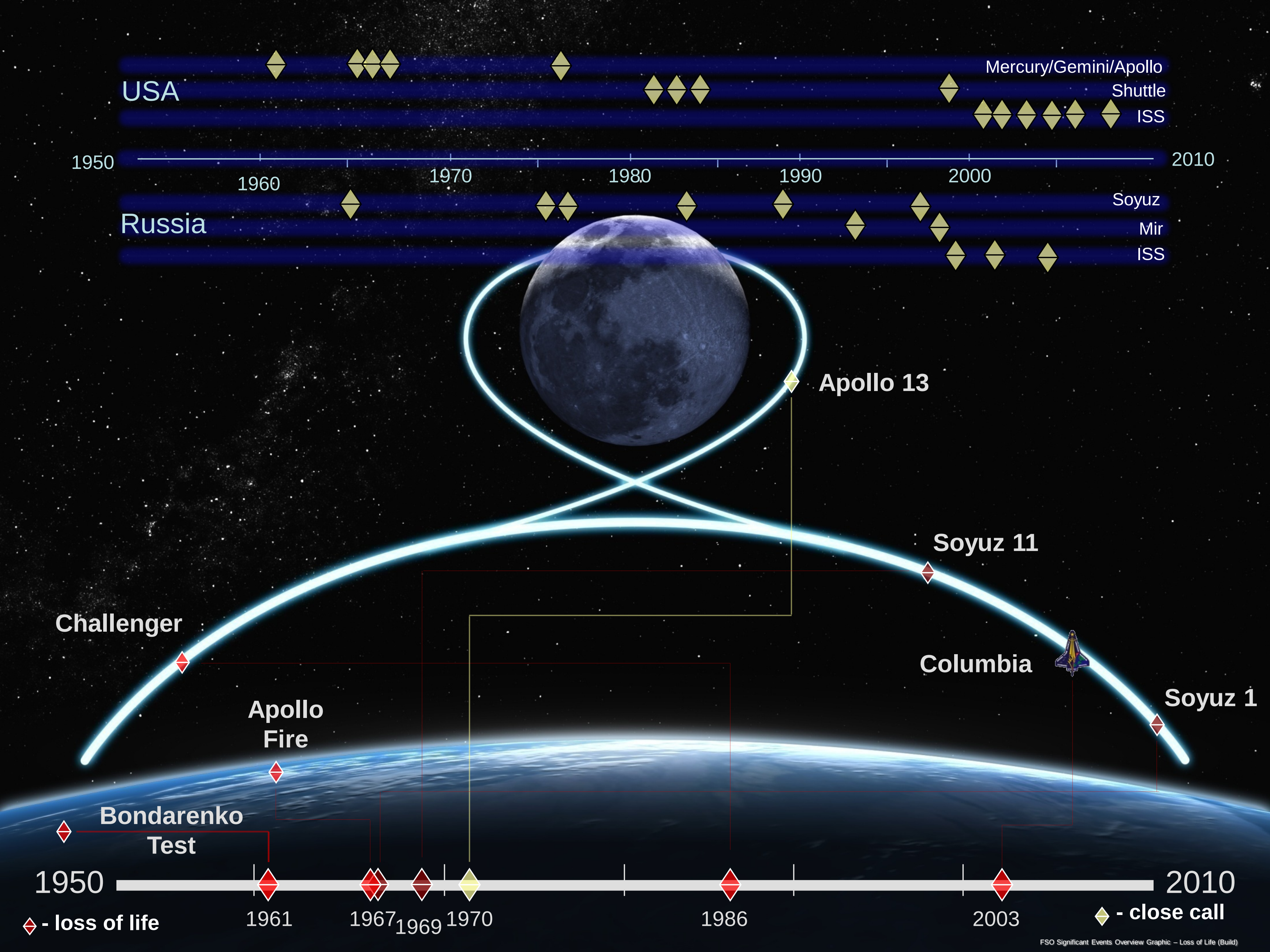
Columbia Crew Survival Investigation Report

What happened to the
STS-107 *Columbia* crew

and what can be learned from it.

Nigel J. Packham
JSC S&MA



USA
Mercury/Gemini/Apollo
Shuttle
ISS
1950
1960
1970
1980
1990
2000
2010
Russia
Soyuz
Mir
ISS
Apollo 13
Soyuz 11
Challenger
Columbia
Soyuz 1
Apollo Fire
Bondarenko Test
1950
2010
1961
1967
1969
1970
1986
2003
- loss of life
- close call
FSO Significant Events Overview Graphic – Loss of Life (Build)

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.

