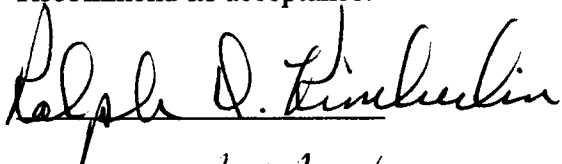
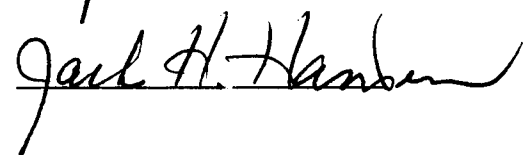


To the Graduate Council:

I am submitting herewith a thesis written by Brett M. Pierson entitled "Flight Test Safety: Lessons Learned From an S-3B Flight Test Mishap During a Frequency Domain Test." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for a degree of Master of Science, with a major in Aviation Systems.


Dr. William Lewis, Major Professor

We have read this thesis and
Recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor
And Dean of the Graduate School

**FLIGHT TEST SAFETY:
LESSONS LEARNED FROM
AN S-3B FLIGHT TEST MISHAP
DURING A FREQUENCY DOMAIN TEST**

A Thesis Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Brett M. Pierson
August 1998

DISCLAIMER

The analysis, conclusions, and recommendations developed within this thesis are the opinions of the author, Brett M. Pierson. They do not express the opinions or official positions of the Naval Force Aircraft Test Squadron, the Naval Test Wing Atlantic, the Naval Air Systems Command, or the United States Navy.

ACKNOWLEDGEMENTS

I would like to thank the team of talented engineers and test pilots whose frank discussions of events past led to the conclusions developed here. Mr. Kevin Smith led the investigation into what really went wrong following an aircraft crash and his tireless efforts have saved lives. Mr. Mark Byers, LCDR Sean Brennan, and CDR Ralph Alderson all contributed with their dedication and their honesty.

Additionally, I would like to thank my wife Sylvia, whose unwavering support and composition skills have proved invaluable.

ABSTRACT

In 1992, an S-3B Viking from the Force Warfare Aircraft Test Directorate broke apart in flight after the vertical stabilizer failed during a flight test event. The mishap flight was one element of a program designed to improve the flying qualities of the simulator by obtaining specific flight parameter data.

The intent of this thesis is to illustrate the process of discovering relevant "lessons to be learned" from the mishap and offer proof that an analysis and application of the lessons will result in improved flight test programs. These "lessons to be learned" were generated by a series of investigations that included documentation searches; interviews with those involved with the test program; and a careful analysis of the program's purpose and methods of data collection. After the extensive post-mishap investigation was completed, it became apparent that a number of errors had taken place during the flight test planning process. Mistakes were made in the areas of test-team composition, aircraft limitation research, test maneuver selection, test technique research, flight clearance authorization, and post-mishap reporting. The process of discovering and applying these lessons resulted in the eventual successful completion of the test program and yielded lessons that should be put into practice by any flight test program.

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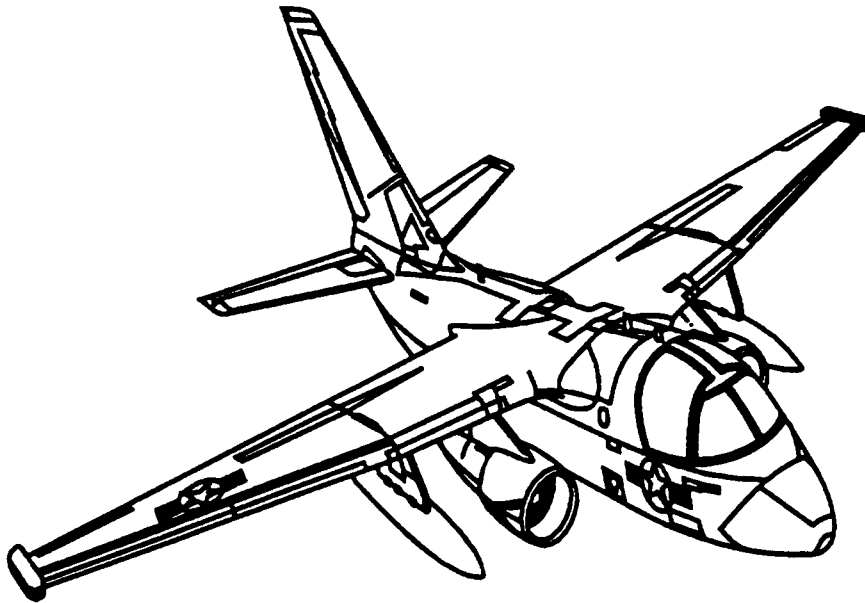
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LIST OF ABBREVIATIONS

AFCS	Automatic Flight Control System
ARS	Aerial Refueling Store
COTAC	Copilot/Tactical Coordinator
DFDC	Digital Flight Data Computer
EFCS	Emergency Flight Control System
FRP	Fleet Replacement Pilot
FRS	Fleet Replacement Squadron
IPT	Integrated Product Team
IGDS	Image Generation and Display System
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command
OFT	Operational Flight Trainer
PFCS	Primary Flight Control System
PID	Parameter Identification
PMA	Program Manager (Aircraft)
SHSS	Steady Heading Sideslip
WST	Weapon System Trainer

I. INTRODUCTION



S-3B Viking

BACKGROUND

At a Safety Stand-down held at the Naval Force Aircraft Test Squadron in the Spring of 1997, Mr. Rogers Smith of the NASA Research facility at Dryden spoke about the lessons learned following a flight test mishap during the testing of the X-31. Mr. Smith postulated during his brief that the numerous “should have” and “could have” lessons developed following a flight mishap were no more than “lessons to be learned” until someone demonstrated that they had actually learned the lessons by repeating a

similar event without incident. Two members of the audience were struck by his comments and set out on independent courses of action that would eventually merge.

The first person, an engineer who had worked S-3B Viking projects for many years, decided that the time had come to honestly assess some mistakes that had been made during a 1992 S-3B flight test event that resulted in the loss of an aircraft. The second person, this author, was then serving as the S-3B Flight Systems Project Officer and set out to put together a brief that was similar to that of Mr. Smith, but generated from the lessons of the same 1992 S-3 mishap. When the Commanding Officer of the Force Aircraft Test Squadron realized that parallel efforts were underway, he recommended that a joint effort be conducted in order to blend the two perspectives. He also suggested that the result might warrant submission as a presentation at the 1997 Flight Test Safety Committee annual symposium.

The presentation was given in April of 1997 [1] and was well received, winning the award for "Best Presentation" at the Annual Symposium. This thesis represents an attempt to formalize and expand dissemination of the results of that extensive and honest study of errors and lessons.

Mention must be made that much of the information presented in this paper appeared in various reports that were protected by the concept of "Privileged Information." Within the Naval Aviation Safety Program, privileged information is defined as information that might not have been made available had its holder not been assured that it would not be used for any purpose other than safety. This author is a graduate of the Aviation Safety Officer course at the Naval Post-Graduate School, has

served as both a squadron and wing Safety Officer, and is extremely familiar with the limits placed on privileged information. Although the mishap investigation report is listed as a reference, it is important to point out that only non-privileged information was taken from the report. Any other information about the events prior to, or during, the mishap was obtained through interviews with the individuals involved and is used with their permission for the purpose of this thesis.

PURPOSE

The purpose of this thesis is to explore the techniques by which lessons can be learned in the aftermath of a flight mishap and to demonstrate that incorporation of those lessons is critical to the success of any future test effort.

DESCRIPTION OF AIRCRAFT

The S-3B Viking is a subsonic, four-place, high wing, twin-engine, multi-mission airplane manufactured by Lockheed Aeronautical Systems Company for land and carrier based missions. Airplane gross weights range from 28,000 to 52,500 lbs. depending on the fuel and internal and external store load. The airplane is powered by two wing pylon mounted General Electric TF34-GE medium bypass ratio turbofan engines rated at 9,275 lbs. of static sea level thrust each. The wing has moderate sweep and taper, two external stores pylons, and both leading and trailing edge flaps. Flight control surfaces include upper and lower wing spoilers and ailerons for lateral control, an elevator for longitudinal

control, and a rudder for directional control. The primary flight control system (PFCS) is operated by control sticks and rudder pedals, is irreversible, and is hydraulically powered. The reversible emergency flight control system (EFCS) engages automatically in the event of a dual hydraulic system failure. The automatic flight control system (AFCS) provides relief to the pilot via automatic pilot and automatic thrust system [2, p. 2,3].

S-3B missions include anti-submarine warfare, anti-surface warfare, mining, aerial refueling, and electronic warfare/reconnaissance. Further information about the S-3 may be found in the aircraft operator's Naval Air Training and Operating Procedures Standardization (NATOPS) Manual [3]. Illustrations of the S-3B general layout and cockpit are presented in Figures B-1 and B-2.

DESCRIPTION OF SIMULATOR

The simulator used by the S-3 community is designated the 2F92B simulator. The Operational Flight Trainer (OFT) portion of the simulator training system is an elevated cockpit that is free to move in pitch, roll and heave. For training that is limited to flight systems only, the OFT is operated in an independent mode and is controlled from an instructor station behind and between the two front seats. To operate as an integrated Weapon System Trainer (WST) the front seat OFT is linked via software to a training cab that contains the two rear seats and a fully functional mission computer. The OFT portion contains a video screen that allows the trainer to be flown visually in whatever weather condition the instructor has programmed at the control console. The original S-3 OFT

was only capable of simulated flight in nighttime conditions, using point sources of light to simulate the aircraft carrier or population centers during overland flight. A simulator improvement program was initiated in 1991 to upgrade the visual presentation to a state of the art Image Generation and Display System (IGDS). The upgrade allowed for simulated daylight flights and contained much more realistic simulations of the aircraft carrier, the shore facility, and (for the first time) other aircraft. This new simulator capability allowed the pilot to attempt to fly in formation with other aircraft or to attempt aerial refueling behind a simulated Aerial Refueling Store (ARS) [4 and 5, p. 1-2].

DEFICIENCIES IN THE CURRENT SIMULATOR TRAINING SYSTEM

Fiscal constraints that exist in the military of the 1990's dictate that the simulator training system must be used to the maximum extent possible. With rising flight hour costs and the inevitable difficulty obtaining replacement parts for an aging airframe, the simulator is an extremely attractive, and efficient, option to wing and squadron commanders. Currently, the OFT training system is not capable of supporting the level of training desired and is also not being used to its full potential. Despite the fact that the visual presentation is much better than the previous nighttime only version, the fidelity of the mathematics model that governs the flight characteristics is lacking. The current simulator control laws do not adequately represent the corresponding flying qualities in the aircraft. In a Technical Memorandum created for the Naval Air Test Center, Hewett and Galloway stated that,

"Generally, Operational Flight and Weapon System Trainers are capable of providing excellent flying qualities and performance simulation of the real airplane. Although hardware limitations are always a factor, it is poor software programming that is responsible for most of the degradation in flying qualities simulation of the typical trainer." [6, p. 4]

Typically, the problem is not that the contractor does not employ skilled programmers, but rather that the data available to the programmers when designing the simulator is preliminary at best. Hewett and Galloway continue,

"Aircraft manufacturers generally rely on the wind tunnel data as a data base. Flight test data are not available because the first training device is usually delivered to the Fleet at about the same time that the first airplane comes off the production line. Since wind tunnel data represent at best only an estimate of airplane flight characteristics, the use of these data as a database for a simulator results in poor flying qualities simulation. In addition, there has been no organized effort within the Navy or by any manufacturer to reprogram a simulator once flight test data are available." [6, p. 4]

The failure of the S-3 simulator to respond like the airplane had been well documented in earlier quantitative tests. Additional deficiencies have been qualitatively observed by the test pilots flying the acceptance and qualification flights and by a generation of S-3 pilots during training. For example, a limited scale test to determine lateral and directional characteristics in the powered approach configuration was conducted in 1976 to "identify the origins of S-3A carrier approach difficulties and to solve them." [7, p.6]. The testing yielded the best set of data to define critical flight parameters of the S-3. Burton commented that "based on this comparison...it was concluded that the original data base did not accurately represent the lateral-directional aerodynamics of the S-3A" [7, p.7]. A presentation of those comparisons, reproduced from Burton's report, can be found in Tables A-1 and A-2. Since the simulator is still

driven by models based on the original database, this inaccuracy serves as a foundation for dissimilar flying qualities. Additional qualitative contributions from a poor control loader and unrepresentative engine model became more pronounced with the implementation of the improved visual system which enhanced the effects of existing deficiencies.

