----- SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT -------

1. ACCIDENT:

Location:	Koehn Dry Lake, California
Date:	October 31, 2014
Time:	1007 Pacific daylight time (PDT)
Vehicle:	Scaled Composites LLC M339 – "SpaceShipTwo"
Registration:	N339SS

2. SYSTEMS GROUP:

Chairman: Michael Bauer
National Transportation Safety Board
Washington, D.C.

Member: Henry Lampazzi
Federal Aviation Administration
Washington, D.C.

Member: Peter Kalogiannis
Scaled Composites
Mojave, CA.

Member: Ken Broughton
The Spaceship Company
Mojave, CA.

3. 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.

The Systems group was formed on November 1, 2014 during the on-scene phase of the investigation. While on scene, the group reviewed the telemetry data (TM) from the vehicle for relevant systems, reviewed maintenance documentation and documented components from relevant systems. In December 2014, the group reconvened in Mojave, CA, and documented feather system components prior to shipment for computed tomography (CT) scanning[1]. In January 2015, after completion of the CT scanning, relevant feather system components were subject to additional teardown inspections. The group also performed a data playback on the PFD for powered flights one and four. Also in January 2015, the Systems Group Chairman participated in interviews with FAA and Scaled Composites employees coordinated by the Operations Group Chairman. At the conclusion of each group activity, all pertinent documentation and photographs were distributed to each of the parties.

The group also did initial documentation of the pilot's parachute, oxygen mask and seat during the on-scene phase. The information from the examination was provided to the survival factors group chairman for further investigation and is not covered in this report.

4. DETAILS OF THE INVESTIGATION:

4.1 Vehicle and system description

The launch system consisted of two experimental vehicles, White Knight Two (WK2) and SpaceShipTwo (SS2). WK2 was the carrier aircraft and carried SS2 to launch altitude where SS2 was subsequently released from WK2 for space flight. SS2 was an eight-seat[2], hybrid-rocket powered, multi-configuration aircraft of composite construction. It had a low-wing, twin-tail boom, outboard horizontal tail, and an "extension-only" tricycle landing gear configuration. The vehicle was designed and built to provide regular suborbital space access for the general public (space flight participants).

As stated in the Experimental Permit Application from Scaled, a nominal mission, Figure 1, would include the following phases:

- Air release of SS2
- Boost phase, which starts with a gliding attitude and ends in a near vertical attitude
- Engine cut-off, at which SS2 will coast to apogee
- Apogee
- Reentry with SS2 in a feathered configuration
- Transition from a feathered configuration to a normal configuration, which begins the glide phase
- Landing (unpowered)

[1] Detailed information related to the CT scans can be found in the CT Specialist's Factual Report
[2] The vehicle configuration during the flight test at the time of the accident did not include the seats for space flight participants. The vehicle cabin contained various test equipment.

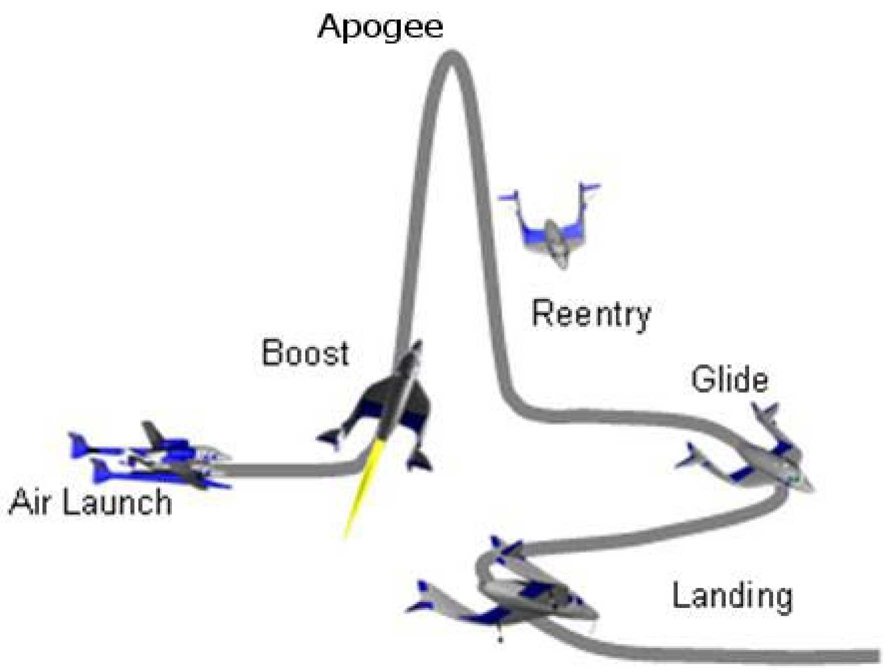


Figure 1 - Nominal design mission for SS2 (Illustration: Scaled Composites)

During the boost phase the vehicle's flight path changes from a gliding attitude to a near vertical attitude. This attitude change is referred to as the "gamma turn" maneuver. The gamma turn occurs after SS2 has entered the transonic[3] region.

4.1.1 Feather System

The feather system was designed to pivot the feather structure up 60 degrees to slow the vehicle during the reentry phase of flight. Scaled provided the following information related to the design of the feather system:

"The design parameters for the feather actuators were selected such that the feather retracting forces provided by the actuators were adequate to retract the feathers during the recovery phase of flight (after re-entry) and less than the feather extending forces caused by aerodynamic loads during the transonic flight regime and gamma-turn maneuver. The design parameters of the locks were selected so that they would maintain the feather in a retracted position during the portions of the trajectory when the feather was not intended to be extended, including the transonic flight regime and the gamma-turn maneuver."

To operate the feather system, the flight crew would first unlock the system by moving the feather lock handle, see Figure 2, down to the unlock position and then extend the

[3] Transonic refers to the condition of flight when flow on aircraft components may be partially subsonic and partly supersonic. The speed of sound in the transonic region is approximately in the range of Mach 0.75 to 1.20, at sea level (Aerodynamics for Naval Aviators).

feathers by pulling the feather handle in the cockpit. The order would be reversed to retract and lock the feathers. The feather lock handle was designed to be placed in either the lock or unlock detent, there are no intermediate position detents. The pilot operating handbook (POH) stated the following:

"The feather lock handle should be deliberately placed in either the full-up (locked) or full-down (unlocked) position at all times. Intermediate handle positions may lead to damaged hardware or an unsafe flight condition."[4]

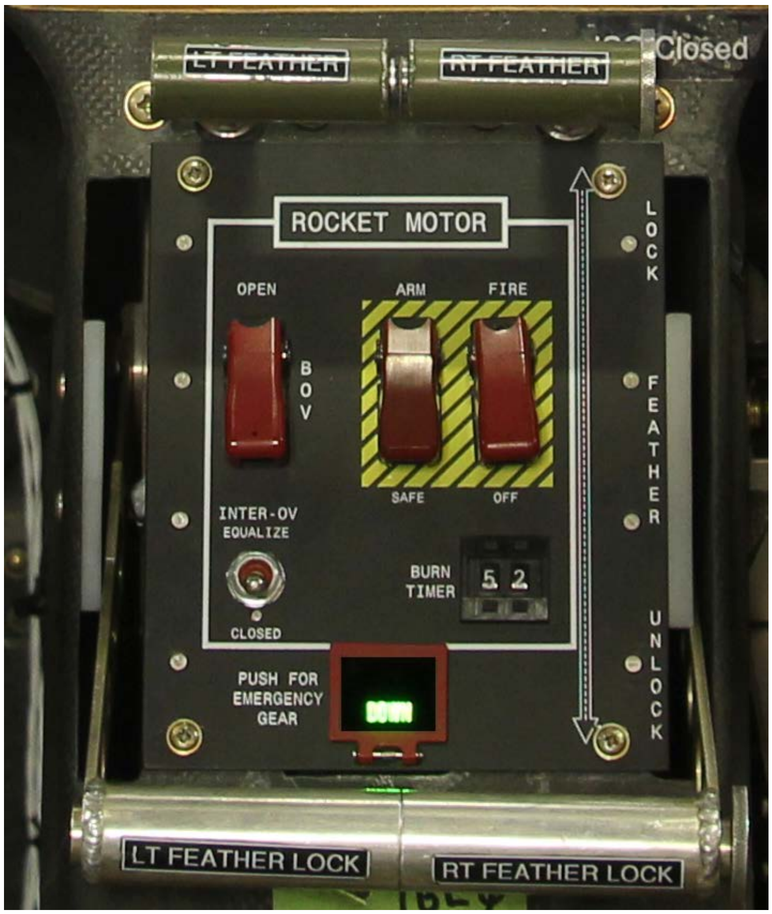


Figure 2 - SS2 feather lock and feather handles (feather lock handles shown in unlock position, feather handle in retract position) (Photo: Scaled Composites)

During the vehicle's preflight checks, the feather locks were cycled to ensure proper operation of the feather lock system. Approximately ten minutes prior to separation from WK2, the feather locks were cycled again to ensure proper operation. For a normal mission profile, during the boost phase and after the gamma turn at 1.4 Mach, the feather locks would be unlocked by the flight crew. The locks would remain in the unlocked

---

[4] SpaceShip Two (SS2) Pilot Operating Handbook, SS2-90BP001 Rev D, dated 3 September 2013.

position until after reentry when the feathers would be retracted, at which time they would be locked for landing.

If the locks were not unlocked prior to 1.5 M during the boost phase, a caution message will annunciate on the center multi-function display (MFD). If the locks fail to open by that point the crew procedures called for the pilots to abort the motor burn in order to minimize loads during the ensuing un-feathered reentry.

During discussions with the NTSB, Scaled engineers revealed the design intent of the feather lock system was "to hold the feathers in the retracted position during all phases of flight except when the feathers were intended to be extended." Based on the system safety analysis, Scaled determined that a procedural mitigation would be put in place requiring the locks to be opened during the latter portion of the gamma turn and prior to 1.8 M during boost.[5] Based on discussions with Scaled engineers, the Mach number chosen for unlocking the feather system was "chosen to provide a safety margin at the lower end of the scale to prevent premature unlocking, and at the higher end of the scale to allow adequate time to abort."[6]

The feather structure, which consisted of the torque tube, feather horns, feather flap and booms were attached to the vehicle through four hinges[7]. Two identical feather lock actuators were mounted in the wing structure and were connected to the lock hooks. Two identical feather actuators were mounted in the aft fuselage and were connected to the feather horns on the torque tube assembly. Additional information on system design and redundancies are discussed in sections 4.1.1.1 and 4.1.1.2.

The left and right side feather systems were supplied with dry compressed air through the pneumatic system on the vehicle. The vehicle was equipped with four high pressure bottles, two each in the leading edges of each of the vehicle's wings. The left side feather lock and feather actuator were supplied by the left inboard bottle. The right side feather lock and feather actuator were supplied by the right inboard bottle, which also provided air to the speed brake, environmental control system (ECS) and nose gear release systems. A simplified schematic of a single side of the feather pneumatic system is shown in Figure 3.

[5] For further information refer to the System Safety Group Chairman's factual report.
[6] Additional information related to in-flight aborts can be found in the Operational Factors Group Chairman's factual report.
[7] Further information on the vehicle and feather structure can be found in the Structures Group Chairman's Factual Report.

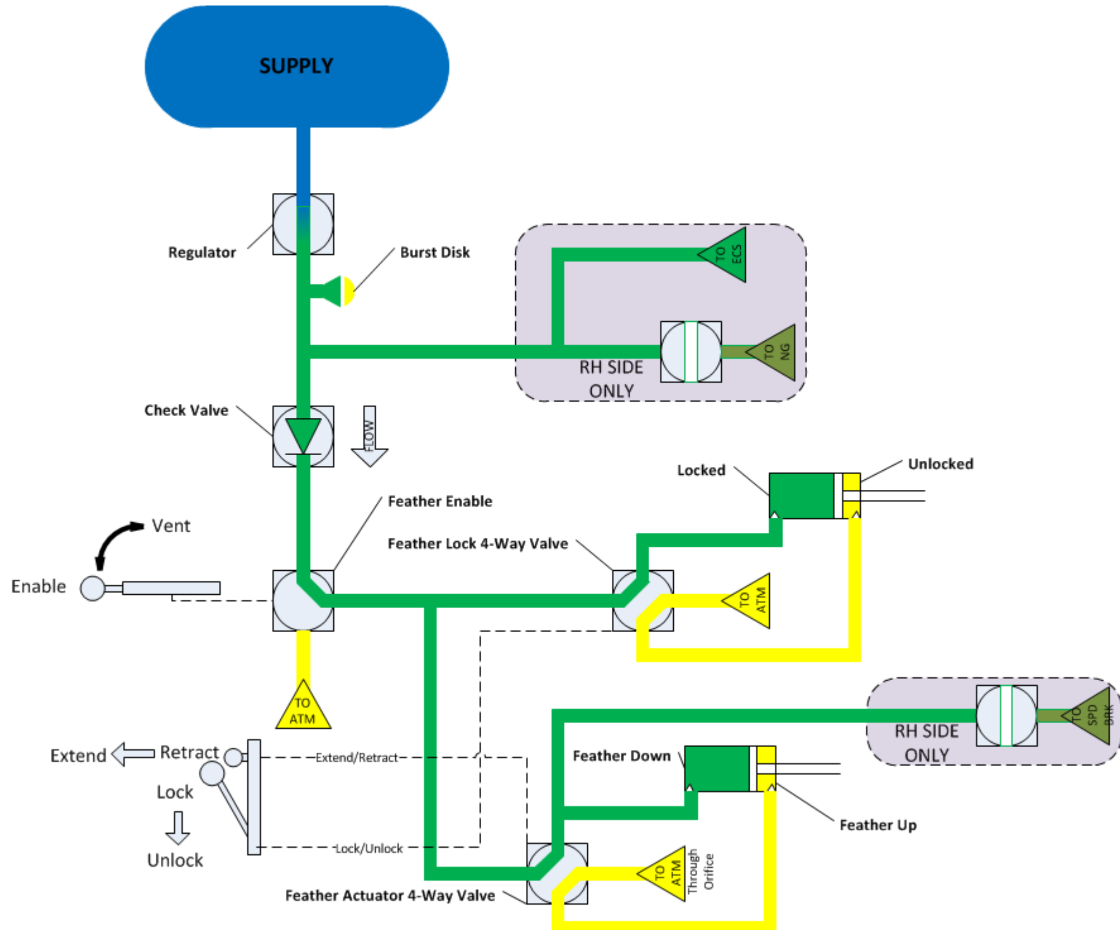


Figure 3 - Simplified feather system schematic

4.1.1.1 Feather Lock System

The vehicle contained a left and right feather lock pneumatic actuator, and each feather lock was individually controlled through a mechanical handle. The handles were connected together through a steel pin for normal operations and in the event of the failure of one side of the system the pin could be removed to allow independent operation of the system[8]. Each handle had a catch installed on the cockpit pedestal structure which acted as a gate. In order for the crew to actuate the handle to the unlock position, the crew member had to move the handle to the right and then down. The position of the feather lock handle was not recorded by the data acquisition system (DAS)[9]. The position of the feather lock handle was recorded on the forward facing cockpit video[10].

[8] An additional crew action, described later, is required in order to allow the system to be operated independently.
[9] Further information regarding the data acquisition system can be found in the Electronic Devices and Flight Data Factual Report.
[10] Further information regarding the forward facing video can be found in the Cockpit Image Recorder Factual Report.

Each lock handle was connected via cables to a four way valve which controlled the supply of regulated pressure from the pneumatics system and vented pressure to atmosphere for its respective actuator. Each valve was connected via aluminum tubing, to the lock actuator mechanisms. The positions of the feather lock valves were not recorded by the DAS.

