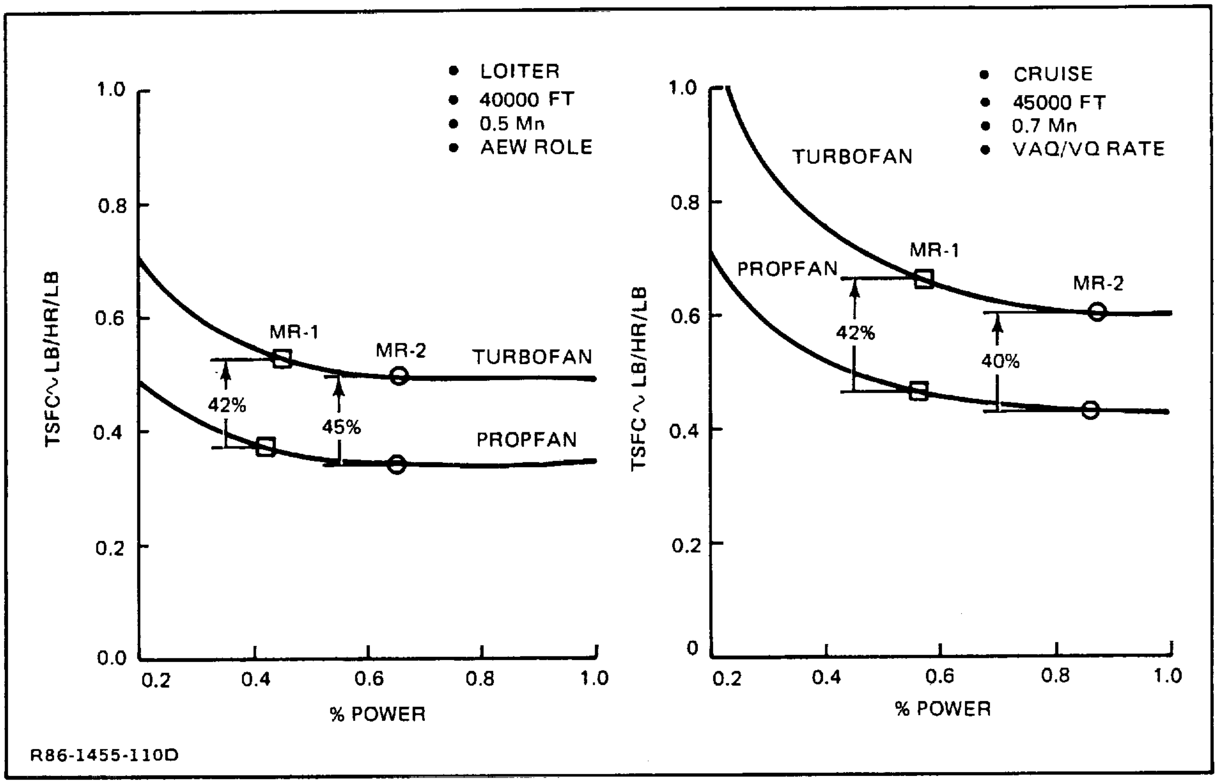

Fig. 105 Propfan & Turbofan SFC Comparison

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Thrust lapse rate, the ratio of thrust available at a given flight condition as compared to sea level static thrust, at the MR1 and MR2 engine sizing conditions is shown in Fig. 106. For both the MR1 and MR2 designs, the turbofans, with better thrust lapse rate characteristics, are better suited to high

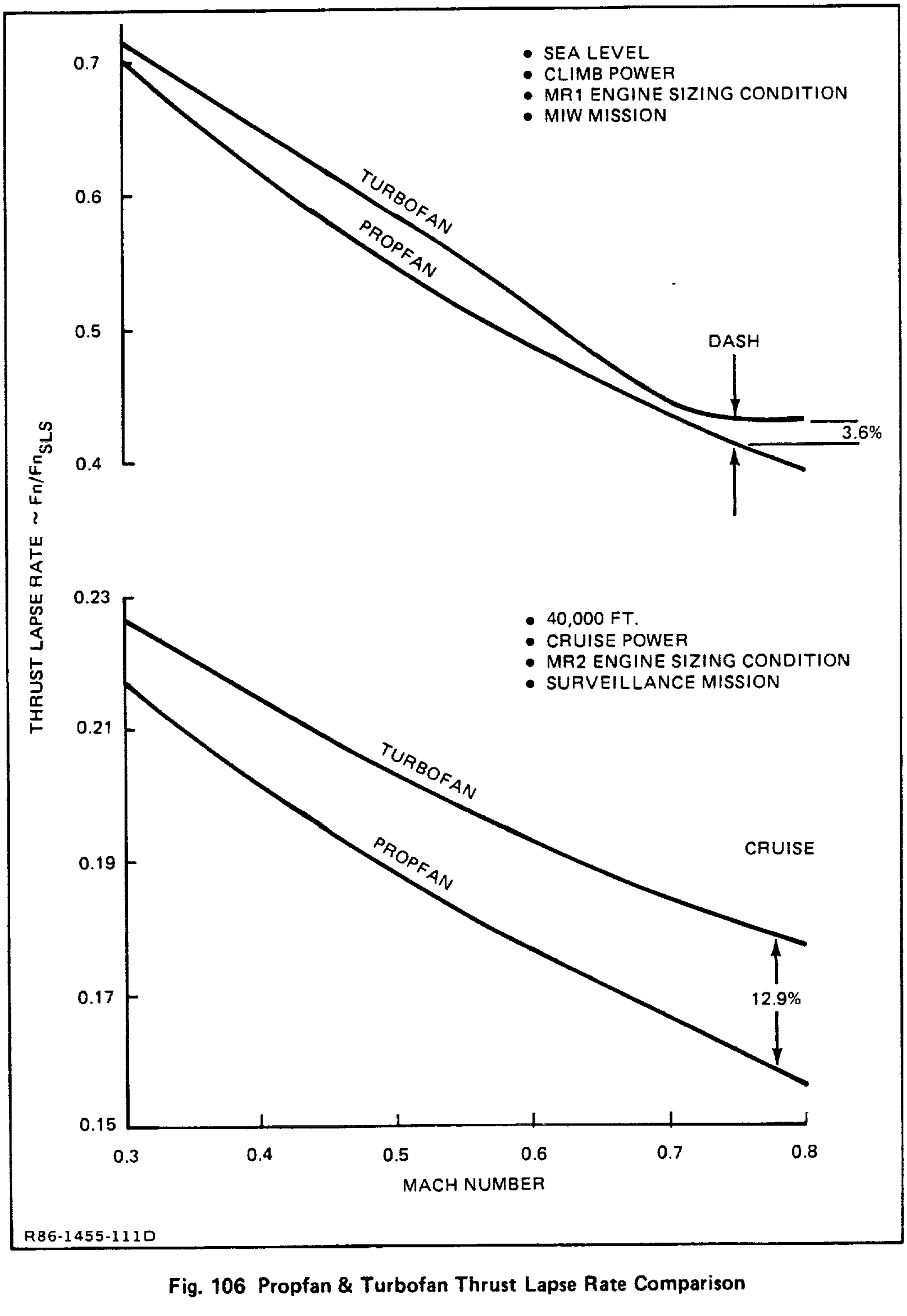

Fig. 106 Propfan & Turbofan Thrust Lapse Rate Comparison

speed cruise sizing constraints and require less upsizing to meet mission requirements for the same size aircraft. This helps to minimize the impact of the growth of the turbofan engine due to the increased fuel loads and overall aircraft growth. The iterated engine sizes of the turbofan MR1 and MR2 engines are 6% and 11% greater than the propfan engines. This growth is less than expected because the penalty, incurred by the turbofans due to their poorer SFCs is partially counter-balanced by their better lapse rate.

The other characteristic that influences aircraft size is engine thrust-to-weight ratio. Table 7 shows the thrust-to-weight ratio of the four MR1 and MR2 engines. The 24% to 33% higher T/W turbofan engines result in a lighter engine installation for a given engine size. This characteristic also helps to minimize overall aircraft growth.

Table 7 Engine Thrust-to-Weight Comparison

AIRCRAFT	ENGINE	T/W*	Δ T/W ~ %
MR1	PROPFAN	3.9	33
	TURBOFAN	5.2	
MR2	PROPFAN	3.7	24
	TURBOFAN	4.6	

*AT ITERATED AIRCRAFT TOGW
R86-1455-112D

10.1.2 Systems Summary

Table 8 summarizes the fully iterated MR1 and MR2 propulsion systems. Two conclusions can be drawn from these results. The first is that the thrust size of a propfan engine required to meet MR1 and MR2 requirements is 6% to 11% less than the corresponding turbofan, due primarily to its better SFC characteristics. The second conclusion is that the engine, whether propfan or turbofan, required for the MR2 aircraft is less than half the size required for MR1. This results from the reduction of mission requirements, specifically MIW dash speed and fuselage size for the COD.

Table 8 MR1 & MR2 Propulsion Systems Summary

	MR1		MR2	
	PROPFAN	TURBOFAN	PROPFAN	TURBOFAN
F*, LB	20000	21100	8888	9900
SHP, HP	11047	–	4910	–
PROP DIA, FT	10	–	7	–
PROPULSION SYSTEM WEIGHT[1], LB	5090	4090	2394	2150
T/W	3.9	5.2	3.7	4.6
TIP SPEED, FT/SEC	750	–	750	–

[1] EXCLUDES NACELLE WEIGHT
R86-1455-113D

10.2 AIRFRAME RESULTS

Weight estimates for the CTOL designs are based on a design philosophy where a high level of commonality was used to ensure multipurpose capability. These weight estimates indicate a 10% decrease in TOGW results from the good SFC characteristics of propfan engines.

10.2.1 Commonality Issues & Weight Estimating Criteria

The development of both MR1 and MR2 designs and accompanying detailed weight empty estimation, Tables 9 through 12 involves evaluation of the structure sizing criteria, development of propulsion system requirements and analysis of required subsystem capabilities. Grumman design philosophy for these future Navy support aircraft is to ensure a high level of commonality between variants, minimizing procurement, operation and support costs while retaining maximum mission effectiveness. The baseline structure and core systems were designed to meet the most critical and demanding mission requirements ensuring full multipurpose capability.

Weight estimates for each MPSNA design are based on Grumman Level II empirical weight estimating equations, preliminary structural assessment of unique design features and application of advanced composites and metallic technologies. These structural and material technology improvements are reflected in lower aircraft weight, improved performance, and/or reduced cost. Level II weight estimating methods, based on actual weight of production aircraft were developed in order to obtain accurate weights of new aircraft designs. These methods have been found to result in a standard deviation of 3.3% when actual and statistical empty weights are compared.

Table 9 MR1 Turbofan Weight Empty Summary (lb)

MISSION GROUP	COD	TANKER	VAQ/VQ	ASW	ASUW	MIW	SURV	AAW	C^3	AEW
WING	4,349	4,349	4,349	4,349	4,349	4,349	4,349	4,349	4,349	4,349
HORIZONTAL TAIL	684	684	684	684	684	684	684	684	684	684
VERTICAL TAIL	598	598	598	598	598	598	598	598	598	598
BODY	6,249	5,611	5,465	5,465	5,465	5,465	5,465	5,465	5,465	5,465
ALIGHTING GEAR	2,375	2,375	2,375	2,375	2,375	2,375	2,375	2,375	2,375	2,375
ENGINE SECTION/NACELLE	–	–	–	–	–	–	–	–	–	–
STRUCTURE SUBTOTAL	**14,255**	**13,617**	**13,471**	**13,471**	**13,471**	**13,471**	**13,471**	**13,471**	**13,471**	**13,471**
PROPULSION	(11,246)	(11,744)	(11,246)	(11,246)	(11,246)	(11,246)	(11,246)	(11,246)	(11,246)	(11,246)
ENGINE (INCLUDES NACELLE)	10,369	10,369	10,369	10,369	10,369	10,369	10,369	10,369	10,369	10,369
FUEL SYSTEM	507	1,005	507	507	507	507	507	507	507	507
MISC PROPULSION	370	370	370	370	370	370	370	370	370	370
FLIGHT CONTROLS	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239	1,239
AUXILIARY POWER PLANT	265	265	265	265	265	265	265	265	265	265
INSTRUMENTS	632	632	632	632	632	632	632	632	632	632
HYDRAULICS & PNEUMATIC	504	504	504	504	504	504	504	504	504	504
ELECTRICAL	933	933	933	933	933	933	933	933	933	933
AVIONICS	1,000	1,000	5,000	5,400	5,400	5,400	5,400	5,000	8,000	8,000
ARMAMENT	–	–	180	180	180	180	180	–	180	180
FURNISHING	850	850	850	850	850	850	850	850	1,500	1,500
AIR-CONDITIONING	635	635	635	635	635	635	635	635	635	635
ANTI-ICE	251	251	251	251	251	251	251	251	251	251
LOAD & HANDLING	12	12	12	12	12	12	12	12	12	12
FIXED ITEMS	240	2,200	200	200	200	200	200	200	200	200
TOTAL WEIGHT EMPTY	32,062	33,882	35,418	35,818	35,818	35,818	35,818	35,238	39,068	39,068
R86-1455-114D										

Table 10 MR2 Turbofan Weight Empty Summary (lb)

MISSION GROUP	ASW	ASUW	AAW	AEW	MIW	VAQ/VQ	C^3	SURV
WING	3,623	3,623	3,623	3,623	3,623	3,623	3,623	3,623
HORIZONTAL TAIL	530	530	530	530	530	530	530	530
VERTICAL TAIL	531	531	531	531	531	531	531	531
BODY	3,693	3,693	3,693	3,693	3,693	3,693	3,693	3,693
ALIGHTING GEAR	1,820	1,820	1,820	1,820	1,820	1,820	1,820	1,820
ENGINE SECTION/NACELLE	–	–	–	–	–	–	–	–
STRUCTURE SUBTOTAL	**10,197**	**10,197**	**10,197**	**10,197**	**10,197**	**10,197**	**10,197**	**10,197**
PROPULSION	(6,179)	(6,179)	(6,179)	(6,179)	(6,179)	(6,179)	(6,179)	(6,179)
ENGINE (INCLUDES NACELLE)	5,589	5,589	5,589	5,589	5,589	5,589	5,589	5,589
FUEL SYSTEM	380	380	380	380	380	380	380	380
MISC PROPULSION	210	210	210	210	210	210	210	210
FLIGHT CONTROLS	905	905	905	905	905	905	905	905
AUXILIARY POWER PLANT	265	265	265	265	265	265	265	265
INSTRUMENTS	620	620	620	620	620	620	620	620
HYDRAULIC & PNEUMATIC	470	470	470	470	470	470	470	470
ELECTRICAL	845	845	845	845	845	845	845	845
AVIONICS	5,400	5,400	5,000	8,000	5,400	5,000	8,000	5,400
ARMAMENT	180	180	–	180	180	180	180	180
FURNISHINGS	819	819	819	1,400	819	819	1,400	819
AIR-CONDITIONING	525	525	525	525	525	525	525	525
ANTI-ICE	227	227	227	227	227	227	227	227
LOAD & HANDLING	12	12	12	12	12	12	12	12
FIXED ITEMS	200	200	200	200	200	200	200	200
TOTAL WEIGHT EMPTY	**26,844**	**26,844**	**26,264**	**30,025**	**26,844**	**26,444**	**30,025**	**26,844**

R86-1455-115D

Table 11 MR1 Propfan Weight Empty Summary (lb)

MISSION GROUP	COD	TANKER	VAQ/VQ	ASW	ASUW	MIW	SURV	AAW	C^3	AEW
WING	4,280	4,280	4,280	4,280	4,280	4,280	4,280	4,280	4,280	4,280
HORIZONTAL TAIL	661	661	661	661	661	661	661	661	661	661
VERTICAL TAIL	591	591	591	591	591	591	591	591	591	591
BODY	6,081	5,443	5,297	5,297	5,297	5,297	5,297	5,297	5,297	5,297
ALIGHTING GEAR	2,299	2,299	2,299	2,299	2,299	2,299	2,299	2,299	2,299	2,299
ENGINE SECTION/NACELLE	849	849	849	849	849	849	849	849	849	849
STRUCTURE SUBTOTAL	**14,761**	**14,123**	**13,977**	**13,977**	**13,977**	**13,977**	**13,977**	**13,977**	**13,977**	**13,977**
PROPULSION	(11,023)	(11,497)	(11,023)	(11,023)	(11,023)	(11,023)	(11,023)	(11,023)	(11,023)	(11,023)
ENGINE	10,180	10,180	10,180	10,180	10,180	10,180	10,180	10,180	10,180	10,180
FUEL SYSTEM	483	957	483	483	483	483	483	483	483	483
MISC PROPULSION	360	360	360	360	360	360	360	360	360	360
FLIGHT CONTROLS	1,106	1,106	1,106	1,106	1,106	1,106	1,106	1,106	1,106	1,106
AUXILIARY POWER PLANT	265	265	265	265	265	265	265	265	265	265
INSTRUMENTS	620	620	620	620	620	620	620	620	620	620
HYDRAULICS & PNEUMATIC	490	490	490	490	490	490	490	490	490	490
ELECTRICAL	942	942	942	942	942	942	942	942	942	942
AVIOINCS	1,000	1,000	5,000	5,400	5,400	5,400	5,400	5,000	8,000	8,000
ARMAMENT	–	–	180	180	180	180	180	–	180	180
FURNISHINGS	850	850	850	850	850	850	850	850	1,500	1,500
AIR-CONDITIONING	654	654	654	654	654	654	654	654	654	654
ANTI-ICE	251	251	251	251	251	251	251	251	251	251
LOAD & HANDLING	12	12	12	12	12	12	12	12	12	12
FIXED ITEMS	240	2,200	200	200	200	200	200	200	200	200
TOTAL WEIGHT EMPTY	**32,214**	**34,010**	**35,570**	**35,970**	**35,970**	**35,970**	**35,970**	**35,390**	**39,220**	**39,220**

R86-1455-116D

Table 12 MR2 Propfan Weight Empty Summary (lb)

GROUP \ MISSION	ASW	ASUW	AAW	AEW	MIW	VAQ/VQ	C^3	SURV
WING	3,429	3,429	3,429	3,429	3,429	3,429	3,429	3,429
HORIZONTAL TAIL	532	532	532	532	532	532	532	532
VERTICAL TAIL	532	532	532	532	532	532	532	532
BODY	3,649	3,649	3,649	3,649	3,649	3,649	3,649	3,649
ALIGHTING GEAR	1,764	1,764	1,764	1,764	1,764	1,764	1,764	1,764
ENG. SECTION/NACELLE	607	607	607	607	607	607	607	607
STRUCTURE SUBTOTAL	**10,513**	**10,513**	**10,513**	**10,513**	**10,513**	**10,513**	**10,513**	**10,513**
PROPULSION	(5,338)	(5,338)	(5,338)	(5,338)	(5,338)	(5,338)	(5,338)	(5,338)
ENGINE	4,788	4,788	4,788	4,788	4,788	4,788	4,788	4,788
FUEL SYSTEM	349	349	349	349	349	349	349	349
MISC PROPULSION	201	201	201	201	201	201	201	201
FLIGHT CONTROLS	920	920	920	920	920	920	920	920
AUXILIARY POWER PLANT	265	265	265	265	265	265	265	265
INSTRUMENTS	620	620	620	620	620	620	620	620
HYDRAULIC & PNEUMATIC	470	470	470	470	470	470	470	470
ELECTRICAL	845	845	845	845	845	845	845	845
AVIONICS	5,400	5,400	5,000	8,000	5,400	5,000	8,000	5,400
ARMAMENT	180	180	–	180	180	180	180	180
FURNISHINGS	819	819	819	1,400	819	819	1,400	819
AIR-CONDITIONING	537	537	537	537	537	537	537	537
ANTI-ICE	227	227	227	227	227	227	227	227
LOAD & HANDLING	12	12	12	12	12	12	12	12
FIXED ITEMS	200	200	200	200	200	200	200	200
TOTAL WEIGHT EMPTY	**26,346**	**26,346**	**25,766**	**29,527**	**26,346**	**25,946**	**29,527**	**26,346**

R86-1455-117D

10.2.1.1 Structure - The basic wing structure for each concept has the inherent capability to meet any of the diverse mission requirements. It was designed to meet the maximum speed, load factor and Flight Design Gross Weight, (FDGW) (N_ZW) defined in the Mine Warfare variant, and standard airframe strength sizing criteria (i.e., takeoff, flight and landing loads, weapons carriage requirement, carrier suite, etc.). Consistent with guidelines outlined in Specification 8860, the FDGW, used to define N_ZW, for Navy support aircraft, is equal to TOGW. Each MR1 and MR2 planform has a gust loading in excess of the flight load. This is a result of the high aspect ratio wing design and the high dynamic pressure environment in the low altitude dash. The N_ZW product of the Mine Warfare variant is more critical to wing strength than the heavier weight, slower speed (lower load factor) and corresponding lower N_ZW product tanker variant.

