National Aeronautics and Space Administration

SPACE SHUTTLE COLUMBIA

LESSONS LEARNED

Scott Thurston, Retired ELVIS 3 Deputy Program Manager, a.i. solutions

Former NASA Columbia Vehicle Manager

David Erickson, NASA Mishap Program Specialist

HONORING THE CREW

SPACE SHUTTLE COLUMBIA LESSONS LEARNED

SPACE SHUTTLE COLUMBIA

STS-107 Crew

L-R: David Brown, Rick Husband, Laurel Clark, Kalpana Chawla, Michael Anderson, William McCool, Ilan Ramon

ABOUT ORBITAL VEHICLE-102 AND STS-107

SPACE SHUTTLE COLUMBIA LESSONS LEARNED

SPACE SHUTTLE COLUMBIA

Orbital Vehicle-102

FIRST OF NASA'S FLEET OF 5 ORBITERS TO FLY IN SPACE

28 flights

7,218 hours in flight

4,808 orbits around the Earth

STS-107 Preparation For Launch

ORBITER PROCESSING FLOW (4 ORBITERS)

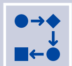
~4-month duration

~40,000 touch labor hours

2 launches per year per Orbiter

~21,000 requirements

24/7 schedule to the hour

 1,000s of procedures containing millions of work instruction

Everything was checked and double-checked!

11-05-2004 05:41

SAFETY! Always Top Priority

Kennedy Mid Tem Schedule
25 day/day Date/day Form/landscape
(FOR PLANNING PURPOSES ONLY)

Assessment
STS121 OV-104 by System
Page 1 of 42

November: 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

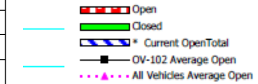
Line	Task
1000	**APU**
1001	APU-170 TEST COUPON INSPECTION (APU)(AFT)121V170G
1002	**COM**
1003	COM-534 INSTALL WVS ANTENNAS #2/3 (COM)(MID)121V534
1004	V5A64.002C//V63-50054 MSBLS WAVE GUIDE INSTALLATION/INSTALL BLANKETS (COM)(FWD)121V5A64
1005	V6044.001 D 5 MSBLS DESICCANT CHECKS (RUN 14) (COM)(FWD)121V181N
1006	COM-528 (MCR 23278) OP 10 ROUTE COAX FOR WVS UHF ANTENNA RELOCATION (COM)(F/M)121VBOOMWIRE
1007	COM-532 (MCR XXXXX) R&R CONNECTOR SAVERS (COM)(FWD)121V532
1008	V1062.001 F 3 ADTA MULTIPOINT PRESSURES TESTING (COM)(FWD)(LPS)121V1062C
1009	V5A04 G ORBITER S-BAND TRANSPONDER #1 INSTALLATION (COM)(FWD)121V5A04
1010	COM-531 GPS SHOCK MOUNT INSTALLATION (COM)(FWD)121V531
1011	V5A53 A ANTENNA SWITCH BEAM CONTROLLER INSTALLATION (COM)(FWD)121V5A53B
1012	V1062.002 D 1 AIR DATA SYSTEMS INTERVAL TESTING (COM)(FWD)(CONTROL BUS DROPS)(LPS)121V1062E
1013	V1288.002 E 1 (CHIT J5624) ORBITER S-BAND RETURN/INSERTION LOSSES (COM)(FWD)(LPS)121V1288
1014	V1348 STOW KU-BAND ANTENNA (COM)(MID)(REQ'S RH PLBD OPEN TO 160)(LPS)121V1276J
1015	V5A31 E 2 NSP #1 INSTALLATION (COM)(FWD)(REQUIRED FOR KU-BAND TESTING)121V5A32
1016	V5A37.002 F 2 KU BAND EA-1/SPA INSTALLATION (COM)(FWD)(REQUIRED KU-BAND TESTING)121V5A09AC
1017	V1348 OP 50/70 DEPLOY KU-BAND ANTENNA (COM)(MID)(REQ'S RH PLBD OPEN TO 160)(LPS)121V1276K
1018	V5A47/48 INSTALL COMSEC UNIT #1/2 INSTALLATION (COM)(FWD)121V5A47
1019	V1178 KU-BAND COMM/RADAR SYSTEMS TEST (COM)(MID)(OMM/SEE MINI FOR CLEARS)(LPS)121V1178
1020	**DPS**
1021	LRU CONNECTOR MATES (DPS)(FWD)121V5A09U
1022	V5L25.001/3 INSTALL IDP #1/3 (DPS)(FWD)121V5L25002D
1023	V5L24.003A3/.005A3 MDU CRT #1/3 INSTALLATION (DPS)(FWD)121V5L24
1024	V5L24.XXX MDU INSTALLATION (DPS)(FWD)121V5L24A
1025	DIG-214 IDP #1/3 LOAD (DPS)(FWD)(LPS)121V214A
1026	V1184 LOAD MMU 1 (DPS)(FWD)(LPS)121V1184F
1027	V5L18.006 A 1 PDU DESICCANT INSPECTION (DPS)(FWD)(RUN 9)121V209Q
1028	V5L18.001A1/.002A1 PDU #1/2 INSTALLATION (DPS)(FWD)121V5L18
1029	V5L19 F 1 HEADS UP DISPLAY ELECTRICAL INSTALLATION (DPS)(FWD)121V5L18A
1030	**ECL**
1031	V1291.005 B 05 FES PURGE (ECL)(AFT)121V284Q
1032	ECL-1365 INSULATION ON LINES VERIFY (ECL)(FWD)121V1365B
1033	ECL-582 (MCR 17177) POTABLE WATER/GN2 FLEXHOSE MOD (ECL)(MOD SQUAD)(FWD)121VFLEY
1034	ECL-1342/3/4 WCL #1 FLEXHOSE R&R (ECL)(MOD SQUAD)(FWD)121VFLEZ
1035	ECL-577 RADIATOR FLEXHOSE RTV (ECL)(MID)121V577E
1036	ECL-1352/1417 WCL #1 FLEXHOSE R&R/X-RAY (ECL)(MOD SQUAD)(FWD)(LOCAL CLEAR)121VFLEAA

