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AN ANALYSIS OF SINGLE-ENGINE RATE-OF-CLIMB CAPABILITIES AND THRUST REQUIREMENTS OF THE S-3 AND ES-3 AIRCRAFT IN SUPPORT OF THE TF34 ENGINE COMPONENT IMPROVEMENT PROGRAM

by

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LIST OF ABBREVIATIONS

3M	Maintenance and Material Management Data System
AEMS	Aircraft Engine Management System
AGM	Aircraft Ground Mishap
AIS	Automated Information System
AOA	Angle of Attack
APR	Automatic Power Reserve
ASO	Aviation Supply Office
ASW	Anti-Submarine Warfare
ATS	Automatic Throttle System
AX	Advanced Attack Aircraft
CIP	Component Improvement Program
DMC	Defense Megacenter
DOD	Department of Defense
ECOMTRAK	Engine Composition Tracking
FADEC	Full Authority Digital Electronic Control
FM	Flight Mishap
FOD	Foreign Object Damage
fpm	Feet per Minute
FRM	Flight Related Mishap
FSD	Full Scale Development
GE	General Electric
GPS	Global Positioning System
IOC	Initial Operating Capability
ITT	Interturbine Temperature
lb st	Pounds of Static Thrust
MNS	Mission Needs Statement
MQT	Model Qualification Test

MRT . . . . Military Rated Thrust
NADEP . . . . Naval Aviation Depot
NALDA . . . . Naval Aviation Logistics Data Analysis
NAS . . . . Naval Air Station
NASP . . . . Naval Aviation Safety Program
NATC . . . . Naval Air Test Center
NATOPS . . . . Naval Air Training and Operating Procedures Standardization
NATSF . . . . Naval Air Technical Services Facility
NAVAIR . . . . Naval Air Systems Command
NAWCAD . . . . Naval Air Warfare Center - Aircraft Division
NF . . . . Engine Fan Speed
NG . . . . Engine Gas Generator Speed
NFO . . . . Naval Flight Officer
NPS . . . . Naval Postgraduate School
NSLC . . . . Naval Sea Logistics Center
OFT . . . . Operational Flight Trainer
PLTS . . . . Parts Life Tracking System
R&D . . . . Research and Development
rpm . . . . Revolutions per Minute
SEROC . . . . Single Engine Rate of Climb
SIMS . . . . Safety Information Management System
SLEP . . . . Service Life Extension Program
VQ . . . . Fleet Air Reconnaisance Squadron
VS . . . . Sea Control Squadron
WSIP . . . . Weapons System Improvement Program

I. INTRODUCTION

A. BACKGROUND

Since the end of the Cold War with the former Soviet Union, the United States Department of Defense (DOD) has undergone a significant amount of budget reduction, personnel drawdown and force restructuring. The "Bottoms-Up Review" approach to restructuring has looked closely at all DOD programs and expenditures with an eye towards reducing the cost of our national defense and providing the "best value" for those dollars which are invested in the future of our defense forces.

As restructuring of our forces occurs and the global situation continues to change, the roles and missions of the DOD are also continuously changing. This is especially true for the United States Navy. With the cancellation of the Advanced Attack aircraft (AX) in the early 1990's the Navy encounters a situation in which no newly designed tactical aircraft will enter the fleet until well into the next century. With continued pressure to support an increasing number of multi-mission operations around the world while at the same time maintaining effective combat readiness levels in a shrinking budget environment, the Navy is faced with an imminent problem in regard to the support of its tactical aircraft fleet.

The aging of the Navy's aircraft coupled with increased operations and fewer assets means that those aircraft currently in the inventory will continue to be utilized beyond their initial planned operational life and be utilized in missions that they were not originally designed for. An example of this "aging" of the fleet and additional mission requirements can be found in the Lockheed S-3 Viking aircraft.

The Viking, which was originally designed as a carrier-based anti-submarine warfare (ASW) aircraft, entered the fleet in 1974 and made its first operational deployment in 1975. Production of the aircraft ended in 1978. Initial operational life (Figure 1) for the S-3 was planned at approximately 30 years based on an estimated life of 13,000 flight hours and 3,000 catapult launches/carrier arrestments (cats/traps). With increased usage, enhanced mission requirements and no replacement aircraft on the horizon, plans are now in place to extend the life of the aircraft through a Service Life Extension Program (SLEP) out to 22,000 flight hours and 4,300 cats/traps [Ref. 1]. This means that the S-3 aircraft will have a useful service life of close to 50 years as it phases out of the Navy's inventory by the year 2025.

In order to sustain this extended operational life of the aircraft, continual improvement and enhancements of the aircraft, its twin engines and associated components, and mission related systems must occur. The Naval Aircraft Engine Component Improvement Program (CIP) is one method that is in place and being utilized to help ensure that engine reliability, maintainability, durability and performance concerns are being constantly addressed over the life of the aircraft.

B. OBJECTIVES

The objective of this thesis is to provide an analytical, unbiased look at the performance of the TF34 engine as installed on the S-3 and ES-3 aircraft, specifically with regard to single engine rate-of-climb (SEROC) capabilities and thrust requirements. SEROC capability refers to the ability of a twin-engine aircraft such as the S-3/ES-3 to safely maintain an acceptable rate-of-climb in the event of the failure or shutdown of one of the two operational engines. This capability becomes a critical flight safety issue when takeoff conditions become such that should an engine fail during takeoff the aircraft would not be able to achieve a positive rate-of-climb.

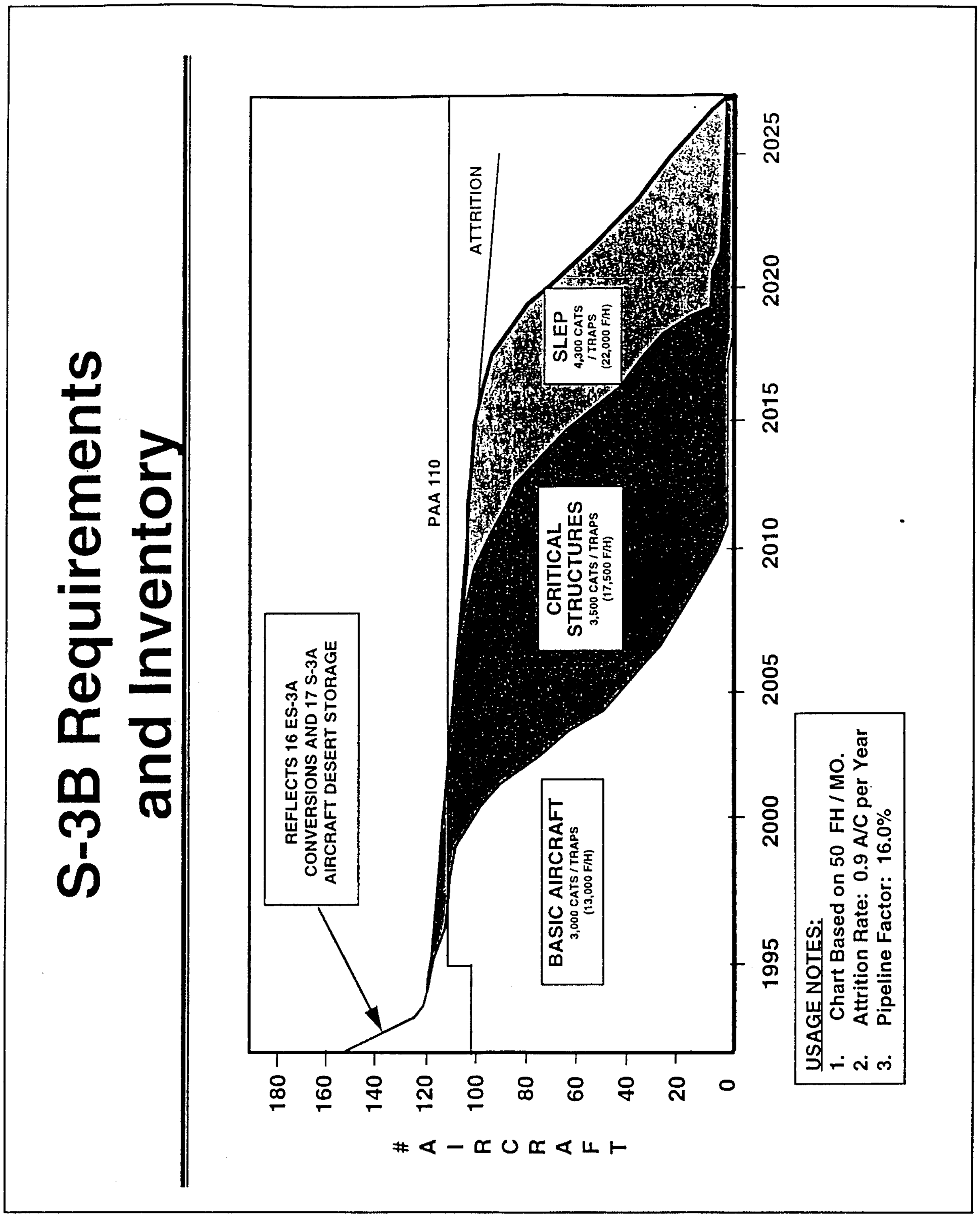


Figure 1. S-3 Type Aircraft, Requirements and Inventory [Ref. 1].

The thesis will attempt to provide Navy decision makers with information to assist in the effective management of proposals and improvements being considered under the TF34 CIP. The intent of this thesis is not to advocate one proposal over another but rather to carefully investigate the present situation, learn from historical data, and solicit operator input, in an effort to provide an acceptable and achievable solution to a recognized problem.

C. RESEARCH QUESTIONS

Research conducted in support of this thesis centers around several key questions. First, how often has a TF34 engine failed inflight? Secondly, when an engine does fail, how often does the failure occur in a critical phase of flight such as takeoff? In answering these first two questions, it can be determined how critical a parameter the SEROC is in relation to the probability that a worst case scenario (heavy aircraft, hot day, engine failure soon after takeoff) will occur. Third, what methods of improvement are currently available to provide for enhanced engine performance in conditions when only one of the two engines is still operational? Fourth, are there other missions or flight phases in which the aircraft would benefit from increased engine thrust performance? Fifth, is there a measure of current engine performance that can be compared with proposed improvements to help illustrate the degree of benefit to be derived from proposed improvements? Finally, are there projects currently underway in the TF34 CIP that could have an impact on improving the performance of the engine thus solving the stated deficiency in SEROC?

D. ASSUMPTIONS AND LIMITATIONS

It is assumed for the purpose of this thesis that there is a stated thrust deficiency with regard to single-engine flight in the ES-3A aircraft as presently configured. This deficiency has been clearly stated in the form of a Mission Needs Statement (MNS) endorsed by Commander Sea Control Wing, U.S. Atlantic Fleet to the Chief of Naval Operations and dated 27 October 1994 [Ref. 2]. No other previously stated deficiencies exist with regard to performance of the TF34 engine as installed on the S-3B aircraft or in flight phases other than SEROC for the ES-3A aircraft.

For the purpose of this thesis it is assumed that the performance of the S-3B Operational Flight Trainer (OFT) is sufficiently realistic in its modeling of actual aircraft and engine performance parameters. All flight test data points used in the analysis were obtained from the S-3B OFT utilizing fleet pilots. The data points gathered were for an S-3B aircraft configuration and would need to be scaled for comparison of performance parameters to the ES-3A aircraft.

The thesis does not attempt to provide any type of cost/benefit analysis of the options discussed herein. Many ideas for engine thrust performance enhancements are in the earliest stages of developmental planning and sufficient cost data is not yet available for comparison. As development of ideas continues, a detailed cost/benefit analysis would be required prior to making a decision.

This thesis is limited in its technical content. It does however serve to provide for an analysis of historical data, modeling of current aircraft engine thrust and SEROC performance, testing of a proposed enhancement to engine thrust performance, and an opportunity for operator input into the realm of possible solutions for the stated problem. The author is not an engineer or a test pilot and makes no claims as such.

E. ORGANIZATION OF THE THESIS

Chapter II provides the reader with background information and an understanding of the Component Improvement Program, a historical look at the S-3 aircraft and how its roles and missions have changed since Initial Operating Capability (IOC), evolution of the TF34 engine, and a look at current technology with regard to improved engine performance.

Chapter III provides an analysis of two historical databases currently in use by the Navy. These databases provide an analyst with historical data with regard to engine performance, reliability, and safety of flight issues. Analysis of this data can help to illustrate the probability of an engine failure occurring during critical takeoff evolutions. By analyzing this data, future performance requirements and capabilities can be anticipated.

Chapter IV explains the methodology used in the thesis research. Discussion includes formulation of the test plan to use S-3 OFT for collection of applicable datapoints and engine thrust modeling. A method of assessing current fleet engine performance through collection of data from operational fleet aircraft, and the use of an aircrew survey to gain an understanding of operator experiences are also included in this chapter.

Chapter V details the application of the methodology discussed in the previous chapter. Results of the testing conducted are presented along with the author's analysis of those results.

Chapter VI concludes the thesis with a summary of the research effort as well as a presentation of conclusions and recommendations resulting from the research.

II. BACKGROUND INFORMATION

A. COMPONENT IMPROVEMENT PROGRAM (CIP)

It is common practice within the military services and the aircraft industry for gas turbine engines to be released into operation prior to having all design problems solved. The trade-off between Full Scale Development (FSD) of the engine and future component improvements is made to ensure that an engine can enter operational service within reasonable time and cost constraints. Deficiencies which were not identified during the research and development (R&D) phase are corrected through continuing investments in design improvements of the in-service engine [Ref. 3].

In an effort to manage this process, the Navy developed the CIP concept in the early 1950's with the goal of enhancing readiness and reducing life-cycle costs for its aircraft propulsion systems and related components. In 1980, in order to comply with DOD directive 5000.40, the Navy issued NAVAIR Instruction 5200.35 [Ref. 4], titled "Policy, Guidelines and Responsibilities for the Administration of the Aircraft Engine Component Improvement Program", which defines the objectives, functions, and limitations of the CIP.

1. Objectives of the Component Improvement Program

The stated objectives of the Navy CIP are to [Ref. 4]:

- Maintain an engine design which allows the maximum aircraft availability at the lowest total cost to the government (primarily production and support cost).
- Correct, as rapidly as possible, any design inadequacy, which adversely affects the safety-of-flight.
- Correct any design inadequacy, which causes unsatisfactory engine operation or adversely affects maintainability and logistic support service.

CIP is designed to be both reactive and proactive throughout an engine's life cycle to resolve newly identified problems, and to find ways to reduce costs of aircraft and engine ownership. This can be done by improving aircraft readiness, and operational reliability and maintainability. Aircraft engines represent a large budgetary expense for both the military and commercial aircraft industries, therefore there is a continuous need for post-development engineering processes to keep engines performing effectively and safely.

2. Functions of the Component Improvement Program

The CIP performs the following functions [Ref. 4]:

- Problem Solving. Investigation and resolution of flight safety problems. Correction of service revealed safety-of-flight problems is the highest priority of the CIP.
- Problem Avoidance. Aggressive mission testing, analytical sampling and engineering analyses designed to forecast low cycle fatigue rates, life limits and detection of other deficiencies prior to their occurring in fleet aircraft.
- Product Improvement. Improve engine maintainability, durability and reliability and provide tangible evidence of a reduced cost of operation and support of engine ownership.
- Product Maturation. Provide engineering support to retain the engine's ability to perform over the lifetime of the engine in the inventory. To use this opportunity to insert improved technology into the engine, its support equipment, accessories and replacement parts.

The Navy's CIP provides engineering support from the time the first engine of a type and model is introduced into the fleet until the last engine of that type leaves the active inventory. The CIP supports the follow-on engineering to identify and resolve all problems encountered by a model during active service, not just those related to the original design specification. The CIP allows for the redesign of engine parts through continued engineering efforts and testing. It also provides improved engine serviceability for parts, maintenance techniques, and increases in engine maintenance service intervals.

3. Limitations of the Component Improvement Program

The CIP is not intended to [Ref. 4]:

- Increase or expand the basic engine performance characteristics beyond those defined in the engine model specification.
- Provide production or modification hardware kits or maintenance labor beyond that necessary for CIP service evaluation testing.
- Provide engineering support to the engine production process.
- Provide for the preparation, publication or distribution of power plant changes.
- Provide data required for the manufacture of engines or changes thereto.
- Provide maintenance engineering or support.

Although the intent of the CIP is not to increase the engine's basic performance characteristics beyond that contained in the specification for the engine model, advances in materials and engine design technologies may serve to increase engine performance characteristics when improvements are made.

B. HISTORY OF THE S-3 AIRCRAFT

On 4 August 1969 Lockheed announced the receipt of a $461 million contract from the Navy to develop a new carrier-based anti-submarine warfare aircraft designated the S-3A Viking. Development was carried out by Lockheed in partnership with Vought Systems Division of LTV and Univac Federal Systems Division of Sperry Rand. Vought designed and built the wing, engine pods, tail unit and landing gear, while Univac developed the digital computer which is the heart of the

Viking weapon system. Two high bypass ratio turbofan engines were provided by General Electric (GE) and Lockheed built the fuselage, integrated the electronics and completed final assembly at their Burbank, CA facility.

The first S-3A prototype rolled out on schedule on 8 November 1971 with the first flight made on 21 January 1972. In May 1972 the Navy announced an order for the first production lot of 13 aircraft with another order for 35 in April 1973 and 45 in October 1973. A total of 187 aircraft were eventually procured with the Navy taking delivery of the final one in June 1978.

In August 1981 the Navy awarded Lockheed a full scale engineering development contract for the S-3A Weapons System Improvement Program (WSIP). Aircraft modified under the WSIP were redesignated S-3B. Improvements included increased acoustic processing capacity, expanded electronic support measure capability, better radar processing, a new sonobuoy telemetry receiver system and provisions for the Harpoon missile. The first S-3B conversions were completed and delivered to the Atlantic Fleet in 1987 and conversion is now complete for both the Atlantic and Pacific Fleets. In addition to the S-3B conversion, all S-3A aircraft were also reconfigured as tanker aircraft being given the ability to transfer fuel from internal tanks to a "buddy store" mounted on the wing pylon. This addition of the tanker capability has had a significant impact on the S-3's mission.

C. HISTORY OF THE ES-3 AIRCRAFT

In March 1988 Lockheed was awarded a $66 million Navy contract for prototype development of an electronic reconnaissance variant of the S-3A, designated ES-3A. The ES-3A was designed to fulfill the role of Battle Group Passive Horizon Extension System for long-range signals monitoring of potentially hostile forces upon the retiring of the EA-3B Skywarrior airframe. Sixteen ES-3A aircraft have been delivered to the Navy.

Conversion of the S-3A to ES-3A involves employing the weapons bay for equipment and replacing the dual controls of the right front seat with tactical displays for the electronic warfare officer. The two rear seat stations are also completely modified and equipped with new displays. Global Positioning System (GPS)/Navstar and Omega navigation systems are added and three AN/AYK-14 processors replace the single AN/AYK-10. Equipment included in the modification adds approximately 3,000 lbs to the basic aircraft weight while 60 additional external antennae and pods significantly increase the airframe drag configuration. No changes to the aircraft powerplant system were included in the conversion.

D. GENERAL ELECTRIC TF34 ENGINE

1. History of Engine

It was announced in April 1968 that Naval Air Systems Command (NAVAIR) had awarded General Electric (GE) a contract for development of the TF34. The high bypass ratio turbofan had won a 1965 Navy competition aimed a providing a tailor made engine in the 9,000 lb static thrust (st) category for the VS(X) application by 1972 within a budget of $96 million. In August 1972 the TF34-GE-2, the initial variant, completed its Model Qualification Test (MQT) and subsequently entered production. The S-3A entered fleet service in February 1974, and in January 1975 GE began shipment of the TF34-GE-400A (9,275 lb st), which replaced the GE-2 as the S-3A engine. The GE-400A model incorporated various improvements, with changed external piping, an adaptive control system for optimizing accessory power extraction, and a simplified rocket gas ingestion system.

2. TF34 Engine Variants

Since the selection of the TF34 engine to power the Navy S-3, GE has continued development of the basic engine configuration and has sold variants of the engine to the Air Force, Army, NASA and commercial airline industry applications.

In 1970 the TF34 was selected to power the twin-engine Fairchild Republic A-10A Thunderbolt II attack aircraft to compete in the AX competition. The A-10A application led in July 1972 to an Air Force contract for development of the TF34-GE-100 (9,065 lb st) with side mounting capability and longer fan ducting. The GE-100 flew in the first A-10A in May 1972. When the A-10A won the AX competition, the TF34-GE-100 was re-engineered to minimize unit cost and formally qualified for production in October 1974.

In 1974 a third version of the TF34, most nearly resembling the original GE-2 engine, was selected to provide auxiliary thrust for the Sikorsky S-72 RSRA (rotor systems research aircraft) for NASA and the Army.

In April 1976 GE's General Aviation Engine Department announced the CF34 as a new turbofan in the 7,000-9,000 lb static thrust class for business and commercial aircraft. A natural derivative of the military TF34, the CF34 is closely similar to the GE-100 but with external configuration tailored to FAA and customer requirements. In January 1980 the CF34 was selected by Canadair to power the Challenger 601, which was certificated in March 1983. The CF34 features an Automatic Power Reserve (APR) capability and variants include the CF34-1A (8,650 lb st), CF34-3A, -3A1, -3B (9,220 lb st with APR/ 8,729 lb st without APR).

E. INCREASING AIRCRAFT PERFORMANCE CAPABILITIES

Several methods are currently available for increasing the performance of an aircraft. The engines may be modified in an effort to produce more thrust for a given aircraft, a different engine which is capable of producing more thrust than the original engine may be installed on the aircraft, aircraft gross weight may be decreased to allow for greater performance from the currently installed engines, or aircraft drag may be reduced by redesign or "cleaning up" of the airframe design. This thesis will consider only those changes involving improvements, modifications or changes to the engines installed on the S-3/ES-3 and will not further discuss changes or improvements with regard to the airframe itself or systems carried within the aircraft.

1. New Technologies for Engine Performance Improvement

Aircraft engine technologies are constantly changing in an effort to develop quieter, more fuel efficient, and more powerful engines. As a result, new technologies can at times be applied to existing engines to increase their performance at a fraction of the cost of developing a new engine.

Allison Gas Turbines has increased the thrust of their T406/GMA3007/GMA2100 family of turbofan engines by approximately 40% [Ref. 5]. The additional power generated widens the commercial and military applications of the engine and provides the military T406 turboshaft version with significant growth capabilities for the future. The increased thrust is achieved by boosting high temperature turbine temperatures by about 200° F. Allison engineers have added an increased temperature high pressure turbine, a cast titanium outer combustor diffuser case, and a ceramic matrix tailcone reinforced with silicon carbide fibers to achieve the higher temperatures.

