NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

SYSTEM SAFETY GROUP CHAIRMAN'S FACTUAL REPORT

April 29, 2015

NTSB ID No.: DCA15MA019

A. ACCIDENT:

Location:	Koehn Dry Lake, CA
Date:	October 31, 2014
Time:	About 1007 local
Vehicle:	Scaled Composites, LLC M339 – "SpaceShipTwo"
Registration:	N339SS

B. GROUP MEMBERS:

Chairman:	Mike Hauf National Transportation Safety Board
Member:	Dan Murray Federal Aviation Administration
Member:	Robert Withrow Scaled Composites, LLC
Member:	Nicolette Dugué Scaled Composites, LLC
Member:	William Robertson Virgin Galactic, LLC

C. SUMMARY:

On October 31, 2014, about 1007 Pacific daylight time,[1] 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.

[1] Unless otherwise indicated, all times in this report are Pacific daylight time based on a 24-hour clock.

D. DETAILS OF THE INVESTIGATION:

The System Safety Group was formed on November 5, 2014, with group members from Scaled Composites, Virgin Galactic and the Federal Aviation Administration (FAA). The group was formed to investigate the experimental permit hazard analysis regulations, to review FAA guidance for conducting a hazard analysis and to review Scaled Composites, LLC (Scaled) approach for demonstrating how they met the Federal Aviation Regulations (FARs) applicable to the hazard analysis.

Activities performed by the System Safety Group included, conducting interviews, reviewing the Federal Aviation Regulations (FARs) applicable to the hazard analysis, reviewing FAA guidance for conducting a hazard analysis, reviewing Scaled's hazard analysis and a familiarization tour of the WhiteKnightTwo and SpaceShipTwo (serial 2) in production at the Virgin Galactic FAITH facility.

On December 10, 2014, the System Safety Group met at the Scaled Composites facility in Mojave, CA and conducted an interview with the Scaled Composites System Safety Analyst in conjunction with the Systems, Operational Factors and Human Performance Group.

From January 14-16, 2015, the System Safety Group conducted interviews of personnel from the office of Commercial Space Transportation (AST) in Washington, DC in conjunction with the Systems, Operational Factors and Human Performance Group.

On January 28, 2015, the System Safety Group Chairman participated in interviews of the FAA AST personnel and Scaled Composites employees.

The System Safety Group Chairman's Factual Report contains documentation relevant to the hazard analysis.

D.1 Commercial Space Launch Act - Background:

The Commercial Space Launch Act of 1984, (CSLA) as codified and amended at 51 U.S.C. Subtitle V, chapter 509 (Chapter 509)[2], authorizes the United States (U.S.) FAA, through delegations, to oversee, license and regulate commercial launch and reentry activities and the operation of launch and reentry sites as carried out by U.S. citizens or within the United States. Chapter 509 directs the FAA to exercise this responsibility consistent with public health and safety, safety of property, and the national security and foreign policy interests of the United States. The FAA is also responsible for encouraging, facilitating and promoting commercial space launches and reentries by the private sector.

Two hearings were held by the House Subcommittee on Space and Aeronautics regarding commercial human space flight during the first session of the 108th Congress on July 24, 2003, and November 5, 2003, to examine the industry and the barriers that exist to investing in entrepreneurial space ventures and with a focus on H.R. 3245, the Commercial Space Act of 2003, respectively.

[2] In 2010 the CSLA, as codified in 49 U.S.C. Subtitle IX, chapter 701, was renumbered and renamed as 51 USC Ch. 509: Commercial Space Launch Activities.

These formal hearings and informal discussions among members of the commercial space transportation industry brought to light concerns about unnecessary regulations and rulemakings; a lengthy licensing process that places excessive financial burdens on applicants; and a lack of regulatory flexibility, which could stifle rapid development of new and innovative launch vehicle designs. As a result, the Committee directed the Secretary of Transportation to review the existing launch licensing regulations for the entire commercial space industry with the goals of eliminating redundant regulations, streamlining the licensing process, and encouraging innovation while protecting public health and safety. These goals would guide AST's development of new regulations for crew, space flight participants, and experimental permits. As an additional result of the formal hearings, on February 4, 2004, the House Space and Aeronautics Subcommittee recommended that the Commercial Space Launch Amendments Act of 2004 (H.R. 3752 the CSLAA), [3] which promoted the development of the emerging commercial human space flight industry while protecting the public health and safety, be brought before the full House for consideration.

A March 1, 2004, legislative report titled "Commercial Space Launch Amendments Act of 2004" stated that, when the CSLA was enacted in 1984, only expendable launch vehicles (ELVs) and certain types of ballistic missiles were available for private sector use. These vehicles were typically used to lift satellites and other types of cargo into space. Since that time, commercial enterprises have pursued the development of reusable launch vehicles (RLVs), which are vehicles designed to enter space and return to Earth substantially intact. Congress amended the CSLA in 1998 to add licensing authority for reentry vehicles, including RLVs. However, there was no express jurisdiction granted under the law for the regulation of commercial human spaceflight. Moreover, the licensing process that existed at the time did not distinguish between experimental and operational RLVs. The Commercial Space Launch Amendments Act of 2004 was thus necessary to achieve several goals to promote the development of the emerging commercial human space flight industry.

Also, according to the March 1, 2004, legislative report, any individual or private entity wishing to conduct a commercial space launch or reentry in the United States or operate a launch or reentry site in the United States had to obtain a license from the FAA to do so. One of the goals of the Commercial Space Launch Amendments Act was to make it easier for the industry to test new types of reusable suborbital rockets[4] by allowing AST to issue experimental permits that can be granted more quickly and with fewer requirements than licenses, thus reducing the regulatory burden on developers of reusable suborbital rockets.

The Committee believed that permits were necessary to enable the development of new and innovative launch vehicle designs and to allow for crew training on experimental vehicles. The Committee instructed AST to model its regulatory approach to permits after the regulations promulgated by the FAA's Aircraft Certification and Regulations Office when issuing experimental certificates for aircraft, where applicable.

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[3] H.R. 3752 was referred to the Senate Committee on Commerce, Science, and Transportation in March 2004, but the act expired before any action could be taken. As a result, the House introduced H.R. 5382 in November 2004, which contained many of the same provisions as H.R. 3752.

[4] The Commercial Space Launch Amendments Act defines a suborbital rocket as a vehicle, rocket propelled in whole or in part, intended for flight on a suborbital trajectory, and the thrust of which is greater than its lift for the majority of the rocket-powered portion of ascent.

On December 23, 2004, Congress passed the Commercial Space Launch Amendments Act of 2004, making the FAA responsible for regulating commercial human spaceflight and establishing an experimental permit regime for developmental reusable suborbital rockets.

The Commercial Space Launch Amendments Act of 2004 included a provision indicating that, after an 8-year period, new regulations regarding commercial human space flight for crews and space flight participants could be proposed. The act stated that "any such regulation shall take into consideration the evolving standards of safety in the commercial space flight industry." The 8-year period was subsequently extended to October 1, 2015.

D.2 Office of Commercial Space Transportation:

The Office of Commercial Space Transportation was established in 1984 as part of the Office of the Secretary of Transportation within the Department of Transportation (DOT). In November 1995, AST was transferred to the Federal Aviation Administration as the FAA's only space-related line of business. AST was established to regulate the U.S. commercial space transportation industry, to ensure compliance with international obligations of the United States, and to protect the public health and safety, safety of property, and national security and foreign policy interests of the United States. Additionally, AST encourages, facilitates, and promotes commercial space launches and reentries by the private sector. The licenses and permits issued by FAA AST include a launch or reentry-specific license, launch or reentry operator license, launch site license, experimental permit, and safety approval.

An experimental permit allows suborbital reusable vehicles to launch or reenter while conducting research and development to test new design concepts, new equipment, or new operating techniques, showing of compliance with requirements for obtaining a license, or crew training.

AST manages its licensing and regulatory work as well as a variety of programs and initiatives to ensure the health and facilitate the growth of the U.S. commercial space transportation industry through the Office of the Associate Administrator for Commercial Space Transportation, along with its five divisions: the Space Transportation Development Division, the Licensing and Evaluation Division, the Regulations and Analysis Division, the Safety Inspection Division, and the Operations Integration Division.

The Licensing and Evaluation Division (AST-200) carries out AST's responsibility to ensure public health and safety by licensing commercial space launches and re-entries, licensing the operation of non-federal launch sites, and determining insurance or other financial responsibility requirements for commercial space launch activities. This division also issues experimental permits for developmental reusable suborbital rockets and safety approvals for launch vehicles, reentry vehicles, safety systems, processes, services, and/or components for commercial space launch operations and personnel performing functions related to licensed/permitted space launch activities[5].

To carry out its experimental permitting function, AST-200 reviews and approves experimental permit applications and develops experimental permit terms and conditions. AST-200 will also lead the evaluation of a request for a waiver from regulatory provisions. The components of the experimental permitting process include: pre-application consultation, policy review, payload review, safety evaluation, financial responsibility determination, and environmental reviews.

[5] Source: http://www.faa.gov/about/office_org/headquarters_offices/ast/about/licensing_evaluation_division.

While AST-200 leads the evaluation of a waiver, other AST divisions are often involved, depending upon what requirements the applicant has requested to be waived. When another AST division does provide input to the evaluation, their results are usually transmitted to AST-200 in the form of a memo. Typically, AST-200 will take the lead in drafting the content of the waiver. They will often use text from memos created by other divisions. The content of the waiver can vary based on a number of factors, including whether the particular regulation has been waived in the past (i.e. once language is approved, AST-200 will often reuse that language on subsequent waivers to the same regulation, where applicable). Once AST-200 has a draft, that draft is circulated for review among the other divisions, AST management, and FAA General Counsel. Each review can make recommend changes to the content of the draft waiver. Once the recommended changes are adjudicated, the content is finalized and the AST-200 Division Manager signs the waiver.