HOLIDAY

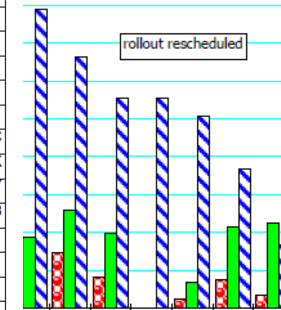
LEGEND: PLANNED WORK, ROUTINE, MINOR HAZARD, MAJOR HAZARD, PRE-OPS, COMPLETE

* Curre
Paper (
OV-102 A
All Vehicles A
Cumm Open

OUT: Jan 16, 2002



FINAL



2/7	12/14	12/21	12/28	1/4	1/11	1/18
100	145	82	0	25	75	34
187	259	198	0	67	214	226
789	663	554	554	507	367	167
261	236	247	247	214	191	115
783	3928	4010	4010	4035	4110	4144

SPACE SHUTTLE COLUMBIA

Environment For KSC Operations Of Space Shuttle System

SPACE SHUTTLE COLUMBIA

Processing Completed in Orbiter Processing Facility

Columbia Launch Day

Launch occurred after 13 delays over two years, due mainly to other missions taking priority

Launch Date: January 16, 2003

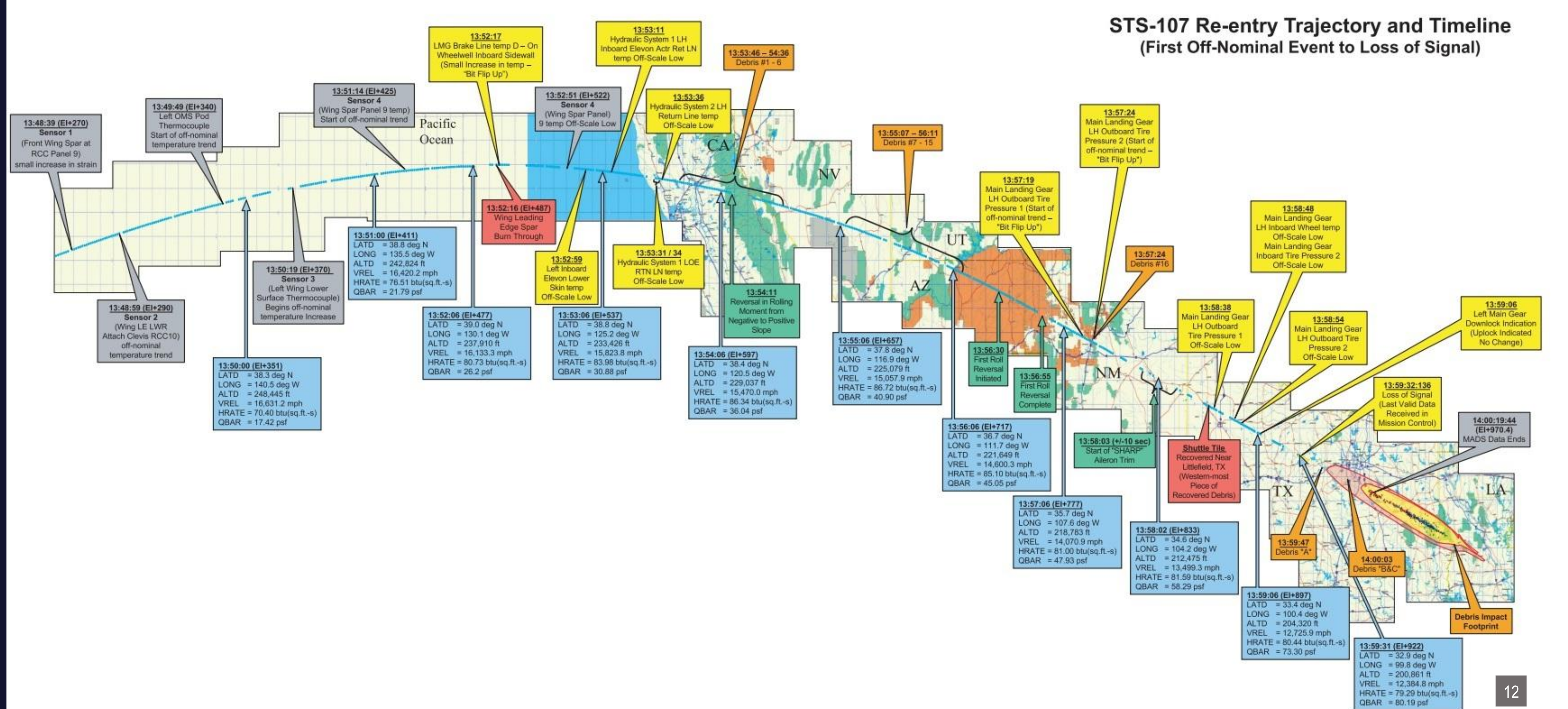
Last mission for OV-102; the crew completed 80+ international scientific experiments

