Columbia Crew Survival Investigation Report

What happened to the
STS-107 *Columbia* crew
and what can be learned from it.

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Notice

The presenter's extended involvement in this investigation has resulted in a certain "comfort" with the subject matter. This comfort should not be interpreted as being cold or unprofessional, nor as a lack of respect for the Columbia crew or their families; it only reflects the fact that extensive time with and exposure to the material has enabled coping with this tragedy and its outcome.

Outcome

- Understand the timeline of events that unfolded as *Columbia* entered the atmosphere on February 1st 2003
- Identify the 5 (five) potentially lethal events encountered by *Columbia* and her crew and the survivability of each event
- Have knowledge of the report that was written which includes recommendations for current and future spacecraft designs and operations
  - NASA/SP-2008-565, *Columbia* Crew Survival Investigation Report is available on-line at http://www.nasa.gov/reports
- Understand that a crew survival analysis is a crucial component of any spacecraft accident

Commander
Rick Husband
Colonel, USAF

Pilot
Willie McCool
Commander, USN

Payload Commander
Mike Anderson
Colonel, USAF

Mission Specialist
Dave Brown
Captain, USN

Mission Specialist
Laurel Clark, M.D.
Captain, USN

Mission Specialist
"KC" Chawla, Ph.D.
Civilian

Payload Specialist
Ilan Ramon
Colonel, Israeli AF

The Crew of STS-107

STS-107 History

113th flight in the Shuttle Program
28th flight of OV-102 *Columbia*
16 day mission

Launch: Jan 16, 2003
15:39 GMT (9:39 am CST)

81.7 seconds into flight, a piece of insulating foam separated from the ET and struck the orbiter's left wing

De-orbit burn: Feb. 1, 2003, 13:15 GMT (7:15 am CST)

Entry Interface (~400k ft, Mach 24.5) occurred at 13:44:09 GMT

Jan 16, 2003

Feb 1, 2003

Planned touchdown was 14:15 GMT (8:15 am CST)

Investigation Background

- *Columbia* Accident Investigation Board (CAIB) chartered in Feb 2003
  - A Crew Survival Working Group (CSWG) was formed to investigate the *Columbia* accident survival gap
    - The group developed a top-level scenario for what happened to the crew module
    - Lack of funding limited the investigation, and no report was published except for what the CAIB put into their report

Investigation Background (cont.)

- CAIB report published in August 2003
  - CAIB report Observation 010.2-1 *“Future crewed-vehicle requirements should incorporate the knowledge gained from the Challenger and Columbia accidents in assessing the feasibility of vehicles that could ensure crew survival even if the vehicle is destroyed.”*
- Spacecraft Crew Survival Integrated Investigation Team (SCSIIT) chartered in October 2004

Investigation Background (cont.)

- SCSIIT Purpose: Form a multi-disciplinary team (engineering, life sciences, crew equipment, crew training, etc) to learn everything possible from these events *to improve both current and future crew survival*
  - Correlate structural/mechanical/thermal engineering with forensic pathology findings for both *Challenger* and *Columbia*
  - Generate a report with specific recommendations for the enhancement of current vehicles and the future designs of manned space vehicles and crew safety equipment, and establish a comprehensive body of information for future efforts
  - Develop "lessons-learned" for investigations and for future spacecraft design engineers, physicians supporting manned space flight, and NASA managers.

Methods

Methods

- To understand the environment the crew experienced, investigators need to look at the accelerations, thermal, and atmospheric aspects of the accident.
- Several sources of data are needed for building an integrated story – video, debris, vehicle telemetry, medical, modeling/ simulation

Methods (cont.)

- Video anchored key events
  - Loss of Control
  - Vehicle breakup
  - Forebody breakup

Methods (cont.)

- Debris analysis proved to be immensely complicated
  - Easy to develop a false scenario from one or two pieces of debris

Methods (cont.)

- Key point to understand is the ballistic number
  - Difficult to determine ballistic number for complex shapes
  - Ballistics analysis cannot account for cascading failures/intermediate configurations

Methods (cont.)

