NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Vehicle Recorder Division
Washington, DC 20594

GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION

External Imagery Factual Report

DCA15MA019

By
Sean Payne

NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, DC 20594

November 18, 2014

External Imagery

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1. EVENT SUMMARY

Location:	Koehn Dry Lake, CA
Date:	October 31. 2014
Vehicle:	Model 339 SpaceShipTwo
Registration:	N339SS
Operator:	Scaled Composites, LLC.
NTSB Number:	DCA15MA019

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.

2. GROUP

A video evidence group was convened on November 18, 2014. The members of the group were:

Chairman: Sean Payne
Mechanical Engineer
National Transportation Safety Board (NTSB)

Member:	Clint Crookshanks Aerospace Engineer (Structures) NTSB
Member:	Dr. Paul Wilde Technical Advisor, AST-4 Federal Aviation Administration (FAA)
Member:	Jonathan Carter Project Engineer Scaled Composites
Member:	Scott Ostrem Chief Engineer The Spaceship Company (Virgin Galactic)

3. DETAILS OF RECORDED MATERIAL

During the on scene portion of the investigation the NTSB collected multiple video recordings from five ground locations that captured the Scaled Composites SpaceShipTwo accident. Additionally, a file was received from the telemetry ground station in the Scaled Composites Control Room that was a recording from SpaceShipTwo's (SS2) onboard boom mounted camera sent via telemetry. Attachment A-1, listed at the end of this report, is a map of camera locations in relation to SS2's flightpath and calculated Instantaneous Impact Point (IIP[1]) during the October 31st event. These files are described as follows:

3.1. MARS Scientific

Provider:	**MARS Scientific**
Camera System(s):	**RED Epic Mysterium-X** **Prosilica GC1830H (VIS / NIR[2])** **Goodrich SU640SDX-1.7RT (SWIR[3])**
Optics:	**3165 mm telescope (RED)** **3120 mm telescope (VIS / NIR)** **960 mm telescope (SWIR)**
Mounting Equipment:	**Two-axis high speed tracking mount[4]**
Tracking Method:	**Automatic, Human Assisted**
Location:	**35°13'14.1"N, 118°01'18.6"W**

[1] For additional information about the IIP, see the Vehicle Performance Study which can be found in the public docket for this accident.
[2] VIS / NIR – Visible light to Near Infrared (400nm – 1000nm)
[3] SWIR – Short Wave Infrared
[4] A multi-sensor mounting platform capable of tracking objects either automatically or with the assistance of a human operator via joystick.

MARS Scientific was contracted by Virgin Galactic to provide imagery for the test flight. MARS Scientific was set up to capture the test event with three cameras that were co-mounted to a trailerable KTM. The KTM trailer (Figure 1) was deployed near the intersection of two dirt roads approximately 12 nautical miles northeast of Mojave Air and Space Port (KMHV), Mojave, California. Figure 2 shows the approximate location of the trailerable KTM mount at the time of recording.

MARS recorded the event with a RED Epic Mysterium-X cinemagraphic camera operating in the visible range. The camera was recording in 5K[5] resolution at 23.98 frames per second (fps). The camera was utilizing a 3048 mm fixed focal length telescope. The camera utilized an internal infrared blocking filter and was time synchronized to a GPS based NTP[6] server for time correlation (see section 4.1). It captured a close field of view of the vehicle during most of the test event (Figure 3).

A Prosilica GC1830H VIS / NIR camera was also co-mounted to the mobile tracking telescope platform. The camera has the capability of capturing images between 400 nanometers (nm) and 1000 nm in wavelength. The camera system provided a resolution of 1380 x 1024 pixels and captured a telescopic field of view of the vehicle during most of the test event (Figure 4). The imager was recording at a frame rate of 30 fps and was utilizing a 3120 mm fixed focal length telescope.

A Goodrich SU640SDX-1.7RT was also co-mounted to the mobile tracking telescope platform. It was deployed to capture the test vehicle in the short wave infrared spectrum (SWIR) between 900nm and 1700nm. The imager was recording at a resolution of 640 x 512 pixels and a frame rate of 30 fps and captured a wide field of view of the accident vehicle (Figure 5). The imager was utilizing a 960mm fixed focal length telescope.

Figure 1: An example of a 3 camera MARS system mounted on a trailer based tracking mount. (photo: MARS Scientific)

[5] 5K – 5120 x 2700 pixels of resolution (RED Epic Mysterium-X).
[6] NTP – Network Time Protocol – A networking protocol for clock synchronization between computer systems.

Figure 2. The location of the MARS KTM at the time of recording.

Figure 3. An exported still from the MARS RED Epic Mysterium-X.

Figure 4. An exported still from the MARS Near Field Infrared Camera (NIR).

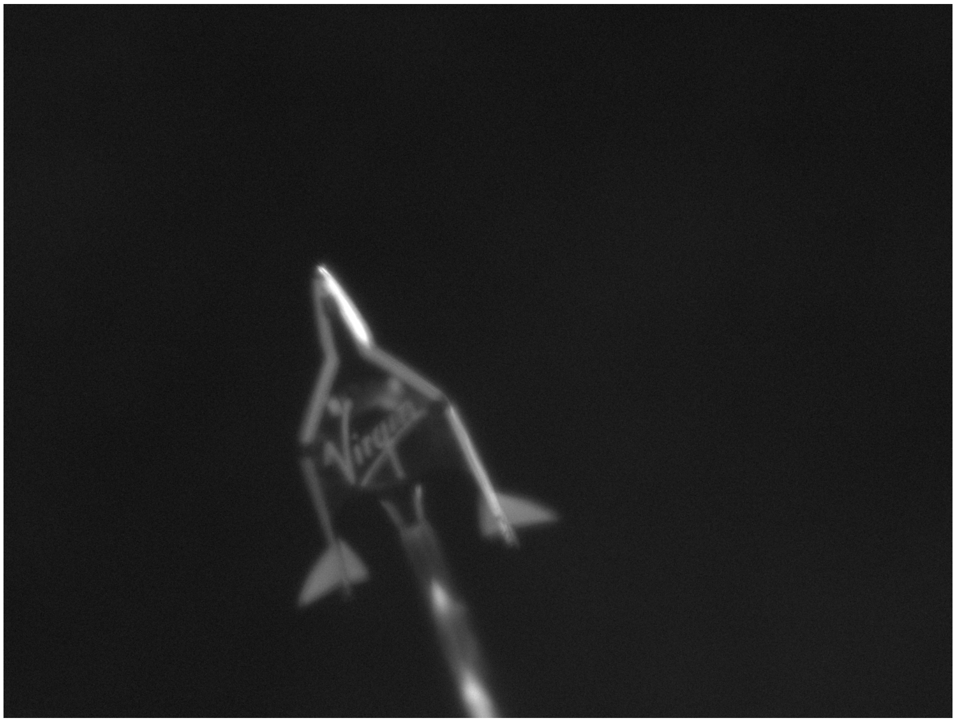
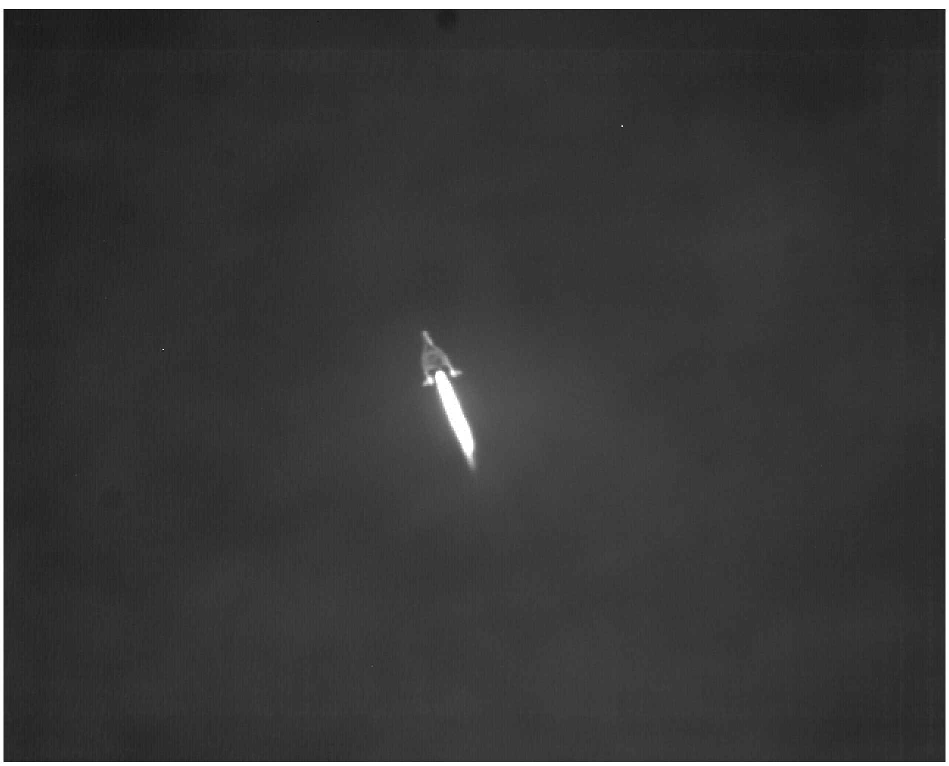


Figure 5. An exported still from the MARS Short Wave Infrared Camera.



3.2. Brandon Wood

Provider: **Brandon Wood (Scaled Employee)**
Camera System(s): Panasonic DMC-GH4
Optics: Astro-Physics 130EDF GT (GH4)
Mounting Equipment: Tripod
Tracking Method: Human
Location: 35° 8'5.2"N, 118° 0'49.3"W

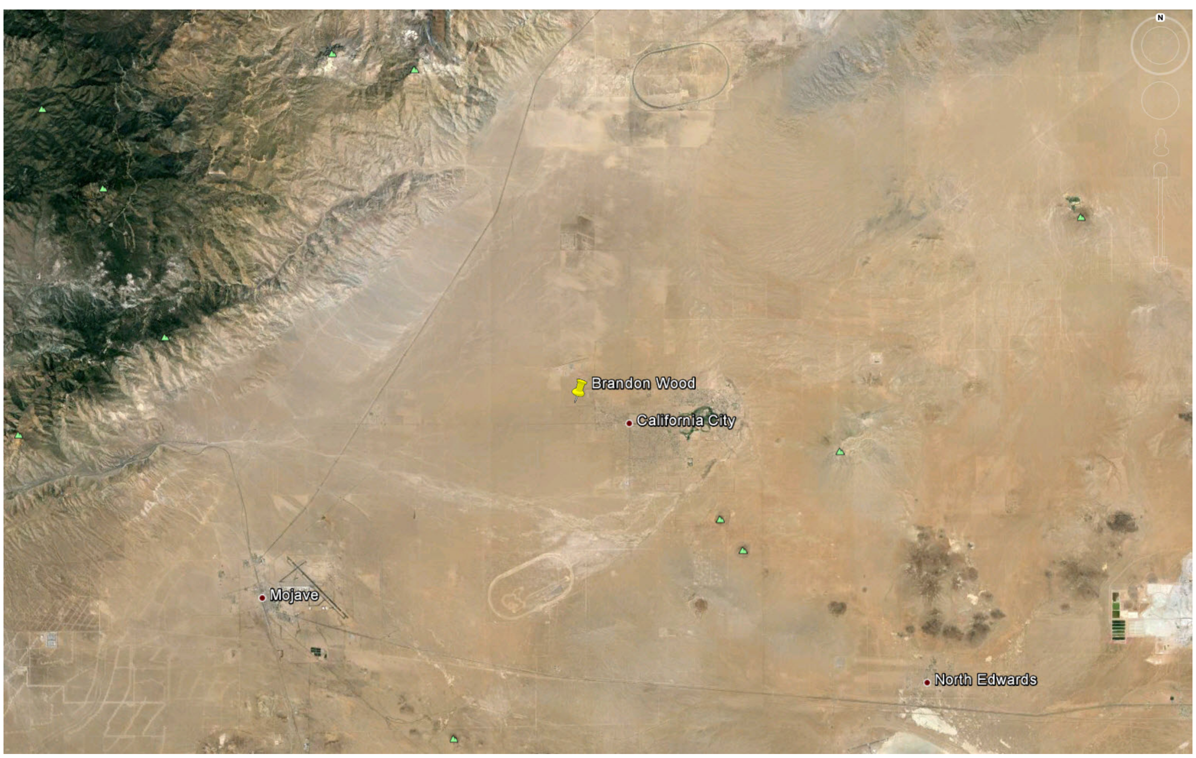
Mr. Wood is a Scaled Composites employee who took the day off to capture the test flight on his own camera. An exported still from his recording is shown in figure 6. Mr. Wood was set up one mile south of California City Airport, California City, California (Figure 7) using a tripod and a Astro-Physics 130EDF GT telescope. The accident was captured on the GH4 using a camera mode that allowed simultaneous capture of 8.8 megapixel[7] digital stills and 4K video. Mr. Wood provided processed and raw still images at 8.8 megapixels, raw video in cinema 4K[8] as well as raw and processed still frame images from the accident video recording captured at a frame rate of 29.97 fps. A portion of the boost phase, portions of the breakup sequence and portions of the spin the vehicle entered post breakup were captured by the recording. The release of SS2 from WK2 was not captured.

The Panasonic DMC-GH4 is a prosumer[9] digital camera capable of recording up to 16 megapixel digital images and 4K resolution video files at 24 fps. The camera has the capability to record 8.8 megapixel stills during video capture which was utilized for the accident recording. The device has a viewfinder and digital display to assist in reviewing and recording images and video.

[7] Megapixel – One million pixels. Can be also used to express the number of image sensor elements in a digital image sensor.
[8] 4K – Cinema 4K – 3840 x 2160 pixels of resolution.
[9] Prosumer – describes a market segment between professional and consumer.

Figure 6. An exported still image from Mr. Wood's Panasonic GH4 camera.

Figure 7. The location of Mr. Wood at the time of recording



3.3. NASA Dryden

Provider:	**NASA Dryden Aeronautical Test Range/Edwards AirForce Base (AFB)**
Camera System(s):	**Panasonic "720HD" (Long Range Optics (LRO))** **Davro, DOS-Z180-400/3000-IZ (RDR-34)**
Optics:	**Canon 86x Tele. With 2x Extender 13.5-2300mm (LRO)** **Maksutov Cassegrain 400-3000mm f/2.2 (RDR-34)**
Mounting Equipment:	**Kineto-Tracking Mount (KTM) (LRO)** **Co-Axial Mounted to Radar Dish (RDR-34)**
Tracking Method:	**Automatic, Human Assisted (LRO)** **Automatic (Radar RDR-34)**
Location:	**34°54'30.94" N, 117°52' 9.28" W (LRO)** **34°57'38.89931" N, 117°54'41.40755" (RDR-34)**

NASA Dryden Aeronautical Test Range (DATR) located on Edwards AFB, CA captured the event from two camera locations. One camera, referred to as the Long Range Optics (LRO) camera, was a Panasonic digital video recorder capturing images at a resolution of 1280 x 720 pixels at a framerate of 59.94 fps. The Panasonic imager was mounted on a fixed base KTM with a 2300mm telescope. This recording captured the vehicle's separation from WK2, rocket motor ignition, portions of vehicle break up, and the main fuselage's inverted flat spin until just prior to impact. The recording was time stamped with an IRIG[10] time stamp affixed at the top of the recording. Figure 8 shows a still image exported from the video recording.

A second camera, the RDR-34 unit, was located just north of Edwards AFB. The RDR-34 imager was a Davro DOS-Z180-400/3000-IZ with a 3000mm telescope. The camera system was co-axially mounted with a radar dish which provided automated tracking of the vehicle. It captured the vehicle's separation from WK2, rocket motor iginition, portions of vehicle break up and main fuselage's inverted flat spin until just before impact. The recording was time stamped with an IRIG time stamp affixed at the top of the recording. Figure 9 shows a still image exported from the video recording. Figure 10 shows the location of the LRO and RDR-34 cameras.

[10] IRIG - Inter-Range Instrumentation Group - A standard for test range timing information.

Figure 8: An exported still from Edwards AFB Long Range Optics (LRO) KTM mount camera.

Figure 9: An exported still from RDR-34 Co-Axial mounted radar system.

Figure 10. The location of the Edwards AFB LRO KTM and RDR-34 at the time of recording.

3.4. Virgin Galactic

Provider:	**Virgin Galactic**
Camera System(s):	**Imperx Bobcat (Pylon Cam)** **Imperx Bobcat (Tail Cam)**
Optics:	**Kowa 5mm f/1.8 (Pylon Cam)** **Kowa 5mm f/1.8 (Tail Cam)**
Mounting Equipment:	**Hard Mounted WhiteKnightTwo (WK2)**
Tracking Method:	**N/A**
Location:	**Right Tail Boom WK2 (Tail Cam, Airborne)** **Release Pylon WK2 (Pylon Cam, Airborne)**

The Imperx Bobcat camera is a high quality, small size, 2/3" color CCD[11] camera that allows the user to control a number of programmable features and communicates via GigE.[12] It has an operating temperature range of -40ºC to +85ºC and shock and vibration performance of greater than 1000g and 100g, respectively. The camera is suited for onboard video applications in extreme environments. The camera has a

[11] CCD – Charged-coupled device. An image sensor that allows conversion of areas of electrical charge to a digital value.
[12] GigE – An interface standard for high-performance industrial and machine vision cameras.

maximum resolution of 1952 x 1112 pixels at a frame rate of 39 fps in color. The cameras were outfitted with a Kowa 5mm f/1.8 lens.

The cameras are part of an onboard camera system aboard WK2 and are used for engineering review and public media purposes. The cameras each recorded the vehicle during the test event, capturing WK2 carrying SS2 to altitude, drop and portions of the breakup. The pylon camera captured a straight down view of the SS2 release and rocket motor fire through breakup and spin entry. The WK2 tail camera captured the release of SS2 and a small portion of the vehicle's subsequent breakup. All videos from WK2, including the two camera views from the Tail and Pylon cameras were downloaded in high definition directly from the system's onboard hard drives. Figure 11 shows the location of each camera mounted on WK2 and SS2. Figure 12 shows an exported image from the recorded video captured by the WK2 tail camera. Figure 13 shows an exported image from the recorded video captured by the WK2 pylon camera.

The camera's views included in this report only include those devices which were either recovered from the vehicle wreckage or added value to the investigation. For additional details, see the Electronic Devices and Flight Data Factual Report which can be found in the public docket for this accident. Figure 11 is also found in this report as Attachment A-2 which is a larger scale version of the same graphic.

Figure 11: Onboard camera orientation on WhiteKnightTwo and SpaceShipTwo.

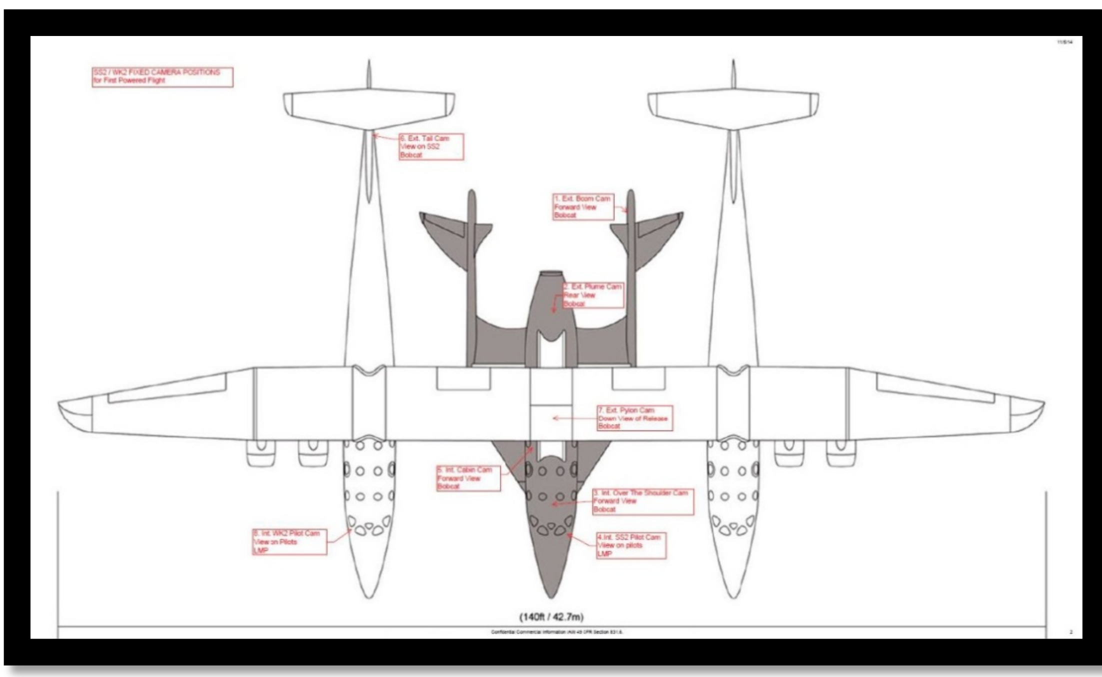


Figure 12: An exported still from the WhiteKnightTwo Tail Camera.

Figure 13: An exported still from the WhiteKnightTwo Pylon Camera.

3.5. Scaled Composites

Provider:	**Scaled Composites**
Camera System(s):	**Imperx Bobcat**
Optics:	**Kowa 5mm f/1.8**
Mounting Equipment:	**Hard Mounted SpaceShipTwo (SS2)**
Tracking Method:	**N/A**
Location:	**Inboard Portion, Left Tail Boom SS2 (Airborne)**

The Imperx Bobcat installed on SS2 was the same as that described in section 3.5. The camera was outfitted with a Kowa 5mm f/1.8 lens.

