

Space Surveillance Contributions to the STS 107 Accident Investigation

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This paper addresses the analyses conducted by the AFSPC Space Analysis Center in support of the Columbia accident investigation. The analyses covered a range of space surveillance issues—from examining the breakup of a rocket body during the STS 107 mission, reviewing results of the recent NASA debris campaign, and assessing a “close approach” reported by the crew on Flight Day 5. Most notably, this paper will show how the Flight Day 2 piece discovered by the 1st Space Control Squadron was analyzed to determine its ballistic and radar characteristics and how this effort helped NASA determine whether this piece was from Columbia and, if so, what it might have been.

INTRODUCTION

On February 1, 2003, the US space shuttle Columbia broke apart during reentry over the southwestern US. As a result of this tragic event, the US government initiated an investigation to determine the cause of the accident. That investigation required a combined effort by the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) to collect information on events leading up to the launch of STS 107, throughout the on-orbit phase of the mission, and during reentry. The on-orbit phase relied heavily on data provided by Space Surveillance Network (SSN) sensors operated by the DoD.

During the investigation, the DoD arm of the investigation process, the DoD Columbia Investigation Support Team (DCIST), under the leadership of the DoD Director of Manned Spaceflight (DDMS), was responsible for collecting data from all DoD sensors, conducting analyses, and passing the data and analysis results to investigators at NASA. The Air Force Space Command (AFSPC) Space Analysis Center (ASAC), now known as the AFSPC Space Analysis Division (HQ AFSPC/XPY) was designated as the lead DoD analysis center, responsible for coordinating all DCIST analysis efforts throughout the investigation. They also led the effort to use SSN sensor data to illuminate or eliminate potential causes of the STS 107 accident.

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The analyses covered a range of space surveillance issues, from examining the breakup of a rocket body during the STS 107 mission, reviewing results of the recent NASA debris campaign, assessing a "close approach" reported by the crew on Flight Day 5, and analyzing the object discovered by the 1st Space Control Squadron (1 SPCS) which had separated from STS 107 on Flight Day 2.

On January 29, the SSN detected the breakup of COSMOS 1849. NASA/JSC asked the ASAC to examine the breakup and assess the likelihood that any debris from that breakup would have been a risk to the STS 107 mission. Analysis based on processing of all available observations showed that none of the 51 debris objects generated posed a risk to the shuttle.

The 2003 Inter-Agency Space Debris Coordination Committee (IADC) Debris Campaign was conducted January 20, shortly after the launch of STS 107. NASA/JSC asked the ASAC to review the data collected during this year's campaign to see if any of these debris objects posed a risk to the shuttle. The ASAC processed several thousand metric observations to generate over 900 new element sets. The final assessment was that only nine of these objects had orbits, which crossed the STS 107 orbit regime, and none of them were found to have close approaches.

Immediately following the Columbia accident, the ASAC began working with the 1st Space Control Squadron in Cheyenne Mountain to review all SSN observations of the US space shuttle to determine if there were any anomalous data. Observations from January 17-19 showed the presence of a small object in orbit with Columbia. Detailed ballistic analysis determined that this piece likely separated from the orbiter on Flight Day 2 (FD2) at low velocity. This was then combined with further analysis to determine the radar characteristics—supported by radar cross section (RCS) analysis at MIT's Lincoln Lab and RCS testing at Air Force Research Lab (AFRL)—to help to narrow the list of candidates for what part of Columbia the FD2 piece might be.

Review of NASA log entries after the accident revealed a report by the STS 107 crew on Flight Day 5 that they saw a "bright object that seems to be moving with them ... at a long distance." NASA/JSC asked the ASAC to perform a conjunction assessment to determine whether this was another satellite or debris from the shuttle. ASAC analysis showed that this observation was most likely an ORBCOMM satellite, which came no closer than 665 km from the orbiter.

COSMOS 1849 BREAKUP

On January 29, 2003—a few days before the ill-fated reentry of Columbia—the Space Surveillance Network reported a breakup of Cosmos 1849. There was some concern on the part of NASA that a breakup fragment from this spacecraft could have impacted Columbia, so further research was needed. Because it takes some time to correctly identify and correlate the pieces from a satellite breakup, NASA requested ASAC assistance to obtain more details.

Cosmos 1849 (18083/1987-048A) was launched on June 4, 1987 as part of an ongoing series of satellites in highly elliptical orbits. With an initial inclination near 62 degrees, this spacecraft made approximately 2 revolutions of the earth each day, with an apogee over 40,000 km and a perigee around 1,000 km. Just days before reentry (it reentered on February 4), Cosmos 1849 had broken up under aerodynamic stress. Several other spacecraft in the highly elliptical Cosmos and Molniya series have experienced aerodynamic breakups.¹

To accomplish this analysis, the ASAC collected all sensor observational data that could have been associated with the breakup. Using in-house software and the AFSPC Astrodynamic Standards software, all available data was carefully analyzed, and 51 element sets on the breakup pieces were created. It was then possible to use conjunction assessment programs to determine if any of the breakup pieces were in close proximity to the Columbia while it was in orbit. This analysis revealed that the orbital phasing of the breakup pieces, when compared to the Columbia orbit, was aligned in such a way that there were no close approaches (less than 1,000 km). In general, the orbit planes of the shuttle and the breakup pieces did not overlap, and none of the breakup pieces were in the “same place at the same time” as the shuttle.