- Aerodynamic models were used to analyze forebody attitude
  - Necessary in determining crew accelerations from highly-directional (and constantly changing) deceleration loads
- This analysis was difficult
  - Aerodynamic model of forebody did not exist
  - Results were highly dependent on initial conditions
  - Aerodynamic properties in hypersonic regime not fully understood

Methods

- Areas that were extraordinarily hard:
  - Materials in a high temperature, low pressure, monatomic oxygen (highly reactive) environment
  - Hypersonic separation dynamics
    - Suit failure – Why? How?
    - Seat Separation
    - Shock wave impingement/shock-shock interaction
  - Emotional impact of analyzing the final moments of the crew's lives

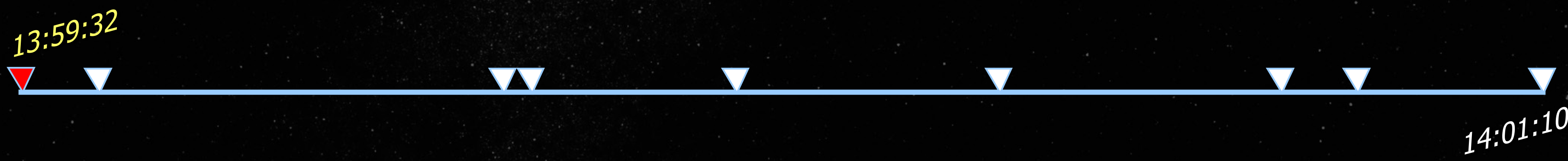
Accident Timeline

Accident Timeline (cont.)

- 13:44:09 Greenwich Mean Time (GMT) (7:44:09 am Central) - Entry Interface (~400,000’, Mach 24.5)

Accident Timeline (cont.)

- 13:44:09 Greenwich Mean Time (GMT) (7:44:09 am Central) - Entry Interface (~400,000’, Mach 24.5)
- 13:58:40 – Backup Flight Software (BFS) Fault Messages were annunciated on board: left inboard tire pressure reading goes off scale low



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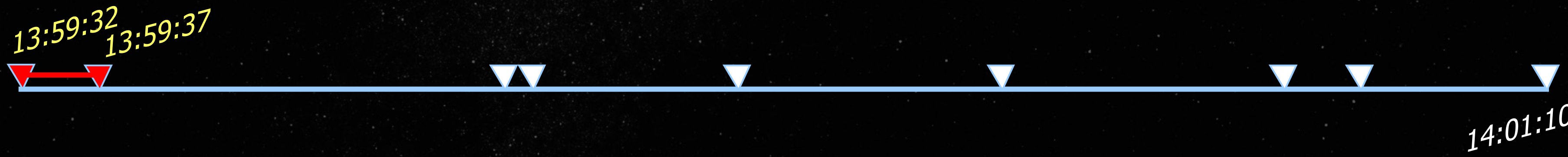

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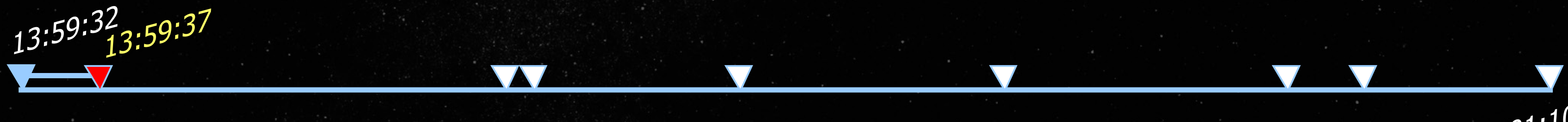
- 13:59:32 - 13:59:37 - Reconstructed General Purpose Computer (RGPC1) data indicate systems nominal, increase to 4 yaw jets & bank angle to try to eliminate yaw error & rate