Allison is also at work on a project which will increase turbine inlet temperatures by about 400° F compared with the AE 3007. Allison's ability to achieve the 400° F increase rests on two technologies. The first is a film-cooled first-stage turbine blade made from second-generation single crystal materials. The second is a first-stage vane that incorporates hybrid Cast Cooled technology. Cast Cooled is Allison's trademark name for a proprietary process in which cast components can be made to incorporate the company's highly effective Lamilloy or laminated alloy transpiration cooling scheme during the casting process.

Pratt & Whitney is relying on increased temperatures, improved materials and higher component efficiencies to develop an upgraded, 90,000 lb thrust PW4000 [Ref. 6]. The growth of the basic 84,000 lb thrust engine is a low-risk, evolutionary effort because many of the qualification and certification tests necessary for the engine have already been run at or above 90,000 lb thrust. To achieve the increased thrust in the PW4000, Pratt engineers will moderately raise turbine temperatures. Increased temperature capable turbine materials and coatings already developed for some military engines will be added to maintain turbine component durability and life.

2. Automatic Power Reserve (APR) System

General Electric has proposed an improvement for the TF34 engine which would serve to increase engine thrust to meet the thrust deficiency in SEROC capability [Ref. 7]. The APR system would implement a "T_5 Control Amplifier Disable" scheme which would remove control amplifier signals from the fuel metering valve in the fuel control when a loss of engine signal is received, thus enabling increased engine performance. A similar APR system is already in use on GE's commercial engine variant (the CF34). The APR system on the CF34 provides an increase in available thrust of over 5% (8,729 lb st to 9,220 lb st) and GE states that as much as a 20% increase is achievable on the military's TF34 engine.

3. Installation of New Engines

Although it would involve substantially greater initial cost than the previously mentioned performance enhancement ideas, the installation of new engines could provide significant savings in maintenance and operating costs over the life of the engine as well as providing an immediate solution to the thrust deficiency problem. As an example, the latest variant of the TF34, GE's CF34-8C, is in the 13,000 lb st class and provides approximately 50% more thrust and a thrust-to-weight ratio 15% higher than the CF34-3A1 engine currently in service worldwide on the Canadair Regional Jet. The CF34-8C features a larger fan, higher flow compressor, new low pressure turbine, and a dual-channel Full Authority Digital Electronic Control (FADEC). In 1994, the CF34 accumulated over 191,000 flight hours with zero inflight shutdowns and an engine related aircraft dispatch reliability of 99.98% was obtained. The replacement of TF34 engines with new CF34 or similar engines could quickly solve any thrust deficiencies of the S-3/ES-3 aircraft.

III. ANALYSIS OF DATABASES

A. INTRODUCTION

This chapter will provide a description of two databases currently in use by the Navy for the collection and analysis or historical aircraft maintenance and safety related data. Procedures for conducting a search of each database will be discussed as well as analysis of the data that was collected. The intent of the research into this historical data is to attempt to determine how often the TF34 engine has failed inflight. Specific attention will be directed to engine failures which may have occurred during the takeoff phase of flight when SEROC capabilities are of the greatest concern to the aircrew.

B. NALDA DATABASE

1. Description of NALDA System

The Naval Aviation Logistics Data Analysis (NALDA) System evolved from a need for improved data analysis capabilities to support growth in sophistication and complexity of naval air weapons and associated support systems. Its primary objective is to utilize state-of-the-art management information systems technology to provide centralized logistics data analysis capabilities [Ref. 8].

Currently, NALDA is an operational Automated Information System (AIS). Computer services are provided by the Defense Megacenter (DMC) Mechanicsburg, PA via a service level agreement. The system has been developed utilizing the Data Base Management System 2000 following a comprehensive evaluation study. The telecommunications network presently consists principally of local dial-up and WATS lines. Data input is provided from the Naval Aviation

Maintenance and Material Management Data System (Aviation 3M) via the Naval Sea Logistics Center (NSLC), Aviation Supply Office (ASO) and the Naval Air Technical Services Facility (NATSF). There are several databases within the NALDA system which are used for engine management. They are the Aircraft Engine Management System (AEMS), the Engine Composition Tracking (ECOMTRAK) and the Parts Life Tracking System (PLTS).

The NALDA system provides a centralized data bank, including maintenance retrieval and analysis capabilities that can be used in an interactive or batch manner through remote terminals in support of the Naval Aviation Integrated Logistics Support community. Both the content of the data bank and the retrieval and analysis capabilities are designed to assist users in making improved decisions affecting fleet aircraft readiness. The primary source of data is the monthly Aviation 3M data received at DMC via NSLC. Secondary sources of data are the Naval Aviation Depots (NADEP) and ASO.

NALDA's capabilities furnish a wide spectrum of uses for managers, engineers, analysts and logisticians utilizing the system. All uses are related to answering questions that arise when personnel deal with day-to-day logistics problems. The ability to access data files interactively produces specific facts on demand. Another aspect is the on-line availability of special programs such as equipment condition analysis, deterministic models, and regression analysis, to predict the effects of actions or to determine cause and effect relationships.

2. NALDA Data Search Procedures Used for this Thesis

Since this author did not have the ability to query the NALDA database directly from the Naval Postgraduate School (NPS), he had to rely on others with NALDA access capability to conduct the requested search. During the course of conducting his research the author obtained

NALDA data from three sources; engineers at the NADEP Alameda, engineers at Powerplants and Propulsion Division at the Naval Air Warfare Center - Aircraft Division (NAWCAD) Patuxent River, and from analysts at Naval Air Systems Command (NAVAIR).

To obtain desired information you must be able to clearly specify exactly what information you are looking for and then have an experienced NALDA operator write the query and extract the data. However, the database is not very user friendly and detailed queries to extract data do not always yield the results you would expect. The more specific you can be concerning the data you are looking for, the better your data quality will be. Transmission of data from these sites was mainly by e-mail which in itself caused some problems in coding and decoding of the attached data. If time permits, it is probably easiest to have the information downloaded to a disk and mailed to you. If you are able to travel to a site with NALDA access ability and have an analyst available to work directly with then you will be assured of obtaining the data you need in a timely manner. NPS is attempting to obtain the capability to access NALDA directly which would be a tremendous asset for future research.

3. Results of Data Search

The NALDA data search conducted asked for all instances of inflight aborts involving TF34 engine-related malfunctions. An inflight abort is defined as the termination of a flight due to a malfunction occurring while airborne which requires a maintenance action to correct . The inflight abort reporting code does not necessarily mean that all incidents involve the failure or shutdown of an engine, but rather that something failed or malfunctioned to a degree that the aircraft was considered to be in a down status awaiting maintenance.

The data query returned 682 events over an almost 20-year period from January 1976 to February 1995 and is included in spreadsheet form as Appendix A. These events were broken down by month into the following categories: DATE (year/month, yymm), FAILURE (NALDA malfunction code), NOMENCLATURE (name of malfunction code failure), EVENTS (number of engines that the particular malfunction occurred on during the month), and FLT. HRS. (total number of TF34 engine flight hours for the month). In analyzing the data, each listing was multiplied by the number of events to arrive at a total of 1382 engine-related inflight abort incidents during the 1976 to 1995 timeframe. Individual incidents were then sorted for those that would have most likely involved a failure or shutdown of the engine inflight. Those malfunction categories chosen for further analysis were flameout, compressor stall, low power/thrust, excessive vibration, and burned or overheated. It is noted that there could certainly have been other malfunctions that may have required the engine to have been shutdown inflight, but there was not sufficient individual incident narrative information contained in the data to enable that determination to be made.

4. Analysis of Results

Analysis of the sorted NALDA data showed that during the given time period 50 events occurred in which an engine failed or was required to be shutdown inflight. These 50 events breakdown in the following manner: Flameouts - 19, Compressor stalls - 5, Low power/thrust - 4, Excessive vibration - 16, Burned or overheated - 6.

Based on a total flight time for the period of approximately 1.065 million hours (flight time data is approximate due to the fact that those months which did not have a reportable incident were not listed for flight time purposes, an average value was calculated from all months with reported flight time, and that value of 4,671 hours/month was used in the calculations), this equates to one engine failure/shutdown per 21,300 flight hours or an average of under three events per year. From the data obtained there was no way to determine what phase of flight the engine failure/shutdown may have occurred. In any case, the rate of TF34 inflight engine failure/shutdown based on historical NALDA data is quite small.

C. NAVAL SAFETY CENTER DATABASE

1. Description of Database

The Naval Aviation Safety Program (NASP) is set forth in OPNAVINST 3750.6 and states the purpose of preservation of human and material resources. The NASP encompasses all activities which may detect, contain or eliminate hazards in naval aviation. The program is based on the doctrine of necessitarianism (events are inevitably determined by preceding causes), and on a corollary of that doctrine (events may be prevented by elimination of their causes) [Ref. 9].

According to the NASP, a hazard is defined as a potential cause of damage or injury and the program is designed to identify and eliminate hazards before they result in mishaps. Mishaps are broken down into three categories, Flight Mishaps (FM), Flight Related Mishaps (FRM), and Aircraft Ground Mishaps (AGM). These categories are further divided into three severity classes; A, B, and C. Class A mishaps involve damage in excess of $1,000,000, loss of an aircraft or any fatality or permanent total disability. Class B mishaps involve damage greater than $200,000 but less than $1M, a permanent partial disability, and/or hospitalization of five or more personnel. Class C mishaps involve damage greater than $10,000 but less than $200K, and/or injuries that result in one or more lost workdays. Any occurrence in which the total cost of property damage is less than $10K and there are no defined injuries in not considered a reportable naval aircraft mishap.

The Naval Safety Center in Norfolk, VA maintains the Safety Information Management System (SIMS), a database which dates back to 1980 and contains all hazards and mishaps reported as required by OPNAVINST 3750.6.

2. SIMS Data Search Procedures Used for this Thesis

The SIMS database, much like the NALDA database, is not very user friendly if you have not received training on its operation. Unlike the NALDA database, however, it is currently accessible from NPS. The Aviation Safety Officer School located on the fourth floor of the West Wing in Hermann Hall has modem access to the SIMS database.

It should be noted though that the data transfer rate is extremely slow and, as with NALDA, if you don't know exactly how to state your query you're not going to get the data you need. An alternate method for obtaining SIMS data was via direct contact with the analysts at the Naval Safety Center. A request for query is included as Appendix B and can be sent via fax or mail to an analyst who will ensure you obtain the data you are searching for. Results of your query can be obtained via fax, mail, or electronic data transmission.

3. Results and Analysis

The request for query submitted for this research effort asked for all S-3 type aircraft engine-related events from 1980 to present. The query returned 79 separate engine-related events dating from 1/27/80 to 9/19/94. Of the events, the breakdown by aircraft type and model was as follows; S-3A = 64, S-3B = 11, ES-3A = 2, US-3A = 2.

Classification of the events reported in the database included 35 flight mishaps, 10 aircraft ground mishaps, and 34 events that were not reportable as mishaps under OPNAV 3750.6. Of the

45 reportable mishaps, four were Class A damage, six were Class B damage, and 35 involved Class C damage.

A total of 49 of the 79 events (62%) were attributed to Foreign Object Damage (FOD) of one form or another. NAVAIR Instruction 3750.6A, *Prevention of Foreign Object Damage to Gas Turbine Engines*, states:

> Damage to gas turbine engines from ingestion of foreign objects continues to plague Naval Aviation. FOD is hazardous to personnel safety, seriously degrades mission capability, and is cost prohibitive. The cost and time involved in the repair of engines damaged by foreign objects depletes limited repair funds and capacity, and impacts commensurately on other programs. Since most FOD is preventable, a continuing and dedicated FOD prevention program is mandatory.

Since engine FOD is considered preventable and efforts are underway to reduce the problem, those 49 FOD events reported in the data will not be considered for further analysis.

Fourteen of the remaining 30 events (17.7% of total reported events) involved the engine failing or needing to be shutdown inflight (two of the shutdowns were attributed to FOD). Four of the 14 (5% of total events) events occurred in the critical flight phase during or shortly after takeoff (Figure 2). Each of these four events involved an engine fire. There were no incidents of dual-engine failures reported.

The total number of TF34 engine flight hours for the last 15 years is approximately 844,000 flight hours according to NALDA records. The rate of reported events involving engine failure during or immediately after takeoff equates to one event every 211,000 flight hours or a rate of 0.47 per 100,000 flight hours. This rate is well below the Naval Aviation Safety Program standard of less

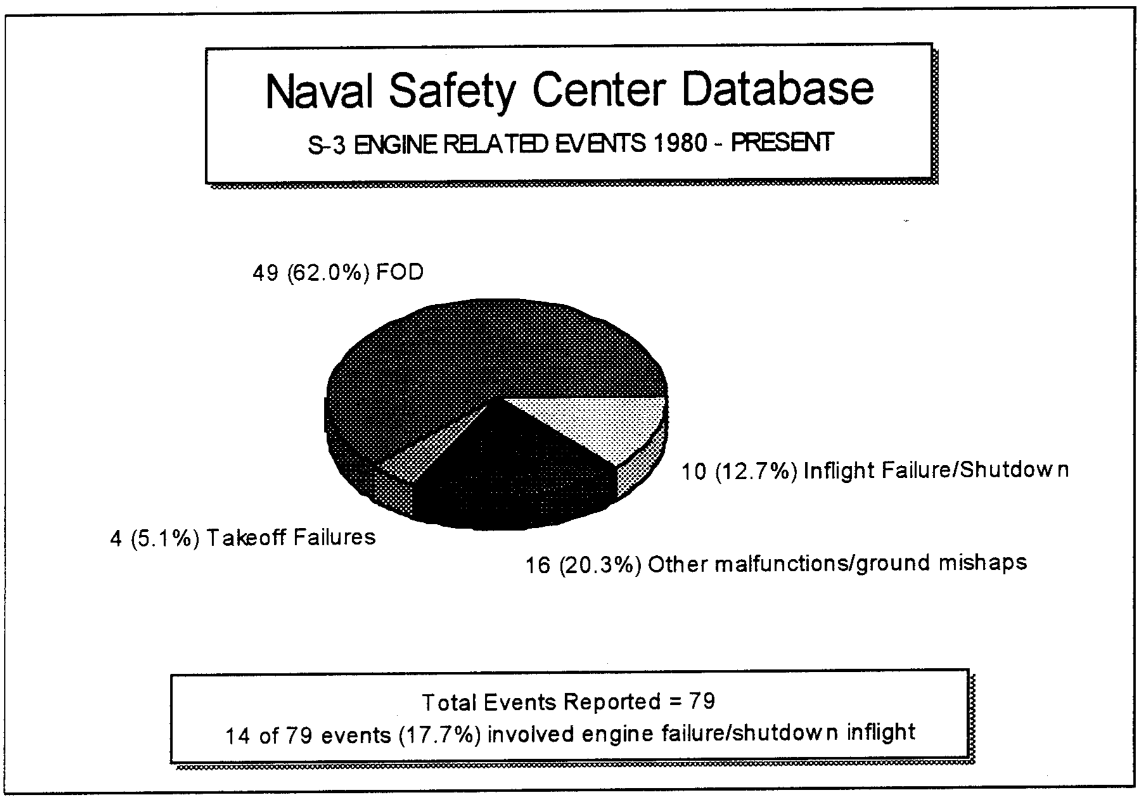


Figure 2. Naval Safety Center Database, S-3 Engine Related Events.

than 2.00 Class A mishaps per 100,000 flight hours. It should be noted that of the four takeoff related events that were reported, two involved only Class C damage while the other two did not meet mishap reporting thresholds for damages. It would appear from the data collected that the probability of a mishap involving engine failure during the takeoff evolution is extremely small. This could lead to the conclusion that while the lack of a positive SEROC is a documented problem for the ES-3A aircraft, it is not likely to be a mishap causal factor based on historical data.

The quality of the data obtained from the Safety Center database must be carefully considered with regard to reporting requirements. Often, only those events in which a reportable mishap actually occurs and is required to be reported is any type of report generated. Submission criteria for Hazard Reports states only that a Hazard Report "should" be submitted whenever a hazard is detected, it is not a formal reporting requirement. Events may occur in which minimum mishap reporting thresholds are not met and the squadron does not bother to send in a hazard report detailing the problem. The fact that an engine fails inflight, in and of itself, does not require that a report be sent to the Safety Center. Likewise, each time that an aircraft launches in conditions that does not enable it to achieve a positive SEROC, a defined hazard exists, but is not necessarily reported. So, while the rate of mishaps in which a SEROC deficiency may have been a factor appears to be extremely low, the number of non-reported events could conceivably be much higher.

IV. METHODOLOGY

A. INTRODUCTION

This chapter will discuss the methodology used to collect data for analysis in the research effort. Three separate methods of data collection have been utilized; flight simulation data points, a collection of actual operational engine data from the fleet, and an aircrew survey.

B. FLIGHT SIMULATION AS A RESEARCH TOOL

The design and development of modern aircraft makes extensive use of flight simulation. A vast range of problems is open to investigation utilizing simulators. The essential feature of all such investigations is to introduce the pilot into a closed loop control situation, so that account is taken of his capabilities and limitations. The expectation is that within the bounds of the experimental conditions, the behavior in the simulator matches the behavior in actual flight situations. Although it is impossible to reproduce on the ground all the characteristics of an aircraft as seen by a pilot in the air, the assumption behind the use of the simulator for research purposes is that the pilot controls the simulator in the same way he would the aircraft. Flight simulation is a vital part of aeronautical research and its use has increased considerably in recent years as equipment has improved and more realistic models have been developed [Ref. 10].

1. Engine Modeling

In simulating performance of those parts of an aircraft which have mechanical components, such as the engine, simulator designers can utilize high or low sophistication design approaches. The requirement to effectively simulate the engine throughout its operating environment so that it will functionally interface with all related systems can be approached by two basic methods and most simulations use a mixture of both methods.

The first method is the total output simulation. In this approach the various required outputs are defined in complex mathematical functions of certain input conditions and are used in an open loop. This method requires a considerable volume of data plus mathematical expertise of a high order. It is difficult to incorporate failure cases for training, it is inflexible, and it is expensive in computation time. Consequently, total output simulation is normally restricted to engineering/research applications where training and real time simulation is not a requirement.

The second method is called the component simulation method. In this method, each major component of the engine, such as the combustor, compressor, turbines, etc ..., is modeled along with the associated component systems such as the oil system and starter system. All the component simulations are then coupled together and use the simulated fuel control unit to close the computation loop in order to provide a close analog of the real engine. Data is derived and supplied by the engine manufacturer from engine and component tests and is correlated with results from engineering simulations. As with the total output method, component simulation also requires considerable mathematical and thermodynamic expertise.

Most simulators use a combination of the two methods previously mentioned and make use of the manufacturer's normalized steady-state performance data. The perceived performance, as seen on cockpit mounted instruments and in flight characteristics, can be sufficiently close to a real nominal engine that any differences observed can be attributed to minor engine-to-engine related differences in real life [Ref. 10].

2. Use of the S-3B Simulator

The S-3B Operational Flight Trainer (OFT) is designated as training device 2F92B. The primary purpose of the trainer is to provide pilot and crew training in the procedures required to fly the S-3B aircraft in fulfillment of its intended missions. The trainer provides facilities for realistically reproducing the complex interrelationships of flight controls, sensor systems, navigation, communication, and automatic pilot operations. Through the use of the OFT, knowledge can be gained in the flying characteristics of the S-3B aircraft as well as the interaction of its many systems [Ref. 11].

The trainer provides numerous advantages over the use of operational equipment for S-3B crew training. The training problem in real-world terms relies upon the experience of the aircrew for a solution. In actual flight training some emergency operating procedures entail prohibitive risks and so are not conducted in flight. The trainer can overcome these inflight limitations and provide the aircrew with the experience necessary to effectively solve real-world problems.

All trainer operational parameters are simulated to a degree sufficient to create the illusion or real-world operations. The OFT flight characteristics are effectively simulated in each axis of pitch, roll, and yaw as are the aircraft inflight performance characteristics of velocity, altitude, angle-of-attack, sideslip, power setting, and aircraft configuration. Cockpit instruments and controls react to aerodynamic and operator inputs as specified or in conformance with actual aircraft characteristics.

The OFT propulsion model design tolerance limits are listed (Table 1) and a graph illustrating simulator output as compared to actual aircraft flight test data is shown (Figure 3). The graph, which plots NG (engine gas generator speed) on the Y-axis and PLA (power lever angle, throttle position), shows OFT thrust both before and after corrections made as a result of instrumented test flights.

TRAINER PARAMETER	TOLERANCE LIMIT
POWERPLANT TOLERANCES:	
Power lever position	5.00%
Fuel flow	5.00% (or 1% of maximum value)
Fuel flow rate of change	25.00%
Fuel depletion rate	5.00% (or 1% of maximum value)
Engine rpm (%)	2.00%
Engine accel & decel time	15.00%
Engine windmilling speed	5.00%
Exhaust gas temperature	Range: 0° - 409° C ± 25° C 410° - 899° C ± 10° C 900° - 1000° C ± 25° C
Bleed air temperature	25° C
Bleed air pressure	10.00% (or 5 lb, whichever is greater)
Exhaust gas temperature rate of change	25.00%
Oil pressure	10.00%
Oil pressure rate of change	25.00%
Fan speed	2.00% (below cruise) 1.00% (cruise and above)
Fan speed rate of change	25.00%
Thrust	3.00% (or 0.3% of maximum value)
Engine light-off time	10.00%

Table 1. S-3B OFT Simulator Capabilities [Ref. 11].