The "boom camera" comprised part of an onboard camera system on SS2 and was used for engineering data review and public media purposes. The camera recorded the vehicle during the test event; capturing WK2 carrying SS2 to altitude, the release from WK2 and portions of the vehicle's breakup. Images captured by this device were used in this report to determine key events during SS2's break-up sequence.

Images from this device were downlinked to a ground station via SS2's telemetry system. Some hardware associated with the device, including the camera's hard drive that contained the high definition recording, was recovered in the wreckage, however, the high definition file was unable to be recovered. Only the lower resolution file from the data stream was recovered from the telemetry ground station and retained.[13]

Metadata[14] written to the video track from the telemetry system indicates the file was recorded to the telemetry ground station at a framerate of 30 fps and a resolution of 704 x 288. The video resolution is consistent with the video being transmitted by the telemetry system in individual field[15] segments to reduce transmission bandwidth[16]. This resulted in the ground station recording a stretched aspect ratio[17] of the telemetered video source. Since each field contains roughly half the vertical resolution of the total frame size, the aspect ratio was changed in post processing to account for the stretch created by the video field transmission; this resulted in roughly a 4:3 aspect ratio and a resolution of 704x576[18]. The images that appear in this report, however, are the unaltered signal in the original aspect ratio and resolution (704 x 288 pixels) recorded by the ground station. The framerate remained unchanged for the recording. Figure 14 shows an exported image from the recorded video captured by the SS2 boom camera.

[13] The Electronic Devices and Flight Data Factual Report describes the recovery efforts; this report may be found in the public docket for this accident.
[14] Metadata – A subset of data that describes and gives information about another, associated set of data.
[15] Fields – One half of the vertical resolution information in an interlaced display.
[16] Bandwidth – The rate of data transfer, bit rate or throughput, measured in bits per second (bit/s).
[17] Aspect Ratio – A factor describing the proportional relationship between and image's width and height.
[18] 704x476 – 4CIF – Common Intermediate Format – A resolution consistent with DVD video.

Figure 14: An exported still from the SpaceShipTwo Boom Camera (telemetry feed).

3.6. Mark Greenberg (Virgin Galactic Contract Photographer)

Provider:	**Mark Greenberg (Virgin Galactic Contract Photographer)**
Camera System(s):	**Canon EOS 5D Mark III** **Canon EOS 70D** **GoPro HERO 3+ Black Edition**
Optics:	**Canon EF 16-35mm f/2.8L II USM (Canon Cameras)** **Canon EF 70-200mm f/2.8L IS USM (Canon Cameras)** **Canon EF 24-105mm f/4.0 IS USM (Canon Cameras)** **Fixed GoPro Lens (GoPro)**
Mounting Equipment:	**Hand Held – Extra 300 Chase Plane**
Tracking Method:	**Hand Held (Still Cameras)** **Head Mounted (GoPro)**
Location:	**Airborne – Front Seat – Extra 300 (N24GA, "Chase"[19])**

Mr. Greenberg is a professional photographer who was hired by Virgin Galactic to photograph the test event while airborne from the Extra 300 chase aircraft. Mr. Greenberg captured some pre-take off activities, portions of the climb to altitude, portions of the release, portions of the vehicle's inverted spin until impact, the pilot under parachute and some post-accident wreckage photographs. The photographer was using 2 still cameras and operating a GoPro Hero in video mode during the accident event.

The Canon EOS 5D Mark III is a professional grade 22.3 megapixel DSLR[20] camera. It contains a full frame[21] CMOS[22] image sensor with an extended ISO[23] range

[19] "Chase" – The call sign for the Extra 300 chase plane referenced in other factual reports found in the public docket for this accident (DCA15MA019).
[20] DSLR – Digital Single Lens Reflex – A mirror and prism system that permits the photographer to view through the lens rather than a stand-alone viewfinder.
[21] Full Frame – A digital image sensor the equivalent size as that of traditional 35mm film cameras (36x24mm).

of up to 102,400. It has a sophisticated autofocus system and can accept a wide range of lenses designed for the EOS camera family. It can record full HD video up to 30 fps at 1920 x 1080 pixels. Still images can be captured at a rate up to 6 fps. The EOS 5D Mark III has the option to allow an external GPS sensor to be added so that each image file can be geo-tagged with a GPS position and timing data. Figure 15 shows an image captured by Mr. Greenberg using his Canon EOS 5D Mark III.

The Canon EOS 70D is a prosumer grade 20.2 megapixel DSLR camera. It contains a cropped sensor[24] APS-C[25] CMOS image sensor with an extended ISO range of up to 25,600. It has a sophisticated autofocus system and can accept a wide range of lenses designed for the EOS camera family. It can record full HD video up to 30 fps at 1920 x 1080 pixels. Still images can be captured at a rate up to 7 fps.

The GoPro HERO 3+ Black Edition is a compact, lightweight, POV[26]digital camera enclosed in a ruggedized housing that allows the camera to be mounted in a variety of positions using an array of supported accessories. The camera supports 1080 HD[27] as well as other lower quality recording resolutions at higher frame rates. The camera can be set to record still images simultaneously or independently of a video stream at a resolution of up to 12 megapixels. The camera includes a wide angle aspherical f/2.8 glass lens that provides a maximum of 170 degrees viewing angle. The camera supports recording to micro SD[28] cards up to 64 gigabytes in size.

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[22] CMOS – A digital image sensor consisting of an integrated circuit containing an array of pixel sensors.
[23] ISO – An International Organization for Standardization standard for film speed.
[24] Cropped Sensor – A term referring to a digital imaging sensor smaller than a 24 x 36mm film negative standard.
[25] APS-C – Advanced Photo System type-C – an image sensor format equivalent in size to negatives 25.1 x 16.7mm in size.
[26] POV – Point of View Shot – A photography technique that records the character's viewpoint from a singular camera location mounted in a manner that represents the character's field of view.
[27] HD – High Definition – A resolution generally consisting of greater than 480 lines of horizontal resolution.
[28] SD – Secure Digital – a standard for nonvolatile memory card used in portable devices.

Figure 15. An image from Mark Greenberg's Canon EOS 5D Mark III taken post vehicle break up.

3.7. Ken Brown

Provider: **Ken Brown**
Camera System(s): Canon EOS 50D
Optics: Canon 75-300mm IS (50D)
Mounting Equipment: Tripod/Handheld
Tracking Method: Handheld
Location: 35°18'3.45"N, 118° 0'4.25"W

Mr. Brown is a private citizen who was filming the test event on the day of the accident with a Canon 50D and a 75-300mm lens. Mr. Brown was set up in the vicinity of Jawbone Ranger Station, Cantil, CA (Figure 16) using a tripod and a Canon lens at 300mm focal length. Mr Brown captured some photographs prior to release, the release, the firing of the rocket motor, portions of the break up sequence, portions of the inverted spin until impact and some post-accident wreckage photos. Figure 17 shows an image captured by Mr. Brown using his Canon EOS 50D.

The Canon EOS 50D is a prosumer grade 15.1 megapixel DSLR camera. It contains a cropped frame APS-C CMOS image sensor with an extended ISO range of up to 25,600. It has a sophisticated autofocus system and can accept a wide range of lenses designed for the EOS camera family. It cannot record video. Still images can be captured at a rate up to 6.3 frames per second.

Figure 16. Mr. Brown's camera location near the Jawbone Ranger Station (Cantil, CA)

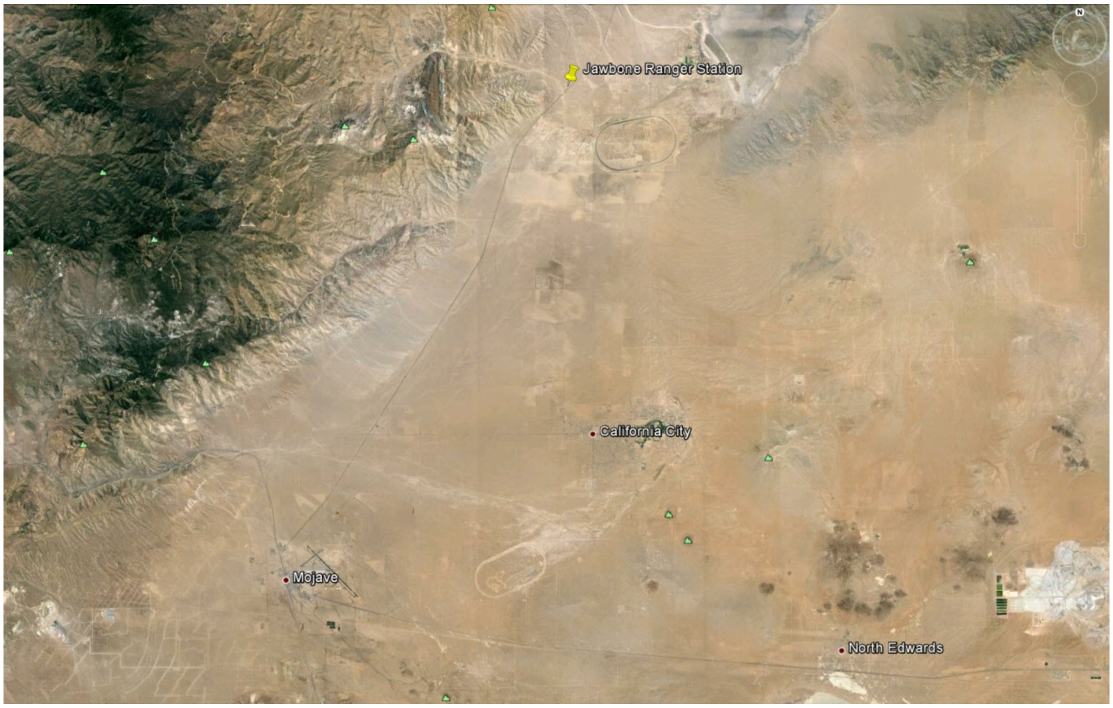
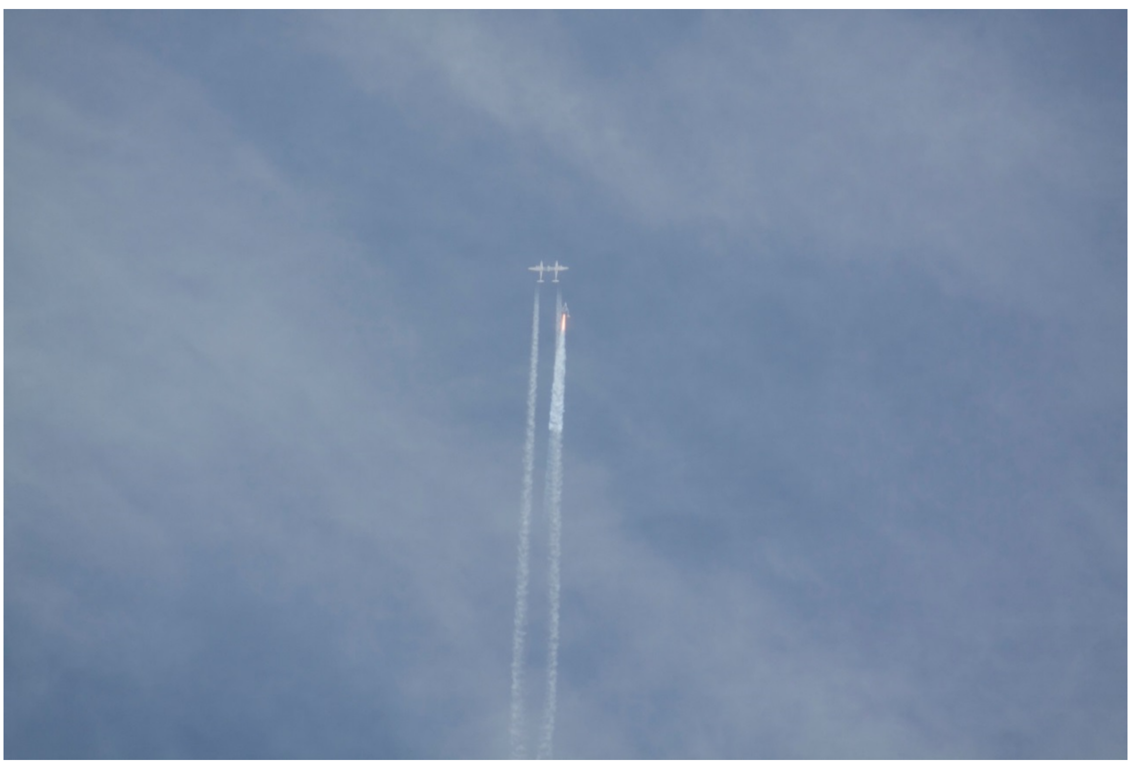


Figure 17. A still image from Mr. Brown's Canon EOS 50D camera.



3.8. Jason DiVenere (Scaled Composites)

Provider:	**Jason DiVenere (Scaled Composites)**
Camera System(s):	**Canon EOS Rebel T2i**
Optics:	**Canon EF 70-200mm f/2.8L USM**
	Canon EF-S 18-55mm f/3.5-5.6
Mounting Equipment:	**Hand Held**
Tracking Method:	**Hand Held**
Location:	**Front Seat – Extra 300 N24GA – Post Accident**

Mr. DiVenere is an engineer and photographer for Scaled Composites who was working during the test event. Mr. DiVenere documented the various wreckage locations post-accident from the Extra 300 chase aircraft. Mr. DiVenere used a Canon T2i to capture the wreckage locations from an aerial vantage point with the goal of capturing the wreckage spread to aid in wreckage identification and search and recovery (Figure 18).

The Canon EOS T2i is a consumer grade 17.9 megapixel DSLR camera. It contains a cropped frame APS-C CMOS image sensor with an extended ISO range of up to 12,800. It has a 9 point autofocus system and can accept a wide range of lenses using the EF and EF-S lens mount. It can record video at 1920 x 1080 resolution at a frame rate of 30 fps. Still images can be captured at a rate up to 3.7 fps.

Figure 18: A cropped aerial photo of a wreckage site taken post-accident by Mr. DiVenere.

4. AREAS OF FURTHER INVESTIGATION

Each video recording and still image was evaluated to determine its potential value to the investigation. For each video file containing imagery of SS2, JPEG[29] or BMP[30] format stills were exported using a nonlinear video editing program. After a review of the images and video, it was determined that the following camera recordings would be evaluated further in this report to assist in determining the breakup sequence of the vehicle.

- MARS Scientific Red Epic Mysterium-X
- MARS Scientific VIS / NIR Infrared
- MARS Scientific SWIR Infrared
- NASA Dryden Test Range/Edwards AFB LRO KTM
- WK2 Pylon camera
- SS2 Boom camera
- Brandon Wood Panasonic GH4
- Mark Greenberg GoPro HERO 3+ Black
- Mark Greenberg Canon EOS 5D MK III

4. Time Correlation and Alignment

The validity of each camera system's timestamp was examined and validated where possible. The following sections summarize time correlation activities for each camera system and associated operator.

According to the Electronic Devices and Flight Data Factual Report, the timing information from the SODAS flight data system was determined to be the authoritative time for this investigation. The Electronic Devices and Flight Data Factual Report indicated that SS2 released from WK2 at 17:07:19.100 UTC. This time was used as a reference to examine the validity of timing information found throughout this report.

Additionally, the IRIG timestamp from the Edwards LRO KTM mounted camera was assumed to be the most accurate source of video time reference for this investigation. The IRIG timing information from this camera system was used throughout to validate and correct time correlation.

4.1. MARS Scientific RED Epic Mysterium-X

The RED Epic camera utilizes a SMPTE-12[31] time code and can be operated at a wide range of frame rates and resolutions. During the Octoober 31st event, the camera

[29] JPEG – Joint Photographic Experts Group. An image file type. A standard method of compression for photographic images and other digital graphics.
[30] BMP – Bitmap Image File – A raster graphics image file that can be stored uncompressed.
[31] SMPTE-12 – Society of Motion Pictures and Television Engineers cooperating standard for timestamping frames of video or film.

was operated at 23.976 fps (24 fps) and was time synchronized to a GPS based NTP server for time correlation. The RED Epic's time stamping information was discarded and the video was aligned with the WK2 and SS2 separation time of 17:07:19.100 UTC using the parameter "SS2_RMC_Carrier_Separated" from the Electronic Recording Devices and Flight Data Factual Report.

The original video file was imported into non-linear video editing software. The moment of separation was best identified and marked as frame 0. Individual frames were then exported from the video at the original record rate of 23.976 fps. Using the time of 17:07:19.100 UTC for vehicle separation, a time stamp was applied to each exported frame. The uncertainty of the location of the exact moment of pylon release was assumed to be within three frames, therefore the timestamp accuracy from this camera system was determined to be three frames or approximately +/- 0.125 seconds.

4.2. MARS Scientific VIS / NIR and SWIR

For time stamping, MARS Scientific utilizes an ESE ES-185U[32] to generate an NTP server for all of the associated camera systems. The ES-185U receives time and date information from up to twelve GPS satellites simultaneously and supplies the data to the user for a variety of timing related uses. MARS utilizes time synching software to crosscheck all the cameras and computers at 60 second intervals to ensure that the GPS timing information provided to each camera's computer from the ESE ES-185U is correlated to each other. The timing information provided by the ESE ES-185U appeared to be in agreement with other data sources, particularly the timestamp information from the Edwards LRO IRIG time, and was assumed to be accurate.

4.3. Brandon Wood Panasonic DMC-GH4

A time correlation video provided by Mr. Wood, P1820010.MOV, captured a brief screen recording of www.time.gov taken on 11/6/2014 at 05:28:22 A.M. EXIF[33] metadata revealed the camera's timestamp was set to 11/5/2014 at 07:27:16 A.M. It was noted that the camera was set to Pacific Daylight Time at the time of the accident, and that on Sun, November 2,2014 2:00 AM Pacific Standard Time took effect. This indicated that Mr. Brown's time offset to internet time was (+) 1 day and (-) 1 hour, 58 minutes and 54 seconds for the Panasonic GH4.

Since www.time.gov does not display fractions of a second, additional time correlation work was performed to correct the time correlation to accommodate a measurement of fractions of a second. Recording P1820010.MOV, was made at 29.97 fps and was two seconds in duration. 21 frames into the recording, a change between 05:28:22 and 05:28:23 PST occured. Adding 0.7 seconds (21/29.97) yielded 05:28:22.300 PST, the time at which the recording began. The new corresponding offset became (+) 1 day and (-) 1 hour, 58 minutes and 53.700 seconds. Lastly, the offset between PDT and UTC was determined to be UTC -7 hours.

[32] ESE ES-185U – A piece of time generating equipment.

[33] EXIF – Exchangeable image file format – A standard that specifies the formats for images, sound and ancillary tags used by digital imaging devices.

The original video recording of the accident event, file P1800092.MOV, EXIF data shows it was created on October 30, 2014 at 11:05:12 A.M. Applying the offset, the time the recording began was October 31, 2014 09:06:18.300 PDT, 17:06:18.300 UTC.

This offset was applied to the timing information found in each exported still from the accident recording provided by Mr. Wood and the resulting timestamps were evaluated. An examination of the resultant timestamp from the time correlation activity revealed that timestamping information was roughly 2 seconds ahead the Edwards IRIG time source. The timing solution generated using a comparison to time.gov was rejected and the individual frames used in this report were manually time aligned to the moment of cabin depressurization. The Electronic Devices and Flight Data Factual Report defines this time as 17:07:33.020 UTC, at which time the signal for cabin pressure drops out. Using this timing solution generated timestamps for the Wood video that were in agreement with other imagery and data sources used in throughout the investigation.

4.4. NASA Dryden Test Range/Edwards AFB LRO KTM

The NASA Dryden Test Range/Edwards AFB LRO KTM mounted camera system utilized an IRIG time stamping system and was assumed to be properly correlated to UTC. No other time correlation was performed. The IRIG time source for this camera was used to validate other time correlation activities throughout this report.

4.5. WK2 Pylon Camera

The provided files contained no timing information. The original video file was imported to a non-linear video editing software. The moment of separation was best identified and marked as frame 0. Individual frames were then exported from the video at the original record rate of 23.976 fps. Using the time of 17:07:19.100 UTC for pylon release, a time stamp was applied to each exported frame. The uncertainty of the location of the exact moment of pylon release was assumed to be within three frames, therefore the timestamping information from this camera system was determined to be three frames or approximately +/- 0.125 seconds.

4.6. SS2 Boom Camera

Timing was established by correlating the IRIG timestamp in the video track's metadata to the recorded images and audio. This timestamp is unique and separate from the displayed IRIG graphic overlay that is present on the original source video. The displayed IRIG graphic overlay present on the original source video is a result of a transmission from the system's ACRA VID-103[34] module and is known to be incorrect by up to 0.9 seconds. For the purpose of this report, the displayed IRIG graphic overlay was rejected and only the video track's metadata IRIG timestamp was attempted to be used as a source of absolute timing information. The displayed IRIG graphic overlay was removed from each image used in this report for clarity and consistency.

[34] ACRA VID-103 – A timecode module in the SODAS instrumentation system.

The timestamp in the metadata showed that the video recording began at 14:34:46.200 on the day of the accident. The timestamp in the metadata was compared to the timing information used in the Electronic Devices and Flight Data Factual Report. The release of SS2 from WK2 was identified in the boom cam video and the frame was noted. Using the camera's record rate of 29.97 fps, the timing information was extrapolated. It was determined that according to the video file's metadata timestamp, the release occurred at 17:07:03.233. This was not consistent with the timing information provided in the Electronic Devices and Flight Data Factual Report which shows release occurring at 17:07:19.100. Due to this inconsistency, all timing information based on this camera's metadata was discarded and manual time alignment using t17he first indication of SS2's release from WK2 was utilized.

