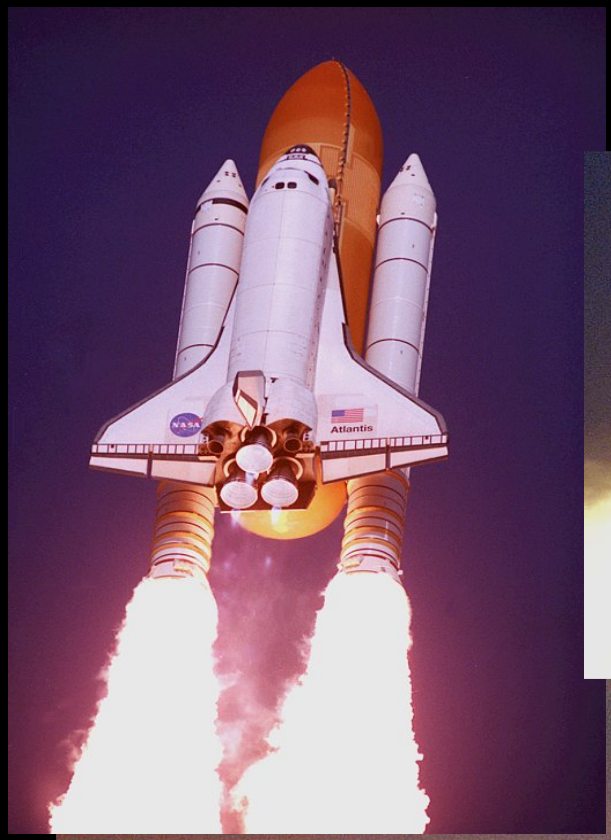


The Challenge of Safe Return of the Space Shuttle to Flight

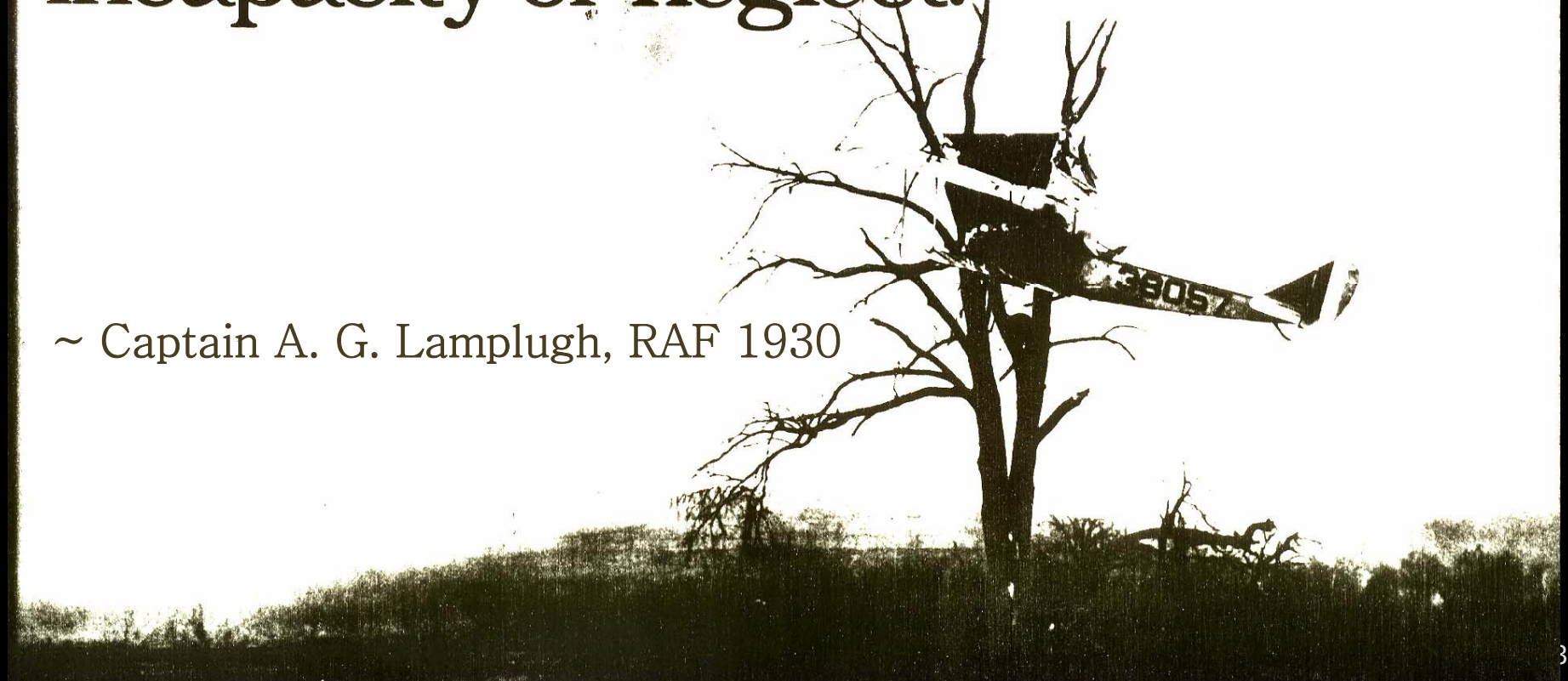
N. Wayne Hale, Jr.
Space Shuttle Program Deputy Manager

