SpaceShipTwo

Koehn Dry Lake, CA; October 31, 2014

FACTUAL REPORT

HUMAN PERFORMANCE

May 19, 2015

DCA15MA019

A. ACCIDENT

Operator:	Scaled Composites, LLC
Location:	Koehn Dry Lake, California
Date:	October 31, 2014
Time:	1007 Pacific daylight time (PDT)
Vehicle:	Model 339 SpaceShipTwo
Registration Number:	N339SS

B. PARTICIPANTS

Katherine Wilson
Senior Human Performance Investigator
Human Performance and Survival Factors Division
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington, DC 20594

Christy Helgeson
Human Factors Specialist
Flight Test Branch
Federal Aviation Administration
1601 Lind Avenue SW
Renton, WA 98057

Clint Nichols
Project Engineer/Test Pilot
Scaled Composites
Hanger 78 Airport/1624 Flight Line
Mojave, CA 93501

Michael Masucci
Test Pilot
Virgin Galactic
FAITH/16555 Spaceship Landing Way
Mojave, CA 93501

C. SUMMARY

On October 31, 2014, about 1007 Pacific daylight time, a Scaled Composites SpaceShipTwo (SS2) reusable suborbital rocket, N339SS, experienced an in-flight anomaly during a rocket powered flight test, resulting in loss of control of the vehicle. SS2 broke up into multiple pieces and impacted terrain over a 5-mile area near Koehn Dry Lake, California. One test pilot (the copilot) was fatally injured, and the other test pilot was seriously injured. SS2 had launched from the WhiteKnightTwo (WK2) carrier aircraft, N348MS, about 12 seconds before the loss of control. SS2 was destroyed, and WK2 made an uneventful landing. Scaled Composites was operating SS2 under an experimental permit issued by the Federal Aviation Administration's (FAA) Office of Commercial Space Transportation under the provisions of 14 Code of Federal Regulations (CFR) Part 437.

D. DETAILS OF THE INVESTIGATION

The Human Performance Group was formed on November 3, 2014. On-scene activities included conducting interviews, reviewing the accident sequence data and videos, running simulator scenarios in conjunction with the Operational Factors Group, and a familiarization tour of the WhiteKnightTwo and SpaceShipTwo Serial Number 2 in production at the Virgin Galactic FAITH facility. The Human Performance Group traveled back to Mojave, California, in December 2014, and January 2015, to conduct additional interviews in conjunction with the Operational Factors and System Safety Groups, and to review additional data. Details of joint Human Performance/Operational Factors/System Safety Group activities are documented in the Operational Factors and System Safety Group Chairmen's Factual Reports.

The Human Performance Group Chairman's Factual Report contains documentation relevant to the flight crew and their pre-accident activities; company training regarding crew resource management and use of parachute systems; company policies and guidance regarding system and employee safety; human factors consideration in SS2; and FAA safety management system.

E. FACTUAL INFORMATION

1.0. Flight Crew Information

The flight crew information was documented through interviews[1], FAA records[2], company records[3], and cellular telephone records.

1.1 The Pilot

The surviving pilot, seated in the left seat, was the pilot flying. He was 43 years old and he lived in Tehachapi, California. He was hired by Scaled Composites on December 16, 1996, as a design engineer, and was promoted to his current position, director of flight operations, on June 27, 2008. A review of employee records did not reveal any disciplinary actions against the pilot.

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[1] See Attachment 1 – Interview Summaries to this report and Operational Factors Group Chairman's Factual Report Attachment 1 – Interview Summaries.

[2] FAA records included medical and certification records.

[3] Company records included personnel records, training records, Outlook calendar items, and electronic data records including data access logs, employee badge usage, email logs, and simulator logs.

His most recent FAA 2nd class medical, dated August 22, 2014, had no limitations listed. He had surgery due to a foot injury on February 25, 2013, and was cleared "for all duties without restrictions" by his physician on August 8, 2013. He had no issues with color vision, and he had never seen a doctor for a sleep disorder. An audiogram hearing test was performed on February 12, 2013, and results showed some diffuse hearing loss in the left ear, ranging from 10-40 dB across the frequencies tested. He did not take any medication, prescription or nonprescription in the 72 hours before the accident that might have affected his performance on the day of the accident.[4] He did not use tobacco products and had one beer the night before the accident about 1800. He had no major changes, good or bad, to his health, financial situation, or personal life that would have adversely affected his performance on the day of the accident. He had no previous aviation accidents or incidents.

He worked on average about 43 hours per week during October 2014, and just over half of his time was spent working on the Tier1B program[5]. The remainder of his time was spent on administrative duties, with the exception of 1 hour on another program and 1 hour on bids and proposals.

The pilot's most recent employee performance evaluation was dated January 23, 2014, and included a review by the vice president of engineering (VP engineering), co-workers and a self-review. Comments focused on both positive aspects of the pilot's performance and areas for improvement. Positive comments focused on his leadership and mentoring ability, sound judgment, professionalism, knowledge of programs and management of the test pilot group. Areas for improvement were his lack of timeliness in bringing up issues/roadblocks and communication/openness. The pilot's previous performance evaluation, dated January 21, 2013, included similar comments from the VP engineering, co-workers and a self-review as were provided in his most recent evaluation.

1.1.1. The Pilot's Pre-accident Activities

On Monday, October 27, 2014, it is unknown when the pilot woke up or left for his 35 minute commute to Scaled Composites. Company electronic data records indicated activity at Scaled Composites facilities by the pilot beginning at 0611. During his work day, he participated in a PF04 (powered flight 04) simulator session with the copilot and attended the PF04 Delta Flight Readiness Review (FRR). According to his timesheet, he worked 9 hours and half of his time was spent on the Tier1B program. Cellular telephone activity was limited and consisted of two text messages sent during his work day. He went to sleep between 2100 and 2200 and had no problems falling asleep or staying asleep. He reported the quality of his sleep as "good".

On Tuesday, October 28, he woke up about 0530 and left for work about 0700. Company electronic data records indicated activity by the pilot between 0625 and 1716. During his work day, he participated in a PF04 simulator session with the copilot, the PF04 card review, and a

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4 (b) (6) [redacted]

The Tier1B program was project name used by Scaled Composites for the experimental permit for SS2.

meeting regarding the control room actuators station. Cellular telephone activity was limited and consisted of one text message sent during his work day. According to his timesheet, he worked 9 hours and half of his time was spent on the Tier1B program. He thought he returned home about 1700 and engaged in family activities until about 2100. He went to sleep between 2100 and 2200 and had no problems falling asleep or staying asleep. He reported the quality of his sleep as "good".

On Wednesday, October 29, he woke up about 0600 and thought he left for work about 0800. Company electronic data records indicated activity by the pilot beginning at 0811 until 1537. During his work day, he attended the Executive FRR, met with FAA inspectors, and participated in a solo simulator session. According to his timesheet, he worked 9 hours and half of his time was spent on the Tier1B program. Cellular telephone activity consisted of a text message sent at 0724, and a phone call and text message sent during his work day. He thought he returned home about 1800 and did family activities until about 2000. He went to sleep between 2000 and 2100 and had no problems falling asleep or staying asleep. He reported the quality of his sleep as "good".

On Thursday, October 30, he woke up about 0400 to adjust his sleep pattern in anticipation for the PF04 flight the next day. He read in bed until about 0500 and then got ready for work. He left for work about 0600. Company electronic data records indicated activity by the pilot beginning at 0649 until 1416. During his work day, he participated in a PF04 nominal simulator session with the copilot, the PF04 Maintenance and Engineering Request (ER) Briefing, the PF04 communication checks, and the PF03 data rerun. According to his timesheet, he worked 9 hours, and half of his time was spent on the Tier1B program. He thought he left work about 1700, picked up his daughter from school at 1730 and then went shopping until 1830. He went to sleep about 1930, and had a slightly harder time than normal falling asleep due to the earlier bedtime. Once he was asleep, he had no problems staying asleep. He reported the quality of his sleep as "good".