In order to correlate timing to the Telemetry Data Factual Report, the original video file was imported into non-linear video editing software. The moment of separation was best identified and marked as frame 0. Individual frames were then exported from the video at the original record rate of 30 fps. Using the reference time of 17:07:19.100 UTC, a time stamp was then applied to each exported frame. The uncertainty of the location of the exact moment of pylon release was assumed to be within three frames, therefore the timestamping information from this camera system was determined to be three frames or approximately +/- 0.1 seconds.

4.7. <u>Mark Greenberg Canon EOS 5D MK III</u>

Mr. Greenberg indicated that the camera body was sent to Canon for a repair between the time of the accident and when the NTSB contacted him for time correlation information. It could not be determined if the factory repair altered battery power to the camera's internal clock, thus resulting in an uncertainty of any possible time correlation using a true time source.

Image D13A2001.JPG showed the vehicle shortly after the rocket motor was fired. D13A2001.JPG's EXIF data indicated the image was taken on the accident day at 13:09:31. Telemetry and compact flash card data from SS2 showed the rocket motor was fired at 17:07:21.580 UTC. Comparing the two times, 3 hours, 57 minutes and 50.580 seconds was added to Mr. Greenberg's Canon EOS 5D MK III timestamp. Due to uncertainties in the time correlation, timing for images from Mr. Greenberg's Canon EOS 5D Mark III camera was determined to be accurate to within +/- 3 seconds.

4.8. <u>Mark Greenberg GoPro Hero 3+ Black</u>

The file of interest, GOPR2606.mp4, showed evidence of SS2's rocket motor firing occurring approximately 2 minutes and 56 seconds into the recording. Comparing this video elapsed time to the SS2 rocket motor firing time captured by the SODAS flight data system at 17:07:21.580 UTC, Mr. Greenberg's GoPro was offset appropriately to reflect the proper time during selected screenshots included in this report. Due to approximations made when identifying the moment of rocket motor firing on this particular recording, the uncertainty of the time correlation was about +/- 2 seconds.

4.9. Ken Brown Canon EOS 50D

The first image in the provided image series, IMG_3905.CR2, indicated the photograph was taken on October 31, 2014 at 10:06:03. Mr. Brown provided a screenshot of www.time.gov to the NTSB which indicated the photograph was taken on November 4, 2014 at 16:37:51. EXIF metadata revealed the camera's timestamp was set to the same date at 19:55:02 P.M. This indicated that Mr. Brown's time offset to www.time.gov was (+) 3 hours, 17 minutes and 11 seconds, thus this time was added to each photograph's timestamp. Since www.time.gov does not display fractions of a second, the uncertainty of the time correlation is +/- 1 second.

4.10. Jason DiVenere Canon Rebel T2i

EXIF data revealed the first image in the series was taken on October 31, 2014 at 14:21:26 PDT. This timestamp appeared consistent with Mr. DiVenere's statement regarding when he began capturing images post-accident. The images' timestamps were not further examined or correlated as they did not capture the vehicle break up sequence.

5. Studied Images with Aligned Timestamps and Enhancements

This section contains exported still images from the various recordings reviewed by the video group. The frame number references contained herein correlate to a chosen time zero and have no relation to any metadata found in the recording. The frame numbers are used solely for reference to specific images. Where times are presented, they are correlated to authoritative time for this accident, as explained in section 4.

5.1. MARS Scientific RED Epic Mysterium-X

Figure 19 shows evidence of the torque tube detaching from the vehicle and exiting the cloud of nitrous.

Figure 19.

Figure 20 shows the lighter colored cabin depressurization gas plume beginning to form. The left and right booms are obscured by the main nitrous plume which is more white in color.

Figure 20.

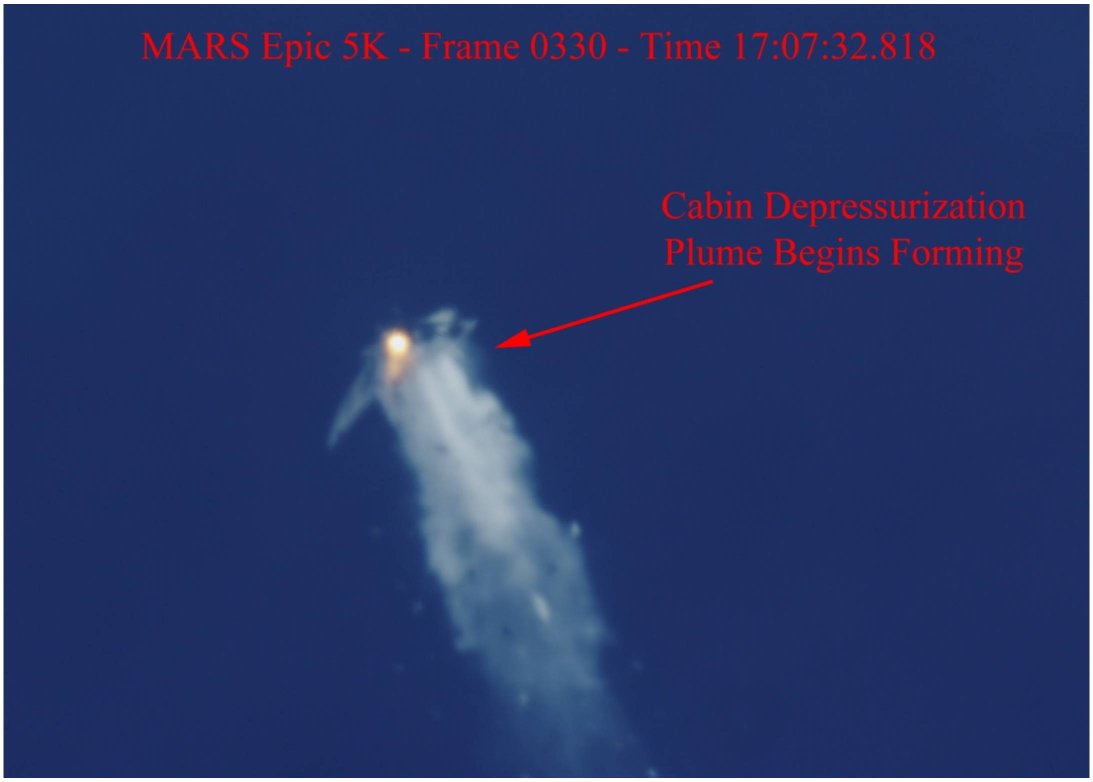


Figure 21 shows additional evidence of the torque tube departing from the vehicle. The two feather actuator horns are visible and indicated in the graphic with two red arrows. The cabin depressurization has become more developed.

Figure 21.

Figure 22 shows evidence of the Case Throat Nozzle Assembly (CTN) separating from the vehicle, a flame still visible near the nozzle end. The torque tube is seen detached from the vehicle and only one feather actuator horn is visible in the camera's frame. The main fuselage is surrounded by a cloud of nitrous.

Figure 22.

5.2. MARS Scientific NIR

This section contains images that were digitally enhanced by either the NTSB or MARS Scientific. MARS digitally enhanced images are denoted in the figure description where applicable.

Figure 23 shows the time of first evidence of debris separating from the vehicle. Unidentified objects obscure the imager's view of the left and right booms.

Figure 23.

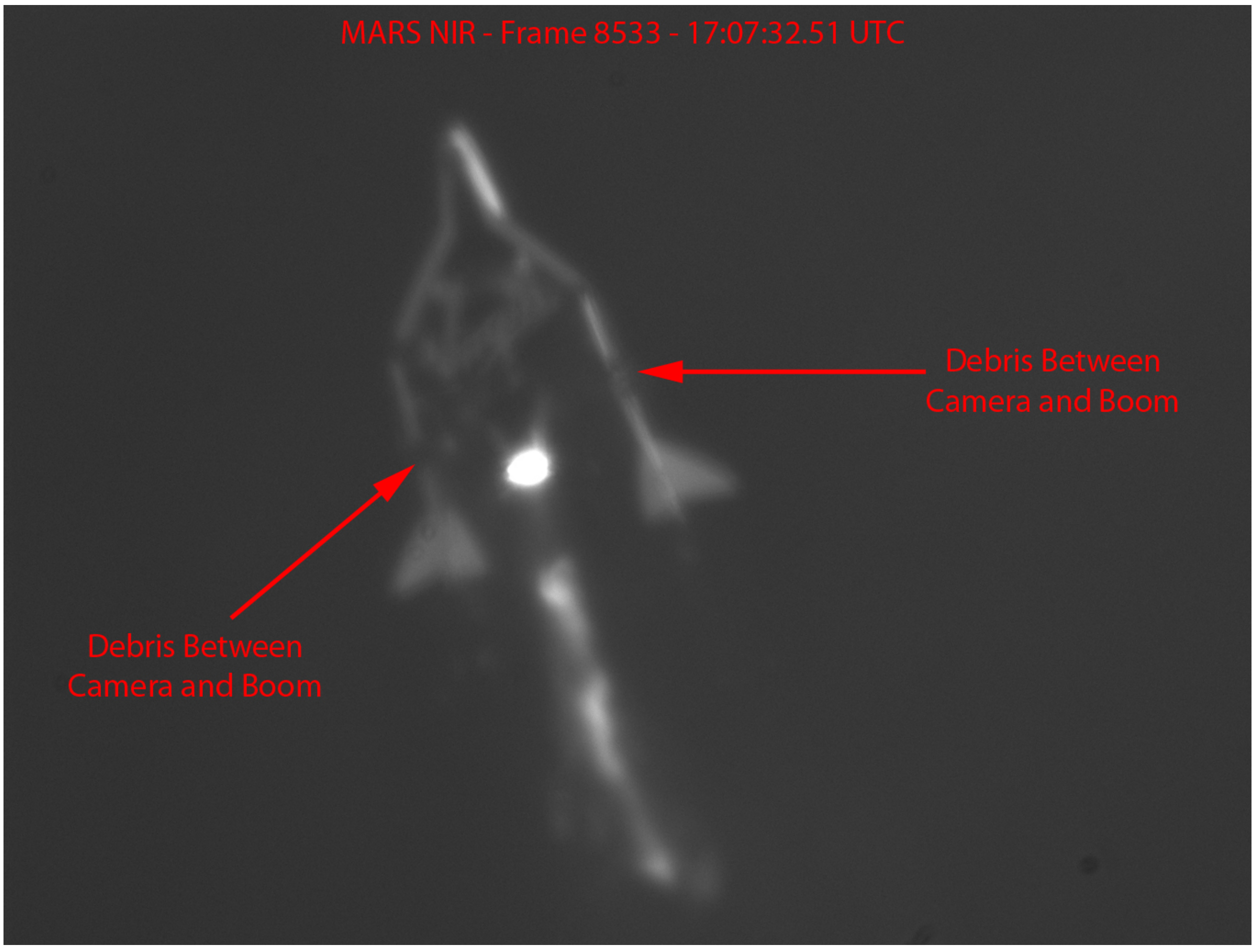


Figure 24 shows additional unidentified debris separating from the vehicle. The likely debris noted in figure 22 propagates from the vehicle, trailing the additional debris.

Figure 24.

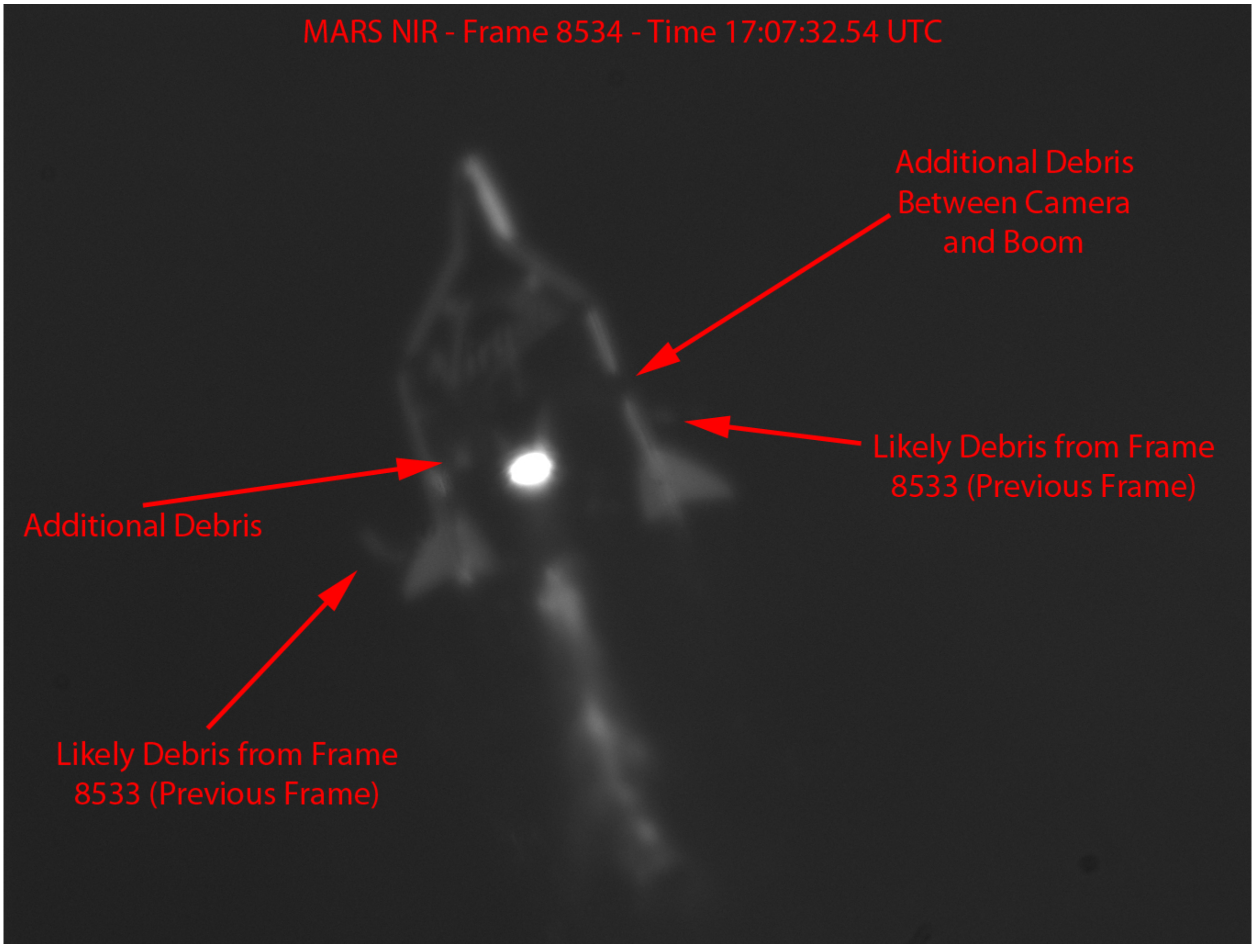


Figure 25 shows additional debris propagation, likely indicated in previous frames. The right boom exhibits a slight inboard rotation toward the center of the vehicle demonstrated by additional surface area of the right vertical stabilizer facing the camera location.

Figure 25.

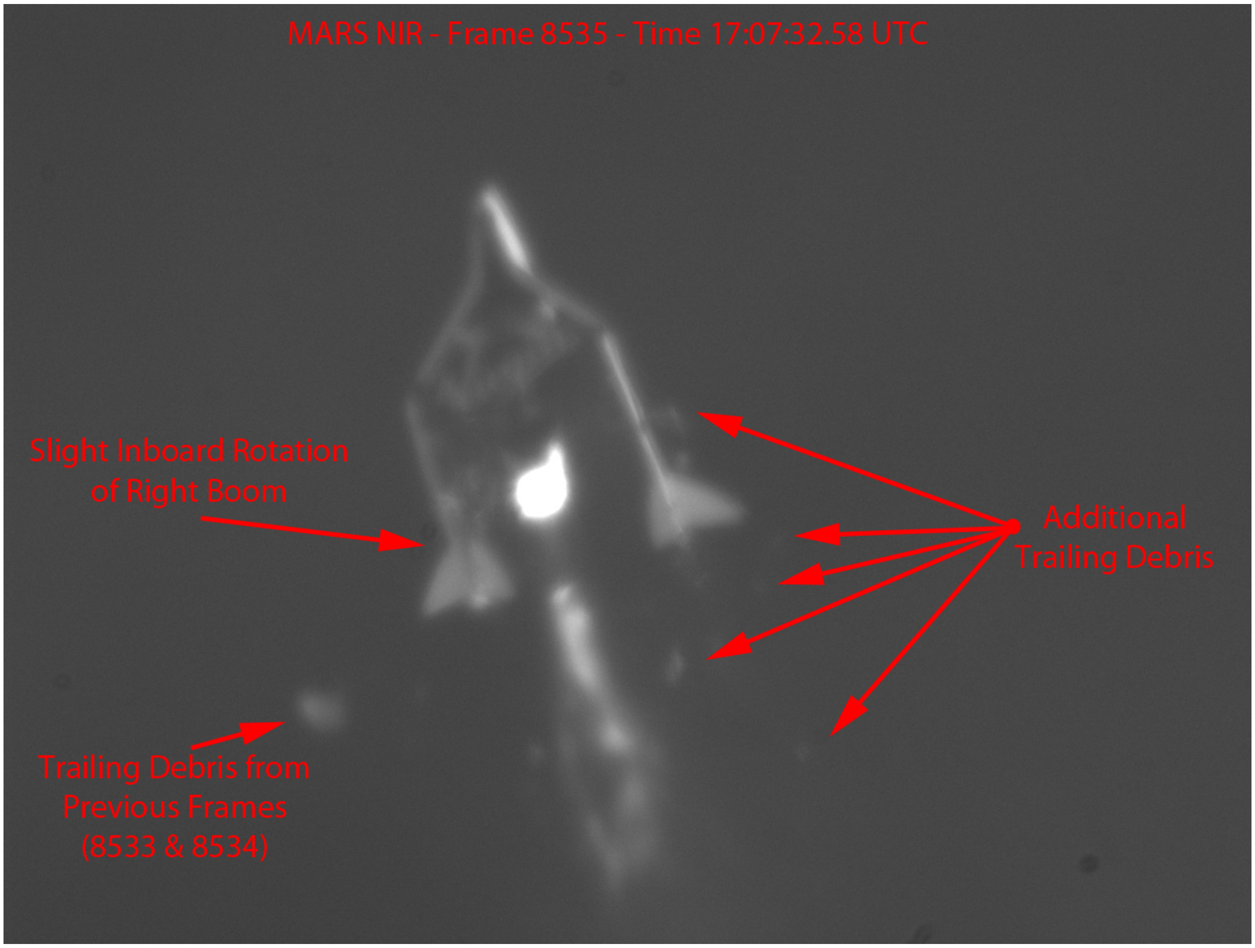


Figure 26 shows a continued inboard rotation of the right boom. Trailing debris also seen propagates from the vehicle.

Figure 26.

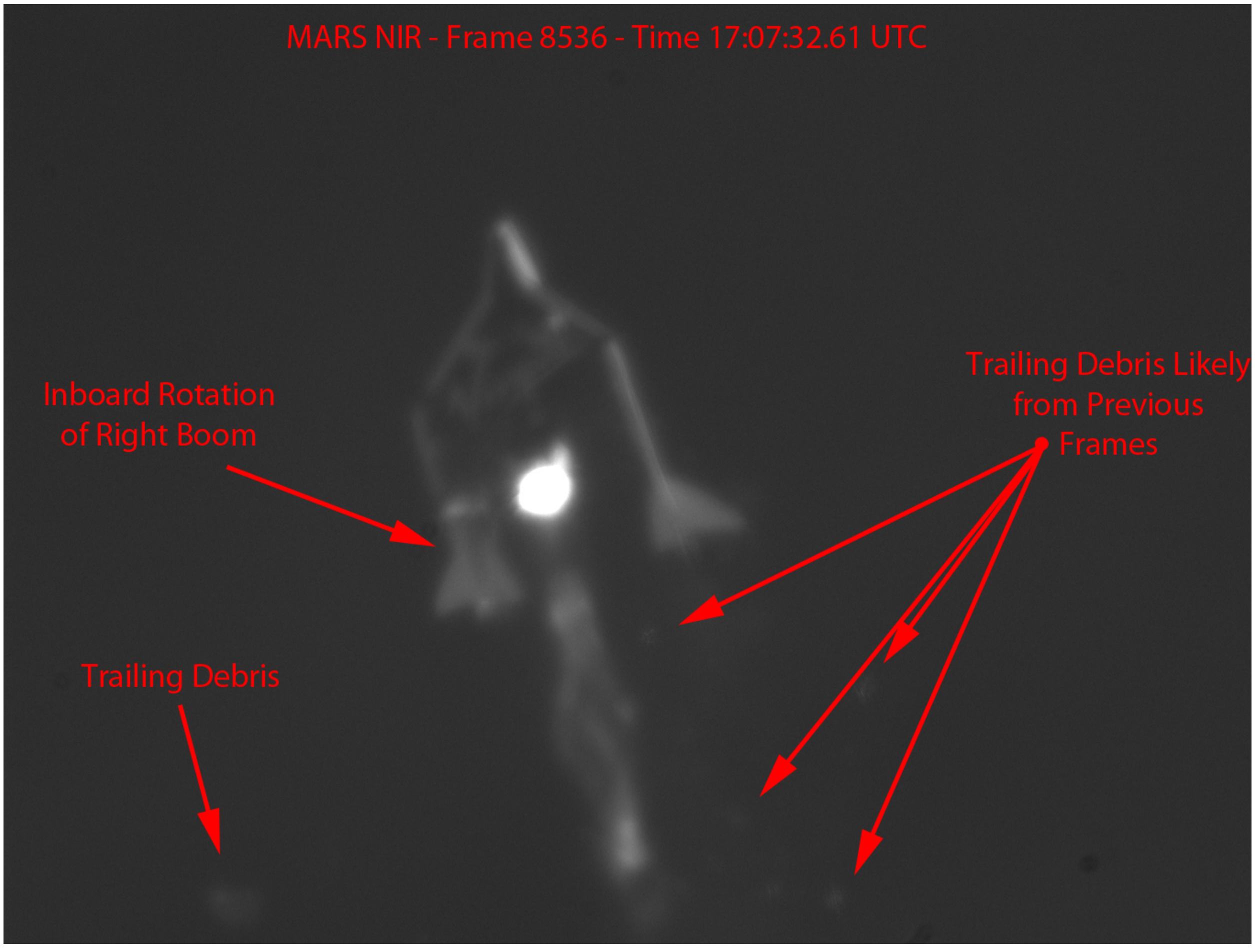


Figure 27 displays a significant inboard rotation of the right boom. The inboard face of the right boom is more apparent to the imager's field of view. Some additional unidentified trailing debris is noted near the bottom of the frame.