Since the new IGDS visual presentation made flying formation possible, the Fleet Replacement Squadron (FRS) added a formation flying section to the OFT syllabus. The logical extension of this simulator syllabus is to attempt to perform in-flight refueling behind an airborne tanker. When the gains of the pilot flying the OFT are increased to the level required to perform a difficult task (such as in-flight refueling), the disparity between the OFT and aircraft become readily apparent. Many pilots who have successfully tanked the S-3 aircraft hundreds of times have reported extreme difficulty in successfully simulating tanking in the OFT. The workload is significantly higher, and the success rates significantly lower, than in the airplane. It is not merely that the simulator is more difficult, but that completely different control inputs and compensations are required. The simulator simply flies so differently that tanking in the simulator is virtually useless as a training aid. A Fleet Replacement Pilot (FRP) who succeeds in tanking the OFT is not any better prepared for an in-flight refueling event (a critical task in successfully completing the FRS) than a student who has never flown the OFT at all.

The data from the 1976 test illustrated some of the problems with the simulator code but did not provide enough data to rewrite the algorithms that drove the trainer. The 1992 OFT Improvement Program set out to accomplish the goal of generating data to completely rebuild the aerodynamic and engine models.

THE OFT IMPROVEMENT PROGRAM

Management of the simulator fleet falls under the cognizance of the NAVAIR Program Manager for Aviation Training Systems (PMA-205). In order to improve the fidelity of the S-3B OFT (2F92B), PMA-205 authorized the formation of a flight test program to obtain flight parameter data that could be reduced to build new software to drive the simulator and improve simulator training. The goal was to develop a simulator that flew much more like the airplane than the current design. A test team was formed and formal planning for the OFT Improvement Program was begun with preliminary research and a study of previous similar testing.

II. THE FLIGHT TEST MISHAP

TEST PLANNING

The test plan was written by a pair of extremely experienced engineers who were familiar with classical flight test techniques and the aerodynamic limits of the S-3. The portion of the test plan that dealt with the parameter estimation data was developed after close coordination with the test teams who had performed similar tests on the F-14 Tomcat and F/A-18 Hornet. At the time, the syllabus at the U.S. Naval Test Pilot School mentioned the technique of frequency domain testing briefly, but did not address the cautions involved with performing tests of this kind or contain the numerous warnings that the present syllabus does. Additionally, a thorough review of academic, industry, and government documentation was conducted since no specific parameter identification (PID) flights or frequency domain testing had been conducted in the S-3 program or by the engineers or test pilots on the test team [5, p.2]. The civilian contractor members of the test team had been a part of previous frequency domain tests in other platforms, but the contractors had only dealt with the data reduction end of the process, not data collection. Since the role of the contractors was to be the same in the OFT Improvement Program, they were eager for the type and quantity of data available through frequency domain testing. Unfortunately, the contractor's eagerness for this data was not tempered by a thorough knowledge of the risks involved with obtaining it.

The purpose of the test was, in part, to “identify high fidelity flight simulation models (aerodynamic; propulsion system; primary, secondary, and emergency flight control systems; gross weight; center of gravity position; and mass moments and product of inertia) for implementation in the Device 2F92B” [2, p. 1]. This plan was unique at the time because all previous PID data collection had been conducted by other platforms to obtain data to build their engineering simulators. This test was to be the first program that collected such data for the improvement of a fleet operational trainer [5, p. 2]. The original processors that drove the S-3 simulation were only capable of processing very simple models but improved processors had been installed that would enable the new models to be much more complex and, hopefully, much more accurate. Additionally, the program office was eager to use the OFT Improvement Program to build the database of S-3 specific parameters. The existing database had proven lacking and the intent was to “piggy-back” as much data collection as possible onto the OFT Improvement Program test flights.

THE PROJECT ENGINEER

The Project Engineer who had co-written the initial test plan was an experienced Flight Test Engineer. He had significant experience with the S-3 flying qualities test program and had previously planned and supervised several complex flight test events. This was, however, his first involvement with frequency domain test work. Prior to his involvement with the S-3 platform, he had worked on numerous E-2C Hawkeye and C-2A

Greyhound flying qualities test programs. His experience on these test programs had equipped him with valuable experience in flight tests that involved high sideslip data points and had given him familiarity with the fact that other airframes incorporated sideslip limits into their operator's NATOPS manuals.

One of the flight tests on which the Project Engineer had worked in the S-3 Viking had been an earlier investigation into the ability of the S-3 to control roll using only inputs from the rudder. An S-3 had been lost immediately after clearing the catapult when it performed a slow roll-off into the water during a routine carrier launch. The initial assessment was that the aircraft had experienced a failure in the lateral control axis. In order to develop emergency procedures in the event that this failure occurred again, a flight test had been conducted to determine the extent of roll control authority while using rudder inputs alone. This test program had involved full deflection rudder inputs at various airspeeds, and in multiple configurations, and had given the Project Engineer, along with the rest of the S-3 test team, a level of confidence in performing maneuvers of this sort.

THE MISHAP PILOT

The pilot of the aircraft on the day of the mishap was an experienced test pilot who had recently completed an extensive investigation of the stall/spin characteristics of the S-3 with the leading edge flaps up. He was familiar with the out-of-control flight environment and comfortable flying the aircraft to the edge of its envelope, but had not

conducted any frequency domain flight tests. Although not the project officer on the OFT Improvement Project, he was familiar with the test plan, had contributed to test planning, and had practiced the maneuvers in the simulator as required by the test plan.

During the first flight event of the series, it was noticed that the aircraft was exceeding the targeted values of sideslip at the medium and low airspeed points. "Targeted values" vice "limits" were being used since there appeared to be no published sideslip limits. A focused evaluation of the NATOPS manual by both the NATOPS Officer (coincidentally, the Mishap Pilot) and Project Officer verified that the higher than expected sideslip values did not pose any special concerns since no sideslip limits could be found in the manual or in any NAVAIR documentation. Test team experience had shown that the sideslip would be reduced at high airspeeds by the design of the vertical stabilizer and increased directional stability at higher speeds. Subsequently, the Mishap Pilot flew the second test event of the series and had just commenced what would eventually become the mishap maneuver when the ground telemetry station failed and caused a flight abort. Since all information available to the test team at the time indicated that the data points were safe and the aircraft was structurally sound, the program continued.

THE MISHAP

An in-flight mishap occurred on the third flight of the OFT Improvement Test Program when the vertical stabilizer failed during a high dynamic pressure, high sideslip parameter estimation data collection maneuver. The critical maneuver was an increasing

frequency, sinusoidal rudder sweep that required the pilot to feed in rudder, reverse rudder, and continue reversing with a continually increasing frequency until a frequency was reached that was so high that the aircraft response was minimal. As the aircraft swung back through a sideslip peak value with the rudder deflected in the opposite direction, the vertical stabilizer failed and caused the aircraft to enter violent oscillations that exceeded all load factor limits, caused the wing to fail due to high structural loads, and ultimately resulted in the loss of the aircraft after the crew ejected. The lost aircraft was the only instrumented S-3 airframe in the inventory and its loss represented a significant and expensive loss to the S-3 Program Office. Both aircrew survived the mishap and both are currently flying, although the pilot's injuries were very severe and required several years and extensive physical therapy to overcome.

Since the instrumentation package continued to send data until well into the mishap, an incredibly detailed version of the mishap sequence was recorded at the Range Directorate Flight Test Monitoring Station. The complete mishap chronology is listed in Table A-3. The critical elements to note from the sequence are that the crew left the cockpit only 0.02 seconds ahead of the fire that resulted from the rupture of the fuel tanks and that the entire event, from final flight control input to loss of aircraft, took only 1.79 seconds.

THE MISHAP INVESTIGATION

In keeping with the requirements of the U.S Navy Safety Instruction (OPNAV 3750.Q) an Aircraft Mishap Board was formed and placed under the charge of a senior officer to administrate. Additionally, due to the expense associated with the loss of the aircraft, a Judge Advocate General (JAG) investigation to determine potential legal liability issues was conducted concurrently. Both boards completed their investigations and made appropriate recommendations [8, p. 23-25 and 9, p. 20,21].

The Aviation Mishap Board published its list of causal factors in the privileged portion of the Mishap Investigation Report, which is unavailable for reference in this thesis due to the special precautions associated with handling privileged information.

The JAG investigation concluded that "the cause of the mishap was structural failure of the vertical fin under loading of 6750 lbs. per foot squared of dynamic sideslip resulting from pilot augmented directional oscillations peaking at approximately 15 degrees sideslip at 365 KEAS and 5000 ft MSL." [9, p. 9]

III. THE INDEPENDENT INVESTIGATION

HISTORY

The purpose of the Mishap Investigation was to define the series of events that formed the mishap chain and recommend steps that would prevent such a chain of events from reoccurring. The function of the JAG investigation was to determine if any legal liability existed in the mishap. Both investigation boards completed their tasking and submitted reports on their findings.

The project Flight Test Engineer who had written the test plan was not convinced that the limited tasking of the two investigations had yielded the full amount of useful information from the mishap. He conducted a detailed independent investigation with the assistance of a structural expert from the S-3 test team and an engineering intern who was working S-3 projects.

The Flight Test Engineer had worked on C-2 Greyhound and E-2 Hawkeye projects and was familiar with the fact that the NATOPS operator's manual for those aircraft incorporated limits on both sideslip and rudder usage while the S-3 NATOPS did not. Although the directional control systems of the S-3 was very different from the four tailed design of the C-2 (Figure 1), and the similarly configured E-2, the fact that the limits were in place for the other two aircraft and omitted in the case of the S-3 proved interesting [10, p. 2-44 and 11, p. 1-3-22].

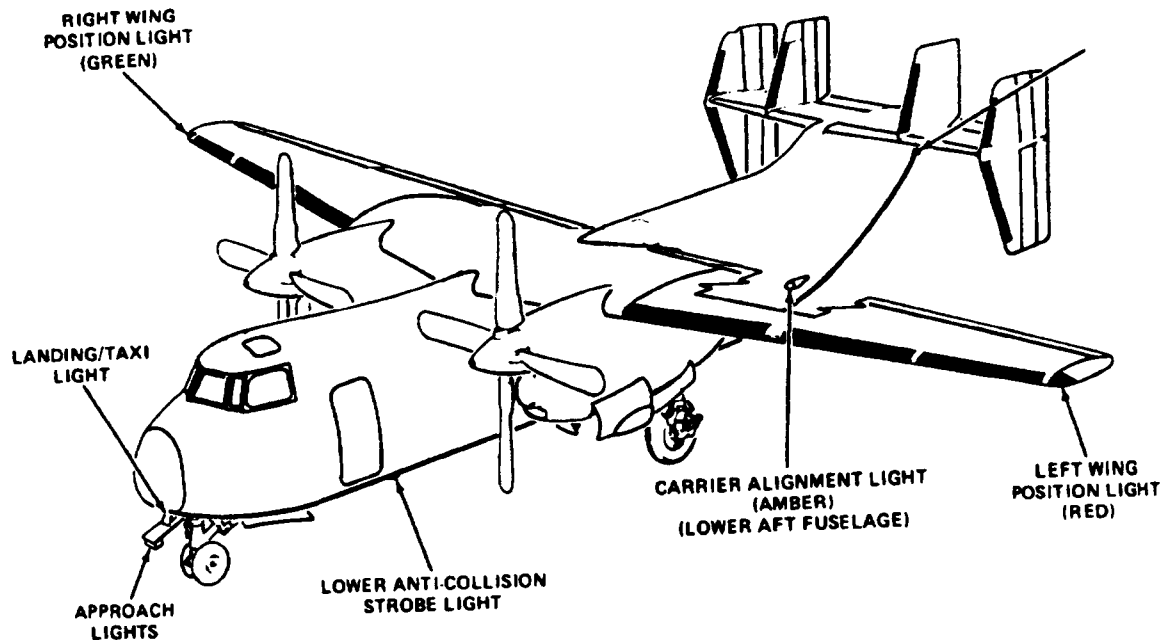


Figure 1
C-2 Vertical Stabilizer Layout

The limits for the C-2/E-2 airframe existed because the aerodynamic force generated by the vertical tail was capable of commanding an attitude that would damage the airframe or cause an unrecoverable unusual attitude. The mishap event had now demonstrated that the S-3 rudder was plainly capable of generating enough force to break the vertical stabilizer, but no limits existed to prevent the aircrew from just such a mishap.

The questions asked in the Project Engineer's independent investigation led to a series of NATOPS changes and, more importantly, to lessons about how limits,

procedures, and even prohibited maneuvers can be compromised or even eliminated during the procurement process.

VERTICAL TAIL LIMITS

The Project Engineer's investigation also revealed a noteworthy deficiency in the documentation available to the test team to research aircraft structural limits. None of the available publications addressed the design limit of the vertical tail. The flight clearance for the OFT Improvement Program that governed the mishap flight did not mention a vertical tail limit [2]. Neither the test plans nor final reports for the final phases of the Naval Preliminary Evaluation tests, conducted in 1972 and 1973 when the Navy accepted the S-3 from Lockheed, mentioned a vertical tail limit [12, 13, 14]. Likewise, neither the Structural Demonstration nor Board of Inspection and Survey Trials addressed any vertical tail limits that had been noted or observed [15, 16]. Furthermore, the NATOPS operator's manual did not give any limitations regarding rudder pedal usage or sideslip limits [3]. Consequently, none of the project personnel, program leadership, test pilots or support engineering staffs were aware of any limitations. In fact, there were no indications in any of the documentation normally associated with test plan preparation or by any members of the test plan review chain that any structural limitations on the vertical tail existed at all, yet plainly a limit had been exceeded during the mishap flight.

