PB93-917003

National Transportation Safety Board Special Investigation Report: Commercial Space Launch Incident, Launch Procedure Anomaly Orbital Sciences Corporation, Pegasus/SCD-1, 80 Nautical Miles East of Cape Canaveral, Florida
February 9, 1993

(U.S.) National Transportation Safety Board, Washington, DC

26 Jul 93

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

PB93-917003
NTSB/SIR-93/02

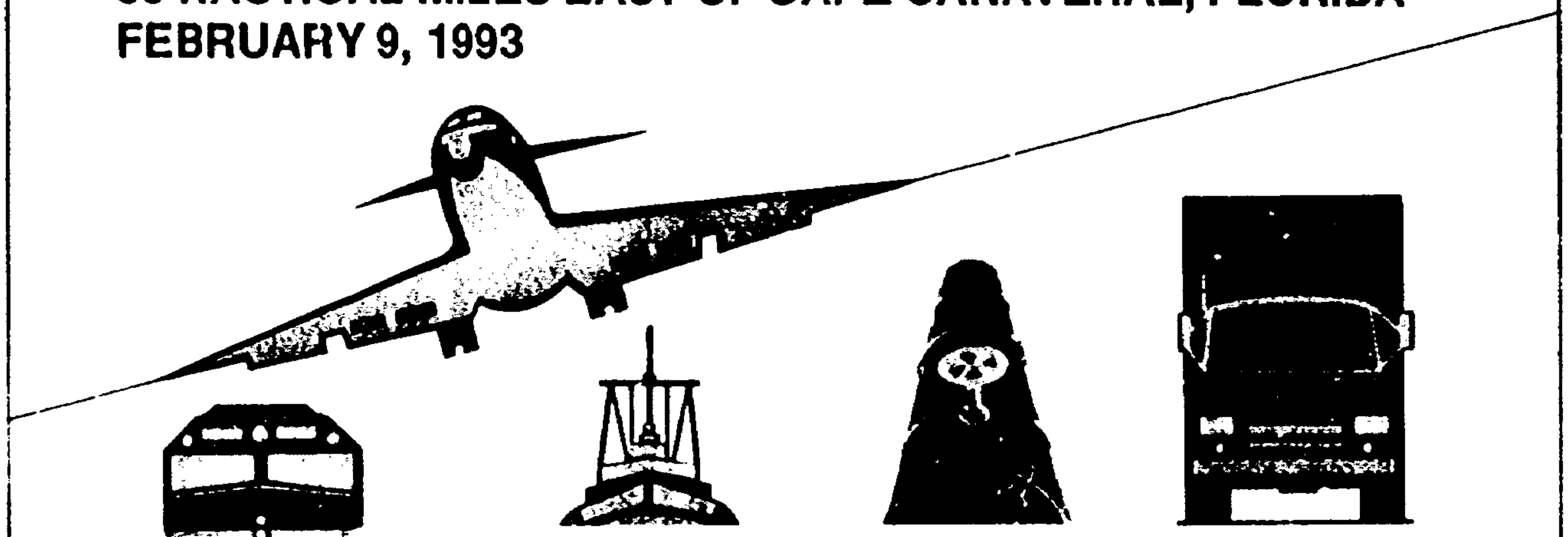
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

SPECIAL INVESTIGATION REPORT

COMMERCIAL SPACE LAUNCH INCIDENT

LAUNCH PROCEDURE ANOMALY
ORBITAL SCIENCES CORPORATION
PEGASUS/SCD-1
80 NAUTICAL MILES EAST OF CAPE CANAVERAL, FLORIDA
FEBRUARY 9, 1993



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Adopted: July 26, 1993
Notation 6108

Abstract: This report explains the procedural anomaly that occurred during the launch sequence of an Orbital Sciences Corporation Pegasus expendable launch vehicle, which was subsequently deployed successfully from an NB-52B airplane, on February 9, 1993. The safety issues discussed in the report include command, control and communications responsibility, launch crew fatigue, launch interphone procedures, efficiency of launch constraints, and the lack of common launch documents. Safety recommendations concerning these issues were made to the Department of Transportation, the National Aeronautics and Space Administration, and the Orbital Sciences Corporation.

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EXECUTIVE SUMMARY

On February 9, 1993, about 0930 eastern standard time, the launch sequence of an Orbital Sciences Corporation Pegasus expendable launch vehicle was aborted by the National Aeronautics and Space Administration range safety officer, in accordance with a previously established launch constraint. Several seconds later, the launch sequence was reinitiated by the Orbital Sciences Corporation test conductor, and the missile separated uneventfully from its carrier aircraft. The ignition and staging of the Pegasus and its subsequent deployment of two satellites into low earth orbit were also uneventful. There were no injuries to personnel involved in the mission and no damage to mission assets.

The launch was conducted under license number LLS-92-028, issued on December 23, 1992, by the Office of Commercial Space Transportation, Department of Transportation. The anomaly was investigated by the Safety Board, following an invitation by the Department of Transportation, in accordance with a Memorandum of Agreement dated June 5, 1989.

The safety issues raised in this report include command, control and communications responsibility, launch crew fatigue, launch interphone procedures, efficiency of launch constraints, and the lack of common launch documents.

ACRONYM/POSITION DESCRIPTION LIST

BDA	Bermuda FPQ-6 Radar Facility
DFRF	NASA Dryden Flight Research Facility
ELV	Expendable Launch Vehicle
ER	USAF Eastern Range
KSC/SLS	NASA Kennedy Space Center Shuttle Landing Strip
LPO	OSC Launch Panel Operator on the NB-52B
MFSO WFF	Missile Flight Safety Officer
NASCOM	NASA NASCOM Operator
NASA-1	**NASA Dryden Ground-to-Air Communications Coordinator** (Provides the primary communication link between the NB-52B and ground controllers)
NB-52B	NB-52B Launch Airplane
OCST/DOT	Office of Commercial Space Transportation
OSC	Orbital Sciences Corporation
PEG	Orbital Sciences Corporation Vehicle Engineer
RCO	**NASA WFF Range Control Officer** (Responsible for planning and coordinating operational support for assigned projects conducted on WFF Test Range; for coordinating and directing project activities during countdown; and serves as Assistant Test Director)
RSO	**NASA WFF Range Safety Officer** (Responsible for implementing ground and flight safety program on WFF Test Range; establishing a "hold" in operations until safety requirements are met; and monitoring and interpreting real-time flight safety displays to detect errant vehicles and initiating proper action, including flight termination)
RS 3	NASA WFF Range Safety Support (Command System)
RS 2	NASA WFF Range Safety Support
RS 1	NASA WFF Range Safety Support
SCD-1	Brazilian Environmental Satellite Aboard Pegasus
TM	NASA WFF Telemetry Coordinator
TD	**NASA WFF Test Director** (Has authority over all operations on WFF Test Range)
TC	**Orbital Sciences Corporation Test Conductor** (Responsible for directing the launch countdown and ensuring that proper countdown procedures and timelines are followed)
UHF	Ultra High Frequency Radio
WFF	NASA Goddard Wallops Flight Facility

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1. FACTUAL INFORMATION

1.1 Background Information and Investigation Protocol

On February 9, 1993, about 0930 eastern standard time (EST),[1] an abort was called for the launch sequence of an Orbital Sciences Corporation (OSC) Pegasus expendable launch vehicle (ELV) by the National Aeronautics and Space Administration (NASA), Goddard Space Flight Center, Wallops Flight Facility (WFF) range safety officer, in accordance with previously established launch constraints. About 30 seconds later, the launch sequence was reinitiated by the OSC test conductor (TC), and the ELV deployed uneventfully from an NB-52B.[2]

The purpose of the Pegasus SCD-1[3] mission was to place two spacecraft (a Brazilian environmental data acquisition and relay satellite and a smaller capabilities demonstration satellite, designated as OXP-1 by the U.S. Air Force (USAF) Space Command and operated by Orbcomm, a subsidiary of OSC) into low earth orbit (LEO). The Pegasus ELV was to be deployed from a USAF

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[1] All times in this report are in eastern standard time (EST) or stated in plus or minus elapsed time as follows: time in minutes and seconds before (T-X:XX) and after (T+X:XX) the deployment of the ELV.

[2] This NB-52B (radio call sign NASA 008) has been used by NASA's Dryden Flight Research Facility (DFRF) and predecessor organizations to deploy many powered and unpowered vehicles, beginning with the North American X-15 series of high altitude research aircraft in the late 1950s. This airplane is neither equipped with a cockpit voice recorder nor a flight data recorder, nor are they required by NASA or the USAF. OSC is in the process of modifying a Lockheed L-1011 Tristar transport airplane for Pegasus launches but will continue to use the NB-52B until the OSC airplane is certified.

[3] SCD is an acronym for Satellite de Coleta de Dados (Satellite to Collect Data).

Boeing NB-52B Stratofortress airplane that was on long-term loan to the NASA/Dryden Flight Research Facility (DFRF).

Ignition and staging of the Pegasus and deployment by the ELV of the two satellites into LEO were also uneventful. There were no injuries to personnel involved in the mission and no damage to mission assets. The launch was conducted under license number LLS-92-028, issued on December 23, 1992, by the Office of Commercial Space Transportation (OCST) of the Department of Transportation (DOT). The interruption in the launch sequence and the associated procedural anomalies prompted this investigation.

On June 5, 1989, a Memorandum of Agreement (MOA) between the National Transportation Safety Board and the Department of Transportation, Office of Commercial Space Transportation, was signed concerning the investigation of commercial space launch accidents by the Safety Board. In summary, the MOA stated that the Safety Board would lead investigations of commercial space launch accidents that result in certain levels of damage or loss of life or the impact of ELV debris outside the impact limit lines of a launch range facility and produce a report on the investigation that would include findings and recommendations. See appendix A.

The launch anomaly that precipitated this report did not fall under any of the categories in the MOA, and was not an "accident," as defined in the MOA. However, because of the potential seriousness of this incident, and the fact that three federal agencies and a commercial federally licensed company were involved, the Office of Commercial Space Transportation asked the Safety Board to conduct an independent investigation. In keeping with the general intent of the MOA, this report will address the timeframe from the takeoff of the NB-52B carrier aircraft until shortly after the release of the Pegasus ELV.

Parties to this investigation included Orbital Sciences Corporation (OSC), the National Aeronautics and Space Administration (NASA), the United States Air Force (USAF), and the Department of Transportation's Office of Commercial Space Transportation (OCST).

As part of the investigation, site visits and interviews were conducted at the NASA Goddard Space Flight Center's Wallops Flight Facility (GSFC/WFF) at Wallops Island, Virginia; the NASA Dryden Flight Research Facility (NASA/DFRF) at Edwards AFB, California; and the 45th Space Wing, USAF, Eastern Range (USAF/ER) at Cape Canaveral, Florida. Interviews were also conducted at the offices of the OCST and OSC. Because the launch anomaly that precipitated this report was not defined as an accident, the Safety Board conducted this as a Special Investigation. All interviews and investigation procedures were conducted pursuant to the guidelines established by the Office of Aviation Safety (Major Investigations Division) of the Safety Board. Findings and recommendations that resulted from the investigation are listed in sections 3 and 4, respectively. No public hearing was held in conjunction with this investigation.

1.1.1 The Pegasus SCD-1 General Mission Information

At the time of the Pegasus launch, the NB-52B was about 80 nautical miles east of Cape Canaveral at a 43,000-foot altitude and within a designated geographic safety area. The ignition of the first stage of Pegasus occurred 5 seconds after the ELV separated from the airplane. The NB-52B was accompanied by two NASA/DFRF Northrop F-18 chase aircraft; one was used as a safety observer, and the other was used as a photographic platform. Transponders aboard the F-18s also provided tertiary radar returns for the ground tracking stations, in the event of lost radar returns from the NB-52B and Pegasus during maneuvers prior to launch.

Initial radar and command support, including the ability to destroy the ELV after launch and ignition, was provided by the USAF/ER at the direction of the RSO or by the ER if deemed necessary. Initial telemetry support was provided by the Merritt Island Tracking Station (MILA) and the USAF/ER. About 140 seconds after release of the Pegasus, WFF and Bermuda Radar (BDA) transmitters assumed command and destruct responsibilities. Overall mission control was conducted from NASA/WFF, and this facility was considered the lead launch range for the mission. MILA provided voice communications relay between WFF and the NB-52B carrier aircraft.

Prelaunch preparations on the ground at DFRF consisted of installing the two satellites in the Pegasus, mating the Pegasus to the modified X-15 pylon under the right wing of the NB-52B, and conducting various systems tests on the four vehicles, among other things. The NB-52B and ELV were then ferried to NASA's Kennedy Space Center Shuttle Landing Strip (KSC/SLS) for further testing and eventual takeoff.[4] One uneventful refueling stop took place at Sheppard AFB, Texas, en route to the KSC/SLS. The landing at KSC/SLS was also uneventful, and the airplane was parked near the departure end of the runway.

Preparations for taxi for mission takeoff included, among other things, the establishment of all voice communications and data radio and video circuits, radar slew checks, flight termination command transmitter certification tests, various range safety checks, removal of launch safety pins from the Pegasus and pylon, and NB-52B engine start.

During the preparation for takeoff, all appropriate managers were made aware that the BDA FPQ-6 (Bermuda) radar array was not mission ready because of a mechanical malfunction. According to the WFF Minimum Safety Requirements, the BDA radar array should have been operational prior to the NB-52B takeoff on February 9. The OCS launch license required it to be operational also. However, the managers made the decision to launch the NB-52B despite the lack of BDA radar because it was probable that the radar would be repaired by Pegasus launch time and also because the mission responsibilities of the BDA station could have been assumed by a WFF radar array. The BDA radar was repaired and in service before the Pegasus launch.

Takeoff and initial climb of the NB-52B were uneventful. Interviews with the three flight crewmembers revealed that they believed the mission called for them to fly as high (up to the 50,000-foot service ceiling of the airplane) and as fast as they could prior to the deployment of the Pegasus. They stated that this seemed logical, because the purpose of the mission was to deploy satellites into earth orbit. This had also been the procedure in the two previous Pegasus launches. However, the planned mission parameters listed in WFF documents called for the airplane to be between 41,000 feet and 43,500 feet upon ELV deployment because a finite area below the aircraft was cleared of ships and air traffic by the U.S. Navy and the FAA, respectively. If the ELV were deployed above 43,500 feet, and the first stage did not ignite, it theoretically could have landed outside of the cleared safety zone.

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[4]The Shuttle Landing Strip was required because its length allowed for safe operation of the modified B-52. The B-52's aerodynamic flap systems were deactivated because the vertical fins of several of its payload vehicles (including Pegasus) protruded above the upper wing surface of the airplane. All takeoffs and landings, therefore, are in a no-flap condition, and require long runways. KSC/SLS was also the longest, most suitable runway on the southeastern U.S. coast. Its southerly location aided in orbital insertion of the satellites, and its coastal location precluded significant overflight of land during the launch.

Contrary to the WFF documents, the OSC (operator) Launch Operations and Mission Constraints Document stated in one section that maximum altitude for launch was "50,000 feet," and, in another section, that the proper launch altitude range was between "40,000 feet and 45,000 feet."

At launch time minus 3:28 (T-3:28) the WFF missile flight safety officer (MFSO) called the test director (TD) on channel 10 to notify him that the NB-52B was about 800 feet above the maximum altitude of 43,500 feet. It took about 10 seconds to reply to this call to the TD, and the entire message took about 10 more seconds to be relayed completely. The range control officer (RCO) heard this conversation, and a discussion concerning the minimum safety requirement between the RCO and the MFSO lasted until T-2:42. The RCO then initiated a conversation with the MFSO and the WFF range safety officer (RSO) concerning the altitude deviation.

NASA-1, responsible for talking directly to the NB-52B aircraft commander on ultra high frequency (UHF) radio was instructed by the RCO on intercom channel 4 to relay to the airplane the need for it to descend or an abort would occur. He relayed this information to the airplane at T-2:27. The NB-52B acknowledged the request at T-2:14.

A request to descend 800 feet would not normally have presented difficulties, according to the aircraft commander and copilot, although the reason for the descent was unknown to them at the time. However, their initial attempt to descend using the autopilot was unsuccessful. When they disconnected the autopilot, they experienced a large amount of aft control yoke force, caused by a considerable amount of nose-up trim that had been induced by the autopilot before the disconnect. They stated that both of them had to forcefully push forward on the control wheel to begin the descent and that, at first, the electric trim system appeared to have been inoperative.[5] The problem appeared to correct itself, and the airplane was below 43,500 feet by about T-1:00.

About this time, the WFF range safety support officer/command system (RS 3) and, shortly thereafter the RSO, noticed on their range safety video screens

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[5]According to the flightcrew, maintenance personnel at DFRF could not duplicate the autopilot malfunction on the ground, and no corrective action was taken. Concerning the inability to trim nose down while applying forward yoke pressure, it is known that the electric trim system can "stall" when large amounts of elevator pressure are applied; however, this anomaly usually occurs at lower altitudes and different airspeeds, according to a representative of the Boeing Group.

what they believed was a short data dropout associated with one of the two flight termination system command destruct receivers.[6] The signal level decrease was a mandatory abort item, according to what became known during the investigation as Special Rule Number One and its clarifying memorandum (see appendix C). The RSO then stated over intercom channel 10 to the RCO, "Bob, I've got a mandatory abort" at T-0:59. The WFF test director heard this call and stated "Abort, abort, abort, abort it." 4 seconds later on channel 1. At T-0:52, the RSO, believing the deployment of the Pegasus would be canceled, stopped the mission programmer, commonly referred to as the countdown clock. He then pushed back from his console because he believed all launch activity had ceased and to perform other post-abort duties. Some other key WFF participants did likewise.

The TC later stated that he was not monitoring intercom channel 1, but he thought he heard someone calling for an abort over the intercom net and, believing it might still have referred to the previous altitude problem, broke in on channel 4, at T-0:50, to ask "Who's calling an abort, please?" The TD, who was monitoring channel 4, responded to this query on channel 1, at T-0:47, with "Abort because of a command receiver call on the range safety officer." The TC stated that he did not receive this response on the intercom channels he was monitoring. The TD's response was not recorded on channel 4, but was recorded on channel 1. At T-0:44, the TC informed NASA-1, on channel 4, "We have abort, abort." NASA-1 transmitted this abort call to the aircraft at T-0:34.

In a postincident statement, the test conductor wrote that because people were standing up, and appeared confused about the validity of the supposed abort, he independently called an abort at T-0:44. He did so because of the confusion in the control room, and not because he knew exactly what went wrong, or because he heard the TD explain the reason for the abort on any intercom channel.[7] He did not remember looking toward the TD at that point. The TD, however, said that when he heard the TC ask on channel 4 who was calling the

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[6]Research in the days following the launch anomaly revealed that the data dropout was actually a telemetry dropout, rather than a failure of one of the command destruct receivers. The only place that this telemetry dropout could be differentiated from a true receiver failure was in the data acquisition and processing room, a facility that is not near the launch control center. According to the WFF RSO, no real-time method existed to differentiate a telemetry dropout from an actual command destruct receiver anomaly.

[7]The OSC TC later stated that when he called his independent abort, he also believed that a mission recycle was possible at that point. This was technically true, according to his understanding of the word abort. However, according to the understanding of the RSO, and according to Special Rule Number One, an abort for a command receiver dropout would have meant a mission cancellation. See appendix C.

abort, he made eye contact with the TC and explained the reason for the abort on intercom channel 1.

At T-0:35, the OSC Launch Panel Operator (LPO) in the NB-52B activated the Pegasus fin batteries, in accordance with his checklist. One second later at T-0:34, NASA-1, having heard the abort call from the TC, relayed to the airplane that an abort was declared because of a loss of a command receiver. At T-0:29, the TC stated two times that the fin batteries were on.[8] One second later, at T-0:28, an unidentified flight crewmember on the airplane responded to both notifications, saying "OK, the fin batteries are on. We understand abort."

The TC later stated that at this point, he turned to the RCO and RS-3 work station area and asked them if there was an abort. He believed the RS-3 responded negatively by waving her hands in a negative motion and stating that it was a telemetry problem. He said based on this, he believed that there was no abort in effect. The RS-3 later stated that she indicated verbally and possibly with an arm motion that the abort was valid.

At T-0:23, the TC stated, "Negative" and 1 second later, NASA-1 advised the NB-52B, "Negative on the abort. Negative." At T-0:20, the OSC LPO on the NB-52B asked, "You want the fin sweep?" (The fin sweep is a test of the control fins on Pegasus conducted shortly after the activation of the fin batteries during a launch sequence). At T-0:19, RS-3 responded to an earlier description of the telemetry dropout by the RSO on channel 10, with "Jack, that wasn't a TM [telemetry] glitch."

NASA-1 responded to the T-0:20 request from the airplane, at T-0:18, with "Keep going." The fin sweep test was then accomplished by the LPO.

During this period of confusion, the OSC (operator) personnel, NASA-1, and the flightcrew of the NB-52B continued the countdown. The crew of the NB-52B was using an onboard countdown clock at this time, according to established procedures. At T-0:08, the TC stated "Go for launch." Two seconds

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[8] The thermal fin batteries are high drain power sources that drive the control fins of the Pegasus. Once activated, they cannot be deactivated, and the Pegasus must be launched within 10 seconds of its planned launch time due to the short life of the batteries. They cannot be recharged or replaced in flight, and the turnaround time for battery replacement on the ground could have been as long as several days. Fin battery activation is irreversible, and stopping the launch sequence for more than a few seconds after fin battery activation would invariably mean a significant delay in mission accomplishment.

later, NASA-1 stated, "NASA-1 is go for launch." At T-0:04, the NB-52B aircraft commander acknowledged with, "OK, go for launch." Also at T-0:04, the RSO stated "Abort Bob" on channel 10. At T-0:02, the RCO asked "Are you saying abort?" followed, at T-0:00, with "Abort, Abort." The deployment of the Pegasus by the aircraft commander of the NB-52B occurred on time, and 1 second later, the NB-52B copilot radioed, "Pegasus away, Pegasus away."[9]

The key WFF personnel (the TD, RCO, and the RSO) stated that they were very surprised to see the Pegasus drop away from the NB-52B on the large television screens in front of the mission control room. They stated, however, that they quickly recovered from their surprise and began to monitor its flight. The ER was monitoring the WFF to NB-52B radio link and was aware that the launch was proceeding. Stage one ignition was announced by the TC at T+0:15. Good telemetry data was being received by this time. The staging of the Pegasus and deployment of the satellites were in accordance with previously established procedures for the mission.