Each wing has the provision for installing the conformal array antennas and may be reconfigured to include that system. Additional weight allowances are included for retaining the maximum wing fuel capacity on all variants and the increased local tip bending associated with the winglet installation. However, a reduction in overall wing bending results from the incorporation of winglets, which is represented in wing weight estimates. All Navy support aircraft structures must be designed to be fail safe, in accordance with Specification 8861. Weight impacts associated with a fail-safe design were minimized with the incorporation of advanced composites and metallics structures which have inherently better tolerances to battle damage. Each MPSNA design incorporates an E-2C type wing folding system ensuring a proven system with enhanced reliability and suitable carrier operations. Wing hard points are provided for external weapons carriage.

Tail surfaces are designed for the gust loading requirement with additional weight increments included for conformal array installations similar to the wing design. A structural increment to the tail was added to the propfan powered concepts due to increased acoustic levels over turbofan designs.

The fuselage structure was sized to ensure adequate strength for all mission requirements and sufficient volume for packaging crew, equipment and systems in addition to the wide matrix of payloads, avionics and weapons. Cargo doors and ramps will be added to the COD variant only, with the structural provisions for this installation and sonobuoy pallet installation included in each variant. Each fuselage includes an incremental weight for conformal weapons carriage. Provisions for installing fuel tanks in the MR1 Tanker variant fuselage result in an increase in body weight for that design only.

Main and nose landing gear are sized to meet the 22 ft/sec sink speed requirement at a landing design gross weight defined as the maximum zero fuel weight plus 50% of the maximum mission fuel, excluding transfer fuel in MR1 tanker variants. The arresting hook and accompanying fuselage structure is sized to meet the kinetic energy associated with the 120 KTAS approach speed at a similar landing weight. Catapult gear strength is that required to meet a takeoff at 1.1 times the maximum gross weight variant. Summaries of the structure weight for each concept are shown in Tables 9 through 12.

10.2.1.2 Propulsion - MR1 turbofan variants share a common propulsion system including engines, fuel systems and miscellaneous propulsion packages. Additional fuel system weight, shown in Table 9, is included in the tanker variant for fuel transfer equipment and tanks. Engine section weight including nacelles, mounts and inlets are bookkept in the engine installation weight. As shown in Table 10, a similar philosophy applies to MR2 turbofan designs. MR1 propfan designs also employ a common propulsion system. Inlet, nacelle cowling, nacelle supports and airframe equipment brackets are included in the engine section weight for the propfan concepts (Tables 11 and 12). Engine installation weight represents the core engine, gearbox and propfan including blades, hubs and spinners. Elimination of the tanker requirement for the MR2 propfan concept resulted in a 100% common propulsion system. Each fuel system weight estimate is based on the maximum required mission fuel, (excluding tanker), thrust and aircraft geometry (i.e., span, length, wing area).

10.2.1.3 Systems - The flight control system capability and weight is based on the concepts' TOGW, wing span, control surface areas, wing area and mission requirements. APU weight represents a system capable of meeting all self start, avionics ground operation and emergency power requirements. Instruments, hydraulics and electrical systems remain unchanged between variants for each notional concept. All variants employ a core avionics system of 1000 lb with additional equipment and sensors added to individual variants. Conformal UHF and X-band radar are included on AEW and ASW variants, respectively, ensuring high mission effectiveness. Jamming equipment on AAW and VAQ/VQ provides SIGINT and ELINT capability. Armament group weight is provided on all concepts requiring weapons carriage.

MR1 propfan and turbofan core furnishing weight is based on COD fuselage area and four crewmembers in the AAW variant. Increased furnishing, equipment and soundproofing weight is added to the AEW for the additional crewmembers. Furnishing weights for MR2 concepts are based on the maximum fuselage area and four AAW crewmembers with additional weight included on AEW variants. No additional soundproofing for propfan concepts was required since the prop plane is located aft of the rear pressure bulkhead.

The ECS group is sized to meet the most stringent air conditioning requirements. For MR1 concepts, pressurization of COD fuselage volume and avionic cooling in the AEW variant sized that core system. For MR2 designs, the core system is tailored to meet AEW pressurization and avionics cooling loads. A common anti-icing system is provided on all variants for windshield de-icing and defogging. Engine inlet de-ice is included in basic engine weight. Higher fixed weight for COD and tanker variants results from incorporation of seat stowage equipment and the in-flight refueling boom respectively.

10.2.2 Dedicated vs Multipurpose

Ten point-designed concepts were developed as baselines for assessing the weight penalty due to commonality. Each baseline has an optimum geometry, propulsion size, system package and fuel to meet its dedicated mission role. The point-designed propfan concepts are 10% lighter than equivalent turbofan vehicles. These differences in TOGW are consistent with MR1 and MR2 designs, ensuring that the development of multipurpose designs did not impact the propulsion system comparison.

As shown in Fig. 107 and 108 large penalties of 20% to 85% result for the development of the MR1 multipurpose designs. These increases in TOGW for a common concept result primarily from the incorporation of the large COD fuselage, increased engine size for low altitude dash and, to a much lesser extent a common planform. MR2 designs with relaxed requirements show smaller increases in TOGW, from 3% to 32%. Elimination of the COD and tanker role reduced the weight and size of MR2 aircraft relative to MR1 candidates. Reducing the sea level dash speed resulted in a more compatible engine thrust size and reduced fuel to meet a similar set of mission requirements. No increase in TOGW was shown for the MR2 Mine Warfare variant when the dash speed was reduced.

The weight increments to develop either the MR1 or MR2 multipurpose designs are high relative to the ten individually sized aircraft. However, this approach appears to produce lighter designs with a higher level of mission effectiveness than a single multimission design and more cost effective than several dedicated mission aircraft.

10.2.3 Propfan vs Turbofan

The main objective of this study is to judge the relative merits of propfans compared to turbofans for multipurpose subsonic naval aircraft. The figures of merit, in addition to thrust size, used to quantify this comparison are primarily TOGW and fuel required. Tables 13 and 14 summarize the TOGW by component for MR1 propfan and turbofan designs.

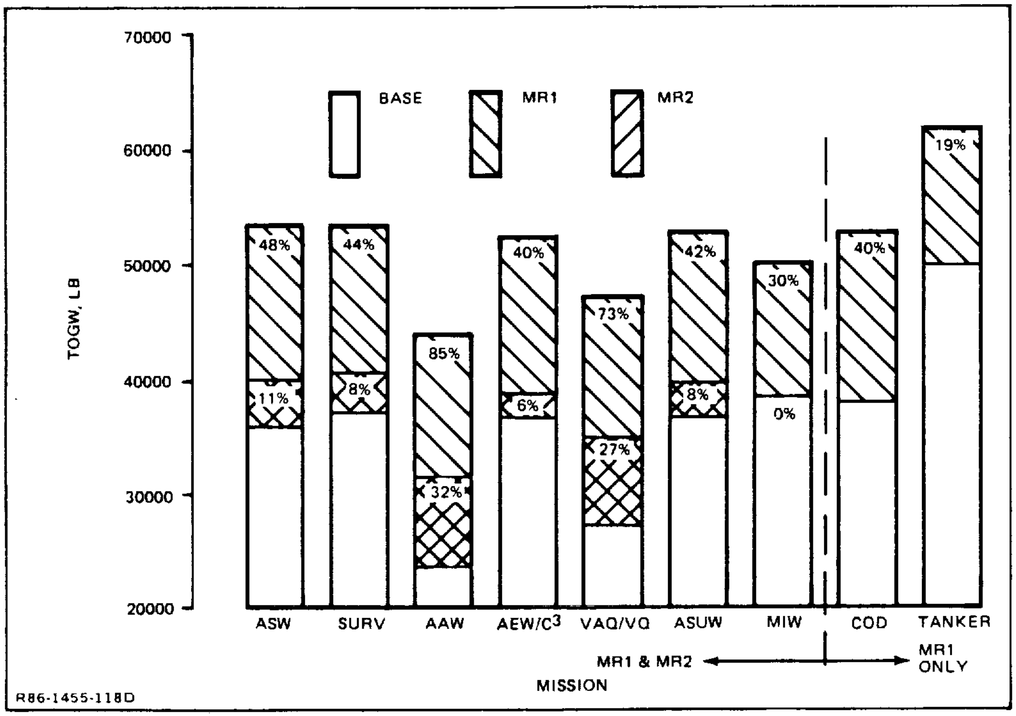

Fig. 107 Commonality Penalty – Propfan Designs

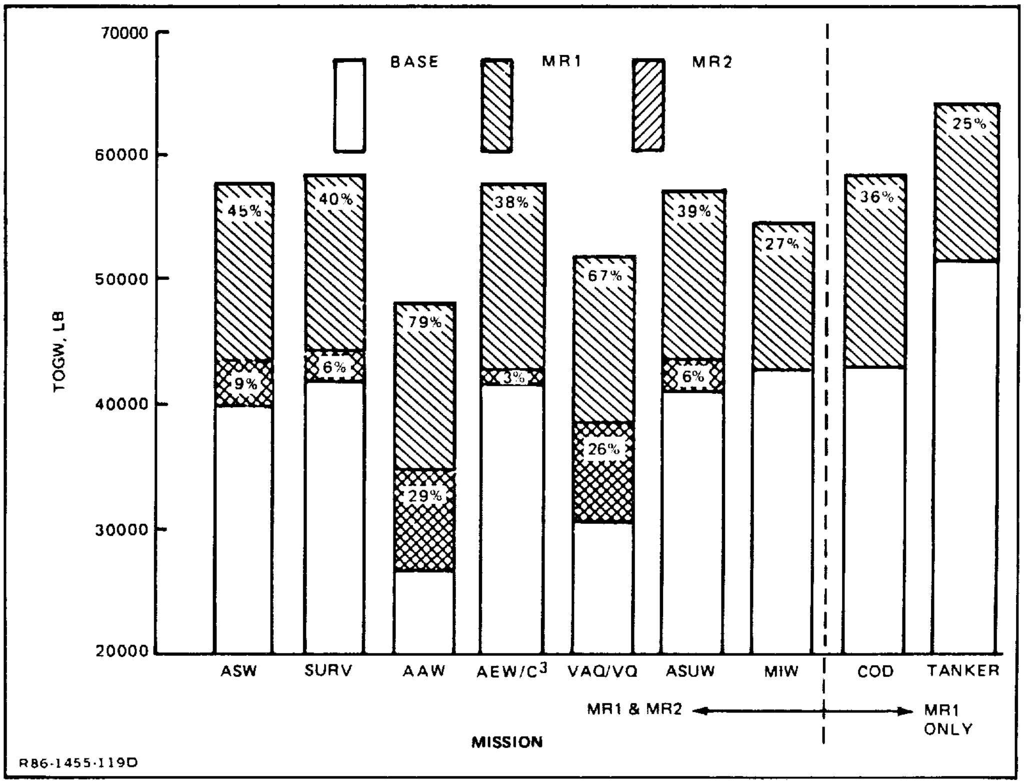

Fig. 108 Commonality Penalty – Turbofan Designs

Table 13 MR1 Propfan Weight Summary (lb)

GROUP \ MISSION	COD	TANKER	ASW	SURV	AAW	AEW	MIW	VAQ/VQ	C^3	ASUW
WEIGHT EMPTY	32,214	34,010	35,970	35,970	35,390	39,220	35,970	35,570	39,220	35,970
FUEL	9,383	(23,000)[1] 3,929	9,073	9,419	7,370	9,990	7,804	8,679	9,990	8,404
CARGO	10,000	–	–	–	–	–	–	–	–	–
WEAPONS	–	–	5,520	5,520	–	1,300	5,024	1,600	1,300	5,520
MISC USEFUL LOAD	1,404	964	2,795[2]	2,795[2]	1,494	1,859	1,473	1,524	1,859	2,795[2]
TOGW	53,001	61,903	53,358	53,704	44,254	52,369	50,271	47,373	52,369	52,689

[1] TRANSFER FUEL

[2] INCLUDES: SONOBUOYS & CHAFF

[3] F* = 20,000 LB

[4] S_W = 620 FT^2

R86-1455-120D

Table 14 MR1 Turbofan Weight Summary (lb)

GROUP \ MISSION	COD	TANKER	ASW	SURV	AAW	AEW	MIW	VAQ/VQ	C^3	ASUW
WEIGHT EMPTY	32,062	33,882	35,818	35,818	35,238	39,068	35,818	35,418	39,068	35,818
FUEL	14,514	(23,000)[1] 5,743	13,651	14,229	11,243	15,318	11,706	13,149	15,318	12,695
CARGO	10,000	–	–	–	–	–	–	–	–	–
WEAPON	–	–	5,520	5,520	–	1,300	5,024	1,600	1,300	5,520
MISC USEFUL LOAD	1,349	909	2,740[2]	2,740[2]	1,439	1,804	1,418	1,469	1,804	2,740[2]
TOGW	57,925	63,534	57,729	58,307	47,920	57,490	53,966	51,636	57,490	56,773

[1] TRANSFER FUEL

[2] INCLUDES SONOBUOYS & CHAFF

[3] F* = 21,100 LB

[4] S_W = 620 FT^2

R86-1455-121D

The results of this study show MR1 propfan aircraft to be 3% to 10% lighter in all missions than similarly optimized turbofan concepts. Higher weight savings are shown for those missions where the lower SFC propfans can be used to their best advantage, long cruise or loiter legs. On lower fuel fraction concepts, tanker, MIW and ASUW, differences between propfans and turbofans are lessened when the lower propfan SFC characteristics are counter-balanced by higher T/W turbofan engines. All MR1 concepts, excluding the light weight AAW concept, result in TOGW aircraft in the 50,000 to 60,000 lb class.

Similarily, MR2 propfan concepts show a 10% decrease in TOGW over turbofan designs, (Tables 15 and 16). Relaxation of the mission requirements reduces the TOGW of the MR2 aircraft to the 40,000 lb class.

Table 15 MR2 Propfan Weight Summary (lb)

MISSION GROUP	ASW	ASUW	AAW	AEW	MIW	VAQ/VQ	C^3	SURV
WEIGHT EMPTY	26,346	26,346	25,766	29,527	26,346	25,946	29,527	26,346
FUEL	5,337	5,224	4,409	6,272	5,866	5,867	6,272	5,815
CARGO	–	–	–	–	–	–	–	–
WEAPONS	5,520	5,520	–	1,300	5,024	1,600	1,300	5,520
MISCELLANEOUS USEFUL LOAD	2,705[1]	2,705[1]	1,404	1,769	1,383	1,434	1,769	2,705[1]
TOGW	39,908	39,795	31,579	38,868	38,619	34,847	38,868	40,385

[1] INCLUDES SONOBUOYS & CHAFF

[2] F* = 8888 LB

[3] S_W = 550 FT^2

R86-1455-122D

Table 16 MR2 Turbofan Weight Summary (lb)

MISSION GROUP	ASW	ASUW	AAW	AEW	MIW	VAQ/VQ	C^3	SURV
WEIGHT EMPTY	26,844	26,844	26,264	30,025	26,844	26,444	30,025	26,844
FUEL	8,431	8,141	6,911	9,857	7,648	8,873	9,857	9,105
CARGO	–	–	–	–	–	–	–	–
WEAPONS	5,520	5,520	–	1,300	5,024	1,600	1,300	5,520
MISC USEFUL LOAD	2,680	2,680[1]	1,379	1,744	1,358	1,409	1,744	2,680[1]
TOGW	43,475	43,185	34,554	42,926	40,874	38,326	42,926	44,149

[1] INCLUDES SONOBUOYS & CHAFF

[2] F* = 9,900 LB

[3] S_W = 550 FT^2

R86-1455-123D

TOGW distributions for the four CTOL AEW designs are shown in Fig. 109. The MR2 and MR1 propfan configurations have 27% and 31% higher propulsion fractions than the turbofan designs, reflecting their lower T/W engine packages. Conversely, the propfan fuel fractions are 42% to 43% lower than the turbofan fuel fractions due to the better SFC characteristics of propfan engines. The fuel fractions of these propfan designs are low, 15% to 20%, when compared to current Navy support aircraft like the E-2C with a fuel fraction of 24%. This low fuel fraction lessens the impact on TOGW of the considerable, 50% to 60%, fuel burned savings of propfan propulsion systems.

