

Vicious Cycle:

X-15 In-Flight Breakup

Leadership ViTS Meeting

March 2011

Bryan O'Connor

Chief, Safety and Mission Assurance

Wilson B. Harkins

Deputy Chief, Safety and Mission Assurance



This and previous presentations are archived at:
<http://nsc.nasa.gov/SFCS>

THE MISHAP

Called "the most successful research airplane in history," the X-15 probed the hypersonic flight environment to carry out experiments whose results would impact the design of the Space Shuttle years later. The X-15's 191st flight was scheduled to take place on November 15, 1967, and it would be piloted by U.S. Air Force Major Mike Adams. During his flight, a drift in heading caused the X-15 to reenter the atmosphere perpendicular to its ballistic flight path. The aircraft departed controlled flight. At 62,000 feet, severe g forces tore the aircraft apart, and Major Adams perished in the crash.

Adaptive Flight Control System

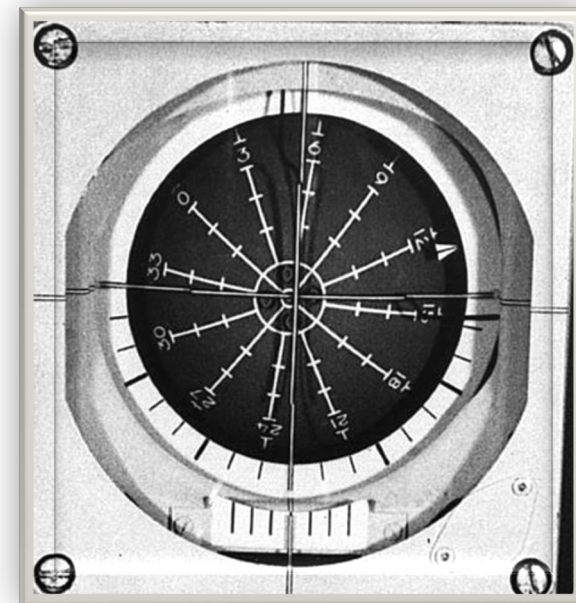
- Minneapolis-Honeywell designed an adaptive flight control system (AFCS) called the MH-96 for the 3rd X-15 aircraft (X-15-3).
- AFCS was designed to increase aircraft stability and control by dampening or amplifying pilot command inputs to account for dynamic pressure on the X-15.
- As altitude increased, gain increased. As altitude decreased, gain decreased (reducing the gain decreased aircraft response to pilot inputs to prevent them from overstressing the aircraft as denser air was encountered).

Reaction Control System

- At high altitude, external stabilizers are ineffective because they lack air against which to push.
- Rocket thrusters in the nose and wing tips comprised a reaction control system (RCS) that controlled aircraft orientation during ballistic flight outside the atmosphere (main engine secured).
- MH-96 in "automatic mode" blended RCS use with aileron, rudder, and stabilizer use per a built-in model to ensure controllability and conserve RCS fuel. Pilot used right-side stick for both systems in automatic mode.
- In "Manual mode," pilot fired the RCS using the left-side stick only.

Attitude Indicator

- Pilots adjusted aircraft pitch, roll, and yaw primarily in reference to the vertical and horizontal needles.
- As the X-15 reached higher altitudes and conducted certain experiments, pilots could activate a switch that would change the vertical needle's input to display roll angle instead of sideslip.



The attitude indicator's ability to display either sideslip or roll angle was a major design departure for an instrument critical to maintaining controlled flight.

WHAT HAPPENED?

Electrical Disturbance, Spin, and In-Flight Breakup

- Seconds after U.S. Air Force Major Mike Adams launched the X-15-3 from beneath the wing of a B-52A, an electrical disturbance disrupted the flight control system, driving MH-96 system gains below 50% and disarming automatic RCS blending as a result.
- Major Adams did report or seem to recognize degraded flight system control. At 140,000 ft, he shut down the engine, switched the attitude indicator to display roll (called PAI mode), and began a scheduled wing-rocking maneuver.
- During the maneuver, Major Adams exceeded the bank angles specified in the flight plan. This could be attributed to the X-15's degraded flight system performance, triggered by intermittent RCS activity and ultimately by RCS deactivation.
- When Major Adams approached his peak altitude, he realized the RCS had not been operating properly, so he used the left side stick to gain manual control over the rocket thrusters.
- All the while, the aircraft had begun a slow but steady yaw to the right.