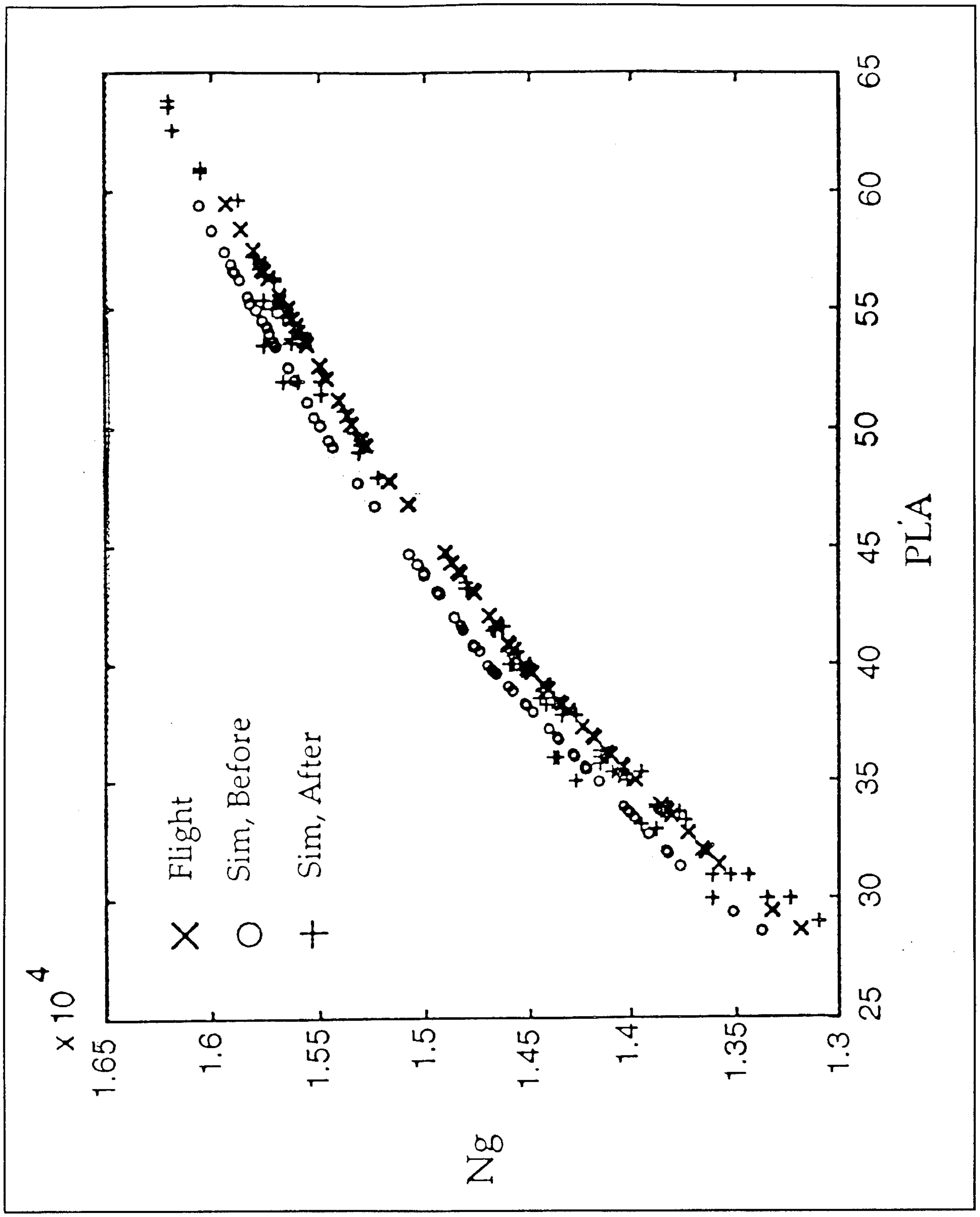


Figure 3. S-3B OFT Propulsion Model Improvements

3. Simulator Datapoint Collection

The purpose of utilizing the S-3B OFT was to gather data with regard to SEROC and engine thrust produced both with and without the engine T_5 system disabled and to compare the rate-of-climb obtained with those performance numbers published in the S-3B NATOPS manual. The use of the T_5 system disable switch would simulate the function of the proposed APR system on the aircraft by allowing the operating engine to run at higher temperatures. The benefit obtained from disabling the T_5 system could then be measured both in terms of increased thrust, and increased SEROC.

Data was collected for a sea-level takeoff of an aircraft weighing 44,000 lbs at temperatures of 60°, 80°, and 100° F. The 44,000 lb aircraft weight was chosen to ensure a positive rate-of-climb would be maintained in all configuration and temperature ranges and because it would closely approximate the weight of a "heavy" aircraft following jettison of external stores in an emergency SEROC situation.

The simulator's thrust model was then used to generate thrust data at various temperature ranges and with varying headwind components to simulate the ram air effect of wind and airspeed on the thrust production of the engine. This data was collected at sea-level and at a 4,000' field elevation and thrust measurements were collected for the engine both with and without the T_5 control system operating in an effort to determine the amount of benefit derived from disabling the T_5 system.

C. EFFECTS OF FAN SPEED DROOP ON THRUST

In a turbofan engine such as the TF34, fan speed (NF) is a good indicator of engine health and the amount of thrust being produced by the engine. Fan speed "droop" is a temporary reduction in fan speed occurring shortly after the throttle is rapidly advanced to the maximum setting from a lower power setting. The reason for this droop in fan speed is due to the varying radial dimensions in engine rotor and stator hardware caused by thermal and centrifugal loads. The magnitude of the droop is dependent on engine conditions just prior to the rapid throttle advance. There are several variables which affect fan speed while the aircraft is on deck and inflight, these include ambient temperature, bleed air extraction, atmospheric pressure and ram air effects.

Testing to measure the amount of fan speed droop was conducted by GE on the TF34-100 (Air Force variant) in 1979 [Ref. 13]. This testing concluded that the TF34-100 fan speed droop transient reached an average value of -1.5% (± 0.5%) from the final stabilization value approximately eight seconds after the throttle was advanced from 90% NG to maximum. The average value was maintained for approximately 16 seconds before stabilizing. This testing recommended that the average droop value be incorporated into pilot ground roll max power checks conducted on the Air Force A-10 aircraft.

With the recent installation of EPAMS (Engine Performance and Monitoring System) on several S-3B and ES-3A aircraft the issue of fan speed droop has again come to light. EPAMS data has shown that the TF34-400 engine reaches peak fan speed at approximately 10 seconds after the throttles have been advanced from idle to maximum. This peak is the value that is currently being used by Navy aircrew as a GO/NO GO criteria on engine health just prior to launch. Following this peak value the NF begins to steadily decrease reaching a minimum at approximately 30 seconds after throttle advance. During carrier operations, this 30-second time period closely corresponds with the amount of time spent at full power just prior to catapult launch. So conceivably, aircraft are being launched at the same time that the engines are producing the minimum amount of thrust available with full power applied.

The thrust model of the S-3B OFT was again utilized to determine the effects of fan speed droop on thrust produced. Data was collected at varying temperature and wind component ranges and with a simulated fan speed droop of -100 to -400 rpm.

In addition to the simulator data illustrating the effects of fan speed droop on thrust, data was collected from operational aircraft to determine the extent of the droop problem on engines currently in the fleet. A TF34 fan speed check data collection card (Figure 4) was distributed to several squadrons in an effort to measure actual fan speeds against NATOPS fan speed check limits and to measure the amount of fan speed droop presently occurring in the Navy's fleet of TF34 engines.

TF34 FAN SPEED CHECK

SQUADRON: ____________	BUNO: ______________	DATE: __________________
OAT: _________________	ALT: ________________	R. Humidity ___ ____________
WINDS: _______________	A/C Heading: __________	Calc. Fan Speed ____________

Idle Fan Speed: ENG. #1 ____________ ENG. #2 ____________

Actual Peak Fan Speed at MRT:

ENG. #1 ____________ ENG. #2 ____________

Actual Stabilized Fan Speed at MRT (wait approx. 30 seconds after peak reading)

ENG. #1 ____________ ENG. #2 ____________

Figure 4. TF34 Fan Speed Check Data Card.

D. AIRCREW SURVEY

An aircrew survey was distributed to the fleet in an effort to gather more historical data and provide for operator input to the research effort and is included as Appendix C. The survey consisted of three sections; background information, single-engine flight information, and performance of the TF34 engine.

1. Survey Background Information

Background information requested was straight forward and easy to complete, it asked the following questions: Pilot or Naval Flight Officer (NFO), VS or VQ Community, Total flight time, S-3 flight time, and ES-3 flight time.

2. Single-Engine Flight Information

This section was designed to obtain historical information from aircrews concerning their experiences in the single-engine flight regime. The intent was to identify the number of times that aircrews have actually experienced critical single-engine flight situations. This section consisted of six multiple choice questions.

The first question asked if an aircrew had ever experienced takeoff conditions in which they did not have a positive SEROC as calculated from the NATOPS performance charts assuming the landing gear retracted. Having the landing gear retracted is the best case scenario, and generally you would not want to attempt takeoff in a condition in which you did not have a positive SEROC especially if you assumed that the landing gear could be retracted. The usual solution to this problem is to down load some weight from the airplane either in the form of external stores or fuel load. The question did not address the issue of jettisoning external stores to provide increased SEROC. The ability to jettison external stores allows the pilot to quickly (less than ten seconds on the S-3) reduce the gross weight of the airplane in the event of an emergency. This is a decision that the aircrew should make during preflight takeoff computations and consideration should be given to reducing the weight of the aircraft prior to takeoff if jettisoning of external stores is the only way to achieve an acceptable SEROC.

Question two of this section was a follow-on question to question one. If the response to question one was yes, then the survey asked what factor had the most significant impact on SEROC. Four multiple choice responses could be chosen from; temperature, field elevation, external stores, and insufficient thrust. The intent of this question was to determine what the aircrew felt the reason for their lack of SEROC was. Was it caused by extremely high air temperature? Was it a consequence of an unusually high field elevation such as NAS Fallon at 4,000 feet? Was it due to a greater than normal amount of external stores being carried? Or, was the lack of SEROC due simply to insufficient thrust being produced from the engine?

The third question sought to determine the number of aircrew who had experienced actual single-engine flight and the number of occurrences if more than once. Question four followed in asking those who had experienced single-engine flight what phase of flight the single-engine situation developed. The intent of these questions was to help determine the frequency of single-engine operations and how often failures occur during takeoff situations. Question five asked specifically about the number of engine related malfunctions which did not involve an engine failure or shutdown but that did occur during the takeoff phase of flight.

The final question in this section of the survey, question six, asked the aircrew if they had ever been required to jettison external stores in an effort to achieve increased SEROC, and if so how many times? The intent of this question was to determine how often aircrew found themselves in a situation that was so critical that external stores were jettisoned. Usually this would involve an engine failure close to the ground with extreme conditions of weight, temperature or elevation. If a crew choose to jettison external stores it was because they needed an increased SEROC and they needed it right away.

3. TF34 Performance Information

Section three of the survey asked questions pertaining to the performance of the TF34 engine on both the S-3 and the ES-3 aircraft. While all the previous questions were multiple choice style, section three asked several short answer type questions in addition to multiple choice questions.

Question one asked if the aircrew felt that the TF34 engines provided sufficient thrust for the mission of the S-3. If the answer was no, question two followed up by asking during what mission/flight phase is additional thrust required? Questions three and four were the same as questions one and two but pertained to the ES-3. The intent of these questions was to determine if there was a perception of insufficient thrust from the TF34 engines and if so during what mission/phase of flight.

Question five asked what precautions must be taken if the engine T_5 control system malfunctions or is disabled. Since T_5 control malfunction is a NATOPS emergency procedure the author was confident that all aircrew would know the required steps of the procedure but the intent was to look for knowledge beyond simple memorization of procedures for an understanding of the T_5 control system, its operation and purpose.

The next question asked simply if the aircrew thought that the disabling of the T_5 control system would provide any advantage in engine performance. Question seven followed it up by asking those that replied yes what the perceived performance advantage would be. The intent of these questions was to measure the knowledge of the T_5 system as it affects engine performance.

The final questions, eight and nine, listed several methods for increasing SEROC and asked for recommendations and reasons why a particular method was chosen. Space was provided for additional methods that were not among those listed to be written in. The intent of these questions was to provide operator input into possible solutions to the stated problem of the lack of sufficient SEROC capabilities of the ES-3A aircraft.

The surveys were designed to be of an anonymous nature and as such did not ask for name, rank, squadron or any identifying data other than designator and community. Space was provided at the conclusion of the survey for those with any additional comments or questions with regard to the TF34 engine or the survey to respond.

V. DATA COLLECTION AND ANALYSIS

A. INTRODUCTION

This chapter will discuss the application of the methodology presented in the previous chapter. Results of the research effort will be presented along with the author's analysis of those results. The areas to be discussed include the use of the S-3 flight simulator to obtain engine thrust and performance data, the fleet engine fanspeed data collection, and the aircrew survey.

B. USE OF S-3B FLIGHT SIMULATOR

The S-3B OFT at NAS Cecil Field was utilized for data collection. Flight data used for collection of SEROC information was obtained utilizing OFT #2 which has full visual capabilities. Thrust model data was collected from both simulators, OFT #2 and OFT #5, with slight variation of raw data numbers between the two models being observed.

A total of 24 separate SEROC flight experiments were conducted for various temperature ranges and aircraft gross weight settings as well as with the T_5 control system both enabled and disabled. The pilot used to fly a given experiment was S-3B NATOPS qualified and fully current in all flight qualifications, representative of an average fleet pilot. Each experiment consisted of a standard takeoff event (no wind conditions) followed by an engine failure malfunction occurring just after rotation. If the experiment involved disabling the T_5 control system, the simulator operator turned the cockpit switch off just after initiating the engine failure to approximate an APR system initiation. Aircraft landing gear was left in the down configuration and the pilot sought to obtain a stabilized rate-of-climb at military rated thrust (MRT, maximum throttle setting) and in accordance with NATOPS procedures for best single-engine rate-of-climb (15 units angle-of-attack (AOA), aircraft banked three to five degrees into the good engine and maintaining aircraft track through moderate rudder input into the good engine). Once a stabilized SEROC was obtained, the experiment was considered completed and applicable information on experimental conditions and simulated flight data was recorded. In an effort to achieve unbiased climb performance, the pilot was not informed of what the NATOPS calculated SEROC values were expected to be.

The use of the simulator thrust model for data collection was conducted by using the OFT instructor console to modify appropriate environmental parameters such as temperature, wind, and field elevation. Engine instrument readings were obtained from direct reading of OFT cockpit gauges and thrust readings were obtained directly from the instructor console performance screen readout.

C. RESULTS AND ANALYSIS OF SIMULATOR EXPERIMENTS

A complete listing of the results of all experiments conducted in the simulator is included in spreadsheet form as Appendix D. In general SEROC performance in the OFT was slightly better than that predicted by NATOPS calculations for all experiments. The effects of disabling the T_5 control system had a tremendous impact on the SEROC that was obtained. As aircraft gross weight and temperature values were increased, SEROC performance diminished as would be expected. However, the SEROC performance with the T_5 control system disabled, expressed in terms of a percentage increase in SEROC capability for a given condition with T_5 operating, consistently increased as takeoff conditions worsened.

Experiments were conducted in sets of three at the same temperature and weight range, first with the T_5 control system operating and then with it disabled. As an example, at a gross takeoff weight of 40,000 lbs and temperature of 60° F the average SEROC with T_5 operating was 625 fpm as shown in the table "Effects of T_5 on Rate-of-Climb" in Appendix D. In the table the first column is TEMP (air temperature, °F), column two is ALT (altitude, field elevation), column three is WT (aircraft gross weight), column four is T/O SPD (NATOPS calculated takeoff speed), column five is DRAG (aircraft drag configuration), column six is GEAR (position of landing gear), column seven is S-3 NATOPS (calculated SEROC), column eight is ES-3 NATOPS (calculated SEROC), column nine is WITH T_5 (SEROC obtained with T_5 operating), column ten is W/O T_5 (SEROC obtained with T_5 disabled), and column eleven is S-3 % INCREASE (percent increase in SEROC for the S-3 with T_5 disabled). With T_5 disabled average SEROC rose to 1075 fpm, an increase of 72% in SEROC performance. Increasing the aircraft weight to 44,000 lbs with temperature still at 60° F yielded average numbers of 403 fpm with T_5 and 883 fpm without, an increase of 119%. Maintaining the 44,000 lb gross weight while increasing temperature to 80° F then 100° F showed the SEROC performance decreasing to average values of 208 fpm and 100 fpm with T_5 and 608 fpm and 483 fpm without T_5, respectively. While the nominal value of SEROC performance decreased, the measure of increased performance without the T_5 control system operating increased from an average value of 208 fpm to 608 fpm (192%) at 80° F and from 100 fpm to 483 fpm (383%) at 100° F. SEROC performance increased most dramatically in the situations when it is most necessary, heavy aircraft on a hot day.

The actual amount of SEROC obtained inflight is very much dependent on pilot flying technique; if the pilot does not maintain best SEROC airspeed (15 units AOA), the rate-of-climb will begin to decrease almost immediately. All performance figures obtained in the simulator are for analysis and comparison purposes only and are not meant to imply that these specific degrees of performance will be achievable in the aircraft.

The results of the experiments collected from the OFT thrust model were also encouraging as far as increased performance of the TF34 engine was concerned. Thrust model tests validated the degree of increased benefit of disabling the T_5 control system as temperature increased as was illustrated in the SEROC test. The table "Altitude and Temperature Effects on TF34 Engine Parameters" in Appendix D illustrates this increased performance. Column one lists the engine parameters being measured, column two is MRT W/T_5 (engine parameters with engine at full power and T_5 operating), column three is MRT NO T_5 (engine parameters with engine at full power and T_5 disabled), column four is % INCREASE (percent increase in thrust with T_5 disabled), columns five, six, and seven provide the same data but at a field elevation of 4,000 ft.

Measured net thrust improvement at MRT when disabling the T_5 control system ranged from approximately 23% at 60° F to over 26% at temperatures of 100° F. These increases were consistent across the board in both OFTs and were observed regardless of the effects of wind, temperature, and elevation on net thrust produced.

The table "Wind and Temperature Effects on TF34 Engine" in Appendix D illustrates the effects of environmental conditions on engine thrust produced. Column one is TEMP (air temperature, °F), column two is WIND (headwind component in knots), column three is WITH T_5 (thrust produced with T_5 operating), column four is W/O T_5 (thrust produced with T_5 disabled), column five is % INCREASE (percent increase in thrust with T_5 disabled), column six is WIND EFFECT (percent of original thrust with T_5 operating due to ram air effects) , and column seven is WIND W/O T_5 (percent of original thrust with T_5 disabled due to ram air effects). The "ram air" effects of increased airflow entering the engine intake, associated with wind and increasing airspeed, were consistently shown to result in a decrease of approximately 1.6% in net thrust per 10 knots of ram air inflow. This "thrust lapse" with increased ram air inflow is consistent with characteristics of a high-bypass turbofan engines such as the TF34. [Ref. 14].

D. USE OF FLEET ENGINE FAN SPEED DROOP CHECK

Actual aircraft fanspeed datapoints were collected from two operational squadrons on the east coast, VS-22 and VS-31. Results of the data collection are contained in the table "TF34 Fanspeed Performance Check" found in Appendix E. Recorded data included squadron, aircraft bureau number, outside air temperature, altimeter setting, relative humidity, and headwind component. Engine performance data measured included target NF (fan speed), idle NF, NF with engines at military rated thrust (MRT), and NF with engines at MRT after approximately 30 seconds to measure amount of NF droop. A total of 34 flights events were recorded providing information on nine different aircraft (18 engines) over a two-week period.

While this check of operational engines measured the amount of fan speed droop on a sample of current fleet engines, the OFT thrust model was able to display the effects of fan speed droop on net thrust produced by the engine. These effects are given in the table "Effects of NF Droop on Engine Thrust" found in Appendix E. Fan speed droop measurements were conducted in the OFT by incrementally reducing the throttle from MRT. Thrust was recorded from the instructor console performance screen at MRT and at each successive 100 rpm NF increment from MRT - 100 rpm to MRT - 400 rpm. Measurements were obtained with temperatures set at 60°, 80°, and 100° F and with headwind components of zero, 15, and 30 kts. The table illustrates the data collection and expresses the result of the simulated NF droop as a percentage of the original thrust value at MRT. For example, at 60° F with zero wind, thrust at MRT was 8,633 lb st. With a simulated NF droop of -200 rpm NF, thrust decreased to 8,040 lb st or 93.13% of the original value.

E. RESULTS AND ANALYSIS OF FAN SPEED DROOP CHECK

With the total of 34 actual flight events recorded, individual engine performance was able to be measured 68 different times. Of the 68 engine performance checks performed, only 24 checks (35.3%) met or exceeded the NATOPS value for target fan speed at MRT. Following the 30-second waiting period to account for stabilized fan speed droop, only nine of the 68 engine checks (13.2%) met or exceeded target fan speed. Of the 59 times that the engines did not meet the targeted fan speed value after accounting for droop, the average value below target fanspeed was approximately 125 rpm NF.

A project conducted in 1981 and presented as a Naval Air Test Center Technical Report in 1983 [Ref. 15] considered a proposal to accept reduced performance/thrust levels from the TF34 engine. This study measured the effects of reduced engine performance, as measured by decreased NF values, on SEROC capabilities. Data analysis from the 1981 Naval Test Center project showed that for each 100 rpm reduction in fan speed approximately 65-70 fpm of SEROC capability was lost. Based on the data collected, 87% of the fleet S-3/ES-3 aircraft are flying with an average loss of approximately 81.25 to 87.50 fpm in expected SEROC capability.

Thrust model data gathered from the OFT also showed the associated decrease in net thrust performance from reduced fan speed. A total of 45 experiments were conducted to illustrate the effects of fan speed droop on thrust produced by the engine. With temperature and wind variations included, the average engine thrust performance decline was in the range of 4 to 5% per 100 rpm of fan speed reduction.

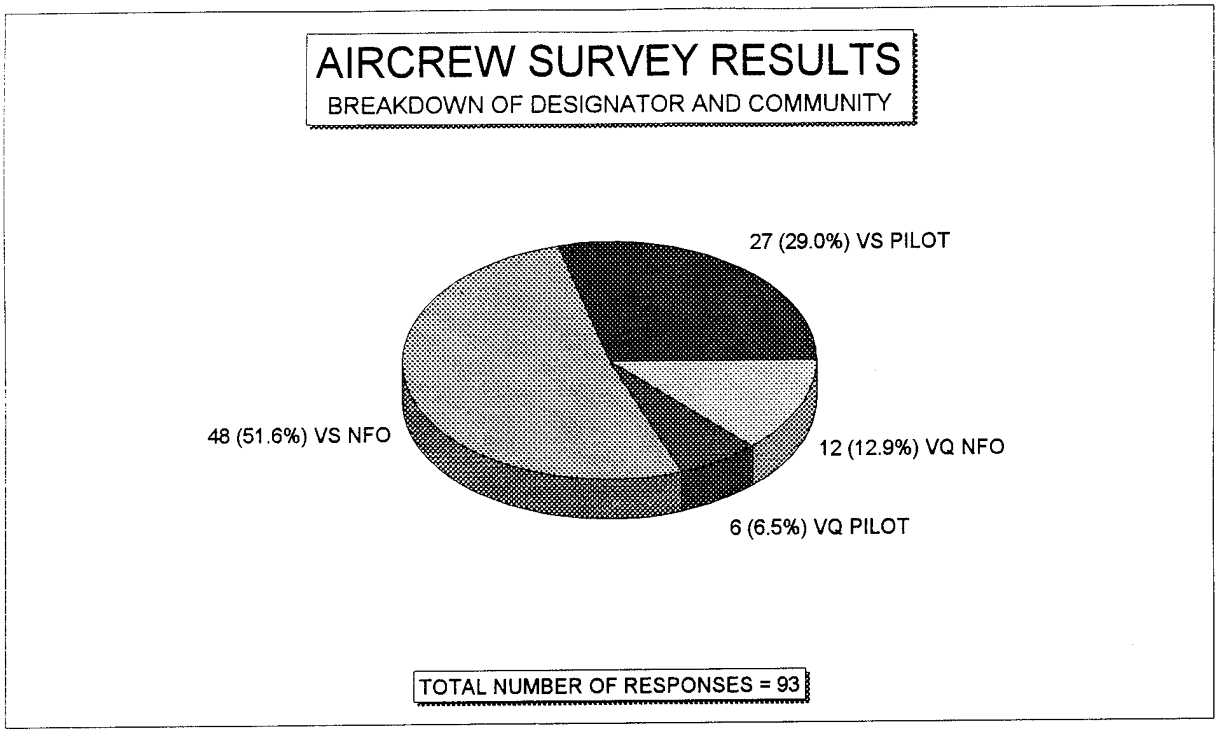
F. USE OF AIRCREW SURVEY

The aircrew survey was distributed to VS and VQ aircrews in both the Atlantic Fleet and the Pacific Fleet. The Atlantic Fleet squadrons selected for the survey are stationed at NAS Cecil Field, Jacksonville, FL. Surveys were distributed and responses were obtained from officers attached to Sea Control Wing U. S. Atlantic Fleet, Sea Control Squadrons TWENTY-TWO (VS-22) and THIRTY (VS-30), and Fleet Air Reconnaissance Squadron SIX (VQ-6). The Pacific Fleet squadrons selected for the survey are stationed at NAS North Island, San Diego, CA. Surveys were distributed and responses were obtained from officers attached to Sea Control Wing U. S. Pacific Fleet, Sea Control Squadrons THIRTY-FIVE (VS-35), FORTY-ONE (VS-41) and Fleet Air Reconnaissance Squadron FIVE (VQ-5). A total of 93 completed survey responses were received.