Program Management Challenges to the Safe Return of the Space Shuttle to Flight

- Columbia Accident
- Technical Challenges
- Cultural and Organizational Challenges
- Complexity of the Problem
- Conclusion

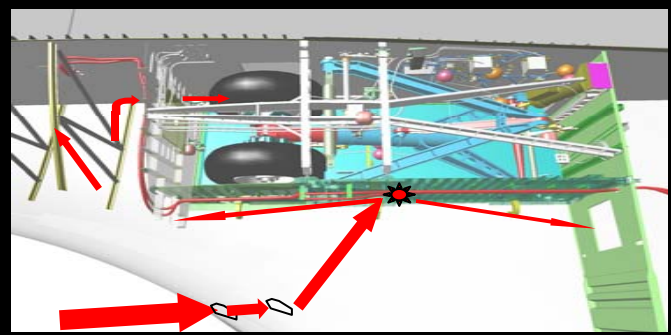
Aviation in itself is not inherently dangerous. But to an even greater degree than the sea, it is terribly unforgiving of any carelessness, incapacity or neglect.

~ Captain A. G. Lamplugh, RAF 1930



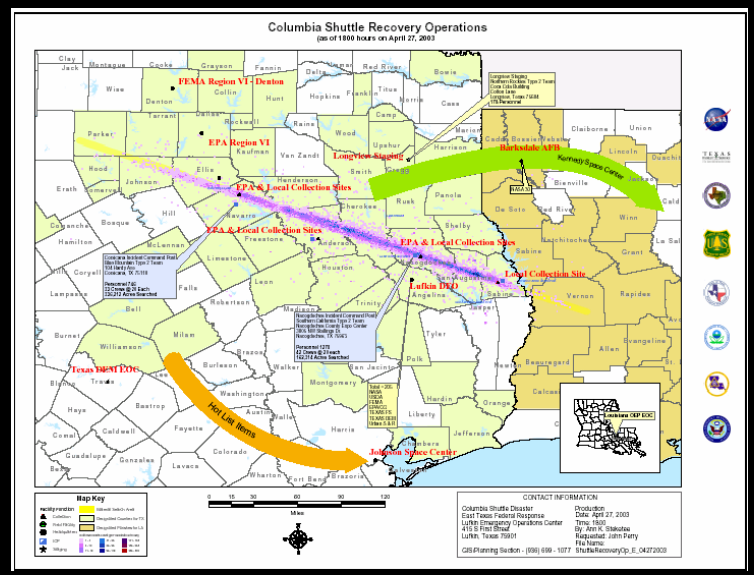
Columbia Accident Scenario

- 81 seconds after launch, foam insulation on the Tank strikes the Shuttle's wing at Mach 2.46
- On re-entry, plasma enters the breached wing
- Plasma flow degrades wing internal structure
- Wing structural failure leads to loss of vehicle control and break-up