RECOVERY EFFORTS

SPACE SHUTTLE COLUMBIA

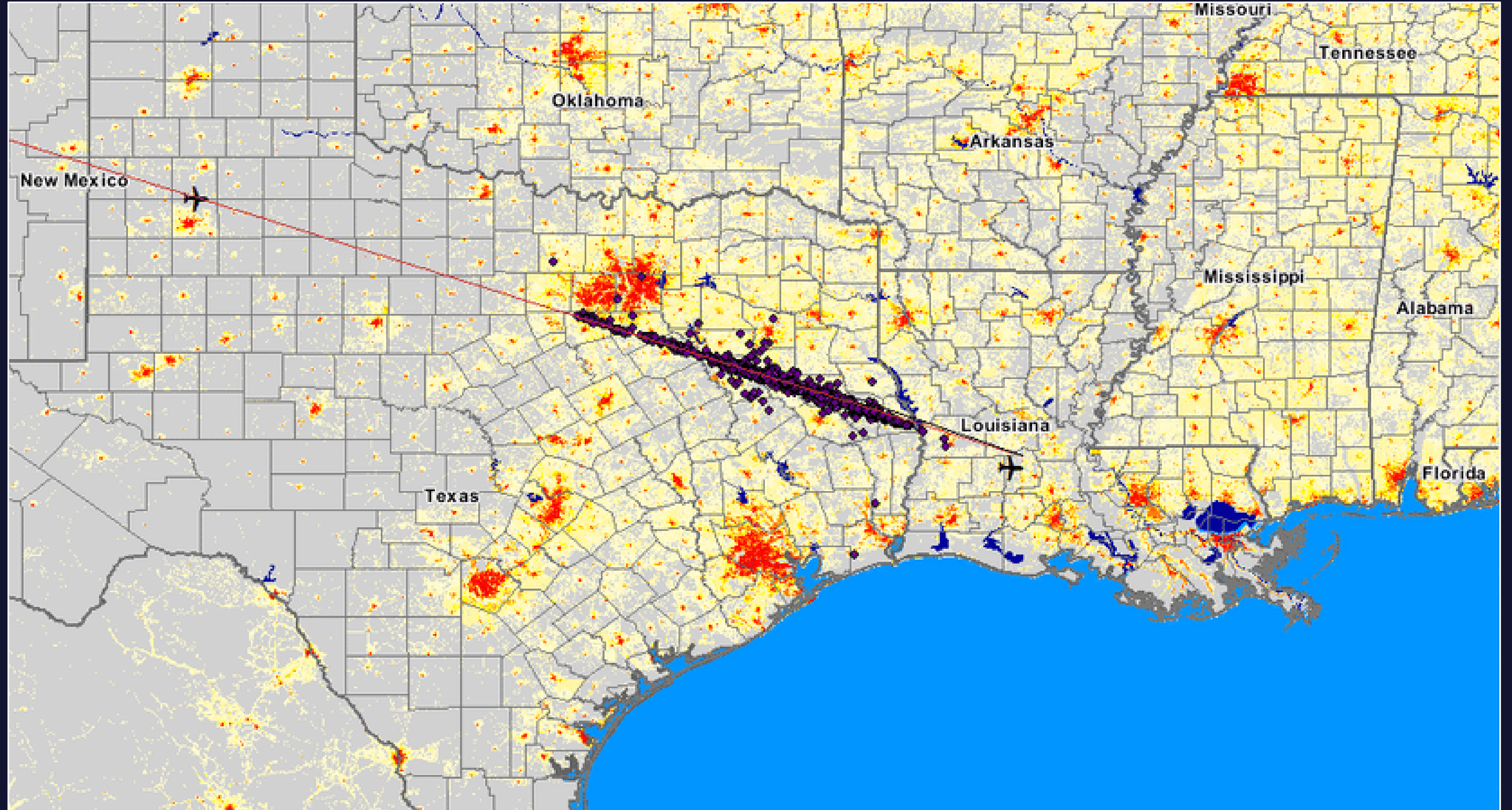
SPACE SHUTTLE COLUMBIA

Trajectory Map



Ground and Air Searches

- **Debris field** was approximately 3,600 square miles (approaching the size of Connecticut)
- **Ground searches** with 20-person strike teams who walked 2 miles either side of center line (using standard SAR protocol)
- **Air searches** were 2 miles to 5 miles either side of center line