The Regulations and Analysis Division (AST-300), develops, manages, and executes the AST Rulemaking Program and the AST Tools and Analysis Program. Under the Tools and Analysis Program, AST-300 conducts flight safety analyses, system safety analyses, and specific types of safety analyses, such as explosive siting analyses, ground hazard area analyses, and aircraft hazard area analyses, in support of licensing and permitting evaluations.

The Safety Inspection Division (AST400), previously implemented under the former Licensing and Safety Division, was established as a separate division in March 2011 for the continued purpose of executing AST's Compliance and Enforcement program. For additional information on AST-400, see the Operation Factors Group Chairman’s Factual Report.

The Operations Integration Division (AST-500) was established in 2012 for the coordination and oversight of operations, programs and initiatives taking place in AST field offices. AST-500 field offices include the Commercial Space Transportation Safety Office at Patrick Air Force Base, Florida, the West Coast Operations Office in Palmdale, California, and the AST Commercial Resupply Services Office in Houston, Texas.

D.3 SpaceShipTwo - Experimental Permit History:

As part of the 14 CFR 413.5 pre-application consultation process to obtain an experimental permit for SpaceShipTwo, Scaled consulted with the Federal Aviation Administration’s Office of Commercial Space Transportation, beginning in March of 2010 and ending when they submitted their formal experimental permit application to AST on January 24, 2012. Reference section D.4.4 of this report for additional information regarding the pre-application consultation process.

In a letter[6] from Scaled to AST, dated, January 23, 2012, Scaled submitted an application to AST for an experimental permit for their SpaceShipTwo reusable horizontal take-off, horizontal landing suborbital vehicle operating out of the Mojave Air and Space Port, Mojave, California. The letter indicated that the vehicle would be flown for the purpose of research and development.

An NTSB review of the experimental permit application (document T1B-90E060 RB.2) that Scaled submitted to AST was reviewed. According to the application, its purpose was to obtain an experimental permit under 14 CFR part 437 to conduct rocket-powered test flights of SpaceShipTwo. As required by

[6] See Attachment 1 –Scaled Composites, LLC, letter to AST dated January 23, 2012.

section 437.23, Scaled provided a program description in their application which stated Scaled Composites (Scaled) is a proof-of-concept and prototyping aerospace company tasked with developing a reliable, reusable, and affordable suborbital commercial space tourism system for Virgin Galactic (VG). This program was called "Tier 1B". The goals for the Tier 1B program were to test and evaluate the vehicles and the systems and thus to improve safety and reliability of manned commercial space flight. Scaled was developing and testing these proof-of-concept vehicles in support of this program. Scaled developed the White Knight Two mother ship (WK2) and SpaceShipTwo (SS2) space plane for the Tier 1B program in order to meet the goals of future commercial manned space flight. Two sections contained within Scaled's application for an experimental permit describe the process Scaled used to comply with the 14 CFR 437.55(a) "hazard analysis" requirements: Section 3.2, titled, "System Safety Analysis 437.29 & 437.55(a)", and section 8.5 titled "system safety analysis approach," dated February 14, 2011. Section 8.6 of the experimental permit presented Scaled's overall system safety analysis (SSA) for SpaceShipTwo.

In a letter from the FAA (AST-200) to Scaled, dated February 7, 2012[7], AST informed Scaled that on January 24, 2012, AST had received Scaled's application for an experimental permit for the SpaceShipTwo reusable horizontal take-off, horizontal landing suborbital vehicle. In the letter, AST confirmed to Scaled that its experimental permit application was complete enough for the FAA to initiate the application review process and that they anticipate making an experimental permit determination within 120 day of its receipt (May 23, 2012).

When AST receives a formal application for an experimental permit, AST-500 will perform an initial screening of the application to determine whether the application is complete enough to be accepted and to start the 120-day review period[8]. A complete enough determination is the final milestone of pre-application consultation. It signals to the applicant that the process has transitioned from the consultation phase to the evaluation phase, and that the FAA lead for the remainder of the application process has transitioned from AST-500 to AST-200.

An application does not have to complete to be accepted. Rather, it must be complete enough to allow AST to initiate its evaluation process. AST uses checklists that step reviewers through each applicable regulation, facilitating a determination of "complete enough" on a regulation-by-regulation basis. AST provides similar checklists to applicants on its website to assist them in assembling a complete enough application. To be considered complete enough, AST must find that the application contains material that directly addresses each regulation, that the material provided is clear and understandable, that it is supported by scientific principles, and that there are no obvious inconsistencies between the responses to different regulations. More comprehensive reviews are performed during the evaluation period. AST can accept an incomplete application if the applicant has identified the missing or incomplete material and provided a plan by which that material will be provided in time to support AST's determination within the required 120-day evaluation period. This is often the case with the verification data required in 437.55(a)(5), where an applicant has identified a risk mitigation measure and developed plans for conducting the necessary testing, inspection or analysis to verify the measure, but has yet to completed the testing, inspection, or analysis.

[7] See Attachment 2 – FAA letter to Scaled Composites, LLC, dated February 7, 2012.
[8] According to 14 CFR Part 413.15 "Review period," the FAA will review an experimental permit application and make a determination within 120 days of receiving an accepted permit application.

By internal policy, AST has 14 calendar days from the date of receipt of an application to notify the applicant in writing whether its application is complete enough or not. During the 14-day review period, there is often some back-and-forth discussion between AST and the applicant to clarify statements made in the application, to identify missing material, or to discuss plans by which missing material will be provided.

Once an application is accepted, AST initiates its permit application evaluation process. An evaluation team is formed, made up of relevant subject matter experts from across AST's divisions and led by an AST-200 Permit Team Lead. An evaluation includes an environmental review, a policy review, a payload review, a safety review, and a financial responsibility determination. Permit evaluation teams generally consist of an environmental specialist from AST-100, multiple analysts from AST-300 specializing in operating area analysis, hazard analysis, and maximum probable loss analysis, and multiple engineers from AST-200 with specialized experience in particular safety critical vehicle systems, such as propulsion, avionics, or flight controls. The Permit Team Lead assigns each member of the team the responsibility for evaluating particular elements of the application. The evaluators check the applicant's materials to ensure that they are complete, rational, and demonstrate compliance with the regulations. Evaluators may enlist the support of other AST subject matter experts or contracted support as necessary. An applicant's use of advisory circulars can expedite this process. The evaluation team meets regularly to discuss evaluation status and issues, and to review and compare its findings. Toward the end of an evaluation, the team prepares an evaluation document. This document identifies the applicable regulations, provides an assessment that summarizes and examines the material that the applicant provided to demonstrate compliance with each regulation, and provides a finding of whether or not that material demonstrates compliance. The evaluation also contains a recommendation from the team to AST management to support a determination of whether or not to grant the permit. At the end of the evaluation, the team provides this recommendation, along with a summary of the application and supporting material, to AST management at a Management Review Board.

In a letter from the FAA (AST-200) to Scaled, dated May 23, 2012, AST informed Scaled that the FAA was issuing an experimental permit, EP 12-007, to Scaled for SpaceShipTwo[9]. The effective date of the experimental permit was May 23, 2012 and the term of the permit was one year from the effective date. An NTSB review of EP 12-007 found that the permit was granted subject to the terms, conditions, and limitations set forth in permit orders A and B[10] and any subsequent orders issued by AST. According to the terms of the permit, Scaled was required at all times to conduct its operations in accordance with the regulations prescribed by AST for the activities authorized by EP 12-007. EP 12-007 authorized Scaled to conduct an unlimited number of launches of SpaceShipTwo utilizing WhiteKnightTwo within the operating area[11] identified by permit order A. Order A also prescribed definitions and conditions applicable to each launch conducted by Scaled under the permit. Two of the conditions, (number 7 and number 8) required Scaled to submit additional information to the FAA for approval before flight[12].

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[9] See Attachment 3 for a copy of FAA letter to Scaled Composites, LLC, dated May 23, 2012 and for a copy of experimental permit, EP 12-007.

[10] Order B prescribes the financial responsibility requirements for permitted activities in accordance with C.F.R. Part 440.

[11] According to Order A, the operating area is R-2508 Complex, which is restricted airspace described in a letter of agreement among Scaled, the R-2508 Complex Control Board, and the Air Force Flight test Center.

[12] According to the FAA, an applicant would typically include the information prescribed by conditions number 7 and 8 in its application. However, in this case, Scaled had not yet completed its work to identify the specific population zones and to mitigate all of its hazards to its criteria. Therefore, it was necessary for AST to include these two conditions as permit terms

Condition number 7 stated that Scaled must submit to the FAA the locations of specific population zones that will be avoided during the key flight safety events of each SS2 mission. Condition number 8 stated that Scaled must submit an updated hazard analysis showing that all identified hazards have been mitigated to Scaled's acceptability criteria and that the FAA must approve this analysis before permitted flight.[13]

On March 6, 2013, Scaled submitted an application to AST to modify and renew the experimental permit, EP 12-007, which was set to expire on May 22, 2013. According to Scaled's application (document T1B-90E076 RA.1), pursuant to 14 CFR 437.85(b)(2) and (c)[14], Scaled requested the FAA to modify its experimental permit as a result of material changes and modifications that were made to SS2 since permit EP 12-007 was issued by the FAA. Scaled's application to modify and renew the permit contained an update to the hazard analysis, as required by condition 8 of Order A of the original permit. The update included a document titled "Clarification of Hazard Analyses Mitigations," dated April 4, 2013,[15] and a document titled "Additional Information about Hazards," dated April 18, 2013.[16]

In a letter from the FAA (AST-200) to Scaled, dated April 23, 2013,[17] the FAA informed Scaled that it had determined that Scaled had met condition 8 of the original permit.