The ASAC provided this information to NASA along with the data used to form this conclusion. NASA conducted their own, independent analysis and confirmed the ASAC findings. Thus, it was possible to discount the Cosmos 1849 breakup as a likely source of on-orbit damage to Columbia.

2003 IADC DEBRIS CAMPAIGN

The Inter-Agency Space Debris Coordination Committee is an inter-governmental organization established to develop and build a technical foundation for addressing the orbital debris environment and related issues. Established in 1993, the IADC membership currently consists of the world’s leading space agencies: ASI (Italy); BNSC (UK); CNES (France); CNSA (China); DLR (Germany); ESA (European Space Agency); ISRO (India); NASDA, ISAS, and NAL (Japan); NSAU (Ukraine), Rosaviakosmos (Russia), and NASA (including DoD and DOS). On a routine basis, the IADC conducts 24-hour debris campaigns to monitor changes on the space debris population as a benchmark.

The 2003 IADC Debris Campaign fortuitously occurred on 2003 January 20—four days after the launch of the STS-107 mission. NASA had previously requested AFSPC support of the IADC campaign by using the Cobra Dane phased-array radar at full power. Cobra Dane is an L-band radar located at Shemya, Alaska that has a demonstrated capability to track very small, uncataloged objects in near-earth orbits. Special provisions had to be made to operate this radar at full power to maximize the collection of data on small debris. This was accomplished and a large amount of data was collected on January 20.

Because of the Columbia accident, NASA requested that the ASAC expedite data processing and analysis of the Cobra Dane debris data collected during the IADC campaign. This was needed to understand if any uncataloged small debris was in close proximity to STS 107 that could have impacted or damaged the shuttle.

The ASAC processed several thousand metric observations collected by Cobra Dane on unknown satellites and processed this data into element sets. It was then possible to create over 900 element sets on objects that were not already in the satellite catalog. Using conjunction assessment programs, these new element sets were compared to the STS 107 orbit. Because the element sets were typically generated using one short arc track from Cobra Dane, these element sets were only valid for less than one day, so it was only possible to compare these objects for about 24 hours. It was found that only nine new objects had altitudes that crossed through the orbit regime used by STS 107. Of these nine objects, none were found to have close approaches to Columbia, primarily due to orbital phasing.

This information was supplied to NASA, and it was possible to determine that no newly detected small object tracked by Cobra Dane was close to the shuttle for the 24-hour period around the observations. However, it should be noted that Cobra Dane cannot see all orbits. Due to its northerly latitude, Cobra Dane's view of objects in 300 km orbits is restricted to about 42 degrees inclination.

FLIGHT DAY 2 PIECE

On February 6, analysis by the 1st Space Control Squadron's Space Analysis Center (1 SPCS/DOM) at Cheyenne Mountain of element sets generated from unassociated sensor observations on their off-line CAVENET computer system revealed a previously undetected object in orbit with STS 107 starting on 18 January. 1 SPCS analysts then performed a COMBO (Computation of Miss Distance Between Orbits) run on STS 107 and the object, which gave a time of closest approach at 1559Z on January 17 (Flight Day 2). 1 SPCS immediately notified the ASAC of their findings.

Common practice at the time of the STS 107 mission was to rely on NASA orbit vectors exclusively for shuttle orbit determination. Consequently, while the SSN was tasked to actively track Columbia, no real-time analysis (differential corrections) using the data was required. As a result, the observations on the piece of debris which had come in during the mission were not noticed. In addition, two of the primary sensors used for tracking Columbia—Cape Cod and Eglin—were not sending observations to 1 SPCS for part of January 17.

The ASAC, in turn, began contacting all SSN sensors, which had tracked STS 107 during its mission, asking site personnel to review all data tapes to see if they had tracked the object, but had not forwarded observations on it. This was done with the hope that, if additional data could be discovered, a more accurate time of close approach could be determined. Additional data was found by Cape Cod, Eglin, and NAVSPASUR, and it was combined with previously obtained data.

This combined data set was used in conjunction with the new High-Accuracy Satellite Drag Model (HASDM) on the special perturbations (SP) Astrodynamic Support Workstation (ASW) to generate as accurate an ephemeris as possible on the FD2 piece. This ephemeris data was then used to narrow down the time of closest approach to between 1500Z and 1615Z, with 1530Z–1600Z being most likely. It was also possible to narrow down the separation velocity to between 0 and 1.5 m/s, with the most likely separation velocity being approximately 0.3 m/sec. This low separation velocity—which suggests the FD2 piece floated away rather than being the result of an impact—makes the exact separation direction and time more uncertain.