1. Results of Survey

Section One of the survey consisted of background information on the respondents. Items of interest included designator, community, and flight time breakdowns. Results of the background information are presented on the next page (Figure 5).

Section two of the survey asked questions dealing with single-engine flight in the S-3/ES-3. The first question in this section asked if the aircrew had ever experienced takeoff conditions in which they would not have a calculated positive SEROC. Of the 93 personnel surveyed, 41 (44.1%) stated that they had at some time experienced such conditions (Figure 6). Question two asked those that responded "yes" to the previous question what factor they felt had the most significant impact on their lack of SEROC capabilities. Answers were split almost evenly among the choices with air temperature being the most consistent response with over 30% of the 36 responses given (Figure 6).



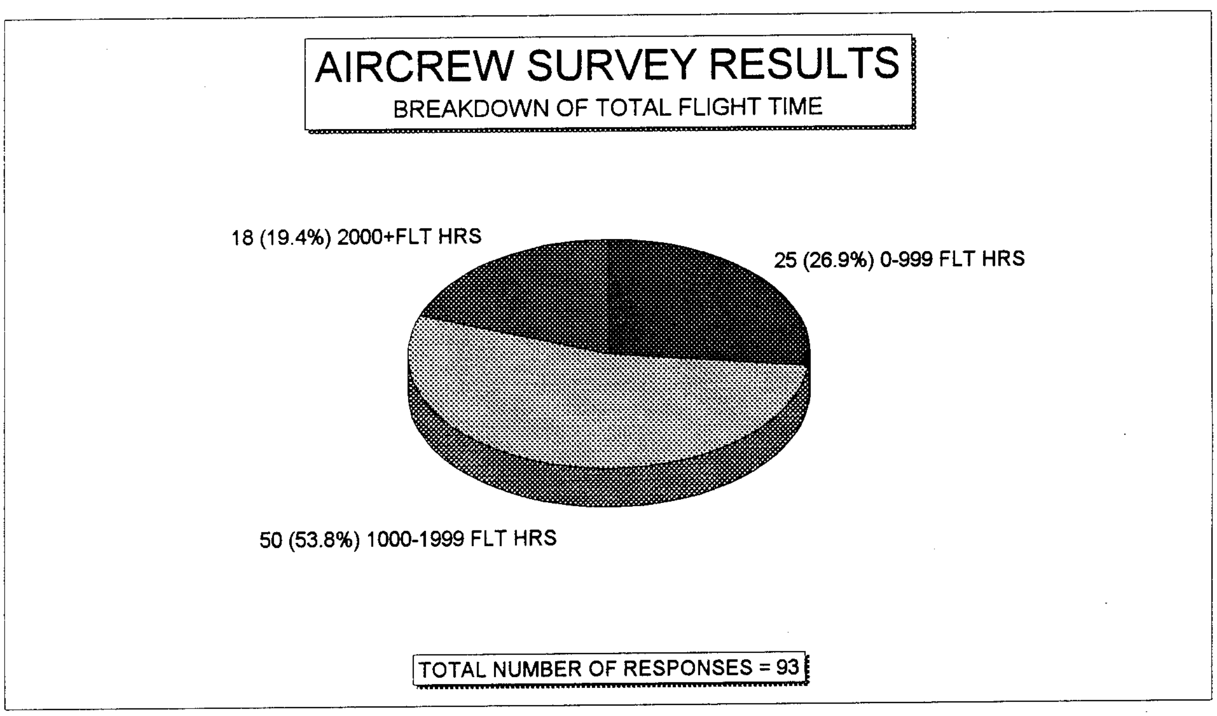
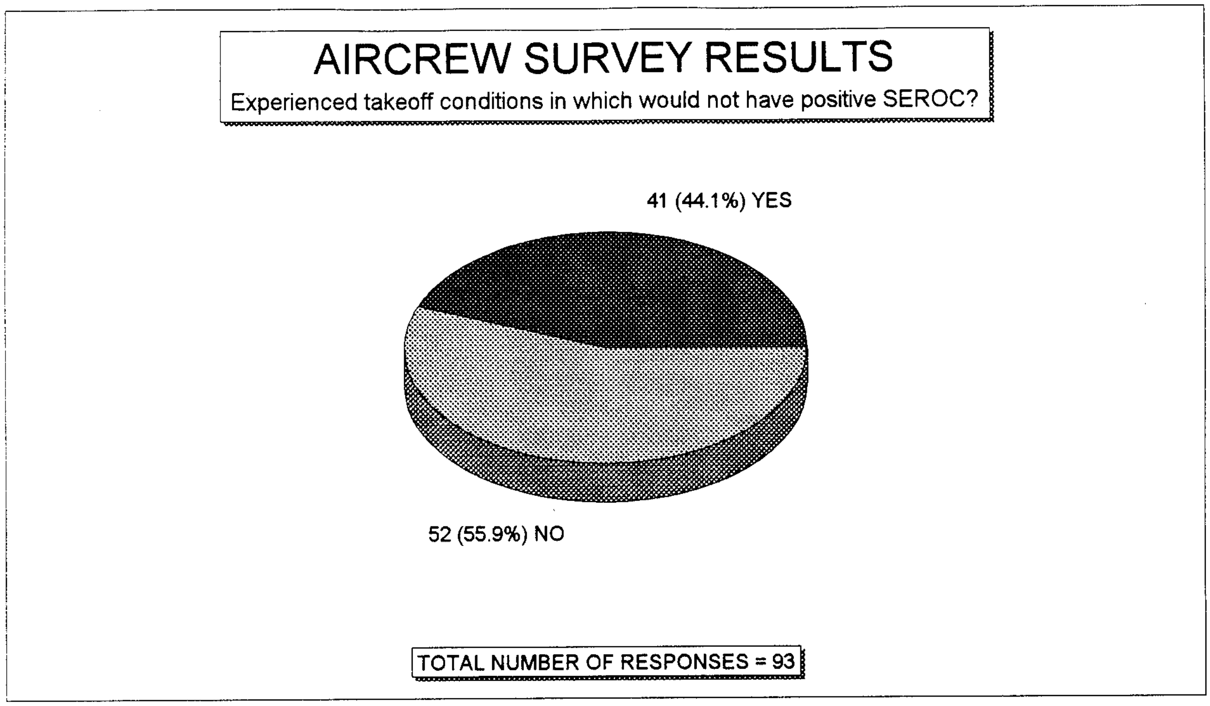


Figure 5. Aircrew Survey Background Information.



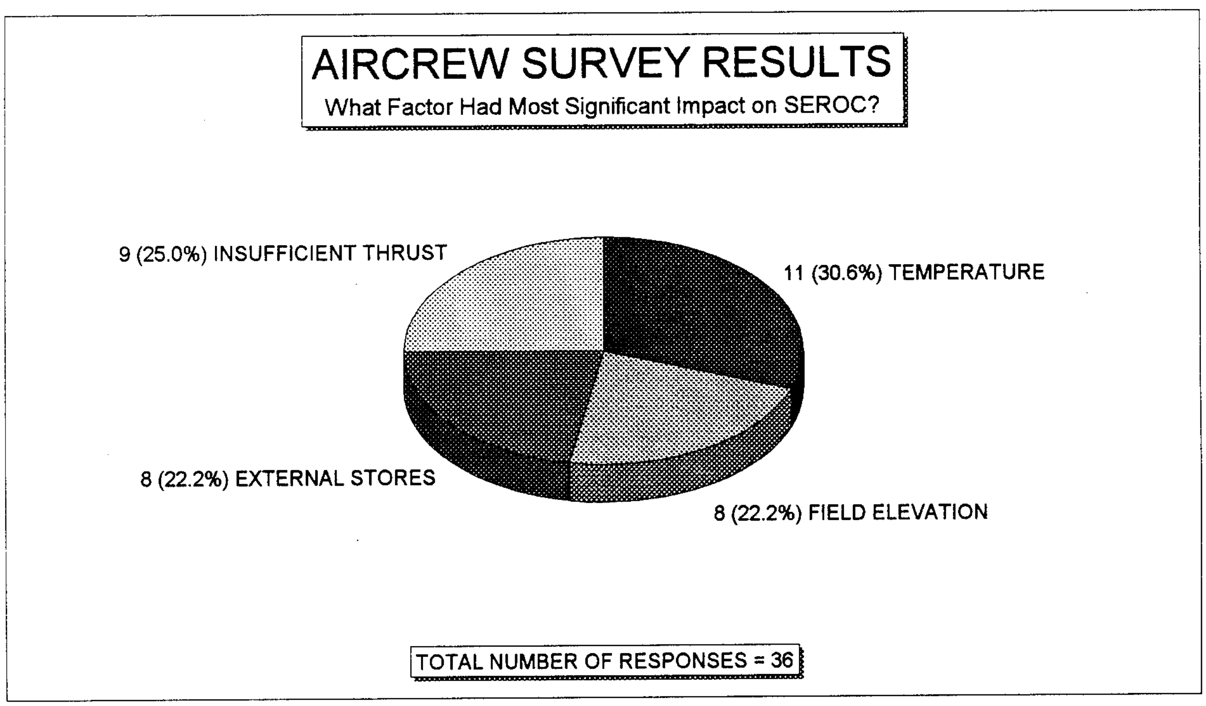
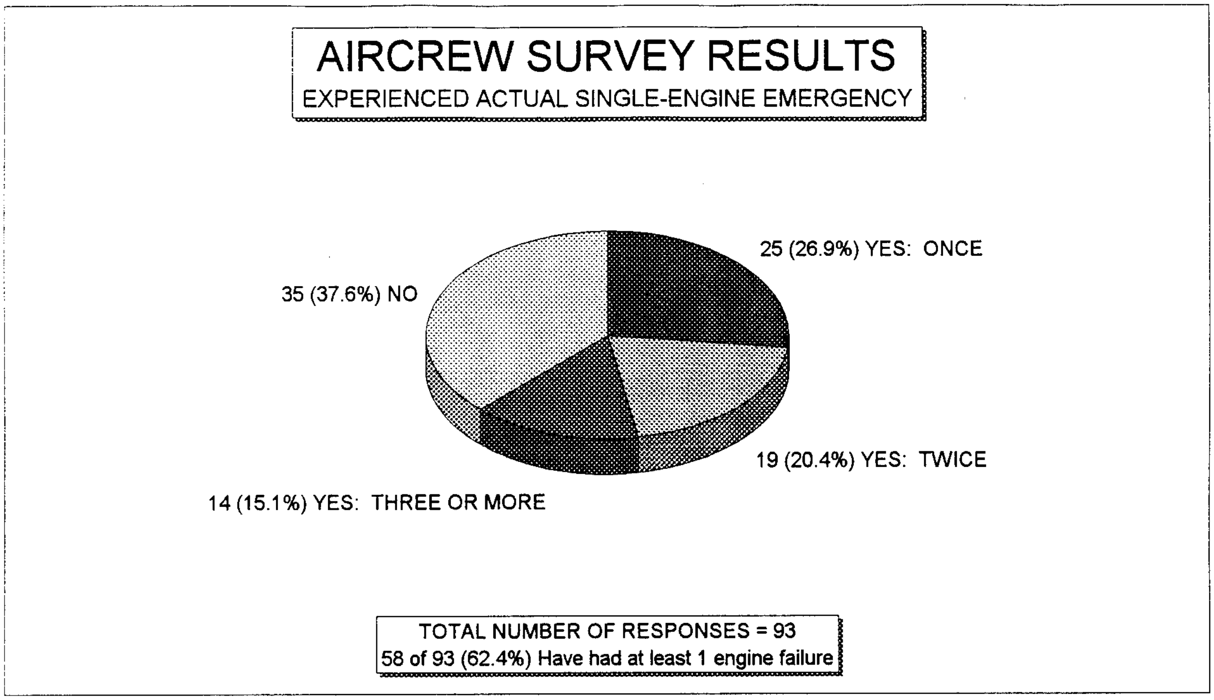


Figure 6. Takeoff Without Positive SEROC.

Question three asked if the aircrew had ever experienced actual single-engine flight, and if so how many times. Results showed that over 62% of the respondents had experienced at least one single-engine emergency situation (Figure 7). Experience of several separate single-engine failures was not uncommon as 14 of 93 (15.1%) responded that they had experienced three or more single-engine failures during their career. The next question asked those that had experienced single-engine flight what phase of flight the engine failure occurred. A vast majority (68.4%) occurred during the cruise or mission related phase of the flight while only four of 76 events (5.3%) occurred during takeoff (Figure 7). Question five asked about other engine related malfunctions that did not involve engine failure or shutdown yet occurred during the takeoff phase of flight. Of the 93 total responses one-third stated that they had experienced at least one engine-related malfunction during takeoff (Figure 8).

The final question in this section, question six, asked if the aircrew had ever been required to jettison external stores in an effort to achieve an increased SEROC. Surprisingly, none of the 93 aircrew surveyed had ever needed to jettison stores.

Section three of the survey asked questions pertaining to the performance of the TF34 engine. The first question asked the aircrew if they felt that the TF34 engine provided sufficient thrust for the mission of the S-3. Two-thirds of those responding stated that they did not think the S-3 had sufficient thrust (Figure 9). The next question asked those that responded "no" to state what mission/phase of flight they thought required more thrust. Respondents could list as many areas as they wanted and 70 of 122 replies (57.4%) listed the takeoff/climbout phase of flight as being the most in need of additional thrust (Figure 9).



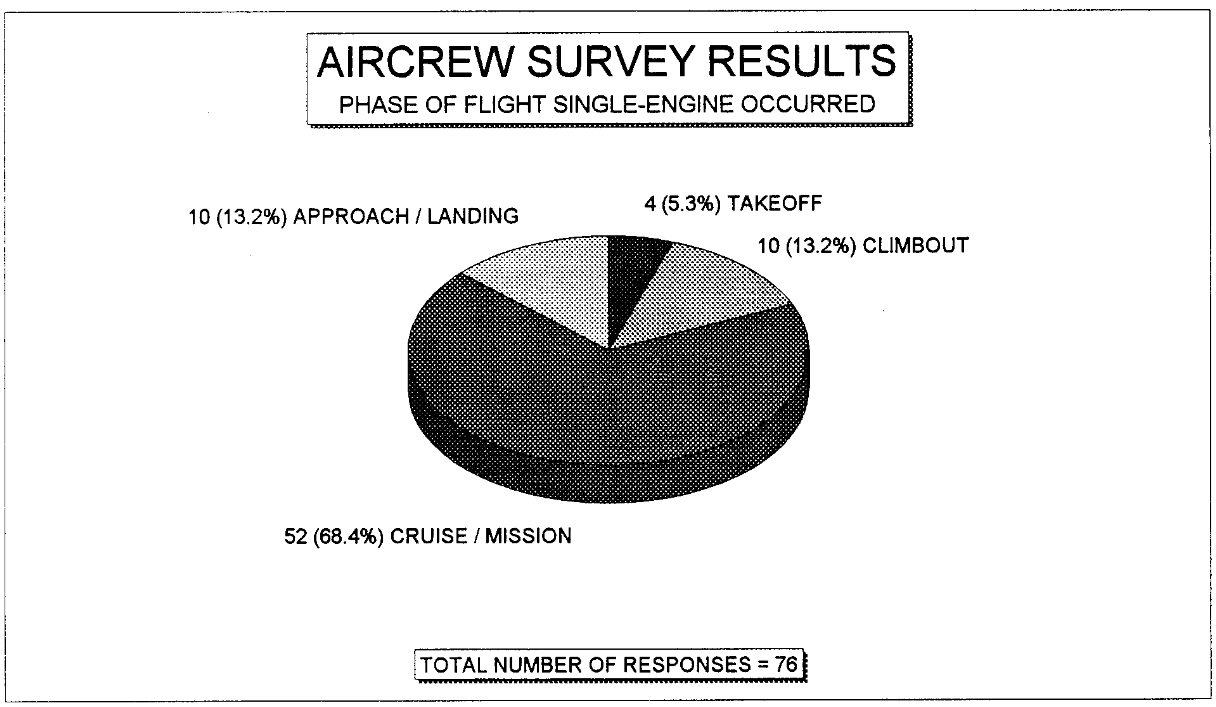


Figure 7. Single-Engine Flight Experiences.

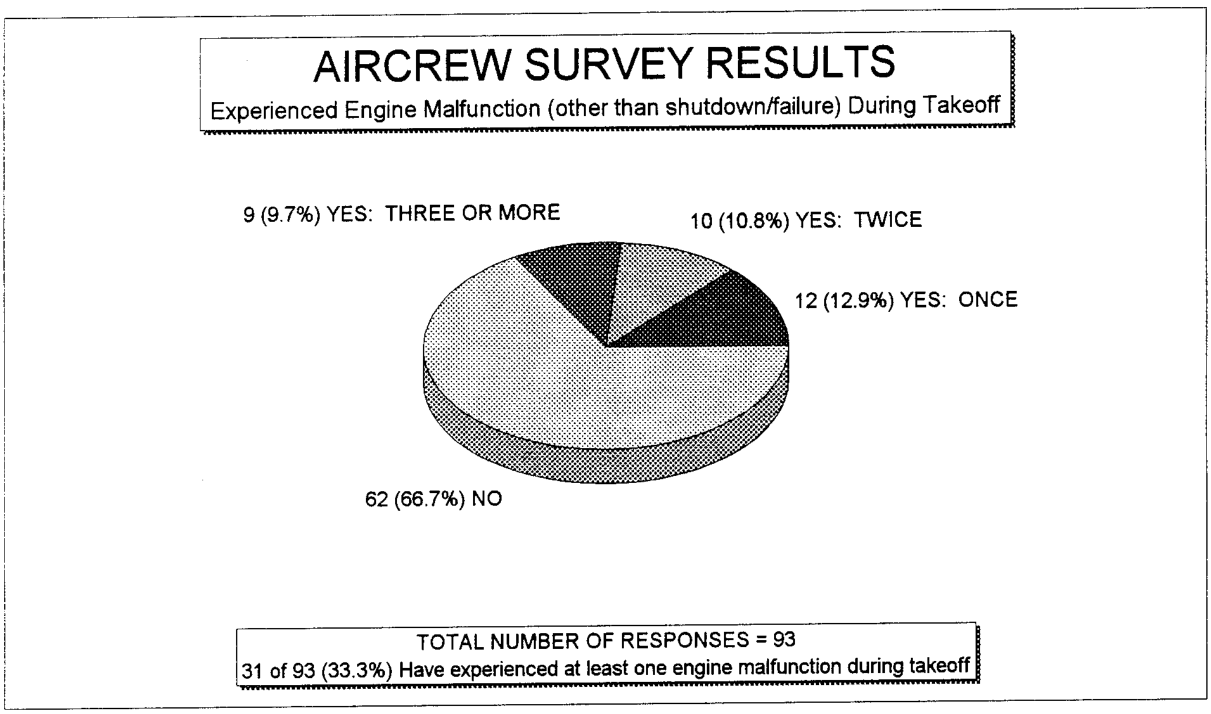
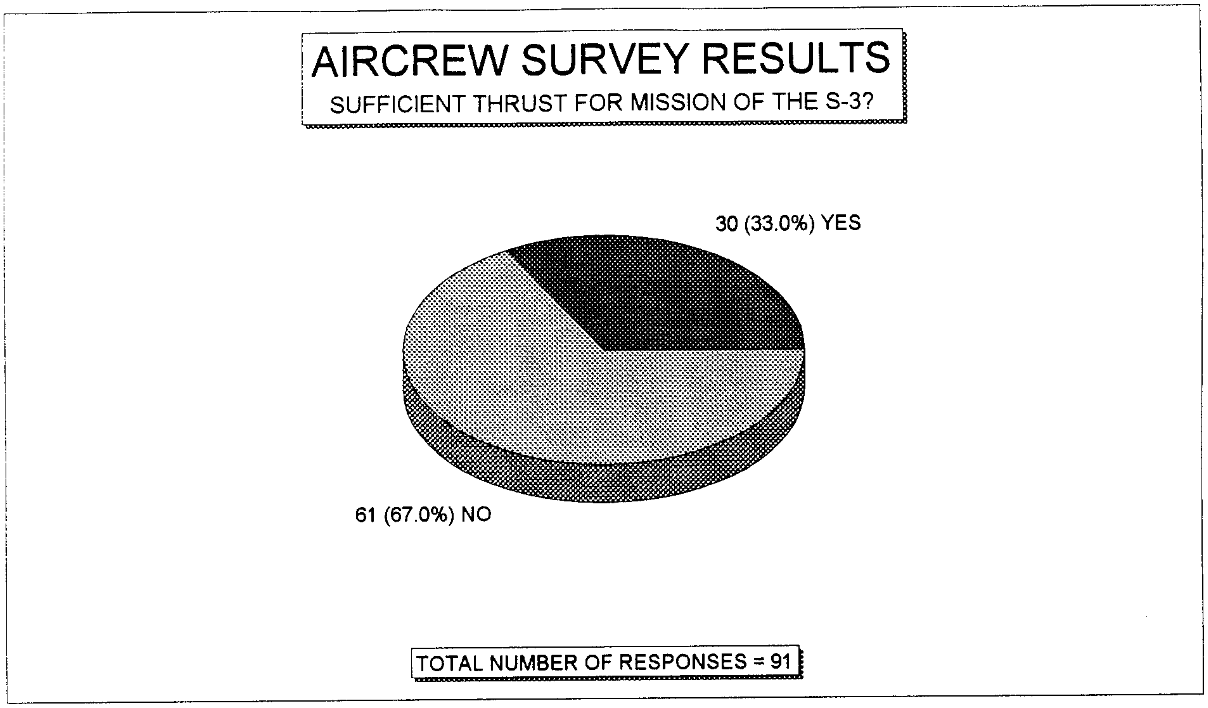


Figure 8. Experienced Engine Malfunctions During Takeoff.