On Friday, October 31, he woke up about 0245 and felt slightly less rested than normal due to the early time. He got ready for work and had breakfast and coffee. He left for work about 0345 and arrived at FAITH to view the vehicles at 0415. Company electronic data records indicated activity by the pilot beginning at 0433. He prepared for the Delta Brief until 0500 then attended the Delta Brief from 0500 until 0600. He had another cup of coffee about 0700 while he waited for the nitrous oxide temperature to rise. He entered SS2 about 0816.

1.2 The Copilot

The copilot, seated in the right seat, age 39, lived in Tehachapi, California. He had no major changes, good or bad, to his health, financial situation, or personal life that would have adversely affected his performance on the day of the accident.

His most recent FAA 2nd class medical dated May 22, 2014, had the limitation "must wear corrective lenses." No medications were listed. His wife said he occasionally took a daily vitamin, and he did not take any medication, prescription or nonprescription in the 72 hours before the accident that might have affected his performance on the day of the accident. He did not use tobacco products and he had a small glass of wine the night before the accident, about

1900-1930. He wore glasses but not contacts, and had no issues with color vision. An audiogram hearing test was performed on February 12, 2013, and the results were normal. He was generally healthy, exercised regularly and enjoyed doing outdoor activities with his family.

He had no previous aviation accidents or incidents. He had received commendations for his performance at work and was a part of the Scaled team that won the Northrop Grumman 2014 President's Award and 2014 Chairman's Award for Excellence.[6] He was never disciplined at work for his performance.

According to his wife, he enjoyed working for Scaled Composites. He had no concerns about working for the company or about the SpaceShipTwo project, although he did not talk about work with her. She did not know if he had any concerns about traveling to an offsite duty location[7] for another Scaled Composites program the week of the accident flight.

In the month preceding the accident, he worked on two other projects in addition to Tier1B and had two days of pilot training. During the month of October 2014, he worked on average about 51 hours per week, ranging from 16-26 hours on the Tier1B project per week, or about 32%-55% of his time.

The copilot's most recent employee performance evaluation was dated January 29, 2014, and included a review by the director of flight operations, engineering manager, co-workers and a self-review. Comments from those reviews focused on both positive aspects of the copilot's performance and areas for improvement. Positive comments included his professionalism, ability and knowledge as a test pilot, leadership, and improvements on communication. Areas for improvement centered on his availability due to competing priorities on projects. The copilot's previous employee performance evaluation, dated January 17, 2013, included a review by the VP engineering, co-workers, and a self-review. Comments from those reviews were similar to his most recent review but included some additional comments. Additional positive comments included his sound judgment, positive attitude, and attention to detail. Additional areas for improvement included his difficulty following a task or policy he did not agree with, difficulty finding a work/life balance, and his struggle with "good enough" and how to apply that to larger aerospace programs.

1.1.2. The Copilot's Pre-accident Activities

The weekend of October 25-26, 2014, the copilot engaged in family activities. He typically woke up about 0630 on the weekends and between 0430 and 0530 on weekdays, and went to bed about 2100-2200. He sometimes would read at night but for how long depended on how tired he was.

On Monday, October 27, his wife did not recall when he woke up but she thought he left the house around 0500 for his 30 minute commute to work. He normally ate breakfast and had a cup of coffee. His wife said his work day was scheduled to start at 0700 but he would arrive before that. Company electronic data records indicated activity beginning at 0558 until 1849. During his work day, the copilot participated in a PF04 simulator session and the PF04 Delta FRR. His

[6] The President's Award was announced on July 28, 2014. The Chairman's Award for Excellence was announced on December 5, 2014, and a subsequent ceremony was held on January 7, 2015.
[7] The offsite duty location was located in the Pacific time zone.

timesheet indicated he worked 10 hours, all on the Tier1B program. Cellular telephone activity began at 0705 and ended at 1720. It is unknown when he arrived home that evening or when he went to bed that night.

On Tuesday, October 28, his wife did not recall when he woke up and did not believe she talked with him while he traveled that day or the next. Company electronic data records indicated he sent an email at 0513 and had activity at Scaled Composites facilities beginning at 0625. During his work day, he participated in a solo PF04 simulator session, a PF04 simulator session with the pilot, the PF04 card review and a meeting regarding the stab station. Cellular telephone activity indicated that he received a number of inbound text messages between 0938 and 1011 but no outbound text messages were sent, and had activity at 1108 and 1109. He departed for an offsite duty location about 1130 and arrived just before 1300. According to a colleague that traveled with the copilot, the copilot had lunch and worked offsite until 1700. His timesheet indicated he worked 12 hours, 5 hours of which were related to the Tier1B program. It is unknown what time he went to bed.

According to a colleague who traveled with the copilot, on Wednesday, October 29, the copilot woke up about 0530 and then had breakfast. They worked offsite from 0700 until 1530 before departing for the return trip to Mojave. He had no active cellular telephone activity that day. He was scheduled to arrive back in Mojave by 1700. Company electronic data records indicated activity at Scaled Composites facilities at 1708 and 1710. His timesheet indicated he worked 12 hours. His wife recalled him getting home about 1715 and he watched a football game with his family. He went to sleep about 2200 after reading in bed.

On Thursday, October 30, he woke up about 0500 and his wife said he slept fine. She did not recall his morning activities or if he ate breakfast and had coffee. Company electronic data records indicated activity beginning at 0639 until 1644. During his work day, he participated in a PF04 nominal simulator session with the pilot, the PF04 Maintenance and ER Briefing, and the PF04 communication checks. He sent an email at 1419 with the subject “out rest of day” and another email at 1644. His timesheet indicated he worked 8 hours all on the Tier1B program. Cellular telephone records indicated activity during his work day and one phone call at 1650. His wife recalled that he got home about 1600 and then participated in family activities outside of their home. He arrived back home around 1800. He discussed the next day’s flight with his wife. He went to bed about 2100 and fell asleep right away.

On Friday, October 31, he woke up about 0300 and his wife said he slept well. He left for work about 0330. His wife thought he ate an apple and granola bar for breakfast on his way to work but was not sure if he had any coffee. Company electronic data records indicated activity beginning at 0406 until 0715. Cellular telephone records indicated he made a phone call to the Mojave Airport Automated Weather Observing System (AWOS) at 0416 and sent two text messages at 0543. He attended the PF04 Delta Brief at 0500 and entered SS2 about 0815.

2.0. Medical and Pathological Information

Specimens taken from the accident flight crew were sent to the FAA Civil Aerospace Medical Institute for toxicological testing. The testing did not detect ethanol or drugs[8] in either pilot. Testing was not performed for carbon monoxide or cyanide for either pilot.

3.0. Scaled Composites Training

3.1 Crew Resource Management Training

The National Test Pilot School, in Mojave, California, provided a crew resource management (CRM) lecture and two control room/simulator exercises on May 3 and May 7, 2012, respectively, at Scaled Composites. The invitation to Scaled Composites personnel stated "this one day short course is designed to review flight test aircrew and control room members the coordination concepts and procedures, the necessary attitude which recognizes the importance of good aircrew coordination for effective mission accomplishment, and the skills to implement the crew coordination procedures. During the review of these topics, the mission of flight test is emphasized in the crew coordination process. Consequently, all in class exercises and examples are centered on flight test scenarios." Training attendees were primarily control room personnel[9] but also in attendance were three test pilots, including the accident crew. The lecture consisted of a PowerPoint presentation that focused on communication, crew concept/synergy, workload management, situational awareness, decision making and threat/error management. The attendees were divided into two groups for the control room exercises. Actual mission profiles were flown in the simulator and preplanned failures were injected that the pilots and control room staff had to respond to.

