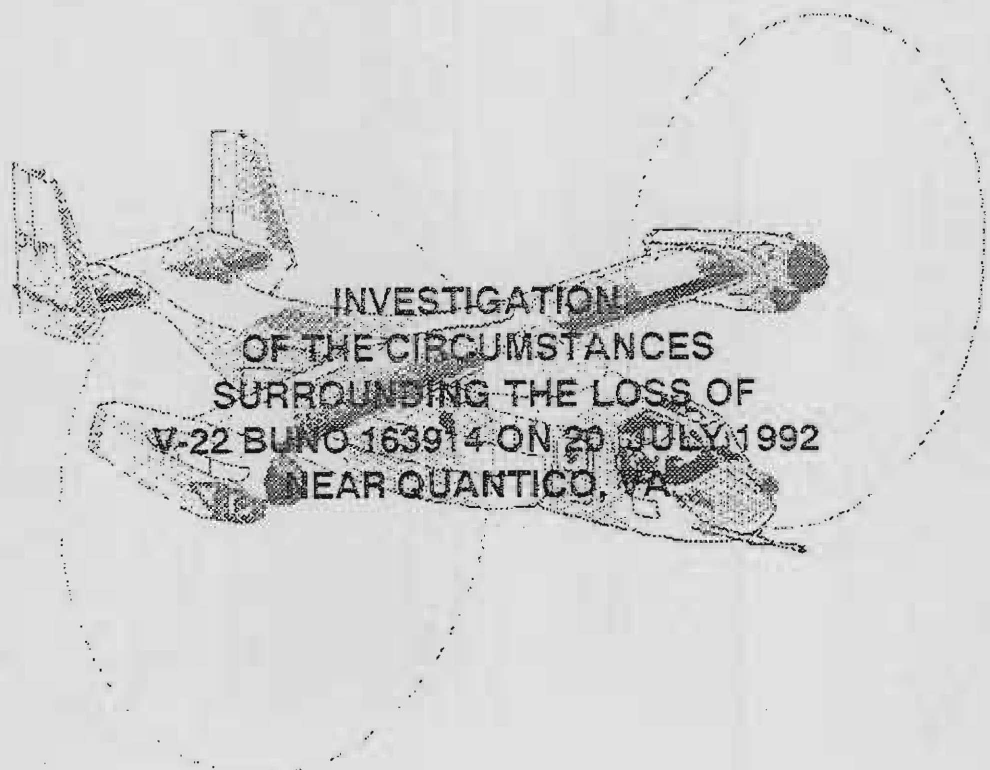
V-22 COURT OF INQUIRY

REPORT

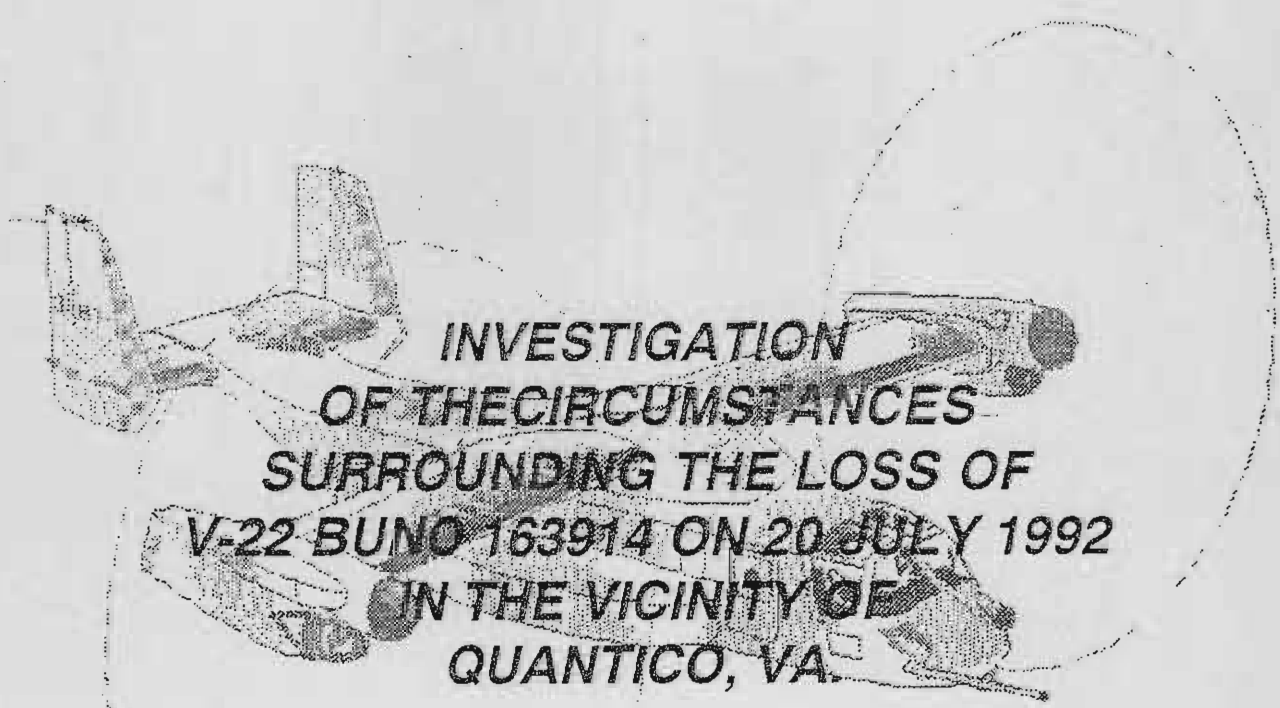


INVESTIGATION
OF THE CIRCUMSTANCES
SURROUNDING THE LOSS OF
V-22 BUNO 163914 ON 20 JULY 1992
NEAR QUANTICO, VA

V-22 COURT OF INQUIRY

REPORT

ORIGINAL



INVESTIGATION OF THECIRCUMSTANCES SURROUNDING THE LOSS OF V-22 BUNO 163914 ON 20 JULY 1992 IN THE VICINITY OF QUANTICO, VA.

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Volume 1

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
WASHINGTON, DC 20361

IN REPLY REFER TO

5830
Ser AIR-5115X/1496S
16 Apr 93

FIRST ENDORSEMENT on CAPT , USN,
ltr of 17 Dec 92

From: Commander, Naval Air Systems Command
To: Judge Advocate General

Subj: RESULTS OF COURT OF INQUIRY INVESTIGATION INTO THE CIRCUMSTANCES SURROUNDING THE CRASH OF V-22 AIRCRAFT BUREAU NUMBER 163914 THAT OCCURRED IN THE VICINITY OF MARINE CORPS BASE, QUANTICO, VA, ON 20 JULY 1992

Encl: (3) Table of Cross References from Court's Findings, Opinions, and Recommendations to Their Discussion in this Endorsement
(4) Privacy Act Advice Acknowledgements
(5) Bell-Boeing Investigation of V-22 Proprotor Gearbox/Engine Torquemeter Shaft Seals
(6) Full Scale Development Contract Clause H-1B
(7) V-22 Daily Flight Report (various)
(8) Egress Training Documentation
(9) Associate Contractor Agreement
(10) Aircraft Nos. 2 & 3 Modification Preliminary Design Review (PDR) (Firewall Modification)
(11) Naval Aviation Training and Operations System (NATOPS) Manual, 14 Feb 92

1. Readdressed and forwarded. The proceedings and the findings of facts, opinions, and recommendations of the Court of Inquiry are approved, except as noted below. References (d) and (e) of the basic correspondence are redesignated enclosures (1) and (2). This endorsement has been coordinated with and is concurred in by the Commander, Defense Contract Management Command (DCMC), and the Program Executive Officer for Air ASW, Assault, and Special Mission Programs.

2. It is always difficult to review an investigation into a mishap that results in loss of life. My heartfelt sympathy goes out to the families and loved ones of Mr. Patrick J. Sullivan; Major Brian J. James, USMC; Master Gunnery Sergeant Gary Leader, USMC; Gunnery Sergeant Sean P. Joyce, USMC; Mr. Robert L. Rayburn; Mr. Gerald W. Mayan; and Mr. Anthony J. Stecyk. We must never lose sight of the valuable contribution to naval aviation made by these brave men, and the fact that they gave their lives in advancing the latest in aviation technology. Although there is little I can say or do to alleviate the grief of their families and loved ones, I hope that

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they can find some measure of solace in the knowledge that they died while contributing to the national defense of our country as true heros. Their invaluable service to our country will never be forgotten.

3. The Court did an outstanding job of investigating the circumstances surrounding the crash of V-22 Bureau Number (BUNO) 163914. The Court's task was difficult and time-consuming, involving a highly complex developmental aircraft. The combination of skills and perspectives residing in the members of Court not only allowed the causes of this crash to be clearly established, but also offered valuable insights into design issues. As noted below, each of the technical concerns identified by the Court is being considered in redesign efforts to ensure prevention of future mishaps and to make the V-22 a more effective weapon systems.

4. This endorsement is organized in three sections. Section I gives this endorser's overview of the mishap and the Court's work. Section II addresses significant themes that flow through the Court's report and this endorsement as to which there are differences between the Court and this endorser. At the end of the discussion of each theme, the significant findings of fact, opinions, or recommendations that relate to the focus of the discussion are identified. Section III addresses in detail each finding of fact, opinion, and recommendation that is clarified or disapproved. A table cross referencing those findings of fact, opinions, and recommendations of the Court that have been modified or disapproved by this endorsement and their discussions are found in this endorsement. That table is attached as enclosure (3).

5. Throughout this endorsement, particularly section II, factual conclusions drawn from V-22 program files are presented and used to comment on the work of the Court. Paragraph 17 is an example of such use of program history. The supporting documentation for these factual conclusions are not attached or specifically referred to in this correspondence since these facts do not bear directly on the causes of the mishap. Rather, they provide the context to help understand the actions taken in this endorsement, particularly, actions on the opinions and recommendations.

6. Although it is not clear that advice required by the Privacy Act was necessary, in the cases of non-Government witnesses who testified during open sessions of the Court, evidence of the fact that such advice was provided is attached as enclosure (4).

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SECTION I - SUMMARY

7. The Court's overview of the mishap in the paragraph entitled "Mishap Overview" in its Executive Summary properly summarizes the essential events that resulted in this mishap. No design deficiencies were discovered which were uniquely tiltrotor in nature. The Court's work clearly shows the primary cause of the mishap to have been the result of flaws in the design of the nacelle that allowed flammable fluid to accumulate in the engine inlet centerbody, and, subsequently, to be ingested by the engine. Further, the engine inlet was not designed to withstand over-pressures from engine surges which allowed a breach of fire containment in the engine bay. The well-documented chain of events that followed put the aircraft in an unrecoverable condition due to a combination of low airspeed and altitude and a rapid descent rate.

a. On 20 July 1992 V-22 BUNO 163914 was being ferried from Eglin AFB, Florida to Marine Corps Base (MCB) Quantico, Virginia. The aircraft experienced multiple emergencies upon entering the downwind leg at Quantico and crashed into the Potomac River, killing all seven crew members upon impact.

b. On downwind following conversion from airplane mode (0° nacelle angle) to 44° nacelle angle, the right engine surged due to the ingestion of a flammable substance through the engine intake. This first surge, which was accompanied by smoke and a flash, was controlled by the aircraft's governing system. The surge caused the Torque Command Limiting System (TCLS) to disengage and the Primary Flight Control System (PFCS) caution light to illuminate. Engine efficiency data shows that the right engine sustained damage during the first surge. Post-mishap inspection of the right engine revealed a 120° arc burned through the combustor liner, attributable to the presence of a flammable substance between the combustor liner and the diffuser case.

c. Additional flammable fluid ingestion and small oscillations of the right engine persisted for several seconds until the pilots reset the PFCS, clearing the frozen TCLS input and causing a rapid power command increase to the engines. Concurrently, the right engine oversped, experienced two surges in quick succession and then failed. Flashes of fire and smoke were associated with the surges.

d. The left engine powered both proprotor systems for several seconds, until failure of the pylon drive shaft due to heat/fire in the right nacelle. Combined right pylon shaft/right engine failure resulted in loss of drive to the right proprotor system. Loss of

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lift/rapid rate of descent and large left yaw followed, No indications of drive system failure were displayed in the cockpit, and the situation was further confused by a false warning of left engine failure.

e. The drive shaft failure produced a hydraulic leak and a Flight Control Computer electrical failure which reduced flight control authority and prevented hydraulic control of the nacelles.

8. All of the Court's Cause Factors are relevant to safe operation of the aircraft. For that reason they have been fully recognized in the redesign effort; however, as discussed below, those that were not shown to have contributed to this mishap have been disapproved as causative factors.

9. The Court correctly identified a number of areas with regard to Bell-Boeing's organizational structure, flight test discipline, and maintenance procedures which I view with concern. PMA-275 and Bell-Boeing management have undertaken a joint review to address these concerns and implement corrective actions where appropriate. Aircraft development is an inherently unforgiving endeavor. Constant vigilance and management attention are required to ensure a safe and successful program.

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SECTION II - DETAILED DISCUSSION OF MAJOR ISSUES

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c. This paragraph addresses the Court's Findings of Fact 169-177, 369-377, 381, 382; Opinions 40-42, 100-102, 109, 134; Recommendation 23.

11. Bell-Boeing Maintenance Practices, Reporting Structure, Personnel Qualifications. This endorser's review indicates that the system used by Bell-Boeing at Eglin AFB to conduct maintenance lacked organization, defined responsibilities and a formal reporting and documentation structure. There was no single reference document that listed all outstanding (deferred or carryover) aircraft discrepancies independent of the source (e.g., pilot squawk, maintenance or engineering discrepancy). Additionally, BUNO 163914 was certified safe for flight prior to all open work items being completed.

a. PMA-275 has directed that Bell-Boeing conduct a review of its maintenance organization and practices for continued V-22 development. The reviewing team will be composed of those people inside and outside the company having knowledge and experience in the industry's current best commercial practices. This review will also examine Bell-Boeing's policies governing prerequisite training, qualification, and certification of maintenance personnel.

b. This paragraph addresses the Court's Findings of Fact 103 to 178; Opinions 27 to 43; Recommendations 9 to 13.

12. Nacelle Design. In the Court's opinion, the upper nacelle on the V-22 should have been designated as a fire zone. The upper nacelle houses the PRGB, tilt axis gearbox (TAGB), pylon drive shaft, swashplate actuators, hydraulic lines/pumps, engine control equipment, and electrical signal carrying lines. In order to provide adequate cooling air flow to both PRGB and TAGB oil coolers, a nacelle blower was incorporated into the aircraft design that pulls air through the nacelle at a rate of 10,000 cubic feet per minute. In addition, upper nacelle air inlet modifications have been made in an attempt to improve the cooling provisions for the gearbox and reduce the operating temperatures in the upper nacelle. The nacelle blower is critical to maintaining adequate airflow to the PRGB and its failure is annunciated to the pilot.

a. The upper nacelle was designated as a no-fire zone predicated on the ability to provide adequate engine compartment fire detection, suppression and containment. In this mishap, the upper nacelle fire originated from the engine surge and subsequent failure of the engine inlet. Had the horizontal firewall been extended forward to the PRGB and the inlet been able to withstand the over-pressure created during the surge, the fire would not have propagated into the upper nacelle. Corrective action to rectify this deficiency

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is being accomplished prior to resumption of flight test. It is impractical to incorporate a fire suppression capability for the upper nacelle due to the difficulties that would be encountered in obtaining adequate suppression agent concentrations with the large airflow volume experienced in that area.

b. This paragraph addresses the Court's Findings of Fact 348, 351, 354, 357-361, 383-390; Opinions 84, 91, 92, 94, 95, 110-112; Recommendations 43-48.

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a. The Court was incorrect in stating (Fact 353) that "the 240°F glass transition temperature was the result of producibility requirements, not a design specification." The glass transition temperature is defined based on the component operating temperature. Once the component operating temperature is specified, a minimum of a 50°F difference between the glass transition temperature and the expected operating temperatures is required. Manufacturing processes will impact the glass transition temperature and are examined through quality control/inspection.

b. At the nacelle Critical Design Review (CDR), upper nacelle operating temperatures were formulated (with a heat transfer analysis using a nacelle aerodynamic math model) based on anticipated PRGB heat generation for worst case hot day conditions. The analysis considered the temperature of composite frames, temperature of critical transmission components and temperature of the air surrounding the analog back-up engine control (exhibit 73).

c. Subsequent to the CDR, data were collected from the Ground Test Article and used to refine the heat transfer model. A ground turn on aircraft BUNO 163911 resulted in high PRGB oil temperatures which prompted a modification to the nacelle inlet air scoops. The heat transfer analysis was not revisited to determine revised upper nacelle component temperatures which resulted from this modification. The pylon drive shaft had never been instrumented to determine shaft temperatures during worst case hot day conditions or following a nacelle blower failure. Bell-Boeing was primarily concerned with the

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high temperatures that would be experienced within the PRGB.

d. This mishap has identified the need to address material selection for upper nacelle components and/or a reduction in the operating temperature environment for the upper nacelle. Temporary modifications being incorporated prior to flight resumption will provide shielding and dedicated cooling air to the pylon drive shaft. Permanent redesign efforts will focus on the following: 1) Selection and qualification of higher temperature composite drive shafts; 2) Relocation of the PRGB oil coolers aft to reduce hot air impinging upon the pylon drive shaft; and 3) Optimizing the airflow characteristics of the upper nacelle.

e. This paragraph addresses the Court's Findings of Fact 282, 283, 284, 285, 286, 287, 288, 290, 291 292, 293, 296, 297, 298, 299, 353, 354, 385, 390; Opinions 60, 61, 62; Recommendation 20.

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c. Specific design changes under consideration include: 1)

Adding a third HPDU in place of the EPDU; 2) Increasing the current conversion rate of the HPDUs and EPDU; 3) Adding short circuit protection to the flight control system wiring to prevent loss of a Flight Control Computer (FCC); 4) Providing back-up FCC signaling and hydraulic power to the HPDUs; and 5) Eliminating the need to select back-up nacelle conversion.

d. This paragraph addresses the Court's Findings of Fact 300, 332, 335, 338, 340, 395, 396; Opinions 76, 81, 88, 89, 115, 116, 134, 135; Recommendations 38, 41.

15. Warning/Caution/Advisory (W/C/A) Design. In the Court's opinion, inadequacies of the W/C/A system design were a cause factor of the mishap.

a. Inter-connect Drive System (ICDS) Failure Indications. There were no means for alerting the pilot to an ICDS failure; however, given the multiple failures that existed in the aircraft at the time of the failure of the ICDS, such an indication would not have altered the outcome. There was no procedure that the pilots could have successfully used to respond to the indication. The requirement to warn the pilots of failure of the ICDS is acknowledged, and has become a pre-requisite for returning the aircraft to flight.

b. Display Format. The shortcomings of the current display format are under review by a W/C/A analysis team.

c. Hydraulics Failure Indications. The leak detection system is designed to preserve the swashplate actuators in the event of a leak in the systems that power those actuators. The pilot is notified of a loss of redundancy in the flight control systems, of the loss of any hydraulic system, or of any parameter that exceeds limits. A method to better annunciate these failures is currently under review by the W/C/A analysis team.

d. Monitor Faults. The Court noted that cautions such as "dual transducer (XDCR) fail" are ambiguous and their resolution can often increase pilot workload. This issue is recognized and is being investigated by the W/C/A team.

e. Engine Surge. The Court correctly noted that the system currently does not present indications of an engine surge condition. In this mishap, events progressed so rapidly that notification of a surge condition in the engine would not have changed the outcome. The feasibility of displaying data to the pilot to aid in his

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situational awareness of the condition of the engines is under review by the W/C/A analysis team.

f. As noted above, the W/C/A system is still being developed and a team has been assembled to analyze the system and make recommendations for incorporation in the Engineering and Manufacturing Development (EMD) baseline aircraft. However, the W/C/A system did not affect the outcome of the rapidly developing mishap scenario which the pilot of aircraft BUNO 163914 faced.

g. This paragraph addresses the Court's Findings of Fact 394, 398-410; Opinions 67, 69, 70, 71, 78, 118-131; Recommendations 28, 32, 34, 50-54, 56, 57.

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e. This paragraph addresses the Court's Findings of Fact 190, 191, 201, 203, 204, 206, 208, 214, 221, 224, 225, 226, 227, 228, 229,230, 231, 233, 234; Opinions 45, 46, 50, 51, 135; Recommendations 16, 17, 18.

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aircraft configured in airplane mode.

a. The TCL sends electrical signals to the cockpit thrust drive actuator to provide inputs to the engine power demand signal (PDS) from the FCC to the Full Authority Digital Engine Controls (FADECs). In helicopter or conversion mode, movement of the TCL will result in both a PDS change and collective blade pitch commands. In airplane mode, movement of the TCL results only in PDS changes. The TCL range of motion has both fore and aft and angular components. Forward and downward motion results in an increase in throttle (PDS) command (and collective blade pitch for helicopter and conversion mode operation). Aft and upward motion of the TCL results in a decrease in throttle (PDS)command (and collective blade pitch for helicopter and conversion mode operation).

b. At the request of PMA-275, additional engineering studies were performed to optimize the design of the TCL and address both egress and ergonomic issues in high workload situations. The studies concluded that a throttle type thrust control lever, void of angular motion, was a preferred configuration.

c. In this mishap, the pilot moved the TCL full forward (maximum power) immediately following failure of the ICDS and the simultaneous illumination of the left hand (LH) engine failure warning (approximately eight seconds prior to water impact). The crew had no way of knowing that the drive shaft had failed and that total drive to the right proprotor was lost. One can only speculate what the pilot was thinking when he moved the TCL full forward. However, it is equally likely that he was consciously attempting to arrest a rapidly increasing rate of descent with increased power; rather than attempting a helicopter type autorotation (but with a misapplication of power).

d. This mishap highlights several technical concerns which will be addressed during redesign efforts and include: 1) Refinement of the control motion of the TCL; 2) Improvements in the W/C/A display system; and 3) Increased simulator training for pilots to include exposure to one engine inoperative/ICDS failure and subsequent ditching/autorotational techniques.

e. This paragraph addresses the Court's Finding of Fact 343; Op[illegible]: Recommendation 39

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f. This paragraph addresses the Court's Findings of Fact 316, 328; Opinions 63, 64, 65, 66, 74, 135; Recommendations 22, 31.

19. Hydraulic System Leak Detection/Isolation. The Court expressed concern that an interchange of hydraulic fluid between systems could allow the contamination of one system to affect the other two. The flight control system incorporates a leak detection/isolation logic which commands the actuation of remote switching valves and isolation valves in an attempt to isolate a leak. The logic is designed to minimize the effects of a hydraulic leak and to retain hydraulic power to the swashplate actuators. Switching and isolation valves were included in the design based on a systems engineering decision to accept the risk of fluid contamination between systems (as a remote possibility), rather than install a fourth pump to provide hydraulic system redundancy. Leak isolation and loss of redundancy are annunciated to the pilot when a leak occurs. (See paragraph 15.)

a. In May 1992, during hover test, aircraft BUNO 163912 experienced a slow leak in hydraulic system #2 between the swashplate actuator and a remote switching valve in the right nacelle. The leak detection logic reacted to the leak by isolating hydraulic system #1 from the RH nacelle and switched hydraulic system #3 into the RH nacelle, i.e., into the leak area. This caused depletion of hydraulic fluid from hydraulic system #3. The Flight Control System (FCS) inhibits the #3 system leak rate monitoring when landing gear are extended. An investigation was conducted and corrective actions were being developed when the BUNO 163914 mishap occurred.

b. In this mishap, the failure of hydraulic system #1 was due to a rate of change in the reservoir level indicating a leak rate greater than the trip point (20 cu.in/sec). The hydraulic leak isolation process depressurized all wing and empennage actuators while guaranteeing pressure to both sides of the swashplate actuators. The leak isolation also excluded system #1 from the RH nacelle and switched system #3 to the RH swashplate actuators. Thus, the isolation logic caused partial loss of hydraulic power to the elevator, rudders, flaperons, and conversion actuators in response to a RH outboard actuator leak. The swashplate actuators are outside the hydraulic system isolation and switching valves; therefore, isolation of the leak was not possible and partial loss of the #1 and #3 hydraulic systems resulted. The #3 hydraulic system failed due to the reservoir level dropping below 150 cubic inches.

c. A thorough analysis of the hydraulic leak detection logic has been conducted as a result of the aircraft BUNO 163912 incident in May 1992. The corrective actions which have been developed address both aircraft BUNO 163912 and BUNO 163914 incidents. Protection against all single leak possibilities, and all but one of the dual leak possibilities, have been incorporated. The dual leak combination that has not yet been addressed is a leak: 1) in the hydraulic line between upper half of a swashplate actuator and the remote switching valve; and 2) in the hydraulic line between hydraulic pump and the switching isolation valve. Further development of the leak detection logic is being conducted to address this remaining possibility.

d. This paragraph addresses the Court's Findings of Fact 334, 336, 337, 342, 404, 406; Opinions 78-80, 126, 127; Recommendations 34-37, 52.

20. <u>Pilot Response to Complete Power or Drive Loss</u>. The Court assumed that the correct response to the multiple failures facing the pilot in this mishap was a helicopter type autorotation. An alternative procedure could be to convert back to airplane mode and treat the combination engine/ICDS failure as any twin engine aircraft would respond to a similar scenario. In the case of the BUNO 163914 mishap, neither response would have prevented the crash due to the low airspeed and altitude combination. With the information gained during the course of this investigation, improved pilot responses to multiple emergencies have been identified which will allow safe V-22 flight operations. Both simulation and flight testing of all engine and ICDS failure scenarios are planned, as soon as feasible, when the V-22 resumes flight testing. The goal is to verify the correct pilot response in each potential emergency situation.

a. The W/C/A displayed to the pilot during this mishap did not provide the pilot with sufficient means to quickly and adequately assess his situation. Although not a causal factor, the crew had no way of knowing that the total drive to the RH proprotor was lost (no cockpit warning for an ICDS failure). Additional problems associated with the W/C/A system, such as prioritization of information on multiple Multi-Function Display page layers, and the large number of nuisance sensor faults must also be addressed. A W/C/A analysis team is currently working to identify and resolve these problems for incorporation into the EMD design. (See paragraph 15.)

b. The preliminary draft NATOPS will be updated to address the engine/ICDS failure scenarios. These emergency procedures will also be included in the pilot training syllabus and practiced in the simulator, along with all other emergency procedures at regular intervals. In-flight practice of these emergency procedures is not practical at this stage of V-22 development due to lack of an adequately cleared envelope.

c. This paragraph addresses the Court's Findings of Fact 221, 316, 318-322, 324-332, 334-337, 340, 342, 343, 398-410; Opinions 64-82, 118-131; Recommendations 49-51, 54-56.

21. Flight Crew Approval Procedures. Authority for personnel to pilot or fly in aircraft under the controlling custody of NAVAIRSYSCOM is delineated in NAVAIRINST 3710.8B. "To fly in" is defined as to participate in a flight as a crewmember, passenger, airborne technician, or any other capacity, other than as pilot or copilot. The approving authority varies depending on the qualifications of the person and the type of flight being conducted. Aircraft held by a contractor can be classified as bailed, Government furnished property, or pre-accepted (DD 250 not yet signed on behalf of the Government).

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c. During the development of multi-crewed aircraft, there is always the question of when to begin flying those crewmembers not considered part of the minimum crew. Prolonged restriction usually delays system development, crew station integration, and crew training. Early introduction of an expanded crew could put crew members at risk unnecessarily. An expanded crew should be flown within an aircraft envelope that has been safely demonstrated. I have established a policy which mandates that a review panel confer prior to increasing crew size to determine if it is prudent. A revision of the NAVAIRSYSCOM instructions is currently being prepared to codify this policy.

d. This paragraph addresses the Court's Findings of Fact 15, 19, 22, 32-36, 41, 43, 45-48, 54-101; Opinions 7-13; Recommendations 4, 5, 7, 8.

22. Flight Discipline. The Court's conclusion that Boeing and/or Navy V-22 management applied undue pressure on Mr. Sullivan to arrive at Quantico as scheduled is circumstantial. Mr. Sullivan elected to take-off from an off-duty runway so as to start on a more northerly heading. He did not wait to join with the chase aircraft as had been briefed. He commenced fuel calculations immediately after take-off to determine if a straight through flight to Quantico was possible. He ignored an instrumentation warning (violating the NAVAIRSYSCOM flight clearance) to return to Eglin. Despite his co-pilot's discomfort with his decision to bypass Charlotte, he continued to press ahead. One can only speculate whether the apparent pressure that Mr. Sullivan felt to arrive at Quantico on time came from external sources or was generated within himself. It should be noted that violating the NAVAIRSYSCOM flight clearance and bypassing Charlotte were not causal to this mishap, but does constitute a serious breach in flight discipline.

a. Pressure to meet schedules is inherent in all flight test programs and was doubtless a factor that was considered by the Eglin test team. Mr. Sullivan and the Eglin detachment probably gave a high priority to arriving at Quantico on time. A welcome had been set up and announced at Marine Corps Headquarters. This pressure would have been reduced had the arrival been postponed and the aircraft take-off delayed.

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b. This paragraph addresses the Court's Findings of Fact 182-187, 196-219; Opinions 44-47; Recommendations 14, 15.

23. Bell-Boeing Flight Test Organization. During the period from 18-20 July 1992, the Bell-Boeing contingent at Eglin Air Force Base (AFB) was down-sized. The Court felt that this reduction in personnel was inappropriate and resulted in insufficient supervision of the maintenance actions prior to BUNO 163914's departure. However, with the exception of the Quality Assurance (QA) manager, those personnel who departed were test engineers and technicians who had been on site for the climatic lab testing. They had no responsibility or accountability for aircraft maintenance. At the time of the Bell-Boeing Team Leader's departure, the climatic test program was complete and only maintenance actions remained. Those individuals remaining were the appropriate personnel to complete the outstanding maintenance actions. However, as noted by the Court, the Boeing QA manager should have been present to certify those maintenance actions were complete.

a. A separate issue raised by the Court was that of unclear lines of authority between Boeing management and the Bell-Boeing Test Team while at Eglin AFB. This is a valid concern which PMA-275 has directed that Bell-Boeing address and correct.

b. This paragraph addresses the Court's Findings of Fact 15, 19, 43, 63, 69, 75-76, 88, 102, 113, 105, 110-120, 128, 130-132, 135, 140, 142, 143, 152, 154, 155, 158, 161, 162, 167; Opinions 13, 14, 21-24, 27-31; Recommendations 5, 9, 10, 11-15.

24. Naval Aviation Training and Operations System (NATOPS) Manual. The Court inadvertently cited an incorrect version of the NATOPS manual in its report. The version used by the Court was dated 15 March 1991. The version in use at the time of the mishap was dated 14 February 1992 and includes several significant changes from the earlier draft. The areas affected include One Engine Inoperative (OEI) procedures, Height-Velocity (H-V) diagrams, single engine flight profiles, and PFCS caution procedures.

a. When the Court referred to the V-22 NATOPS manual, it implied that the NATOPS is a validated reference document which dictates how the pilot is to operate the aircraft. While the V-22 is in development, the NATOPS is a draft document. The NATOPS is, itself, in development and is continually modified and updated as more data are accumulated through flight test. It is, therefore, impractical to have a comprehensive, detailed, and accurate NATOPS manual at this stage of the V-22's development.

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b. This paragraph addresses the Court's Findings of Fact 411, 412, 413, 414, 415, 416; Opinion 132; Recommendations 55, 56, 57.

25. GFR Responsibilities. GFR responsibilities are outlined in Defense Logistics Agency Manual (DLAM) 8210.1, Vol. 2, para. 2-2. The GFR's responsibilities and actions prior to the mishap of V-22 aircraft BUNO 163914 are clarified below:

a. Review Currency and Qualifications of Ground and Flight Crew Personnel:

(1) Boeing issued a monthly Test Pilot Qualification list to identify pilot currency and a monthly PAFC list to identify other than pilot personnel cleared to fly. Only those contractor personnel identified on one of these two lists were cleared to fly aboard contract aircraft. Government approval of contractor personnel was automatically canceled upon physical disqualification of those personnel. Pilot and non-crewmember flight training records of personnel identified on the lists were routinely audited.

(2) When requested, flight training records of Navy pilots not attached to NAVAIRWARCENACDIV, Patuxent River, authorized to fly on V-22 aircraft, were certified by COMNAVAIRWARCEN (NAWC-23B) with a copy of the certification provided to the GFR.

b. Project Agreement Flight Clearances (PAFC):

(1) B5

(2) B5

B5

(3) B5

B5

(4)

B5

c. Delegation of GFR duties to geographically separated locations:

(1) If additional support is required by the "home" facility GFR when the contractor operates from a geographically separated location, the GFR may delegate his duties. However, the delegated GFR will, as much as possible, rely on approvals granted at the home facility so as not to burden the contractor with unnecessary duplication. The DPRO Boeing GFR did not delegate his duties to anyone at Eglin AFB when the aircraft departed for Eglin in February 1992 for the following reasons:

(a) There was a controlled environment during climatic lab testing.
(b) No flight envelope expansion flights were planned.
(c) Scheduled flights were limited to basic airworthiness flights upon completion of lab testing and a ferry flight from Eglin AFB to Quantico, VA.

(2) Delegation of GFR duties to an individual at Eglin AFB would not have prevented this mishap. However, there is no doubt that ambiguity existed in the approval procedures governing those who participated in the flight. Efforts are ongoing to eliminate those ambiguities. In the future, delegation of GFR duties off-site to a responsible individual familiar with the pertinent regulations and program objectives will be made in an effort to facilitate communications between the test team and the home facility GFR.

e. This paragraph addresses the Court's Findings of Fact 19-22, 27-31, 41, 42, 44-56, 63, 68, 69, 72-76, 80-96; Opinions 4-6, 8; Recommendation 4.

26. <u>Aircraft Custody</u>. Prior to delivery, newly produced aircraft are tested by DPRO flight crews on behalf of the Navy. If acceptable, a Material Inspection and Receiving Report (DD 250) is

executed. For Navy aircraft, an Aircraft Custody/Status Change (XRAY) Report, accepting the aircraft into the Naval Inventory, is generated. Subsequent aircraft assignment is promulgated via a message originated by the Naval Aviation Depot Operations Center after coordinating with the OPNAV Support Systems Branch. This message assigns the first long-term controlling custodian for the aircraft. That controlling custodian originates an Aircraft Transfer Order which assigns the reporting custodian for the aircraft. During the short time interval between signing of the DD 250 and delivery of the aircraft to the first reporting custodian, the NAVAIRSYSCOM is the aircraft controlling custodian. When aircraft are provided to a contractor for developmental or operational support, NAVAIRSYSCOM remains the controlling custodian and the cognizant DPRO is the reporting custodian.

a. Although the above process was widely practiced, it was not clearly delineated in a governing directive. V-22 BUNO 163914 was accepted for the government via a DD 250. Records do not indicate that the other administrative steps were taken to add the aircraft to the naval inventory. To help preclude future problems of this nature, changes have been sent to the CNO for inclusion in the Aircraft Inventory Reporting System (OPNAVINST 5442.2 Series). OPNAVINST 5442.2G, dated 6 Jul 92, now stipulates: 1) how aircraft are added to the Naval Inventory; and 2) who the reporting and controlling custodians are for contractor-held aircraft. COMNAVAIRWARCEN is coordinating with DCMC to have DD 250s for Naval aircraft forwarded to his headquarters office. Once a DD 250 is received, a tracking system can be initiated to verify that an acceptance XRAY has been generated, thus entering the aircraft into the Naval Inventory and properly initiating the chain of custody.

b. This paragraph addresses the Court's Findings of Fact 4-12; Opinion 3; Recommendation 1.