Purpose of this briefing

- Summarize the investigation activities, key findings and recommendations
  - Discuss how recommendations are being addressed by Shuttle and Orion

NASA/SP-2008-565, *Columbia* Crew Survival Investigation Report is available on-line at http://www.nasa.gov/reports

Agenda

- Background
- Methods
- Accident Timeline
- Key Findings/Recommendations

Background

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
  - Best for broad assessments
    - fire?
    - directional loading?
    - thermal events?

Methods (cont.)

- Thermal and loads are inter-related due to the trajectory, and are driven by ballistic number
  - Report includes a “Ballistics Tutorial”
  - Trajectory (translation) models can also provide thermal exposure estimates
- 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 (cont.)

- Attempted to develop the cabin depressurization timeline from both angles
  - What did medical data indicate
    - Literature search of past depress accidents
  - What did debris indicate
    - Structural debris – middeck floor
    - Debris cluster analysis of crew module structure vs. crew equipment
    - Depressurization tests on drink bags and hygiene packages
  - Boundary driven – “not greater than,” “no earlier than,” etc

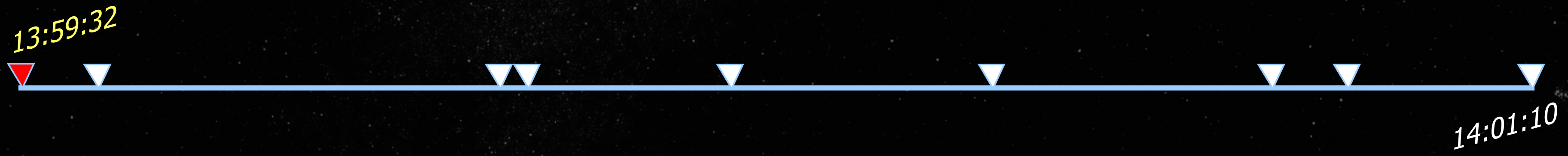
Methods

- Areas that were extraordinarily hard:
  - Materials in a high temp., 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)
- 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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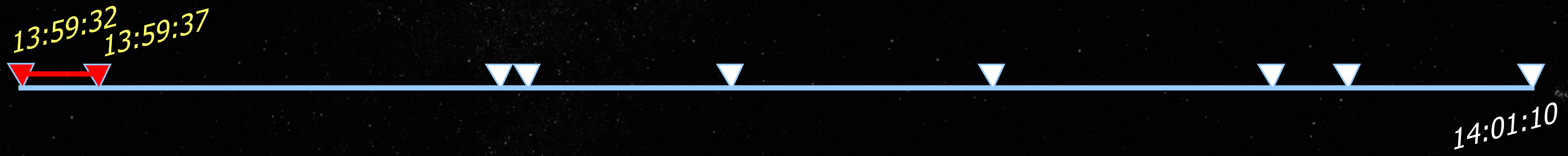

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- 13:59:32 - 13:59:37 - Reconstructed General Purpose Computer (RGPC1) data indicate systems nominal, increase to 4 yaw jets & bank angle to try to eliminate yaw error & rate