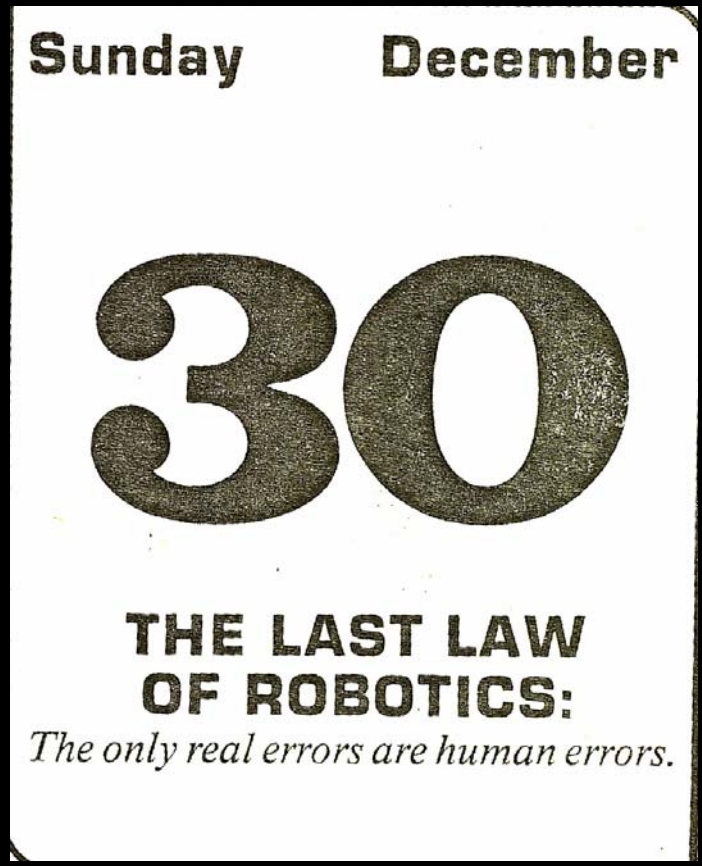


Columbia Impact on Human Space Flight

February 1, 2003



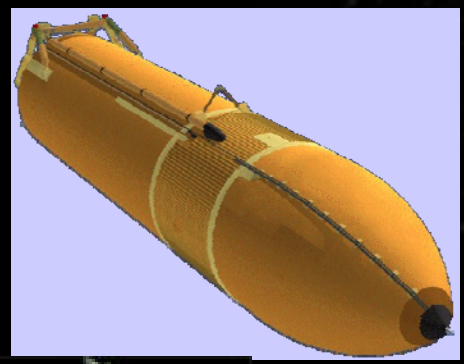
- Shuttle Fleet Grounded
- Space Station Crew Reduced to Two
- Space Station Assembly on Hold
- Dependence on ISS Partnership

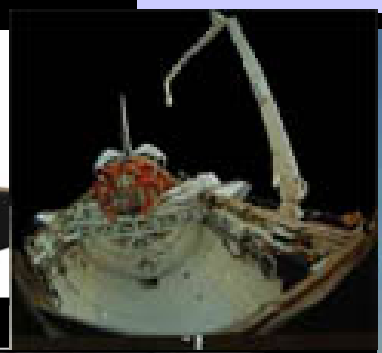

Sunday December
30
THE LAST LAW OF ROBOTICS:
The only real errors are human errors.