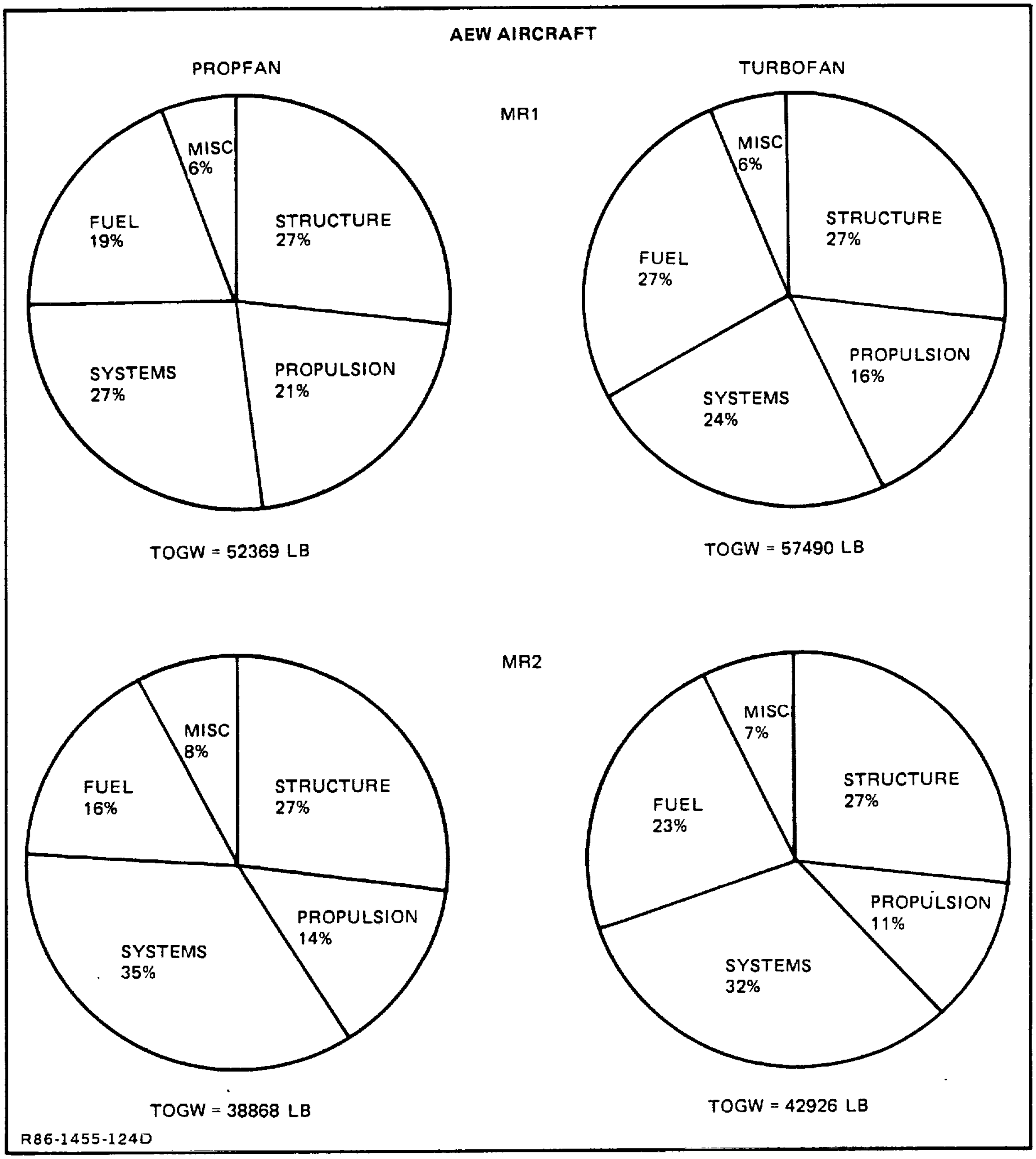

Fig. 109 CTOL Aircraft Weight Distribution

All figures of merit, summarized in Table 17, are better for propfan CTOL designs than for equivalent technology turbofan designs. The largest benefit is seen in fuel burned which iterates into a reduction in required engine and aircraft size.

Table 17 Propfan vs Turbofan CTOL Results

AEW MISSION						
FIGURES OF MERIT	MR1 AIRCRAFT			MR2 AIRCRAFT		
	PROPFAN	TURBOFAN	Δ	PROPFAN	TURBOFAN	Δ
TOGW, LB	52369	57490	10%	38868	42926	10%
F*, LB	20000	21100	6%	8888	9900	11%
FUEL, LB	9990	15318	53%	6272	9857	57%

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11 - V/STOL DESIGN RESULTS

The V/STOL propfan MPSNA aircraft design, shown in Fig. 110, is a high wing, coplanar H-tail concept. The aircraft is powered by two single-rotation, wing-mounted, ten-bladed, tractor propfans that rotate, along with the wing outer panel, 90 degrees during vertical operation. Four core engines, two mounted on each side of the fuselage, drive the props. This aircraft has both V/STOL and STOVL capability. A component weight summary is shown in Table 18.

11.1 CONCEPT DEVELOPMENT

Design groundrules for a V/STOL multimission aircraft are somewhat different from those guidelines for its CTOL counterpart. These changes include revised fuel allowances, and thrust requirements, listed in Table 19.

The V/STOL configuration development philosophy was to design an MR1 aircraft and an MR2 aircraft that satisfy vertical and conventional takeoff and landing criteria. The iterative configuration development process initially used the CTOL design groundrules, altered to meet unique V/STOL requirements (fuel allowances, T/W), an advanced technology base (weight, aerodynamics), and propulsion system data for the preferred propfan (four cores/two props). This process is shown schematically in Fig. 111. Each configuration was tested against the initial groundrules, mission requirements, carrier suitability criteria, and STOVL as well as V/STOL operation capability. If any of these requirements were not satisfied the process was reinitialized and the aircraft was resized in an effort to meet all design criteria.

This iterative design process showed that a convergent design solution that met all MR1 or MR2 requirements with a prop size allowing both V/STOL and STOVL operation was not possible. A reduced set of mission requirements, discussed in Subsection 11.2, was necessary to develop a viable carrier based multipurpose V/STOL design.

Maximum prop height compatible with STOVL operation and hangar deck height constraints limited the prop diameter to approximately 22 ft and the aircraft TOGW to 68,000 lb. Propfan systems producing more thrust, at the preferred power loading of 37 SHP/d^2, discussed in Subsection 11.2.1, have larger diameter blades and inadequate ground clearance in addition to hangar deck height interference.

Within these constraints, development of a V/STOL design to meet MR1 requirements was not possible due to the large payload and fuselage size for these concepts. For this reason, the COD and tanker variants were eliminated. The aircraft fuselage was sized to accommodate the AEW avionics payload, similar to MR2 CTOL designs. The propulsion system was sized by the takeoff thrust to meet the vertical 1.05 thrust loading requirements in the AEW, C^3, ASW, ASUW, Surveillance and MIW missions.

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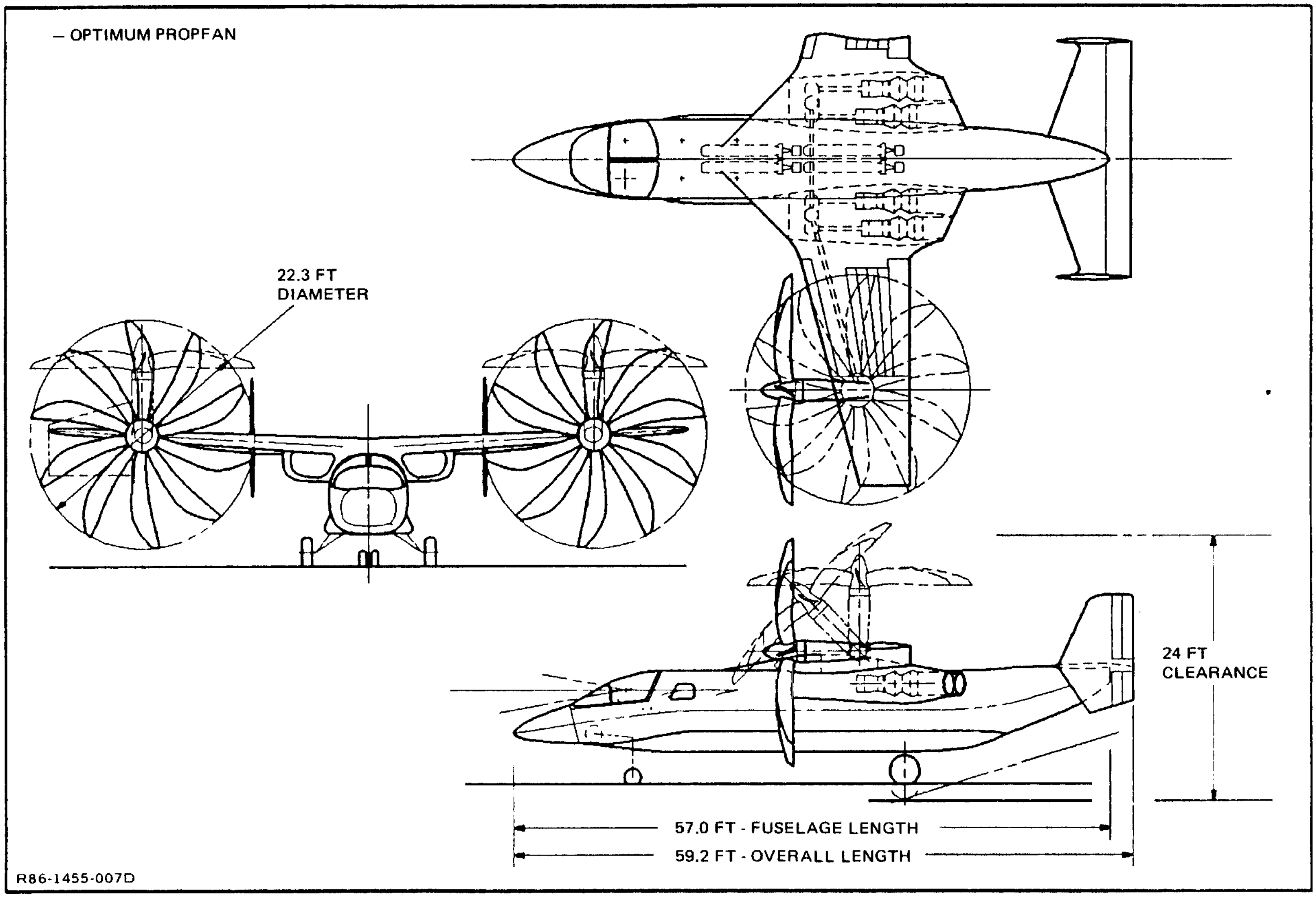

Fig. 110 Concept of V/STOL Aircraft

Table 18 V/STOL Weight Summary (lb)

GROUP \ MISSION	ASW	ASUW	AAW	AEW	MIW	VAQ/VQ	C^3	SURV
STRUCTURE	14,284	14,284	14,284	14,284	14,284	14,284	14,284	14,284
PROPULSION	22,750	22,750	22,750	22,750	22,750	22,750	22,750	22,750
SYSTEMS	12,503	12,503	12,103	15,684	12,503	12,103	15,684	12,503
WEIGHT EMPTY	49,537	49,537	49,137	52,718	49,537	49,137	52,718	49,537
FUEL	10,038	10,038	12,697	12,013	11,856	12,896	12,013	10,038
CARGO	–	–	–	–	–	–	–	–
WEAPONS	5,520	5,520	–	1,300	5,024	1,600	1,300	5,520
MISCELLANEOUS USEFUL LOAD	2,905	2,905	1,604	1,969	1,583	1,634	1,969	2,905
TOGW	68,000	68,000	63,438	68,000	68,000	65,267	68,000	68,000
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Table 19 V/STOL Fuel Allowances & Thrust Requirements

CONDITION	
TAKEOFF	LANDING
• 2 MIN MAXIMUM CONTINUOUS POWER + 0.5 MINUTES MAXIMUM POWER • 1.05 INSTALLED TROPICAL DAY VERTICAL T/W	• 10 MIN S.L. LOITER + 5% FUEL LOAD • 1.03 INSTALLED TROPICAL DAY EVL T/W WITH ONE ENGINE OUT (OEI)
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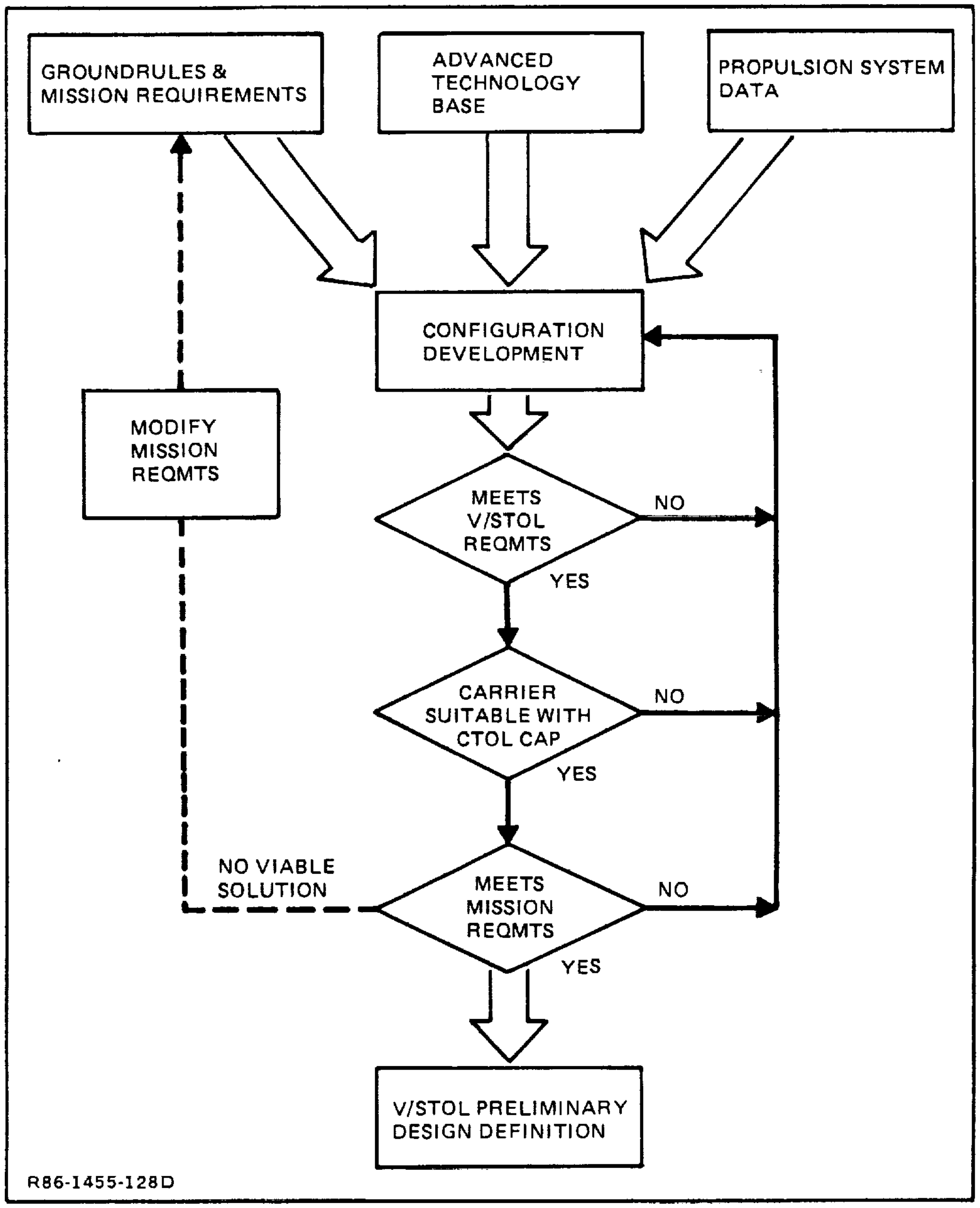

Fig. 111 V/STOL Concept Development Process

The resulting configuration has a TOGW of 68,000 lb, total aircraft thrust of 89,924 lb, propfan diameter of 22.3 ft, and a maximum internal fuel capacity of 12,896 lb. The fallout mission performance of this fixed size aircraft was determined and is described in Subsection 11.3.

11.2 PROPULSION SYSTEM

The V/STOL aircraft propulsion system, summarized in Table 20, employs four core engines, mounted as twin packs on each side of the fuselage, powering two wing-mounted opposite-rotation propfans. The propulsor is an advanced technology single-rotation, ten-bladed, propfan connected to the P&WA STS679 by a power transmission system. The propfan nacelle and wing outer panel rotate 90 degrees for vertical operation.

Table 20 V/STOL Propulsion System Summary

NUMBER OF CORE ENG'S	4
F*/CORE	22,481 LBS
SHP/CORE	9202 SHP
NUMBER OF PROPFANS	2
PROPFAN DIAMETER	22.3 FT
SHP/D^2	37.02 SHP/SQ FT
WEIGHT	21,800 LBS
UNINSTALLED T/W	4.1
VERTICAL T/W	3.3

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11.2.1 Concept Development

The propulsion system requirements for a V/STOL aircraft are different than those for a CTOL aircraft, resulting in a different engine configuration for the V/STOL concept. The engines are sized by thrust required for vertical operation resulting in lower disk-loaded propfans and high aircraft thrust-to-weight making thrust lapse with speed and altitude less critical. Engine thrust-to-weight becomes more critical, since propulsion system weight is a much larger fraction of aircraft weight for a V/STOL aircraft. The V/STOL propulsion group fraction is 33.5%, almost 2.5 times the CTOL MR2 propulsion fraction of 13.7% (see Fig. 112).

The two engine sizing constraints for a V/STOL configuration are takeoff with all engines operating and landing with One Engine Inoperative (OEI) for an Emergency Vertical Landing (EVL). EVL was the key factor in choosing the number of core engines required. Figure 113 illustrates the classic inverse relationship between thrust per input horsepower and power loading. As the number of core engines increases from two to four, the power loading increases with a decrease in thrust per horsepower. However, the input horsepower available after loss of an engine increases with the number of cores in the system. The final result is an increase in the percentage of thrust available with an engine out as a function of the number of cores. With two cores, EVL is the engine sizing requirement with approximately 68% of full thrust available with OEI. The two core configuration, sized to meet EVL, is oversized at takeoff by 18%, as shown in Table 21, and does not provide a good match between takeoff and landing engine size requirements.