INVESTIGATION QUESTIONS

The investigation initiated by the Project Engineer was designed to answer the following questions:

- (1) How likely is it that the vertical tail design limit will be exceeded during future flight test or normal fleet operation?
- (2) Are flight manual changes warranted?
- (3) Was the documented Mishap Investigation Board vertical tail design limit correct?
- (4) Could simple plots be created to define the critical combinations of airspeed and angle of sideslip that could damage the airframe?

With the assistance of several structural experts, the cooperation of contractor personnel and exhaustive hours of careful document review, answers to these questions were eventually found.

INVESTIGATION FINDINGS

The Project Engineer's independent investigation used engineering data to determine that a vertical tail design limit did exist and was possible to exceed in both flight test and in fleet operation. In fact, the investigation found evidence that this limit had been exceeded during previous flight tests. A test to determine roll authority with a lateral control failure using full rudder deflection had exceeded the design limit several times, but never reached the ultimate limit (Figure B-3). Additionally, the rudder doublets that had immediately preceded the sinusoidal rudder frequency sweep during the mishap flight had

exceeded the design limit as well (Figure B-4). In fact, the fleet's routine practice of using large sideslip maneuvers (wing down with top rudder) to reduce excessive closure during high-speed formation rendezvous was exceeding the design limit if performed aggressively and with an abrupt rudder input.

The investigation also discovered that prior flight clearances for operation to design limit had not addressed or defined the actual design limit. The lack of guidance and missing information regarding design limits, combined with the fact that fleet and flight test representative maneuvers could apparently exceed them, led the investigation team to realize that operators needed far more information.

RELATED MISHAPS

The independent investigation conducted an exhaustive search for similar mishaps in an attempt to learn from previous lessons and discovered that similar incidents had in fact occurred. During a flight test in 1971, a C-2 Greyhound crashed following full rudder pedal application at low airspeed and low altitude. In 1973, an E-2 Hawkeye unexpectedly rolled completely inverted during a steady heading sideslip test maneuver at low airspeed. While these incidents were due to exceeding an aerodynamic limit, rather than a structural limit, they illustrated how NATOPS limits are often generated.

In the aftermath of investigations into the above referenced incidents, sideslip limits and guidance for rudder pedal usage were eventually added to both the C-2 and E-2 NATOPS operator's flight manuals. Further investigation revealed that the NATOPS for the A-3 Skywarrior, C-130 Hercules, E-6 Mercury, and P-3 Orion also contained

combinations of sideslip limits and restrictions on rudder pedal usage. Although the C-2 and E-2 vertical stabilizer and rudder are very different from those of the S-3, the other aircraft, specifically the C-130, have similar designs that incorporate a high horizontal stabilizer with a large rudder to overcome asymmetric yaw forces during engine out operation. The manuals provided strong evidence that limits should have been incorporated all along as well as examples of how limits could be phrased and incorporated.

IV. LESSONS TO BE LEARNED

FLIGHT MANUAL INVESTIGATION

The Project Engineer's independent investigation agreed wholeheartedly with the findings of the Aircraft Mishap Board that flight manual changes were clearly needed. The manual omissions were apparent in the light of similar limits in other airframes.

The difficult task was to determine exactly how to word the change to clearly define the limit. The S-3 Viking does not contain a sideslip gauge. In fact, the concept of sideslip as a flight parameter is not typically addressed at all in the manual or during training at the Fleet Replacement Squadron. If the investigation team were to recommend new warnings and cautions, they would have to be worded to make sense to the average fleet pilot and provide a level of safety without imposing undue operational constraints.

The investigation team took a two pronged approach. First, they summarized the critical flight maneuvers in terms of rudder pedal input and submitted recommended changes to the NATOPS change authority. The changes were phrased as follows:

"Do not make abrupt, uncoordinated rudder pedal inputs or alternating left and right pedal inputs above 250 KIAS. Although the rudder servo operating pressure is reduced from 3,000 to 750 psi with flap settings less than 57 percent, the rudder can generate enough sideslip to overstress and fail the vertical fin" [5, p. 2-97]

"Rudder trim can generate enough sideslip to overstress and fail the vertical fin at high airspeeds [5, p. 2-100]

Second, the investigation team prepared a NATOPS supplement, (S-3B Flight Test Limitations and Critical Flight Conditions) included herein as Appendix C, which was to be used in flight test at Patuxent River. Specifically, the plots of sideslip envelope, Appendix C-6 (labeled as Figure D-2), and sideslip limitations, Appendix C-7 (labeled as Figure D-3), would have to be referenced regularly by testers in any structural evaluation. The arrangement would institute a method by which the fleet pilot could be armed with enough information to ensure flight safety without confusion while allowing the test community to have a reference that contained the critical lessons from the mishap in specific engineering terms.

FLIGHT MANUAL LESSONS

The lesson to be learned in the area of the Flight Manual involves research. A test team in the research phase of their test plan development should review the NATOPS flight manuals for airplanes of similar configuration or design for relevant cautions, warnings or limitations. If questions arise as to why certain limitations exist in one, but not the other, those questions must be researched thoroughly until acceptable answers are found. In his presentation about the X-31 mishap, Mr Rogers Smith emphasized that the test team needs to keep asking questions until answers that they can understand are reached. Mr Smith pointed out that the Test Pilot/Test Engineer team needs to remember that they are an intelligent, educated, highly trained unit. If a support engineer is talking "over the head" of the test team, the team needs to press harder for an explanation that they can understand or get another engineer with better communication skills.

Another flight manual lesson applies to the manual itself. The flight manual specification needs to be revised to ensure better accountability during the contractor test program. It is critical that the flight and structural limitations section is complete prior to the first flight in the government test flight phase. How this loss of limits is possible will be addressed further in the limits investigation section.

TRAINER INVESTIGATION

In an effort to determine what else could be done to preclude future occurrences of vertical tail failure, the Project Engineer's investigation team looked at the 2F92B trainer itself. The PID maneuvers outlined in the test plan [2], specifically the sinusoidal frequency sweeps, were not techniques taught and practiced at the U.S. Naval Test Pilot School. In order to ensure an adequate margin of safety, the test plan required that the maneuvers be practiced in a simulator. To accomplish this, the project pilots traveled to Naval Air Station Cecil Field in Jacksonville, Florida. NAS Cecil had three of the 2F92B simulators that were slated for the upgrades that this project was to produce. Each pilot practiced the required maneuvers until they could be performed accurately and with acceptable repeatability. Although the simulators were required for PID maneuver practice, not a structural check, the low fidelity and lack of structural limits incorporated into the simulator gave the test team a false sense of security that the maneuvers could be performed safely in the airplane.

After the mishap, the investigation team conducted a trainer investigation that reviewed the OFT crash detection logic. They found that the primary limits, airspeed and

normal acceleration, were included in the logic and that exceeding either of these would result in the trainer "crashing." A crash was indicated to the operator by the controls freezing, the video presentation dropping off line, and a red light flashing at the center of the video screen.

The team subsequently submitted an equipment change request to the Trainer Management Team (TMT) and the Program Manager for Trainers (PMA-205). The request, if approved, would incorporate a vertical tail design limit with the same logic as the other parameters. The exceedance of a dynamic sideslip limit would result in a similar trainer "crash" and allow aircrew to experience the level of rudder input required to develop excessive sideslip. Since maneuvers typically performed in the fleet can generate excess structural loads, the change is imperative. Additionally, the improved simulator logic would allow future test teams to practice maneuvers for safety as well as for technique.

TRAINER LESSONS

The trainer development community and the military Program Managers for Aircrew Training need to establish a standard for crash detection logic that addresses all relevant flying qualities and structural limitations. No such standard currently exists and each platform incorporates whatever limits seem appropriate during the design or is expected to be encountered during the course of normal operation. A truly representative trainer would aid the operational user as well as the user who is developing a flight test program.

As everyone in Naval Aviation is being increasingly driven to rely on their simulator to meet currency and proficiency requirements, a simple question needs to be asked of each pilot: Can you crash your trainer through structural failure?

LIMITS INVESTIGATION

The investigation into the “missing limits” focused on the process of producing the operator’s flight manual. A potential problem with flight manual limits could be traced to the very beginning of the contractor’s flight test program. The investigation team started with what seemed like a simple question. From where do flight manual limits originate?

The team conducted a thorough document review that traced back to the original Lockheed demonstration planning and progress reports [17, 18]. These reports contained what was assumed to be a complete set of design limits. In fact, the reports contained design limits for all flight parameters except sideslip. In addition to design limits, the reports also contained more stringent operational limits that established recommendations for flight clearance limits for each Navy test phase. The difference between the two may seem trivial, but it is, in fact, the essence of what went wrong with the process.

When an aircraft program begins the design phase, it is specified to a certain flight envelope that is required by the user, in this case the U.S. Navy. In the early flight test phases, the aircraft is restricted to a smaller, more conservative, and thus safer, flight envelope. For example, a new supersonic fighter will have a first flight operational limit of some medium-air-speed sub-sonic velocity. As the aircraft reaches an operational limit successfully, the operational limit will be expanded until it matches the design limit. At this

time, the aircraft operating envelope will be defined for the fleet user since the aircraft has proved to be as capable as was specified by the Program Manager. Since the aircraft may have proved to be somewhat more capable than specified (or somewhat less capable), the flight manual limits evolve from the airframe contractor recommendations. An operational limit during flight test may remain as an operational fleet limit or may be discarded in favor of the contracted design limit.

Another component in the development of flight limits is the fact that the airframe contractor recommendations are based partly upon maneuvers required by the demonstration specification of the customer. The contractor builds and tests an aircraft to the specifications required by the customer. The customer's specifications are based on the mission requirements at the time of purchase. There is nothing inherently wrong with this arrangement; it is simply a good business practice. Unfortunately, it puts the burden on the Program Manager to accurately predict any future missions for the airframe. In the case of the S-3 Viking, an accurate prediction would have been virtually impossible. The aircraft is being used in different missions, and flown more aggressively than the design team, or original test team, could possibly have imagined. Aggressive flight test maneuvers, like sinusoidal frequency sweeps, were not required by the original test phase and were not considered in contractor demonstration limits. Ultimately, the airframe contractor recommendations are processed by the cognizant flight clearance authority and passed to the customer tester. The flight clearance process will be further analyzed in the Flight Clearance Investigation section.

LIMITS LESSONS

The lessons regarding flight limits can be summarized with an old cliché about making assumptions. As the mission life of naval aircraft is extended and budgets continue to decline, the longevity of “corporate knowledge” becomes more important. It was apparent in the independent investigation that flight limits, and even prohibited maneuvers, could get “lost” over time. In the case of the S-3, an operational test limit on sideslip existed during the early phases of the Navy Preliminary Evaluation [12] but was lifted for the final phases [14] as the aircraft was safely flown to design limits.

Because the operational limit was lifted, rather than replaced with a defined design limit, the assumption was made that the design limit of the tail was beyond the operational envelope of the vertical tail. In other words, the test team performing the research for the OFT Improvement Program assumed that the lack of a published design limit meant that the rudder was not capable of generating enough force to damage the vertical stabilizer as long as the other limits (airspeed, normal load factor) were followed. In fact, the lack of a design limit merely meant that the original acceptance test plan never required a data point that approached the design limit, therefore none was provided. Often, the development of flight limits can be a vicious circle wherein customer needs drive contractor tests, which in turn support customer needs. As a result, test teams cannot assume that the flight manual can stand alone as a complete and correct reference with which to plan a test flight program. The prudent test team should compare original airframe contractor flight test results, operational manuals, flight clearance recommendations, and flight test restrictions for apparent anomalies [18, 19, 20, 21].

Discrepancies in any of these source documents should be discussed at length with both the flight clearance authority and airframe contractor personnel. Making any assumptions about something as potentially catastrophic as flight limits has proven to be a very dangerous practice.

MANUEVERS INVESTIGATION

One of the primary maneuvers planned to generate PID data was the sinusoidal frequency sweep. Since a rudder sweep was not specifically prohibited by the NATOPS operating manual, the test team and flight clearance authority did not focus on the structural problems that could be associated with rudder sweeps. As was pointed out in the Limits Lessons section, the assumption was that the use of the rudder could not generate enough force to damage the vertical stabilizer regardless of the maneuver performed. Given the fact that this assumption was found to be untrue, the question was asked: Are contractor structural demonstration requirements adequate?

The answer was that the maneuvers used for flight testing and fleet operation could, in fact, result in significantly higher loads than the structural demonstration maneuvers developed. It was noted that aircraft utilization and mission profiles change over time. For example, the S-3 is now expected to last more than twice the service life originally anticipated. Service Life Assessment Plan (SLAP) and Service Life Extension Plan (SLEP) testing are currently underway to assess the fatigue and structural concerns raised by this expectation, but the airframes continue to fly during this testing. Over time, new missions, new weapons systems, and new training techniques dramatically change the

way the airplane is flown. The ever changing mission and introduction of new flight test techniques could result in far more adverse maneuvering loads than were anticipated during structural demonstration flights and preliminary Navy flight tests.