In a letter from the FAA (AST-200) to Scaled dated May 22, 2013 the FAA granted Scaled the requested renewal[18]. An NTSB review of EP 12-007 (Rev 1) found that the renewal was subject to similar terms, conditions, and limitations set forth in the original permit with the exception of the requirement for Scaled to submit an updated hazard analysis, which was no longer included as a term and condition of the permit.

On July 18, 2013, the FAA published a notice of waiver (72 *Federal Register* Vol. 78, No. 138, Pg. 42994) titled "Waiver of 14 CFR437.29 and 437.55(a) for Scaled Composites, LLC." This notice published a waiver relieving Scaled from the requirements of sections 437.29 and 437.55(a) to provide the FAA with a hazard analysis that "identifies, mitigates, and verifies and validates mitigation measures for hazards created by software and human error." Reference section D.7 of this report for further information regarding the waiver.

On March 17, 2014, Scaled submitted an application to AST to renew and modify its experimental permit, EP 12-007 (Rev 1). In a letter from the FAA (AST-200) to Scaled, dated March 28, 2014[19], AST informed Scaled that it had received the application and determined that additional information/clarification was needed to complete the evaluation. AST provided Scaled with a list of items to be addressed. An NTSB review of AST's list of items did not find any related to software errors.

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and conditions. It is not uncommon for an applicant to plan to complete some of the elements of their analysis or testing during the evaluation period or after the issuance of a permit but before flight.

[13] According to Order A, the term "flight" meant the flight of SS2 commencing upon takeoff of WhiteKnightTwo from Mojave Air and Space Port with the intent to launch SS2.

[14] Part 437.85 provides information on allowable design changes; modification of an experimental permit.

[15] See Attachment 4 – Scaled document titled "Clarification of Hazard Analyses Mitigations," dated April 4, 2013.

[16] See Attachment 5 – Scaled document titled "Additional Information about Hazards," dated April 4, 2013.

[17] See Attachment 6 – FAA letter to Scaled Composites, LLC, dated April 23, 2013.

[18] See Attachment 7 for a copy of FAA letter to Scaled Composites, LLC, dated May 22, 2013 and for a copy of experimental permit, EP 12-007 (Rev1).

[19] See Attachment 8 – FAA letter to Scaled Composites, LLC, dated March 28, 2014.

However, item number 6 requested that Scaled update its hazard analysis to address potential pilot incapacitation due to vibration.
In a letter from the FAA (AST-200) to Scaled dated May 21, 2014, the FAA informed Scaled that it was again waiving the requirements of 14 CFR 437.29 and section 437.55(a).[20] The letter stated that the waiver was necessary because Scaled's application for renewal of its permit did not fully meet those requirements.

An NTSB review of EP 12-007 (Rev 2) found that the permit was granted on May 21, 2014 (with an effective date of May 23, 2014) and was subject to similar terms, conditions, and limitations set forth in revision 1 of the permit[21].

On July 16, 2014, Scaled submitted an application to AST to modify the experimental permit, EP 12-007 (Rev 2) to reflect material changes made to SpaceShipTwo. In a letter from the FAA (AST-200) to Scaled, dated October 14, 2014[22], AST indicated the following: "On May 21, 2014, the FAA waived specific hazard analysis requirements of 14 CFR 437.29 and 437.55(a) for the second renewal of Experimental Permit No. 12-007. The FAA waived the requirements that Scaled provide a hazard analysis that identifies, mitigates, and verifies and validates mitigation measures for all hazards. For the same reasons stated in the May 21, 2014 waiver, the FAA waives 14 CFR 437.29 and 437.55(a) for the permit modifications listed in this letter."

D.4 Experimental Permit for Reusable Suborbital Rockets:

D.4.1 Brief Overview:

Prior to the enactment of the CSLAA in 2004, a launch license was the only mechanism available to the FAA to authorize the launch of a space launch vehicle. On April 6, 2007, the FAA published its final rule entitled "experimental permits for reusable suborbital rockets" (*Federal Register* Vol. 72, No. 66, pgs. 17001 to17024).[23] The final rule became effective on June 5, 2007. In that rule, the FAA amended its commercial space transportation regulations under the Commercial Space Launch Amendments Act of 2004. The FAA established application requirements for an operator of a manned or unmanned reusable suborbital rocket to obtain an experimental permit. The FAA also established operating requirements and restrictions on launch and reentry of reusable suborbital rockets operated under a permit.

An experimental permit is an authorization issued by the FAA to allow an experimental reusable suborbital rocket to launch or reenter while conducting research and development to test new design concepts, new equipment, or new operating techniques, showing compliance to obtain a license, or crew training. As an alternative to licensing, this permit is processed faster than a license, allows a permittee to conduct an unlimited number of launches and reentries for a particular vehicle design, and is valid for a one-year renewable term. Some of the key components of the permitting process are:

- Pre-application Consultation (14 CFR 413.5):
- Acceptance of an application (14 CFR 413.11):
- Complete application (14 CFR 413.13):

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[20] See Attachment 9 – FAA letter to Scaled Composites, LLC, dated May 21, 2014.
[21] See Attachment 10 – Experimental Permit Number EP 12-007 (Rev2).
[22] See Attachment 11 – FAA letter to Scaled Composites, LLC, dated October 14, 2014.
[23] See Attachment 12 – Experimental Permit Rule for reusable suborbital rockets.

- Issuing a permit (14 CFR 413.19):
- Permit renewal (14 CFR 413.23):

According to Subpart D, titled "Terms and Conditions of an Experimental Permit," a permittee must ensure that a launch or reentry conducted under an experimental permit is safe, and must protect public health and safety and the safety of property. A permittee must also conduct any launch or reentry under an experimental permit in accordance with representations made in its permit application, with subparts C and D of part 437, and with terms and conditions contained in the permit.

Section 437.85 titled "Allowable design changes; modification of an experimental permit" states the following:

(a) The FAA will identify in the experimental permit the type of changes that the permittee may make to the reusable suborbital rocket design without invalidating the permit.

(b) Except for design changes made under paragraph (a) of this section, a permittee must ask the FAA to modify the experimental permit if:

(1) It proposes to conduct permitted activities in a manner not authorized by the permit; or

(2) Any representation in its permit application that is material to public health and safety or the safety of property is no longer accurate or complete.

(c) A permittee must prepare an application to modify an experimental permit and submit it in accordance with part 413 of this subchapter. If requested during the application process, the FAA may approve an alternate method for requesting permit modifications. The permittee must indicate any part of its permit that would be changed or affected by a proposed modification.

(d) When a permittee proposes a modification, the FAA reviews the determinations made on the experimental permit to decide whether they remain valid.

(e) When the FAA approves a modification, it issues the permittee either a written approval or a permit order modifying the permit if a stated term or condition of the permit is changed, added, or deleted. An approval has the full force and effect of a permit order and is part of the permit record.

D.4.2 Application Process (Acceptance, Completion, and Review Period):

According to 14 CFR 413.23 "License or permit renewal," a licensee or permittee may apply to renew its license or permit by submitting to the FAA a written application for renewal at least 90 days before the license expires or at least 60 days before the permit expires. A license or permit renewal application must satisfy the requirements set forth in part 413 and any other applicable part of chapter III. The application may incorporate by reference information provided as part of the application for the expiring license or permit, including any modifications to the license or permit. An applicant must describe any proposed changes in its conduct of licensed or permitted activities and provide any additional clarifying information required by the FAA. The FAA reviews the application to determine whether to renew the license or permit for an additional term. The FAA may incorporate by reference any findings that are part of the record for the expiring license or permit. After the FAA finishes a favorable review, the FAA issues an order modifying the expiration date of the license or permit. The FAA may impose additional or revised terms and conditions necessary to protect public health and safety and the safety of property and to protect U.S. national security and foreign policy interests. The FAA informs a licensee or permittee, in writing, if the FAA denies the application for renewal and states the reasons for denial. If the FAA denies an application, the licensee or permittee may follow the procedures of §413.21 of this part.

D.4.3 FAA's Approach to Developing Guidelines for a Hazard Analysis:

An FAA-authored paper titled "FAA's Implementation of the Commercial Space Launch Amendments Act of 2004 – The Experimental Permit" describes the FAA's approach in developing guidelines for obtaining and maintaining an experimental permit and describes the core safety elements of those guidelines.[24] Section 4 titled "Core Safety Measures in FAA's Experimental Permit Guidelines" states that the experimental permit guidelines include a variety of safety measures that protect the public. A Hazard Analysis is one of the core safety measures and is described in section 4.1 of the paper. This section states that an applicant performs a hazard analysis and provides the results to the FAA. Typical elements of a hazard analysis include:

- Identifying and describing hazards,
- Assessing risk using qualitative severity and likelihood levels,
- Identifying and describing risk elimination and mitigation measures to reduce the risk to acceptable levels, and
- Demonstrating that the risk elimination and mitigation measures are correct, complete, and achieve an acceptable reduction in risk.

The report also states that the U.S. Department of Defense, the National Aeronautics and Space Administration, and the aerospace industry have successfully used hazard analyses for decades to identify, characterize, and analyze hazards and reduce risks to acceptable levels. The guidelines include the following criteria to determine the acceptability of the risks:

- The occurrence of any hazardous condition that may cause death or serious injury to the public should be extremely unlikely, and
- The likelihood of an occurrence of any hazardous condition that may cause major property damage to the public, major safety-critical system damage or reduced capability, decreased safety margins, or increased workload should be remote.