The two feather lock actuators were pneumatically actuated and located in the forward outboard portion of the wing tip. The actuators were attached to an over-center hook mechanism, Figure 4. The lock hooks captured hardened pins in the forward tip of each boom tusk. The left and right feather locks were interconnected with a steel cable. The interlock cable was a redundancy to the system and allowed for mechanical operation in case of a pneumatic system or lock actuator failure.

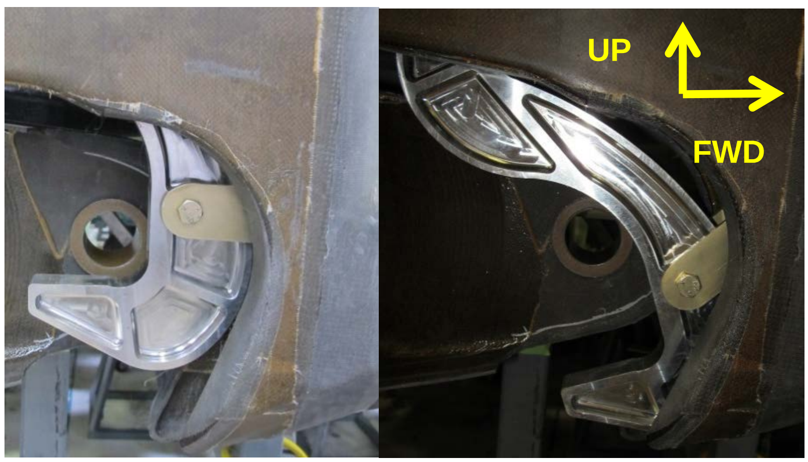


Figure 4 - Current production feather lock hook shown in the locked (left) and unlocked (right) position (note: boom and pin not shown)

Pressure switches were mounted to the lock and unlock ports of the actuator and indicate on the MFD whether each of the circuits was pressurized. A micro-switch was installed on the shaft that is coupled to the over-center hook mechanism. This micro-switch provided an unlocked/not unlocked indication for the crew. A separate micro-switch was installed on the pulley located near the interconnect cable assembly to provide a locked/not locked indication on the MFD for the crew. The pressure switch indications and micro-switch positions were recorded by the DAS.

4.1.1.2 Feather Retract/Extend System

The feather actuators were part of a pneumatic/mechanical system that extended and retracted the feathers to aerodynamically configure the vehicle for reentry and glide to landing. As the indicated airspeed would decrease below 20 KEAS and the vehicle nears apogee, the feathers were designed to be manually extended for the reentry configuration.

Each feather actuator was controlled by a feather handle in the cockpit. The feather handles were connected together via a steel pin for normal operations. The feather handle could be placed in either the extended or retracted position; there were no intermediate positions for the feather system. In the event of the failure of one side of the system, the pin could have been removed to allow independent operation of the system[11]. In order for the crew to command the feather, the handles would be pulled out to extend the feather and pushed in to retract the feather. The position of the feather handles was not recorded by the DAS. The position of the feather handles was recorded on the forward facing cockpit video[12].

Each feather actuator handle was connected via a set of control rods and a bell crank to a four way valve which controlled the supply of regulated pressure from the pneumatics system and vented the pressure to atmosphere. Each valve was connected, via aluminum tubing to its respective feather actuator mechanisms. The positions of the feather actuator four way valves were not recorded by the DAS.

The two feather actuators were mounted to the right and left sides of the aft fuselage on either side of the rocket motor case/throat/nozzle assembly (CTN) and were pneumatically actuated. The actuators were connected to feather horns on the torque tube and when the actuators were extended the torque tube rotated to extend the feather flap assembly. The left and right feather actuators were connected structurally through the torque tube. In the event one actuator was inoperable, the working actuator would rotate the torque tube in certain failure conditions. Basic design specifications for the feather actuator were provided by Scaled engineering and are contained in Table 1.

Table 1 - Basic Feather Actuator Design Specifications

Retracted Length (in)	(Feather Position = 0°) 55.4
Extended Length (in)	(Feather Position = 60°) 88.2
Nominal Operating Pressure (psi)	625
Flow Pressure (psi)	500
Extension Piston Area (in^2)	70.9
Retracted Piston Area (in^2)	61.3
Nominal Retraction Moment @ 485 psi (ft·lbs)	35,700

Pressure transducers were installed on the extend and retract ports of the feather actuator. A string pot was also installed on the right feather horn on the torque tube and connected to the aircraft structure to indicate feather position[13]. The pressure transducer and string pot indications were recorded by the DAS and displayed to the crew on the MFD.

[11] An additional crew action, described later, was required in order to allow the system to be operated independently.
[12] Further information regarding the forward facing video can be found in the Cockpit Image Recorder Factual Report.
[13] A string pot, or string potentiometer, is used to measure linear position with a flexible cable that retracts and extends from a spring loaded drum. The drum is typically attached to a potentiometer or rotary encoder.

4.1.1.3 Feather Enable (Vent) Valves

If the left or right feather system experienced an abnormal condition, pressure in each system could be independently vented through the use of the feather enable (vent) valves.[14] The valves were located on the cockpit floor between the crew member seats. Each valve handle was connected to a lanyard and attached to the crew member's seat. The left enable valve lanyard was attached to the pilot's seat and the right enable valve lanyard was connected to the copilot's seat. If the crew pulls on the lanyard the valve handle would rotate to the vent position and the pneumatic lines for that side are vented to atmosphere.

4.1.1.4 Feather System Indications

A full-time display of the lock status and feather position was displayed continuously on the center MFD, Figure 5.

Figure 5 - Trim strip feather status display (shown unlocked and extended)

Additional feather system indications were also provided to the crew by an optionally selectable feather systems page on the MFD, Figure 6.

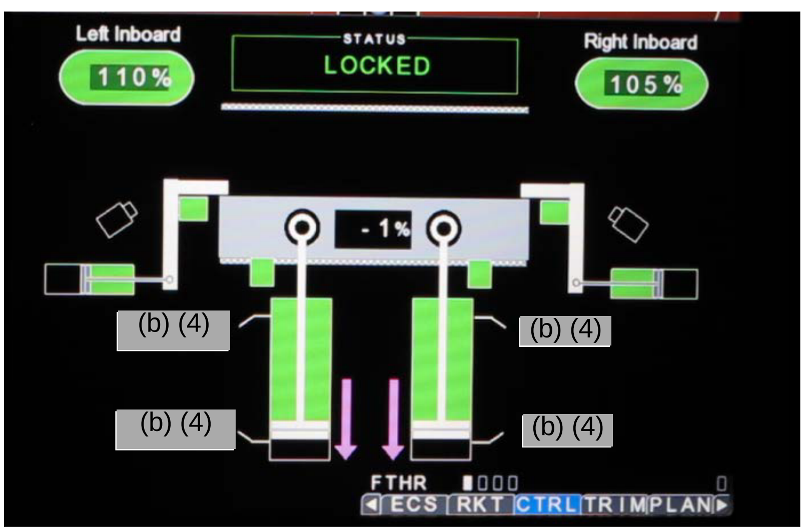


Figure 6 - MFD feather subpage (feather locked and retracted)

[14] Abnormal conditions could consist of loss of supply air, pneumatic jam, linkage or valve failure, mechanical jam, or others.

A LED backup indicator of lock status and feather position was also provided in the cockpit and was located on the cockpit panel on the pilot's side adjacent to the caution and warning indicator lights, Figure 7.

Figure 7 - Feather LED backup indicator on SS2

The center MFD would also display messages on the crew alert system (CAS). There were three CAS messages related to the feather system:

- Warning – ***Feather Delta P*** – this message indicates that the feather actuators are working against each other, based on pressure values.
- Caution – ***Feather Locks*** – this message indicates that both locks are not unlocked above 1.5M.
- Caution – ***Feather Unsafe*** – this message indicates that the feather is in the up position and both locks are not unlocked.

4.1.2 Display System (MFD/PFD)

SS2 contained three multifunction displays, a left, right and center unit. The MFDs were designed, programmed and built by Scaled Composites. The MFDs provided the crew with flight, navigational and system information throughout the mission. Each MFD had an upper and lower half for the display of information. The left and right displays were normally configured with primary flight display (PFD) information on the upper half and the lower display defaulted to the map display, but these displays could be reconfigured by the crew.

The center display was normally set to the MFD display configuration. In that configuration the upper right portion of the display showed the CAS messages. The messages were in three categories; advisories, cautions and warnings. Advisory messages were informational and did not require crew actions. Caution messages were conditions that should have been monitored and would have required crew action depending on the phase of flight. Warning messages were conditions that required crew intervention or action and may have jeopardized the mission or vehicle safety. The lower half of all MFDs could be reconfigured by the crew to display various system pages.

4.1.2.1 Airspeed and load information displayed on the PFD

Airspeed information was displayed in the upper left corner of the PFD display as shown in Figure 8. Knots equivalent airspeed (KEAS) was always displayed, regardless of ADC or INS source as a dial indication in the upper left corner. The Mach and true airspeed (TAS) indications were to the right of the KEAS dial and displayed as digital readouts. Below the KEAS dial was g-load information in a digital readout. Normal acceleration, “Nz”, was always displayed. During the boost phase, longitudinal acceleration, “Nx”, was displayed below the normal acceleration readout.

The airspeed display of KEAS from the INS source was calculated by applying inertial velocities and altitude to a standard atmospheric model. The calculation of KEAS did not account for winds aloft or atmospheric variances from the standard atmosphere. The Mach indication from the INS source was calculated in a similar method to INS based KEAS and did not account for winds aloft or atmospheric variances from the standard atmosphere.

There was also an indication in the upper left and upper right corners which indicated if the display was using inertial navigation system (INS) “I” data or air data computer (ADC) “A” data as the source of the equivalent airspeed, Mach, altitude and vertical speed indications. When the airspeed and altitude information were sourced from the INS, the background of the airspeed and altitude indicators would turn to gray.

In a nominal configuration the left PFD equivalent airspeed, Mach, altitude and vertical speed indications were sourced from the left side ADC and left side INS. The right PFD equivalent airspeed, Mach, altitude and vertical speed indications were sourced from the right side ADC and right side INS. The display selection of INS or ADC derived air data was controlled by pilot selections of ADC/INS/AUTO toggle on the display. Under normal conditions the display of INS or ADC data was in the AUTO mode. In AUTO mode the source of airspeed information would change from ADC to INS if any of the following conditions occurred:

- Airspeed above 0.80M
- Altitude above 60,000 feet
- Feather not down

The selection of ADC/INS/AUTO for the displays was not recorded by the DAS.

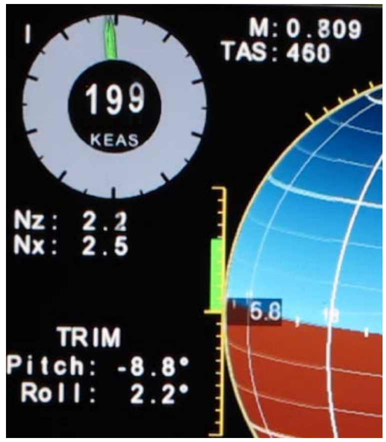


Figure 8 - PFD upper left corner of display showing airspeed, Mach, accelerations and trim indications (INS mode as noted by the "I" and gray background)

Below the g indications, the pitch and roll trim values were displayed in the form of a digital readout.

4.1.3 Pneumatics/ECS System

The pneumatics system supplied dry, compressed air to various systems in addition to the feather system described in the previous section. The systems included the primary and emergency environmental control system (ECS), primary and secondary reaction control system (RCS), primary and emergency nose gear release, emergency main gear release and the speed brake. The primary main gear release was through mechanical means.

Four high pressure cylindrical bottles supplied the source air for the various systems. The bottles were located in the leading edges of each wing, two on each side.

The left outboard bottle provided dry, compressed air for the primary RCS and a tertiary source of cabin make-up air.

The left inboard bottle provided dry, compressed air for the left feather actuator and the left feather lock.

The right inboard bottle provided dry, compressed air for right feather actuator, right feather lock, primary ECS cabin make-up air, speed brake extension and primary nose gear release.

The right outboard bottle provided dry, compressed air for the emergency RCS, emergency ECS cabin make-up air, and emergency main and nose gear release.

4.1.4 Flight Control System

Primary subsonic flight controls of SS2 consisted of pitch and roll elevons and yaw rudders. Primary supersonic longitudinal and lateral flight control was provided by symmetrical and differential stabilizer movement respectively through the electrically powered actuators. The systems were mechanically reversible systems. The crew controlled the surfaces through a yoke shaped center stick and rudder pedals. Primary trim of the pitch and roll systems were controlled via the primary electric horizontal stabilizer actuators with crew inputs via the hat switches on the yoke. Secondary trim of the pitch and roll systems were controlled via the secondary electric horizontal stabilizer actuators with crew inputs via the switches on the instrument panel. The vehicle did not have rudder trim. Drag control was via a ventral speed brake.

4.1.5 Electrical System

After isolation from WK2, SS2 was powered by two main battery packs and one emergency battery pack. The vehicle had two separate electrical busses each powered by its respective battery pack. An emergency bus could be powered by the emergency battery pack in the event of the failure of the two main busses. There was also an additional bus that was fed by all three battery packs. The system also included a bus tie relay that could connect the left and right main buses if one of the busses lost power.

4.2 System Examinations

During the on scene phase of the investigation, the Systems group chairman was briefed by the Scaled and The Spaceship Company (TSC) group members on the operation of the various vehicle systems. The group conducted reviews of telemetry data and the maintenance records of the vehicle. Wreckage recovery and documentation was completed by the vehicle recovery group. After the wreckage was recovered to a secured hangar, various feather system components were identified by the group for examination and testing.

4.2.1 Telemetry Data Observations

Working in parallel with the Data group, data from the telemetry system and from the vehicle was reviewed for relevant systems using the Scaled Composites telemetry data system and with exported tabular data[15].

4.2.1.1 Feather System Data

The systems group reviewed data from powered flights 02 (PF02), 03 (PF03) and 04 (PF04). Data from PF02 and PF03 included the data recorded at the L-10 point until the feather was retracted. [16] Data from PF04 included the ground checks and the L-10 point until the end of recorded data for the accident flight.

Based on the flight test card for PF04, the feather lock actuators were to be unlocked after the vehicle obtained a speed of 1.4 M. For PF02, the feather lock actuators were

[15] Further information and additional data from the telemetry data system can be found in the Electronic Devices and Flight Data Factual Report.
[16] L-10 is ten minutes prior to launch of the vehicle.

unlocked when the vehicle reached a speed of 1.2 M. For PF03 the feather lock actuators were unlocked when the vehicle reached a speed of 1.3 M. The unlocking speed for the feather locks on the previous powered flights was modified due to the rocket motor burn times. The rocket motor burn time for powered flights PF02 and PF03 was 20 seconds and for the accident flight, PF04, the planned burn time was 38 seconds[17].

Pressure transducers provided the data system and crew indication system with information on the supply pressure from the bottles and the pressure provided downstream of the pressure regulators.

The feather lock handle positions and positions of the four-way valves were not instrumented by Scaled. Based on discussions with Scaled and TSC, the lock micro switch positions were concurrent with the lock hooks being in the full locked position and the unlock micro switch positions were concurrent with the lock hooks being in the full unlocked position. While the actuator and hook are in motion, the lock switch would indicate “not locked” and the unlock switch would indicate “not unlocked”.

During the PF04 L-10 checks at approximately 10:00:00 PDT, Figure 9 and Figure 10, the feather actuator lock and unlock switches changed state as the lock actuators moved the hook from the lock to the unlock position. The downstream regulator pressure in the left side decreased slightly after the lock actuator cycling. Based on the micro-switch data, the locks cycled from a locked to an unlocked state in approximately 1.7 seconds and from an unlocked to locked state in 1.3 seconds.