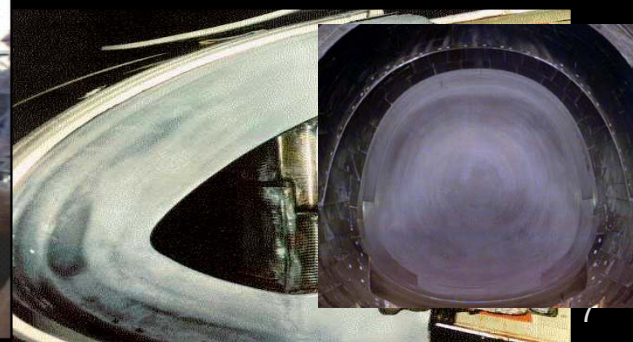
Columbia Accident Investigation Board

29 Recommendations for Improvement in the Following Categories:

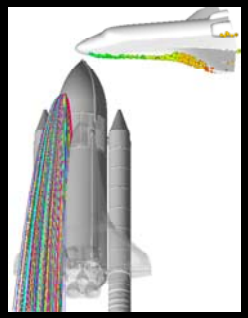
- Thermal Protection System Monitoring and Repair
- External Tank
- Vehicle Imaging
- Bolt Catcher Separation Mechanism
- Flight Hardware Closeout Documentation
- Foreign Object Debris Program
- Launch Schedules
- Wire Inspection Techniques
- Orbiter Sensor Data
- Independent Technical
- Engineering Authority
- Closeout Photo Process
- Mission Management Team Training
- Re-Certification of the Shuttle for Flights beyond 2010







Return to Flight Rationale



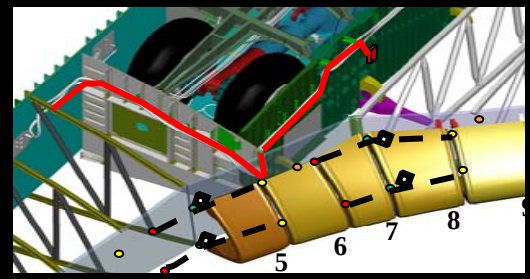
Primary Hazard Control

I
Elimination of Critical Debris

Warning Devices

II
Impact Detection During Ascent

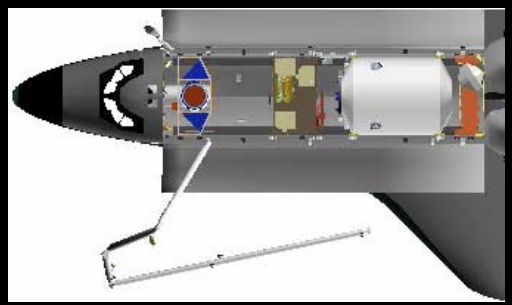
III
On-Orbit Debris Impact/Damage Detection



Special Procedures

IV
On-Orbit TPS Repair (Tile & RCC)

V
Crew Rescue



Return to Flight Rationale

Fundamental Flight Rationale is identification and elimination of critical ascent debris

- Critical debris sources defined as those which
  - Have an unacceptably high probability of liberation
    and …
  - Have an aerodynamic transport mechanism to impact in a vulnerable location
    with …
  - Enough energy to cause catastrophic damage to the TPS

Additional Risk Mitigation against unforeseen failures or highly unlikely scenarios