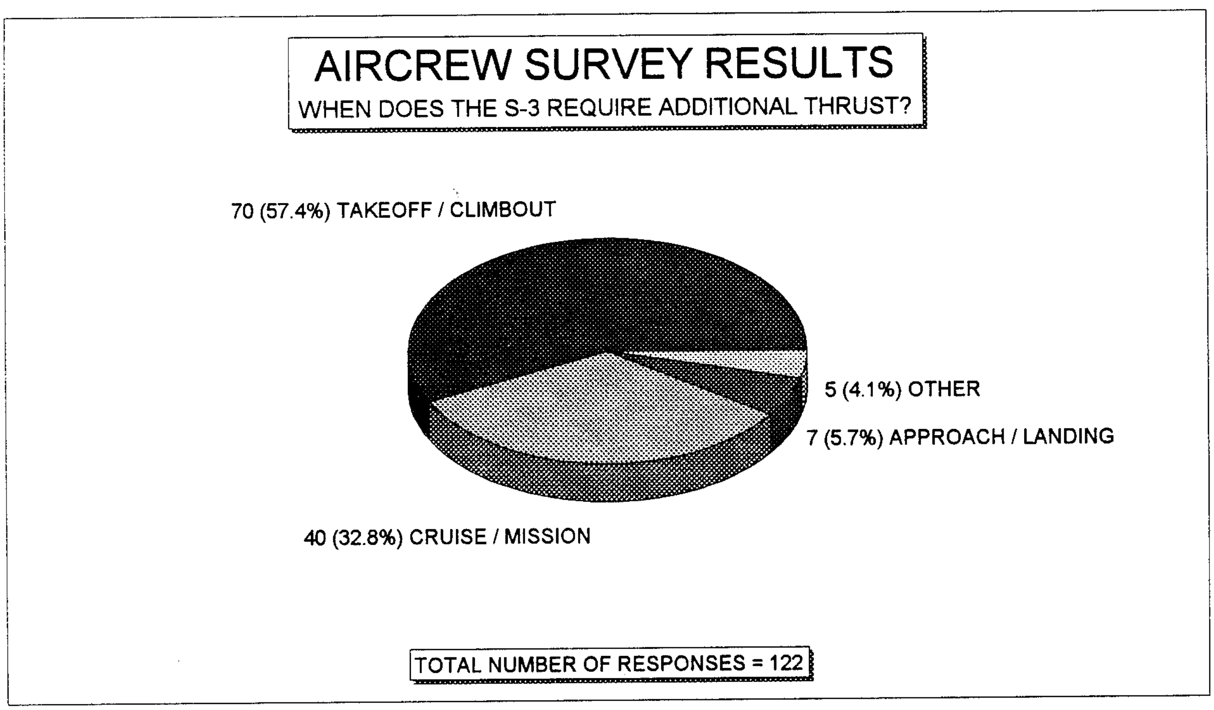


Figure 9. Thrust Requirements for Mission of the S-3.

The next two questions were the same as the previous two but with regard to the ES-3 rather than the S-3. Of the 55 responses, 45 (81.8%) did not think the ES-3 had sufficient thrust for its mission (Figure 10). As with the S-3, the flight phase identified as most in need of additional thrust was takeoff/climbout, generating two-thirds of the responses (Figure 10).

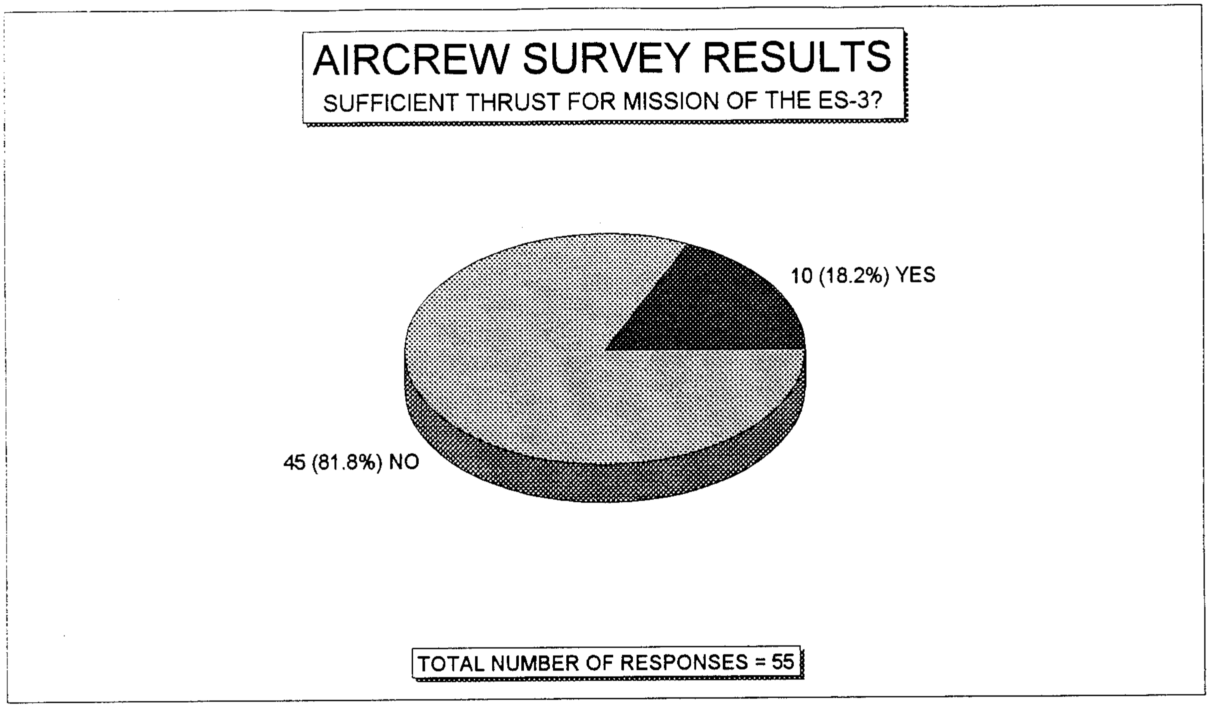
The next question asked if the aircrew thought that disabling the engine's T_5 system would provide any advantage in engine performance. Thirty-three of 93 response (35.5%) answered "yes" correctly, the remaining 64.5% stated that it would not or they did not know (Figure 11).

The final question of the survey asked what method of improving SEROC would be most recommend. Almost 50% stated that new or improved engines would be the best method, only 4.7% stated that performance was satisfactory and no changes were required (Figure 11).

2. Analysis of Survey Results

In studying the results of the survey, several key areas are worthy of further discussion. First, 41 of the 93 surveyed had experienced takeoff conditions without a positive SEROC. What occurs when conditions do not enable a positive SEROC? Ideally aircraft weight will be adjusted down by either downloading fuel or stores. However, this does not always happen. Interviews conducted with several aircrew indicated that operational necessity often prevails and that the aircraft are launched regardless of SEROC capabilities. The question that must be asked is when does "Operational Necessity" overrule prudent safety-of-flight considerations? Is it ever necessary to put an airplane and its crew in jeopardy, regardless of the probability of failure, or can steps be taken to ensure that these conditions will not routinely occur?

Secondly, the question should not be "will an engine fail?", but rather,"<u>when</u> will an engine fail?" Survey results indicate a high probability that even with an inherently reliable engine such as



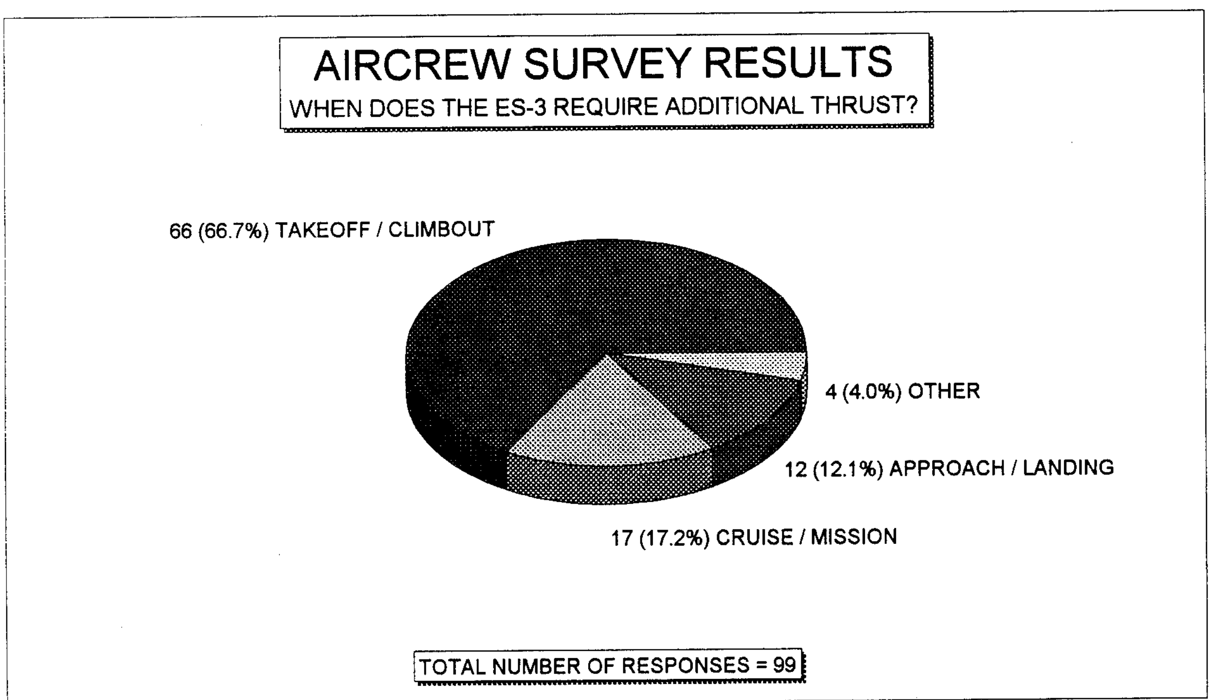
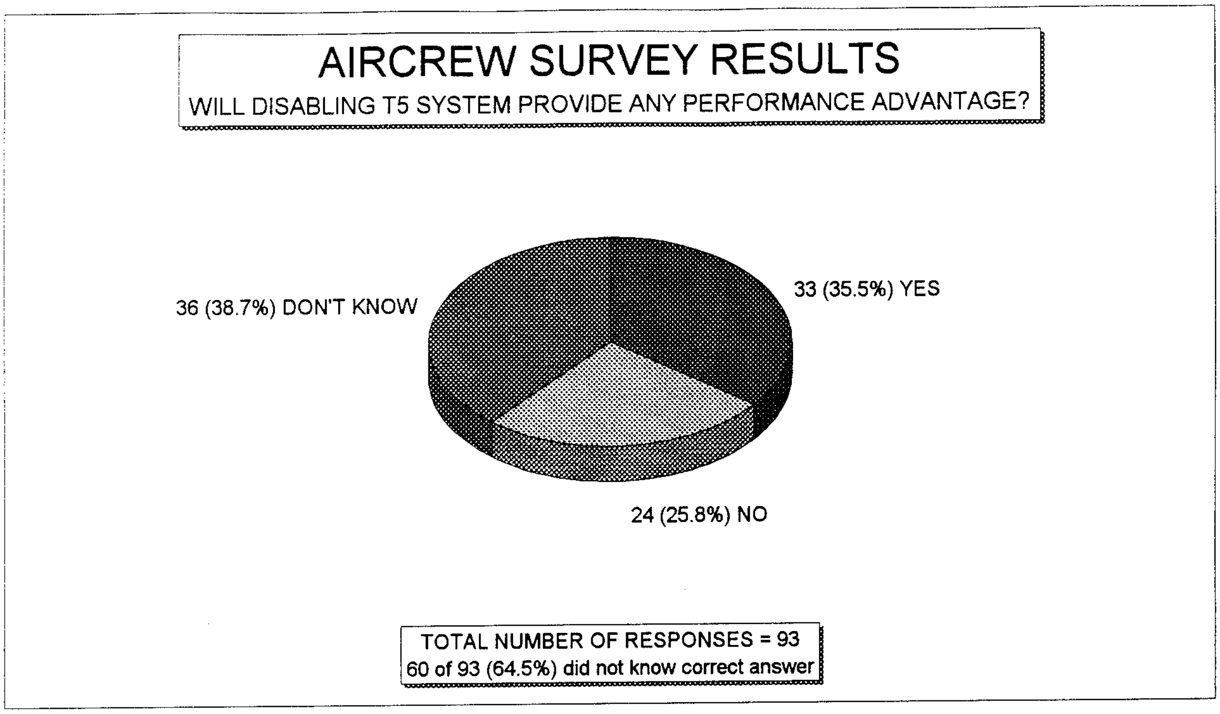


Figure 10. Thrust Requirements for Mission of the ES-3.



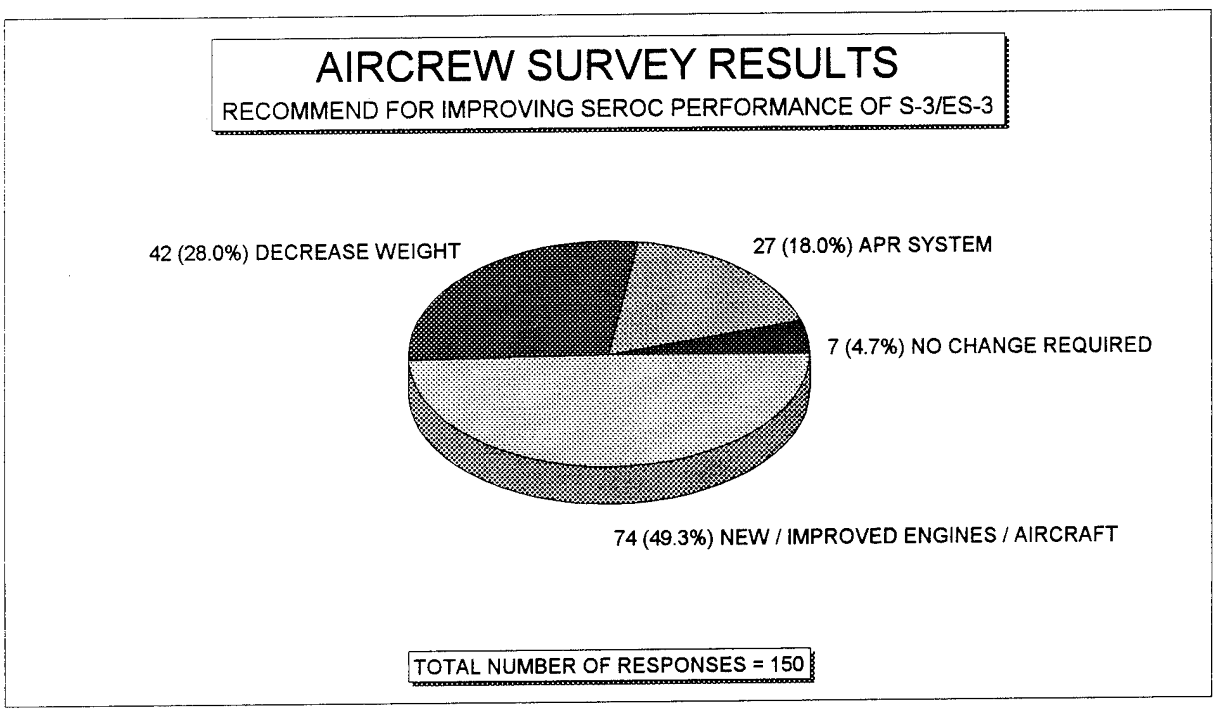


Figure 11. Disabling the T_5 System; Recommendations for Improved SEROC.

the TF34 you will experience single-engine flight at least once during your career. Although the survey shows only four engine failures occurring during takeoff phase, the low number can be explained by the small amount of time spent in that particular phase of flight. In a typical three-hour flight, only about five minutes (or less than 3% of flight time) occurs in the takeoff phase yet this accounts for over 5% of the failures. If you include the climbout portion of flight, when SEROC capability would still be critical, then 18.5% of the reported failures occurred during a critical phase of flight.

A third factor which is very important in this analysis is the fact that of those surveyed, no one has ever had to jettison external stores in order to achieve an increased SEROC. The results of this question would seem to indicate that regardless of the probability of engine failure occurring and, even if it does occur in the takeoff or climbout phase of flight, the chance of failure in which an improved SEROC is required for flight safety is extremely low. It is assumed that had additional SEROC been required an aircrew would have jettisoned stores. Without any external stores installed the S-3B would not require any increased SEROC. The ES-3A, however, due to its higher base weight would not have a sufficient positive SEROC at temperatures above approximately 80° F even without any external stores loaded according to NATOPS performance charts. Since both aircraft routinely takeoff with both a drop tank and an aerial refueling store installed, it might be expected that external stores would have been required to have been jettisoned at some time. The question and its results illustrate (at least in this small sample size) that, based on aircrew experiences, an actual event requiring the immediate jettisoning of stores to provide for improved SEROC has not yet occurred.

The survey does serve to clearly illustrate the perception of the fleet that neither aircraft presently possesses sufficient thrust for its mission. It is interesting to note that just under five percent reported that performance was satisfactory and no changes were required. The other 95%, as could be expected, were in favor of taking steps to improve the performance of their aircraft. The majority of responses indicated that if cost were not a factor, new engines would be the most desirable solution. Taking cost considerations into account, the most consistent answers included coupling improvements to the present engines with reductions in aircraft gross weight to achieve significantly better performance. While the takeoff/climbout phase was overwhelmingly listed as the phase of flight most in need of additional thrust, other mission areas where additional thrust capabilities would improve effectiveness were also mentioned. These areas included the mission tanker role, the ability to reach higher altitudes faster, and single-engine waveoff concerns. Thus, the fleet is not only aware of the lack of SEROC capabilities, but would also like to see improved engine performance in order to more effectively accomplish their missions.

Results of the survey also point out a need for training in the area of engine systems and performance. This is illustrated by answers given to the questions concerning the engine T_5 control system. When asked what precautions must be taken if the engine T_5 control system malfunctions or is disabled many responded with the NATOPS immediate action memory item: THROTTLE - IDLE (move the throttle to the idle position). Several responded that interturbine temperature limits (ITT) must be closely observed but no one mentioned the CAUTION listed in the NATOPS manual: DO NOT USE ATS (Automatic Throttle System) WITH T_5 DISABLED. The next question which asked about any performance advantage obtained from disabling the T_5 system, just over one-third answered correctly. Of those who did answer correctly, many also commented that the extra performance was not without cost; "disabling T_5 will probably cause overtemp and damage engine", was a typical reply. Almost two-thirds answered the question incorrectly or did not know enough about the system to speculate. As a point of reference, this author, who has over 1,600 S-3 flight hours, was not aware of the performance benefits achievable by disabling the T_5 system either until research into the subject began. Clearly, there is a need to get this information out to the fleet. Everyone should be aware of possible performance implications especially if there is potential for preventing a mishap.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The objective of this thesis was to provide an analytical, unbiased look at the performance of the TF34 engine as installed on the S-3 and ES-3 aircraft; specifically with regard to single-engine rate-of-climb (SEROC) capabilities and thrust requirements. The purpose being to provide Navy decision makers with information to assist in the effective management of proposals and improvements being considered under the TF34 Component Improvement Program (CIP). To achieve this objective of an evaluation of engine performance capabilities and requirements and in answer to the research questions stated in the Chapter One introduction, the following research procedures were conducted:

- Background information concerning the CIP, S-3 and ES-3 aircraft, and the TF34 engine, was obtained and discussed in Chapter II.

- A discussion of several new engine technologies and proposed methods being considered for improvement of SEROC performance was presented in Chapter II.

- An analysis of two historical databases maintained by the Navy was conducted in an effort to determine the frequency of TF34 engine failure/inflight engine shutdown events. The results of this analysis of the Naval Aviation Logistics Data Analysis (NALDA) system and the Naval Safety Center database are presented in Chapter III.

- An further analysis of historical engine failure data was conducted to determine the frequency of engine failure/shutdown events during the critical takeoff phase of flight. The results of this analysis are presented in Chapter III.

- The S-3B Operational Flight Trainer (OFT) and associated engine thrust model was utilized in an effort to predict and measure the effects of proposed performance improvements on SEROC and engine thrust production. A discussion of the use of flight simulators as a research tool and results and analysis of data obtained in the simulator is presented in Chapters IV and V.

- Fleet engine data was obtained in an effort to assess the health of the engines currently in an operational status. A comparison of the performance of actual engine fan speed with NATOPS targeted fan speed was conducted. In addition to the data collected, a discussion of the characteristic of engine fanspeed (NF) droop and the use of the simulator thrust model to illustrate degraded engine performance is contained in Chapters IV and V.

- A survey of S-3 and ES-3 aircrew was conducted to provide operator input into the research and to gather more specific historical data concerning actual experiences in the single-engine flight experiences. The survey methodology is presented in Chapter IV while results and analysis are discussed in Chapter V.

B. CONCLUSIONS

The stated SEROC deficiency for the ES-3A aircraft is a valid safety-of-flight issue that deserves immediate attention. Although the analysis of historical engine data and the responses from aircrew on the survey indicated that the TF34 engine performance has been reliable and the likelihood of experiencing an engine failure during critical takeoff evolutions is small, the unnecessary risk to aircraft and crew cannot be condoned. Except in times of war or extreme operational necessity, aircrew should not be expected to take a jet flying if the possibility of an engine failure during takeoff leaves them no other option than to eject. The capability for improved SEROC performance exists right now with the current TF34 engine as illustrated in the simulator tests conducted. Through the disabling of the engine T_5 control system or otherwise allowing the engine to be run hotter, sufficient thrust for an acceptable SEROC can be generated.

The gains in performance obtained from allowing the engine to run hotter are not without detrimental consequences in an engine's life management. Thus, an acceptable economic balance between performance requirements and engine life needs to be determined. Current TF34 CIP projects are in place for the expressed purpose of increasing the service life and maintenance intervals of the engine. Tradeoffs between performance and life management issues should be addressed in the specific CIP proposals for these projects.

