Overview of the Orbiting Carbon Observatory (OCO) Mishap Investigation Results For Public Release

SUMMARY

The Orbiting Carbon Observatory was a National Aeronautics and Space Administration satellite mission that was launched on an Orbital Taurus XL launch vehicle. On Feb. 24, 2009, the OCO mission (Taurus T8) lifted off from Launch Complex 576-E at Vandenberg Air Force Base (VAFB) in California at 4:55:31 a.m. EST.

The OCO mission was lost in a launch failure when the payload fairing of the Taurus launch vehicle failed to separate during ascent. A payload fairing is a clamshell-shaped cover that encloses and protects a payload on the pad and during early flight. Fairings are a standard component of expendable launch vehicles, and they are always jettisoned as soon as possible after a launch vehicle has achieved an altitude where aeroheating is no longer a risk to the satellite. On this flight, the fairing should have been jettisoned shortly after Stage 2 ignition. However, the fairing remained attached for the remainder of the flight. The OCO satellite was separated from the Stage 3, but was contained within the still attached fairing. The OCO satellite and the vehicle coasted to an apogee of 615 km, (short of the desired 642 km) with an apogee velocity of 7.2 km/sec. This apogee was only 300 m/sec short of the desired orbital velocity. Failure to shed the fairing mass prevented the satellite from reaching its planned orbit; resulting in atmospheric reentry. Aeroheating and reentry loads most likely caused break-up and/or burn-up. Any surviving pieces were dispersed in the Pacific Ocean near Antarctica.

The cost of the mission was $209 million; therefore, the incident was classified as a Type A mishap. A NASA Mishap Investigation Board (MIB) was formed by William Gerstenmaier, associate administrator for the NASA Space Operations Mission Directorate. The MIB, chaired by Arthur F. Obenschain, deputy director of the NASA Goddard Space Flight Center, began its investigation in early March.

No physical evidence was available for examination. However, the MIB performed hardware testing, performed or reviewed engineering analysis and simulation data, reviewed telemetry data, impounded more than 2,000 documents and conducted 78 interviews of critical personnel associated with the mission at all levels. Using this data the MIB was able to analyze and validate that the mishap cause was failure of the fairing to separate upon command. The analysis performed conclusively shows that the ascent system performance and actual flown trajectory is consistent with carrying the extra mass of the fairing past its intended separation point. As part of its investigation, the MIB developed a fault tree and an event and causal factor tree. After identifying causes using the fault tree, the MIB developed and documented in a formal report recommendations aimed at avoiding such occurrences in the future.

NASA has completed the agency's assessment of the OCO MIB report. The report is NASA-sensitive, but unclassified (SBU), because it contains company proprietary information; the report also contains information restricted by the International Traffic in

Arms Regulations (ITAR). As a result, the OCO mishap investigation report was deemed not releasable to the public. The following provides an overview of publicly releasable findings and recommendations regarding the OCO mishap.

MISSION OVERVIEW

The Orbiting Carbon Observatory was an experimental NASA Earth System Science Pathfinder Program mission. The OCO satellite was designed to make space-based measurements of atmospheric carbon dioxide and provide NASA with insight to the sources of human and natural carbon emissions, as well as pinpointing potential carbon “sinks” on the surface of the Earth. The measurements from OCO were intended to help scientists better understand CO_2 concentrations in the Earth’s atmosphere.

The OCO satellite project was managed by the Jet Propulsion Laboratory (JPL) in Pasadena, Calif., for NASA’s Science Mission Directorate. Orbital Space Systems Group built the satellite under contract to JPL.