An after action report was provided by the National Test Pilot School instructors to Scaled Composites. Feedback received included:

- Attendees were very attentive and engaged in the process.
- Both simulator briefs lacked mission specific limits and used non-standard terminology.
- Simulator exercises should be briefed more thoroughly.
- Engineers spoke up when they detected an incomplete understanding by the test conductor of an ongoing situation. "This is exactly the attitude required for an efficient control room."
- [The accident copilot] pointed out that everyone in the room engaged in the emergency when it occurred and neglected their area of responsibility.
- The development of IADS displays in the control room was impressive, but needed some improvement; for example, all displays should conform to a specific standard, and new, intuitive displays should be created to conform to the "expanding complexity of Scaled projects" and to allow use by multiple users.

[8] Drugs tested for were amphetamines, opiates, marihuana, cocaine, phencyclidine, benzodiazepines, barbiturates, antidepressants and antihistamines.
[9] Control room personnel were both seasoned and inexperienced, and not all personnel were familiar with the Tier1B program.

- Modify how information was presented on the main plasma displays to decrease clutter and the mental processing/workload required to interpret numerical values displayed, and make problems/issues more salient to increase situational awareness.

3.2 Parachute Training

The Butler Parachute Systems parachutes used by the accident crew were owned by Virgin Galactic but were similar to the parachutes owned by Scaled Composites. Scaled Composites' aircrew members were provided with a briefing on use of the parachutes owned by Scaled Composites.[10] The date of the briefing and who attended the briefing could not be found in company records, however, the briefing was provided by the Scaled Composites director of quality assurance and covered the following topics:

- Fit, preflight and operation of the mask and helmet.
- How the parachute works and description of the various components such as Capewell operation, oxygen activation, how to preflight the parachute, check pack history log
- Operation of the CYPRES device and how to preflight it
- Proper fitting of the parachute, including demonstration
- Clothing should be worn during flights: flight suit, gloves, boots
- Basic skills such as free flight position and landing procedures

Some pilots were also provided with the "Aircrew Survival Equipmentman [sic] 3&2; Naval Training Command Rate Training Manual," Chapter 3 "Personnel Parachute Familiarization". In addition, manuals for the types of parachutes available for use by Scaled aircrew were available for self-study.

According to Scaled Composites[11], "the pilot in command of each flight was responsible for knowing all who flew were familiar with use of the parachutes, how to open hatches or canopies, and how to leave the aircraft." Scaled Composites said that, at the time of the accident, they were unaware that activation of the emergency oxygen required a two-hand pull. However, in March 2014, Butler Parachutes modified the "High Altitude Emergency Parachute System User's Guide" to state that activation of the emergency oxygen required both hands, and on May 13, 2014, Butler delivered a report to the Scaled Composites director of quality assurance which concluded the oxygen system could be activated with ease when using two hands and no modifications were being made to the system.[12]

4.0. Scaled Composites Manual Excerpts

4.1 Engineering Handbook

The Scaled Composites "Engineering Handbook," chapter 7 "Testing and Test Safety," section 7.1 "Desktop procedure – System Safety," revision H, dated June 12, 2013, stated:

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[10] Email communication sent to the NTSB from Scaled Composites on February 9, 2015.
[11] Email communication sent to the NTSB from Scaled Composites on February 9, 2015.
[12] See the Survival Factors Group Chairman's Factual Report for additional information on the parachute and emergency oxygen systems.

Scaled Composites approach to System Safety is documented in the "Desktop Procedure – System Safety". This procedure is for the assurance of System Safety. It applies to all programs where Scaled Composites is the prime contractor. Where Scaled Composites is a subcontractor, System Safety contract provisions will be a subset of the prime contract. We all must ensure that Scaled Composites' approach to System Safety is consistent and compliant with industry, state and federal standards and designed to meet, when required, the intent of customer contractual requirements. This process shall be applied to all programs that involve ground and or flight tests of aerospace vehicles. Customer requirements may be added if required by contract. The overarching principle is "Question Not Defend". This means that each employee of Scaled is responsible and encouraged to question the safety of the product or operation at any time, and that Scaled management shall document and respond promptly to the concerns expressed.

The Scaled Composites "Engineering Handbook," chapter 7 "Testing and Test Safety," section 7.3 "Flight Testing," subsection 7.3.1 "Introduction," revision H, dated June 12, 2013, stated:

Flight Ops

Flight Safety
Scaled Composites has implemented several processes to aide in the safe conduct of flight test operations. These processes are modeled after Air Force standards and include:

Configuration Control
In order to maintain control of the vehicle configuration, and thus ensure both safety (in knowing the precise test configuration) and test efficiency (same issue), all modifications to the vehicle must be documented, in writing, in the aircraft and engineering records. This documentation will be done in the following way:

For discrepancies or maintenance requirements that do not change the design of the aircraft, the Scaled Maintenance/Discrepancy forms will be used. Any discrepancies identified by the flight or maintenance crews will be entered into these forms, with the resolution of these issues as described in the Scaled Maintenance Plan.

For modifications to the vehicle test configuration, all requests for such modifications will be transmitted to the Crew Chief via the Engineering Request (ER) form. Specifically, the Scaled PE [project engineer], the PBM [program business manager] or his designee must sign off the ER. The Maintenance and ER status will be briefed to the flight crew by the Crew Chief at each preflight mission briefing.

Scheduling
A Flight/Maintenance Schedule form will be published in advance of the preflight briefing. This schedule will identify flight target date and times, requested fuel load, requested cg [center of gravity] location/ballast requirements, test areas/airspace, and any special test equipment required. It will also identify specific crew requirements, including flight crew, chase crew, ground vehicles and crew, photographers, and maintenance staff required. This schedule will be approved and signed by the Test Director or his designee.

Briefings

There are three types of flight briefings: the Technical Interchange Meeting, Preflight Briefing, and Post flight Briefing.

Technical Interchange Meeting

Prior to a Preflight briefing, a Technical Interchange Meeting (TIM) will be held among appropriate Scaled and customer engineering and test personnel, with no limitations to attendance. This meeting can be held face-to-face, or via telephony or other means. The goal of the TIM is to attain concurrence regarding specific tests requested for the next flight. It is expected that both Scaled and the customer will have input to this process, with Scaled providing recommendations for either modifications or specific tests to be performed, and the customer requesting specific data or modifications. All aircraft configuration modifications will be handled per the Scaled ER process.

From the specific requests during this meeting, and the overall test plan, Scaled will prepare its specific flight cards for the next flight. The Scaled Mission Director or his designee will initial the test cards before the flight is conducted.

Preflight

There will be a face-to-face preflight briefing held before each flight, in accordance with the Scaled Mission Briefing Guide (MBG). Participants will include all those designated on the flight/maintenance schedule or otherwise invited by the Scaled Test Director.

The Test Pilot will conduct the briefing. The goals of the briefing are to review the test vehicle status, the requirements of other participants, and the specific conduct of the tests to be performed. Tests not specifically briefed will not be conducted during the flight without the mutual agreement of the Scaled Test Director and the Test Pilot.

