NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, DC 20594

SURVIVAL FACTORS GROUP CHAIRMAN'S FACTUAL REPORT

July 23, 2015

I. ACCIDENT

Operator	:	Scaled Composites, LLC
Vehicle	:	Model 339 SpaceShipTwo [N339SS]
Location	:	Koehn Dry Lake, CA
Date	:	October 31, 2014
Time	:	1007 Pacific daylight time (PDT)[1]
NTSB #	:	DCA15MA019

II. SURVIVAL FACTORS GROUP[2]

Group Chairman	:	Jason T. Fedok National Transportation Safety Board Washington, DC
Member	:	Tom Fowler Butler Parachute Systems Roanoke, VA
Member	:	Roberto Montanez Butler Parachute Systems Roanoke, VA
Member	:	Guillermo Salazar Federal Aviation Administration Fort Worth, TX
Member	:	Eric Hansen Scaled Composites Mojave, CA
Member	:	Matthew Stinemetze Scaled Composites Mojave, CA

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

[2] Not all group members were present for all activities.

Member : Frederick "C.J." Sturckow
Virgin Galactic
Mojave, CA

III. SUMMARY

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

IV. DETAILS OF THE INVESTIGATION

1.0 Vehicle Configuration

SS2 was configured with only two pilot seats for the test flight. For planned commercial service, SS2 was designed to carry six participants in forward facing seats – three on the left side of the vehicle and three on the right side of the vehicle, with a central aisle; however, no participant seats were installed at the time of the accident. The survival factors group examined the cabin and pilot seats of WK2, which, according to both Scaled Composites and Virgin Galactic group members, were fundamentally identical to that of the accident vehicle.[3] The remainder of this section will describe the observations made of the cabin of WK2.

1.1 Exits

There were two plug-type exits. An oval-shaped exit was used as the main entry and was on the left sidewall, behind and below the pilot's seat. A carbon fiber lip bracket on the floor aided in the correct positioning of the plug exit. When closed, a metal handle was rotated 90 degrees counter-clockwise to provide a physical barrier to prevent the exit from being pushed inward from the outside when the cabin was unpressurized. The metal handle was directly connected to an external open-closed position indicator on the outside of the fuselage. There was a small pressure-fitted plug in the center of the exit that, per emergency procedures, was to be removed by the copilot in the event of a bailout scenario, after the cabin pressure had been dumped to 13,000 feet (cabin altitude)

[3] In addition to the two pilot seats, the WK2 cabin was configured with one flight engineer seat on the left side of the cabin in the middle position. The seat appeared similar to the pilot seats.

via the cabin dump switch. There were two similar 4-inch diameter pull plugs located next to the pilot and copilot. Removal of any of the three manual plugs would equalize the interior and exterior pressure allowing the main exit hatch to be brought inward and stowed inside the vehicle. After the vehicle had been properly configured per the emergency procedures the copilot would bail out, followed by the pilot a short time later.

The second exit was a round plug on the right side of the fuselage in the middle participant side window position. Both exits had dual seals – an interior, small bulb-type seal and the rim of the plug exit had a wider, flat face frame seal that would mate with seal material affixed to the fuselage wall. The emergency exit had one metal handle on the forward edge of the exit, which allowed the exit to be pulled inward. Because of its round shape it could not be thrown outside through the opening and procedures called for the exit to be kept inside during an emergency egress. There was a 90 degree lock/unlock latch – similar to that of the main cabin exit – on the forward edge of the exit.

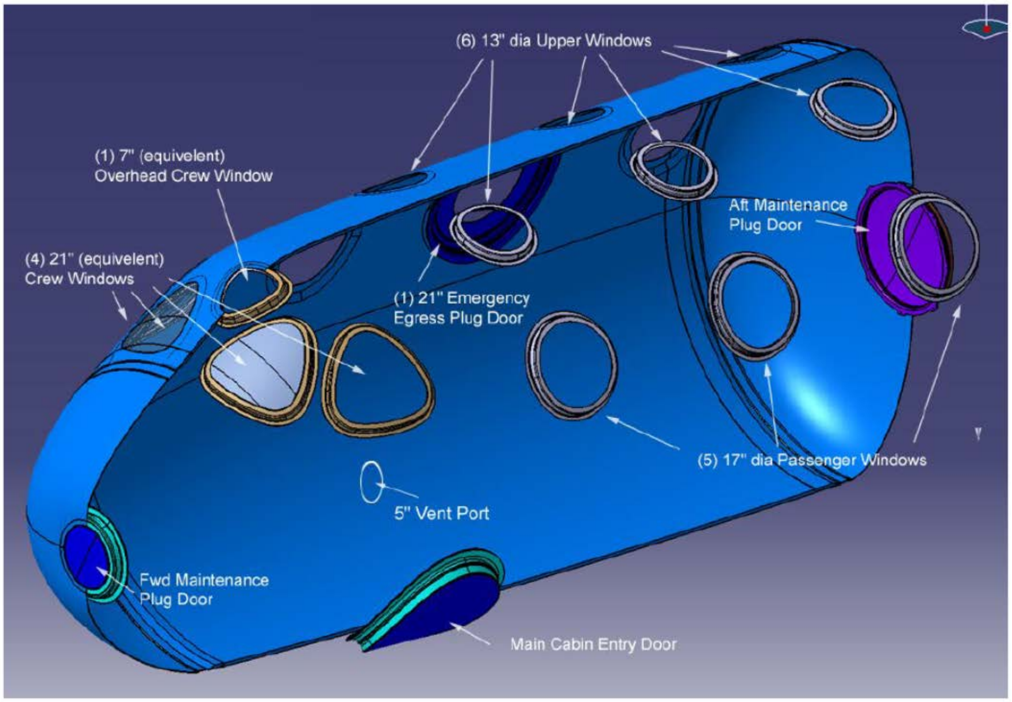

Figure 1. Cabin diagram of SS2 showing exits and windows.

1.2 Crew Seats

Both pilot seats were affixed to a raised pedestal/section of floor in the nose of the cabin pressure vessel called the "crew station." The crew station was a carbon fiber assembly with an elevated flat floor approximately 22 inches above the main cabin floor. (see attachment 1) The crew seats were attached to this pedestal to improve visibility over the nose of the spaceship. Large aluminum plates were permanently bonded to the top of the crew station floor and the four seat attachment floor fittings (per seat) were permanently bolted through the aluminum plates and composite floor panel. The seats were not adjustable in any direction and variations in pilot size were addressed by movable rudder pedals and selectable thickness seatpan cushions.

The seats mounted to the forward floor fittings by being slid forward and two dual-pronged metal fittings engaging with a horizontal bolt on the floor fitting. After engagement, the aft fittings of the seat could be mounted vertically on the horizontal bolt of the aft floor fittings. This process would correctly mount the seat but the seat would not be secured to the fittings until two latches were engaged to the aft fittings. This process was accomplished via two quick release carabiners on the lower aft portion of the seats. Pushing forward on the carabiners lowered a cam latch onto the horizontal bolts of the aft seat fittings, securing the seats to the fittings and floor structure. According to Scaled Composites, this design facilitated quick removal of a pilot and his seat (as a unit) by rescue personnel in the event of an emergency and the pilot was incapacitated and unable to evacuate. The carabiners were affixed to the carbon fiber seat by Velcro strips and placards were on the back of the seat with instructions for first responders on how to remove the seat and where to "PULL."

On WK2, the carabiners were only secured with Velcro. On SS2 the release mechanisms were pinned (locked) in place with ball detent, quick release pip pins once the seat has been installed. This locked the seat mechanisms and prevented seat detachment during acceleration from the rocket motor.

The pilot's seat was removed from WK2 and placed on the hangar floor for examination. The seat structure was entirely composite and manufactured in three pieces by Scaled Composites. The first piece contained the seatpan, parachute pocket portion of the seatback and front face of the headrest. The second major piece was the seatback down to the lumbar/pelvic region. The third part of the assembly was all of the internal gussets/stiffeners (the main was a center keel running from bottom under the seat pan and up the center of the seat back into the headrest. In the manufacturing process, the internal structure was installed into the forward portion. The final closeout was a bonding operation where the back portion was glued/bonded together and the seam running up both sides of the seatback and then it was "wet taped" with carbon fiber tape and epoxy, to create a one piece structure. The seat had no data tag information and when asked whether any seat testing was performed on the seat design, a Scaled Composites group member recalled that testing had been performed "a long time ago." (see section 1.3 of this report)

A thick seat cushion manufactured by Oregon Aero was simply affixed to the composite seatpan via Velcro strips. The cushion was marked "not a flotation device." It did not contain a data tag or FAA TSO information. Each pilot chose a desired level of thickness for their seat cushion based on their individual height and comfort level and installed the cushion of their preference on each individual flight.

The seat restraints were a five-point acrobatic restraint manufactured by Hooker Harnesses. All of the restraints were affixed to hard points (bolts) on the structure of the carbon fiber seat and there were no inertia reels. The padded shoulder straps were individually adjustable and terminated in receptacle fittings. There was an adjustable length crotch strap that also terminated in a receptacle fitting. There were also dual padded lapbelts (anchored to 4 individual bolt positions). Both lapbelts had hook/lever fittings used to fasten the restraints after the fitting of the shoulder harnesses and crotch straps had been threaded through the insert portion of the belt fittings. The hook/lever would then be rotated around the receptacle fitting of the opposite lapbelt and locked in place by a spring loaded ball detent. One of the outboard lapbelts also contained a ratchet device which was used to tighten down the lapbelts.

