Is it a Space Plane or Rocket? The Unique Aspects of a Commercial Space Accident Investigation.

E. Lorenda Ward
ISASI Member # MO6251
Sr. Investigator-in-Charge
U.S. National Transportation Safety Board

Ms. Ward was hired by the National Transportation Safety Board (NTSB) in November 1998 as an aerospace engineer specializing in aircraft structures. In May 2001, she was promoted to Investigator-in-Charge (IIC). She has served as the IIC for numerous major aircraft accident investigations, including the recent commercial space investigation of SpaceShipTwo. She has also served as the US Accredited Representative for foreign accident and incident investigations all over the world. She received both her bachelor and master of aerospace engineering from Auburn University, Auburn, Alabama. Before beginning work with the NTSB, Ms. Ward worked as a civilian aerospace engineer for the US Navy.

On October 31, 2014, the Scaled Composites SpaceShipTwo (SS2) reusable suborbital rocket, N339SS, broke into multiple pieces during its fourth rocket-powered flight test 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 13 seconds before the breakup. SS2 was destroyed, and WK2 made an uneventful landing. Scaled Composites was operating SS2 under an experimental permit issued by the U.S. Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) under the provisions of 14 *Code of Federal Regulations* (CFR) Part 437.

The NTSB launched a go-team to begin the first fatal commercial space accident investigation. There was a lot of international interest in the investigation and the SS2 investigative report was adopted on July 28, 2015, 9 months after the accident. This was not an easy undertaking since the SS2 investigation had unique aspects, which included investigating a commercial space vehicle, working with parties who had not participated in a NTSB investigation and were

unfamiliar with our processes, dealing with proprietary data and US laws regarding the export of defense- and military-related technologies, learning new terminology, understanding the differences between space and aviation regulations, and the "learning period" the US Congress had established.

Accident overview. Scaled developed WK2 and was developing SS2 for Virgin Galactic, who planned to use the vehicles to conduct future commercial space suborbital operations. SS2 was equipped with a feather system that rotated a feather flap assembly with twin tailbooms upward from the vehicle's normal configuration or unfeathered (0º) to 60º to stabilize SS2's attitude and increase drag during reentry into the earth's atmosphere.

Figure 1: SpaceShipTwo release from WhiteKnightTwo

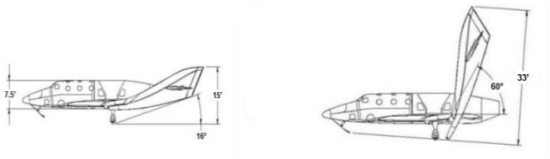

Figure 2: Normal and feathered configuration

After release from WK2 at an altitude of about 46,400 feet, SS2 entered the boost phase of flight. During this phase, SS2's rocket motor would propel the vehicle from a gliding flight attitude to an almost-vertical attitude, and the vehicle would accelerate from subsonic speeds, through the transonic region (0.9 to 1.1 Mach), to supersonic speeds. The flight test data card

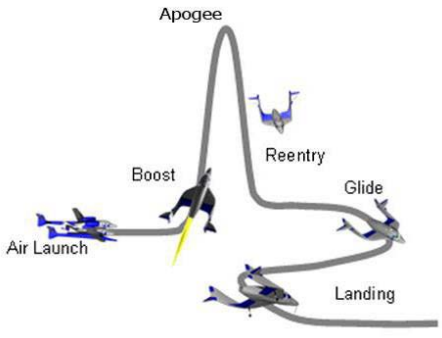

Figure 3: Mission Profile

used during the accident flight indicated that the copilot was to unlock the feather during the boost phase when SS2 reached a speed of 1.4 Mach. However, a forward-facing cockpit camera and flight data showed that the copilot unlocked the feather just after SS2 passed through a speed of 0.8 Mach. Afterward, the aerodynamic and inertial loads imposed on the feather flap assembly were sufficient to overcome the system; as a result, the feather extended uncommanded, causing the catastrophic structural failure.