Post flight

There will be a face-to-face post flight briefing held immediately after each flight, in accordance with the MBG. Participants will be the same as for the preflight briefing. The Scaled Test Pilot will conduct the briefing, to include review of discrepancies and maintenance items, significant test results, and recommendations for any issues and for the next flight. At this meeting, a tentative schedule will be set for the next flight, and for the activities required to support it.

Test Conduct

Once the airplane has had its preflight inspection, no one will approach the airplane in the hangar or on the ramp without specific concurrence of the Crew Chief.

All personnel not specifically involved with a ground or flight test will remain a safe distance from the airplane at all times, and shall not approach the airplane or interfere with the test without the concurrence of the Crew Chief or his designee.

Only Scaled vehicles, unless otherwise agreed, will be allowed on the Scaled ramp during tests. All vehicle movements on the ramp, taxiways, or runways, will adhere to Mojave Airport and Scaled directions and regulations. Any special accommodations for spectators, photographers, etc., must be coordinated in advance with Scaled and the Mojave Airport.

The test team monitoring specific flight or ground tests will be segregated from nonparticipants so as to minimize any interference with the team's responsibilities. This team is critical to the safe conduct of the tests.

The Scaled Composites "Engineering Handbook," chapter 7 "Testing and Test Safety," section 7.3 "Flight Testing," subsection 7.3.3 "Flight Test Review Procedure," revision H, dated June 12, 2013, stated:

Scaled Flight Test Review Procedure

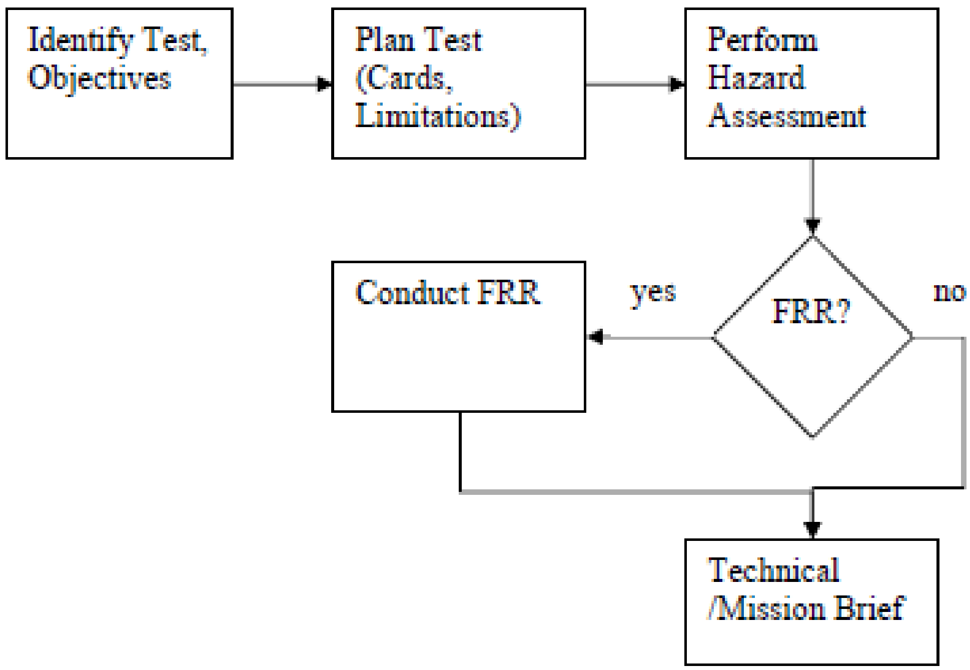
The purpose of test reviews are to ensure that adequate planning for test has been conducted, test setup / vehicle / system is ready to be tested and that all hazards, safety issues and planned mitigations have been addressed.

Flight test readiness reviews are designed to augment Scaled's system safety process of "Question Not Defend" not to replace it. FRRs are required when starting flight tests of a new vehicle or existing vehicle with significant modifications; after any modifications to primary structure; after significant aerodynamic modifications; Any required increase to the approved flight operating limitations; Upon request of the Safety Official, normally the President of Scaled Composites. The FRR by design allows pier [sic] review of test plans, procedures, safety analysis, system under test and requires management buyoff. It should be noted that if an FRR is not required, that the objective of the FRR process is still conducted by the Test Director, although in an informal way.

The FRR shall be conducted by the FRR Chairperson (normally the President of Scaled Composites) with relevant material briefings from the Project Engineer and/or Responsible Engineer and/or Test Director necessary for subject matter familiarity. This should include but not necessarily be limited to functional requirements, design specifications, previous testing conducted and results, safety analysis with identification of any high risk items. For modifications to existing flight vehicles, all configuration changes from the last reviewed configuration shall be presented. Test plans, test cards, limitations, test personnel, relevant training shall be presented. Determination of safety of flight parameters and go/no go criteria shall be reviewed and updated as required. Upon completion of the briefing the FRR board shall make determination of readiness, identify any actions required (updates to test plan / cards, limitations, go / no go criteria). The FRR chairperson will ensure attendee lists are generated, all relevant actions identified. All related briefing material, attendee lists, and actions shall be archived.

If determination has been made that an FRR is not required, all flights shall have test plans / cards reviewed and signed by the Test Director.

All tests shall be briefed with test team members at [sic] using Scaled Briefing Guide.



Process Example [formatting original]

Test Owner identifies test objectives
Test Owner plans test
Test Owner conducts Hazard Assessment
Safety Officer (Test Director) coordinates with the Safety Official and determines the need for an FRR and determines the scope and objectives of the FRR.
Safety Official or his specified delegate is FRR Chairperson and selects FRR board
Safety Officer ensures that at least one subject matter expert is in attendance at the FRR ideally selected from outside the scope of the program.
Project Engineer assembles relevant subject matter definition and distributes to FRR attendees and board.
FRR Chairperson conducts FRR with aid of FRR checklist
FRR board creates action list
FRR board updates Limitations, Go/No Go criteria
Mission/Crew Brief Conducted with test team using Scaled Mission Briefing Guide

Flight Readiness Review Briefing Checklist

This checklist should be used as a guide to the FRR Chairperson.

1. Test Plans and Objectives
2. Test System Description and Design Review
3. Hazard Assessment
4. Configuration changes since last FRR
5. Open discrepancies
6. Known deficiencies or test anomalies
7. Test Cards
8. Limitations
9. Go/No Go Lists
10. Instrumentation
11. Test Personnel
12. Attendee List
13. Action List
14. Briefing material archived

4.2 Desktop Procedure

The Scaled Composites "Desktop Procedure **–** System Safety," revision dated July 2013, stated:

> **Procedure Owner – President of Scaled Composites, LLC**
>
> **Purpose –** To ensure Scaled Composites System Safety is consistent and compliant with industry, state, and federal standards and designed to meet, when required, the intent of customer contractual requirements. This process shall be applied to all programs that involve ground and/or flight tests of aerospace vehicles. Customer requirements may be added if required by contract. The overarching principle is "Question Not Defend." This means that each employee of Scaled is responsible for and encouraged to question the safety of the product or operation at any time, and that Scaled management shall document and respond promptly to the concerns expressed.
>
> **Scope** - This procedure is for the assurance of System Safety. It applies to all programs where Scaled Composites is the prime contractor. Where Scaled Composites is a subcontractor, System Safety contract provisions will be a subset of the prime contract.
>
> **Process Summary:**
>
> - The President of Scaled Composites, LLC shall hold the ultimate responsibility and authority for safe operations and testing. The President may delegate his duties as he deems appropriate. The President and any delegate have the responsibility to make products safe for use in their operational environment. Objectives are to safeguard personnel, protect equipment, and assure safety considerations are implemented during the performance of a program by applying safety processes and procedures.
>
> - The President or his delegate shall appoint a Safety Officer (SO) for each program who will report directly to him. The SO will be the Scaled Composites single point of contact for Safety for that program. The Safety Officer will normally be

the Project Engineer or Program Manager during design, fabrication, and ground test activities. The Director of Flight Operations or his delegate shall serve as the SO once the vehicle has transitioned into flight test and shall be responsible for safety of all test activities from the time of vehicle pre-flight to post-flight. The SO has the responsibility to make products safe for use in their operational environment. Objectives are to safeguard personnel, protect equipment, and assure safety considerations are implemented during the performance of a program by applying safety processes and procedures and by working with the site EH&S representative and others to achieve these objectives as required.