There were two pieces of emergency equipment in the WK2 cabin. A small, 1.25 lb. Halon 1211 fire extinguisher was mounted the interior sidewall near the copilot's right knee. A standard aviation crash axe was mounted aft of the pilot's seat on the floor near the main cabin exit.

1.3 Scaled Composites Seat Design and Testing

Scaled Composites manufactured the seats for both WK2 and SS2 and provided a seat testing report dated May 19, 2008. The report referenced Scaled Composites Interior/Seat Requirements document SS2-82E010 (Revision IR) and stated that the two limiting static loads that were considered for testing were 10g maximum down load and 26g forward load.

The static 10 g maximum entry down load was simulated by placing sacks of shot bags on a platform that was placed onto the seatpan. The test was performed to limit load with a 2,652 lb. load. The test was considered successful because there was no visible damage to the seat. For the static 26g forward test, a hydraulic ram was used to pull on cables which were attached to the seatbelt harness. The line of action of the ram was intentionally offset to 10 degrees of yaw from the centerline. The test was to be conducted to the ultimate load of 6,760 lbs. but only proceeded to 5,500 lbs. when a 1.28 inch deflection of the head rest was noted. The seat was examined after the test and no deformations, yields, or failures were identified.

2.0 SS2 Wreckage Documentation

The survival factors group convened in Mojave, CA on December 2, 2014. At that time the SS2 wreckage had been recovered and was stored in Scaled Composites hangar facilities. With the exception of the crew seats and equipment, which had been set aside, all of the vehicle wreckage that the group examined was designated as having been recovered from "Site 4."

2.1 Pilot's Seat and Equipment

The pilot's seat was still in one piece but continuity was only established between the seatback composite structure and the seatpan structure by the two steel quick release linkages that were connected to the two quick release carabiners. The outboard cam latch could be moved from open to closed by movement of any of the broken components relative to one another. The inboard cam latch was jammed in the unlocked position. The lockout pip pin for the outboard quick release linkage was broken off of the seat. The lockout pip pin for the inboard quick release linkage was intact. There was a complete fracture of the composite material where the seatback joined the seatpan. The linkages had been pulled through the composite material in a vertical direction. The outboard linkage had torn through approximately 2.25 inches of composite and was twisted outboard. The inboard seat stiffener had a fracture 4.5 inches from the base of the seat. The middle stiffener composite material was disbonded from the inner, white ROHACELL foam through its full length. There were no witness marks, bright scuffing or obvious, significant damage to any of the two attachment points of either of the two seat attachment brackets. The forward corner of the inboard bracket was deformed slightly inboard.

The seatback height measured 49 inches. The seatpan height was about 13.5 inches at its thickest part. There was a 15 inch fracture of the outboard seatback seam beginning about 5 inches from the base of the seat. There was a 6x4 inch section of missing composite material at the right shoulder area on the aft side of the seatback and there was associated scuffing that severed the wire to the accelerometer on the headrest about 5 inches below the accelerometer and 13 inches from the top of the headrest. There was a 2.5x2 inch depression fracture of the composite material directly beneath the leather carry strap which propagated into the larger fracture and missing material at the right shoulder area. There was a 6-inch long scuff on the inboard seatback seam, with no associated fracture, just above the lapbelt attachment points. The inboard right portion of the seatpan had a 6 inch fracture. There was scuffing and a 5-inch long indentation at the top of the headrest without a fracture.

There was a 10-foot long red parachute static line attachment to a grommet on the lower inboard portion of the seat. A 30 inch yellow lanyard at the end of the line served as the connection between the static line and the CYPRES 2 (Cybernetic Parachute Release System 2) device.

Restraint information (from lapbelts)
Hooker Custom Harnesses
Model # 1011230
Rated strength 1500 lbs.
Date of manufacture 5/26/09
Conforms to TSO C22F

Crotch strap model# 1CS924J
Date of manufacture 6/2/10
Rated strength 1500 lbs.

The right shoulder harness was adjusted to a 26 inch belt length and the left shoulder harness was adjusted to a 28 inch belt length. The right inboard lower lapbelt was adjusted to 21 inches while the upper was adjusted to 22 inches. The left, upper outboard lapbelt (with ratchet) was adjusted to 17 inches and the lower was adjusted to

23 inches. There was no obvious damage, scuffing or fraying to any of the seatbelts. There was no obvious damage to any of the seatbelt fittings and the seatbelts were unfastened.

It was noted that both shoulder harness fittings would affix through the male fitting of the upper lapbelt, which was on the inboard side. The fitting of the crotch strap would affix through the male fitting of the lower lapbelt which was on the outboard side. It was noted that to unfasten the seatbelts, the pilot would need to make two distinct actions in opposite directions. The outboard (upper) hook/latch needed to be rotated in the clockwise direction and the inboard (lower) hook/latch needed to be rotated in the counterclockwise direction to release the seatbelts.

An Oregon Aero 2X thick seat cushion was present with the seat. It was not damaged. A red, white, and blue Gentex HGU-55P helmet was present in a flight bag labeled with the pilot's name. According to Scaled Composites, the flight bag[4] was found by a citizen and turned in to the Kern County Sheriff's Office (KCSO). The helmet had been recovered at the site where the pilot was transported to the hospital and was returned separately to hangar 75. There were two small areas of delamination of paint on the left side of the helmet. One was about the size of a quarter and the other about the size of a dime. There was no denting or crushing. The Plexiglas visor was missing and the elastic attachment strap had been torn from the mounting buttons. There was also minor scuffing noted. The data tag inside the helmet read "11/6/13." According to Scaled Composites, that was the date of the last overhaul and the helmet was donated to the pilot for the SpaceShipOne (SS1) program around 2003. The oxygen mask, oxygen hose, and communication cord (earbuds) were present and undamaged. There was a small amount of red staining inside the mask. One left-handed flight glove, a black sock, a plush "flat cat" toy, a urine bag, a carabiner, and a pair of black leather flight boots were also present in the bag.[5] There was a 1 inch triangular tear in the leather of the lower, outboard portion of the right boot heel and a smaller tear on the left, inner boot heel.

2.2 Copilot's Seat and Equipment

The majority of the seatpan and supporting composite structure was not present with the exception of the outboard internal stiffeners and quick release mechanism. The carabiner was in its normal position and was pinned. A small section of composite material was pulled away from the seatback but was still connected to the pip pin and carabiner mechanism. The linkage arm leading from the carabiner to the aft cam latch was bent and twisted but remained connected to a section of composite seatpan containing the entire outboard seat attachment bracket and both attachment points, forward and aft. The bracket was deformed 4.5 inches from the forward attachment point and bowed outboard and slightly upward. The outboard cam latch was in the unlocked

[4] Flight bags were normally attached to the back of each pilot's seat for flight.

[5] According to Scaled Composites, the flight glove, sock, boots, and helmet were recovered at the pilot's landing location. The items were collected and placed in the flight bag post-accident when they were logged in to hangar 75.

position and the linkage was intact. The pip pin was broken off from the seatback. The left, inboard linkage, carabiner, and pip pin were completely torn out of the seatback and only remained connected to the seat attachment bracket via the linkage.

The midseat stiffener was mostly missing and the inboard stiffener was completely missing. Both leather removal straps were in place and secured with fasteners. The inboard carabineer and plunger assembly had been pulled through the bottom of the seatback and was found in a separate piece that was severely twisted in the outboard direction. The forward inboard floor fitting was still engaged with the forward seat attachment point and was removed by hand. The forward, inboard portion of that fitting was deformed downward. The outboard, aft side of the inboard clevis of the floor fitting was partially torn and deflected outboard. Bearing deformation was noted on the interior surfaces of the bolt holes of both webs. The bolts were still in place and not obviously damaged.

The linkage arm of the inboard cam latch was bent. The cam latch was in the open position and rotated freely but its range of motion was limited due to the bending damage to the linkage arm and it could not be closed. Other than the fracture from the pullout of the linkage arm, the back of the seatback was intact up to 22 inches on the inboard portion where there was a fracture on the seam through the top of the headrest. There was a transverse fracture of approximately 5 inches about 27 inches above the base of the seatback with associated inward crushing of the material - from the aft to the forward direction. This fracture radiated around to the front portion of the seatback about 4 inches. On the outboard seam there was a fracture about 5 inches from the bottom edge of the seatback that radiated upward about 18 inches where a 15 inch portion of outboard seat frame rail was missing up to the headrest. This included the outboard attachment point for the leather quick removal strap. The headrest was completely fractured and the aft shell was found as a second piece with the forward composite layer missing.

There were multiple fractures of the interior surface of the seatpan and seatback. There was a 7 inch fracture of the right outboard edge that radiated inboard to the center stiffener of the seatback. This was a continuation of the fracture previously described on the aft of the seatback. There was a radiating fracture almost from the center point of the seatback in three directions – outboard 6 inches, inboard 9 inches, and directly up about 12 inches to the fracture of the headrest. The composite material of the seatpan forward of the aft Velcro strip was missing.

<u>Restraint information (from lapbelts)</u>
Hooker Custom Harnesses
Model #1011230
Rated strength 1500 lbs.
Date of manufacture 5/26/09
Conforms to TSO C22f

Crotch strap model# 1CS924J
Model 1CS924-illegible

Date of manufacture 6/2/illegible
Rated strength 1500 lbs.