MANEUVERS LESSONS

In order to ensure the safety of fleet aircrew and test teams alike, the maneuvers performed in structural demonstrations need to be reviewed periodically. As new weapons systems are added, the maneuvers required to maximize those weapons systems need to be checked against the original structural demonstration. As new test techniques are developed, the same review must be conducted. Before flight clearances are requested for the test program, the test team needs to be sure that a structural limit has not surfaced that was previously masked by operational use. If it is determined that a potential conflict exists, a structural test program needs to be conducted to expand the envelope and clear the maneuver or technique before it is implemented as an acceptable part of another test plan. If the structural test plan is deemed too costly or time consuming, the advisability of the new system or technique must be questioned.

FLIGHT CLEARANCE INVESTIGATION

One area of concern to the Project Engineer's investigation team was that the flight test was conducted under an approved test plan and with NAVAIR flight clearance authorization. What went wrong with the process that allowed the mishap flight to launch. Is the flight clearance process adequate?

No, the flight clearance process is not adequate because it does not always accomplish precisely what is needed, nor does it consistently incorporate adequate emphasis on engineering analysis. For example, the flight clearance process is not necessarily geared toward giving the test team what they really need. A significant amount of time during the flight clearance process is spent ensuring that a myriad of administrative and bureaucratic processes is handled appropriately. In the case of the mishap test plan, a significant effort was made to shut the test down entirely. This attempt was not based on any perception that the maneuvers were unsafe, but on the fact that some officials in the Structures Department felt that there was no need to replace the existing wind tunnel data with flight test data at all [9, p. 13,14]. The program sponsor, PMA-205, felt that the need was very real and worth considerable expense to accomplish. This bureaucratic argument between NAVAIR branches shifted the focus of the process away from the pure engineering effort that could have found some of the problems. Too often, not nearly enough effort is dedicated to performing engineering analysis that supports the completion of a project. Notably, two pieces of advice were offered as "appropriate" to the investigative team. First, the advice often given to children that still seems pertinent -- be careful what you ask for, you might just get it. The second piece of advice was given by a senior flight clearance officer at NAVAIR who reminded the investigative team that the "testers are supposed to be smarter than the flight clearance authority."

FLIGHT CLEARANCE LESSONS

The lesson that was made clear during the investigation, especially in light of the comment by the senior flight clearance officer is that test teams should not depend on the flight clearance process to identify limits. Instead, they need to work with the flight clearance authority to come to a consensus decision regarding the maneuvers and applicable limits. Furthermore, they need to use the flight clearance process merely to verify and confirm their own limits generated via meticulous research and sound engineering practices. Ultimately, the test team cannot assume anything; they must research and verify each limit themselves.

Additionally, another lesson regarding the flight clearance process is that the NAWCAD flight clearance process requires that the test team obtain a NAVAIR flight clearance for the performance of any non-standard maneuver. Unfortunately, the NATOPS operator's manual does not contain a list of standard maneuvers; by what criteria should maneuvers be considered non-standard? It is incumbent on the flight test team to classify any maneuver not explicitly performed during the contractor's structural demonstration flight series as non-standard. Although a sinusoidal frequency sweep should clearly have been classified as non-standard, the test team now knows that a simple rudder doublet at high airspeed could generate the required force to fail the S-3 vertical stabilizer. The test team needs to understand that the operating limitations in flight clearances and flight manuals are maneuver dependent. The assumptions made by the authors of the NATOPS manual at the time the limits were generated may or may not be valid for the test plan under development.

MISHAP REPORT PROCESS

The Aircraft Mishap Board met as directed and reached their conclusions as required by the Naval Safety Instruction. The Navy position on mishaps is that each mishap is the conclusion of a "chain of events" that lead to the final event. By definition, a causal factor is any event that would have prevented the mishap, had it been prevented. Stopping any one causal factor breaks the "chain." Typically, the findings of a mishap board are promulgated through the Naval Message system to all activities that operate an aircraft of the type involved in the mishap (i.e. ALL VIKING AIRCRAFT ACTIVITIES). Typically, this approach ensures that the lessons of the mishap, and the events that formed the chain, will be read and understood by the operators of the same model aircraft. By this method, each aircrew will then be able to recognize a similar event in the future as a potential link and break the chain before a mishap occurs.

The problem with this approach is that it does not recognize the specific needs and responsibilities of the flight test community. There is virtually no likelihood that any S-3 fleet pilot will be flying at 5,000 feet and 365 knots while performing full deflection rudder reversals. Therefore, the mishap report is of limited utility to the fleet pilot for this reason. On the other hand, the Program Office of another platform might be contemplating a similar flight test program, but will not receive the full Mishap Investigation Report because they do not belong to the same, aircraft specific, message routing group used to distribute the report.

Another problem with the Aviation Mishap Board process is that it must operate under strict time constraints. After the loss of an aircraft, it is likely that the entire fleet is waiting expectantly to assure themselves that they are not unwittingly at risk from the same causal factors. Due to the strict time constraints, the report may not be entirely accurate if some of the data required to reach conclusions is not readily available. As a result of using preliminary data, and not being able to wait until a thorough study of all source data was complete, the Aviation Mishap Board convened for the S-3 mishap documented a vertical tail design limit in terms of $q\beta$, the product of sideslip angle and dynamic pressure, of 3,000 (psf)(deg). After the Project Engineer's independent investigation was complete, the actual vertical tail design limit was found to be a $q\beta$ value of 2,600 (psf)(deg), Appendix C-7 (labeled Figure D-3). Because of this rush to meet time constraints by the Mishap Board, the flight manual and trainer software changes were based upon incorrect $q\beta$ values.

MISHAP REPORT LESSONS

Several lessons about the Mishap Investigation process can be taken from the investigation conducted by the Project Engineer's team. Primarily, it appears that significant value would be added to the flight test process if recommendations of general, but not platform specific, flight test safety interest could be extracted from mishap reports and made available to the entire flight test community. Although the privileged

information contained in safety investigations must continue to receive the legal protection that it is currently afforded, we cannot overlook that the reason for safety investigation reports is to put the knowledge into the hands of those who stand to prevent a future mishap. In the event of a flight test related mishap, it is the flight test community who needs that information. Symposium events, such as the Society of Experimental Test Pilots or Flight Test Safety Committee meetings, go a long way toward increasing the visibility of mishaps, but the symposiums do not have anywhere near full attendance by the test community nor are they held often enough to be effective. Two choices present opportunities to rectify this problem. The Safety Office at NAVAIR, or the Atlantic and Pacific Test Wings, should implement some sort of summary and distribution process. Additionally, a new "ALL FLIGHT TEST ACTIVITIES" address group for test related investigation reports could be established by the Naval Safety Center to further extend the distribution of mishap related information.

Another lesson can be found in the impact that the results can have on the test community in general and on the mishap crew in particular. In a flight test mishap, it is important that the Mishap Board consider the differences between operational flying and flight test work. A fleet pilot is constantly making independent decisions about the maneuvers that he is performing, but a test pilot is reproducing a carefully scripted plan generated by a flight test team and approved by numerous levels of review chains. The Mishap Board was essentially asked to decide -- Is a test pilot protected from a finding of "pilot error" if he or she is performing a test exactly as planned and approved?

Since Aviation Mishap Boards base decisions on the operational environment, a test pilot is not protected by an approved test plan at all. In the case of the S-3 mishap, the Mishap Board is alleged by the Mishap Pilot to have determined that pilot error was a causal factor. If this is true, such a determination may have been made by a flawed analysis such as: The plane crashed because the vertical tail broke. The vertical tail broke because the rudder was at full throw. The rudder was at full throw because the pilot's foot was commanding it there. Therefore, the causal factor is pilot error. The impact of such a determination on the test community cannot be overemphasized. A test pilot is trained from the beginning to follow a test plan exactly as approved. In an interview with this author, the mishap pilot expressed that he was willing to fully take the blame that was due to him as a part of a test team that had written a flawed test plan. He expressed bitterness, however, that he should be singled out for specific blame because he had executed an approved test plan.

V. APPLICATION OF LESSONS

RESTART OF TEST PROGRAM

Despite the mishap flight, the OFT Improvement program was still extremely important to PMA-205 and to the Viking community. An effort to complete the test series began immediately after the mishap investigation was complete, but was delayed by the lack of another instrumented test aircraft. During 1995, an S-3 Viking aircraft, bureau number 159743, was transferred from the fleet to the test team at Force Warfare, NAS Patuxent River, MD. The aircraft spent most of 1995 in the instrumentation installation process, receiving an instrumentation package similar to the one lost in the mishap. A new test plan was signed in early 1996 after a significant engineering check and process review effort at every level in the approval chain. The test flight series was completed without incident in the summer of 1996. The "lessons to be learned" that Mr Rogers Smith mentioned in his safety brief had truly become "lessons learned" by the S-3 Integrated Product Team (IPT).

PLANNING LESSONS APPLIED

A study of all related documentation was conducted that was much more thorough than the original, 1992 pre-test documentation study. The second study of all applicable limits, all original source material, all original contractor flight test data, preliminary Navy test results, and similar aircraft NATOPS operator's manuals was fully incorporated into

the new flight test plan. The new NATOPS limits and warnings produced by the Project Engineer's independent investigation were incorporated into the test plan or addressed individually by NAVAIR flight clearance. Numerous technical working groups were convened with all appropriate personnel attending and all questions raised by the engineers were answered clearly and thoroughly before the plan progressed to the next level. The flight test team expected careful scrutiny by the chain of command and flight clearance authority, and they were not disappointed. The test plan for the OFT improvement plan was, by all accounts, a high visibility plan, but the test team was ready for the questions and was sure that they wanted exactly what they were requesting.

MANEUVERS LESSONS APPLIED

The test pilots that were assigned to OFT Improvement Program practiced the required maneuvers in the improved trainer to develop timing and check response. The value of the frequency domain testing performed during the mishap flight was questioned and it was discovered that the required information could be obtained by exciting the dynamic modes of the aircraft with a 3-2-1-1 maneuver [22, p. 1152]. The maneuver is described by Breeman et al as follows:

“The 3-2-1-1 signal consists of a series of alternating step inputs which the duration satisfies the ratio 3:2:1:1 (i.e. 3 times the positive, 2 negative, 1 positive and 1 negative). Because of its simplicity the manoeuvre is very easy to perform manually. The multistep signal has a rather wide bandwidth compared to the other input signals. This allows an effective excitation of the aircraft over a large frequency range. By proper selection of the time unit, the maximum of the energy spectrum can be concentrated around the short period frequency of the aircraft. [23, p. 4-7]

The length of the 1-count (x in Figure 2) used in the OFT Improvement flight test varied depending on the airspeed, altitude, and configuration of the airplane. Figure 2 shows the ideal rudder pedal deflection trace for a properly performed 3-2-1-1 maneuver.

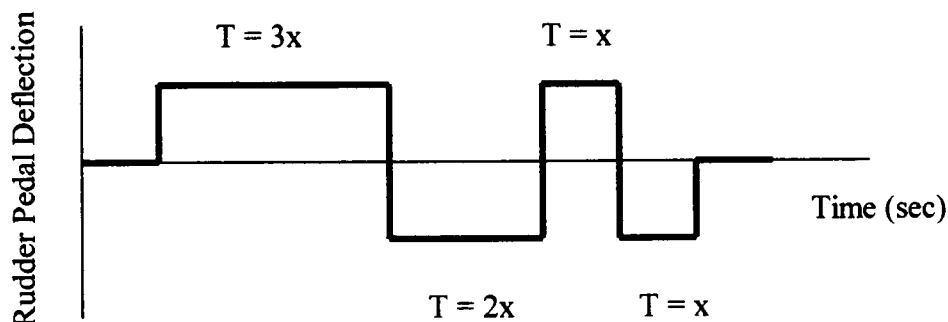


Figure 2
3-2-1-1 Maneuver Rudder Displacement

The classic, steady-heading sideslip (SHSS) maneuvers were still performed, they were just performed to a flight control release instead of driving the controls back to a neutral position which could inadvertently produce directional control inputs and increase the dynamic sideslip ($q\beta$) at the tail.

While the content of the data gathered using this technique was acknowledged to be less than the full frequency sweep originally envisioned, a programmatic decision was made that only the data necessary to complete the OFT software rewrite would be obtained. The loss to the S-3 program was that the database of flight characteristics planned with the frequency sweep testing would no longer be “piggy-backed” onto the OFT Improvement Program. The visibility and pressure generated by the mishap had limited the team to only the data absolutely necessary to accomplish the goal.

FLIGHT TEST LESSONS LEARNED

During the flight test, a dedicated engineer in the telemetry control room monitored the critical parameters. The $q\beta$ sideslip limit for each data point was carefully reviewed prior to the test point. In addition to the dedicated flight test engineer, the copilot monitored a sensitive sideslip gauge added during the instrumentation installation. The pilots during the second evaluation had the benefit of knowing that the critical combination of forces was there, and not too far from where they were flying. It was easier for the pilots to sense that the $q\beta$ forces were building uncomfortably now that they knew to look for it. The pilots flew each flight with the knowledge that a call to neutralize controls and recover could come at any time, and the several instances of rapidly building $q\beta$ forces that occurred were handled without incident.