Although the proposed Automatic Power Reserve (APR) system has the capability to resolve the SEROC problem, it should not be viewed as the "fix" to the situation. Many details involved in the design and operation of such a system must still be worked out and at best would still leave the aircrew in a situation where they are relying on the system to work as advertised should an engine fail. You cannot assume that the system is going to work perfectly when required just as you can't assume that you'll be able to jettison external stores or raise the landing gear. The development required to make the system fool-proof would make it cost prohibitive and anything less than a perfectly reliable system would leave the aircraft in the same situation it's in right now.

While the SEROC issue for the ES-3A is the only documented mission need for additional thrust, this thesis has shown that the general perception of the S-3 and ES-3 communities is that the aircraft does not have sufficient thrust to adequately meet mission requirements. A specific mission requirement that has tactical considerations is that of mission tanker. With the retiring of the A-6 aircraft from the Navy inventory, the S-3B/ES-3A aircraft are now the only organic tankers for the carrier air wing. The S-3 is capable of meeting all requirements as a recovery or overhead tanker. As a mission tanker, however, the S-3 leaves a lot to be desired. With the composition of the carrier air wing continuing to evolve with increasing numbers of F/A-18 aircraft, the mission tanker role becomes more and more critical. Increased thrust would help to make the S-3 a more suitable mission tanker and provide greater organic capability to the air wing.

The problem of fan speed droop is not one that is going to go away. As the engines get older, performance will continue to decline. Fanspeed droop is a characteristic of the engine that will continue. However, performance improvements should take the droop factor into account and provide an adequate margin of excess thrust such that droop is not considered critical. The TF34 Program Management Team is currently studying the problem in an attempt to quantify the effects of fanspeed droop and determine necessary thrust requirements. Many fleet aircraft are not meeting the current NATOPS criteria for target fan speed value. If this target value is indeed GO/NO-GO criteria for the engine, then engine performance must be increased or the NATOPS target values must be adjusted down.

The performance charts in the S-3B NATOPS manual are based on flight tests conducted in 1978 utilizing an S-3A aircraft with relatively new engines and do not take into consideration the effects of engine age and wear on performance. Fortunately, the ES-3A performance data is current with the flight profiles having been flown in 1993. If the issues of engine performance and thrust requirements are to be properly addressed, current, accurate aircraft performance data must be available.

There is a need for education of aircrew in important aspects of the engine, its systems, and performance factors. The fleet needs to know information that has the potential to save an aircraft and the crew. Although disabling the T_5 system will cause an overtemp on the operating engine, that cost is insignificant compared to the cost of a Class A mishap. The T_5 system disable should not be used indiscriminately, but, in certain situations it may provide the aircrew with enough extra thrust capability to avoid a mishap.

C. RECOMMENDATIONS

Based on the research results the following recommendations are proposed:

- Take the steps necessary to solve the stated deficiency in ES-3A SEROC as soon as possible. New engines or an APR system are not required. By simply increasing the engine operating temperature limits sufficient thrust to maintain an adequate SEROC can be obtained.

- Conduct an engine performance/life management tradeoff analysis to determine how much increased performance can be obtained without having a significant detrimental effect on engine reliability, maintainability, and availability.

- Conduct flight tests with the S-3B aircraft to obtain more current performance charts for the NATOPS manual. These tests can determine the effect of engine age and wear on performance parameters and will provide aircrew with more realistic data for flight planning purposes.

- A change to the S-3/ES-3 NATOPS manuals should be made to ensure that all aircrew are aware of the performance and engine life implications of operating the TF34 engine with the T_5 control system disabled.

- The VS and VQ communities must document their need for increased engine performance for specific missions. When a valid mission need is clearly articulated the acquisition system can begin the steps necessary to fulfill the need.

By implementing these recommendations, the Navy can be assured that the S-3 and ES-3 aircraft will be able to safely and effectively accomplish their assigned missions throughout the remainder of their planned operational service life.

APPENDIX A. NALDA DATA

This appendix contains the complete listing of data generated by the requested query of the NALDA database for all TF34 engine-related malfunctions which were reported with an inflight abort. The data is presented in spreadsheet format and is sorted by month and year of occurrence, failure code and nomenclature, number of engines which reported the failure for the time period, and the total flight hours for the time period.

	DATE	FAILURE	NOMENCLATURE	EVENTS	FLT HRS
1	7601	37	FLUCTUATES,UNSTABLE FREQ RPM	2	2755
2	7601	334	TEMPERATURE INCORRECT	2	2755
3	7601	374	INTERNAL FAILURE	2	2755
4	7601	730	LOOSE	2	2755
5	7602	242	FAILED TO OPERATE REASON UNKNOWN	2	2669
6	7602	306	CONTAMINATION,NON METTALIC DIRTY	2	2669
7	7602	730	LOOSE	2	2669
8	7603	242	FAILED TO OPERATE REASON UNKNOWN	2	3524
9	7603	730	LOOSE	2	3524
10	7604	37	FLUCTUATES,UNSTABLE FREQ RPM	2	3991
11	7604	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	3991
12	7604	242	FAILED TO OPERATE REASON UNKNOWN	2	3991
13	7604	318	DECELERATION IMPROPER	2	3991
14	7604	823	NO START	2	3991
15	7605	69	FLAME OUT	2	3788
16	7605	242	FAILED TO OPERATE REASON UNKNOWN	4	3788
17	7606	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	3914
18	7606	242	FAILED TO OPERATE REASON UNKNOWN	8	3914
19	7606	525	PRESSURE INCORRECT	2	3914
20	7607	242	FAILED TO OPERATE REASON UNKNOWN	2	3687
21	7607	306	CONTAMINATION,NON METTALIC DIRTY	2	3687
22	7607	374	INTERNAL FAILURE	2	3687
23	7608	180	CLOGGED,OBSTRUCTED,PLUGGED	2	3856
24	7608	242	FAILED TO OPERATE REASON UNKNOWN	2	3856
25	7608	381	LEAKING-INTERNAL OR EXTERNAL	2	3856
26	7608	410	LACK OF LUBRICATION	2	3856
27	7609	180	CLOGGED,OBSTRUCTED,PLUGGED	2	4228
28	7609	242	FAILED TO OPERATE REASON UNKNOWN	2	4228
29	7609	334	TEMPERATURE INCORRECT	2	4228
30	7609	410	LACK OF LUBRICATION	2	4228
31	7610	170	CORRODED	2	4686
32	7610	242	FAILED TO OPERATE REASON UNKNOWN	6	4686
33	7610	374	INTERNAL FAILURE	2	4686
34	7610	381	LEAKING-INTERNAL OR EXTERNAL	2	4686
35	7610	730	LOOSE	2	4686
36	7611	180	CLOGGED,OBSTRUCTED,PLUGGED	2	3856
37	7611	306	CONTAMINATION,NON METTALIC DIRTY	4	3856
38	7612	37	FLUCTUATES,UNSTABLE FREQ RPM	2	3728
39	7612	242	FAILED TO OPERATE REASON UNKNOWN	2	3728
40	7612	306	CONTAMINATION,NON METTALIC DIRTY	2	3728
41	7701	69	FLAME OUT	2	4370
42	7701	242	FAILED TO OPERATE REASON UNKNOWN	8	4370
43	7701	304	FOD-INGESTION OF A/C PART	2	4370
44	7701	381	LEAKING-INTERNAL OR EXTERNAL	2	4370
45	7702	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4450
46	7702	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4450

47	7702	372	METAL IN OIL STRAINER FILTER	2	4450
48	7702	410	LACK OF LUBRICATION	2	4450
49	7703	185	CONTAMINATION	2	4992
50	7703	381	LEAKING-INTERNAL OR EXTERNAL	4	4992
51	7703	525	PRESSURE INCORRECT	2	4992
52	7704	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4949
53	7704	242	FAILED TO OPERATE REASON UNKNOWN	4	4949
54	7704	374	INTERNAL FAILURE	2	4949
55	7704	730	LOOSE	2	4949
56	7705	37	FLUCTUATES,UNSTABLE FREQ RPM	2	5386
57	7705	117	DETERIORATED/ERODED	2	5386
58	7705	374	INTERNAL FAILURE	2	5386
59	7705	690	VIBRATION EXCESSIVE	2	5386
60	7706	37	FLUCTUATES,UNSTABLE FREQ RPM	2	5581
61	7706	127	ADJUSTMENT/ALIGNMENT IMPROPER	4	5581
62	7706	242	FAILED TO OPERATE REASON UNKNOWN	2	5581
63	7707	70	BROKEN,BURST,CUT,TORN	2	4809
64	7707	190	CRACKED,CRAZED	2	4809
65	7707	242	FAILED TO OPERATE REASON UNKNOWN	4	4809
66	7707	282	LOW OUTPUT,READING OR VALUE	2	4809
67	7707	381	LEAKING-INTERNAL OR EXTERNAL	10	4809
68	7707	730	LOOSE	2	4809
69	7707	823	NO START	2	4809
70	7708	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	5453
71	7708	185	CONTAMINATION	2	5453
72	7708	242	FAILED TO OPERATE REASON UNKNOWN	8	5453
73	7708	381	LEAKING-INTERNAL OR EXTERNAL	2	5453
74	7708	615	SHORTED	2	5453
75	7708	730	LOOSE	2	5453
76	7709	37	FLUCTUATES,UNSTABLE FREQ RPM	4	5710
77	7709	242	FAILED TO OPERATE REASON UNKNOWN	6	5710
78	7709	372	METAL IN OIL STRAINER FILTER	2	5710
79	7709	696	FLUID LOW	2	5710
80	7710	70	BROKEN,BURST,CUT,TORN	2	4847
81	7710	177	FUEL FLOW INCORRECT	2	4847
82	7710	180	CLOGGED,OBSTRUCTED,PLUGGED	2	4847
83	7710	242	FAILED TO OPERATE REASON UNKNOWN	4	4847
84	7710	381	LEAKING-INTERNAL OR EXTERNAL	2	4847
85	7712	108	BROKEN OR MISSING SAFETY WIRE	2	4594
86	7712	372	METAL IN OIL STRAINER FILTER	2	4594
87	7712	730	LOOSE	2	4594
88	7712	823	NO START	2	4594
89	7801	185	CONTAMINATION	2	5002
90	7801	242	FAILED TO OPERATE REASON UNKNOWN	2	5002
91	7802	242	FAILED TO OPERATE REASON UNKNOWN	4	4947
92	7802	525	PRESSURE INCORRECT	6	4947
93	7803	127	ADJUSTMENT/ALIGNMENT IMPROPER	4	5746

94	7803	525	PRESSURE INCORRECT	2	5746
95	7804	8	NOISY	2	5236
96	7804	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	5236
97	7804	242	FAILED TO OPERATE REASON UNKNOWN	8	5236
98	7804	381	LEAKING-INTERNAL OR EXTERNAL	4	5236
99	7804	823	NO START	2	5236
100	7805	37	FLUCTUATES,UNSTABLE FREQ RPM	2	7830
101	7805	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	7830
102	7805	242	FAILED TO OPERATE REASON UNKNOWN	6	7830
103	7805	374	INTERNAL FAILURE	2	7830
104	7805	381	LEAKING-INTERNAL OR EXTERNAL	4	7830
105	7805	696	FLUID LOW	2	7830
106	7806	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4909
107	7806	160	CONTACT/CONNECTION DEFECTIVE	2	4909
108	7806	242	FAILED TO OPERATE REASON UNKNOWN	8	4909
109	7807	242	FAILED TO OPERATE REASON UNKNOWN	2	4947
110	7808	8	NOISY	2	6135
111	7808	242	FAILED TO OPERATE REASON UNKNOWN	6	6135
112	7808	372	METAL IN OIL STRAINER FILTER	2	6135
113	7808	374	INTERNAL FAILURE	2	6135
114	7808	381	LEAKING-INTERNAL OR EXTERNAL	2	6135
115	7808	730	LOOSE	2	6135
116	7809	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4960
117	7809	69	FLAME OUT	2	4960
118	7809	242	FAILED TO OPERATE REASON UNKNOWN	2	4960
119	7809	334	TEMPERATURE INCORRECT	2	4960
120	7809	374	INTERNAL FAILURE	2	4960
121	7809	525	PRESSURE INCORRECT	2	4960
122	7810	135	BINDING STUCK OR JAMMED	2	5811
123	7810	242	FAILED TO OPERATE REASON UNKNOWN	4	5811
124	7810	381	LEAKING-INTERNAL OR EXTERNAL	2	5811
125	7810	537	LOW POWER OR THRUST	2	5811
126	7811	170	CORRODED	2	4517
127	7811	180	CLOGGED,OBSTRUCTED,PLUGGED	2	4517
128	7811	185	CONTAMINATION	2	4517
129	7811	242	FAILED TO OPERATE REASON UNKNOWN	6	4517
130	7811	525	PRESSURE INCORRECT	2	4517
131	7811	690	VIBRATION EXCESSIVE	2	4517
132	7811	730	LOOSE	2	4517
133	7812	242	FAILED TO OPERATE REASON UNKNOWN	2	4078
134	7812	334	TEMPERATURE INCORRECT	2	4078
135	7812	381	LEAKING-INTERNAL OR EXTERNAL	2	4078
136	7901	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4713
137	7901	161	OUTPUT INCORRECT	4	4713
138	7901	180	CLOGGED,OBSTRUCTED,PLUGGED	2	4713
139	7901	242	FAILED TO OPERATE REASON UNKNOWN	4	4713
140	7901	303	FOD-BIRD STRIKE DAMAGE	2	4713

141	7901	381	LEAKING-INTERNAL OR EXTERNAL	2	4713
142	7902	242	FAILED TO OPERATE REASON UNKNOWN	4	4791
143	7902	615	SHORTED	2	4791
144	7903	170	CORRODED	2	5423
145	7903	242	FAILED TO OPERATE REASON UNKNOWN	8	5423
146	7903	381	LEAKING-INTERNAL OR EXTERNAL	2	5423
147	7904	37	FLUCTUATES,UNSTABLE FREQ RPM	2	5007
148	7904	69	FLAME OUT	2	5007
149	7904	127	ADJUSTMENT/ALIGNMENT IMPROPER	4	5007
150	7904	242	FAILED TO OPERATE REASON UNKNOWN	4	5007
151	7904	381	LEAKING-INTERNAL OR EXTERNAL	4	5007
152	7904	398	OIL CONSUMPTION EXCESSIVE	2	5007
153	7904	410	LACK OF LUBRICATION	2	5007
154	7905	242	FAILED TO OPERATE REASON UNKNOWN	2	4950
155	7905	334	TEMPERATURE INCORRECT	2	4950
156	7905	381	LEAKING-INTERNAL OR EXTERNAL	2	4950
157	7905	766	OUT OF SPEC	4	4950
158	7906	242	FAILED TO OPERATE REASON UNKNOWN	8	4695
159	7906	381	LEAKING-INTERNAL OR EXTERNAL	4	4695
160	7906	900	BURNED OR OVERHEATED	2	4695
161	7907	37	FLUCTUATES,UNSTABLE FREQ RPM	2	3438
162	7907	106	MISSING BOLTS,NUTS,SCREWS,ETC.	2	3438
163	7907	180	CLOGGED,OBSTRUCTED,PLUGGED	2	3438
164	7907	242	FAILED TO OPERATE REASON UNKNOWN	4	3438
165	7907	381	LEAKING-INTERNAL OR EXTERNAL	2	3438
166	7907	690	VIBRATION EXCESSIVE	2	3438
167	7908	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4668
168	7908	242	FAILED TO OPERATE REASON UNKNOWN	2	4668
169	7909	242	FAILED TO OPERATE REASON UNKNOWN	2	4180
170	7910	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4627
171	7910	242	FAILED TO OPERATE REASON UNKNOWN	10	4627
172	7911	242	FAILED TO OPERATE REASON UNKNOWN	4	3957
173	7911	306	CONTAMINATION,NON METTALIC DIRTY	2	3957
174	7912	242	FAILED TO OPERATE REASON UNKNOWN	10	3472
175	8002	161	OUTPUT INCORRECT	2	4267
176	8002	242	FAILED TO OPERATE REASON UNKNOWN	4	4267
177	8003	242	FAILED TO OPERATE REASON UNKNOWN	4	5281
178	8003	381	LEAKING-INTERNAL OR EXTERNAL	6	5281
179	8004	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4498
180	8004	242	FAILED TO OPERATE REASON UNKNOWN	6	4498
181	8004	381	LEAKING-INTERNAL OR EXTERNAL	2	4498
182	8004	730	LOOSE	2	4498
183	8005	177	FUEL FLOW INCORRECT	2	5179
184	8005	180	CLOGGED,OBSTRUCTED,PLUGGED	2	5179
185	8005	242	FAILED TO OPERATE REASON UNKNOWN	2	5179
186	8005	374	INTERNAL FAILURE	2	5179
187	8005	381	LEAKING-INTERNAL OR EXTERNAL	2	5179

188	8005	525	PRESSURE INCORRECT	4	5179
189	8005	801	NO DEFECT-REMOVED FOR MODIFICATION	2	5179
190	8006	242	FAILED TO OPERATE REASON UNKNOWN	2	5047
191	8006	282	LOW OUTPUT,READING OR VALUE	4	5047
192	8006	306	CONTAMINATION,NON METTALIC DIRTY	2	5047
193	8006	410	LACK OF LUBRICATION	2	5047
194	8006	730	LOOSE	2	5047
195	8007	242	FAILED TO OPERATE REASON UNKNOWN	6	5625
196	8007	525	PRESSURE INCORRECT	2	5625
197	8007	690	VIBRATION EXCESSIVE	2	5625
198	8008	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4307
199	8008	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4307
200	8008	242	FAILED TO OPERATE REASON UNKNOWN	16	4307
201	8008	525	PRESSURE INCORRECT	2	4307
202	8009	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4984
203	8009	242	FAILED TO OPERATE REASON UNKNOWN	4	4984
204	8009	334	TEMPERATURE INCORRECT	2	4984
205	8009	381	LEAKING-INTERNAL OR EXTERNAL	4	4984
206	8009	410	LACK OF LUBRICATION	2	4984
207	8010	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4419
208	8010	242	FAILED TO OPERATE REASON UNKNOWN	4	4419
209	8010	334	TEMPERATURE INCORRECT	2	4419
210	8010	381	LEAKING-INTERNAL OR EXTERNAL	2	4419
211	8010	730	LOOSE	2	4419
212	8011	242	FAILED TO OPERATE REASON UNKNOWN	10	4803
213	8012	242	FAILED TO OPERATE REASON UNKNOWN	6	4318
214	8012	381	LEAKING-INTERNAL OR EXTERNAL	2	4318
215	8101	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4754
216	8101	135	BINDING STUCK OR JAMMED	2	4754
217	8101	242	FAILED TO OPERATE REASON UNKNOWN	10	4754
218	8101	381	LEAKING-INTERNAL OR EXTERNAL	4	4754
219	8102	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4655
220	8102	177	FUEL FLOW INCORRECT	2	4655
221	8102	306	CONTAMINATION,NON METTALIC DIRTY	2	4655
222	8102	381	LEAKING-INTERNAL OR EXTERNAL	2	4655
223	8103	160	CONTACT/CONNECTION DEFECTIVE	2	4733
224	8103	190	CRACKED,CRAZED	2	4733
225	8103	242	FAILED TO OPERATE REASON UNKNOWN	4	4733
226	8103	304	FOD-INGESTION OF A/C PART	2	4733
227	8103	334	TEMPERATURE INCORRECT	2	4733
228	8104	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4830
229	8104	242	FAILED TO OPERATE REASON UNKNOWN	6	4830
230	8105	106	MISSING BOLTS,NUTS,SCREWS,ETC.	2	5425
231	8105	127	ADJUSTMENT/ALIGNMENT IMPROPER	6	5425
232	8105	410	LACK OF LUBRICATION	2	5425
233	8106	70	BROKEN,BURST,CUT,TORN	2	5417
234	8106	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	5417

235	8106	242	FAILED TO OPERATE REASON UNKNOWN	4	5417
236	8107	242	FAILED TO OPERATE REASON UNKNOWN	2	5028
237	8107	350	INSULATION BREAKDOWN	2	5028
238	8108	37	FLUCTUATES,UNSTABLE FREQ RPM	2	5140
239	8108	160	CONTACT/CONNECTION DEFECTIVE	2	5140
240	8108	242	FAILED TO OPERATE REASON UNKNOWN	4	5140
241	8108	381	LEAKING-INTERNAL OR EXTERNAL	2	5140
242	8109	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	5509
243	8109	242	FAILED TO OPERATE REASON UNKNOWN	4	5509
244	8109	690	VIBRATION EXCESSIVE	2	5509
245	8110	242	FAILED TO OPERATE REASON UNKNOWN	4	4440
246	8111	177	FUEL FLOW INCORRECT	2	4918
247	8111	180	CLOGGED,OBSTRUCTED,PLUGGED	2	4918
248	8111	282	LOW OUTPUT,READING OR VALUE	2	4918
249	8111	306	CONTAMINATION,NON METTALIC DIRTY	2	4918
250	8112	37	FLUCTUATES,UNSTABLE FREQ RPM	2	3704
251	8112	381	LEAKING-INTERNAL OR EXTERNAL	2	3704
252	8112	730	LOOSE	2	3704
253	8201	69	FLAME OUT	2	4814
254	8201	70	BROKEN,BURST,CUT,TORN	2	4814
255	8201	242	FAILED TO OPERATE REASON UNKNOWN	4	4814
256	8201	315	RPM FLUCTUATION OR INCORRECT	2	4814
257	8201	381	LEAKING-INTERNAL OR EXTERNAL	4	4814
258	8202	161	OUTPUT INCORRECT	2	4484
259	8202	242	FAILED TO OPERATE REASON UNKNOWN	4	4484
260	8202	350	INSULATION BREAKDOWN	2	4484
261	8202	410	LACK OF LUBRICATION	2	4484
262	8202	730	LOOSE	2	4484
263	8203	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4941
264	8203	303	FOD-BIRD STRIKE DAMAGE	2	4941
265	8203	381	LEAKING-INTERNAL OR EXTERNAL	4	4941
266	8204	242	FAILED TO OPERATE REASON UNKNOWN	6	5154
267	8205	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4406
268	8205	242	FAILED TO OPERATE REASON UNKNOWN	2	4406
269	8205	730	LOOSE	2	4406
270	8206	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4771
271	8206	242	FAILED TO OPERATE REASON UNKNOWN	4	4771
272	8206	282	LOW OUTPUT,READING OR VALUE	2	4771
273	8206	306	CONTAMINATION,NON METTALIC DIRTY	2	4771
274	8206	730	LOOSE	2	4771
275	8206	922	OVERTEMP LIMITS EXCEEDED(EMS)	2	4771
276	8209	20	WORN,STRIPPED,CHAFFED,FRAYED	2	5137
277	8209	69	FLAME OUT	2	5137
278	8209	242	FAILED TO OPERATE REASON UNKNOWN	4	5137
279	8209	282	LOW OUTPUT,READING OR VALUE	2	5137
280	8209	381	LEAKING-INTERNAL OR EXTERNAL	2	5137
281	8209	525	PRESSURE INCORRECT	2	5137