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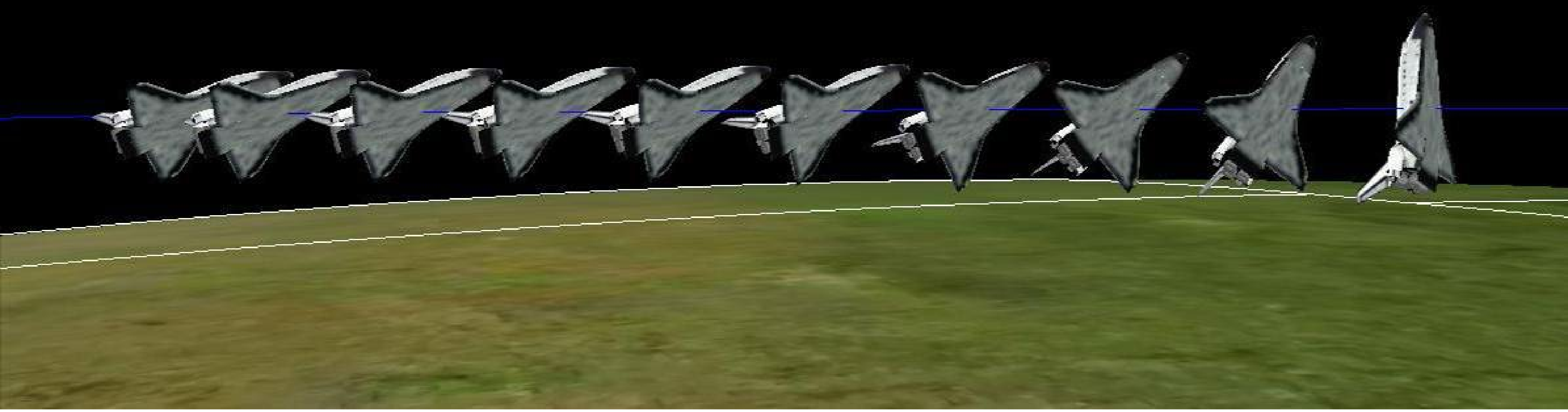
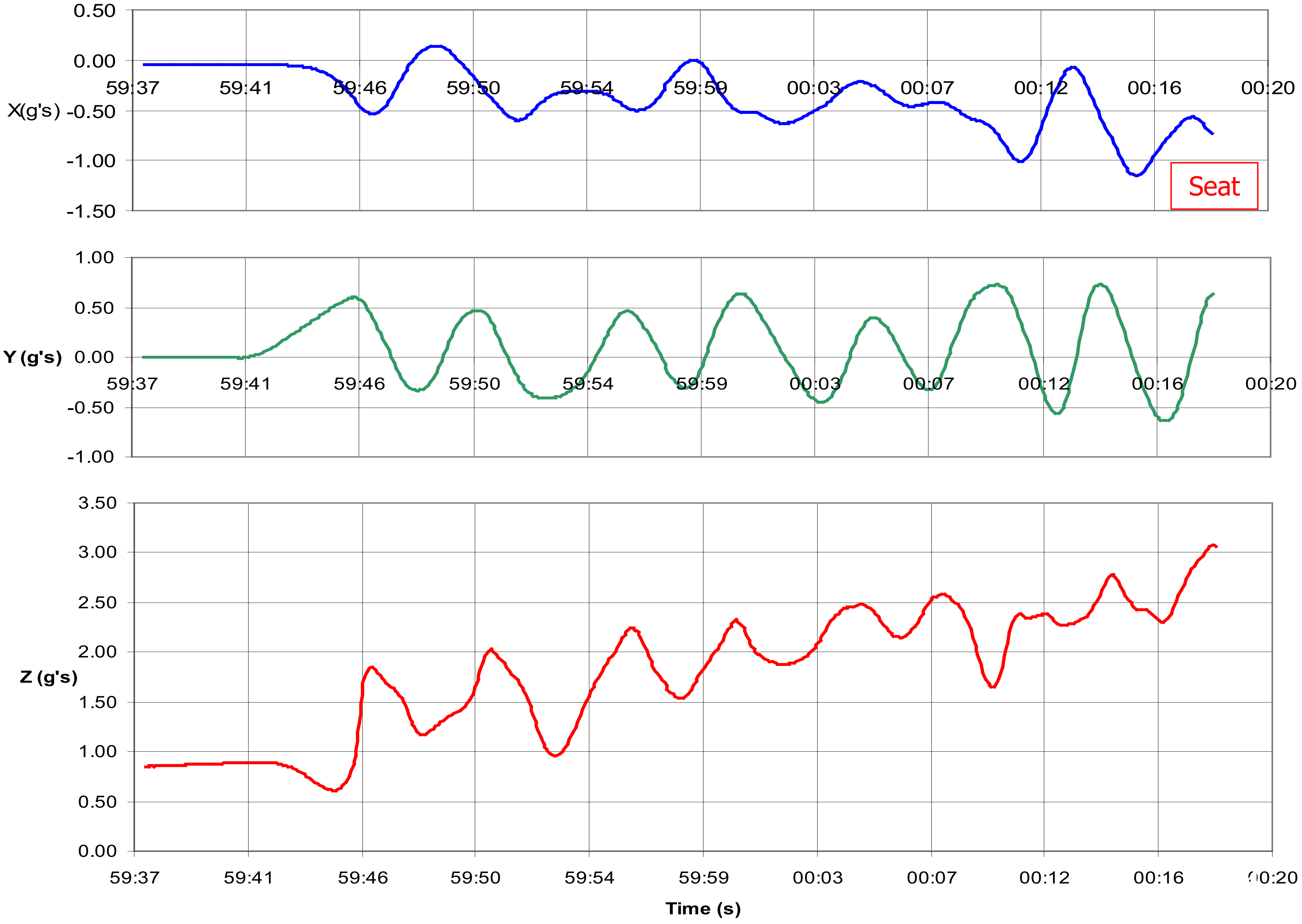
- 13:59:32 - 13:59:37 - Reconstructed General Purpose Computer (RGPC1) data indicate systems nominal, increase to 4 yaw jets & bank angle to try to eliminate yaw error & rate
- 13:59:37 - Start of vehicle Loss of Control (LOC), *based on Roll Ref alarm at 13:59:46*
  - Vehicle dynamics were within human tolerance (probably no injuries, but probably disorienting)