These analysis results are consistent with a scenario where a piece of the orbiter floated away after a series of maneuvers. Columbia had just completed a series of maneuvers on January 17, moving from tail-first to right wing-first at 1442Z and returning to tail-first orientation at 1517Z. The FD2 piece is believed to have separated between 1500Z and 1630Z. The first confirmed SSN track for the FD2 piece was at 1857Z. It was tracked by the Beale, Cape Cod, and Eglin phased-array radars and the Naval Space Surveillance (NAVSPASUR) fence until 2146Z on January 19. Best estimates are that the FD2 piece decayed from orbit between 0145Z and 0445Z on January 20.

With analysis suggesting that the FD2 piece came from the shuttle, the investigation turned to trying to determine what it might have been. Determination of the ballistic coefficient put it near $0.10 \text{ m}^2/\text{kg}$, which would imply a relatively lightweight object. The radar cross section (RCS) analysis suggested a flat object approximately 0.4 m by 0.3 m. Exact determination of the size was complicated since the wavelength of the UHF phased-array radars ($\sim 0.7 \text{ m}$) was close to the size of the object.

The FD2 piece was initially in a semi-stable or slow rotation on January 17. By January 18, the estimated rotation period was about seven seconds. By January 19, the rotation period had decreased to about three seconds. This information was used by MIT's Lincoln Laboratory to assess aerodynamic characteristics.

The ASAC worked closely with NASA and the Air Force Research Laboratory (AFRL) to match the ballistic and radar characteristics with potential candidate pieces from Columbia. Items from the shuttle bay (e.g., thermal blankets), shuttle exterior (e.g., thermal blankets, heat tiles), and shuttle wing (e.g., full and partial Reinforced Carbon-Carbon (RCC) wing leading edge panels, ear muffs, carrier panels, horse collars, RCC T-seals) were all examined. AFRL made extensive radar signature measurements to assess each piece's radar cross-section characteristics. Additional modeling by MIT's Lincoln Laboratory helped to further refine the analysis.

Of the two dozen candidates considered, thermal blankets and the complete RCC panel were eliminated because they did not meet the ballistic criteria. Of the remaining candidates, the most likely candidate based on the RCS criteria was an RCC wing leading edge panel fragment. The discovery and subsequent analysis of the FD2 piece was

considered in NASA's final determination of the sequence of events leading up to the Columbia tragedy.

FLIGHT DAY 5 OBJECT

After the accident, NASA reported that upon reviewing their logs:

We found a Flight Day 5 entry (21/08:51:30 GMT) indicating that the crew had called down saying that they had seen a "bright object that seems to be moving with them ... at a long distance."

NASA requested that the ASAC perform a COMBO (Computation of Miss Distance Between Orbits) run from January 21 at 0839Z to January 21 at 0854Z in order to determine what object it might have been.

NASA requested identification and analysis of all objects that were within a specified "box" around Columbia during the time period in question. Existing ASAC software tools made identification of all candidate objects reasonably easy and indicated that the minimum miss-distance of the closest object was around 350 km. The problematic part of the analysis was determining which of the 250+ candidates were most likely to be visible from the Shuttle's windows, and if they were in line with the crew's description given the attitude of the vehicle at the time of the event.

Most of the objects could be eliminated by virtue of the fact that they were not in the specified region for a sufficient amount of time (at least 10 minutes of the 16-minute event window). Only six objects were identified as possibilities and only five of these were identified as likely candidates based on object size, attitude stability, illumination angles, reflective surfaces, orbit trajectory, and visibility from the shuttle's windows. Comparison of all these variables, along with the aid of an STK visualization model, indicated with reasonable certainty that the object in question was an Orbcomm satellite.

Orbcomm FM-9 (25116/1997-084E) was visible for the entire 16-minute analysis window. The Orbcomm satellites have two 1.07-meter diameter, sun-tracking solar arrays that would have produced a fairly bright reflection in the general direction of the shuttle's location and the beta angles for this conjunction were ideal for visibility from the shuttle. The shuttle's attitude was such that the object would have been visible from the crew cabin windows (most likely the overhead ports, and possibly the payload bay windows). The trajectory and orbital velocity of the object would have made it appear to "move along with them." Orbcomm FM-9's attitude was stable and would have produced a steady reflection for the duration of the event (as opposed to the flashing that might be expected from a spinning or tumbling object). No other candidate was identified that fit these criteria as closely as Orbcomm FM-9.

CONCLUSIONS

The AFSPC Space Analysis Center played a key role in helping NASA reach their final conclusions regarding the cause of the Columbia accident. Working with the Space Surveillance Network sensor sites, they were able to quickly eliminate several hypotheses regarding potential impact with orbital debris. More importantly, the discovery and analysis of the Flight Day 2 piece—working with the Space Surveillance Network sensor sites, the 1st Space Control Squadron in Cheyenne Mountain, the Air Force Research Laboratory, and MIT's Lincoln Laboratory—was considered in NASA's final determination of the cause of the STS 107 accident.

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REFERENCES

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