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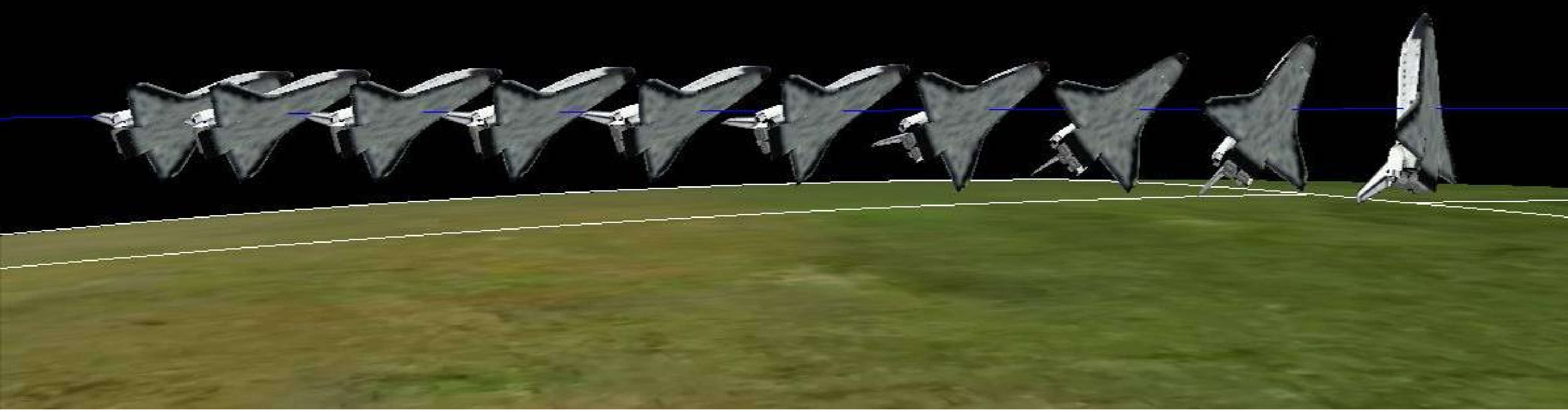
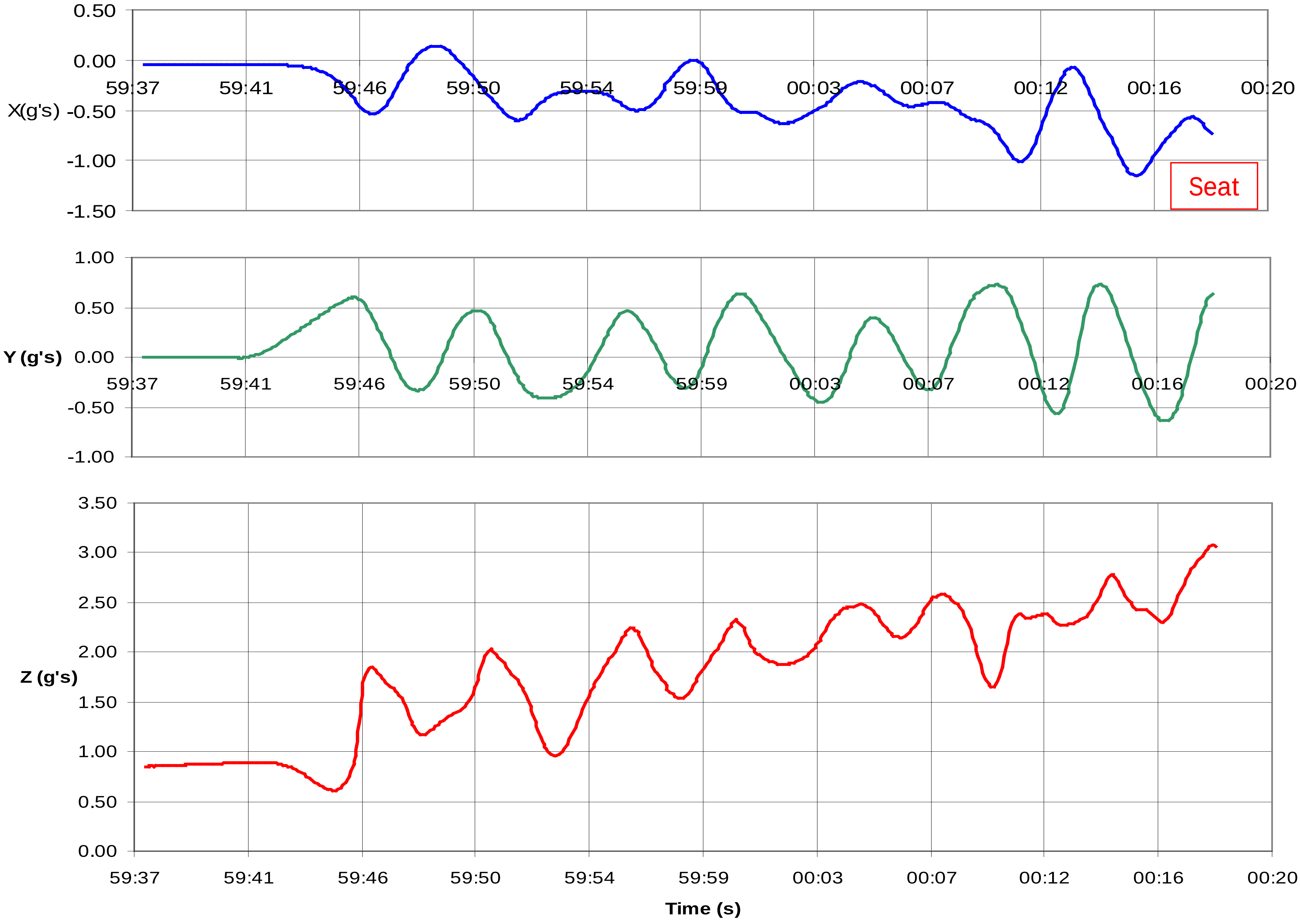
- 13:59:32 - 13:59:37 - Reconstructed General Purpose Computer (RGPC1) data indicate systems nominal, increase to 4 yaw jets & bank angle to try to eliminate yaw error & rate
- 13:59:37 - Start of vehicle Loss of Control (LOC), *based on Roll Ref alarm at 13:59:46*
  - Vehicle dynamics were within human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