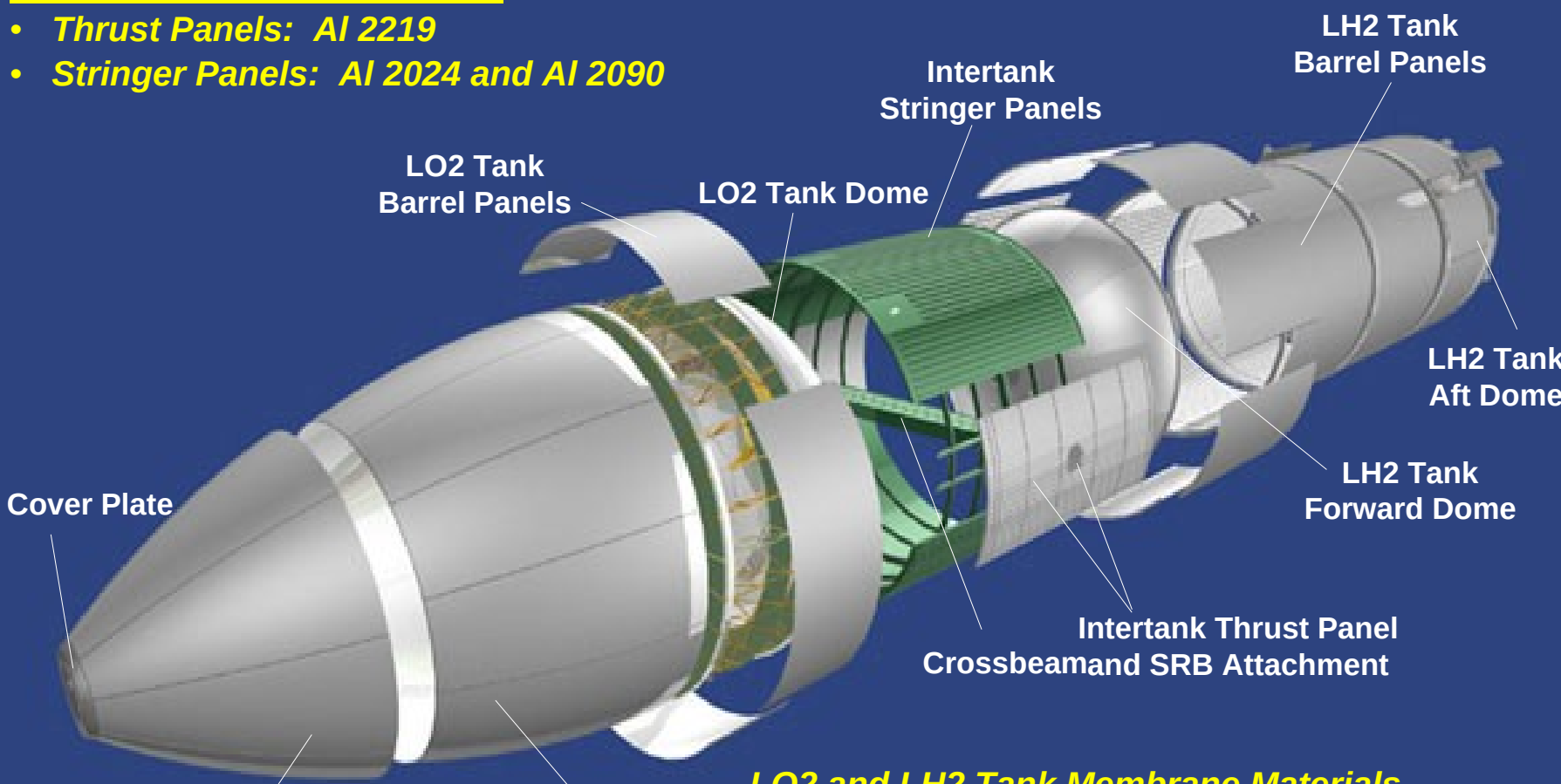
- Improved ascent imagery for engineering data
- Added on-orbit inspections for critical impact identification
- New thermal protection system (TPS) repair capability
- International Space Station (ISS) Contingency Shuttle Crew Support (CSCS) for Rescue