Lapbelts – Inboard

Both attachments points were undamaged and secured to the seat structure. On the lower belt the distance between the adjuster and a linear separation was 15 inches. The linear separation occurred at the seatbelt's male fitting retention loop and the fitting was still connected to the outboard portion of the lower lapbelt (that had a fractured hook/latch). On the upper inboard lapbelt there was 14 inches of belt material between the seatbelt attachment fitting and the ratchet. The seatbelts showed no evidence of warping or thread damage except for a small section of belt damage near the ratchet, about 1 inch from the sewed connection to the belt pad. The ratchet handle side plates were deformed/twisted upward and the handle crossbar was missing. There was a 2-inch long tear on the inboard portion of the seatbelt pad, on the lower portion. The female fitting on the upper inboard lapbelt was undamaged, and the hook/latch was not secured in the ball detent latch. There was a very small shiny scrape mark on the inside of the lower portion of the hook/latch.

Lapbelts – Outboard

Both seatbelt attachment fittings were secure in the composite material and undamaged. Both the upper and lower outboard lapbelts had linear separations 12 inches from the seatbelt attachment fittings without associated fraying or warping Neither belt had any damage other than the linear separations. There were two additional pieces of webbing, each 7-inches long, that were still partially secured to the lapbelt pad. The lower fitting was the female fitting which contained the latch/hook. The latch/hook arm, used to secure and release the lower lapbelt, was fractured at the ball detent latch leaving a witness mark on the upper surface. The male fitting was still engaged with the hook/latch which remained secured in the ball detent and was undamaged. There was a small amount of fraying on the lower portion of the belt where the webbing is attached to the fitting. There was also a 1-inch long tear of the outboard, upper portion of the lapbelt pad.

Crotch Strap

The crotch strap was adjusted in length to 11.5 inches. The bolt had been pulled free from the composite structure and was undamaged. The crotch strap fitting was not damaged or deformed except for a very small gouge in the metal. There was red staining on the webbing.

Shoulder harnesses

The outboard shoulder harness was still threaded through its pad which had a small tear 2 inches from the upper snap. No data tag information was present and the belt had red staining throughout. There was a small webbing abrasion 3 inches from seatbelt attachment fitting. The belt adjuster was positioned to 12 inches and total length between fittings was 23 inches. The fittings were not damaged or deformed and no witness marks were present. Some thread fraying was present on the lower portion of the harness. The belt material was torn with significant fraying at the adjuster itself and the belt appeared to have been pulled outboard at the adjuster.

The inboard shoulder harness also measured 12 inches to the adjuster with red staining throughout. The total length between fittings was 22.5 inches. No data tag information was present. The harness was still snapped in place to the belt pad. No damage or fraying was noted to the belt or the fitting, except for a small section of the underside of the belt near the adjuster. No damage was noted to the adjuster or fittings. The belt had been pulled free from the composite seat structure and some composite material remained attached to the attachment bolt. The corresponding outboard seat frame/spar was located in the main hangar.

Helmet

The copilot's Gentex HGU-55 helmet was fractured into multiple pieces. The back half and left side were held together by the edge roll. The left ear cup/speaker was with the fragmented left half. The receiver for the mask bayonet was not attached to the helmet. The right portion of the helmet was separate and fractured into small pieces held together by its edge roll. The right ear cup/speaker was present, but not with the helmet. Its cable was torn off at the speaker. The receiver for the mask bayonet was present on the right helmet segment. The insert portion was present but no longer attached to the helmet. The headliner was intact but was not in the helmet. The visor was not identified. The skull cap was present and showed multiple tears and abrasions.

Flight Document Knee Board

The knee board assembly was in two pieces. The actual hard knee board was not in the main assembly and was not found. The upper portion of the knee board (around clip area) and the loop flap were torn off of the main assembly. Velcro was intact and showed evidence of a linear separation.

Data Acquisition System (DAS) Knee Board

The DAS knee board was present and broken into two major pieces. One segment was the front/digital display. It was broken/bent over backward (outside curve along lateral axis approximately 90 degrees). The screen was shattered and in multiple sections. The second segment was the knee board or thigh mount section/back half. The mount bolts were broken off of the display. The Velcro thigh strap was not present.

Oxygen Mask

The oxygen mask was present but fractured into multiple pieces. The major portion of the mask contained the microphone. Valves were present in multiple small pieces. The gray oxygen mask hose was present but broken into two segments. The hose was disconnected at the mask interface and the mask portion of the hose was not with the mask. The SS2-mated ECS panel was folded/bent around a major portion of the oxygen hose approximately 18 inches below the mask end of the hose and just above where it would connect to the CRU-60. (See figure 2) The portion of the oxygen hose where it attaches to the CRU-60 was present, but disconnected from the CRU-60. However, the internal assembly string was still in place which loosely connected the hose to the CRU-60 the remainder of the hose.

The mask hose electrical cable was attached to the segmented sections of the hose. The bottom portion of the cable where it attached to the vehicle was torn off. The fitting was found elsewhere in the wreckage. The section above the connector was attached to the hose and wrapped with the ECS panel as described above. The upper, Y section was still attached to the mask oxygen hose. The microphone section of the cable was torn off. The end of the cable that went to the ear cup/speakers was present, but the connector was damaged. The in-ear speaker cable connecter was not attached and the speakers and wires were not identified. All of the cables showed evidence of damage (abrasions, kinks, and tears).

CRU-60

The CRU-60 was a plumbing fitting affixed to the right-side parachute harness on the pilot's chest. It enabled flow of oxygen to a crewmember in either nominal or emergency situations. The crewmember received oxygen output from the CRU-60 through a hose that attached from his mask to the top/side of the unit. This connection was locked in place and cannot be disconnected without human interaction. There were two oxygen inputs into the CRU-60: normal spacecraft oxygen from the ship regulator or emergency bottle oxygen from the parachute system. Spacecraft oxygen normally flowed through the CRU-60 to the pilot through the hose attached to the bottom of the CRU-60. This CRU-60 connection was an omni-directional disconnect. This disconnect was designed such that with a hard tug, the aircraft hose would disconnect from the CRU-60/pilot. When that happened a check valve inside the CRU-60 closed, eliminating back flow out of the open connection. The emergency bottle must then be enabled to start oxygen flow from the bottle through the CRU-60 to the pilot through his hose/mask. The emergency bottle hose attachment to the CRU-60 was also a locked connection that was designed not be disconnected without human interaction. In summary, the CRU-60 was a Y-connector that allowed the pilot to receive oxygen from either the ship or the emergency bottle.

The CRU-60 was present but detached from the mounting plate on the copilot's parachute. The fitting where the parachute oxygen bottle hose would attach was not present on the CRU-60. The black CRU-60 rubber hose was abraded and cut in multiple locations. The fitting to the mask hose was present, but the hose was disconnected and held together via the internal assembly string. The quick disconnect portion where the CRU-60 mated to the aircraft oxygen supply hose was present and intact with a section of that hose approximately 20 inches long. The vehicle hose clip was present, but damaged. The remainder of the vehicle hose was present in two additional pieces. The end of the oxygen line where it connected to the regulator was present, but the retention device was not on the hose.

2.3 Cabin Structure

A section of lower cabin floor just inside and forward of the main entry door was identified as were three pieces of the crew station riser that supported the pilot seats. All four seat attachment floor plates were identified. Each plate contained two (a forward and an aft) floor fittings for the crew seats except for the inboard copilot plate. That plate was missing the forward fitting and was deformed downward. The floor fitting that was found still attached to the inboard, forward seat attachment fittings of the copilot's seat was retrieved and the deformation of both pieces matched well. None of the fitting's attached bolts were located and appeared to have sheared cleanly. The other fittings and floor plates were undamaged.

2.4 Emergency Equipment

One heavily damaged red 1.25 lb. Halon 1211 fire extinguisher and its bracket was identified.

2.5 Environmental Control System (ECS)

The Scaled Composites' Pilot Operating Handbook SS2-90P001 REV D, dated September 3, 2013, section 2.2.5 *Supplemental Pilot Oxygen* described the philosophy behind the pilots' use of oxygen via the ECS. It stated that the environment inside the spaceship was "shirt-sleeve" with plenty of "makeup air" to carry the occupants through any emergencies. However, because the cabin was hermetic during the spaceflight portion of the mission, any fumes or smoke in the cabin could incapacitate the crew. It stated that "using the outflow systems… is an acceptable means of venting fumes. However, the duration, quantity, effects, etc. are beyond the scope and schedule for the T1b program to resolve. For these reasons we believe spaceflights should fly with supplemental oxygen for the crew."

Oxygen delivery to the pilots was accomplished via a CRU-72A military regulator that regulated the oxygen from sea level up to 30,000 ft., above which it delivered 100% oxygen. (See figure 2) Each regulator received oxygen from a 2000 psi aviator's oxygen bottle. According to their procedures, the pilots were to pre-breathe 100% oxygen for 30 minutes during the climb to launch altitude to provide "some margin in useful consciousness for an 'event'." They would then remain on 100% oxygen for the duration of the mission.

Figure 2. SS2 ECS components.

Vehicle Oxygen Bottles

Two green crew oxygen bottles were identified. Neither bottle was charged.

The pilot's oxygen bottle was a Composite Overwrapped Pressure Vessel (COPV) with a Kevlar overwrap on a metal liner. It was not crushed. The bottle had approximately 20 abrasions through the outer resin wipe/paint exposing frayed, fuzzy fibers. The back side of the bottle had three locations where there were scorch marks approximately 1 3/4 inch diameter that accompanied punctures through both the overwrap and the metal liner. The bottle had one metal mount strap still attached with some safety wire still in place near the top end. The metal manifold was still threaded into the boss on the top of the bottle. The "AN" fitting and copper oxygen hose were missing with a section of safety wire broken at the interface. The top on/off handle was also missing with the fitting bent over 45°. The fill port and line were missing. The pressure gauge was missing.