13:59:37 – 13:59:46



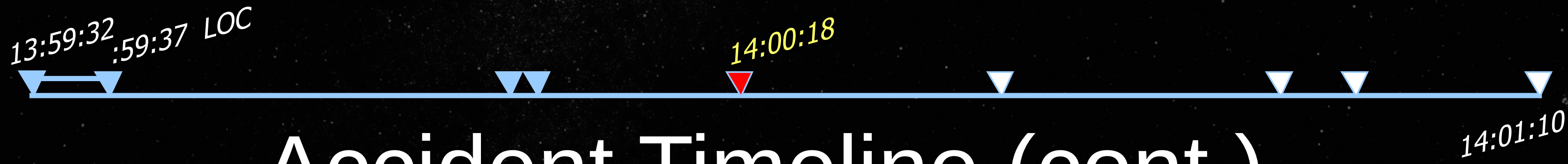
LOC Sim Video CDR POV Sim Video



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)

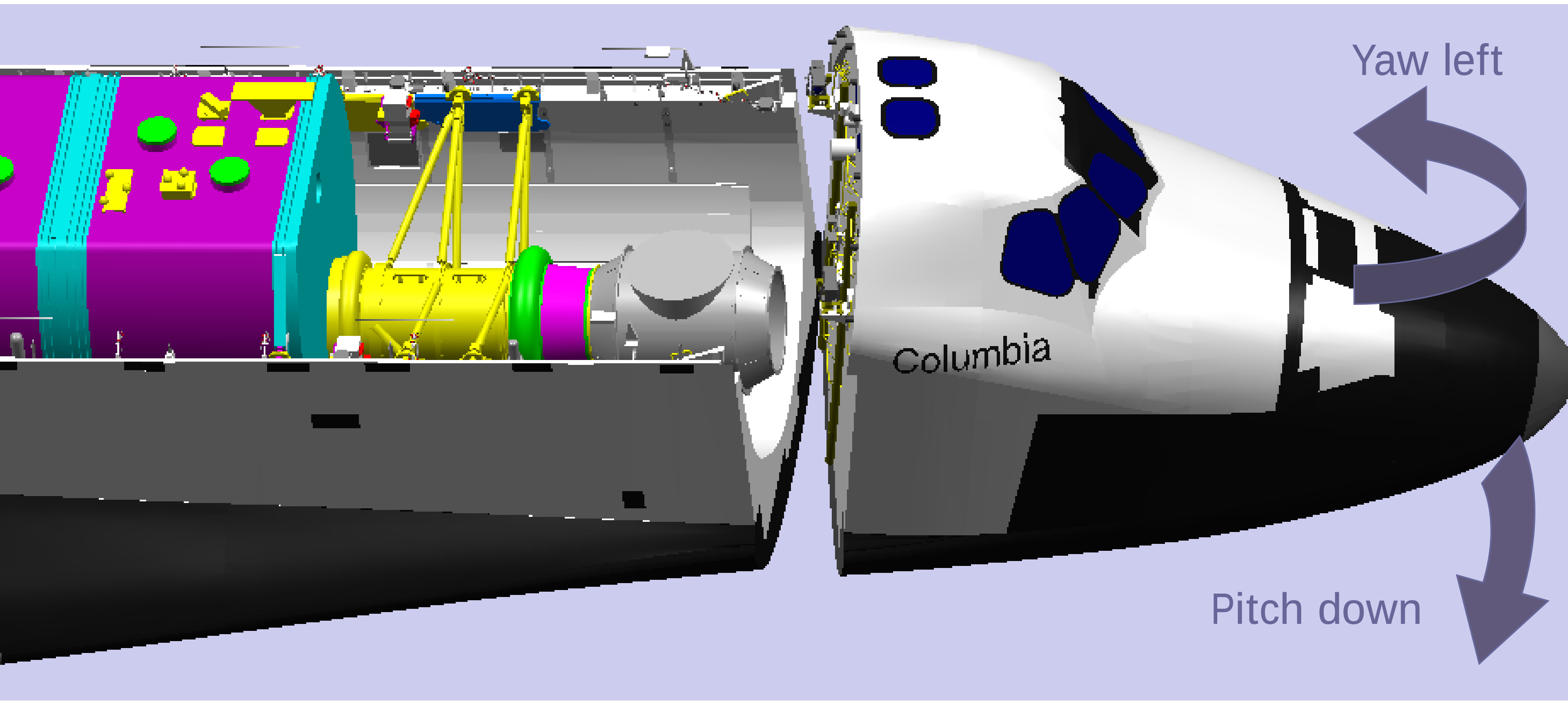
Accident Timeline (cont.)