External Tank

External Tank Structural System Overview

Intertank Membrane Materials

- ***Thrust Panels: Al 2219***
- ***Stringer Panels: Al 2024 and Al 2090***



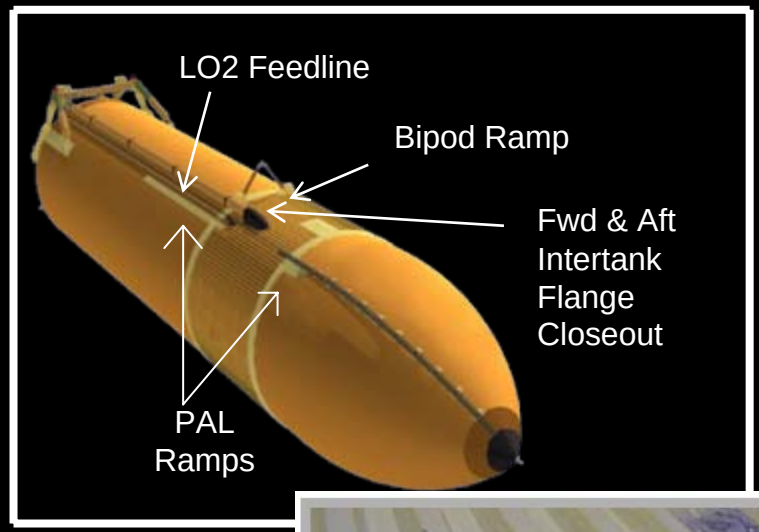
LO2 and LH2 Tank Membrane Materials

- ***Barrel Panels, Gores, and Ogives: Al 2195***
- ***Dome Caps: Al 2219***

External Tank (ET) TPS Certification

***CAIB Recommendation 3.2-1**:*

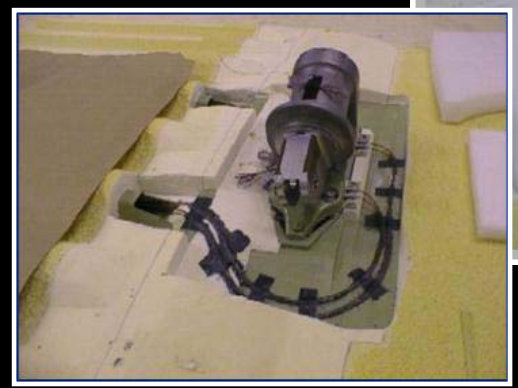
Initiate an aggressive program to eliminate all ET TPS debris shedding at the source ...



NASA Implementation:

Eliminate or minimize potential for critical zone debris

Return to Flight with a certified foam application

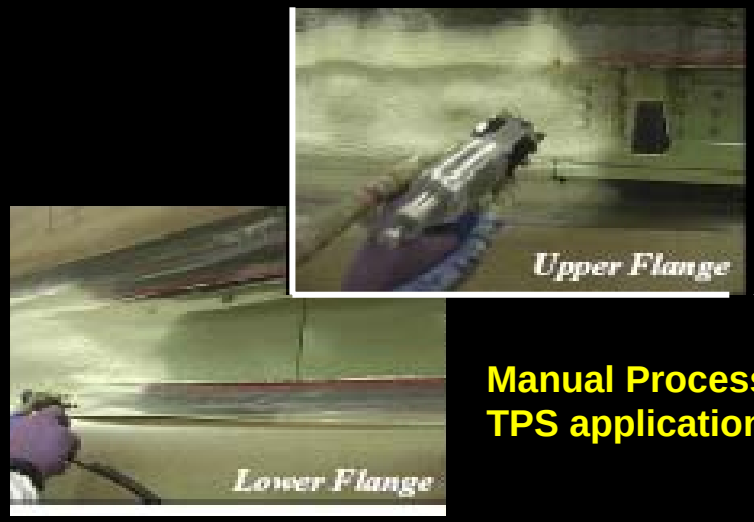


Redesigned Bipod Fitting

Intertank Flange / PAL Ramp

External Tank Certification

LO2 Feedline Bellows
Ice Elimination

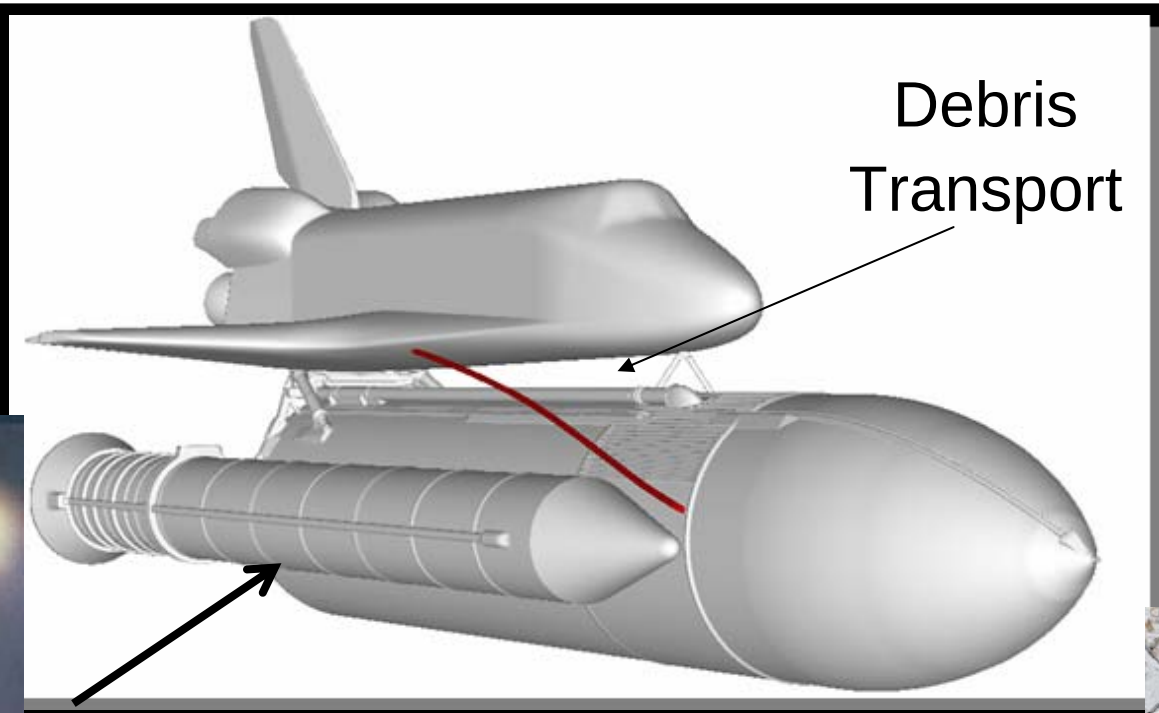


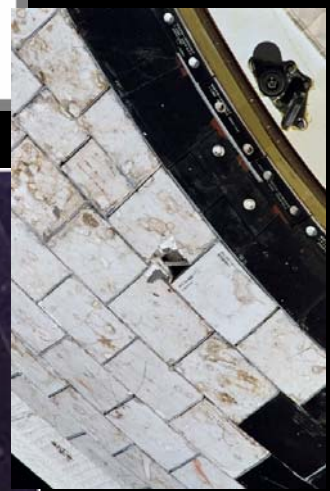
Manual Process
TPS application

Intertank Flange /
PAL Ramp Improvements
(Debris Elimination)