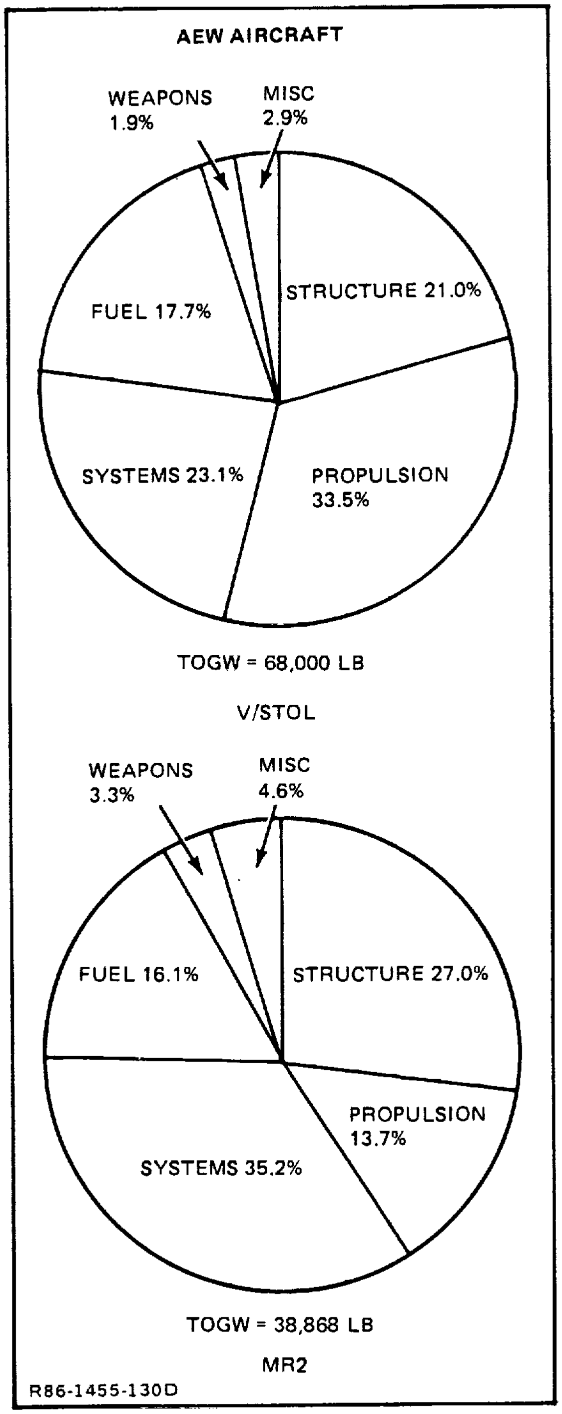

Fig. 112 MR2/V/STOL Weight Distribution Comparison

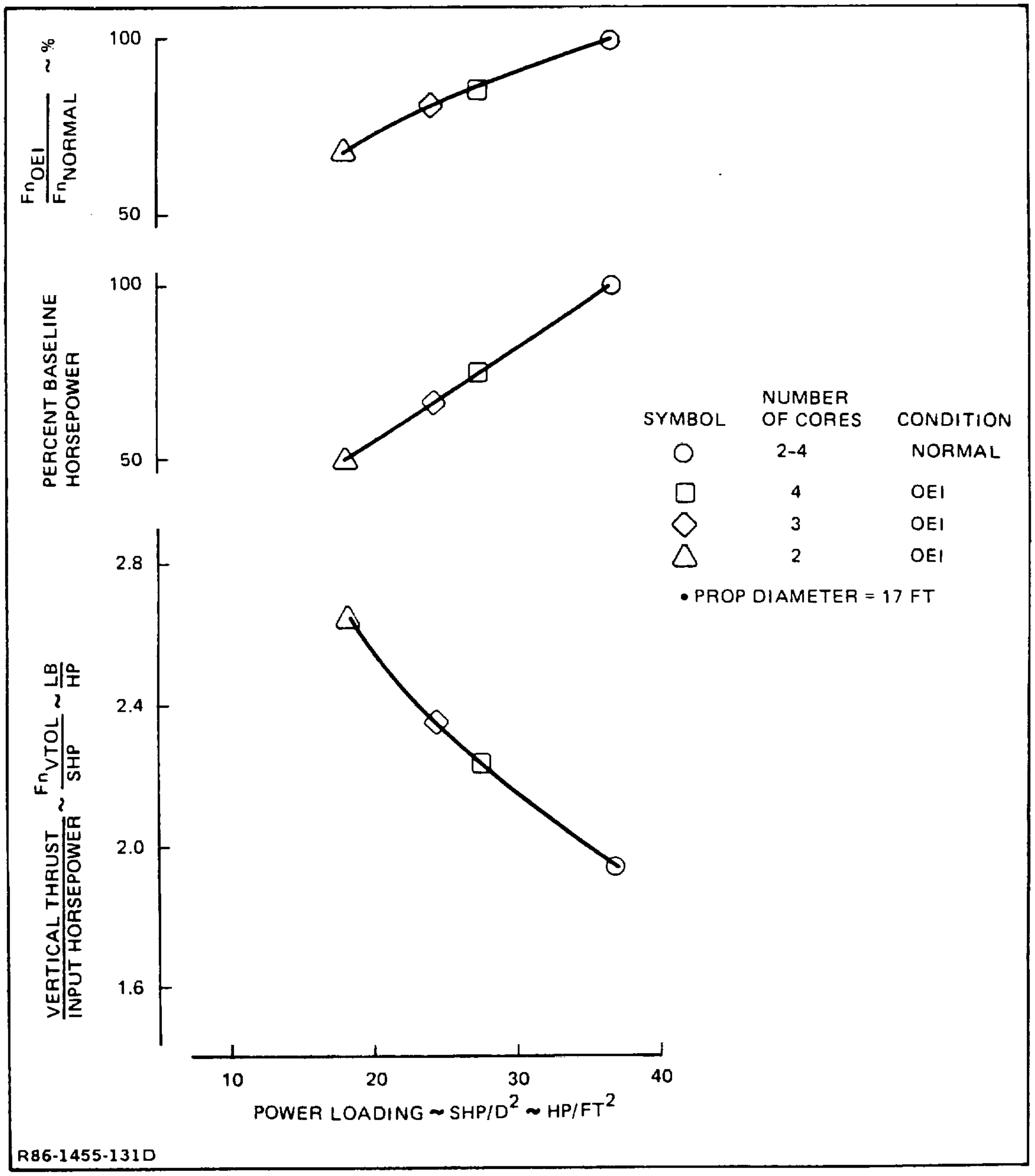

Fig. 113 Available OEI Thrust

Table 21 Core Configuration Selection

CONFIGURATION	SIZING CONDITION	TO/EVL MATCH
2 CORES	EVL	18% OVERSIZED FOR TO
3 CORES	EVL	<1% OVERSIZED FOR TO
4 CORES	TO	7% OVERSIZED FOR EVL
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A three-core configuration provides a better match with almost 81% of full thrust available with OEI. This configuration provides a better match between takeoff and landing requirements, less than 1% engine oversizing at takeoff. This benefit was overridden by limited access and resulting maintainability problems of the center core.

A four-core concept, arranged as twin packs one on each side of the fuselage, was chosen as the preferred configuration. With high engine out performance, 86% of total thrust, the propulsion system is sized by takeoff with the core engines oversized by 7% for EVL. In addition, maintainability is improved over a three-core system with adequate access to all engines.

Cross-shafting was required to assure flight safety during engine out conditions. As can be seen in Fig. 114, each twin pack and propfan is connected to a cross shaft, a series of bearings and couplings for required flexibility and a bevel gearbox for right angle turns. In the event of a core failure, it can be disengaged by an overrunning clutch to prevent the system from driving a dead core.

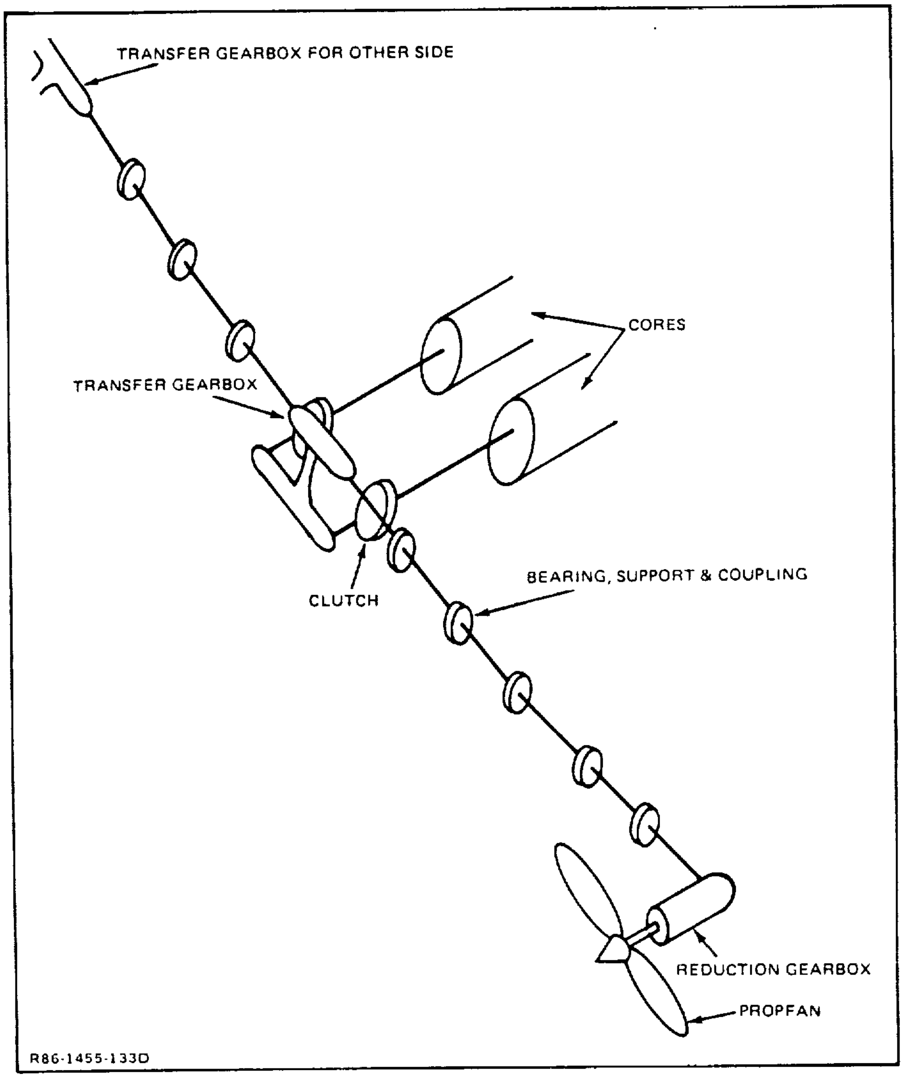

Fig. 114 V/STOL Power Transmission System

11.2.2 Thrust Requirements

V/STOL aircraft engine sizing constraints, based on previous Navy study aircraft, are 1.05 vertical takeoff installed thrust-to-weight ratio, and 1.03 emergency vertical landing thrust-to-weight ratio. All engine sizing is based on tropical day sea level performance.

Table 22 illustrates that takeoff is the more stringent of these two requirements where thrust loading required for vertical takeoff of the AEW, C^3, MIW, ASW, ASUW, and Surveillance aircraft is 1.05. The uninstalled sea level standard day thrust loading necessary to maintain this installed tropical day thrust loading of 1.05 is 1.32 for our configuration. Landing with OEI is a less stringent requirement than takeoff resulting in a slight mismatch in required engine size. The power plant for all variants is oversized at EVL by 7% to 15%. To retain propulsion system commonality, lighter AAW and VAQ/VQ designs are also oversized at takeoff.

Table 22 Thrust Requirements

	AEW/C^3	AAW	MIW	ASW	ASUW	VAQ/VQ	SURV
TOGW, LB	68,000	63,438	68,000	68,000	68,000	65,267	68,000
STORES, LB	1,300	–	5,024	7,002	7,002	1,600	7,002
FUEL, LB	12,013	12,697	11,856	10,038	10,038	12,896	10,038
ZFZS WEIGHT, LB	54,687	50,741	51,120	50,960	50,960	50,771	50,960
EVL LAND FUEL, LB	1,000	1,000	1,000	1,000	1,000	1,000	1,000
EVL WEIGHT, LB	55,687	51,741	52,120	51,960	51,960	51,771	51,960
OEI THRUST, LB	61,654	61,654	61,654	61,654	61,654	61,654	61,654
TO THRUST, LB	71,442	71,442	71,442	71,442	71,442	71,442	71,442
TO T/W	1.05	1.13	1.05	1.05	1.05	1.09	1.05
OEI T/W	1.11	1.19	1.18	1.19	1.19	1.19	1.19
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11.2.3 Weight

Much of a V/STOL propulsion system must be designed to minimize weight. In the design of the V/STOL concept this included the use of the 10% higher thrust-to-weight ratio single rotation propfan when compared to a counter-rotation system (4.36 vs 3.98 standard day uninstalled T/W at a nominal core horsepower size with equal diameter propfans) at the cost of fuel efficiency. Engine reduction gearboxes were changed to the in-line split path type from the offset compound idler type used in the CTOL designs because they are 26% lighter. Installation of the reduction gearbox in the nacelle on the wing allows the cross shaft to rotate at engine speed. This results in reduced shaft torque for a given power output, permitting the use of smaller, lighter shafts vs a system where speed reduction takes place before power transmission. The single gearbox, used to transfer power from each pair of core engines to the cross shaft, was slightly lighter than one gearbox for each core.

The propfan diameter was also sized with weight as an important criterion. It was necessary to balance the thrust-to-weight of the engine system, favoring larger propfans with low power loadings, with operational limits on physical size. These limits include ground clearance for STOVL operation and hangar deck height of 25 ft. Figure 115 shows installed vertical thrust-to-weight as a function of thrust required and disk loading. The disk loading for maximum thrust-to-weight is SHP/d^2=26 or a diameter over 26 ft at a TOGW of 68,000 lb. The selected propfan, a loading of SHP/d^2=37, corresponds to a 22.3 ft diameter blade at V/STOL aircraft size. This smaller prop size permits STOVL operation when nacelles are unrotated with only a 4.2% penalty in engine thrust-to-weight.

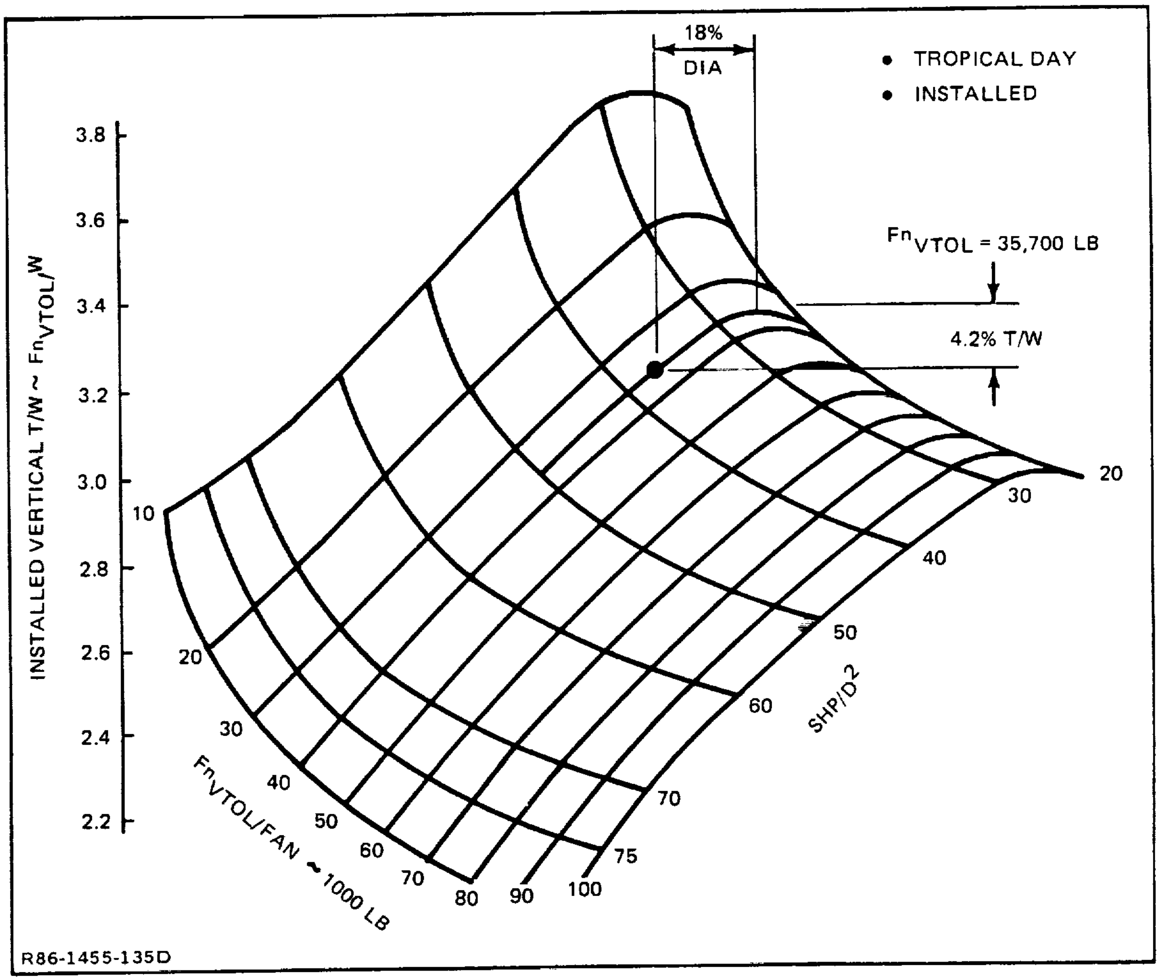

Fig. 115 Installed Vertical Engine Thrust-to-Weight

To maximize vertical thrust and minimize resulting engine size, it was desirable to minimize the flat plate effect of the wing when the engine nacelle is rotated. This was achieved by tilting the outboard section of the wing with the nacelle during vertical operation. The inboard portion of the wing in the propfan slipstream incorporates a trailing edge single-slotted flap which deflects 90 degrees and slots in the remainder of the inboard washed section to minimize blockage. This design reduces thrust loss due to wing blockage to approximately 12% of thrust.

Propulsion system weights are detailed in Table 23. The weight of the cores, reduction gearboxes, and propfans was calculated according to Ref 3. Power transmission system weights were calculated according to Ref 4.

Table 23 V/STOL Propulsion System Weights

COMPONENT	NUMBER	WEIGHT (LB)	
CORE ENGINE	4		7126
POWER TRANSMISSION SYSTEM			1782
OVERRUNNING CLUTCH	4	577	
TRANSFER GEARBOX	2	719	
BEARINGS & COUPLINGS	13	255	
SHAFTS	1	231	
REDUCTION GEARBOX	2		3845
PROPFAN	2		9047
			21,800

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11.3 V/STOL MISSION SUMMARY

Final V/STOL mission performance was generated and compared to the initial MR2 mission requirements. These design sensitivities were developed using Grumman's aircraft sizing tool, the WISE computer code. These fallout performance data were constrained by both the 68,000 lb TOGW restriction and the maximum internal fuel load. Detailed mission capability is shown in Fig. 116 through Fig. 119 and summarized in Table 24.