For PF04, SS2 was released from WK2 at 10:07:19.10 PDT based on the SS2_Carrier_Separated discrete signal change of state. At 10:07:28.80 both the left and right unlock pressure switches indicated pressure in the unlock circuit, Figure 11 and Figure 12. The vehicle’s speed per the recorded data at this point was just above 0.92 M. At 10:07:29.50, both the left and right lock position switches transitioned from locked to not locked. At 10:07:31.04, the left unlock position switch transitioned from not unlocked to unlocked. At 10:07:31.10, the right unlock position switch transitioned from not unlocked to unlocked. The total unlock time was approximately 1.6 seconds.

At approximately 10:07:30.6, the feather position parameter indicated the start of movement of the feathers[18]. At this time, the feather retract (down) pressure was approximately 432 psig in the left actuator and 460 psig in the right actuator. The pressure readings for the extend (up) pressure for both actuators were slightly less than 0 psig.

As the feather began to extend over the next 1.8 seconds, the pressure in the retract (down) side of the feather actuators continued to increase. During the extension sequence

---

[17] Additional information on the unlock speed set point can be found in the Operational Factors Group Chairman’s factual report.

[18] Feather position was recorded by the DAS in percent of travel. Fully down, 0% was equivalent to 0° of feather position and fully up, 100% was equivalent to 60° of feather position.

a maximum pressure in the retract (down) side of the feather actuators of approximately 710 psig in the left actuator and 759 psig in the right actuator was recorded. The pressure readings for the extend (up) pressure for both actuators was slightly less than 0 psig during the feather extension. After 10:07:32.44, data for the feather position was considered unreliable.

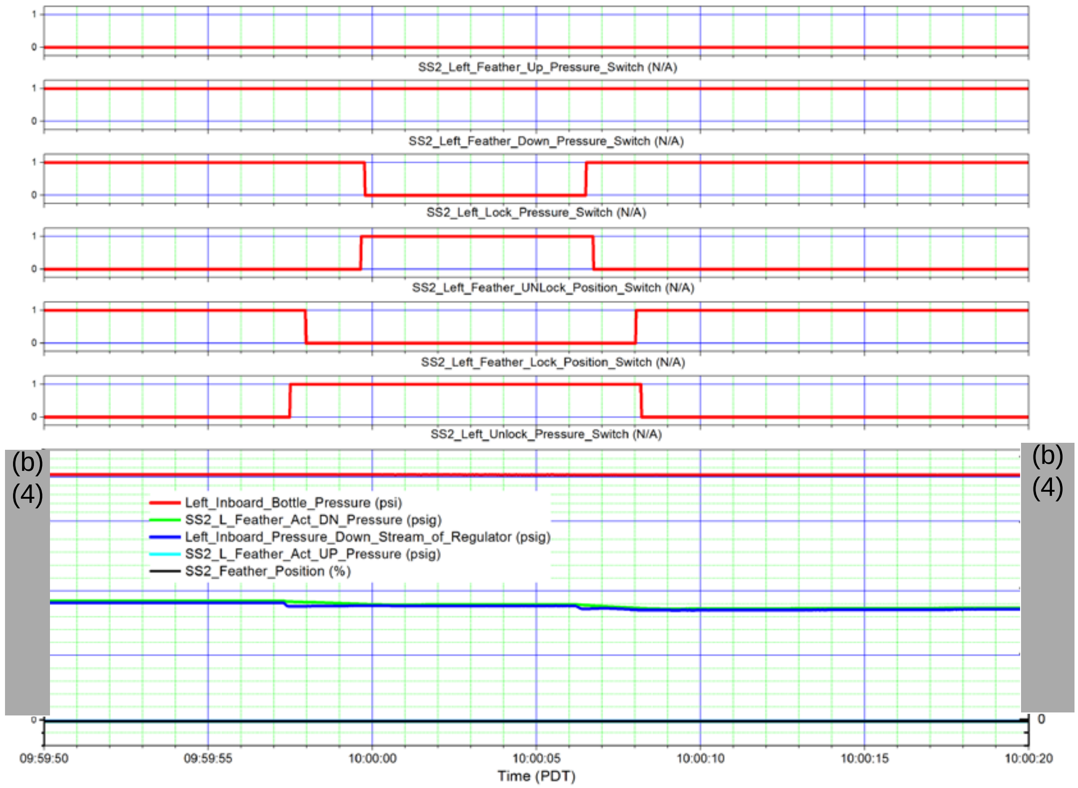


Figure 9 - Flight data from the L-10 left feather lock check

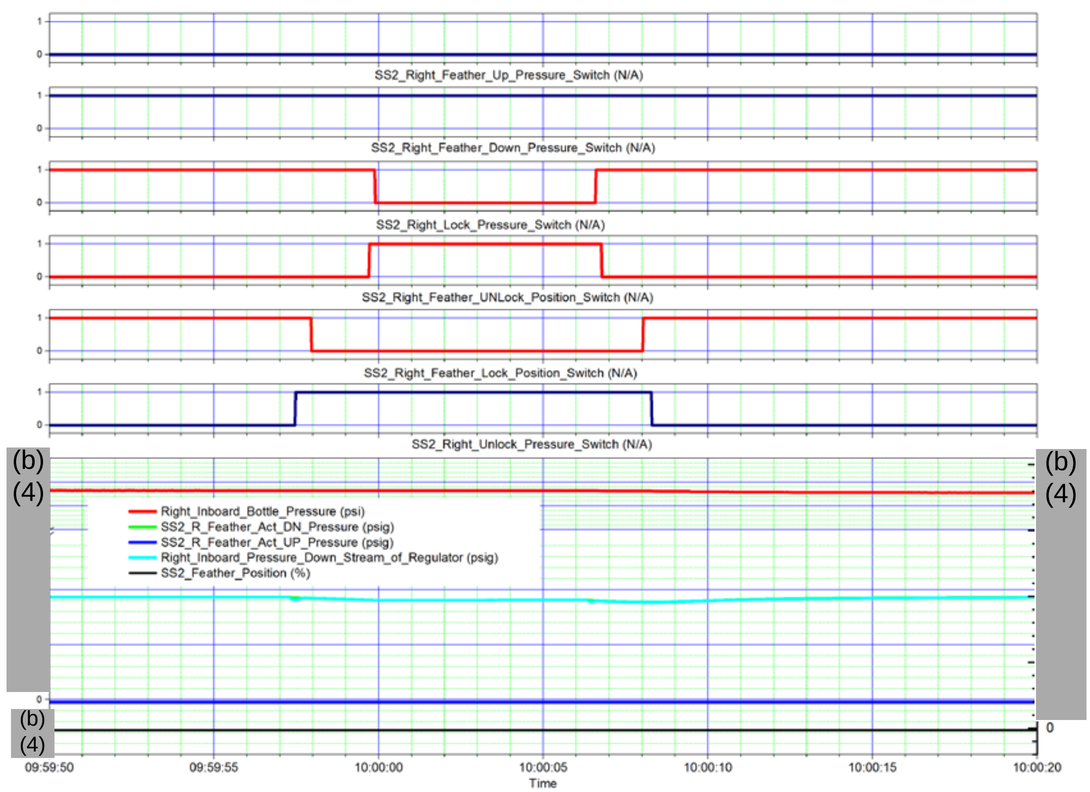


Figure 10 - Flight data from the L-10 right feather lock check

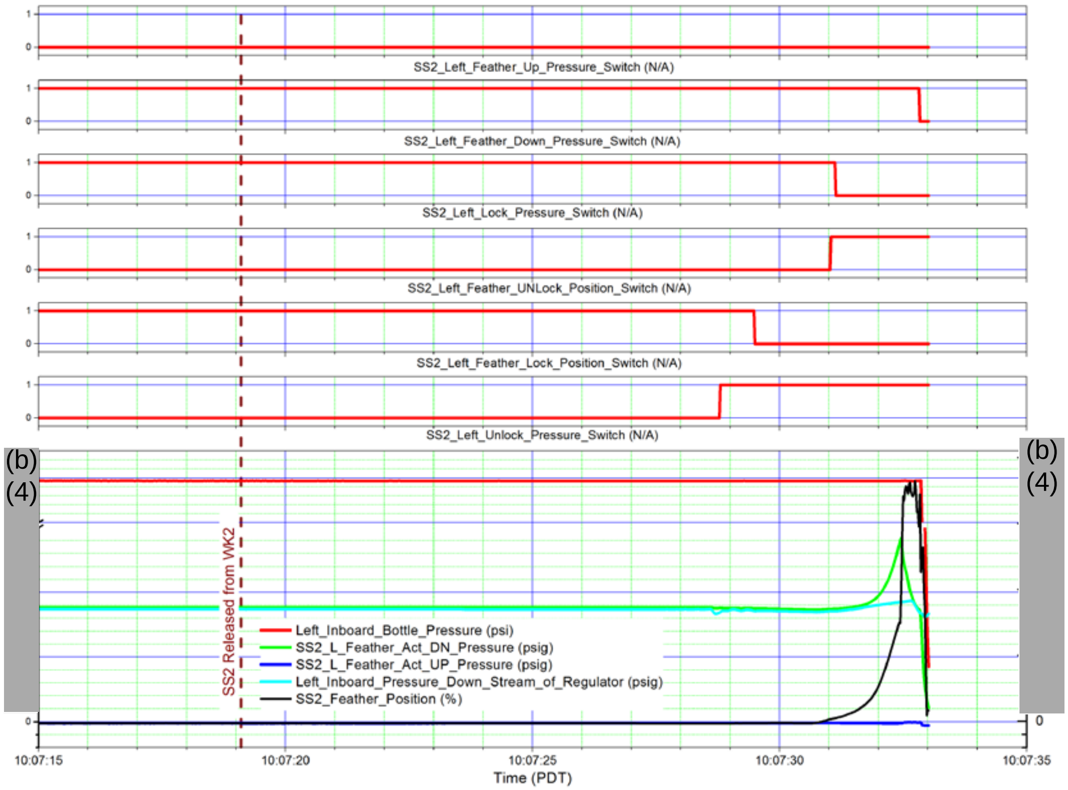


Figure 11 - Flight data from SS2 release to end of recording for the left feather system

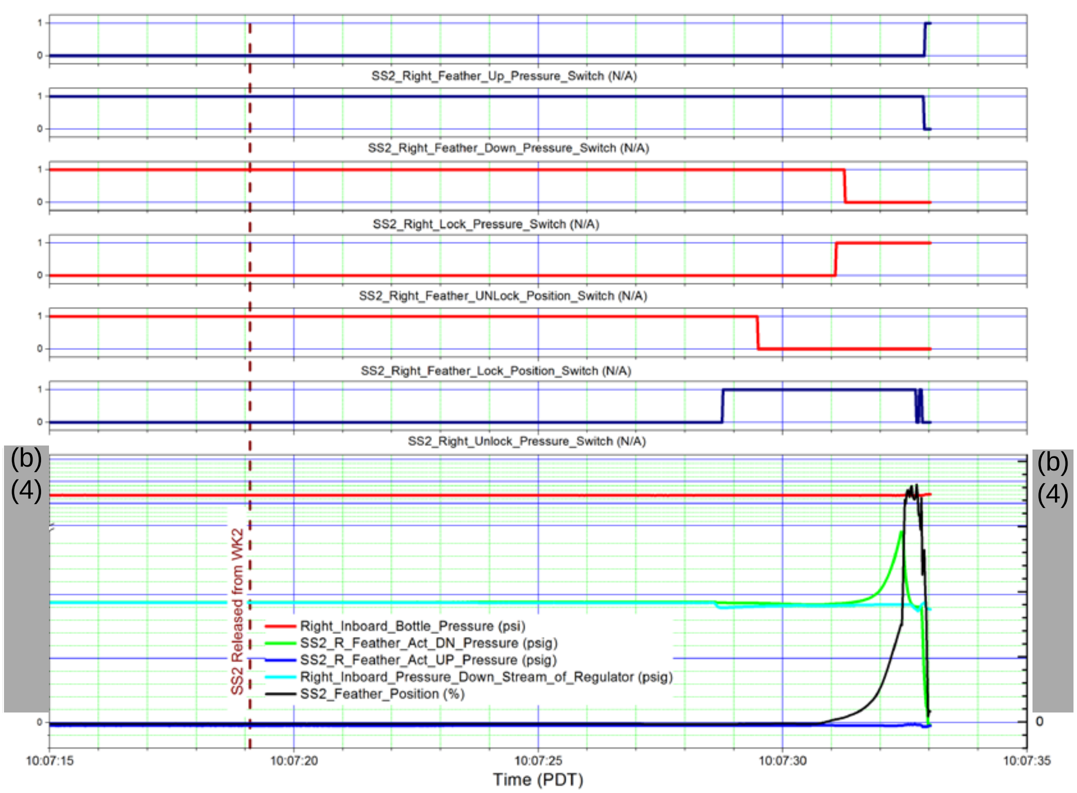


Figure 12 - Flight data from SS2 release to end of recording for the right feather system

4.2.1.2 Display System (MFD/PFD) Data Review and Playback

During the climb to the launch altitude of PF04, the center MFD went through an automatic reset which resulted in a reboot of the center MFD about 09:28 PDT. The MFD was successfully rebooted and the test team determined the flight could continue.

A review of the TM data from L-10 to the end of the recorded data indicated that the following CAS messages were displayed. The messages in Table 2 all posted after the feather began to move at 10:07:30.6 PDT.

Table 2 - CAS messages displayed during PF04 from L-10 until end of recorded data

Message	Level	Approximate Time (PDT)
SPD BRAKE DISAGREE	Caution	10:07:32.52, 10:07:33.20
STAB FAULT SEC	Caution	10:07:32.82
RMC ABORT	Warning	10:07:33.00
PSC FAULT	Caution	10:07:33.00
STAB FAULT PRI	Warning	10:07:33.20
ETHERNET FAULT	Caution	10:07:33.20
STAB CMB ERROR	Caution	10:07:33.34
DAU FAULT	Caution	10:07:33.54
MOT PRESS LO	Caution	10:07:33.54
NAVCOM FAIL 1	Caution	10:07:33.54
STAB OFF R	Caution	10:07:33.54

At the Scaled Composites control room, play back of the recorded data was performed and the data was used to drive a flight-worthy spare MFD. Display of ADC/INS data was in the AUTO mode for all of the playbacks. For certain playbacks the group configured the lower half of the MFD to display the feather system display.[19] The group did not note any anomalous behaviors of the display system during the flight playback. Information related to the playback of the PFD display is included with this report as attachment 1.

The flight display was also configured to represent the software configuration for powered flight 01 (PF01) and PF03. Data from each of the representative flights was played through the MFD in order to compare the changes to the PFD in the upper left corner around the airspeed indications. For PF04, the MFD software was updated and the display included the addition of the trim position indications on the PFD, Figure 13.

[19] For information regarding the MFD configurations during the accident flight refer to the Cockpit Image Recorder Factual Report.

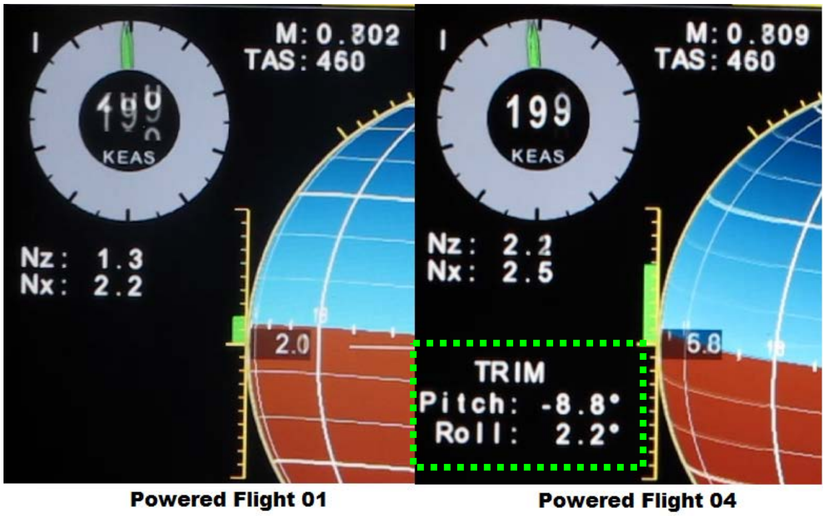


Figure 13 - Upper left portion of PFD display showing differences between PF01 and PF04 (green highlighted box)

4.2.1.3 Other Systems

Based on the review of the TM data, no anomalies were noted related to the pneumatics/ECS, flight control and electrical systems prior to the feather movement after the feather unlock occurred.