13:59:37 – 13:59:46

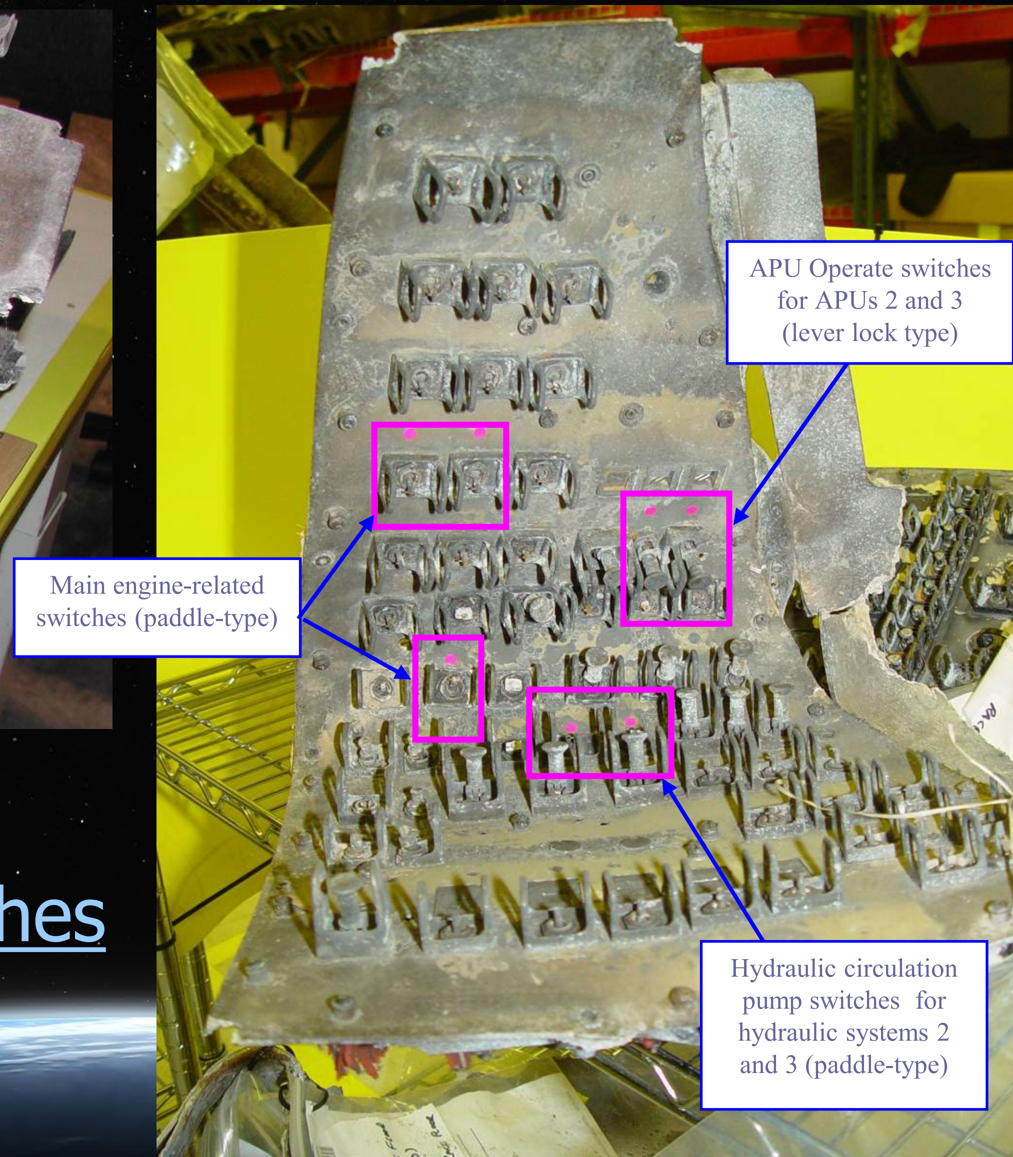




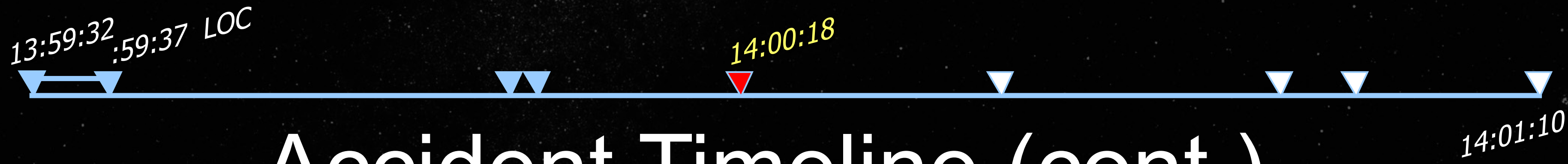
0.50
0.00
X(g's) -0.50
-1.00
-1.50
59:37
59:41
59:46
59:50
59:54
59:59
00:03
00:07
00:12
00:16
00:20
Seat
1.00
0.50
Y (g's) 0.00
-0.50
-1.00
3.50
3.00
2.50
2.00
Z (g's)
1.50
1.00
0.50
0.00
Time (s)

Accident Timeline (cont.)

- 14:00:03 - 14:00:05 – RGPC2 data indicate cabin parameters were normal, auxiliary power units (APUs) were running but hydraulic pressures and quantities were zero
  - Panel R2 APU switches



Panel R2 APU switches



Accident Timeline (cont.)