1.2 Injuries to Persons

No persons were injured during the launch sequence.

1.3 Damage to Launch Vehicle

No damage occurred to the launch vehicle.

1.4 Other Damage

No other damage occurred.

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[9] A combined transcript of interphone and UHF radio transmissions for channels 1, 4, 10, and 12 is included in appendix B; however, it would be misleading to take this transcript as a literal account of all conversations that ensued during the last several minutes prior to the Pegasus deployment. Much conversation and gesturing took place off the intercom nets that were not recorded. Information on these conversations could only be obtained from participant interviews. Exact accounts of the off-net conversations varied among interviewees. In addition, it was not possible to determine what intercom channels were being monitored by specific launch team participants, so exactly who heard what on the intercom system or in off-net conversation is open to question. All interviewees indicated that conditions during this timeframe were confusing and disjointed.

1.5 Personnel Information

1.5.1 NASA Wallops Test Director (TD)

The TD has authority over all operations on the WFF test range. He or she is responsible for assuring that all range policy, criteria, and external agreements are satisfied during the operations.

The Wallops TD for Pegasus SCD-1, age 50, was first employed by NASA in 1967 as a project engineer and had been promoted to WFF Test Director about 4 years before this incident. He had previously worked for the U.S. Naval Air Development Center. He reported that during his career he had been involved in a multitude of small launches, several of the Scout satellite launches and about 100 major launches of other vehicles. He said he had stopped previous launches as late as 1/2 second prior to launch. Regarding previous launch anomalies concerning go/no-go decisions, he recalled an incident during an air-launched missile program when a range user deliberately launched a test weapon even though the airplane was outside its geographic firing box.

The TD's normal work schedule was 0800 to 1630, Monday through Friday, although he said he often became involved in work after hours. On Sunday, February 7, he spent the afternoon and evening until about 1900 on a rehearsal for the Pegasus launch planned around the arrival time of the NB-52B at the NASA-Kennedy Space Center. On Monday, February 8, he worked from 0800 to 1400 on a dress rehearsal for the Pegasus launch and remained at work until 1630. He said that he slept from 2100 until midnight, and returned to WFF to begin the launch activities at 0200, as scheduled. He characterized his workload for this launch by noting that "I've experienced much worse."

1.5.2 Orbital Sciences Corporation Test Conductor (TC)

The TC is responsible for directing the launch countdown and ensuring that proper countdown procedures and timelines are followed. He or she provides a "go" or "no-go" recommendation to the OSC Mission Director based on the status of the ground launch team. The OSC Mission Director has overall launch authority with respect to vehicle issues.

The TC, age 33, was employed by OSC in June 1990. His title was Pegasus Program Manager, and he served as test conductor on the previous Pegasus launch. Before OSC, he had worked for 5 years in the U.S. Air Force as a launch controller for the Titan rocket, and he had served as a self-employed consultant for the aerospace industry. He is a graduate of the Air Force launch controller training program. He indicated that during his career he had been involved in eight or nine Titan launches, two previous Pegasus launches and a number of Pegasus launch rehearsals and test flights. He had participated in two safety investigations of Titan rocket mishaps and one concerning the Pegasus rocket.

On Sunday, from 0800 to 2100, he was in the WFF mission control room tracking the NB-52B ferry operation. He ate dinner and was asleep at the hotel by 2300. On Monday, he awoke about 0700 and arrived at WFF for a meeting from 0800 to 0830. He participated in the dress rehearsal and debriefing from 0900 until about 1700. He characterized his evening as hectic, consisting of dinner, meeting representatives from Brazil, and being required to change his motel. He went to bed between 2300 and midnight, and awoke at 0100 on Tuesday to arrive at WFF and begin the count for launch at 0200. Asked whether he felt well rested, he stated "no, not really." He characterized his workload as "excessive for everybody, especially at the KSC where they were sleeping on sofas."

1.5.3 NASA Wallops Range Control Officer (RCO)

The designated RCO is responsible for planning and coordinating operational support for assigned projects conducted on the WFF Test Range. He/she is responsible for coordinating and directing project activities as necessary during the countdown. He/she also serves as Assistant Test Director.

The RCO, age 57, was employed by WFF in 1959. He had previously worked as a draftsman for the Navy. He had been involved in several thousand launches, and indicated that he was familiar with many previous launch anomalies, several involving a go/no-go launch decision.

The RCO was not on duty on Saturday, February 6. He went to bed about 2230. On Sunday, he arose between 0500 and 0600. He participated in the NB-52B landing rehearsal from 1230 to 1930 and went to bed between 2100 and 2130. He awoke about 0600 on Monday, February 8, and spent most of the day at the launch dress rehearsal. He left WFF about 1530, ate dinner, and retired about 2130. He arose between 2345 and midnight, and prepared to go to WFF for the 0200 start of the countdown.

1.5.4 NASA Wallops Range Safety Officer (RSO)

The GSFC/RSO is responsible for: (1) implementing the ground and flight safety program on the WFF Test Range or remote operations; (2) approving any deviation from the requirements set forth in safety plans; (3) reviewing all conditions subject to safety plan limits and establishing a "hold" in operations, when necessary, until all safety requirements are met; (4) monitoring and interpreting real-time flight safety displays to detect errant vehicles and, if deemed necessary, initiating proper action, including flight termination; (5) determining and authorizing proper safety procedures to be followed during unplanned operational contingencies; and (6) appointing an Operational Safety Officer for unplanned operational contingencies.

The RSO, age 52, began full-time employment at WFF in 1963 following summer visits as an electrical engineering student. During his career, he was involved in several thousand launches. He had participated in 8 to 10 accident investigations of missiles destroyed by range safety officers.

The RSO was off duty on Saturday, and went to bed between 2300 and 2400. He awoke at 0600 on Sunday, and was at work at WFF from 1300 to 1900. He went to bed at his normal time, 2130 to 2200. On Monday, February 8, he deliberately awoke at 0200 and watched television for a short while in preparation for being awake the next night. He awoke again at 0530. He participated at the launch dress rehearsal from 0800 to 1530, went home and ate dinner, then went to sleep by 1800. He awoke between 2315 and 2330 to prepare for the 0200 countdown on Tuesday. The RSO said that this was the first time he deliberately awoke the night before a launch, and said that during the actual launch he felt "very fresh." He characterized his workload as "heavy."

1.5.5 Dryden NASA-1

The NASA-1 position in the Dryden Command Center provided the primary communication with the NB-52B. The NASA-1 operator, age 68, had been employed by DFRF since 1959. Previous work included military service, employment with an airplane manufacturer, and flight testing with ship-launched missiles. During his career he had been involved in 12 launches of ship-launched missiles and, in the previous Pegasus rehearsals, in test flights and launches in which he served as NASA-1. OSC personnel stated that he was familiar with Pegasus program procedures and practices. He had served on several accident investigation boards.

On Saturday, NASA-1 was off duty and completed routine activities around his home in California. He went to bed between 2200 and 2230 PST (pacific standard time) which was earlier than normal. On Sunday, he arose at 0430 PST and spent much of the day flying by commercial airline to Wallops Island. He went to bed about midnight local time (EST). On Monday, February 8, he awoke about 0800 and spent most of the day at WFF. His activities included the rehearsal and debriefing for the launch. He left WFF between 1600 and 1700, ate dinner with a colleague, and went to bed at 2200. On Tuesday he awoke between 0200 and 0300 and arrived at WFF between 0500 and 0530 to join the countdown in progress.

1.5.6 Dryden NB-52B Aircraft Commander

The NB-52B aircraft commander was the pilot-in-command of the launch airplane. He had the launch switch at his position and activated it for the actual launch.

The NB-52B aircraft commander, age 56, began employment at DFRF in 1986 as a research pilot. He had previously completed engineering school and had served 30 years in the U.S. Air Force, including work as a test pilot. He had also served for 17 years as a NASA astronaut and flown on two Shuttle Transport System orbital flights. He was also involved in early Shuttle suborbital testing. Regarding previous anomalies, he had experienced various system failures including an engine failure during the launch of a space shuttle orbital flight. In previous flights, he had called aborts in the last 30 seconds before an operation. The aircraft commander had served as a flight crewmember on the two previous Pegasus launches. He had worked closely with the Pegasus program from its inception.

On Friday, February 5, he was involved in a final meeting and crew briefing concerning the launch mission, and he returned home between 1600 and 1700 PST. On Saturday, he completed routine activities at home which included monitoring weather information for the upcoming ferry trip. He went to bed by 2000 PST. On Sunday, he arrived at DFRF for a 0430 PST prelaunch briefing, and he spent most of the day ferrying the NB-52B/Pegasus to Florida. After what he characterized as a long day, he drove 40 minutes to a hotel in Cocoa Beach, Florida, and went to bed between 2130 and 2200 EST. On Monday, February 8, he awoke between 0530 and 0600 and spent from 0900 to 1900 in launch preparations including a rehearsal flight, debriefing, briefing for the launch, and final paperwork. He had dinner in a restaurant, and went to bed between 2030 and 2100. On Tuesday, February 9, he awoke at 0330. He characterized the workload level during the days prior to the launch as busy, but he "never felt out of sorts. No time to read a paper, but no panicky rush." He said that this launch was a little busier than the two previous Pegasus launches.

1.6 Expendable Launch Vehicle Information

The standard Pegasus system consists of a 3-stage, solid propellant ELV that is inertially guided and 3-axis stabilized during flight. Launching a Pegasus rocket from an airplane flying at an altitude above about 40,000 feet reduces the amount of effort needed to overcome the Earth's gravity by as much as 10 to 15 percent, depending upon many variables. Pegasus SCD-1 was the third orbital launch of the Pegasus. Two previous launches from the U.S. west coast placed an OSC Pegasus satellite into orbit on April 5, 1990, and seven microsatellites into orbit for the Defense Advanced Research Projects Agency on July 17, 1991. (See figure 1).

The first stage consists of a solid rocket motor that provides the vast majority of the endoatmospheric thrust. A triangular wing made of composite material, mounted on a fairing above the first stage body, provides lift during the first stage burn. First stage guidance is provided by three composite aerodynamic control fins at the rear of the ELV. Small solid rocket motors in the composite fins are ignited during the last seconds of the first stage burn to provide necessary control authority in the upper atmosphere.

The second stage consists of a solid rocket motor that is guided in pitch and yaw by thrust vector control. Roll is controlled by a cold gas (nitrogen) reaction control system. During the coasting portion of the flight, all axes are controlled with the cold gas system. All major flight termination system components are mounted on the second stage.

The third stage consists of a solid rocket motor and is guided in a similar manner to the second stage. The avionics components and the fin thermal batteries are mounted on this stage. The Pegasus can also have a fourth liquid-fueled stage.

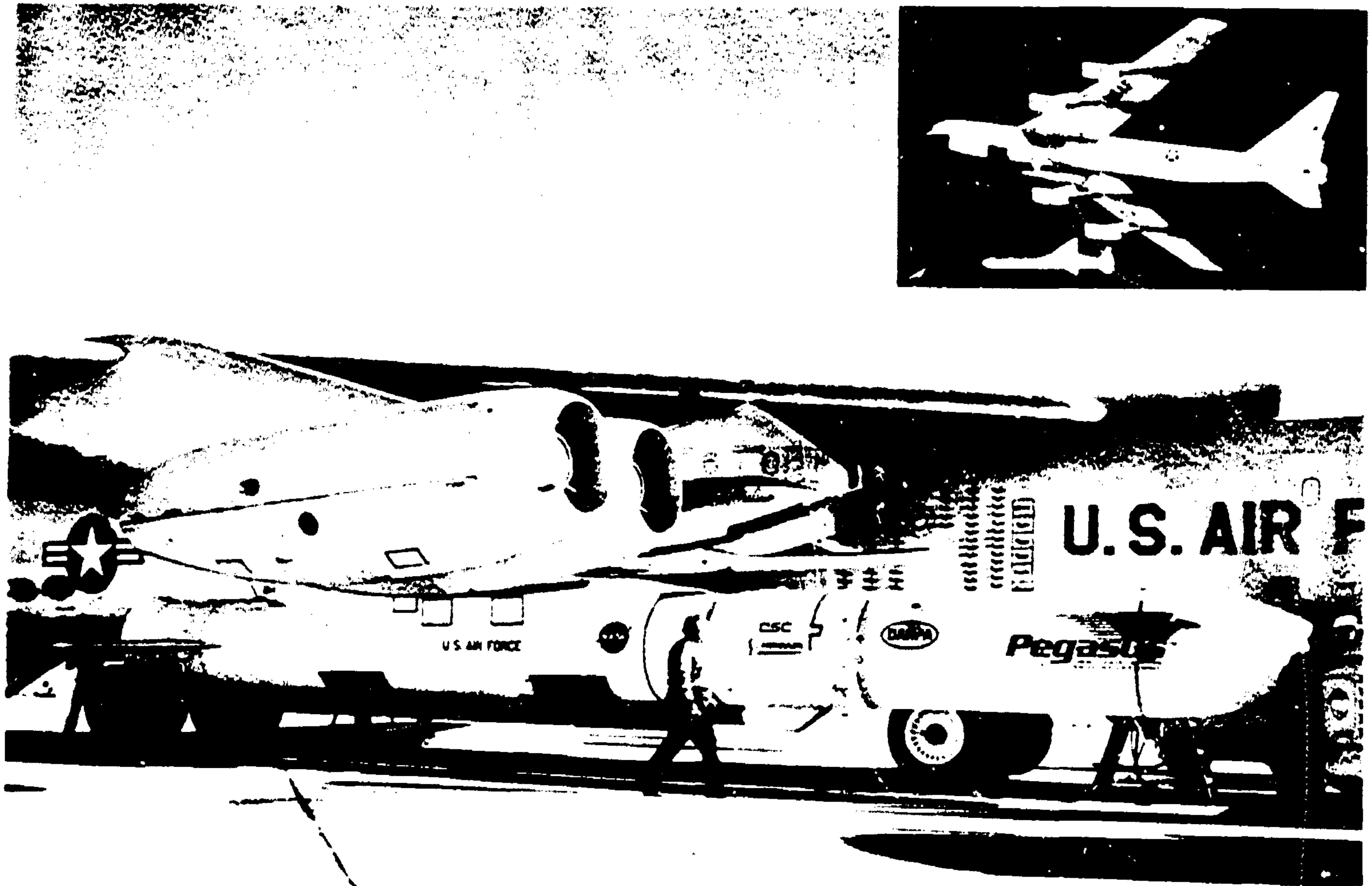

Figure 1.--NB-52B and Pegasus.

The length of the Pegasus ELV is about 50 feet, its wingspan is 22 feet, and its diameter is about 50 inches. Upon launch, the ELV weighs approximately 41,000 pounds.

1.6.1 Flight Termination System

The flight termination system (FTS) used for the Pegasus vehicle consists of two identical dual redundant command destruct systems. Each system consists of a command receiver and various shaped charges placed at critical points throughout the vehicle. Both command destruct receivers are fed signals from an array of three antennas that are mounted on the second stage housing. Each of the command destruct systems are powered by self-contained batteries. To inhibit an inadvertent destruct command during captive flight, several interlocks must be removed before the command destruct signal can fire the destruct charges. The ability to destroy the Pegasus vehicle from the ground exists from 2.8 seconds after it is released from the host airplane up to the time of second-third stage separation.

The FTS aboard the Pegasus vehicle was powered up at all times during the flight. The ground transmitter was also continuously transmitting a carrier signal. The receivers aboard the Pegasus vehicle lock on and track the ground transmitter's carrier signal. To allow ground controllers to monitor the health of the command destruct system, several key parameters are inserted into the telemetry data stream. These parameters include voltage, current, and temperature for each battery. Also, the signal strength of the carrier signal received by each of the command receivers is monitored. This signal strength parameter was an indication of how well the command receiver is receiving the ground transmitter's carrier signal. When the command is given to destroy the vehicle, a specific tone pattern is transmitted on the carrier wave. When the receivers aboard the Pegasus receive the preassigned tone pattern from the ground, they send an electrical signal through the interlocks to the destruct charges.

Several ground transmitter sites were designated to support the Pegasus launch. The Cape Canaveral transmitter would be the primary destruct transmitter during the first 140 seconds of launch. After the first 140 seconds, the ELV would be high enough above the horizon for the WFF transmitter to become the primary site and BDA became available to provide a backup destruct command.

The RSO at WFF was the primary individual to initiate a command destruct of the vehicle. Due to hardware limitations, the RSO could not directly control the ER command destruct transmitters. To initiate destruction of the vehicle during the first 140 seconds of flight, he would have to say the agreed upon code word over the RSO primary and backup nets. The ER flight control officer, upon hearing the code word, would activate another circuit to transmit the destruct code to the vehicle. After the first 140 seconds of flight, the RSO would say an agreed upon transfer of control code word and activate the carrier signal of the ER command destruct transmitter. Upon hearing the code word, the ER personnel would shut their transmitter down. The RSO then had direct control and could send the destruct command directly. If the primary destruct system failed, the BDA RSO was standing by to destroy the vehicle upon hearing the code word over the RSO net. WFF did not have direct control over the BDA command destruct transmitter.

One of the agreed upon range safety rules was that no command receiver dropouts could occur during the last 6 minutes of captive flight prior to the launch. This rule was a compromise between WFF and the ER management over concerns that the ER had about the ability of the Pegasus vehicle to receive the FTS signals throughout the entire flight envelope. In the early stage of launch planning, the ER had requested new FTS antenna pattern data[10] for ER flights to ensure that there would be adequate command destruct signal strength during flight. New data was not available for the Pegasus vehicle and would have to have been generated by flying either a live or an inert Pegasus vehicle under the wing of a maneuvering NB-52B airplane. Due to the limited availability of the inert Pegasus vehicle, this data collection flight would have delayed the launch by several months.

The flightpath and limited turning maneuvers of the launch airplane during the last 6 minutes of flight were preplanned to preclude the likelihood of command receiver dropouts.

During the launch, the telemetry from the vehicle was monitored to ensure that the signal strength of either of the two command receivers did not fall below a specified minimum threshold. The telemetry data associated with the command receiver signal strength was transmitted once every major frame or every 200 milliseconds (5 times a second). At T-0:71 during the countdown, the telemetry data showed that the number one command receiver's signal strength had dropped to a value that was below the minimum acceptable threshold. This momentary dropout

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[10]Antenna pattern data is derived from a test flight of the Pegasus/NB-52B. During this test flight, turns, ascents, and descents are made by the airplane. Points of radio signal blockage or shadowing because of the maneuvering are noted to ensure that minimal radio signal interference exists during the actual launch of Pegasus.

(40 milliseconds, or one frame of telemetry data) quickly recovered to its previous value. The abort was called at T-0:59.

There were no other reported equipment problems or outages associated with the FTS on the day of the launch.

1.6.1.1 Flight Termination Criteria

According to the GSFC/WFF Operations and Safety Directive (WFF/OSD) for ORW-0322 Pegasus/SCD-1, the following conditions will require flight termination action:

A. Instantaneous impact point (IIP) violation of destruct limits.

B. Violation of flight elevation or flight azimuth limits.

C. All data is lost at both WFF and ER and the vehicle is capable of violating a flight termination limit.

D. During the planned release drop in the planned release area, an unignited vehicle falls below 20,000 feet altitude.

E. Two or more data sources (telemetry or radar) indicate:

1. Loss of flight computer.

   Flight computer loss will be determined from telemetry data through combinations of the following events:

   a. Loss of vehicle power.

   b. Stopped or erratic data from TM words originating from the flight computer.

   c. Erratic vehicle flight.

2. No fairing separation.

   Fairing separation can be determined by:

a. Discrete telemetry word T-5.

b. Discrete telemetry word T-6.

c. Acceleration spike at fairing separation time.

d. For near nominal trajectories, nominal velocity following fairing separation time.

F. Three sigma low third stage performance will not achieve a minimum perigee of 50 NM.

G. The second stage burnout velocity or flight azimuth limits are violated.

H. Vehicle system failures which would result in uncontrolled flight.

I. Following release in the contingency drop area, after the vehicle has fallen 5,000 feet (or for 18 seconds).

J. Ten seconds following an emergency drop of the Pegasus vehicle from the B-52.

1.7 Launch Constraint and Safety Information

Launch constraints, mission constraints, minimum safety requirements, and the like, for Pegasus SCD-1 were contained in two documents available to some, but not all, of the launch participants. For the most part, OSC (operator) safety information was contained in the Pegasus F3/M13 SCD1 Mission Notebook, and WFF safety information was contained in the Operations and Safety Directive for ORW-0322 Pegasus/SCD-1. Portions of these documents are reproduced in appendix G of this report, and pertinent rules are highlighted in bold print there.

1.8 Coordination and Communication

1.8.1 Coordination and Communication Between Agencies

The ER flight control officer speculated that time and cost constraints limited the coordination of prelaunch meetings for the Pegasus launch. OSC personnel disagree. They stated, for instance, that OSC was told not to meet with the ER and that WFF would accomplish all coordination with the ER. According to the ER Deputy Director of Safety, there were many meetings between the ER and WFF beginning in late September concerning range safety, but neither OSC or DFRF were represented. The RCO stated that all early planning meetings had been by teleconference and speaker phones only, and that there was no actual meeting of all parties involved in the launch until the Friday (4 days) before the launch. OSC personnel disagreed with this also. They stated that there were at least two face-to-face mission procedure meetings between OSC and WFF and numerous other planning meetings.

The NB-52B pilot said that the principals involved in approving the launch operations and mission constraints document were never in the same room together as they had been for West Coast launches. He also said that there were no full-up simulations of failure situations.

The OSC Mission Director said that the parties involved were not introduced to each other. The DFRF Project Manager said that he heard an abort call prior to launch by the test director (TD) but had no idea who he was, why he was there, or what his authority was.

An OCST observer said that he had seen other launches in which a central person was in control and that all participants had recognized and acknowledged that person's authority. However, he indicated that he did not observe such a central authority for the Pegasus launch. Further, there was no documentation for the launch that spelled out the authority of the specific launch personnel.