President – The President or his specified delegate shall be responsible for the following actions:

- Establish a safety conscious design culture.
- Prepare and implement a System Safety Program Plan when required to meet the contract provisions and customer needs. The requirements of such System Safety Program Plan shall be in addition to the requirements of this Desktop Procedure.
- Work with the Operations Manager and EH&S Lead to ensure that company operations are conducted in accordance with local, state, and federal requirements and best commercial safety practices. Participate in the design and evaluation of manufacturing and assembly operations and facilities to ensure safe and efficient human interfaces with program hardware, software, and the environment.

Flight and Ground Test

- Participate in flight and ground test readiness reviews and safety reviews as the Chairperson.
- Conduct and participate in external Safety Review Boards (SRB) as requested.
- Ensure that Flight Limitations are generated and maintained.
- Review flight line procedures for safety considerations.
- Perform flight line safety surveillance.
- Ensure that test operations documentation is kept accurate and up to date.
- Chair, designate and assure a mishap review board is convened in the event of an accident. Perform mishap investigations and maintain a database for lessons learned.
- Support attendance of key test personnel at appropriate technical forums (e.g., SETP, FTSW, SFTE) and training sessions.
- Document and review the following hazard analyses where required by contract.
  - Subsystem Hazard Analysis
  - System Hazard Analysis
- Mentor, design, and support engineering groups for awareness of safety requirements and to establish a safety-conscious design culture.
- Maintain explosive hazard classification for components.

A Flight Readiness Review (FRR) shall be conducted:

- Prior to starting flight tests of a new vehicle.

  - This review should establish the approved test envelope for the planned test series, so additional FRRs should not be required unless the plan is changed so as to increase the test envelope requirements.
- After any modification to primary structure.
- After any significant aerodynamic modifications that are expected to significantly alter the handling qualities (not to include minor changes like fences, fairings, or vortex generators).
- Any required increase to the previously approved flight operating limitations.
- Upon request of any company officer.

A Ground Test Readiness Review (TRR) shall be conducted:

- When a ground test may put involved test participants or noninvolved personnel at risk of bodily harm prior to mitigating measures being put in place.
- When a potential test failure would put at risk test assets exceeding approximately $100,000 in value in either test assets or program schedule, as determined by the PM, PBM, or PE.
- Upon request of any company officer.

All formal test reviews shall have presentation material archived, a list of attendees retained, and follow-up documentation of actions and closure of any open issues from the review.

It is the responsibility of the Safety Officer to ensure that at least one subject matter expert is in attendance at each of these reviews. This person or persons should be selected by the Safety Officer from outside the specific program. It is expected that any issues raised by any of the team be resolved by the team. However, should any disagreement remain either among the team or by the outside expert or experts, such disagreement shall be resolved by the President or assigned delegate.

Per an email dated July 10, 2013, to engineers and management, Scaled Composites' president delegated his responsibilities per the "Desktop Procedure – System Safety" to vice president/general manager .

4.3 Employee Handbook

The Scaled Composites "Employee Handbook" section A, subsection A.1 "Our Mission Statement" super-subsection A.1.1 "Basic Operating Principles of Scaled Composites, LLC," revision dated May 2013, stated:

1. All groups, departments, management, etc., must make their number one priority the support of the projects.
2. An enormous factor in Scaled's success is its strict focus on project objectives. If it's not required to fulfill the contract requirements or to ensure safe performance of the program, don't do it! "Nice-to-haves" have little or no benefit to us.
3. The project manager / project engineer must be delegated practically complete control of his/her program in all aspects, consistent with company policies. The project

manager is responsible for performing his/her program on-cost and on-schedule, and in compliance with contract requirements.

4. Projects deal with support groups directly. Priorities of the support groups are negotiated by the projects with management support as required.
5. Project teams should be co-located to the maximum extent possible.
6. Engineers should be able to personally fabricate anything that they design. Engineers are expected to work closely with the fabrication team in the execution of the project.
7. The project team must build an environment of mutual trust, close communication, and support among engineering, the fabricators and the support organizations.
8. A very simple drawing and drawing release system with great flexibility for making changes must be provided and can and should be adapted to each project's needs. Engineering should strive to keep at least 2 weeks backlog for the shop.
9. There must be a minimum number of reports required, but important work must be recorded thoroughly and easily available to subsequent projects.
10. Quality and safety are everyone's responsibility. Question, don't defend: when questioned about work or design, don't take offense. Take the time to understand the question and work together to resolve the concern. Inspection and/or reviews that are based on contract requirements should not be considered the primary means of finding defects. Quality is not just about the hardware – we should strive for quality in everything we do - it's an attitude not a process.
11. Project leaders are the safety officers for their projects and must conduct operations in accordance with company policies. Policies are necessary but not sufficient: use common sense.
12. Prioritize taking on projects that involve us flight testing what we build.
13. When practical, "off the shelf" equipment should be used if it meets the design requirements. Suitability should be thoroughly verified early in the project.
14. There must be mutual trust between Scaled and its customers with open, honest, and frequent communication. This should be accomplished through a single point of contact on both ends.
15. Protection of the proprietary information of both Scaled and our customers is paramount. In particular, progress and test dates should never be disclosed for fears of undue schedule pressures leading to safety risks.
16. Because the goal is to foster a culture where creativity & exceptional talent are the norm not the exception, and also because it is understood that Mojave is a "hostile" living environment, staff should be rewarded with plentiful, unique projects not found anywhere else in the world. The project leadership should provide the team with technical ownership of large portions of those programs, safe and comfortable facilities in which to conduct them and opportunities for learning and leadership.

The Scaled Composites "Employee Handbook" section A, subsection A.2 "Scaled Composites' Flight Test Slogan: 'Interrogo Haud Defenso'," revision dated May 2013, stated:

> Loosely translated, the slogan is "Question, not defend." It represents our flight test philosophy - never try to defend a product, always question if it is the best it can be. The components in the patch are the local desert and the sky (from blue to black) signifying that we test from the lowest altitudes to the highest. The graphic is the Scaled logo,

> representing a generic airplane in flight and our "out of the box" approach to design and test.

The Scaled Composites "Employee Handbook" section C "Ethics and Standards of Business Conduct", subsection C.8 "OpenLine," dated May 2013, stated, in part:

> The Northrop Grumman Office of Ethics and Business Conduct provides a nationwide 800 number for employees, customers, suppliers and Northrop Grumman stakeholders who would like to seek guidance on an ethics or compliance issue or concern, or who would like to report a violation without fear of retribution.

The Scaled Composites "Employee Handbook" section J "Open Door Policy," revision dated May 2013, stated, in part:

> Scaled Composites values employees as its most important resource and places a high priority on ensuring fair and consistent treatment. The company is committed to creating an environment of mutual trust and professionalism where problems can be fairly resolved through an interactive process that encourages better communication at all levels.
>
> You are encouraged to work with your management to achieve resolution concerning any problems impacting your work. Employees needing additional assistance should contact Human Resources for advice and assistance regarding any work-related issues. Employees can also utilize the OpenLine as referenced in section C.8 of this handbook.