D.4.4 Pre-application Consultation:

Under section 14 CFR 413.5 "Pre-application Consultation," a prospective applicant must consult with the FAA before submitting an application to discuss the application process and possible issues relevant to the FAA's licensing or permitting decision. According to FAA Advisory Circular (AC) 413-1, titled "License Application Procedures," dated August 16, 1999, pre-application consultation is mandatory in order to allow both an applicant and the FAA the opportunity to identify potential issues relevant to the FAA's licensing determination.[25] Pre-application consultation allows a prospective applicant to familiarize the FAA with its proposal and the FAA to familiarize the prospective applicant with the licensing process. It is intended to provide an efficient and effective process leading to the development of a substantially complete application. It should also ensure that an applicant is aware of the responsibilities of a licensee.

AC 413-1 also states that pre-application consultation is not a formal structure or need not be accomplished within a set timetable. Early consultation is advisable to enable the applicant to identify potential licensing issues at the planning stage when changes or modifications to an applicant's program or commercial space transportation application are less likely to result in significant delays or costs to the

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[24] See Attachment 13 – FAA-authored paper titled "FAA's Implementation of the Commercial Space Launch Amendments Act of 2004."

[25] See Attachment 14 – FAA Advisory Circular 413-1, titled "license Application Procedures," dated August 16, 1999.

applicant. This avoids potential wasted efforts by a prospective applicant in preparation of an application. For new launch concepts, the pre-application process allows a prospective applicant and AST's Licensing and Evaluation Division to identify an efficient process for the applicant to demonstrate the safety of any proposed launch, reentry, or operation of a launch or reentry site.

According to AC 413-1, the requirement for pre-application consultation does not require personal face-to-face meetings. For many proposals consultation may be made by telephone, electronic mail, or other means. A prospective applicant's concept, issues and schedule nearly always drive the schedule and order of such discussions. Space transportation concepts are often very complex, and the establishment of a good working relationship with FAA early in the life cycle of a commercial space transportation program is beneficial to all participants. The submittal by an applicant of parts or elements of the necessary material for review as they are developed is strongly recommended. In all cases, the FAA encourages the proposed applicant to submit, as part of the process, application material in draft, and the FAA will review and provide informal feedback on the content.

During an interview[26], AST indicated that during this process they review how an applicant is proposing to demonstrate compliance with the relevant regulations and then would provide guidance on what the applicant is proposing. If the applicant is unable to meet a regulatory requirement, the option would be to issue a waiver[27]. If the applicant can demonstrate either qualitatively or quantitatively an equivalent level of safety, then a waiver may not be needed. As part of the pre-application consultation process to obtain an experimental permit for SpaceShipTwo, Scaled consulted with the FAA (AST) beginning in March of 2010 up until they submitted their formal experimental permit application to AST on January 24, 2012.

During an interview[28] with the NTSB, an AST employee indicated that in an effort to reduce the burden on an applicant, such as Scaled, from having to interface with multiple individuals from AST during a project, they identified an individual from AST to be their main point of contact with Scaled throughout the lifecycle of the SpaceShipTwo project. This individual's role was to interface with Scaled, build a relationship, and facilitate communication between Scaled and AST.

During Scaled's pre-application consultation process (March of 2010 - January 24, 2012), AST's main point of contact with Scaled was a member of the AST West Coast Field Operations office[29] located in Palmdale, California. In about 2012, AST created the AST-500 Operations Integration Division for the primary purpose of building relationships, facilitating communication and conducting pre-application consultations with applicants. AST's main point of contact with Scaled became a member of AST-500 during this timeframe and continued to perform the same day-to-day interfacing with Scaled.

During an interview[30] with the NTSB, AST's main point of contact with Scaled described the communication process between Scaled and AST. When Scaled would provide her with information

[26] Reference NTSB interview summary of Mr. Kenneth Wong on Wednesday, January 14, 2015.
[27] During the pre-application consultation process, waivers are not typically discussed with applicants (and particularly new applicants) as they believe that they can meet the requirements. However, there are exceptions, and they generally come up with experienced applicants (those who have received licenses/permits in the past for other programs). An applicant may know up front that it will have a hard time meeting a particular regulation and will discuss the need for a waiver during consultation process. AST, would consider the waiver during the evaluation process.
[28] Reference NTSB interview with Mr. Randy Repcheck on January 14, 2015.
[29] The West Coast Field Operations office was its own office and was separate from the other AST divisions.
[30] For additional information, reference Operational Group Chairman's interview summaries.

(such as draft experimental permit applications, hazard analysis, etc.) or submit questions, she would typically submit the information/questions to the AST-200 (Licensing & Evaluation Division) Permit Team Lead. She indicated that the lead would then provide the information to the other permit evaluation team members, which would include representatives from AST-200, AST-100 (Space Transportation Development Division) and AST-300 (Regulations & Analysis Division); she did not have regular direct interaction with the personnel working in the other divisions. She also stated that when an individual from one of these divisions had a question for Scaled, they would submit the question through the AST-200 Permit Team Lead, who would work with her, as the AST-500 point of contact, to pass the question along to Scaled. Typically, after the questions were submitted to Scaled, AST-500 would set up a technical interchange meeting (TIM) between AST and Scaled engineers to provide clarification and discussions.

In addition to interfacing with AST during the approximate two-year consultation process, Scaled submitted two draft versions of their experimental permit for SS2 and presented briefings to AST regarding the overall plan. During the process, Scaled provided their draft experimental permit material (including the hazard analysis) to their AST point of contact, who forwarded the information on the AST 200 Permit Team Lead and then to the rest of the permit evaluation team. Team members would review the information contained within the application and get comments back to the AST point of contact.

A Scaled Employee[31] interviewed by the NTSB, indicated the functional hazard analysis (FHA), fault tree analyses (FTA) and the assumptions in the fault trees were discussed with the FAA during the pre-application meetings. The FAA asked questions about Scaled's methodologies. This included questions regarding how Scaled arrived at the quantitative hazard likelihoods (i.e. probabilities) used in the FTAs, and how Scaled's hazard analysis addressed the regulatory requirement to protect public safety considering that the hazard severity classification Scaled used were developed in terms of the effect of the hazard on the vehicle, occupants, and crew. There were also questions on how Scaled's analysis addressed hazards before mitigations and how particular systems were being analyzed. The Scaled employee did not recall any indication from the FAA during those conversations that Scaled's approach did not demonstrate compliance with the regulations.

In February 2011, AST-300 contracted with ACTA Inc.[32] (a risk management company) who contracted with Great Circle Analytics to provide AST with support in the areas of system safety and hazard analysis. This support included providing assistance to the FAA's evaluation of the Scaled's SS2 draft experimental permit application, dated February 21, 2011, which included evaluating portions of a preliminary version of Scaled's System Safety Analysis, and approach to system safety.

On March 7, 2011, Great Circle Analytics provided AST-300 with a summary report of their significant findings from their preliminary evaluation of the Scaled's SS2 draft experimental permit hazard analysis. An NTSB review of Great Circle's March 7 report found that provided an assessment of Scaled's hazard identification.

The report indicated that "*Scaled Composites approach incorporates two different inductive methods, Fault Tree Analysis and Functional Hazard Analysis. Both methods begin with a hazardous condition and work backward to the cause. Supplementing those methods are common cause analyses which try to*

[31] For additional information, reference NTSB interview with Mr. Robert Withrow on January 28, 2015.
[32] ACTA Inc., founded in 1982, is a U.S. company that evaluates range safety hazards and risks from launch vehicle debris, blast and toxic gases, for the Department of Defense, the FAA, NASA, and international companies and agencies.

identify the potential for a single failure or condition causing loss of a system or subsystem. The FHA and FTA are both identified as acceptable methods in AC 437.55-1, and AC 23.1309-1 is identified as a reference in AC 437.55-1. As such, the tools used are acceptable for an experimental permit. A suggested addition to this approach to improve Scaled's understanding of failures would be the use of a Failure Modes and Effects Analysis (FMEA), which is a bottom-up, deductive method that allows for analysis of failures of components as well as hazards. A FMEA is not a requirement for an experimental permit, however."

The report contained only one reference to the hazards identified for the feather system. The comment was in reference to the classification of the hazard "misleading feather position indication." Scaled had classified the hazard as minor and the report questioned if the hazard should be "catastrophic" if the crew thinks the feather is up, but it is not.

The report also indicated that Scaled used the values of E^{-2} ($1x10^{-2}$) and E^{-1} ($1x10^{-1}$) for routine and non-routine human actions, respectively. The report recommended that FAA/AST request the rationale for those values. For example, researchers have found that possibility of human errors can actually increase when tasks become routine because people can become less focused on the task.

On January 22, 2015, the NTSB[33] conducted an interview with Great Circle Analytics[34].

The Great Circle summary report was not provided to Scaled.

D.5 Hazard Analysis:

D.5.1 Requirements:

According to 14 CFR 437.29 "Hazard Analysis" an applicant must perform a hazard analysis that complies with 14 CFR 437.55(a) and an applicant must provide to the FAA all the results of each step of the hazard analysis.

Requirement 14 CFR 437.55 "Hazard Analysis" states:

(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 component, subsystem, or system failures or faults, software errors, environmental conditions; human errors, design inadequacies, or procedural deficiencies.

   (2) Determine the likelihood of occurrence and consequence for each hazard before risk elimination or mitigation.
   (3) Ensure that the likelihood and consequence of each hazard meet the following criteria through risk elimination and mitigation measures:

[33] The System Safety Group Chairman, along with the Systems Group Chairman, Operational Factors and Human Performance Group chairman conducted the interview.
[34] See attachment 25 – Interview summaries.

(i) The likelihood of any hazardous condition that may cause death or serious injury to the public must be extremely remote.
(ii) The likelihood of any hazardous condition that may cause major property damage to the public, major safety-critical system damage or reduced capability, a significant reduction in safety margins, or a significant increase in crew workload must be remote.