To enable direct comparison of vehicle performance with the MR2 CTOL design, the baseline weapons and systems compliment was retained while mission fuel and associated performance was reduced, if applicable, to maintain the 68,000 lb TOGW limit. Low payload and systems weight in the AAW mission, along with less stringent mission requirements, allowed the V/STOL concept to meet all AAW groundrules at a TOGW less than 68,000 lb. VAQ/VQ employs the maximum internal fuel capacity and showed minimal degradation in mission performance, also at a lower TOGW. In those missions with high payload or avionics fractions (AEW, C^3, Surveillance, ASW, ASUW), fuel was offloaded to maintain the TOGW limits. This reduction in fuel and the incompatibility of the propulsion system for high altitude cruise and loiter resulted in a significant decrease in mission performance. For STOVL applications, these variants could be loaded with full fuel, improving mission performance but limiting flight load factor.

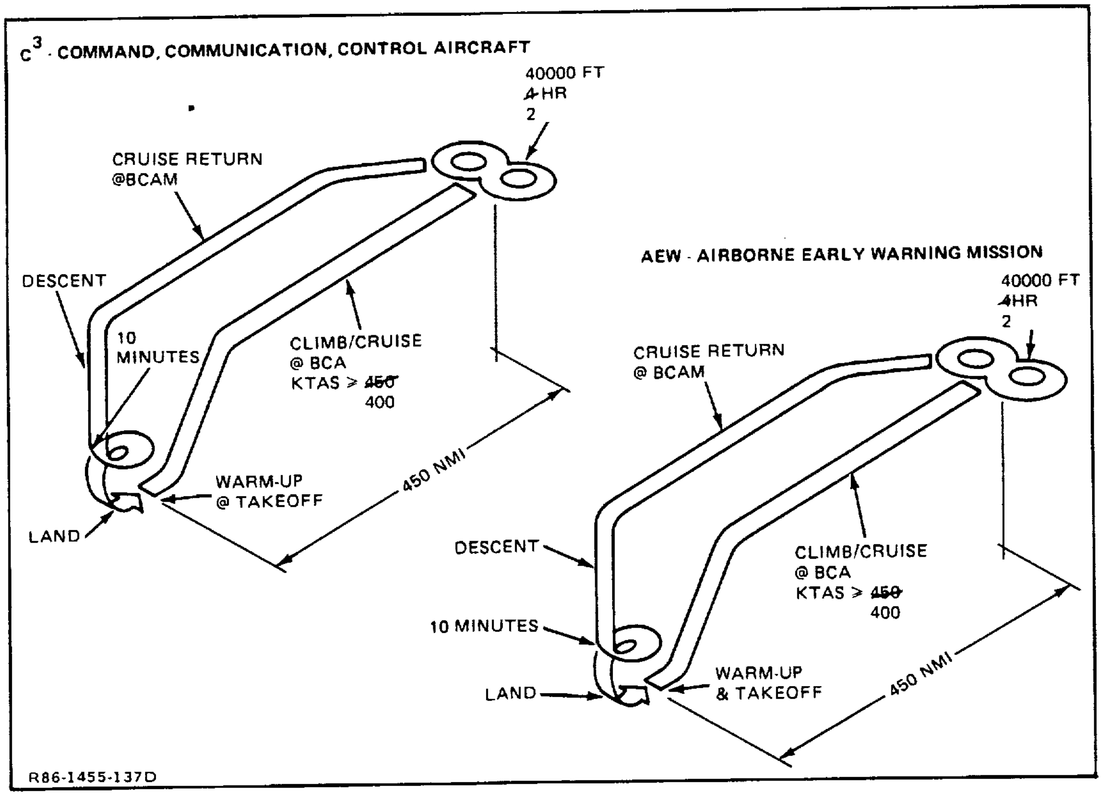

Fig. 116 V/STOL Mission Capability: AEW, C^3

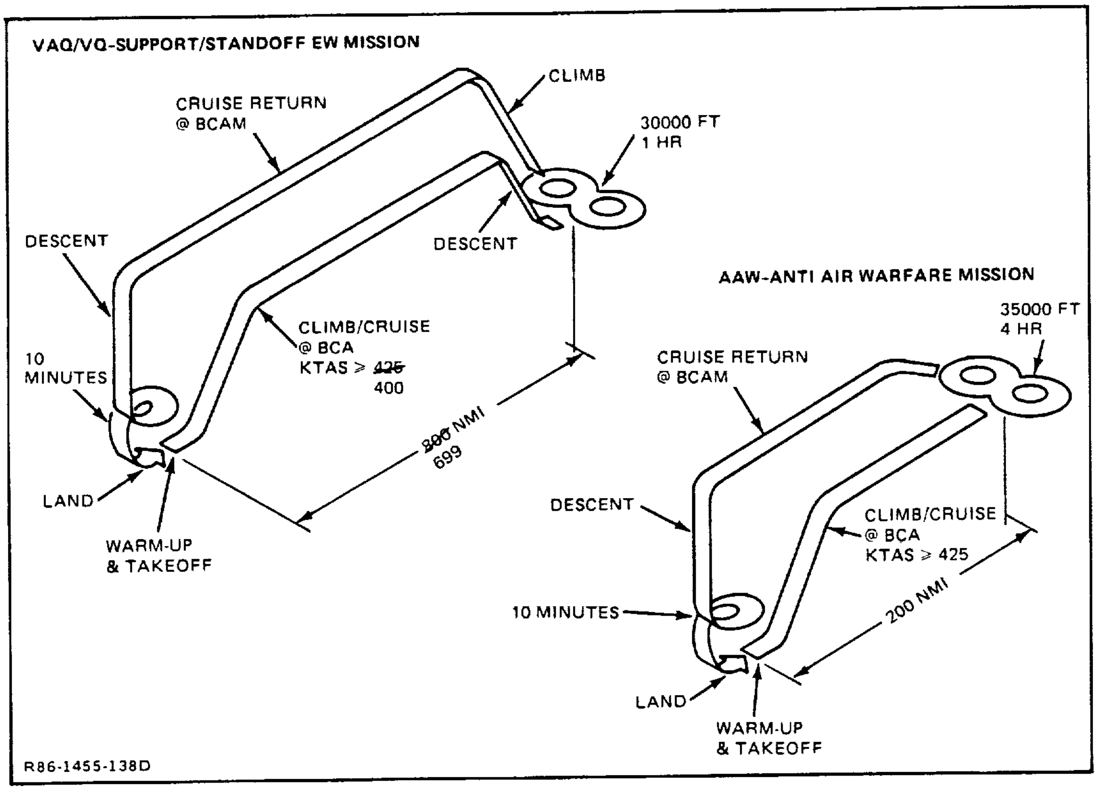

Fig. 117 V/STOL Mission Capability: AAW, VAQ/VQ

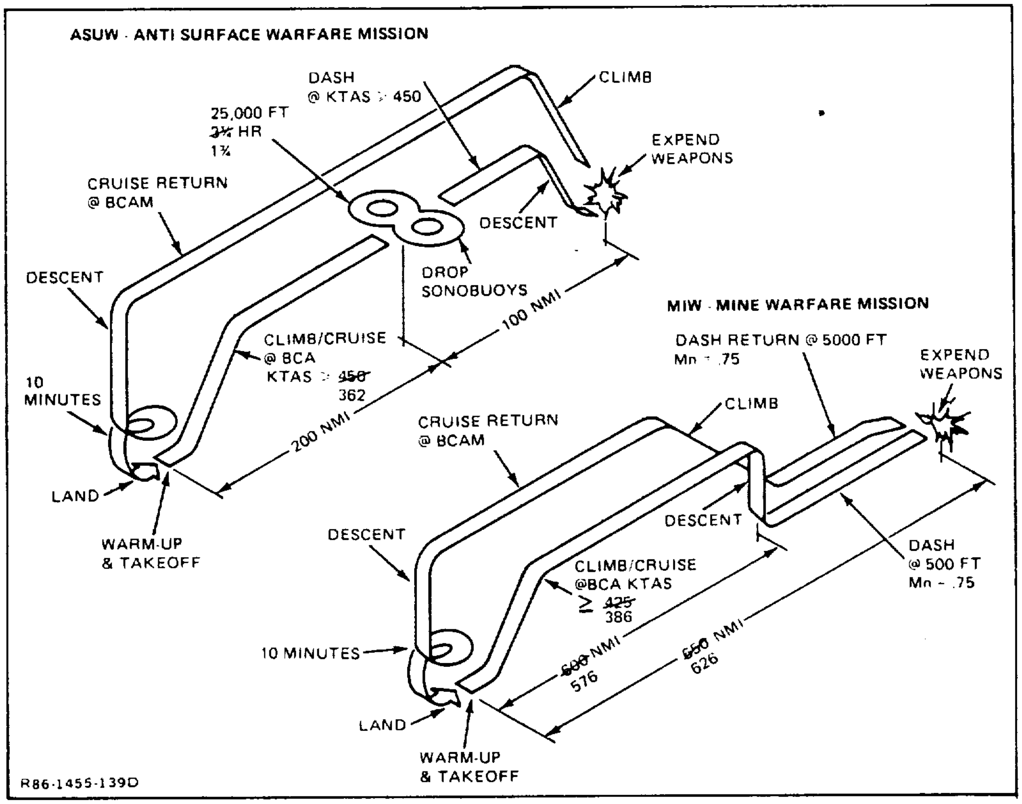

Fig. 118 V/STOL Mission Capability: MIW, ASUW

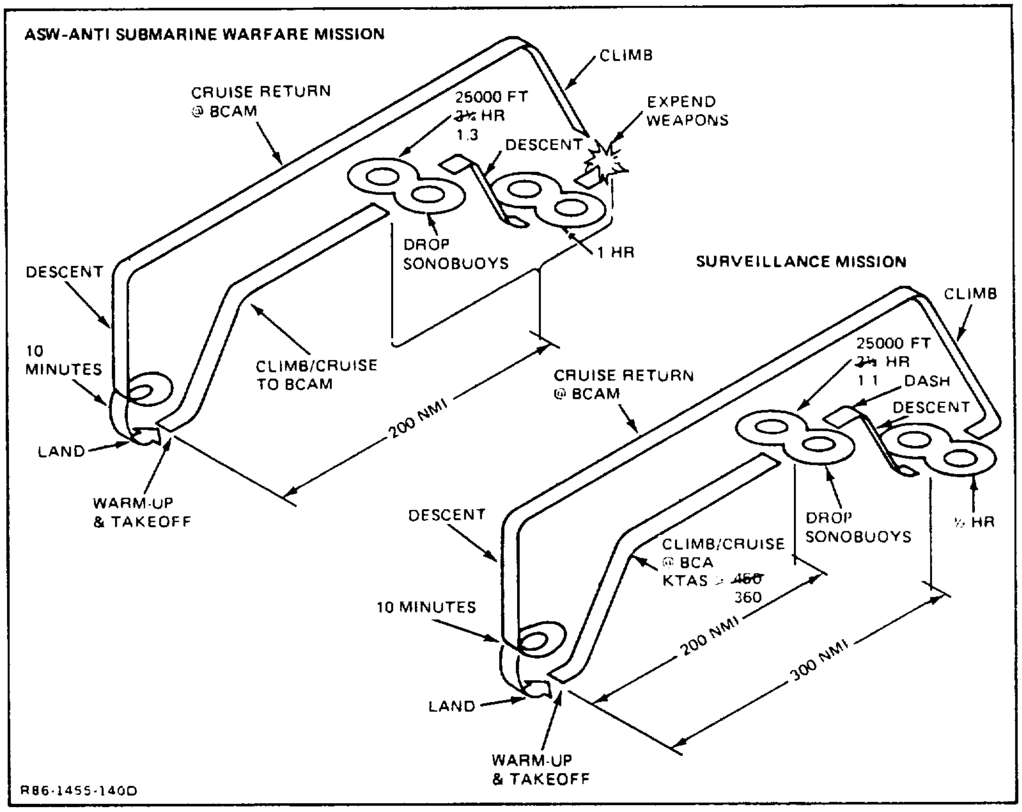

Fig. 119 V/STOL Mission Capability: ASW, Surveillance

Table 24 V/STOL Mission Performance Summary

REQUIREMENT	AEW/C^3	AAW	MIW	ASW	ASUW	VAQ/VQ	SURV
CRUISE SPEED	•	√	•	N.A.	X	•	X
CRUISE RADIUS	√	√	•	√	√	•	√
LOITER ALTITUDE	√	√	N.A.	√	√	√	√
TOS	X	√	N.A.	X	X	√	X
DASH SPEED	N.A.	N.A.	√	N.A.	√	N.A.	√
DASH RADIUS	N.A.	N.A.	√	N.A.	√	N.A.	√

√ MEETS REQUIREMENT

• NEARLY MEETS REQUIREMENT

X FAR SHORT OF REQUIREMENT

N.A. NOT APPLICABLE

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Tradeoffs in radius, speed, loiter time, fuel and payload are required to develop the optimum blend of design parameters and maximize the effectiveness of a V/STOL design. Figure 120 shows sensitivity in mission radius relative to loiter time, altitude and cruise speed for the V/STOL candidate in the AEW mission. Baseline mission goals are also shown for comparison. Similar tradeoffs in future studies would be required for all mission roles along with operational effectiveness trades to develop a fully compliant V/STOL candidate.

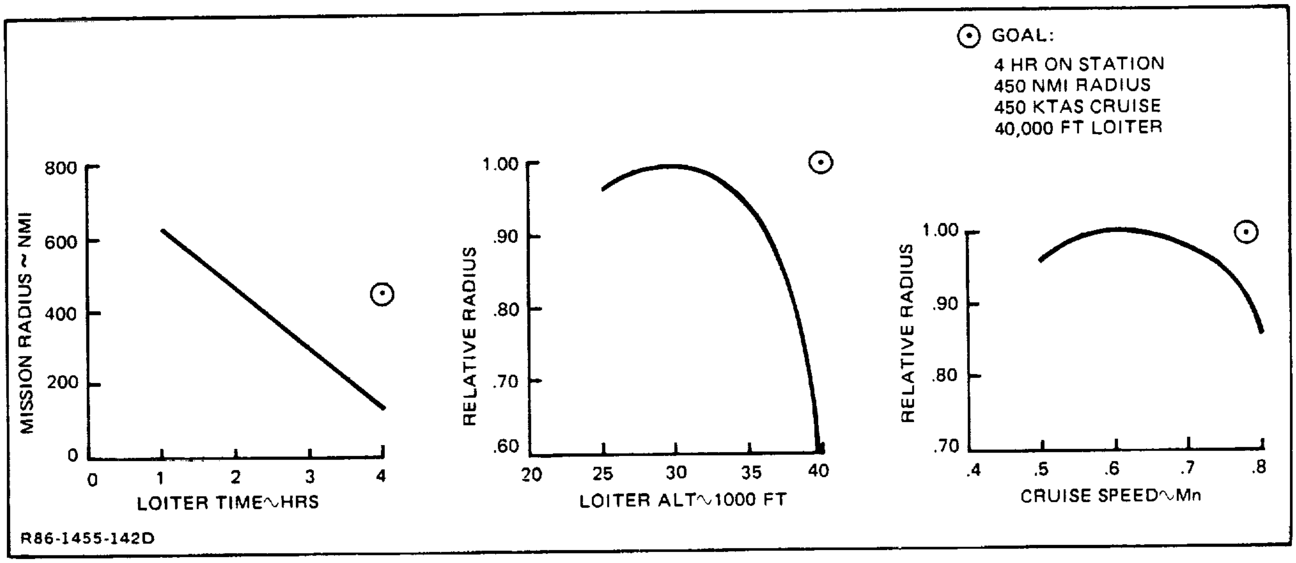

Fig. 120 AEW Mission Sensitivities

11.4 STOVL MISSION SUMMARY

Fallout performance of a STOVL derivative of the V/STOL concept was estimated. The design approach used the V/STOL concept as a point of departure in a development process similar to the one depicted in Fig. 111. Appropriate modifications to this approach for a STOVL concept included:

- Revised fuel allowances
- Engine thrust sized by EVL criteria
- Utilization of maximum internal fuel capacity.

The result of this evaluation is summarized qualitatively in Table 25. Improvements in cruise speed, radius and loiter endurance are shown for the STOVL concept compared to the V/STOL concept.

Table 25 STOVL Mission Performance

REQUIREMENT	AEW/C^3	AAW	MIW	ASW	ASUW	VAQ/VQ	SURV
CRUISE SPEED	√	√	√	N.A.	√	√	√
CRUISE RADIUS	√	√	√	√	√	•	√
LOITER ALTITUDE	√	√	N.A.	√	√	√	√
TOS	X	√	N.A.	•	•	√	X
DASH SPEED	N.A.	N.A.	√	N.A.	√	N.A.	√
DASH RADIUS	N.A.	N.A.	√	N.A.	√	N.A.	√

√ MEETS REQUIREMENT N. A. NOT APPLICABLE

• NEARLY MEETS REQUIREMENT

X FAR SHORT OF REQUIREMENT

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This STOVL concept is still deficient when compared to MR2 requirements. Significant penalties over the CTOL MR2 propfan design include:

- 70% increase in TOGW
- 67% increase in engine core size
- 30% increase in SFC at cruise and loiter
- 145% increase in propulsion fraction.