Structural Composites Industries (SCI)
MFG Part Number - 1274467
MFG Test Date -12/08
5 Year Retest
Case Code No. - 58943
Empty weight - 7.3lbs.
Volume – 650 cu. in.
AmSafe Part Number - B21507-02
The bottle also had CGS tag stating "Next Test Due 10-2018"
Bottle Liner S/N 18405

The copilot's oxygen bottle was a COPV with a Kevlar overwrap on a metal liner. It was crushed to approximately half thickness approximately one quarter of the length from the bottom end. There were also slight indentions in other locations. The bottle had significant abrasions through the outer resin wipe/paint exposing frayed, fuzzy fibers. There were no indications of scorch marks on the bottle. The bottle had one metal mount strap still attached with some safety wire still in place near the bottom end. The metal manifold was still attached to the bottle. However, it was bent approximately 45° to the side at the boss interface expositing the sealing O-ring and the manifold threads. The "AN" fitting and copper oxygen hose were missing with a section of safety wire broken at the interface. The top on/off handle was also missing with the fitting bent over 45°. The fill port and line were missing. The pressure gauge was missing.

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MFG Test Date -12/08
5 Year Retest
Case Code No. - 58943
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Volume – 650 cu. in.
AmSafe Part Number - B21507-02
The bottle also had CGS tag, but it was unreadable.
Bottle Liner S/N 18404

ECS Panel

The ECS panel was bent primarily around the vertical axis with both sides inward/forward, but was also bent forward along a lateral axis. The guards were missing from the 'dump' and 'emergency enable' switches. The switch bodies from those switches were not present, so no position information could be determined. The locking ECS/RCS interconnect switch arm and lockout were present. The lever was in the "on/connect/up" position and the switch was bent up approximately 80° in the same direction. This was similar to bending of the panel. The switch could be moved out of this position with nominal unlocking action. It could not be back-driven in this direction due to the locking mechanism. However, with the switch in the down position it could be pushed past the lock into the final "on/connect/up" position as it was found (i.e. the lock has been damaged in the up direction of motion). The primary enable switch lever arm and lockout were also present. The switch was also bent almost 90 degrees vertically. It was in the "off" center position and the lock was undamaged. The two pneumatic backup valves were not in the panel.

ECS Panel Pneumatic Valves

Both the primary microneedle valve and the emergency manual pneumatic valves from the ECS panel were identified. The primary microneedle valve actuation handle was not present and its stem was broken off inside the valve body. The body was intact but both the 'in' and 'out' pneumatic connections were broken off. The area where the valve was attached to the panel was present and had carbon material remaining from the panel. The assembly nut between the body and the handle was finger tight. When the valve was opened the needle appeared to be in a 'near-closed' or 'closed' position. No witness marks or damage were observed inside the valve.

The emergency plug valve was almost completely intact. One pneumatic fitting was intact in the main body, the other broken off inside the body. The body mount structure to the panel was intact with carbon fragments where it had been mounted. The valve stem and structural handle were in place although the knob was not found. The valve could be opened with nominal effort.

Pilot Oxygen Regulator

The CRU 72/A oxygen regulator was mostly intact. The switch panel was bent forward from the bottom, right corner approximately 90 degrees. All three levers were intact, but appeared to be broken internally. No position could be determined. The flow indicator was present, but functionality could not be determined. The connection to the crew oxygen line was intact, but the oxygen hose was not connected. The oxygen line from the ship was not present on the regulator, but was found with the wreckage.

Copilot Oxygen Regulator

The CRU 72/A oxygen regulator was present, but broken into multiple sections. The main segment (body) was detached from the face plate. The connection to the crew oxygen line was broken off. The oxygen line from the vehicle was not present on the regulator. The face plate was present, severely bent, and had only the center (white) lever arm attached. The acrylic name plate was not found. No information could be determined about the position/state of the levers.

2.6 Parachute Systems

The Aircrew Parachute System was manufactured by Butler Parachute Systems (BPS) and consisted of four major sub-assemblies: 1) harness and container, 2) parachute canopy, 3) oxygen system and 4) automatic activation device (AAD).

2.6.1 Pilot's Parachute

The parachute was documented on December 2, 2014 as it was found in Scaled Composites hangar 75. The parachute was identified as belonging to the surviving pilot by group members from both Scaled Composites and Virgin Galactic. The harness was retained and shipped to NTSB headquarters in Washington, DC for further testing. (see section 3.5 of this report)

Butler standard high-altitude harness and container
P/N 101-14241.75 (AAD O2)
S/N 30246

Canopy
Butler model HX-500/24
S/N 30038 (consistent with the packing data card)

Oxygen System
MS22069 Aviator Bottle (modified with BPS custom bracket and housing for over-the-shoulder pull)
P/N 10567
Lot 29033
DOM: 8/19/13

Automatic Activation Device
CYPRES 2
Aircrew
S/N 91369

The parachute harness was found in good condition, with no signs of damage on any of the components. Continuity was established in all harness straps. No stitching was damaged on any part of the system, including all load-bearing harness components. There were no signs of excessive loading or webbing fraying on any of the harness components. The container was found in good condition with minimal amounts of dirt and no evidence of any broken stitching or cloth damage.

The oxygen handle (green pud) was found stowed in its Velcro pocket. The oxygen bottle was found to be full (>1800 psi). It was securely stowed inside the pocket with the safety line around the neck of the bottle still tied. The bottle was not removed from the container. The oxygen hose was found disconnected from the CRU-60 adapter, which was undamaged. A few grains of dirt were found inside the CRU-60 where the bailout oxygen hose was supposed to be connected, but none were visible inside the oxygen hose itself. The plug assembly/fitting at the end of the oxygen hose was securely attached to the hose and showed no signs of damage/stretching.

The CYPRES 2 cutters were found in the activated position, with the guillotine blade fully covering the closing loop hole. The closing loops were also found cut cleanly. The CYPRES 2 power was cycled in accordance to the self-test procedure of the CYPRES 2 Aircrew Manual. After a countdown from 10 to 0 the unit displayed "1111" consistent with an error code for an activated unit. The code remained displayed until manually turned off about 30 minutes later. The CYPRES 2 unit was found installed in accordance to the manufacturer's recommendation with the cables against the pack-tray and the arming housing on top. The cutter cables were not damaged. The static line was found attached to the seat and fully extended, about 10 feet long. The CYPRES 2 had data logging capabilities and non-volatile memory and was retained by the NTSB. (See section 3.6)

The parachute canopy was found with no damage. The condition was consistent with a nominal speed deployment. The pilot chute[6] and deployment bag remained attached via the Type 3 loop between the apex of the canopy and the pilot chute channel

[6] A pilot chute was a very small parachute, usually spring-loaded, whose function was to extract the main parachute from the container.

bridle. The vent cap was not blown and the mid ties of the four leaf vent cap were intact. The top tie was missing consistent with a nominal deployment. Every gore (1/24th of the canopy) of the parachute was examined and no holes or broken stitching were found. The canopy was dirty in some spots. The slider was found in good condition with no damage to the stitching, cloth, mesh or grommets. The lines were tangled and were not untangled due to the time requirements associated with that task, but good continuity could be visually established with no broken lines. The risers were found in good condition with no evidence of broken stitching. The riser releases were of the Capewell J1 style, and were found disconnected from the harness and container.

The rigger's lead seal was not found, although the ripcord pin had the remains of the red seal thread associated with the FAA required seal. According to BPS, it was not uncommon for the seal to be lost during an emergency opening, as it was designed to be a tamper-proof device to prevent resealing of the parachute.

The packing data card showed the last repack date of 10 September 2014 and had the signature and certificate number of the packer. The repack date was the first after initial assembly in March 2014. The information on the data card matched the serial number of the components. The next repack date would have been March 9, 2015, per current FAA regulations.

2.6.2 Copilot's Parachute

The parachute was documented on December 2, 2014 as it was found in Scaled Composites hangar 75. The parachute was identified as belonging to the fatally injured copilot by group members from both Scaled Composites and Virgin Galactic.

Butler standard high-altitude harness and container
P/N 101-14241.75 (AAD O2)
S/N 30249

Canopy
Butler model HX-500/24
S/N 30039

Oxygen System
MS22069 Aviator Bottle (modified with BPS custom bracket and housing for over-the-shoulder pull)
P/N 10567
Lot 29033
DOM 8/19/13

Automatic Activation Device
CYPRES 2
Aircrew
S/N 91368

The parachute system was found with the pilot chute outside of the container, with the bridle from the parachute having a linear separation approximately 18 inches away from the deployment bag. The linear separation did not show any evidence of fraying. The pilot chute itself was in good condition with no broken stitching, no holes in the cloth or mesh, and the spring was extended to its full length and properly assembled. The pilot chute was a BPS Part Number 108-41, SN 29675.

The parachute harness/container was found with the ripcord handle fully stowed in the pocket, but the container was open. The ripcord pins were pulled out of the closing loops, thus allowing the container to open and expose the pilot chute and deployment bag. The ripcord housing was severely damaged causing significant compression and bending at the tab that secures the housing to the container just above the ripcord pocket. It appeared that it caused the ripcord pins to move. The tab itself separated from the ripcord cover. The visible cable on the handle showed slight signs of bending, but no kinking. The cable ball end was found properly flush with the end of the cable.