(4) Identify and describe the risk elimination and mitigation measures required to satisfy paragraph (a)(3) of this section. The measures must include one or more of the following:
(i) Designing for minimum risk,
(ii) Incorporating safety devices,
(iii) Providing warning devices, or
(iv) Implementing procedures and training

(5) Demonstrate that the risk elimination and mitigation measures achieve the risk levels of paragraph (a)(3)(i) of this section through validation and verification. Verification includes:
(i) Test data,
(ii) Inspection results, or
(iii) Analysis.

(b) A permittee must carry out the risk elimination and mitigation measures derived from its hazard analysis.

(c) A permittee must ensure the continued accuracy and validity of its hazard analysis throughout the term of its permit.

D.5.2 FAA Guidance for 14 CFR 473.55 Hazard Analyses:

FAA advisory circular (AC) 437.55-1, titled, "Hazard Analyses for the Launch or Reentry of a Reusable Suborbital Rocket under an Experimental Permit" dated April 20, 2007, provides guidance for applying a systematic and logical hazard analysis[35] to the identification, analysis and control of public safety hazards and risks associated with the launch and reentry of a reusable suborbital rocket under an experimental permit.[36] AC 437.55-1 provides an acceptable approach to performing a hazard analysis as required by 14 CFR 437.55. According to AC 437.55-1, other approaches that fulfill regulatory objectives may be acceptable to the FAA.

Section 5 of AC 437.55-1 provides the information and steps describing one means for an applicant to perform an acceptable hazard analysis. According to the AC, there are four main steps in the hazard analysis process. These steps are: (1) identify and describe the hazards, (2) determine and assess the risk for each hazard, (3) identify and describe risk mitigation and elimination, and (4) validate and verify risk elimination measures.

Section 6 of AC 437.55-1 provides information on updating the hazard analysis. This section states that a hazard analysis is performed early in the launch vehicle development process to identify hazards and risks

[35] According to section 5 of AC 437.55-1, a hazard analysis is an iterative process used to identify and characterize hazards, assess risks, identify risk reduction measures, and provide evidence that the risks have been reduced.
[36] See Attachment 15 – FAA Advisory Circular, 437.55-1, dated April 20, 2007.

in order to influence system design and operation to prevent mishaps. As required by section 437.55(c), a permit holder must ensure the continued accuracy and validity of its hazard analysis throughout the term of the permit. Therefore, the launch vehicle operator should also implement a process to update the hazard analysis and risk assessment to reflect the knowledge gained during the life of the system.

Section 7 "Acceptable Methods" provides information on common analytical approaches to identifying and characterizing hazards and risks. One of the acceptable analytical approaches listed is a functional hazard analysis (FHA)[37]. This approach may satisfy the regulatory requirements of identifying and characterizing hazards and risks as long as the approach includes the information described in section 5 "hazard analysis" of the AC. Section 7 also indicated other approaches that may satisfy the regulatory requirements such as a preliminary hazard analysis, failure modes and effects analyses (FMEA), or failure modes, effects and criticality analyses (FMECA).

D.5.3 Scaled's Methodology and Approach for Compliance with Sections 437.29 & 437.55:

D.5.3.1 System Safety General:

Scaled's application for an experimental permit (document T1B-90E060 RB.2) provided information on the process Scaled used to comply with the 14 CFR 437.55(a) hazard analysis requirements; this information was provided in Section 3.2, titled, "System Safety Analysis 437.29 & 437.55(a)." In their application, Scaled indicated that a comprehensive system safety analysis (SSA) was performed for SpaceShipTwo (SS2) and its Rocket Motor Two (RM2) systems and that this process was compliant with 14 CFR 437.55(a). Scaled indicated a number of sources were used for guidance in conducting the SSA including Advisory Circular (AC) 437.55-1, "Hazard Analysis for the Launch or Reentry of a Reusable Suborbital Rocket under an Experimental Permit."

Scaled's approach to the SSA comprised several different analytical tools, including a functional hazard assessment (FHA), fault tree analysis (FTA), and Common Cause Analysis, including Common Modes Analysis (CMA) and Zonal Safety Analysis (ZSA). An FHA is a systematic, top-down, comprehensive examination of vehicle and system functions to identify potential Minor, Major, Hazardous, and Catastrophic Failure Conditions that may arise as a result of a malfunction or a failure to function.
A FTA is a deductive failure analysis which focuses on one particular undesired event and provides a method for determining causes of this event. A CMA analyzes the design and implementation and looks for elements that may defeat the redundancy or independence of functions within the design. A ZSA is a process which allows consideration of installation aspects of individual systems/items and the mutual influence among several systems/items installed in close proximity on the aircraft and ensures that the equipment installation meets the safety requirements with respect to basic installation, interference between systems and maintenance errors.

Section 3.2 of document T1B-90E060 RB.2 described Scaled's approach to protecting the uninvolved public. Scaled indicated that because SS2 is a piloted vehicle, the safety analysis shows that *significant* risk to the uninvolved public and their property is prevented for those hazards which leave the vehicle in an adequately controllable state. In those cases, the crew can and would pilot the ship so as to avoid injury to the public. Hazards in the catastrophic or hazardous class are required to have very low

[37] According to AC 437.55-1, the definition of a FHA is a systematic, comprehensive examination of vehicle and system functions to identify potentially hazardous conditions that may arise as a result of an anomaly.

probability because they may prevent the crew from performing this function (the crew may be disabled or the craft may be uncontrollable) and thus directly present risk to the uninvolved public as well as the crew and the craft.

This section of the report also described how Scaled's SSA process was equivalent to that suggested in AC437.55-1 and how it met the 14 CFR 437.55 requirements. Scaled indicated that it categorized hazards according to their effect on the aircraft or crew. If the effect of a specific hazard was such that it could not credibly result in the outcomes described in Section 437.55(a)(3)(i) and Section 437.55(a)(3)(ii), no further analysis was needed. When a hazard met the criteria defined by Section 437.55(a)(3) prior to mitigation, no risk mitigation measures were required and Section 437.55(a)(4) was not applicable. These hazards correspond to the severity categories of major, minor, or no safety effect that Scaled used in its FHA. For higher severity hazards, Scaled performed a fault tree analysis using either conservative or other[38] component failure probability values. If the likelihood of occurrence of the hazard demonstrated by the FTA did not exceed 1×10^{-6} per flight hour[39], no further analysis was needed. For these hazards, the results of the FTA demonstrated compliance with Section 437.55(a)(3) with no further risk elimination or mitigation measures required. If the likelihood of occurrence of the hazard exceeded 1×10^{-6} in the preceding step, some sort of risk elimination or mitigation measures were required. Scaled identified these hazards in the FHA with an "M" for mitigation, and/or a "P" to indicate the need for a procedure. For these hazards, Scaled performed an additional FTA for the hazard with the mitigation applied to reduce the likelihood of occurrence below 1×10^{-6}. Here, the results of the FHA/FTA with mitigation applied demonstrated compliance with Section 437.55(a)(3), and 437.55(a)(4).The FHA/FTA and qualitative mitigations delivered to the FAA on April 4, 2013 and April 18, 2013, and accepted by the FAA on April 23, 2013 were the supporting evidence satisfying Section 437.55(a)(4).

Section 8.5 of Scaled's experimental permit contains a document (T1B-90E060), titled "system safety analysis approach," dated February 14, 2011. This document described the approach (SSA) Scaled used to meet the requirements of 14 CFR Part 437.55 and compares it to the approach contained within AC 437.55-1.

Section 8.6 of Scaled's experimental permit contains a document (T1B-90E033), titled "functional hazard assessment (FHA) for Scaled's model M348 WhiteKnightTwo (WK2) dated February 11, 2014, and M339 SpaceShipTwo (SS2) space plane," dated October 02, 2014. This document presents Scaled's overall system safety analysis for SpaceShipTwo. There are two parts to this document; the first part (T1B-90E033_Part-1_SS2_FHA_E) covers the purpose, methodology, definitions, and the White Knight Two (WK2) analysis and findings, the second part (T1B-90E033_Part-2_SS2_FHA_J) contains the detailed SSA for SpaceShip Two and Rocket Motor Two (RM2).

[38] Failure rates provided by the manufacturer of the component or documented as historical rates in commonly used industry documents.

[39] While AC 437.55-1 considers likelihood of occurrence over the period of an entire mission, Scaled normalized all probability values to represent failures per flight hour. A nominal SpaceShipTwo mission is approximately one hour in duration. Some components are not used for the entire mission (for example, the propulsion system is only used for a minute or so) and so the probability of failure of those components are lower. Scaled continues to use the per-hour probabilities for those components adding conservatism to the analysis.

D.5.3.2 System Safety Analysis Approach:

Document T1B-90E060, titled "system safety analysis approach," indicated that the system safety analysis (SSA)[40] approach Scaled used was derived from several sources of industry best practices including those related to experimental aircraft and certificated aircraft such as AC 23.1309-1D "System Safety Analysis and Assessment for Part 23 Airplanes.[41]" Scaled's approach focused on "mission safety," meaning the ability to complete (or abort) any particular mission while assuring the safety of the vehicle and crew. The background section of the document states a successful mission protects the public as well as the crew and the ship; only conditions that prevent a safe conclusion to a mission present a risk to public safety or to property. Section 437.55 requires a *Hazard Analysis* to determine the risk to *public health and safety* and to property presented by the permitted flights.

The functional hazard analysis (FHA) section of T1B-90E060 indicated that an FHA was a structured process that identified hazards by first identifying the functions of SS2. Once the functions were identified, the FHA process identified the functional failure and their consequences for each function. For each functional failure, Scaled identified the effects they can impose on the crew/passenger and the vehicle. They then applied a classification to them based on their effect on the crew/passenger and the vehicle. Mitigation and control measures to reduce or minimize the risk were then determined.