4.2.2 Feather System Components Recovered and Retained

The group examined the vehicle wreckage on two separate occasions. Components related to the feather system were identified and segregated from the main wreckage. The following components were identified:

- Left and right inboard supply bottles
- Left and right feather actuators[20]
- One of two feather lock valves
- Left and right feather actuation valves
- Left and right feather enable valves
- Left and right pressure regulators
  - Attached fittings to the regulators included the burst discs
  - The left and right regulator fittings included the check valves
- Left and right feather lock/unlock handles
- Left and right feather extend/retract handles
- Feather LED backup panel

[20] The right feather actuator was not initially recovered during the on scene phase of the investigation. The actuator was recovered in late December 2014. For further information refer to the Vehicle Recovery Group Factual Report.

The following feather system components were identified for examination and testing:

- Left and right feather actuators
- Four-way valves
- Left and right feather enable valves
- Left and right pressure regulators

4.2.3 Maintenance Records Review

The aircraft log book stated that the date of manufacture was June 26, 2010. Prior to the accident flight, SS2 had accumulated 83.03 hours in service with a total of 6.27 hours of flight time[21].

The systems group was provided with the vehicle's maintenance records starting with the vehicle's conditional inspection on September 4, 2014 until the accident flight on October 31, 2014. The last conditional inspection was completed on October 1, 2014. The conditional inspection included servicing and detailed inspections of the feather system components. The feather actuators underwent a borescope inspection as part of the conditional inspection. The feather and feather lock actuators were last lubricated as part of preparations for glide flight 30, on September 15, 2014. Two discrepancies related to the feather system noted during the conditional inspection were corrected and closed prior to flight. The first discrepancy was due to the damage to the right feather actuator's cap which occurred during reinstallation. The second discrepancy was due to a failure of a wire connection on the feather up actuator position switch.

During the last conditional inspection, the feather lock valves and the feather actuation valves were modified per an engineering change to add valve lock tubes to the supply ports. During feather actuator testing conducted by TSC, which included the four-way valve and other system components, a partial port blockage of the four-way valve was discovered which restricted airflow to the system. The blockage was due to the valves' internal packing rotating with the ball/stem assembly when tested at cold temperatures below its specified envelope during a highly accelerated life test (HALT). The valve lock tubes were installed to the valve supply port to restrict the packing from rotating with the ball/stem assembly.

The feather actuators flown on the vehicle for PF04 were originally installed on the vehicle in April 2011, which was prior to glide flight 05 and before any of the vehicle's powered flights. From mid-October 2013 to mid-November 2013, both feather actuators underwent a complete rebuild. The rebuild was due to a complete actuator teardown that was part of the vehicle's special inspection program. The special inspection called for a

[21] Service time included flight time when SS2 was mated to WK2. Flight time was when SS2 was decoupled from WK2 and performing powered or glide flights.

complete teardown of the actuators at 150 cycles or 2 years, whatever came first. At the time of the accident, each feather actuator had accumulated 83 cycles[22].

On October 8, 2014 the feather system, during preflight checks for PF04, underwent a leak check. The check included exercising the feather locks, extending the feathers and holding the feather positions, both extended and retracted, for one hour to check for leaks in the system. The leak check was successful with no anomalies noted.

4.3 Feather System Component Examinations

During the investigation, nine of the feather system components were subjected to a teardown inspection. Prior to the teardown inspection, all the components except for the feather actuators were inspected using computed tomography (CT). The components were visually inspected by the systems group prior to packaging and shipping to the CT vendor under NTSB direction. The results of the CT inspections are in the Computed Tomography Specialist's Factual Report.

4.3.1 Left Hand (LH) Feather Actuator:

4.3.1.1 LH Feather Actuator -Data Plate Information:

Manufacturer:	Scaled Composites
Part Number:	SS2-10A900 (Not Marked)

4.3.1.2 LH Feather Actuator - Examination:

The actuator was placed on a service cart and an external visual inspection was performed. Figure 14 shows the left hand feather actuator as found by the vehicle recovery group.

[22] One cycle consisted of one extension and one retraction of the actuator.

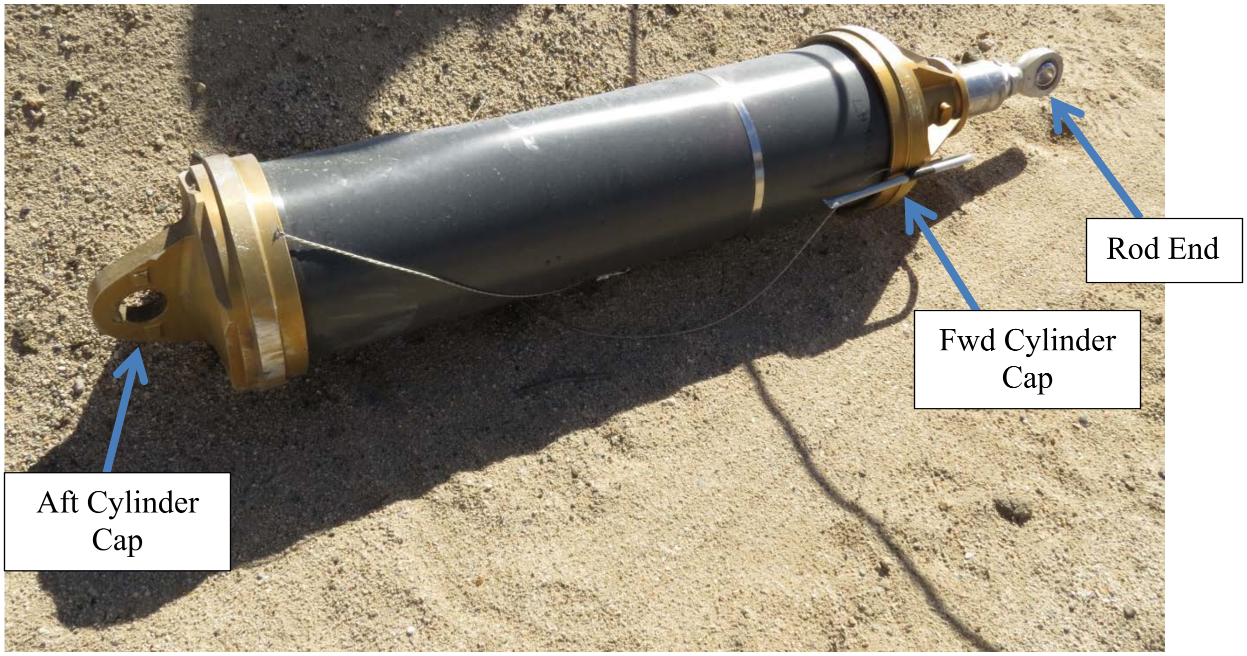


Figure 14 - LH feather actuator as found

The aft cylinder cap had multiple areas of scratches and debris embedded in the surface, consistent with impact damage. There were no threads exposed on the cap or cylinder.

The spherical bearing and retention snap ring were not present on the aft cylinder cap. The snap ring groove was in good condition, with loose debris in the snap ring groove and around the bearing race. The sides of the aft cylinder cap attach fitting (where the actuator interfaces with the aft vehicle structure) had symmetrical marks, consistent with impact.

The extend port fitting was present with only a b-nut attached to the fitting. The flex line from the pneumatic system was not present. The safety wire between the extend port and the aft cylinder cap was present and secure.

There are two safety wire runs normally attached from the aft cylinder cap to the forward cylinder cap. One of the safety wire runs was still connected between the two caps, however the wire was loose and exhibited signs that the wire was “pulled” and was starting to unravel. The other safety wire run was not connected to the aft actuator cap, with damage consistent with the safety wire being pulled out from its attachment point.

The cylinder was found breeched approximately 7 inches from the edge of the aft cylinder cap. The breach was approximately 6 inches along the circumference of the cylinder wall. A piece of blue seal could be seen embedded in the breached area, Figure 15. Yellow marks along the cylinder could be seen in two places. The yellow coloring was consistent with the plastic cases used for housing the sensors of the breach detection system for the rocket motor.

Figure 15 - LH feather actuator cylinder breach with seal exposed

The cylinder was buckled in on the lower inboard side. The area of buckling was approximately 21 inches long. The cylinder had one surface mount thermocouple attached at the approximate center of the cylinder. The thermocouple wire was severed. The band clamp, which was used to secure a bracket to hold the flex line to solid tube interface, was present and secured to the cylinder, but the bracket was not present. There were no threads exposed between the forward cylinder cap and the cylinder.

The forward cylinder cap had multiple scratches and debris embedded in the cap surface, consistent with impact damage. The forward cylinder cap had one surface mount thermocouple attached. The thermocouple wire ran along the cylinder wall and was severed. One of the stiffener webs, at the approximate 3 o'clock position from top-dead-center was fractured at the fillet edge. The lubrication port was present and secure with safety wire intact. The solid tubing connected to the retract port was loose, the b-nut was secure and the torque stripe was intact. There was approximately 11 inches of tubing recovered with the actuator.

The piston shaft was extended approximately 3 7/8" from the forward cylinder cap, Figure 16. A circumferential score was present approximately 1 ¼" from the end of the shaft, as measured from the beveled end. Debris, consistent with sand, was present at the scraper, which was mounted in the forward cylinder cap. The scraper did not show signs of exterior damage.

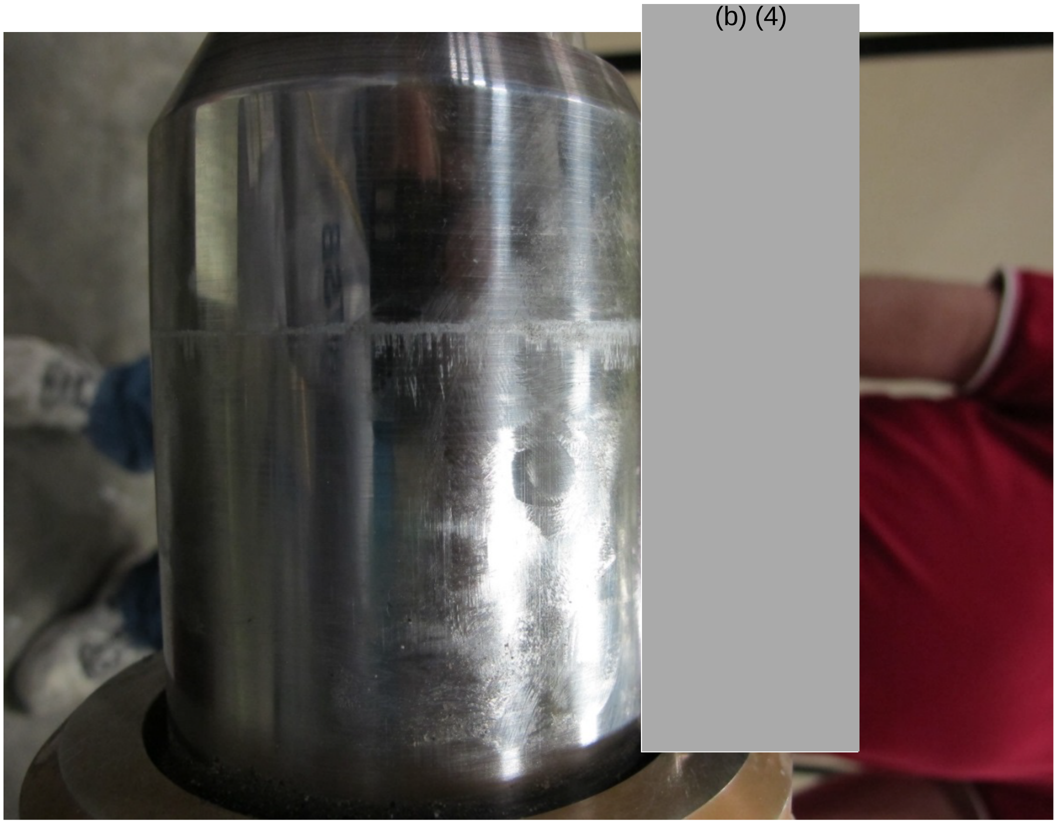


Figure 16 - Exposed end of the LH feather actuator shaft

The rod end jam nut safety wire was present, intact but loose. The spiral groove slip reluctor key was displaced from the rod end groove in the rod end by approximately 5-10°. The jam nut was removed and it was determined that the rod end was rotated from its original position by approximately 5-10° and the keys from the reluctors (in two places) were embedded in the threads of the rod end, Figure 17. The rod end was removed with normal removal forces applied.

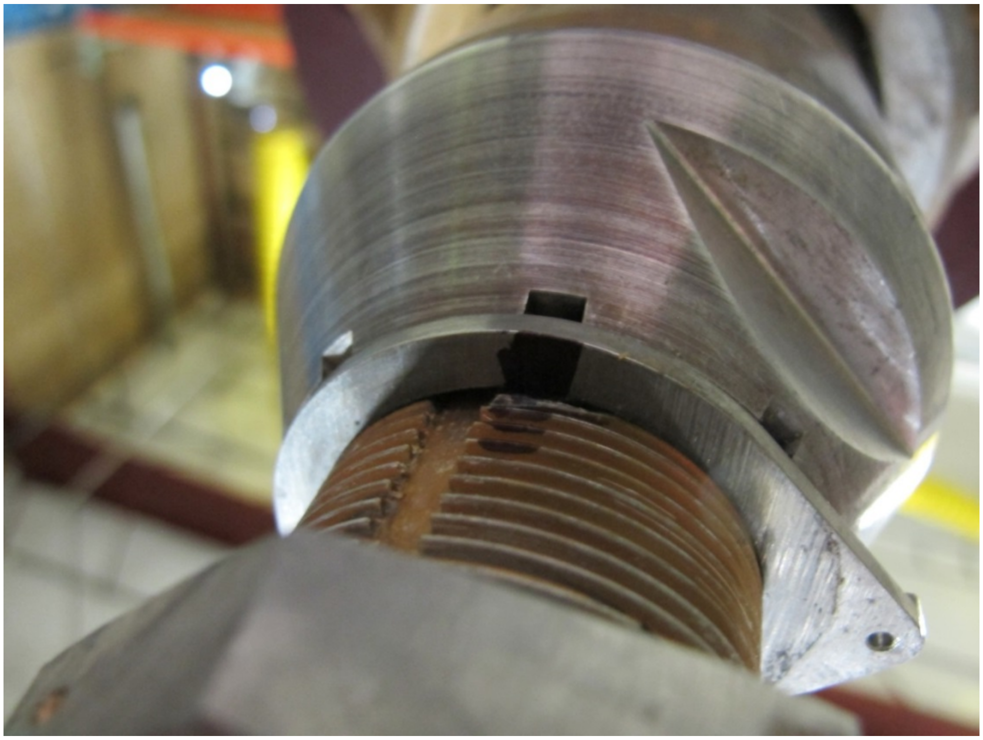


Figure 17 – Displacement of the reluctor key (black mark) with LH rod end groove

The rod end had surface scrapes on both sides of the main face. The spherical bearing was present and the snap ring to secure the bearing was also present. Impact marks in the outer bearing race were consistent with the attach pin striking the outer race due to over rotation of the pin assembly, Figure 18.