5.0. Human factors considerations in SS2

Scaled Composites did not have a dedicated human factors expert on staff, but several engineers and a test pilot said they had a college-level course or professional experience in human factors. According to the vice president/general manager of Scaled Composites, they had a "history of building things" and relied on input from the pilots to identify and resolve ergonomics and human factors issues. He said Scaled Composites did not need to hire an outside human factors company because they did that internally. They were a research company and would "change things up" to see if it worked.[13]

5.1 Vibration Testing

Scaled Composites wrote a white paper titled "SS2 Vibration Environment: Human Factors," revision A dated November 8, 2011. The paper discussed five major concerns when considering the effects of vibration on a crew, specifically: 1) reduced training task capability; 2) loss of visual acuity, and resulting error in interpreting visual data; 3) adverse physiological reactions; 4) biodynamic reactions, and resulting uncontrolled body movements; and 5) tolerance limits, uncomfortable or painful response. The paper concluded that the "limiting factors are tracking, amplified by the configuration of SS2 pilot interface, and visual impairment in the man critical region."

[13] See Attachment 1 – Interview Summaries.

The Scaled Composites PowerPoint presentation titled "SS2 Dynamic Loads Rev A: Global Structural Loads, Human Factors, Local Loads," dated December 8, 2011, discussed human factors issues with vibration. The presentation stated, in part: "major resonance at 8 Hz in y/z can cross couple with head resonance fore/aft; peak at 10 Hz in X axis has potential to cause labored breathing and slight pain to the pilot; and peaks at 11.5 Hz can cause difficulty in reading the instrument panel." A conclusion in 2011 stated "anecdotal evidence from SS1 shows current SS2 rocket motor needs significant improvement in the 5-10 Hz range." The rocket motor design used in PF04 was modified since 2011 to reduce levels of vibration and the rocket motor control (RMC) abort criteria took vibration levels into account.

The Scaled Composites "Crew Vibration Test Plan" described vibration testing conducted on May 17-18, 2012 with the purpose of developing "limits for SS2 vehicle vibration based on flight crew capability." Testing equipment included a shaker table[14], a fixture, a multifunction display unit (MFD)[15], and a crew seat. Accelerometers were placed on the shaker table and the pilot's head, and were recorded with the shaker table system. The pilot wore a parachute and helmet (no mask) to represent an actual flight but so as to not hinder communication.

As described in the Pilot Vibration Evaluation PowerPoint following the testing, each pilot was subjected to two tests, random vibration and sine vibration. (b) (4) [redacted] Seven pilots and engineers participated in the testing and performed various tasks at each g amplitude in X axis, such as verifying selected approach, changing the airport to EDW, and reading the altitude and Mach number.

Results of the sine vibration testing included the following:

- 100% of participants responded that 0.3 g acceleration at 7 Hz at was acceptable.
- 80% of participants responded that 0.4 g acceleration at 7 Hz was acceptable.
- 20% of participants responded that 0.5 g acceleration at 7 Hz was acceptable.

Observations as listed in the Pilot Vibration Evaluation included, in part:

- Slightly higher G may be acceptable for very short duration (less than a second) similar to what we have seen from motor burns
- Steady state vibration at 7 Hz should be kept at or below 0.4 g
- At 7 Hz, visibility degrades before vibration level is uncomfortable (up to 1 minute)
- Moving head ½" away from headrest dampens vibration almost completely
- Lightly resting head on headrest increases perception of vibration
- Holding head hard against rest improves vibration relative to light resting

Test result were provided to the rocket motor team for consideration in developing the SS2 rocket motor and related abort criteria.

[14] Scaled Composites owned a Dynamic Solutions DS-4400VH-12 shaker table.
[15] The MFD was driven by the Tier1B simulator to provide realistic launch guidance.

5.2 Cockpit design

According to engineers interviewed, the general layout of the cockpit was based around the nitrous tank, which was 90 inches in diameter, and the forward pressurant tank in the nose.[16] The windows were laid out around the 90-inch diameter "circle". Head placement was important so the seat was designed to maximize the pilots' view out of the window while allowing sufficient clearance from the window to move around and not strike the head in the event of an accident. Eye position was also critical for view over the nose during the landing phase. Placement of the center console was considered next to ensure that pilots could easily access the panel but still have sufficient room for egress. Pilots were involved in the process to ensure proper ergonomics. According to the former chief aerodynamicist, the center console was designed to resemble the throttle quadrant on the WK2 because the pilots would be flying both vehicles. The cockpit was symmetrical so the line of sight to the center console was the same for both pilots.

The pilots' seats in SS2 were fixed to the floor and not adjustable. To adjust a pilot's view out of the windows, seat cushions were interchangeable and of various thicknesses based on the pilot's height and desired line of sight out of the cockpit. The seat backs were hollowed out to allow room for the parachutes worn by the pilots. Rudder pedals could only be adjusted by a maintenance action and some pilots used rudder blocks on the pedals themselves in order to reach them more easily. The accident crew used nominal seat cushions and no blocks on the pedals for PF04.

5.3 Display design

Scaled Composites designed and developed the primary flight display (PFD) for SS2 in house. According to a the avionics project engineer on the Tier1B program, most changes made were in response to a pilot request. The design and implementation was an iterative and collaborative effort with the pilot group, and he worked primarily with the accident pilot because he had an avionics development background and SpaceShipOne experience. He said the high level avionics architecture was developed through "collaboration, discussion and prototyping."[17] The avionics group would install any new changes in the simulator first for evaluation. Pilots would be briefed at the simulator pre-brief on the updates. Once the design was accepted for flight test, the software would be released for installation in vehicles and the Pilot Operating Handbook would be updated as necessary.

The avionics group referenced FAA advisory circulars (AC) and a notice, specifically AC 20-145 Guidance for Integrated Modular Avionics (IMA) that Implement TSO-C153 Authorized Hardware Elements [cancelled on October 28, 2010], AC 25-11A Electronic Flight Deck Displays [cancelled on October 7, 2014 by AC 25-11B], AC 25-15 Approval of Flight Management Systems in Transport Category Airplanes, and Notice 8110.98 Addressing Human Factors/Pilot Interface Issues of Complex Integrated Avionics [cancelled on date unknown].

Incorporated into the PFD was an analog indicator in the upper left-hand corner of the display. The knots equivalent airspeed (KEAS) was displayed in analog and digital form, as well as true airspeed (TAS) and Mach" (see Figure 1, item 18). Mach and true airspeed text fields were

[16] See Attachment 1 – Interview Summaries.
[17] See Attachment 1 – Interview Summaries.

located to the right of the airspeed indicator and Nz below it. According to the Scaled Composites Pilot Operating Handbook, the PFD displayed current Nz, and during the boost phase, a second line displayed current Nx (see Figure 1, item 17).

The Tier1B avionics project engineer did not recall a discussion on font size or the use of any reference for determining size of the Mach font. The avionics team did make a change in the Mach display going from two digits past the decimal to three digits past the decimal based on a request from a pilot so that they could better determine the rates of Mach number change for test points on WhiteKnightTwo.[18]

Figure 1. Airspeed and G portion of primary flight display.