Ground Searches

- More than **25,000 people** from **270 organizations** took part in debris recovery operations
- Searchers expended over **1.5 million hours**
- Searchers covered over **700,000 acres** by foot
- Searchers covered more than **2.3 million acres**

Recovery Operations

- Initially, NASA expected to recover **less than 10%** of the hardware debris
- Searchers recovered **over 84,000 individual pieces** of Orbiter debris weighing more than 84,900 pounds
- Final hardware recovery was **38% of the Orbiter's dry weight**

Columbia Shuttle Recovery Operations
(April 1, 2003)

Collaborations and Partnerships

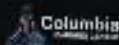
EVERY INVOLVED ORGANIZATION HAD ITS SPECIALITY:

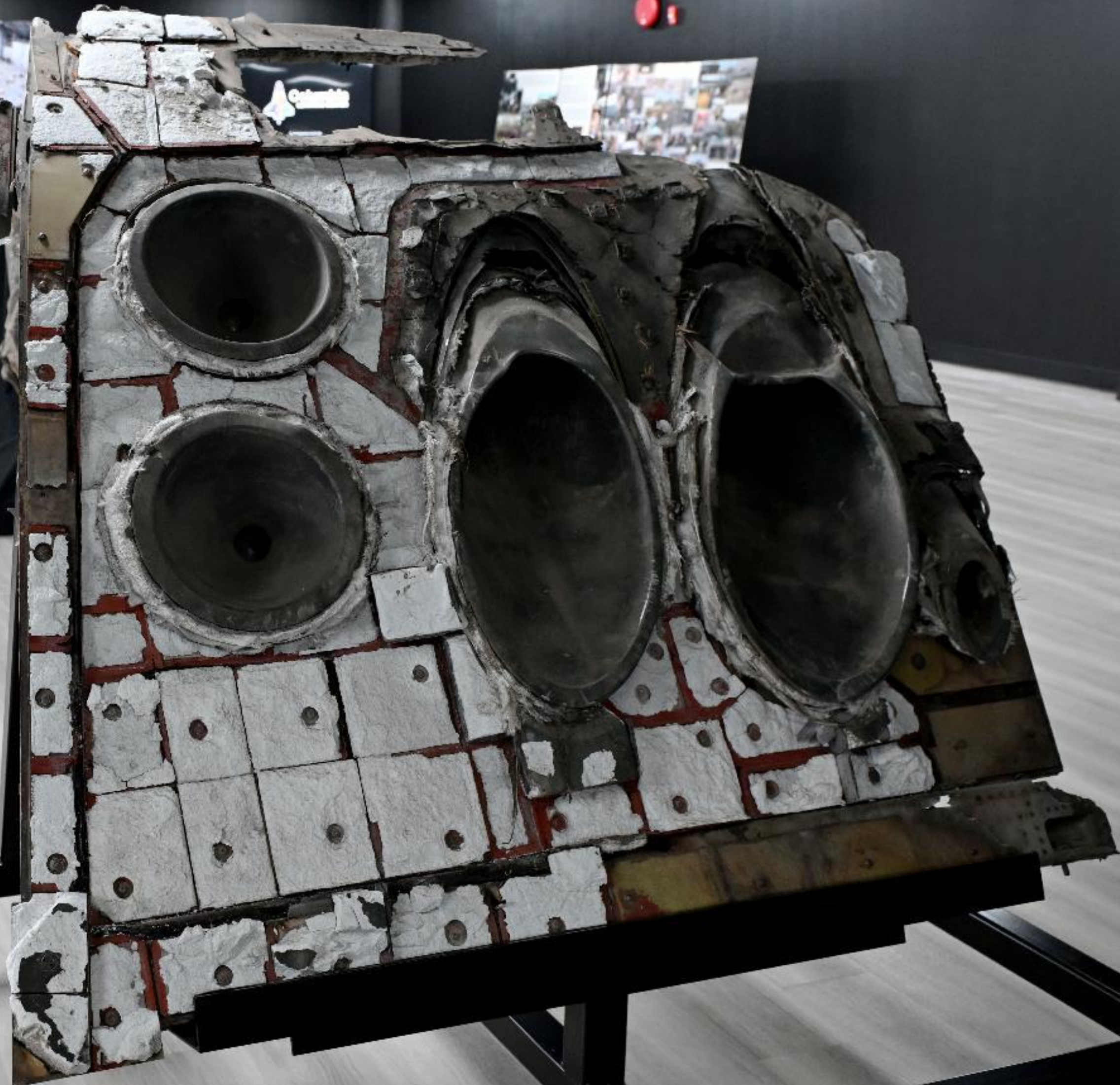
- **NASA:** Integrated large, highly technical operations
- **NTSB:** Expertise in mishap investigation and recovery
- **FEMA:** Support and infrastructure for large disasters
- **U.S. Forest Service:** Ability to quickly mobilize and accurately direct large groups of firefighters to remote areas
- **National Imagery and Mapping Agency (NIMA):** Detailed area maps
- **EPA:** Hazardous systems identification and recovery (also included near real-time site data collection)
- **FBI**: Specialized in crew recovery
- **National Guard** units: Heavy lifting operations and helicopters
- **Department of Texas Public Safety and local authorities:** On-site knowledge of terrain, people, and capabilities
- **Public:** Constant source of support with search support, food, shelter, and emotional support