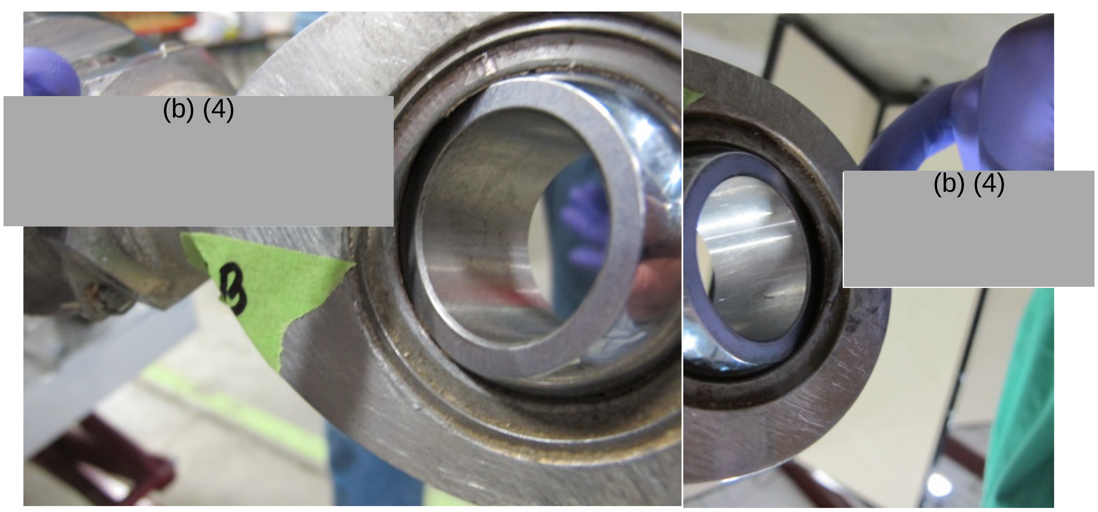


Figure 18 - Impact marks on the outer race of the LH actuator rod end bearing

The aft cylinder cap was difficult to remove and required greater than normal torque. During the cap removal one of the cylinder seals was damaged. Four pieces of the seal were recovered. The second cap seal was intact and exhibited no signs of cuts or dry areas. The cap was removed and the interior of the cylinder between the piston head and cap. Debris lined the cylinder walls and was consistent with the soil at the recovery location. No scoring or wear marks could be seen on the cylinder walls. Fluid, consistent with (b) (4) lubricant was present. On the interior of the aft cap, markings consistent with contact of the piston head were present, Figure 19. Based on discussions with Scaled engineering, during normal operations the piston head should not contact the aft cylinder cap.

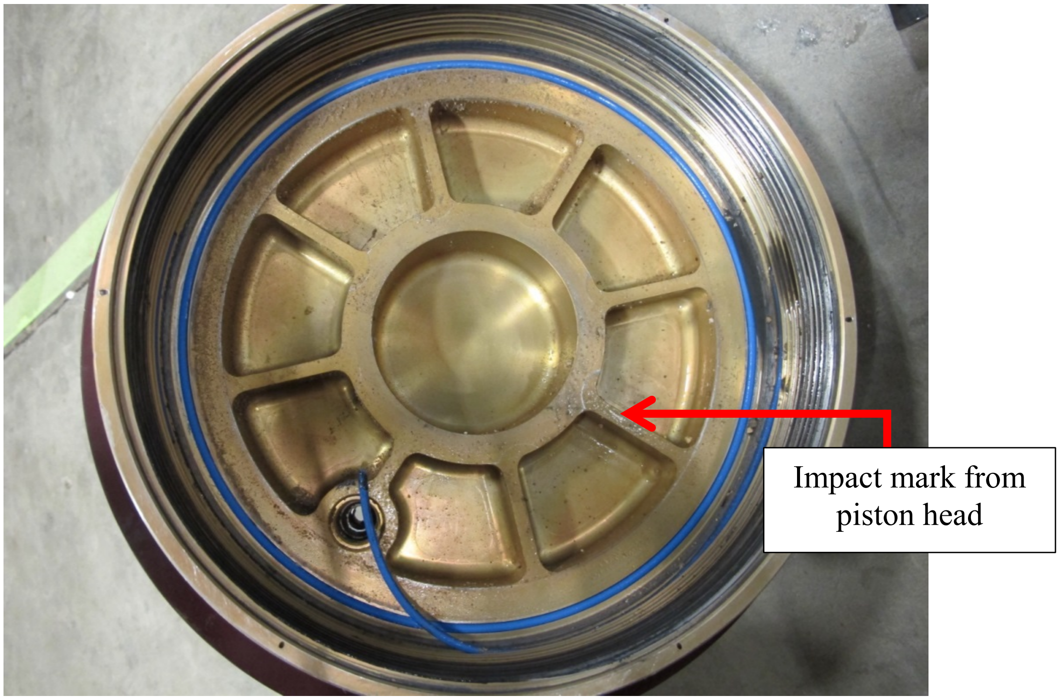


Figure 19 - Interior of aft cylinder cap with seal and impact marks from piston head

In order to facilitate the inspection of the cylinder below the piston head, the cylinder was cut approximately 14 ¼ inches from the aft cylinder cap. The piston head and cylinder wall portion along with the actuator shaft was removed from the forward portion of the cylinder. Once separated, grooves were machined in the cylinder walls in two places, 180° from each other, to remove the piston head and shaft. The cylinder walls on the forward portion of the cylinder did not show any signs of scoring or wear marks. Marks in the surface finish of the cylinder walls were present in the location of the piston head. The surface finish in the regions around the buckling, did show signs of cracking and flaking of the surface finish. The extend hard stop was removed and visually inspected. Wear marks consistent with interfacing with the (b) (4) washers were present on the hard stop.

The scraper, backup rings and O-ring were removed from the forward cylinder cap. The components were in good condition. Visual inspection revealed no signs of cuts or non-lubricated components.

The spiral lock, which secures the piston shaft bushing retaining plate, was easily removed. The piston shaft bushing retaining plate was removed and showed signs of damage and appeared to be cupped. Per design, the plate should be flat.

The piston shaft bushing was removed and visually inspected. The bushing was lubricated. Wear lines could be seen longitudinally in the surface of the bushing. There were no areas with scratches or deep gouges.

The spiral lock which secured the extend snubber coil ring spacer was present and removed. The extend snubber coil ring spacer and (b) (4) washers were removed and inspected. No visual signs of damage were present.

The main piston backup plate was removed. All supporting hardware for the main piston backup plate was present.

The piston shaft was removed from the piston head. The seal between the shaft and piston head was present and did not exhibit any signs of cuts and was well lubricated.

The main piston head was damaged along the outer edge of the seal gland towards the rod end of the piston. The damage area was confined to approximately 6 inches along the outer circumference. A portion of the piston head material was separated from the piston head and located in the cylinder. The piston O-ring at the rod end of the piston was damaged and separated into two pieces, one of which was located in the breech area. Other than the damaged areas the O-ring showed no additional signs of cuts and was well lubricated. The backup rings were present. The O-ring and backup rings at the aft side of the piston head were present, and showed no signs of cuts and were well lubricated.

4.3.2 Right Hand (RH) Feather Actuator:

4.3.2.1 RH Feather Actuator -Data Plate Information:

Manufacturer: Scaled Composites
Part Number: SS2-10A900 (Not Marked)

4.3.2.2 RH Feather Actuator - Examination:

Prior to the visual inspection the structural attach points were removed from the actuator.

The actuator was placed on a service cart and an external visual inspection was performed. Overall the actuator appeared to have a slight bow along its length. Figure 20 shows the right hand feather actuator as found.

Figure 20 - The RH feather actuator as found

The aft cylinder cap had multiple areas of scratches and debris embedded in the surface, consistent with impact damage. There were no threads exposed on the cap or cylinder.

The sides of the aft cylinder cap attach fitting (where the actuator interfaces with the aft vehicle structure) had symmetrical impact marks consistent with the mounting bracket. During the condition inspection, the aft cylinder cap sustained minor damage during reinstallation at the interface with the aft structural fitting and was repaired. The area of the repair was noted.

The bearing retention snap ring was not present and the spherical bearing was present on the aft cylinder cap. The snap ring groove was in good condition, with loose debris in the snap ring groove and around the bearing race. The ball bearing was loose inside the bearing race.

The extend port fitting was present with the flex line attached to the fitting. The safety wire between the extend port and the aft cylinder cap was present and secure. The torque stripe indicated a slight clocking of the fitting.

The attached flex line was complete and connected to a tee (used for instrumentation). A portion of a carbon fiber bracket normally attached to the vehicle structure was also present.

The design included two safety wire runs from the aft cylinder cap to the forward cylinder cap. One of the safety wire runs was still connected between the two caps, however the wire was loose and exhibited signs that the wire was "pulled" and was starting to unravel. The other safety wire run was not connected to the forward actuator cap, with damage consistent with the safety wire being pulled out from its attachment point.

The cylinder was breeched approximately 2 inches from the edge of the aft cylinder cap, see Figure 21. The breech was approximately 5 inches long along the circumference of the cylinder wall. The presence of lubrication fluid seeping from the inside of the cylinder to the outside could be seen.

Figure 21 - The RH feather actuator breach

The cylinder was buckled along the length of the cylinder, except for a small portion near the aft cap end and around the piston. The band clamp, which was used to secure a bracket to hold the flex line to solid tube interface, was present and secured to the cylinder, but the bracket was not present. There were no threads exposed between the forward cylinder cap and the cylinder.

The forward cylinder cap had multiple areas of scratches and debris embedded in the cap surface, consistent with impact damage. The forward cylinder cap had one surface mount thermocouple attached. The thermocouple wire ran along the cylinder wall and was severed. The stiffener webs were in good condition. The lubrication port was present and secure with safety wire intact. A portion (approximately ¾ inch) of solid tubing connected to the retract port was loose, the b-nut was secure and the torque stripe was intact. The safety wire from the retract port was present and secure.

The piston shaft was extended approximately 3/16" from the forward cylinder cap, Figure 22. Debris, consistent with sand, was present at the scraper, which was mounted in the forward cylinder cap. The scraper did not show any signs of external damage.

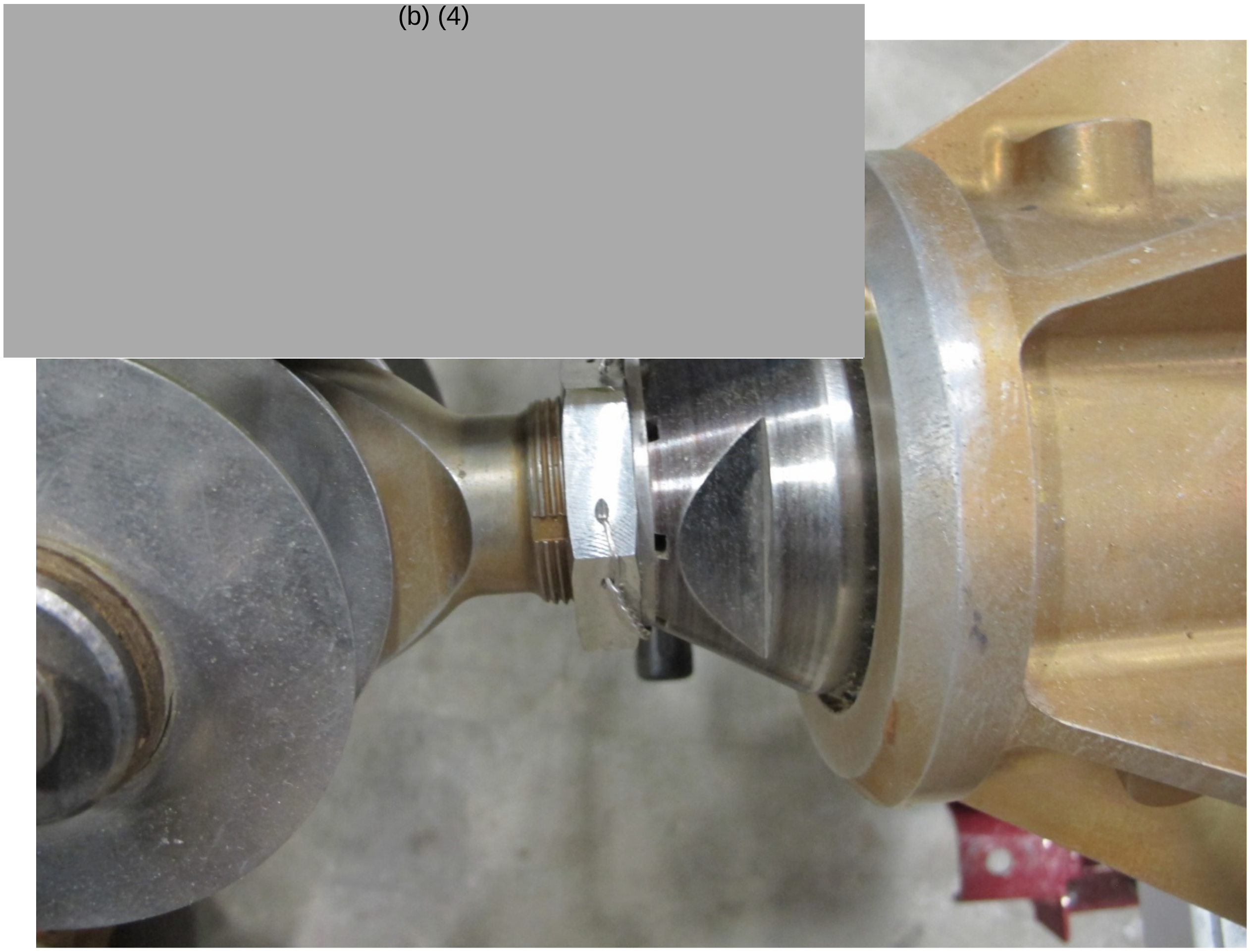


Figure 22- Exposed end of the RH feather actuator shaft

The rod end jam nut safety wire was present, intact but loose. The spiral groove slip reluctor key was displaced from the rod end groove in the rod end by approximately 2°. The jam nut was removed and it was determined that the rod end was rotated from its original position by approximately 2° and the keys from the reluctors (in two places) were embedded in the threads of the rod end, Figure 23. The rod end was removed with normal removal forces applied. It was noted that the shaft was rotated approximately 90° off nominal position.