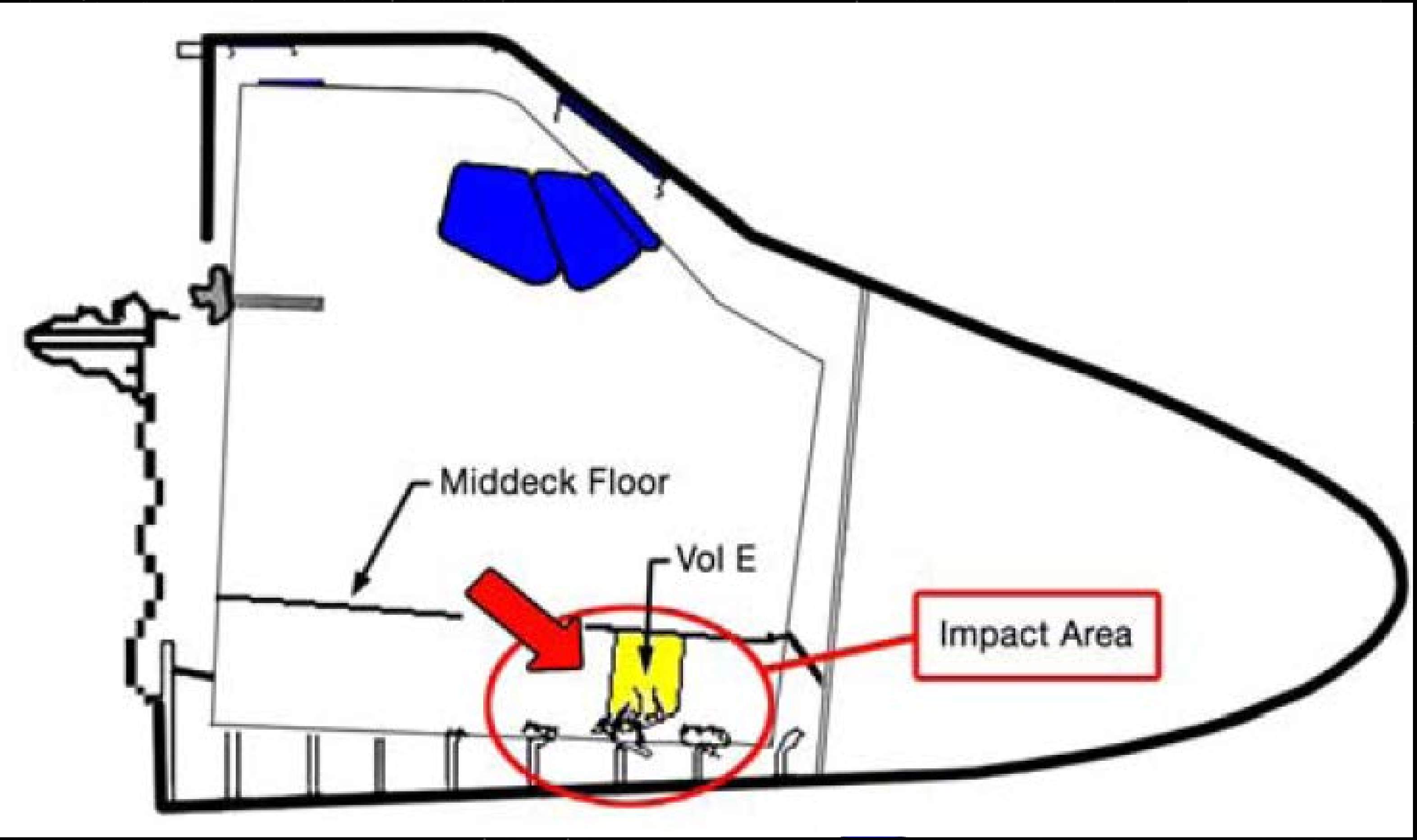
- 14:00:03 - 14:00:05 – RGPC2 data indicate cabin parameters were normal, auxiliary power units (APUs) were running but hydraulic pressures and quantities were zero
  - Panel R2 APU switches



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
- 14:00:18 – Main vehicle break-up, or “Catastrophic Event” (CE), based on video & Operational/ Experimental (OEX) recorder power loss
  - Forebody separation was due to starboard payload bay sill failure (thermal), and the starboard X-link pulled through the 582 ring frame. The forebody yawed left and pitched down, and the port X-link failed at the 582. The crew module shifted inside the forward fuselage, causing impacts & probable breaches (Vol. E damaged from below)


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.)