The CYPRES 2 control cable was found with a linear separation about 2 inches away from the control unit. The CYPRES 2 could not be turned on due to the separated cable. The CYPRES 2 was found in the pocket in the proper orientation, with the housing up and the cables down. The CYPRES 2 cutter cable connector and its mating connector on the CYPRES 2 unit were both found severely crushed. The cutter connector was broken and separated from the receptacle end on the CYPRES 2 unit. Both cutters were found in the inactivated position. The closing loops were found intact. The CYPRES 2 static line was found fully extracted from the stowage flutes, but the yellow CYPRES 2 activation cable at the static line end was found in place still secured by the cotton thread tackings. On the other end, the CYPRES 2 red, static line had a linear separation 5 feet, 6 inches away from the yellow cable loop, and it showed no signs of tension loading or fraying at the separation. The remaining lanyard was found attached to the seat.

The Capewell J1 riser release on the left side was found in the open and released position. The male fitting was found right next to it with the riser still under the riser cover flap, with no sign of movement inside the flap. The flap was found closed with the Velcro mating. The left chest strap was found with a clean linear separation across the webbing without any signs of warping or fraying. The left strap was routed properly across the left main lift web. The left side leg strap had slight fraying at the edge of the webbing.

The right strap V-Ring was disconnected from the corresponding snap, and showed signs of scuffing along its length. The main lift web on the right side had a clean linear separation right below the CRU-60 plate mounting pad with no signs of loading or fraying. The top of the CRU-60 plate was broken away, with small remaining surfaces attached to each of the four screws. The ripcord D-ring was found in the fully stowed position. The emergency oxygen handle (pud) was found fully stowed in its pocket with the Velcro mating in line with the corresponding Velcro inside the pocket. The green fabric on the emergency oxygen handle showed extensive damage, particularly inboard and on the top corner. The oxygen cable was bent and the heat shrink covering the sleeve was broken. The link connecting the cable loop and the oxygen handle was found in good condition and closed beyond finger tight. The Capewell release on the right side was found closed with the riser still attached, but with the release cable broken and frayed at the inboard ball. After unsnapping the three snaps holding the oxygen mounting pad, the bottom of the CRU-60 plate was found in good order. The right chest strap was also found properly routed inside.

The oxygen hose was found still attached to the container, but separated from the CRU-60 fitting. The hose CRU-60 connector was bent and had debris inside. The brass ferrule was slightly crushed and there was a gap between it and the knurled fitting. The oxygen hose showed no damage and it was routed properly inside its channel. The oxygen pouch was found with the zipper closed but with the zipper tab unsnapped. After opening the zipper, the bottle was found inside with the bracket bent. The bracket was missing the left screw, and the right side screw (side with manufacturing markings) and the back screws (side away from the gauge) were in place. The oxygen needle was found halfway in between the “Refill empty” mark and the “1800 full” mark. The entire head assembly was found pulled out of the bottle, exposing the white seal tape about four threads deep. A flat screw driver was inserted in the hose to check for the presence of the brass nipple, and its presence was verified.

The pin flap was opened and the rigger seal was found inside with the red seal thread broken. The initials on the seal were VWM. The packing data card showed the last repack date of 30 July 2014 in Tehachapi, CA and had the signature and certificate number of the packer. It was the first repack on the system after initial assembly.

The suspension lines were all attached to the risers via the rapid links. Two groups of lines were established with good continuity. All the lines were stowed in the elastic bands. The lines were holding the deployment bag closed via the corresponding rubber bands. The canopy was pulled out and found to be properly folded and packed. The canopy data panel was found with a corresponding serial number 30039. The apex of the canopy was connected to the deployment bag via the proper attachments. The canopy was not inspected in detail as it was not deployed in the accident, but a visual inspection showed no signs of damage.

3.0 Parachute Information

3.1 Basics of Parachute Operation

Group members from Butler Parachute Systems provided information about how the parachute system was designed to operate. The parachute was designed for arresting the descent of a crewman after emergency egress at altitude. It was equipped with a standard ripcord handle which was designed to initiate parachute deployment by pulling the ripcord closing pins from the closing loops. It was also equipped with a static line that attached to a hard point on the seat and activated the CYPRES 2 AAD into the "on" or "sharp" mode if a crewmember were to bailout or become separated from his seat. Upon egress, the static line attached to the pilot's seat pulled a pin that activated the CYPRES 2 AAD into "on" mode. The CYPRES 2 was designed to activate (and deploy the parachute) after all of the following four conditions were met:

1. The lanyard was pulled.
2. A time delay of 5-7 seconds after (1) expired.
3. The altitude was below 13,000ft as measured by the internal pressure sensor, calibrated to Standard Day MSL.
4. The vertical speed exceeded 35 m/sec (about 6,500 ft./min)

All four conditions were required to be met for the CYPRES 2 to cut the closing loops. This occurred when two small pyrotechnic charges fired and guillotine blades were propelled into the cord loops, cutting them.

The parachute could also be manually activated by pulling the ripcord handle located on the left side of the harness. Either pulling the ripcord or a CYPRES 2 activation would result in the container opening. Once the container opened the spring-loaded pilot chute would extend and launch into the air. It would catch air and generate enough drag to pull the deployment bag out of the container, with the parachute canopy inside. The pilot chute would pull the deployment bag away from the container, un-stowing the lines from the elastic bands first, until it got to the rubber bands closing the deployment bag. When the lines pulled out of the rubber bands, the deployment bag would open and the canopy would come out. The canopy would reach full suspension line stretch and begin to inflate. If the speed was high enough (roughly more than 160 knots depending on weight and altitude) the pilot chute tie would break followed by the zip-strip and eventually the pilot chute would disconnect. Otherwise, the pilot chute would remain attached. The parachute was also equipped with a sacrificial "four-leaf" vent cap that was tied together with break cord and was designed to open or blow at high speeds to minimize the opening shock. At low speeds the vent cap would remain closed to increase the pressure inside the canopy and accelerate the inflation.

When the canopy reached "line stretch," the Butler Aerospace Technologies "sombrero" slider would inflate, followed by the parachute canopy. After canopy opening, the slider would then come down the lines to about the half-way point. At this point, the parachute would be fully inflated and could be steered by pulling on the rear risers. If no steering took place the parachute would descend to the ground in a wide circular orbit. The rate of descent was dependent on both the weight of the person and the altitude.

The oxygen system was designed to be activated inside the spaceship when needed, regardless of whether egress was required. The oxygen flow was activated by unstowing the green pud on the upper, right-front parachute harness strap and pulling the pud. A portion of pud was stowed in a pocket with 1 inch Velcro tape, and it needed to be peeled out of the pocket before pulling on it. Butler Parachute Systems stated that a two-handed pull was required, with a force of up to 40 lbs. (typically 35), to activate the oxygen. Pulling the handle broke a brass nipple inside the oxygen hose at the top of the bottle releasing oxygen into the hose, through the CRU-60 and into the pilot's oxygen mask.

3.2 Development of P/N 10567 Oxygen System

Group members from Butler Parachute Systems also provided historical information about the parachute oxygen system's design and development. In the development of the P/N 10567 oxygen system, BPS modified the MS22069 oxygen bottle by installing a bracket to allow for an over-the-shoulder routing. Older Butler parachute models used a "green apple" (spherical green wooden handle) at the end of the cable to activate the oxygen flow. On the BA-22, an old USAF system, the oxygen bottle was right side up, but the cable was routed in such a way that it exited the container around the waist area and the activation pull's direction was across the body. The cable was not protected except by the fabric of the container. On Butler systems, the oxygen bottle was inside the container and right side up, with the oxygen cable routed through a bracket and protective metal housing assembly that allowed for a 90 degree upward change of direction. The cable ran through a flexible housing and routed over the shoulder and down to just above the CRU-60. According to BPS, the motion to activate the oxygen was "down and away" and this routing increased the force requirement to about 35 lbs. nominal (40 maximum) and required a two-handed pull or "a strong one-handed operation."

The following information on oxygen system activation was contained in the BPS *High Altitude Emergency Parachute System User's Guide* (Revision B – November 2012):

12. Activating the Emergency Bailout Oxygen

Activate the emergency oxygen before you bailout of the aircraft. The oxygen can be activated at any time regardless of the emergency. The emergency oxygen can be used if you are going to stay inside the aircraft for an emergency landing.

To activate the emergency oxygen:

Grab the green handle on the right side of the harness with either hand and make a fist.

Pull the handle forcefully downward. You will only achieve a short stroke before the cable stops and the system delivers oxygen.

Repeat this step if you don't receive oxygen.

Page • 14 Revision B – November 2012 Document Number:

Figure 3. BPS *High Altitude Emergency Parachute System User's Guide* Revision B.