FLIGHT TESTS COMPLETED

Flight testing was safely completed in summer 1996 and the data is being reduced at the contractor facility as this thesis is being written. The data will be used to develop the new aerodynamic and engine models for the operational flight trainer. The instrumented aircraft has also proved invaluable to the Digital Flight Data Computer (DFDC) program and several structural surveys, and will continue to serve the S-3 IPT for years to come.

VI. CONCLUSIONS

The following conclusions regarding the development of lessons learned following a flight test mishap are presented as a summary and represent only the opinions of this author.

FLIGHT TEST PLANNING

The original flight test team did not have the required expertise in the area of frequency domain testing to embark on a parameter identification flight test of the type envisioned. While the test team was extremely experienced in conventional flight test, the only members of the team with frequency domain flight test experience were the contractors responsible for data reduction. Their experience was limited to the use of data in algorithm development, and did not encompass knowledge of the risks associated with data collection.

The decision to use the OFT Improvement Program as a means to develop an extensive database of flight parameters placed the test team in the position of attempting to get data of a higher fidelity than was required to accomplish the program objectives. Although "piggy-backing" flight test is both a common occurrence and a fiscal reality, the decision in this case led the team to focus on the wealth of data available through frequency domain testing rather than on a careful analysis of what data was required and how to safely obtain it.

The flight test team did not have an adequate knowledge of the aerodynamic or structural limits of the S-3 airframe. Insufficient contractor documentation and a lack of structural corporate knowledge at the flight clearance authority and NAVAIR class desk levels aggravated this lack of knowledge and compounded the problem. This fact is illustrated by the failure of the test team to record telemetry on what turned out to be the critical limiting parameter of the test, vertical tail loads. Although operational test limits for sideslip were used during the earliest stages of flight testing, they were never replaced with published design limits after being lifted upon test completion. To this day, the only published operational limits are the ones developed by the test team after the mishap, and only then with the benefit of the mishap data to support conclusions (Appendix C).

The flight test team did not adequately pursue answers to the questions that arose during the flight planning process. When it became apparent that there were no published rudder or sideslip limits, the team questioned this omission and pursued answers, but ultimately made assumptions that were invalid and accepted answers that were not adequately supported by data. While certain portions of the explanations regarding aerodynamic rudder limits were technically correct, the extension of those assumptions to the dynamic and untested frequency domain was overly optimistic.

The NAVAIR flight clearance process broke down and failed to provide the test team with the engineering review and oversight for which it was designed. Much of the process was consumed by bureaucratic argument over the need to replace wind tunnel data with flight test data at all, rather than the safety of the process by which it was to be obtained. In the post mishap analysis, this failure of oversight served mainly to provide

shelter to those seeking programmatic distance between themselves and the failed test flight.

FLIGHT TEST EXECUTION

The test team demonstrated an insufficient knowledge of the theories and techniques of frequency domain flight test by designing maneuvers that did not adequately consider the potential risks involved. The maneuvers were designed around driving the flight controls to achieve the desired output without due consideration for the amplitude of the input. Higher control deflections than required were used, and the low fidelity of the simulator used to practice the test techniques gave the test team a false sense of security regarding the safety of the maneuvers.

POST MISHAP REPORTING

A finding of pilot error in the case where no foreknowledge of the potential consequences of maneuvers exists is not valid. A test pilot flying an approved test plan and adhering to planned procedures must be protected from a finding of pilot error if something goes wrong with the test. Test pilots are taught from the first day of training that the test plan is the backbone of the test flight and that it must not be violated. To assign error for following that tenet is both unreasonable and irresponsible.

VII. RECOMMENDATIONS

Recommendations of a programmatic or organizational nature have not been reproduced from the section in which they appeared. Rather, the following recommendations are flight test specific and should be considered a summary of the lessons learned and applied from this flight test mishap and may be used as final checks in any flight test program. Although some of the recommendations may seem obvious, it is important to note that obvious items have, and will continue to, cause mishaps.

- The composition of a flight test team for frequency domain testing must reflect the required expertise and knowledge specifically called for by the tests being conducted.
- The goals and requirements of any flight test program must be carefully examined to ensure that the necessary information is being obtained in the proper fashion.
- An adequate knowledge of all limitations of the airframe involved in flight test must be obtained before the testing begins.
- Do not rely on the flight manual or trainer to perform roles for which they were not designed. Both were intended for the operational arena, not flight test.
- All questions that arise during planning must be adequately answered before testing begins. Lack of data opposing a conclusion can not be considered equal to the presence of data supporting the conclusion.
- Consensus must be reached at all levels of the flight test team, including those members external to the organization that serve in a supervisory capacity.

- Rely on the flight clearance authority only to verify analysis conducted by the team, do not count on them to produce independent results.
- The flight test engineers and test pilots that design maneuvers to obtain data must fully understand the concepts of the flight test regime. This may require extreme effort on the part of the test team in the case of a regime not taught during formal test pilot training.
- The test pilot must be aware that while diverging from the test plan will certainly leave them open to administrative action, abiding by the same test plan will not necessarily protect them from it.

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APPENDICES

APPENDIX A
TABLES

Table A-1
Comparison of S-3 Power Approach Results with Wind Tunnel Data

Parameter	Wind Tunnel Data	NATC Parameter ID
L'_p	-1.683	-1.855
L'_r	0.383	1.113
L'_β	-2.065	-2.825
N'_p	-0.606	-0.526
N'_r	-0.302	-0.1299
N'_β	0.837	0.9319
Y_p	-0.0026	-0.0026
Y_r	0.0075	0.0384
Y_β	-0.121	-0.1306

Table A-2
S-3 Power Approach Modal Characteristics

Modal Characteristics	Conventional Results ⁽¹⁾	Wind Tunnel Data	NATC Parameter ID results
Spiral Mode Time Constant (sec) ⁽²⁾	Slightly Divergent to Neutral	157.73	18.1
Roll mode Time Constant (sec) ⁽³⁾	-0.51	-0.546	-0.539
Dutch Roll Frequency (rad/sec)	1.417	1.287	1.412
Dutch Roll Damping	0.10	0.0998	0.113

Notes: (1) Hand measurement techniques
(2) Positive sign indicates divergent spiral mode
(3) Negative sign indicates convergent spiral mode

Table A-3
Mishap Chronology

Timeline	Mishap Event
15:17:36.57	Vertical tail fails
15:17:37.08	Load factor of negative 4 (-4 g)
15:17:37.49	100 degree/second left roll
15:17:37.52	COTAC pulls ejection handle
15:17:38.00	Load factor of positive 4 (+4 g)
15:17:38.34	Starboard wing fails and ejection seats clear the aircraft
15:17:38.36	Cockpit consumed by fireball

APPENDIX B
FIGURES

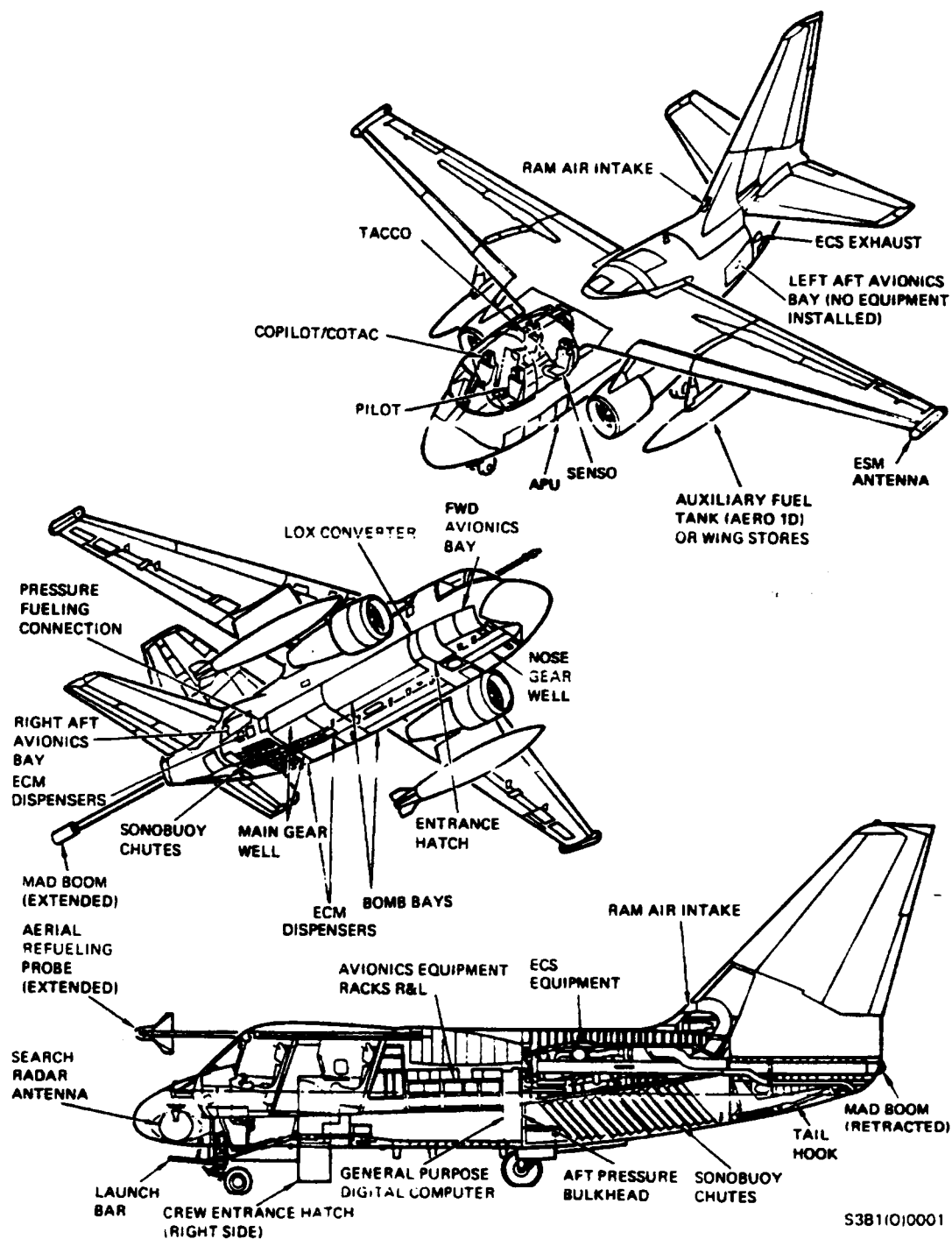


Figure B-1
S-3B General Layout

Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.

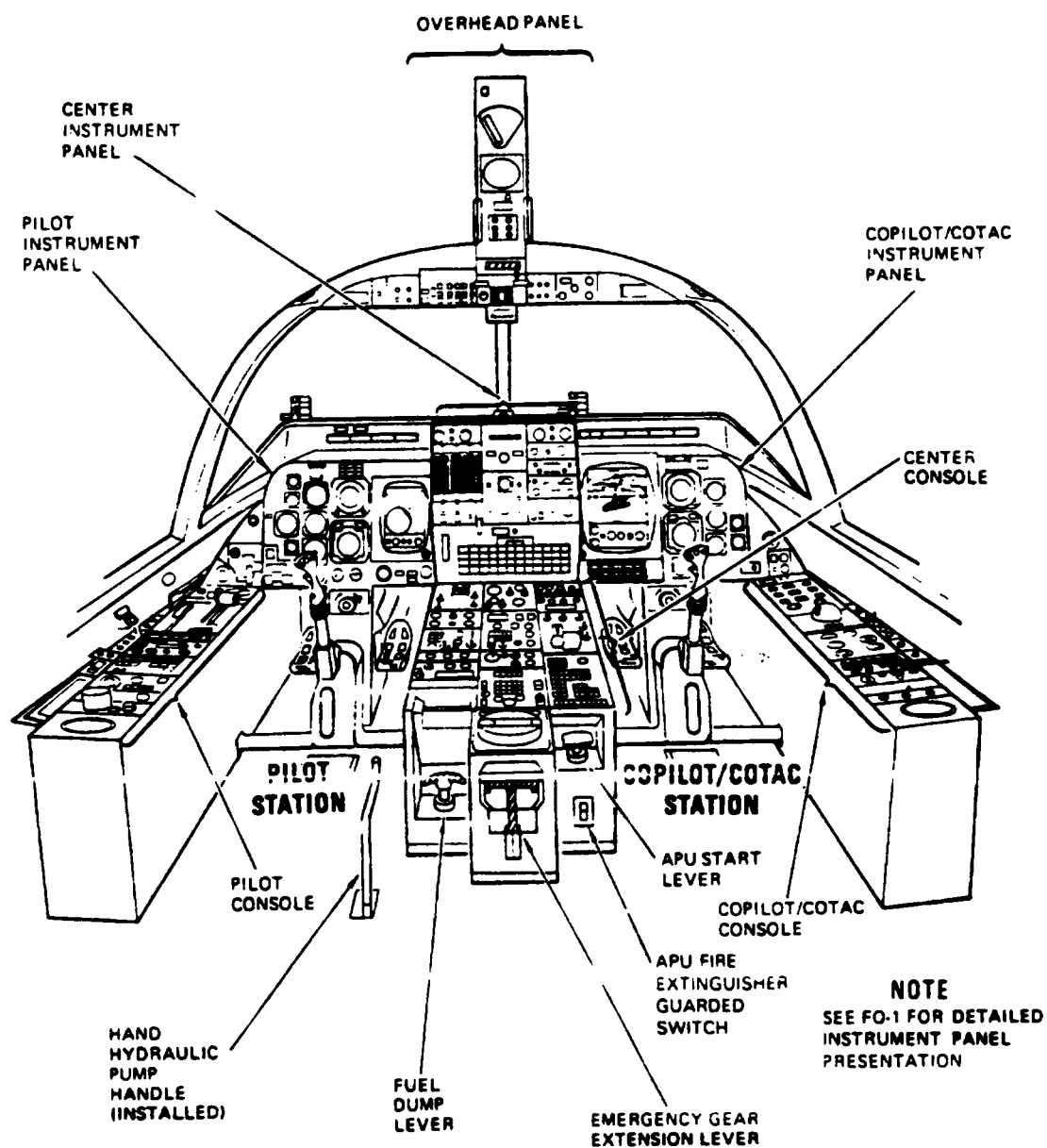


Figure B-2
S-3B Aircraft Cockpit Layout

Source: NAVAIR 01-S3AAB-1, NATOPS Flight Manual Navy Model S-3B Aircraft, Department of the Navy, 1 October 1993.