Foam Strike Test Video

Foam Strike

Forward Reaction Control System
(FRCS)
Columbia





Nose Landing Gear

EXIT
Tunnel Adaptor Assembly

VERTICAL TOP TRAILING EDGE

SILTS POD

VERTICAL STABILIZER LEADING EDGE

L/H OMS POD LEADING EDGE

/xb70.ksc.nasa.gov/depeng/emaps/

RECONSTRUCTION EFFORTS

SPACE SHUTTLE COLUMBIA

RECONSTRUCTION

- In addition to recovering the crew—all within a five-mile area, 250 miles long—searchers also recovered about 38% of the shuttle
  - Systems experts performed debris identification
- **Workers at Kennedy Space Center knew the hardware so well they could pick up almost anything and knew what it was, despite the damage**
- Investigators created a 3D reconstruction of Columbia's left wing leading edge
  - This helped them to understand the order in which the structure came apart and to determine that heat first entered the wing in the location where photo analysis indicated the foam had struck

COLUMBIA ACCIDENT INVESTIGATION BOARD

SPACE SHUTTLE COLUMBIA

Columbia Accident Investigation Board (CAIB)

INVESTIGATION OF PHYSICAL FAILURES AND ORGANIZATIONAL WEAKNESSES

- Assembled within **2 hours** of the loss of signal from the returning spacecraft.
- A staff of more than **120** and about **400** NASA engineers supported the investigation and the Board's 13 members.
- They examined more than **30,000** documents, conducted more than **200** formal interviews, heard testimony from dozens of experts, and reviewed more than 3,000 inputs from the general public.
- The CAIB Report was a multi-volume report that outlined the CAIB's findings after nearly **7 months** of investigation.
- The investigation included: 1) Physical failures that led directly to *Columbia's* destruction; 2) Underlying weaknesses, revealed in NASA's history of organizational practices and cultural traits that were detrimental to safety; and 3) "Other significant observations" made during the investigation. Left uncorrected, any of these factors could contribute to future Shuttle losses.

Columbia Accident Investigation Board

Board Statement: "In this Board's opinion, unless the technical, organizational, and cultural recommendations made in this report are implemented, little will have been accomplished to lessen the chance that another mishap will follow." – CAIB Report

CAIB Report Summary (continued)

ACTIONABLE RESULTS: 29 RECOMMENDATIONS WITH 99 FINDINGS

- **41 Findings related to NASA organization mostly associated with communication and authority paths**
  - Most notable was establishment **of Independent Technical Authorities for Engineering and Safety and Mission Assurance (S&MA) directly to NASA Administrator**
- Remaining findings as additional information for NASA to consider