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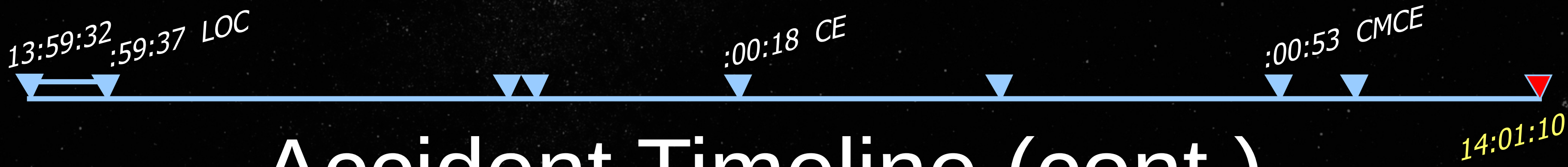
- 14:00:53 – Crew module break-up, or "Crew Module Catastrophic Event" (CMCE), based on video
- 14:00:59 – Cabin depress complete No Later Than (NLT) time, based on video – crew module lost significant structural integrity by this time



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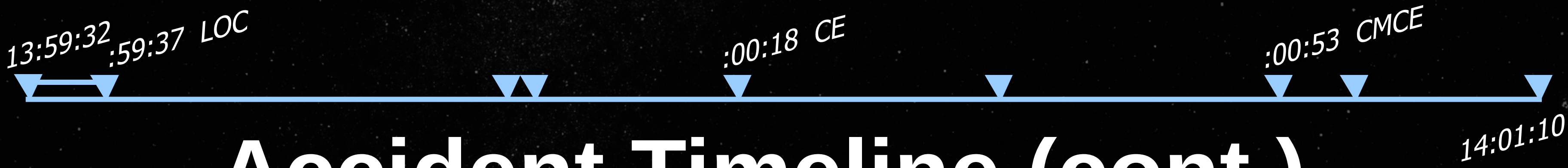
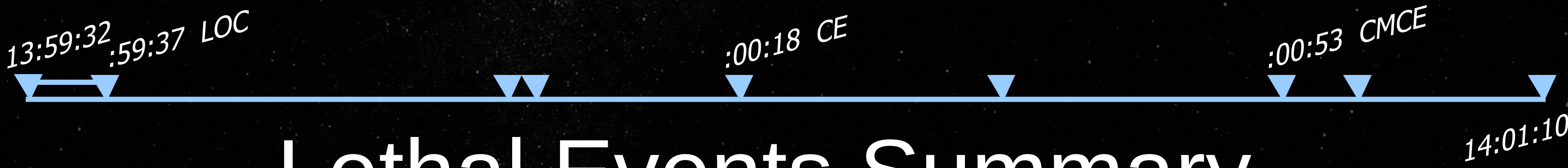
- 14:01:10 - Total Dispersal, based on video
  - Apache video of CMCE thru TD



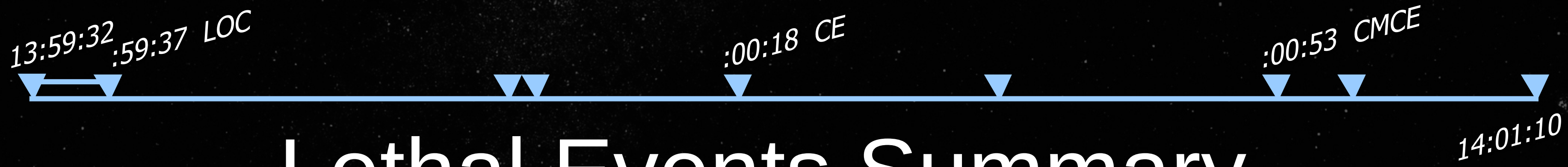
Accident Timeline (cont.)

- 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 Findings and Recommendations

Vehicle Design and Operations

- Three crewmembers did not complete glove donning, one did not complete helmet donning nor seat strap-in. The deorbit preparation period of shuttle missions is so busy that crew members frequently do not have enough time to complete the deorbit preparation tasks prior to the deorbit burn.
  - *Future spacecraft and crew survival systems should be designed such that the equipment and procedures provided to protect the crew in emergency situations are compatible with nominal operations. Future spacecraft vehicles, equipment, and mission timelines should be designed such that a suited crew member can perform all operations without compromising the configuration of the survival suit during critical phases of flight*
  - Shuttle D/O Prep training partially addresses this. Hardware and timeline issues not addressed by Shuttle
  - Constellation suits and Orion have requirements to accommodate suit donning in 1 hour. Cabin reconfiguration operations are not addressed

Vehicle/Suit interfaces

- The current Advanced Crew Escape Suit (ACES) was added after the shuttle cockpit was designed and built. In many cases, the operations that the crew must perform are difficult to perform while wearing the suit. Some crewmembers must choose between not wearing portions of the suit (gloves) to perform tasks efficiently, or wearing their gloves to protect against off-nominal atmospheric situations at the expense of nominal operations
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  - Orion is being designed to be operable by a pressure suited crewmember

Vehicle Redundancy

- Complete loss of hydraulic pressure to the aerosurfaces resulting from the breach in the left wing was the probable proximal cause for the vehicle LOC
  - *Future vehicles should be designed with a separation of critical functions to the maximum extent possible and robust protection for individual functional components when separation is not practical*
  - Orion required to comply with the requirement in JSC Design and Procedural Standards, Section G-2