Figure 27.

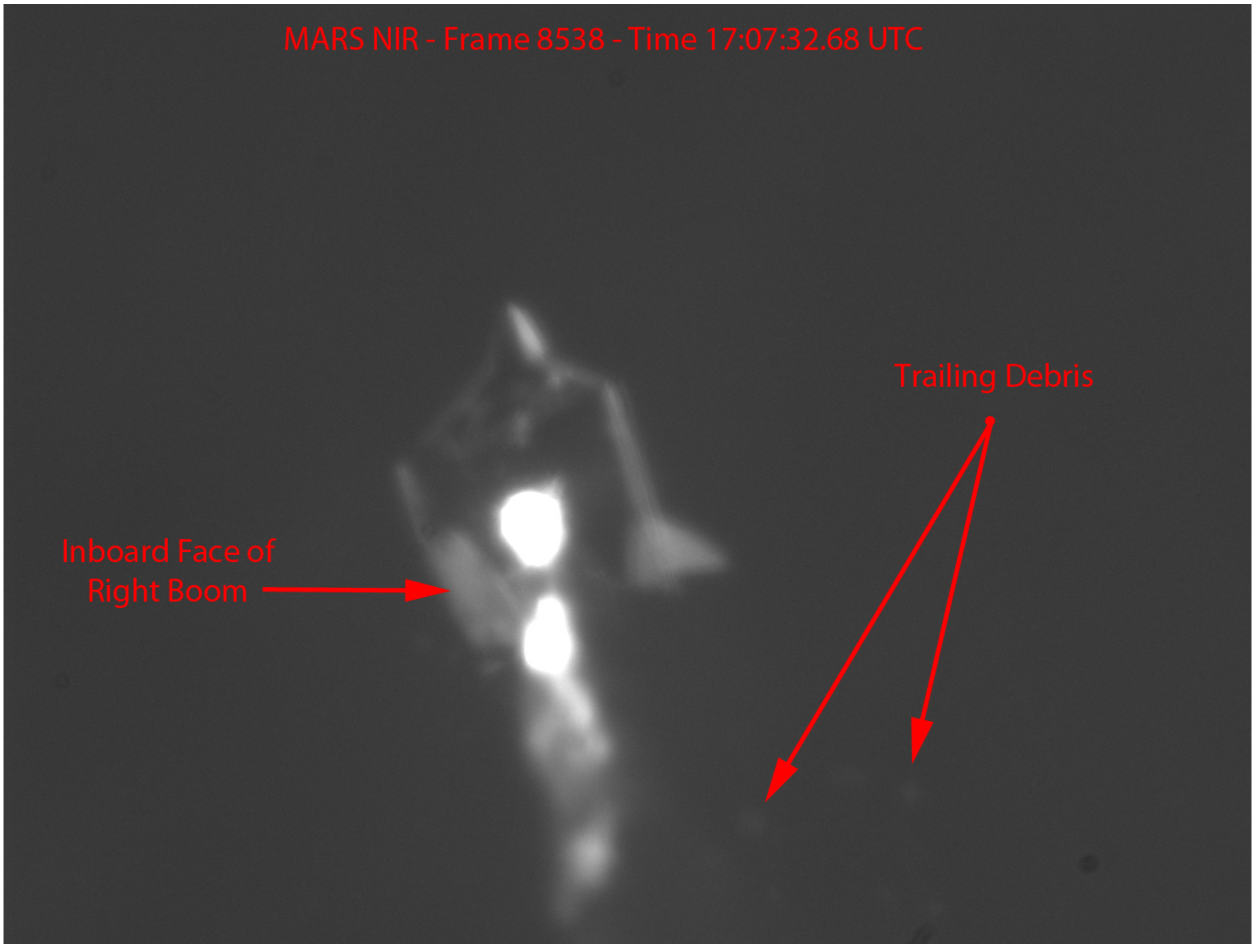
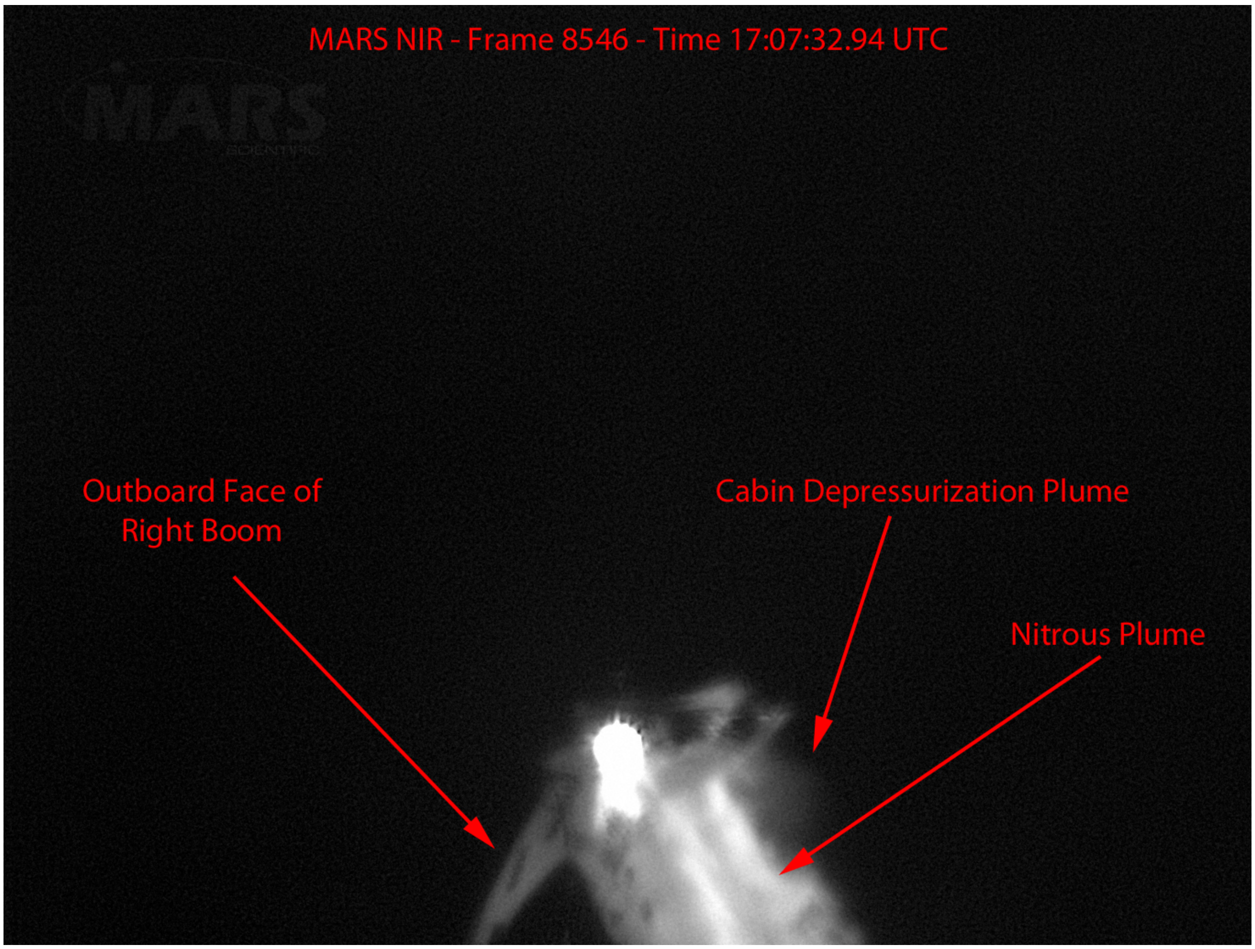


Figure 28 shows the vehicle has continued to pitch up in a manner inconsistent with the expected flight profile. The nitrous plume is still visible trailing the aft portion of the main fuselage structure. The outboard face of the right boom is near the bottom left portion of the frame. A second, smaller and lighter in color, gas plume is visible forming near the main cabin area of the vehicle. The group determined this secondary gas plume was associated with cabin depressurization.

Figure 28. MARS Enhanced.



In Figure 29, the main fuselage of the vehicle was momentarily lost from the imager's frame. The CTN is separated from the vehicle. An area of higher heat energy is near the nozzle end of the CTN.

Figure 29. MARS Enhanced.

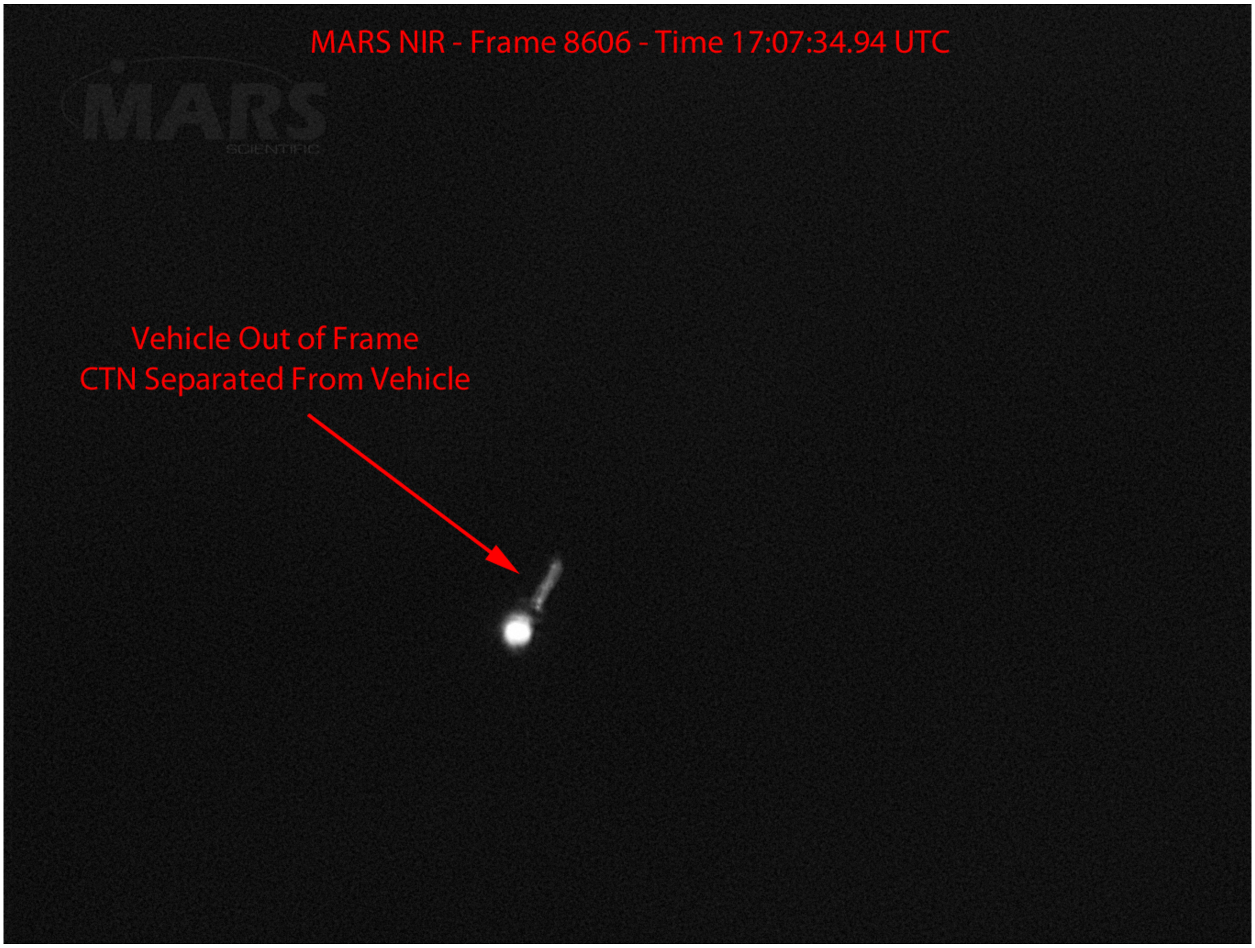


Figure 30 shows the main fuselage of the vehicle back within the imager's frame. The main fuselage is missing the nose section containing the crew cabin. An object consistent with the size and shape of a feather actuator is in the lower left portion of the frame. During the on-scene portion of the investigation, a feather actuator was absent from the wreckage sites. Later, on December 12, 2014, the missing feather actuator was located.

Figure 30.

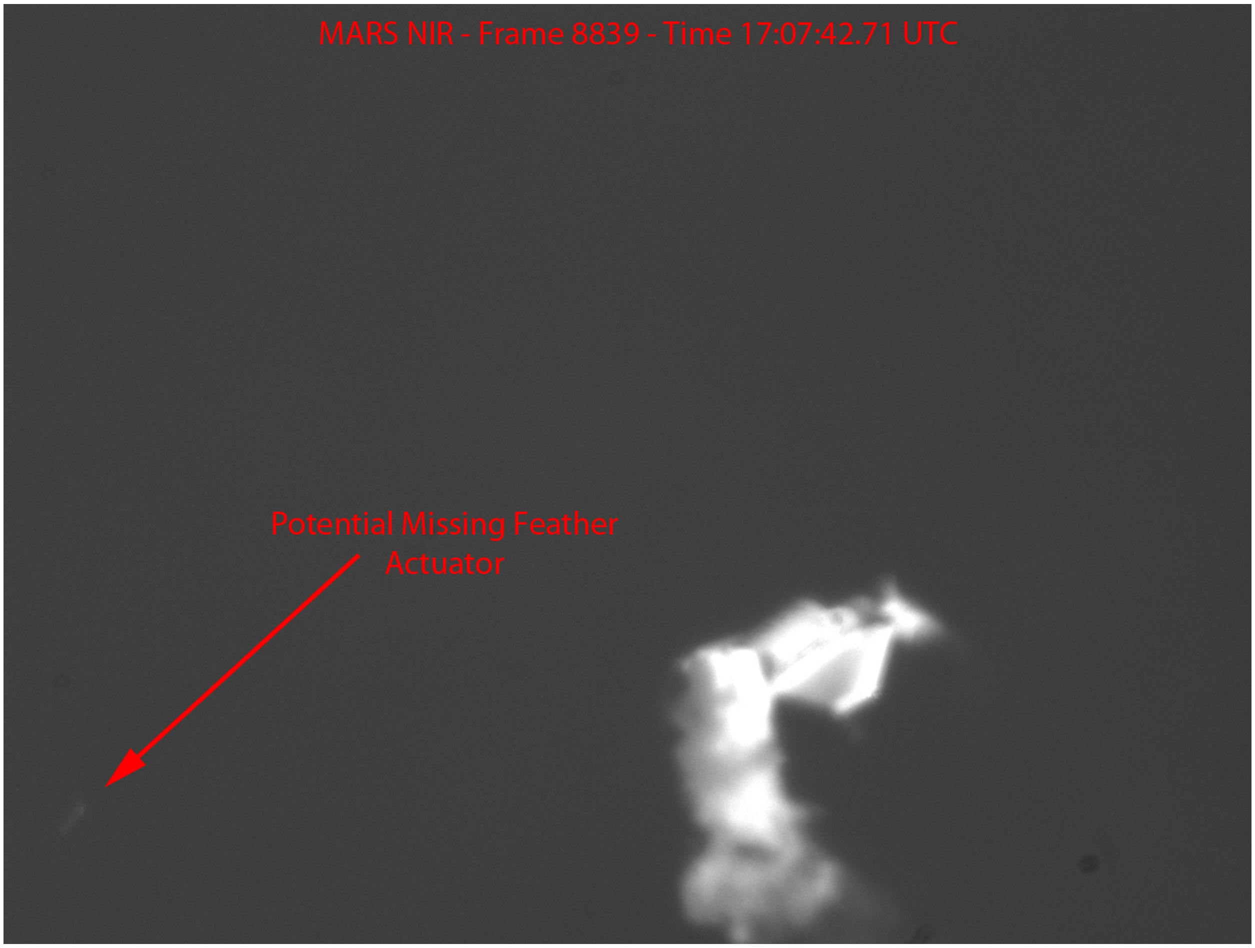


Figure 31 shows the main fuselage section of SpaceShipTwo. Nitrous gas is seen escaping in large volume from the rear of the main fuselage. Some smaller areas of plumed gas are near the forward portion of the main fuselage. The main fuselage is missing the nose section. Wiring and/or flight control cables are trailing the left wingtip. Some additional wiring and/or flight control cables are trailing the right wingtip.

Figure 31. MARS Enhanced.

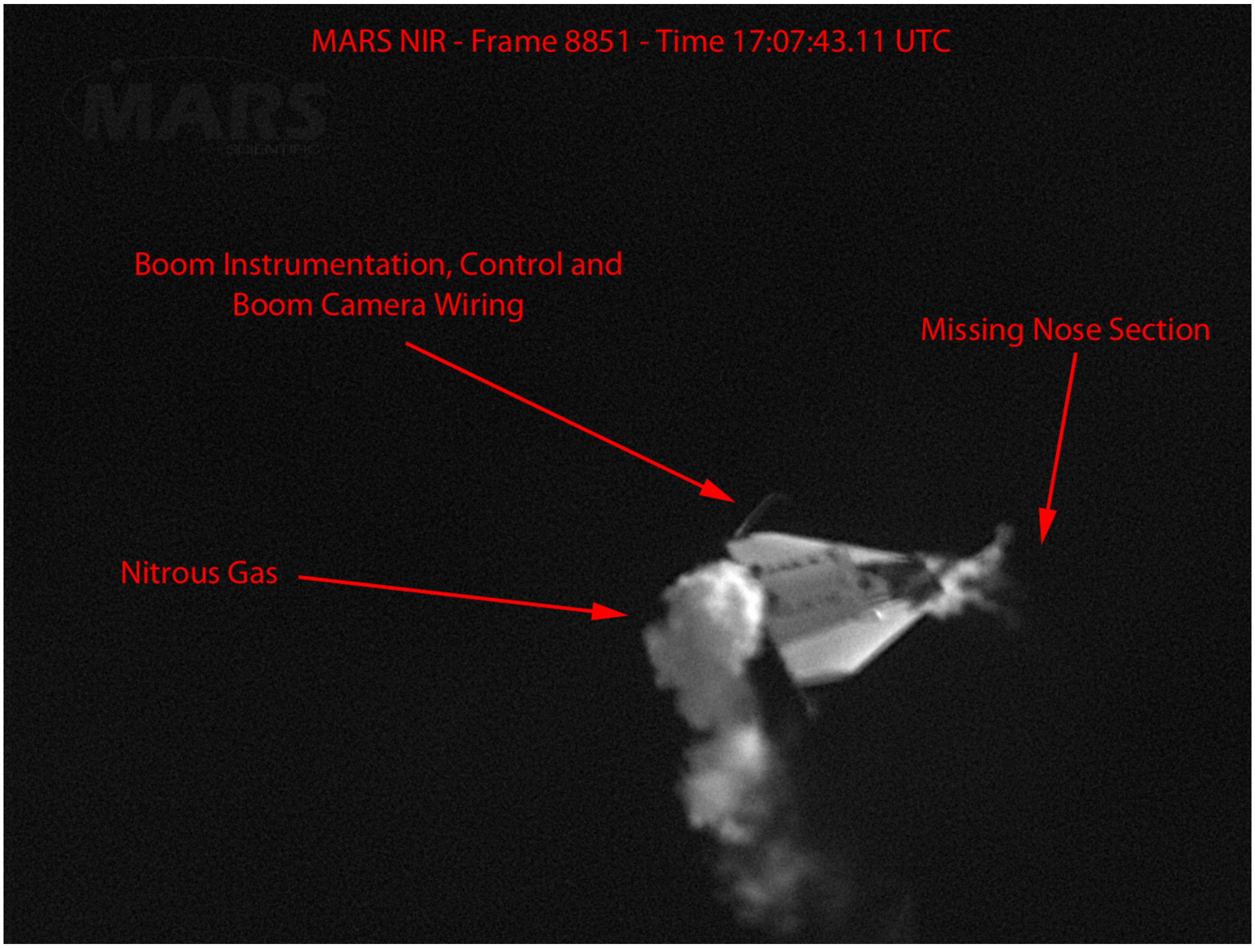
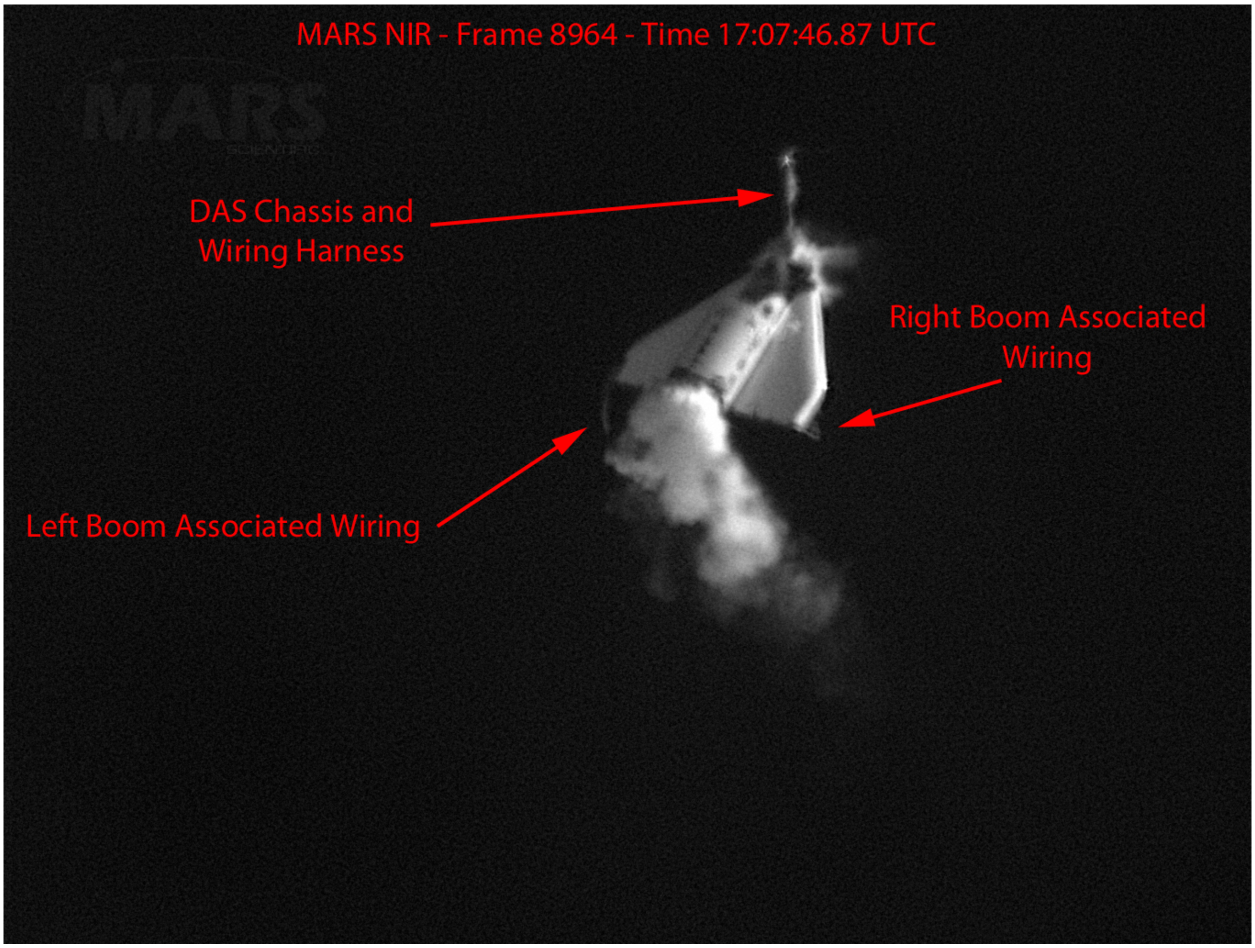


Figure 32 shows wiring and/or cables associated with the left and right booms trailing the main fuselage structure. An object consistent with the SODAS[35] chassis and associated wiring harness is attached to the forward portion of the main fuselage structure. The motion of the recorded image series indicates the vehicle had entered an inverted flat spin and the SODAS chassis was being held to the vehicle by its wiring harness until impact.