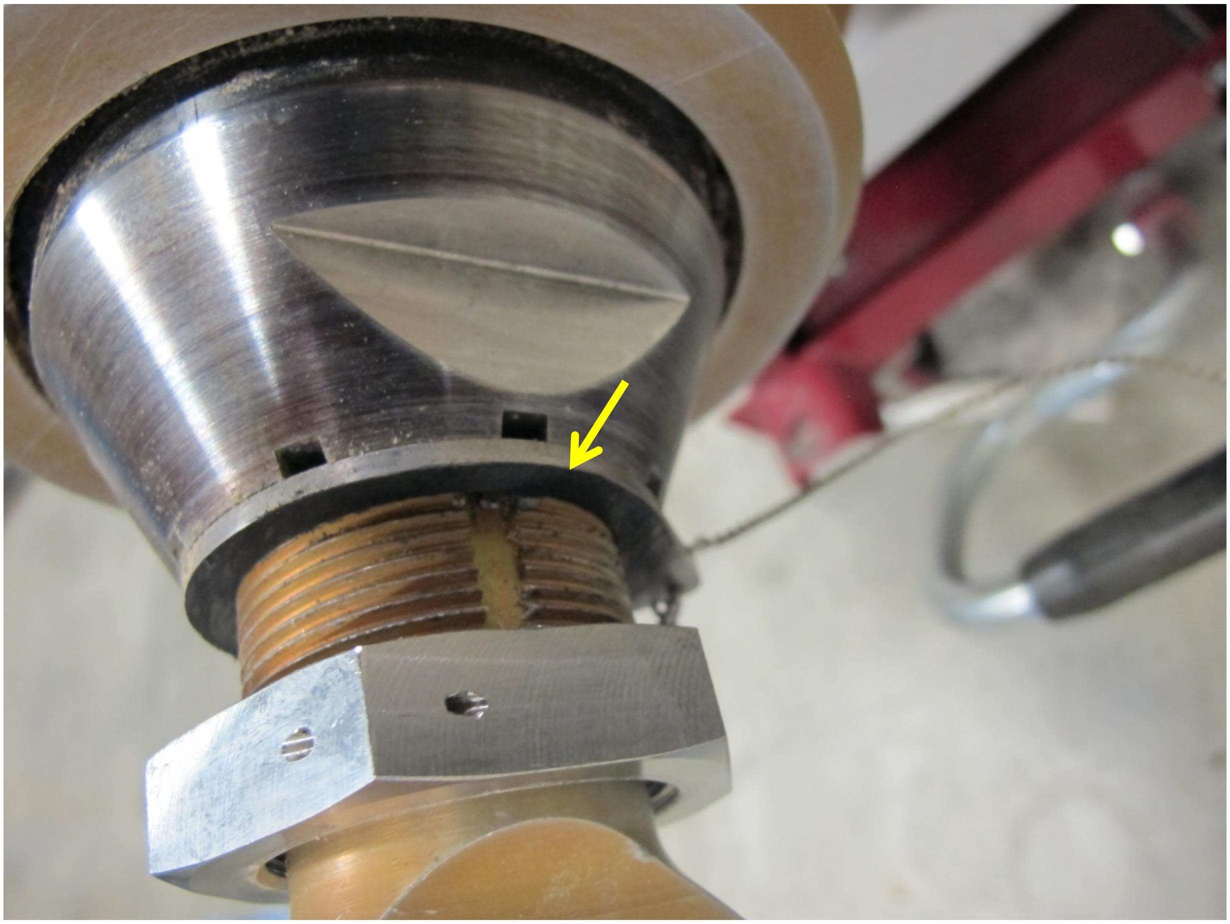


Figure 23 - Displacement of the reluctor key(yellow arrow) with RH rod end groove

The feather horn attachment hardware was present on the actuator and removed to facilitate further inspection. The rod end had surface scrapes on both sides of the main face. The spherical bearing was present. The snap ring was also present but not found in its snap ring groove. Debris were present in the snap ring groove.

Due to the damage to both the cylinder and the aft feather cap, the aft cylinder cap could not be removed through normal methods. The cap was machined off in stages until the cap could be separated from the cylinder. The cap seals were intact and exhibited no signs of cuts or dry areas. The cap was removed and the piston head was almost at the edge of the cylinder top. Fluid, consistent with (b) (4) lubricant was present. On the interior of the aft cap, markings consistent with an impact with the piston head were present.

In order to facilitate the inspection of the cylinder below the piston head, the cylinder was cut in two places. The piston head and cylinder wall portion along with the actuator shaft were removed from the forward portion of the cylinder. Once separated, grooves were machined in the cylinder walls in two places, 180° from each other, to remove the piston head and shaft. The cylinder walls did not show signs of scoring or wear marks. Marks in the surface finish of the cylinder walls were present in the location of the piston head.

The surface finish in the regions around the buckling, did show signs of cracking and flaking of the surface finish. Due to the buckling damage, the extend hard stop could not be removed to be fully visually inspected. It could be seen that the hard stop was slightly buckled on the side near the cylinder buckling. Wear marks consistent with interfacing with the (b) (4) washers was present on the hard stop.

The scraper, backup rings and O-ring were removed from the forward cylinder cap. The components were in good condition. Visual inspection revealed no signs of cuts or non-lubricated components.

The spiral lock, which secures the piston shaft bushing retaining plate, was easily removed. The piston shaft bushing retaining plate was removed and showed signs of damage and appeared to be cupped. Per design, the plate should be flat.

The piston shaft bushing was removed and visually inspected. The bushing was lubricated. Wear lines could be seen, longitudinally in the surface of the bushing. There were no areas with scratches or deep gouges.

The spiral lock which secures the extend snubber coil ring spacer was present and removed. The extend snubber coil ring spacer and (b) (4) washers were removed and inspected. A small nick was noted on the outer edge of the inner (b) (4) washer.

The main piston backup plate was removed. All supporting hardware for the main piston backup plate was present.

The piston shaft was removed from the piston head. A circumferential score was present at approximately 5/8” and 1 ¼” from the end of the shaft, as measured from the beveled end. The seal between the shaft and piston head was present and did not exhibit any signs of cuts and was well lubricated. Two marks were also noted on the shaft, approximately 10 inches from the beveled end.

The main piston head showed some signs of denting along the outer edge of the seal gland towards the rod end of the piston in the area closest to the cylinder wall breech. The damage area was confined to approximately 5 inches along the outer circumference. Both sets of O-rings and backup rings on the piston head were present and showed no signs of cuts and were well lubricated.

4.3.3 RH Regulator:

4.3.3.1 RH Regulator -Data Plate Information:

Manufacturer: (b) (4)
Part Number:
Serial Number:

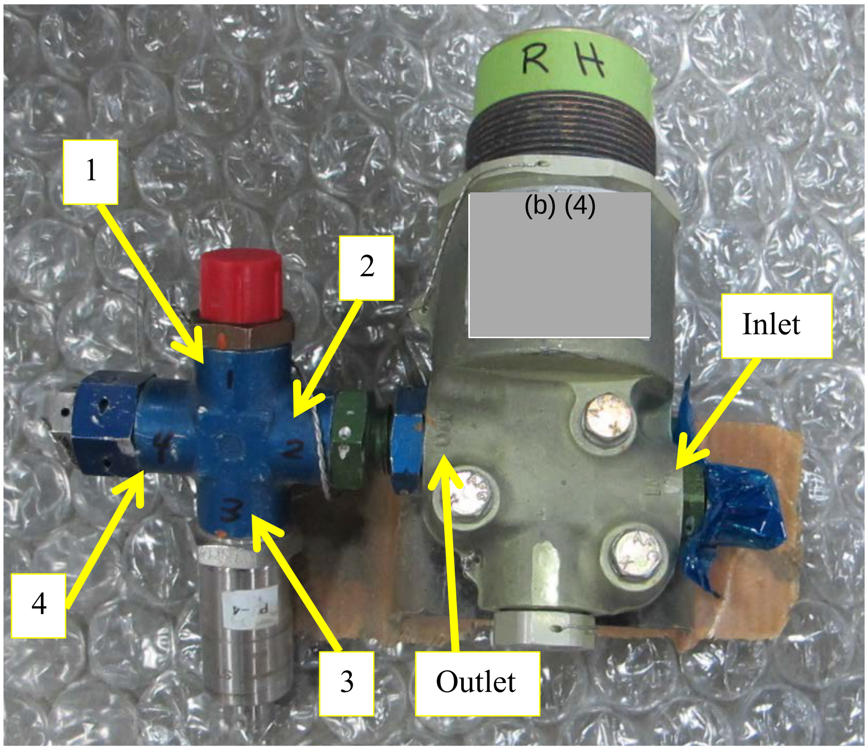


Figure 24 - RH Regulator with ports identified

4.3.3.2 RH Regulator - Examination:

Prior to the examination, the structural brackets and the cross fitting with components that were attached to the regulator were removed. Figure 24 shows the regulator prior to shipment for CT scanning.

The port labelled “1” on the cross had a fitting installed. The fitting was removed and the O-ring was present and in good condition with no visible cuts or damage.

The port labelled “2” on the cross was connected to the outlet port of the regulator. The cross was removed with the union attached to the regulator at the same time. The jam nut was tight and the safety wire was present and intact. The jam nut was loosened and the fitting was removed. The backup ring and O-ring were present and in good condition with no visible cuts or damage.

The port labelled “3” on the cross had a pressure transducer, identified as PT-4 attached. The electrical connector did not show signs of visible damage. The transducer was removed and the sensing face of the transducer was visually inspected with no damage noted. The O-ring was present and in good condition with no visible cuts or damage.

The port labelled “4” on the cross had a (b) (4) burst disc installed. The O-ring was present and in good condition with no visible cuts or damage. The frangible face of the burst disc was intact, Figure 25.

Figure 25 - Burst disc from RH regulator

The outlet port on the regulator contained small flecks of debris.

The inlet port had the remains of a portion of supply tubing and a b-nut. The fitting on the inlet port’s safety wire was present and secure. Small debris was present in the input port. The fitting was removed and the O-ring was present and in good condition with no visible cuts or damage.

The setting end of the regulator jam nut was secure, present and the safety wire was intact.

An exterior visual inspection of the vent port showed the presence of minor debris consistent with sand.

The assembly plug on the base of the unit was secure and the safety wire was present and intact.

After the regulator was tested, the assembly plug was removed to view the vent seat of the regulator. The internal components were clean with no visible signs of debris. The poppet tip was clean.

4.3.3.3 RH Regulator-Functional Test:

After the removal of the fittings and a visual inspection of the regulator, a functional test was performed. Details of the test procedure and results can be found in appendix A.

During the test and after air was flowing through the regulator, the outlet valve was closed abruptly and caused the vent port to open on the regulator. This was indicated by a whistling noise and airflow being felt out the vent port. The valve continued to regulate pressure at the nominal value. The whistling noise and airflow from the vent port was not present during the initial portion of the test.

4.3.4 LH Regulator

4.3.4.1 LH Regulator-Data Plate Information:

(b) (4)

Manufacturer: [redacted]
Part Number: [redacted]
Serial Number: [redacted]

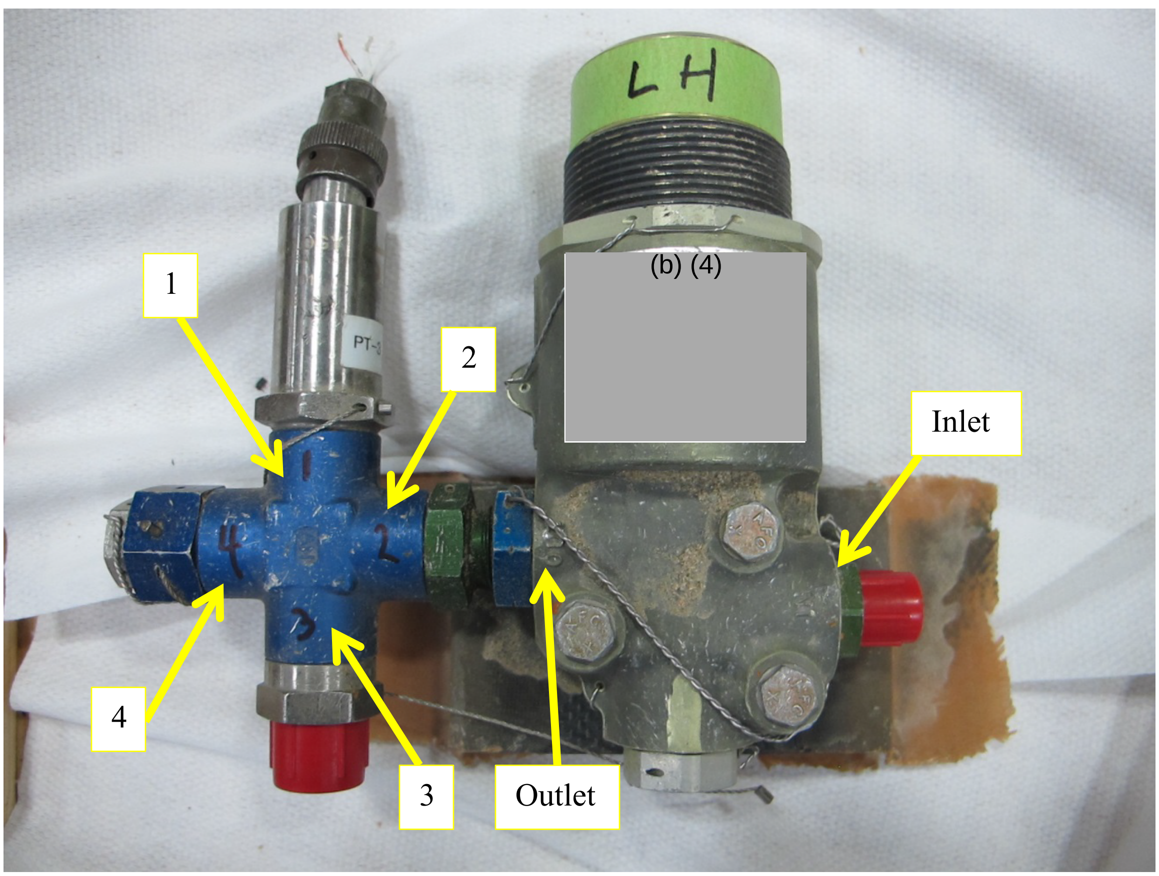


Figure 26 - LH Regulator with ports identified

4.3.5 LH Regulator-Examination:

Prior to the examination, the structural brackets and the cross fitting with components that were attached to the regulator were removed. Figure 26 shows the regulator prior to shipment for CT scanning.

The port labelled “1” on the cross had a pressure transducer, identified as PT-3 attached. The electrical connector was damaged. The transducer was removed and the sensing face of the transducer was visually inspected with no damage noted. The O-ring was present and in good condition with no visible cuts or damage.

The port labelled “2” on the cross was connected to the outlet port of the regulator. The cross was removed with the union attached to the regulator at the same time. The jam nut was tight and the safety wire was present and intact. The jam nut was loosened and the fitting was removed. The backup ring and O-ring was present and in good condition with no visible cuts or damage.

The port labelled “3” on the cross had a check valve installed. The from direction arrow indicated the valve would flow from the regulator (supply) to the feather system. The O-ring was present and in good condition with no visible cuts or damage. A visual inspection of the upstream port (supply side) revealed no signs of debris. A visual inspection of the downstream port (feather system) revealed minor amounts of debris, consistent with sand. The check valve was manually activated using a q-tip and the valve opened and closed nominally.

The port labelled “4” on the cross had a (b) (4) burst disc installed. The O-ring was present and in good condition with no visible cuts or damage. The frangible face of the burst disc was intact, Figure 27.

Figure 27 - Burst disc from LH regulator

The outlet port on the regulator was clean with no visible debris.

The fitting on the inlet port's safety wire was present and secure. The fitting was removed and the O-ring was present and in good condition with no visible cuts or damage.

The setting end of the regulator jam nut was secure, present and the safety wire was intact.

An exterior visual inspection of the vent port showed the presence of minor debris consistent with sand.

The assembly plug on the base of the unit was secure and the safety wire was present and intact.

After the regulator was tested, the assembly plug was removed to view the vent seat of the regulator. The internal components were clean with no visible signs of debris, except for the tip of the poppet where it interfaces the vent seat. The poppet tip had a small amount of debris consistent with sand.

4.3.6 LH Regulator-Functional Test:

After the removal of the fittings and a visual inspection of the regulator, a functional test was performed. Details of the test procedure and setup can be found in appendix A.

The regulator passed the test with no anomalies noted.

4.3.7 RH Feather Valve

Prior to the teardown and inspections of the parts, a review of the vehicle build photos and CT scanned images were researched to determine the installed position of the valve in the vehicle. The group determined that this valve was installed in the right hand side of the system.