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*
  - Not currently addressed by Constellation requirements or designs

Crew Suits

- Lethal injuries resulted from inadequate upper body restraint and protection during rotational motion
  - *Design suit helmets with head protection as a functional requirement. Suits should incorporate conformal helmets with head and neck restraint devices*
  - The Constellation Suit has head impact and head/neck injury protection requirements

Crew Seats

- The seat inertial reels did not lock. Lethal injuries resulted from inadequate upper body restraint and protection during rotational motion
  - *The current shuttle inertial reels should be manually locked at the first sign of an off-nominal situation*
  - Shuttle crews are now instructed to lock inertial reels at the first sign of an off-nominal situation. Also added a step to the LOC/Breakup procedures
  - *The use of inertial reels in future restraint systems should be evaluated to ensure that they are capable of protecting the crew during nominal and off-nominal situations without active crew intervention*
  - Shuttle seat inertial reels have been changed to MA-16 type (seat acceleration-sensing in addition to strap acceleration-sensing)
  - Orion seats do not use inertial reels

Crew Seats

- The seat restraint system caused lethal-level injuries to the unconscious or deceased crew members when they separated from the seat
  - *Future spacecraft suits and seat restraints should use state-of-the-art technology in an integrated solution to minimize crew injury and maximize crew survival in off-nominal acceleration environments*
  - Orion seats are being designed with Occupant Protection as a key driver. Design features include lateral bolsters, flail restraints, and wide belts.

Crew Training

- The current training regimen separates vehicle systems training from crew escape training.
  - *Incorporate objectives in the astronaut training program that emphasize understanding the transition from recoverable systems problems to impending survival situations*
  - Not currently addressed formally in crew training
  - Informally addressed by CDR and crew escape training

Crew Procedures

- The vehicle LOC emergency egress procedures taught to the STS-107 crew did not address a LOC occurring during entry
  - *Assemble a team of crew escape instructors, flight directors, and astronauts to assess orbiter procedures in the context of ascent, deorbit, and entry contingencies. Revise the procedures with consideration to time constraints and the interplay among the thermal environment, expected crew module dynamics, and crew and crew equipment capabilities*
  - For Shuttle – in work
  - *Prior to operational deployment of future crewed spacecraft, determine the vehicle dynamics, entry thermal and aerodynamic loads, and crew survival envelopes during a vehicle LOC so that they may be adequately integrated into training programs*
  - Not yet addressed for Orion

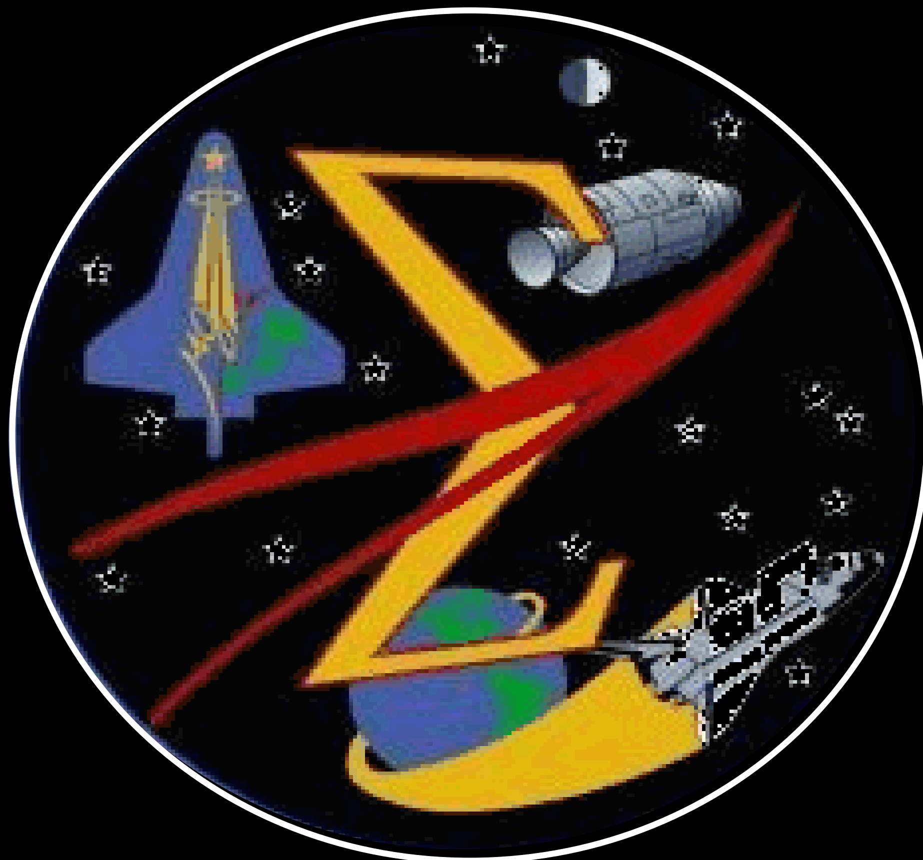
Investigation Process

- SCSIIT 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. This led to delays in completing the SCSIIT work and, in some cases, significant decrease in availability or complete loss of members of the SCSIIT.
  - *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 SCSIIT 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.