The most recent change to the PFD portion of the display was the addition of pitch and roll trim indications, based on a request from both Scaled Composites and Virgin Galactic test pilots. The development of the pitch and roll trim indication was an iterative process, the first design being a graphical representation. According to the Scaled Composites project engineer avionics, the final indication was "rolled back to a simple textual trim display to meet the software qualification time line."[19]

5.4 Feather system

Operation of the feather system required a 2-step process. The handles were designed such that the feather system had to be unlocked before the feathers could be extended. The feathers were unlocked by moving the feather unlock handle slightly to the right, out of the detent, and then pulling down to the stop. According to the former chief aerodynamicist, the handle itself was a safeguard from inadvertent unlocking and moving the handle downward required "a bit of force" so that the pilot would know he was moving the handle.[20] As stated in the Scaled Composites Pilot Operating Handbook (POH), revision D, dated September 3, 2013, section titled "Feather Lock Handle," "During boost the feather locks are normally opened at 1.4 Mach after the gamma turn and if not open at 1.5 Mach a caution will annunciate. If the locks fail to open the boost should be aborted. The locks remain open until the feather is lowered at the end of the reentry and the MFD "OK TO LOCK" message and back-up panel light illuminates." The feather was

[18] See Attachment 1 – Interview Summaries.
[19] See Attachment 1 – Interview Summaries and Attachment 2 – Simulator Test Plan Notes.
[20] See Attachment 1 – Interview Summaries.

actuated by “using the large pull/slide ‘trombone’ handle on the center console” and pulling the handle rearward until it reached its stop.

According to a Scaled Composites project engineer, the original intent was for the feather system to be unlocked when in space. However, he said there were concerns about “an inherent system risk” of a jammed actuator and it was “an easy procedural change” to unlock the feather system at 1.4 Mach. The former chief aerodynamicist who developed the feather system stated in a post-accident interview that 1.4 Mach was established as the speed to unlock that gave a significant safety margin beyond the transonic region where the upward forces on the tail exceeded the resistance capability of the actuators. According to the Tier1B program manager, there was a small window in which they counted on the pilot “to do the right thing” so they did not build any safeguards into the system. The former chief aerodynamicist further stated that because there were no regulations or relevant advisory circulars for suborbital spaceships, Scaled Composites used a 3-second reaction time for pilots to abort the flight if the feathers did not unlock. He said it was “kind of a standard” and “consistent with engine out reaction time”[21]. The engineers worked with the pilots and the pilots agreed with the reaction time allowed. During a “town hall” meeting held on October 22, 2014, at Scaled Composites, it was discussed that once the feather locks have been commanded to the unlock position and did not unlock, the pilots had 5 seconds to shut the motor down and recover the vehicle.[22]

According to Scaled Composites engineers and test pilots interviewed, the boost phase was a high workload phase of flight and duties were divided between the pilot and copilot. The copilot would unlock the feather at 1.4 Mach, with or without a callout, as indicated on the PF04 test card. Because of the workload, the speed was not crosschecked by the pilot flying.[23]

Test pilots were made aware of the speed at which to unlock the feathers by referencing the POH, normal procedures, and flight test cards; it was also discussed formally in meetings and informally. There was no documentation in the POH that discussed the risk of unlocking the feather before 1.4 Mach, but according to interviews, pilots were aware of the risk of unlocking the feather during the transonic phase of flight.[24] According to the former chief aerodynamicist, he was not sure if there was an official document that showed the tail load during the transonic region that was given to the pilots. The tail loads during the transonic region were discussed in an email on July 8, 2010, and in a presentation at the Feather FRR on April 12, 2011, however, the risk of a catastrophic event was not emphasized on the slide. In a second presentation given at the April 2011 Feather FRR, a screen shot titled “Fault Tree Analysis SS2 Feather” showed the functional hazard assessment which stated an uncommanded feather operation during boost was catastrophic. It also showed the fault tree analysis which “assumes the feather has been

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[21] See 14 CFR 23.367 and 14 CFR 25.367; also see FAA AC 25-7C – Flight Test Guide For Certification of Transport Category Airplanes.[http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1020494; accessed March 10, 2015].

[22] In attendance at the town hall meeting were management and engineers, including the director of flight operations, from Scaled Composites, Virgin Galactic and The Spaceship Company.

[23] See Attachment 1 – Interview Summaries to this report and Operational Factors Group Chairman’s Factual Report Attachment 1 – Interview Summaries.

[24] The transonic region was described as occurring between 0.9 and 1.1 Mach.

unlocked, so only the feather actuation has to fail uncommanded."[25] According to the vice president, they never imagined that the feather system would be unlocked too soon. He believed pilots were aware of when to unlock the feather system, because that was how they did it in the simulator. [26]

According to interviews with FAA AST personnel, some were aware that unlocking the feather during the transonic phase could lead to a catastrophic failure; however, that specific issue was not looked at because while "the team might have discussed it, but it wasn't one of those items, because of the limitations we have on the permit, that we really looked at that particular issue." Asked if there was any discussion about Scaled Composites mitigating the risk of this catastrophic failure, one AST 200 staff member said "Well, there was no, that I know of, no legal requirement that they need to mitigate that risk."[27]

For additional information on the feather system, see the Operational Factors, System Safety, and Systems Group Chairmen's Factual Reports.

5.5 Flight simulator

Scaled Composites test pilots prepared for PF04 using a fixed-based simulator with a 180-degree curved screen.[28] According to the permit application submitted to the FAA, the simulator comprises:

- Detailed duplication of the SS2 cabin layout: avionics, switches, controls, windows, etc.
- Wrap around video simulation and sound effects.
- Detailed and precise SS2 flight dynamics.
- The ability to simulate both control forces and effectiveness in all flight regimes.
- The ability to simulate wind profiles.
- The ability to simulate thrust asymmetries.
- The ability to simulate a huge array of failure conditions.

According to a Scaled Composites project engineer, the force required to unlock the feathers in the simulator was less than the forces required to do the same action in SS2.[29] Pilots also did not wear flight suits, helmets, or gloves in the simulator as worn during actual powered and glide flights in SS2.[30]

6.0. PF04 Flight Readiness Reviews and Delay

Scaled Composites held three flight readiness reviews (FRR) prior to PF04 – a FRR, a Delta FRR and an Executive FRR. The FRR was held on October 3, 2014, the Delta FRR was held on

[25] The accident crew was on the distribution list for the email on July 8, 2010. A sign in sheet could not be located for the Feather FRR to confirm if the accident crew was in attendance. See Attachment 3 to this report. The fault tree analysis assumes that a pilot follows the proper normal and emergency procedures for a given situation. See the System Safety Group Chairman's Factual Report for additional information on the system safety analysis.
[26] See Attachment 1 – Interview Summaries to this report and Operational Factors Group Chairman's Factual Report Attachment 1 – Interview Summaries.
[27] See Operational Factors Group Chairman's Factual Report Attachment 2 – Interview Transcripts.
[28] For additional information on simulator training, see the Operational Factors Group Chairman's Factual Report.
[29] See Attachment 1 – Interview Summaries.
[30] See Attachment 2 – Simulator Test Plan Notes.

October 27, 2014, and the Executive FRR was held on October 29, 2014. According to those in attendance at the FRRs, there was no discussion of the feather system.[31] A review of the FRR, Delta FRR and Executive FRR presentations revealed discussions of the feather system related to supersonic feather reentry, feather hinge moments, and unlocking the feather at 1.4 Mach. A review of the FRR action items revealed several items related to the feather system but no items were found related to the pilots use of the feather system. PF04 was originally scheduled to take place on October 23, 2014, but was delayed out of concerns over trajectories and the new loads and was rescheduled for October 31, 2014. According to the Vice President of Engineering, "there was pressure to have PF04 completed on October 31, but not undue or unreasonable pressure."[32]

7.0. FAA Regulations and Oversight

The FAA's Office of Commercial Space Transportation (AST) was tasked with the mission "to ensure protection of the public, property, and the national security and foreign policy interests of the United States during commercial launch or reentry activities, and to encourage, facilitate, and promote U.S. commercial space transportation."[33] Regulations were established to provide direction and accountability and advisory material was published to provide additional guidance to operators. Human factors-applicable regulations can be found in 14 CFR 437 Experimental Permits and 14 CFR 460 Human Space Flight Requirements.