11.5 V/STOL/STOVL DESIGN SUMMARY

Attempts to develop a fully compliant propfan powered V/STOL or STOVL vehicle were restricted by:

- Low thrust-to-weight engines. Viable V/STOL and STOVL designs require high thrust-to-weight propulsion systems. Preliminary analyses showed that uninstalled engine thrust-to-weight ratios of 6:1 or greater produce aircraft within the carrier weight and geometric constraints shown in Fig. 121
- Missions tailored for CTOL operations. The benefits for V/STOL designs can only be fully realized when they are operated from a dispersed base reducing the required cruise speeds, mission radii and loiter times

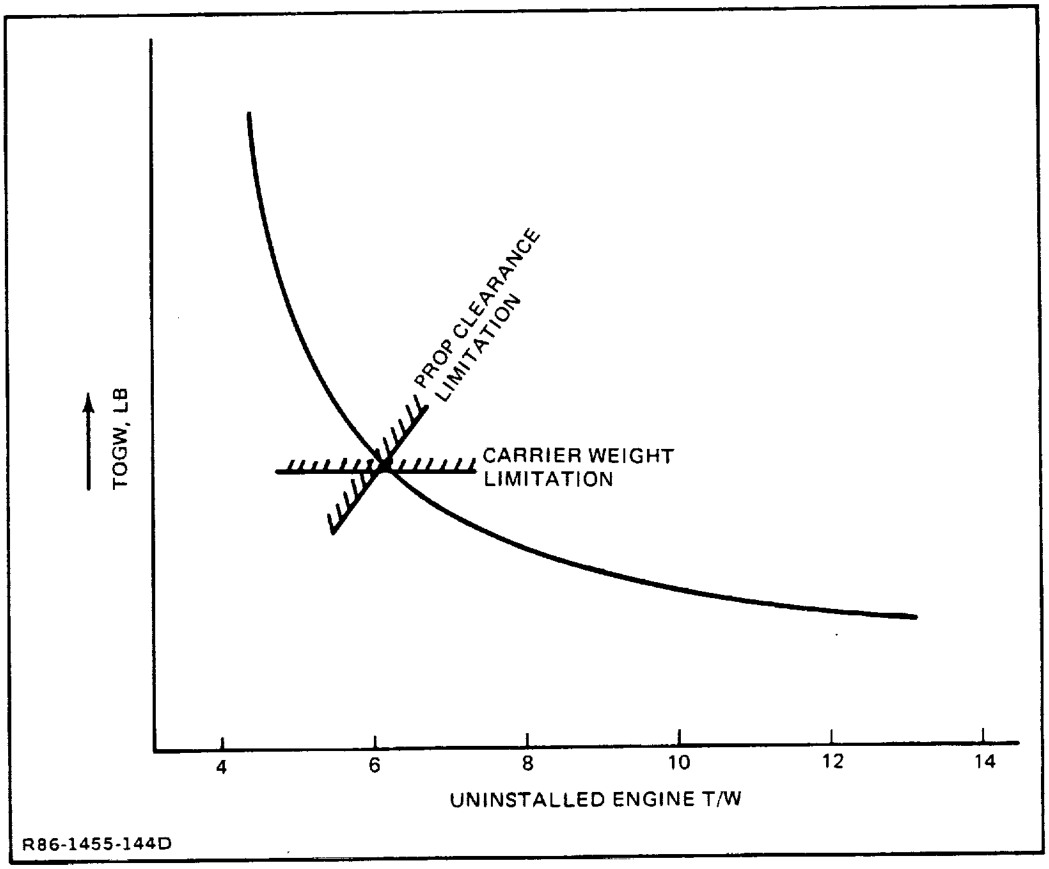

Fig. 121 TOGW Variation with Engine Thrust-to-Weight

- Takeoff and up-and-away engine thrust requirements. Considerable mismatch between these conditions forces low power cruise and loiter operation where SFC characteristics are not optimum. When compared to the MR2 CTOL aircraft the V/STOL design has 21% to 32% increased SFC at loiter and cruise, respectively, as shown in Fig. 122. This results in a fuel burned penalty and reduces mission performance
- Carrier suitability requirements. Conventional wing folding systems, similar to the CTOL designs, could not be employed due to the large wing-mounted propfans. A complicated wing/prop folding scheme is necessary to achieve acceptable V/STOL spotting factor
- Conformal radar installation. Integration of the conformal radar in the wing leading edge is restricted by the large propfan disks.

Mission capability of the V/STOL aircraft is much reduced over the MR2 propfan CTOL design in spite of a 75% TOGW increase. A STOVL derivative design showed improved performance over the V/STOL concept but is less capable and 70% heavier than the MR2 CTOL vehicle. An operations analysis study followed by a change in mission scenarios and requirements to reflect basing on dispersed ships could make V/STOL or STOVL propfan designs more attractive, but the basic limitations listed above still apply. At this time, no basing assumptions could be postulated to accommodate the MPSNA vehicles due to both their large size (68,000 lb) and large numbers per ship.

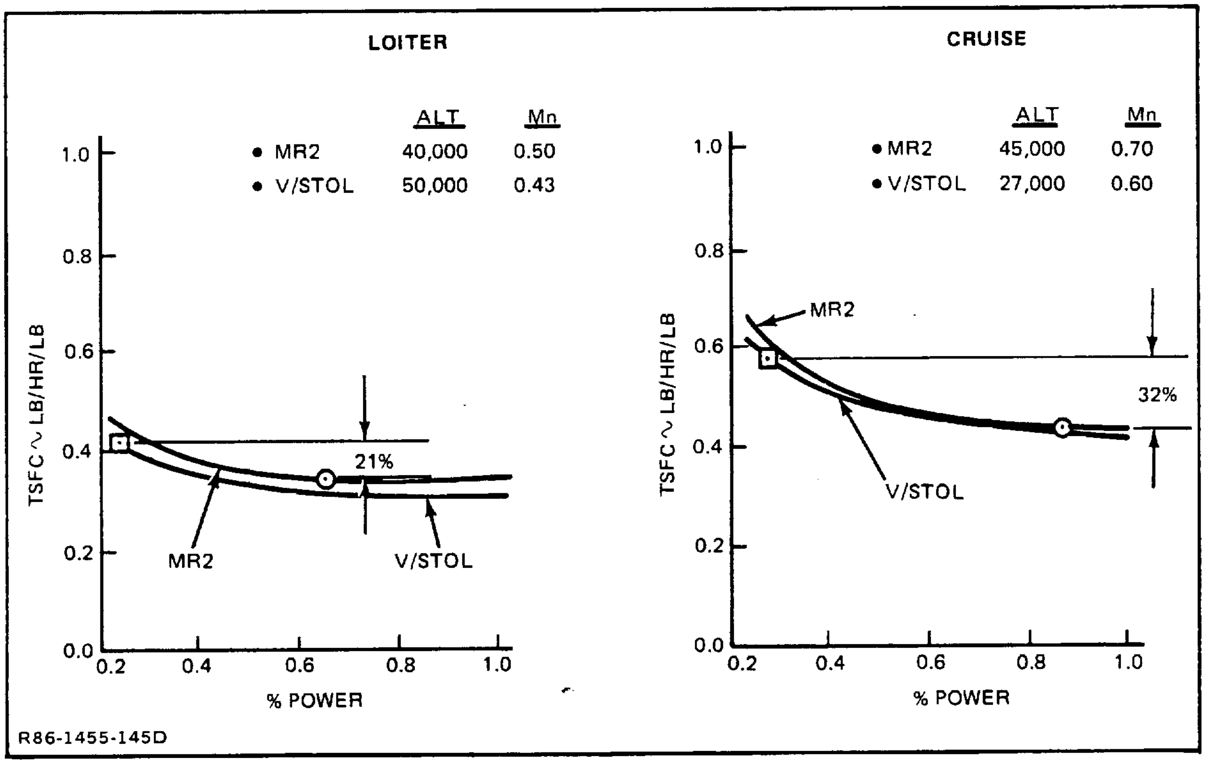

Fig. 122 V/STOL & MR2 CTOL SFC Comparison

More suitable V/STOL mission requirements and scenarios could be obtained from the Navy V/STOL Type "A" studies done in the 1970s and early 1980s. Shorter mission radii and loiter times combined with higher thrust-to-weight engines produced credible V/STOL concepts. Grumman is continuing to pursue this design (Grumman Design 698) under NASA and Navy Studies.

From the results obtained, the propfans available for this study do not lend themselves to V/STOL operation for the Navy missions outlined. Significant breakthroughs in engine thrust-to-weight and more appropriate V/STOL mission scenarios providing equal effectiveness would be required to make propfan powered V/STOL aircraft a viable alternative.

12 - ADVANCED TECHNOLOGY RESEARCH PLAN

12.1 PROPULSION TECHNOLOGIES

Propulsion technologies requiring development to ensure an acceptable level of risk encompass all elements of a potential propfan engine. This includes the gas generator, gearbox, propfan, and components unique to the UDF. The emphasis of a military propfan technology program will be to optimize and redefine the designs being developed for the commercial market.

12.1.1 Engine Technologies

Current engine cycles in both geared and ungeared systems are being optimized for commercial airline service, and are not optimized for carrier based multipurpose use. Engines used in the MPSNA study were representative of a commercial engine with cycle parameters (pressure ratios, operating temperatures, component configurations and efficiencies) selected for that application. The MPSNA mission requirements should be utilized to redefine a military engine cycle appropriate for this aircraft. The most obvious change would be to increase turbine temperatures resulting in higher thrust-to-weight engines while reflecting military, not commercial, service life requirements. In addition, philosophies and ratings consistent with military needs, as discussed in Subsection 9.2.2, should be incorporated in these propfan designs.

Engine components assessed during a military development program may change the commercial designs. The engine size being developed for the commercial market may be too large for an MPSNA configuration, particularly MR2 designs. The gas generator should be assessed with regard to the particular thrust range of interest. Specifically, a compressor could be designed as an axial-axial or an axial-centrifugal based on a combination of requirements, one of which is engine airflow or thrust size.

Near-term component technologies, applicable to geared or ungeared systems, can be demonstrated on a variety of currently available full-scale engines. Engine testing could be timed to take full advantage of programs like APSI/ATEGG/JTDE. Technology advances from these and follow-on programs should be reviewed and incorporated in propfan engine builds as appropriate.

A major material development program is being pursued by both Pratt & Whitney and General Electric under the High Performance Turbine Engine (HPTE) Study funded by the Air Force. This study is directed towards materials for a high temperature engine cycle with application to high speed propulsion systems in the year 2000 time period. These materials could also be utilized for subsonic engines and incorporated in component engine tests. Some of the materials include:

- Metal Matrix Composites
- Intermetallics
- High Temperature Titanium Alloys

- Refractory Metals
- Hybrid Structures
- Polymeric Composites.

The materials technology plan should utilize MPSNA propulsion requirements incorporating moderate temperature composites, high strength metal matrix composites, intermetallics and hybrid structures.

Model testing is underway to confirm pusher designs with respect to exhaust/prop interaction. One solution is to use a lobed exhaust system, discussed in Subsection 4.3, to provide a lower average exhaust temperature to the propfan blades. Three years of tractor model testing provide an excellent background with recovery, distortion, and stability levels established. Development work for tractor applications includes propeller, inlet, and compressor compatibility testing.

12.1.2 Gearbox Technologies

The primary objectives of an advanced gearbox technology program are to design, fabricate and test a high horsepower gearbox. Critical technologies have been identified and a plan formulated to verify readiness by mid-1987. Gearbox program plans are shown in Fig. 123. Generic technologies applicable for advanced commercial and military systems will be generated as a result of these rig tests. Improved analytical code generation is ongoing and will continue in a parallel path with component development.

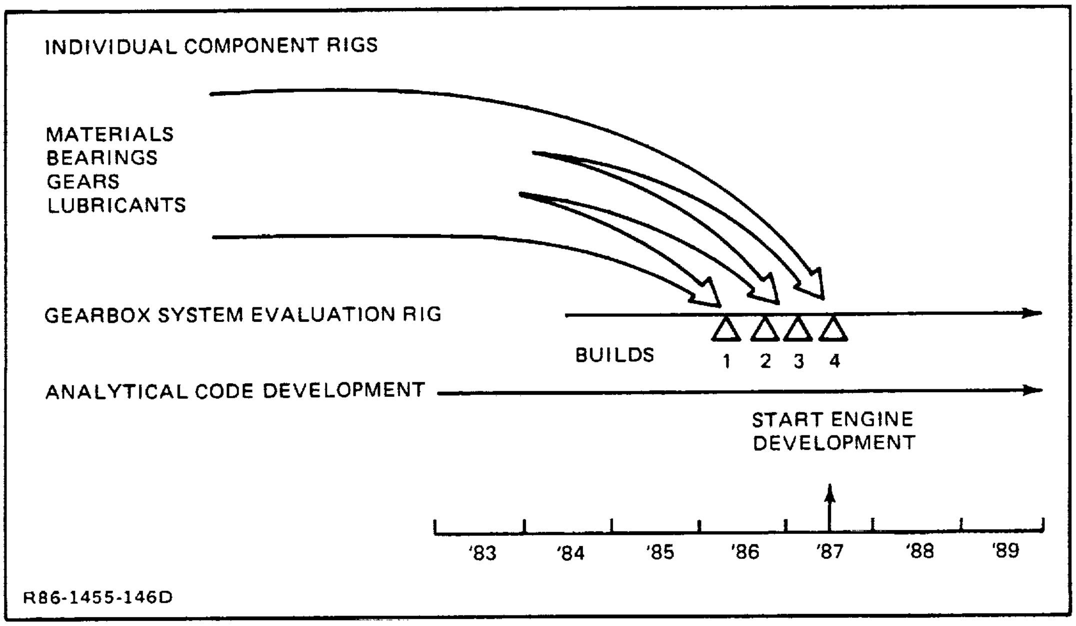

Fig. 123 Gearbox Technology Plan

12.1.3 UDF Fan Engine Technologies

The elimination of the UDF as a preferred MPSNA concept was based on the mismatch between MIW requirements and the high OPR (44:1) of this design. Mission requirements for an MPSNA vehicle have not been fully established and may not include this low altitude dash. In addition, the design of a production version of the UDF concept could be a lower OPR engine design and provide a better match for operation in a high dynamic pressure environment. Due to the uncertainties in both requirements and engine design, technologies necessary for development of a military application UDF follow.

The initial mission profiles being defined by the MPSNA studies indicate the need to increase the subsonic cruise and dash speed and disk loading capability of the unducted blading. The two-foot propulsion simulators currently in use at NASA Lewis and General Electric could be utilized to explore the upper speed and loading capability of blade configurations which incorporate design considerations for reduced RCS signatures. These efforts could be initiated within FY 86. In addition, there exists one-foot propulsion simulators at NASA Langley and several of the airframers. These simulators could be utilized to explore installation effects that will be peculiar to the military applications. Performance effects of close coupling the fuselage/engine could be used to understand the installation and performance tradeoffs with regard to carrier-deck operation and reduced observables. These installation study efforts could be initiated within FY 87.

The counter-rotating turbine utilized in the propulsor has been configured primarily by the commercial engine requirements, and component test rigs will be built by General Electric (in 1987) to further support their performance cycle development. Continued utilization of this component turbine rig could be pursued to determine correct stage loading and other cycle matching parameters for an engine optimized to the MPSNA missions. This effort could be initiated in FY 87 with actual rig test evaluations in FY 88.

Initial core engine tests to support the commercial UDF development will occur in FY 89. The initial demonstrators under the HPTE plan will have gone to test in that time period. Upon completion of this first production configuration UDF, and the first high technology HPTE demonstrator, it would be timely to incorporate the advanced technology as appropriate into the UDF gas generator for verification of this technology application to the smaller thrust class engines being identified by military requirements.

The high speed blading peculiar to the UDF represents a unique materials requirement: fully composite blading which must have low observable features and damage tolerance. Research should be centered on the blading material requirements of the propulsor with special attention paid to low cost material/manufacturing technologies.

The NASA Lewis-supported "Revolutionary Opportunities for Materials and Structures Study (ROMS)," being conducted by General Electric, is pursuing development of a technology plan for a year 2000 UDF engine. This plan will detail advanced engine cycles and advanced material goals. Under this effort, materials and structure applications are being evaluated for utilization in the subsonic propulsion regime for commercial transport category airplanes. Development plans resulting from this study could be scrutinized for synergism with MPSNA propulsion requirements in addition to evaluation of results of the HPTE study, discussed in Subsection 12.1.1. Application of HPTE and ROMS technologies could be used to pursue 6:1 thrust to weight ratio engines. A four-step technology approach to reach this thrust-to-weight goal is illustrated in Fig. 124.

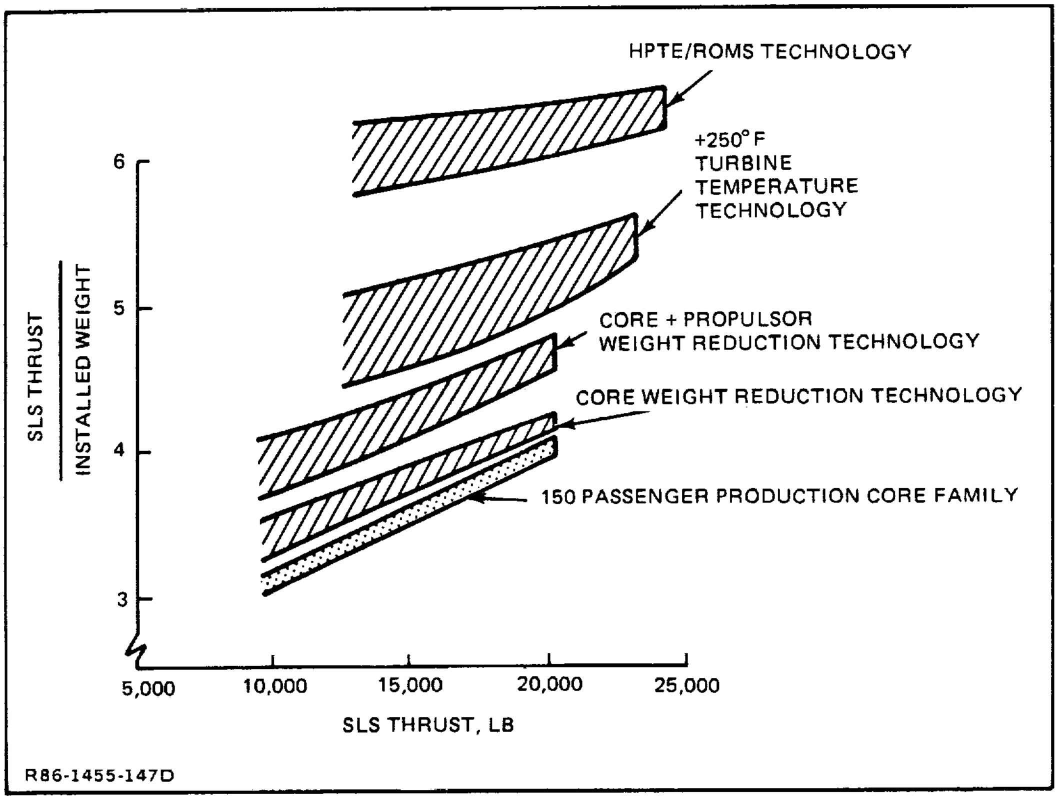

Fig. 124 UDF Projected Thrust-to-Weight Trends

Development of a UDF engine by General Electric for commercial applications continues. A proposed development program of a military derivative UDF through full-scale development is illustrated in Fig. 125. A detailed schedule for technology tasks is shown in Fig. 126.

12.1.4 Propfan Technologies

Technology development plans have been formulated by Hamilton Standard for NASA as part of the APET program. The conceptual design of a pitch change mechanism developed under this program identified advanced technology features which will require development to establish their acceptability for future production. Figure 127 shows a schedule to meet technology readiness for a commercial propfan program in 1988. This should meet technology requirements of a military program with an IOC of 1990 to 1995. The start date for this plan is 1985.