Columbia Reconstruction Project Team

CAUSE OF MISHAP

SPACE SHUTTLE COLUMBIA

Physical Cause of Mishap

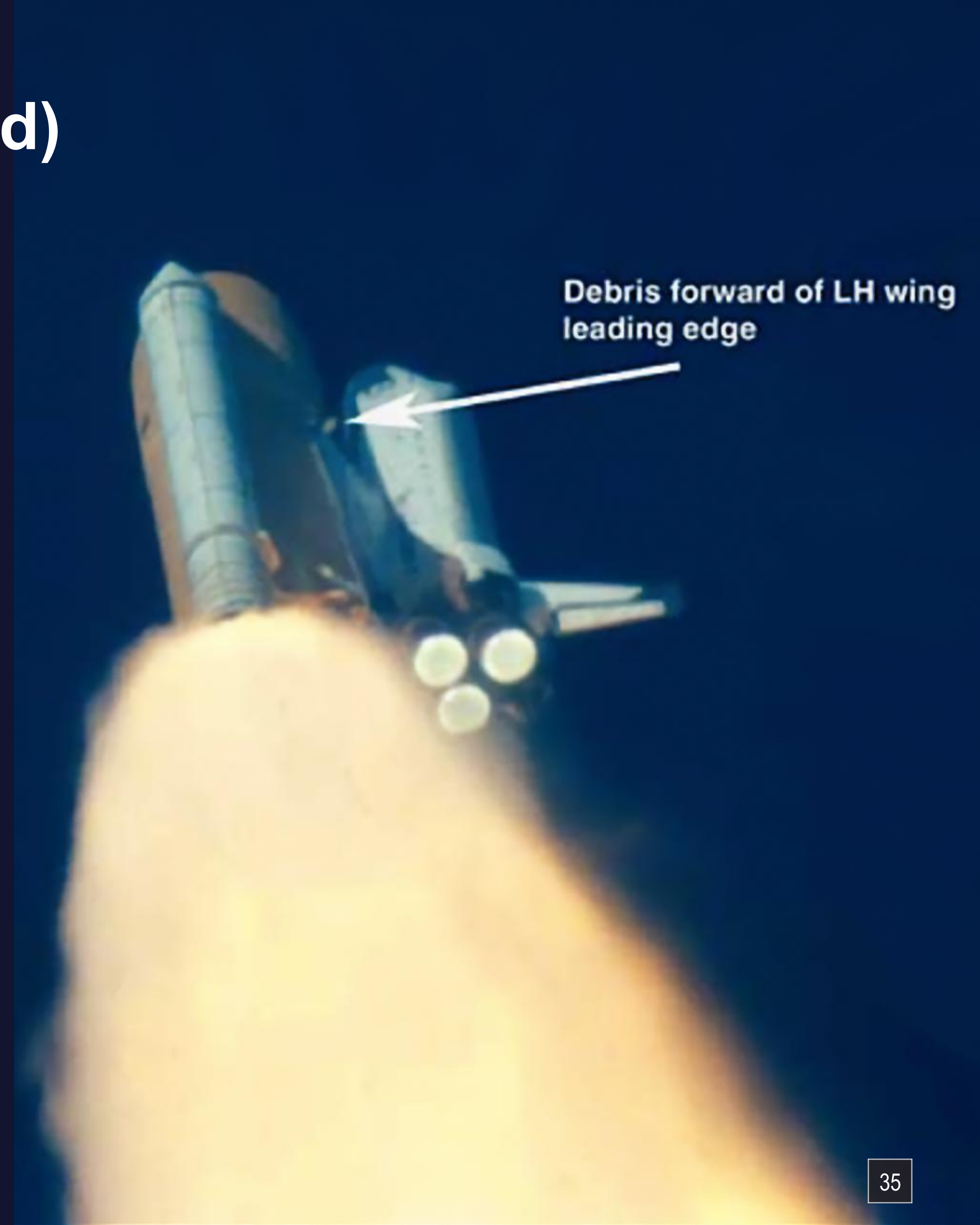
FEB. 1, 2003

- **Upon reentering the atmosphere on Feb. 1, 2003, the *Columbia* orbiter suffered a catastrophic failure during reentry, due to a breach that occurred during launch**

Physical Cause of Mishap (continued)

FOAM STRIKE ON WING

- Falling foam from the External Tank struck the Reinforced Carbon Carbon (RCC) panels on the underside of the left wing during liftoff, damaging the thermal protection system.
- This breach allowed superheated air, which can exceed 2,800°F, to enter the wing itself. As the shuttle flew over California, the structure inside the wing began to melt, deform, and break away.
- Led to structural degradation of vehicle: The shuttle lost control, tumbled and eventually broke apart completely.