27. <u>Defense Federal Acquisition Regulation Supplement (DFARS)</u>

B5

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a. DCMC Headquarters is sponsoring a joint service meeting to address these issues which may result in a change to DLAM 8210.1 or a recommendation to the Defense Acquisition Regulation Council to revise DFARS clause 252.228-7002. Cognizant NAVAIRSYSCOM representatives will participate in this process.

b.

B5

c. This paragraph addresses the Court's Findings of Fact 27-31, 40, 43-47, 49, 54, 58-60, 62; Opinions 4-6, 12; Recommendations 2, 3, 6.

SECTION III - ADDRESSAL OF SPECIFIC COURT OF INQUIRY FINDINGS

28. This endorser concurs with all of the Court's findings of fact, opinions, and recommendations, except as noted in this section.

29. ADMINISTRATION

a. Fact 19 - Concur with comment: Clause H-1B, (enclosure (6)), paragraph (d), does not include " . . . if the flight was not approved by the Commander, DPRO . . ." as an exception to government assumption of risk for damage, loss or destruction.

b. Fact 24 - Concur with comment: The contract states "that the contract price does not and will not include, except as may be otherwise authorized in this clause, any charge. . . for insurance . . ."

c. Fact 27 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

d. Fact 28 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

e. Fact 29 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

f. Fact 30 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

g. Fact 31 - Do not concur: B5

(See paragraph 27.)

h. Opinion 4 - Do not concur: B5

(See paragraph 21.)

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i. Opinion 5 - Concur with comment: DCMC Headquarters is sponsoring a joint service meeting to address the conflicting policy guidance. This may result in a change to DLAM 8210.1 or a recommendation to the Defense Acquisition Regulation Council to revise the DFARS. The PCO will modify the EMD contract, if required, to implement appropriate changes once the Office of the Secretary of Defense (OSD) resolves the issue. (See paragraph 27.)

j. Opinion 6 - Do not concur: b5 (See paragraph 27.) b5

k. Recommendation 2 - Concur with comment: DCMC Headquarters is sponsoring a joint service meeting to address the conflicting policy guidance. This may result in a change to DLAM 8210.1 or a recommendation to the Defense Acquisition Regulation Council to revise the DFARS. The PCO will modify the EMD contract, if required, to implement appropriate changes once OSD resolves the issue. (See paragraph 27.)

30. MISHAP AIRCREW

a. Fact 35 - Concur with comment: From 9 April 1991 to 3 February 1992, MGYSGT Leader was a V-22 crewmember on 12 flights with a total of 17.0 flight hours. (enclosure (7))

b. Fact 36 - Concur with comment: From 12 April 1991 to 24 May 1991, GYSGT Joyce was a V-22 crewmember on 11 flights with a total of 12.9 flight hours. (enclosure (7))

c. Opinion 8 - Concur with comment: Major b6 had received egress training, but the training was improperly documented.

d. Opinion 10 - Concur with comment: Mr. b6 had updated his annual egress qualification, but it was not properly documented.

e. Opinion 11 - Concur with comment: Mr. b6 had updated his annual egress qualification, but it was not properly documented.

31. FLIGHT OPERATIONS:

a. Fact 40 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

b. Fact 49 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B,

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(enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

c. Fact 54 - Concur with comment:DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

d. Fact 58 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

e. Fact 60 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B, (enclosure (6)), governed approval of flight operations and crew members in FSD. (See paragraph 27.)

f. Fact 64 - Concur with comment: Mr. b6 and Mr. b6 both updated their annual egress qualifications, (enclosure (8)), but they were not properly documented.

g. Opinion 12 - Concur with comment: DLAM 8210.1 was not in effect for the FSD contract. The ground and flight risk clause H-1B governed approval of flight operations and crew members in FSD. (See paragraph 27.)

h. Opinion 13 - Do not concur:

b5 (See paragraph 21.)

i. Opinion 14 - Do not concur:

b5

(See paragraph 25.)

j. Opinion 17 - Concur with comment: A process for the GFR to verify qualifications of flight personnel on site during climatic lab tests was not in effect. (See paragraph 25.)

k. Recommendation 3 - Concur with comment: The GFR cannot align contractual procedure with DLAM 8210.1 until the PCO modifies the contract. DCMC Headquarters is sponsoring a joint service meeting to address the conflicting policy guidance. This may result in a change to DLAM 8210.1 or a recommendation to the Defense Acquisition Regulation Council to revise the DFARS. The PCO will modify the EMD contract, if required, to implement appropriate changes once OSD resolves the issue. (See paragraph 27.)

l. Recommendation 7 - Do not concur:

B5

32. AIRCRAFT MAINTENANCE

a. Fact 114 - Concur with comment: Boeing's maintenance employee qualification system meets the requirements of the contract; however, a more formal procedure for documentation of Boeing helicopter employee qualifications is desirable. (See paragraph 11.)

b. Fact 149 - Concur with comment: The government does not get all copies of coordination memos. The government only receives coordination memos in those instances where the different contractors cannot agree upon a specific issue. The coordination memo process is established in the Associate Contractor Agreement, (enclosure (9)).

c. Fact 171 - Concur with comment: The torquemeter shaft seals were either lost upon crash impact or removed during disassembly by the engineering investigation team. If the seals had not been installed prior to flight, the leakage rate would have been approximately one gallon per minute and would have been obvious upon start. (See paragraph 18.)

d. Fact 173 - Do not concur:

B5

(See paragraph 18.)

e. Opinion 28 - Concur with comment: Boeing's maintenance employee qualification system meets the requirements of the contract; however, a more formal procedure for documentation of Boeing Helicopter employee qualifications is desirable. (See paragraph 11.)

f. Opinion 29 - Concur with comment: Boeing's maintenance employee qualification system meets the requirements of the contract; however, a more formal procedure for documentation of Boeing Helicopter employee qualifications is desirable. (See paragraph 11.)

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g. Opinion 41 - Do not concur: B5 (See paragraph 10.)

h. Opinion 42 - Do not concur: B5

(See paragraph 10.)

i. Recommendation 10 - Do not concur: te B5 is

j. Recommendation 12 - Concur with comment: Boeing's maintenance employee qualification system meets the requirements of the contract; however, a more formal procedure for documentation of Boeing Helicopter employee qualifications is desirable. (See paragraph 11.)

33. FLIGHT PLANNING/CLEARANCE AND COMPLIANCE

a. Fact 182 - Do not concur: B5

b. Opinion 44 - Do not concur: B5

c. Opinion 46 - Concur with comment: The first sentence is based on one witness's opinion and circumstantial evidence (See paragraph 22.) Also, it should be noted that the fuel transfer problem was successfully resolved, and checkout of CONDM was acceptable for ferry flight.

d. Opinion 47 - Do not concur: B5

e. Opinion 49 - Do not concur: B5

34. MISHAP FLIGHT CHRONOLOGY

a. Fact 221 - Concur with comment: At time stamp 12:42:03-10, the statement "Wf [Fuel Flow] lags power changes" is incorrect.

CONDM data indicate that Wf was actually decreasing, as other engine parameters were increasing, which indicates that the FADEC was trying to control an uncommanded power increase. Also, an entry at time stamp 12:42:25.1 was omitted which was the first and only attempt by the pilot to change the nacelle angle.

b. Fact 222 - <u>Concur with comment</u>: From Exhibit 63, the RH Nr was approximately 230 RPM, not 280 RPM.

35. <u>MISHAP AIRCRAFT AND SYSTEMS</u>

a. Fact 226 - <u>Concur with comment</u>: The NAVAIRSYSCOM flight clearance did not require that these three parameters be monitored to the warning level as implied in this paragraph.

b. Fact 227 - <u>Do not concur</u>:

b5

Contractor personnel.

c. Fact 230 - <u>Concur with comment</u>: CONDM was not intended to have the capability for extended data storage. Its purpose was to provide the flight crew with safety-of-flight monitoring of selected structural parameters. (See paragraph 16.)

d. Fact 261 - <u>Concur with comment</u>: The stated faults represented the control system recognition of the probable cause of engine behavior that was counter to commands and schedules. The engine was decelerating faster than was possible without severe mechanical failure, resulting in the Compressor Variable Geometry (CVG) guide vanes being improperly positioned, i.e., "failure" to provide the commanded level of control.

e. Fact 268 - <u>Do not concur</u>: b5

f. Fact 275 - <u>Concur with comment</u>: The data analysis reported in Exhibit 60 showed that a failure occurred between the RH rotor and the input to the TAGB. Exhibit 60 data analysis did not specifically isolate failure to the pylon shaft. Pylon drive shaft failure was determined from subsequent engineering investigations.

g. Fact 283 - <u>Concur with comment</u>: It should be noted that the overstress fracture of the clamps indicate a crash impact type failure, not in-flight failure. Additionally, the last sentence, which asserts that the absence of abrasion on the hose indicates the

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shaft failed prior to impact, is speculative.

h. Fact 300 - Concur with comment: Based on the Failure Modes and Effect Analysis (FMEA), failure of the ICDS was considered to be a catastrophic failure which would cause the loss of the aircraft. An FMEA does not analyze beyond a catastrophic failure mode.

i. Fact 304 - Concur with comment: Exhibit 60 did not report the Midwing Gearbox oil filter button popping and subsequent maintenance actions on 20 July 1992.

j. Fact 326 - Do not concur:

B5 | B4

k. Fact 331 - Concur with comment: The reduction in pitch to the LH rotor by the FCS alleviated thrust imbalance, leaving the pilot with virtually no control power to effect a roll input.

l. Fact 335 - Do not concur:

B5

(See

m. Fact 343 - Do not concur: B5

(See paragraph 17.)

n. Fact 351 - Concur with comment: Unsealed cutouts in the horizontal firewall were added to accommodate flight test instrumentation wiring bundles. Fireproof gaskets are being installed to insure integrity of the firewall. (enclosure (10))

o. Fact 353 - Do not concur: B5

(See paragraph 13.)

p. Fact 357 - Do not concur:

B5

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q. Fact 372 - <u>Do not concur</u>:

B5

r. Fact 380 - <u>Concur with comment</u>: Maintenance personnel consistently indicated in their testimony that there was very little nacelle area leakage. However, a pilot report (3-6-92 daily report of enclosure (7)) from the climatic lab indicated that leaks in the nacelle were more significant than indicated by contractor maintenance personnel.

s. Fact 382 - <u>Concur with comment</u>: Engine oil cannot be discounted as part of the recovered oil residue. Engine and gearbox oil are chemically similar with the exception of one additive present in gearbox oil. There was insufficient residue to determine whether the additive was, or was not, present.

t. Opinion 50 - <u>Do not concur</u>: The NAVAIRSYSCOM flight clearance did not specify to what level CONDM parameters were to be verified. There were no CONDM problems at takeoff.

u. Opinion 51 - <u>Do not concur</u>: CONDM was designed for an OT

B5

v. Opinion 56 - <u>Concur with comment</u>: B5

w. Opinion 58 - <u>Do not concur</u>:

B5

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cleared itself, so why not make use of the first FADEC if the second FADEC fails? When the second FADEC fails, the metering valve stays at the last commanded position allowing the engine to continue running. The FCC should then provide total torque and Nr control. Re-select of a failed FADEC might restore total control, but an intermittent problem could return and cause a failure in a more critical flight regime than when it first occurred.

x. Opinion 63 - Do not concur:

B5

paragraph 18.)

y. Opinion 65 - Do not concur:

B5

paragraph 18.)

z. Opinion 67 - Concur with comment: The phrase "monitor-induced failure" places the wrong emphasis on the proper reaction of the system to a significant disparity between engine and rotor torque. The mast torque sensors were declared invalid when average mast torque was well in excess of commanded mast torque. This was the result of ingestion of an alternate fuel that resulted in an uncommanded engine acceleration, combined with an already degraded engine from the first surge.

aa. Opinion 68 - Do not concur:

B5

bb. Opinion 70 - Do not concur:

B5

paragraph 15.)

cc. Opinion 71 - Concur with comment: The last sentence of

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this opinion exceeds the statement of Fact 322.

dd. Opinion 72 - <u>Concur with comment</u>: The V-22 has a thrust power management system and an engine fuel control. Using the FADECs to set an engine fail bit to annunciate an engine failure and commence OEI compensation is a recommendation that needs more study before implementing.

ee. Opinion 75 - <u>Concur with comment</u>: The reduction in pitch to the LH rotor by the FCS alleviated thrust imbalance leaving the pilot with virtually no control power to effect a roll input.

ff. Opinion 76 - <u>Do not concur</u>:

B5

(See paragraph 14.)

gg. Opinion 77 - <u>Concur with comment</u>: The primary source of yaw control power at 58° nacelle is differential cyclic pitch. The cause of the rapid rate of descent was the loss of rotor thrust (which contributes approximately half of the total lift) following the ICDS failure.

hh. Opinion 78 - <u>Concur with comment</u>: The W/C/A system currently alerts the crew to a failure of any hydraulic system, a system parameter outside normal limits, or the degradation in redundancy of any of the flight control system actuators. The current presentation of these data can be improved, and is under investigation by the W/C/A analysis team. (See paragraphs 15 & 19.)

ii. Opinion 81 - <u>Do not concur</u>:

B5

(See paragraph 14.)

jj. Opinion 82 - <u>Do not concur</u>:

B5

kk. Opinion 88 - <u>Do not concur</u>:

B5

(See paragrapn 14.)

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ll. Opinion 89 - Do not concur:
1. (See paragraph 14.)

mm. Opinion 90 - Concur with comment: A redesign will eliminate the possibility of secondary damage from shaft flail. The last sentence implies that the aircraft could have been recoverable after the engine/ICDS failure, which is not substantiated. (See paragraph 14.)

nn. Opinion 91 - Concur with comment: Recirculated exhaust gas was taken into account for the margin cited. (See paragraphs 12 & 13.)

oo. Opinion 101 - Do not concur:
See paragraph 10.)

pp. Opinion 102 - Do not concur:
(See paragraph 10.)

qq. Opinion 106 - Do not concur:

rr. Opinion 108 - Do not concur:

ss. Opinion 109 - Do not concur:
(See paragraph 10.)

tt. Opinion 112 - Do not concur:

uu. Recommendation 16 - Do not concur:
(See paragraph 16.)

vv. Recommendation 17 - Do not concur:
(See paragraph 16.)

ww. Recommendation 18 - Do not concur:

(See paragraph 16.)

A 11 85

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xx. Recommendation 20 - Concur with comment: A redesign of the pylon shaft to withstand higher operating temperatures is underway. The upper nacelle area will continue to be designated a no-fire zone and protected accordingly. (See paragraphs 12 & 13.)

yy. Recommendation 22 - Do not concur:

18.)

zz. Recommendation 25 - Do not concur:

actuators.

aaa. Recommendation 28 - Concur with comment: The PFCS reset procedures were addressed in the version of the preliminary draft NATOPS current at the time of the mishap. (See paragraph 24.)

bbb. Recommendation 29 - Do not concur:

(See paragraph 15.)

ccc. Recommendation 30 - Concur with comment: The functional allocation between the FADEC and FCC will be addressed in the redesign effort. The current allocation of functions between FCS and FADEC was driven by the complexity of the FCS.

ddd. Recommendation 32 - Concur with comment: The PFCS reset procedures were addressed in the version of the preliminary draft NATOPS current at the time of the mishap. (See paragraph 24.)

eee. Recommendation 33 - Concur with comment: The W/C/A Analysis Team is investigating the need for an individual rotor speed display. (See paragraph 15.)

fff. Recommendation 34 - Concur with comment: The W/C/A system alerts the crew to a failure of any hydraulic system, a system parameter outside normal limits, or the degradation in redundancy of any of the flight control system actuators. The current presentation of these data can be improved, and is under investigation by the W/C/A Analysis Team. (See paragraph 15.)

ggg. Recommendation 35 - Do not concur: B5

y

hhh. Recommendation 37 - Do not concur: B5

(See paragraph 19.)

iii. Recommendation 42 - Concur with comment: Failure and battle damage analyses have been done. Because of the BUNO 163914 mishap, these analyses will be re-evaluated.

jjj. Recommendation 44 - Concur with comment: The upper nacelle and pylon drive shaft must be adequately isolated from fire. (See paragraphs 12 & 13.)

kkk. Recommendation 45 - Concur with comment: Unsealed cutouts in the horizontal firewall were added to accommodate flight test instrumentation wiring bundles. Fireproof, sealed connectors were used for routing basic aircraft wiring through the firewall. Cutouts for the engine mounts were fitted with fireproof, flexible seals. (See paragraph 12.)

lll. Recommendation 46 - Concur with comment: A redesign is underway to insure that the upper nacelle will remain a no-fire zone. (See paragraph 12.)

36. AIRCREW/AIRCRAFT INTERFACES

a. Fact 396 - Do not concur: B5

(See paragraph 20.)

b. Fact 399 - Do not concur: B5

(See paragraph 15.)

c. Fact 406 - Concur with comment: By design, hydraulic leak detection/isolation is not displayed until functionality is lost. (See paragraph 19.)

d. Fact 410 - Concur with comment: An ICDS failure detection and annunciation design is being developed as part of the W/C/A

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Analysis Team investigations. (See paragraph 15.)

e. Fact 411 - <u>Concur with comment</u>: The version of the preliminary draft NATOPS, (enclosure (11)), which was current at the time of the mishap, did include a recommended OEI configuration. (See paragraph 24.)

f. Fact 412 - <u>Concur with comment</u>: The version of the preliminary draft NATOPS, (enclosure (11)), which was current at the time of the mishap, included power-off glide and landing profiles in both airplane and helicopter modes (See paragraph 24.)

g. Fact 413 - <u>Do not concur</u>:

(See paragraph 24.)

h. Fact 414 - <u>Do not concur</u>:

(See paragraph 24.)

i. Fact 415 - <u>Concur with comment</u>: The version of the preliminary draft NATOPS, (enclosure (11)), which was current at the time of the mishap, did provide procedures for the various PFCS cautions. (See paragraph 24.)

j. Fact 418 - <u>Concur with comment</u>: There were documented UHF/VHF communication problems in FSD; however, the flight clearance did not require a chase aircraft. If emergency communications had been required, the aircraft would have been headed toward a destination field, not away from one. Radio transmission/reception with stations ahead or abeam the V-22 was adequate.

k. Opinion 115 - <u>Do not concur</u>:
e paragraph 14.)

l. Opinion 116 - <u>Do not concur</u>:

See paragraph 24.)

m. Opinion 117 - Do not concur:

al B-5

n. Opinion 119 - Do not concur:

(See paragraphs 15 & 16.)

o. Opinion 120 - Concur with comment: Reducing the update rate of W/C/A messages may not be the best solution since the pilot must be given ample time to identify the fault and take corrective action. The W/C/A Analysis Team will recommend a solution to this problem. (See paragraph 15.)

p. Opinion 125 - Do not concur:

See paragraph 15.)

q. Opinion 127 - Concur with comment: The W/C/A system currently alerts the crew to a failure of any hydraulic system, a system parameter outside normal limits, or the degradation in redundancy of any of the flight control system actuators. The current presentation of these data can be improved, and is under investigation by the W/C/A analysis team. (See paragraphs 15 & 19.)

r. Opinion 133 - Concur with comment: This mishap occurred on a ferry flight not requiring a chase aircraft. During flight test, the chase aircraft will be within visual range. The test aircraft also will be closer to ground monitoring and more reliable communications can be expected.

s. Opinion 134 - Do not concur:

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V(7) rming

s a

t. Opinion 135 - Do not concur:

u. Recommendation 52 - Concur with comment: The W/C/A system currently alerts the crew to a failure of any hydraulic system, a system parameter outside normal limits, or the degradation in redundancy of any of the flight control system actuators. The current presentation of these data can be improved, and is under investigation by the W/C/A analysis team. (See paragraphs 15 & 19.)

v. Recommendation 53 - Concur with comment: The W/C/A Analysis Team is reviewing the necessity to display momentary flight exceedances to the crew. However, acknowledgement by the crew should not be necessary in order to record subsequent exceedances. (See paragraph 15.)

w. Recommendation 54 - Concur with comment: The W/C/A Analysis Team is investigating the need for an individual rotor speed display.

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(See paragraph 15.)

x. Recommendation 56 - Concur with comment: The version of the preliminary draft NATOPS, which was current at the time of the mishap, did provide identification and response procedures to engine failures. It also included procedures for engine failures and ICDS failures, but no procedures for a combination of both. (See paragraphs 15 & 24.)

y. Recommendation 57 - Concur with comment: The version of the preliminary draft NATOPS, which was current at the time of the mishap, did include steps for resetting PFCS faults. The W/C/A Analysis Team is assessing the annunciation of dual transducer failures. (See paragraph 15.)

z. Recommendation 58 - Do not concur:

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Copy to:
CNO (w/o encl)
CMC
DCMC
Dir, FAA
COMNAVSAFCEN

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EXECUTIVE SUMMARY

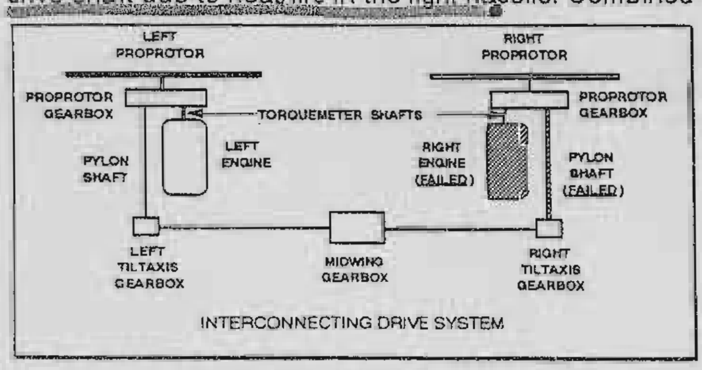
MISHAP OVERVIEW

On 20 July 1992 V-22 BUNO 163914 was ferried from Eglin AFB, Florida where it had undergone Climatic Laboratory testing, to MCB Quantico, Va. The aircraft experienced multiple emergencies upon entering the downwind leg at Quantico and crashed into the Potomac River, killing all seven crew members upon impact.

On downwind following conversion from airplane mode (0° nacelle angle) to 44° nacelle angle, the right engine surged (stall with flow reversal) due to the ingestion of a flammable substance (probably proprotor gearbox oil) through the engine intake. This first surge, which was accompanied by smoke and a flash, was controlled by the aircraft's governing system. The surge caused the Torque Command Limiting System (TCLS) to disengage and the Primary Flight Control (PFCS) caution light to illuminate. Engine efficiency data shows that the right engine sustained damage during the first surge. Post-mishap inspection of the right engine revealed a 120° arc burned through the combuster casing, attributable to the presence of a flammable substance between the combuster liner and the diffuser case.

Additional oil ingestion and small oscillations of the right engine persisted (probably unnoticed by the pilots) for several seconds until the pilots reset the PFCS, clearing the frozen TCLS input and causing a rapid power command increase to the engines. The right engine oversped, experienced two surges in quick succession and then failed. The left engine also oversped, as its power turbine did not declutch from the left proprotor system (which was driven to overspeed by the right engine through the interconnecting drive system). Flashes of fire and smoke were associated with the surges.

The left engine powered both proprotor systems for several seconds, until failure of the pylon drive shaft due to heat/fire in the right nacelle. Combined right plyon shaft/right engine failure resulted in loss of drive to the right proprotor system. Loss of lift/rapid rate of descent and large left yaw followed. No indications of drive system failure were displayed in the cockpit, and the situation was further confused by a false warning of left engine failure.



The drive shaft failure produced a hydraulic leak and a Flight Control Computer electrical failure which reduced flight control authority and prevented hydraulic control of the nacelles. Electric conversion was not a viable backup due to its slow rate. Without hydraulic nacelle control there was virtually no chance of executing a successful/survivable ditching.

CAUSE FACTORS

The primary cause of the mishap was a flammable fluid leak which was ingested by the right engine. This leak may be attributable to maintenance error in installing an oil seal backwards on the torquemeter shaft. As it was not determined conclusively that the reversed oil seal caused the leak, the possiblity of other leaking seals/sources cannot be ruled out. The leak triggered an unfortunate chain of events:

- An oil seal probably allowed proprotor gearbox oil to leak out, with the inlet centerbody serving as a pathway to the engine intake.
- The leak was ingested by the right engine, damaging the engine's combustion liner, causing the engine to both surge and fail.
- One or more of the surges damaged the engine inlet centerbody, allowing heat and fire into the nacelle area above the right engine compartment.
- The heat raised the temperature of the composite pylon drive shaft above its glass transition temperature of 240° F, causing it to fail while under load from the left engine.
- Upon failure, the drive shaft damaged wiring and hydraulic lines and/or fittings on the adjacent swashplate actuator, resulting in a hydraulic leak and degraded electrical control of the actuators.
- The hydraulic system isolation logic preserved hydraulic pressure to the actuators, but the electrical damage prevented hydraulic control of the nacelles, which was needed for a rapid conversion to helicopter mode for ditching.
- The wiring damaged by the drive shaft failure also caused failure of a flight control computer, further degrading flight control authority.

Secondary cause factors include:

- Inffective QA of the oil seal installation
- Inability of the inlet to withstand engine surge pressures
- Accessibility of the engine intake to external flammable fluid sources
- Analysis which led to the use of low glass transition temperature composite material for the pylon drive shaft
- Inability of the pylon shaft to operate under load at temperatures above 240° F
- Inadequate protection of the upper nacelle from fire/heat intrusion
- Lack of adequate hydraulic nacelle conversion capability due to swashplate actuator damage by the failed pylon shaft
- Lack of adequate nacelle conversion redundancy
- Failure of warning system to adequately alert pilots to engine oscillations/surges and ICDS failure

TECHNICAL CONCERNS

No design deficiencies were discovered which were uniquely tiltrotor in nature. However, several areas of V-22 design warrant change as a result of this accident:

- Drive shaft material change to improve heat tolerance
- "Murphy-proof" torquemeter shaft oil seal design to prevent backwards installation
- Improved engine firewall integrity, in view of multiple heat paths through the wall into the nacelle
- Engine inlet center body modification to preclude any chance of fluid pooling upstream of the engine and improved strength to accommodate engine surges without material failure
- Additional cockpit display or other means of improving the display of warnings, cautions and advisories to the pilots
- Improved failure detection and annunciation logic to preclude false warnings and to provide display of drive system failure
- Software improvements to accommodate rate changes in various parameters without causing properly operating systems to be tripped off line (e.g. TCLS)
- Maturity of the OTIIA data system (CONDM) for stand alone use without ADAS or telemetry.

PRELIMINARY STATEMENT

The Court of Inquiry (COI) was convened on 24 July 1992 to investigate the circumstances surrounding the loss of V-22 BUNO 163914 in the vicinity of MCB Quantico, Va. on 20 July 1992. The results of the COI investigation are presented in twelve volumes:

Volume	Contents
01	Report (Executive Summary, Preliminary Statement, Findings of Fact, Opinions, Recommendations and Appendices)
02-03	Record of Proceedings: Testimony
04-12	Record of Proceedings: Exhibits

A safety investigation by an Aircraft Mishap Board (AMB) was already in progress at that time. Every effort was made to conduct the COI's investigation on a not to interfere basis with the AMB, and to avoid inadvertent access to privileged information obtained by the AMB.

The senior member of the AMB served as the Contracting Officer's Technical Representative (COTR) for the contract which produced the Engineering Investigations (E.I.'s) related to the mishap aircraft. The E.I. teams were managed by the AMB, which controlled the flow of data to the teams. The COI obtained copies of the E.I.'s following review and acceptance by the COTR. On 28-29 October 1992 the COI hosted an E.I. Review with contractor and government representatives from the Engine, Drivetrain and Flight Control & Hydraulic Systems E.I. Teams. The review resolved inconsistencies between E.I.'s, identified minor errors, clarified technical issues and generated formal E.I. revisions. The review also provided a formal opportunity for dialogue and data exchange between the teams, to ensure the quality of analysis was not impacted by compartmentalization that existed during the initial phase of E.I. development.

Subsequent to the E.I. revisions and the AMB's report, the forward right torquemeter shaft seal was discovered to have been installed backwards, providing the most probable primary cause factor for the mishap. Pertinent seal and installation information was preserved for follow on engineering or safety investigation purposes in Exhibits 83 and 84.

A tremendous amount of detailed mishap information is available from the E.I.'s. The Findings of Facts portion of the COI report does not present this detailed information, unless needed to make the report readable and/or to lay the foundation for opinions and recommendations. The following E.I.'s were utilized by the COI and are included as exhibits:

- Mission Computer
- Flight Control Computer
- Data Storage Units
- FADEC
- Fuel System
- Engine System
- Drivetrain
- Flight Control & Hydraulic Systems

In the course of the investigation, multiple trips were made by COI members to Bell, Boeing and government V-22 facilities. At Bell's Plant #6 in Arlington, Texas members inspected the mishap aircraft's right nacelle, which was reconstructed from pieces salvaged from the Potomac River. The reconstruction, along with the opportunity to inspect intact V-22 aircraft at the plant, proved most valuable to the COI's investigation. Viewing a recreation of the last portion of the mishap flight in the Manned Flight Simulator at NAWC AD Patuxent River, Md. also enhanced the analysis of the mishap.

COI members viewed the original video tape of the aircraft crash made by a Boeing employee who was awaiting the arrival of the mishap aircraft at MCB Quantico. The viewing was held at Boeing, Philadelphia and was not part of a formal court session. The purpose of the viewing was to confirm the validity of the video tape analysis contained in the Flight Control & Hydraulics Systems E.I. As a result of the viewing, revisions were subsequently made to the E.I. All pertinent information from the tape was included in the E.I. along with still photographs of selected video tape frames. Copies of the tape were considered to be of little value, as critical detail was lost during the copy process. Boeing retains the original tape as proprietary property.

Both Bell and Boeing requested to be made parties to the investigation. Their requests were denied by the Commander, Naval Air Systems Command in August 1992. It was pointed out that sessions of the COI were to be open to the public, unless closed by the President of the COI for security or other good reasons. In practice, the interests of the contractors were accommodated by permitting their legal counsel to sit and confer with their employees during court sessions. Also, contractor legal counsel were given opportunities to recommend additional personnel to testify, to ensure that their issues were fully addressed. This process resulted in a good working relationship with Bell-Boeing and resulted in COI consideration of both government and contractor viewpoints.

All court sessions were open to the public, with the press generally in attendance. Sessions were held at MCB Quantico Va., NAS Patuxent River Md. and the Washington Navy Yard.

At the request of the Federal Aviation Administration (FAA), Mr. a FAA Test Pilot, was assigned to the COI as a limited, non-voting member. Mr. participated in all aspects of the investigation following his assignment and functionally performed as any other member of the COI. The participation of the FAA was both professional and valuable, providing a civil perspective which enhanced the scope of the investigation.

Additional personnel assigned in support of the Court of Inquiry consisted of:

LTCOL	, USMC	Technical Advisor
MAJ	USMC	Counsel
LCDF	USN	Assistant Counsel
MAJ	USMC	Maintenance Advisor
SSGT	, USMC	Administrative Assistant
Mr.	DPRO Boeing	Maintenance Data Analyst

It is felt that the formality of a COI, vice a one officer Judge Advocate General (JAG) investigation was warranted for this mishap, due to the political sensitivity of the V-22 program and the extent of contractor involvement in the operation and maintenance of the mishap aircraft. The formal requirement to receive all testimony in a court session allowed personnel being interviewed to clearly determine whether or not they were speaking for the record. This enhanced the ability of the members to discuss/learn the V-22 aircraft during the conduct of the investigation. Excellent cooperation was received from all contractor and government personnel involved in the investigation, and it was not necessary to exercise the COI's subpoena power.

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FINDINGS OF FACT

ADMINISTRATION

BACKGROUND

1. Due to Department of Defense reorganization, the Army Plant Representative Office (ARPRO) at Bell Helicopter Textron and the ARPRO at Boeing Helicopters have each been changed to a Defense Plant Representative Office (DPRO). Each DPRO, as a command under the Defense Logistics Agency (DLA), functions as the government agency providing oversight and administration of government contracts at the contractor facility. Throughout the remainder of this document, only the term "DPRO" will be used, even if original documentation or exhibits used the term "ARPRO".

2. The Full Scale Development (FSD) contract, N00019-85-C-0145, defined obligations of the government and Bell-Boeing in developing and testing the V-22 aircraft. The ultimate goal of the contract was to "design from Critical Design Review (CDR) to completion, develop, fabricate and furnish six (6) V-22 FSD aircraft." (Exhibit 34, p. 2-1)

3. Contract modification P00011, signed Jun 87, estblished the bureau numbers for the six V-22 prototype aircraft, including the mishap aircraft. The mishap aircraft was assigned bureau number (BUNO) 163914. (Exhibit 74)

4. The FSD contract provides that the Government will provisionally accept the aircraft upon completion of at least one hour of flight and after certification by the Contractor that the aircraft can perform scheduled Contractor flight tests. (Exhibit 34, p. 19)

5. An agreement between DLA and the Departments of the Air Force, Army and Navy assigned DLA the responsibility for accepting government aircraft. (Exhibit 37)

6. The government provisionally accepted BUNO 163914 on 26 April 1990, in accordance with Clause H-10 of the Contract. (Exhibit 35)

7. BUNO 163914 was provided to Boeing Helicopters as government furnished property (GFP) at time of acceptance, and on 20 July 1992, BUNO 163914 was considered GFP. (Exhibit 35; R0930 p. 32)

8. Naval Air Systems Command (NAVAIRSYSCOM) has been designated as the controlling custodian for aircraft provided to non-naval organizations as GFP. (Exhibit 41, p.4)

9. NAVAIRSYSCOM was the controlling custodian for BUNO 163914. (Exhibit 41, p.4; R1007 p. 402)

10. The DPRO at Boeing Helicopter was the reporting custodian for BUNO 163914. (R0930 p. 8 and 17; R1007 p. 402)

11. The court discovered no evidence that the reporting custodian for BUNO 163914 was assigned in writing. (All Exhibits and Testimony)

12. As of 16 Nov 92, none of the six V-22 prototype aircraft, including BUNO 163914, had been entered into the Aircraft Inventory Reporting System (AIRS) data base. (Exhibit 62, para 1)

13. In accordance with the FSD contract, BUNO 163914 was sent to Eglin AFB, Florida to undergo testing at the McKinley Climatic Laboratory, to ensure the aircraft met the design requirements of the V-22 detail specification. (Exhibit 27, p. 1, 13, 16; R0814 p. 3)

14. BUNO 163914 was ferried from Wilmington, DE, to Eglin AFB, Florida on 3 February 1992 in accordance with the test plan. Testing began shortly thereafter and was completed on 23 May 1992. (Exhibit 27, p.3; Exhibit 20, p.9; Exhibit 22, p.1,22)

15. Climatic Lab testing was conducted in accordance with the Bell-Boeing Test Plan. A NAVAIRSYSCOM Test Clearance message authorized the testing under specific conditions, and authorized the participation of NAWCAD pilots, crew chiefs and test engineers in Climatic Lab tests. The contractor was responsible for providing spares support, maintenance, test planning and test conduct for BUNO 163914. (Exhibit 26; Exhibit 27, App. A)

16. NAVAIRSYSCOM flight clearance messages were re-issued to DPRO Bell and DPRO Boeing for V-22 flight operations following the Climatic Lab testing. The flight clearances authorized DPRO release of V-22 aircraft for flight under specific conditions. COMNAVAIRSYSCOM 062002Z JUL 92 provided flight clearance specifically for V-22 BUNO 163914; COMNAVAIRSYSCOM 082001Z JUL 92 provided flight clearance for V-22 ferry flights between test facilities. (Exhibit 16)

17. The mishap flight (ninety-third flight of BUNO 163914) on 20 July 1992 was a Category D Support Flight, conducted in accordance with the test plan, to ferry the aircraft from Eglin AFB to MCAS Quantico. The purpose for the stop at MCB Quantico was to conduct an egress demonstration and to allow headquarters personnel an opportunity to see the aircraft. (Exhibit 27, p.3; Exhibit 38, p.3; Exhibit 40, p. 4-3; R1008, p. 447, 459, 475, 516)

18. V-22 Flight operations were suspended until further notice on 21 July 1992. (Exhibit 30)

FULL SCALE DEVELOPMENT CONTRACT

19. Under the V-22 FSD contract, the government assumed the risk of loss and destruction of the aircraft, in general, but reserved at least six specific exceptions. (Exhibit 34, Schedule H-1B, p. 7-11 and 7-12). Exceptions (paraphrased) to government assumption of risk for damage, loss or destruction include:

- For any loss and destruction of the aircraft resulting from failure of the Contractor due to willful misconduct or lack of good faith of any of the Contractor's managerial personnel, to maintain and administer a program for the protection and preservation of the aircraft in the open and during operation.