4.3.7.1 RH Feather Valve-Data Plate Information:

(b) (4)

Manufacturer:
Part Number:
Serial Number:

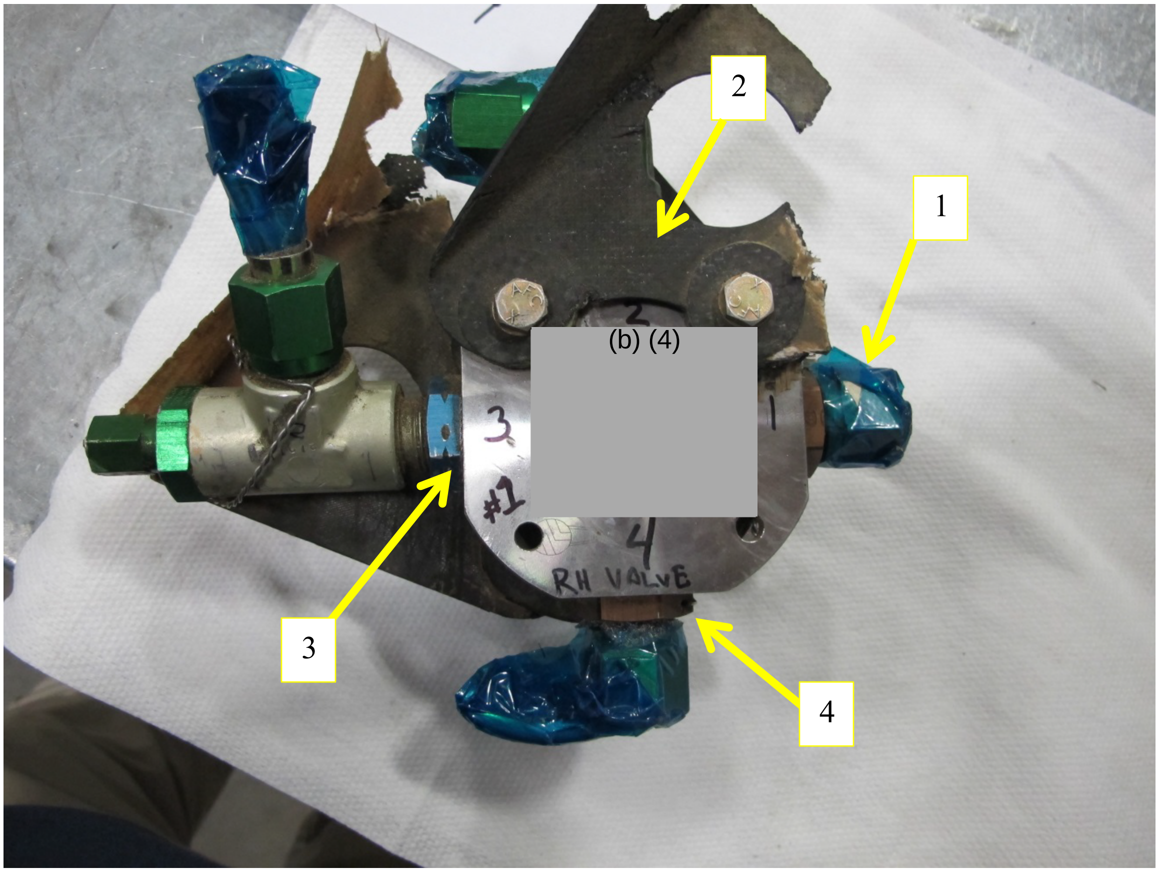


Figure 28 - RH Feather Valve with ports identified

The valve ports were modified by Scaled prior to the installation in the vehicle to accept standard MS-threaded hardware.

The valve was modified while installed on the vehicle to add a valve lock tube to the valve on the supply port.

4.3.8 RH Feather Valve-Visual Examination:

On the back side of the valve, the ports were identified by laser etched numbers 1 through 4, Figure 28. The port numbers were cross-referenced to the system schematic lines. The group determined the valve port identifications were as follows:

- Port 1 – Vent
- Port 2 – Up
- Port 3 – Supply
- Port 4 – Down

The valve mounting nut safety wire was present but not connected. The nut was loosened and the bracket was rotated approximately 30° to align 90° with the outboard bracket[23]. The safety wire position with the bracket mounting hole was confirmed.

The base portion of the handle was still attached to the valve. The handle set screw was tight and the handle was subsequently removed.

Port 1 contained a portion of a fitting, a small section of tubing and a b-nut which were subsequently removed. The safety wire was present and secure. The O-ring was present and in good condition with no visible cuts or damage. There was some debris, consistent with sand, present in the port.

Port 2 contained a 90° elbow fitting, a portion of the tubing and a b-nut that was subsequently removed. The safety wire was present and secure. The O-ring was present and in good condition with no visible cuts or damage. There was some debris, consistent with sand, present in the port.

Port 3 contained a T-fitting and fitting nut which were removed. The safety wire was present and secure. The O-ring and backup ring were present and in good condition with no visible cuts or damage. The valve lock tube was present and easily removed with the fitting. There was some debris present in the port.

Port 4 contained a portion of the fitting, a section of the tubing and a b-nut that was subsequently removed. The safety wire was present and secure. The O-ring was present and damaged. The remaining portion of the fitting was removed. There was some debris, consistent with sand, present in the port.

Figure 29 contains images of the four ports showing the position and debris in each port as found during the examination.

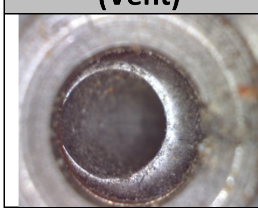
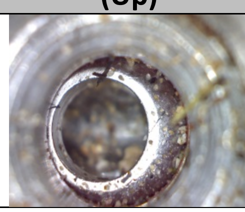
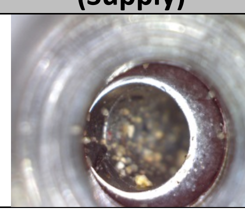
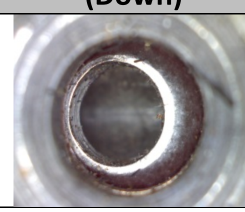
Port 1 (Vent)	**Port 2 (Up)**	**Port 3 (Supply)**	**Port 4 (Down)**
			

Figure 29 - Images showing position of valve ball for each port in the RH feather valve

Air blown through port 1 resulted in air blowing through port 4 (Vent to Down).

Air blown through port 2 resulted in air blowing through port 3 (Supply to Up).

[23] The bracket was repositioned to match the correct alignment of the brackets as installed on the vehicle.

The ball valve nut was removed and the (b) (4) washers were present and undamaged.

The plastic packing was removed and found undamaged.

The ball face had no visual signs of scoring. The ball shaft did have a circumferential score located 1 3/16 inches from the shaft top.

The four ball seats were present and did not show any visual signs of damage.

4.3.9 LH Feather Valve

Prior to the teardown and inspections of the parts, a review of the vehicle build photos and CT scanned images were researched to determine the installed position of the valve in the vehicle. The group determined that this valve was installed in the left hand side of the system.

4.3.9.1 LH Feather Valve-Data Plate Information:

Manufacturer: (b) (4)
Part Number:
Serial Number:

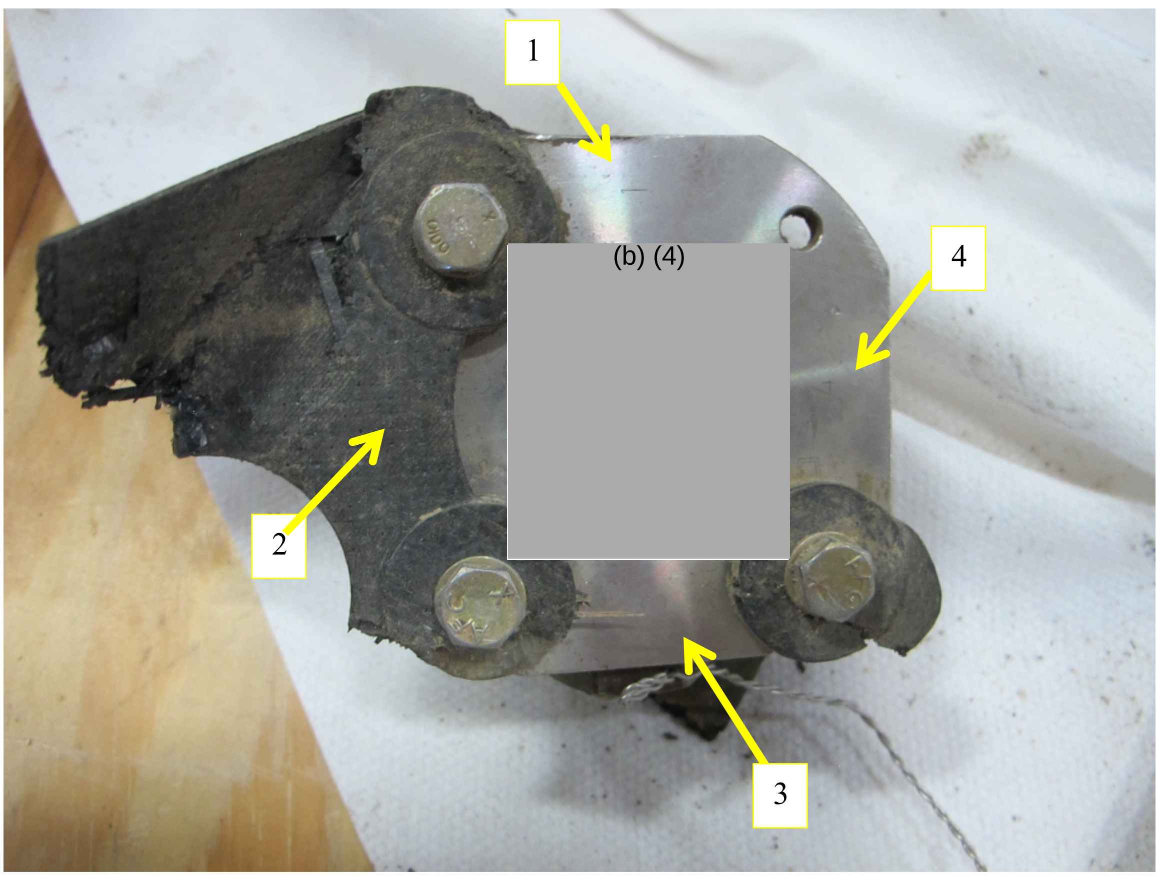


Figure 30 - LH Feather Valve with ports identified (port 2 obscured by structure)

The valve ports were modified by Scaled prior to the installation in the vehicle to accept standard MS-threaded hardware.

The valve was modified while installed on the vehicle to add a valve lock tube to the valve on the supply port.

4.3.9.2 LH Feather Valve-Examination:

On the back side of the valve, the ports were identified by laser etched numbers 1 through 4, Figure 30. The port numbers were cross referenced to the system schematic lines. The group determined the valve port identifications were as follows:

- Port 1 – Supply
- Port 2 – Up
- Port 3 – Vent
- Port 4 – Down

The valve mounting nut safety wire was intact and secure. The valve shaft and mounting fitting were damaged and precluded removal of the structure recovered with the valve.

The port 1 fitting was broken off below the O-ring gland. The O-ring was not present. The remaining portion of the fitting was removed. The valve lock tube was not present in the port. An exemplar valve lock tube was inserted into the recovered fitting and the insert passed through without difficulty. There was some debris, consistent with sand, present in the port.

The port 2 fitting was broken off below the O-ring gland. The O-ring was not present. The remaining portion of the fitting was removed. There was some debris, consistent with sand, present in the port.

The port 3 fitting was broken off above the fitting nut and was removed. The O-ring was present and in good condition with no visible cuts or damage. The safety wire was present but not intact. There was some debris present in the port.

The port 4 fitting was broken off below the O-ring gland. The O-ring was present and damaged. The remaining portion of the fitting was removed. There was some debris, consistent with sand, present in the port.

Figure 31 contains images of the four ports showing the position and debris in each port as found during the examination.

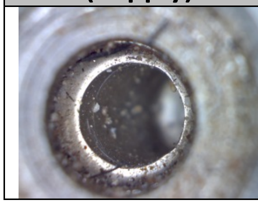
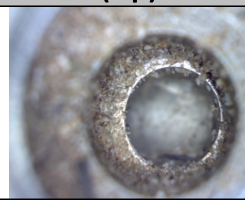
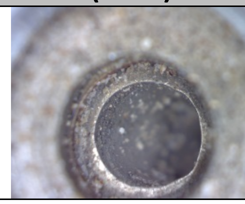
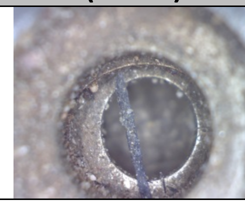
Port 1 (Supply)	Port 2 (Up)	Port 3 (Vent)	Port 4 (Down)
			

Figure 31 - Images showing position of valve ball for each port in the LH feather valve

Air blown through port 1 resulted in air blowing through port 4 (Supply to Down).

Air blown through port 2 resulted in air blowing through port 3 (Vent to Up).

Due to the damage to the shaft, the valve was not disassembled further.

4.3.10 Feather Lock Valve:

Prior to the teardown and inspections of the parts, a review of the vehicle build photos and CT scanned images were researched to determine the installed position of the valve in the vehicle.

Due to the damage to the valve the group could not determine which position, left or right, this valve was installed in.

4.3.10.1 Feather Lock Valve -Data Plate Information:

(b) (4)

Manufacturer: [redacted]
Part Number:
Serial Number:

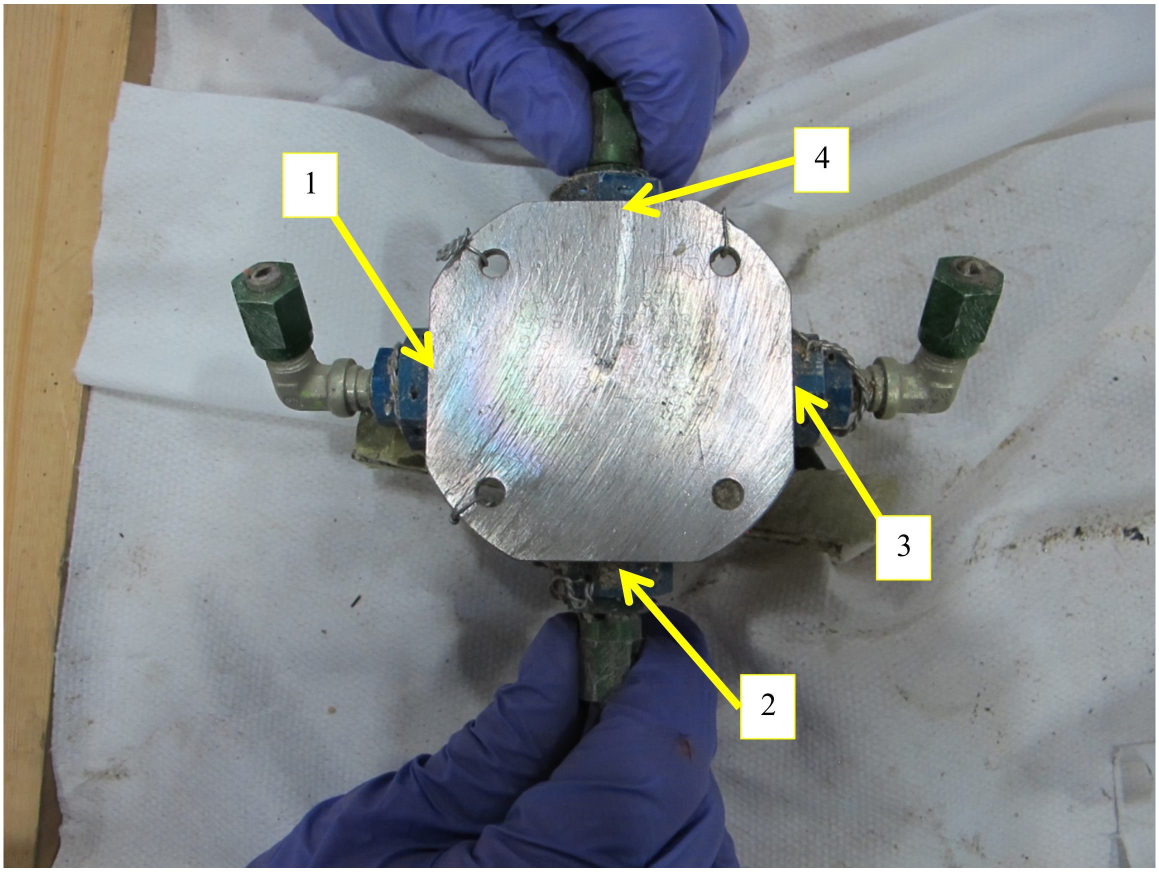


Figure 32 - Feather lock valve with ports identified (after support structure removed)

The valve ports were modified by Scaled prior to the installation in the vehicle to accept standard MS-threaded hardware.