The three technology items to be addressed are a capacitor signal transfer, a high pressure hydraulic power module and a rotating electronic control module. The program will include the design, fabrication and testing of a

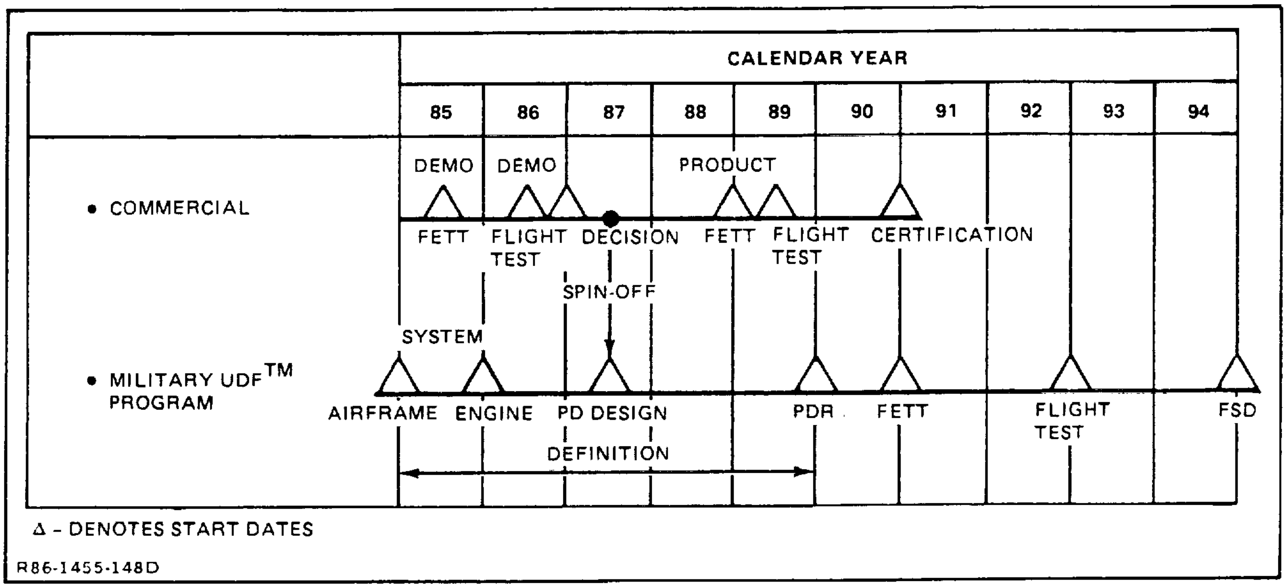

Fig. 125 UDF Military Derivative Development Program

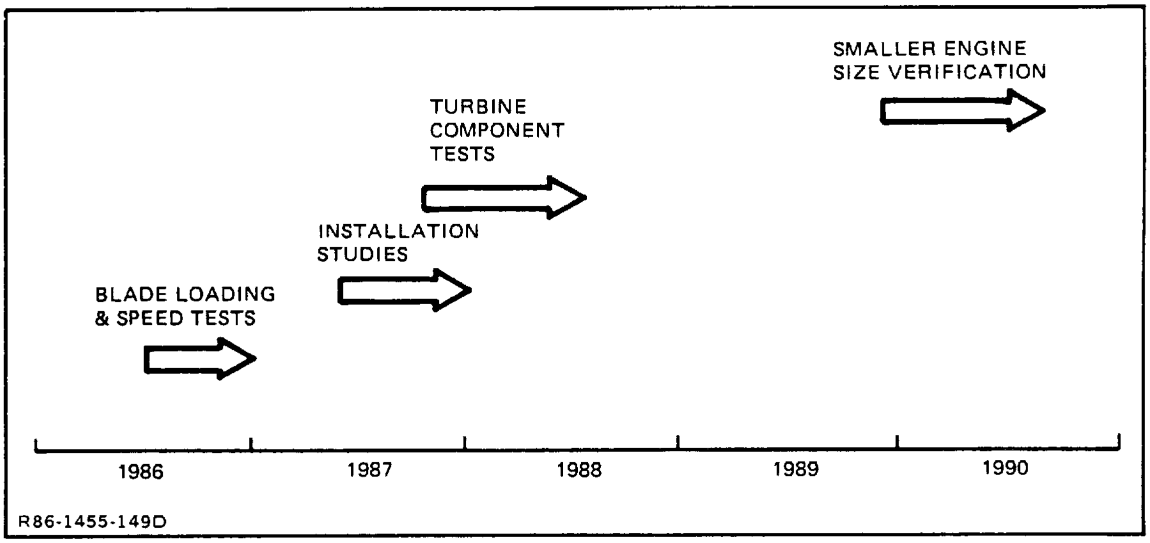

Fig. 126 Proposed UDF Technology Tasks

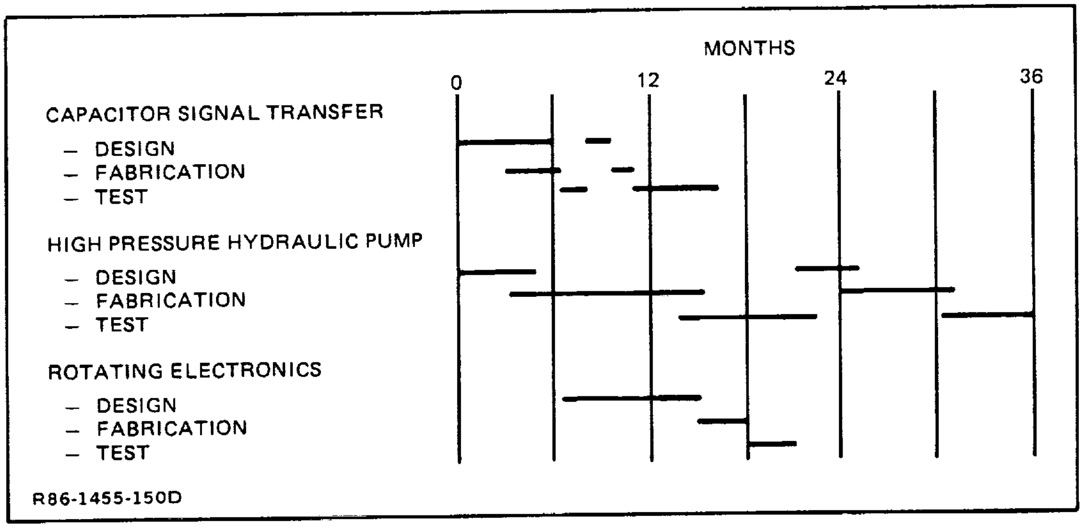

Fig. 127 Propfan Technology Plan

shielded capacitor system to reduce its susceptability to electromagnetic interference and vulnerability to lightning strike interference while ensuring that the capacitor does not emit electromagnetic interference. The control signal transfer technique developed will be adaptable to propfan systems and will eliminate the need for brushes and slip rings.

The second item in the technology plan is to design and build a gear pump sized for the requirements of a propfan system. The program will establish the feasibility of a 4750 psi gear pump and define hardware suitable for advanced pitch change systems. Testing to determine torque characteristics, leakage, endurance and susceptibility to cavitation will be conducted.

The remaining technology feature to be addressed in this program is the operational characteristics and survivability of an electronic controller operating in a rotating field. Environmental requirements of this system will be established and dynamic tests conducted. These include whirl and vibration tests. These programs, coupled with ongoing programs, will provide technology readiness of a propfan prior to launch of a military 1990s aircraft.

12.2 ADVANCED MATERIALS & MANUFACTURING TECHNOLOGIES

A comprehensive summary of candidate materials and manufacturing process technologies for advanced composites is presented in Fig. 128. This summary highlights the improved materials, manufacturing and assembly technologies that will be evaluated and developed, if applicable, to reduce the MPSNA TOGW and cost. Included are the structural applications, some advantages and disadvantages, a technology time line and, if currently not available, tasks required for implementation.

Advanced titanium and aluminum manufacturing and assembly processes are shown in Fig. 129 and 130. Availability dates of these processes, based on the development of specific technologies or facilities, are generally categorized as either Near Term (1995) or Far Term (2001).

TECHNOLOGY	APPLICATIONS	ADVANTAGES	DISADVANTAGES	TECHNOLOGY TIME LINE	IMPLEMENTATION
1. IMPROVED MATERIALS					
IMPROVED MATRICES	UNIVERSAL	HIGHER STRAIN AFTER MOISTURE EXPOSURE AT HIGHER SERVICE TEMP	NEW DESIGN ALLOWABLES REQUIRED		UNDER DEVELOPMENT. WILL NOT BE QUALIFIED BY TAD
IMPROVED FIBERS & INCREASED USE OF HYBRIDS	UNIVERSAL	HIGHER SPECIFIC PROPERTIES	NEW DESIGN ALLOWABLES REQUIRED. IMPROVED MATRICES REQUIRED		UNDER DEVELOPMENT. WILL NOT BE QUALIFIED
LOWER-RESIN-CONTENT PREPREGS	UNIVERSAL	LOWER FABRICATION COSTS. IMPROVED WEIGHT CONTROL	IMPROVED FACILITIES & VERIFICATION REQUIRED		UNDER DEVELOPMENT. WILL NOT BE QUALIFIED
THERMOPLASTIC MATRICES (GR/PEEK)	LIGHTLY LOADED STRUCTURES	POTENTIAL FOR RAPID PROCESSING	NEW DESIGN ALLOWABLES REQUIRED		UNDER DEVELOPMENT. WILL NOT BE QUALIFIED
2. IMPROVED TOOLING					PRODUCTION READY
THERMALLY-COMPENSATED TOOLING	UNIVERSAL	CUTTER DIMENSIONAL CONTROL	HIGHER TOOL DESIGN COSTS		
NICKEL-ELECTROFORM INNER MOLD LINE COVER TOOLS	COVERS	IMPROVED FIT-UP TO SUBSTRUCTURE. LOW COST FOR MULTIPLE TOOLS	DIFFICULT TO MAKE CHANGES. OUTER CONTOUR FINISH & TOLERANCES RELAXED		IN PRODUCTION
MOLDING RIBS, SPARS & LOWER COVERS CONCURRENTLY (CO-CURING)	FINS HORIZONTAL STABILIZER	MINIMIZES FIT UP TIME & PART TRACKING	COMPLEX TOOLING. KITTING OF LAYUPS REQD TO MAINTAIN SCHEDULE. VERIF REQD		TECHNOLOGY AVAILABLE PRODUCTION FACILITIES REQUIRED
MOLDING STRINGERS MINOR FRAMES & SKINS CONCURRENTLY (CO-CURING)	FUSELAGE	MINIMIZES FIT-UP TIME & PART TRACKING	COMPLEX TOOLING. KITTING OF LAYUPS REQD TO MAINTAIN SCHEDULE. VERIF REQD		SCALE-UP OF EXISTING CONCEPT. PRODUCTION FACILITIES REQUIRED
PADDED TOOLS FOR INTEGRAL SKIN/SPAR ASSEMBLY	TORQUE BOXES	LESS MARK-OFF ON COVERS			NEEDS CONCEPT DEMONSTRATION
IMPROVED REMOVABLE MANDRELS FOR INTEGRAL STRUCTURE	UNIVERSAL	INCREASED DESIGN, FLEXIBILITY & DIMENSIONAL CONTROL. LOWER COST	REQUIRES IMPROVED TECHNOLOGY FOR REMOVING INTERNAL TOOLING		AFTER QUALIFICATION (UNDER DEVELOPMENT)
3. IMPROVED PLY GENERATION					PRODUCTION READY
TAPE PREPREG IN ROLLS IN 90° & ±45° ORIENT	UNIVERSAL	REDUCED IN-HOUSE HANDLING. INCREASES OUTPUT OF NC CUTTER	REDUCED STRUCTURAL EFFICIENCY		
UTILIZE NEW GERBER 60 IN. PLY CUTTER	UNIVERSAL	SIXTY-INCH MATERIAL AVAILABLE. FEWER PLY SEGMENTS TO HANDLE	POTENTIAL FOR HIGHER TRIM SCRAP. STACKING PROBLEMS		CUTTER AVAILABLE FOR PRODUCTION
STRUCTURALLY-OPTIMIZED FABRICS (STYLE 143 OR UNIWEAVE)	UNIVERSAL	REDUCED IN-HOUSE HANDLING. INCREASES OUTPUT OF NC CUTTER	REDUCED STRUCTURAL EFFICIENCY		AFTER QUALIFICATION (UNDER DEVELOPMENT)
4. INCREASED USE OF AUTOMATED PLY STACKING FOR CONTOURED PARTS	FUSELAGE	REDUCED LABOR COST. INCREASED REPRODUCIBILITY	REQUIRES EXTENSIVE DEVELOPMENT TO IMPROVE EXISTING SYSTEMS		TECHNOLOGY AVAILABLE FOR MODERATE CONTOURS. ADDITIONAL FACILITIES REQD FOR PRODUCTION.
5. IMPROVED AUTOCLAVE PROCEDURES (HIGHER-PRESSURE CURES, COMPUTER CONTROL)	UNIVERSAL	REDUCED LABOR COST & FLAWS	FACILITIES REQUIRED		TECHNOLOGY READY. ADDITIONAL FACILITIES & MODIFICATIONS REQUIRED
6. NON-AUTOCLAVE CURING					
ENERGY RESISTANT MATERIAL (ERM) PROCESS	PANELS	IMPROVED RESISTANCE TO HYDRAULIC RAM IMPACT. LOW-COST CORE SUBSTITUTE	SLIGHTLY HIGHER WEIGHT & TOOLING COSTS		TECHNOLOGY READY. ADDITIONAL FACILITIES READY FOR PRODUCTION
SHEET MOLDING COMPOUNDS (SMC) & CHOPPED-FIBER COMPOUNDS	LIGHTLY LOADED COMPLEX SHAPES	IMPROVED DIMENSIONAL CONTROL. LOW LABOR COSTS	REDUCED PROPERTIES. HIGH TOOLING COSTS		PRODUCTION READY
VACUUM CURING OF PRE-BLED PARTS IN OVEN	UNIVERSAL	LARGER-SIZE PARTS AT MODERATE FACILITY COSTS	POTENTIAL FOR LOWER PROPERTIES. REQUIRES EXTENSIVE EVALUATION & VERIFICATION		PROMISING RESULTS FROM CURRENT DEVELOPMENT PROGRAM. MUST BE QUALIFIED
PRESS-MOLDINGS OF CONVENTIONAL PREPREGS	SECONDARY STRUCTURE	IMPROVED DIMENSIONAL CONTROL. LOW LABOR COSTS	POTENTIAL FOR POROSITY. HIGH TOOLING COSTS		PRODUCTION READY. HIGH VOLUME WOULD REQUIRE SOME ADDITIONAL FACILITIES
7. IMPROVED ASSEMBLY METHODS					
ROBOTIC ASSEMBLY	UNIVERSAL	REDUCED LABOR COST. INCREASED REPRODUCIBILITY	SYSTEM OFF-LINE FOR EXTENDED PERIODS		INITIAL TECHNOLOGY READY. FURTHER TECHNOLOGY REQUIRED FOR FULL PRODUCTION
IMPROVED DRILLING PROCEDURES (ADAPTIVE CONTROL, NEW CONFIGS)	UNIVERSAL	IMPROVED HOLE QUALITY	FURTHER DEVELOPMENT REQUIRED		MUST BE QUALIFIED. IMPROVED TOOLS & PROCESSES ARE AVAILABLE
8. IMPROVED INSPECTION & FLAW DETECTION TECHNIQUES & AUTOMATED NDI	UNIVERSAL	IMPROVED CONFIDENCE IN STRUCTURE. POSSIBILITY OF HIGHER ALLOWABLES			PRODUCTION READY
R86-1455-151D				1980 1990 2000	