- For any loss and destruction of the aircraft sustained during flight, if the flight crew members conducting such flight were not approved in writing by the DPRO.

- If the flight was not approved by the Commander, DPRO, Boeing Vertol Comany, Ridley Township, PA and/or Commander, DPRO, Bell Helicopter Textron, Ft. Worth Tx.

- When damage, loss or destruction is covered by insurance.

20. DLA conducted a legal review of the DFAR Part 252 Ground and Flight Risk clauses, and determined that the GFR was the appropriate flight approval authority on behalf of the contracting officer. (Exhibit 42b)

21. DLA granted LTC Palmer, the DPRO Boeing Government Flight Representative (GFR), authority to approve contractor personnel and procedures for operating aircraft in which the

Government, by contract, assumed the risk of loss, damage, or destruction. LTC Palmer succeeded MAJ Ginder as GFR on 18 Apr 92. (Exhibit 42a)

22. The monthly Project Agreement Flight Clearance for July 92 was requested by the Boeing Flight Test Engineer on 19 Jun 92 and approved by the GFR on 23 Jun 92. The Flight Clearance listed pilots by name, and a statement that "test engineers and flight crew members will be flown as required"; the activities on the request included shakedown flights prior to departure from Eglin, and ferry flights from Eglin to Quantico, and Quantico to Wilmington. (Exhibit 30)

23. The government was a self-insurer of BUNO 163914. (R1007, p.429/430)

24. In accordance with the contract, the contractor cannot bill the government for any insurance costs for the aircraft. (Exhibit 34, p.7-13)

25. The court discovered no evidence that the contractor insured the aircraft. (All exhibits and testimony)

26. The Integrated Logistics Support Detail Specification to the FSD contact requires the contractor to maintain BUNO 163914 during the development phase of the contract. (Exhibit 34)

27. Defense Logistics Agency Manual (DLAM) 8210.1 requires that the GFR make every reasonable effort to ensure that contractors operate, maintain, service, repair, and otherwise handle military aircraft according to the methods, procedures, and standards specified in the contract. The GFR is tasked with a review of the contract for deficient contract procedures/omissions which could affect aircraft ground and flight safety. (Exhibit 38, Vol.2, p.3)

28. DLAM 8210.1 also requires the GFR to notify the Administrative Contracting Officer (ACO) when the contract does not include contractor compliance with Vol. 1 of DLAM 8210.1, and assist the ACO in the preparation of a deficiency report to be sent to the Procuring Contracting Officer (PCO). (Exhibit 38, Vol. 2, p.3)

29. DPRO Boeing personnel, including the GFR, wanted clarification with the language of the Ground and Flight Risk Clause in the contract. On 27 March 1992 the GFR submitted a contract deficiency report to the ACO recommending that contract N00019-85-C-0145 be updated to incorporate the latest version of DLAM 8210.1/NAVAIRINST 3710.1C. The ACO concurred and forwarded the recommendation to the Procuring Contracting Officer (PCO) with a supplemental memorandum on 28 April 1992. The ACO memorandum also requested a change of wording in the contract to clarify that the GFR, specifically, had authority to approve flights. (Exhibits 43; Exhibit 44; R0930, p.33-36; R1007, p.411-414)

30. The PCO did not respond in writing, but discussed the deficiency report and memorandum by phone with the ACO. The PCO did not immediately implement the deficiency report recommendation because he did not see an immediate urgency after his conversation with the ACO. The PCO stated that Bell-Boeing was already performing as if DLAM 8210.1 were a part of the contract. (R1007 p. 426 and 428)

31. In the latest contract issued, 22 Oct 92, the changes requested in the defiency report were not incorporated. The new H-8 clause refers to "Contractor Flight Operations", DLAR 8210.1, (the superseded regulation) vice "Contractor's Flight and Ground Operations", the current DLAM 8210.1. In addition, the new contract refers to the Contracting Officer as the release authority for flight crewmembers, when the contract should refer to the GFR as the release authority for flight crewmembers and non-crewmembers. (Exhibit 43; Exhibit 81)

CONTRACTOR DECISIONS

Though not considered cause factors, various Boeing personnel made decisions which were not consistent with flight safety. Established maintenance procedures were violated in order to make 20 July commitments at MCB Quantico. Several key Boeing personnel, including the Team Leader, departed Eglin AFB prior to the ferry flight, leaving behind a reduced crew complement. The relieving Team Leader proceeded to MCB Quantico rather than doing an onsite relief at Eglin AFB, shifting the focus to the next event while critical maintenance actions remained outstanding. In the hurry to make the Quantico overhead time, Auxiliary Power Unit (APU) problems encountered on turnup for launch were not resolved prior to flight, creating uncertainty as to the ability to restart the aircraft following the planned enroute crew switch and refueling at Charlotte. The situation was much like a post-deployment flyoff from a ship, which has proved to be a high risk evolution requiring attention to detail and hands on supervision.

The Boeing Pilot in Command violated the NAVAIR flight clearance and did not adhere to the preflight brief which he conducted with the chase crew. The pilot submitted to the pressure to meet the MCB Quantico commitment and failed to act conservatively with this developmental aircraft. The mishap aircraft never slowed to allow the chase aircraft to join as briefed, apparently trying to conserve fuel and facilitate a one leg flight to MCB Quantico. Even when faced with a caution for which the Flight Clearance specified "land as soon as possible at the nearest suitable landing site", onboard troubleshooting provided a plausible rationale to continue. Although not definitively ascertained, it is felt that this experienced pilot was subjected to strong pressures to get the V-22 to Quantico for the welcoming ceremony on 20 July.

GOVERNMENT/CONTRACTOR INTERFACE

Under the Participatory Test Program, Military Test Team government aircrew are permitted to fly with a Boeing pilot in command. Boeing submitted the names of participating military pilots to the GFR for approval along with the names of Boeing personnel who would be flying in a 30 day period. Standard Boeing practice had deviated from the requirement to advise the GFR that non-pilot military personnel would be flying. Total crew disclosure is necessary to adequately control access to the developmental V-22 aircraft and ensure that qualifications are met. The mishap crew complement could be justified, but it exceeded the mission essential minimum, which should be the guideline for crew size at this point in the test program. Additionally, control of the manning process was inadequate as three of the Boeing non-pilot crew members flew with expired flight physicals and were not included on the currency list submitted to the GFR. It is recommended that the Participatory Test Program guidelines be revised to improve coordination between the participants. Greater direct DPRO/NAWC(AD) interface, without the contractor as the middle man, is warranted to ensure the DPRO, as Reporting Custodian, is fully cognizant of the names, qualifications and currency of the personnel who will fly in the aircraft. The V-22 is still a developmental aircraft and should receive the same special considerations afforded other test aircraft.

An examination of the administrative process by which the Navy and DPRO's jointly manage naval aircraft is recommended. It was found that <u>no</u> V-22 aircraft were reflected in the Navy's Aircraft Inventory Reporting System, since DPRO Boeing did not submit the appropriate XRAY message. This was due to lack of familiarity with the Navy system by DPRO Boeing (a former Army PRO) and lack of guidance from the Navy. A spot check of the T-45 aircraft inventory, which is reported by DPRO St. Louis (a former <u>Navy</u> PRO), showed all BUNOs accounted for in the reporting system.

MISHAP AIRCREW

PERSONNEL AND QUALIFICATIONS

32. The following personnel were onboard BUNO 163914 at the time of the incident (Exhibit 9):

Patrick J. Sullivan, Boeing Employee, Pilot In Command
MAJ Brian J. James, USMC, Co-Pilot
MGySgt Gary Leader, USMC, Crew Chief
GySgt Sean P. Joyce, USMC, Crew Chief
Robert L. Rayburn, Boeing Employee, Test Engineer
Gerald W. Mayan, Boeing Employee, Instrumentation Engineer
Anthony J. Stecyk, Boeing Employee, Crew Chief

33. Patrick J. Sullivan, , a pilot for Boeing Helicoper Company, was Pilot-in-Command of BUNO 163914 on 20 July 1992. Federal Aviation Administration (FAA) certificates 2025313 and 2025313CFI listed Mr. Sullivan as an Airline Transport Pilot and a Certified Flight Instructor with numerous ratings, including multi-engine and instrument. Mr. Sullivan was [redacted] He had in excess of 6000 hours total flight time, with more than 5300 hours first pilot time. He was a graduate of U.S. Naval Test Pilot School, Class 80, Dec 1981. Mr. Sullivan completed a V-22 flight training syllabus and was certified on 14 May 1990 to be pilot-in-command and NATOPS qualified in the V-22. He was approved as an instructor pilot in the V-22 on 15 Nov 1990. Mr. Sullivan successfully completed a V-22 check flight on 25 September 91, flying 1.8 hours. On 3 January 1992 Mr. Sullivan passed Natops Open and Closed book exams on the V-22. On 22 January 1992 the FAA re-authorized Mr. Sullivan to operate the V-22 Tiltrotor Category Experimental Aircraft. He received a Second Class Medical Certificate on 18 Feb 1992. On 22 February 1992 Mr. Sullivan completed V-22 emergency egress training. From Mar 1989 through July 1992 Mr. Sullivan logged 349.5 hours in the V-22 simulator, 35.1 hours in the V-22 Ground Test Article (GTA), and 155.2 hours in the V-22. Mr. Sullivan flew on 42 of the 93 flights for BUNO 163914, logging 44.3 of the 104.4 flight hours flown on the aircraft. On 28 flights, Mr. Sullivan was pilot-in-command, logging 31.9 flight hours; on 14 flights, Mr. Sullivan was copilot, logging 12.4 flight hours. (Exhibits 17 and 29)

34. MAJ Brian J. James, on active duty and assigned to Rotary Wing Aircraft Test Directorate (RWATD), Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River in a flying status, was the copilot of BUNO 163914 on 20 July 1992. He [redacted] 1992. He was a graduate of the U.S. Naval Test Pilot School, in Jun 91. He was found physically qualified and aeronautically adapted for duty involving flying, Service Group 1, on 26 July 1991. On 11 Feb 1992, MAJ James participated in maintenance ground run 45 on BUNO 163914 as copilot to Mr. Sullivan, in which 2.1 hours auxiliary power unit (APU) use were logged and 0.7 rotor hours. On 10 Jul 1992 he had accumulated 3727.7 flying hours, which included 61.5 hours of V-22 simulator flight time and 3.9 hours of V-22 flight time. MAJ James flew as copilot on 3 of the 93 flights for BUNO 163914: Two flights on 13 July and the mishap flight on 20 July. (Exhibits 17 and 29)

35. MGySgt Gary Leader, on active duty and assigned to Marine Aviation Detachment, RWATD, NAWCAD, Patuxent River, in a flying status, was a crew chief on BUNO 163914 on 20 July 1992. He [redacted]. The Commanding Officer, Marine Aviation Detachment, NAWCAD, Patuxent River, MD ordered MGySgt Leader to duty in a flying status on 31 January 1992 for the period 1 October 1991 until 30 September 1992. He was found physically qualified and aeronautically adapted for duty involving flying, Class 2 as aircrewman for helicopters, on 16 October 1991. On 14 April 1992 MGySgt Leader was authorized to act as an aircrewman for the V-22 aircraft in [redacted]

the performance of Category D flight tests. MGySgt Leader flew on 3 of the 93 flights for BUNO 163914, totalling 7.2 flight hours, including the ferry flight from Wilmington to Quantico and the mishap flight. From 24 February 1992 to 19 May 1992 MGySgt Leader participated in 20 test runs of BUNO 163914 inside the Eglin Climatic Hangar, in which 36.7 hours auxiliary power unit use was logged and 15.1 hours rotor time. Mr. Sullivan participated in six of the 20 test runs in which MGySgt Leader participated at Eglin. (Exhibits 22 and 29)

36. GySgt Sean P. Joyce, on active duty and assigned to Marine Aviation Detachment, RWATD, NAWCAD, Patuxent River, in a flying status, was a crew chief on BUNO 163914 on 20 July 1992. He was designated a crew chief in the V-22 aircraft on 16 April 1991. The Commanding Officer, Marine Aviation Detachment, NAWCAD, Patuxent River, MD ordered GySgt Joyce to duty in a flying status on 31 January 1992 for the period 1 October 1991 until 30 September 1992. He was found physically qualifed and aeronautically adapted for duty involving flying on 16 January 1992. On 14 April 1992 GySgt Joyce was authorized to act as aircrewman for the V-22 aircraft in the performance of Category D flight tests. GySgt Joyce flew one flight in BUNO 163914 prior to the mishap flight. From 28 February 1992 to 19 May 1992 GySgt Joyce participated in 16 test runs of BUNO 163914 inside the Eglin Climatic Hangar, in which 30.1 hours auxiliary power use was logged and 15.9 hours rotor time. Mr. Sullivan participated in four of the 16 test runs in which GySgt Joyce participated at Eglin. (Exhibits 22 and 29)

MEDICAL

37. Autopsies were performed on the bodies of all seven people onboard the mishap aircraft at the Armed Forces Institute of Pathology on 22-24 July 1992. Each individual onboard the mishap aircraft died of severe blunt force injuries. Nothing in the autopsy results of any individual revealed any pre-existing condition or problem that may have been a cause factor in the mishap. (Exhibit 32, p.6-51)

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). (Exhibit 32, p.5-51)

39. The body of Mr. Sullivan was recovered on 21 July 92. His body was found on the left side of the cockpit, still restrained by the seat belt and harness assembly for the left seat of the cockpit. The bodies of MGySgt Leader, GySgt Joyce, Mr. Rayburn and Mr. Stecyk were found approximately one mile south of the wreckage site on 22 Jul 92. The body of MAJ James was found near the wreckage on 22 Jul 92, still restrained to the right seat of the cockpit. The body of Mr. Mayan was found near the wreckage on 23 Jul 92. (Exhibit 64a)

FLIGHT OPERATIONS

CONTRACTOR FLIGHT OPERATIONS

40. Defense Logistics Agency Manual (DLAM) 8210.1/NAVAIRINST 3710.1C (Vol 1) establishes the requirements for all Contractor Flight and Ground Operations involving all work performed on Government aircraft. DLAM 8210.1 (Vol 2) establishes policy and procedures to be followed by Government Flight Representatives. DLAM 8210.1 superseded DLAR 8210.1/ NAVAIRINST 3710.1B on 22 Nov 91. (Exhibit 38)

41. "The GFR is responsible for surveillance of all contractor aircraft flight and ground operations involving Government aircraft and other aircraft for which the Government assumes at least some of the risk of loss." (Exhibit 38, Vol. 1, para 2-3)

42. A Memorandum of Understanding between the V-22 Program Manager and DPRO Boeing states that DPRO Boeing will "provide designated GFR functions for all FSD related flights from the contractor's test facilities." (Exhibit 36)

43. Boeing prepared a Flight Test Operations and Procedures (FLOP) Manual, Document Number D210-10415-2, in part to fulfill the requirements of NAVAIRINST 3710.1B/DLAR 8210.1. The Manual serves as an instrument for government approval of Boeing flight operations, and furnishes a standard for government monitoring and evaluation. Boeing required written government approval of the FLOP prior to conducting flight operations. (Exhibit 39, p.10)

44. The latest revision of the Boeing FLOP Manual was approved by the GFR on 24 Jan 92 for release on 7 Feb 92. It refers to DLAR 8210.1 which was superseded by DLAM 8210.1. (Exhibit 39, p.1)

45. DLA audited both the Boeing FLOP and DPRO Flight Operations procedures before LTC became GFR on 18 Apr 92. That review found no shortcomings in those procedures. In addition, LTC reviewed the Boeing and DPRO procedures on 15 Apr 92 and found no problems. (Exhibit 39; R0930 p.23)

46. DLAM 8210.1 requires requests for flight approval to be submitted on DLA Form 644, or equivalent. Among other things, the form provides for a listing of flight crew and non-crew personnel by name and position. (Exhibit 38, Vol 2, Encl 5)

47. The Boeing FLOP Manual requires flight clearances for FSD aircraft such as the V-22 to be submitted for GFR approval in accordance with Flight Test Working Agreement 8-7300-903. The Agreement specifies Boeing Form 20930, the Project Agreement Flight Clearance. The Boeing form is equivalent to DLA Form 644, as set up in the sample, except that it allows guest pilots and observers (if approved by the Contracting Officer) without requiring their names and positions to be listed on the form. The Agreement does specify names and positions for crew members and non-crew members. (Exhibit 39, p.38; Exhibit 39c, Attachment 2)

48. The Project Agreement Flight Clearance submitted by the Flight Test Engineer for July 92, and approved by the GFR, listed pilots by name, along with a provision for "Guest Pilots as approved by NAVAIR". The Clearance did not include LTCOL who flew as a co-pilot on 13 Jul 92, and was listed on the Flight Plan as a co-pilot for one of the two planned legs of the mishap flight. For non-pilots, the clearance stated that "Test engineers and flight crew members will be flown as required..." (Exhibit 9; Exhibit 17b; Exhibit 30)

49. DLAM 8210.1 states that, when the contractor is operating at remote or geographically separated locations, the "home GFR" <u>may</u> require support from someone at that location.

However, "the GFR will, as much as possible, rely on approvals granted at the home facility so as not to burden the contractor with unnecessary duplication." DLAM 8210.1 also states that any responsible individual, when the GFR is not available, may be requested to monitor and provide information to the GFR. (Exhibit 38 (Vol 2), p.4)

50. LTC stated that when the contractor goes offsite, the type of flying and testing to be done determines how the GFR will continue to provide surveillance. (R1008, pp. 9-10)

51. When testing was done at NAS Patuxent River, it was not unusual to have the GFR designate someone at NAWC AD as the onsite GFR representative. During DT periods, the RWATD Operations Officer was the GFR representative. (R0804, p.41; R1023, p.76)

52. The GFR decided that GFR functions would be performed at Philadelphia for all operations related to the Climatic Lab at Eglin. His decision was based on the small amount of flying to be accomplished, without envelope expansion, limited to airworthiness flights after Climatic Lab reconfiguration and a ferry flight to Quantico. (R0930, p.10/11)

53. The GFR did not issue a "request for support" letter, but kept track of aircraft progress using the daily summary reports. (R0930, p.11/46; R1004, p.41)

CURRENCY

54. Currency and qualification requirements are determined by crew position/role during the conduct of the flight. DLAM 8210.1 defines "Flight crewmember" to include pilot, co-pilot and crew chief. "Noncrewmember" is defined to include technicians and systems engineers. The Boeing (FLOP) Manual defines three flight-related categories: "Flight crewmember" to include pilots and co-pilots; "Designated third crewmember" for crewchiefs; and "Non-crewmembers" to include flight test engineers and liaison engineers. The FLOP Manual also groups third crewmembers and non-crewmembers together as "Flight Personnel" when listing general requirements. (Exhibit 38, p.1; Exhibit 39, p. 16, 33, 34)

55. Boeing issues a Test Pilot Qualification sheet, published near the end of each month, to identify pilot currency. Expiration dates are listed for currency and proficiency in each aircraft qualified, FAA CFI and flight physicals. A provision is made on the sheet to insert the letters "NC" if a pilot is not current in any category. (Exhibit 30b)

56. Boeing issues a Flight Clearance list, published near the end of each month, to identify non-pilots who are cleared to fly in military aircraft. The Flight Clearance list shows an expiration month for each individual based on their flight physical and, starting with the 30 Mar 1992 list, a separate expiration date for each individual based on egress training. Third crewmembers are identified with an asterisk on the Flight Clearance list. (Exhibit 30b)

57. The Memorandum of Agreement between NAWCAD, Patuxent River, and Bell-Boeing for the Participatory Test Program states that military pilots will meet the same requirements as contractor pilots, as spelled out in NAVAIRINST 3710.1B. (Exhibit 45, p.2)

58. As defined in both the DLAM and the Boeing FLOP, Mr. Sullivan was a flight crewmember, and Mr. Rayburn and Mr. Mayan were noncrewmembers. Boeing considered Mr. Stecyk to be a crew chief, which is a flight crewmember by the DLAM 8210.1, and a third crewmember by the Boeing FLOP. (Exhibits 38 and 39)

59. Boeing requires its pilots to complete one flight and one landing in a type or model aircraft every 45 days in order to maintain currency in that aircraft, and to comply with the currency requirements of DLAM 8210.1/NAVAIRINST 3710.1C. (Exhibit 39, p.15)

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60. DLAM 8210.1 requires one takeoff, one instrument approach (if required to operate by instrument flight rules) and one landing every 45 days in each type aircraft to maintain currency. (Exhibit 38, p.14)

61. Boeing pilots are also required to be properly licensed and rated by the Federal Aviation Administration, and possess at least a current class II FAA Medical Certification. (Exhibit 39, p.17/18)

62. In aircraft for which the government assumes the risk for loss, damage, or destruction, pilots of functional flights (termed "Other" flights in DLAM 8210.1) are required to possess at least 1000 hours total time as first pilot, and co-pilots of functional flights are required to possess at least 500 hours total time as first pilot. (Exhibit 38, p. 13; Exhibit 39, p.27)

63. Both Boeing and the Navy require annual egress training and flight physicals of pilots, co-pilots, and other personnel performing specific duties during a flight, including third crewmembers and non-crewmembers. The Project Agreement Flight Clearance signed by Mr. Rayburn on 19 Jun 92, and approved by the DPRO GFR on 23 Jun 92, stated that test engineers and flight crew members flown in BUNO 163914 would meet requirements with respect to flight physicals, egress training, and aircraft familiarity, but did not list any third crewmembers or non-crewmembers by name. (Exhibits 30, 38, 39)

64. Mr. Sullivan, Mr. Mayan, MGySgt Leader and GySgt Joyce all participated in V-22 egress training during the last twelve months. Mr. Rayburn last participated in V-22 egress training on 22 May 91, which expired on 22 May 92. Mr. Stecyk participated in Egress/Bailout Procedure training on 3 Oct 91, and V-22 Explosive Escape System training on 7 Apr 92, but did not participate in the V-22 egress training course, number C95034. LTCOL stated that he and MAJ James had accomplished egress training as part of their V-22 training with the contractor, but MAJ James had nothing in his record to show participation in V-22 egress training. (Exhibit 29; R1008, p.455)

65. MAJ James, MGySgt Leader, and GySgt Joyce all had current medical flight clearances in their qualification records. (Exhibit 32, Pp.1-3)

66. Of the Boeing personnel onboard BUNO 163914, only Mr. Sullivan had a current flight physical in his qualification record. Mr. Rayburn's last flight physical expired on 29 March 1992. Mr. Stecyk's last flight physical expired on 22 March 1992. Mr. Mayan's last flight physical expired on 13 March 1992. (Exhibits 9, 29, and 32, P.4)

67. Boeing was required to maintain records for flight authorization/qualification, currency, medical certification and training (to include egress training) for all V-22 personnel. (Exhibit 39, p. 16, 34)

68. The GFR has a responsibility to review the currency and qualifications of ground and flight personnel, and ensure that only current, qualified personnel perform on authorized missions or activities. The GFR is provided the opportunity to inspect the contractor's Qualification and Training Records. Government approval of Contractor personnel is automatically cancelled upon physical disqualification of those personnel. (Exhibit 38, Vol. 2, p.5; Exhibit 39, p. 17, 18)

69. The Boeing FLOP Manual states that the pilot in command will be responsible for insuring that all flight crewmembers and flight personnel are approved for flight. The FLOP also states that a monthly report listing the qualification status of all crewmembers will be filed in the pilot's office, the Director's Office, and a copy forwarded to the GFR. None of the clearance or qualification lists were sent to the detachment at Eglin. (Exhibit 39, p. 13, 15; R1006, p.362, 387)

70. The last Boeing Test Pilot Qualification chart prior to the mishap (for pilots), issued 30 June 1992, listed Mr. Sullivan as current and proficient in all categories, with V-22 currency to expire

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on 11 Jul 92. When Mr. Sullivan completed one takeoff and one landing prior to 11 July he complied with the 45-day requirement, and renewed his currency. At the time of the mishap he was current in the V-22. (Exhibit 30b; R0930, p.7)

71. The 30 Jun 92 Test Pilot Qualification chart also listed a V-22 currency expiration date of 14 Jun 92 for Mr. and Mr , rather than NC for Not Current. (Exhibit 81)

72. The last Boeing Flight Clearance letter prior to the mishap (for non-pilots), issued 20 June 1992, listed the individuals cleared to fly in military aircraft, including expiration dates for flight physicals and V-22 egress training. The letter also identified designated third crewmembers. None of the Boeing noncrewmembers or third crewmember on the mishap flight were on the list. Neither was Mr , a crew chief (third crewmember) who had flown on most of the check flights at Eglin prior to the mishap flight. A further review of Mr. training record showed that his physical had been accomplished 7 Jan 92, but was overdue for V-22 egress training during his flights at Eglin. (He later attended V-22 egress training 18 Sep 92). (Exhibits 30b, 81)

73. At the time of the mishap, the Boeing computer system for tracking the currency requirements of flight personnel was set up so that when an individual's medical clearance or training qualification expired his or her name was removed from the next clearance list issued. (R0930 p. 26,27)

74. Mr. Stecyk last appeared on the 21 Feb 92 Flight Clearance list, which showed him with an expiration date of Mar 92. Mr. Stecyk was not designated as a third crewmember on that list. Mr. Stecyk also had nothing in his record to indicate that he had ever been designated a crew chief. Mr. Mayan last appeared on the 30 Mar Flight Clearance list, which showed him with a flight physical expiration date of Mar 92, and a V-22 egress expiration date of Sep 92. Mr. Rayburn last appeared on the 30 Mar Flight Clearance list, which showed him with a flight physical expiration date of Mar 92, and a V-22 egress expiration date of May 92. Mr. did not appear on any of the lists as far back as the 21 Feb 92 list. (Exhibits 29, 81)

75. In a 24 Jul 92 letter, Boeing notified the GFR that Mr. Rayburn, Mr. Mayan, and Mr. Stecyk had flown on the mishap flight with expired flight physicals. All three Boeing personnel had been removed from the Boeing Flight Clearance Authorization list by Apr 92, but off-site supervisors at Eglin AFB were not notified, and supervisors at the Boeing Flight Test Center failed to adequately review proposed flight crew composition. (Exhibit 33)

76. On 28 July 1992 the DPRO Boeing GFR formally notified Boeing and the ACO that three Boeing personnel had flown aboard BUNO 163914 with expired contractor physicals, placing Boeing in non-compliance with approved Flight Test and Operations Procedures and the specific flight clearance. (Exhibits 30, 33, 39)

77. Mr. stated on 6 Oct 92 that he had modified Boeing procedures so that non-current personnel remained on the Flight Clearance list, highlighted with shading, and a shaded box was placed on the test cards (used for each flight) to require a check for currency. (R1006, p.366)

PARTICIPATORY TEST PROGRAM

PROGRAM GUIDELINES

78. The FSD contract contains a provision for flight test participation by government personnel, including on-site technical representation for engineering, pilot and supervisory personnel, and government pilot flight participation. The provision required that a Memorandum of Agreement

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(MOA) be drafted between NATC (now NAWCAD, Patuxent River) and Bell-Boeing. (Exhibit 34, Sched H-4F)

79. The MOA for V-22 Participatory Flight Tests was signed 29 June 1987, revised 3 May 1989, and amended in June, 1990, to clarify the scheduling/approval process. The MOA designated NAWCAD, Patuxent River as Test Authority for all V-22 FSD flight testing, and established a V-22 Program Office at Patuxent River for the Multi-Service Test Team (MTT), with permanent MTT detachments at each contractor facility. The MOA specified test involvement by MTT flight crews and flight test engineers. (Exhibit 45, p.1/2)

80. NAVAIRSYSCOM approved a participatory flying program on 12 March 1990 for pilots and engineers, for the period between DT-IIA and DT-IIB. The guidelines for participatory flights required, in part (Exhibit 57):

- A contractor test pilot to be Pilot-in-Command;
- GFR concurrence that the NAVAIR guidelines had been met;
- NAWCAD pilots to be qualified and certified as Category "D" pilots, along with completion of classroom, simulator and flight training for the V-22;
- Neither high-risk testing nor envelope expansion;
- Event-critical V-22 test instrumentation to be calibrated and operating correctly.

81. To Qualify as a Category "D" pilot, a military pilot must graduate from the Navy Test Pilot School, complete a contractor conducted ground school, complete two familiarization flights, and receive a letter from NAWCAD/Rotary Wing awarding this designation. (Exhibit 40, p.5-4; R1008, p.446).