- The attitude indicator (set to PAI) showed that the aircraft required a roll to the right, but mishap investigators believe Major Adams instead interpreted the PAI vertical needle as sideslip rather than roll angle.
- Major Adams made a yaw input to the right, which further increased the X-15's heading deviation.
- Now the aircraft had begun descending, but Major Adams was unaware that it was yawed at right angles to its flight path.
- At 240,000 ft, Major Adams radioed to ground control that the aircraft "seems squirrely," but flight monitors could not track aircraft heading, were unaware of his severe situation, and could only suggest to keep the angle of attack high for reentry.

- The X-15 entered a Mach 5 flat spin. Major Adams held both reaction and aerodynamic controls against the spin. After three revolutions, the aircraft stopped rotating and entered a 45-degree inverted dive.
- 130,000 ft of altitude remained for Major Adams to recover from the dive, but he had been severely buffeted by forces eventually exceeding 15 g vertically and 8 g laterally. Any inputs he made, if he was still conscious, would have been resisted by the flight control system, which had initiated and sustained a limit-cycle oscillation.
- Major Adams was unable to eject before the X-15-3 broke apart.

PROXIMATE CAUSE

NASA and the USAF convened an accident board that concluded Major Adams had inadvertently initiated, then increased right drift off his required aircraft heading because of distraction, misinterpretation of the attitude indicator, and possible vertigo. This led to the spin. Post-spin limit-cycle oscillation induced by the MH-96 imposed severe pitch and yaw forces for approximately fifteen seconds until the airframe broke apart. Major Adams was unable to overcome the oscillation or to eject, probably due to the severe *g* forces.

UNDERLYING ISSUES

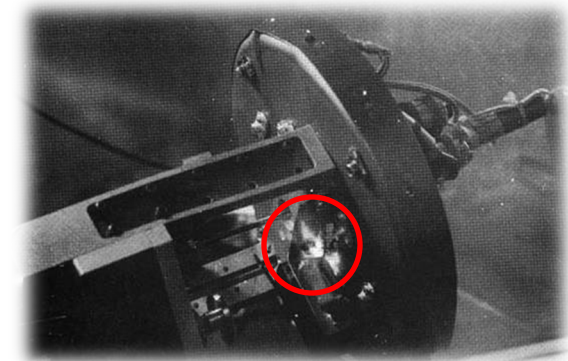
Qualification of Hardware

- Mishap investigators determined that the electrical disturbance had been initiated by an electrical arc from a traversing probe carried in the aircraft's right wingtip pod.
- Testing later showed that the traversing probe's capacitor exhibited electrical arcing tendencies at pressures equivalent to 80,000-90,000 ft.
- The traversing probe had been used on a previous X-15-1 flight. No qualification requirements existed at that time, and project personnel believed the component was safe to use.

Qualification of Flight Crew

- The official accident investigation report postulates that Major Adams likely suffered from vertigo because of his seeming lack of awareness of his heading deviation.
- In 1963, Major Adams took a vertigo test whose results showed that he had an unusual susceptibility to vertigo. But he was considered overall to be physically qualified for test pilot duties.
- Astronauts were required to undergo advanced vertigo "labyrinth sensitivity" tests, but X-15 pilots were not, despite being subject to microgravity. The board recommended the advanced test for X-15 candidates, but the project ended.

Complicated Instrumentation: The attitude indicator's ability to display two different settings added a degree of complexity that heavily impacted the pilot's ability to cope in a critical situation. The mishap investigation board recommended using the attitude indicator "only in the conventional manner."



The red circle highlights arcing exhibited when a traversing probe was placed in an altitude chamber.

FOR FUTURE NASA MISSIONS

- Pilots who flew the X-15 faced an unprecedented challenge: control a hypersonic aircraft at higher altitudes and speeds than ever before while simultaneously conducting experiments.
- After 190 missions, pilots had mastered the demanding task load while handling numerous anomalies.
- The X-15-3 introduced a digital, adaptive flight control system which brought additional complexity with new cockpit instrumentation whose source data demanded constant cross-checks.
- As commercial and government designers again conceive winged vehicles to carry humans above, then reenter Earth's atmosphere at high speeds, the X-15 program provides valuable lessons today.
- Qualification of hardware, software, crew, and passengers must be as uncompromising as space itself.



U.S. Air Force Major Mike Adams stands beside the X-15 in March, 1967.