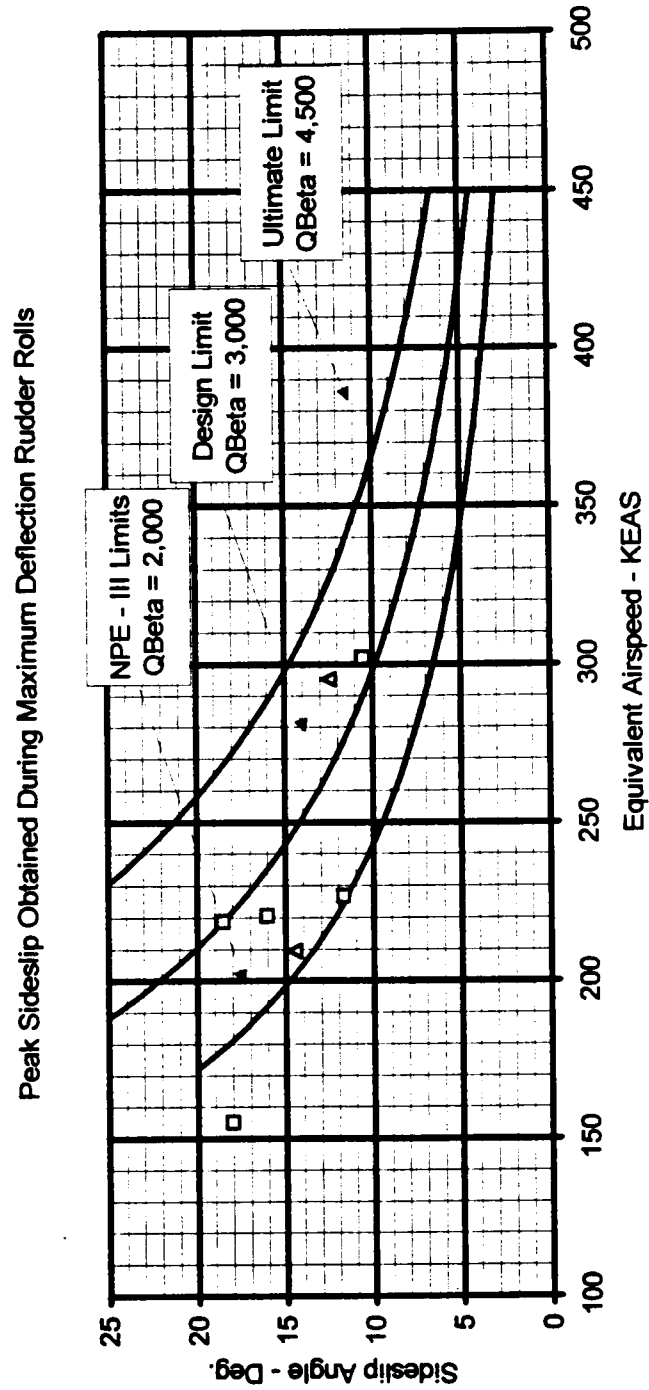


Figure B-3
Maximum Sideslip Obtained During Rudder Rolls

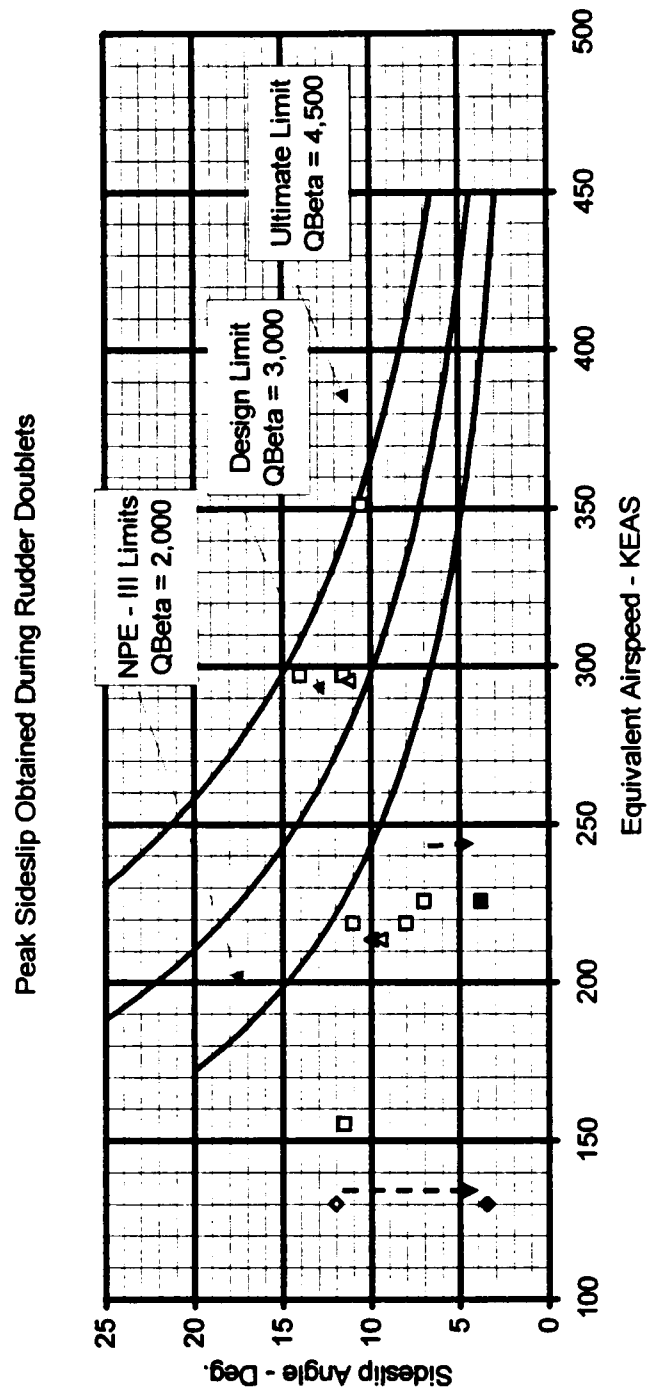


Figure B-4
Maximum Sideslip Obtained During Rudder Doublets

APPENDIX C
S-3B FLIGHT TEST LIMITATIONS AND CRITICAL FLIGHT CONDITIONS
(SUPPLEMENT TO NATOPS)

**S-3B FLIGHT TEST LIMITATIONS
AND CRITICAL FLIGHT CONDITIONS
(Supplement to NATOPS)**

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**S-3B FLIGHT TEST STRUCTURAL LIMITATIONS
AND CRITICAL FLIGHT CONDITIONS
(Supplement to NATOPS)**

- Ref: (a) Lockheed Document No. LR 25100, S-3A Demonstration Data Report of 29 Aug 1973.
(b) Lockheed Document No. LR 24451, S-3A Demonstration Planning and Progress Report, Rev 17, of 10 Dec 1973.
(c) Lockheed Document No. LR 24688, Flight Load Parameters and Airload Distributions.
(d) Lockheed Document No. LR 24695, Empennage Loads Summary, Rev A, of 25 Feb 1977.
(e) Lockheed Document No. LR 24623, S-3A, Static Load Test of Airplane For Critical Flight Conditions, of 11 Nov 1971.

1 GENERAL

1.1 The flight test structural limitations presented herein are applicable to the test airplane, S-3B BuNo 159743, and were developed from references a through e to address critical flight conditions and maneuvers not adequately covered in the S-3B NATOPS flight manual. Component critical flight loads are also presented.

2 ENVELOPES

2.1 Maneuvering and sideslip envelopes are presented in figures D-1 and D-2, respectively. Maneuvers producing limit loads and critical components are identified by the data points defining the corners of the envelopes. Data points were obtained from the results of the S-3A structural demonstration reported in references a and b. Precautions and prohibited maneuvers are noted in the figures and the following paragraphs. These restrictions are in addition to NATOPS and are summarized below.

2.2 SUMMARY OF PRECAUTIONS AND PROHIBITED MANEUVERS

2.2.1 Prohibited maneuvers:

- Flight in sustained buffet.
- Accelerated stalls and abrupt pull-up's to stall above 2.5 g's (upper left corner of the V-N diagram, figure D-1).
- Oscillatory rudder pedal inputs (frequency sweeps).
- Maneuvers producing sideslip angles greater than 21.6 degrees or the product of sideslip and dynamic pressure ($q\beta$) of 2600 psf-deg whichever is less (figure D-2).

2.2.2 Precautions (maneuvers which can result in excessive loads):

- Rudder rolls can produce sideslip excursions beyond limit load conditions.
- Avoid abrupt, large amplitude directional control input (step and doublet).
- Avoid abrupt rudder checkback at sideslip limits (use a smooth rudder input to reduce sideslip).
- Rolling pullout maneuvers can produce significant increases in normal acceleration due to pitch up resulting from spoiler deflection and inadvertent aft stick input. Large sideslip excursions can also result during roll maneuvers.

2.3 SIDESLIP ENVELOPE

2.3.1 Vertical stabilizer loads, as function of sideslip angle and dynamic pressure, are presented in figure D-3. Limit loads were defined by the design limit loads of references c and d and the S-3A structural demonstration test results of reference a. The ultimate load achieved during the static load test of reference e was 230% of limit as shown in figure D-3. Data from the 1992 OFT improvement flight tests were plotted to illustrate excursions in sideslip which can result from various maneuvers

and the accuracy of the static test as compared with the fin failure point of 244% limit load. Compliance with the guidelines in paragraph 2.2 will prevent excursions in sideslip angle above limit load. For reference, the ultimate vertical stabilizer loads envelopes and flight conditions are presented in figure D-4 and yaw rates for the design limit load maneuvers are presented in figure D-5.

2.4 MANEUVERING ENVELOPE

2.4.1 The V-N diagram for 8,000 ft is presented in figure D-1. Maneuver load factor limits for flaps down configurations are presented in the NATOPS flight manual. S-3A structural Maneuvers which developed limit loads used to demonstrate the structural airworthiness of the S-3A airframe are illustrated. Accelerated stalls above 2.5 g and flight in sustained buffet are restricted since horizontal stabilizer loads have been measured in this regime and are suspect of causing cracks in the horizontal stabilizer hinge fittings.

2.4.2 Rolling pullout load factor limits are 1.0 g to 80% of the positive limit shown in figure D-1. Rolling pullout maneuvers produce wing and aileron limit loads and moderate to large excursions in sideslip angle. Wing loads are largest in high speed rolls where high wing torsion is produced due to the combination of deflected aileron and spoiler, and high roll rate, and where higher load factors are obtained due to the nose up pitching moment on the airplane. Spoiler extension in a roll results in an airplane nose up pitching moment which produces a an incremental load factor, without any additional pilot longitudinal control displacement. The incremental load factor increases with increases in airspeed, as shown in figure D-6 for a 1.5 g entry, and is independent of the initial entry load factor for entry load factors above about 1.7 g's. The effect of entry load factor on incremental load factor is shown in figure D-7 and peak roll rates observed during the maneuver are presented in figure D-8. Scatter in the peak load factor data of figure D-6 is due the small inadvertent pilot longitudinal stick motions accompanying full lateral control deflections. The small inadvertent aft stick motions during a large lateral control deflection roll can be enough to exceed limit load factor and should be monitored closely at high entry load factors.