ORGANIZATIONAL CAUSES

SPACE SHUTTLE COLUMBIA

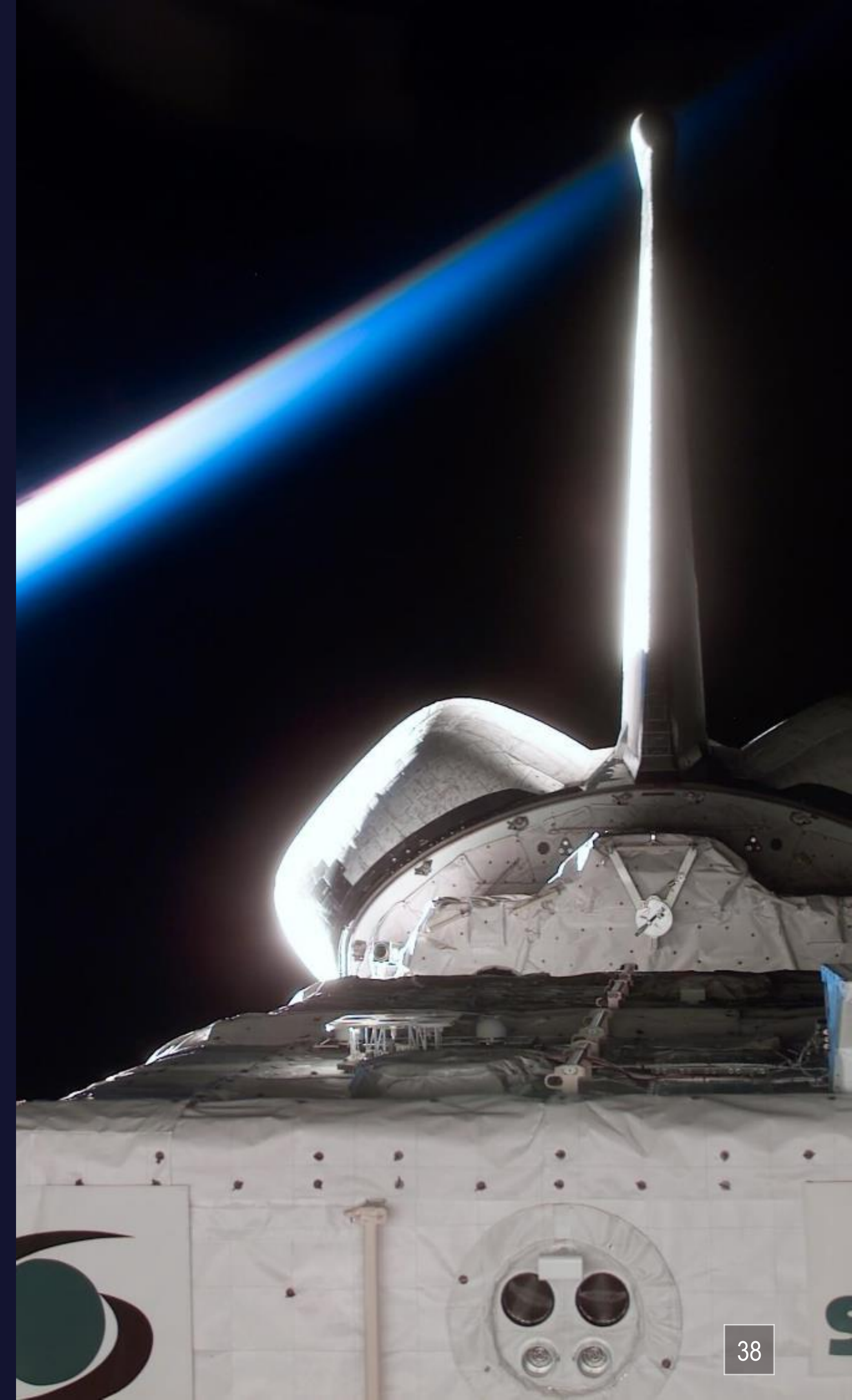
Schedule and Organizational Pressure

- Pressure to complete the ISS build out
- Compromises to gain approval for the Shuttle Program
- Subsequent years of resource constraints
- Lack of an agreed national vision for human space flight

Poor Communication

- Organizational barriers prevented effective communication of critical safety information
- Professional differences of opinion were stifled
- Safety recommendations made by Rogers Commission after Challenger mishap were ignored

“The silence of Program-level safety processes undermined oversight; when they did not speak up, safety personnel could not fulfill their stated mission to provide ‘checks and balances.’ A pattern of acceptance prevailed throughout the organization that tolerated foam problems without sufficient engineering justification for doing so.” – CAIB Report



Organizational Barriers

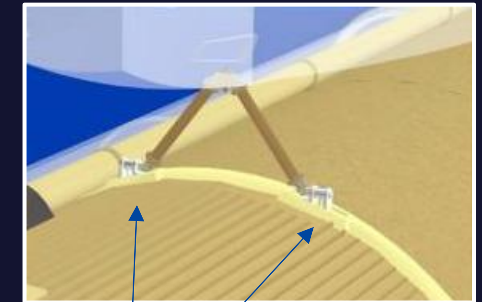
INFORMAL CHAIN OF COMMAND AND DECISION-MAKING PROCESSES

+ Procedures were in place to address any ‘out of family’ issues with coordinated expertise of NASA’s own and contractor engineering, but fell outside of Shuttle Program procedures and managers
  + Debris Assessment Team found it difficult to have their concerns heard by Shuttle Program managers and decision-makers
+ Management failed to:
  + Consider if the debris strike was a safety-of-flight concern
  + Utilize wide range of expertise and opinion available
+ Management decisions reflected:
  + Missed opportunities
  + Blocked communication
  + Flawed analysis
  + Ineffective leadership
+ **Management unknowingly created ‘blind spots’ that prevented them from recognizing the threat the foam strike posed**

Misunderstood Hardware/ Reliance on Past Success

- Shuttle orbiter qualification conducted 30 years earlier
- Foam loss not fully understood
- External tank and bipod ramp not flight tested in complex environment