282	8210	242	FAILED TO OPERATE REASON UNKNOWN	2	5554
283	8210	696	FLUID LOW	2	5554
284	8210	730	LOOSE	2	5554
285	8211	242	FAILED TO OPERATE REASON UNKNOWN	2	3654
286	8211	334	TEMPERATURE INCORRECT	2	3654
287	8211	381	LEAKING-INTERNAL OR EXTERNAL	2	3654
288	8212	170	CORRODED	2	3999
289	8212	730	LOOSE	2	3999
290	8301	185	CONTAMINATION	2	4838
291	8301	242	FAILED TO OPERATE REASON UNKNOWN	4	4838
292	8301	334	TEMPERATURE INCORRECT	2	4838
293	8301	410	LACK OF LUBRICATION	2	4838
294	8302	242	FAILED TO OPERATE REASON UNKNOWN	10	3851
295	8303	242	FAILED TO OPERATE REASON UNKNOWN	2	6076
296	8303	381	LEAKING-INTERNAL OR EXTERNAL	4	6076
297	8303	707	SHORTED,INTERNAL	2	6076
298	8303	730	LOOSE	4	6076
299	8304	37	FLUCTUATES,UNSTABLE FREQ RPM	6	5404
300	8304	184	UNDECODED	2	5404
301	8304	185	CONTAMINATION	2	5404
302	8304	374	INTERNAL FAILURE	2	5404
303	8305	230	DIRTY	2	5261
304	8305	304	FOD-INGESTION OF A/C PART	2	5261
305	8305	334	TEMPERATURE INCORRECT	2	5261
306	8305	373	METAL CONTAMINATION-CHIP DETECTOR	2	5261
307	8306	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	3951
308	8306	242	FAILED TO OPERATE REASON UNKNOWN	4	3951
309	8306	381	LEAKING-INTERNAL OR EXTERNAL	2	3951
310	8306	410	LACK OF LUBRICATION	2	3951
311	8306	684	NO OR WEAK STABILIZATION	2	3951
312	8306	730	LOOSE	2	3951
313	8307	70	BROKEN,BURST,CUT,TORN	2	3980
314	8307	242	FAILED TO OPERATE REASON UNKNOWN	2	3980
315	8307	381	LEAKING-INTERNAL OR EXTERNAL	6	3980
316	8308	242	FAILED TO OPERATE REASON UNKNOWN	6	5930
317	8308	374	INTERNAL FAILURE	2	5930
318	8308	381	LEAKING-INTERNAL OR EXTERNAL	4	5930
319	8309	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	4365
320	8309	242	FAILED TO OPERATE REASON UNKNOWN	4	4365
321	8310	37	FLUCTUATES,UNSTABLE FREQ RPM	2	5068
322	8310	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	5068
323	8310	242	FAILED TO OPERATE REASON UNKNOWN	4	5068
324	8310	381	LEAKING-INTERNAL OR EXTERNAL	4	5068
325	8311	37	FLUCTUATES,UNSTABLE FREQ RPM	2	5073
326	8311	127	ADJUSTMENT/ALIGNMENT IMPROPER	2	5073
327	8311	242	FAILED TO OPERATE REASON UNKNOWN	8	5073
328	8311	374	INTERNAL FAILURE	2	5073

329	8311	381	LEAKING-INTERNAL OR EXTERNAL	2	5073
330	8312	242	FAILED TO OPERATE REASON UNKNOWN	2	4263
331	8401	180	CLOGGED,OBSTRUCTED,PLUGGED	1	4761
332	8401	381	LEAKING-INTERNAL OR EXTERNAL	1	4761
333	8401	410	LACK OF LUBRICATION	1	4761
334	8402	20	WORN,STRIPPED,CHAFFED,FRAYED	1	5731
335	8402	242	FAILED TO OPERATE REASON UNKNOWN	1	5731
336	8402	381	LEAKING-INTERNAL OR EXTERNAL	1	5731
337	8402	410	LACK OF LUBRICATION	1	5731
338	8403	242	FAILED TO OPERATE REASON UNKNOWN	4	6252
339	8403	306	CONTAMINATION,NON METTALIC DIRTY	1	6252
340	8403	381	LEAKING-INTERNAL OR EXTERNAL	2	6252
341	8403	690	VIBRATION EXCESSIVE	1	6252
342	8403	730	LOOSE	1	6252
343	8404	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	4203
344	8404	242	FAILED TO OPERATE REASON UNKNOWN	1	4203
345	8404	381	LEAKING-INTERNAL OR EXTERNAL	1	4203
346	8404	525	PRESSURE INCORRECT	2	4203
347	8406	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	5139
348	8407	180	CLOGGED,OBSTRUCTED,PLUGGED	1	4869
349	8407	242	FAILED TO OPERATE REASON UNKNOWN	1	4869
350	8407	304	FOD-INGESTION OF A/C PART	1	4869
351	8408	242	FAILED TO OPERATE REASON UNKNOWN	1	5799
352	8408	303	FOD-BIRD STRIKE DAMAGE	1	5799
353	8408	381	LEAKING-INTERNAL OR EXTERNAL	1	5799
354	8409	1	GASSY	1	4475
355	8409	329	STARTING STALL/HUNG START	1	4475
356	8410	20	WORN,STRIPPED,CHAFFED,FRAYED	1	5518
357	8410	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	5518
358	8410	242	FAILED TO OPERATE REASON UNKNOWN	1	5518
359	8411	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4766
360	8411	70	BROKEN,BURST,CUT,TORN	1	4766
361	8411	374	INTERNAL FAILURE	1	4766
362	8412	242	FAILED TO OPERATE REASON UNKNOWN	1	4075
363	8412	381	LEAKING-INTERNAL OR EXTERNAL	1	4075
364	8502	170	CORRODED	1	4418
365	8502	242	FAILED TO OPERATE REASON UNKNOWN	3	4418
366	8503	242	FAILED TO OPERATE REASON UNKNOWN	1	5507
367	8503	374	INTERNAL FAILURE	1	5507
368	8504	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5143
369	8504	242	FAILED TO OPERATE REASON UNKNOWN	3	5143
370	8504	374	INTERNAL FAILURE	1	5143
371	8505	242	FAILED TO OPERATE REASON UNKNOWN	1	5262
372	8505	690	VIBRATION EXCESSIVE	1	5262
373	8505	730	LOOSE	1	5262
374	8506	242	FAILED TO OPERATE REASON UNKNOWN	1	4692
375	8506	730	LOOSE	1	4692

376	8507	69	FLAME OUT	1	5807
377	8507	180	CLOGGED,OBSTRUCTED,PLUGGED	1	5807
378	8507	242	FAILED TO OPERATE REASON UNKNOWN	2	5807
379	8508	304	FOD-INGESTION OF A/C PART	1	5759
380	8508	374	INTERNAL FAILURE	1	5759
381	8508	410	LACK OF LUBRICATION	1	5759
382	8508	525	PRESSURE INCORRECT	1	5759
383	8509	242	FAILED TO OPERATE REASON UNKNOWN	3	5276
384	8509	306	CONTAMINATION,NON METTALIC DIRTY	1	5276
385	8510	20	WORN,STRIPPED,CHAFFED,FRAYED	1	5336
386	8510	69	FLAME OUT	1	5336
387	8510	334	TEMPERATURE INCORRECT	1	5336
388	8510	381	LEAKING-INTERNAL OR EXTERNAL	1	5336
389	8510	525	PRESSURE INCORRECT	1	5336
390	8511	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4858
391	8511	70	BROKEN,BURST,CUT,TORN	1	4858
392	8511	306	CONTAMINATION,NON METTALIC DIRTY	1	4858
393	8511	922	OVERTEMP LIMITS EXCEEDED(EMS)	1	4858
394	8512	20	WORN,STRIPPED,CHAFFED,FRAYED	1	4211
395	8512	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4211
396	8512	135	BINDING STUCK OR JAMMED	1	4211
397	8512	180	CLOGGED,OBSTRUCTED,PLUGGED	1	4211
398	8512	242	FAILED TO OPERATE REASON UNKNOWN	3	4211
399	8512	374	INTERNAL FAILURE	1	4211
400	8601	70	BROKEN,BURST,CUT,TORN	1	5518
401	8601	190	CRACKED,CRAZED	1	5518
402	8601	242	FAILED TO OPERATE REASON UNKNOWN	2	5518
403	8601	374	INTERNAL FAILURE	1	5518
404	8601	730	LOOSE	1	5518
405	8601	823	NO START	1	5518
406	8602	242	FAILED TO OPERATE REASON UNKNOWN	1	5769
407	8602	374	INTERNAL FAILURE	1	5769
408	8602	381	LEAKING-INTERNAL OR EXTERNAL	1	5769
409	8603	374	INTERNAL FAILURE	2	5319
410	8603	537	LOW POWER OR THRUST	1	5319
411	8604	306	CONTAMINATION,NON METTALIC DIRTY	1	5946
412	8604	381	LEAKING-INTERNAL OR EXTERNAL	1	5946
413	8604	703	PROGRAM FAILURE	1	5946
414	8605	374	INTERNAL FAILURE	2	5289
415	8606	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	5391
416	8606	525	PRESSURE INCORRECT	1	5391
417	8607	458	OUT OF BALANCE	1	5134
418	8607	525	PRESSURE INCORRECT	2	5134
419	8608	20	WORN,STRIPPED,CHAFFED,FRAYED	1	5423
420	8608	374	INTERNAL FAILURE	1	5423
421	8609	185	CONTAMINATION	1	5416
422	8609	374	INTERNAL FAILURE	2	5416

423	8610	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5770
424	8610	69	FLAME OUT	1	5770
425	8610	320	ENGINE COMPRESSOR STALLS	1	5770
426	8610	374	INTERNAL FAILURE	2	5770
427	8611	20	WORN,STRIPPED,CHAFFED,FRAYED	1	5622
428	8611	70	BROKEN,BURST,CUT,TORN	1	5622
429	8611	185	CONTAMINATION	1	5622
430	8611	320	ENGINE COMPRESSOR STALLS	1	5622
431	8611	374	INTERNAL FAILURE	3	5622
432	8612	374	INTERNAL FAILURE	4	4085
433	8701	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	4634
434	8701	190	CRACKED,CRAZED	1	4634
435	8701	320	ENGINE COMPRESSOR STALLS	1	4634
436	8702	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4600
437	8702	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	4600
438	8702	374	INTERNAL FAILURE	1	4600
439	8702	690	VIBRATION EXCESSIVE	1	4600
440	8703	314	ACCELERATION IMPROPER	1	4917
441	8703	374	INTERNAL FAILURE	2	4917
442	8704	374	INTERNAL FAILURE	2	5312
443	8705	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5333
444	8705	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	5333
445	8705	374	INTERNAL FAILURE	1	5333
446	8705	525	PRESSURE INCORRECT	1	5333
447	8706	37	FLUCTUATES,UNSTABLE FREQ RPM	2	5493
448	8706	334	TEMPERATURE INCORRECT	1	5493
449	8706	374	INTERNAL FAILURE	2	5493
450	8707	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5396
451	8707	160	CONTACT/CONNECTION DEFECTIVE	1	5396
452	8707	320	ENGINE COMPRESSOR STALLS	1	5396
453	8707	374	INTERNAL FAILURE	1	5396
454	8708	185	CONTAMINATION	1	5405
455	8708	374	INTERNAL FAILURE	2	5405
456	8708	398	OIL CONSUMPTION EXCESSIVE	1	5405
457	8708	615	SHORTED	1	5405
458	8708	823	NO START	1	5405
459	8709	374	INTERNAL FAILURE	1	5294
460	8710	306	CONTAMINATION,NON METTALIC DIRTY	1	5409
461	8710	374	INTERNAL FAILURE	3	5409
462	8711	69	FLAME OUT	1	4536
463	8711	374	INTERNAL FAILURE	2	4536
464	8711	381	LEAKING-INTERNAL OR EXTERNAL	1	4536
465	8712	37	FLUCTUATES,UNSTABLE FREQ RPM	1	3820
466	8801	69	FLAME OUT	1	4497
467	8801	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	4497
468	8801	290	FAILS DIAGNOSTIC AUTOMATIC TEST	1	4497
469	8801	374	INTERNAL FAILURE	1	4497

470	8801	381	LEAKING-INTERNAL OR EXTERNAL	1	4497
471	8801	525	PRESSURE INCORRECT	1	4497
472	8802	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4786
473	8802	314	ACCELERATION IMPROPER	1	4786
474	8802	374	INTERNAL FAILURE	2	4786
475	8802	900	BURNED OR OVERHEATED	1	4786
476	8803	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5476
477	8803	320	ENGINE COMPRESSOR STALLS	1	5476
478	8803	823	NO START	1	5476
479	8804	374	INTERNAL FAILURE	5	5217
480	8804	690	VIBRATION EXCESSIVE	1	5217
481	8805	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5312
482	8805	70	BROKEN,BURST,CUT,TORN	1	5312
483	8805	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	5312
484	8805	185	CONTAMINATION	1	5312
485	8805	525	PRESSURE INCORRECT	1	5312
486	8806	160	CONTACT/CONNECTION DEFECTIVE	1	5215
487	8806	282	LOW OUTPUT,READING OR VALUE	1	5215
488	8806	374	INTERNAL FAILURE	2	5215
489	8806	922	OVERTEMP LIMITS EXCEEDED(EMS)	1	5215
490	8807	180	CLOGGED,OBSTRUCTED,PLUGGED	1	4781
491	8807	374	INTERNAL FAILURE	2	4781
492	8807	766	OUT OF SPEC	1	4781
493	8808	70	BROKEN,BURST,CUT,TORN	1	5140
494	8808	180	CLOGGED,OBSTRUCTED,PLUGGED	1	5140
495	8808	374	INTERNAL FAILURE	2	5140
496	8808	410	LACK OF LUBRICATION	2	5140
497	8809	70	BROKEN,BURST,CUT,TORN	1	5974
498	8809	374	INTERNAL FAILURE	1	5974
499	8809	537	LOW POWER OR THRUST	1	5974
500	8810	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	4697
501	8810	180	CLOGGED,OBSTRUCTED,PLUGGED	1	4697
502	8810	374	INTERNAL FAILURE	2	4697
503	8810	381	LEAKING-INTERNAL OR EXTERNAL	1	4697
504	8811	374	INTERNAL FAILURE	4	5037
505	8812	374	INTERNAL FAILURE	4	4569
506	8901	180	CLOGGED,OBSTRUCTED,PLUGGED	1	5367
507	8902	282	LOW OUTPUT,READING OR VALUE	2	5040
508	8902	374	INTERNAL FAILURE	1	5040
509	8903	374	INTERNAL FAILURE	4	4997
510	8903	525	PRESSURE INCORRECT	1	4997
511	8904	374	INTERNAL FAILURE	1	4830
512	8905	70	BROKEN,BURST,CUT,TORN	1	5406
513	8905	190	CRACKED,CRAZED	1	5406
514	8905	281	HIGH OUTPUT,READING OR VALUE	1	5406
515	8905	374	INTERNAL FAILURE	4	5406
516	8905	381	LEAKING-INTERNAL OR EXTERNAL	1	5406

517	8905	410	LACK OF LUBRICATION	1	5406
518	8905	935	SCORED,SCRATCHED,BURNED,GOUGED	3	5406
519	8906	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5203
520	8906	374	INTERNAL FAILURE	2	5203
521	8906	922	OVERTEMP LIMITS EXCEEDED(EMS)	1	5203
522	8907	381	LEAKING-INTERNAL OR EXTERNAL	1	4759
523	8908	160	CONTACT/CONNECTION DEFECTIVE	1	5238
524	8908	306	CONTAMINATION,NON METTALIC DIRTY	1	5238
525	8908	374	INTERNAL FAILURE	1	5238
526	8908	766	OUT OF SPEC	1	5238
527	8908	922	OVERTEMP LIMITS EXCEEDED(EMS)	1	5238
528	8909	70	BROKEN,BURST,CUT,TORN	1	4713
529	8909	160	CONTACT/CONNECTION DEFECTIVE	1	4713
530	8909	381	LEAKING-INTERNAL OR EXTERNAL	1	4713
531	8909	525	PRESSURE INCORRECT	1	4713
532	8910	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	5518
533	8910	180	CLOGGED,OBSTRUCTED,PLUGGED	2	5518
534	8910	381	LEAKING-INTERNAL OR EXTERNAL	1	5518
535	8911	766	OUT OF SPEC	1	4051
536	8912	290	FAILS DIAGNOSTIC AUTOMATIC TEST	1	3789
537	8912	374	INTERNAL FAILURE	2	3789
538	8912	381	LEAKING-INTERNAL OR EXTERNAL	1	3789
539	8912	922	OVERTEMP LIMITS EXCEEDED(EMS)	2	3789
540	9001	69	FLAME OUT	1	4963
541	9001	180	CLOGGED,OBSTRUCTED,PLUGGED	1	4963
542	9002	20	WORN,STRIPPED,CHAFFED,FRAYED	1	4805
543	9003	900	BURNED OR OVERHEATED	1	5751
544	9004	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	4689
545	9004	398	OIL CONSUMPTION EXCESSIVE	1	4689
546	9005	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4908
547	9005	374	INTERNAL FAILURE	1	4908
548	9005	696	FLUID LOW	1	4908
549	9006	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4369
550	9006	190	CRACKED,CRAZED	1	4369
551	9006	374	INTERNAL FAILURE	3	4369
552	9006	381	LEAKING-INTERNAL OR EXTERNAL	1	4369
553	9006	803	NO DEFECT-REMOVED FOR TIME CHANGE	1	4369
554	9007	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4443
555	9007	374	INTERNAL FAILURE	2	4443
556	9008	37	FLUCTUATES,UNSTABLE FREQ RPM	1	5214
557	9008	374	INTERNAL FAILURE	1	5214
558	9008	381	LEAKING-INTERNAL OR EXTERNAL	2	5214
559	9008	956	ABNORM FUNC OF COMPUTER MECH. EQUIP	1	5214
560	9009	180	CLOGGED,OBSTRUCTED,PLUGGED	1	5051
561	9009	374	INTERNAL FAILURE	1	5051
562	9009	398	OIL CONSUMPTION EXCESSIVE	1	5051
563	9010	690	VIBRATION EXCESSIVE	1	4675

564	9011	374	INTERNAL FAILURE	1	4171
565	9011	615	SHORTED	1	4171
566	9011	799	NO DEFECT	1	4171
567	9101	282	LOW OUTPUT,READING OR VALUE	1	4822
568	9101	290	FAILS DIAGNOSTIC AUTOMATIC TEST	1	4822
569	9101	374	INTERNAL FAILURE	1	4822
570	9101	525	PRESSURE INCORRECT	2	4822
571	9102	170	CORRODED	1	4830
572	9102	374	INTERNAL FAILURE	1	4830
573	9102	381	LEAKING-INTERNAL OR EXTERNAL	1	4830
574	9103	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4343
575	9103	70	BROKEN,BURST,CUT,TORN	1	4343
576	9103	190	CRACKED,CRAZED	1	4343
577	9103	374	INTERNAL FAILURE	4	4343
578	9105	37	FLUCTUATES,UNSTABLE FREQ RPM	1	4157
579	9105	374	INTERNAL FAILURE	1	4157
580	9106	20	WORN,STRIPPED,CHAFFED,FRAYED	1	4656
581	9106	374	INTERNAL FAILURE	2	4656
582	9108	374	INTERNAL FAILURE	3	5253
583	9109	374	INTERNAL FAILURE	1	4699
584	9109	410	LACK OF LUBRICATION	1	4699
585	9110	70	BROKEN,BURST,CUT,TORN	1	4630
586	9110	306	CONTAMINATION,NON METTALIC DIRTY	1	4630
587	9111	190	CRACKED,CRAZED	1	3836
588	9111	374	INTERNAL FAILURE	2	3836
589	9201	37	FLUCTUATES,UNSTABLE FREQ RPM	1	3355
590	9201	135	BINDING STUCK OR JAMMED	1	3355
591	9201	374	INTERNAL FAILURE	2	3355
592	9201	690	VIBRATION EXCESSIVE	1	3355
593	9202	70	BROKEN,BURST,CUT,TORN	1	4188
594	9202	190	CRACKED,CRAZED	1	4188
595	9202	374	INTERNAL FAILURE	2	4188
596	9202	381	LEAKING-INTERNAL OR EXTERNAL	1	4188
597	9203	37	FLUCTUATES,UNSTABLE FREQ RPM	2	4498
598	9204	185	CONTAMINATION	1	3874
599	9204	190	CRACKED,CRAZED	1	3874
600	9204	334	TEMPERATURE INCORRECT	1	3874
601	9204	374	INTERNAL FAILURE	1	3874
602	9205	306	CONTAMINATION,NON METTALIC DIRTY	1	3726
603	9205	314	ACCELERATION IMPROPER	1	3726
604	9205	374	INTERNAL FAILURE	1	3726
605	9205	381	LEAKING-INTERNAL OR EXTERNAL	1	3726
606	9205	525	PRESSURE INCORRECT	1	3726
607	9206	170	CORRODED	1	4880
608	9206	290	FAILS DIAGNOSTIC AUTOMATIC TEST	1	4880
609	9206	374	INTERNAL FAILURE	1	4880
610	9206	381	LEAKING-INTERNAL OR EXTERNAL	1	4880