82. NAVAIRSYSCOM extended participatory flying through DT-IIC following a Dec 90 request from NAWCAD. (Exhibit 58)

83. COMNAVAIRSYSCOM 051716Z APR 91 issued the flight clearance for DT-IIC. The clearance authorized DPRO release of BUNO 163912 to NAWCAD test pilots, and release of BUNO 163914 to NAWCAD test pilots, crew chiefs and engineers. (Exhibit 59)

84. Developmental Test (DT) IIC terminated 19 August 1991. In November 1991 NATC asked that the participatory flight program be extended through DT-IID. NATC specifically asked that crew chiefs and flight test engineers be cleared to fly on nonejection seat aircraft (BUNO 163914). (Exhibit 56)

85. Bell-Boeing recommended to NAVAIRSYSCOM on 15 January 1992 that the participatory flight program be resumed. Bell-Boeing supported the NAWCAD request for approval of engineers and crew chiefs, requesting that preference be given to engineers to reduce follow-on DT testing requirements. Bell-Boeing also recommended that flight clearances released in connection with such flights apply to testing at Contractor facilities and transit flights between test centers. The MOA does not specifically address aircrewmen or crew chiefs, but refers to flight crewmembers (Exhibits 45, 55)

86. LTCOL b6 stated that the Participatory Flight Program was initiated again just prior to the ferry flight from Wilmington to Eglin in Feb 92. (R1008, p.450)

87. On 1 Apr 92 NAVAIRSYSCOM extended "integrated Navy-Contractor engineering flight testing" until 30 Sep 1992. (Exhibit 54)

CREW SELECTION

88. The MTT detachment Officer-in-Charge was designated the on-site Test Authority Program Manager (TA-PM). In a separate MOA between the V-22 PMA and the DPROs at Bell and

Boeing, the TA-PM was responsible for coordinating all activities involving the DPRO with the GFR and appropriate DPRO personnel. In the NAWCAD MOA as it relates to operations at Boeing, the TA-PM (LCDR) was also jointly responsible, with the Manager of V-22 Flight Test at Boeing (Mr.), for coordinating participatory flights, and identifying flights and crew seat assignments where MTT participation would enhance program objectives. (Exhibit 36, p.7; Exhibit 45, p.3)

89. As the TA-PM, LCDR worked with the Mr. Rayburn, Mr. , Mr. and Mr. Sullivan to identify candidate participatory flights and crew seat assignments (pilot or co-pilot) for military flight crew members. He verbally passed the flight information to LTCOL at the RWATD V-22 Program Office, who approved the list. Prior to LTCOL arrival at NAWCAD, LCDR usually recieved the names of pilots selected to be on the participatory flights verbally from LTCOL predecessor, and passed those names to Boeing management. Mr. also stated that he was an interface, with NAWCAD, for participatory flights, and coordinated with Mr. Sullivan. After he became the deputy V-22 Program Manager early in 1992, LTCOL chose to pass the names of participating pilots directly to the Boeing Project pilot (Mr. Sullivan). (R1006, p.323/329; R1008, p.452/457; R1023, p.62/64)

90. The RWATD V-22 program office forwarded verbal requests for flight of non-crewmembers directly to Boeing. (R1006, p. 324)

91. RWATD maintains all military V-22 flight records. Information that military flight crew members had been issued Category "D" flight qualification letters was passed verbally from LTCOL to LCDR . Typically the NAWC Det passed only the names of participatory flight crewmembers to the contractor, who then passed it to the GFR. Boeing assumed that any flight crew members and non-crewmembers authorized by NAWCAD were cleared to fly. LTCOL had no dialog with the GFR, but felt that the TA-PM at each contractor location maintained direct liaison with the GFR. (R1006, p.344; R1008, p.451/454/455; R1023, p.61/65)

92. The project pilot (Mr. Sullivan) and the Boeing Manager of Flight Operations (Mr.) decided which Boeing pilots would fly a given flight. The Test Director made a decision on test engineers required for particular flights, subject to the approval of Mr. or Mr. (the Test Operations Manager). The Pilot-in-command was allowed to modify crewmember decisions. (Exhibit 33; R1006, pp. 315,321-322, 369)

93. Past Boeing management practice was for the Test Director to prepare the Project Agreement Flight Clearance for the month, and have the Manager of V-22 Flight Test sign it prior to submission to the DPRO for approval. At the time of the mishap, the practice was to have the Test Director sign the Clearance and submit it directly to the GFR for approval, which complies with the Boeing FLOP Manual. The Project Agreement Flight Clearance sent to LTC for the month of July 92 was signed by Mr. Rayburn, the Test Director. LCDR did not receive a copy of the flight clearance, and neither did LTCOL (Exhibit 33, pp.1,39; R1006, p. 321; R1008, p. 453; R1023, p. 68)

94. Mr. stated that Boeing is not required to list test engineers and crew chiefs by name on the Project Agreement Flight Clearance. (R1006, p. 329)

95. P206. The GFR stated that he had only been briefed about military pilots in the participatory flight program, and would not have approved military crew chiefs and non-crewmembers without a coordinated, staffed program (similar to the program for pilots). He was not aware of military crew chiefs being on board the mishap flight, and felt that his predecessor was not aware that a military engineer and crew chief had been on the ferry flight to Eglin. (R0930, p.17/18/23)

96. Mr. was aware that military non-pilots had flown on the ferry flight to Eglin, and thought that one military crew chief, along with a military co-pilot, would be on the return flight. LCDR was also aware that Capt and MGySgt Leader (both from RWATD) had flown on

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the flight to Eglin, but felt he was not responsible for letting the GFR know. (R1006, p.324; R1008, p.463; R1023, p.65)

97. LTCOL stated that he and MAJ James arrived at Eglin on 12 July with the intention of completing their two-flight (Category D) requirement, which they did on 13 July, and participating on the ferry flight to Quantico as co-pilots. He stated that the use of government pilots was encouraged on ferry flights, such as the mishap flight, due to the benign flight environment and the opportunity for government pilots to gain V-22 experience. LTCOL discussed the ferry flight with Mr. Sullivan a week prior to the flight. LTCOL had also discussed with both MAJ James and Mr. Sullivan the need for him to be the Marine pilot exiting the aircraft at Quantico rather than MAJ James. (R1008, p.447,448, 449, 453, 458, 459)

98. The Court could find no evidence that established a "minimum essential" crew list for particular flight evolutions. (All exhibits and testimony)

99. Mr. stated that a meeting was held at Eglin near the first of July to discuss the ferry flight, including crew composition and the use of a local flight to Hurlburt Field to check crew coordination for the ferry flight. He attended the meeting along with Mr. Mr. Rayburn, Mr. , and a Boeing pilot, probably Mr. . In addition to selecting Boeing crew positions, the determination was made to use a Marine co-pilot, and it was decided that there was one more available seat for a military participant. The Navy elected to fill the seat with a crew chief. Mr. expected that Mr. would work out personnel details with the NAWCAD representative and get Mr. Sullivan's approval. Mr. does not recall talking about the use of a military crew chief, and did not specifically make any arrangements. He stated that it was common knowledge, by the time he left on 18 July, that it was planned to have one or more military crew chiefs onboard aboard. (R1006, p.327/339/340/341/342/374/375/383)

100. LTCOL stated that GYSGT Joyce was a last-minute addition to the mishap crew. The original plan had been for Mr. to be onboard, but he decided not to go, since his family was in Florida with him, and the military was offered the additional seat. (R1008, p.518)

101. LTCOL felt that the size of the crew was not excessive for a low risk ferry flight with no intention to gather data. He felt that the real limiting factor was the availability of oxygen, most of the flight would be at 15,500 ft. He stated that MGySgt Leader and GySgt Joyce would be performing crew chief duties, such as checking aircraft status and reservicing systems as required. Both had flown a number of flights before, and were well qualified to perform those assignments. LCDR also concurred with the crew complement, citing their extensive experience during DT-IIC. (R1009, p.461; R1023, p.74)

AIRCRAFT MAINTENANCE

BOEING MAINTENANCE PERSONNEL AND ORGANIZATION

102. The following key maintenance personnel were assigned in support of BUNO 163914 at Eglin AFB (Exhibit 52, Tab A, p.1-80; R1006, p. 370-372):

Name	Stamp #	Eglin Team Function	Authorized to Perform	Authorized to Sign
	N/A	Test Team Leader		
	N/A	Relieving Test Team Leader		
Rayburn, R.	N/A	Test Director		Flight Release
	N/A	Operations Supervisor		
	807B8	QA Manager		
	879BA	QA Inspector Preflight A		Flight Release
	A0363	Flight Test Crew Chief	Daily, Turn	Flight Release
Stecyk, A.	A2258	Flight Test Mechanic A	Daily, Turn	
		Flight Test Crew Chief	Daily, Turn	
	62072	Flight Mechanic A	Daily, Turn	
	A2221	Flight Mechanic A	Daily, Turn	

103. Mr. , the Test Team Leader, departed Eglin on 18 July 1992, two days prior to the mishap flight. The relieving Test Team Leader (Mr. did not do an on site relief, and the supervision of the remaining effort was left to a group consisting of the Test Pilot, Test Director and the Operations Supervisor. (R1006, p. 370-372)

104. The role of the Test Team Leader at Eglin was primarily one of coordination vice direct line management, with authority to resolve conflicts residing at Boeing headquarters in Philadelphia. (R1001, p. 57-60, 110-112)

105. The Boeing employee record for Mr. A. Steyck shows no entries for job classification as a Flight Test Crew Chief. The highest qualification listed is for Flight Test Mechanic A and Offsite Mechanic General. (Exhibit 52, Tab A, p. 15, 55-59)

106. The Boeing Job Description requirements for Flight Test Crew Chief exceed the requirements for Flight Test Mechanic A. (Exhibit 52, Tab A, p. 15, 16, 24, 25)

107. According to testimony, Mr. Steyck may have been temporarily assigned as a Flight Test Crew Chief by Mr. (Operations Supervisor), but there is no supporting administrative evidence in his Employee Record. (Exhibit 52, Tab A, p. 55-59; R1006, p. 348, 349)

108. Mr. Steyck had performed as a Flight Test Crew Chief in 1991, although not documented in his Employee Record. (Exhibit 52, Tab A, p. 55-59, 72)

109. A Boeing Personnel Roster dated 31 August 1992 (post-mishap) listed Mr. Steyck as both Flight Test Mechanic A and Flight Test Crew Chief. (Exhibit 52, Tab A, p. 1-4)

110. Boeing indicated that it is a common practice to temporarily assign Flight Test Mechanic A's as Flight Test Crew Chiefs when a Flight Test Crew Chief is not available for any reason. (Exhibit 52, Tab A, p. 72)

111. There is no formal training (other than on the job training) and qualification process (e.g., open/closed book examinations and/or board review) for a Flight Mechanic A to be designated as Flight Test Crew Chief. (Exhibit 52, Tab A, p. 15, 16, 24)

112. Boeing's only formal requirement for designation as "Inspector, Preflight A" (ie., QA Inspector) is to meet the requirements of the Job Description. (Exhibit 52, Tab A, p. 15, 16)

113. The current Boeing Job Description for Inspector, Preflight A, dated 1955, does not contain or identify any prerequisites, experience or requirements for this job. (Exhibit 52, Tab A, p. 18)

114. Boeing allows the individual QA inspector to decide whether or not he/she has the expertise needed to perform specific inspections. (R1001, p. 103-107)

115. Boeing has no formal training and qualification process to evaluate/re-evaluate the capability of QA Inspectors to exercise full systems QA authority. (R1001, p. 169-170; (Exhibit 52, Tab A p. 15-16)

116. There is no evidence of V-22 Quality Assurance (QA) Inspector training in Mr. training record, although he was trained as a QA Manager. (R1001, p. 94-97, Exhibit 52, Tab A, p. 27, 30)

117. Mr. performed QA inspector duties in addition to his assignment as QA Manager. (R1001, p. 105-106)

118. Mr. the QA Inspector at Eglin had minimal on the job training (OJT) and no formal QA training on any of the V-22 systems. (R1001, p. 170-171)

119. The proposed maintenance organization for the Eglin detachment depicted in the Climatic Laboratory Test Plan differed most significantly from the normal situation at Wilmington in that the QA inspectors worked for the Operations Supervisor. (Exhibit 52, Tab A, p. 10)

120. The Eglin maintenance organization was verbally revised prior to the start of Climatic Laboratory testing to have the QA Manager (Mr. , report directly to the Boeing QA organization in Philadelphia, but to coordinate with the Eglin Team Leader (Mr.). (R1001, p. 58-60, 110-111)

REQUIREMENTS FOR AIRCRAFT FLIGHT RELEASE

SAFE FOR FLIGHT CRITERIA

121. The symbols to be used for documenting Safety of Flight (SOF) discrepancies on the Aircraft and Maintenance Inspection Record are defined by Boeing QA Operating Instructions 210.34 and 210.26. (Exhibit 52, Tab B p. 86-87, 95, 103)

122. Boeing utilizes U.S. Army pamphlet DA PAM 738-751 (TAMMS A) as primary guidance for determining SOF conditions/discrepancies and applying appropriate SOF symbols (eg., red X, circle red X) to the Aircraft and Maintenance Inspection Record. (Exhibit 52, Tab B p. 99, 101, 104, 105, 108)

VALIDITY OF INSPECTIONS PRIOR TO MISHAP FLIGHT

123. A Daily Inspection is to be accomplished prior to each day's flight operation. The Daily is valid for 72 hours provided no flight or maintenance is performed. The Daily Inspection incorporates the requirement of a Turnaround Inspection in its entirety. (Exhibit 52, Tab B, p. 109-111)

124. The Aircraft Flight Release (AFR) form is incorporated at the end of both the Daily Inspection and Turnaround Inspection forms. The AFR is required to be signed by the aircraft Crew Chief, QA Inspector and Flight Test Engineer prior to the pilot accepting the aircraft. In

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addition to the QA Inspector and Crew Chief certifying by signature that the required inspection has been satisfactorily completed, they must also initial blocks indicating whether the aircraft is cleared for flight operations or ground operations only. (Exhibit 52, Tab B p. 110, 131, 134, 141)

125. Boeing QA instruction states that "no work is permitted on the aircraft once the AFR is signed. Should it become necessary for work to be accomplished after the AFR is signed, a Break of Inspection must be initiated and all signatures on the AFR will be voided by the inspector by drawing diagonal lines through the signatures. Upon completion of necessary rework and applicable inspections, the AFR will be revalidated and the pilots will be notified that the aircraft is again ready for operation." (Exhibit 52, Tab B p. 133)

126. A Daily Inspection should not be started on incomplete aircraft or aircraft with safety of flight discrepancies unless approved by Quality Assurance Management. (Exhibit 52, Tab B p. 111)

127. The "Date/Time Started" block on the last Daily Inspection form was not filled in. Testimony indicated the Daily Inspection was started on 18 July 1992. Eleven areas were stamped as complete by QA inspectors on 18 July 1992 and the final completion was not signed off until 1755, 19 July 1992. (Exhibit 52, Tab B, p. 140-141; R1001, p. 69)

128. The QA Manager, Mr. authorized initiation of the last Daily Inspection with open BOI's and SOF discrepancies. (R1001, p. 82)

129. A Break of Inspection (BOI) is "the removal or disconnecting of any portion of a previously inspected and accepted installation in an aircraft, aircraft section, or component." (Exhibit 52, Tab B p. 143)

130. The following maintenance actions/conditions were outstanding during the time the Daily Inspection was being performed on 18-19 July 1992:

- At completion of work on 18 July, items 5, 6, and 9 (right hand nacelle HPDU return line, left hand nacelle hydraulic heat exchanger/oil cooler, left hand nacelle hydraulic isolation valve) on the BOI Record were incomplete ("open") and were not signed off until 20 July following functional checks. (Exhibit 52, Tab B p. 149-150)

- On 18 July BUNO 163914 had two open safety of flight ("Red X") discrepancies (lost screw and cracked hydraulic oil cooler) which were not signed off as complete until 19 July, but which had been downgraded to "Circle Red X" status for a ground run only. (Exhibit 52, Tab B p. 151-152; R1001, p. 84-85)

- On 19 July the "RH Sponson Boost Pump" was removed and replaced. The portion of the Daily Inspection covering the area where the boost pump maintenance was performed (paragraphs 14,16, and 17 of the Daily Inspection form) had previously been signed off as complete on 18 July. (Exhibit 52, Tab B p. 140-141, 150, 155)

131. There are no stamps on the Daily Inspection sheet for any type of reinspection of the areas worked on during the sponson boost pump installation. (Exhibit 52, Tab B p. 140-141)

132. When the Daily Inspection was signed off as complete on 19 July, items 5, 6, 9, and 10 (right hand nacelle HPDU return line, left hand nacelle hydraulic heat exchanger/oil cooler, left hand nacelle hydraulic isolation valve, RH sponson boost pump) of BOI sheet 243 were still incomplete. (Exhibit 52, Tab B p. 141, 149-150)

133. The QA Inspector (Mr. testified that he should not have signed off the Daily Inspection as complete with open Breaks of Inspection. (R1001, p. 176-177, 180)

134. The QA Inspector (Mr. did not initial the cleared for ground operations or cleared for flight operations portions of the last Daily Inspection's AFR block, but he testified that his signature on the AFR meant that he had cleared the aircraft for <u>both</u> ground and flight operations. (R1001 p. 179-180; Exhibit 52, Tab B p. 141)

135. The Crew Chief (Mr.) initialed <u>both</u> the cleared for ground operations and cleared for flight operations portions of the last Daily Inspection's AFR block, but testified he had intended that the aircraft be cleared for ground run only. (R1001, p. 141; Exhibit 52, Tab B p. 141)

136. The back sheet of Flight Test Worksheet 3030 dated 19 July indicates that Ground Run #81 of 0.7 hours duration took place on that date (time not specified). Testimony indicated that the ground run took place after the last Daily Inspection's AFR had been signed. (Exhibit 52, Tab B p. 156-157; R1001, p. 141, 163, 174, 175)

137. A Turnaround Inspection is required <u>between</u> successive flights during a given day's operations. (Exhibit 52, Tab B p. 104)

138. On 20 July a Turnaround Inspection was performed on BUNO 163914 due to having performed a ground run, although there was no formal requirement since the aircraft had not flown since the Daily Inspection was performed. (Exhibit 52, Tab B p. 158-159; Exhibit 84)

139. Maintenance required to close out the four Breaks of Inspection that were open during the last Daily Inspection was completed on the evening of 19 July and signed off on the morning of 20 July. The last Turnaround Inspection was initiated on 20 July. (R1001, 151-153; (Exhibit 52, Tab B p. 158)

140. Both the Crew Chief (Mr.) and QA Inspector (Mr. who signed the Turnaround Inspection's AFR testified that they thought the last Turnaround Inspection was sufficient and that an updated Daily Inspection was not required. (R1001, p. 142-143, 174-177)

141. Unlike a Daily Inspection, a Turnaround Inspection does not require the opening of any access panels. (Exhibit 52, Tab B p. 113-130, 160-164)

<u>COMPLIANCE WITH SCHEDULED INSPECTIONS</u>

142. A Safety of Flight (SOF) Inspection was performed 23-25 June 1992 by DPRO QA. All discrepancies noted were non-safety of flight problems, except for a leaking hydraulic isolation valve in the left nacelle, which was subsequently corrected. (Exhibit 52, Tab B p. 165-187)

143. The Aircraft Inspection and Maintenance Record, Form 54791, is used to indicate scheduled maintenance inspections due before next flight (as a minimum). The crew chief is responsible for the preparation of the Aircraft Inspection and Maintenance Record prior to the first flight of each day. (Exhibit 52, Tab B p. 82)

144. A Flight Test Interface Panel (FTIP) Switch checkout is required to be performed during every 15 day/35 hour inspection for aircraft equipped with the Analog to Digital Aircraft System (ADAS) data monitoring equipment. ADAS was removed from BUNO 163914 on 11 July 1992 and was not installed during the mishap flight.(Exhibit 52, Tab B p. 188, 198-202, 204, 209, 210)

145. Engine fuel nozzle removal for inspection and replacement is a 50 engine hour requirement with a 20 hour extension authorized for convienence of maintenance scheduling. (Exhibit 52, Tab B p. 193, 217)

146. When the mishap aircraft departed Eglin enroute Quantico, the right engine fuel nozzles had 64.1 hours in service (5.9 hours remaining until mandatory changeout/inspection). (Exhibit 52, Tab B p. 218- 236)

147. The engine fuel nozzles did not exceed the 70 hour limit during the mishap, as the engine run time from Eglin to Quantico was only 4 hours (1.9 hours remaining on nozzles at time of impact). (Exhibit 52, Tab B p. 218)

148. Maintenance records included an informal letter from Allison to Mr. R. Rayburn dated 14 July 92 addressing upcoming fuel nozzle replacement. The letter indicated that due to unavailability of replacement nozzles because of a strike at Allison, it would be necessary to operate beyond the 70 hour limit without fuel nozzle changes. (Exhibit 52, Tab B p. 237)

149. The informal letter from Allison to Boeing bypassed the coordination memo system established by the FSD contract and Bell-Boeing/Allison agreement. The coordination memo system was designed to include both government and contractor participation in areas of technical concern. (Exhibit 52, Tab B p. 238-239)

<u>CHECK FLIGHT AND GROUND RUN REQUIREMENTS</u>

150. A Maintenance Operational Check (MOC) is a ground run functional checkout. A MOC is required prior to flight whenever any system or component has been disturbed and there are no other means available to verify its proper operation or function. (Exhibit 52, Tab B p. 242)

151. A MWGB oil filter popout button was found popped and BOI item 11 was initiated on 20 July. The popped button was accompanied by cockpit WRA indications of "impending oil bypass". The filter was pulled, QA inspected the filter, the button was reset and the assembly reinstalled, with no abnormalities having been noted. A MWGB filter MOC entry on the Aircraft Maintenance and Inspection Record was initiated by the Crew Chief (Mr. , but was not closed out prior to the mishap flight. (Exhibit 52, Tab B p. 150, 154; R1001, p. 134, 155, 156; R1006, p. 223, 224, 264)

152. Testimony indicated that the MWGB filter MOC was to be completed by the Flight Test Crew Chief, Mr. Steyck, so that the Crew Chief and QA Inspector could help with the logistics of moving the maintenance effort out of Eglin. The MOC was to be performed during turnup on APU power prior to taxi for take off, even though the Turnaround Inspection's Aircraft Flight Release (AFR) was already signed as cleared for <u>flight</u> operations by both the QA Inspector (Mr. , and Crew Chief (Mr.). (Exhibit 52, Tab B p. 158-159; R1001, p. 134-135, 156-159, 178, 188)

153. Testimony revealed that Mr. Steyck performed a MWGB filter MOC and found the filter popout button again popped. The aircraft was turned up a second time, but a second check of the popout button prior to takeoff was not witnessed. (R1002, p. 268-269)

154. The QA Inspector and Crew Chief (Mr. I who signed the AFR did not reinspect the MWGB area subsequent to the MOC. (R1001, p. 157-159, 178, 188-192, 194)

155. Maintenance records needed to closeout the MWGB filter MOC were not available at Eglin at the time of the MOC as they had been taken to Destin at approximately 0800 on 20 July for delivery to the chase aircraft. (R1001, p. 178; R1002, p. 270-271, 307)

156. Post mishap analysis of aircraft onboard data instrumentation showed no indication of an impending oil bypass situation for the MWGB. (Exhibit 77)

157. The Aircraft Flight Release (AFR) is contained on the last page of the Daily and Turnaround Inspection forms. No work is permitted on the aircraft once the AFR is signed.

Should it become necessary for work to be accomplished after the AFR is signed, a Break of Inspection must be initiated and all signatures on the AFR will be voided by the inspector....Upon completion of necessary rework and applicable inspections, the AFR will be revalidated.... (Exhibit 52, Tab B p. 133)

158. The MWGB filter MOC was initiated subsequent to the signing of the AFR on the Daily Inspection form. The Daily Inspection's AFR was not voided or revalidated after 19 July 1992 as required. (Exhibit 52, Tab B p. 133, 141, 150)

159. The Boeing QA Instruction requires a check flight when fixed or movable flight control surfaces have been replaced or adjusted. The nacelles of the V-22 are considered movable flight control surfaces in accordance with NATOPS. (Exhibit 52, Tab B p. 242, 244)

160. The nacelle resolvers were rerigged on 14 July 1992 following right hand HPDU replacement. (Exhibit 52, Tab B p. 245-256)

161. The QA Inspector testified that in his opinion a check flight is required when the nacelles are rerigged. (R1001, p. 195-196, 199)

162. The QA Inspector testified that whether or not an inflight check of the nacelle rigging was to be performed was an issue between the pilot and the flight test engineer (Mr. Rayburn) (R1001, p. 198-200)

163. DPRO Bell Helicopter Textron, Inc (BHTI) indicates that an inflight check in addition to ground maintenance is necessary in the case of re-rigging of the nacelles following a hydraulic power drive unit (HPDU) replacement to check nacelle down stop loads. (Exhibit 52, Tab B p. 257-258)

164. Downstop loads can be checked in flight using onboard instrumentation. If loads are too high, the nacelle angle can be increased to move the nacelles off the downstops. (R1008, p. 489-490)

165. Boeing QA Instruction QAOI 210.34 requires that an entry "test flight required for...." shall be made on the Aircraft and Maintenance Inspection Record whenever an inflight check is required. (Exhibit 52, Tab B p. 87)

166. There were no Aircraft Maintenance and Inspection Record entries indicating test flights required during the time between the first pos-Climatic Laboratory shakedown flight and the mishap flight. (Exhibit 52, Tab B p. 151-154, 211-212, 265-277)

167. All inflight checks were arranged directly with the pilots by the Flight Test Engineer without the required corresponding entries being made in the maintenance records or being discovered as lacking by the QA Inspector. (R1001, p. 197-201)

168. Specifically, there was no maintenance entry made requiring a maintenance check flight for the nacelles being re-rigged (in conjunction with a HPDU change) on 14 July 1992. A ground functional check was performed. (Exhibit 52, Tab B p. 151-154)

SIGNIFICANT PRE-MISHAP FLIGHT MAINTENANCE RELATED ACTIVITIES

169. The following significant maintenance actions and flights occurred shortly before the mishap flight: (Exhibit 52, Tab B p. 81; Exhibit 84; R1002, p. 268-269)

February 9	RH proprotor gearbox input clutch change (LeCloux/Ott)
February 10	RH engine reinstalled (Rose/Lynch)
May 27	LH engine removed (Steyck/Ott)

	LH proprotor gearbox input clutch change (Steyck/
May 28	RH engine removed and BOI stamped OK for reinstallation (/(
	RH proprotor gearbox input clutch change (/(
June 8	Reinstalled LH engine (Steyck/(
June 12	Reinstalled RH engine (/
June 27	First ground run (GR-79) following Climatic Lab testing
July 2	First shakedown maintenance check flight (X-85)
July 7	Flight X-86, 0.7 hours
July 8	Flight X-87, 1.2 hours
July 9	Flight X-88, 0.5 hours
July 10	RH inlet removal ( )
--	RH PRGB filter bowl removed/reinstalled (/
July 12-13	15 Day/35 Hour Inspection (/ /
July 13	RH Inlet BOI reinstalled/inspected (/(
July 13	Maintenance shakedown flights (X-89 through X-92) totalling 2.3 hours. No further flights prior to mishap flight.
July 14	Hydraulic Power Drive Unit (HPDU) change
July 15	Functional check of Hydraulic Power Drive Unit (HPDU) (
July 17	Ground run (GR-80)
July 18	- Daily Inspection initiated with <u>4 open Breaks of Inspection</u> (right HPDU return line, left hydraulic oil cooler, left hydraulic isolation valve, right conversion actuator fairing) and <u>2 SOF conditions</u> (lost bolt in left nacelle, left hydraulic oil cooler cracked). QA Manager gave OK to start. - Right fuselage area on Daily signed off as complete. - Entry on Maintenance and Inspection Form for MOC MWGB for oil leak
July 19	- R/R right forward sponson boost pump (Daily was previously completed in area) - MOC MWGB oil leak signed off - Daily signed off at 1755 with <u>4 open BOI's requiring MOC's</u> (right sponson boost pump, left hydraulic cooler, right HPDU drain line, left hydraulic isolation valve) - Ground run (GR-81) of 0.7 hours was completed after the Daily to satisfy the 4 MOC requirements (but no BOI sign offs until next day)
July 20	- The 4 open BOI's were signed off - Turnaround Inspection started at approximately 0630. - MWGB oil filter popup button found popped. Filter removed, inspected and replaced. - MOC for MWGB oil filter initiated on BOI sheet and Aircraft Inspection and Maintenance Record.(- Turnaround Inspection and AFR signed as cleared for flight with MWGB MOC still pending. - Approximately 0800 maintenance records transferred to chase plane at Destin airfield. - Upon MWGB MOC on APU by Mr. Stecyk, filter button found popped second time. - Unknown if second MOC performed. - Aircraft launched on ferry flight.

170. The RH torquemeter shaft was removed from the PRGB as an integral part of the engine on 28 May due to a PRGB clutch change. The torquemeter shaft oil seals were replaced on 28 May as documented by initialling of the "OK to Install block of the BOI. The shaft was reinstalled on 12 June in conjunction with replacement of the right engine. (Exhibit 84)

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171. The RH torquemeter shaft forward oil seal was found to be installed backwards during post-mishap inspection of the wreckage. Both the forward and aft seals were missing from the LH torquemeter shaft. (Exhibits 83)

172. The forward oil seal on the RH torquemeter shaft was not removed/replaced in the course of the Engine E.I. (Exhibit 84)

173

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174. Maintenance personnel did not note accumulation of lubricating oil in the right inlet housing centerbody on 12 July 1992, which was the last removal of the cowlings prior to the mishap on 20 July 1992. (R 1002, p. 228, 229)

175. Lubricating oil could not have accumulated in the non-breeze side of the right inlet housing center body during the proprotor gearbox filter bowl replacement on 10 July 1992, as the cowling was removed and not replaced until 13 July 1992. (Exhibit 52, Tab B p. 286)

176. Although maintenance personnel worked on the aircraft in airplane mode, they did not have an opportunity to observe airplane mode-only leak indications, as flights always ended with helicopter mode for taxi. (R1002, p. 240-241)

177. Maintenance personnel performing Daily and Turnaround Inspections in the right nacelle area indicated that the following leak indications were common (R1002, p. 216-217, 246-247, 281, 284; R1001, p. 130):

- Very small ("quarter or nickel" size) puddle of lubricating oil in the engine inlet.
- Slight oil film on the torquemeter housing coupler
- Engine inlet housing centerbody was dry on the non-breeze side, but had film on the breeze side which dripped down onto engine inlet
- Overall very dry, no fluid loss necessitating use of drip pans in hangar

178. Fuel transfer from the RH sponson tank to the feed tanks was not operating properly from 8 July until 19 July, even in the boosted transfer mode. The problem was corrected on 19 July with the replacement of the RH sponson boost pump. (Exhibit 48, Section 5 p. 5-15)

FLIGHT PLANNING/CLEARANCE AND COMPLIANCE

PLANNING

179. The mishap flight on 20 Jul 92 was planned and flown under Visual Flight Rules (VFR). The following weather conditions were present:

- The launch weather at Eglin was essentially clear, with scattered clouds at 4000 feet, 15,000 feet, and 25,000 feet. (Exhibit 6)

- A surface analysis of weather conditions from Eglin to Quantico showed a weak, quasi-stationary frontal system, located east of the route of flight and moving slowly eastward. Very little weather activity was present all along the route of flight. (Exhibit 6, R0730, p.15/16)

- Wind speed varied along the route of flight from negligible over Eglin AFB, to 5 knots from a westerly direction over South Carolina, to 10 knots from a westerly direction over North Carolina and Virginia. At higher altitudes the wind speed was as high as 15 knots. (Exhibit 6; R0730, pp.15-16)

- At the level cruising altitude, approximately 15,500 feet, the aircraft was above the freezing level by at least 1500 feet throughout the enroute portion of the flight. (Exhibit 6; R0730 P.16)

- The weather observation at Quantico at the time of the crash listed scattered clouds at 4000 feet, visibillity of seven miles, no obstructions to vision, a wind speed of 2 knots coming from the southeast with no gusts, and occasional light turbulence from the ground up to 6,000 feet. (Exhibit 6; R0730, p.18)

180. On the morning of 19 July, LTCOL b6 MAJ James, and Mr. Sullivan changed the flight plan in the aircraft's computer to include a stopover at Charlotte, and reviewed the procedures for using the multi-function displays in the cockpit. (R1008, p.465)

181. A preflight brief was conducted Sunday afternoon in the hangar at Eglin. Attendees included LTCOL , MAJ James, Mr. Sullivan, Mr. Rayburn, Mr. and Mr. . Mr. and Mr. were Boeing V-22 pilots who would fly the King Air chase aircraft. (R1008, pp.466,474, and 511)

182.

B5 B6 ...dedicated to the program and the aircraft."

183. Although Boeing management considered the King Air to be a Logistics Support Aircraft, the King Air was briefed on 19 Jul as a chase aircraft. The role for the chase aircraft during the ferry flight was briefed to include: Providing visual inspection of the mishap aircraft; advising the mishap aircraft the nearest divert field if that became necessary; providing accurate altitude readings for the mishap aircraft; and carrying an essential crew to provide technical assistance, if required, enroute to Quantico. (R1006, p.330; R1008, p.469; R1010, p.8)

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184. The chase aircraft, with its passenger load, did not have enough fuel to go non-stop to Quantico. Because of the need to refuel the chase enroute, and uncertainty concerning the fuel system and fuel burn rate of the V-22, the briefing specifically stated that there would be no attempt to fly non-stop from Eglin to Quantico. (R1008, p.471; R1010, p.10)

185. Boeing had not obtained a facilities permit to land the chase aircraft at Eglin, which caused Boeing to operate the chase aircraft out of Destin airport, approximately 10 miles away from Eglin. (R1010, p.12)

186. The briefing called for the King Air to take off from Destin, orbit, then execute a join-up in the form of a running rendezvous when the V-22 launched from Eglin and turned to the north. Visual contact was to be maintained during the flilght. (R1008, pp. 468,481)

187. The briefing provided for a communications check, to be done between the V-22 and the chase aircraft, while both aircraft were still on the ground. Instead, Mr. Sullivan communicated with Mr. by telephone after the initial problems with the V-22 (impending bypass on the mid-wing gearbox and hot oil on the APU). Mr. Sullivan briefed that Eglin ground, or clearance delivery, would call Destin by telephone and alert the chase crew when the V-22 was turning rotors. He also stated that he could hear the chase aircraft on the radio; the chase could not hear him. (R1010, p.12/13)

FLIGHT CLEARANCE

188. The NAVAIRSYSCOM clearances authorized DPRO to release the aircraft to both contractor and government pilots for ferry flights between various test facilities, including Eglin AFB, Wilmington, DE, and Quantico, VA. (Exhibit 16)

189. The Boeing FLOP Manual did not require a chase plane for the ferry flight. Boeing requires a chase plane under the following circumstances: (Exhibit 39, p.40)

- For initial flights of prototype aircraft (25-75 hours of flight time);
- When aircraft structural integrity is being investigated;
- When the established flight envelope is being expanded; or
- When aircraft configuration does not permit an observer, and the pilot or copilot may be preoccupied with cockpit duties.