AC 437.55-1, Section 5b titled "determine and assess the risk for each hazard" describes a method and provides examples for how an applicant can characterize and address the risk of the hazard after it has been identified and described. The AC instructs "to characterize the risk, an applicant assigns qualitative severities and likelihoods to the hazards." The AC also contains a risk acceptability matrix[42] that incorporated the risk requirements of 14 CFR 437.55(a)(3). For the risks (high) that do not satisfy the criteria of 14 CFR 437.55(a)(3), an applicant must implement risk elimination or mitigation measures to reduce the risk to acceptable levels. The AC includes the following criteria from 14 CFR 437.55(a)(3):

- The likelihood of any hazardous condition that may cause death or serious injury to the public must be extremely remote.
- The likelihood of any hazardous condition that may cause major property damage to the public, major safety-critical system damage or reduced capability, a significant reduction in safety margins, or a significant increase in crew workload must be remote.

To determine risk acceptability, Scaled used the Allowable Qualitative Probability, Classification of Failure Conditions, and Allowable Quantitative Probabilities for a class I aircraft from figure 2 of AC-23.1309-1D. These are similar to the Hazard Severity (table 1) and the Hazard Likelihood (table 2) tables from AC-437.55-1. These are evaluated against the Risk Acceptability Matrix table (table 3) in AC-437.55-1. Hazards that fell in the Marginal (Major) or Negligible (Minor) columns of the Risk Acceptability Matrix table required no risk elimination or mitigation measures. Hazards that fell in other areas of the Risk Acceptability Matrix required further analysis to determine the likelihood of the occurrence. If, after determining the likelihood of occurrence, the Risk Acceptability Matrix then showed acceptable risk, no further risk elimination or mitigations measures were required. All remaining hazards require risk elimination or mitigation measures.

[40] An SSA was defined by Scaled as a systematic, comprehensive evaluation of an implemented system, its architecture and its installation to show compliance with the safety requirements.

[41] See Attachment 16 – FAA Advisory Circular, 23-1309-1D, dated 1-16-2009.

[42] A risk acceptability matrix categorizes risks relative to a target level of safety (i.e. an acceptable risk threshold) based on the combination of a hazard's likelihood and severity.

The hazard classification terminology contained within AC 23.1309-1D (reference figure 2 in the AC) differs from the terminology contained within AC-437.55-1 (Reference table 1 in the AC). Scaled listed the hazard classifications and described their differences. As an example, Scaled included the following in T1B-090E060:

- No Safety Effect (NSE), similar to the *Negligible* classification in AC-437.55., presenting no risk to public safety or property.
- Minor, similar to *Negligible* in AC-437.55, presenting no risk to public safety or property.
- Major, similar to *Marginal* in AC-437.55, presenting only minor risk to public safety or property, but perhaps causing injuries to crew or damage to the vehicle.
- Hazardous, similar to *Critical* in AC-437.55, presenting risk to public safety or property.
- Catastrophic, similar to *Catastrophic* in AC-437.55, presenting serious risk to public safety or property.

T1B-90E060 also stated that each severity classification was associated with an acceptable probability and qualitative probability tag with each severity, and that these probabilities were comparable to those in AC-437.55-1. Scaled explained that it did not use qualitative probabilities, but instead computed quantitative probabilities for hazards categorized as Hazardous or Catastrophic using the FTA. The following quantitative probabilities were used:

- Minor: Probable, (E-3), similar to the more common form of *Occasional* in AC-437.55-1.
- Major: Improbable (E-4), similar to the more rare form of *Occasional* in AC-437.55-1.
- Hazardous: Improbable (E-5), similar to *Remote* in AC-437.55-1.
- Catastrophic: Extremely Improbable (E-6), similar to *Extremely Remote* in AC- 437.55-1.

The fault tree analysis (FTA) section of T1B-90E060 indicated that each section identified by the FHA as presenting a hazardous or catastrophic condition would be evaluated by constructing a fault tree. The systems were then evaluated as follows:

- Construct a fault tree by examination of the design of the systems involved in the function.
- Assign conservative failure rates to the components of the system.
- Determine if the system meets the allowable probability for the category of the hazard.
- Redesign the system(s) or apply mitigations for those systems which do not meet the allowable probabilities.

Report T1B-90E060 also indicated that the quantitative probabilities used in the FTA were derived using the following process:

- Conservative probabilities were assumed as follows:
    - E^{-3} for systems or components (which was the worst case probability found in Scaled's probability database)
    - E^{-2} for human actions under moderate workload or environmental stress
    - E^{-1} for human actions under high workload or environmental stress
- Scaled's probability database was taken from:
    - Manufacturers information
    - Military Specifications (Mil specs)
    - Non-Electrical Parts Reliability Database (NPRD)

Part 1 of the document (T1B-90E033), titled "functional hazard assessment (FHA)" indicated that because of the R&D nature of the program a program wide E^{-3} failure rate was used as a base for all events; this rate was conservative based on standard aerospace industry methodology. The Non-Electrical Parts Reliability Database (NPRD), MIL-HDBK-217, manufacturer's information, or other available values were sometimes used for more specific failure rates. The document also indicated that the NPRD shows a highest (worst) failure rate of any part as E^{-3} supporting the use of the program wide E^{-3} value.

Report T1B-90E060 also indicated that if the first pass of the FTA (with the conservative assumed failure rates) met the allowable probabilities for the hazard category, Scaled considered the system robust enough because the other fail rates described above are lower and the resulting fault tree would have a lower failure probability. Otherwise, other failure rates are used if they are available. If neither FTA passes probabilities, redesign or mitigations would be necessary.

The steps were repeated and updated as the development life cycle progressed. The fault trees were updated to account for improvements in the systems design as a result of testing and evaluation data as it became available during development.

In an interview with the NTSB, a Scaled project engineer[43] indicated that human error was addressed in the hazard analysis in two ways: (1) it was analyzed in the FTA[44] by accounting for pilot reaction that is used to mitigate a hazardous or catastrophic event (i.e. a pilot corrective action) and (2) generally mitigated with procedures and training. According to Scaled, they were not aware of an industry-recognized analytical tool for performing this analysis. Scaled also indicated that the aviation guidance in AC 23.1309 (page 33) states that quantitative analysis of this nature is not considered feasible, and Scaled was not aware of industry-recognized qualitative probabilities for specific human errors. Scaled considered human error in accordance with FAA guidance, and identified and discussed specific hazards. As a result of those discussions Scaled recognized that those hazards needed to be mitigated and applied the following mitigations to address those hazards: procedures, training, and simulator preparation.

AC 437.55-1 states, "Information on human error can be found in The Human Factors Analysis and Classification System-HFAC". The HFAC publication described a "general human error framework around which new investigative methods can be designed and existing accident databases restructured." The document states in the abstract, "Specifically, the HFACS framework has been used within the military, commercial, and general aviation sectors to systematically examine underlying human causal factors and to improve aviation accident investigations." This document does not provide an analytical method for addressing human error in the design of new spacecraft.

T1B-90E060 indicated that once the hazards were identified and the probabilities were evaluated using the FTA, the FHA was completed by adding any required mitigations or corrections for those hazards that did not meet the allowable probabilities. This process was iterative with the SSA influencing the design of the vehicle, and subsequent vehicle changes were reanalyzed in the SSA.

In the summary section of T1B-90E060, Scaled indicated that it's SSA for SS2 met the requirements of 14 CFR 437.55 because:

- The design of the vehicles is such that mission assurance results in the protection of public health and safety and property.
- The approach is similar to (and partially recognized) by AC-437.55-1.

[43] See Attachment 25 for witness interviews.
[44] See Attachment 17 for two examples (FTA 3.14 & 15.07) on how human error was included in the fault trees.

- The approach is derived from industry practices for certificated aircraft, which have higher standards than experimental aircraft.
- Has been validated with selected Monte Carlo testing.

D.5.3.3 Functional hazard assessment (FHA) for SS2:

As previously stated, section 8.6 of Scaled's experimental permit contains a document (T1B-90E033), titled "functional hazard assessment (FHA)" which presented Scaled's overall system safety analysis (SSA) for SpaceShipTwo. There are two parts to this document; the first part (Part 1) covers the purpose, methodology, definitions, and the WhiteKnightTwo (WK2) analysis and findings, the second part (Part 2) contains the detailed SSA for SpaceShipTwo and RocketMotorTwo (RM2). For the purpose of this report, Part 1 will be discussed in this section and Part 2 will be discussed in another section with a specific focus on the hazard analysis for the feather system.

Part 1 of the document states that the Systems Safety Analysis only addresses systems; Structure was analyzed and validated separately. Scaled's goal in conducting the SSA was to clearly identify each failure condition along with the rationale for its classification.

In the document, Scaled stated that systems reliability analyses provided input to the system safety process in the following areas: (1) Identifying potential reliability or safety problems of the system and the risks associated with those problems, (2) Comparing alternate designs to improve reliability and eliminate or mitigate safety problems. (For example, an analysis can help identify mitigation measures or evaluate the effects of component failures on reliability of safety-critical systems.), (3) Assisting in defining operational, test, and safety requirements. (For example, the analysis could result in requirements for hardware, software, procedures, and training to reduce the risks identified.), (4) Providing results that can be used to evaluate whether safety criteria and requirements have been met (For example, as part of the validation and verification effort to determine whether an item will perform its intended function under specified conditions).

Part 1 of the document also contains several paragraphs describing Scaled's methodology and definitions for FHA, FTA, Common Cause Analysis (including Common Modes Analysis and Zonal Safety Analysis) and hazard classifications.[45] For the flight test phase of the SS2 program, only the high risk functions (hazardous and catastrophic) were analyzed beyond the FHA. Functions identified with a class of major or minor were not analyzed beyond the FHA because the issue is controllable and does not endanger the passenger, crew, or vehicle. The document also defined failure condition classifications as: "A condition having an effect on either the vehicle or its occupants, or both, either direct or consequential, which is caused or contributed to by one or more failures or errors considering flight phase and relevant adverse operational or environmental conditions or external events." Failure Conditions were classified according to their severity and defined as follows:

- Major:
  Failure Conditions that would reduce the capability of the vehicle or the ability of the crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins or functional capabilities; a significant increase in crew workload or in conditions impairing crew efficiency; or a discomfort to the flight crew or physical distress to passengers or cabin crew, possibly including injuries.