Figure 4: Feather Lock Handle – Unlocked Position

Figure 5: SpaceShipTwo Wreckage

Safety Issues:

- Lack of human factors guidance for commercial space operators
- Efficacy and timing of preapplication consultation process
- Limited interactions between the FAA/AST and applicants during the experimental permit evaluation process
- Missed opportunities during the FAA/AST's evaluations of hazard analyses and waivers from regulatory requirements

Probable Cause:

Scaled Composites' failure to consider and protect against the possibility that a single human error could result in a catastrophic hazard to the SpaceShipTwo vehicle. This failure set the stage for the copilot's premature unlocking of the feather system as a result of time pressure and vibration and loads that he had not recently experienced, which led to uncommanded feather extension and the subsequent aerodynamic overload and in-flight breakup of the vehicle.

• Limited inspector familiarity with commercial space operators • Incomplete commercial space flight database for mishap lessons learned and • Need for improved emergency response planning.	

As a result of this investigation, NTSB issued safety recommendations to the FAA and the Commercial Spaceflight Federation. For more information about the SS2 accident investigation, see the NTSB's website, www.ntsb.gov, and access the public docket for this investigation (DCA15MA019) and/or the final report (NTSB/AAR-15/02).

Why the investigation was unique. At the time of the accident, Scaled had built and was testing SS2 and had delivered WK2 to Virgin Galactic. Scaled had planned on transitioning SS2 to Virgin Galactic towards the end of the 2014. After the accident, Virgin Galactic took over the building and testing responsibility for the second SS2 vehicle. So which organization gets the recommendations when who was operating the vehicle would no longer build or test it and who is now building the vehicle was not operating the accident vehicle. Do you investigate the commercial space industry or just this accident?

Organizational relationships. Scaled Composited, Virgin Galactic, Butler Parachute Systems and the FAA were parties to the investigation. Although the FAA's Office of Accident Investigation and Prevention was very familiar with our investigative process, the FAA's Office of Commercial Space Transportation was not. In addition, the parties were familiar with each other but not with us. It is not unusual to have at least one party organization unfamiliar with NTSB processes but it was a challenge initially to have all of the parties unfamiliar. To

overcome this challenge some things had to be repeated, we had to move group members around to different groups for a better fit, and made sure that questions or concerns were addressed quickly.

There were growing pains but in the end the parties stated that the investigation was better because we were leading it and they also learned from us. They also hoped that we had learned from them. They stated that they felt like their voice was heard, felt like they had participated and even when there were small disagreements our rationale was fully explained to them. If we did not have their professionalism, openness, responsiveness and their willingness to trust our process we would not of been able to complete this investigation within 9 months.

Lack of certification regulations. Unlike commercial aviation, the FAA has a very limited role in commercial space. Because commercial space is an emerging transportation industry, the US Congress established a "learning period" that limited the FAA's involvement to protecting the public and property during commercial space launches and encouraging, facilitating, and promoting the commercial space industry. The learning period is currently set to expire on October 1, 2015, but there is working legislation in the US Senate and US House of Representatives to extend the date to at least 2020. As a result, the FAA was not responsible for certifying commercial space vehicles, and it appears that the FAA will not have such authority any time in the near future.

Data. Lots and lots of data. Although there was no requirement for crash protected data recorders on commercial space vehicles there was a lot of data to be gathered. There were videos and telemetry data from SS2, videos from WK2, photos from the Extra-300 chase plane, and ground-based videos and photos from range facilities and private photographers. SS2 had a

forward facing cockpit camera that provided telemetry video to Scaled Composites control room. We were able to watch this video the first day on-scene and it was very useful in determining the events that led to the accident.

SS2's flight test data instrumentation system, referred to as the Strap On Data Acquisition System (SODAS), was the main source of flight data used during the investigation of this accident. SODAS telemetered data from SS2 to ground-based stations and was the only source of information for numerous vehicle performance and system operating status parameters. Without SODAS, critical investigative data, including the status of the feather and Mach numbers, would have been unavailable to the NTSB.