Figure 32. MARS Enhanced.



[35] SODAS - Strap On Data Acquisition System – "DAS Chassis" – The onboard instrumentation system for SS2.

5.3. MARS Scientific SWIR

The figures contained in this section were digitally enhanced by MARS Scientific.

Figure 33 shows the first identifiable moment of debris separation from the right side of the vehicle.

Figure 33. MARS Enhanced.

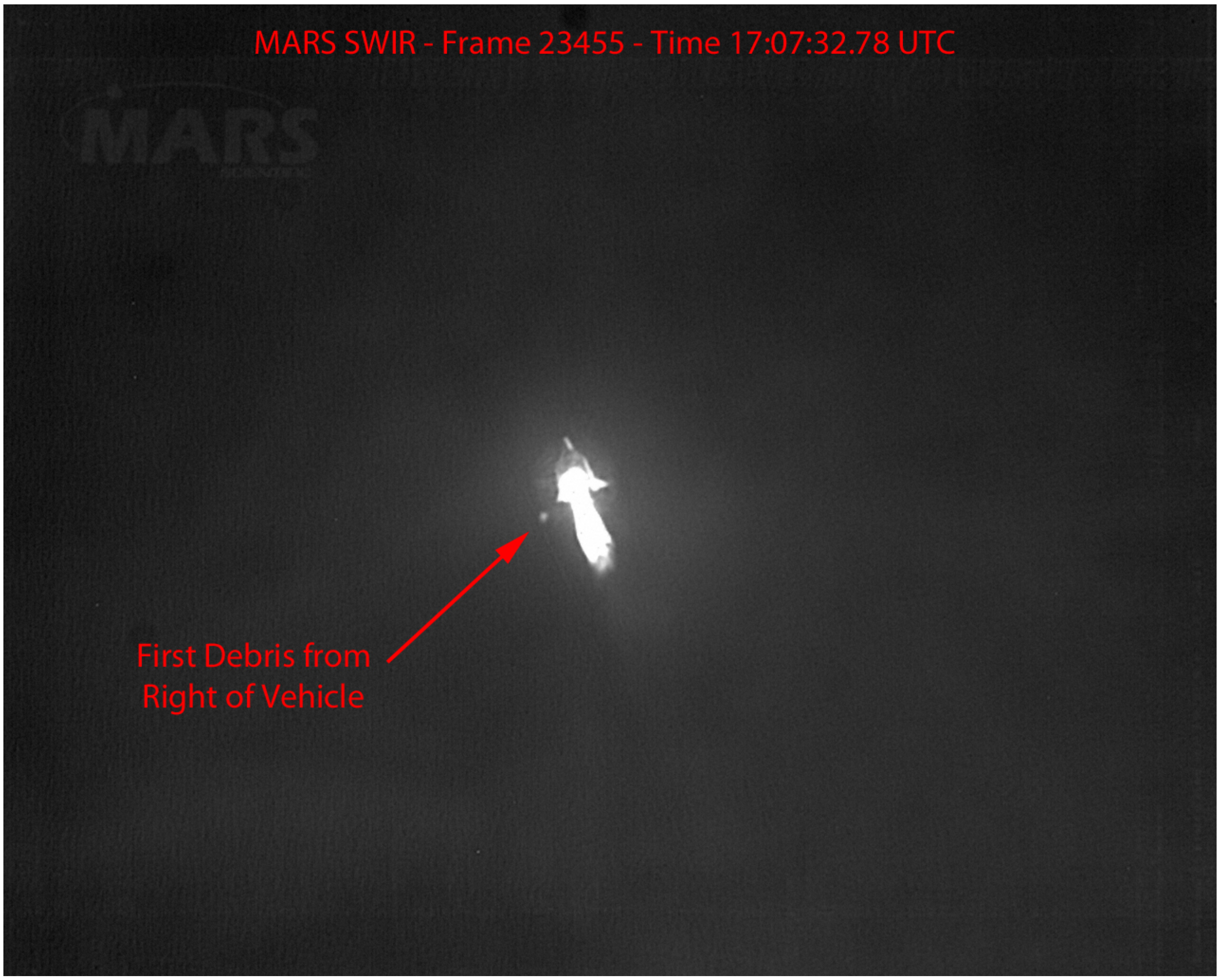


Figure 34 shows unidentified debris from the right side of the vehicle propagating from the previous frame. Additionally, the first evidence of unidentified debris from the left side of the vehicle is visible.

Figure 34. MARS Enhanced.

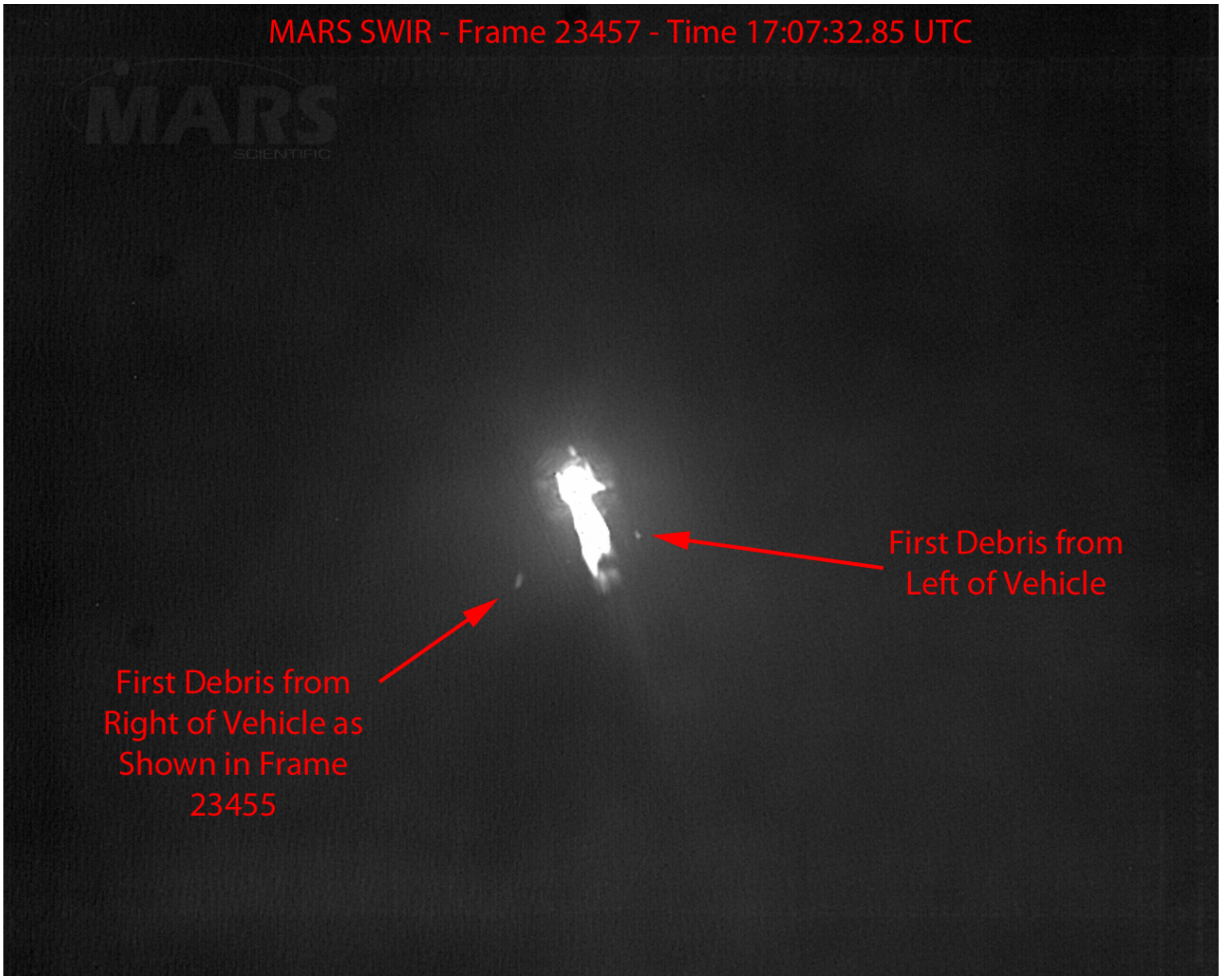


Figure 35 shows the moment just after separation of the left and right booms from the vehicle.

Figure 35. MARS Enhanced.

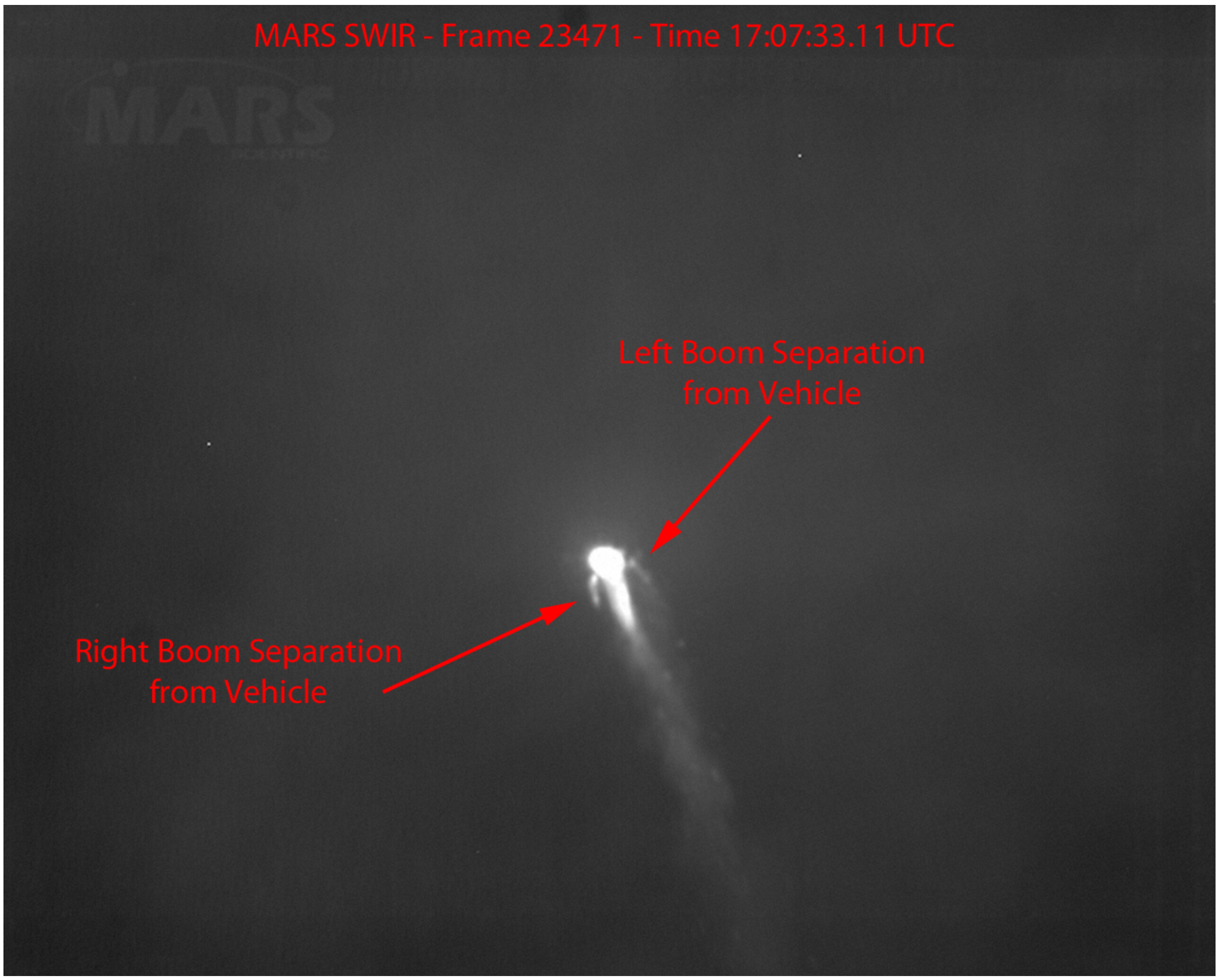


Figure 36 shows separation of the CTN from the vehicle. An area of heat energy facing the imager implies the nozzle is facing toward the MARS ground station.

Figure 36. MARS Enhanced.

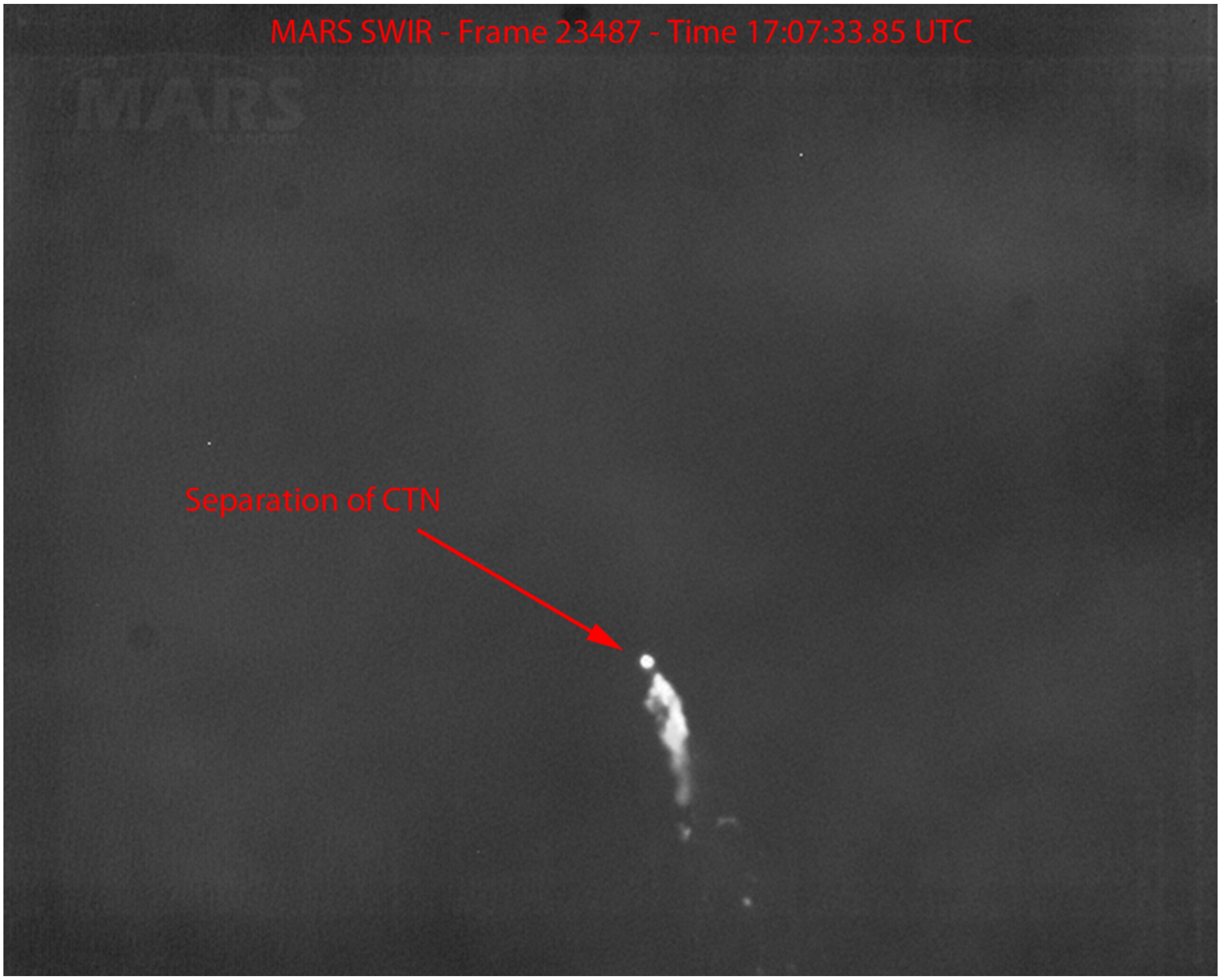


Figure 37 shows the CTN has become further removed from the main fuselage area. An object consistent with the torque tube and attached feather actuator horns is in the lower portion of the frame.

Figure 37. MARS Enhanced.