1.8.1.1 The Dress Rehearsal

The OSC Mission Director characterized the rehearsal as "chaotic" and said that some of the problems reappeared during the launch activities. He said that there was extensive review of mission notebook pages, "hoards" of people were walking around, and people were not in their assigned seats. Also, he said that there was no review of the mission rules or constraints during the dress rehearsal. For example, there was no briefing of an altitude limit rule that surfaced before the launch. He stated that he learned later that WFF launch documents had different page numbers on pages copied from the OSC (operator) launch book and that WFF had selectively changed and deleted part of the OSC protocol.

The DFRF Project Manager indicated that at the time, he thought WFF was operating under the DFRF rules used on the first two Pegasus launches. He said that these rules had worked smoothly then and had not been changed since that time. By contrast, the altitude anomaly was a complete surprise to him and the other DFRF personnel (including the flightcrew). Special Rule Number One, the abort rule concerning command receiver signal dropout, was also a surprise. DFRF NASA-1 said that his greatest concern on this mission was the rehearsal, which gave him the feeling that there was "something so different" about this control room that he felt uneasy.

During the dress rehearsal, an abort was executed that was called by the TC. According to the mission constraints document, an abort call can result in a recycle, a hold for the day, or a jettison of the Pegasus ELV. The rehearsed abort resulted in a recycle; that is, the airplane flew in a circular pattern to return to the drop box area for another launch attempt, and the launch countdown was reinstated. The RCO indicated that this recycle rehearsal procedure was accomplished informally, and that no individual was uniformly recognized as responsible for the reinstatement of the countdown (although the RCO indicated that he was probably the individual responsible).

1.8.2 Technical Communications Aspects

1.8.2.1 Intercom Setup in the Mission Control Room

The mission control room layout at the WFF at the time of the Pegasus launch consisted of eight work stations and one test director's station containing two consoles in the main mission control room. Two range safety stations were also located in an adjacent range safety room. All of these stations had at least two intercom control panels, and the test director's consoles had three panels.

Each intercom control panel consisted of 12 monitoring switches, a volume control for each channel, a built-in speaker, and an output jack for an external headset. Each of the 12 monitoring switches had three positions: speaker, phone, and monitor/transmit. With the switch in the speaker position, audio information from that channel was heard on the built-in speaker. With the switch in the phone position, the audio information from that channel was heard on the headset. With the switch in the monitor/transmit position, the individual would hear any audio information on that channel and would be able to transmit on that channel from his headset microphone when he pushed a push-to-talk switch. The push-to-talk switches were either floor-mounted foot switches or hand-operated clip-on switches, usually worn on the individual's belt.

There was no limit to the number of available channels that an individual could monitor or on which an individual could transmit. If an individual monitored multiple channels, all of the audio information was mixed together and sent to either the speaker or headset at the set volume levels. There were no indicators to alert the operator as to what channels were selected or were active (in use). The only means for an individual to verify if a conversation was on a particular channel would be to monitor that channel exclusively. If a person was monitoring multiple channels, he or she would not have a visual means to determine the channel on which the conversation was taking place.

During the Pegasus launch the 12 channels were assigned as follows:

Channel 1	Range Operations
Channel 2	Radar
Channel 3	Telemetry
Channel 4	Mission Director
Channel 5	Launch Coordinator
Channel 6	Track Coordinator
Channel 7	Telemetry Coordinator
Channel 8	Range Safety Officer Voice (primary)
Channel 9	Range Safety Officer Voice (backup)
Channel 10	Range Safety Officer
Channel 11	Orbital Sciences Corporation
Channel 12	UHF[11] Voice Monitor

[11]Ultra High Frequency air-ground radio communications between the WFF mission control and the launch aircraft.

All of the audio information on the intercom channels was recorded at the WFF except channels 8, 9, and 11 which, according to the WFF personnel, were inadvertently not recorded.

All of the nonlocal intercom channels (channels 5, 6, 7, 8, 9, and 12) were available through the NASA NASCOM communication system to other remotely located range participants. These participants included the USAF ER control center, the BDA radar tracking site, and the MILA radar tracking site located several hundred miles south of Cape Canaveral, Florida.

1.8.2.2 Radio Communications with the Launch Airplane

The NB-52B was equipped with limited range (line-of-sight) UHF pilot-to-ground radios. Because of their limited range, the WFF mission control room communicated with the launch airplane via satellite up/downlinks. Information from WFF was remotely transmitted via satellite to a UHF transmitter at Cape Canaveral, Florida, and then on to the airplane and vice versa. This permitted continuous contact with the launch airplane on the ground and throughout its flight. The link included primary and backup frequencies and transmitters.

Due to hardware incompatibilities, special modifications of the intercom system had to be made to allow the TC and NASA-1 to transmit from the WFF mission control room to the airplane. The normal intercom selection and keying of the microphone did not work for the remote UHF transmitter. Two special UHF radio handsets were wired into station 3 where the NASA-1 and TC were located.

To transmit on the UHF radio from these two positions, a special hand-held microphone was required. This meant that the test conductor (TC) and NASA-1 had to wear a normal headset to transmit and monitor on the other intercom channels and either use the built-in speaker or another headset to communicate with the airplane. When they needed to transmit on the UHF radio, they had to use the hand-held microphone. This prevented anyone not seated at station 3 from transmitting on the UHF radio; however, everyone in the control room could monitor the UHF radio conversations on channel 12.

The first two launches of the Pegasus had been controlled by the USAF Western Range. The OSC and DFRF personnel involved in the launch had been located in a separate room remote from the control room. The OSC Test Conductor said he preferred this arrangement because it forced everyone to use the intercom and forced everyone to exercise proper communication discipline.

All WFF, OSC, and DFRF personnel involved in launch control were seated in two adjoining rooms, separated by an open sliding door, at the control center. Flight personnel and ER support range personnel were located in Florida. A portion of the communication in the WFF control center was off net. The TC said that at some points, he was required to communicate with the RCO off net by yelling, since the RCO was several work stations away from him. Also, NASA-1 said he heard conversations in the room that were not on the intercom net. The OSC Mission Director characterized the communication situation in the control room as "chaotic" in the last seconds before the incident. He contrasted this unfavorably to discipline in the Western Range control room that he characterized as "brutally formal." NASA-1 said that communication discipline in the control room was "not the best," and that in the final 30 seconds before launch there was off-net conversation, noise, people moving around, and droning voices that he later attributed to people discussing that the launch was aborted.

According to the RCO, the final calls for an abort were made both on net and off net. He recalled the TD calling for an abort in a loud and distinct voice, and said that he did not hear any calls of "no abort" in the room. The TC said that he initially calle.' : or an abort of the launch based on confusion in the control room and off-net calls i. - an abort. He also stated that he called for an abort because it would allow a 25-minute recycle time to sort things out.

An OCST observer, who monitored the radio communication remotely from the ER range control center in Florida, stated that it was very difficult to follow what was happening compared with other launches. She said that people who had not identified themselves were transmitting, and that it was unclear who was saying what and with what authority. She said that at one point during the countdown, everyone normally switches to a single communication channel but that this did not occur on February 9.

The TD stated that Channel 1 was the "launch channel" for all command and control activity and that everyone except the airplane's flightcrew was required to monitor Channel 1. He was not monitoring the air-to-ground channel (12), and thought incorrectly that the abort had taken place before the batteries on the rocket were activated. By contrast, the TC was speaking on and monitoring Channel 4 as the principal channel and did not monitor Channel 1. He stated that

Channel 4 had been established by WFF as the "launch channel" during the dress rehearsal, and noted that the control room team had exercised an unplanned abort successfully during rehearsal that he called on Channel 4. He said that during the second Pegasus launch, he found he could not listen to all nets, so the Western Range decided that the mission director channel and the air-to-ground UHF channel were the critical channels to monitor. NASA-1 indicated that he expected that others were monitoring the UHF channel along with him and that they would interrupt him if he made a mistake. The fact that the RSO did not confirm the abort after he called "go on," at T-0:18, indicated to him that he (NASA-1) was correct.

1.8.3 Radio Telemetry Data from the Pegasus Vehicle

Two channels of one-way telemetry data were being transmitted by the Pegasus vehicle to the ground receiving stations. The first channel consisted of a 2269.5 MHz FM/FM modulated stream of high sample rate vibration data collected from various sensors onboard the Pegasus. The second telemetry channel was a 2288.5 MHz PCM[12] FM modulated data stream containing approximately 300 discrete measurements of various aspects of the vehicle's health and guidance systems during the launch.

Both of the telemetry data streams were transmitted continuously by the Pegasus. The primary receiving station for the telemetry data was the ER site in Florida. There were also three backup telemetry receiving sites at WFF, BDA, and MILA. WFF and BDA could not receive telemetry data directly during the first 140 seconds of flight because the altitude of the ELV would be below the horizon for these sites. Therefore, the primary telemetry data was received and rebroadcast through the NASCOM system at Cape Canaveral (via satellite link) to the WFF mission control room where it was decoded. There were no provisions at the ER or at BDA to decode and interpret the telemetry data.

The basic PCM telemetry stream consisted of a unique 16-bit synchronization (sync) word followed by an 8-bit counter word. The counter word was followed by 285 8-bit data words making one complete minor frame of data. The minor frames were organized in groups of five in the data stream. Each group of five minor frames comprised one major frame of data. The first minor frame of each major frame had a sync word followed by a counter value of zero, then the 285

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[12]PCM pulse coded modulation: A standard method of time sampling multiple parameters and assembling the data in a serial data stream for transmission.

data words. The remaining four minor frames contained the same beginning sync word but each had a counter value of one through four, respectively, followed by 285 data words.

The various performance and navigation parameters from the Pegasus were sampled and inserted into the data stream. Some critical parameters were sampled and inserted in each of the minor frames. Some less critical parameters were sampled only once per major frame and thus appeared only in every fifth minor frame. The bit rate of the PCM data stream was set at 57,600 bits per second. At this speed, a complete frame of data was transmitted every 40 milliseconds. A parameter, found once in each of the five frames, was transmitted to the ground approximately 25 times a second. A parameter sampled in one frame out of five was only updated 5 times a second.

The telemetry data from the Pegasus was relayed from the primary receiving site at Cape Canaveral to the WFF mission control room. The telemetry data stream was decoded in the mission control room by sets of personal computers. Each set of computers (primary and backup) was assigned particular telemetry parameters to decode. These decoded values were then recorded on a paper strip chart and also sent to other graphic display computers for presentation to the various operator stations.

At each operator station there were four cathode ray tube (CRT) displays. Each operator could, via a key pad, select the video data to be presented on any CRT screen. This feature allowed an operator to custom configure the telemetry or graphical data for monitoring on the CRT screens. Several large screen projection TV systems were located in the front of the mission control room. These displays were also custom configured to display either video or telemetry data to the entire control room.

No telemetry equipment outages were reported during the launch, but there were several periods of momentary losses of data during the prelaunch and launch of the ELV. These losses of data were experienced at various times during airplane maneuvering before launch and at stage and fairing separations during the powered boost phase of the flight of the missile. These losses were characterized by a loss of synchronization between the decoding computer and the incoming data stream. The loss of synchronization was as short as 40 milliseconds (one frame) and as long as several seconds when multiple frames were lost.

1.9 Wreckage and Impact Information

Not applicable.

1.10 Tests and Research

None.

1.11 Additional Information

1.11.1 Interagency Agreements and Relationships

Unlike launches made by the government, the Pegasus launch was made by a commercial (for-profit) company under a license granted by the OCST. As indicated by the ER Deputy Director of Safety, commercial space activities began in the launch industry in 1989 and "we're still on the learning curve."

According to the OSC Mission Director, the Pegasus launch was on a fixed-price contract. Once the commercial arrangements were completed with the Brazilian government, the company was able to complete the rocket and launch arrangements in about 6 months. An original launch date in December 1992 was slipped to February because of technical issues related to cross-country transit of the ELV. The Mission Director indicated that OSC was prepared to launch as many as 12 Pegasus ELVs per year. He suggested that the commercial industry was undergoing a difficult transition since the U.S. Government was the exclusive source of range services for all launches, but under national policy, commercial launches had the lowest priority for government launch range use. The Mission Director also noted that dealing with multiple agencies was difficult because of expense, and that even within NASA, there were multiple entities such as DFRF and WFF.

DFRF specializes in testing new airplane concepts, and DFRF worked with OSC in the original development and testing of the Pegasus. Both organizations participated in the first two launches of the Pegasus ELV that were controlled by the U.S. Air Force Western Range and launched off the coast of California. They carried noncommercial test and military payloads. The OSC Mission Director characterized the relationship between DFRF and OSC (operator) as an excellent example of the federal government and the commercial space industry working together.

1.11.1.1 Government Launch Range Selection for Pegasus SCD-1

Because of technical issues related to the desired orbit of the SCD-1 satellite, which was the first commercial use of Pegasus, it was necessary for the mission to be launched off the U.S. southeastern coast. Two ranges located on the east coast became involved in the launch activity: WFF, in Virginia, normally launches smaller classes of rockets, and the U.S. Air Force ER, in Florida, normally provided range safety support for manned space flights and larger rockets. However, the ER had provided range safety support in previous programs involving a number of small ground-launched suborbital sounding rockets launched by OSC and several orbital missions for other groups. ER personnel indicated that the performance of OSC was no better or worse than that of other new commercial companies, but that OSC was not as experienced as such established commercial companies as McDonnell Douglas or General Dynamics.

The OSC Mission Director said that the WFF was chosen as the lead range for the February 9 Pegasus launch for complex reasons, including the fact that it was substantially less expensive to use than the ER. The ER was selected as a support range when it was determined, for technical reasons, that radar coverage was needed from Florida as well as Virginia. The ER was asked to provide support coverage during the first 140 seconds of the launch until the vehicle reached sufficient altitude to be covered directly by WFF. Although WFF and the ER worked together regularly on launch activity, this was apparently the first time that WFF had been designated as the lead range. According to the TC, WFF dealt with the ER, and OSC was not involved in the organizational interface.

The ER Deputy Director of Safety expressed surprise that the ER was not designated as the lead range, and noted concern that the ER was given only 2 1/2 months notice to prepare for its support role. He said that this was the shortest preparation time he had ever been given for a complex vehicle launch. The test conductor characterized WFF as having cooperative people and less bureaucracy than the Air Force.

1.11.1.2 The Development of Special Rule Number One

The arrangements for the range support necessary for a commercial contract developed into an area of temporary disagreement between the ER, WFF, and OSC. At first, the ER's role was limited to assistance in ELV tracking and destruction under the direction of WFF. Subsequently, the USAF 45th Space Wing commanding officer directed that his ER range safety office be given greater authority for the launch as a condition for receiving ER support. One significant request by the ER range safety office, for additional antenna pattern tests of the Pegasus/NB-52B configuration that might be developed from a practice flight with a dummy rocket, was refused by OSC. Antenna test pattern data from previous west coast Pegasus flights was not considered acceptable by the ER.

According to the OSC Mission Director, completing the required antenna pattern tests would have cost an additional $500,000 and was not justified. In addition, the single existing inert Pegasus was required at that time to be a part of the modification program for the Lockheed L-1011 to be used on future Pegasus launches. He said that earlier the company had worked hard to qualify the Pegasus vehicle for the Western Range and that the Pegasus had already flown five times in captive or powered flight off the west coast. He suggested that for a private company it was prohibitively expensive to add new rules at the last minute.

According to the RSO, the ER demands were upsetting because WFF wanted to help the company control its costs. After initially agreeing to serve in a subordinate support capacity, the ER wanted to be co-equal during the period that its hardware and people were involved and wanted to duplicate an earlier range safety analysis made by WFF. ER personnel speculated that complying with the ER demands added to the cost of the project for the company and cost justification seemed more concentrated and serious with OSC than with other commercial customers. They said, however, that they did not recall cost issues emphasized as much in previous suborbital OSC launches.

To resolve the disagreement over antenna pattern tests and allow the launch to proceed, ER, WFF, and OSC agreed to the rule that a flight termination system dropout during the last 6 minutes prior to the launch was cause for a mandatory abort. Personnel from WFF and ER expressed differing opinions about the practicality of this abort rule, which became known as Special Rule Number One. The RSO stated that WFF personnel had planned the airplane flightpath to avoid signal shadowing and to minimize the possibility of telemetry dropout, following evidence of shadowing and momentary telemetry dropouts in the data from the two Pegasus launches off the West Coast. One ER person said that the rule should have been acceptable as long as the airplane remained in straight-and-level flight. However, the ER Deputy Director of Safety indicated after the February 9 launch anomaly that momentary telemetry dropouts were normal and that he thought there was a high probability of such an FTS dropout during the Pegasus launch activities.

OSC's interpretation of Special Rule Number One was that it was meant to apply to any signal that indicated a dropout of the flight termination system itself. They believe that it was well known that a millisecond dropout, where the telemetry dropped to a zero value and then instantaneously returned to the correct level, did not indicate a problem with the underlying FTS system. In contrast, they believe, the anticipated "shadowing" and "multipath" problems (about which the ER was concerned) would be reflected in more lengthy, gradual decreases and gradual increases in telemetry signal strength.

The OSC Mission Director said that the resulting rule was more unnecessary than it was bad, and that the ER's demands were added late in the launch preparation process, in what he believed was a very heavyhanded way. The Mission Director indicated that after the company became involved with two ranges, problems arose because OSC was uncertain who had the true authority. Special Rule Number One stated that following such an FTS signal dropout, the NB-52B flight would be considered as a data run and that a minimum of 3 working days would elapse before another launch attempt could be made. However, during a postincident interview, the OSC Mission Director indicated that in the event of such an abort, he would consult with the ER commanding general and a senior WFF authority via teleconference and try to find a way to save the launch. Similarly, the test director indicated that following the actual abort call in the launch sequence, he expected the airplane to return to the geographic drop box for another launch attempt during the 90 minutes remaining in the launch window.

DFRF personnel were not involved in the discussions that resulted in Special Rule Number One and were not briefed on this rule prior to the Pegasus launch. DFRF personnel indicated that such telemetry dropouts were routine with airplane operations and that they had been observed during the previous Pegasus launches. DFRF NASA-1 characterized any rule to abort based on a momentary telemetry dropout as appropriate for launch from a static pad but inappropriate for launch from a maneuvering airplane. The DFRF Project Manager said that he would not have agreed to this rule if he had been aware of it.

1.11.2 The Role of OCST in the Licensing and Oversight of Pegasus SCD-1

In the normal course of operation, the OCST would be requested by an operator to grant a launch operator's license for a number of launches that fell within specific preapproved and well-defined parameters. If a future launch fell outside of those specified parameters, the operator would have to apply for a modification to its license. In this case, in September 1992, OSC applied for an operators license to authorize Pegasus launch activities from the Western Range and from the ER, including the SCD-1 mission scheduled for December 1992. According to the OCST personnel, a review of the application revealed "numerous deficiencies" and OSC was so advised in late September 1992. At that point, OSC requested a launch-specific license for the Pegasus SCD-1 mission. An application was submitted by OSC, and the license for the Pegasus SCD-1 mission was issued on December 23, 1992, for a scheduled January 7, 1993 launch. OSC would still have to resolve the cited deficiencies in the overall operators license application to conduct future Pegasus launches.

Unlike commercial aviation operations from airports locally owned and operated, all U.S. space launch facilities are currently operated by the U.S. Government. Whereas the FAA has jurisdictional and enforcement responsibilities over airports, the OCST has no such responsibilities over U.S. launch ranges. The OCST can recommend safety-related changes to launch ranges, but it can only require such changes by working with the private operators of ELVs through launch licensing requirements.

The OCST licensed the Pegasus launch and provided two compliance monitors (inspectors) to observe compliance with licensing requirements. During the launch, an OCST Pegasus inspector was located in a room with a console off the main mission control room at WFF and was able to watch a small portion of the activity in the control room. A second inspector was located at KSC to observe the takeoff of the NB-52B and the ER control room activities.

According to the OCST Pegasus inspector located at WFF, his responsibility was to observe for licensing compliance but not to intervene in the launch process. Early in the countdown procedure, he was asked by an OSC representative to attend a meeting concerning the unavailability of the BDA radar array. He declined, indicating that it was not OCST policy to become involved in operational decisions or to serve in an advisory role to the launch company. He later said that if he observed something so extraordinary as to affect safety, he would telephone his office and allow the OCST Associate Director for Licensing and Safety to determine whether the launch should be suspended.

The OCST inspector in place at the KSC, and later in the ER control room, was not given WFF or OSC mission documentation, including launch constraints or mission rules, until after the incident on February 9.

Concerning the license and license orders issued by OCST for Pegasus SCD-1, a postincident NASA GSFC Review Committee Final Report stated that WFF personnel were not offered the opportunity to review the license documents prior to the launch. The report stated that the license documents committed WFF to "some very specific requirements" not fully communicated to WFF, and that some of the requirements may not have been accomplished.[13] OCST personnel said that such coordination would be the responsibility of the licensee, in this case, OSC.

1.11.2.1 OCST Staffing

The OCST official responsible for leading the license approval effort, who was also the OCST inspector located at WFF, indicated that the staffing was sufficient to complete timely license assessments under current criteria, including the launch-specific Pegasus application; however, OCST's staffing was not sufficient for any expanded role. The second OCST compliance monitor expressed similar views. She said that OCST had previously been involved with veteran companies but that with young companies and new, unorthodox vehicle types[14] being developed for commercial space, she believed that OCST needed to have closer inspection regimes and to participate more directly in the industry.

1.11.3 Flight and Duty Time Requirements

WFF had a duty time policy document in effect at the time of the launch. It included the guideline of a maximum of 8 routine work hours per day, 5 days per week. However, duty time limits for launch operations were 16 hours

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[13] National Aeronautics and Space Administration, Goddard Space Flight Center, Wallops Flight Facility Review Committee Final Report, March, 1993, p. 16.