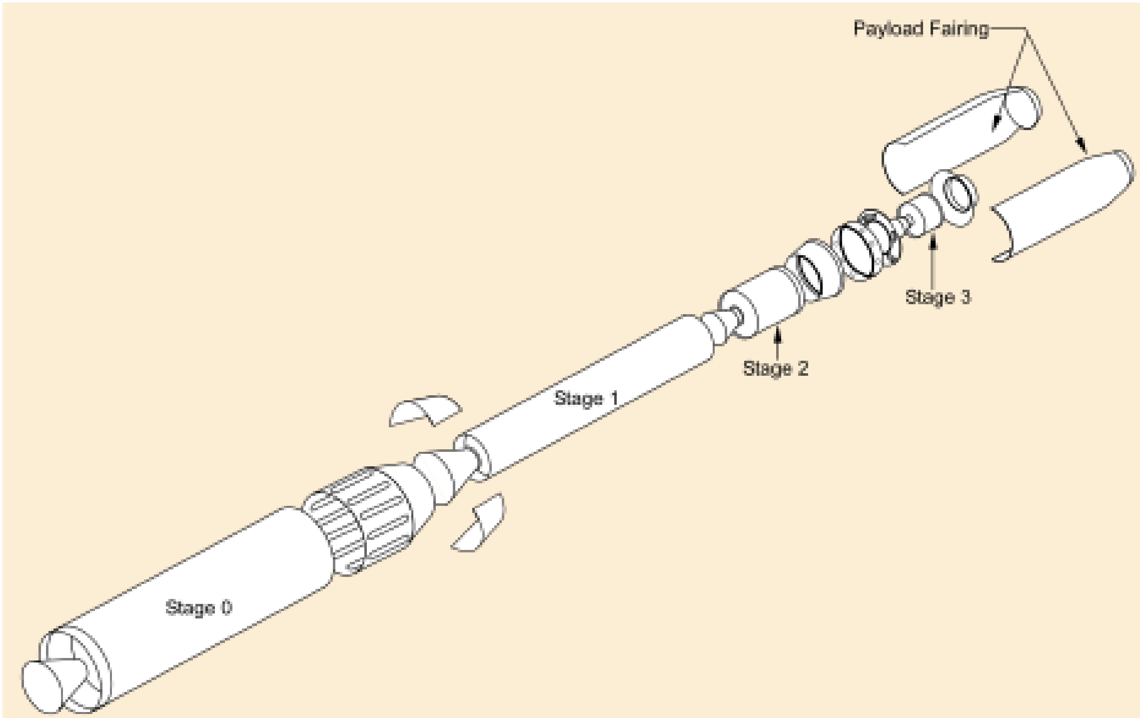
SELECTION OF LAUNCH VEHICLE

The OCO launch service was procured under the NASA Launch Services Program Small Expendable Launch Vehicle Systems contract in October 2003. The OCO mission was the first time that the Taurus XL 3110 configuration was flown. It was also the first time that a NASA satellite was a primary payload on a Taurus launch vehicle. The Orbital Launch Services Group provided the Taurus launch, under contract to NASA’s Launch Services Program at NASA’s Kennedy Space Center in Florida.

TAURUS LAUNCH VEHICLE SYSTEM DESCRIPTION

Taurus is a four-stage, inertially guided, all solid fuel, ground launched vehicle, designed and built by Orbital’s Launch Services Group. The Taurus launch vehicle is available in multiple configurations that differ in fairing size, and orbital insertion performance.

The OCO mission flew the Taurus XL 3110 configuration which uses motors adapted from Orbital’s Pegasus Program. The vehicle uses the Castor 120 booster with an Orion 50SXLG for Stage 1, an Orion 50XLG for Stage 2, and an Orion 38 for Stage 3. The OCO mission used the 63-inch diameter payload fairing.



Taurus Launch Vehicle

TAURUS 63-INCH FAIRING SYSTEM DESCRIPTION

The 63-inch composite fairing system consists of two bisector shells with acoustic blankets attached to the inside of the fairing halves. The fairing shell consists of a 90-degree half, which encompasses 0 to 180 degrees in the vehicle coordinate system, and a 270-degree half, which encompasses the 180 to 360 degree portion. The 90-degree half includes the nose cap, pyrotechnic separation systems, and the environmental control system (ECS) ducting for payload ground processing. The 270-degree half contains the majority of the telemetry sensors. The two fairing halves are structurally joined during the payload encapsulation process along their longitudinal edges using frangible joints (referenced as “frangible side rail”). A frangible base ring around the bottom edge structurally attaches the payload fairing to the launch vehicle. During nominal flight the frangible joints (side rails and base ring) are severed using ordnance, then a set of pneumatic thrusters push the fairings outward on hinge pairs separating the fairing halves.

Sensors are mounted to the fairings to provide temperature, pressure, and acoustic environment. Fairing separation breakwires are included on each half and monitored in telemetry.

DESCRIPTION OF MISHAP

The OCO was launched Feb. 24, 2009 aboard the Taurus T8 launch vehicle from Space Launch Complex 576-E at Vandenberg Air Force Base (VAFB) in California. Following the 9:55:31 UTC liftoff, the launch proceeded nominally up to Stage 2 ignition. Vehicle telemetry was received until the Taurus transmitters were commanded off at 10:09:58 UTC. A contingency was declared at 10:11:09 UTC.

MISHAP CAUSES AND RECOMMENDATIONS

NASA's major goal in performing mishap investigations is to improve safety and mission success probability by identifying the causes of a mishap, and by providing recommendations that will prevent future occurrences of similar events. By performing analyses to determine 'why' the mishap occurred, the MIB did identify four potential causes that could have led to the failure.