3 CRITICAL FLIGHT LOAD CONDITIONS

3.1 A summary of component critical flight loads is presented in table 1. Table 2 provides a description of the structural demonstration maneuvers referenced in table 1. The information was excerpted from references a and b.

TABLE D-1
S-3A/B COMPONENT CRITICAL FLIGHT LOAD SUMMARY

Component	Measurement	Mission/Config.	Test or Maneuver	Wt. (lbs)	CG (%mac)	Ve (kts)	nz (g)	Test nW % of Design	% Limit Load	Comments
Wing	BL 51 Shear-Tors.	ALT. 2 (Asym Store)	H Alt Pulout	39.9	18.4	458	3.78	118	102	Up Shear LE Up Tors.
	BL 100 Shear-Tors.	ALT. 1 + 2 Aero 1D's	Emerg Store Release	43.2	28.5	464	3.05	103	91	Up Shear LE Up Tors.
	BL 134 Shear-Tors.	ALT. 1	Subsonic Pulout	36.1	17.4	450	3.80	-	107	Up Shear LE Up Tors.
	BL 191 Shear-Tors.	Primary	Rolling Pulout	36.9	29.3	436	3.18	-	88	Up Shear LE Dn Tors.
	BL 238 Shear-Tors.	Primary	Rolling Pulout	36.9	29.3	436	3.18	-	97	Up Shear LE Dn Tors.
	BL 283 Shear-Tors	ALT. 2 (Asym Store)	Rolling Pulout	41.9	28.5	439	3.45	-	88	Up Shear LE Up Tors.
Wing L.E. Flap	BL 327 Bend-Tors.	ALT. 2 (Asym Store)	Rolling Pulout	41.9	28.5	439	3.45	-	107	Up Shear LE Up Tors.
	#21B. Link Aial Load	Primary	Pull Up	36.6	17.0	250	3.50	100	60	Extrapolated Compr Load
Wing T.E. Flap	#31B. Link Aial Load	Primary	Pull Up	36.6	17.0	250	3.50	100	68	Extrapolated Compr Load
	Carriage Bend. Moment	Primary + Man Flaps	Accelerated Stall	38.0	18.0	188	3.50	-	83	Extrapolated Up Load
Speed Brake	Flap Panel Bend. Mom.	Primary + Man Flaps	Accelerated Stall	38.0	18.0	188	3.50	-	95	Extrapolated Up Load
	Inbd Panel IB. Rod Load	Primary	Speed Reduct. Man	38.4	29.0	445	-	-	98	Compr. Load
Aileron	Rod Aial Load	Primary	Rolling Pulout	35.3	29.0	450	2.60	-	89	Extrapolated Compr. Load
	BL 33 Bend-Tors. Load	ALT. 3 (Sym Store)	H Alt Pulout	41.0	18.3	450	3.35	107	115	Dn Shear LE Up Tors.
Horizontal Stabilizer	BL 33 Rear Beam Shr	ALT. 3 (Sym Store)	H Alt Pulout	41.0	18.3	450	3.35	107	107	Dn Shear Stress
	Aial Load	ALT. 1	Subsonic Pulout	36.1	17.4	450	3.80	107	102	Tension Load
Horizontal Stabilizer Actuator Elevator	Hinge Moment	ALT. 1	Pull Up	38.7	17.9	227	3.38	102	78	Torsion Load
	WL 272 Bend Shr-Tors	Primary	H Speed Dyn Yaw	34.2	28.5	433	1.00	94	100	-
Vertical Stabilizer	WL 272 Bend Shr-Tors	Primary	Low Speed Dyn Yaw	36.5	27.0	186	1.67	100	100	-
	Bend. Moment	Primary	Wind Up Turn Stall	37.6	29.2	246	3.35	98	95	-
Rudder Counter-Balance	Bend. Moment	ALT. 3 (Sym Store)	Pull Up (abrupt)	44.1	18.5	219	3.07	106	93	-
	Outer Door Bend. Mom.	Primary (Doors Open)	H Speed Sideslip	34.2	29.4	430	-	-	85	Opening Moment
Bomb Bay Doors	Inner Door Fwd Link load	Primary + Man Flaps (Doors Open)	Low Speed Sideslip	38.5	26.0	214	-	-	31	Tension Load
Mad Boom	Root Vert. Bend. Mom.	Primary + Man Flaps	Wind Up Turn Stall	37.3	17.7	163	2.30	95	64	Up Bending Load
	Mid BM. Lat. Bend. Mom	Primary + Man Flaps	Wind Up Turn Stall	37.6	17.7	178	2.50	103	37	Side Bending Load

TABLE D-2
STRUCTURAL DEMONSTRATION TEST MANEUVERS

Maneuver	Required load factor	Speed to be attained in combination with required load factor	Pressure altitude	Special requirement (except as specified in this column 6, airplane shall be as specified in 3.12.1.4)
pull-up	At least n_z	$V = \sqrt{\frac{2n_z W}{\rho_0 K C_{N_{Lmax}} S}}$ where V = Speed for the test, knots n_z = Design limit load factor W = Weight of the airplane specified for the test, pounds S = surface area, sq. ft. ρ_0 = Air density, slugs/cu. ft. $C_{N_{Lmax}}$ = Max normal force coefficient as determined for the $C_{N_{Lmax}}$ vs M data obtained during test of 3.12.1.8 $K=1.25$ for $M < 0.6$ Not less than V_L at altitude at which the required load factor is attained.	Not greater than 8,000 feet	These tests shall be performed with the bomb-bay doors closed and repeated with the bomb-bay doors open. These tests shall be performed so as to develop: (1) The specified load factor at a speed not greater than the specified speed; or alternatively, (2) The specified load factor at the minimum speed at which the load factor can be developed in a symmetrical pull-out in a vertical plane by applying maximum longitudinal control force (see definitions) in not more than 0.5 second and maintaining that force until the maximum attainable load factor has been reached. If the results of developmental tests indicate that attainment of the specified conditions by (1), above, is not possible and that compliance with the procedure of (2), above, would result in exceeding the limit strength of the airplane, the contractor, by means of analyses, wind-tunnel tests, and/or flight tests, shall determine the design changes needed to permit attainment of the specified conditions with the procedure of (2), above, shall install the changes and shall demonstrate the specified conditions.
High-altitude pull-out	At least n_z	Not less than V_L at altitude at which the required load factor is attained.	Not less than 8,000 feet, but not greater than 40,000 feet Optional	Perform a symmetrical pull-out at an altitude selected by the contractor as being critical and substantiated by the performance in build-up flights of not less than 6 pull-outs to the maximum speeds that can be attained in combination with the specified load factor.
Landing configuration pull-up Low-Speed Dynamic Yaw	At least 2.0 Optional	Not lower than the maximum EAS for V_L as specified in MIL-A-8860 EAS equal to $0.6V_H \pm 10$ knots at sea level	Optional	Develop specified load factor and speed in the landing approach configuration.
High-speed Steady Sideslip	Optional	EAS not less than 430 knots	Optional	Perform to left and to right by applying a rudder pedal force of at least 300 pounds in not more than 0.3 sec, maintaining that force until the maximum over swing angle of sideslip is attained and the airplane attains a steady sideslip, and maintaining not greater than 10 degrees angle of bank. Recovery shall be made by reducing the directional control displacement to zero in not more than 0.3 sec.
High-Speed Dynamic Yaw	Optional	EAS not less than 430 knots	Optional	Perform to left and to right by moving directional control slowly in the appropriate direction, maintaining not greater than 10 degrees of bank, until a rudder-pedal force of at least 300 pounds has been reached. For airplanes having bomb-bay doors, the doors shall be open for tests to the left and closed for doors to the right, or vice versa. Perform to left and to right by applying a rudder pedal force of at least 180 pounds in not more than 0.3 sec, maintaining that force until the maximum over swing angle of sideslip is attained and the airplane attains a steady sideslip, and maintaining not greater than 10 degrees angle of bank. Recovery shall be made by reducing the directional control displacement to zero in not more than 0.3 sec.

TABLE D-2 CONT'D

Maneuver	Required load factor	Speed to be attained in combination with required load factor	Pressure altitude	Special requirement (except as specified in this column 6, airplane shall be as specified in 3.12.1.4)
Subsonic rolling pull-out	At least $0.8n_z$	EAS equal to that at which maximum rate of roll can be attained at the specified load factor ± 10 knots but not greater than $M=0.85$.	Not greater than 10,000 feet	Perform test at a speed selected by the contractor as being critical and substantiated as being critical by performance in build-up flights of tests at both speeds. Test g is not required if test 1) is performed at not less than V_L-20 knots EAS or at the maximum safe EAS. Perform to left and to right with the rudder control held fixed in its position for trim for zero rudder pedal force in wings-laterally-level flight at the specified speed by any one of the following methods: (1) The required load factor shall be attained coincidently with at least 90 percent of the peak value of rolling velocity attainable with a maximum lateral control force in a rudder-fixed roll at the specified speed; or (2) From a bank angle of not less than 60 degrees, and a load factor not greater than 1.5, the airplane shall be rolled in the direction to reduce the angle of bank by applying maximum lateral control force in not more than 0.5 second and maintaining this force until the required load factor is imposed. The required load factor shall be attained from the initial angle of bank; or (3) From a bank angle of not less than 45 degrees, and a load factor not greater than 0.5, the airplane shall be rolled in the direction to reduce the angle of bank by applying maximum lateral control force in not more than 0.2 second the maintaining this force until the required load factor is imposed. The required load factor shall be attained after the airplane has rolled not less than 45 degrees from the initial angle of bank.
High speed rolling pull-out	At least $0.8(n_z)$	At least V_L-20 at the altitude at which the test is performed.	Not greater than 10,000 feet	

MODEL S-3A/B AIRPLANE

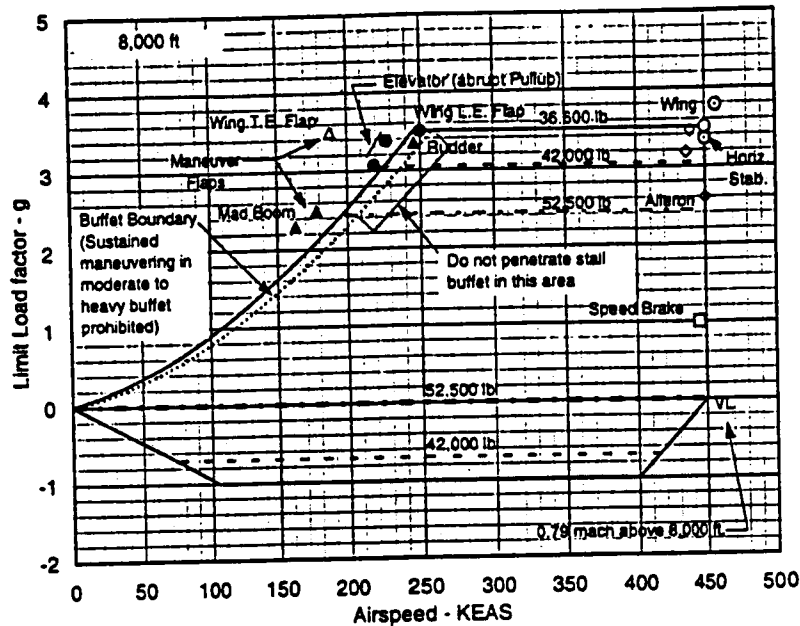


Figure D-1
Maneuvering Envelope

Data points reflect maneuvers producing limit design loads for the respective components. (ref: LR 25100, S-3A Demonstration Data Report)

- High Altitude Pullout
- Subsonic Pullout
- ◇ Rolling Pullout
- △ Accelerated Stall
- Pull Up
- ▲ Wind Up Turn Stall Buffet
- Speed Reduction Maneuver

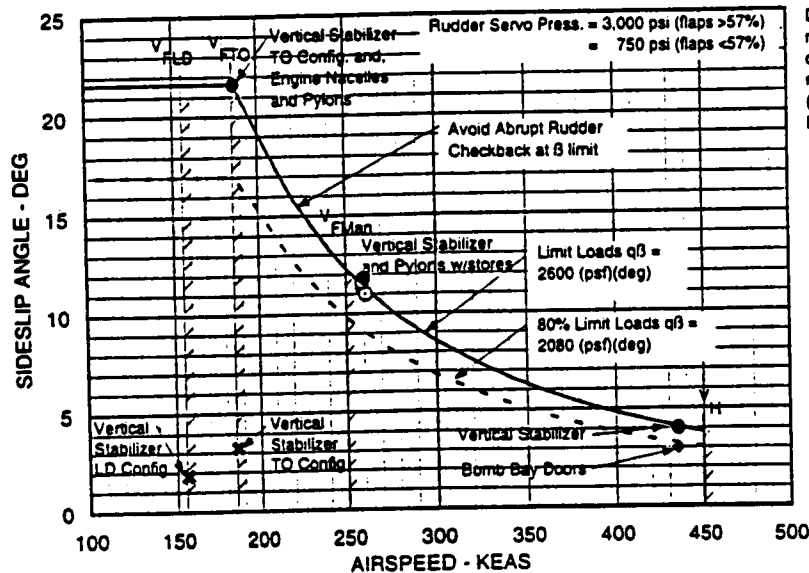


Figure D-2
Sideslip Envelope

Data points reflect maneuvers producing limit design loads for the respective components. (ref: LR 25100, S-3A Demonstration Data Report)