[45] See Attachment 18 – Methodology section of Scaled's document T1B-90E033.

- Hazardous:
  Failure Conditions that would reduce the capability of the vehicle or the ability of the crew to cope with adverse operating conditions to the extent that there would be the following:
  (i) A large reduction in safety margins or functional capabilities;
  (ii) Physical distress or higher workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely; or
  (iii) Serious or fatal injury to an occupant other than the flight crew.

- Catastrophic:
  Failure Conditions that are expected to result in multiple fatalities of the occupants, or incapacitation or fatal injury to a flight crewmember, normally with the loss of the vehicle.

D.5.3.4 System Safety Analysis – Feather System:

For SS1, the selected design included actuators for extending and retracting the feathers and locks to maintain the feathers in the retracted position during most portions of the planned trajectory. The basic design elements of SS1, and the design of the feather system, including the feather locks and feather actuators, were carried forward to SS2.

Scaled employed aerodynamic analysis to model the loads SS2 would encounter during flight, including the transonic flight regime and the gamma turn maneuver. Analysis confirmed that during the transonic flight regime and the gamma turn maneuver, the aerodynamic forces on the feather exceeded the maximum design limits of the feather actuators. In the absence of locks, Scaled engineers confirmed that these loads would result in motion of the feather system which would result in the loss of pitch control, which could potentially result in a catastrophic airframe failure. The design parameters for the feather actuators were selected such that the feather retracting forces provided by the actuators were adequate to retract the feathers during the recovery phase of flight (after re-entry) and less than the feather extending forces caused by the aerodynamic loads during the transonic flight regime and the gamma-turn maneuver[1]. The design parameters of the locks were selected so that they would maintain the feather in the retracted position during the portions of the trajectory when the feather was not intended to be extended, including the transonic flight regime and the gamma-turn maneuver.

It should be noted that the feather locks were not added as mitigation against the inability of the feather actuators to hold the feather retracted during all flight phases. The locks were a design feature to hold the feathers in the retracted position during all phases of flight except when the feathers were intended to be extended. This was done because the size of feather actuators required to hold the feather in position in the transonic and gamma turn phases of flight was not considered a design solution due to weight.

SS2 was designed and intended to be operated with the feather locks engaged during the transonic flight regime and the gamma-turn maneuver to prevent deployment of the feather system during these stages of flight.

[1] The gamma-turn maneuver is the portion of powered flight where SS2 transitions from a horizontal flight path to a vertical flight path.

D.5.3.5 Functional Hazard Analysis – Feather System:

As part of their system safety analysis for SS2, Scaled performed a qualitative functional hazard analysis (FHA) to identify and characterizing hazards and risks. This analysis included identifying the vehicle functions to be evaluated, identifying safety-critical failure modes and the effects the failure mode could impose on the crew/passenger and vehicle, applying a classification to the failure mode and identifying mitigation measures to reduce the risk. One of the vehicle functions identified by the FHA process was "provide and remove configuration for atmospheric entry." For this function, Scaled identified and listed the following three hazards along with their phase of flight, effect of failure, hazard classification and mitigation: (1) "feather fails to operate" during entry[46], which was classified as catastrophic, (2) "uncommanded[47] feather operation," which was classified as catastrophic during the boost[48]and landing phase and classified as major for entry, and (3) "misleading feather position indication," which was classified as major during entry and minor for the boost and landing phases.[49]

For the hazard, "feather fails to operate" during entry, the FHA listed a procedural mitigation used after the gamma-turn maneuver which stated the following: "the feather locks will be unlocked during boost, giving the ability to abort full trajectory, if the lock will not allow feather operation; mitigates a lock jam failure, see note in FTA."

As previously stated, compliance with the section 437.55 regulation was shown by fault tree analysis for hazards identified as hazardous or catastrophic; hazards that were identified with a class of major or minor were not analyzed beyond the FHA because Scaled believed that the hazard was controllable and would not endanger the passengers, crew, or the vehicle. Based on the catastrophic severity categorization of the three hazards identified with the feather system, Scaled performed an FTA for the following hazards: (1) "feather fails to operate during entry," (2) "uncommanded feather during boost" and, (3) "uncommanded feather during landing."

The different flight phases represent different aerodynamic load conditions and different sensitivities to various potential failures. The feather locks were intended to remain engaged (to maintain the feather in the retracted position) in all flight phases except during the period from Mach 1.4 during boost until the feather was retracted after reentry. For this condition, any failures of the feather actuator system would not immediately lead to adverse consequences. After the gamma-turn maneuver (when aerodynamic forces are lower), the feather locks were intended to be released, because any failures in the feather actuator system could lead to adverse consequences during the re-entry phase. In other words, if the feather locks do not release (unlock) after the early boost phase, there is a risk of an un-feathered re-entry which was considered extremely risky and likely catastrophic. After re-entry, the failure of the locks to reengage presents risk of un-commanded feather motion during the glide and landing phase of the flight. Each of these failure conditions were treated separately in Scaled's FHA and related analysis.

The NTSB reviewed Scaled's "feather fails to operate during entry" and "uncommanded feather during boost" fault tree analysis to determine how these hazards were analyzed.

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[46] Scaled's FHA report dated December 20, 2011, defined "Entry" as beginning at feather unlocking and ends at feather re-locking.

[47] Uncommanded is defined as "an action not requested or intended by the crew"

[48] Scaled's FHA report dated December 20, 2011, defined "Boost" as including rocket light and sub-, trans- and supersonic flight with motor on and off.

[49] See Attachment 19 – Functional Hazard Assessment section of Scaled's document T1B-90E033.

D.5.3.6 Uncommanded Feather during Boost – Fault Tree:

Scaled's fault tree titled "13.02 uncommanded feather operation, boost," dated June 21, 2011 listed the events that Scaled had identified and analyzed as potential failure conditions resulting in uncommanded feather operation.[50] Scaled's analysis showed that the probability of failure for the hazard "uncommanded feather operation during boost" was extremely remote[51] and therefore met Scaled's quantitative requirement of $1x10^{-6}$. Their analysis identified the following two failure conditions that needed to be satisfied in order for the hazard to occur: (1) right actuation boost and (2) left actuation boost. The fault tree also contained a note[52] that stated: "locks are already released." According to Scaled, this fault tree was developed based on the assumption the crew would release the feather locks at the appropriate time (1.4 Mach for Powered Flight Four [PF04] the accident flight) during boost.

T1B-90E033_Part-2_SS2_FHA_J of Scaled's report titled "functional hazard assessment…" listed the assumptions Scaled used to develop their fault trees. Two of the assumptions were: (1) The flight crew is properly trained through simulator sessions, and (2) the flight crew will follow the Normal and Emergency Procedure for a given situation.

As previously stated, the feather locks were a design feature to hold the feathers in the retracted position during all phases of flight except when the feathers were intended to be extended. According to Scaled, their System Safety Analyst determined the fault tree did not need to include the failure condition "feather locks fail" as an event whose failure effects would result in uncommanded feather operation because "feather locks fail" was not identified as hazardous or catastrophic due to the reliability of the locks. However this failure condition was analyzed in the fault tree titled "13.03 uncommanded feather operation, landing,[53]" dated June 21, 2011; its probability of failure was found to be extremely remote.

For the "uncommanded feather operation during boost" hazard, Scaled determined that the worst case scenario was after the feather locks were unlocked. During the beginning portion of boost the locks are performing their primary function of holding the feather down and the likelihood of lock failure was extremely remote. Given the reliability of the locks, Scaled determined that the failure of the actuators to hold the feathers down after the feather locks had been removed was the worst case failure scenario. If the fault tree met the requirements without the locks in place then it follows that adding the locks as a design feature during the boost phase would make the hazard even less probable.

D.5.3.7 Feather Fails to Operate During Entry:

Scaled's fault tree titled "13.01 "feather fails to operate," dated May 03, 2011 listed the events that Scaled had identified and analyzed as potential failure conditions resulting in the feather failing to operate during entry.[54] Scaled's analysis showed that the probability of failure for this hazard was occasional[55] and therefore did not meet Scaled's quantitative requirement of $1x10^{-6}$ in any one mission. The fault tree contained a note that stated: "*Lock failure is mitigated out of this FTA due to procedure (Unlock 20 to 35*

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[50] See Attachment 20 - Fault tree titled "13.02 uncommanded feather operation, boost," dated June 21, 2011.
[51] Reference FAA Advisory Circular 435.55-1, dated April 20, 2007.
[52] According to Scaled, not all assumptions are captured as notes; however, credible and relevant assumptions are often captured as notes.
[53] See Attachment 21 - Fault tree titled "13.03 uncommanded feather operation," dated June 21, 2011.
[54] See Attachment 22 - Fault tree titled "13.01 "feather fails to operate," dated September 20, 2011.
[55] Reference FAA Advisory Circular 435.55-1, dated April 20, 2007.

seconds after rocket motor RM start (turning the corner complete), if fails no safety effect due to low apogee not requiring the feather for entry, abort mission)."