[14] Another somewhat unusual ELV/satellite combination currently undergoing OCST license processing is designated Conestoga/Comet. The Conestoga ELV is a conventional static-launched rocket. The Comet satellite, however, is unique in commercial operations in that following its orbital work, it will release an unguided payload that will reenter the atmosphere and land at a designated area in Utah.

per day, with no more than 72 working hours per 7 days. An 8-hour minimum off-duty period is required between normal work shifts, and 10 hours off duty is required between shifts when the work period is 16 hours or more. The WFF policy allows for waivers of the above guidelines and limits, but no waivers were requested for the Pegasus SCD-1 launch. The WFF test director said that the work policy had been in effect since the STS-51L Challenger space shuttle accident. According to the OSC Mission Director, the debriefing of the rehearsal on the day before the Pegasus launch was accelerated to allow for launch and flight crewmember rest requirements.

OSC had a duty time policy modeled after that of NASA, according to an OSC representative. They included provisions for a maximum 12-hour shift, with at least 8 hours of rest after such a shift. Extension of a shift to 16 hours was allowable, subject to prior OSC safety approval. At least 8 hours of rest was required after a 16-hour shift. Strict duty time requirements applied to the pilot of the NB-52B, limiting him to a 14-hour maximum duty day.

2. ANALYSIS

2.1 General

The anomaly that prompted this investigation was the interruption of the flight termination system signal which, according to established procedures, was cause for a mission abort. The abort command was issued by the WFF range safety officer. However, the launch sequence was reinitiated by the OSC (operator) test conductor without coordinating with some but not all of the other launch participants. When the vehicle was launched, several launch participants were not immediately prepared.

The Safety Board's investigation of this incident revealed that the actual launch of the Pegasus was not hazardous, and that the ELV functioned properly and achieved its mission objectives. The speed and efficiency with which the WFF launch team recovered from the surprise of the Pegasus deployment were noteworthy. In addition, the ability to destroy the Pegasus was not jeopardized at any time during the flight. However, the investigation uncovered numerous deficiencies in the premission planning, organization, and approval processes, as well as last-minute improvisations during the launch countdown activities. They created an unsafe situation that could have led to an accident or the intentional but unnecessary destruction of the Pegasus ELV following its release from the NB-52B.

There were no mechanical or electrical failures involved in the incident, although, for unknown reasons, telemetry was interrupted momentarily prior to ELV deployment causing the command receiver signal strength to decrease below an established minimum threshold.

This incident involved major command, control and communications breakdowns between several space launch entities. Most of these breakdowns were predictable, and could have been easily prevented if the OSC/DFRF contingent had been more familiar with the NASA WFF procedures, and vice versa. One or more overly restrictive and impractical launch constraints were also in place that jeopardized the success of the mission. The Safety Board believes that solutions to the inevitable problems of integrating two different technically oriented cultures should include the creation of common procedures and practical constraints for commercial space launch operations.

Not all of the intercom channels in the mission control room were recorded, nor was the intercom monitoring ability recorded. Much pertinent conversation during the 2 minutes prior to the Pegasus deployment occurred off the intercom net and also was not recorded. Accounts of details during this period differed among interviewees, but the Safety Board believes that each person provided a straightforward account of events surrounding the launch anomaly as he or she remembered them. Each individual agreed that for several moments confusion reigned and that changes in procedures are necessary. Therefore, this analysis will focus on the communications breakdowns, the launch constraints, and the lack of common procedures that existed on February 9. It will offer possible solutions to these problems, rather than simply an accounting of errors made by specific individuals.

2.2 Organizational Cultures: Commercial Enterprises and Government Agencies

The Safety Board believes that there were two different organizational cultures working in the mission control room on the morning of February 9--the WFF contingent with its own history and background; and the OSC/DFRF contingent, with its unique history, background and goals. The Board believes that these two cultures did not have enough time to integrate their goals and operating procedures into a single protocol that could address, in a timely and safe manner, the several communications and procedural anomalies that arose.

The OSC/DFRF team had worked together in developing the Pegasus and had successfully launched the ELV twice before. The first two launches were on military missions. By the time that planning for the Pegasus SCD-1 mission occurred, the OSC (operator) and the DFRF personnel had already rehearsed extensively together and developed common procedures. The previous launches were conducted by the USAF Western Range that utilized an enforced and automatic intercom communications discipline because launch personnel were in separate rooms. Formal military communications protocol was also in place. In addition, because OSC was familiar with DFRF policies and procedures, the OSC/DFRF team developed a culture in which the NB-52B aircrew (that included an OSC launch panel operator) had considerable authority. For example, the Pegasus mission was designed so that after a certain point in the countdown, the principal countdown clock was in the airplane, rather than in the mission control center on the ground.

By contrast, WFF had a great deal of launch expertise. Individuals had worked together for many years, and some of them had participated in thousands of sounding rocket launches. The control center consisted of two adjacent rooms separated by a sliding door and contained all major launch personnel. This allowed for more informal dialogue and gesturing across the room among individuals familiar with each other. As the test conductor (TC) suggested, WFF had "cooperative people and less bureaucracy than the Air Force." To WFF, the center of authority was in the control room even in the infrequent remote launches from airplanes directed by WFF.

Both groups had an admirable history of success in their respective activities, and the Safety Board is confident that the groups could have worked together successfully if they had coordinated better.

One possible point of stress that overshadowed the entire Pegasus SCD-1 operation was that this was a commercial launch and was subject to more stringent financial and time constraints than earlier launches by both teams (including the earlier launches of the Pegasus). The Pegasus was on a fixed-price contract with penalties if the launch was delayed beyond a target date. Once commercial arrangements were completed with the Brazilian government, OSC completed the launch planning arrangements in about 6 months, a remarkably short period of time.

WFF was chosen by OSC as the lead range at least partly because it was less expensive than the ER, and, as lead range over the ER for the first time, it had difficulty negotiating for range support from the USAF. There was evidence that time and cost constraints could have limited the coordination of prelaunch meetings. The RCO stated that all early planning meetings had been by teleconference and speaker phones only, and that there was no actual meeting of members of the parties until the Friday before the launch on Tuesday. It must be noted that OSC personnel believe that much more useful coordination occurred than was described by the WFF interviewees.

There was only one dress rehearsal in preparation for the actual launch. Although significant coordination problems appeared during the rehearsal, there was no additional time in the launch schedule to permit further rehearsal. Later, the ER Deputy Director of Safety commented that "we're still on the learning curve" in commercial space; this was evidenced by the short preparation time allowed by OSC for a complex mission with several participating agencies.

The respective groups from the launch effort, representing different cultures, were unable to define a single individual with the acknowledged responsibility of authorizing a go/no go launch decision. The dress rehearsal that the launch personnel performed the day before the launch demonstrated that such authority was absent. According to the RCO, an abort, recycle and reinitiation of the countdown were successfully performed, but he was unsure of the individual or individuals who were responsible for their success.

By contrast, commercial aviation owes much of its safety record to clearly delineated lines of authority that all airspace users acknowledge and respect. The pilot-in-command, by tradition and regulation, is ultimately responsible for the safe operation of the aircraft. The air traffic controller has the authority and responsibility to separate aircraft under his or her control. The maintenance technician has the authority and responsibility to determine the quality of a maintenance action.

No such authority existed in the Pegasus launch. Perhaps this is due to the novelty of this type of commercial space operation. In contrast to previous noncommercial space operations, several organizations with different histories, motives, and responsibilities were cooperating on a single venture. DOT was tasked with encouraging and regulating commercial launch ventures. OSC (operator) acknowledged this fact and was determined to enter the field to succeed as a profit-making commercial space launch entity. WFF and DFRF were given the responsibility for range safety and the airborne launch, respectively. ER supported range safety functions. Yet each played a significant role in the launch sequence.

The Safety Board concludes that the organizations did not develop delineated lines of authority for this commercial venture, similar to those developed for civil aviation endeavors. The absence of clearly defined procedures and individuals having recognized authority over the launch sequence contributed to the launch anomaly. Therefore, the Safety Board believes that to prevent a recurrence of such mishaps, the OCST should develop clearly delineated statements of authority for the conduct of commercial space launch ventures. These statements should become part of the launch licensing process.

2.3 Launch Crew Rest and Fatigue Factors

The last minutes before actual launch are among the most critical in any launch sequence. It is a period when the individuals involved in launch decisions must be most alert. In the case of the Pegasus launch, the most critical and stressful period was around 0930, about 7 1/2 hours after the launch countdown began at 0200.

An evaluation of fatigue factors related to the Pegasus launch was conducted at the request of the Safety Board by members of the NASA-Ames Research Center Fatigue Countermeasures Program, one of the leading research programs on fatigue in the United States. The resulting report is included as appendix D.

The researchers examined the sleep/wake patterns of the six individuals most central to the launch decision during the 26 hours preceding the launch/orbital insertion of Pegasus. Basing their analysis on the results of the Safety Board's interviews with the individuals involved, and using conservative assumptions when necessary, the researchers concluded that the average total sleep received by the key individuals in the 26 hours prior to the deployment of Pegasus was 3.7 hours. The sleep time ranged from the NB-52B aircraft commander's 7 hours to the TC's remarkably low 1.5 hours. The researchers further analyzed the 48-hour period before the launch to determine total sleep loss over a long period of time. According to the researchers, a cumulative sleep loss would be in a range that could create major degradations in waking performance and alertness.

The researchers also noted that many countdown activities occur between 0300 and 0500. This is the period where research has shown that the human body's daily physiological rhythms (known as circadian rhythms), affecting normal activity and alertness, would be at a low point of activity and alertness.

Based on their review, the researchers concluded that "it would certainly appear that sleep loss and circadian disruption could have been contributory factors to the launch anomaly described. Fatigue could have contributed to decrements in communication, information processing, personnel coordination, decision-making, and reaction time to information. The more time-critical the decisions and actions, the greater the potential for a fatigue effect." In the 3 minutes prior to the launch, there were many instances of such time-critical decisions.

In addition to other factors, including cultural differences and inadequate preparation, the Safety Board believes that fatigue also adversely affected the performance of critical personnel. Because the interaction of these factors precludes identifying the influence of a single factor operating alone, the Safety Board could not determine with certainty the extent to which fatigue contributed to the incident. Nonetheless, based on the evidence, the Safety Board is confident that fatigue was present among critical personnel and that it had a significant adverse influence on the performance of the personnel involved in the launch anomaly.

The Board notes that the NB-52B aircraft commander displayed the best sleep history of the six persons studied, reflecting the strict duty requirements adopted by the aviation community of which he was a member. The remaining five persons, all ground launch personnel, were also subject to duty time requirements, but they were less stringent. Interest in duty time issues has been relatively recent within the space launch community. A duty time policy for launch personnel was adopted by NASA following the Challenger accident, and a policy modeled after that of NASA was applied to OSC personnel shortly thereafter.

Unfortunately, duty time limits were the reason the Pegasus dress rehearsal debriefing was cut short, suggesting that the industry should do much more to integrate duty time requirements into its operations. The fact that the dress rehearsal was scheduled during normal daytime hours rather than the night hours of the actual countdown also leads the Safety Board to believe that the industry might not adequately appreciate the true effects of fatigue caused by circadian rhythm disruption and sleep loss on human performance. The Safety Board supports the use of duty time requirements for launch personnel, and strongly supports further research, such as that being conducted in collaborative efforts between NASA-Ames and NASA-Johnson Space Center on flight controllers involved in space shuttle operations. The Board believes strongly that the commercial space industry could benefit from greater awareness and efforts to reduce the adverse effects of fatigue for launch operators. Therefore, the Safety Board believes that as an initial step in this direction, the OCST should mandate mandatory rest periods before the launch for key participants that provide for adequate and specified time periods for uninterrupted sleep. Because of the unique characteristics of space launch operations, the quantitative criteria for such rest periods should be developed by human performance experts to ensure that the specified rest periods are designed to match the needs of the specific tasks.

One problem concerning fatigue that is not a normal part of other technical operations is that a launch team is often subjected to rolling launch delays that can extend over several days before a decision is made to stand down for an extended period of time. Researchers must take this into account when devising optimum rest/work cycles for launch participants.

2.4 Launch Readiness Reviews and the Prelaunch Rehearsal

Launch readiness reviews are meetings held near the launch date to preview the launch sequence of events, resolve any last minute problems, and review launch constraints, among other things. Separate launch readiness reviews, or their equivalents, were apparently held by OSC, DFRF, WFF, and the ER. Although each review may have addressed each organization's separate role in the proposed Pegasus launch, the total effectiveness of the readiness review concept was thwarted because there was little or no direct communication between organizations in the readiness review process. The Safety Board believes that Pegasus mission planners probably hoped that any potential prelaunch problems could be solved in a final dress rehearsal at WFF the day before the launch.

By almost all accounts, the dress rehearsal for the Pegasus SCD-1 mission was conducted in a disjointed and hurried manner. Further, the rehearsal was stopped early because of launch and flightcrew rest requirements. Also, only one unintentional abort scenario occurred, and, most importantly, confirmed lines of authority and responsibility were not established among the diverse groups in attendance. As inadequate as it was, planning and procedural flaws discovered during the dress rehearsal for Pegasus SCD-1 should have been a clear indication to participants that serious deficiencies existed in the basic coordination between agencies, and that these deficiencies should have been remedied prior to the actual launch. Because of the uniqueness and complexity of the proposed mission, the Safety Board believes that the launch should have been delayed and that one or more follow-on dress rehearsals should have been conducted at least until the procedural confusion was eliminated.

The Safety Board therefore believes that OCST should establish minimum requirements for commercial space launch readiness reviews and launch dress rehearsals, and make these requirements mandatory by placing them in a license order adjunct to a commercial launch license. These requirements should ensure that the readiness reviews are attended by all key participants of a proposed launch, that they emphasize common procedures among organizations, and that they fully explain launch constraints and mission rules. The dress rehearsals should include practice aborts and contingency exercises. OCST compliance monitors should be present at the readiness reviews and launch dress rehearsals of new or unique launch operations.

2.5 Interphone Communications Procedures and Equipment

An examination of the interphone conversation transcripts and descriptions of interphone procedures given to the Safety Board by participants revealed serious communications problems that jeopardized the success of the mission. Also, a lack of clear interphone channel assignments, especially during the final stages of the countdown, contributed greatly to the confusion that existed just prior to the deployment of the ELV. Further, the physical arrangement of the microphones, speakers, and headsets, added to the disorder.

2.5.1 Interphone Channel Assignments

The channel assignments for the key people involved in the launch are listed in the table below. There is no positive record of which channels the individuals were monitoring at any given time during the launch sequence.[15]

CH 1 Range Operations	CH 4 Mission Director	CH 10 Range Safety Officer	CH 12 NB-52B Air-to-Ground Communications
WFF/RSO	DFRF/NASA-1	WFF/RSO	DFRF/NASA-1
WFF/RCO	OSC/TC	WFF/MFSO	OSC/TC*
WFF/TD	WFF/RCO	WFF/RS3	DFRF/NB-52B (AC)
	OSC/PEG	WFF/RCO	DFRF/NB-52B (CP)
	OSC/TD	WFF/TD	OSC/NB-52B (LPO)
			OSC/TD*
			DFRF/Program Manager*
			ER/RSO*

*Monitor capability only

As can be seen from this channel assignment breakdown, no WFF personnel were monitoring the air-to-ground or ground-to-air transmissions on intercom channel 12 (NB-52B communications), and no OSC (operator) personnel

[15] The investigation revealed that several intercom channels were not recorded on February 9. While this did not materially affect our understanding of the launch anomalies or the outcome of the investigation, the lack of recordings could become a problem under different circumstances. The Safety Board believes that WFF should guarantee the operability of all recording systems prior to each launch from its facility.

were monitoring channels 1 (range operations) or 10 (range safety officer). The only WFF person monitoring channel 4 (mission director) was the WFF/RCO.

The Safety Board believes that the individuals most involved in proceeding with the launch during the period of maximum confusion (the TC and NASA-1) were not monitoring the two channels most involved with range safety (channels 1 and 10). Conversely, the WFF individuals with an overall safety responsibility for the launch (with the exception of the WFF/RCO) were not monitoring the intercom channels (4 and 12) having the most to do with the operation of the launch platform, the NB-52B. The Safety Board believes that the true decision makers should be allowed access to, and input concerning, real-time information, rather than receiving second-hand information, or, in some cases, none at all.

The Safety Board therefore believes that interphone assignments for Pegasus launches should be apportioned among launch parties to allow decision makers from each party direct, real-time access to decision makers of the other parties. In addition, according to traditional space launch interphone practice, the key participants should be monitoring a single communications channel at some established point in the countdown checklist and should continue to monitor this launch channel during the final countdown sequence and after launch.

2.5.1.1 NASA-Ames Intercom Transmission Study

An evaluation of communications issues related to the Pegasus launch was conducted at the request of the Safety Board by the Crew Factors Group, NASA-Ames Research Center. The report is included as appendix B.

As part of the evaluation, researchers completed a numerical coding of communication patterns based on the Safety Board's transcript of mission control room intercom recordings. The researchers analyzed each discrete transmission as a "speaker turn," and found 140 such "speaker turns" in the transcript (excluding a small number of transmissions that could not be identified in terms of speaker or could not be interpreted). They reported that 74 "speaker turns," or 53 percent of all communications, represented a WFF speaker talking to another member of the WFF contingent; 40 percent of all communications represented an OSC speaker or a DFRF speaker talking to another member of the OSC/DFRF contingent; while only 7 percent of all communication was directed across WFF to OSC/DFRF contingent boundaries. In both cases, the two abort situations began with communications from a WFF speaker. Much of the 7 percent cross-team communication was on Channel 4 between the RCO and NASA-1, and this communication eventually and belatedly resolved the altitude abort situation. There were no corresponding cross-team communications observed between WFF and OSC/DFRF directed at solving the subsequent command destruct receiver dropout problem.

The study indicated that the within-contingent communications, for the most part, followed their own protocols. For example, the NASA-1 to NB-52B communications followed standard radio communications protocol with call signs and acknowledgments. WFF contingent members communicated more informally, showing inconsistent use of call signs, personal names, and conversational style. It stated that "While an informal style may be effective when team members have had experience working together, standard forms are needed when there is a lack of shared experience upon which to base one's expectations. In this case, lack of familiarity across teams plus a lack of protocol for cross-team communications could have contributed to several misunderstandings."

The Safety Board believes that in many ways, the Pegasus launch team was a team in name only, partly because of the intercom channel assignment decisions made during the planning for the mission, and partly because of the other factors unique to the diverse groups that were participating in the effort, as previously discussed.

2.5.2 Interphone Procedures

For the most part, basic interphone discipline was not followed in the WFF control room on the morning of February 9. In almost all of the recorded intercom transmissions, the standard, time-tested radio communications methods of: 1) identifying the person being addressed, 2) identifying the originator of the message, 3) identifying the channel or frequency being used, and 4) succinctly and unambiguously stating the message, were not followed. Numerous instances of statements or questions without the titles or channels indicated are evident throughout the interphone conversations. In some cases, speakers, or their targets, are identified but only by first names (on one occasion, a first name and last name were used). Participants also stated that very vague physical gestures between launch controllers occurred.

This extremely informal interphone procedure might have been considered acceptable by the WFF launch teams involved with small sounding rockets. However, with a launch team as large as the Pegasus team, and with such remote entities as the ER and the airborne NB-52B, a relaxed situation was unacceptable and almost guaranteed confusion. In addition, the OSC and DFRF participants in the control room had not worked previously with the WFF team. Indeed, some of them had only been introduced to the WFF contingent the day before the launch. For instance, the DFRF Pegasus Project Manager stated that when a WFF individual called an abort, he had no idea who the person was or what authority he had to stop the operation. Effective coordination of the launch became impossible because of inadequate communications procedures and confusion over authority.

To its credit, OSC (operator) did recognize the value of good interphone discipline and included standard interphone procedures in its mission documents. Also, except for one instance concerning a request for an altitude readout from the airplane, communications between NASA-1 and the NB-52B flightcrew followed accepted radiotelephone protocols.

2.5.3 Interphone Equipment

The physical arrangement of the communications equipment also led to its underutilization and accidental misuse. A basic shortcoming, applicable to both static and airborne launches from WFF, was that the controllers had no definitive way of knowing which communications intercom net was being used when they heard communications over the speakers or in headsets. WFF personnel overcame this shortcoming, to a certain extent, by recognizing the voices of the various speakers. Also, as stated earlier, basic intercom protocol of identifying the intercom channel in every transmission would have aided communication coordination. However, the OSC and DFRF staff were unfamiliar with the WFF staff or their voices, and basic intercom protocol was not used on February 9. The Safety Board therefore believes that WFF should study the feasibility of installing indicator lights on its communications consoles that will illuminate whenever an intercom channel is in use. In that way, each addressee of a message could determine quickly the channel in use, and therefore reduce message length and channel usage significantly.

2.5.4 Communications Phraseology

In addition to the other shortcomings concerning communications procedures, some launch participants contributed to the confusion in the last minutes before the ELV deployment by inadvertently misspeaking, misusing, or misunderstanding terminology that was unique to the air-launched Pegasus mission.

The word "abort" for instance, as defined in OSC mission constraint documents, means that either the mission can be recycled, or that it is canceled for the day. Other participants, including the WFF RSO, believed that an "abort" meant that the rest of the flight would be considered a data collection run[16] and that no mission recycle (and no Pegasus launch) could occur during the flight. This is a stricter definition of "abort" than was understood by OSC personnel and is the main reason that the RSO and other WFF participants pushed back from their consoles following the abort call for the telemetry data dropout. They thought the launch would not occur, and they were going on to other duties.

As another example, when the question of the launch altitude was developing during the launch sequence, the RSO stated to the RCO, "Bob, ask him to give a readout on his display - at the airplane." The RCO then asked, "What, you mean on his altimeter?" The RSO replied in the affirmative, and the RCO then directed NASA-1 to, "Get an altimeter reading from, ah, NASA-008." A short while later, NASA-1 asked the NB-52B, "008, NASA-1, say altimeter." The copilot on the airplane responded to this directive, as most pilots would, with the barometric altimeter setting, rather than the altitude of the airplane. Later, the copilot, after a second query, provided the altitude of the airplane. The elapsed time between when the RSO first asked about the airplane's altitude and when he actually received the answer was more than 70 seconds. By then, the question had become almost moot.

This particular confusion in terminology occurred because the WFF RSO (unfamiliar with aviation terminology) and NASA-1 (who later stated that he misspoke the request) did not differentiate between the vague phrases "Get an altimeter reading" and "Say altimeter," and the more precise phrases, "Determine his altitude" and "What is your altitude?"