7.1 Rest Rules for Vehicle Safety Operations Personnel

14 CFR 437. 51 Rest rules for vehicle safety operations personnel, stated:

> A permittee must ensure that all vehicle safety operations personnel adhere to the work and rest standards in this section during permitted activities.
>
> (a) No vehicle safety operations personnel may work more than:
> (1) 12 consecutive hours,
> (2) 60 hours in the 7 days preceding a permitted activity, or
> (3) 14 consecutive work days.
> (b) All vehicle safety operations personnel must have at least 8 hours of rest after 12 hours of work.
> (c) All vehicle safety operations personnel must receive a minimum 48-hour rest period after 5 consecutive days of 12-hour shifts.

7.2 Hazard Analysis

14 CFR 437.29 Hazard analysis, stated:

[31] See Attachment 1 – Interview Summaries to this report and Operational Factors Group Chairman's Factual Report Attachment 1 – Interview Summaries.
[32] See Attachment 1 – Interview Summaries to this report and Operational Factors Group Chairman's Factual Report Attachment 1 – Interview Summaries.
[33] For additional information on FAA AST, see http://www.faa.gov/about/office_org/headquarters_offices/ast/ [accessed March 19, 2015], the System Safety Group Chairman's Factual Report, Operational Factors Group Chairman's Factual Report, Operational Factors Group Chairman's Factual Report Attachment 1 – Interview Summaries, and Operational Factors Group Chairman's Factual Report Attachment 2 – Interview Transcripts.

(a) An applicant must perform a hazard analysis that complies with §437.55(a).
(b) An applicant must provide to the FAA all the results of each step of the hazard analysis required by paragraph (a) of this section.

14 CFR 437.55 Hazard analysis, stated, in part:

(a) A permittee must identify and characterize each of the hazards and assess the risk to public health and safety and the safety of property resulting from each permitted flight. This hazard analysis must—
  (1) Identify and describe hazards, including but not limited to each of those that result from—
    (i). Component, subsystem, or system failures or faults;
    (ii). Software errors;
    (iii). Environmental conditions;
    (iv). Human errors;
    (v). Design inadequacies; or
    (vi). Procedural deficiencies.

Additional guidance on how to perform a hazard analysis to identify, analyze and control public safety hazards and risks associated with the launch and reentry of a reusable suborbital rocket operating under an experimental permit was provided to operators in FAA AC 437.55-1.[34]

Scaled Composites submitted an experimental permit application on January 24, 2012, which was reviewed by the FAA's Licensing and Evaluation Division (AST-200). According to the AST-200 manager, there was no one in the division with a degree in human factors, however, there were two pilots on his staff that were familiar with human factors concepts. The FAA issued an experimental permit to Scaled Composites on May 23, 2012, which was granted renewal on May 22, 2013. On July 18, 2013, the FAA published a notice of waiver, "Waiver of 14 CFR 437.29 and 437.55(a) for Scaled Composites, LLC," which waived them of the need to comply with regulations 437.29 and 437.55(a). A renewal of the permit and waiver was granted again on May 21, 2014.

7.3 Operator Training of Crew

14 CFR 460.7 Operator training of crew, stated in part:

(a) *Training device fidelity.* An operator must
  (1) Ensure that any crew-training device used to meet the training requirements realistically represents the vehicle's configuration and mission, or
  (2) Inform the crew member being trained of the differences between the two.

7.4 Human Factors

[34] See AC 437.55-1 " Hazard Analyses for the Launch or Reentry of a Reusable Suborbital Rocket under an Experimental Permit" [http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22304/; accessed March 18, 2015].

14 CFR 460.15 Human factors, stated:

> An operator must take the precautions necessary to account for human factors that can affect a crew's ability to perform safety-critical roles, including in the following safety critical areas—
> (a) Design and layout of displays and controls;
> (b) Mission planning, which includes analyzing tasks and allocating functions between humans and equipment;
> (c) Restraint or stowage of all individuals and objects in a vehicle; and
> (d) Vehicle operation, so that the vehicle will be operated in a manner that flight crew can withstand any physical stress factors, such as acceleration, vibration, and noise.

7.5 Safety Management System

The FAA Safety Management System (SMS) initiative is a "formal, top-down business approach to managing safety risk, which includes a systemic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures."[35] The initiative further states, in part, "by recognizing the organization's role in accident prevention, SMSs provide to both certificate holders and FAA [emphasis original]:

- A structured means of safety risk management ***decision making***
- A means of demonstrating safety ***management capability*** before system failures occur
- Increased confidence in ***risk controls*** though structured ***safety assurance*** processes
- An effective interface for ***knowledge sharing*** between regulator and certificate holder
- A ***safety promotion*** framework to support a sound ***safety culture***"[36]

FAA Order 8000.369A[37] "Safety Management System," Chapter 1 "General Information," dated May 8, 2013, stated in part (formatting original):

1. Purpose of This Order. This order:
   - **a.** Governs the Federal Aviation Administration (FAA)Line of Business (LOB) and Office implementations of Safety Management Systems(SMS),which meet the International Civil Aviation Organization (ICAO) State Safety Program (SSP) framework, into the overall FAA SMS.
   - **b.** Explains the SMS principles and requirements.
   - **c.** Establishes the FAA SMS Executive Council and FAA SMS Committee.
   - **d.** Standardizes terminology for SMS.
   - **e.** Requires FAA organizations to develop implementation or continuous improvement plans for SMS.
   - **f.** Requires FAA organizations to establish guidance for their own SMS activities and their industry segment on implementing SMS.

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[35] See http://www.faa.gov/about/initiatives/sms/ [accessed February 27, 2015].
[36] See http://www.faa.gov/about/initiatives/sms/explained/ [accessed February 27, 2015].
[37] For the complete Order, see: http://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.information/documentID/1021106 [accessed April 16, 2015].

2. **Audience.** This order applies to the Air Traffic Organization (ATO), Aviation Safety Organization (AVS), Office of Airports (ARP), Office of Commercial Space Transportation (AST), the Office of the Next Generation Air Transportation System (ANG),and the Hazardous Materials Safety Program Office in the Office of Security and Hazardous Materials Safety (ASH). This order is written to allow for application to other FAA organizations as later deemed appropriate.

The FAA "Commercial Space Transportation Fiscal Year 2015 Business Plan,"[38] dated January 21, 2015, stated in part (formatting original):

> **Core Activity: Safety Management System**
>
> Support FAA's SMS Executive Council and FAA SMS Committee on SMS concerns affecting multiple lines of business. Modify AST's Safety Management System (SMS) as required to conform with FAA-wide policy, in order and to address industry's safety risk management issues more effectively.
>
> **Activity Target 1:**
> Modify AST's Safety Management System (SMS) as required to: (1) conform with FAA-wide policy, and (2) address industry's safety risk management issues more effectively. Due September 30, 2015.
>
> **Activity Target 2:**
> Used as place holder awaiting results of first FAA SMS Executive Council Meeting in FY 2015. Due September 30, 2015.

[38] For the complete AST FY15 business plan, see http://www.faa.gov/about/plans_reports/media/2015/AST_Business_Plan.pdf [accessed April 21, 2015].