Terminology. We had to determine the similarities and differences among various commercial space terms. For example, in Scaled Composites' experimental permit application, SS2 was referred to as a "space plane," and WK2 was referred to as the "mother ship." However, SS2 is also referred to as a reusable suborbital rocket. Also, when WK2 and SS2 were conducting a glide flight, the flight was operating under an experimental certificate from the aviation side of the FAA. When WK2 and SS2 were conducting a powered flight in which the rocket motor was going to be fired, the launch was being conducted under an experimental permit from the commercial space side of the FAA.

Remote wreckage location. In order to protect the public, the operating area for SS2 was in a remote location. The main wreckage debris fell within a 5 mile area with seven different sites, separated by some distance, which made it hard to maintain security. Smaller debris was found up to 33 miles away and was collected when the public reported an object that might be from SS2. The remote location did not allow for cell phone coverage so communication was

challenging for the groups working out at the wreckage site. The on-site team had to drive to a different location to make a call or if the team at the command post wanted to contacted the team in the field, messages had to be relayed through the Sherriff's office. Wreckage was difficult to access so off-road and 4-wheel drive vehicles were used. Removal and transportation of the wreckage was difficult due to the soft sand and heavy pieces. The semi-truck got stuck a few times and had to be dug out. Wreckage was moved at night due to size of the truck and public road permits to get the truck from accident site to recovery hanger.

How not to go to jail. On-scene there was extreme sensitivity with releasing photos and videos of the wreckage site due to company proprietary concerns and U.S. International Traffic in Arms Regulations (ITAR). In addition, there were discussions about being able to hold an open Board Meeting or opening a public docket because of ITAR. What information would we be able to release to the public and would there be enough information to support the findings, probable cause and recommendations? Our general counsel worked closely with the legal counsel from both Scaled Composites and Virgin Galactic, and multiple U.S. government agencies, including the Defense Office of Prepublication and Security Review (DOPSR), Defense Technology Security Administration (DITSA), National Aeronautics and Space Administration (NASA) and the Department of State (DOS). Multiple meetings were held to review the group chairmen's factual reports and attachments. We were fortunate that DOPSR, DTSA, NASA and DOS worked our reviews into their schedules so they could give us a quick response. In the end, the agencies determined that the redactions that we had been done to protect company proprietary information was sufficient to protect ITAR concerns as well.

How did we get prepared? NTSB signed a Memorandum of Agreement with the Office of Commercial Space Transportation, then under the Secretary of Transportation, in 1989, which

established the relationship, notification procedures, coordination requirements and reporting responsibilities for each of the agencies for a commercial space accident investigation. NTSB's Office of Aviation Safety, Major Investigation Division, then spent more than 20 years preparing for a commercial space accident. This work included identifying a core "space" team within NTSB, arranging advocacy visits, attending industry conferences, and participating in training and tabletop activities. In addition, a tri-chair working group was established with NTSB, FAA/AST and NASA. The group has monthly telephone conferences and quarterly meetings.

Interestingly enough, this was not the first space investigation the NTSB has conducted. We completed a special investigations report into the February 9, 1993, commercial space launch incident of an Orbital Sciences Corporation (Orbital), now Orbital ATK, Pegasus launch procedure anomaly. As a result, NTSB made safety recommendations to the Department of Transportation, National Aeronautics and Space Administration (NASA), and Orbital.

What does the future hold? Since 1989 there have been 238 licensed launches, with 23 US launches (11 commercial) in 2014. From the FAA's *Commercial Space Transportation Year in Review*, "In 2014, the United States, Russia, Europe, China, Japan, India, Israel, and multinational provider Sea Launch conducted a total of 92 orbital launches, 23 of which were commercial." Three of the 92 launches failed, 1 which was a commercial launch. The numbers do not include the SS2 launch accident because it was a permitted launch and not a licensed launch. The commercial space industry continues to grow and may be the next major mode of transportation. Is your agency ready to answer the call??