The Safety Board believes that the advantages of using NASA-1 as a relay and filter point for information to and from the NB-52B outweigh the disadvantages. Historically, manned space missions, from the time of NASA's

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[16]Refer to the WFF memorandum, "Clarification of FTS Signal Requirements During B-52 Flights" in appendix C. Note that other reasons for aborting a mission would not call for a data collection run and mission cancellation, according to this memorandum. Contrary to the memorandum, several WFF personnel, including the RSO, stated to Safety Board investigators that any abort meant mission cancellation. In other words, to OSC, "abort" meant a possible cancellation, while to WFF, "abort" meant a definite cancellation of the mission.

Mercury program through the Space Shuttle program, have used one individual as the main link between the spacecraft and the ground. The busiest people, those most subject to information overload, are usually the ones in the moving vehicle, be it a spacecraft or an airplane, rather than those manning launch consoles. These busy individuals should not be burdened with the task of determining to whom, among the several launch controllers, their conversations should be directed.

However, these examples of terminology confusion also highlight how difficult it is to accurately relay safety-related information or requests to an airplane, when all communications to the airplane might have to be passed through several individuals to NASA-1, and then through him to the airplane. The Safety Board believes that NASA and OSC should study the feasibility of allowing the key safety individual on the launch team--the range safety officer--direct radio access to the airplane for Pegasus launches. If a similar arrangement had been in place on February 9, the RSO could have quickly indicated to the NB-52B aircraft commander that an altitude abort situation had developed much earlier than actually occurred. The countdown could have been stopped at that point and a mission recycle could have been contemplated. As it happened, the resolution of the altitude problem took so long that for some launch participants, particularly the test conductor (TC), the potential altitude abort became confused with the supposed command receiver dropout abort that occurred later.

2.6 The Decision to Launch the NB-52B with Malfunctioning BDA Radar Facilities

The Safety Board believes that the decision to allow the NB-52B to take off, even though the BDA radar array was inoperative, was not prudent given the circumstances. However, the Board also believes that the entire problem could have been avoided if the launch managers had not made this particular minimum safety requirement so restrictive. Another practical and safe solution to the problem was to allow the WFF radar array to assume the responsibility of the BDA array. This type of unnecessarily restrictive thinking also existed in the creation of Special Rule Number One by the ER with tacit approval by OSC and WFF. Special Rule Number One precipitated the launch anomaly, which is the subject of this report.

2.7 Special Rule Number One and Its Impact on Launch Operations

Many factors contributed to the abort decision by the RSO and the decision to proceed with the launch by the TC. However, the basic reason the abort was called was the interrupted telemetry signal indicating a command receiver malfunction 59 seconds prior to the planned launch.

According to Special Rule Number One, during the last 6 minutes of captive flight of the Pegasus, the received signals from both of the command receivers had to be above a minimum threshold or an abort would be called. There were no provisions in the agreement that distinguished between command receiver problems or problems with the received telemetry data. It also did not matter, according to the agreement, that the data dropout was of such a short duration.

At T-0:59, a drop below the minimum threshold value of the number one command receiver's signal strength was observed. This fact was communicated to the RSO who initiated the abort. The initial assessment from the telemetry controllers was that it was indeed a command receiver abnormality. This assessment was based on the nature of the deviation and the lack of any other telemetry problems, and was discovered, following the incident, to be false, although the controllers had no way of knowing at the time that it was false.

Given this information, the Safety Board believes that the decision by the RSO to abort the launch was prudent and in accordance with arrangements previously agreed to by USAF ER, WFF, and OSC personnel. The Board also believes, however, that the USAF's Special Rule Number One was so restrictive that, in all probability, most Pegasus launches would have been aborted under such restrictions. Several individuals at NASA/DFRF, all very experienced in air-launched vehicle operations, stated that data dropouts, such as the one experienced on February 9, happen frequently. Unfortunately, they were not aware of the rule until after the launch anomaly. In hindsight, the general consensus of opinion of those people interviewed (with the notable exception of most of the USAF personnel) concerning Special Rule Number One was that the dynamics of air launch operations, in contrast to the relatively stable conditions during a static pad launch, would preclude a successful, sustained launch schedule of Pegasus-type vehicles. The Safety Board believes that OSC (operator) and WFF planners acceded to the USAF's insistence on Special Rule Number One with reluctance, and in frustration, because ER facilities were necessary, due to time and monetary constraints, for the organization and execution of the Pegasus mission.

The only people not consulted when this rule was being formulated were the aviation-oriented DFRF personnel, who, from an air operations standpoint, were the most capable of assessing the potential liability of such a strict rule. The

DFRF organization had been air launching vehicles for many years and had a good idea of the near impossibility of maintaining a continually pure telemetry data stream from a moving airplane/payload combination.

The Safety Board therefore believes that if rules resembling Special Rule Number One are contemplated for Pegasus launches, then appropriate individuals, such as those at DFRF, should be consulted to aid in the determination of the need for such restrictive rules.[17]

2.8 The Role of OCST in Commercial Space Launch Operations

The overall role of OCST in commercial space operations is similar to that of the FAA regarding civil aviation, in that OCST is tasked with promoting the commercial space industry, and, concurrently, regulating that industry. However, at this stage in the development of a viable U.S. commercial space industry, the role of the OCST in safety-related matters is somewhat limited and indirect. For instance, one of the two license orders (the other had to do with insurance requirements) for the Pegasus SCD-1 mission (see appendix F) placed responsibility for public safety on OSC personnel, who, in turn, contracted with WFF to conduct public safety-related operations. The license also stated that OSC "shall comply with GSFC/WFF range and flight safety procedures and requirements...." In a sense, these requirements levied upon launch operators tended to remove OCST from direct oversight of commercial space safety.

A comparison between the OCST and its aviation counterpart, the FAA, revealed that unlike the FAA, the OCST only has enforcement jurisdiction over the operator of the transportation mode, in this case, OSC. Activities that are the responsibility of NASA or the USAF are not officially within the purview of the OCST. In addition, in the case of Pegasus, OCST has elected only to license

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[17]Interestingly, it is possible, but not provable, that the telemetry data dropout, which precipitated the abort call and subsequent confusion, which, in turn, precipitated the continuation of the launch sequence, was directly caused by last minute maneuvering of the NB-52B. The maneuvering, in turn, was caused by the fact that the NB-52B crew was unfamiliar with the 43,500-foot altitude restriction listed in the WFF mission constraints document.

If the maneuvering did cause the data dropout, then the fact that the 43,500-foot restriction was not disseminated during launch readiness review, or a dress rehearsal, precipitated the entire incident sequence of events. Had the last minute maneuvering not occurred, Special Rule Number One would not have been invoked and the launch would have proceeded as planned, with no confusion. More probably, however, the overly restrictive nature of Special Rule Number One might have doomed the launch sequence to disarray, even if the airplane had been in straight-and-level flight.

activity "commencing upon take-off of the B-52 airplane from the Shuttle Landing Facility...." and did not choose to enlarge its sphere of influence to include pretakeoff activity.

Given the limitations outlined above, and in light of the activities on February 9, the Safety Board believes that the responsibilities of OCST compliance monitors, now somewhat administrative in nature, should be broadened. Their responsibilities should also include safety monitoring of the preparation for launch procedures and documentation not covered by current launch licensing parameters. These procedures and documentation could include, but not be limited to, ELV preparation, transport of the ELV to the launch site, arming of safety devices, launch readiness reviews and rehearsals, and a review and approval of specific launch checklists and constraints for each type of launch.

The Safety Board could not determine the validity of WFF's claim that the OCST license documents committed WFF to obligations of which WFF was not aware. However, to prevent this problem from occurring in the future, the Safety Board believes that OCST should furnish, for informational purposes, copies of proposed license agreements to all parties mentioned in the license prior to issuing the launch license.

2.9 The Lack of Common Safety-Related Documents Among Pegasus Launch Parties

The Safety Board believes that one of the most inexplicable aspects of the launch operation on February 9 was the lack of common safety-related documents and launch checklists used by the OSC contingent and the WFF contingent. Much of the confusion concerning the correct launch altitude, abort and abort cancellation procedures, and meaning of Special Rule Number One could have been eliminated easily if one safety rule book and one set of checklists had been planned, agreed to, and used by all parties to the launch. Therefore, the Safety Board believes that for future commercial space operations, one safety directive, safety notebook, or similarly entitled document should be devised for each launch or type of launch. It should emphasize the intended safety of the operation and should clearly list and consolidate mission constraints, mission rules, and special launch rules. If it is not feasible to make it a stand-alone document, identical safety sections should be included in each launch party's mission notebook used on the day of the launch. In addition, the Safety Board recommends that for future commercial space operations, one single set of launch checklists be devised for each launch or type of launch, and that each participant's checklist be current for the rehearsal for the launch.

2.10 Final Observations

Given the confusion that existed just before the launch of the Pegasus, and the unexpected nature of the release of the ELV, it would have been understandable if the WFF RSO had destroyed the ELV via the command destruct radios, as soon as it was an appropriate distance away from the NB-52B, in accordance with conservative safety practices. If the WFF launch contingent had not recovered from the surprise of the release as rapidly as it did, the RSO might have activated the destruct charges, and the Pegasus mission would have been a failure.

The Pegasus functioned as it was designed to during and after its launch, and its payloads were placed into orbit. In retrospect, the launch of the Pegasus was probably the safest alternative under the circumstances, despite the significant procedural confusion that occurred prior to its launch. However, aside from the monetary aspects and the intangible effects on the prestige of the commercial space industry, there were safety hazards associated with the events that occurred prior to the launch.

For instance, if the Pegasus had been intentionally destroyed by the RSO shortly after launch because of the confusion, there was no absolute guarantee that the air space and sea space below would have been clear of ships or airplanes, despite strong efforts to clear these spaces. Also, there was a potential risk to the NB-52B as a result of the destruction of the vehicle. Further, if the launch had been aborted because of the confusion, the NB-52B would have had to land in a no-flap configuration with the 41,000-pound Pegasus under its wing. Although internal safety locks on the Pegasus would have been functioning, the external safety pins that are in place during ferry flights and ground operation had been removed for the launch. Consequently, there was a definite risk associated with such a landing.

Lessons learned in past years concerning group interaction, the value of common procedures, fatigue and circadian rhythm awareness, and human ergonomics are being applied by the aviation industry on a daily basis. Such applications by the commercial space industry could improve the quality and safety of commercial space operations.

3. CONCLUSIONS

3.1 Findings

1. All launch team members were, by virtue of their experience, qualified to perform their duties during the launch.

2. The launch was licensed by the OCST.

3. There is a high probability that fatigue caused by the disruption of circadian rhythms and sleep loss adversely affected the performance of some critical personnel during the launch.

4. Intercom channel assignments were not well planned, standard intercom protocol was not followed, and no common intercom channel was considered primary by personnel in the mission control facility, contributing to the confusion that commenced prior to the launch.

5. No formal launch readiness reviews were held that were attended by all key launch team participants. Also, the single dress rehearsal for the launch was disjointed and abbreviated, did not consider various abort scenarios, and, most importantly, did not confirm the lines of authority and responsibility of team members.

6. The ER's Special Rule Number One, which precipitated the incident, was overly restrictive, and the practical ramifications of the rule were not fully understood by the ER, OSC and WFF prior to its acceptance.

7. DFRF, the organization that could have understood the ramifications of Special Rule Number One, was not consulted prior to the acceptance of the rule and was unaware of it prior to the deployment of the Pegasus.

8. The safety-related launch altitude limitation of 43,500 feet was included in WFF mission constraint documents but not in OSC documents. OSC documents contained altitude restrictions that

conflicted with each other. Therefore, key parties operated on conflicting assumptions about the correct launch parameters of the Pegasus ELV.

9. The pilots of the NB-52B experienced an autopilot malfunction during the subsequent directed descent that delayed their level off below 43,500 feet until about 1 minute prior to scheduled launch.

10. About 1 minute prior to scheduled launch, a one-frame telemetry dropout occurred that was interpreted by the WFF RSO and other WFF controllers as a command receiver signal dropout, which was a mandatory abort item, according to Special Rule Number One. An abort of the launch was called by the WFF RSO, in accordance with Special Rule Number One.

11. The TC became confused by activities concerning the abort call that he heard off the intercom net. He issued an abort call of his own because he was confused, and he later rescinded it because he believed the reasons for aborting the launch no longer existed.

12. The launch of Pegasus SCD-1 occurred under unsafe conditions because of general communications confusion and a lack of clear lines of authority and responsibility in the mission control room.

13. WFF and ER personnel responded to the unexpected launch in a rapid and positive manner that allowed the continued flight of Pegasus and the proper insertion of the SCD-1 and OXP-1 satellites into orbit.

14. The capability to destroy the Pegasus was maintained throughout the flight of the ELV.

15. There was an overall lack of adequate planning, organization, and implementation of the Pegasus SCD-1 launch that was the result of a lack of clearly delineated command, control, and communications assignments on the part of the key participants.

4. RECOMMENDATIONS

As a result of the investigation of this incident, the National Transportation Safety Board makes several recommendations to the Department of Transportation, the National Aeronautics and Space Administration, and the Orbital Sciences Corporation.

Recommendations to the Department of Transportation are as follows:

Require that, as a condition for license for commercial space launches, as a minimum, the company applying for the license include in its license application:

- o Clearly delineated statements of authority for all parties and key individuals involved in the launch, including individuals (or positions) authorized to abort the mission, hold the countdown, or resume the countdown, following a hold. (Class II, Priority Action) (A-93-87)

- o Specific details and criteria for launch readiness reviews and launch dress rehearsals. (Class II, Priority Action) (A-93-88)

- o A plan for the approval of checklists for the launch, including a provision for ensuring the currency and consistency of each participant's checklist during the dress rehearsal for the launch. (Class II, Priority Action) (A-93-89)

- o A provision for mandatory rest periods before the launch for key participants that provide for an adequate and specified time period for uninterrupted sleep. The quantitative criteria for such rest periods should be developed by appropriate human performance experts to ensure applicability to the assigned tasks. (Class II, Priority Action) (A-93-90)

- A communications plan for:

    1. a provision that interphone or other communication assignments be apportioned to allow decision makers from each party direct access to the decision makers of other parties and that proper radio-telephone communication phraseology is used, and

    2. a provision that key participants in the launch monitor a common intercom channel at an established point in the countdown and that these participants continue to monitor this channel during the final countdown sequence and after launch. (Class II, Priority Action) (A-93-91)

- A plan for approval of a safety directive or safety notebook for the launch to emphasize the safety aspects of the launch operation and to clearly list and consolidate mission constraints, rules, and special launch rules, as well as abort procedures. (Class II, Priority Action) (A-93-92)

- For launches from remote sites or aircraft, a plan to assure that essential communications interruptions resulting from antenna patterns are improbable. Practical considerations should be given for tolerable interruptions that may be associated with transient conditions, such as aircraft maneuvers. (Class II, Priority Action) (A-93-93)

Recommendations to the National Aeronautics and Space Administration are as follows:

- Study the feasibility of installing at the Wallops Flight Facility indicator lights on communications consoles that illuminate whenever an intercom channel is in use. (Class II, Priority Action) (A-93-94) o Study the feasibility of allowing the Range Safety Officer direct radio access to the launch airplane for Pegasus launches. (Class II, Priority Action) (A-93-95)

o Test the operability of all recording systems prior to each launch from the Wallops Flight Facility. (Class II, Priority Action) (A-93-96)

Recommendations to the Orbital Sciences Corporation are as follows:

Require, as part of ELV launch planning documentation:

o Clearly delineated statements of authority for all parties and key individuals involved in the launch, including individuals (or positions) authorized to abort the mission, hold the countdown, or resume the countdown, following a hold. (Class II, Priority Action) (A-93-97)

o Specific details and criteria for launch readiness reviews and dress rehearsals. (Class II, Priority Action) (A-93-98)

o Comprehensive, previously reviewed, checklists for the launch, including a provision for ensuring the currency and consistency of each participant's checklist during the dress rehearsal for the launch. (Class II, Priority Action) (A-93-99)

o Mandatory rest periods before the launch for key participants that provide for an adequate and specified time period for uninterrupted sleep. The quantitative criteria for such rest periods should be developed by appropriate human performance experts to ensure applicability to the assigned tasks. (Class II, Priority Action) (A-93-100)

o A communications plan that would include, at a minimum:

1. a provision that interphone or other communication assignments be apportioned to allow decision makers from each party direct access to the decision makers of other parties and that proper

radio-telephone communication phraseology are used, and

2. a provision that key participants in the launch monitor a common intercom channel at an established point in the countdown and that these participants continue to monitor this channel during the final countdown sequence and after launch. (Class II, Priority Action) (A-93-101)

- A safety directive or safety notebook for the launch to emphasize the safety aspects of the launch operation and to clearly list and consolidate mission constraints, rules, and special launch rules, as well as abort procedures. (Class II, Priority Action) (A-93-102)

- For launches from remote sites or aircraft, a plan to assure that essential communications interruptions resulting from antenna patterns are improbable. Practical consideration should be given for tolerable interruptions that may be associated with transient conditions such as aircraft maneuvers. (Class II, Priority Action) (A-93-103)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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John Hammerschmidt
Member

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Member

July 26, 1993

APPENDIX A

OCST/NTSB MEMORANDUM OF AGREEMENT

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APPENDIX H

OCST/NTSB

Appendix H is an appendix to the reimbursable Memorandum of Agreement between the Department of Transportation and the National Transportation Safety Board entered into on May 15, 1975, and establishes the relationships, notification procedures, coordination requirements, and reporting responsibilities of the Office of Commercial Space Transportation (OCST) and the National Transportation Safety Board (NTSB) in connection with accident investigations associated with commercial space launch activities, and identifies areas in which exchanges of data and use of resources or services of one agency by another may be requested.

1. ACCIDENT INVESTIGATION

The NTSB will investigate all commercial space launch accidents resulting in:

a. Known impact of a commercial launch vehicle, its payload or any component thereof outside the impact limit lines designated by the launch range facility; or

b. A fatality or serious injury (as defined in 49 CFR 830.2) to any person who is not associated with commercial space launch activities and who is not located on the launch range facility; or

c. Any damage estimated to exceed $25,000 to property which is not associated with commercial space launch activities and which is not located on the launch range facility.

Nothing in this agreement impairs the authority of the NTSB to investigate any other commercial space launch accident which, in the judgment of the Board, is subject to Section 304(a)(1)(F) of the Independent Safety Board Act of 1974.

Any other investigations of commercial space launch accidents by NTSB, other than those described above, will be subject to the mutual agreement of NTSB and OCST.

2. ACCIDENT NOTIFICATION

NTSB and OCST agree to notify each other promptly of the occurrence of all commercial space launch accidents which NTSB will investigate as provided for in paragraph 1.

3. ACCIDENT INVESTIGATION PROCEDURES

The following general procedures govern investigations of commercial space launch accidents by NTSB:

a. The accident investigation will be under the control and direction of the NTSB investigator-in-charge.

b. NTSB will be solely responsible for releasing factual information on the investigation to the public and will assign the official spokesperson for the investigation.

c. OCST shall be designated by NTSB as a party to each accident investigation and public hearing, and will, in turn, designate a principal representative as the OCST coordinator for each accident.

d. Selection of other OCST personnel to participate in the investigation shall be determined by the OCST coordinator and subject to approval by the NTSB investigator-in-charge. The coordinator shall work with the investigator-in-charge in conducting his activities.

e. OCST personnel assigned to a particular investigative group shall work under the direction of the group chairman and shall remain with the assigned group until that phase of the investigation has been completed or they are released by the investigator-in-charge and the OCST coordinator. They will submit to the group chairman whatever information they obtain during the course of the investigation.

f. The investigator-in-charge shall keep the OCST coordinator informed of the progress of the investigation.

g. Pertinent records obtained and factual reports prepared during the investigation shall be made available to OCST through the OCST coordinator in a timely and orderly manner.

h. In the event additional facts are needed by OCST but not required by the NTSB, they may be obtained by the OCST coordinator following notification of the NTSB investigator-in-charge, on the condition that it does not interfere with the ongoing NTSB investigation. In obtaining such facts, OCST personnel shall make it clear that they are not acting under NTSB direction. In addition, the OCST coordinator shall notify the NTSB investigator-in-charge of any OCST intent to take any enforcement action, if the NTSB investigation is not yet completed.

i. Subject to the provisions of section 304(a)(1) of the Independent Safety Board Act of 1974, as amended, nothing in this agreement impairs the authority of OCST to conduct investigations of accidents under applicable provisions of law or to obtain information directly from parties involved in, and witnesses to, a commercial space launch accident.

j. The NTSB investigator-in-charge shall not release any wreckage until OCST agrees that it is no longer needed. In the event OCST requests NTSB to retain control of any wreckage for a period of time beyond NTSB's investigative needs, that period of time shall not exceed 60 days from the date of request. OCST shall be responsible for the storage and security costs, if any, for this additional time.

4. EXCHANGE OF INFORMATION

NTSB and OCST will each provide to the other copies of all accident reports, research reports, studies and other documents normally available to the public upon request. In addition, NTSB and OCST shall each have access to the other's accident data files and tapes on a continuing basis.

Approved:

[signed by] Stephanie Lee-Miller June 5, 1989
Office of Commercial Space Transportation

[signed by] James Kolstad June 5, 1989
National Transportation Safety Board

APPENDIX B

MISSION CONTROL ROOM INTERCOM AND RADIO TRANSCRIPTS

A transcript was prepared of 4 of the 12 WFF mission control room intercom channels that were in use during the launch of the Pegasus vehicle. The attached transcript contains information extracted from the NASA WFF transcript dated February 19, 1993, (revision-1), and from information obtained in reviewing the cassette copies of the original recordings. The transcript covers from approximately 4 minutes before launch through 2 minutes after launch.

The transcript is arranged into four columns, one for each of the channels. Column one contains information that was heard on intercom channel 1, the WFF Test Director's channel. Column two contains information that was heard on intercom channel four, the Mission Director's local channel. Column three contains information that was heard on channel ten, the WFF Range Safety primary channel. The last column contains the audio information that was heard on channel 12, the air-to-ground radio channel.