Bipod Ramp, as flown

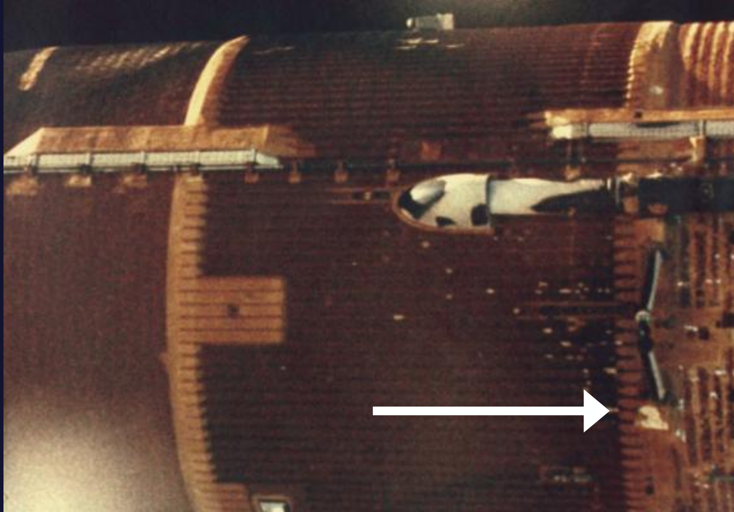


Bipod Location

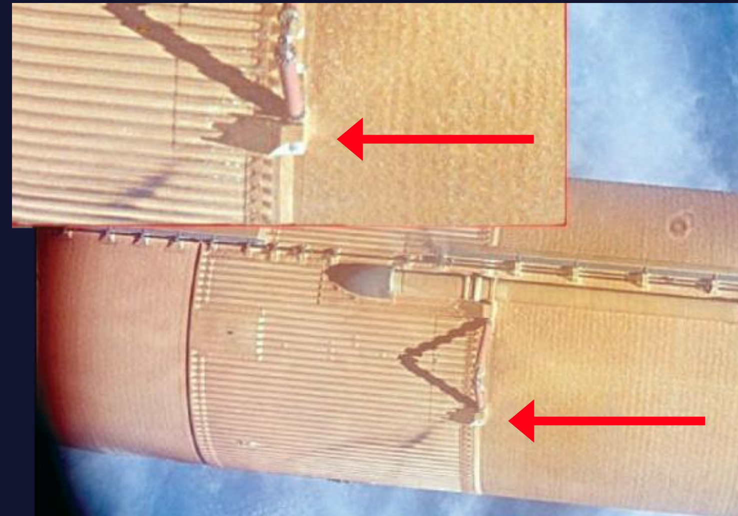
Bipod Redesign

Normalization of Deviance

- An unsafe practice becomes accepted over time as normal if it does not immediately cause a disaster or result in an undesired outcome
- Become blind to warning signs of potential problems
- Previous Shuttle flights had foam impact damage
- Damage was considered “post-flight repair” not “safety of flight;” it had become normalized



The first known instance of Bipod Ramp shedding occurred on STS-7 which was launched on June 18, 1983.



Only three months before the final launch of Columbia, the Bipod Ramp foam had come off during STS-112.

Underestimation of Risk

- Mischaracterization of the Shuttle as operational rather than developmental
- Hazard reports and risk analyses not completely data-based
- Scope of hazard due to foam loss not understood
- Risks were accepted without adequate analysis
- Risk-averse Safety Culture did not exist
- **Cognitive biases allow us to make faster decisions without conscious deliberation, which may result in a lack of sound, well-informed decision making**

Lack of Strong Safety Culture

- NASA's organizational culture had as much to do with the Columbia accident as the foam did
- Safety programs didn't emphasize a risk-averse philosophy
- Employees were not empowered to speak up, communicate safety issues, or stop an operation at the first hint of a problem

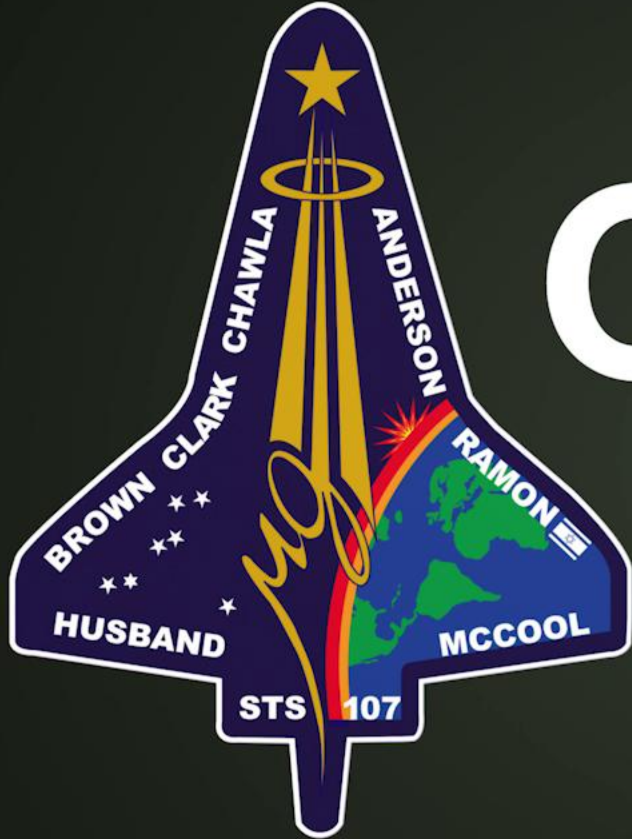
KEY TAKEAWAYS

SPACE SHUTTLE COLUMBIA

Takeaways You Can Apply

- **Resist Normalization of Deviance**
  - Remain alert to deviances and take appropriate steps
  - Ask yourself, “Why is this safe? Do I have actual data or only ‘common knowledge?’ If I do have data, is anything new in the situation?”
- **Recognize Cognitive Biases**
  - Avoid making systematic errors in thinking based on our tendency to seek out information that supports our opinions or beliefs
- **Avoid Organizational Silence**
  - Speak up; Don’t become complacent
  - Eliminate environments where we cannot or will not voice opinions or disagreement
- **Foster a Strong Safety Culture**
  - Ensure employees don’t fear reprisal

Remember every employee and contractor matters to the success of NASA and its missions.



Columbia

LEARNING CENTER

Thank You!

SPACE SHUTTLE COLUMBIA