- ✱ Rudder Kick
- Dynamic Yaw
- Dynamic Yaw (stores)
- ◆ Steady Sideslip

MODEL S-3A/B AIRPLANE

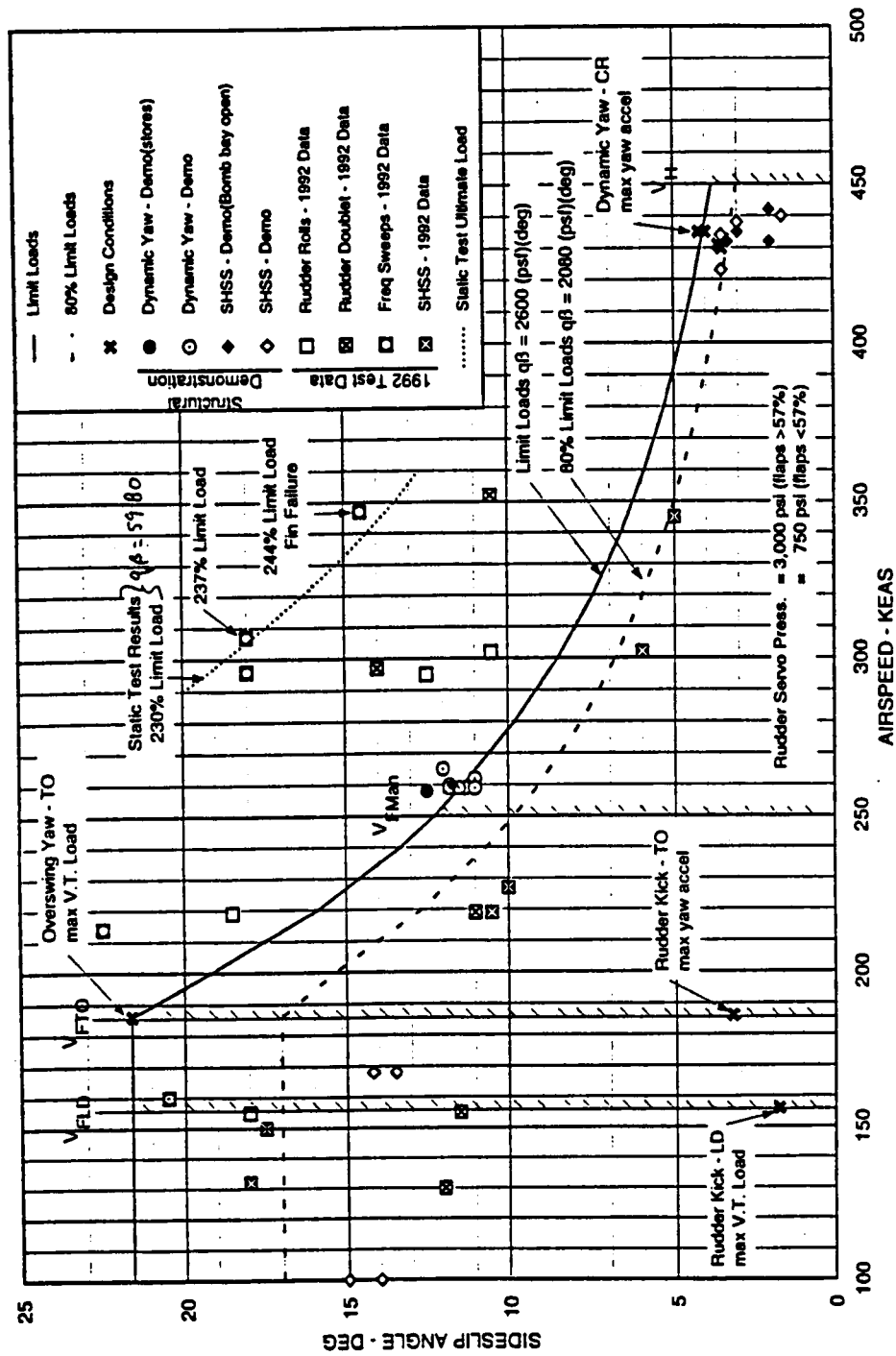


Figure D-3
Sideslip Limitations For Vertical Stabilizer Design Loads

MODEL S-3A/B AIRPLANE

Condition	Maneuver	Configuration	GW (lb)	CG (%mac)	Airspeed (KEAS)	B (deg)	r (deg)
421	Overswing yaw - Max V.T. Load	TO	36,574	27.0	186	21.6	27.0
429	Rudder Kick - Max Yaw Accel	TO	36,574	13.9	186	3.2	24.0
431	Rudder Kick - Max V.T. Load	LD	52,539	25.3	156	1.8	24.0
A	PHAA & WUT Buffet Loads	CR	36,574	14.0	218-255	0.0	0.0
B	Dynamic Yaw- Max Yaw Accel	CR	34,227	29.5	432	4.0	4.0
-	* Rolling Pull Out	CR	36,574	14.0	420	-	-

Note: * Rolling Pull out maneuvers do not define the loads envelope, however, loads during these maneuvers are approximately 91 percent of condition 431.

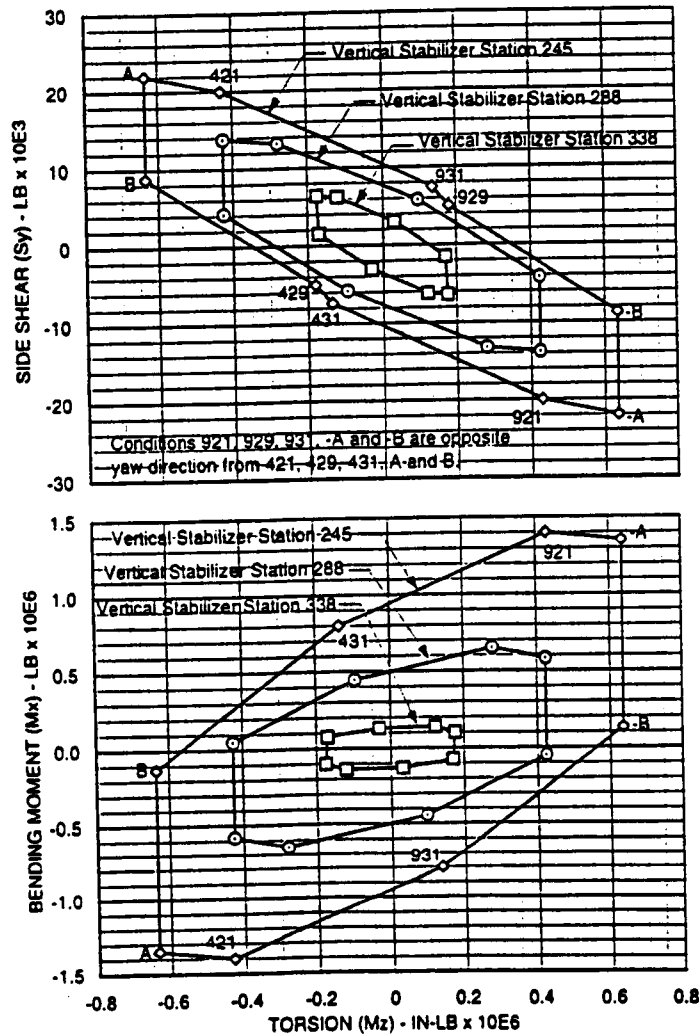


Figure D-4
Ultimate Vertical Stabilizer Loads Envelope - Flight Loads

MODEL S-3A/B AIRPLANE

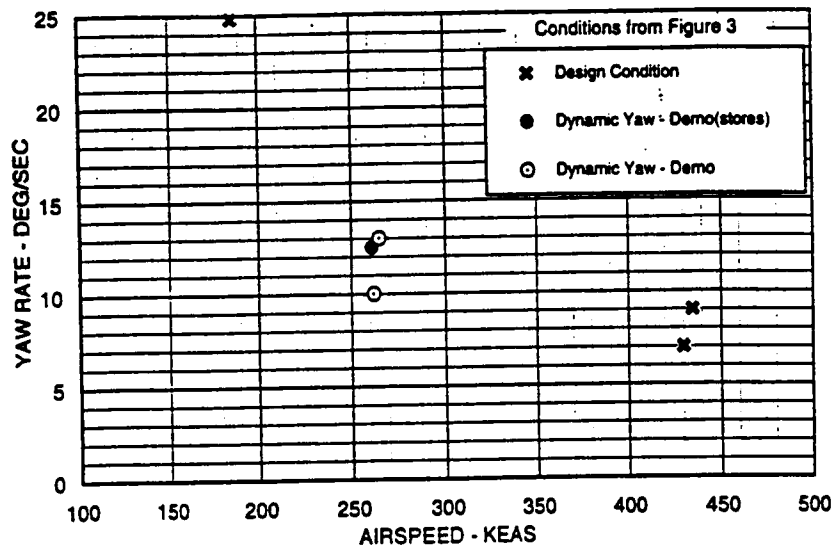


Figure D-5
Yaw Rate Generated During Dynamic Yaw

MODEL S-3A/B AIRPLANE

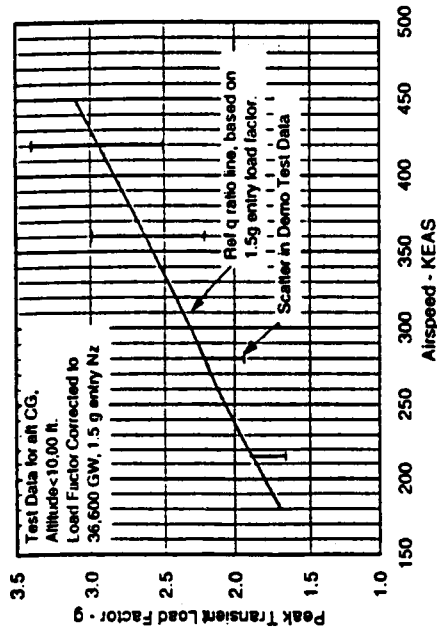


Figure D-6
Peak Load Factor During Rolling Pullouts

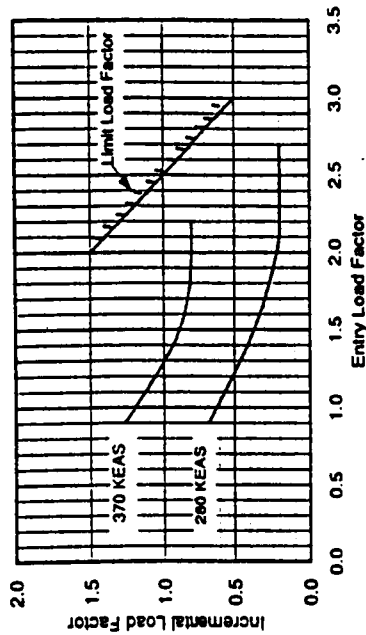


Figure D-7
Effect of Entry Load Factor on Incremental Load Factor During Rolling Pullout

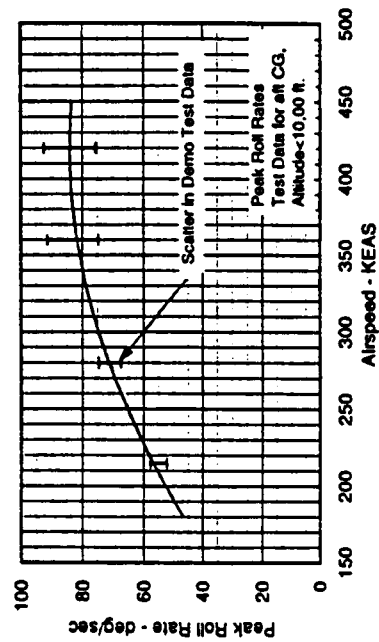


Figure D-8
Peak Roll Rates During Rolling Pullouts

VITA

Brett Matthew Pierson was born in Anchorage, Alaska on 29 June 1966. He is a native of Fort Lauderdale, Florida and graduated from Sebring High School in June 1983. After graduating from the U.S. Naval Academy in 1987 with a Bachelor of Science in Aerospace Engineering, he attended flight training and was winged as a Naval Aviator in November 1989. Following deployments to the Persian Gulf, for Operation Southern Watch, and Somalia, for Operation Restore Hope, Brett was selected for training as a Test Pilot in July 1994. Upon completion of the curriculum at the U.S. Naval Test Pilot School at NAS Patuxent River Maryland in December, 1995, Brett reported to the Force Aircraft Test Squadron where he served as the S-3/ES-3 Project Officer for the Flight Systems/Ordnance Team. Currently he is undergoing Category II refresher training at the S-3 Fleet Replacement Squadron in preparation for his return to the operational Viking community as a squadron department head.

Brett resides in San Diego, California with his wife, the former Sylvia Basilio, and their dog, Stonewall, and cat, Chuck.