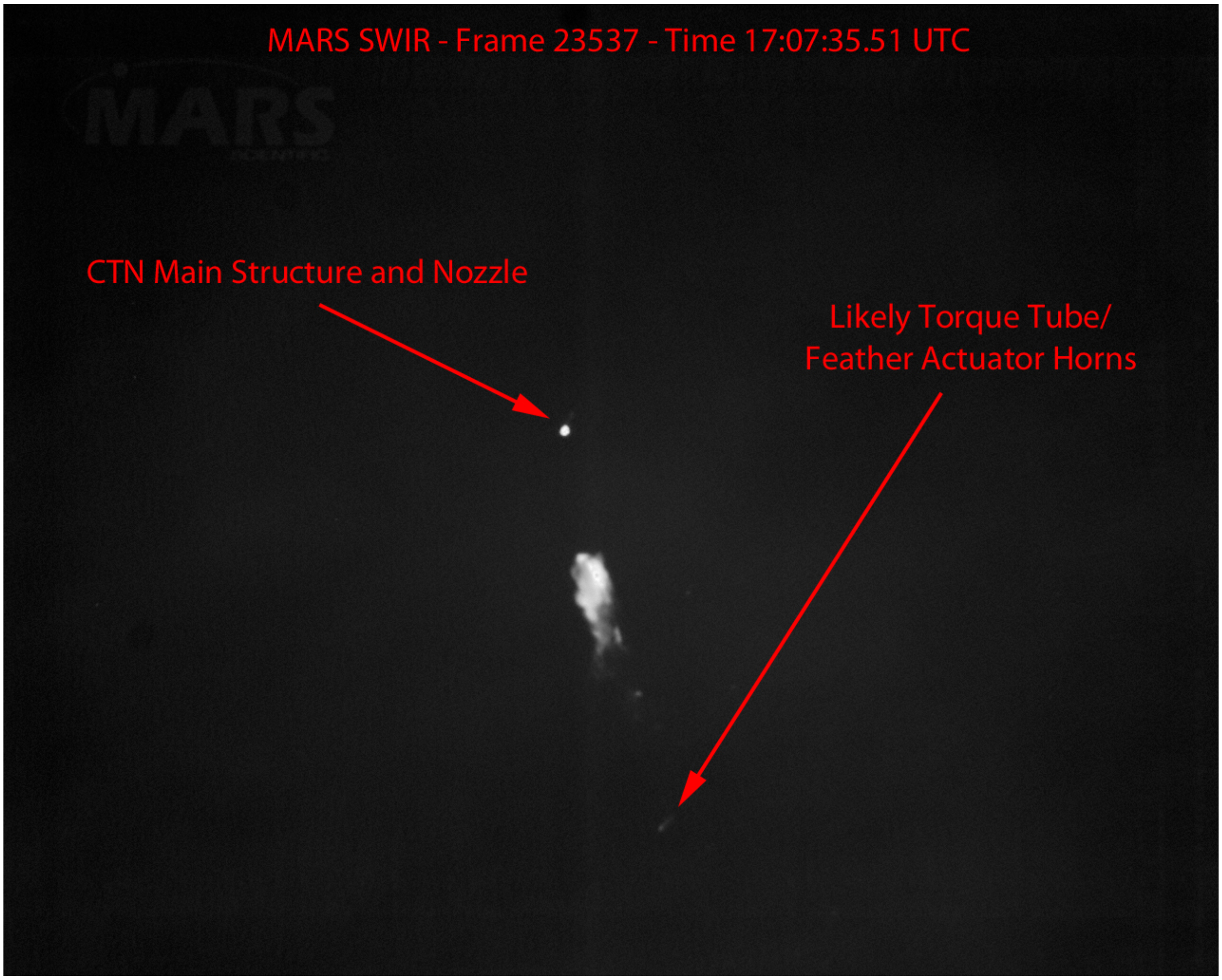
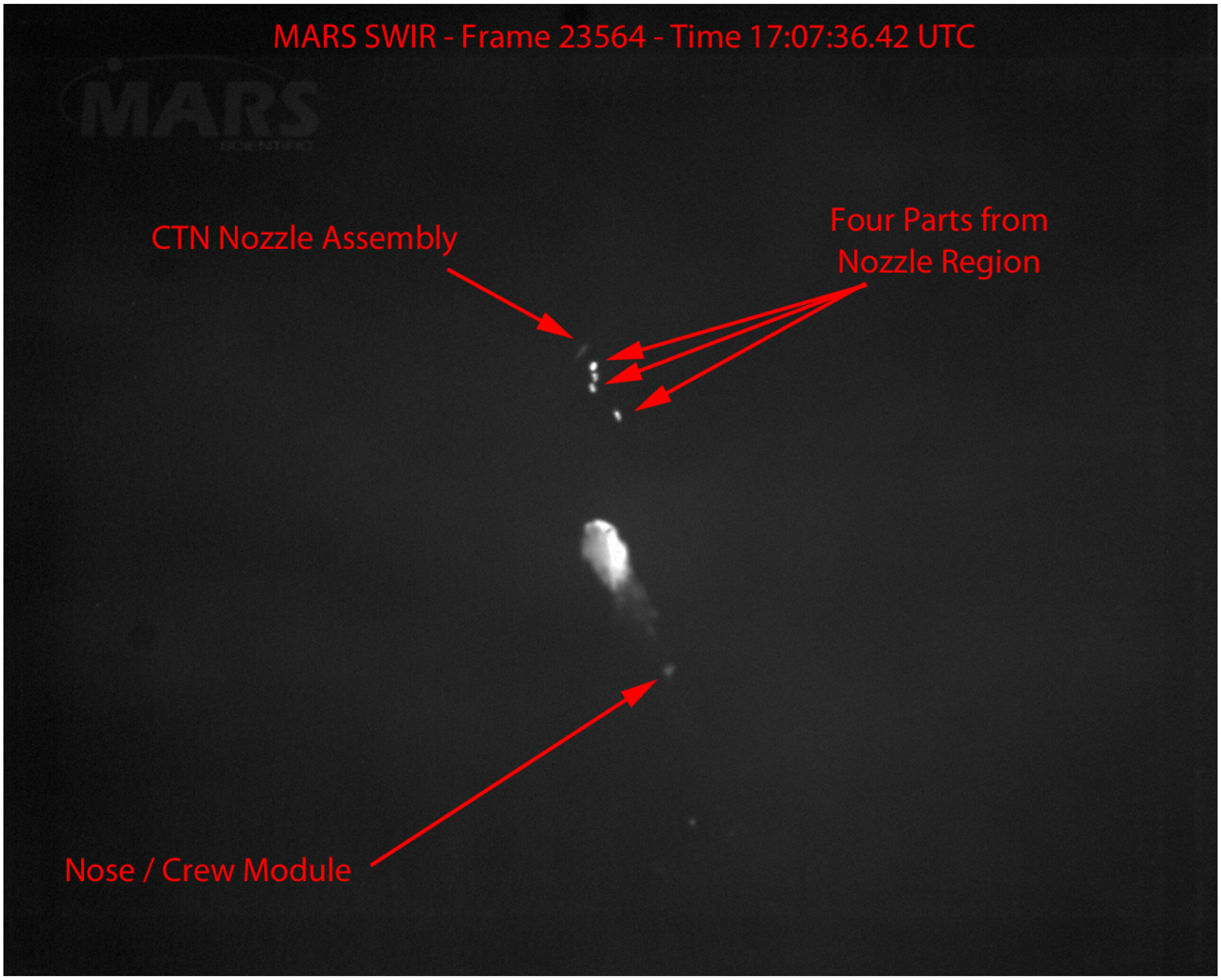


Figure 38 shows the CTN assembly has shed four identifiable parts containing a higher heat energy. The nose section containing the crew module is separated from the main fuselage structure.

Figure 38. MARS Enhanced.



5.4. Brandon Wood Panasonic DMC-GH4

Figure 39 shows the first visible evidence of the feather opening. The feather tusk region is clearly disjointed from the main wing area on the left side of the vehicle.

Figure 39.

Figure 40 shows evidence of unidentified debris between the camera and the left and right booms. Additionally, the feather tusks are further displaced from the main wing.

Figure 40.

Figure 41 shows three pieces of unidentified debris have separated from the vehicle and have come between the left and right booms and the camera.

Figure 41.

Figure 42 shows additional trailing debris propagating in the flight path of the vehicle. The right boom exhibits an inboard rotation toward the centerline of the vehicle.

Figure 42.

Figure 43 shows the rocket motor nozzle oriented more directly toward the camera's lens indicating the vehicle is pitched up in an unusual manner. Additional unknown debris is trailing in the vehicle's flightpath.

Figure 43.

Figure 44 shows the left boom has begun to rotate inboard toward the vehicle. The right boom is obscured behind the main fuselage.

Figure 44.

Figure 45 shows a nitrous plume has become visible. The leading edge of the right feather tusk is on the right side of the vehicle. The left boom is still attached to the main fuselage structure. Additional unidentified debris is trailing the vehicle behind the vehicle's flightpath.

Figure 45.

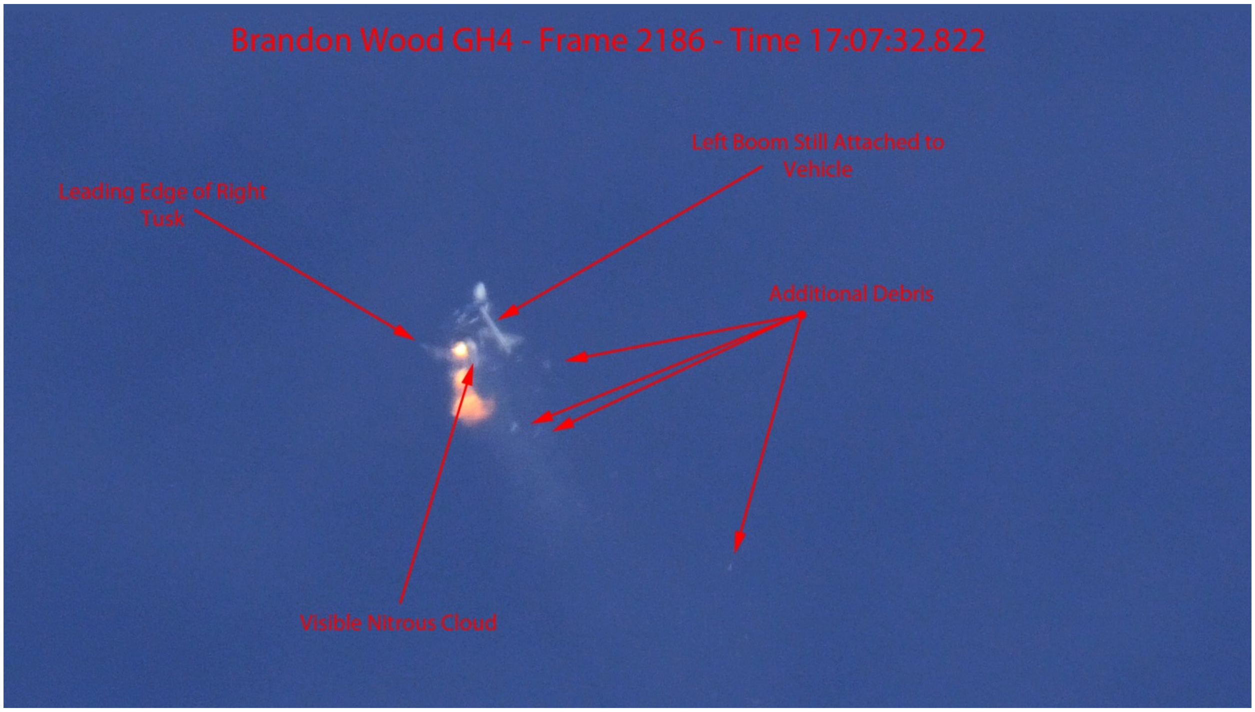


Figure 46 shows a distinct nitrous plume. The leading edge of the right feather tusk is on the right side of the main fuselage. The left boom appears to still be attached to the vehicle.

Figure 46.

Figure 47 shows a secondary gas plume in the area near the main cabin, a result of a compromise in the cabin structure and indicative of cabin depressurization. The main nitrous plume has continued to grow larger in size. Additional unidentified debris is trailing in the vehicle's flightpath.

Figure 47.

Figure 48 shows the first recorded images from the Wood camera exhibiting left and right boom separation. The main fuselage of the vehicle is mostly out of the camera's frame.

Figure 48.

Figure 49 shows separation of the CTN from the main fuselage area. The nose section containing the crew module is clearly separated from the fuselage. The outboard right boom is separated from the vehicle with the outboard face toward the camera and trailing in the flightpath. The left boom is rotated inverted. The outboard portion of the left boom is with the left horizontal stabilizer attached.

Figure 49.

Figure 50 shows the nose section containing the crew module separated from the vehicle. Flight control and/or systems cables are trailing the nose section's structure. The left boom is containing the left horizontal stabilizer and missing the left mega strake. The right boom is partially out of the camera's frame.

Figure 50.

Figure 51 shows the main fuselage enveloped in a plume of nitrous. The nose and crew module is still in the camera's frame and separated from the vehicle. The torque tube is behind the main fuselage area containing the two feather actuator horns.

Figure 51.

Figure 52 shows the fuselage inverted and in a flat spin. The SODAS chassis is attached to the main fuselage structure affixed by the associated wiring harness. The nose section is trailing the aircraft's flightpath. The nose section shows an upper right nose panel section is absent from the nose structure. Three crew windows are visible.

Figure 52.

5.5. Edwards AFB Long Range Optics (LRO)

Figure 53 shows the first visible evidence of nitrous venting.

Figure 53.

Figure 54 shows a secondary gas plume forming near the forward part of the main fuselage. This gas plume is likely associated with cabin depressurization.

Figure 54.

Figure 55 shows the nose section still attached to the main fuselage. A small region of dark pixels located on the upper part of the fuselage indicates a compromise in the fuselage structure. By this moment, the booms are separated from the vehicle.

Figure 55.

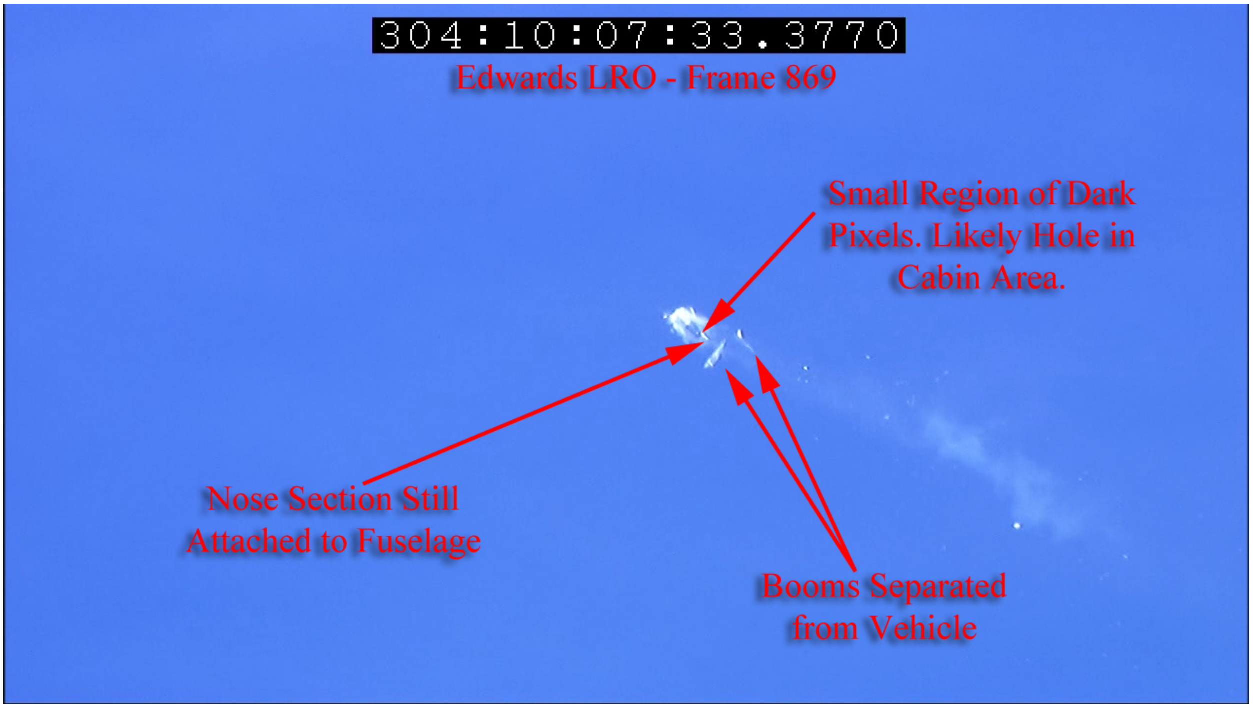


Figure 56 shows the CTN separated from the vehicle. The nose section is separating from the vehicle's main fuselage. The left and right booms are separated from the vehicle and further displaced from the image in figure 53.

Figure 56.

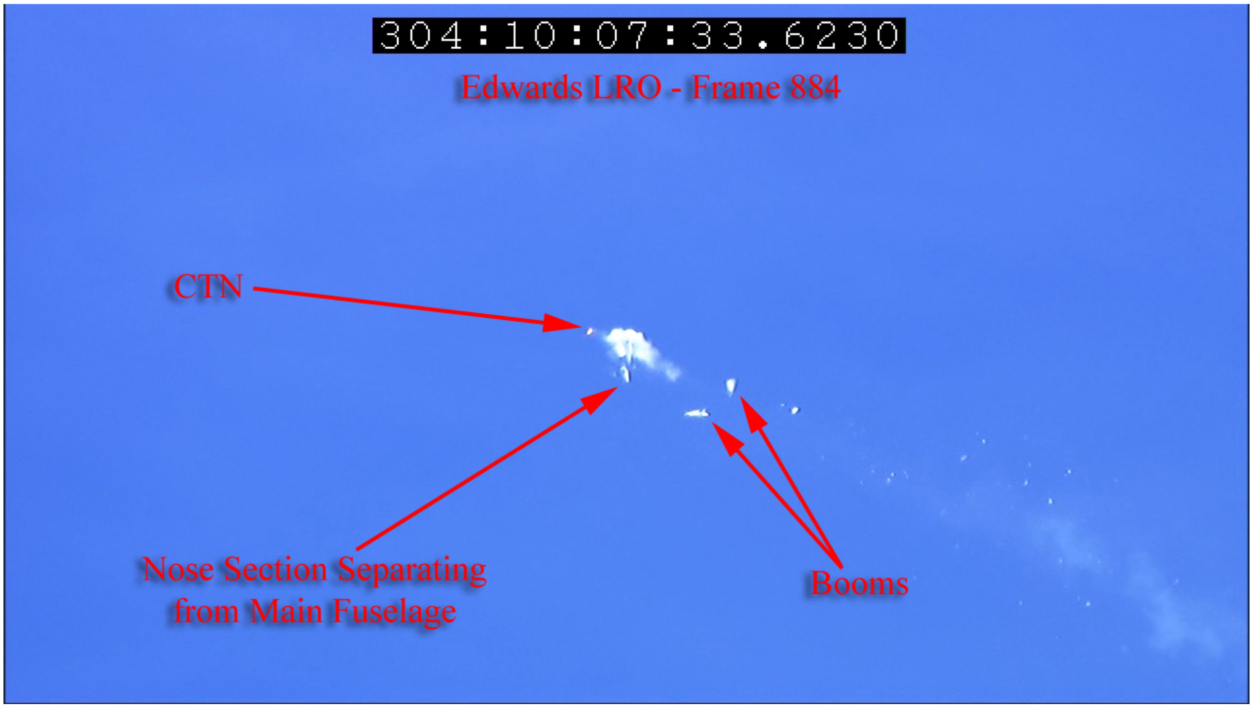


Figure 57 shows the vehicle broken into multiple large parts. The CTN is separated above the main fuselage. The nose section has completely separated from the main fuselage. The left and right booms are trailing the vehicle along the flightpath. Additional debris is behind the vehicle.

Figure 57.

5.6. WK2 Pylon Camera

Figure 58 shows the first evidence of debris.

Figure 58.

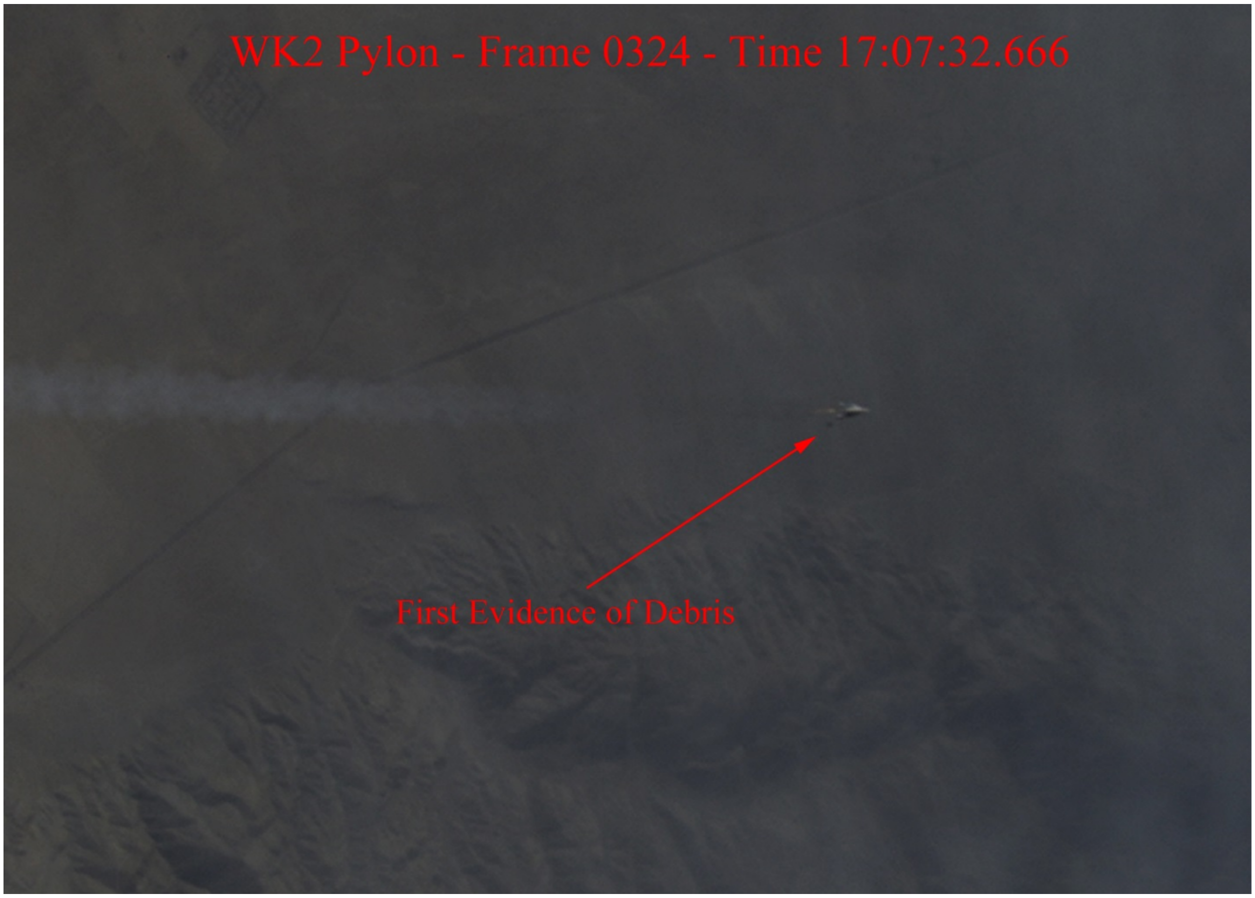


Figure 59 shows medium size debris trailing the vehicle. The left and right booms are separated from the vehicle. The rocket motor is rotated backwards to the direction of flight.

Figure 59.