POSITION ABBREVIATION KEY

CD	WFF Range Control Officer (countdown)
RCO	WFF Range Control Officer
TM	WFF Telemetry Coordinator
TD	WFF Test Director
TC	Orbital Sciences Test Conductor
PEG	Orbital Sciences Vehicle Engineer
MFSO	WFF Missile Flight Safety Officer
RSO	WFF Range Safety Officer
DQ	WFF Data Quality Officer (real-time computers)
RS 3	WFF Range Safety Support (Command System)
RS 2	WFF Range Safety Support
RS 1	WFF Range Safety Support
NASCOM	NASCOM Operator
NB-52	BNB-52B launch airplane
-1	Voice identified as pilot
-2	Voice identified as co-pilot
-3	Voice identified as Orbital Sciences Launch Panel Operator

NASA 1	Airborne Communications Coordinator
UNK	Unknown source
*	Unintelligible word
()	Questionable text
(())	Editorial insertion
-	Pause

Note: Times are expressed in T- minutes: seconds prior to launch, and T+ minutes after launch

TIME	SOURCE	WALLOPS TEST DIRECTOR CHANNEL 1	SOURCE	MISSION DIRECTORS (LOCAL) CHANNEL 4	SOURCE	WALLOPS RANGE SAFETY CHANNEL 10	SOURCE	GROUND-AIR COMMUNICATIONS CHANNEL 12
T-3:54	CD	All stations, we're at 4 minutes and counting			CD	All stations, we're at 4 minutes and counting		
T-3:48	RCO	Roger, it looked like I missed it by about 4 seconds. I think we're ahead of you.			RCO	Roger, it looked like I missed it by about 4 seconds. I think we're ahead of you.		
T-3:44			TC	Item 2 complete. Transient power on. PBS, TC. You did verify transient power on and nominal.				
T-3:42	RCO	I'll give you a mark at 3.			RCO	I'll give you a mark at 3.		
T-3:38			PBS	that is correct				
T-3:31					RSO	30 seconds. 3:30.		
T-3:36	UNK	We okay, Bob?	TC	Item 3 complete. Standby.				
T-3:28					MFSO	Bob Long, RSO on 10.		
T-3:18					TD DQ	Go Ahead, RSO. 3:20.		
T-3:17					MFSO	Be advised we're still showing velocity about 8 - altitude about 800 feet above the maximum altitude for launch. Do you intend to bring it down before you get to the drop point?		
T-3:13	RCO	Go Go	RCO	Go Go.				
T-3:04			TC	RCO, standby with strip charts, please.	RSO	Stand by.		
T-3:01					DQ	RTCS and RTBS, DQ.		
T-3:03							B-52(1)	Three minutes. Ready - ready - Rock. Minus 32 degrees outside air temp.
					RSO	Mark.		
T-2:59								
T-2:58	RCO	We can't live with this? We're going to have to abort? Is this what you're saying?	RCO	We can't live with this? We're going to have to abort? Is this what you're saying?	RCO	We can't live with this? We're going to have to abort? Is this what you're saying?		
T-2:57							NASA 1	Roger, that and any fuel quality ?
T-2:56					MFSO	Your altit - Your altitude of aircraft exceeds the maximum allowable altitude for release.	B-52(1)	Upper level winds are 220 at 86 knots.
T-2:45	RCO	In other words, we're going to have to abort if we don't get down 8 000 feet?			RCO	In other words, we're going to have to abort if we don't get down 8 000 feet?		
T-2:42					MFSO	That's affirmative.		
T-2:40	RCO	We gotta get down NASA 1. We gotta get down 800 feet or we're going to have to abort.	RCO	We gotta get down NASA 1. We gotta get down 800 feet or we're going to have to abort.	RCO	We gotta get down NASA 1. We gotta get down 800 feet or we're going to have to abort.		
T-2:37					MFSO	You need to be below forty-three-five.		
T-2:33	RCO	Got to be below forth-three-five.	RCO	Got to be below forth-three-five.	RCO	Got to be below forth-three-five.		

TIME	SOURCE	WALLOPS TEST DIRECTOR CHANNEL 1	SOURCE	MISSION DIRECTORS (LOCAL) CHANNEL 4	SOURCE	WALLOPS RANGE SAFETY CHANNEL 10	SOURCE	GROUND-AIR COMMUNICATIONS CHANNEL 12
					RSO	Bob, ask him to give a readout on his display - at the aircraft.		
T-2:31								
T-2:27							NASA 1	008, NASA 1. Descend approximately 000 feet.
T-2:25	RCO	What? You mean, on his altimeter?	RCO	What? You mean, on his altimeter?	RCO	You mean, on his altimeter?		
T-2:23						RSO	Yes.		
T-2:22	RCO	Get an altimeter reading from NASA ah 000.	RCO	Get an altimeter reading from NASA ah 000.	RCO	Get an altimeter reading from ah NASA 000.		
T-2:21							B-52(1)	What was that?
T-2:19							NASA 1	You'll have to descend about 000 feet is you can. That's a requirement for space.
							B-52(1)	Descend 000. Okay.
T-2:14								
T-2:13							NASA 1	Copy.
T-2:10	RCO	What, what does NASA. What does 009 say on his altimeter, NASA 1.	RCO	What, what does NASA. What does 008 say on his altimeter, NASA 1.	RCO	What, what does NASA. What does 008 say on his altimeter, NASA 1.		
T-2:05							NASA 1	008, NASA 1. Say altimeter.
T-2:01							B-52(2)	Two minutes now.
T-2:00					RSO	2 minutes.		
T-1:58							B-52(2)	Altimeter is two-nine-five-two.
T-1:54			TC	Charts on. Standby for fin sweep test.			NASA 1	NASA 1 copy.
T-1:48	RCO	Altitude on - altimeter.	RCO	Altitude on - altimeter.	RCO	Altitude on -		
T-1:46					RSO	Bob, you need to get him down.		
T-1:44	RCO	He's coming down Jack.	RCO	He's coming down Jack.	RCO	He's coming down Jack.		
T-1:41							B-52(1)	IR-61 is inertial.
T-1:30			WHK	Readout, verify lock.				
T-1:30	TM	TM's go.						
T-1:29	RCO	NASA 1, is he ah descending?	RCO	NASA 1, is he ah descending?	RCO	NASA 1, is he ah descending?		
T-1:27							NASA 1	That's affirm.
T-1:26	RCO	What does his altimeter say, altitude wise?	RCO	What does his altimeter say, altitude wise?	RCO	What does his altimeter say, altitude wise?		
T-1:22							NASA 1	00, say altimeter
T-1:20							B-52(1)	Okay. We're at forty-three-seven and pushing down. Descending now.
T-1:14	TM	Affirmative.						

TIME	SOURCE	WALLOPS TEST DIRECTOR CHANNEL 1	SOURCE	MISSION DIRECTORS (LOCAL) CHANNEL 4	SOURCE	WALLOPS RANGE SAFETY CHANNEL 10	SOURCE	GROUND-AIR COMMUNICATIONS CHANNEL 12
T-1:07					RSC	Bob Long, we're go. Let him go like he is.	NASA 1	Forty-three-five is the launch altitude.
T-1:06	RCO	Roger.	RCO	Roger.	RCO	Roger.		
T-1:03							B-52(1)	Okay, we're close to that.
T-1:01							B-52(2)	1 minute- now.
T-0:59			TC	Item 9. LI's 1 minute.	RSO	Ah Bob, I've a mandatory abort.		
T-0:58	TM	Readout go.						
T-0:56	TD	Abort. Abort. Abort. Abort it.						
T-0:56							NASA 1	Pick up launch heading.
T-0:51					RSO	And it's on the command receivers.		
T-0:50	TM	Negative.	TC	Who's calling an abort, please?				
T-0:47	TD	Abort because of a command receiver call on the Range Safety Officer.						
T-0:44			TC	TC on 4. NASA 1, we have abort. Abort.				
T-0:39	RCO	Did you lose a command receiver, Jack.	RCO	Did you lose a command receiver, Jack.				
T-0:37					RSO	Yes. It went below the threshold - and that means we're in the data collection mode.		
T-0:36							UNK	- Fin batteries -.
T-0:34							NASA 1	Abort, abort. Abort. We have lost a command receiver, it looks like.
T-0:28			TC	Fin battery are on. Fin batteries are on.				
T-0:27							B-52(3)	Okay, the fin batteries are on. We understand abort.
T-0:23			TC	Negative.				
T-0:22							NASA 1	Negative on the abort - Negative.
T-0:20							B-52(3)	You want the fin sweep?
T-0:19					RS 3	Jack, that wasn't a TM glitch.		
T-0:18							NASA 1	Keep going.
T-0:16			TC	Do we have command receivers up?	RSO	That was what?	B-52(2)	16 seconds.
T-0:15							B-52(3)	Fin sweep.

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TIME	SOURCE	WALLOPS TEST DIRECTOR CHANNEL 1	SOURCE	MISSION DIRECTORS (LOCAL) CHANNEL 4	SOURCE	WALLOPS RANGE SAFETY CHANNEL 10	SOURCE	GROUND-AIR COMMUNICATIONS CHANNEL 12
T-0:14					RS 3	That was not a TM glitch.		
T-0:13					RSO	That was not a TM. Okay.		
T-0:11					RS 3	TM had acquisition. It's the command receiver.		
T-0:10			PBS	PBS is go.			B-52(2)	10 seconds.
T-0:08			TC	Go for launch.				
T-0:07							B-52(2)	One.
T-0:06			TC	Range go.	UNK	??	NASA 1	NASA 1 is go for launch.
T-0:04					RSO	Abort, Bob.	B-52(1)	Okay, go for launch.
T-0:02	RCO	Are you saying abort?	RCO	Are you saying abort?	RCO	Are you saying abort?		
T-0:00	RCO	Abort, abort.	RCO	Abort, abort.	RSO	Joyce, was that good data?		
T+0:01							B-52(2)	Pegasus away, Pegasus away.
T+0:05			TC	Pegasus away.	RSO	It's gone.		
T+0:07			PBS	All S&A's armed. B-52 sep good.				
T+0:11					RSO	Roger.		
T+0:15			TC	We have Stage 1 ignition.				
T+0:16					RSO	We got it.	B-52(2)	Now to chase video.
T+0:17					RS 3	I have no TM		
T+0:19			TC	Stage 1, 77 seconds burn time.	RS 1	No TM		
T+0:20					RS 2	Bad data.		
T+0:24					RSO	Get the clock going.		
T+0:25	TD	Programmer, get the clock running.						
T+0:29					RS 1	We got data. We got data. We got data.		
T+0:31	TM	JDI data's good.			RS 2	You have accelerating vehicle.		
T+0:32	RCO	Start the programmer.	RCO	Start the programmer.				
T+0:36					RS 3	I've got TM. AGC is good.		
T+0:39					MFSO	Roger that, FCO		
T+0:40			PBS	Batteries look good.				
T+0:41					RS 1	Body angles are nominal.		
T+0:43					NASCOM	NASCOM switch to JDI data.		
T+0:44					MFSO	FCO, we're flying down nominal.		
T+0:46					RSO	Roger		
T+0:47					RSO	We have good sources on nominal.		

TIME	SOURCE	WALLOPS TEST DIRECTOR CHANNEL 1	SOURCE	MISSION DIRECTORS (LOCAL) CHANNEL 4	SOURCE	WALLOPS RANGE SAFETY CHANNEL 10	SOURCE	GROUND-AIR COMMUNICATIONS CHANNEL 12
T+0:50					MFSO	Mike, do you have TM?		
T+0:51					RS 1	yes I have TM and body angles look good.		
T+0:53			TC	Telemetry looks good.				
T+0:57			TC	Motor pressures are looking good.				
T+1:00			TC	PBS, TC. Give me some feedback.				
T+1:03			PBS	Everything normal. Pressure's good. Batteries good. Attitude good.	MFSO	Roger Jack. I got no - no valid velocity and telemetry displays.		
T+1:07					RS 2	You have good acceleration.		
T+1:10			TC	RCO, this is TC. Give me some feedback on range please.				
T+1:11					RSO	Okay off the digital, Bob. the IP is going nominal.		
T+1:14					MFSO	- Climb IP.		
T+1:16			TC	We have fin rocket ignition. Mark. Event 3.				
T+1:20					RS 2	Okay, we're getting a loss of acceleration. Looks like first stage burnout.		
T+1:23					RSO	Roger, I agree		
T+1:25					RS 1	We're off in time that going to be.		
T+1:27			TC	Mark 4, Stage 1 burnout.	RSO	Right. We understand. Let's go with it.		
T+1:29	RCO	How's TM looking?			RCO	How's TM looking.		
T+1:31	TM	TM's good.			RS 1	TM looks good. Body angles look good.		

APPENDIX C

MEMORANDUM CLARIFYING FTS SIGNAL REQUIREMENTS DURING NB-52B FLIGHT

National Aeronautics and
Space Administration

Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, Virginia 23337-5099

NASA

Reply to Attn of: 824.1 December 23, 1992

TO: 832.3/Robert T. Long

FROM: 824.1/Head, Ground and Flight Safety Section

SUBJECT: Clarification of FTS Signal Requirements During B-52 Flight

This memorandum is to clarify/define the safety requirement listed under Mission Rules "special Rules prior to B-52 drop" rule no. 1.

Range Safety requires the complete FTS system to be certified prior to launch. Certification test are planed during prelaunch testing at KSC. After B-52 take-off, a ferry period of approximately 50 minutes occurs prior to Pegasus launch. During this period the command receivers are operating and Range Safety will monitor their operation through telemetry. The monitoring data available includes AGC from both command receivers and temperature levels within the vicinity of the command receivers.

During this period, the following will result in a mission abort:

1. Temperatures less than -40° C
2. Signal levels of less than -93 dbm on either of the two command receivers during the final straight and level run to the drop point.
3. The opinion of the Safety monitors is that a command receiver problem exists on either receiver.

The "straight and level" period is defined as the period of B-52 flight which occurs after the B-52 pilot calls "straight and level" on his final run to drop and will not be less than six (6) minutes prior to drop.

Requirement 3 above is required because Range Safety recognizes that signal levels of less than -93 dbm are possible due to RF shadowing and multipath during the flight period from take-off to the "straight and level" portion of flight. It is expected that these periods won't be continuous and there will exists periods which it is reasonable to expect signal levels greater than -93 dbm. Safety determination of "reasonable" will be made by utilizing tracking information, plots of AGC signals, and monitoring communications between the Range Control Center and the B-52.

In the event a mission abort occurs due to 2 or 3 above, the B-52 flight will be considered a data run and will continue in order to obtain flight information. Following data collection, Range Safety will require a minimum of 3 working days in order to review the data before another launch attempt can be made.

John L Parks Jr

John L. Parks, Jr.

cc:
824/F. R. Sawyer

APPENDIX D

NASA-AMES RESEARCH CENTER LETTER ON FATIGUE FACTORS

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

NASA

Reply to Attn of: FLT: 262-4

April 28, 1993

Malcolm Brenner, Ph.D.
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington DC 20594

Dear Dr. Brenner,

Thank you for contacting the NASA Ames Fatigue Countermeasures Program regarding the recent Pegasus launch anomaly. Our program has been investigating fatigue, sleep loss, and circadian disruption in a variety of operational environments over the past 12 years. Our research provides insight for both cause and prevention and your position provides a theater for education about our findings.

Enclosed are the results of our examination of the Human Performance Investigator's Factual Report. The results address the effects of physiological components and fatigue, and then suggest countermeasures for avoiding a future potential incident.

We appreciate your interest in our research and activities, and we would be pleased to work with you in the future. Please feel free to call us if you have questions related to the enclosed results or any other issues. We hope you find this information useful.

Sincerely,

Mark R. Rosekind
Flight Human Factors Branch
(415) 604 - 3921

Keri J. Weldon
Flight Human Factors Branch
(415) 604 - 0020

PEGASUS LAUNCH ANOMALY; EVALUATION OF CONTRIBUTORY FATIGUE FACTORS

Mark R. Rosekind, Keri J. Weldon, and J. Victor Lebacqz
Flight Human Factors Branch
NASA Ames Research Center

INTRODUCTION

The National Transportation Safety Board's Human Performance Investigator's Factual Report describes the successful launch of the Pegasus M13/F3 rocket on February 9, 1993. An investigation was initiated to examine an anomaly that occurred in the final minute of the launch that almost resulted in a launch abort. The Human Performance Investigator's Factual Report was examined to identify specific physiological variables that may have created a fatigue factor that contributed to the launch anomaly. The results of this examination are reported here. First, this report will address two major physiological components that may have contributed to the launch anomaly, then suggest how fatigue may have been a contributory factor, and finally, suggest areas that may be useful as potential fatigue countermeasures for future launch operations.

ACUTE SLEEP LOSS

Extensive scientific research has clearly demonstrated that sleep is a vital physiological function, much like eating and drinking. When deprived of this vital physical need the brain becomes sleepy and physiological sleepiness can result in major decrements in essentially all areas of human performance. Therefore, sleep loss can definitely lead to decrements in such areas as alertness, psychomotor coordination, decision-making, mood, information processing, memory, etc. These decrements can have a profound effect on human performance capabilities in operational environments. The scientific literature demonstrates that as little as one hour less sleep than is usually required by an individual can lead to decreases in waking performance and alertness. Two hours less sleep than is usually required by an individual can create major degradations in these areas during wakefulness. It also has been demonstrated that sleep loss can be accumulated over days, resulting in a cumulative sleep debt. Therefore, even acute sleep loss can affect waking levels of performance and alertness and over time build into a cumulative sleep debt.

Based on the information provided in the Human Performance Investigator's Factual Report, an analysis of the sleep/wake patterns of the 6 individuals identified was conducted. Two specific analyses were performed: 1) total sleep in the 26 hr period surrounding the launch and 2) cumulative acute sleep loss prior to launch. Incomplete data were available and therefore several assumptions were made, though these were conservative estimates whenever required. An important caveat is that all of this analysis is based on third hand, self-report data, collected after the fact.

1) Total sleep in the 26 hr period surrounding the launch. The total amount of sleep reported from Monday morning wakeup (2/8/93) through Tuesday morning (2/9/93) at about 1000 (0930 launch time), about a 26 hr period, was calculated for the 6 individuals. The total amount of sleep obtained in the 26 hr period surrounding the launch for each individual was as follows: WOD--3 hrs; TC--1.5 hrs; RCO--2.5 hrs; RSO--3.5 hrs; NASA-1--4.5 hrs; and B-52 pilot--7 hrs. The overall average for this group of 6 key individuals was 3.7 hrs of sleep in the 26 hr period surrounding the Pegasus launch. This ranged from the pilot's 7 hrs of sleep to the TC's 1.5 hrs.

2) Cumulative acute sleep loss prior to launch. The 48 hrs preceding the launch was examined for total reported sleep. The cumulative number of hours of sleep lost was calculated by subtracting the reported sleep time from an expected average of 8 hrs sleep per night (total of 16 hrs total sleep expected over 48 hrs). The cumulative sleep loss for each of the 6 individuals identified in the report was as follows: WOD--5 hrs; TC--6.5 hrs; RCO--5 hrs; RSO--5.5 hrs; NASA-1--3.5 hrs; and B-52 pilot--1.5 hrs. For example, WOD obtained only 11 out of 16 expected hours of sleep, resulting in 5 hrs of cumulative sleep loss in the 48 hrs prior to launch. Overall, as a group, these 6 key individuals averaged 4.5 hrs of cumulative sleep loss in the 48 hrs preceding the Pegasus launch. As a group, these individuals had lost 25% of their usual, and likely required, sleep. Their sleep debts ranged from 1.5 hrs in the pilot to 6.5 hrs of sleep loss in TC.

Therefore, as a group, these 6 key individuals averaged 3.7 hrs of sleep in the 26 hrs surrounding the launch and averaged 4.5 hrs of cumulative sleep debt in the 48 hrs leading up to the launch, a cumulative sleep debt representing over 25% of their usual sleep requirement. The lowest sleep loss overall (best sleep) was reported by the pilot, while TC had the highest cumulative sleep debt and the lowest total sleep immediately preceding the launch.

CIRCADIAN DISRUPTION

A second major physiological factor affecting waking performance and alertness is circadian rhythms. An area in the brain (the suprachiasmatic nucleus) controls the 24 hr patterns of physiological functions. This includes 24 hr fluctuations in body temperature, hormone secretion, sleep/wake patterns, rest/activity, performance (both physical and mental), and many other bodily functions. There are two periods of maximal sleepiness in a person's usual 24 hr day. One of these occurs between roughly 3-5 am every morning. During this period, performance and alertness are at low points, the body's temperature is at its lowest point, and the brain is essentially programmed to be sleeping. The Pegasus launch countdown was initiated during this period of maximal sleepiness. This timing may have led to both decreased alertness and performance during the initial countdown activities, and is also the key factor in creating the sleep loss described previously. Essentially, key personnel are awake performing activities when physiologically their brains are programmed to be asleep. While it is obviously possible to avoid sleep, the physiological pressure to sleep is maintained and may affect waking levels of performance and alertness.

WAS FATIGUE A CONTRIBUTORY FACTOR IN THE LAUNCH ANOMALY?

There are two major physiological variables that can result in fatigue: sleep loss and circadian disruption. While other variables can also play a role in creating fatigue, scientific research has clearly documented the relationship between these physiological variables and fatigue. The word fatigue is used in this context to represent the summation of the various factors that lead an individual to experience "fatigue." Individuals may report fatigue or use many other words to describe their state, for example, tired, sleepy, foggy, etc. Scientific research has also demonstrated that individuals are typically very poor at subjectively reporting their alertness and performance. There is usually a discrepancy between an individual's self-report of their alertness and their physiological level. This inaccuracy usually tends to reports of greater alertness than indicated by physiological or performance measures. Therefore, a sleepy individual's self-report that they are alert and performing well would be expected often to be highly inaccurate and not reflect degraded performance or alertness. This is one of the mechanisms that creates vigilance performance and other difficulties in operational settings. An individual has experienced sleep loss, perhaps accumulated a sleep debt, and is working in opposition to their brain's programming to be asleep (for example during a 3-5 am window). The individual's inability to accurately detect and report their level of physiological sleepiness could contribute to a performance decrement that leads to an incident or accident.