The investigation carried out by the MIB resulted in validation that the Taurus launch vehicle fairing failed to separate upon command. Fairing sensor data (microphone, temperature, acceleration) and the separation breakwire indicated that the fairing did not separate from the launch vehicle. Simulation models of Taurus performance, assuming the fairing did not separate, were developed. The models showed good agreement and analytically demonstrated performance impacts that are consistent with the performance experienced on the OCO mission.

The MIB analyzed the payload fairing system design, manufacturing, inspection, assembly, and testing, and associated telemetry in order to identify a more detailed cause. The MIB was unable to determine which component or subcomponent was the direct cause for the fairing not to separate, but identified a number of hardware components whose failure modes could be potential causes: fairing base ring frangible joint, electrical subsystem and the pneumatic system hot gas generator (HGG) including its pressure cartridges. The potential causes with specific recommendations are summarized below.

1) Frangible Joint Subsystem failure caused fairing not to separate.

It could not be determined if the frangible joint base ring fractured completely as designed. An incomplete fracture could have resulted in the fairing not separating. The MIB looked at the materials used and their characteristics and made the following recommendations:

1. Verify that the Taurus launch vehicle frangible joint (fairing rail, base ring, and Stage 2/ Stage 3) extrusions have a traceable pedigree on future NASA missions. If pedigree cannot be verified, remove and replace the assigned hardware with frangible joints that have a complete pedigree.

2. Establish a single heat treat lot requirement for aluminum used to manufacture extrusion and perform sub-scale tests on the lot.

3. Institute permanent marking (which cannot be removed during processing) along the length of the extrusion at intervals to ensure traceability.

4. Implement a common procurement and assembly process for frangible joints used on Taurus similar to Orbital's other programs.

2) Electrical Subsystem failure caused fairing not to separate.

It could not be determined if the transient bus supplied sufficient electrical current to initiate the required ordnance devices. Insufficient current could have resulted in an insufficient quantity of ordnance devices firing causing the fairing not to separate. The MIB made the following recommendations:

5) Rescale Taurus launch vehicle telemetry to allow the transient power bus measurements to fully capture peak currents during flight.

6) Institute a process that monitors, captures, and analyzes PDU current output profiles during acceptance test and flight simulations.

3) Fairing Pneumatic System failure caused fairing not to separate.

It could not be determined if the fairing pneumatic system supplied sufficient pressure to separate the fairing. The fairing pneumatic system consists of the hot gas generator (HGG) system, thrusters, and pneumatic tubing. The HGG system consists of the HGG body, manifold, and pressure cartridges. If insufficient pressure was supplied to the thrusters then the fairing would not have separated. The MIB made the following recommendations:

7) Implement items 'a' through 'e' below into the HGG system. If the items cannot be fully implemented, then replace the HGG system with an alternate fairing jettison system that does not use a hot gas generator system:

    a) The HGG system should be qualified and acceptance tested in the flight-like configuration and environment.

    b) Define and document the HGG sustainer grain propellant radiographic acceptance criteria, including the engineering rationale and applicability for using non Orbital criteria for the Taurus application.

    c) Modify HGG design to retain small propellant pellets and preclude movement during dynamic environments.

    d) Assure that HGG ignition occurs when the HGG system is subjected to all induced thermal and dynamic environments.

    e) Provide a controlled, verifiable and repeatable means for mounting the HGG in the Taurus Launch Vehicle fairing for flight, qualification and acceptance testing for flight, for all future NASA missions.

8) Demonstrate that the pressure cartridges initiation charge remains in contact with the bridgewire after being subjected to Taurus thermal and dynamic environments.

9) Establish functional performance requirements for PCs which screen for workmanship and lot-to-lot variability (i.e., time to first pressure, time to peak pressure and thermal time constant).

10) Assure manufacturing and inspection processes are consistent with the PC design requirements.

4) Flexible Confined Detonating Cord (FCDC) Snagged on Frangible Joint Side Rail Nut Plate

It could not be determined if the FCDC snagged on the frangible joint side rail nut plate preventing the fairing from separating. The MIB made the following recommendation:

11) Route the FCDC, or implement a physical barrier, to exclude the possibility that the FCDC would snag on a nut plate cover.

Further analysis is in work by NASA Launch Service Program that may demonstrate that the possibility of the FCDC snagging is remote. It may be possible to show based on available acceleration data and modeling that this particular failure mode was not a contributor to this failure. This additional work is very time consuming and may yield inconclusive results. Rather than hold up the report and findings, it was decided to release the findings. Improved routing of the FCDC is a prudent action even if later analysis shows that this was not a possible direct contributor to the failure.

During the course of the mishap investigation, several observations related to quality control, configuration management and programmatic processes were noted by the MIB. Although these observations were not direct contributors to the mishap, the MIB determined that they could be beneficial for future programs.