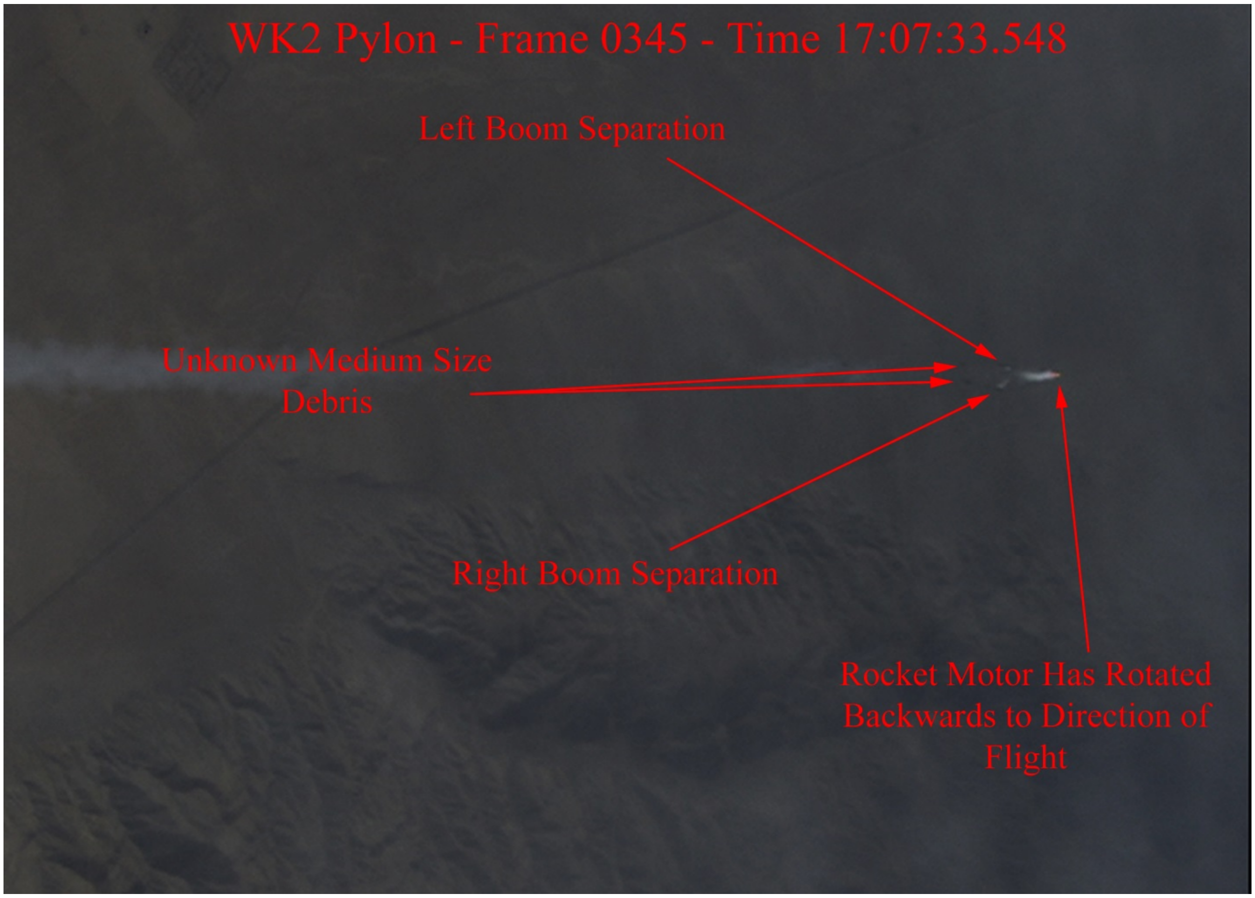
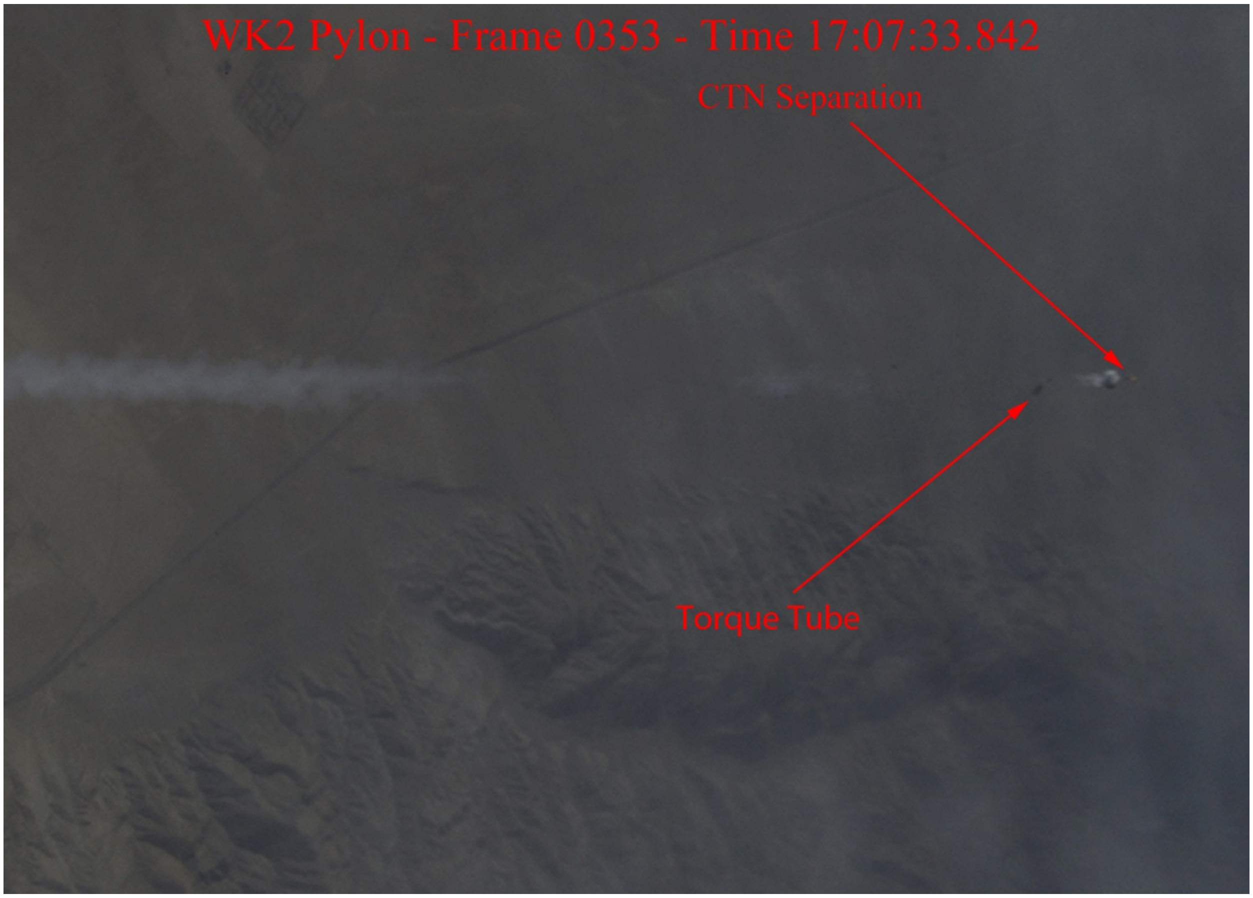


Figure 60 shows separation of the CTN from the main fuselage structure. A large dark part consistent in size and shape of the torque tube is trailing the vehicle's flightpath.

Figure 60.



5.7. SS2 Boom Camera

Section 5.7 primarily contains imagery from the SpaceShipTwo boom camera telemetry feed at a resolution of 704 by 288. Further data recovery efforts yielded a high definition video file (1920 by 1080) from the boom camera hard drive. Recovery details for this device can be found in the Electronic Devices and Flight Data Group Chairman's Factual Report which can be found in the public docket for this investigation. Select figures from the recovered high definition file were added to this report and referenced in this section to a corresponding frame number from the standard definition telemetry recording.

Figure 61 shows a foil covering from the rocket motor being ejected from the nozzle near the moment of firing as expected.

Figure 61.

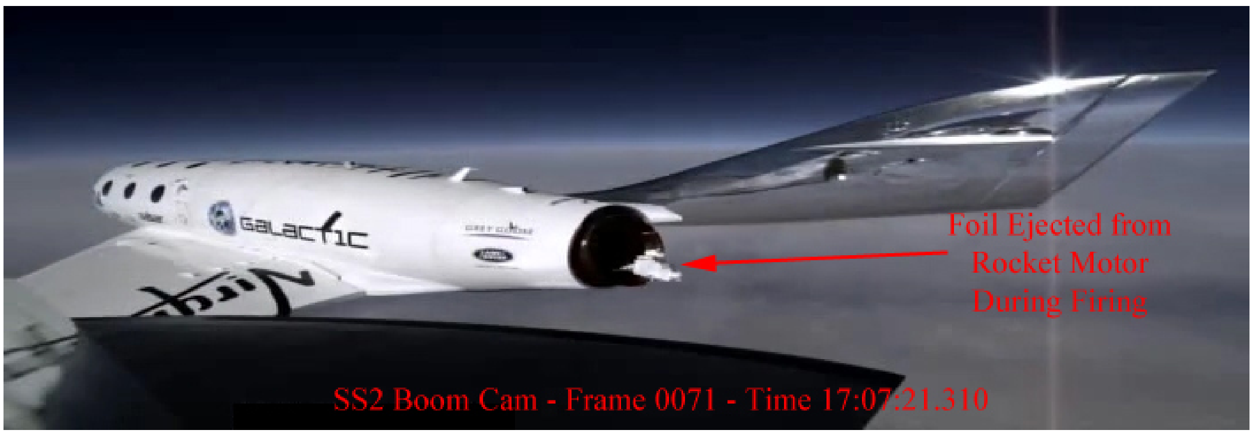


Figure 62 is the last frame exported from the recording that shows the feather in a undeployed and nominal position. A vertical line was drawn at the intersection of the right boom's leading edge and the contour of the upper fuselage structure to illustrate the feather's relative position. In every frame prior to this, the feather position is nominal. By figure 62 and forward, the exported images show positive feather movement indicated by the incongruity between the vertical line and the relative position of the right boom's leading edge and the contour of the fuselage.

Figure 62.

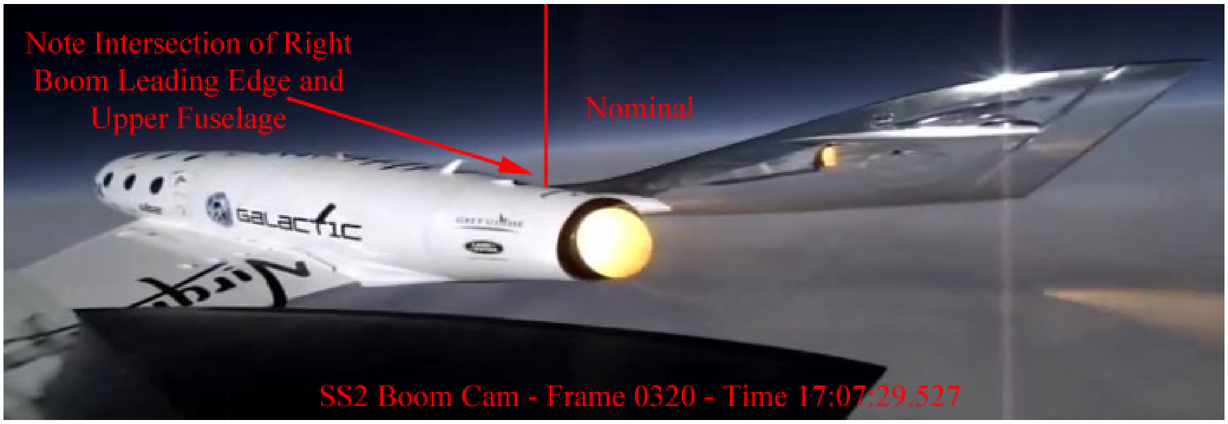


Figure 63 contains the first evidence indicating feather position movement. The vertical line from figure 62 was transposed onto figure 63. A slight change in relative position between the right boom leading edge and the upper contour of the fuselage was noted. Additionally, a region on the inner surface of the right boom covered in aluminized Kapton is observed having a slightly larger surface area indicating that the feather had slightly changed position. Slight feather movement was observed in frame 0330 (not shown) using the same techniques (Time 17:07:29.857) but was unable to be clearly presented in a graphics format.

Figure 63.

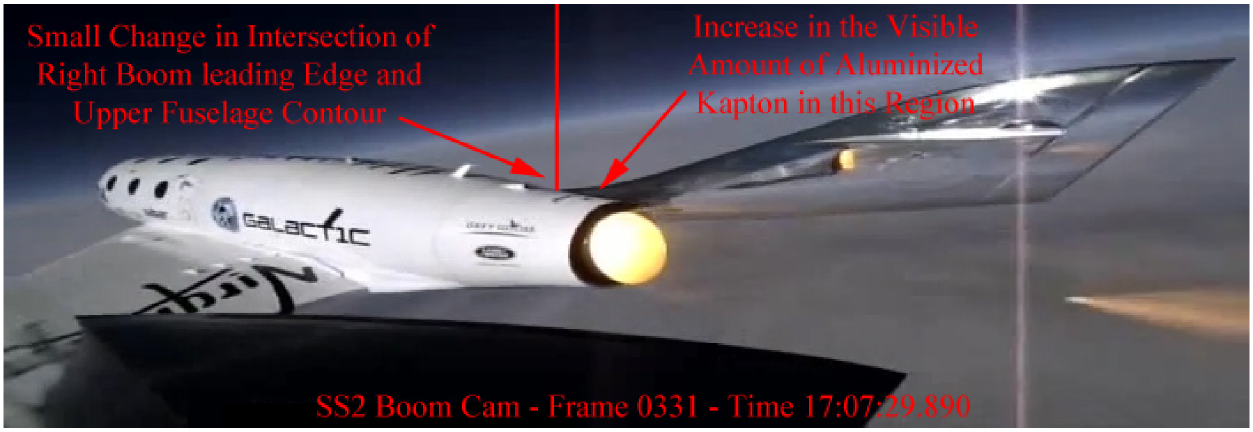


Figure 64 shows a portion of the right boom leading edge is visible to the left of the transposed vertical line applied from the previous figures. By this frame, movement of the feather is apparent when compared to figures 62 and 63.

Figure 64.

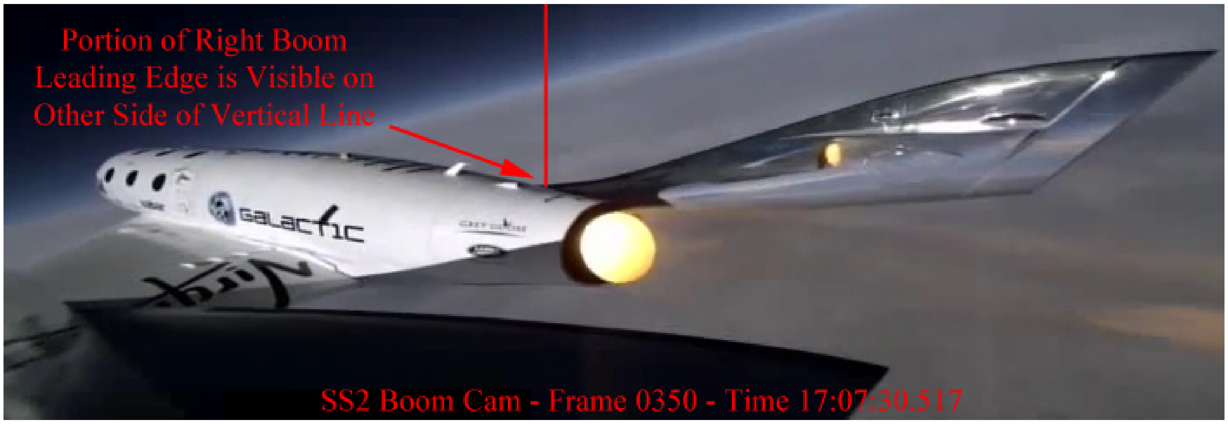


Figure 65 shows an increase in feather movement. The vehicle continues to pitch upward.

Figure 65.

Figure 66 is the last exported frame from the recording that was clear and did not contain video artifacts likely associated with the abrupt removal of power to the camera system. A significant increase in feather position is noted.

Figure 66.

Figure 67a shows the last frame in the series of exported images where the feather flap hinge line does not exhibit displacement. The feather flap hinge line in this image appears nominal.

Figure 67b is the corresponding still frame exported from the boom camera hard drive containing high definition imagery.

Figure 67a.

Figure 67b.

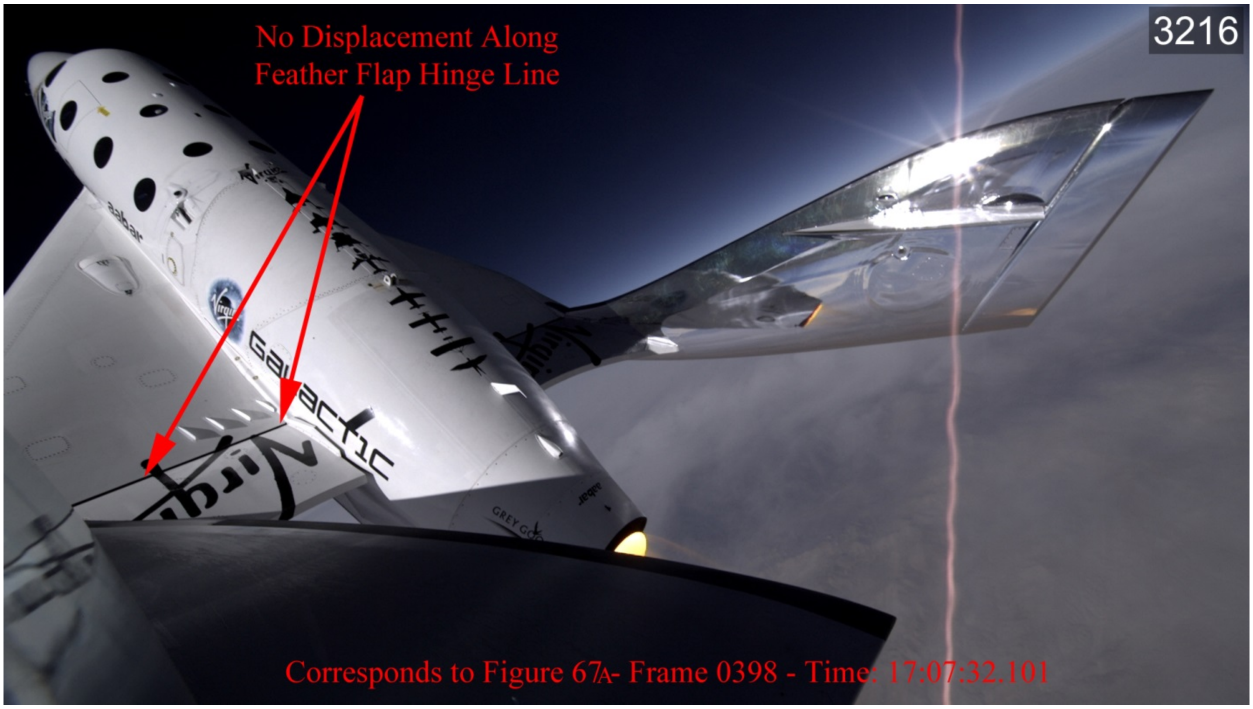


Figure 68a shows the first frame in the series of exported images where a displacement is exhibited along the feather flap hinge line. From this moment forward, the feather structure appears to become further displaced from the main structure of the vehicle.

Figure 68b is the corresponding still frame exported from the boom camera hard drive containing high definition imagery. Figure 68b shows greater detail of the cracks forming on the outboard root fairings and the lightweight "taco" area. The high definition file also shows the Kapton foil failing in the upper left hand corner of the frame, the area near the leading the edge of the left boom structure.

Figure 68a.

Figure 68b. Recovered HD still image.

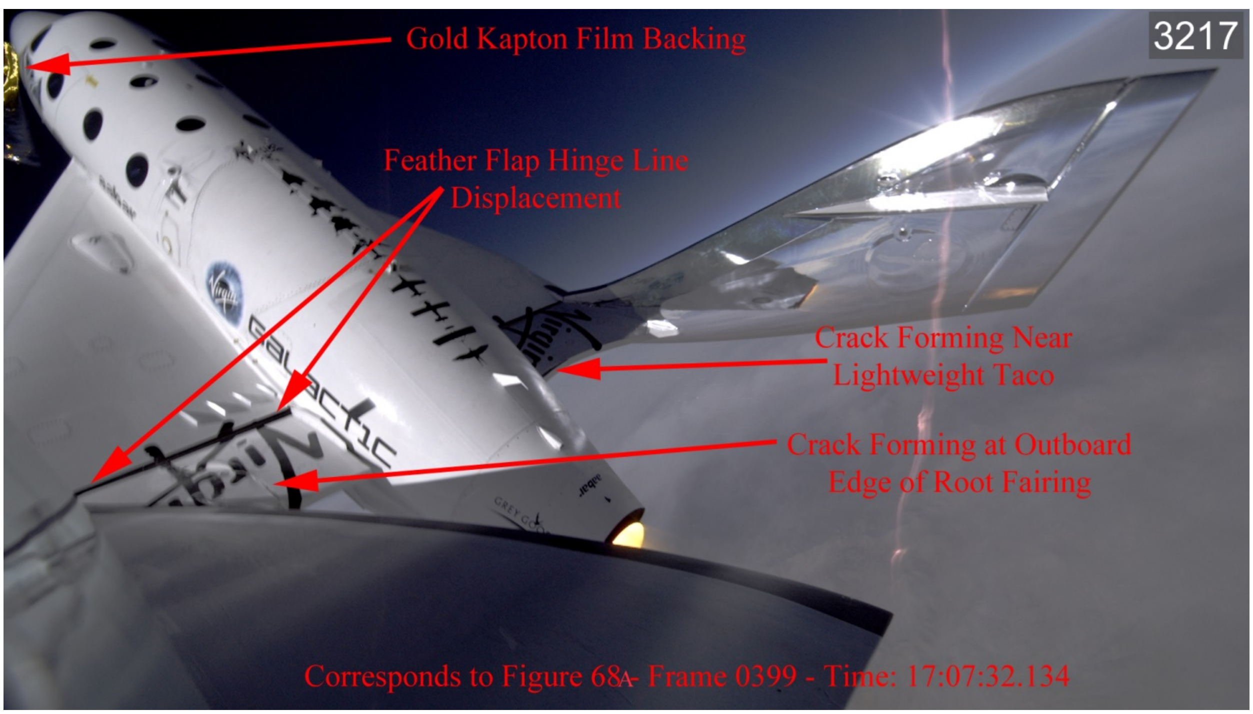


Figure 69a shows a field of view change apparent in the recorded images. The nose section is no longer visible. The change in field of view could possibly be attributed to the left boom structure being forced longitudinally outward, rotating inward, or a combination of both. Increased displacement is exhibited along the feather flap hinge line on the left side of the vehicle.