In most operational environments, individuals are not aware of the severe consequences associated with sleep loss and circadian disruption. Nonetheless, sleepiness and fatigue have been shown to have contributed to major accidents such as Three Mile Island, the Exxon Valdez, and even the Challenger. An appendix in the Rogers Commission Report specifically addresses the issue of fatigue related to the sleep loss and circadian disruption created by the shiftwork demands of shuttle operations. This was one factor in the creation of specific duty time policies initiated by NASA to address this issue.

There is often a lively debate when the issue of fatigue is raised as a contributory factor in an incident or accident. In most cases, the investigations take place after the fact and diligently attempt to recreate the circumstances surrounding a particular incident or accident. Frequently, the primary "cause" is identified as human error. For example, in aviation investigations 70-80% of the accidents are attributed to human error. The specific human error can range from a missed checklist item to flaps in the wrong position to an undetected fuel imbalance to an almost infinite number of performance errors. However, the principal mediating variable may very well have been fatigue. Sleep loss, an accumulated sleep debt, and circadian disruption can have profound effects on waking performance and alertness. These decrements can be the primary "cause" for missing a critical checklist item, not remembering an important piece of information, slowed reaction time, missed communications, poor coordination among personnel, and a wide range of other "errors." There is, however, no blood test for fatigue. Therefore, any investigation that attempts to recreate the circumstances of an incident or accident after the fact may identify the specific "error" but if the *cause* of that error was fatigue it may go undetected. It is likely that fatigue has been a contributory factor in many more incidents and accidents than can ever be demonstrated by post-accident investigations.

From the information provided in the Factual Report, it would certainly appear that sleep loss and circadian disruption could have been contributory factors to the launch anomaly described. Fatigue could have contributed to decrements in communication, information processing, personnel coordination, decision-making, reaction time to information, etc. The more time-critical the decisions and actions, the greater the potential for a fatigue effect.

STRATEGIES TO MAXIMIZE ALERTNESS AND PERFORMANCE DURING FUTURE PEGASUS LAUNCH OPERATIONS.

Overall, the factors previously discussed come together to have an effect on the overall operational safety margin. Clearly, operational environments require 24 hr activities. The challenge is to identify areas of physiological vulnerability that can reduce human performance capabilities and introduce strategies that maximize alertness and performance during operations. The following section will identify some areas that may be useful to help maintain the safety margin in future Pegasus launch operations.

The Fatigue Countermeasures Program in the Flight Human Factors Branch at NASA Ames Research Center has been investigating and developing countermeasures for sleep loss and circadian disruption since 1980. The activities of this program are highlighted because they provide an inhouse NASA resource to utilize in addressing the issues raised by this report. A critical first activity is education and training about fatigue, sleep loss, circadian disruption, sleepiness, and potential fatigue countermeasure recommendations. This information lays the foundation for all personnel to understand the effects of fatigue and how certain countermeasure strategies might be utilized within the specific operational requirements of a Pegasus launch. The information is critical for individuals monitoring a panel, for managers making critical decisions, for individuals creating work schedules, and essentially all personnel involved in an altered or extended shift operation. The Fatigue Countermeasure Program is currently in the process of implementing a Fatigue Education and Training Module for aviation industry personnel including pilots, flight attendants, schedulers, managers, etc. Therefore, a model for this type of education and training module has been developed.

The Fatigue Countermeasures Program has initiated a collaborative study of Flight Controllers in the Missions Operations Directorate (MOD) at Johnson Space Center to examine similar shiftwork issues related to shuttle operations. This project is in the process of identifying areas of vulnerability and then will develop a variety of specific strategies to implement in the MOD environment. The strategies will be evaluated to determine their effectiveness in reducing the adverse effects of fatigue, sleep loss, and circadian disruption and promoting alertness and performance during 24 hr operations. These strategies might include a wide variety of recommendations from specific scheduling alternatives, to rest guidelines, to specific operational strategies for use during a shift. Clearly this current collaborative Ames/Johnson activity could be directly applicable to the Pegasus launch operations.

Further understanding of the specific operational requirements of a Pegasus launch could lead to focused recommendations to minimize the adverse effects of fatigue and to maximize performance and alertness.

APPENDIX E

NASA-AMES RESEARCH CENTER LETTER ON CREW COORDINATION AND COMMUNICATION

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

May 6, 1993

Reply to Attn of: FLR: 262-3

Malcolm Brenner, Ph.D.
National Transportation Safety Board
490 L'Enfant Plaza East, S.W.
Washington D.C. 20594

Dear Dr. Brenner,

The following is a summary of my observations on some aspects of the recent Pegasus/SCD-1 launch operation incidents that occurred on February 9, 1993. These observations will focus on aspects of the operation pertaining to crew coordination and communication.

I have been a research psychologist at NASA Ames Research Center (Aerospace Human Factors Research Division) for nearly eight years, conducting and coordinating research in the area of Crew Factors and Crew Resource Management, a program of research with a 15-year history. Although my area of specialization is communication processes and issues pertaining to information transfer, crew factors research is also concerned with environmental and socio/organizational effects on team performance, leadership and management strategies for facilitating crew coordination, and the implications of such research on team structure, management and training. The common goal of these various research efforts is to identify how crew factors influence overall team performance so that we can better safeguard against crew error and enhance system safety. Although most of our crew factors research has focused on flightdeck operations, we have begun to extend this work beyond the cockpit. In particular, I have gained some familiarity with the launch operations at Kennedy Space Center and Cape Canaveral over the last three or four years.

Thank you for your interest in our Crew Factors research and approach. If you have any questions about the following report, please feel free to call. I will be happy to help in anyway I can on this, and any future investigations.

Sincerely,

Barbara G. Kanki

Barbara G. Kanki
Crew Factors Group
Off: (415) 604-5785
FAX (415) 604-3323

A CREW FACTORS PERSPECTIVE ON THE PEGASUS/SCD-1 LAUNCH OPERATION INCIDENTS (February 9, 1993)

This review is organized in two sections. The first section gives a crew factors perspective on five contributory factors discussed in three separate reports of the incidents[1] that I reviewed. There appeared to be general agreement on the following factors: 1) communication, 2) roles and responsibilities, 3) documentation and mission constraints, 4) pre-launch preparations, and 5) mission management. Each of these topics not only contain human factors elements, but human factors elements that focus on the group rather than the individual level. A body of crew factors research have addressed many of these topics, and I have given a few examples that relate to the various factors.

The second section gives a crew factors analysis of the communications transcribed by the NTSB[2]. Although it is only a snapshot of the operational environment and events, there are patterns that describe the way in which the various teams were interacting during the critical minutes surrounding launch time.

A Crew Factors Perspective

Factor 1: Communication (Establishing predictable ways of communicating, a shared understanding of the situation, the use of standard protocols)

The coordination of tasks among flightdeck crewmembers is facilitated by the fact that pilots share the same knowledge and skills. Standard operating procedures (SOPs) extend the shared knowledge base by setting up expectations about who is doing what and when. To the extent that both pilots have the same cognitive or mental representation regarding the general state of the aircraft (i.e., location, course, altitude, weather, flaps and slats configuration, etc.), the simultaneous or sequential coordination of tasks is made easier. Second-guessing other crewmembers is not an efficient way of gaining information; especially in high workload, critical phases of flight or during emergency situations.

Communication is an important aspect of standard operating procedures because in some cases it defines the procedures formally, and in other cases it is used informally to create or access a shared knowledge base. Checklists and written procedures are two cases in which communication is used to define or specify what tasks need to be done, who should do them, what order and when they should be done.

Conventionalized patterns of information exchange serve the same purpose; i.e., to create expectations about how and when important information is made available. When information is made available in a predictable way, more efficient understanding and utilization of that information is accomplished.

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[1] The three reports reviewed included: the Management Review Panel Report, the Wallops Island Flight Facility summary, and the Orbital Sciences Corporation report.

[2] The transcription of communications was provided by the NTSB, Specialist's Factual Report of Investigation, Launch Control Room Intercom Recordings.

For example, Kanki, Greaud, and Irwin (1991) have shown that similarity of communication patterns may be a distinguishing feature of high performing flightcrews. This research has demonstrated that the higher performing crews share similar communication patterns while lower performing crews show more heterogeneous patterns. For example, consistent with the earlier findings (Foushee et al., 1986), in four of five best performing crews, captains and first officers generated essentially the same proportions of speech types (commands, questions, acknowledgements, etc.). The five lower performing crews used in these analyses showed no consistent pattern of speech types.

Factor 2: Roles and Responsibilities (Definition of roles).

In a field study of flightcrews, Ginnett (1987) found that effective leaders explicitly affirmed or elaborated upon the rules, norms, task boundaries, etc. that constituted the "normative" model of the organizational task environment. Specifically, they briefed both flightdeck and cabin crews about interface tasks, physical and task boundaries, and other norms for performing their task (regarding safety, communication and cooperation). They established clear authority dynamics, as well as their own technical, social and managerial competence. Each effective leader covered the above areas in the process of team creation prior to flight (e.g., crew briefings), and behaved consistently with this model during task execution.

In contrast, ineffective leaders were not similar to the effective leaders, nor were they similar to each other. In a variety of ways, they tended to either abdicate their leadership responsibilities, or in some cases, actively undermine their crew's normal expectations. In one way or another, these captains tended to leave their crew-members guessing. Although it is not clear whether a performance decrement would be detectable under completely routine operations, a confluence of multiple stressors that demand active crew coordination and creative problem solving may require a greater degree of predictability and team preparedness.

Factor 3: Documentation & Mission Constraints (Unambiguous rules and documents).

It is fairly obvious that documents and missions constraints should be clearly understood by all personnel and should be as free from inconsistencies and ambiguities as possible. However, it is also possible to regulate too much; that is, build so many rules about "the" official procedure that unanticipated deviations and last minute changes will be impossible to incorporate quickly. Nevertheless, two practices that can greatly facilitate a shared understanding of procedures and constraints are the following: 1) that all key players (organizations) develop the procedure together so a more balanced systems perspective can be achieved and so that the implementation of the procedure will contain few surprises, and 2) that pre-launch preparations serve as a vehicle for reinforcing the essential rules and constraints in the most current revisions, and thus facilitate a shared understanding among all teams involved.

Factor 4: Pre-Launch Preparations (Appropriate preparation/briefings/ debriefings for integrated multi-organization operation).

On the topic of briefings, Ginnett's study (1987) mentioned above found that quality and content of captain briefings clearly distinguished the effective from ineffective leaders. Also relevant to the area of pre-launch preparations is the practice of high-fidelity simulations of operations (called Line oriented flight training in the air transport industry). Simulations provide the opportunity to practice and improve team skills, and are especially useful for training teams to better handle abnormal conditions and emergencies. Two critical elements in conducting an effective simulation include: (1) design of an appropriate scenario; i.e., one that requires team skills, problem solving, communication, etc. in a realistic way and (2) appropriate implementation of the training itself, including effective briefings, debriefings and scheduling that does not conflict with other requirements. In short, these kind of exercises are useful for imparting basic and updated information, defining roles and responsibilities, and practicing standard protocols under normal and abnormal conditions. However, it is essential that the exercise serve the integrated team, not the individual interests cf separate subteams.

Factor 5: Mission Management (Team members had not worked together).

A full mission simulation study conducted by Foushee, Lauber, Baetge and Acomb (1986) showed that flightcrews that had flown together recently performed significantly better than crews that had not flown together. This was found in spite of the fact that the crews that had flown together were in the post-duty condition (i.e., high fatigue condition). Crews that had NOT flown together were in the pre-duty condition, (low fatigue condition). Thus, in spite of being more fatigued, the crews that had some familiarity with the way their fellow team members worked together, gave them the performance advantage. In general, the post-duty crews communicated more overall, used more statements of intent and acknowledgements, and had more initiatives from subordinate crewmembers.

It has been suggested (Foushee et al., 1986; Kanki & Foushee, 1989) that the time spent flying together before the simulation increased the ability of crewmembers to anticipate each other's actions and interpret the style and content of their communication. The communications analysis of these data (discussed earlier) revealed that the higher performing crews actually used speech patterns that were conventionalized; that is, the patterns showed a standard, and hence more predictable form than the lower performing crews. In addition, a more infonned or "familiar" style was adopted by post-duty crews that allowed for greater dialogue among crewmembers without impairing authority structure (captains still assumed their command responsibilities).

A Crew Factors Analysis of Communications

The transcribed communications were analyzed in units that corresponded, for the most part, to "speaker turns" (transmissions). Speaker turns were also grouped into "interaction units" consisting of sequences of communications that were specifically directed toward a person and elicited responses from them. In some cases, communications did not form sequences (or interactions) because they were simple call-outs or they did not elicit a response that could be heard on the net. These interaction units (communication sequences) were coded with respect to: the participants interacting, the channels on which they were speaking, and their approximate placement in time. Individuals identified by callsign (or by name) were also coded in terms of their organizational affiliation. The following are some general findings associated with this data[3]

Observation 1: Most communications are "within-team" interactions that do not cross team boundaries.

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[3] Data = all communications transcribed from channels 1, 10, 4, and 12 from T-3:54 to T+1:31.

Individual speakers were defined as either WFF (related to Wallops Island Flight Facility) or OSC/DFRF (related to Orbital Sciences Corporation or NASA Dryden)

There was a total of 140 speaker turns (transmissions) excluding a small number of turns that could not be identified in terms of speaker or were uninterpretable.

Of the 140:
74 or 53% of all communications were directed within the WFF team
56 or 40% within the OSC/DFRF team
10 or 7% crossed WFF-OSC/DFRF team boundaries

Recoding speaker turns into interaction sequences revealed the following as the most common interactions:

Within WFF team

RCO - RSO (ch 1/10)
RCO - MFSO (ch 1/10)
RS1 or RS2 or RS3 - RSO (Ch 10)
RCO - RSO - MFSO - RS1,2,3 (Ch 10)

Within OSC/DFRF team

TC - PEG (ch 4)
NASA1 - B-52 (ch 12)

Cross-team communications (n=8 of 140) occurred on channel 4, RCO -> NASA1 (between T-2:40 and T-1:40). While these communications were time-consuming in terms of number of links and transmissions required, they DID solve the altitude problem (altitude problem resolved about T-1:05). It is also interesting that these communications never formed interaction sequences (i.e., they did not receive a direct acknowledgement or verbal response). Nevertheless, the information was received and acted upon.

The only other apparent cross-team communications (n=2 of 140) were TC -> RCO transmissions on channel 4. Because there were no interactive responses received, it was difficult to interpret these communications.

No cross-team communications were observed between WFF and OSC/DFRF (during T-1:12 to T-:00) that were directed toward solving the FTS/CDR dropout problem. Although some face-to-face communications were discussed in the reports as well as assumed non-verbal acknowledgements, these were outside the established net protocols.

Observation 2: Inconsistent use of communication protocols.

Within-team communications followed their own protocols (e.g., NASA-B52 followed standard radio communication protocol with callsigns and acknowledgements, WFF team members communicated more informally, inconsistent use of callsigns, personal names, and conversational style). While an informal style may be effective when team members have had experience working together, standard forms are needed when there is a lack of shared experience upon which to base one's expectations. In this case, lack of familiarity across teams plus a lack of protocol for cross-team communications could have contributed to several misunderstandings.

Studies have shown that crew errors and less effective performances are related to non-standard forms of communications and absence of acknowledgements. In addition to the communication studies mentioned earlier, several Aviation Safety Reporting System (ASRS) studies have pointed out problems relating to lack of acknowledgements or "readbacks" in the pilot to air traffic controller environment. Two common errors are (1) hearing what you expect to hear (Billings & Reynard,1981) and (2) misinterpreting silence as "agreement" or verification (Monan, 1983).

Considering the Pegasus incidents, comments made in several of the reports seem to fall into these categories; for instance, assuming non-verbal concurrence by others occurred several times. When standard protocols are lacking, it is especially easy to make these kinds of assumptions. Nonverbal behaviors are usually redundant information channels that accompany speech and perform important functions, but in this case they seem to be interpreted out of context.

While a recommendation for adopting standard communication protocols is hard to dispute, especially when the integrated team has had little prior experience working together, I would simply add the caution that too much regulation may also work against effective team coordination. For instance, there may be very different requirements for teams that work together every day compared to teams that work together the first time they meet (e.g., fixed aircrews vs. transport crews). Furthermore, many examples from both research and actual cases attest to the fact that a certain amount of flexibility may be needed in order to coordinate crew actions in unusual circumstances, or combinations of circumstances. Since there is a whole system of crew factors affecting any complex operation, an overdependence on controlling one factor or another may be of questionable value. For instance, what might be left "unregulated" in terms of one procedural protocol may be more than adequately covered by a clear authority structure and adequate briefings, and this added flexibility may be very desirable in some conditions. Since no written procedure can cover all possible combinations and sequences of problems, mechanisms must be available for online, creative crew coordination.

References

Billings, C.E., & Reynard, W.D. (1981). Dimensions of the information transfer problem. In Billings, C.E. & Cheaney, E.S. (Eds.), Information transfer problems in the aviation system (NASA Technical Paper 1875). Moffett Field, CA: NASA Ames Research Center.

Foushee, H. C., Lauber, J. K., Baetge, M. M., & Acomb, D. B. (1986). Crew factors in flight operations III: The operational significance of exposure to short-haul air transport operations. (NASA Technical Memorandum 88322). Moffett Field, CA: NASA Ames Research Center.

Ginnett, R. G. (1987). The formation of airline flight crews. In R. S. Jensen (Ed.), Proceedings of the Fourth International Symposium on Aviation Psychology (pp. 399-405). Columbus, OH: Ohio State University.

Ginnett, R. G. (1993). Crews as groups: Their formation and their leadership. In E. L Wiener, B. G. Kanki & R. L. Helmreich (Eds.), Cockpit Resource Management (pp. 71-98), San Diego: Academic Press.

Kanki, B. G., Greaud, V. A. & Irwin, C. M. (1991). Communication variations and aircrew performance. International Journal of Aviation Psychology. 1, 2, 149-162.

Kanki, B. G. & Palmer, M. T. (1993). Communication and crew resource management. In E. L Wiener, B. G. Kanki & R. L. Helmreich (Eds.), Cockpit Resource Management, (pp. 99-136), San Diego: Academic Press.

Monan, W. P. (1983) Addressee errors in ATC communications: The call sign problem. (NASA Contractor Report 166462). Moffett Field, CA: NASA Ames Research Center.

APPENDIX F

OCST PEGASUS SCD-1 LICENSING DOCUMENTS

Office of Commercial Space Transportation License

License Number: LLS-92- 028

ORBITAL SCIENCES CORPORATION

is authorized, subject to the provisions of the Commercial Space Launch Act of 1984, and the orders, rules, and regulations issued under it, to conduct commercial space launch activities.

General. The licensee is authorized to conduct the launch of a Pegasus launch vehicle transporting the SCD-1/OXP payload to low earth orbit, commencing upon take-off of the B-52 aircraft from the Shuttle Landing Facility (SLF) at the John F. Kennedy Space Center (KSC), to take place no later than June, 1993.

This license is granted subject to the terms, conditions, and limitations set forth in licensing order A,B , and any subsequent orders issued by the Office of Commercial Space Transportation.

The licensee shall at all times conduct its operations in accordance with the regulations prescribed by the Office of Commercial Space Transportation for the activities authorized by this license.

US Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590

Issued On: December 23, 1992

Effective On: December 23, 1992

Associate Director for Licensing Programs

License Order No. LLS-92-028A

OFFICE OF COMMERCIAL SPACE TRANSPORTATION ORDER REGARDING COMMERCIAL SPACE LAUNCH ACTIVITIES AUTHORIZED BY LICENSE NO. LLS-92-028 ISSUED TO

ORBITAL SCIENCES CORPORATION

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1. Authority: This Order is issued to Orbital Sciences Corporation (OSC) under the Commercial Space Launch Act of 1984, as amended, 49 U.S.C. App. 2601 et seq (Act) and the Commercial Space Transportation Licensing Regulations (Regulations), 14 C.F.R. Ch. III.

2. Purpose: This Order amends License No. LLS-92-028 issued concurrently by the Office of Commercial Space Transportation (Office), authorizing OSC to conduct commercial space launch activities; and prescribes as conditions to License No. LLS-92-028 certain requirements applicable to such activities.

3. Applicability: For purposes of License No. LLS-92-028 and any orders issued by the Office pertaining to activities covered by License No. LLS-92-028, the terms "commercial space launch activities" and "commercial launch activities" shall mean the launch of a Pegasus launch vehicle transporting the SCD-1/OXP payload to low earth orbit, commencing upon take-off of the B-52 aircraft from the Shuttle Landing Facility (SLF) at the John F. Kennedy Space Center (KSC), to take place no later than June, 1993.

4. Government Launch Support Agreement(s): OSC shall enter into, and there shall be in full force and effect, an agreement (or agreements) providing for access to and use of United States Government launch property and launch support services, including the B-52 aircraft, to support commercial launch activities and provide public safety-related operations required for activities carried out under License No. LLS-92-028. This agreement (or agreements) must be in effect prior to commencement, and OSC shall comply with any requirements of such agreement (or agreements) that may affect public safety during the conduct, of commercial launch activities authorized under License No. LLS-92-028.

5. <u>Public Safety Operations</u>: OSC is responsible for all public safety-related operations necessary for the protection of public safety, up to and including SCD-1 and OXP separation in low earth orbit and subsequent on-orbit operations of the launch vehicle. OSC has contracted with the NASA Goddard Space Flight Center/Wallops Flight Facility (GSFC/WFF) to conduct and provide public safety-related operations required for activities carried out under License No. LLS-92-028 up to and including orbital insertion. OSC shall comply with GSFC/WFF range and flight safety procedures and requirements, in accordance with the commercial support agreement executed by and between OSC and GSFC/WFF.

6. <u>Reporting Requirements</u>:

   (a) OSC shall complete and submit to the Office the "Department of Transportation / U.S. Space Command (DOT/USSPACECOM) Launch Notification Form" at least fifteen (15) days prior to launch.

   (b) OSC shall report to the Office any failure to release the Pegasus launch vehicle after take-off of the B-52 aircraft from the SLF.