3.3 Scaled Composites' 2013 Pull Force Concern

On November 12, 2013, two Scaled employees attempted to discharge an oxygen bottle prior to shipping a parachute system back to California. They discovered that it was extremely hard to pull the emergency oxygen activation handle. On November 18, 2013 Scaled employees retested the system after returning to Mojave and verified that it took about 50 lbs. to activate oxygen flow. The next day, the director of quality assurance at Scaled Composites sent an email message to BPS expressing concerns regarding the pull force required to activate the oxygen bottle stating that Scaled had measured a force of up to 50 lbs. to activate a bottle, which they considered too high. Between that date and May 8, 2014, BPS conducted a series of tests on oxygen systems. (See attachment 2)

In the BPS tests, several test subjects of different size and gender donned the parachute and attempted to activate the bottle while in a seated position by pulling on the oxygen activation handle as outlined in the *High Altitude Emergency Parachute System, User Guide*. Seven tests were attempted using a one handed pull. None of the subjects were able to activate the bottle with only one hand. The subjects then used a two-handed pull and reported oxygen activation was "easy." Four tests were conducted with the current design where the activation cable turned 90 degrees 3/8" from where it exits the bottle. Ten tests were conducted with a redesigned bracket without the 90 degree turn. The results showed the current design required an average 37.3 lb. pull for activation while the experimental design required an average 32.9 lb. pull for activation. The test reports concluded that:

> The test design bracket marginally reduced the pull force necessary to activate the bottle by approximately 10% (4 lb.). The test design bracket compromises the profile of the parachute system; the cable housing creates a snagging hazard because it routes out-and-up the pack where the current design routes straight up the parachute pack.
>
> Given the ease at which everybody was able to activate the bottle with two hands and the marginal improvement in pull force with the test design, along with the profile compromise, Butler Parachute Systems abandoned the consideration of switching to the new bracket. We have established a maximum acceptable pull force of forty pounds for the High Altitude Back Pack.

The report was delivered in person to the Scaled director of quality assurance on May 13, 2014 during a BPS visit to Mojave to conduct contracted training on the use and maintenance of the parachute system at Virgin Galactic. However, Scaled had already improvised an in-house solution to the problem. On November 27, 2013, after assigning an engineer to the problem, Scaled designed and fabricated a Delrin block to help the cable make the 90 degree corner. (See figure 4)[7] The solution was tested and a drop in activation forces to 35 lbs. was achieved. According to the director of quality assurance, "this was deemed acceptable by [the director of flight operations] and no further work was done on improving this number."

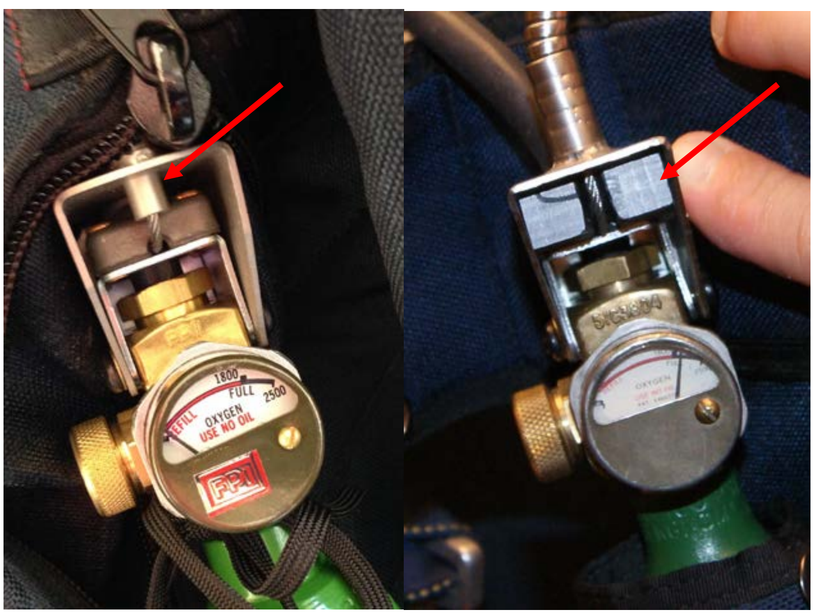

Figure 4. A photograph of an unmodified oxygen bottle (left), and one modified by Scaled Composites with a Delrin block (right, red arrow)

[7] Note that the cable housing was cut off flush with the bracket (red arrow, left picture).

The BPS *High Altitude Emergency Parachute System User's Guide* was revised in March 2014 and contained revised wording in the section describing the activation of the oxygen system. The words "grab the green handle on the right side of the harness with either hand and make a fist" were changed to "grab the green handle on the right side of the harness with both hands and make a fist." The words "…apply sustained force on the cable until you receive oxygen… Keep applying sustained force until you receive oxygen" were added to the newer version.

12. Activating the Emergency Bailout Oxygen

Activate the emergency oxygen before you bailout of the aircraft. The oxygen can be activated at any time regardless of the emergency. The emergency oxygen can be used if you are going to stay inside the aircraft for an emergency landing.

To activate the emergency oxygen:

Grab the green handle on the right side of the harness with both hands and make a fist.

Pull the handle forcefully downward and apply sustained force on the cable until you receive oxygen. You will only achieve a short stroke before the cable stops. Keep applying sustained force until you receive oxygen.

Page • 14 Revision C – March 2014 Document Number:

Figure 5. BPS *High Altitude Emergency Parachute System User's Guide* revision C.

3.4 Parachute Information from Virgin Galactic

Although Scaled Composites was the operator of the accident flight, the pilots chose to use Virgin Galactic parachutes during the flight as a matter of convenience because both WK2 and SS2 were staged at the VG hangar. (See attachment 3 for interview summaries) Both companies had the same P/N BPS parachutes. When asked whether they had any knowledge of the difficulties Scaled had encountered with the oxygen system activation prior to the accident flight, VG's life support officer/pilot stated via email that "we all understood that the pull on the green apple [pud] was harder than desired. We actually took a delay in our original Butler purchase order since they were working [oxygen] issues before sending us the chutes with their subcontractor. I was under the impression that our chutes had a reduced pull than the original Scaled chutes (prior to their mod)." He added, "we elected not to try and mod the chutes ourselves. We wanted Butler to be responsible for any modifications to the TSO chute even though the O2 system is not covered by any FAA TSO's on emergency chutes." Finally he stated that "we never gave Butler a requirement for a single hand pull. It (like the chute D-ring) were [sic] always designed as a two hand pull. I do not recall asking for the

Velcro on the pug [sic], but I always looked at that as a "get in and out" of the seat kind of Velcro and not as something I wanted velcroed that tightly during flight."

When asked whether VG had performed training on the BPS parachutes prior to the accident, VG's life support officer/pilot wrote:

> "We received our initial Butler training from Butler here in Mojave when they delivered the parachutes... It was attended by myself as the life support pilot and a few of our maintenance personnel who were going to be responsible for delivering the chutes to the rigger for repack. At that time we decided we wanted to purchase the device to service the [oxygen] bottle so we could practice some green apple pulls. We never got to practice any green apple pulls prior to the accident, but we all knew they were high pull forces (close to 35 pounds—that was what I remember Butler promising…even though I remember them saying they were continuing to work on a lower pull force with the supplier). We have since done a pull test since we finally received all of the required items to service the bottles.
>
> After I received that initial training from Butler, I posted the required manuals on a shared location for the VG pilots and spent a real short period of time with them the first time we flew with our Butler chutes. They were operationally/procedurally equivalent to the Scaled Butler chute (even though they had performed some mods) so we didn't have to spend a lot of time on the chutes. I also spent some time with [the accident pilot] prior to his first use of our parachutes (either a glide flight or a WK2 flight…I don't remember). I flew a WK2 flight with [the accident copilot] several weeks before the accident and we also used our VG parachutes. I answered some of his questions…but, like I said…procedurally, the chutes are identical so we didn't spend a lot of time on them."

3.5 Post-accident Pull Force Testing

On January 16, 2015, the survival factors group convened at NTSB HQ in Washington D.C. to perform a series of tests on the P/N 10567 oxygen system of the surviving pilot's parachute harness. As stated earlier in this report, the group found the green pud oxygen handle still stowed inside its Velcro pouch and the oxygen bottle itself was still fully pressurized during initial wreckage documentation.

In the first series of tests a harness and digital force gauge were affixed to the green pud and a series of tests were conducted to determine how much force was required to remove the green pud from the Velcro pocket. Three different motions were used during the tests: straight down and away from the body, across the body, and straight away from the body. The resulting forces ranged from 14.1 lbs. to 23.1 lbs. (see attachment 4)

Two additional tests were conducted. The first measured the amount of force required to break the brass nipple and discharge the oxygen bottle on the accident harness. The measured result was 57.8 lbs. The second test measured the force necessary to pull the pud from the Velcro pocket and break the brass nipple of an oxygen bottle (in one motion) that was not charged. The measured result indicated it took 34.9 lbs. to extract the pud and 55.3 lbs. to break the nipple.

When asked for possible causes about the higher values achieved in these tests compared to those in the BPS May 2014 tests, BPS replied that they had performed additional testing in-house that also showed higher average values (44 lbs. with a standard deviation of 6.9). They stated "it is possible that the nipples we had back then were on the low end, or that our instrumentation or test method was somehow different. If you look at the construction of the nipples, it is going to be very difficult to get a consistent breaking force with a low scatter." Additionally the company added that "we are continuing to research the matter and we will work towards finding a better solution, both internally and working with Scaled/Virgin… we do intend to emphasize to our customers that the bottle is designed to be activated inside the aircraft, prior to egress, with a two hand activation motion, and as soon as you recognize an oxygen failure (whether bailout is required or not). We will also emphasize that single handed operation may not be achievable."

3.6 Post-accident AAD data recovery

The CYPRES 2 had data logging capabilities and non-volatile memory and the pilot's device was retained by the NTSB. The CYPRES 2 was manufactured by Airtec GmbH & Co. KG Safety Systems of Germany. The data from the pilot's unit was successfully downloaded at the SSK Industries, Inc. facility in Lebanon, OH on April 10, 2015.[8] Analysis of the data provided by Airtec engineers indicated that the pilot's AAD activated at 11,590 feet[9] MSL and that the device's cutters, which allowed the parachute to release, activated at 10,870 feet MSL. The pilot's average vertical velocity after the device's activation and prior to the activation of the cutters was 135 miles per hour (approximately 60 meters/second or 200 feet/second).