190. The NAVAIRSYSCOM flight clearance did not require a chase plane for the ferry flight, since the V-22 was equipped with a CONDM package. The clearance did require, as a minimum, that the following parameters be displayed on the CONDM warning panel:

- Armpit strain;
- Bondline striker load; and
- Mast torque

The clearance also stated that any Return To Base (RTB) indication shall "require the pilot to land as soon as possible at the nearest suitable airfield." (Exhibit 16)

191. The CONDM warning for armpit strain and bondline striker load was "RTB RTR". The warning for mast torque was "RTB QM". Either of the RTB RTR warnings took precedence over RTB QM. (Exhibit 79)

192. The flight clearance restricted airspeed to 230 Knots Equivalent Air Speed (KEAS) and permitted flight up to 15,500 ft. The clearance permitted non-stop flight between Eglin and Wilmington. (Exhibit 16)

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193. The Boeing FLOP Manual requires aircraft to have at least 30 minutes of fuel remaining upon landing. Mr. stated that Boeing considered minimum fuel in the V-22 to be approximately 1000 pounds, roughly the amount of fuel with the feed tanks full. (Exhibit 39, p.50; R1006, p.334)

COMPLIANCE

194. The King Air crew received a call from Eglin at 0925 indicating that the V-22 was turning rotors. The chase aircraft launched at 9:36, and orbited overhead Destin at 1500 feet. Mr. Sullivan verified, with Eglin ground control at 9:46, that the chase had been informed of their engine start. The engine start was carried out using the "emergency" setting on the APU. (Exhibit 71, p.1; R1010, p.13)

195. At 0950 local time, while still on deck at Eglin, Mr. Stecyk stated that the V-22 seemed "to be pushing a lot of hydraulic fluid out of the Number Two side." The status checked OK, but someone else felt that the quantities of 32, 32 and 20 were "pretty high". There is no indication that aborting/delaying the flight was considered at this point. (Exhibit 71, p.3/4)

196. BUNO 163914 launched at 09:55. When the V-22 launched, it turned north, away from the chase aircraft obiting to the South-southeast. (Exhibit 71, p.5; R1008, p. 468)

197. At 0959, while the V-22 continued its climb to the north, Mr. Sullivan started trying to establish communication with the chase aircraft. In the V-22 cockpit, between 10:03 and 10:04, they discussed using frequencies of 122.8 and 122.7. At 1005:25 MAJ James tried to reach the chase on 122.75 without getting an answer. (Exhibit 71, p.7)

198. The chase aircraft tried to call BUNO 163914 on frequency 122.75 while orbiting, but could not establish communication. Shortly after 10:00 the King Air switched to Eglin tower, and discovered the V-22 was 29 miles north of Eglin. (R1010, p.14)

199. At approximately 10:11 BUNO 163914 and the chase aircraft made radio contact and passed their locations to each other, but the V-22 transmissions were very weak. Mr. aboard the chase, indicated that the chase aircraft would try to catch up. (Exhibit 71, p.9)

200. The V-22 aircraft has a "dead cone" behind it for radio communication, a known problem. Since the chase aircraft was approaching it from behind, all transmissions from the V-22 were very, very garbled, unreadable or broken. At 10:15 the chase aircraft was still unable to understand BUNO 163914, but stated that they would be at 170 knots in the climb. (R1010, p.14)

201. Mr. Sullivan noted the "RTB RTR" CONDM warning indication at approximately 10:16. Mr. Rayburn suggested that it could be a pitch link, and requested that Mr. Mayan take a look at the instrumentation. (Exhibit 71, p.11)

202. At 10:18 Mr. Sullivan requested that MAJ James, who was at the controls, maintain 15,500 feet and 200 knots. (Exhibit 71, p.11)

203. At 10:20 MAJ James noted that the "QM" caution had just come up on the CONDM display. Mr. Sullivan stated: "Mast Torque. We know the mast torque is up." Mr. Rayburn stated that if they were unable to isolate the rotor they would have to land. (Exhibit 71, p.12)

204. At 10:22 Mr. Sullivan successfully communicated to the chase aircraft that they were troubleshooting an RTB from the CONDM display; he also requested that the aircraft be slowed to 170 knots. (Exhibit 71, p.12/13)

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205. At 10:24 the chase aircraft was approximately 40 miles behind, receiving the V-22 transmissions with a loud squeal in the background. (Exhibit 71, p.13)

206. At 10:25 Mr. Rayburn reported that the data fluctuations were probably related to a wiring problem, stated that they probably didn't have any kind of a clearance to continue, and asked Mr. Sullivan how he called it. Mr. Sullivan elected to continue the flight. Mr. Rayburn also pointed out that they had lost monitoring capability for that parameter, and the best they could do would be to have Mr. Mayan check the fluctuations periodically. (Exhibit 71, p.14)

207. At 10:27, after asking Mr. Rayburn for a ground speed/fuel remaining computation, Mr. Sullivan stated "We'll have 567 miles to go", (the distance to Quantico). (Exhibit 71, p. 14)

208. At 10:35 the chase aircraft was 38 miles behind, and notified BUNO 163914 that they were unable to gain because the V-22 was going too fast. The V-22 acknowledged, but took no action to slow down. Mr. Rayburn reported that it appeared that virtually everything on the left-hand head was breaking up, indicating a slip ring wiring problem. (Exhibit 71, p. 16)

209. At 10:46 Mr. Rayburn calculated that they would be on deck at Quantico with 700 pounds of fuel if they flew non-stop. Mr. Sullivan indicated that they should have more than that, because they would get better performance as they got lighter, and save some fuel in the descent. (Exhibit 71, p.18)

210. At 10:53 the chase was still having difficulty reading BUNO 163914 transmissions, when they were approximately 34 miles apart. At 10:54 Mr. Sullivan notified the chase plane that they were considering going all the way to Quantico, and asked the chase if they would be able to make it. The chase aircraft replied "negative". (Exhibit 71, p.20)

211. At 10:55 they had an MC-1 failure, which they later reset. At 11:00 Mr. Sullivan confirmed that fuel was transferring normally. (Exhibit 71, p. 20, 21)

212. After hearing calculations regarding ground speed and fuel amounts at 11:06, Mr. Sullivan decided that flying direct to Quantico was possible, and should be attempted if feasible, because otherwise "we'd never get out of Charlotte". He decided to keep an eye on things and make a decision outside of Charlotte. (Exhibit 71, p. 23)

213. At 11:07 the chase aircraft was 29 miles behind, and able to communicate with BUNO 163914. (Exhibit 71, p.23)

214. At 11:11 Mr. Sullivan and Mr. Rayburn discussed whether a chase plane was required. They decided that because a CONDM package, vice an ADAS package, was being used a chase plane was not mandatory. (Exhibit 71, p. 24)

215. At approximately 11:24 Mr. Sullivan asked if anyone had any problems with proceeding non-stop to Quantico. MAJ James expressed concern that LTCOL would be angry (that he didn't get to fly the final leg in to Quantico that he'd been planning for a long time). Mr. Rayburn's only concern was forward sponson fuel transfer; as long as it continued to transfer, he had no objection. At 11:25 Mr. Sullivan made the choice to continue to Quantico, and notified the chase aircraft. (Exhibit 71, p.27/28/37)

216. During further discussion Mr. Sullivan noted that if they went into Charlotte, they wouldn't be getting out that day, and there were no safety issues. Mr. Rayburn also thought the decision was sound, but thought there would be "a lot of Monday morning quarterbacking" after the flight. (Exhibit 71, p.28)

217. At 11:42 Mr. Sullivan computed that they would have about 1000 pounds of fuel remaining at Quantico. (Exhibit 71, p.32)

218. At 11:56 Sullivan asked MAJ James to call Flight Service and change the flight plan. Mr. Rayburn calculated that they would have 20 minutes of fuel remaining when they landed at Quantico. (Exhibit 71, p.35)

219. At 12:07 they estimated that they would land at Quantico with approximately full feed tanks (1000 pounds). (Exhibit 71, p.37)

220. During the descent at approximately 12:30, the airspeed was up to 238 knots for a brief period of time. (Exhibit 71, p.44)

MISHAP FLIGHT CHRONOLOGY

221. The mishap flight analysis is presented in four phases (Initial Flight Segment, Right Engine Surge and Accelerations, Right Engine Surges and Failure, Drive System Failure) as follows in Central Standard Time: (Exhibits 63A, 63C)

PHASE 1:	INITIAL FLIGHT SEGMENT
09:37:16	The analog backup computer (ABC) is declared failed in FCC #2 (known nuisance failure). Cleared by PFCS (Primary Flight Control System) RESET.
09:44-45	Right-hand engine start, then left-hand engine start
09:47:30	APU to stop
09:49:45	Periodic APU FAIL begins
09:52:35	Taxi
09:55:20	STOL takeoff at 60° nacelle angle.
09:56:10	Conversion to airplane mode
09:56:40	Periodic ECS FAIL begins
09:57	Continuous Near-real time Data Monitoring (CONDM) system warnings of Conversion Actuator Loads
10:16	CONDM "RTB RTR" warning
10:20	CONDM "RTB QM" (Mast Torque) warning reported in cockpit, but generally "RTB RTR" displayed due to warning priority system.
10:25	Crew evaluates problem as probably due to wiring. Mr. Sullivan (mishap pilot in command) decides to continue flight, vice landing as soon as possible.
10:51:40	Copilot MFD failure
11:24	Mr. Sullivan advises chase plane that he is bypassing Charlotte and proceeding direct to Marine Corps Base Quantico.
12:29:05	Airspeed 240 kt in descent (exceeded flight clearance 230 kt limit)
12:39:10	Initiate procedures for 200 kt fly-by at Quantico
12:40	Flaps to 20°, Nr to 100%
12:41:36	Start conversion from 0° to 44° nacelle angle
12:41:44.6	Nacelle conversion to 44° complete
PHASE 2:	RIGHT ENGINE SURGE AND ACCELERATIONS

12:41:50	44° nacelle angle, 120 kt, 1300 ft AGL (Above Ground Level)
12:41:52.3	Uncommanded power increase begins: Rapid increase in right engine Ng (gas generator turbine speed), Qe (torque) and MGT (Measured Gas Temperature) with no increase in power demand signal (PDS) or fuel flow (W_f). (Math modeling indicates an external source of flammable substance was consumed by the engine during this time period.)
12:41:53.6	Initiated nacelle conversion from 44° to 58°
12:41:54.1	Both left and right FADECs set the "FADEC on limit" bit (due to Np's at or over 105%).
12:41:54.2	L FADEC LIMITING caution. (No caution displayed for right FADEC limiting)
12:41:54.5	Stream of dark smoke exited the right nacelle exhaust, followed by a flash of light also at the exhaust, followed by a smaller, less dense stream of smoke. (Video data: ±1 sec accuracy)
12:41:55.6	Right engine surge (flow reversal) and rise in compressor inlet temperature
12:41:55.7	Completed nacelle conversion to 58°
	Left engine PDS momentarily increased due to OEI compensation triggered by right engine deceleration.
12:41:55.9	Dual left and right mast torque sensors declared failed causing the Primary Flight Control System (PFCS) fail light to illuminate and the torque command limiting system (TCLS) to hold its output fixed at -1.5 in. (Torque sensor failure was declared due to an engine to mast torque integrity check.)
12:42	Unexplained noise heard in cockpit by copilot
12:42:01	Right engine recovered from surge. The right engine now operating less efficiently than before the surge.
12:42:03	Faint white trail behind aircraft noted (Video data)
12:42:03-10	Three minor uncommanded accelerations in right Ng, MGT, accompanied by low specific fuel consumption (indicating further ingestion of flammable material unaccounted for by Wf). Wf lags power changes.
12:42:07	Second white trail behind aircraft noted. (Video data)
PHASE 3:	**RIGHT ENGINE SURGES AND FAILURE**
12:42:10	PFCS reset by crew causing TCLS to reactivate and to rapidly increase the PDS to both engines.
12:42:11	Series of three very bright flashes of light within 0.1 seconds. The first flash exited the engine exhaust. The second flash was seen on top of the nacelle above the engine inlet and below the rotor hub. The third flash was seen at the engine exhaust, where the first was seen. All three flashes were very

large, appearing to be as long as the nacelle itself (18 ft). (Video data: ±1 sec accuracy)

12:42:11.25 Recoverable right engine surge (brought on by TCLS' initiated PDS increase and additional flammable material ingestion by degraded engine.)

12:42:12.8 Unrecoverable right engine surge (prior to full recovery from preceeding surge) causing right engine shutdown.

12:42:13 Left engine picks up the load and drives both left and right rotor systems via the interconnecting drive shaft system.

PHASE 4: DRIVE SYSTEM FAILURE

12:42:15.0 Rapid increase on right proprotor gearbox and tilt axis gearbox oil temperatures.

12:42:16 58° nacelle angle, 100 kt in a slight rate of descent passing through 700 ft AGL.

12:42:18.7 Right mast torque (Qm) rapidly decreased to zero as the interconnecting drive system failed. (The drive shaft between the right proprotor gearbox and right tilt axis gearbox failed.)

Average Nr decreased. (With a failure of the right engine and the rotor interconnect shaft, the right Nr drooped, causing a decrease in average Nr. The reduction in average Nr caused the rotor governor to reduce in collective pitch, resulting in an overspeed of the left rotor/engine system. This overspeed was controlled to approximately 107% by FADEC Np limiting.)

Uncommanded right roll (Due to the rapid reduction of thrust on the right rotor as Nr drooped. A reduction in collective pitch by the rotor governor alleviated the thrust imbalance, assisted the pilot in stabilizing the roll axis.)

Uncommanded left yaw and right sideslip. (The uncommanded left yaw was due to the torque imbalance which was caused by high left Nr and low right Nr.)

Increase in rate of descent.

T12:42:19 All FCC #2 sensors and actuators (except Nr), hydraulic system 1, and all three channels of the right outboard swashplate actuator failed. (A function called "third fail inhibit," which prevents all channels on swashplate actuators from being turned off in the event multiple failures occur, continued to control the actuators as expected.)

Hydraulic system 1 was declared failed due to a leak resulting in loss of:
- Hydraulic nacelle control
- Left/right rudder control
- Inboard flaperon surface control

12:42:19.1 Left FADEC warning of a "Np overspeed". (Left engine Np was 111%.)

12:42:19.4 FCC #1 elevator, rudder, flaperon and conversion actuators are declared failed. (These failures are caused by the hydraulic system #1 attempting to isolate its leak.)

12:42:20	Left Np and Nr peak at 113%. Arrested by FADEC limiting
12:42:20.2	Left engine declared failed by the FCS. (False indication caused by deceleration resulting from FADEC limiting)
12:42:25.1	FCC #2 and the electric backup conversion control from FCC #3 failed. (Nacelle backup switches were not selected and this condition would not have prevented electric conversion actuator control.)
12:42:25.9	Second failure of the left inboard swashplate actuator. (This failure was generated in FCC 3 which controls the A and Standby channels for the left inboard actuator.) The hydraulic system 3 "reservoir low" bit is set, but no Warning or Caution other than "DUAL HYD FAIL". (This indicates that hydraulic system 3 reservoir dropped below 150 in^3.)
12:42:26.9	Hydraulic system 3 was declared failed, resulting (in combination with hydraulic system 1and FCC 2 failures) in loss of control of: - Elevator surface - Outboard flaperon surfaces (Hydraulic system 3 depleted its fluid through the leak detected in hydraulic system 1.) FCC 3 air data system failed.
12:42:27.2	Hydraulic system 3 "low pressure" bit set.
12:42:28.2	End of data, probable time of impact.

222. Aircraft state at impact is estimated to have been: (Exhibits 63A, 63C)
- Rate of descent: 6300 ft/min
- Impact "g" loading: 79g
- Longitudinal body axis velocity: 81 kt
- Lateral body axis velocity: 60 kt
- Pitch attitude: 14° nose down
- Bank angle: 3° right wing down
- Left Nr 397 RPM, right Nr 280 RPM

223. Subsystems that did not change state during the final two minutes of the flight (Exhibits 63A, 63C):
- Aircraft Electrical System
- Hydraulic System 2 (although FCC control was lost)
- Mission computer and FCC 1553 bus interfaces

MISHAP DATA

224. The Combined Operational Near-term Data Monitor (CONDM), an onboard self-monitoring safety of flight instrumentation package developed for the V-22 OTIIA government evaluation flight test program was operable during the mishap flight. Selected safety of flight parameters were monitored and compared to pre-programmed caution and warning limits. Flight exceedences were enunciated to the pilots by way of a cockpit console lighting display in the form of a warning or caution. Limited flying qualities and flight controls related parameters (primarily loads, vibration and engine related parameters) were recorded on CONDM. (Exhibit 63A)

225. The following CONDM warnings and cautions were capable of being displayed in the cockpit. The list is in order of priority of warnings. The pirority of the cautions is the same, except that transmission adapter striker and mast torque are the first and second priorities, respectively. (Exhibit 79)

Parameter	Warning	Caution
Engine Turbine Radial	RENNPG LENNPG	ENG 1P RENNPG LENNPG
Transmission Armpit Strain	RTB DS	DS
Transmission Armpit Crack	RTB DS	
Transmission Adaptor Striker (bondline)	RTB DS	BND LINE
Pitch Link Load	RTB RTR	RTR
Yoke Beam Moment	RTB RTR	RTR
Mast Torque	RTB QM	QM
Yoke Chord Moment	RTB RTR	RTR
FADEC Temperature	RTB TMP	
Bellows Temperature	RTB TMP	
Engine Accessory Gearbox		ENG 1P ENG 6P
Resultant Flapping		FLAPG

226. The NAVAIR Ferry Flight Clearance required cockpit warning for the following parameters for CONDM-only flights (Exhibit 16):
- Mast torque
- Transmission bondline striker load
- Transmission armpit strain

227.

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228. Only the single highest priority CONDM warning and caution can be displayed. Lesser priority warnings/cautions will not be displayed in the cockpit unless the higher priority ones cease to be active. The cockpit display cannot be cleared/acknowledged to show lesser priority problems. When a parameter passes through the threshhold from caution to warning, the caution will extinguish and the warning will be annunciated. (Exhibit 79)

229. When a CONDM monitored parameter exceeds the caution or warning threshhold for approximately 0.24 seconds or more, the attention light is illuminated for at least five seconds.

The pilot may reset the annunciated warning or caution, which will cause the light and the alphabetic annunciation to cease if the exceedance no longer exists. If the exceedance still exists, resetting will have no effect on the light or alphabetic annunciation. (Exhibit 79)

230. Starting at 10:16 CST during the mishap flight, the CONDM recorded numerous warning level exceedances in left Yoke Beam Moment (parameter 30BB21), left Mast Torque (20MT51) and left Yoke Chord Moment (30BC21). No caution level-only exceedances were recorded. Both yoke parameters caused warning light illumination and display of an "RTB RTR" warning. The Mast Torque warning, "RTB QM" was generally masked by the higher priority Yoke Beam Moment "RTB RTR" warning. The warnings were continuously displayed from 10:16 to 10:39:36. Due to MCU chip storage capacity, only limited exceedance data was stored, with no data available after time 10:39:36. (Exhibit 79)

231. The Data Logger was used to record all Mission Computer 1553 bus traffic during the mishap flight, which included status and information passed between the Mission Computers and six electronic units (three flight control computers, two nacelle interface units and one wing interface unit. (Exhibit 63A)

232. Non-Volatile Memory (NVM) is resident in each FCC. This memory is used to store a history of FCS failures. A maximum of fifteen failures can be stored on a 256 byte page. A new page is used whenever power to an FCC is cycled. All Weapon Replaceable Assemblies (WRAs) are assigned unique codes which will be stored in NVM in the event of failure. Stored along with this code is a time of failure occurrence, or time tag. (Exhibit 63A)

233. Data Logger and CONDM both acquire data from the Mission Computer 1553 bus. For most of the cases, CONDM lags Data Logger by 300 to 500 ms. (Exhibit 63A)

234. The CONDM sampling rate is 82 ms. The Data Logger data rates vary, depending on the request rate on the Avionics Bus. (Exhibit 63A)

235. Engine data is sent to the Mission Computer by way of the FCC. Engine data is transmitted at 40 Hz to the FCC and after processing is buffered to the Mission Computer Bus at 160 Hz. This data is requested by the Mission Computer at 10 Hz. Engine data is used in control paths for engine, mast torque, and rotor rpm monitoring in addition to being sent to the Mission Computer. The FCC processes engine rpm data at 40 Hz, engine torque at 10 Hz and engine fail indication at 10 Hz. (Exhibit 63A)

FUEL SYSTEM

236. The aircraft fuel system provides fuel to both engines throughout the aircraft flight envelope, using a fuel transfer system and fuel feed system controlled by two Fuel Management Units (FMUs). Fuel is transferred from the sponson tanks to left and right wing feed tanks, and fed into the left and right engines, respectively. Fuel is normally transferred in a suction mode, unless the aircraft is above 10,200 feet, when boosted mode is used. Boosted mode can also be selected by the pilots from the cockpit fuel system display. During normal operation, the FMU balances the fuel level in the sponson tanks, using the Cross-Transfer mode to send fuel from the high side to both wing tanks; when left and right sponson tank levels match, the Normal Transfer mode is used, and sponson fuel is sent from each side to the respective wing tank. (Exhibit 28, Section 2.4)

237. The mishap aircraft was configured with 3 sponson tanks (1 left, 2 right) in addition to the left and right wing tanks. The FMUs correctly balanced the fuel by transferring fuel from the two right sponson tanks to both wing tanks first (Cross-Transfer mode), then transferring fuel from the left and right sponson tanks to the left and right wing tanks respectively (Normal Transfer mode). (Exhibit 48, p. 3-1)

238. On the mishap flight, the pilots operated the fuel system in the boosted mode (vice suction) throughout the flight. (Exhibit 48, App. G, L/R FMU Data Words)

239. The fuel transfer system worked properly throughout the mishap flight, providing proper fuel balance between left and right hand sponson tanks, and transfer from the sponson tanks to keep the feed tanks full. During the entire flight, both feed tanks remained within their normal range (520-600 lb) of fuel quantities. (Exhibit 48, p. 3-1)

240. At time of impact, the fuel was balanced between both sides, with approximately 1375 total pounds of fuel remaining, and 1100 pounds of fuel in the feed tanks. (Exhibit 48, App. G)

241. The feed tanks provided fuel continuously to both engines. The left engine recieved fuel until the end of the flight. The right engine received fuel until it was shut down by the FADEC, moments before impact. There was no evidence of fuel starvation to the right engine. (Exhibit 48, p. 3-7)

242. Fuel samples taken from the Eglin AFB fuel truck which last serviced the mishap aircraft were normal. (Exhibit 52, Tab C)

ENGINE SYSTEM

243. The V-22 is powered by two Allison T406-AD-400 tuboshaft engines, located in the nacelles on the end of each wing. Described from front to back, each of the modular engines has a torquemeter assembly, a 14-stage axial compressor with variable guide vanes, an annular combustor, a 2-stage gas generator turbine, and a 2-stage power turbine. The compressor is connected to, and powered by, the gas generator turbine. The power turbine is connected to the torquemeter assembly, and provides the operating power to the proprotor via the torquemeter assembly and the proprotor gearbox. (Exhibit 28, Sec. 2.2)

244. Each engine on the V-22 is controlled by a Full Authority Digital Engine Control (FADEC). The Flight Control Computer (FCC) sends a Power Demand Signal (PDS) to the FADEC. The PDS is a computed signal based on the TCL position, ECL position, AFCS output and TCLS output. The FADEC converts the PDS to a temperature corrected gas generator speed (Ng) command, and regulates the fuel flow (Wf) command, to the Fuel Pump and Metering Unit (FPMU), to maintain the commanded Ng. The FADEC also controls the compressor variable guide (CVG) vanes, with fuel pressure, to provide for optimum airflow through the compressor. Each FADEC is backed up by an identical FADEC which will take over automatically if the operating FADEC fails. A parallel Analog Backup Engine Computer (ABEC) is also selectable by the pilot if both FADECs fail to control the engine. (Exhibit 28, Sec. 2.2; Exhibit 63, p.117)

245. Acceleration and deceleration schedules are incorporated in FADEC algorithms to regulate the rate of change of fuel flow and are designed to provide smooth, stable engine performance. There is also a limit of 3000 lb/hr on the maximum fuel flow rate, a minimum fuel flow limit to prevent the FADEC from commanding less than self-sustaining fuel flow (130 lb/hr), and a lean blowout limit to prevent excessively rapid decreases in fuel flow that might result in a flameout. (Exhibit 63, p.120)

246. In addition to the limits listed above for normal operation, engine protective limits have been set for safety purposes to prevent steady state engine operation above specified values. The FADEC monitors the engine for exceedences in Power Turbine Speed (Np), Gas Generator Speed (Ng), Engine Torque (Qe), and Measured Gas Temperature (MGT). The following actions are taken by the FADEC in response to exceedences of limit values (Exhibit 28, Chap. 4; Exhibit 50, Sec. 4.3; Exhibit 63, App. A):

- The FADEC cuts back fuel at Np (15750 RPM) to avoid exceeding the maximum transient Np If the engine reaches Np (17100 RPM) the FADEC shuts down the engine by energizing a cutoff solenoid in the FPMU that shuts off fuel;
- The FADEC cuts back fuel at Ng (15339 RPM) to avoid exceeding the maximum transient Ng If the engine reaches Ng (16750 RPM) the FADEC shuts down the engine via the FPMU cutoff solenoid;
- The FADEC cuts back fuel at) Measured Gas Temperature (MGT); and
- The FADEC cuts back fuel at

247. The following FADECs were installed on the mishap aircraft (Exhibit 49, p. 6):

Engine	FADEC	FADEC Ser #	Software Ver	Cmptr Ser #
RH	A	BX31853	T40PPU36A	J01V005A
RH	B	BX31824	T40PPU36A	J01T014
LH	A	BX31829	T40PPU36A	J01V032
LH	B	BX31850	T40PPU36A	J01W113

248. Fault codes stored in each FADEC indicate events that occur during each flight, although not the order or time of the events. All FADEC memory was recovered. The following faults, by individual FADEC, were recorded (Exhibit 49, p. 11):

A11B-4

- RH FADEC A: Torque Sensor Fault; Failure to Auto-relight; CVG Stepper Motor Fault; FPMU Fail
- RH FADEC B: Torque Sensor Fault; Failure to Auto-relight
- LH FADEC A: ABEC Fault; Torque Calibration Fault
- LH FADEC B: ABEC Fault; Torque Calibration Fault

249. Engine Summary. The RH engine was damaged by ingestion of a combustible fluid from an external source causing outside burning/melting of the combustion liner and two recoverable surges. (A surge is defined as an airflow reversal in the engine.) The distressed engine then suffered a heavy, unrecoverable surge. This was due to either compressor FOD, combustion liner damage, ingestion of combustible fluid or a combination of two or more of those conditions. The RH engine could not maintain speed and was shut down by the control system. The LH engine went to One Engine Inoperative (OEI) status and ran at the torque limit for nearly six seconds, when the engine saw a loss of load as a result of a failure in the drivetrain. The LH engine then operated on the overspeed limiter at low power demand, until water impact. (Exhibit 50, pp. 1 and 44)

250. Both engines operated normally on the temperature corrected Ng (Ng_C) control schedules, as commanded by the PDS from the flight control computer, for Phase 1 of the flight (prior to 12:41:50) (Exhibit 50, p. 33/37).

251. An uncommanded RH engine power increase, leading to the first recoverable engine surge, started at 12:41:52.3. The uncommanded power increase resulted from the ingestion of a flammable fluid into the engine inlet. (Exhibit 50, p.33; Exhibit 60, p.4-4; Exhibit 63, p.23).

252. During the first recoverable surge event on the RH engine, the engine control system adjusted fuel flow (Ng governing) in an attempt to maintain Ng_C control in response to the PDS. (The fuel flow trace indicated that fuel flow was reduced to the minimum allowable on the deceleration fuel flow schedule). No FADEC faults were set during the first surge event, but the FADEC status sent to the Flight Control Computer (FCC) showed FADEC A "On Limit", which corresponded to the fuel flow schedule for Np exceeding the 105% overspeed limit. (Exhibit 50, p. 33; Exhibit 63, p. 23).

253. The first surge on the RH engine at 12:41:55.6 was marked by a step 20°F rise in inlet temperature which was similar to a previous flight test incident on another engine. The surge was particularly identifiable because the inlet temperature sensor registers changes in temperature very slowly; to get such a rapid rise in inlet temperature, a much higher pulse of hot air was needed. Using a computer model, the actual inlet temperature was calculated to increase 125°F (from 85°F to 210°F) in less than one tenth of a second. (Exhibit 50, p. 33; Exhibit 50d)

254. An external/unmetered flammable fluid was ingested into the RH engine during the first surge event, as indicated by the increasing Ng, MGT and Qe at the same time that fuel flow was reduced to the minimum allowable. Further analysis was completed that showed at least five distinct events of combustible fluid ingestion by the RH engine between the first surge event and engine failure. The analysis was based on observed specific fuel consumption versus the specific fuel consumption normally required to produce the observed engine horsepower output. The analysis is corroborated by a shift in the relationship between Ng and Wf after the first surge event. (Exhibit 50, p.33; Exhibit 50e; Exhibit 63, p.26)

255. The RH engine exceeded its transient MGT operating limit of 1621°F by reaching 1646°F during the first surge event. (Exhibit 50, p.34; Exhibit 60, p.4-4).

256. The RH engine was degraded after the first surge event, requiring more fuel flow to produce a given Ng. (Exhibit 63, p.25).

257. At 12:42:10 a PFCS Reset, performed by the crew in response to a "Dual Transducer" caution, momentarily reactivated the torque command limiting system (TCLS). TCLS increased PDS in an attempt to provide the level of torque commanded by the TCL. An increase in right/left fuel flow, Ng and Qe occurred initially in response to the PDS increase. (Exhibit 71, P. 49; Exhibit 63, p. 16)

258. The RH engine sustained a second recoverable surge at 12:42:11.2, with a rapid 20°F inlet temperature rise. Actual temperature was calculated, using the computer model, to rise 95° (from 85°F to 180°F) in one tenth of a second. Immediately following the surge, the RH engine experienced an uncommanded decrease, then increase, in Ng and Qe. The changes exceeded the flight control computer engihe failure detection logic, and the RH engine was "declared failed", even though it continued to operate. As a result, the PDS to the LH engine was boosted with One Engine Inoperative (OEI) compensation. (Exhibit 50, p.36; Exhibit 50d; Exhibit 63, p. 16/20).

259. A rapid increase in RH engine Np, Ng, Qe and MGT continued after the second surge event, even though the FADEC responded by cutting fuel flow to the deceleration fuel flow limit. These conditions were a further indication of an additional flammable fuel source. (Exhibit 50, p. 35)

260. The increased power from the RH engine caused both LH and RH power turbine/ rotor systems to overspeed to 108%. Both the LH and RH FADECs reported limiting at 12:42:12.3, as a result of LH and RH Np greater than 105%, and RH MGT greater than 1640°F. (Exhibit 63, p.16).

261. The RH engine sustained a third, unrecoverable, surge at 12:42:12.8. The surge was indicated by a large step increase in inlet temperature, (calculated to be 350°F, from 100°F to 450°F in 1½ seconds), and a rapid uncommanded decrease in Ng and Qe. The surge and inlet temperature increase were similar to the results of a FOD incident on the Ground Test Article. The rapid drop in Qe caused both RH FADECs to register a "Torque Sensor" fault. RH engine flameout and RH engine ignition requests were initiated by FADEC A (the FADEC in control). When Ng decreased below 8500 RPM, FADEC A declared a "Failure to auto-relight" fault (also recorded by FADEC B) and shut off fuel to the engine. The positioning of the variable inlet guidevanes lagged the rapidly decreasing Ng, and FADEC A erroneously declared the "CVG stepper motor" and associated "FPMU" faults. These last two faults also caused FADEC A to declare itself failed, and yeild control of the engine to FADEC B. (Exhibit 50, p.35; Exhibit 50d; Exhibit 63, p. 16/17).

262. There were no anomalies with the LH engine, which operated either on the normal Ng_c control schedule, or on limiting schedules for Np or torque. The "ABEC" fault recorded by both LH FADECs was not corroborated by aircraft data, and probably occurred as a result of water impact. The "Torque Calibration" fault resulted from a failure to re-calibrate with the proper torquemeter values after FADEC A was changed during maintenance at Eglin AFB. Because of the "Torque Calibration" fault, both LH FADEC A and LH FADEC B used default calibration values to calculate torque. (Exhibit 50, p. 38-40).

263. The LH engine received a momentary increase in PDS from the FCC during the first RH engine surge. The FCC provides momentary compensation when two of the three conditions for engine failure detection are met (rapid Ng decrease and rapid torque decrease). The LH PDS signal reverted to normal as the RH engine recovered. (Exhibit 50, p.4; Exhibit 63, p.118).

264. Following the second RH engine surge the FCC sensed all of the One Engine Inoperative parameters, declared the RH engine failed, and boosted the PDS signal to the LH engine. The power ouput from the RH engine, due to the ingestion of flammable fluid was greater than the LH engine power with boosted PDS. As a result, the RH engine powered the rotor system until RH

engine failure at approximately 12:42:13. The excessive RH power output prior to failure was reflected in an Np overspeed (past 105%). Since RH Np is coupled through the rotor system to the LH engine, an identical LH Np overspeed occurred. Both engine FADECs reduced fuel flow to prevent further overspeed (Np limiting). (Exhibit 50, p.35; Exhibit 63, p.29).

265. The LH engine powered the rotor system until the driveshaft failed at 12:42:18.7. Following the driveshaft failure, the RH rotor speed (Nr) began to decay (unpowered by either engine) which caused the average Nr to decrease. The FCC responded by reducing collective pitch on the rotor system in an attempt to maintain 100% Nr, which kept the LH engine in an overspeed condition. The LH FADEC responded by reducing fuel flow to minimum to reduce/prevent further overspeed. The rapid decel from FADEC limiting caused the FCC to declare a LH engine failure, although the LH engine continued to operate at the low fuel limit. (Exhibit 63, p.31).

266. The RH engine showed significant damage, other than impact damage, that occurred during engine operation. The outer liner wall of the combustion liner was missing for approximately 120° in circumference, and from the primary holes to the cooling baffle behind the dilution holes. Missing material and condition of remaining wall material indicates that a combustion process took place outside the chamber (vice normal burning inside) which resulted in liner wall failure. Further indication of abnormal combustion and intense heating is matched by hardware distress downstream in the turbine area, where an estimated 2660°F temperature exceeded the maximum turbine temperature of 2290°F. Analysis of combustible fluid sources concluded that an additional combustible fluid had to have entered the engine inlet. (Exhibit 50, p.30-31).

267. The RH engine also received Foreign Object Damage (FOD) to the compressor blades and vanes from an object entering the engine intake. Several pieces recovered from the compressor are from an electrical connector. (Exhibit 50, p.32).

268.