611	9206	561	UNABLE TO ADJUST LIMITS	1	4880
612	9207	306	CONTAMINATION,NON METTALIC DIRTY	1	3999
613	9207	525	PRESSURE INCORRECT	1	3999
614	9208	20	WORN,STRIPPED,CHAFFED,FRAYED	1	4268
615	9208	69	FLAME OUT	1	4268
616	9208	180	CLOGGED,OBSTRUCTED,PLUGGED	1	4268
617	9208	381	LEAKING-INTERNAL OR EXTERNAL	1	4268
618	9209	190	CRACKED,CRAZED	13	4809
619	9209	374	INTERNAL FAILURE	1	4809
620	9210	170	CORRODED	1	4235
621	9210	374	INTERNAL FAILURE	1	4235
622	9210	381	LEAKING-INTERNAL OR EXTERNAL	2	4235
623	9211	374	INTERNAL FAILURE	1	3911
624	9212	374	INTERNAL FAILURE	1	3475
625	9212	410	LACK OF LUBRICATION	1	3475
626	9302	170	CORRODED	1	3573
627	9302	281	HIGH OUTPUT,READING OR VALUE	1	3573
628	9302	374	INTERNAL FAILURE	2	3573
629	9303	70	BROKEN,BURST,CUT,TORN	1	4527
630	9303	823	NO START	1	4527
631	9304	37	FLUCTUATES,UNSTABLE FREQ RPM	1	3211
632	9304	160	CONTACT/CONNECTION DEFECTIVE	1	3211
633	9304	374	INTERNAL FAILURE	2	3211
634	9305	381	LEAKING-INTERNAL OR EXTERNAL	1	3453
635	9306	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	3699
636	9306	190	CRACKED,CRAZED	1	3699
637	9306	290	FAILS DIAGNOSTIC AUTOMATIC TEST	1	3699
638	9307	70	BROKEN,BURST,CUT,TORN	1	3243
639	9307	282	LOW OUTPUT,READING OR VALUE	1	3243
640	9308	374	INTERNAL FAILURE	1	3267
641	9309	37	FLUCTUATES,UNSTABLE FREQ RPM	1	3903
642	9309	170	CORRODED	1	3903
643	9309	177	FUEL FLOW INCORRECT	1	3903
644	9309	180	CLOGGED,OBSTRUCTED,PLUGGED	1	3903
645	9309	374	INTERNAL FAILURE	1	3903
646	9309	900	BURNED OR OVERHEATED	1	3903
647	9311	170	CORRODED	1	3437
648	9311	290	FAILS DIAGNOSTIC AUTOMATIC TEST	2	3437
649	9311	314	ACCELERATION IMPROPER	1	3437
650	9311	374	INTERNAL FAILURE	2	3437
651	9311	823	NO START	1	3437
652	9312	170	CORRODED	1	2640
653	9312	465	UNDERSPEED	1	2640
654	9401	334	TEMPERATURE INCORRECT	1	3189
655	9401	374	INTERNAL FAILURE	1	3189
656	9402	37	FLUCTUATES,UNSTABLE FREQ RPM	1	3591
657	9402	180	CLOGGED,OBSTRUCTED,PLUGGED	1	3591

658	9402	374	INTERNAL FAILURE	1	3591
659	9403	282	LOW OUTPUT,READING OR VALUE	1	4062
660	9403	290	FAILS DIAGNOSTIC AUTOMATIC TEST	1	4062
661	9404	37	FLUCTUATES,UNSTABLE FREQ RPM	2	3533
662	9404	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	3533
663	9406	20	WORN,STRIPPED,CHAFFED,FRAYED	1	4009
664	9406	282	LOW OUTPUT,READING OR VALUE	1	4009
665	9406	374	INTERNAL FAILURE	1	4009
666	9406	381	LEAKING-INTERNAL OR EXTERNAL	1	4009
667	9406	900	BURNED OR OVERHEATED	1	4009
668	9407	127	ADJUSTMENT/ALIGNMENT IMPROPER	1	2938
669	9408	37	FLUCTUATES,UNSTABLE FREQ RPM	1	3303
670	9409	185	CONTAMINATION	1	3573
671	9410	70	BROKEN,BURST,CUT,TORN	1	2853
672	9410	160	CONTACT/CONNECTION DEFECTIVE	1	2853
673	9410	381	LEAKING-INTERNAL OR EXTERNAL	1	2853
674	9411	37	FLUCTUATES,UNSTABLE FREQ RPM	1	3845
675	9411	374	INTERNAL FAILURE	1	3845
676	9411	525	PRESSURE INCORRECT	1	3845
677	9412	374	INTERNAL FAILURE	1	3440
678	9412	525	PRESSURE INCORRECT	2	3440
679	9501	170	CORRODED	1	3582
680	9501	374	INTERNAL FAILURE	1	3582
681	9501	381	LEAKING-INTERNAL OR EXTERNAL	1	3582
682	9502	525	PRESSURE INCORRECT	1	3171

APPENDIX B. NAVAL SAFETY CENTER REQUEST

Due to the unclassified nature and unlimited distribution of this thesis, data obtained from the Naval Safety Center Safety Information Management System (SIMS) database is not included as a part of the thesis. This appendix contains an example of the request for query of the Aviation Safety database required to obtain information from the Naval Safety Center. If there is a need for the data, complete the request and fax or mail to the Naval Safety Center.

____
(date)

REQUEST FOR QUERY OF THE AVIATION SAFETY DATA BASE

From: ______________________________________
(Unit/Billet or Code)

To: NAVSAFECEN Data Retrieval, Code 15A

1. A query of the Naval Safety Center Aviation Safety Data Base is requested for the following criteria:

   a. AIRCRAFT: ____________

   b. TIME FRAME (yrmo): _______ to _______ (77 - date, online)

   c. SCOPE (mishaps/hazards; circle as appropriate):

   ALFA BRAVO CHARLIE HAZARD BIRD STRIKE NMAC PHYS EPISODE EMBK LDG

   FLIGHT FLIGHT RELATED GROUND

   d. SPECIFIC CRITERIA: __________________________________

   ____

2. This information will be used for the following (check/fill in as appropriate):

   ( ) MISHAP INVESTIGATION:

   ______ (unit) ________ (sev/clas) MISHAP ______ (serial) of ______ (date)

   ( ) HAZARD REPORT
   ( ) SAFETY STAND DOWN on ____________ (date)

   ( ) GENERAL SAFETY TRAINING

   ( ) Other (specify): __________________________________

   ____

3. Point of Contact (print):

   Name/Rank: ______________________________________

   Unit: ____________ Billet/Code: ________________

   DSN prefix: ______ COMM (area code)-exchange: (_____)-_____

   VOICE EXT: ______ FAX EXT: ______ DUTY OFF EXT: ______

REQUEST FOR QUERY OF THE AVIATION SAFETY DATA BASE page 2

__________ / ______________ / __________
(Unit) (POC) (date)

4. Special Instructions:

   a. The PRIORITY of this request is (circle appropriate):

IMMEDIATE	TIME CRITICAL	ROUTINE
(Safety of Flight/ Mishap Investigation)	________ (NLT date)	(3-6 weeks for response)

   b. Delivery method requested (circle appropriate):

   MAIL FAX PICK-UP VOICE/PHONE OTHER: __________

   c. SNDL Unit mailing address (required; retrieval cannot be made without correct mailing address):

   ____

   ____

   ____

   ____

   d. Other instructions: ____________________

   ____

   ____

   ____

5. Disclaimer: Requestor acknowledges and agrees that the information provided from this request is FOR OFFICIAL USE ONLY and will be used only for safety in the purpose stated in paragraph 2. Deviation of use or release of information beyond the specified scope requires express written authorization form the Commander, Naval Safety Center. Requestor further acknowledges that portions of the information supplied may be "privileged information" as defined in OPNAVINST 3750.6 (series) the unauthorized release or use thereof is a violation punishable under the Uniform Code of Military Justice.

Signed: ____________________
(name/rank/service)

APPENDIX C. AIRCREW SURVEY

This appendix contains a copy of the complete aircrew survey as well as the results of the survey in spreadsheet format.

S-3 / ES-3 AIRCREW SURVEY

The following survey is being conducted to aid in a research effort investigating single-engine rate-of-climb capabilities and requirements for the S-3 and ES-3 aircraft. Input is being solicited from Pilots and NFO's currently assigned to VS / VQ Squadrons on both the east and west coasts. Your assistance in completing this survey will help provide valuable input to Navy decision-makers and contribute to improved safety-of-flight and mission performance for the S-3 and ES-3 aircraft in the years ahead.

This survey should take approximately **10 MINUTES** to complete. Please answer **all** questions to the best of your ability. Answer by circling your response where there is a multiple choice question. If there is a blank space provided following a question state your own opinion or preference, there is no right or wrong answer. If a question does not apply to you please write **N/A** next to that question number and proceed to the next question.

There is space provided following the last question for any additional comments or questions that you might have. All responses will be kept anonymous and confidential so there is no need for your name, rank, or other personal data other than what is asked for.

Thank you for your attention and assistance in completing this survey.

I. BACKGROUND INFORMATION (Circle your responses)

1. Designator — A. PILOT B. NFO
2. Community — A. VS B. VQ
3. Total Flight Time (hrs) — A. 0-499 B. 500-999 C. 1000-1499 D. 1500-1999 E. 2000+
4. S-3 Flight Time (hrs) — A. 0-499 B. 500-999 C. 1000-1499 D. 1500-1999 E. 2000+
5. ES-3 Flight Time (hrs) — A. 0-499 B. 500-999 C. 1000-1499 D. 1500-1999 E. 2000+

II. THE FOLLOWING QUESTIONS INVOLVE SINGLE-ENGINE FLIGHT IN THE S-3/ES-3

1. Have you ever experienced take-off conditions in which you would not have a calculated positive single-engine rate-of-climb with the landing gear retracted?

   A. YES B. NO

2. If you answered **YES** to the previous question, which of the following factors do you feel had the most significant impact on your single-engine rate-of--climb? (circle one that most applies)

   A. Temperature B. Field Elevation C. External Stores D. Insufficient Thrust

3. Have you experienced an actual single-engine emergency situation? If yes, how many times?

   A. YES 1 2 3 4+ B. NO

4. If you answered **YES** to the previous question, during what phase of flight did the single-engine condition occur? (if multiple events circle all that apply)

   A. Takeoff B. Climbout C. Cruise/Mission D. Approach E. Landing

5. Have you ever experienced an engine related malfunction, that did not require shutting down the engine, during or immediately after takeoff? If yes, how many times?

   A. YES 1 2 3 4+ B. NO

6. Have you ever been required to jettison external stores in an effort to achieve an increased rate-of-climb? If yes, how many times?

   A. YES 1 2 3 4+ B. NO

III. **THE FOLLOWING QUESTIONS PERTAIN TO THE PERFORMANCE OF THE TF-34 ENGINE AS PRESENTLY CONFIGURED ON THE S-3/ES-3.**

1. Do you feel that the TF-34 engines provide sufficient thrust for the mission of the S-3?

   A. YES B. NO

2. If you answered **NO** to the previous question, during what mission/flight phase is additional thrust required?

   A. Takeoff B. Climbout C. Cruise/Mission D. Approach E. Landing F. __________

3. Do you feel that the TF-34 engines provide sufficient thrust for the mission of the **ES-3**?

   A. YES B. NO

4. If you answered **NO** to the previous question, during what mission/flight phase is additional thrust required?

   A. Takeoff B. Climbout C. Cruise/Mission D. Approach E. Landing F. __________

5. What precautions must be taken if the engine T_5 control system malfunctions or is disabled?

   ____

   ____

   ____

6. Will the disabling of the engine T_5 control system provide any advantage in engine performance?

   A. YES B. NO C. Don't know

7. If you answered **YES** to the previous question, what performance advantage do you perceive?

   ____

   ____

   ____

8. Several methods of increasing single-engine climb performance for the S-3/ES-3 are being evaluated. Which of the following methods would you recommend?

   A. No changes required, performance is satisfactory

   B. An Automatic Power Reserve (APR) system which would provide increased thrust from the operating engine in the event of a single-engine failure.

   C. Decrease aircraft gross weight by utilizing new technologies to decrease internal component and systems weight.

   D. New engines with increased thrust.

   E. OTHER IDEAS? ______________________________

   ____

   ____

9. Why would you prefer the method selected in the previous question?

   ____

   ____

   ____

THANK YOU FOR YOUR ASSISTANCE IN COMPLETING THIS SURVEY. PLEASE FEEL FREE TO ADD ANY ADDITIONAL COMMENTS OR QUESTIONS RELATING TO THIS SURVEY OR ANY ASPECT OF TF-34 ENGINE PERFORMANCE, RELIABILITY, OR MAINTAINABILITY.

IF YOU HAVE A QUESTION THAT YOU WOULD LIKE ANSWERED DIRECTLY, PLEASE LEAVE YOUR NAME AND AUTOVON NUMBER AS A POINT OF CONTACT. THANK YOU.

	AIRCREW SURVEY							
	VS PILOT	VS NFO	VQ PILOT	VQ NFO		TOTAL		
	27	48	6	12		93		
	Flight Time Breakdowns							
	VS PILOT	**0-499**	**500-999**	**1000-1499**	**1500-1999**	**2000+**		**TOTALS**
	TOTAL	1	2	3	5	8		19
	S-3	2	4	5	4	4		19
	VQ PILOT							
	TOTAL			2	1	2		5
	S-3	2	1		1			4
	ES-3	1	3					
	VS NFO							
	TOTAL	2	8	12	10	3		35
	S-3	8	7	15	3	2		35
	VQ NFO							
	TOTAL	2	1	1	6			10
	S-3	10						10
	ES-3	8	2					10
		0-499 flt hrs	**500-999 flt hrs**	**1000-1499 flt hrs**	**1500-1999 flt hrs**	**2000+ flt hrs**		
	TOTAL	**6**	**19**	**25**	**25**	**18**		93
	S-3	**22**	**12**	**20**	**8**	**6**		68
	ES-3	**9**	**5**					14
			0-999 FLT HRS	1000-1999 FLT HRS	2000+FLT HRS			
			25	50	18			
QUES. #								
	A	**B**	**C**	**D**	**E**		**TOTALS**	
II - 1	41	52	YES	NO			93	
	TEMPERATURE	FIELD ELEVATION	EXTERNAL STORES	INSUFFICIENT THRUST				
II - 2	11	8	8	9			36	
	YES: ONCE	YES: TWICE	YES: THREE OR MORE	NO				
II - 3	25	19	14	35			93	
	TAKEOFF	CLIMBOUT	CRUISE / MISSION	APPROACH / LANDING				
II - 4	4	10	52	10			76	
	YES: ONCE	YES: TWICE	YES: THREE OR MORE	NO				
II - 5	12	10	9	62			93	
	YES	NO						
II - 6	0	93					93	
	YES	NO						
III - 1	30	61					91	
	TAKEOFF / CLIMBOUT	CRUISE / MISSION	APPROACH / LANDING	OTHER				
III - 2	70	40	7	5			122	
	YES	NO						
III - 3	10	45					55	
	TAKEOFF / CLIMBOUT	CRUISE / MISSION	APPROACH / LANDING	OTHER				
III - 4	66	17	12	4			99	
III - 5								
	YES	NO	DON'T KNOW					
III - 6	33	24	36				93	
III - 7								
	NO CHANGE REQUIRED	APR SYSTEM	DECREASE WEIGHT	EW / IMPROVED ENGINES / AIRCRAFT				
III - 8	7	27	42	74			150	
III - 9								

APPENDIX D. SIMULATOR DATA

This appendix contains the complete listing in spreadsheet format of all data collected utilizing the OFT and associated thrust model for measurement of SEROC and thrust performance parameters.

EFFECTS OF T-5 ON RATE-OF-CLIMB

TEMP	ALT	WT	T/O SPD	DRAG	GEAR	S-3 NATOPS	ES-3 NATOPS	with T-5	w/o T-5	S-3 % increase
60	SL	40000	115	A	DOWN	510	460	600	1000	66.67%
								675	1100	62.96%
								600	1125	87.50%
								625	**1075**	**72.00%**
60	SL	44000	121	A	DOWN	330	280	400	900	125.00%
								420	850	102.38%
								390	900	130.77%
								403	**883**	**119.01%**
80	SL	44000	121	A	DOWN	190	80	200	600	200.00%
								225	625	177.78%
								200	600	200.00%
								208	**608**	**192.00%**
100	SL	44000	121	A	DOWN	60	-120	75	500	566.67%
								125	500	300.00%
								100	450	350.00%
								100	**483**	**383.33%**

ALTITUDE AND TEMPERATURE EFFECTS ON TF34 ENGINE PERFORMANCE PARAMETERS

	SEA LEVEL			4,000 ft		
	MRT w/T5	**MRT no T5**	**% increase**	**MRT w/T5**	**MRT no T5**	**% increase**
Temp=60						
Fuel Flow	3000	3900		2700	3500	
NG	97	101		97	101	
ITT	810	930		810	930	
NF	6400	7200		6500	7300	
Thrust	8599	****	****	7804	9603	23.05%
Temp=80						
Fuel Flow	2800	3500		2500	3200	
NG	97	102		97	101	
ITT	810	930		810	930	
NF	6300	7000		6400	7100	
Thrust	7950	9717	22.23%	7237	8899	22.97%
Temp=100						
Fuel Flow	2600	3300		2300	2900	
NG	97	102		97	101	
ITT	810	930		810	930	
NF	6200	6800		6250	6950	
Thrust	7270	8977	23.48%	6625	8232	24.26%

**** Thrust output was greater than maximum display value of 10,000

WIND AND TEMPERATURE EFFECTS ON TF34 ENGINE THRUST

OFT - 2

TEMP	WIND	with T-5	w/o T-5	%increase	wind effect	wind w/o T-5
60	0	8634	****	****		
60	20	8314	****	****	96.29%	
60	30	8187	****	****	98.47%	
60	40	8060	9895	22.77	98.45%	
60	50	7933	9764	23.08	98.42%	98.68%
60	60	7805	9633	23.42	98.39%	98.66%
80	0	7814	9631	23.25		
80	15	7635	9448	23.75	97.71%	98.10%
80	30	7451	9259	24.27	97.59%	98.00%
100	0	7107	8894	25.14		
100	15	6933	8717	25.73	97.55%	98.01%
100	30	6753	8533	26.36	97.40%	97.89%

OFT - 5

TEMP	WIND	with T-5	w/o T-5	%increase	wind effect	wind w/o T-5
60	0	8589	****	****		
60	20	8398	****	****	97.78%	
60	30	8206	****	****	97.71%	
60	40	8079	9962	23.31	98.45%	
60	50	7951	9831	23.64	98.42%	98.69%
60	60	7824	9699	23.96	98.40%	98.66%
80	0	7841	9706	23.79		
80	15	7665	9515	24.14	97.76%	98.03%
80	30	7469	9324	24.84	97.44%	97.99%
100	0	7132	8967	25.73		
100	15	6951	8782	26.34	97.46%	97.94%
100	30	6770	8596	26.97	97.40%	97.88%

**** Thrust output was greater than maximim display value of 10,000

APPENDIX E. FAN SPEED DROOP DATA

This appendix contains the complete listing in spreadsheet format of all data collected utilizing the operational engine fan speed performance check as well as the OFT thrust model measurement of the effects of fan speed droop.

TF34 FANSPEED PERFORMANCE CHECK

Squadron	Aircraft #	Temp (F)	Altimeter	Humidity	Headwind	Target NF	#1 Idle	#2 Idle	#1 MRT	#2 MRT	#1 Droop	#2 Droop
VS-31	160602	50	30.05	66	9	6560	1800	1800	6500	6500	6450	6400
VS-31	159769	59			10	6520	1900	1800	6400	6300	6400	6300
VS-31	160602	62	30.05	42	3	6490	1900	1900	6450	6500	6400	6500
VS-31	159769	65	30.07	75	2	6480	1800	1750	6400	6400	6350	6400
VS-31	160138	66	29.82	60		6480	2000	1750	6500	6500	6400	6350
VS-31	158865	66	30.06	43		6480	2000	2000	6400	6400	6300	6250
VS-31	160138	68	29.79		8	6470	1900	2000	6500	6500	6400	6400
VS-31	158865	70	30.01	73	3	6460	2000	2000	6350	6350	6300	6300
VS-31	159769	70	30.01	73	3	6460	2000	2000	6400	6400	6300	6350
VS-31	160143	71		66		6450	1980	2000	6450	6400	6325	6200
VS-31	160138	71	30.13	47		6450	2000	1800	6500	6400	6350	6200
VS-22	159760	73	30.13	43	2	6450	1750	1800	6300	6400	6200	6300
VS-31	158865	74		79		6430	2000	2000	6450	6450	6350	6350
VS-22	160600	75			3	6430	2000	2000	6400	6400	6300	6300
VS-31	159769	76	29.96	52	10	6420	1900	1900	6400	6400	6300	6325
VS-31	160603	76	30.06	69		6420	1800	1900	6475	6475	6400	6300
VS-31	159769	77	30.06	70	-4	6420	1900	1800	6300	6600	6200	6500
VS-31	160602	77	30.00	48	4	6420	1800	1900	6400	6400	6350	6350
VS-31	160602	77	29.80	69	11	6420	1950	1925	6400	6400	6300	6280
VS-31	160138	78	30.07	64	6	6410	2000	1900	6400	6350	6300	6250
VS-31	160138	79	29.78	56	10	6400	2000	1800	6400	6300	6300	6200
VS-22	159760	79	30.03		-4	6400	1900	2000	6300	6400	6100	6300
VS-31	160138	80	29.92	91	0	6400	2000	1800	6300	6200	6200	6150
VS-22	159747	80	30.12	43	2	6400	2000	2000	6600	6700	6400	6700
VS-31	160603	82			-6	6380	2600	2600	6700	6600	6500	6500
VS-31	160138	82	29.78	41		6380	2000	1800	6400	6300	6300	6200
VS-31		82	30.00		9	6380	1900	1900	6350	6350	6200	6250
VS-31	160143	88		47	15	6350	2000	2000	6400	6250	6350	6100
VS-31	160143	88	30.00	35	5	6350	1880	2000	6350	6200	6250	6150
VS-31	158865	88	30.00	35	5	6350	1730	1750	6400	6410	6400	6400
VS-31	160603	89	29.92	29	-6	6340	1800	1900	6400	6500	6300	6250
VS-31	160138	90	29.95	91	-6	6340	2000	1800	6300	6200	6200	6150
VS-31	160603	91	29.95	29	0	6330	1800	2200	6450	6450	6300	6300
VS-31	160138	91	29.79	32		6330	2100	1900	6400	6300	6200	6100

(BLANK SPACES INDICATE DATA ENTRIES WERE NOT RECORDED ON FORM)

EFFECTS OF NF DROOP ON ENGINE THRUST

TEMP	WINDS	NF@MRT	THRUST	-100 NF	% chg	-200 NF	% chg	-300 NF	% chg	-400 NF	% chg
60	0	6750	8633	8294	96.07%	8040	93.13%	7768	89.98%	7462	86.44%
60	15	6750	8442	8105	96.01%	7848	92.96%	7579	89.78%	7226	85.60%
60	30	6750	8252	7920	95.98%	7678	93.04%	7262	88.00%	7051	85.45%
80	0	6650	7992	7697	96.31%	7412	92.74%	7111	88.98%	6779	84.82%
80	15	6650	7805	7466	95.66%	7165	91.80%	6967	89.26%	6632	84.97%
80	30	6650	7620	7284	95.59%	6988	91.71%	6735	88.39%	6461	84.79%
100	0	6550	7320	7038	96.15%	6809	93.02%	6511	88.95%	6220	84.97%
100	15	6550	7138	6855	96.04%	6626	92.83%	6363	89.14%	6012	84.23%
100	30	6550	6958	6640	95.43%	6416	92.21%	6163	88.57%	5884	84.56%

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