3.7 Post-accident testing by Scaled Composites

As stated in section 2.6.1, the pilot's oxygen hose was found disconnected from the CRU-60 adapter. Scaled Composites performed two tests to investigate whether pulling the hose fitting from the CRU-60 was possible, what loads would be required to do so, and whether such loads would cause visible damage to either component.

Each test made use of the Scaled Composites Instron machine which pulled on the components until failure. The first test consisted of pulling on the oxygen supply hose.

[8] SSK Industries, Inc. was the United States service center for CYPRES 2 devices.

[9] The AAD activation would have been triggered by the detachment of the 30 inch yellow lanyard that was affixed to the 10 foot static line connecting the pilot's parachute to his seat.

The hose failed at the brass ferrule of the interconnect at approximately 18 lbs. It was noted that the hose seemed to stretch and stay stretched after the test. The amount of stretch was estimated to be about 10%. The second test pulled on the actual interconnect fittings that fasten the hose into the CRU-60. The failure occurred when the attach nipples on the CRU/60 were sheared off. The load at failure was 204 lbs. No deformation of the attach fitting was noted after the test.

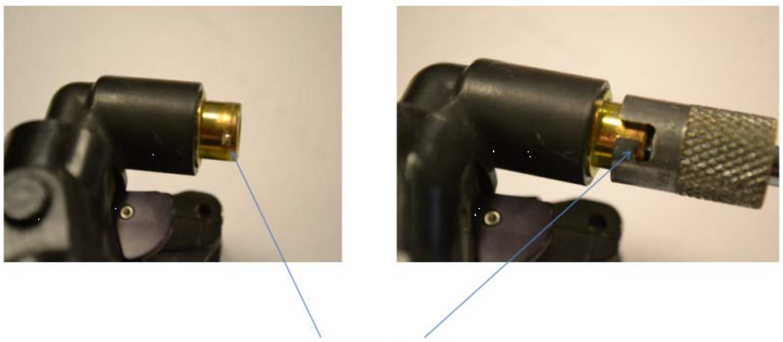

Figure 6. Damage to CRU-60 hose fitting after Scaled Composites testing.

3.8 Post-accident Changes at Scaled Composites and Virgin Galactic

A February 11, 2015 email from Scaled Composites indicated that there was ongoing work with BPS to develop a solution to the difficulties encountered with activating the oxygen cylinder, with the ultimate goal being a "rework of all of our parachutes to a common configuration." Scaled Composites' stated desire was for "a suitable, coordinated redesign of the emergency oxygen activation [to] allow an either hand, single-handed activation, whether in the seat, free falling, or in chute."

A June 16, 2015 email from Scaled Composites provided copies of a newly-developed training outline for the parachute system that consisted of 1.) the construction and operation of all system components, including the emergency oxygen system; 2.) egress procedures; 3.) canopy steering; and 4.) landing. The email also included a new pre-flight checklist to be used by pilots to inspect the parachute and emergency oxygen systems.

The training was "one-on-one, hands-on training with the instructor working with all the life support equipment laid out on a table on the hangar floor, next to the aircraft. Training is completed with up to about four students at a time, with instructor demonstrations followed by student operation of actual equipment. Training for one student takes about an hour and a half. Four students takes about two and a half hours. The students connect and disconnect all items, actually activate the parachute and emergency oxygen, and follow the preflight inspection checklist for survival gear. The students are trained on the functions and operation the CYPRES system to include best practices for use of the CYPRES activation lanyard. From a suitable platform, the students practice ground contact and energy dissipation technique to minimize chances of injury."

A June 26, 2015 email from Scaled Composites confirmed that both Scaled pilots who flew with parachutes had successfully completed the training program and that training records had been created for each individual that would be updated on an annual basis. The initial training session was conducted by a Scaled Composites employee who had been a military and civil parachutist with approximately 500 jumps; however, as of July 15, 2015, Scaled had contracted with an external vendor to provide ongoing annual refresher training. Additionally, Scaled Composites purchased equipment to replace the nipples on and recharge the emergency oxygen bottles – allowing pilots to experience the forces necessary to activate the emergency oxygen system while wearing both their helmet and parachute.

Finally, Scaled Composites stated that they have removed the "pud"-style emergency oxygen handles and were using an "emergency oxygen loop" that they found would allow a pilot to activate the oxygen system with a "strong one-handed pull with a thumb through the loop." Scaled Composites was continuing to work with BPS on the development of a new emergency oxygen system. For more information about Scaled Composites' pre-accident parachute training, see the Human Performance Group factual report.

A February 24, 2015 email from Virgin Galactic indicated that all VG pilots received annual egress training in January 2015. One VG test pilot was selected to activate an oxygen system on a parachute system that needed to be sent out for a scheduled repack. He stated that, "it definitely took two hands and was much harder than needed. Also, there was no positive indication that I had activated the Emergency [oxygen] so I pulled it multiple times." He also stated that while a permanent fix was being discussed with BPS, VG pilots would use an ad-hoc procedure involving the "cocking the pud by partially removing it from the Velcro." Finally, he added that, "many pilots think the old green apple had better human factors and could be pulled by either hand in the event of injuries."

4.0 Accident Narrative

The surviving pilot was interviewed by the survival factors group on January 16, 2015, in Washington D.C. (see attachment 3) He stated that he and the copilot both preflighted their parachutes on the day before the accident. Although they were Scaled Composites employees, they chose to use Virgin Galactic parachutes out of convenience because WK2 and SS2 preflight operations were being run out of the Virgin Galactic hangar. Nothing abnormal was discovered during their examinations but the pilot stated that he did not specifically check the connection between his oxygen hose and the CRU/60 on the parachute harness. The parachutes were left in SS2 overnight and were donned prior to takeoff on the morning of the accident.

He stated that the flight was nominal until the time of release. The last thing he recalled in SS2 was a very violent, large pitch-up with high Gs, and grunting noises. He heard a loud bang followed very quickly by signs of a rapid cabin depressurization. In the background he heard the sound of "paper fluttering in the wind," which he believed was the sound of pieces of the cabin coming apart. There was then a period when he had no recollection, which he attributed to "G-LOC" (G-induced Loss of Consciousness) due to the unexpected onset of high Gs for which he was not prepared.

The next thing he remembered was being outside of SS2 and seeing a wide expanse of desert from a high altitude. He was falling in a stabilized position with his head slightly down and he had to look up to see the horizon. He was not tumbling. He unfastened his seatbelt without difficulty and assumed the free fall with his arms out and legs apart. He then experienced another period of unconsciousness or lack of memory followed by a "sudden jolt" when the parachute opened. He did not pull the D-ring for the rip cord and evidence indicated that the parachute's automatic CYPRES 2 device activated the parachute. He recalled attempting to activate his oxygen but was unsure at what point in his descent he made the attempts. It was either during one or both periods of consciousness. He tried "many, many, many times" and "just got the feeling" that it was not working and he never got oxygen flow. He also stated that he "didn't know what to expect or what it should feel like… it just didn't feel like it did anything." When asked if he used one or two hands he stated that he only used one hand – his left.

His right shoulder was dislocated and fractured and he was unable to control his descent under canopy but landed without additional significant injury. The Extra 300 chase airplane circled him numerous times while he was both in the air and on the ground. The first helicopter to land was from the National Test Pilot School. They examined him and eventually got a backboard and stabilized him on it. He was taken to a second helicopter which had landed, which he presumed was the Mercy Air helicopter. That helicopter transported him to Antelope Valley Hospital in Lancaster, CA for treatment.

5.0 Medical and Pathological Information

There were two flight crewmembers on board SS2 at the time of the accident. The pilot was liberated (in his seat) from the vehicle as it broke up and parachuted to the ground. The copilot was identified still restrained in his seat with the cockpit wreckage at "Site 4." (See vehicle recovery group chairman's factual report)

5.1 Pilot's Injuries

According to medical records from Antelope Valley Hospital in Lancaster, CA, the surviving pilot arrived via a Mercy Air helicopter at 1153 on October 31st and was discharged on November 3rd. A summary of the pilot's injuries can be found in attachment 5.

5.2 Copilot's Injuries

An autopsy was performed on the fatally injured copilot by the Coroner's Section of the KCSO. The official autopsy report dated March 15, 2015 was received by the

NTSB on March 19, 2015 and a summary of the copilot's injuries can be found in attachment 5.

5.3 Injury Table

Injuries	Flight Crew	Cabin Crew	Participants	Total
Fatal	1	0	0	1
Serious[10]	1	0	0	1
Minor	0	0	0	0
None	0	0	0	0
Total	2	0	0	2

Table 1. NTSB injury table.