T1B-90E033_Part-2_SS2_FHA_J contains a conclusion section describing the results of the hazard analysis and the fault tree analysis. The SpaceShipTwo vehicle has four systems that were classified as Safety Critical, meaning a failure of one of those systems could present risks to the uninvolved public that exceed the limits defined in 14 CFR 437; one of these systems is the feather system. In the feather system, the locks and feather actuators are the most likely to cause failure of the system. The locks are operationally mitigated as stated in T1B-90E033_Part-2_SS2_FHA_J, by initiating the opening of the locks with sufficient time to abort the boost if the locks become jammed or non-operational. If the boost is aborted, the feather system is unnecessary for continued safe flight and recovery. A note contained within this section states the following: there is a procedural mitigation in place for the hazard "feather fails to operate during entry" which must be performed to improve the functional reliability. The feather locks must be unlocked and confirmed unlocked immediately after the gamma-turn. If the locks fail to open, the flight must be aborted directly. The feather locks are required to hold the feather down during the high tail-up forces. The high loads occur approximately during the first 15[56] seconds of the rocket burn including the gamma-turn. After the gamma-turn, the loads are less and the feather actuators can hold the feather down[57]. The risk, if this procedural mitigation is not followed, is a greater possibility of the inability to feather. The vehicle would then not be able to re-enter safely. With mitigation (feather locks removed) the probability of failure for this hazard was occasional. By unlocking the feather locks, the pneumatic system upstream of the manual ball valves is verified in-flight to be fully operational, increasing the reliability of the feather actuation.

D.6 Traceability/Procedural Mitigations:

As previously stated, there was a procedural mitigation in place for the "feather fails to operate during entry" hazard which Scaled determined needed to be performed to improve the functional reliability of the feather system. This procedural mitigation involved unlocking the feather locks after the transonic region to address the potential risk of the feather locks jamming.

According to Scaled, procedural mitigations arising out of the system safety analysis are noted in the functional hazard assessment and /or the fault tree analysis and further incorporated operationally in the appropriate documents, including the Pilot Operating Handbook (POH), the Normal Procedures (NPs), the Emergency Procedures (EPs), maintenance documents, the Flight Operations Limitations Document (FOLD), and flight test cards.

Procedural mitigations, particularly those that if not performed or performed incorrectly, could potentially result in catastrophic failures were reviewed with the responsible parties during flight readiness reviews (FRRs) and flight briefings prior to each flight. Pilots and ground support reviewed these procedures during simulator sessions, which would typically occur at least weekly during the weeks leading up to a flight. With regard to the feather unlock and procedural mitigation to reduce the risks of jammed locks, those topics were regularly and repeatedly discussed and trained "against" in the SS2 program including during the six formal simulations with the pilots and ground support in the final weeks leading up to PF04.

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[56] According to Scaled, the 15 second number was used to provide an approximate timeframe for the portion of the boost phase where these events occur.

[57] Reference the Structure's Group Chairman's Factual report for additional information regarding feather loads.

The SpaceShipTwo (SS2) Pilot Operating Handbook (SS2-90P001, Revision D, dated September 3, 2013) documented the configuration, systems, operating limitations, procedures and performance of the SS2 suborbital space plane. The scope of the SS2 Pilot Operating Handbook (POH) included design philosophy and lessons learned as appropriate to document the design and development of the vehicle.

According to the POH, although there are two redundant feather actuators, if one actuator jams the entire feather is jammed because both actuators are connected through the feather structure and unless the other actuator can produce enough force to overcome the jam, the feather will remain jammed. This could lead to a feather down re-entry or the inability to return to glide configuration after re-entry. A similar scenario is true for the feather locks, where a jammed actuator could result in the inability to feather. In this case the flight would be immediately aborted before feathering was mandatory. If an actuator stops moving because a vent line is clogged then a redundant vent line can be selected. Stringent preflight procedures were put in place to avoid contaminants and the actuators were regularly serviced and lubricated to avoid jamming issues.

The "Feather Lock Handle" section of the POH states that "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 Multifunction Display (MFD) "OK TO LOCK" message and back-up panel light illuminates."

The "General – Feather" section of the POH defines a nominal mission sequence as follows:

- Captive Carry: Feather locks closed
- Spaceship Drop: Feather locks closed
- Initial Rocket Boost: Feather locks closed
- After Gamma Turn at 1.4 Mach: Feather locks opened (abort boost if feather does not unlock)
- After Rocket Burnout and <20 KEAS: Feather extend
- Feathered Reentry: Feather remains extended
- End of Reentry (<1.2 Nz): Feather retraction
- When Feather is Fully Retracted: Feather locks closed

The POH also includes a warning that states, "Although the feather locks are cycled during normal preflight and prerelease checks, inadvertently actuating the feather will likely result in catastrophic failure of the mated pair."

The normal SS2 pilot procedures for preflight, flight and post-flight were defined in the SS2 Normal Procedures manual (SS2-90P002, Revision J, Change 5, dated 14 October 2014). Generally, checklists from the Normal Procedures manual were referenced by pilots to accomplish required tasks based on the phase of flight. The "Boost Phase" section of this manual states: "@ >1.4 Mach Pilot Not flying (PNF) feather – Unlock." This manual does not include warnings or cautions regarding the feather system.

D.7 Waiver:

The FAA issues an experimental permit under authority granted to the Secretary of Transportation under 51 U.S.C. Section 50906 which is further delegated to the FAA Administrator. The FAA may waive an experimental permit requirement if the waiver (1) will not jeopardize public health and safety or safety of property, (2) will not jeopardize national security and foreign policy interests of the United States, and (3) will be in the public interest. 51 U.S.C. Section 50905(b)(3); 14 CFR 404.5(b).

On July 18, 2013, the FAA published a notice of waiver (72 *Federal Register* Vol. 78, No. 138, Pg. 42994) titled "Waiver of 14 CFR437.29 and 437.55(a) for Scaled Composites, LLC.[58]" This notice published a waiver granted to Scaled from the requirements of sections 437.29 and 437.55(a) to provide the FAA a hazard analysis that "identifies, mitigates, and verifies and validates mitigation measures for hazards created by software and human error."

According to the waiver, in its application to renew its experimental permit, Scaled included modifications within the permit to reflect changes that had been made to SpaceShipTwo. The waiver also indicated that, although Scaled had provided updates to its original hazard analysis for the FAA's assessment, Scaled did not meet the requirements of sections 437.29 and 437.55(a) because it did not identify human or software errors as "causing hazards on the grounds that the mitigations it had in place would prevent the hazards from occurring." The waiver referenced Scaled's aircraft and spacecraft design redundancy, flight and maintenance procedures, and ground and flight crew training as mitigations against hazards caused by human and software errors.

D.7.1 Scaled's Response to Waiver:

The NTSB System Safety Group requested that Scaled explain its understanding of the issues related to the waiver under 14 CFR 437.55 issued by the FAA in July 2013. In a letter dated February 16, 2015, Scaled provided their formal response to the NTSB[59].

The NTSB could not find any evidence that AST provided Scaled with an official letter informing the company of the July 18, 2013, notice of waiver[60].

D.7.2 AST Response to Waiver:

The NTSB System Safety Group sent a formal request to the AST and requested them to provide the NTSB with their official response to several questions regarding the waiver. In a letter dated April 15, 2015, the AST provided their formal response to the NTSB[61].

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[58] See Attachment 23 - FAA waiver titled "Waiver of 14 CFR 437.29 and 437.55(a) for Scaled Composites, LLC.

[59] See Attachment 24 for Scaled's formal response to the NTSB regarding the waiver.

[60] In an interview with the NTSB, a Scaled employee indicated that Scaled became aware of FAA's intent to issue a waiver towards the end of June 2013.

[61] See Attachment 26 for AST's response to the waiver questions.

E. LIST OF ATTACHMENTS:

Attachment 1: Scaled Composites, LLC, letter to AST dated January 23, 2012.
Attachment 2: FAA letter to Scaled Composites, LLC, dated February 7, 2012.
Attachment 3: FAA letter to Scaled, dated May 23, 2012 and experimental permit, EP 12-007
Attachment 4: Scaled document titled "Clarification of Hazard Analyses Mitigations."
Attachment 5: Scaled document titled "Additional Information about Hazards."
Attachment 6: FAA letter to Scaled Composites, LLC, dated April 23, 2013
Attachment 7: FAA letter to Scaled, dated May 22, 2013 and experimental permit, EP 12-007 (Rev1)
Attachment 8: FAA letter to Scaled Composites, LLC, dated March 28, 2014.
Attachment 9: FAA letter to Scaled Composites, LLC, dated May 21, 2014.
Attachment 10: Experimental Permit Number EP 12-007 (Rev2).
Attachment 11: FAA letter to Scaled Composites, LLC, dated October 14, 2014.
Attachment 12: Experimental Permit Rule for reusable suborbital rockets.
Attachment 13: FAA-authored paper titled "FAA's Implementation of the CSLA Act of 2004."
Attachment 14: FAA Advisory Circular 413-1, titled "license Application Procedures,"
Attachment 15: FAA Advisory Circular, 437.55-1, dated April 20, 2007.
Attachment 16: FAA Advisory Circular, 23-1309-1D, dated 1-16-2009.
Attachment 17 Examples (FTA 3.14 & 15.07) on how human error was included in the fault trees.
Attachment 18: Methodology section of Scaled's document T1B-90E033.
Attachment 19: Functional Hazard Assessment section of Scaled's document T1B-90E033.
Attachment 20: Fault tree "13.02 uncommanded feather operation, boost," dated June 21, 2011.
Attachment 21: Fault tree titled "13.03 uncommanded feather operation" dated June 21, 2011.
Attachment 22: Fault tree titled "13.01 "feather fails to operate," dated September 20, 2011.
Attachment 23: FAA waiver "Waiver of 14 CFR 437.29 and 437.55(a) for Scaled Composites, LLC.
Attachment 24: Scaled's formal response to the NTSB regarding the waiver.
Attachment 25: Witness interviews.
Attachment 26: AST Response to NTSB Information Request 15.132 – Five Question Set.

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