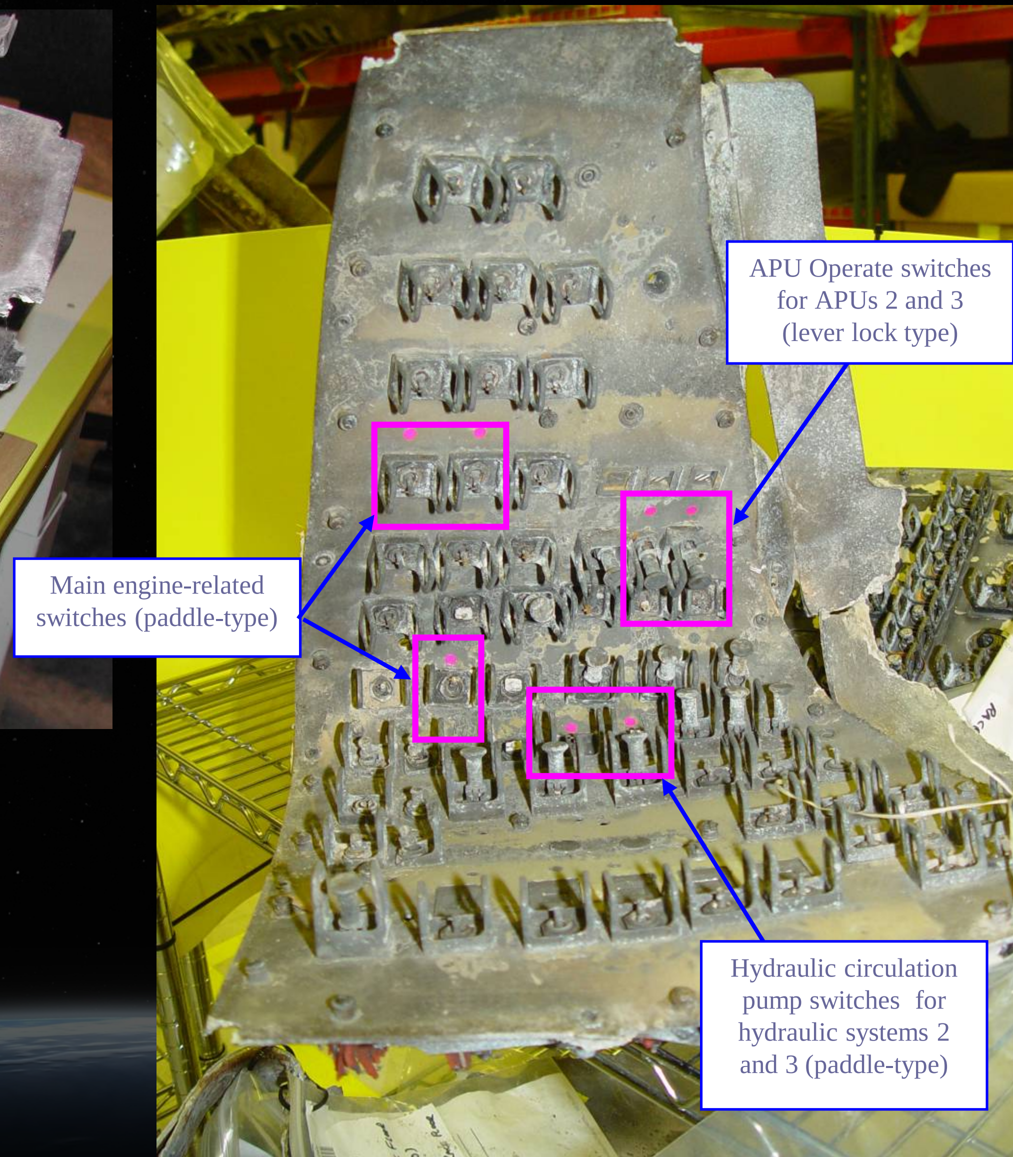


Ad Astra Per Aspera – Semper Exploro

To the Stars Through Adversity - Always Exploring

Apollo 1 – Challenger – Columbia

СОЮЗ 1 - СОЮЗ 11


APU Operate switches for APUs 2 and 3 (lever lock type)
Main engine-related switches (paddle-type)
Hydraulic circulation pump switches for hydraulic systems 2 and 3 (paddle-type)

Return

ORBITER STRUCTURE

Return