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DRIVE SYSTEM

INTRODUCTION

269. All components analyzed with the exception of the right pylon shaft, right flexible couplings on the pylon shaft and the centerbody of the right engine air inlet, were found to have been fractured during impact. (Exhibit 60, p 3-5)

270. Both the left and right rotor systems, including the mechanical portions of the flight controls were intact at the time of impact. All damage is consistent with sudden stoppage/impact. All metalic component fractures were from overload, either tension, tension/bending or shear. (Exhibit 60, paragraph 5.2.1)

271. Following nacelle conversion from airplane mode to intermediate nacelle angles of from 44° to 58° and at about 120 knots and 1300 feet altitude, the right engine experienced two events (phases 2 & 3) of power increase independent of measured fuel flow. Engine surges occurred on both events and a subsequent over temperature and right engine failure occurred on the second event (phase 3). Review of the video tape of this same time frame revealed four very large"flashes", one during the first event and three (almost simultaneously) during the second event. The last three flashes are very large, with the second engulfing the aft top of the nacelle at a level above the engine inlet. (Exhibit 60, p 3-1; Exhibit 63a, p 239-241)

272. Other than the FCS rotor torque sensor faults, no other failures, faults or anomalies were observed for the left engine, TPMS, FADEC's and drivetrain. The drive system did not exceed any design limit loads during the first event. (Exhibit 60, paragraph 4.2)

273. The second event was characterized by an apparent surge of the right engine followed by a continued power increase independent of PDS and measured fuel flow. It then flamed out after exceeding the MGT limit of 1640°F (phase 3). No drive system design limit loads were exceeded during this event and the drive system continued to transmit power from the engines to the rotors as designed. (Exhibit 60, paragraphs 4.3 & 4.3.3)

274. The right nacelle lateral vibration transient response to the first engine surge was three times that of the left nacelle. This anomaly is attributted to a problem with the accelerometer or its signal conditioning, or could have been caused by excessive heat. (Exhibit 60, p 4-6)

275. A third event (phase 4) occurred approximately six (6) seconds after the right engine failure. The right rotor had continued to receive power, then being supplied by the left engine, until the Interconnecting Drive System (ICDS) failed. The right rotor lost torque and its speed decayed rapidly. The data analysis showed this failure to be the pylon shaft between the right TAGB and the right PRGB. (Exhibit 60, p 3-1)

276. Shortly after the right engine failed, the right PRGB and the right TAGB oil temperature increased at an abnormally rapid rate and continued to rise for approximately 6 seconds until just after the ICDS failure. (Exhibit 60, p 3-1)

DRIVE SHAFTING

277. The fractures of all shafting and couplings other than the right pylon segment were the consequence of structural failure of the wing or pylon support members at impact, or were salvage damage. (Exhibit 60, par. 5.2.2)

278. The left and right rotors desynchronized at 12:42:18.2 and the right rotor speed decreased, indicating failure of the ICDS. This was approximately six seconds after the right engine failed. (Exhibit 63, paragraph 3.2.3.3)

279. The right pylon composite driveshaft failed in flight and was the point of primary subsystem failure. (Exhibit 60, p 5-1; 3-2)

280. Both flexible couplings of the right pylon shaft system failed in flight subsequent to and as a result of the composite shaft failure. (Exhibit 60, p 3-2)

281. Interconnect drive shafting in the V22 is carbon filament /epoxy resin composite tube construction. (Exhibit 60, paragraph 5.1.2.2)

282. Ultrasonic inspection data from the original manufacturing records showed that the shaft had no significant defects and readily met acceptance criteria. (Exhibit 60, paragraph 5.1.2.1)

283. The clamps retaining the PRGB breather filter/dryer were found failed. In-flight fatigue failure of the PRGB breather filter/dryer clamps and displacement of the filter dryer could have allowed the hose to contact and abrade the pylon shaft. The clamp fractures were due to over stress, not fatigue. The hose for the left nacelle had contacted the left pylon shaft on impact and fragments of composite fiber were embedded into the stainless steel over braid for the hose. This did not occur on the right hose, indicating that the hose did not abrade the pylon shaft and that the shaft failed prior to impact. (Exhibit 60, p 5-8)

284. Epoxy resins have a drastic reduction of strength with increasing temperatures above the glass transition temperature (Tg), the temperature at which the epoxy matrix loses strength and stiffness. In the case of the V22 interconnect drive shafting, Tg is approximately 240°F. (Exhibit 60, p 3-2)

285. The recovered portion of the right pylon shaft had exceeded its glass transition temperature, resulting in failure of the tubular carbon filament wound structure while under one engine inoperative (OEI) conditions. Some of the ductile deformations observed are impossible without exceedance of the glass transition temperature. Additionally, there are indications that twisting of the shaft occurred while at the glass transition temperature. (Exhibit 60, p 3-2; paragraph 5.1.2.1)

286. The fiberglass/epoxy overwrap on the recovered piece of the right pylon shaft was discolored. Temperature exposure tests were conducted and visual comparisons made to pieces of the right shaft outer diameter and inside diameter overwrap. These tests confirmed that the shaft was exposed to extreme temperatures. The specific initial failure mode (i.e., torsional shear, torsional buckling, bending due to whirl) or location could not be determined from the recovered piece alone. However, a whirling failure mode is not consistent with the failure of the forward coupling or the vibration data which indicates that <u>whirling did not occur</u>. Wires wrapped around the failed component were determined to be a secondary result of the failure. (Exhibit 60, paragraph 5.1.2.1)

287. The splined adapter which mates with the TAGB bevel pinion forms the coupling hub for the right pylon shaft aft coupling. The splined end of the adapter shows no indications of failure. The diaphrams were cleanly sheared from the hub.The diaphrams were sheared axially from the hub due to excessive angular misalignment (bending) of the coupling. Since the fracture of this coupling is not due to torsional shear, it is not a primary failure. The <u>excessive misalignment would be consistent with</u> a <u>whirling</u> or <u>flailing</u> pylon shaft, or <u>gross deflection of the nacelle</u>

structure. There was no indication of gross nacelle deflection until impact. From analysis of vibration data, there was no indication of shaft whirl prior to failure. (Exhibit 60, paragraphs 5.1.2; 5.1.2.2)

288. The right pylon shaft forward coupling OD clamp ring and diaphragm pack was found attached to the forward end pieces of the right pylon shaft. The hub had remained attached to the interconnect gear on the Right Proprotor gearbox. Three of the OD clamp ring bolts/nuts were missing from coupling. The diaphragms were sheared axially from the hub due to an excessive axial load primarily from tension (extension) of the coupling. The missing bolts were lost due to secondary coupling impact. Since the fracture of this coupling is not due to torsional shear, it is not a primary failure. The excessive axial extension would be consistent with shortening of the pylon shaft due to buckling, or gross deflection of the nacelle structure. There is no indication of gross nacelle deflection until impact. (Exhibit 60, paragraph 5.1.2; 5..1.2.1; 5.1.2.3)

289. The rotor system was intact at time of impact. All damage is consistent with sudden stoppage/impact. (Exhibit 60, paragraph 5.2.1)

290. The rotor shafts and the components in the interconnect drive system were not subjected to loads in excess of design limits. (Exhibit 60, p 3-1)

291. No significant torque transients of these drive system components had been reported during prior operation. The highest torque previously reported for the ICDS was 112% of the maximum continuous rating. This torque level does not exceed the transient rating of 113%. (Exhibit 60, p 6-1)

292. There has been a low incidence of exceedance of the drive system maximum continuous ratings previously, as indicated by the low accumulated fatigue damage. Both PRGB's had less than one hour of in-flight OEI operation and time at greater than 4000 HP. Calculated fatigue damage fraction reported for the ICDS is 0.429% and .0016% for the right proprotor input. (Exhibit 60, p 6-1)

293. The drive system had recently completed climatic survey tests and post test visual inspection, ground runs and maintenance flights. (Exhibit 60, p 6-2)

294. Non-flight one engine inoperative (OEI) time of 2.65 hr was accumulated during climatic lab testing. The highest ICDS torque experienced during these tests was approximately 81% of the interconnect system maximum continuous rating. This load level occurred for less than .4 hr. The remainder of the OEI time was at or below 51% of the maximum continuous power rating. (Exhibit 60, p 6-2)

295. Previous engine transients which excited the drive system torsional modes were reviewed to assist in estimating the interconnect drive shaft (ICDS) torque during the mishap. Two types of engine transients were reviewed: (1) momentary pulse in engine torque; and (2) sudden loss of all engine power. The ICDS torque discussed here is referenced to wing shaft rpm. The highest ICDS oscillatory response due to a pulse was seen during airplane mode testing on V22 serial number 90001 during a left engine compressor surge. The derived torque was within of the measured value. The highest ICDS torque due to sudden loss of torque from one engine was on V22 S/N 90001 during a FOD occurrence while ground running the aircraft. The ICDS torque went from a 4000 in-lb nean to a 25,000 in-lb mean with an initial oscillation of 10,000 in-lb. The dynamic amplification for the 61% engine torque drop was 1.4. (Exhibit 60, paragraph 6.2.1)

296. For the pylon shafts, the maximum continuous rating is lb, the transient rating is in-lb, the limit static torque is , and the ultimate static torque is ' in-lb. During the OEI operation following the failure of the right engine, the left pylon shaft transient rating was exceeded by less than 6%. The transient rating was not exceeded by the right pylon shaft due to the power extractions by the left tilt axis gearbox, midwing gearbox, and right tilt axis gearbox. The calculated combined losses and accessory load for the drive system are compatible with expected values during the relatively steady state conditions at this time. (Exhibit 60, paragraph 4.4.3)

297. A test program was conducted during October 1988 to demonstrate qualification performance capabilities of the driveshaft tube assemblies for the V22. Two pylon mount driveshaft assemblies were tested. (Exhibit 72a, paragraph1.0)

298. One pylon mount tube assembly was subjected to 95% relative humidity and 160°F until equilibrium weight gain was obtained. It was then heated to 180°F and torqued at a rate of 2000 inch pounds per second to 39,600 inch-pounds, held for ten seconds and then ramped, at the same rate to failure at inch-pounds. The driveshaft tube assembly complied with the specification requirements in all respects. (Exhibit 72a, paragraph 5.5.3)

299. The choice of composite construction for the pylon drive shaft was based on weight savings, damage tolerance and its ability to provide a stiffer, more easily balanced high speed shaft. (R1110, R 1120, p 7-8)

300. Failure analysis for drive shafts addressed single failure modes only and did not address the possibility of collateral damage from a failed drive shaft leading to multiple system failures. (R1110; R1120, p 17-18)

301. The impact on nacelle operating temperatures of a blower fan failure wasn't an initial design consideration, but was looked at late as a result of two nacelle blower failures early in the program. It was calculated that the nacelle temperature could be kept at around 224°F by maintaining a 150 Kt airspeed. (R 1120, p 13-14)

GEAR BOXES

302. All gearboxes were recovered, disassembled and examined and found to be free of failures or damage related to the in-flight portion of the mishap. There were no gear, bearing, internal shaft or clutch failures up to the time of impact. (Exhibit 60, p 3-2; paragraph 5.2.2)

303. Instrumented lubrication system components were installed during climatic lab testing and replaced with production parts following the tests. Test PRGB input quills were installed during the climatic tests. The original flight quills were installed following the tests. Maintenance runs were conducted and leak checks performed following the component replacements. (Exhibit 60, p 6-2)

304. The last records of maintenance activity for the drive system was the PRGB oil-pump drive and oil filter element inspection. (Exhibit 60, p 6-2)

305. Chip detector log sheets show no history of significant debris generation by any gearbox. (Exhibit 60, p 6-2)

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306. The mishap occurred after a continuous 2 hour 44 minute flight with no drive system anomalies indicated or reported. No over torques were experienced during the flight prior to the mishap events. (Exhibit 60, p 6-3)

307. During the ferry flight, the right TAGB oil pressure gradually changed from 60 - 68 psi to 51 - 60 psi during airplane mode operation; consistenly lower than the left TAGB oil pressure for the entire flight. No factual explanation can be provided for this, but it could be related to a missing O-ring (internal) on the pressure regulator. (Exhibit 60, p 6-2)

308. The right TAGB and midwing gear box (MWGB) oil pressures fluctuate more than the other gearboxes due to the constant frequency generator being in series with the gearbox lube system. (Exhibit 60, p 6-3)

309. Prior to departure from Eglin, the drive system, excluding the proprotor gearboxes had operated a total of 209.2 hours (excluding ground run 81, Test 173). Flight time was 101.6 hours. (Exhibit 60, p 6-1)

310. V132 The proprotor gearboxes had been replaced with zero time (new) units at 96.9 hours operating time, 52.4 hours flight time. (Exhibit 60, p 6-1)

311. The right TAGB bevel section was properly attached to right nacelle spindle. (Exhibit 60, paragraph 5.2.2.4)

312. The right PRGB was found attached to right pylon structure. No damage or degradation of the mounting system was evident. The mast was intact and supported the proprotor hub and remains of the rotors. (Exhibit 60, paragraph 5.2.2.5)

313. The engine torque housing remained attached to the gimbal ring, which remained attached to the proprotor gearbox input quill housing. (Exhibit 60, paragraph 5.2.2.5)

FLIGHT CONTROL AND HYDRAULIC SYSTEMS

314. The primary flight control system (PFCS) provides basic aircraft control, power management, force feel, and trim control in all flight modes. Three redundant digital flight control computers (FCC) convert the pilot inputs to electrical signals which are transmitted by wire to the flight control servoactuators and engine controls. Complete flight control system redundancy (computers, sensors, data buses, hydraulic and electrical power sources, and control actuation) is provided. (Exhibit 28, p. I-2-53)

315. The V-22 Thrust Power Management System (TPMS) provides power control and rotor speed governing for all modes of flight. The inputs to the TPMS include pilot inputs, in the form of Thrust Control Lever (TCL) and Engine Condition Lever (ECL) positions; engine measurements, which include gas generator speed (Ng) and engine torque (Qe); and aircraft measurements, rotor speed and mast torque (Qe). The output of the TPMS is a Power Demand Signal (PDS), sent to the Full Authority Digital Engine Control (FADEC), and rotor pitch command, sent to the swashplate actuators. The governor maintains average rotor speed at the required helicopter (100%) or airplane (83.8%) rotor speed by regulating symmetric collective pitch. (Exhibit 63, p. 245-254)

316. The increased power from the right engine during the first surge event caused an overspeed of the power turbine and rotor systems to 108%. The FADECs responded as expected, initially reducing right engine fuel flow due to the uncommanded increase in Ng, then to both engines in response to the Np overspeed. The peak left or right mast torques during the surge was 60% and 70% respectively. (Exhibit 63, p. 36-46; Exhibit 60a, p. 4-5)

317. The rapid deceleration of the right engine momentarily set OEI compensation on the left engine. OEI compensation doubles the power demand of the good engine (within FADEC limits) but is "latched" only if the failed engine torque decreases below ft -lbs. (Exhibit 60a, p.4-4; Exhibit 63, p. 251)

318. Dual mast torque sensor failures were declared by all FCCs at 12:41:55.9, resulting in the TCLS being frozen at a power level equivalent to -1.5 inches of TCL and illumination of a DUAL XDCR FAIL caution. The -1.5 inches bias was created by the TCLS reduction of the PDS in response to the uncommanded power increase. (Exhibit 63, p.45)

319. The validity of the mast torque signal is checked by rate and range monitors and supplemented by engine/mast torque comparison. The simultaneous failure of all sensors typically indicates the torque sensors failed through the engine to mast torque integrity check. (Exhibit 63, p.94)

320. The failure of dual mast torque sensors caused the MFD digital display of mast torque to freeze. Although the MFD indicated approximately 55%, the actual mast torque was much less, thus the rate of descent following the surge. (R1023, p. 13-14)

321. The TCLS reduces the PDS to provide a linear mast torque vs. TCL schedule and prevents steady state overtorques. The full forward position of the TCL is limited to 100% of the transmission rating with TCLS ON and the engine power available with TCLS OFF (no overtorque protection). The authority of the TCLS is equivalent to 2 inches or 50% of total TCL movement. The cockpit displays do not indicate the TCLS contribution to the PDS during normal operations nor the magnitude of the bias following a failure. (Exhibit 63, p. 247)

322. A DUAL XDCR FAIL is a critical flight control system failure, and the flight crew must manually reset the system by pressing the PFCS FAIL/RESET switch on the glareshield. However, the large number of nuisance sensor failures experienced during FSD has made resetting the PFCS a common occurrence rather than an emergency procedure. (Exhibit 63, p.94-97; Exhibit 28, p. V-14-8)

323. The dual mast torque sensors and TCLS was reactivated at 12:42:10.0 by the flight crew. Activation of the TCLS with a -1.5 inch bias was equivalent to a 1.5 inch step increase in TCL. The demanded power increase from the damaged right engine contributed to the subsequent surge events. (Exhibit 63, p.50, 94-97)

324. The FCS declared the right engine failed at 12:42:11.2 and set OEI compensation on the left engine. The FCS detected a deceleration rate exceeding the fast failure algorithm, i.e, Ng and torque more than - b4 rpm/sec and b4 -lbs/sec, respectively. The OEI compensation was "latched" when engine torque momentarily decreased below b4 -lbs. (Exhibit 63, p.50-52, 251)

325. The FCS declared the right engine failed, annunciated the failure to the flight crew, and set OEI compensation on the right engine before the actual failure of the engine. The FCS monitors the engine operation and declares the failure, but does not control the engine shut-down. The right engine continued to run several second after the FCS declared the engine failed. (Exhibit 63, p. 50-52, 251)

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327. The failure of the mast torque sensors caused TCLS to freeze, holding its output fixed at a position equivalent to -0.3 inch of TCL. There is no indication that another RESET of the PFCS was attempted. (Exhibit 63, p. 54)

328. The sudden loss of right rotor torque due to the ICDS failure resulted in an overspeed (Np above 105%) of the left engine and rotor. The peak Np speed was 113%, or within 1% of automatic fuel shut-off. Rotor governing, thus Np control, uses average rotor speed, therefore normal governing of the left engine/rotor was not possible with the average rotor speed below 100%. (Exhibit 63, p.73, 148-151; Exhibit 60, p.4-12)

329. The FCS declared the left engine "failed" following the ICDS failure. This "false" indication of failure was caused by the rapid rate of change in average rotor RPM and the decay in the buffered FADEC Np speed. Although the left engine continue to operate on Np limiting until impact. (Exhibit 63, p. 110)

330. The governing function of the FCS reduced collective pitch in both rotor systems in an attempt to maintain the commanded average rotor speed of 100%. The loss of thrust to both rotors resulted in a high rate of descent. Even though the left engine was providing power, the "flat-pitch" in the rotor system provided very little thrust. (Exhibit 63, p.73-74)

331. The reduction in left rotor collective pitch by the FCS alleviated the thrust imbalance caused by the right engine and ICDS failures, allowing the pilot to stabilize the aircraft roll axis. (Exhibit 63, p.59)

332. Failure of the right hand pylon shaft caused damage to the right outboard swashplate actuator, resulting in failure of FCC #2 and a leak in hydraulic system #1. (Exhibit 63, p.103)

333. The failure of hydraulic system #1 was due to rate of change in the reservoir level, indicating a leak rate greater than 20 cubic inches/sec b4 l/min). (Exhibit 63, p.103-108)

334. The first step in the hydraulic leak isolation process is to depressurize all wing and empennage actuators while guaranteeing pressure to both sides of the swashplate actuators. The leak isolation also limited system #1 pressure to the left nacelle and switched system #3

pressure to the right swashplate actuators. Therefore, the isolation logic caused partial loss of hydraulic power to the elevator, rudder, flaperon, and conversion actuators in response to the right outboard actuator leak. (Exhibit 63, p.110)

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336. The swashplate actuators are outside the hydraulic system isolation and switching valves, therefore isolation of the leak was not possible and partial loss of the primary (#1) and the utility hydraulic (#3) systems resulted. (Exhibit 63, p.116-120)

337. The utility hydraulic system (#3) failed due to reservoir level below B4 :ubic inches. The FCS inhibits the utility system leak rate monitoring when the landing gear are extended. (Exhibit 63, p.115-116)

338. Left and Right electric conversion actuator FAIL was reported prior to impact. This failure, in conjunction with the failure of hydraulic conversion control, would indicate total loss of nacelle control. Post accident simulation suggests that electrical conversion was possible, however, the backup conversion rate is too slow to have changed the final outcome. (Exhibit 63, p.110-114; R1023, p. 29)

339. The torque imbalance caused by different rotor speeds and the loss of rudder control resulted in the buildup of a yaw rate and large sideslip angle prior to impact. (Exhibit 63, p.59)

340. The aircraft electrical system did not contribute to the mishap. The failure of FCC #2 was a result of the electrical connector being damaged on the right outboard swashplate actuator following ICDS failure. (Exhibit 63, p. 75)

341. The failure of the six (6) swashplate actuator hydraulic fittings was caused by the overload conditions at impact and was not related to defective fittings. Rosan manufactures the hydraulic fittings on the swashplate actuators. (Exhibit 63, p. 157-158; Exhibit 78)

342. Prior to departure from Eglin, the aircraft was observed "to be pushing a lot of hydraulic fluid out of the Number Two side." The interchange of hydraulic fluids between the systems during the pre-start flight control system check has been noted during FSD. This interchange can cause a system to be "over serviced", and the venting overboard following engine start. (R1002, p. 276; PE 7, p. 4)

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AIRFRAME

GENERAL

344. V22 BUNO163914 completed testing in the Eglin AFB Climatic Lab that included tests at temperature extremes from -65° F to 125° F, rain tests during both static and wind conditions, and other tests for a total of 39 data events. (Exhibit 20, p.11; R0814 p.5)

345. The MV22 FSD specification requires the wing and fuselage structure to be designed for a 3 g lateral impact and the local fuselage structure, wing attach fittings and affected stow structure shall be designed to support the wing in a crash up to 115% of the wing failing load. The aircraft is designed to be able to sustain (on a solid surface) longitudinal impacts with up to 5° nose down and 60 fps forward velocity on a minus 8° flight path without the loss of more than 15%of the living space in either the cockpit or cabin with the landing gear extended or retracted. The occupants shall not experience accelerative loading beyond human tolerance during a level 24 fps vertical velocity impact with the landing gear down. The width of the cockpit or cabin shall not be reduced more than 15% due to any 30 fps lateral impact. (Exhibit 75, p 83--85)

346. The troop seats are crashworthy to 10 g forward, ± 3.4 g lateral, and 20 g vertical. The pilots' seats conform to the static load design criteria of MIL-S-58095, which requires the ability to sustain static loads of 35 g forward, 20 g lateral, and 25 g vertical (downward). In a dynamic situation, the stroking seat should provide some protection in up to 51 g vertical deceleration with an onset time of .036 sec. (Exhibit 76, p 146)

347. In this mishap the aircraft is estimated to have impacted the water at descent rate of 6300 ft per minute, with a longitudinal velocity of 85 knots and a fourteen degree nose down attitude. (Analysis of the video of the mishap indicates the lateral velocity was 60 knots.) The impact energy of this mishap would have been 17 times greater than the ditching design condition. It was assumed that at these velocities the water would act as a hard surface and there would be 12 feet of stopping distance (deformation of the impact surface and structure), which results in 79g decelerative loading on the structure. This loading is well beyond the structural capabiities of the fuselage or human tolerance. (Exhibit 63a, p288-290)

348. All components analyzed, except the right pylon shaft, right pylon shaft flexible couplings and the centerbody of the right engine air inlet, were found to have been fractured during impact. (Exhibit 60, p 3-5)

349. The engine mount system did not show any signs of malfunction prior to the aircraft impact. All of the aft mounts failed statically at approximately midway between the engine and the pylon support. The gimbal mount was intact. However the engine broke away from the engine torque shaft at its front frame. Both left and right engine mounts sustained the same type failures. (Exhibit 60, paragraph 5.2.3.1)

350. Both the left and right rotor systems, including the mechanical portions of the flight controls were intact at the time of impact. All damage is consistent with sudden stoppage/impact. All metalic component fractures were from overload, either tension, tension/bending or shear. (Exhibit 60, paragraph 5.2.1)

351. Through examination of several V22 aircraft at the contractors' facilities, the Members of this Court of Inquiry observed that the integrity of the horizontal firewall for both engine compartments is compromised by numerous cutouts for wiring and the aft engine mounts.

352. During testing at 125° F, with 84% Nr and 15% proprotor mast torque, the right engine FADEC A temperature peaked at 178° F. The highest FADEC temperature recorded during the post shutdown analysis was 208° F on the left engine FADEC A. (Exhibit 49b)

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354. The results of heat transfer analysis for operation at SL, 125°F indicate that the transmission adapter (adjacent to the pylon drive shaft) would reach 224°F and the air flowing around the ABEC (also adjacent to the pylon drive shaft) would reach 205°F (hover) and 225°F (airplane mode, 250 knots). The upper nacelle air management system is rated at 9900 cubic feet per minute (585 lb/min). The upper nacelle total design cooling air flow is 328 lb/min. (Exhibit 73, p. 11, 12, 17, 18)

INLET

355. The engine surge evident near the end of the engine acceleration would normally have produced a forward traveling pressure pulse into the engine air inlet. The data did not indicate a pressure pulse because engine inlet pressure and temperature transducers have low frequency response characteristics and do not capture the peak amplitudes for rapid changes. A compressor inlet temperature (T2) rise to 105°F was observed in conjunction with the surge. (Exhibit 60, paragraphs 4.1 & 4.2.2)

356. Using a computer model, the actual inlet temperature was calculated to increase 125°F (from 85°F to 210°F) in less than one tenth of a second.

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358. The right engine air inlet was damaged in flight, creating an opening into the upper nacelle space. (Exhibit 60, p 5-1)

359. Reconstruction using recovered pieces of the right engine inlet revealed that at least two pieces of the inlet, both adjacent to the aft joint, were broken out prior to impact. One piece, the fiberglass doubler that covers the engine torque meter cutout seal was detached from the inlet and found wrapped around the aft inboard engine mount, above the horizontal firewall. It was extremely deformed and charred on both sides, while the other piece had scorching on its non-breeze side only. (Exhibit 60, p 3-4; paragraph 5.1.1.2)

360. The joining surfaces of the right engine inlet centerbody were scorched on the edges and non breeze side nearest the engine. The elastomeric seals between the inboard and outboard inlet halves were not recovered. (Exhibit 60, p 3-4)

361. None of the recovered inlet fragments, except the two known to have broken out prior to impact, had any indication of scorching or other heat damage on the breeze side (white painted finish). (Exhibit 60, p 3-4, 5-1)

FLUID SOURCES

362. Recorded flight data and the absence of witness marks indicating blower rotation indicate that the engine air particle separator (EAPS) systems were off during the final stages of the flight. (Exhibit 60, paragraph 5.2.4)

363. No evidence of hydraulic leaks was found at the right nacelle EAPS shut off valve in subsequent bench testing. (Exhibit 60, paragraph 5.2.4)

364. All recovered hydraulic system tubes, joints and valves in the nacelle were examined, in place, for indications of leakage and none were found. No indications of concentrated burned surfaces adjacent to tubing or valves were found on the reconstructed nacelle. No evidence of pooled combustibles was found in the upper nacelle or in the non breeze side of engine air inlet structure. (Exhibit 60, p 3-3)

365. The right PRGB and right TAGB were each examined closely for any possible source of oil leaks relating to a source of combustible fluid. No conclusive sources were found. (Exhibit 60, paragraph 5.2.2)

366. The right TAGB oil filler cap and adapter assembly was intact, but the cap was not installed when the accessory section was recovered. It could not be determined whether the filler cap was in place during operation, but even if it was not, the proximity of this filler cap to the blower in the aft portion of the nacelle greatly reduces the chances of oil moving forward in the nacelle. (Exhibit 60, p 3-4 & paragraph 5.2.2.4)

367. The right TAGB carbon shaft seals were undamaged except that the blower drive seal carbon element had a 90 degree segment broken out. The external O-rings were inspected and determined to be undamaged. The internal O-ring for the pressure regulator was not installed. Although this does not allow an external leak, it would affect oil pressure regulation. (Exhibit 60, paragraph 5.2.2.4)

368. The right PRGB was inspected with particular attention to potential external oil leaks:

- The engine input carbon seal was intact. The seal was a configuration which has little history of leakage problems. No leakage occurred when statically tested for leakage between the carbon element and the cup.

- The pylon shaft seal is a magnetic carbon face seal, unlike the other spring loaded seals. Debris and rust on the wear ring indicates the carbon element was not in contact with the wear ring while the parts were submerged. These pieces can be forced apart under a shock load, and remain apart because the magnetic force is insufficient to overcome the O-ring friction to draw the two pieces together again with the increased distance between the two parts. When cleaned up, the wear ring surface showed a normal contact pattern with the carbon element. All seal O-rings were in good condition. There was no indication of a leak at this location.

- The upper mast and lower mast seals were in good condition. All associated O-rings were in place and in good condition. There was no indication of external leakage.

- The O-rings for the filter manifold interface with the case (5 pcs) and the filter bowl were all in good condition.

– The fracture face of the oil manifold was evaluated by BHTI Field Investigation engineer and determined to be consistent with an overload and not a fatigue failure. The filter bowl was intact as were the O-rings for the drain valve and the bypass indicator mounted to the filter bowl. The drain valve and the bypass indicator did not leak when tested with freon.

– The oil sampling valve cap was in place and the O-rings in good condition. The O-ring for the valve installation was in good condition. The valve, when tested with freon, did not leak.

– The lube pump seals were verified as good by pressure testing the pump assembly.

– The oil filler cap was installed in the adapter that had broken from the gearbox. The O-rings on the filler cap and adapter were in good condition as was the O-ring for mounting the filler adapter to the case.

– The drain valves on the input quill, helical sump, lube inlet line, and planetary sump were all good and able to seal fluid except the planetary sump drain valve which had experienced impact damage. After removing some deformed material from the impact damage, the valve did seal.

– The main case/cover and input quill gaskets show no damage to the elastomeric seal. Mating surfaces on the case, cover and input quill housing show no scratches or other damage. (Exhibit 60, paragraph 5.2.2.5)

369. Subsequent to completion of the Drive Train and Engine Engineering Investigations, the forward "V" ring (seal) which seals the input end of the right engine torque shaft (torquemeter) was found to be installed backwards. The left engine torquemeter seals were missing. (The mating seal surface on the left overrunning clutch race was broken.) The torque shafts accompanied the engines during the engine E.I.'s. However the "V"seals were not examined during the engine E.I. (Exhibit 83, CO NADEP Ch. Pt memo and Mr B6 Allison Div of GM memo dtd 3 Dec 92.)

370. A test was conducted at the BHTI Drive System Test Facility to determine the leakage rate of an incorrectly installed torque shaft forward seal. The test was conducted twice. Once with the seal installed correctly and once with the seal installed reversed. The reversed configuration was run at 12576 rpm and at 15000 rpm at 2° and 60° nacelle angle with no leakage of oil. The seals used in the test were the same configuration as those recovered from V22 number 4. The seals from V22 number 4 had swelled .003 to 007 inch and were stretched 0.2 inches. They were not used in the test. (Exhibit 83, BHTI memo dated 1 Dec 92)

371. Examination of the torque shaft, torque shaft seals and other parts salvaged from V22 number 4 did not reveal any additional proof of seal orientation nor abnormal operating conditions. (Exhibit 83, BHTI memo dated 1 Dec 92)

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373. The procedures for the removal and replacement of the torquemeter seals contained in the technical manuals, blue prints and logistic support analysis manuals were vague and introduced the potential for incorrect installation. (Exhibit 83, AD1 memo & enclosures)

374. Boeing Helicopters representatives stated that they believe the torque meter "V" seals were replaced with new seals and checked when the right engine was reinstalled during May 92 at Eglin AFB. (Exhibit 84, memo dated 11 Dec 92)

375. Boeing Helicopters representatives stated that they believe the torque meter "V" seal related to the17 Dec 90 maintenance action on V22 aircraft number 2 had a nick in it, but was correctly installed. (Exhibit 84, memo dated 11 Dec 92)

376. The Program QA manager at Boeing Stated that " Due to the fact the V22 does not have a validated set of maintenance manuals, mechanics rely upon engineering drawings and their own experience for engine instalation and reinstallation." (Exhibit 84, memo dated 11 Dec 92)

377. Engine Removal and Installation instructions contained in A1-V22AA-290-300 dated 1 Nov 1991 contains changes that provide specific guidance and illustrations on the correct installation of the torquemeter seals. (Exhibit 83)

378. There was no evidence of a sealing device being installed between O.D. surface of the right engine inlet halves and the engine air inlet coupling. There is documentation authorizing the use HM #426 Teflon tape in lieu of a 901BK4606-101 seal. (Exhibit 60, paragraph 5.1.1)

379. The amount of fluid that could be trapped at various nacelle angles in the right engine inlet center body, assuming that the elastomeric seal between the lower inboard centerbody and outboard centerbody is intact and not leaking was determined by calculation and by test with the following results:

Nacelle Angle Test Condition (degrees)	Calculated Amount of Trapped Fluid (oz)	Measured Angle (degrees)	Measured Amount of Trapped Fluid (oz)
0	30.72	- 0.75	26.24
5	28.48	4.5	22.40
20	—	20	22.40
44	6.08	44	6.40
58	0.00	58	0.00

Note: The maximum was found to be approximately 26.24 oz at 0° nacelle angle. At 38° fluid started to pour into engine coupler end. At 55° all trapped fluid had poured into engine coupler end. (Exhibit 60, Appendix K, p 1, 2)

380. Maintenance personnel consistently indicated that V22 BUNO 163914 leaked very little in the nacelle area. Small static leaks from the area of the input quill tend to seep through inlet centerbody split line and at most form a quarter size puddle in the center of the inlet. There is never more than an oil film on the inside of the inlet center body and the inlet coupling surfaces. (R1001, p 130; R1002, p 241-247, 281-287)

381. An analysis of residue adhering to the splitter lip was found to be principally oil from the transmission system. (Exhibit 60, paragraph 5.2.4)

382. The oil residue from the inside surface of the right engine air inlet coupler was chemically tested and found to be analytically similar to gearbox oil {Exxon Turbine Oil 25 (DOD-L-85734)}. (Exhibit 60, paragraph 5.1.1)

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FIRE DAMAGE AND ANALYSIS

383. The right nacelle sustained heat damage internally before impact. (Exhibit 60, paragraph 5.1)

384. Reconstruction of the right nacelle revealed streaks of scorching indicating three paths of heat moving up from the engine inlet area touching components situated inside the nacelle, but outside of the engine compartment (above the fire wall), on both sides and under the PRGB. (Exhibit 60, p 3-3)

385. On the outboard side of the right nacelle, which houses the pylon shaft, the flow of heat was up across the outboard swashplate actuator boot, over the forward end of the pylon shaft installation and aft along the entire length of the nacelle. (Exhibit 60, p 3-3)

386. On the inboard side of the right nacelle, the heat path was over the gearbox oil manifold, the inboard swashplate actuator boot, wire bundles and the pylon down-stop arm and aft over the top of the pylon support member. (Exhibit 60, p 3-3)

387. Under the PRGB, the portion of the composite frame that bridges over the engine air inlet was extensively scorched on both sides. Wires, connectors and tubing along the upper nacelle side of the horizontal firewall were scorched. (Exhibit 60, p 3-3)

388. There was evidence of exposure to heat on the right PRGB. All indications exist aft of the baffle at the main case/cover split line.