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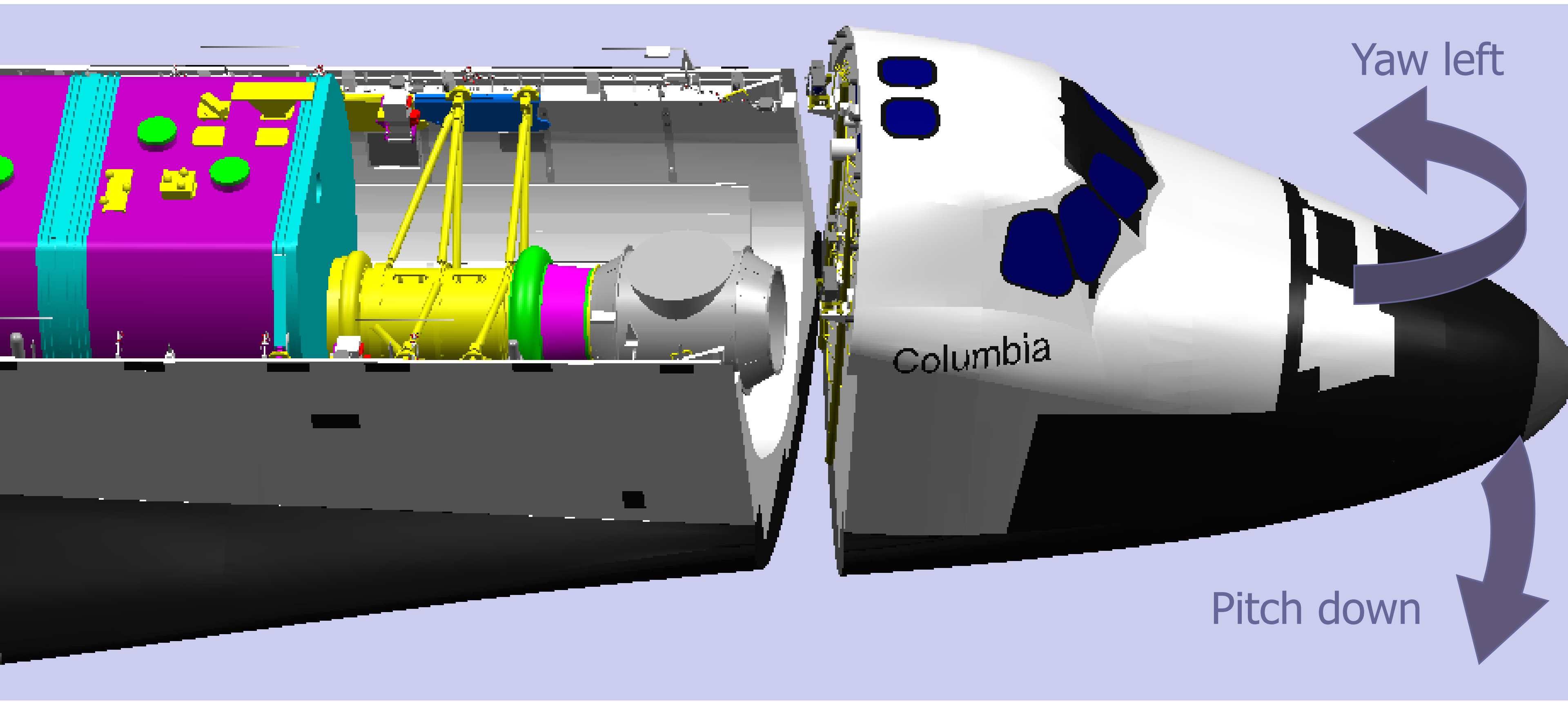
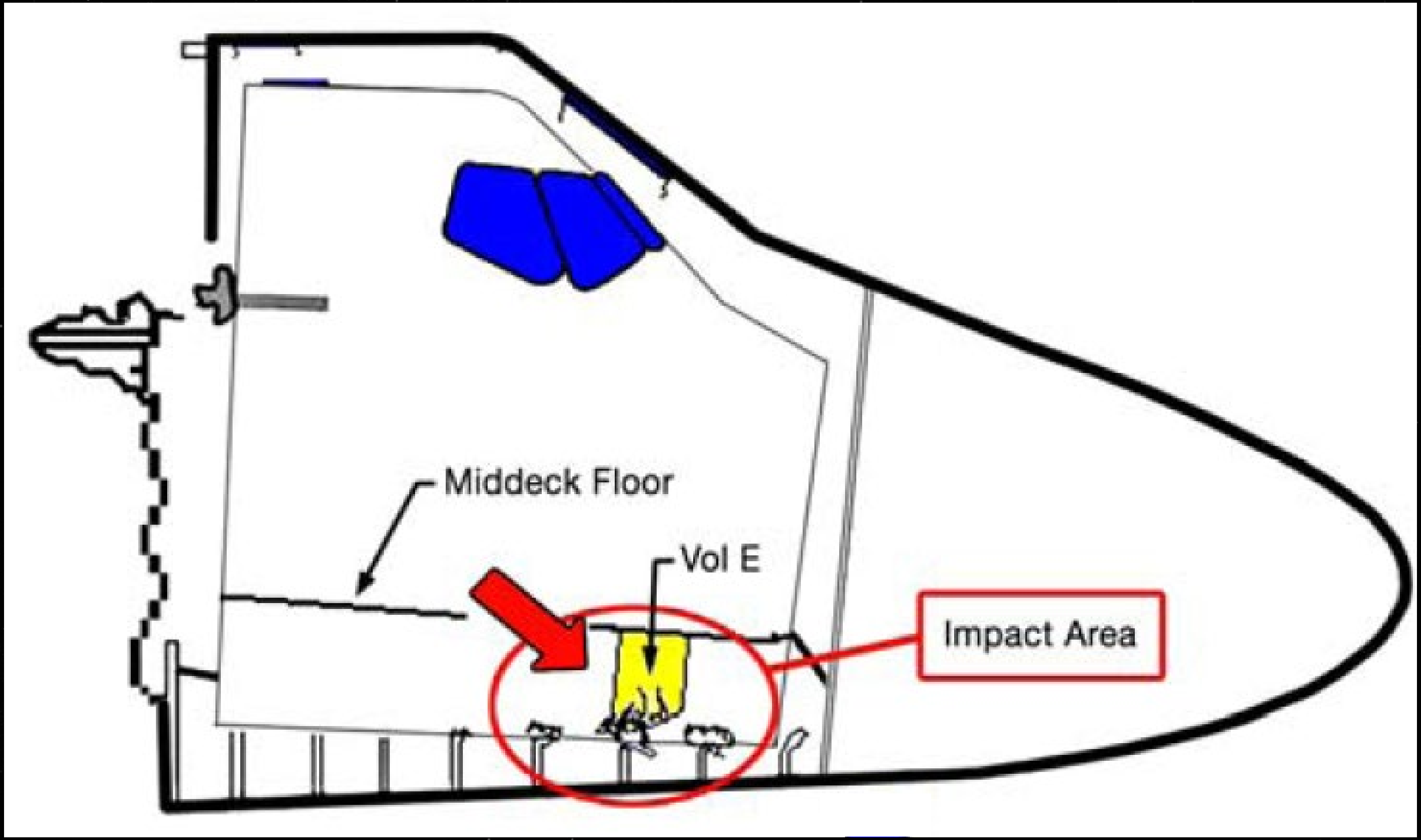
- 14:00:18 – Main vehicle break-up, or “Catastrophic Event” (CE), based on video & Operational/ Experimental (OEX) recorder power loss