6.0 Airport Information

The Mojave Air and Space Port (MHV) was a public use, general aviation airport one mile east of Mojave, CA. It was not certified by the FAA as a 14 *CFR* Part 139 airport. It had three asphalt runways. Runway 12/30 measured 12,503 by 200 feet, runway 08/26 measured 7,049 by 100 feet, and runway 04/22 measured 4,746 feet by 50 feet. (see figure 7)

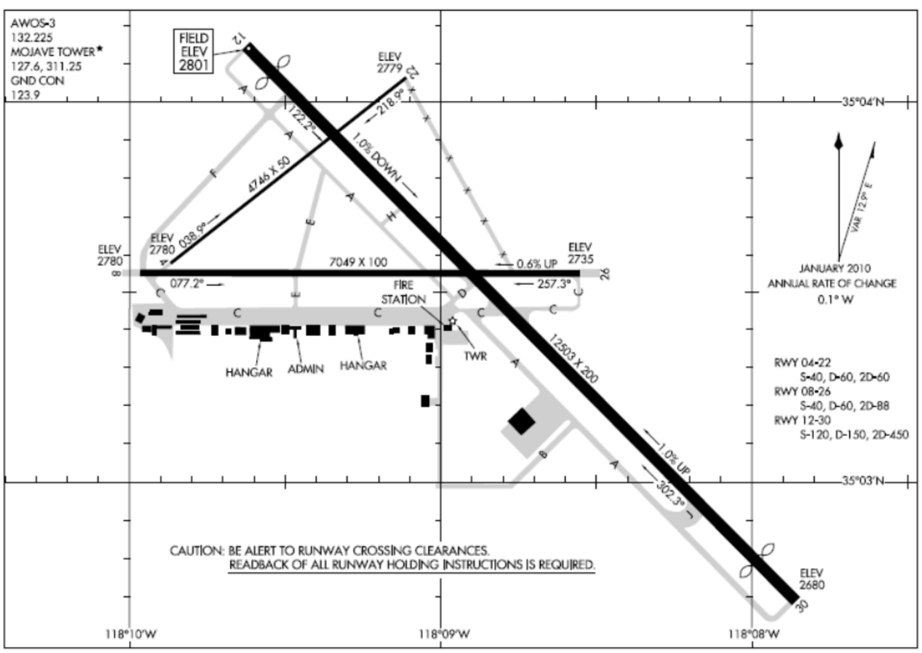

Figure 7. Airport diagram of MHV.

[10] 49 *CFR* § 830.2 defines serious injury as "any injury which: (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date of the injury was received; (2) results in a fracture of any bone (except simple fractures of the fingers, toes, or nose); (3) severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; (5) involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface."

7.0 Emergency Planning and Response Narrative

7.1 Scaled Composites Emergency Response Planning

To meet their obligations under 14 CFR 431.45, 14 CFR 437.41 and 14 CFR 437.75(b) Scaled Composites developed a mishap investigation plan and emergency response plan for the SS2 program. (see attachment 6) Per the emergency response plan, the first notification of a mishap was to be made to the Mojave ATC tower who would, in turn, notify Joshua Approach Control and the East Kern Airport District Aircraft Rescue and Firefighting (ARFF) at MHV. ARFF would then notify the Kern County Emergency Communications Center (ECC) of an Alert 3, which would initiate a three engine company response with KCFD, KCSO, and CHP response.

The emergency response plan was part of a larger Scaled Composites' emergency planning document. This 71-page document was developed after a Scaled Composites testing accident in 2007 and was to be used in the event of 1) an aircraft in-flight emergency, 2) an aircraft accident involving injury or property damage, 3) a fire that required fire department assistance, 4) an accident during which an employee was critically or fatally injured, or 5) an accident involving an employee which damages property or causes injuries. The document:

- Identified key Scaled Composites personnel and provided multiple contacts phone numbers for each
- Identified critical assignments (in checklist format) for key Scaled Composites personnel
- Contained detailed information about the construction materials, fluids, gases, batteries, etc. for each Scaled Composite vehicle
- Listed contact information for local emergency response agencies including fire departments, police departments, ambulances, hospitals and military installations
- Maps of MHV and the surrounding areas
- Northup Grumman's Incident Response and Notification process
- Information and forms related to Occupational Health and Safety incident
- Roster and contact information for all Scaled employees

Upon notification of a qualifying event, the plan called for "all members of the Management Group, plus Director of Human Resources, Director of Flight Operations and Scribe meet in [the Scaled Composites President's] Office… all other [plan] members report to their desks."

7.2 MHV Planning For SS2 PF04

The MHV airport manager provided a binder that included information regarding the emergency response planning leading up to powered flight 04. The binder contained an October 22, 2014 restricted airspace request to Edwards Air Force Base for the scheduled flight on October 31, 2014. The requested flight route and profile is shown in figure 8.

Figure 8. SS2's planned flight path for PF04

The binder also contained a 19-slide PowerPoint presentation by Scaled Composites, dated October 28, 2014. The presentation was titled "Tier 1B Operations and Safety Briefing" and provided information about the planned timeline of events, planned operations locations, risks, safety zones, and contingency and emergency operations. It indicated that there was a planned 0600 first responders briefing (conducted by the airport) on the morning of the flight. WK2 takeoff was scheduled for 0715, SS2's drop was estimated at 0800 with SS2 landing at 0815. One slide stated that, in the event of an inflight emergency, to take "immediate actions as needed to meet emergency. ATC coordinated by telephone from control room. Standard mishap response protocols."

The MHV airport manager provided the 0600 briefing to the local emergency responders. A copy of the PowerPoint slides of the briefing are included as attachment 7. The slides indicated that the off-Mojave response was under the direction of the assistant chief of the KCFD. The two KCFD assets listed on the slide were helicopter 408 and Engine 14. The slides did not specifically state the staging location for helicopter 408. The binder also included a timeline of events that has been incorporated into a timeline attachment 8.

7.3 Emergency Response Narrative

WK2/SS2 took off from MHV at approximately 0919. A full crew of EKAD ARFF firefighters from MHV were at the airport and assigned to respond to an on-airport incident. Additionally, representatives from KCSO, KCFD, MHV operations staff, security, the ATCT, and EKAD (MHV) ARFF were on scene and many attended the airport manager's 0600 safety briefing. On some of the previous SS2 powered flights, a KCFD helicopter was prepositioned at MHV; however, that did not happen on the day of the accident. According to KCFD H408's pilot, he received notification about the flight the night prior and was told to remain on standby in Keene, CA, rather than preposition at MHV. He reported that it was normal to receive notification of a SS2 powered flight approximately 2-4 prior to a scheduled flight.

SS2 was released from WK2 at 1007:18 and broke up in flight 18 seconds later. Scaled Composites had an Extra 300 chase pilot following the flight and the observations made by the pilot of the airplane became the primary source of information about the accident. The pilot made numerous notifications to "Scaled Base" operations, ATC, and other aircraft over the next 45 minutes. Significantly, he reported the presence of a parachute at 1010:06 indicating the high likelihood of at least one survivor. About one minute and 30 seconds later he reported that "the vehicle is on the deck now" and requested SAR forces respond to the area of Koehn Lake. Almost immediately after the accident the KCFD on scene commander text messaged the pilot of KCFD H408 that there were problems with the flight and to "get ready." At 1018 he again text messaged the pilot and instructed him to launch. The pilot reported that this method of dispatch was not standard operating procedure and that dispatch must come through the county's ECC, which it did, about 5 minutes later. After preflight, the helicopter took off at 1030 and shortly thereafter received coordinated for the crash site from the ECC.

While this was occurring, the airport manager at MHV got in his vehicle and drove directly to the National Test Pilot School (also at MHV) and directed their helicopter to launch to the accident site. The airport manager stated that this was "an audible" and not part of the preplanned response. The helicopter had to be pulled from its hangar and preflighted and eventually took off at approximately 1041 with an MHV firefighter/EMT, a NTPS flight surgeon, and a photographer on board. (see attachments 3 and 9) This UH-1N helicopter (call sign Tiger 1) arrived on scene at 1051:53 and was the first helicopter to land at the survivor's location. KCFD H408 arrived about the same time but initially landed near a piece of wreckage before repositioning to the survivor's site and landing there at 1058. Medical personnel from both helicopters approached the pilot and the MHV firefighter/EMT immediately requested the dispatch of Mercy Air 14 through the KCFD captain who arrived on H408.

Mercy Air was a full-service air medical transport system owned that operated Mercy Air 14, a Bell 407, at MHV. The advanced life support helicopter was operated under contract to the KCFD and could only be dispatched through the Kern County ECC.

Both the Mercy Air lead pilot and flight nurse from the accident response flight stated in their interviews that Mercy Air staff was not included on briefings prior to test flights or any other activity on the airport. They indicated that the only way they knew when Scaled Composites was having an operation was "when we see their employees walking out of their hangar." (see attachment 3 and 9)

On the morning of the accident Mercy Air 14 had returned from a call at 0600 and saw WK2/SS2 at the end of the runway. The helicopter then went out-of-service for a time but was actually in the air flying over airport property in a maintenance test flight at the time of the accident. The flight nurse stated she knew something was wrong when the NTPS helicopter was quickly pulled out of the neighboring hanger, preflighted, loaded with medical personnel and equipment, and took off. Mercy Air 14 landed a few minutes later and was immediately put back into service with the ECC. Less than a minute later they were put on standby for an Alert 3 by ECC, but when she called and asked if they wanted Medic 14 to launch, she was told "no" and they were left on standby. At 1100 they heard a request over the radio for Mercy Air 14 to respond to the site and ECC dispatched them at that time. Mercy Air 14 arrived at the survivor's location at 1116:25. At that time the survivor had been "packaged" on a backboard and litter and was immediately placed into Mercy Air 14 for transport. Mercy Air departed the scene at approximately 1123 and arrived at Antelope Valley Hospital at 1153, 1 hour and 46 minutes after the accident.

Jason T. Fedok
Survival Factors Investigator

Attachments

1- Photographs
2- BPS 2014 pull test report
3- Interview summaries
4- BPS/NTSB 2015 parachute component pull test report
5- Injury chart
6- Scaled Composites' SS2 Mishap Investigation Plan and Emergency Response Plan
7- MHV 10/31/2014 safety briefing PowerPoint slides
8- Timeline of events
9- Emergency responder statements