Figure 69b is the corresponding still frame exported from the boom camera hard drive containing high definition imagery. The high definition file shows a portion of missing Kapton on the right boom structure and the continued failure of the upper feather flap skin and root fairings. Video artifacting has become present on the recovered high definition file.

Figure 69a.

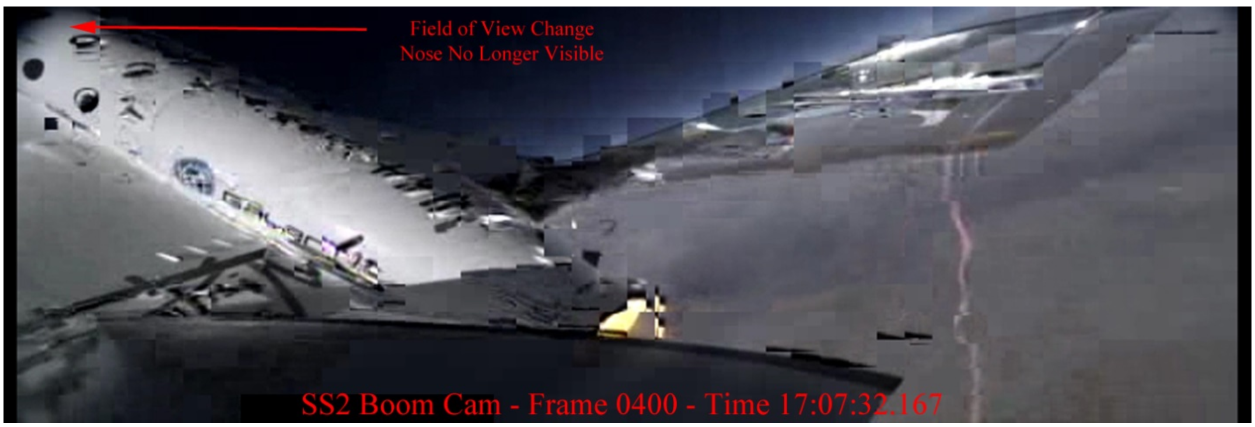


Figure 69b.

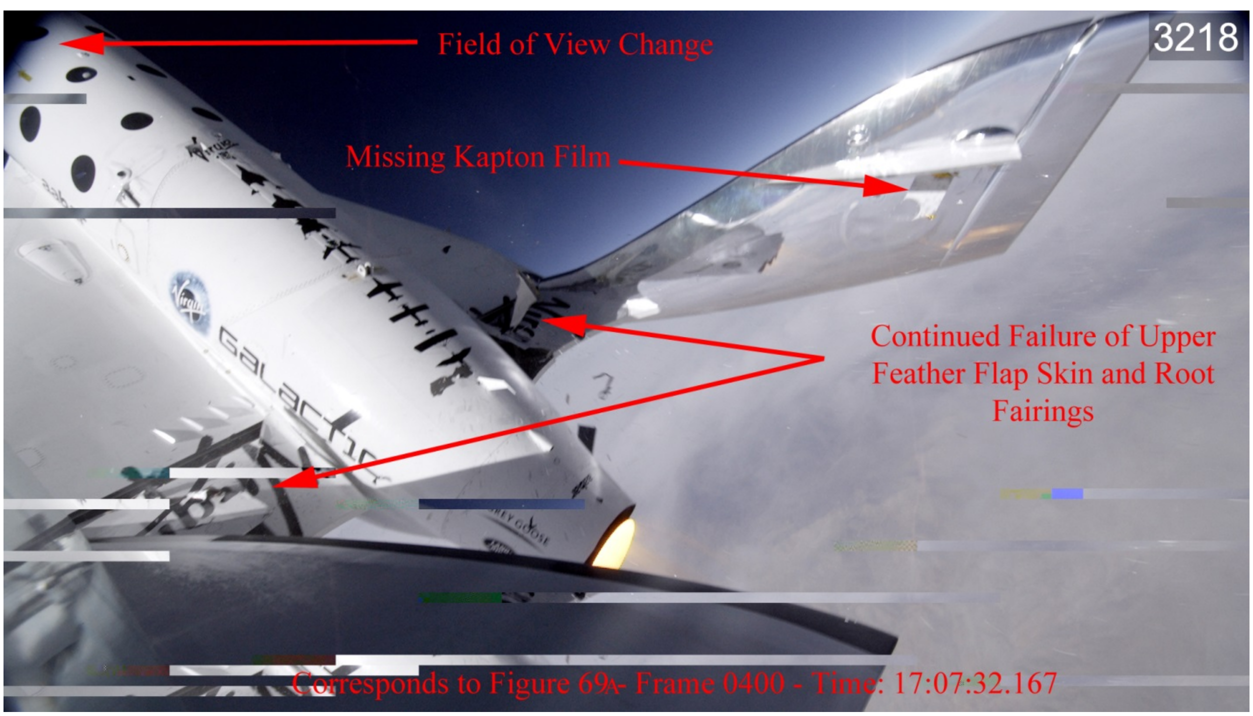


Figure 70a shows a further change in the camera's field of view, only one window is visible near the main fuselage. Evidence of debris separation likely not attributed to video artifacting is near the center of the frame. Further separation between the wing trailing edge and the feather flap is visible.

Figure 70b is the corresponding still frame exported from the boom camera hard drive containing high definition imagery. The high definition file shows the right feather flap structure completely failing. A skin panel from the bottom surface of the vehicle is seen removed from the structure and the left inboard upper root fairing structure is continuing to fail. Figure 70b is the last usable high definition file recovered from the boom camera hard drive. All subsequent recovered imagery contained heavy digital artifacting.

Figure 70a.

Figure 70b.

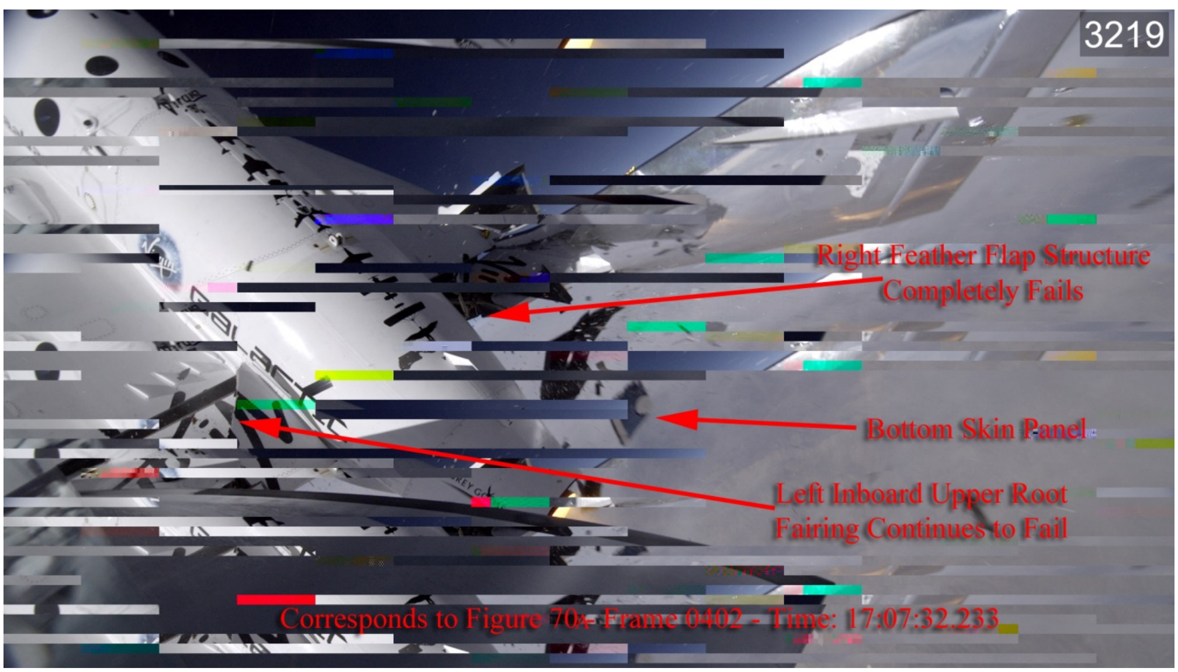


Figure 71 shows the upper surface of the right mega strake becoming visible to the camera's field of view. This indicates the right boom has begun to rotate inboard toward the centerline of the vehicle.

Figure 71.

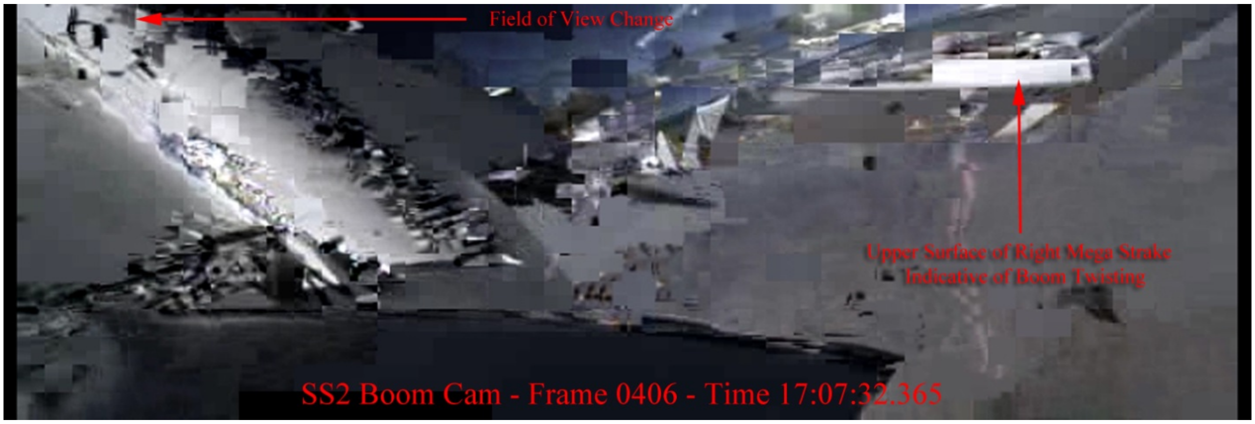


Figure 72 shows an increase in the visibility of the upper surface of the right mega strake indicating further rotation of the right boom inboard toward the centerline of the vehicle. An open area is visible near the feather flap hinge line consistent with the color of the surrounding background near the left hand portion of the frame. Additionally, a crack has begun to propagate from the feather flap hinge line into the fuselage near the tail cone section of the vehicle.

Figure 72.

Figure 73 shows separation of the aft fuselage in the region of the tailcone. The crack along the feather flap hinge line has greatly increased in displacement. Background is visible between separated portions of the vehicle. The tailcone has begun to twist along the region of displacement, indicated by the “Virgin DNA” graphic becoming clearly misaligned (yellow line). Separation along the feather flap hinge line on the right side of the vehicle is also apparent, with background visible in the region of displacement. The right boom has mostly separated from the vehicle’s main structure and has continued to roll inboard with the upper surface of the right megastrake becoming more apparent to the camera’s field of view. The Virgin logo on the right side of the vehicle near the feather flap hinge line is attached to the right boom structure and separated from the vehicle.

Figure 73.

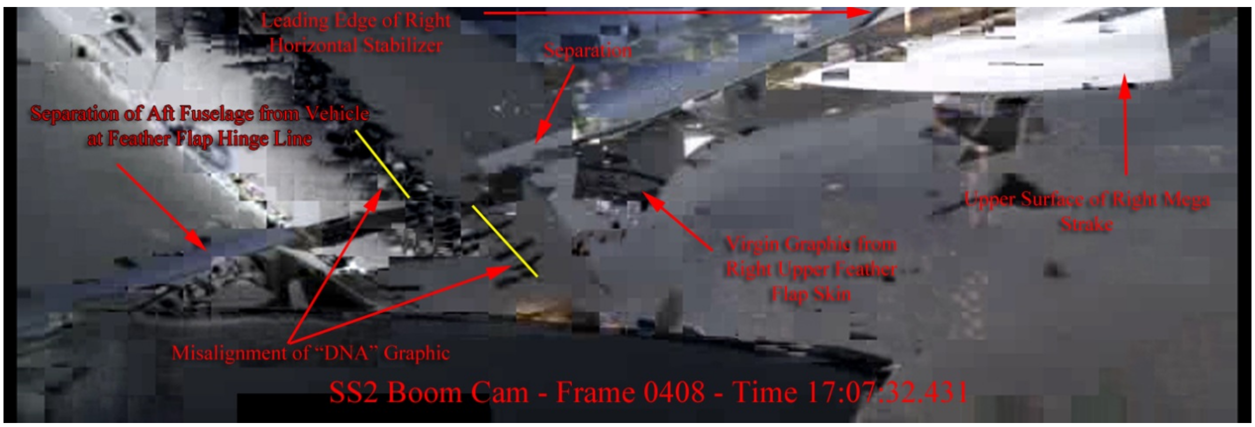


Figure 74 shows the camera has begun to power down and the recorded image is rapidly losing fidelity. The upper surface of the right mega strake is more apparent, indicating a continued roll inboard toward the center line of the vehicle. The "Virgin DNA" graphic on the upper portion of the main fuselage is in close view, indicating a significant change in displacement between the camera and the main fuselage.

Figure 74.

Figure 75 is an exported image of the first full frame of camera signal loss. It is the second to last frame of recorded images.

Figure 75.

Figure 76 is the last frame of the camera recording recorded by the telemetry ground station. There is complete signal loss.

Figure 76.

5.8. Mark Greenberg GoPro Hero 3+ Black

Figure 77 is the first frame from GoPro file GOPR2606.mp4 that captured the pilot under parachute.

Figure 77.

Figure 78 shows the pilot under parachute near the center of the frame. Additionally, some medium to large size falling debris is near the center and left hand portions of the frame.

Figure 78.

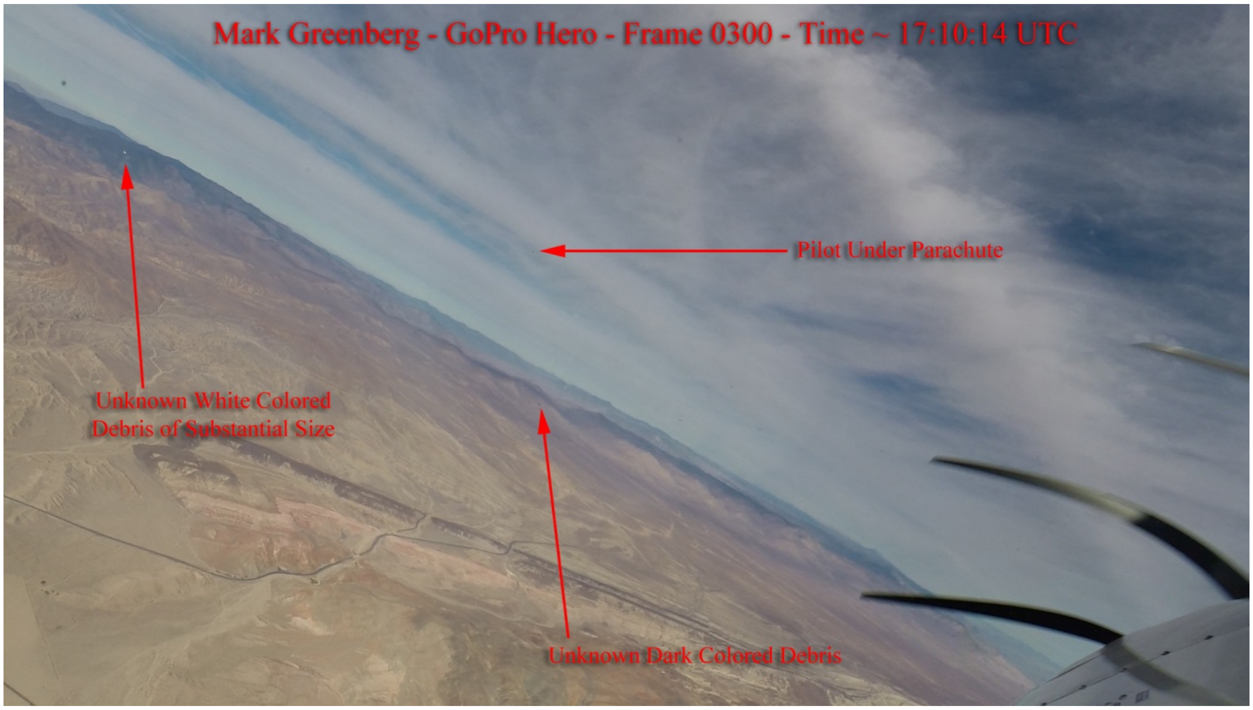


Figure 79 shows the pilot under parachute more clearly visible in the frame.

Figure 79.

5.9. Mark Greenberg Canon EOS 5D Mark III

Figure 80 is the first still photo taken from Mr. Greenberg's still camera that clearly captured the pilot under parachute.

Figure 80.

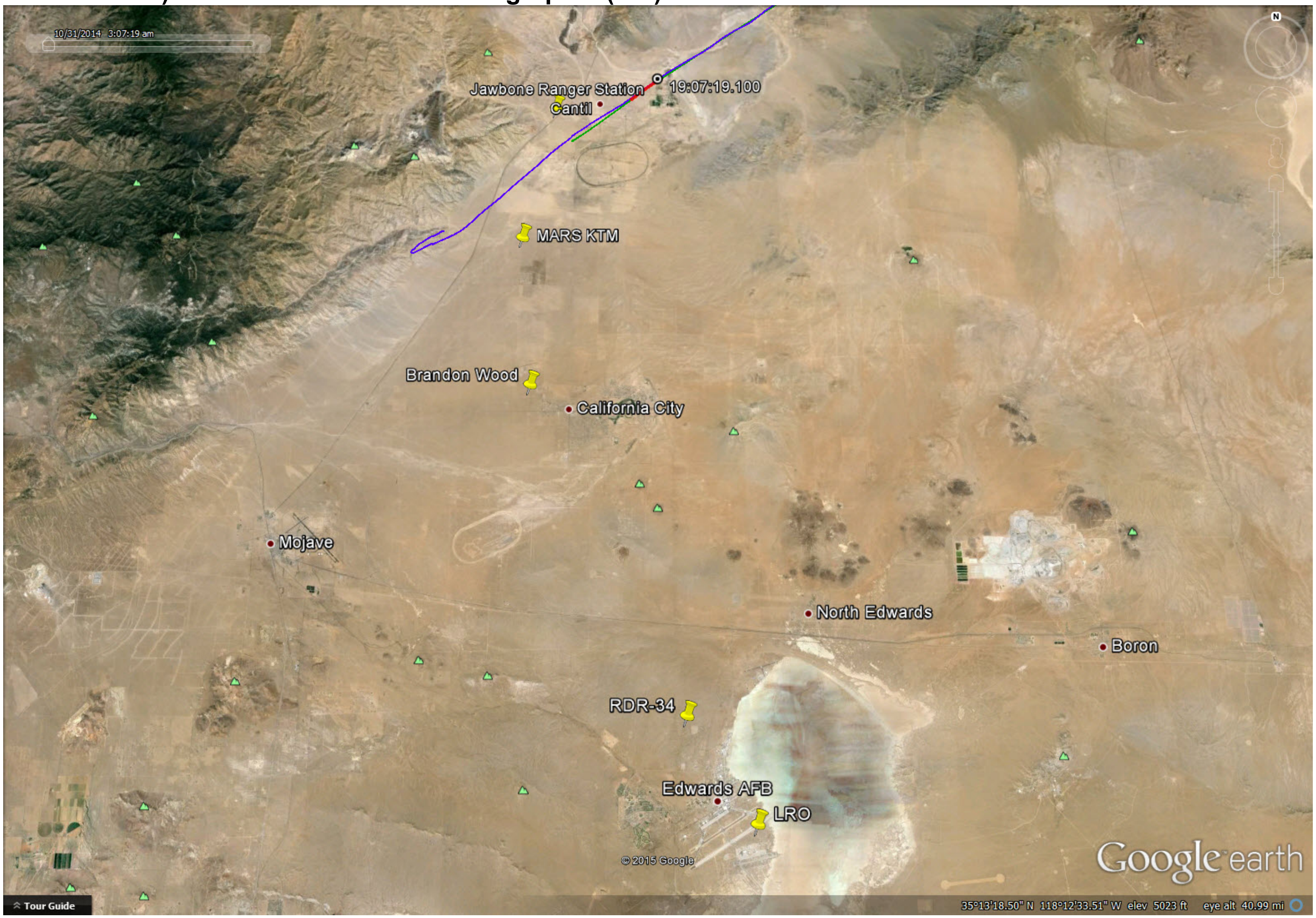
Figure 81 is the first photo taken from Mr. Greenberg's still camera that captured the pilot with his armed raised.

Figure 81.

Figure 82 is the last photo taken of pilot under chute while descending.

Figure 82.

Attachment A-1: An overview of camera locations, the calculated Instantaneous Impact Point (IIP) for SS2 (green and blue) and SS2's recorded GPS flightpath (red) between 17:07:19.100 and 19:07:32.100 UTC.



Attachment A-2: Onboard Camera Locations on WK2 and SS2.