- Scorching on the lube pump indicates a heat flow direction from below the pump traveling up.
- Paint burning occurred where it was applied over pro-seal sealant at case joints. This paint was burned at the main case/cover joint on both the inboard and outboard sides of the input section. It occurred mostly in a section from the center line of the first idler gear to the bottom of the interconnect section on the outboard side and to just above the lube pump on the inboard side.
- Paint was burned from the pro-seal of the joint of the pylon shaft seal retainer on the bottom side.
- The aft end of the oil pump showed sooting. The data tag bonded to aft end of the pump was missing and the remaining adhesive was crazed.
- The overboard drain line and fitting attaching it to the pylon shaft seal retainer was melted. A portion of the melted and collapsed plastic drain line was attached to the gearbox at another location aft and lower than the pylon shaft seal retainer. (Exhibit 60, paragraph 5.2.2.5)

389. All three right nacelle firewalls were free of heat damage and were determined to be intact prior to impact. (Exhibit 60, paragraph 5.1.3.2)

390. The heat in the right nacelle was of short duration (3 to 10 seconds) and high intensity (1200°F to 1550°F). This bracketing of the heat level was determined from a laboratory test of heated samples produced from corresponding actual pieces of the left nacelle. (Exhibit 60, paragraph 5.1.3)

391. The left nacelle sustained severe structural damage during impact, but the physical evidence did not reveal any heat affected areas and the in-flight data reflected normal parameters. (Exhibit 60, paragraph 5.2.5)

392. The left engine inlet did not exhibit any signs of being affected by heat; there was no evidence of blistering and/or charring of any of the pieces recovered. (Exhibit 60, paragraph 5.2.3.2)

AIRCREW/AIRCRAFT INTERFACE

MISHAP SIMULATION

393. Post mishap simulations indicate that the control laws functioned as expected and the Flight Control System operated normally before failure of the ICDS. (Exhibit 63, p.31)

394. Post accident simulations, using the mishap aircraft data, indicate that diagnosis of the failures was difficult from visual information readily available to the flight crew. The WCA system did not provide the flight crew with clear and discrete information that would assist in diagnosis of the failures. (R1023, p. 26; Exhibit 80)

395. The sequence of failures that led to the fatal mishap began with the aircraft in a configuration and at an airspeed appropriate for single engine flight, but did not provide sufficient time or altitude to establish a survivable configuration for a combination of engine and ICDS failures. (R1023, p. 30)

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397. To duplicate the rudder position data of the mishap aircraft in the simulator, the attitude command and beep integrators were initialized to equal and opposite values. This initialization resulted in saturation of the directional AFCS port and produced a good match to the measured rudder position. (Exhibit 63, p.31)

DISPLAYS AND WARNING/CAUTION/ADVISORY SYSTEM

398. The Warning, Caution and Advisory (WCA) system displays warning messages in red characters at the top of each MFD screen in dedicated positions. The message associated with a given caution (yellow) or advisory (white) is displayed at the bottom of each MFD, cautions on the left and advisories on the right. Only one caution or advisory (highest priority) can be displayed at a time, with a downward arror indicating additional messages. The CMS functioned as designed, including display of Warnings, Cautions and Advisories on the top/bottom of the MFD and on the Caution Summary page until impact. (Exhibit 28; Exhibit 80)

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400. Dual right and left mast torque sensor failures resulted in the TCLS and the MFD display of mast torque being frozen. The rescheduling of the TCL/PDS relationship due to the TCLS failure (and -1.5 inch bias) effected the sensory control and the loss of the torque display effected the visual control of rotor torque. (Exhibit 63, p. 45; R1023, p. 14)

401. A failure of the mast torque signals by more than one FCC resulted in illumination of the DUAL XDCR FAIL caution and the PFCS FAIL/RESET warning lights in the cockpit. This is a critical failure and reactivation requires a flight crew to manually reset by pressing the PFCS FAIL/RESET switch on the glareshield. (Exhibit 63, p. 94; Exhibit 28, p. V-2-8)

402. Following the second major surge of the right engine, the pilot's MFD displayed a "R ENG FAIL" warning, a "ECS FAIL" caution , and an "R ENG TEMP" advisory. The ECS FAIL failure did not contribute to the mishap, but delayed the display of the second DUAL XCDR FAIL message on the MFD. (Exhibit 80)

403. The failure of the right engine FADEC A resulted in an Advisory message on the MFD for R FADEC A FAIL. This message was the highest priority advisory and remain displayed on the MFD until impact. (Exhibit 80)

404. Immediately following the ICDS failure, the Caution Summary page displayed numerous DUAL sensor and actuator failures, but did not indicate the failures of Hydraulic system #1 and FCC #2. A FCC failure is normally an advisory message, but becomes more critical when combined with a hydraulic system failure. (Exhibit 80)

405. The failures of the ICDS, the #1 hydraulic system, and FCC #2 resulted in numerous messages indicating flight control failures; however, the priority of these messages were too low for display on the MFD. The MFDs indicated L ENG FAIL and R ENG FAIL warnings, L ENG Np OVERSPEED caution, and R FADEC A FAIL advisory. (Exhibit 80)

406. The WCA system did not display to the hydraulic system #1 failure or that leak isolation procedures were in progress. The leak was detected and isolated before the reservoir LOW advisory was activated, therefore no system fault was annunciated until the "DUAL HYD SYS FAIL" just before impact. (Exhibit 80)

407. Failure of both electric conversion actuators was reported at 12:42:25.1, however, this message was no displayed on the MFDs. The electrical conversion actuator fail message is a low priority advisory, and would not replace the R FADEC A FAIL message displayed on the MFD. This failure, in conjunction with the hydraulic failures, indicates total loss of conversion actuator control. Post accident simulation tests suggest that electrical conversion was possible, therefore, the failure message was "false." (Exhibit 63, p. 110-114)

408. The RPM LO warning was displayed on the pilot's MFD to indicate average rotor RPM below 95%. The system originally provided a warning for proprotor RPM below 81% only, but was modified to provide a warning for the helicopter mode. (Exhibit 28, p. I-2-98; Exhibit 80)

409. The CMS requires the flight crew to select the appropriate "page" to monitor the operation or determine the status of the systems. A review of several pages of information may be required to determine the aircraft status. (Exhibit 28, p. I-2-1)

410. The V-22 test pilots received their emergency procedures training in simulators. The simulators display both left and right rotor speeds (normally superimposed), with the digital readout of the average speed. Recognizing an ICDS failure was possible in the simulator by observing the "split" in the left and right rotor speeds. The aircraft displays the average rotor speed only, therefore the ICDS failure was probably not recognized. (R1023, p. 20)

LIMITATIONS AND PROCEDURES

411. The NATOPS Flight Manual provide no recommended aircraft configuration for an engine failure, however, the contractor pilots suggest a speed of 100-130 knots and a nacelle angle of 60 degrees to minimize the power required. The mishap aircraft was in the appropriate configuration for OEI, but not for the subsequent failures. (R1023, p. 41)

412. The desireable configuration for a power off landing is with the nacelle aft and at an airspeed near [illegible] knots. The normal nacelle conversion rate is 8 degrees/sec and the power off descent rate is more than [illegible] min, therefore several hundred feet of altitude is necessary to recognize the failures and transition to a survivable configuration. The conversion rate is

significantly slower following hydraulic failures, so the altitude/time required to make the transition is increased. (R1023, p. 26-30)

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415. The only NATOPS emergency procedure for illumination of the PFCS FAIL/RESET light is to press the switch to reset the fault. If a critical fault exit and cannot be reset, a mission abort is recommended. No procedures are provide for determining the severity of the failure before attempting the RESET. (Exhibit 28, p. V-14-8)

416. The NATOPS emergency procedures provide a WARNING that "Engine fuel shutoff will occur at 114% Np resulting in a dual engine failure." This mishap demonstrates that the flight crew may have no control over an overspeed condition, but must rely on the FCS and FADEC to limit the severity of the overspeed. Following ICDS failure, the peak rpm during the left engine overspeed was 113%, or within 1% of automatic engine shutdown. (Exhibit 28, p.V-14-6)

417. The flight crew has an option for selecting the information to display on the two MFDs. The takeoff and landing procedures used by Bell pilots recommend selection of the engine page for the pilot flying the aircraft, but Boeing leaves the selection of displays to the individual pilots. (R1110, p. 29)

418. Coordination between the V-22 and the chase aircraft during the ferry flight was effected by poor VHF communications. This difficulty between the V-22 and other transceivers at the 6 o'clock position has been documented during FSD. (R1008, p. 472)

OPINIONS

ADMINISTRATION

BACKGROUND

1. BUNO 163914 was a pre-production, government-owned aircraft provided as Government Furnished Property to Boeing Helicopter Company for the purpose of V-22 Full Scale Development. (Findings of Fact 4, 6, 7)

2. Flight operations conducted at Eglin AFB and the ferry flights to and from Eglin AFB were authorized flights conducted in accordance with the U. S. Navy Full Scale Development contract and test plan. (Findings of Fact 2, 13, 14, 15, 17)

3. Although it appeared to be generally accepted knowledge that NAVAIRSYSCOM was the controlling custodian and DPRO Boeing was the reporting custodian, neither were specifically assigned in writing. Clear authority and defined responsibility should be established for each aircraft. A similar omission occurred with the failure to enter the aircraft into the Aircraft Inventory Reporting System. (Findings of Fact 8, 9, 10, 11, 12).

FULL SCALE DEVELOPMENT CONTRACT

4. The mishap flight and the crew members conducting the mishap flight were approved in writing by the DPRO GFR, which met the requirements for written approval by the DPRO Commander. (Findings of Fact 19, 20, 21, 22)

5. The changes to the FSD contract proposed by DPRO would not significantly change the current Boeing procedures. Both the ACO and the PCO indicated that, because of other contracts, Boeing was already operating as if DLAM 8210.1 were in the contract. The DLA legal opinion stated that the GFR was the appropriate authority at the DPRO for flight approval, and the GFR was delegated that authority by DLA. The proposed changes would provide proper clarification of procedures and responsibilities, and prevent future misunderstandings. (Findings of Fact 20, 21, 27, 28, 29, 30)

6. The PCO did not properly update the new contract when it was reissued in Oct 92. Changes recommended by the DPRO were not incorporated. The contract should refer to DLAM 8210.1 instead of the superseded DLAR 8210.1, and incorrectly refers to the Contracting Officer as the flight release authority instead of the GFR. (Finding of Fact 31)

MISHAP AIRCREW

7. Mr. Sullivan was an experienced test pilot and an experienced V-22 Pilot, familiar with flying BUNO 163914. Mr. Sullivan was current and qualified in the V-22 aircraft. (Findings of Fact 33, 59, 60, 61, 62 64, 66)

8. MAJ James was an experienced test pilot with experience in the V-22 limited to simulator time and several flights. MAJ James was qualified to be a co-pilot in the V-22, but not current due to lack of egress training. His lack of egress training had no bearing on the outcome of the mishap. (Finding of Fact 34, 57, 59, 62, 64)

9. MGySgt Leader and GySgt Joyce were experienced aircrewmen with flight experience in the V-22. They were both current and qualified to be aircrewmen (crew chiefs) in the V-22. (Findings of Fact 35, 36, 64, 65)

10. Mr. Rayburn and Mr. Mayan were experienced engineers with flight experience in the V-22. They were both qualified in the V-22 as non-crewmembers, but not current due to lack of current flight physicals. Mr. Rayburn was also not current because his annual egress training had expired. Their lack of currency had no bearing on the outcome of the mishap. (Findings of Fact 64, 66)

11. Mr. Stecyk was an experienced mechanic with flight experience in the V-22. He was not specifically qualified as a crew chief or current in the V-22, and would have to be designated a non-crew member. His records do not indicate his designation as a crew chief, nor was he designated on the 21 Feb 92 Flight Clearance list (the most recent one he appeared on) as a third crewmember. He was not current because he had not completed the V-22 egress training course, and did not have a current flight physical. His lack of currency and qualification had no bearing on the outcome of the mishap. (Findings of Fact 64, 66, 74)

FLIGHT OPERATIONS

CONTRACTOR FLIGHT OPERATIONS

12. Boeing Form 20930, the Project Agreement Flight Clearance, does not comply with DLAM 8210.1, since it allows the phrase "guest pilots and observers" to be placed on the form instead of specifically listing all crew members and non-crew members by name and position. (Findings of Fact 46, 47)

13. Boeing did not follow its own procedures for listing personnel on Form 20930, by using the statement "Test engineers and flight crew members will be flown as required..." instead of a list by name and position. Even the senior V-22 Flight Test Manager felt that Boeing was not required to submit names and positions of non-pilots. (Finding of Facts 46, 47, 48, 94)

14. DLA and the DPRO Boeing GFR gave tacit approval to Boeing to submit a non-compliant Flight Clearance. The DLA audit accepted Boeing procedures, the GFR approved the procedures, and the GFR accepted the Project Agreement Flight Clearance each month. The GFR should have required, prior to approval, that Boeing procedures be updated to reference DLAM 8210.1 vice the superseded DLAR 8210.1. The GFR also should have rejected the Project Agreement Flight Clearance until it met DLAM 8210.1 requirements, and provided the correct level of visibility. (Findings of Fact 40, 41, 42, 44, 45, 48)

15. The GFR fulfilled the requirements of DLAM 8210.1 by continuing to perform his GFR responsibilities from Philadelphia while the aircraft was at Eglin, and receive information via daily reports regarding BUNO 163914 status and progress. (Findings of Fact 49, 52, 53)

16. By using the word "may", DLAM 8210.1 does not specifically require the GFR to designate a supporting GFR for off-site operations, nor does it specifically require that an individual be designated to monitor and provide information to the home facility GFR. (Finding of Fact 49)

CURRENCY

17. The GFR, LTC , failed to insure that only qualified and current flight crewmembers and non-crewmembers were aboard the mishap flight or any of the preceding flights at the Climatic Lab. As a minimum, prior to approval, he should have requested adequate

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qualification and currency listings from all participating agencies, and cross-checked them against a proper Project Agreement Flight Clearance. (Finding of Fact 68)

18. The lack of a listing by name and position of everyone to be in the aircraft made it impossible for the GFR to verify currency and qualification. Boeing should have submitted the flight clearance in accordance with their own procedures, and the GFR should not have accepted it without a specific listing of all crew members and non-crew members by name and position. (Finding of Fact 63)

19. The GFR failed to assemble adequate information to perform his responsibilities. He had no written record for military personnel, who were presumed qualified, and no names on the flight clearance to corroborate contractor personnel. Had he scrubbed names against qualification lists, the GFR would have discovered that MAJ James, Mr. Rayburn, Mr. Mayan, Mr. Stecyk and Mr. were not current. (Findings of Fact 63, 91)

20. Since the Project Agreement Flight Clearance is the monthly flight plan, both LCDR and LTCOL should have obtained a copy. Had either of them looked at the clearance, they might have discovered the omission of LTCOL . (Finding of Fact 93)

21. The Pilot in Command, Mr. Sullivan, failed to ensure that all flight crewmembers and embarked personnel were approved for flight as required by the Boeing FLOP Manual. (Finding of Fact 69).

22. The Test Director, Mr. Rayburn, submitted a Project Agreement Flight Clearance stating that "all personnel would be qualified" without ensuring that the personnel flying the aircraft met the requirements, or were on the clearance. (Findings of Fact 47, 48)

23. The senior V-22 Flight Test Manager, Mr. , failed to ensure that Flight Clearance and Qualification lists were sent to his managers and pilots at Eglin, making it difficult for the currency and qualifications to be checked prior to the start of flight operations. (Finding of Fact 69)

24. The Boeing system for tracking currency and qualifications did not adquately alert management to overdue/missing currency and qualification requirements. As a result, non-current personnel, including the mishap crew, were routinely flying in the aircraft at Eglin. Testimony indicated changes in the system to correct the Flight Clearance listings, but didn't mention changes to alert management to non-current pilots on the Qualification Sheets. (Findings of Fact 55, 56, 67, 71, 72, 73, 74, 77)

PARTICIPATORY TEST PROGRAM

25. The V-22 Test Authority did not operate in accordance with the MOA. Coordination and communication with the contractor and the GFR, which was designed to go throught the TA-PM on-site at the contractor's facility, did not always occur. The result was a verbal flow of information through disparate channels with ineffective communication. Government crew selections and qualifications should have been presented in writing to the contractor and the GFR. All personnel aboard the aircraft should have been listed on the Project Agreement Flight Clearance (as discussed elsewhere) and a copy should have been sent back to NAWCAD. (Findings of Fact 78, 79, 80, 88, 89, 90, 91)

26. From testimony and documentation there appears to be an unclear picture concerning the participation of military crew chiefs in the participatory Test Program. NAWCAD and Boeing support military crew chief participation, but the MOA does not clearly address the subject and NAVAIR declines to endorse it (except for DT-IIC). (Findings of Fact 83, 85, 87)

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AIRCRAFT MAINTENANCE

BOEING MAINTENANCE PERSONNEL AND ORGANIZATION

27. The key Boeing personnel who performed maintenance on BUNO 163914 at Eglin AFB were appropriately qualified and designated for the duties they actually performed, with the exception of Mr. Steyck (Flight Test Crew Chief) and Mr. (as QA Inspector in addition to QA Manager). (Findings of Fact 102, 105, 112, 117)

28. Boeing's lack of formal qualification processes for Flight Test Crew Chiefs and QA Inspectors could lead to maintenance error and jeopardize safety of flight. (Findings of Fact 110-113, 115, 117, 118)

29. Boeing exhibited inadequate control of the QA process by allowing QA Inspectors to decide for themselves which systems and areas they are qualified to inspect. (Findings of Fact 114, 115, 118)

30. The Boeing organization at Eglin AFB from 18 to 20 July 1992 was inappropriately downsized, inadequately supervised and was too focused on the departure of both the team and the aircraft to ensure satisfactory completion of maintenance requirements. This was evidenced by numerous administrative errors associated with the final maintenance effort, compared to performance documented by the earlier DPRO Boeing QA inspection of Boeing at Eglin AFB. (Findings of Fact 103, 127, 128, 130, 131, 132, 134, 135, 140, 142, 152, 154, 155, 158, 161, 162, 167)

31. The Boeing off-site organization used at Eglin AFB contributed to inadequate coodination of the maintenance effort, as all key maintenance personnel were not required to report to a single, fully accountable maintenance manager. Neither the Flight Test Engineer or the QA Manager/Inspector (both key maintenance personnel) worked for the Operations Supervisor (closest "Maintenance Officer" equivalent) . (Findings of Fact 120, 167, 119)

MAINTENANCE REQUIREMENTS

32. The mishap aircraft was released for flight and flew without a valid Daily Inspection, as the last Daily Inspection performed prior to the mishap flight was invalid for the following reasons (Findings of Fact 130-133):

- Signed off as completed with four open Breaks of Inspection (right HPDU return line, left hydraulic oil cooler, left hydraulic isolation valve, right conversion actuator fairing).

- The right fuselage area was signed off as inspection completed on 18 July 1992, but the integrity of the area was broken on 19 July 1992 due to the removal/replacement of the right sponson boost pump. There was no subsequent sign off of a reinspection as required.

33. The Turnaround Inspection performed subsequent to the last Daily Inspection did not fulfill the requirement for a new/updated Daily Inspection. (Findings of Fact 123, 137, 138, 141)

34. A new/updated Daily Inspection was not performed due to confusion on the part of Boeing maintenance personnel concerning maintenance inspection requirements. (Findings of Fact 125, 140)

35. Boeing maintenance personnel failed to comply with existing maintenance regulations and sound maintenance practices in signing off both the last Turnaround and Daily Inspections <u>prior</u>

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to performance of the Maintenance Operational Check of the midwing gearbox oil filter. (Findings of Fact 125, 150, 152-154, 157, 158)

36. The first Maintenance Operational Check (MOC) of the midwing gearbox (MWGB) oil filter was performed by Mr. Steyck during the ground run on 20 July 1992, but was not properly documented prior to the mishap flight. (Findings of Fact 152-155)

37. Although not witnessed, a second undocumented MOC of the MWGB was most probably performed by Mr. Steyck, since the first MOC had resulted in another popped filter button. The required QA inspection was not performed on the filter removal/reinstallation completed by Mr. Steyck in preparation for the second MOC. (Findings of Fact 152-155)

38. The Allison letter to Boeing permitting engine operation beyond the 70 hour fuel nozzle replacement requirement due to a strike at Allison, did not present valid engineering justification for continued operations which should have been acceptable to Boeing. (Findings of Fact 145, 148, 149)

39. Re-rigging the nacelles did not require a dedicated maintenance check flight with a minimum crew complement prior to the mishap flight. (Findings of Fact 164)

PRE-MISHAP FLIGHT MAINTENANCE IN RIGHT NACELLE AREA

40. It is unlikely that the forward seal on the RH torquemeter shaft was reversed and reinstalled incorrectly during the course of the Engine E.I. The seal was probably installed incorrectly when the RH engine was prepared/inspected for reinstallation on 28 May. (Findings of Fact 169, 170-172)

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43. The problems that occurred with the fuel system during the post-Climatic Lab check flights were correctly diagnosed and repaired prior to the mishap flight. (Findings of Fact 239, 241)

FLIGHT PLANNING/CLEARANCE AND COMPLIANCE

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45. Mr. Sullivan did not comply with the flight clearance by continuing the flight with an RTB RTR warning on the CONDM display, and should have landed at the nearest suitable field as stated in the flight clearance. There were no provisions in the clearance for onboard troubleshooting. Continuing the flight with the RTB RTR warning was significant, even if troubleshooting revealed that it might be only a wiring problem, because the presence of the RTB RTR warning made it impossible for other lower priority warnings to be displayed. Any real RTB RTR warning would not have been noticed, since the RTB RTR light was already on. Additionally, the NAVAIRSYSCOM Flight Clearance required monitoring mast torque, which could not be displayed since it has a lower priority than RTB RTR. (In fact the RTB QM warning and a lesser RTB RTR warning were masked by the active RTB RTR display). The crew did not indicate during any of their discussions of the CONDM package that they understood the consequences of the current display masking the display of other problems. (Findings of Fact 224, 225, 230, 190, 191, 201, 203, 206)

46. Boeing and Government management placed undue pressure (real or implied) on Mr. Sullivan and the Boeing Eglin detachment to get BUNO 163914 to Quantico. The detachment personnel departed as scheduled, and the welcoming set up at Quantico for 20 July was announced at Marine Corps Headquarters. The pressure would have been greatly reduced if the Quantico arrival had been postponed and detachment personnel rescheduled for later departure, allowing time to resolve fuel transfer problems and complete the checkout of the CONDM system. The unwillingness to take time to rendezvous with the chase indicated a "non-stop flight" attitude on the part of Mr. Sullivan from the beginning, probably because of the APU problems at Eglin. The illuminated CONDM display only strenghtened Mr. Sullivan's resolve for a non-stop flight, in spite of the suggestion from Mr. Rayburn that "they probably didn't have the clearance to continue." Immediately after making the decision to continue flying with the RTB RTR warning, Mr. Sullivan asked Mr. Rayburn for a fuel computation for the distance to Quantico. Mr. Sullivan noted that they would not be leaving Charlotte that day if they landed there. Other Findings in this report show that the APU and CONDM problems did not ultimately cause the aircraft to crash. (Findings of Fact 17, 182, 187, 207, 215, 216)

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48. The flight crew did not comply with the flight clearance during the descent, when they exceeded the maximum airspeed of 230 knots by 8 knots. (Findings of Fact 192, 220)

49. BUNO 163914 had an unacceptable radio range aft of the aircraft, particularly for the transmitter. Without a chase aircraft nearby to relay transmissions in an emergency, independent operations away from the immediate vicinity of an airfield could be a safety of flight concern. Only when the chase aircraft was inside of 30 miles were they able to hear the V-22 transmissions without static or squeal. Outside of 40 miles the transmissions were garbled to the point of being unreadable. (Findings of Fact 200, 205, 210, 213)

MISHAP AIRCRAFT AND SYSTEMS

MISHAP DATA

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FUEL SYSTEM

52. The aircraft fuel system was properly configured and transferred fuel correctly during the mishap flight. Although suction mode would probably have worked as designed, the boosted mode selected by the pilots was an advisable precaution based on previous flight/ground problems with the fuel system. (Findings of Fact 178, 236, 237, 238)

53. The failure and shut-down of the right engine was not due to fuel starvation, or any other malfunction related to the fuel system. (Findings of Fact 239, 240, 241)

ENGINE SYSTEM

54. The LH engine operated properly, in accordance with all control laws, throughout the flight. There were no failures or abnormalities related to the LH engine. (Findings of Fact 250, 262, 263, 265)

55. The RH engine operated properly, in accordance with all control laws, throughout the flight. The RH engine failed due to the ingestion of flammable fluid(s) and foreign objects from unknown sources during the final two minutes of flight. (Findings of Fact 250-261, 266, 267)

56. The engine is susceptible to stalls or surges when flammable fluid and/or FOD is ingested. (Findings of Fact 254, 256, 259, 261)

57. Both engines were incorrectly declared "failed" by the FCC during the sequence of events. The RH engine was declared failed prematurely, in which case the FCC "erred to the good" by latching OEI compensation. Declaring the LH engine failed, when it continued to operate, had no effect on engine operation but served to display a confusing and distracting message in the cockpit. (Findings of Fact 258, 265)

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59. The V-22 engines can be started only when the APU is operating. The low reliability of the APU and the inability to start the engines without the APU will affect aircraft availability during operations, and may have contributed to the decision to bypass Charlotte. (Findings of Fact 187, 194, 216, 268)

DRIVE SYSTEM

DRIVESHAFTING

60. The pylon drive shaft did not fail due to exceedance of design torque limits. No drive system design limit loads were exceeded and the right pylon transient rating was not exceeded. (During static testing the sample pylon shaft did not fail until almost three times the limit static torque was reached.) (Findings of Fact 273, 290, 296, 298)

61. The right pylon shaft did not fail due to manufacturing defects, previous fatigue damage, abrasion with nearby objects or shaft whirl. (Findings of Fact 282, 283, 286, 287, 291, 292, 293)

62. The pylon shaft was subjected to temperatures of 1200°F to 1550°F, well above its glass transition temperature of 240°F, for 3 to 10 seconds and failed under load (buckling) during OEI conditions approximately six seconds after the failure of the right engine. (Findings of Fact 284, 285, 286, 288, 385, 390)

GEARBOXES

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FLIGHT CONTROL AND HYDRAULIC SYSTEMS

64. The ingestion of a flammable fluid in the right engine resulted in an overspeed of both engine power turbines and the rotor system. The FADEC does not govern the power turbine speed, but will reduce the fuel flow when the speed exceeds 105%. The overspeed of the left engine was in response to the right engine surge and resulted in the annunciation of both left and right engine problems. The "false" indication of a left engine problem made diagnosis of the actual problem more difficult. (Findings of Fact 316)

65. The dynamic response to the right engine surge resulted in a transient overspeed of both engines and the drive system to 108%. This response indicates that "de-clutching" of an engine from the drive system is primarily designed for "steady state" conditions caused by an engine failure and does not provide engine protection from a rotor overspeed. (Findings of Fact 316)

66. A review of the swashplate actuator positions during the first engine surge does not indicate a change in collective pitch to control the overspeed condition. Simulation tests indicate that the governor reacted to the overspeed by adding 8 degrees of collective pitch while TCLS removed 12 degrees (since mast torque exceeded commanded mast torque). The net results was a reduction in collective pitch rather than an increase in pitch to control the overspeed. Since the mast torques were well below the maximum continuous rating, the rotor speed governing should have contributed to controlling RPM. (Findings of Fact 316)

67. The mast torque sensors did not fail but were declared "invalid" by the FCS due to an exceedence of the rate/range monitors or the mast/engine integrity check. The monitor induced failure disrupted engine control and the PFCS RESET contributed to the subsequent engine surges. The "monitor-induced" failure of a critical control function complicated pilot identification of the problem and increased the flight crew workload during the emergency. (Findings of Fact 318 thru 322)

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69. Illumination of the "DUAL XDCR FAIL" caution on the MFD and the PFCS FAIL/RESET warning on the glareshield alerted the flight crew of the dual mast torque failure. A variety of faults can cause the "DUAL XDCR FAIL" message, therefore the flight crew must "page down" into the WRA status pages to diagnose the failure. Since the flight crew response to a critical system failure must be accurate and prompt, the annunciation of the failure should be distinct and concise. This mishap demonstrated the shortcomings of the Warning, Caution and Advisory system. (Findings of Fact 320 thru 322)

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71. The large number of nuisance sensor faults during V-22 FSD tests has been caused by "monitor declare failures", not actual sensor failures. The significance of a "DUAL XDCR FAIL" message has been diminished by these nuisance failures and the pilot's response to RESET the faults has become mechanical rather than procedural. The mishap data indicate that the flight

crew did not determine the cause of the failure or correctly determine the consequences of resetting the failed sensors. (Findings of Fact 322)

72. Since the FADECs control the normal and shut-down operations of the engines, it seems appropriate for the FADEC to also "declare" when an engine fails. The FADECs "set" an engine fail bit that could be used to annunciate an engine failure and "cross-talk" between the left and right engine FADECs could be used to set OEI compensation. The FCS monitors engine operations based on FADEC information, thereby creating an additional "layer" of data processing and increases the probability of "false" failures. (Findings of Fact 324, 325, and 329)

73. The RESET of the PFCS reactivated the TCLS, resulting in a rapid increase in power on both engines to reduce the -1.5 inch bias. Dual left and right mast torque sensors were again declared invalid by the FCS, probably due to the rapid torque increase. The "false" declaration of a critical failure occurred at a crucial time, resulting in the loss of TCLS (with -0.3 inch bias) and freezing of the mast torque indication. The redundancy and "fail-operate" design of the V-22 flight control system should reduce pilot workload, not compound the confusion associated with an emergency. (Findings of Fact 326 and 327)

74. Loss of the ICDS caused an overspeed of the left engine and rotor that peaked at 113%, before being reduced to 107% by FADEC Np limiting. An overspeed to 114% would result in automatic fuel shut-off and failure of the "good" engine. The design characteristic that allows a concurrent overspeed in both engines and rotors complicate failure analysis and increases the probability of a dual engine failure. Any failure or maneuver that overspeeds the rotor speed to 114%, will cause a dual engine shut-down. (Findings of Fact 328)

75. There is no evidence that the flight crew correctly diagnosed the combination of failures, however, the FCS's reduction of the left rotor pitch alleviated the thrust imbalance and allowed the pilot to control the aircraft roll axis. (Findings of Fact 328, 330, and 331)

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77. The pitch in the rotor system provides the primary lift and control of the aircraft in the helicopter mode, therefore analysis indicates that loss of rudder and flaperon control is not critical. The failure mode and effects analysis was based on failure of either the hydraulic or FCC control of the actuators, not multiple failures created by a severed drive shaft. During this mishap, loss of rudder and flaperon control contributed to the large sideslip angle and high descent rate at impact. (Findings of Fact 334 and 335)

78. The purpose of the leak isolation process is to preserve the pressure for the swashplate actuators. However, a hydraulic leak at the swashplate actuators is "outside" the isolation valves, and will result in partial loss of a primary and the utility hydraulic systems. The WCA system should alert the flight crew when a hydraulic leak is detected, the location of the leak, and indicate the success of leak isolation. This information is essential for fault diagnosis and prompt reaction to potential flight control difficulties. (Findings of Fact 334 and 336)

79. Hydraulic system #3 was declared failed due to low reservoir level since the rate of change monitoring of the reservoir quantity is inhibited when the landing gear are down.

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. The "Third Fail Inhibit" logic designed into the flight control system prevented the loss of swashplate actuators, even following the combination of failures that was experienced. Although the sequence of events and combination of failures experience during this mishap were more critical than the design can accommodate, the leak isolation and "third fail inhibit" performed as expected. (Findings of Fact 337)

80. The hydraulic systems are critical for control of the aircraft and must be potected from single failures that can effect all three systems. The interchange of hydraulic fluid between the systems could allow the contamination of one system to effect all three systems, potentially jepordizing aircraft control. (Findings of Fact 342)

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AIRFRAME

GENERAL

83. In this mishap, the aircraft impacted the water with an energy 17 times greater than the ditching design condition. It was severe and nonsurvivable, exceeding human tolerance, the structural capabilities of the airframe and combined energy absorbing capabilities of the airframe and the crew and passenger seats. (Findings of Fact 345, 346, 347)

84. The Rotor System and all Mechanical Rotor Controls, the Engine Installation, Engine Air Particle Separator System, the Drive System, the Airframe, specifically including the Nacelles, included cowlings, firewalls, exhaust systems, wiring and associated hydraulic systems were intact and operating as designed until the final 40 seconds of the flight. (Findings of Fact 269, 270, 272, 277, 302)

85. The right engine combuster and turbine section damage, the right engine inlet fairing damage, the right pylon drive shaft failure, and collateral flail and fire damage in the right nacelle occurred prior to impact. All other damage to the airframe and its components was the result of impact or salvage. (Findings of Fact 270, 272, 349, 392)

86. Both the left and right rotor systems, including the mechanical portions of the flight controls were intact and functioned as designed until impact. The rotor shafts and the components in the interconnect drive system were not subjected to loads in excess of design limits. (Findings of Fact 270, 289, 290)

87. The right pylon composite driveshaft was the point of primary subsystem failure, causing flail damage to adjacent hydraulic lines and electrical wiring that directly resulted in the loss of hydraulic system #1 and FCC #2. (Findings of Fact 279, 280, 335, 338)

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90. The failure mode and effects analysis considered only single failures, and therefore failed to address the consquences of collateral damage associated with failure of the pylon drive shaft. In this particular case the proximity of the pylon shaft to critical flight control components resulted in the immediate loss of two stages of the flight control system (PC-1 & FCC-2) and loss of hydraulic control to the nacelle conversion actuators, which was essential to the successful execution of survivable landing (ditching). (Findings of Fact 300, 332, 335, 346)

91. Hot Day (125°F) operating temperatures of the upper nacelle are predicted to be within 20°F of the pylon driveshaft Tg (240°F) with the nacelle blower operating normally. The effects of a blower failure or exhaust gas recirculation in a hover could easily exceed the pylon shaft Tg. (Findings of Fact 353, 354)

92. The effects of an engine fire in the lower nacelle could by conduction cause lower portions of the upper nacelle structure to exceed its approximate 300°F Tg and could also pass through the wiring holes and the aft engine mount hole, directly threatening the composite pylon driveshaft and critical flight control components. Battle damage that results in an engine compartment fire could also damage the firewall and allow high temperature gases/flames into the upper nacelle. (Findings of Fact 352, 353, 354)

93. The climatic laboratory testing demonstrated the potential for nacelle temperatures in excess of 200° F. (Findings of Fact 353)

INLET

94. The engine inlet fairing design point of 345 KEAS is not adequate to protect the inlet structure from the effects of an engine surge. (Findings of Fact 357)

95. The forward traveling pressure pulse associated with one or more of the engine surge events damaged the right engine air inlet allowing the entrance of hot gases/ flames into the upper nacelle, which directly contributed to the cause of this mishap. (Findings of Fact 355, 358)

96. The lack of an effective system to prevent fluids from collecting in the engine inlet centerbody directly contributed to the cause of this mishap. (Findings of Fact 249, 251, 379)

FLUID SOURCES

97. The engine inlet fairing design will retain fluids that might leak from the proprotor gearbox and upper nacelle area. The amount of fluid that can be trapped depends on nacelle angle and the integrity of the elastomeric seal between the centerbody halves. The maximum that could be trapped is 26.2 ounces. Trapped fluid would start to flow into the engine coupler end at 38° nacelle angle. At 55° <u>all</u> trapped fluid would have poured out of the inlet centerbody (and into the engine inlet). (Findings of Fact 378, 379)

98. Fluid trapped in the right inlet centerbody was the most probable initial source of flammable fluid ingested into the right engine. The source and magnitude of the associated leak was not determined with certainty. However, it is apparent that a flammable fluid continued to leak into the engine inlet after the first surge event, and after all trapped fluid would have emptied from the inlet centerbody at 55° nacelle angle. The second event consumed about as much flammable fluid as the first event. (Findings of Fact 254, 259)

99. The initial leak may have been seepage which accumulated in a much larger quantity than usual due to the length of the mishap flight, 2 hours and 44 minutes in airplane mode. The subsequent leakage may have been from the same source and/or an additional source, aggravated by the sudden acceleration and overspeed associated with the each surge event. (Findings of Fact 306)

100. The right engine/PRGB forward torque meter seal was probably installed incorrectly (reversed). The torque meter housing and shafts would not have been tampered with prior to being sent with the engines to the contractor facility for E.I. Since the E.I. team did not inspect the torque shafts, they were probably left in the same condition as when recovered from the Potomac River. The left torquemeter seals were probably lost during impact when the mating seal surface of the overrunning clutch race broke. (Findings of Fact 369, 372, 373, 376)

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103. The lower than normal right tilt axis gear box oil pressure was probably related to a missing O-ring (internal) on the pressure regulator. (Findings of Fact 307)

104. The right proprotor gearbox and right tilt axis gear box each were examined closely for any possible source of oil leaks relating to a source of combustible fluid with no conclusive sources found. (Findings of Fact 365)

105. The hydraulically powered engine air particle separator (EAPS) systems and their associated plumbing and shutoff valves were not the source of the flammable fluid that was ingested into the right engine. (Findings of Fact 362, 363)

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107. There were no indications of hydraulic leaks or of pooled combustibles in the upper nacelle prior to the failure of the right pylon shaft. (Findings of Fact 364)

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FIRE DAMAGE & ANALYSIS

110. The Right nacelle sustained heat damage internally before impact. The origin of the heat/flames was initially from the engine inlet through the damaged area of the inlet fairing (at and adjacent to the inlet fairing coupling) and into the area a few inches above the "bowl" of the inlet center body at high velocity, similar in effect to a blow torch. There is no evidence to suggest that there was sustained burning of a liquid fuel on the surfaces of the inlet center body (bowl) or coupling area. From there the pattern of scorching indicates intensified heat/flames, possibly due to the ignition of residual flammable fluid or vapor, flowing up and back into the upper nacelle. (Findings of Fact 359, 360, 361, 383, 384, 385, 386, 387, 388)

111. The large bright flashes associated with the engine surges are evidence that the fuel/air mixture being ingested into the engine inlet was exploding/ burning as a result of the reverse flow of the hot gases from the engine compressor/combuster sections. There is a high probability that hot/burning gases were drawn through the damaged inlet into the centerbody and upper nacelle by the nacelle blower. The long duration of exceptionally high inlet temperature associated with the final surge/engine failure contributed several seconds of heated and/or burning gases, possibly causing the ignition of residual flammable fluids, etc in the upper nacelle. (Findings of Fact 271, 273, 384, 390)

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113. There was no fire inside the right engine compartment. (Findings of Fact 389)

AIRCREW/AIRCRAFT INTERFACE

MISHAP SIMULATION

114. Post accident simulation tests confirm that the sequence of events and combination of failures were more critical than the present design can accommodate. However, failure logic such as hydraulic leak isolation and third failure inhibit for swashplate actuator control contributed to aircraft control during the emergency. (Findings of Fact 393)

115. Post accident simulation tests were conducted to examined the sequence of failures and to evaluate procedures for managing such emergencies. These tests suggest that the most survivable configuration would be with the nacelles full aft and a descent airspeed of about 100 knots. The conversion from a 60 degree nacelle position, using the backup electrical conversion, would require several thousand feet of altitude. The loss of hydraulic nacelle control during this mishap, emphasizes the inadequacy of the backup conversion system and is considered a cause factor for this mishap. (Findings of Fact 395)

116. The NATOPS does not define a preferred OEI configuration, however, the contractor pilots recommend a nacelle angle of 60 degrees and an airspeed of 100-130 knots to minimize drag. However, the 60 degree nacelle angle is not a desirable configuration for an autorotational (power off) descent since the rotor driving force is also minimized. The mishap aircraft was in the preferred OEI configuration when the problems began, but subsequent failures prevented nacelle conversion for a survivable power off landing. The NATOPS procedures for an OEI approach should account for the capabilities and limitations for the aircraft to re-configure for an emergency landing. (Findings of Fact 395)

117. The malfunction in the yaw axis of the AFCS may explain the objectionable lateral-directional oscillation discussed during the cruise portion of the ferry flight. The inadequate cockpit indication of degraded AFCS operations was noted during FSD tests. (Findings of Fact 397)

DISPLAYS AND WARNING/CAUTION/ADVISORY SYSTEM

118. The reliability of the CMS was demonstrated during this mishap by the continued display of the warning, caution, and advisory messages until impact. The presentation of the messages should be improved to provide the flight crew the "essential" information in a "timely" manner. The present system design requires the flight crew to manually search for the information needed to analyze a failure message. (Findings of Fact 398)

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120. The MFD displays only one caution and one advisory concurrently, and that message is held for 5 seconds before being updated. During dynamic situations, the MFD display of higher priority messages may be delayed or missed, and the messages displayed may not show the most serious fault. During this mishap, the display of the DUAL XCDR FAIL caution was delayed for 3 seconds while the lower priority L FADEC LIMITING message was being displayed. The update rate of WCA messages should be increased to provide the flight crew with the most "current" and most "critical" information. (Findings of Fact 399)

121. The control of rotor torque is critical for managing normal or emergency procedures, therefore the display of mast torque information is crucial. The loss of a valid mast torque display following the initial engine surge complicated the flight crew's ability to determine the problem. A mast torque increase is normal for a TCLS failure, yet during this mishap the aircraft lost power without a visual indication of "why". Although the TCL position was not changed and the MFD was indicating the same mast torque, the aircraft was descending. The redundancy designed into the V-22 should make the probability of a mast torque display failure extremely remote. (Findings of Fact 400)

122. A failure or malfunction that affects the accuracy of the mast torque display on the MFD should be annotated to highlight the degradation. The MFD presently uses different colors, flashing boxes, etc. as methods to emphasize displayed parameters. (Findings of Fact 400)

123. The annunciation of DUAL XDCR FAIL signifies two failures in the following sensors: rotor torque, control position, nacelle position, nacelle rate control, rotor rpm, or roll rate. The criticality of these failures are different and the pilot response to analyze the fault should also be different. The WCA system should provide discrete cautions for the different failures, and NATOPS procedures should be developed to provide appropriate flight crew actions for each failure. (Findings of Fact 401)

124. The #1 (left side) always preceeds the #2 (right side) in the priority of cautions and advisories. Except for an engine or ICDS failure, the power turbine speeds of both engines will be the same, therefore an overspeed in either engine will be annunciated as a "L FADEC LIMITING" or a "L Np OVERSPEED". This mishap demonstrated the confusion caused by the annunciation of faults for the wrong engine. The simulataneous display of more than one caution or advisory would help to identify the malfunctioning engine. (Findings of Fact 401 and 402)

125.