   (c) OSC shall report to the Office any accident, incident or other occurrence, as defined in the Office's Accident Response and Investigation Plan dated May 1991, occurring in the course of activities carried out under License No. LLS-92-028. The report shall describe in detail the manner in which the accident, incident or other occurrence occurred and OSC's role in the same; and the nature and extent of any damage, injury, or loss resulting from such accident, incident or other occurrence. A final report detailing the findings of an OSC investigation shall be submitted upon completion of the investigation.

7. <u>Changes</u>: OSC shall inform the Office of any proposed material changes in any representation made in its license application or in its launch plans or operations as described in the application. Such changes may include, but are not limited to, the configuration of the launch vehicle, the Pegasus flight path, and the payload. Any such change is subject to prior approval by the Office. Also OSC shall notify the Office in the event that OSC applies to GSFC/WFF for a waiver to, or knowingly deviates from, GSFC/WFF's flight safety requirements or procedures.

8. Records: OSC shall maintain all records, data and other material needed to verify that activities carried out under License No. LLS-92-028 conform to representations made in its license application. In case of an accident, incident or other occurrence, as defined in the Office's Accident Response and Investigation Plan dated May, 1991, which results in loss or injury to the public or threatens public safety, OSC shall preserve all records, data and other material relating to the vehicle, its payload, and operations associated with commercial space launch activities.

9. Monitoring: In order to determine compliance with License No. LLS-92-028, and in accordance with Section 405.1 of the Regulations, 14 C.F.R. § 405.1, OSC shall allow and cooperate with Federal officers or employees or other individuals authorized by the Office to observe any activities of the licensee, its contractors or subcontractors, associated with the conduct of commercial space launch activities carried out under License No. LLS-92-028.

10. Transfer: License No. LLS-92-028 is not transferable without the approval of the Office.

11. Financial Responsibility: OSC shall comply with financial responsibility requirements as shall be specified by order of the Office.

12. Other Requirements:

(a) The authority granted by License No. LLS-92-028 is subject to such other terms, conditions and limitations the Office may prescribe in order to protect public health and safety, the safety of property, or the national security or foreign policy interests of the United States.

(b) License No. LLS-92-028 authorizes only the conduct of the commercial launch activities specified herein. It does not relieve OSC of its obligation to comply with such other requirements of law or regulation that may apply to the conduct of its activities. This License does not convey permission to use any Federal launch range, related facilities, or other U.S. Government property.

13. Compliance: Failure to comply with the requirements of the Act, the Regulations, any other regulations issued by the

License Order No. LLS-92-028A

Office pursuant to the Act, or any term or cond'tion of License No. LLS-92-028 shall be sufficient grounds to revoke License No. LLS-92-028 and/or impose other penalties as provided in Section 405.7 of the Regulations, 14 C.F.R. § 405.7.

THE OFFICE OF COMMERCIAL SPACE TRANSPORTATION

By: ______________________

Norman C. Bowles, Associate Director
for Licensing and Safety

Issued: December 23, 1992

License Order No. LLS-92-028B

OFFICE OF COMMERCIAL SPACE TRANSPORTATION
ORDER REGARDING FINANCIAL RESPONSIBILITY REQUIREMENTS UNDER SECTIONS 15(c) AND 16 OF THE COMMERCIAL SPACE LAUNCH ACT FOR

ORBITAL SCIENCES CORPORATION

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1. Authority: This Order is issued to Orbital Sciences Corporation (OSC) under Sections 15(c) and 16 of the Commercial Space Launch Act (Act), as amended, 49 U.S.C. App. 2601 et seq (Act).

2. Purpose: This Order amends License No. LLS-92-028 issued concurrently by the Office of Commercial Space Transportation (Office), authorizing OSC to conduct commercial space launch activities; and prescribes as conditions to License No. LLS-92-028 financial responsibility requirements applicable to such activities.

3. Financial Responsibility - General: OSC must demonstrate compliance with the financial responsibility requirements set forth in this Order, in such form and manner as specified by the Office, at least fifteen (15) days prior to launch. Upon demonstrating to the Office that it has complied with the requirements of this Order, this Order shall preempt any provisions in agreements between OSC and any agency of the United States Government governing access to or use of launch property or services, including the B-52 aircraft, for commercial launch activities, which address financial responsibility, allocation of risk and related matters covered by Sections 15(c) and 16 of the Act during the conduct of commercial launch activities.

4. Definitions. For purposes of this Order:

   (a) "Private party launch participants" shall mean OSC, the contractors, subcontractors and customers of OSC and the contractors and subcontractors of such OSC customers.

(b) "Government launch participants" shall mean the United States and its agencies, contractors and subcontractors.

(c) "Contractors" and "subcontractors" shall mean contractors and subcontractors, respectively, at any tier, including suppliers of any kind, that are involved in commercial launch activities.

(d) "Customers" shall mean customers of OSC or users of OSC's launch services, for commercial launch activities.

5. Insurance Requirements: OSC shall obtain and maintain in effect, at no cost to the United States, a policy or policies of insurance as set forth below:

(a) Liability insurance in the amount of Ten Million Dollars ($10,000,000) to protect private party launch participants and government launch participants, and their respective personnel involved in commercial launch activities, to the extent of their potential liabilities, against successful claims by third parties (as defined in Section 4(11) of the Act) for death, bodily injury, or loss of or damage to property resulting from commercial launch activities carried out under License No. LLS-92-028.

(b) Property insurance in the amount of Fifteen Million Dollars ($15,000,000) to compensate government launch participants for loss of or damage to their property, both real and personal, including but not limited to the B-52 aircraft, resulting from commercial launch activities carried out under License No. LLS-92-028.

(c Bankruptcy or insolvency of any insured shall not relieve the insurer of any of its obligations under any policy.

(d) The limits established for insurance prescribed herein shall apply separately to each occurrence and in the aggregate with respect to claims arising out of commercial launch activities carried out under License No. LLS-92-028.

(e) Each policy shall pay claims from the first dollar of loss, without regard to any deductible, to the limits of such policy.

(f) Each policy shall provide that coverage shall attach upon commencement of commercial space launch activities, and shall remain in force for a period of thirty (30) days following payload insertion into orbit, and may not be replaced, canceled, changed, withdrawn, or in any way modified to reduce the limits of liability or the extent of coverage, nor expire by its own terms, prior to such time.

(g) The policies prescribed herein shall not be invalidated by any action or inaction of OSC or any other insured, and shall insure OSC and each other insured regardless of any breach or violation of any warranties, declarations or conditions contained in such policies by OSC or any other insured (other than by OSC or such other insured, as the case may be, and then only as against such insured).

(h) The policies prescribed herein may provide such exclusions as determined by the Office to be usual for the type of insurance involved. The certifications required under subparagraph (l) of this Section 5 shall specify any such exclusions in sufficient detail to permit the Office to make the determination provided for in this subparagraph (h).

(i) The liability insurance shall be primary without right of contribution from any other insurance which is carried by any insured, and shall expressly provide that all the provisions thereof, except the limits of liability, shall operate in the same manner as if there were a separate policy with and covering each insured.

(j) Each policy shall be placed with insurers of recognized reputation and responsibility satisfactory to the Office.

(k) Except as to claims resulting from the wilful misconduct of the United States Government or its agents, the insurer shall waive any and all rights of subrogation against each of the parties protected by the insurance required under subparagraphs (a) and (b) of this Section 5.

(l) OSC shall provide proof of the required insurance by (i) certifying to the Office in a writing signed by an officer of OSC that it has obtained insurance in compliance with this Order, and (ii) filing with the Office a certificate or certificates of insurance showing insurance coverage by one or more insurers of a currently effective and properly endorsed policy or policies of insurance in compliance with this Order. OSC shall maintain such policies at OSC's principal place of business, available for inspection by the Office.

6. Waivers of Claims.

(a) Agreement. OSC and its customer shall enter into an agreement with the Department of Transportation on behalf of the United States, in the form attached hereto, providing for each party to waive claims it may have and to assume responsibility for property damage it sustains and for bodily injury and property damage sustained by its own employees, resulting from commercial space launch activities carried out under License No. LLS-92-028, regardless of fault; and further providing for each party to extend such waiver of claims and assumption of responsibility to its respective contractors and subcontractors.

(b) Compliance. OSC shall demonstrate compliance with the requirements set forth in section 6(a) at least fifteen (15) days prior to launch.

7. Payment of Claims by the United States: Payment by the United States of third party claims as provided in Section 16(b) of the Act shall be subject to notice by OSC to the Office that the aggregate of successful claims arising out of commercial space launch activities carried out under License No. LLS-92-028 exceeds the amount of liability insurance coverage required under subparagraph (a) of Section 5 hereof. Such notice shall specify the nature, cause and amount of such excess claims, and the party or parties liable for payment of such excess claims, and any other information reasonably required by the Office in order to implement the provisions of Section 16(b) of the Act.

In lieu of a policy or policies of insurance as required under Section 5 hereof, OSC shall have the right to demonstrate its financial responsibility in a form satisfactory to the Office and on substantially the same terms and conditions as set forth herein. Proof of financial responsibility as required by this

License Order No. LLS-92-028B

Order shall not relieve OSC of financial responsibility for the liabilities and obligations set forth in Sections 15(c) and 16 of the Act.

THE OFFICE OF COMMERCIAL SPACE TRANSPORTATION

By: ______________________________

Norman C. Bowles, Associate Director
for Licensing and Safety

Issued: December 23, 1992

License Order No. LLS-92-028C

OFFICE OF COMMERCIAL SPACE TRANSPORTATION
ORDER AMENDING LICENSE ORDER NO. LLS-92-028B REGARDING
FINANCIAL RESPONSIBILITY REQUIREMENTS FOR
COMMERCIAL SPACE LAUNCH ACTIVITIES
AUTHORIZED BY LICENSE NO. LLS-92-028
ISSUED TO

ORBITAL SCIENCES CORPORATION

---

1. Authority: This Order is issued to Orbital Sciences Corporation (OSC) under Sections 15(c) and 16 of the Commercial Space Launch Act, as amended, 49 U.S.C. App. 2601 et seq (Act).

2. Purpose: This Order amends License Order No. LLS-92-028B issued to OSC on December 23, 1992, by the Office of Commercial Space Transportation (Office), prescribing financial responsibility requirements applicable to commercial launch activities authorized to be conducted by OSC under License No. LLS-92-028.

3. Amendment: License Order No. LLS-92-028B is hereby amended by deleting paragraph 5(a) in its entirety and substituting the following in its place:

   Liability insurance in the amount of Fifteen Million Dollars ($15,000,000) to protect private party launch participants and government launch participants, and their respective personnel involved in commercial launch activities, to the extent of their potential liabilities, against successful claims by third parties (as defined in Section 4(11) of the Act) for death, bodily injury, or loss of or damage to property resulting from commercial launch activities carried out under License No. LLS-92-028.

4. Effective Date: This amendment is effective as of the date of this Order. Except as modified by this Order, License

License Order No. LLS-92-028C

Order No. LLS-92-028B otherwise remains the same and in full force and effect.

THE OFFICE OF COMMERCIAL SPACE TRANSPORTATION

By: ______________________

Norman C. Bowles, Associate Director
for Licensing and Safety

Issued: January 14, 1993

APPENDIX G

LAUNCH CONSTRAINT AND SAFETY INFORMATION

MISSION CONSTRAINTS DERIVED FROM WFF DOCUMENTS

1. WFF Minimum Safety Requirements

According to the WFF Operations and Safety Directive, minimum safety requirements for the different phases of the mission are as follows:

A. B-52 Takeoff From the Shuttle Landing Strip

1. Operational and redundant command sites at ER, BDA, and WFF.

2. All required FTS checks successfully completed.

3. Operational radar sites at MILA (19.14), JDI (28.14), and BDA FPQ-6.

4. Operational and redundant telemetry sites at MILA, BDA, and WFF.

5. Operational and redundant WFF real-time computers.

6. All required data flow tests successfully completed.

7. All real-time data displays, including airplane vectoring operational.

8. Operational communications links between WFF, ER, BDA, and B-52 airplane. Redundant voice lines between RSO and the ER flight control officer and between the RSO and the BDA RSO.

9. Verification of preestablished command destruct and command transfer code words (ER and BDA).

10. The location of the contingency drop hazard area has been determined and has been reported clear of ships.

11. WFF, ER, and BDA Range Safety GO.

B. Pegasus Release From the NB-52B

1. Radar and IMU data agree during captive flight.

2. No airplane, other than participating airplane, reported in the release airplane hazard area.

3. All supporting airplane are confirmed in acceptable locations.

4. The B-52 airplane is within the release box and flying a heading between 087 degrees and 097 degrees true. The B-52 airplane is at an altitude between 41,000 and 43,500 feet and has a ground speed between 390 and 612 knots.

5. All required FTS parameters being monitored on telemetry are within acceptable limits.

6. At least two tracking data sources, one of which must be beacon tracking radar, must be providing good data.

7. Required flight safety telemetry data must be good.

C. Contingency (Unscheduled) Drop of Pegasus From the NB-52B

1. The contingency drop area will be defined and Notices to Airmen and mariners will be issued prior to launch. The contingency drop area (i.e., emergency jettison area) is that oceanic surface area in which a planned drop of the Pegasus occurs for emergency purposes.

2. The contingency drop hazard area must be reported clear of ships and nonparticipating airplanes.

3. During the operation, one of the following two contingency drop hazard areas will be selected.

   a. The B-52 airplane is within the contingency drop box (10 NM x 10 NM) and flying a heading within 51 degrees of the designated jettison heading. The B-52 airplane is at an altitude less than 43,500 feet and has a ground speed less than 612 knots.

   b. The B-52 airplane is within the contingency drop box (4 NM x 4 NM) and flying a heading within 51 degrees of the designated jettison heading. The B-52 airplane is at an altitude less than 20,000 feet and has a ground speed less than 612 knots.

4. Power is OFF on the Pegasus vehicle.

D. Emergency Drop of the Pegasus From the NB-52B

An emergency drop (immediate) of the Pegasus will be performed for contingencies which produce an immediate danger to the B-52.

WFF GENERAL MISSION RULES

Mission Rules concerning the range safety function, according to the WFF/OSD for this mission, were as follows:

1. The RSO will initiate a destruct request to ER flight control officer via a code word if any destruct criteria are violated.

2. The ER flight control officer will initiate a destruct action upon receipt of a code word from the RSO or a violation of a destruct line on the ER IIP display.

3. Command destruct responsibility will be transferred via code word from the RSO.

4. Command destruct transfer will not occur if communications are lost between the RSO and the ER flight control officer.

5. For the first 150 seconds of flight, destruct limit lines will provide an 8 second reaction time to account for the worst case time required to effect destruct via a code word. After 150 seconds, destruct limit lines will provide a 6 second reaction time.

6. Destruct action initiated due to no vehicle ignition will be repeated until impact or a destruct has been verified.

7. No command destruct action will be taken while IIP is within 3 NM of land.

8. No command destruct action will be taken until 5 seconds after nominal drop from the B-52.

9. A destruct action will be initiated by a code word from the RSO after the vehicle has fallen 5,000 feet (or for 18 seconds). Once initiated, the destruct action will be repeated until verification of a water impact.

10. Command destruct transfer will occur with a one second overlap, i.e., WFF on at 140 seconds with ER off at 141 seconds.

11. Command destruct transfer will be delayed if Wallops elevation look angle is less than 0.5 degrees or if the WFF command destruct antenna does not have an acquisition source.

WFF SPECIFIC MISSION RULES

Specific mission rules between command transfer from the ER to WFF and the end of the mission or rules to handle contingencies that would result in use of the ER command transmitters after command destruct capability is transferred to WFF were as follows:

1. The RSO will initiate any destruct action through the WFF command transmitter.

2. A transfer of the command destruct transmitters to the Bermuda or ER will be implemented as a contingency if the WFF command system fails.

WFF SPECIAL RULES

Two Special Rules were promulgated concerning this Pegasus launch. The Special Rules prior to drop from the B-52 were as follows:

1. A mission abort will occur if there is a FTS dropout during the final 6 minute run prior to drop.

2. A loss of communications with the pilot of the B-52 airplane or between the RSO and ER flight control officer will result in a mission abort.

Note: Specific details on Special Rule 1 above are defined in the December 23, 1992, memo with the subject "Clarification of FTS Signal Requirements During B-52 Flight". See Appendix C.

MISSION CONSTRAINTS DERIVED FROM OSC DOCUMENTS

NB-52B AIRPLANE CONSTRAINTS

No.	Data Point	Constraint
1.	Operational limits	0.3 g to 1.7 g
2.	B-52 maximum airspeed	< 260 KIAS/Mach 0.82
3.	Safety Chase	Mandatory
4.	Video Chase	Required (Recorded Video Mandatory)
5.	Fuel Loading	Bingo as Briefed
6.	Crew limits	4 Crew, all in seats
7.	Daylight	All flight operations between sunup and sundown
8.	Maximum altitude	< 50,000 feet
9.	Maximum thrust	Maximum rated thrust
10.	Loran	1 mandatory for takeoff
11.	Turbulence	No greater than light turbulence
12.	Abrupt Maneuvers	None
13.	Pylon Hook Release Pressure	Mandatory (> 1500 psi at T.O.)
14.	Pathfinder airplane (Starcast)	Mandatory

OSC MISSION CONSTRAINTS TERMINOLOGY

OSC mission documents contain the following guidance concerning mission constraints terminology:

> The following sections will outline in detail the mission constraints for the Pegasus vehicle, its support equipment, the Western Test Range [sic] support equipment, the B-52 carrier airplane, the mission control center and the payload. The following is a list of the terminology used in defining the mission constraints. Unless otherwise specified any deviation from these constraints must be approved by the Mission Directors. Failure to meet the criteria defined herein will cause a NOGO situation for the Pegasus launch until the item can be corrected. For each constraint the required status for a GO for launch condition will be identified. In addition the required action for a NOGO condition will also be identified. If the criteria has a waiver requirement, i.e. Mandatory, Required, or Desired, this will be stated. Some criteria are based on the requirement for a particular piece of equipment to be functioning. For these cases the launch constraint is defined as the launch status in the event of loss of that component, the waiver priority and the required action.
>
> M Mandatory Cannot be waived
> R Required Waiverable by the Mission Director
> D Desired Valuable by the Test Conductor and NASA Flight Controller
>
> For Range Safety purposes the terms are defined as follows:
>
> MANDATORY: A safety hold will be imposed for failure of any MANDATORY items. Lack of support items designated as MANDATORY would severely impact flight safety. Exceptions will only be implemented by direction of the Director of the Wallops flight facility and/or the ESMC Commander.
> REQUIRED: A safety hold will not normally be imposed for failure of required support items. Failure of REQUIRED support items could substantially impact flight safety. Depending on the specific circumstances, the Wallops RSO and/or the ESMC Commander may upgrade REQUIRED support to MANDATORY as deemed necessary.

DESIRED: A safety hold will not be imposed for the failure of DESIRED support items. The Wallops RSO, or the ESMC Commander may upgrade DESIRED support to REQUIRED or MANDATORY if the conditions warrant the increase.

Abort - An Abort shall be called by anyone on the Launch Net who identifies a situation where a mission rule has been broken or an unsafe situation has developed. In this event the Abort Checklist shall be performed which [will] place the vehicle in a safe mode and takes all systems off battery power. Once complete the Test Conductor will determine if another launch attempt should be made (Mission Recycle) or the mission should be scrubbed for the day (RTB).

Mission Recycle - When an abort is called the pilot will begin the mission recycle turn as described previously. The mission recycle checklist begins the second launch attempt countdown at PREV, L-10 minutes. The count will proceed to place the vehicle on Avionics battery power at L-8 minutes with the final 4 minutes of the countdown identical to the first attempt. Note that the second launch attempt will be identical in position and relative time as the first attempt.

RTB - In the event the mission has been scrubbed the Mission Abort Checklist will be performed and the B-52 and Pegasus shall return to NASA/KSC. In the event the B-52 is unable to land at NASA/KSC, the B-52 will land at a predetermined landing site.

Jettison - In event of a hazardous situation on the Pegasus or the B-52 which will not permit the B-52 to land with the Pegasus attached, the LPO will perform the Jettison Checklist and the aircraft commander will drop the Pegasus at a predetermined location.

Emergency Situation - In the event of an emergency situation develops on the Pegasus or the B-52 in which the presence of the Pegasus on the B-52 places the airplane and crew in danger will be cause for a Emergency Situation Checklist. In this case the appropriate Emergency Situation Checklist (Fire, Smoke, Immediate Hazard, Ordnance Unsafe) will be performed and the aircraft commander will determine if the Pegasus must be jettisoned for aircrew safety.

OSC COUNTDOWN OPERATIONS PROCEDURES

OSC mission documents state the following regarding countdown operations:

All countdown operations will be controlled by the Pegasus Countdown Checklist. The entire checklist will be performed on two communications networks, the Pegasus Launch Network and the UHF Mission Frequency. The Pegasus Launch Network (Launch Net) is controlled by the Test Conductor. Only checklist items or information pertaining to the checklist shall be discussed on the Launch Net. Other nets have been established to work the indirect details involved with the launch countdown. The UHF Mission Frequency is used only for communications with the airborne contingent of the launch team (B-52 and chase). The only people on the ground which are authorized to use this frequency are NASA 1 and the B-52 Air Controller at Wallops.

The proper net protocol will be as follows:

1. Identify the person who you are contacting.

2. Identify yourself.

3. Identify which net you are on.

4. i.e. "PEG, this is Test Conductor on OSC Launch Net."

5. The person should acknowledge i.e. "Test Conductor, PEG, go ahead".

6. If you are completing an item on the checklist which should be acknowledged, ground personnel should direct this to the Test Conductor and aircrew should direct this to NASA 1.

7. Test Conductor will track checklist progress and will periodically give a status of the checklist.

8. All holds called on the ground shall be called on the Launch Net. If there is an emergency action required, NASA 1 will immediately contact the aircrew to take the appropriate action. If there is not an emergency situation, the team will follow the anomaly resolution process discussed in section 5.3.

9. All holds called by aircrew will be called on the Mission Frequency to NASA 1. If there is an emergency situation, the aircrew will immediately take the appropriate action to bring the Pegasus or B-52 back to a safe condition. If there is not an emergency situation, the team will follow the anomaly resolution process discussed in section 5.3.

* U.S. G.P.O.:1993-341-938:80002

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DATE:
10-26-93

NTIS