Yaw left
Columbia
Pitch down



LOC-CE Quad Video CE Video

Accident Timeline (cont.)

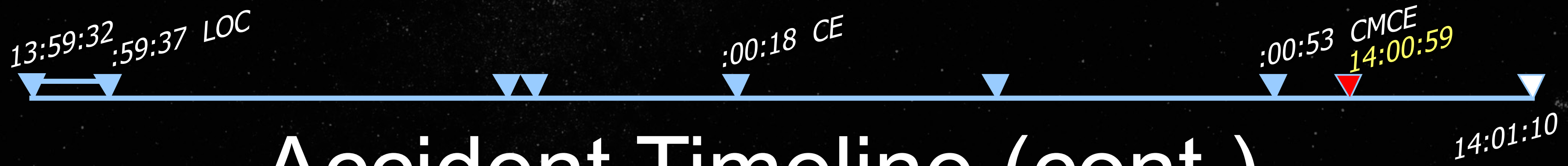
- 14:00:03 - 14:00:05 – Reconstructed General Purpose Computer (RGPC) data indicate cabin parameters were normal, auxiliary power units (APUs) were running but hydraulic pressures and quantities were zero
  - Panel R2 APU switches
- 14:00:18 – Main vehicle break-up, or “Catastrophic Event” (CE), based on video & OEX recorder power loss
  - Medical evidence indicates that the cabin pressure condition at CE was within the bounds of human survival. Therefore the cabin depressurization started No Earlier Than (NET) the CE at 14:00:18

Accident Timeline (cont.)

- 14:00:35 – Cabin depressurization start No Later Than (NLT) time, based on ballistics on patch
  - First lethal event: cabin depressurization (unconsciousness in ~6-8 seconds)

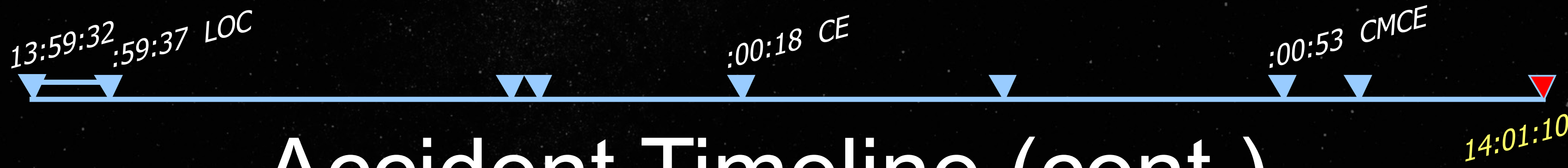
Accident Timeline (cont.)

- 14:00:35 – Cabin depressurization start No Later Than (NLT) time, based on ballistics on patch
- 14:00:53 – Crew module break-up, or "Crew Module Catastrophic Event" (CMCE), based on video



Accident Timeline (cont.)