126. The triple redundancy designed into the V22 prevents an individual failure of a hydraulic system or flight control computer from being critical. However, the combined failures of hydraulic system #1 and FCC #2 seriously degraded aircraft control without the WCA displaying an appropriate message. The WCA system should recognize the seriousness of combined failures and display messages that accurately reflect the criticality. (Findings of Fact 404)

127. The automatic hydraulic leak isolation procedure performed as expected. However, the WCA system did not display the failure of hydraulic system #1, nor did it alert the flight crew that leak isolation procedures were being performed. A caution is provided for a dual hydraulic system failure or when pressure or temperature is out of limits, but does not display a message for leak isolation. The WCA system should provide a message for a hydraulic leak or the partial failure of a primary system due to the isolation process. (Findings of Fact 406)

128. Simulation tests suggest that electrical conversion would have functioned if the flight crew had selected the backup mode on the overhead panel. Due to the low altitude and slow conversion rate of the backup system, the false annunciation of a failure had no effect on the final outcome of the emergency. (Findings of Fact 407)

129. The pilot's ability to rapidly scan cockpit instruments and caution panel has been lost in the V-22. To determine the reason for a faults listed on the MFD or WCA summary page, the flight

crew must "page down" to the WRA equipment status information. The requirement to review several pages of information hampers the pilot's ability to rapidly diagnosis an emergency situation. (Findings of Fact 409)

130. Only one caution and one advisory message can be displayed on the MFD, with the presence of additional messages indicated by a downward arrow. Pressing the ACK key will acknowledge the displayed message and call up the next prioritized message. Since the L side has priority over the R side, the initial MFD display of a caution may be misleading. (Findings of Fact 399, 405 and 398)

131. The reliability of the CMS and WCA system was demonstrated during this mishap by continued performance until impact. The amount of information available to determine system status is significantly improved over previous aircraft. However, the display of system information and warning, caution, and advisory messages should be modified to reduce the flight crew workload during emergency conditions. (Findings of Fact 398 thru 410)

LIMITATIONS AND PROCEDURES

132. Flight tests have not been conducted to establish the Height-Velocity limitations of the V-22, however the preferred OEI configuration and the power off procedures have been established. The evaluation of flight control system malfunctions is needed to determine if the single engine profile is appropriate for subsequent failures. If different aircraft configurations are appropriate for different failures, the WCA system must clearly annunciate the failure and the NATOPS must present appropriate flight crew procedures for each emergency. (Findings of Fact 411 and 413)

133. The lack of reliable communication between the V-22 and chase aircraft (or ground stations) increases the risk during pilot intensive testing. The purpose of chase aircraft or ground monitoring stations is lost when the communications are not reliable. (Findings of Fact 418)

MISHAP CAUSE FACTORS

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TECHNICAL CONCERNS

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RECOMMENDATIONS

ADMINISTRATION

1. NAVAIRSYSCOM should evaluate the processes involved with acceptance of Navy aircraft from contractors and aircraft inventory reporting. Particular emphasis should be given to acceptance of pre-production aircraft, reporting procedures for aircraft returned to contractors as Government Furnished Property, written designation of Controlling and Reporting custodians, and AIRS data base entry.

2. NAVAIRSYSCOM should remove ambiguities and clarify contract language to make the contract reflect the latest instructions and procedures.

FLIGHT OPERATIONS

3. The GFR should require that Boeing procedures be revised so that they are aligned with DLAM 8210.1. In addition, forms used by Boeing in place of forms required by DLAM 8210.1 should be reviewed for equivalency.

4. The GFR should establish a flight clearance process that will allow him to verify the currency and qualification of all ground and flight personnel using government aircraft. He should refuse to accept a flight clearance unless all participating personnel are listed by name and position.

5. Boeing should revise their flight qualification/flight clearance process to prevent flight or ground operation with unauthorized personnel. Active management tools and process training for managers should be considered.

6. DLA should rewrite the requirement for remote/geographically separated operations in DLAM 8210.1 to specifically require either a designated GFR on-site, or a designated individual to report to the home GFR.

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8. As the Test Authority, NAWCAD should take positive steps, through the on-site TA-PM's, to provide feedback on the monthly flight clearance, with written verification to the GFR of military qualifications and copies of the flight clearance to all concerned.

AIRCRAFT MAINTENANCE

9. DPRO Boeing and Boeing should jointly assess the adequacy of QA inspectors in performing QA checks of actual maintenance, as opposed to their administrative checks. The QA of the right hand torquemeter shaft installation may have failed to discover the backwards installation of the oil seals.

10. DPRO Boeing should more closely monitor Boeing off-site maintenance activity. The post Climatic Laboratory QA inspection by the DPRO was prudent, but should have been completed after the shakedown flights in view of the extensive maintenance performed in conjunction with the testing.

11. The Boeing maintenance organization should be revised for off-site, detachment style operations, such as at Eglin AFB, to provide stronger, more centralized control of the maintenance effort. Focusing maintenance responsibility on a single, fully accountable maintenance manager should minimize the rushed "fly off" errors.

12. DPRO Boeing should review the Boeing policies concerning qualification/requalification of QA inspectors, crew chiefs and other maintenance personnel and coordinate changes to ensure that personnel are properly trained for the job assigned. The present system lacks adequate formal control of the personnel assignment process and does not include a formal training syllabus specific to a type of aircraft or system. Allowing QA personnel, for instance, to decide for themselves which systems they are qualified to QA, is not a sound maintenance practice.

13. DPRO Boeing and Boeing should conduct a joint review of requirements for Daily and Turnaround Inspections and Aircraft Flight Release, emphasizing what is needed when inspections are performed with open Breaks of Inspection and pending Maintenance Operational Checks. A formal training syllabus and certification/qualification process is needed for personnel authorized to sign an Aircraft Flight Release.

FLIGHT PLANNING/CLEARANCE AND COMPLIANCE

14. Boeing should ensure that flight briefings are standardized to include flight limitations, restrictions and go/no-go criteria.

15. Government and contractor senior managers should examine programs and procedures to make sure that safety is prioritized above cost and schedule. Both should work to create an atmosphere, real or implied, that makes employees at every level in the organization feel comfortable "stopping the presses" to correct deficiencies that could threaten lives or hardware.

AIRCRAFT AND SYSTEMS

DATA

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ENGINE SYSTEM

19. The capability to start the V-22 engines with an external power source should be developed or the reliability of the APU should be improved to prevent mission aborts due to APU malfunctions.

DRIVE SYSTEM

20. The pylon shaft's relatively low glass transition temperature of 240°F warrants further consideration and possible redesign in view of the possibility of relatively high operating temperatures in the upper nacelle, due to fire or during "hot day" conditions when nacelle temperatures can exceed 210°F.

21. Since the pylon drive shaft is critical for single engine operations, its close proximity to the engine compartment should be a consideration in engine failure or battle damage analysis since damage that would cause an engine failure/fire is also likely to breach the firewall.

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23. The "V" rings (oil seals) which are required on the input end of the engine torquemeter shaft lend themselves to improper installation. A alternative design that is not so critical in terms of orientation should be considered.

FLIGHT CONTROL AND HYDRAULIC SYSTEMS

24. The monitoring rates/ranges and integrity check of the mast torque signals should be adjusted to eliminate the nuisance failures and insure continued functioning during emergency conditions. Simulation tests should be conducted to identify potential emergency conditions where a "declared" failure of the mast torque signals could jeopardize the aircraft/crew. Additionally, simulation of critical operational maneuvers should be conducted to assure that nuisance failures of the mast torque sensors cannot create a hazardous flight condition.

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26. Each rotor is equipped with three (3) mast torque sensors and each engine has two (2) engine torque sensors. This redundancy should provide the flight crew with actual (or calculated) mast torque indications following a failure. The third sensor or a calculated value based on engine torque could be displayed following a dual sensor failure. The display of mast torque should be modified to insure a valid display following a failure and the MFD should be annotated by colors, boxes, flashing, etc, if the failure effects the accuracy.

27. The RESET of the TCLS contributed to the unrecoverable surges by commanding a rapid power increase from a damaged engine. The CMS does not display sufficient information to determine the TCLS contribution to the PDS during normal operations or the bias following a failure. The flight crew should be provided with sufficient cockpit information to determine if a RESET of a failed TCLS is advisable.

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should be improved to provide more explicit messages, or critical information must be readily available to assist the flight crew in making the correct decision.

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30. FADECs are successfully used in other aircraft to monitor the engine operations. The monitoring of engine operations by the FCS adds another "layer" of data processing and increases the probability of failures. The logic for using FCS vs. FADEC monitoring of engine operations should be evaluated.

31. The possibility of a dual engine failure caused by the overspeed protection should be evaluated. If a malfunction or maneuver can cause an overspeed to 114%, a dual engine "shut-down" will be the consequence. Tests should be conducted to determine if system failures or aggressive maneuvering can overspeed the power turbine/rotor system to the fuel "shut-off" limit of 114%.

32. The NATOPS procedure for a flight control fault is to acknowledge the MASTER CAUTION and press the PFCS FAIL/RESET switch to reset the fault. Additionally, the failure message DUAL XDCR FAIL will be displayed for a variety sensor faults. This mishap suggests that the cause of a failure should be determined before attempting to reset the fault. A single NATOPS procedure for the "PFCS FAIL/RESET" message may not be appropriate. The NATOPS emergency procedures should be expanded to provide a strategy for evaluation of a failure.

33. The use of average rotor speed by the FCS was beneficial in maintaining aircraft control during the emergency descent, however a display of individual rotor speeds was needed for failure analysis. The display of individual rotor speeds would provide an indication of ICDS failures and is needed by the pilot during an emergency landing following such failure. Analysis of ICDS failures should be conducted to determine the appropriate failure annunciation and to determine the preferred method to display individual rotor speeds.

34. Since the hydraulic systems are crucial for aircraft control, the flight crew should be advised of any system degradation. The switching logic in the FCC automatically attempted to isolate the leak, however the flight crew was not advised of a hydraulic fault until the "DUAL HYD SYS FAIL," following failure of the utility system. The WCA system should include discrete messages advising the flight crew of a leak, the status of the isolation procedures, and the failure (or partial isolation) of a single hydraulic system.

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36. The swashplate actuators are located outside the hydraulic system isolation valves, therefore a leak at the actuators will not be isolated and will eventually result in partial loss of the primary and the utility hydraulic systems. A thorough analysis of the hydraulic isolation system should be conducted to verify the "Two-Fail Operate or Safe" design logic. The review should

consider the potential for "hidden failures" that would jeopardize the success of the leak isolation process.

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38. The survivability of the V-22 following critical component failures is based on the pilot's ability to position the nacelles in a desirable landing configuration. The slow nacelle conversion rate, especially following hydraulic failure(s), will dictate whether the conversion is possible within a given altitude. The normal and backup nacelle conversion rates should be evaluated to determine acceptable performance for execution of emergency procedures.

39. The operation of the TCL should be modified to be consistent with the design. The present design of the TCL is physically arranged and operates in an angular motion similar to a helicopter collective. Consequently, a "negative transfer" of habit could result in incorrect TCL inputs. The TCL design should "look like a throttle and operate like at throttle", "look like a collective and operate like a collective", or be a design "unique" to the V-22.

AIRFRAME

40. The pylon driveshaft is an extremely high speed shaft operating in close proximity to critical flight control components, hydraulc lines and electronics. Design considerations should include the need to shield the shaft from potential abrasion by wires, tubing, etc and to prevent collateral damage to critical flight control components in the event of a shaft failure.

41. The nacelle conversion actuators function as primary flight controls in the most critical phases of flight and directly impact the effectiveness all other flight control actuators and surfaces. Therefore their level of redundancy, reliability and survivability should at least equal that of the swashplate actuators.

42. Failure and battle damage analysis protocols should follow a total system approach and should consider the potential for collateral damage leading to multiple system failures.

43. Hot Day (125°F) operating temperatures of the upper nacelle are predicted to be within 20°F of the pylon driveshaft Tg (240°F) with the nacelle blower operating normally. The possible effects of a blower failure or exhaust gas recirculation in a hover on nacelle operating temperatures needs to be a part of future nacelle design considerations.

44. The possible effects of an engine fire on the lower portions of the upper nacelle structure should be evaluated due to its approximate 300°F Tg.

45. The engine compartment horizontal firewall should be redesigned to eliminate holes that might allow high temperature gases/flames to enter the upper nacelle.

46. The upper nacelle should have fire detection and protection until adequate firewall protection is incorporated and potential fuel and ignition sources in the upper nacelle are eliminated.

47. The engine inlet fairing design point should be improved to provide sufficient strength to protect the inlet structure from the effects of an engine surge during all flight regimes.

48. Any engine inlet redesign should include a system to prevent fluids from collecting in the engine inlet centerbody.

AIRCREW AIRCRAFT INTERFACE

MISHAP SIMULATION

49. Simulation of the mishap indicates that diagnosis of the failures was difficult from visual information readily available to the flight crew. Tests should be conducted to examine the failure of critical components to determine:

- Appropriate failure message
- Display of information needed to analyze the failure
- NATOPS emergency procedures
- NATOPS limiatation

DISPLAYS AND WARNING/CAUTION/ADVISORY SYSTEM

50. The WCA system should be improved to provide timely and discrete messages that assist the flight crew in analysis of a failure. The essential information should be displayed without the flight crew "paging down" to find the information needed. A "pictorial" display of the flight control and hydraulic systems with the failures annotated would be beneficial.

51. The lines available for Cautions and Advisories on the MFDs should be increased to allow the display of additional messages and the display of cautions should be given priority over advisories. A centrally located, dedicated display for the WCA system would eliminate the need to display the messages on the primary flight MFDs.

52. The WCA system should be modified to annunciate a hydraulic leak and the status of the leak isolation procedure. The criticality of the hydraulic systems dictates that the crew be aware of potential control system problems.

53. The peak value of momentary exceedances should be "recorded" on the system status pages to provide the flight crew with information essential for failure analysis. Acknowledgment of the exceedance by the flight crew should reset the status to allow recording of subsequent exceedances.

54. The flight crew displays should provide individual rotor RPMs. Simulation tests should be conducted to examine ICDS failures, determine the appropriate annunciation of the failure, and provide procedures for continued flight and landing with a failure.

LIMITATIONS AND PROCEDURES

55. Simulation and flight tests should be conducted to develop height-velocity limitations with special emphasis on altitude required to configure the aircraft for an emergency landing. Pilot training should include simulation of engine(s), control system(s), and ICDS failures. The training should provide the pilots with an understanding of the failure analysis, the degradation caused by failures, and the preferred configuration to minimize the landing risks. Both military and contractor pilots should be required to complete the simulation training prior to participation in the flight test program.

56. The NATOPS should be revised to provide procedures for verifying engine(s), ICDS, and the combination of engine/ICDS failures. The pilot response to the failures should include the recommended nacelle configuration to minimize the landing risks.

57. The emergency procedures section of the NATOPS manual should be revised to provide flight crew steps to evaluate the cause of DUAL XDCR FAIL faults as part of the system RESET.

This mishap demonstrated the need to determine the cause of a failure prior to resetting the system.

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BS

MISHAP CAUSE FACTORS

59. As the source of the flammable fluid leak which was ingested by the RH engine was not determined with certainty, maintenance procedures should be established to closely monitor leaks and oil consumption, with particular attention to the proprotor gearbox. Maintenance procedures for tracking oil consumption and servicing should be reviewed to ensure that data is preserved and subjected to engineering review.

TECHNICAL CONCERNS

60. Specific recommendations applicable to aircraft technical concerns are presented in the Recommendations sections entitled "MISHAP AIRCRAFT AND SYSTEMS" and "AIRCREW/AIRCRAFT INTERFACE". In general, detailed recommendations have been avoided, leaving it to the systems engineering process to select the best overall technical solutions. Recommendations were made for areas in which there was a perceived need for improvement, recognizing that the COI's recommendation would not necessarily be the final fix. The technical recommendations are intended to foster engineer and pilot interaction, resulting in changes that will improve the ability of the aircrews to safely operate the V-22.

V-22 Court of Inquiry Report submitted by:

Captain, U.S. Navy
President

Colonel, U.S. Marine Corps
Member

Commander, U.S. Navy
Member

Authentication

Captain, U.S. Navy
President

Major, U.S. Marine Corps
Counsel for the court

Documents appended

- Appendices A, B and C to the Report
- Record of Proceedings:
  Transcripts of Testimony (Volumes 2 and 3)
  Exhibits (Volumes 4 through 12)

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APPENDIX A

ABBREVIATIONS

ABBREVIATION	MEANING
ABC	Analog Backup Computer
ABEC	Analog Backup Engine Control
ACO	Administrative Contracting Officer
ADAS	Analog to Digital Aircraft System
AFCS	Automatic Flight Control System
AFB	Air Force Base
AFR	Aircraft Flight Release
AGL	Above Ground Level
AIRS	Aircraft Inventory Reporting System
AMB	Aircraft Mishap Board
APU	Auxiliary Power Unit
ARPRO	Army Plant Representative Office
BHTI	Bell Helicopter Textron, Inc.
BIT	Built-in Test or Binary Digit
BOI	Break of Inspection
BUNO	Bureau Number
CAPT	Captain
CG	Center of Gravity
COI	Court of Inquiry
DLA	Defence Logistics Agency
DLAM	Defence Logistics Agency Manual
DLAR	Defence Logistics Agency Regulation
DME	Distance Measuring Equipment
DPRO	Defense Plant Representative Office
DT	Developmental Test
EAPS	Engine Air Particle Separator
ECL	Engine Control Lever
ECS	Environmental Control System
EI	Engineering Investigation
F	Farenheit
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FCC	Flight Control Computer
FCS	Flight Control System
FSD	Full Scale Development
FLOP	Flight Test and Operational Procedures
FMU	Fuel Management Unit
FSD	Full Scale Development
FTIP	Flight Test Interface Panel
FPM	Feet Per Minute
FPS	Feet Per Second
GFP	Government Furnished Property
GFR	Government Flight Representative
GR	Ground Run
GW	Gross Weight
HPDU	Hydraulic Power Drive Unit
Hz	Hertz
ICDS	Interconnecting Drive System
I_n	Nacelle Angle
ICS	Intercommunication Control System
JAG	Judge Advocate General
JASS	V-22 (JVX) Applications & Systems Software
JVX	Joint Services Vertical Lift Aircraft, Experimental
KCAS	Knots Calibrated Airspeed

KEAS	Knots Equivalent Airspeed
KT	Knots
LCDR	Lieutenant Commander
LTC	Lieutenant Colonel (Army)
LH	Left Hand
LTCOL	Lieutenant Colonel (Marine Corps)
MAJ	Major
MC	Mission Computer
MCB	Marine Corps Base
MFD	Multi-Function Display
MGT	Measured Gas Temperature
MOA	Memorandum of Agreement
MOC	Maintenance Operational Check
MSL	Mean Sea Level
MTT	Multi-service Test Team
MWGB	Mid-Wing Gearbox
NAS	Naval Air Station
NATC	Naval Air Test Center
NATOPS	Naval Aviation Training and Operating Procedures
NAVAIR	Naval Air Systems Command
NAVAIRINST	Naval Air Systems Command Instruction
NAWCAD	Naval Air Warfare Center, Aircraft Division
Nr	Proprotor speed
Ng	Gas Generator Speed
NIU	Nacelle Interface Unit
Np	Power Turbine Speed
NVM	Non-Volitale Memory
O-ring	Oil Ring
OD	Outer Diameter
OEI	One Engine Inoperative
OJT	On the Job Training
OPEVAL	Operational Evaluation
OT	Operational Test
PCO	Procuring Contracting Officer
PDS	Power Demand Signal
PFCS	Primary Flight Control System
PMA	Program Manager, Air
PRGB	Proprotor Gearbox
PRO	Plant Representative Office
PSID	Pounds Per Square Inch Differential
QA	Quality Assurance
Qm	Mast Torque
RH	Right Hand
RPM	Revolutions Per Minute
RR	Rejection Report
R/R	Remove/Replace
RTB RTR	Return to Base, Rotor
RWATD	Rotary Wing Aircraft Test Directorate
SFC	Specific Fuel Consumption
S/N	Serial Number
SOF	Safety of Flight
STOL	Short Takeoff and Landing
TAGB	Tilt Axis Gearbox
TA-PM	Test Authority Program Manager
T_2	Compressor Inlet Temperature
TCL	Thrust Control Lever

APPENDIX B

LISTING OF TRANSCRIPTS OF TESTIMONY

TRANSCRIPTS OF TESTIMONY

TRANSCRIPT		Page	Volume
30 JULY 92 AT MCB QUANTICO, VA. (TRANSCRIPT R0730)			2
SGT	Quantico Tower	02-14	
MSYGT	Weather NCOIC	14-19	
31 JULY 92 AT MCB QUANTICO, VA. (TRANSCRIPT 0731)			2
Mr.	V-22 Test Pilot/Eyewitness	21-39	
CWO-4	Quantico Airfield Ops Officer	39-51	
OC	Officer Candidate Eyewitness	51-54	
OC	Officer Candidate Eyewitness	55-59	
SGT	Waterskier/Eyewitness	59-69	
Mr.	Capitol Police/Eyewitness	69-79	
Mr.	Capitol Police/Eyewitness	80-86	
Mr.	Search by Boat	86-98	
Mr.	Quantico Marina	99-104	
Mr.	Quantico Marina	104-107	
Mr.	Quantico Marina	107-112	
SGT	HMX-1 V-22/Eyewitness	113-124	
04 AUG 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R0804)			2
MAJ	HMX-1 V-22/Eyewitness	01-22	
BGEN	Eyewitness	22-26	
Mrs.	Eyewitness	27-31	
Mr.	NAWC(AD) Wilmington Det/Eyewitness	32-58	
14 AUG 92 AT NAS PATUXENT RIVER, MD. (TRANSCRIPT R0814)			2
CAPT	Climatic Lab	01-31	
Mr.	Climatic Lab	01-15	
22 SEP 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R0922)			2
No Witnesses		01-3	
30 SEP 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R0930)			2
LTC , USA	GFR DPRO Boeing	05-49	

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		Page	Volume
01 OCT 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R1001)			2
Mr	Boeing QA Manager	52-119	
Mr.	Boeing Crew Chief	120-167	
Mr.	Boeing Preflight Inspector	168-203	
02 OCT 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R1002)			2
Mr.	Boeing Off-Site General Mechanic	206-252	
Mr.	Boeing Off-Site General Mechanic	252-309	
06 OCT 92 AT WASHINGTON NAVY YARD (TRANSCRIPT 1006)			3
Mr.	Boeing V-22 Flight Test Senior Manager	313-350	
Mr.	Boeing Helo Director of Flight Test	351-367	
Mr.	Boeing V-22 Test Ops Manager	368-395	
07 OCT 92 AT WASHINGTTON NAVY YARD (TRANSCRIPT R1007)			3
CDR I . . USN	NAVAIR Flight Clearance	399-409	
Mr.	DPRO Boeing ACO	410-421	
Mr.	NAVAIR PCO	422-440	
08 OCT 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R1008)			3
LTCOL	V-22 Deputy PM RWATD	443-528	
23 OCT 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R1023)			3
Mr.	Bell V-22 Project Pilot	01-54	
LCDR	PMTR for NAVAIR/ NAWC DET OIC	55-103	
10 NOV 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R1110)			3
Mr.	Boeing V-22 Test Pilot	05-46	
Mr.	NAVAIR Engineer	47-69	
Mr.	NAVAIR Engineer	70-87	
Mr.	NAVAIR Engineer	88-96	
17 NOV 92 AT WASHINGTON NAVY YARD (TRANSCRIPT R1118)			3
No witnesses		01-06	

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EXHIBITS

Number	Subject	Volume
1A to 1F	Appointing Orders & Requests for Party Status	4
2A to 2E	Diagrams of Aircraft	4
3	Audio Cassette - from Quantico Tower	4
4	Transcript of Exhibit 3 - Quantico Tower Tape	4
5	Video Cassette of Radar Transmissions	4
6	Weather Information	4
7	Diagram/Drawing by SGT	4
8	Photo of Osprey 01 (not BUNO 163914/Osprey 04)	4
9	DD175 Flight Plan	4
10A to 10XX	Statements from OCS Candidate Eyewitnesses	4
11A to 11D	Statements from 4 other OCS Candidate Eyewitnesses	4
12	Quantico Air Facility Ticker	4
13A to 13G	Map of Quantico (NYG) & Potomac River (1:50000)	4
14	Statment	4
15	Eglin Weather Briefing (DD Form 175-1)	4
16	Flight Clearance messages (3)	4
17A ,B	BUNO 163914 Flight History	4
18	CONDM's Use during Development Test (DT) II-C	4
19	CONDM's Use during Operational Test (OT) II-A	4
20	Capt Climatic Lab Test Brief	4
21	Climatic Hangar End of Test Report (by message)	4
22	Chronology of Climatic Laboratory	4
23	NAWCAD's Personnel Roster for Climatic Laboratory Tests	4
24	Voided	4
25	Flight Clearance Message dtd 29 Jan 92	4
26	Climatic Laboratory Test Clearance (superseded by Exhibit 16)	4
27	NAWCAD Support Test Plan - Climatic Laboratory Test	4
28	V-22 NATOPS Flight Manual	5
29	Flight Qualifications of V-22 Aircrew	5
30	Boeing's July Clearance Request to DPRO (Project Agreement)	6
31	TAD Orders for MAJ James, GYSGT Joyce, MGYSGT Leader	6
32	Med Quals/Autopsies/Death Certificates	6
33 post acc.	GFR Letter To Boeing: Non-Compliance with Flight Ops Procedures	6
34	Excerpts from Full Scale Devlopment (FSD) Contract	6
35	DD250 Provisionally Accepting BUNO 163914	6
36	MOA between NAVAIR & DPROs dtd 13 May 87	6
37	Tri-service Agreement Flight Test Ops - 21 Apr 92	6
38	Vols I & II DLAM 821d0.1; NAVAIRINST 3710.1C	6
39A	Boeing Flight Test Operations & Procedures (FLOP)	6
39B	Bell Flight Operating Procedures	6
39C	16 Oct 92 Memo by Boeing's	6
40	NAVAIRTESTCENINST 3710.15E dtd 7 Nov 90	6
41	NAVAIRINST 3710.8B dtd 1 Nov 88	6
42A	DLA Letter Appointing LTC GFR dtd 15 Apr 92	6
42B	Correspondence Concerning GFR Responsibilities	6
43	DPRO Contract Deficiency Report dtd 27 Mar 92	6
44	DLA letter to NAVAIR dtd 28 Apr 92 (Contract issues)	6
45	MOA NATC/Bell-Boeing dtd 29 Jun 87 (Part. Fly Program)	6
46	V-22 Turnaround Inspection (7/20) & Daily Inspection (7/19)	6
47	Amendment to Exhibit 45 dtd 21 Jun 90	6
48	Fuel System Engineering Investigation (EI)	7

Number	Subject	Volume
49A	Full Authority Digital Engine Control (FADEC) EI	7
49B	Climatic Lab FADEC Cooling Problem	7
50A	Engine Engineering Investigation (EI)	8
50B	Engine Diffuser Case Analysis	8
50C	Engine Compressor Vanes Analysis	8
50D	Allison Compressor Inlet Temp ltr dtd 12 Oct 92	8
50E	Combustible Fluid Ingestion Analysis	8
50F	Revisions to Engine E.I. dtd 9 Nov 92	8
50G	T-406 Test Report No. 89A26 dtd 30 Jan 89	8
50H	Engine Air Inlet Design Criteria ltr dtd 5 Nov 92	8
51	Fuel Management Unit (FMU) EI	9
52	BUNO 163914 Maintenance Information Notebook	9
53	MOA for Conduct of V-22 Aircraft Inspections by DPRO	9
54	NAVAIR ltr 1 Apr 92 Extending Participatory Flying until 30 Sep 92	9
55	Boeing's Suggested Restrictions on Participatory Flying dtd 15 Jan 92	9
56	NATC Request for Expanded Participatory Flying	9
57	NAVAIR ltr 12 Mar 90 Expanded NAWC Participation	9
58	NAVAIR ltr undated Extension of Participatory Flying	9
59	Flight Clearance for V-22 DT-IIC/ 5 Apr 91	9
60A	Drivetrain EI, Vol 1	10
60B	Drivetrain EI, Vol 2	10
60C	Thermal Analysis of Pylon Shaft	10
60D	Drivetrain EI Revision A dtd 22 Sep 92	10
61	Letter from Mr. Clarifying his Testimony	10
62	Memo Indicating No V-22 Aircraft in AIRS Data Base	10
63A	Flight Control & Hydraulic System EI	11
63B	Additional Flight Control EI Information from Mr.	11
63C	Flight Control EI Revision dtd 18 Sep 92	11
63D	Photographs of Selected Frames of Boeing's Mishap Videotape	11
64A to 64G	Recovery Operations	11
65	Mission Computer EI	11
66	Flight Control Computer EI	12
67A	Data Storage Units EI	12
67B	Memo Explaining Data Logger Correlation to Video Tape	12
68	Excerpts Concerning V-22 Test Program	12
69	DPRO Boeing GFR Survey of Boeing, April 1992	12
70	Flight Clearance for NAWC(AD) Test Pilots to Fly V-22, 11 Jul 90	12
71	Mishap Flight Voice Transcript	12
72A	Driveshaft Qualification Test Report dtd 13 Oct 88	12
72B	NAVAIR Acceptance of Driveshaft Qualification Test Report	12
73	Excerpts from V-22 Critical Design Review Presentation	12
74	Contract Modification Establishing BUNOs for Six V-22 Aircraft	12
75	V-22 Engineering Data Report 901-930-001	12
76	Excerpts from V-22 Specification SD-572-1/ Crashworthy Seats	12
77	Data Logger Warning/Caution/Advisory Data	12
78	Defective Hydraulic Fittings Memorandum dtd 1 Dec 92	12
79	OTIIA Data Monitoring System Description	12
80	V-22 Aircraft 4 Mishap - Analysis of Warning/Caution/Advisory Data	12
81	Selected Boeing Monthly Clearance and Qualification sheets	12
82	Aircraft Flight Risk Clause (H-8) from V-22 EMD Contract dtd 22 Oct 92	12
83	Torquemeter Shaft Information	12
84	Miscellaneous Amplifying Information from Boeing	12

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17 December 1992

From: Captain
To: Commander, Naval Air Systems Command

Subj: RESULTS OF COURT OF INQUIRY INVESTIGATION INTO THE CIRCUMSTANCES SURROUNDING THE CRASH OF V-22 AIRCRAFT BUNO 163914 THAT OCCURRED IN THE VICINITY OF MARINE CORPS BASE, QUANTICO, VA ON 20 JULY 1992

Ref: (a) JAGINST 5830.1
(b) Commander, Naval Air Systems Command ltr Ser AIR-09J/0533 dtd 24 July 1992
(c) Commander, Naval Air Systems Command ltr Ser AIR-09J/0607 dtd 18 August 1992

Encl (1) ~~(d)~~ V-22 Court of Inquiry Report
(2) ~~(e)~~ V-22 Court of Inquiry Record of Proceedings

1. In accordance with references (a) and (b), a Court of Inquiry was convened on 24 July 1992 to conduct the subject investigation. Mr. of the Federal Aviation Administration (FAA) participated in the investigation in accordance with reference (c) as a limited member. The investigation is complete as of this date.

2. The results of the investigation are presented as ~~references~~ enclosures ~~(d)~~ (1) and ~~(e)~~ (2) in twelve volumes (binders). The Report (Volume 1) includes an Executive Summary, Preliminary Statement, Findings of Fact, Opinions, Recommendations and Appendices. The Record of Proceedings consists of Testimony in Volumes 2 through 3 and Exhibits in Volumes 4 through 12.

3. The original and seven copies of the Report and Record of Proceedings have been provided to AIR-09J. The classification of all documentation is "unclassified".

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