The valve was modified while installed on the vehicle to add a valve lock tube to the valve on the supply port.

4.3.10.2 Feather Lock Valve-Visual Examination:

On the back side of the valve, the ports were identified by laser etched numbers 1 through 4, Figure 32. The port numbers were cross-referenced to the system schematic lines. The group determined the valve port identifications were as follows:

- Port 1 – Could not be determined (Lock or Unlock)
- Port 2 – Vent
- Port 3 – Could not be determined (Lock or Unlock)
- Port 4 – Supply

The valve mounting nut safety wire was intact and secure. The valve bracket could be rotated by hand and was slightly loose.

The port 1 fitting was removed and the O-ring and backup ring were present and in good condition with no visible cuts or damage. There was some debris present in the port.

The port 2 fitting was removed and the O-ring and backup ring were present and in good condition with no visible cuts or damage. The safety wire was present and intact. There was some debris present in the port.

The port 3 fitting was removed and the O-ring and backup ring were present and in good condition with no visible cuts or damage. The safety wire was present and intact. There was some debris present in the port.

The port 4 fitting was removed and the O-ring and backup ring were present and in good condition with no visible cuts or damage. The safety wire was present and intact. The valve lock tube was present and easily removed with the fitting. There was some debris present in the port.

Figure 33 contains images of the four ports showing the position and debris in each port as found during the examination.

Port 1 (Unknown)	Port 2 (Vent)	Port 3 (Unknown)	Port 4 (Supply)

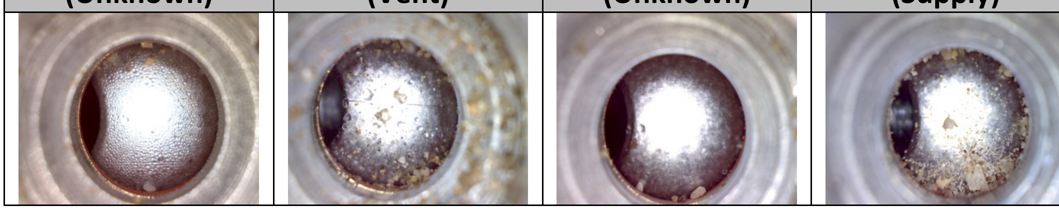


Figure 33 - Images showing position of valve ball for each port in the feather lock valve

Air blown through port 1 resulted in air blowing through all remaining ports.

The ball valve nut was removed and the (b) (4) washers were present and undamaged.

The plastic packing was removed and found undamaged.

The ball face had no visual signs of scoring. The ball shaft did have a circumferential score located 1 ¼ inches from the shaft top.

The four ball seats were present and did not show any visual signs of damage.

4.3.11 RH Feather Enable Valve (Feather System Vent Valve):

4.3.11.1 RH Feather Enable Valve (Feather System Vent Valve) -Data Plate Information:

(b) (4)

Manufacturer: [redacted]
Part Number: [redacted]

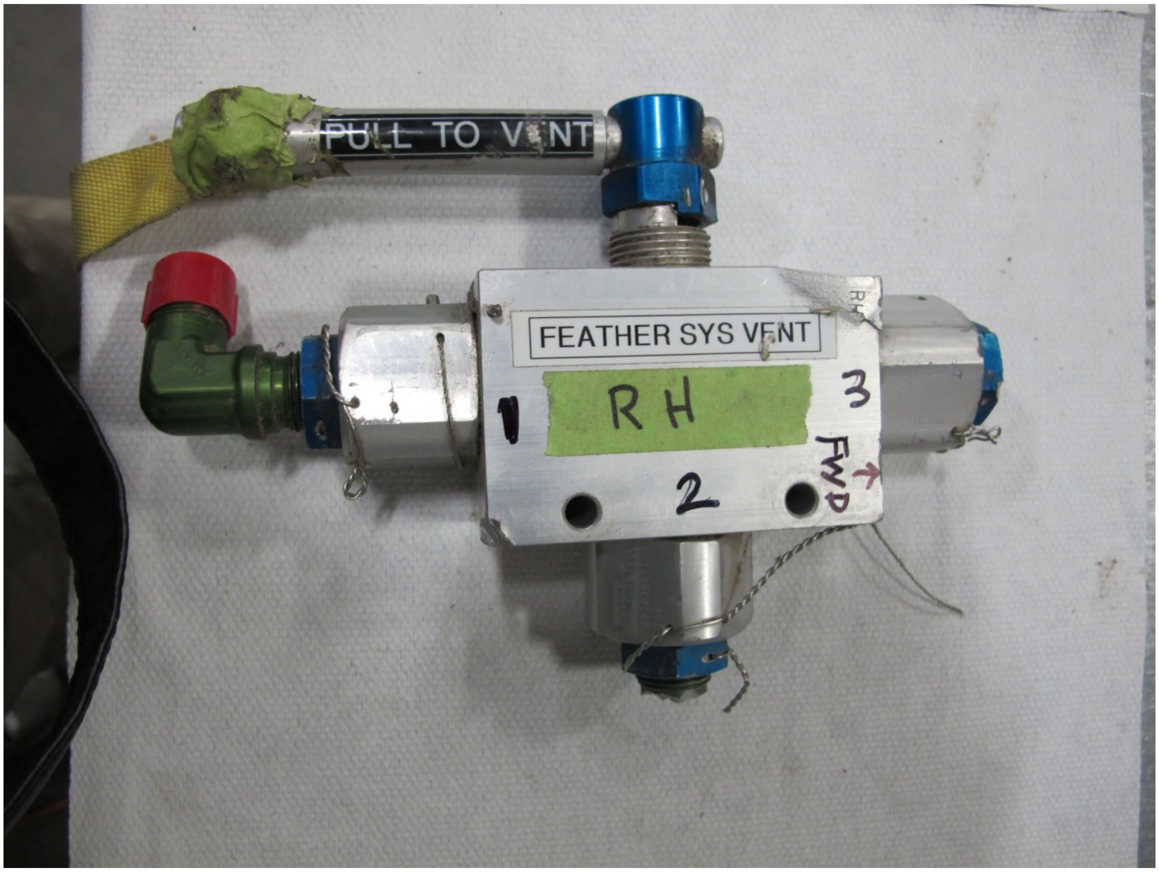


Figure 34 - RH feather enable valve

4.3.11.2 RH Feather Enable Valve (Feather System Vent Valve)-Visual Examination:

Prior to inspection, using design and build data, the ports were labelled 1 through 3 and were connected to the following routes per the schematic, Figure 34. The group determined the valve port identifications were as follows:

- Port 1 – Vent
- Port 2 – Feather System
- Port 3 – Supply

The fitting at port 1 was a 90° elbow. The safety wire was secure and intact. The O-ring and backup ring were present and in good condition with no visible cuts or damage. A thin film on the inside of the port was present consistent with (b) (4) lubricant.

A partial fitting at port 2 was found attached to the valve. The jam nut was loose. The safety wire was loose and broken. The O-ring and backup ring were present and in good condition with no visible cuts or damage. Debris consistent with sand was present in the port.

A partial fitting at port 3 was found attached to the valve. The safety wire was secure and intact. The O-ring was present and in good condition with no visible cuts or damage. Debris consistent with sand was present in the port.

Small airflow was applied to port 1 with no apparent flow between the other ports.

Small airflow was applied to port 3 with apparent flow at port 2 (Feather System to Supply).

The handle was loose and found in its nominal position. The shaft hole on the handle was elongated and the set screw was loose. No attempt was made to actuate the valve.

The nylon strap (which is normally affixed to the co-pilot's seat) was attached to the handle. The strap was complete and not severed. Portions of the strap still had aluminum tape attached.

4.3.12 LH Feather Enable Valve (Feather System Vent Valve):

4.3.12.1 LH Feather Enable Valve (Feather System Vent Valve)-Data Plate Information:

(b) (4)

Manufacturer:
Part Number:

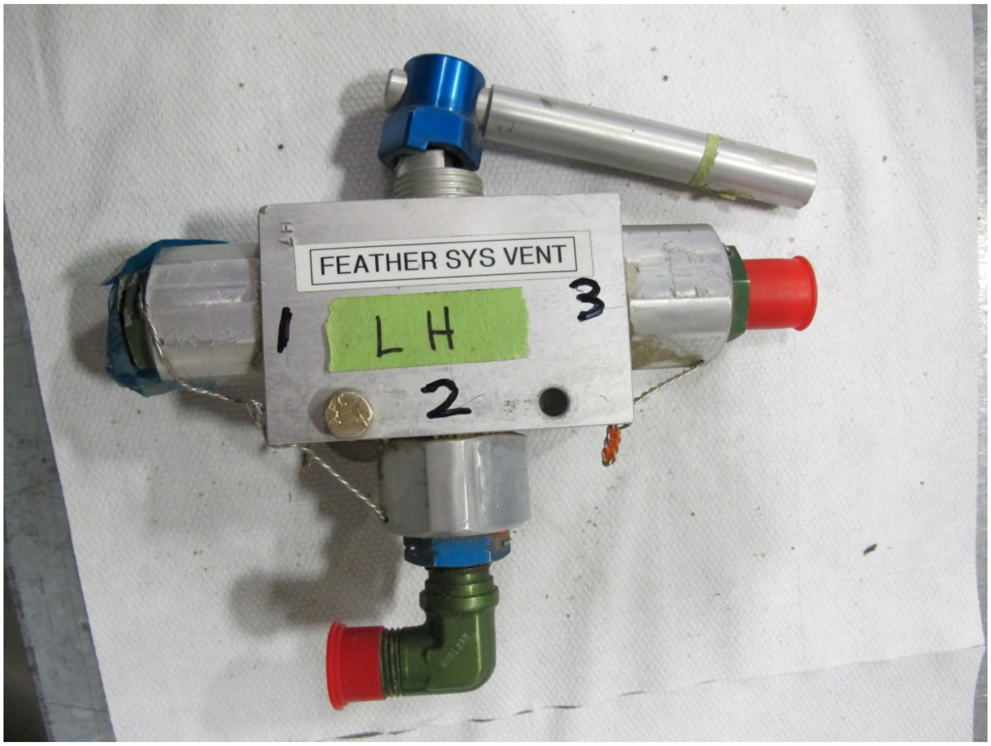


Figure 35 - LH feather enable valve

4.3.12.2 LH Feather Enable Valve (Feather System Vent Valve)-Visual Examination:

Prior to inspection, using design and build data, the ports were labelled 1 through 3 and were connected to the following routes per the schematic, Figure 35. The group determined the valve port identifications were as follows:

- Port 1 – Vent
- Port 2 – Feather System
- Port 3 – Supply

The fitting at port 1 was partially intact. The safety wire was secure and intact. The valve packing nut was 1/8 of a turn loose. The O-ring was present and in good condition with no visible cuts or damage. Debris, consistent with sand was present in the port.

The fitting at port 2 was a 90° elbow. The safety wire was loose but intact. The O-ring and backup ring were present and in good condition with no visible cuts or damage. Debris, consistent with sand was present in the port.

The fitting at port 3 was present. The safety wire was secure and intact. The O-ring was present and in good condition with no visible cuts or damage. Debris, consistent with sand was present in the port.

Small airflow was applied to port 3 with no apparent flow between the other ports.

Small airflow was applied to port 1 with apparent flow at port 2 (Feather System to Vent).

The handle was loose and found in a position 180° from nominal position. The handle shaft was bent approximately 10° from the axis of rotation. The handle stops exhibited signs of impacts mark both on the handle and the valve body. No attempt was made to actuate the valve.

4.3.13 Feather System-Cockpit Controls:

4.3.13.1 Feather Unlock Handles-Visual Examination:

Both the left and right feather unlock handles were recovered in the wreckage.

Figure 36 - LH feather unlock handle

The LH feather lock handle was found attached to a portion of the center pedestal structure, Figure 36. The handle was bent in an outboard direction at the structure. The handle was found in the lock position. The control cables that connect with the feather lock valve were also attached to the handle.

Figure 37 - RH feather lock handle

The RH feather lock handle was found separated from the center pedestal structure, Figure 37. The handle was bent in multiple directions. The handle position could not be determined. The control cables that connect with the feather lock valve were also attached to the handle.

4.3.13.2 Feather Retract/Extend Handles-Visual Examination:

Both the left and right feather retract/extend handles were recovered in the wreckage.

Figure 38 – Left and right feather extend handle

Both handles were found separated from the center pedestal structure and their respective mechanical linkages, Figure 38. The handle positions could not be determined.

A APPENDIX A

The regulator pressure tests were verified using a current production regulator prior to the testing. The test setup consisted of a pressure supply tank with a variable inlet pressure regulator, and an outlet pressure gage (Fluke 717 10000G Pressure Calibrator) and a valve connected to the unit under test, Figure A-1.

Figure A-1 – Regulator pressure test setup – Supply tank and outlet valve not shown

A.1 Test Procedure:

The test procedure was as follows:

1. Apply 1000 psig to the inlet port and record the outlet pressure
2. Increase the pressure to 3000 psig and record the outlet pressure
3. Hold pressure for 10 minutes while maintaining 3000 psig
4. After 10 minutes record the outlet pressure
5. Open the outlet valve and let the air flow for 20 seconds, record the pressure just prior to the end of 20 seconds.
6. Close the outlet valve and record the outlet pressure
7. Hold pressure for 10 minutes while maintaining 3000 psig
8. After 10 minutes record the outlet pressure
9. Test Complete

A.2 Production Regulator Test Results

The results of the current production regulator are as follows:

Inlet Pressure (psig)	Outlet Pressure (psig)	Notes:
500	482	Leak Check, initial system check
1000	482	
3000	482	Time = 0 min
3000	479	Time = 10 min
3000	445	After 20 seconds flow time
3000	485	Time = 0 min
3000	480	Time = 10 min

A.3 RH Regulator Test Results

The results of the RH regulator are as follows:

Inlet Pressure (psig)	Outlet Pressure (psig)	Notes:
1000	483	
3000	483	Time = 0 min
3000	477	Time = 10 min
3000	440	After 20 seconds flow time
3000	483	Time = 0 min (Whistling, air venting from vent port)
3000	480	Time = 5 min (Whistling, air venting from vent port – Needle Valve on supply tank closed)
3000	478	Time = 6 min (Whistling, air venting from vent port – Needle Valve on supply tank closed)
3000	483	Time = 7 min (Whistling, air venting from vent port – Needle Valve on supply tank closed)
3000	483	Time = 8 min (Whistling, air venting from vent port – Needle Valve on supply tank closed)
3000	483	Time = 10 min (Whistling, air venting from vent port – Needle Valve on supply tank closed)

A.4 LH Regulator Test Results

The results of the LH regulator test are as follows:

Inlet Pressure (psig)	Outlet Pressure (psig)	Notes:
1000	491	
3000	491	Time = 0 min
3000	489	Time = 10 min
3000	419	After 20 seconds flow time
3000	494	Time = 0 min
3000	479	Time = 10 min