- 14:00:35 – Cabin depressurization start No Later Than (NLT) time, based on ballistics on patch
- 14:00:53 – Crew module break-up, or “Crew Module Catastrophic Event” (CMCE), based on video
- 14:00:59 – Cabin depress complete No Later Than (NLT) time, based on video – crew module lost significant structural integrity by this time



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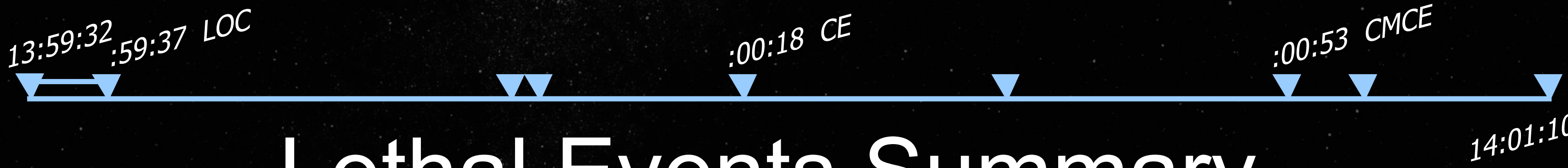
- 14:00:53 – Crew module break-up, or "Crew Module Catastrophic Event" (CMCE), based on video
- 14:00:59 – Cabin depress complete No Later Than (NLT) time, based on video – crew module lost significant structural integrity by this time
- 14:01:10 - Total Dispersal, based on video

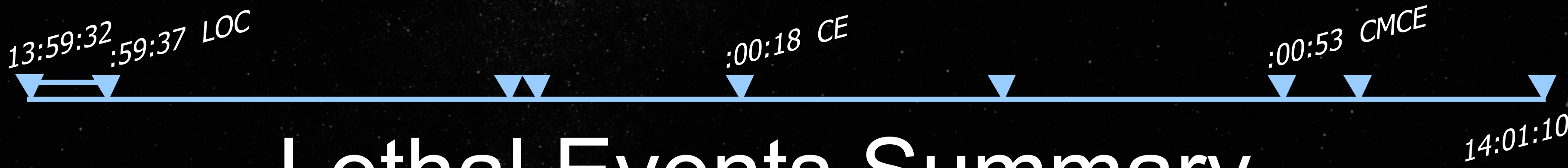
Accident Timeline (cont.)

- Following CE and CMCE (unconscious crew):
  - Second lethal event: exposure to a dynamic rotating environment with nonconformal helmets and a lack of upper body restraint
  - Third lethal event: separation from the crew module and seats with associated forces, material interactions, and thermal consequences
  - Fourth lethal event: exposed to near vacuum (~0.03 psi @140,000’), aerodynamic accelerations, and cold temperatures
  - Fifth lethal event: ground impact



Lethal Events Summary

- First lethal event: cabin depressurization unconsciousness in ~6-8 seconds
  - SURVIVABLE with current shuttle crew escape hardware
- Second lethal event: exposure to a dynamic rotating environment with nonconformal helmets and a lack of upper body restraint
  - SURVIVABLE with current technology
- Third lethal event: separation from the crew module and seats with associated forces, material interactions, and thermal consequences
  - NOT SURVIVABLE with current technology



Lethal Events Summary

- Fourth lethal event: exposed to near vacuum (~0.03 psi @140,000’), aerodynamic accelerations, and cold temperatures
  - SURVIVABLE**?** with current technology (if equipment remains intact)
- Fifth lethal event: ground impact
  - SURVIVABLE with current shuttle crew escape hardware (if equipment remains intact and automatic parachute sequence is initiated)

Key Finding and Recommendation Example

Crew Suits

- None of the crew members lowered and locked their visors
  - *Future spacecraft crew survival systems should not rely on manual activation to protect the crew*

Investigation Process

- The investigation effort suffered from a low priority relative to other shuttle program recovery efforts. Team members had to divide their time between the investigation work and the work for their home organization.
  - *In the event of a future fatal human spaceflight mishap, NASA should place high priority on the crew survivability aspects of the mishap both during the investigation as well as in its follow-up actions using dedicated individuals appropriately qualified in this specialized work.*

Summation

The *Columbia* Crew Survival Investigation was performed with the belief that a comprehensive, respectful investigation could provide knowledge that would improve the safety of future space flight crews and explorers.

By learning these lessons and ensuring that we continue the journey begun by the crews of Apollo 1, *Challenger*, and *Columbia,* we help to give meaning to their sacrifice and the sacrifice of their families. It is for them, and for the future generations of explorers, that we strive to be better and go farther.

Ad Astra Per Aspera – Semper Exploro

To the Stars Through Adversity - Always Exploring

Apollo 1 – Challenger – Columbia

СОЮЗ 1 - СОЮЗ 11