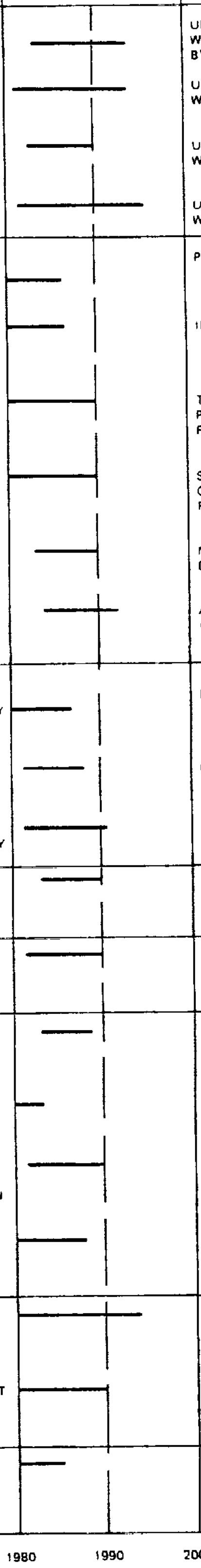

Fig. 128 Candidate Advanced Manufacturing Process Technologies for Composites

TECHNOLOGY	MATERIALS	APPLICATIONS	ADVANTAGES	DISADVANTAGES	IMPLEMENTATION
SUPER-PLASTIC FORMING (SPF)	TI 6AL-4V TI 6AL-6V-2SN TI 6-2-4-2	MODERATE USE FOR FRAMES, RIBS, STRINGERS, LONGERONS STIFFENERS	REDUCED PARTS COUNT. COST, WEIGHT. INCREASED FORMABILITY & PART COMPLEXITY	POOR MATERIAL UTILIZATION. PARTS MUST BE TRIMMED AFTER FORMING	PRODUCTION-READY FACILITIES. HIGH VOLUME WOULD REQUIRE ADDIT FACILITIES FAR TERM
WELDED BUILT UP STRUCTURES	ALL TITANIUM ALLOYS	MODERATE USE FOR FRAMES, BULKHEADS, FITTINGS, LANDING GEAR	REDUCED COST, WEIGHT. INCREASED THROUGHPUT & NEAR-NET-SHAPE SIZE POTENTIAL	REQUIRES STRESS RELIEF AFTER WELDING SPECIAL TOOLING & WELD REPAIR REQUIRED	PRODUCTION READY NEAR TERM FAR TERM
LASER TRIMMING	LIMITED TO TITANIUM & STEEL SHEET PRODUCTS	SELECTIVE USE FOR TITANIUM AND STEEL SHEET METAL APPLICATIONS	MINIMAL TOOLING REQUIREMENTS. REDUCED LABOR INTENSITY	LIMITED TO TITANIUM & STEEL SHEET	ADAPT TO DETAIL PART REQUIREMENTS NEAR TERM
SUPERPLASTIC FORMING/DIFFUSION BONDING (SPF/DB)	TI 6AL-4V TI 6AL-6V-2SN TI 6-2-4-2	MODERATE USE FOR FRAMES, DECKS, BLKHDS, DOORS, VANES	REDUCED PARTS FASTENERS, WEIGHT, COST. IMPROVED DESIGN FLEX. MMC COMPATIBLE	INSPECTABILITY. REPAIRABILITY ISSUES. PARTS TRIMMED AFTER FORMING	PRODUCTION-READY FACILITIES. HIGH VOLUME WOULD REQUIRE ADDIT FACILITIES FAR TERM
ROOM-TEMP FORMABLE SHEET	TI 15-3 (TI 15-3-3-3)	MODERATE USE FOR FRAMES & STIFFENERS	COLD FORMABLE BEFORE SOL. HT. TR., REDUCING MFG COST. EXCELLENT MECH PROPERTIES	POTENTIAL COSTS FOR CLEANING & CHEM MILLING	PRODUCTION READY FACILITIES. HIGH VOLUME WOULD REQUIRE ADDITIONAL FACILITIES NEAR TERM
HOT ISOSTATIC PRESSING (HIP)	PREP. POWDERS TI 6-4, 6-6-2 TI 10-2-3 CORONA 5	SELECTED APPLICATIONS SUCH AS FITTINGS, BLKHDS, LANDING GEAR	INCR. DESIGN FLEX. NEAR-NET SHAPES. WIDE SIZE RANGE. MMC COMPATIBILITY	REQUIRES COSTLY IN PROCESS CONTROLS SINGLE SOURCE FOR POWDER & HIP	PRODUCTION-READY BUT LIMITED TO SINGLE SOURCE. NEAR TERM
ISOTHERMAL (HOT-DIE) FORGING	TI 6AL-4V TI 6AL-6V-2SN TI 10-2-3 TRANSAGE 175	SELECTED APPLICATIONS SUCH AS FITTINGS, BLKHDS, LANDING GEAR	NEAR-NET SHAPES. COST-COMPETITIVE TO HIP PROCESS	VERY EXPENSIVE TOOLING. PART SIZE & SHAPE LIMITATIONS	PRODUCTION-READY BASED ON SIZE & SHAPE LIMITATIONS NEAR TERM
ADVANCED TI CASTINGS	TI 6AL-4V TI 10-2-3 TRANSAGE 175	SELECTED APPLICATIONS SUCH AS ENGINE COMPT.	REDUCED PARTS COUNT. NET SHAPES, IMPROVED DESIGN FLEX. & MECH PROPERTIES	FOR HIGH-QUANTITY APPLICATIONS. REPAIR WELDING REQUIRED. HIGH SCRAP RATE	PRODUCTION-READY BUT LIMITED NUMBER OF SOURCES. NEAR TERM
DIFFUSION BONDING (DB)	TI 6AL-4V	SELECTED APPLICATIONS SUCH AS LARGE FRAMES, BLKHDS HEAVY FITTINGS	REDUCED MACHINING COSTS, PARTS & FASTENER COUNTS & LABOR	SERIOUS INSPECTION CONCERNS. SOLE PROD SOURCE. EXPENSIVE TOOLING	ONLY PRODUCTION FACILITY IS ROCKWELL GRUMMAN HAS TECHNICAL CAPABILITY FAR TERM
STRESS-WAVE RIVETING	A-286 RIVETS & TI PLUGS IN ALL STEEL & TI MATERIALS	MODERATE USE	FATIGUE ENHANCEMENT. REDUCED LABOR COST APPLIC TO DRIVEMATIC FUEL SEALING TECHNO.	REQUIRES DEDICATED AUTOMATED WORK STATIONS. HIGH TOOLING COSTS	WOULD REQUIRE AUTOMATION. PRESENT CAPABILITY IS MANUAL NEAR TERM
WELD-BONDING	ALL TI SHEET & TI METAL-MATRIX COMPOSITES	SELECTED APPLICATIONS SUCH AS DOORS, COVERS & PANELS	REDUCED FASTENERS TOOLING & WEIGHT IMPROVED FATIGUE PROPERTIES	COSTLY IN-PROCESS CONTROLS	TECHNICALLY AVAILABLE BUT NOT PRESENTLY UTILIZED FAR TERM
WELD-BRAZING	ALL TI SHEET & TI METAL-MATRIX COMPOSITES	SELECTED APPLICATIONS SUCH AS ENGINE COMPT.	IMPROVED JOINT STRENGTH	COSTLY ELEVATED-TEMPERATURE PROCESS HIGH-TEMP. VACUUM FURNACE REQUIRED	TECHNICALLY AVAILABLE BUT NOT PRESENTLY UTILIZED FAR TERM
TITANIUM-MATRIX COMPOSITES	BORON/TI & SICF/TI	SELECTED APPLICATIONS SUCH AS LOCAL REINF. OF CRITICAL AREAS IN FITTINGS	HIGH SPECIFIC STRENGTH AND STIFF. HIGH TRAN & TEMP SPF/DB & HIP COMPATIBLE	HIGH FIBER, CONSOLIDATION COSTS. LIMITED MECH PROPS VARY	LIMITED SOURCES WITH SCALE-UP CONCERNS FAR TERM

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Fig. 129 Candidate Advance Manufacturing Process Technologies for Titanium Alloys

TECHNOLOGY	MATERIALS	APPLICATIONS	ADVANTAGES	DISADVANTAGES	IMPLEMENTATION
LOW-COST FASTENERS	7050 RIVETS. STL. TI GROOVE -PREPORT (GP) LOCKBOLTS	REPLACEMENT FOR DD RIVETS. REPLACEMENT FOR HI-TIGUE FASTENERS	ROOM TEMP STRENGTH OF DD RIVET. NO SHELF LIFE REQUIREMENT ADAPTS TO DRIVEMATIC	REQUIRES HIGHER DRIVING FORCES. REQUIRES SPECIAL TOOLING FOR DRIVEMATIC	PRODUCTION READY. NOW BEING USED ON C-2 PROGRAM NEAR TERM
AUTOMATED ASSEMBLY DRILLING	ALL ALUM. & TI ALLOYS	MODERATE USE ON WING BOX STRUCTURES	REDUCED LABOR INTENSITY, IMPROVED QUALITY	LIMITED TO WING BOX TYPE STRUCTURES	ADAPT TO ASSEMBLY REQUIREMENTS NEAR TERM
ADVANCED CASTINGS	ALUM. ALLOYS A357 & A201	SELECTIVE APPLICATIONS SUCH AS CANOPY FRAMES, SPEED BRAKES, INLET FRAMES	REDUCES PARTS COUNT MAKES COMPLEX SHAPES. FATIGUE IMPROVEMENTS WITH HIP	LIMITED ALLOY SELECTION. TOOLING COSTS JUSTIFIED FOR HIGH-VOLUME APPLIC	A357 COMMERCIALLY AVAILABLE. A201 REQUIRES DEVELOPMENT FAR TERM
ROBOTICS	ALL ALUM. ALLOYS	MODERATE USE FOR DETAIL PARTS & ASSEMBLIES	REDUCED LABOR INTENSITY. IMPROVED QUALITY. IMPROVED THROUGHPUT	APPLICATIONS MAY BE LIMITED TO ALUMINUM STRUCTURES	ADAPT TO DETAIL PART REQUIREMENTS DEVELOP ROBOT ASSY TECHNOLOGY FAR TERM
ADVANCED MACHINING CELLS	ALL ALUM. & TI ALLOYS	EXTENSIVE APPLICATIONS FOR BULKHEADS, BEAMS & FRAMES	REDUCED LABOR INTENSITY. IMPROVED MACHINE UTILITY. INCREASED THROUGHPUT	INITIAL CAPITAL INVESTMENT REQUIRED	DEVELOPMENT OF GANTRY -STYLE MACHINE TECHNOLOGY REQUIRED FAR TERM
SUPER-PLASTIC FORMING (SPF)	SUPRAL 100. 150 & 220. 7475. ALUM. -LITHIUM	EXTENSIVE APPLICATIONS FOR SECONDARY STRUCTURE & DOORS	IMPROVED FABRICABILITY, REDUCED PARTS, LABOR COSTS & WEIGHT	PRESENTLY LIMITED TO SECONDARY STRUCTURE	DEVELOPMENT FOR HIGH-STRENGTH ALLOYS REQUIRED FAR TERM
ULTRASONIC WELD-BONDING	MOST ALUM. SHEET ALLOYS & AL-MMC	SELECTIVE APPLICATIONS SUCH AS SKIN/STRINGER PANELS & DOORS	IMPROVED STRUCTURAL EFFICIENCY. CRACK GROWTH PROPERTIES. REDUCED PROD COST	MAY NOT BE COST-COMPETITIVE WITH DRIVEMATIC. MORE MATL & PROCESS CONTROL	TECHNOLOGY AVAILABLE BUT NOT PRESENTLY BEING UTILIZED FAR TERM
ROLL--BONDING	MOST ALUM. SHEET ALLOYS	SELECTIVE APPLICATIONS FOR SECONDARY STRUCTURE & DOORS	COMPATIBLE WITH ALUM SPF. REDUCED PARTS & FASTENERS. MAY REDUCE TOOL REQUIREMENTS	PART SIZE/SHAPE LIMITATIONS. HIGH -VOLUME APPLICATIONS REQUIRE CLAD MATL	WOULD REQUIRE SPECIAL ROLLING MILL FACILITIES FAR TERM
ALUM. -MATRIX COMPOSITES	BORON/AL SICF/AL SICW/AL SICP/AL	SELECTIVE APPLICATIONS FOR LOCAL REINFORCEMENT	HIGH SPECIFIC STRENGTH & STIFFNESS HIGH TEMPS. TAILORABILITY	HIGH MATERIAL & MFG COSTS LIMITED SHAPES. SHT. PLATE SCALE-UP. LIM. DATA	LIMITED MATERIAL & CONSOLIDATION SOURCES. HIGH-VOLUME CAPABILITY QUESTIONABLE FAR TERM
ADHESIVE LAMINATING OF METALS	ALL ALUM., TI AND STEEL ALLOYS	SELECTIVE APPLICATIONS	FATIGUE ENHANCEMENT REDUCED WEIGHT, COST. REDUCED FASTENER COUNT	GREATER IN-PROCESS CONTROLS. SPECIAL HANDLING. INCOMPLETE DATABASE	TECHNOLOGY AVAILABLE BUT NOT PRESENTLY BEING UTILIZED FAR TERM

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Fig. 130 Candidate Advanced Manufacturing Process Technologies for Aluminum Alloys

13 - CONCLUSIONS

The results of this study indicate that propfan propulsion is a viable power plant for the CTOL missions outlined. The benefits of using propfans are:

- A 10% reduction in aircraft Takeoff Gross Weight (TOGW) when compared to an equivalent technology turbofan aircraft
- A 6 to 11% reduction in engine thrust required when compared to an equivalent technology turbofan aircraft
- A more than 50% reduction in mission fuel required when compared to an equivalent technology aircraft.

Application of a propfan to an advanced multimission Navy Support vehicle indicates that all the FOM established for this study are in favor of the propfan propulsion system as compared to the turbofan system.

From the results obtained, the propfans available for this study do not lend themselves to vertical operation for the Navy missions outlined. This is a result of:

- Low thrust-to-weight ratio propfan engines. The installed tropical day thrust-to-weight ratio of these propulsion systems is less than 3.5
- Missions tailored to conventional Navy operations with high cruise speeds, long loiter times and mission radii
- Increased fuel required when compared to a vehicle sized by conventional requirements. Low power propfan engine operation where Specific Fuel Consumption (SFC) characteristics are not optimum result from considerable mismatch between vertical takeoff and flight thrust requirements.

Propfan propulsion is a viable power plant for an MPSNA, assuming the necessary technologies are developed. Grumman will continue to evaluate propfans in future mission support aircraft studies as these technologies emerge.

APPENDIX A - SYMBOLS & ABBREVIATIONS

AAW - Anti-Air Warfare
A_C / A_{THR} - Inlet duct capture area to inlet throat area - contraction ratio
ACAP - Inlet Capture Area, in^2
A_{ENG} / A_{THR} - Inlet duct area at engine flange to inlet throat area-diffusion ratio
AEW - Airborne Early Warning
a/g - Longitudinal Acceleration
AI - Artificial Intelligence
ALQ - Airborne Countermeasures Special Purpose
ALWT - Advanced Light Weight Torpedo
AMRAAM - Advanced Medium Range Anti-Air Missile
APET - Advanced Propfan Engine Technology
APSI - Aerodynamic Propulsion System Integration
APU - Auxiliary Power Unit
AR - Aspect Ratio
ASW - Anti-Submarine Warfare
ASUW - Anti-Surface Warfare
ATEGG - Advanced Turbine Engine Gas Generator
ATES - Advanced Technology Engine Study
A_W - Wetted Area, ft^2

BCA - Best Cruise Altitude
BCAM - Best Cruise Altitude and Mach number
BL - Butt Line
BPR - Bypass Ratio

C_D - Drag Coefficient
C_{D_P} - Parasitic Drag Coefficient
C_f - Friction Coefficient
C_{f_e} - Equivalent Friction Coefficient

CFD - Computational Fluid Dynamics
CG - Center of Gravity
C_L - Lift Coefficient
C/L - Centerline
COD - Carrier Onboard Delivery
C_P - Power Coefficient
CTOL - Conventional Takeoff and Landing
C^3 - Command, Communication, Control

D_{BOAT} - Boattail Drag, lb
DECM - Defensive Electronic Counter Measures
DIA - Diameter, ft

D_{SCRUB} - Scrubbing Drag, lb

ECM - Electronic Counter Measures
ECS - Environmental Control System
ELINT - Electronic Intelligence
EVL - Emergency Vertical Landing
EW - Electronic Warfare

FCS - Flight Control System
FDGW - Flight Design Gross Weight, lb
FETT - First Engine to Test
Fn - Net Thrust, lb
FOM - Figures of Merit
FS - Fuselage Station
FSD - Full Scale Development
ft - Feet
FUS - Fuselage
FY - Fiscal Year
F* - Sea Level Static Uninstalled Maximum Thrust, lb

GE - General Electric
Gr/Ep - Graphite Epoxy

HARM - High Performance Anti-Radiation Missile
HIP - Hot Isostatic Pressing
HP - Horsepower
HPTE - High Performance Turbine Engine Study
hr - hour(s)

in. - inches
IOC - Initial Operating Capability
IR - Infra-red
IR&D - Independent Research and Development

JTDE - Joint Technology Demonstrator Engine

KTAS - Knots True Air Speed

LAP - Large-Scale Advanced Propfan
lb - Pounds
LDGW - Landing Design Gross Weight, lb
LE - Leading Edge
LFC - Laminar Flow Control
L/D - Lift to Drag Ratio

MAC - Mean Aerodynamic Chord
max - Maximum
min - Minimum
MISC - Miscellaneous
MIW - Mine Warfare
MMC - Metal Matrix Composite

MMVX - Multi-mission carrier based experimental aircraft
Mn - Mach number
MPSNA - Multiple Purpose Subsonic Naval Aircraft
MR1 - Mission Requirements 1
MR2 - Mission Requirements 2

N - Engine Speed, revolutions per minute
NACA - National Advisory Committee for Aeronautics
NADC - Naval Air Development Center
NLF - Natural Laminar Flow
nmi - Nautical Miles
N_zW - Ultimate Load Factor times Flight Design Gross Weight

OEI - One Engine Inoperative
OPR - Overall Pressure Ratio

PD - Preliminary Design
PDR - Preliminary Design Review
psi - Pounds per square inch
P_T - Total Pressure - lb/in^2
PTA - Propfan Test Assessment
P_{T1}/P_{TO} - Propfan pressure rise
P_{T2}/P_{T1} - Inlet duct pressure recovery
P_{T2}/P_{TO} - Total pressure recovery
P&WA - Pratt & Whitney Aircraft

R - Gas Constant - Ft-lb/lb/°R
Rad - Radians
RCS - Radar Cross Section
Re_L - Reynold's Number per unit Length
RENO - Reynold's Number
R_f - Roughness Factor
ROMS - Revolutionary Opportunities for Materials and Structures Study
RPM - Revolutions per minute
R/C - Rate of Climb

Sec - Second
SERC - Single Engine Rate of Climb
SFC - Specific Fuel Consumption
SHP/d^2 - Propfan disk loading, hp/A^2
SIGINT - Signal Intelligence
SLS - Sea Level Static
SPF/DB - Superplastic Forming/Diffusion Bonding
SR - Single Rotation
S_{ref} - Wing Reference Area, ft^2
STA - Station
STOVL - Short Takeoff and Vertical Landing
SURV - Surveillance Mission
S_w - Wing Area, ft^2
S_{wet} - Aircraft wetted area, A^2

TAD - Technology Availability Date
TAMB - Ambient Temperature (Static), °F
TI - Titanium
TO - Takeoff
TOGW - Takeoff Gross Weight, lb
TOS - Time on Station, hrs
TSFC - Thrust Specific Fuel Consumption - lb/hr/lb
T_T - Total Temperature - °F
T_{T1}/T_{TO} - Propfan Temperature Rise
T_2 - Total Temperature at Compressor Face, °F
T_4 - Combustor Exit Temperature - °F
t/c - Root thickness to Chord ratio
T/W - Thrust-to-Weight ratio

UDF - Unducted Fan Engine
UHF - Ultra High Frequency

VAQ/VQ - Support/Standoff Electronic Warfare
V_{app} - Approach Speed, KTAS
$V_{S_{PA}}$ - Power on stall speed, KTAS
V/STOL - Vertical or Short Takeoff and Landing
V_{TIP} - Propfan tip speed, ft/sec
W - Aircraft weight, lb
W_a - Airflow, lb/Sec
$W_{a_{cor}}$ - Corrected airflow, lb/sec
WISE - Weight Integrated Sizing Estimates
WL - Water Line
WOD - Wind Over Deck
W/S - Wing Loading, lb/ft^2

ZFZS - Zero Fuel Zero Stores

α - Angle of Attack, deg

Δ - Difference or Change

δ - Relative absolute pressure

γ - Ratio of specific heats - Cp/Cv

θ - Relative absolute temperature

2θ - Inlet included conical angle, deg

μ - Coefficient of absolute viscosity, $lb\text{-}sec/ft^2$

ρ - Air density, $lb\text{-}sec^2/ft^4$

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16. Abstract

This study was conducted to identify the benefits of a propfan propulsion system relative to a comparable technology turbofan system for a multipurpose subsonic naval aircraft. The propfan powered aircraft are consistently 10% lighter in takeoff gross weight, burn 50% less fuel with 6% to 10% smaller thrust engines than the turbofan designs. The improvement in the figures of merit for the propfan concepts results from the good specific fuel consumption characteristics of these propulsion systems. From the results obtained, the propfans available for this study do not lend themselves to vertical takeoff or landing operation for the Navy missions outlined. Propulsion system technology requirements for a propfan powered mission support aircraft were formulated and a recommended technology research and development plan proposed.

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