ET Camera System

Debris Transport

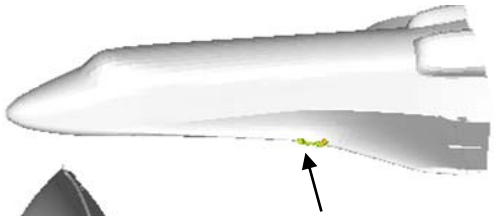




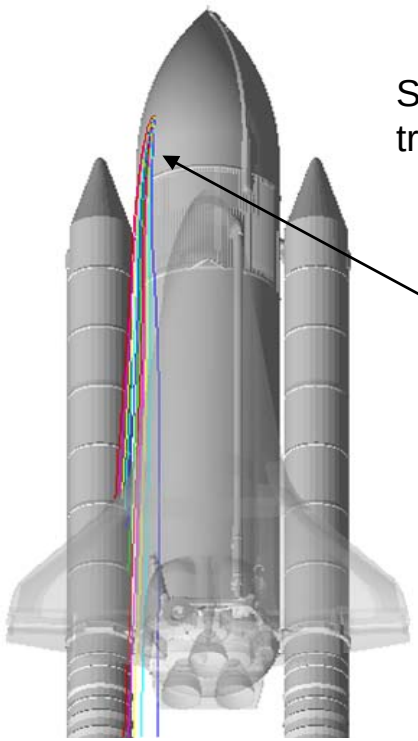
Damage Assessment

Debris Transport Analysis

Pre-STS-107 Transport Methodology



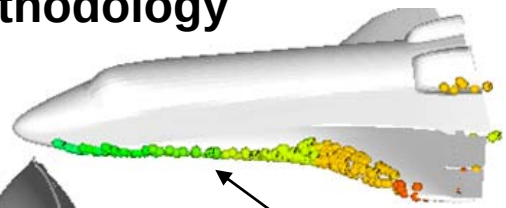
Small population of trajectories and impacts



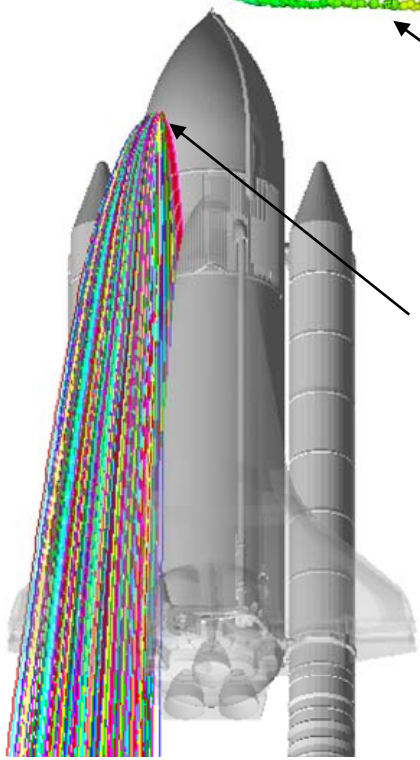
Single initial condition for each debris release location results in a single impact location per debris release location.

Impact map built from multiple release locations.

Current Debris Transport Methodology

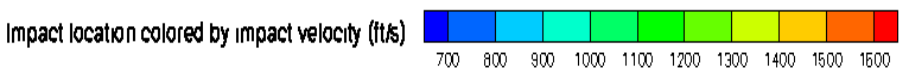


More complete population of trajectories and impacts



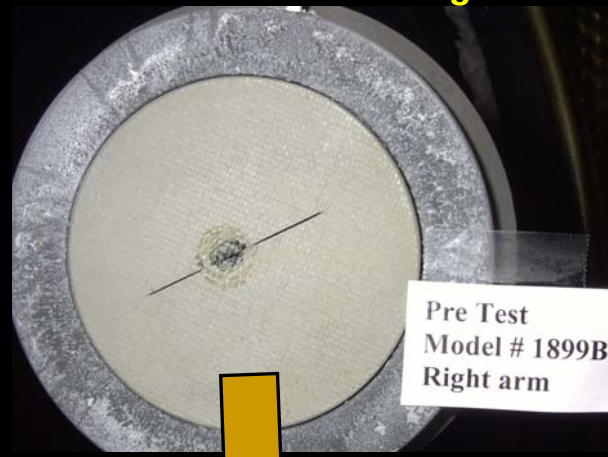
Multiple (dispersed) initial conditions for each debris release location result in multiple impact locations per release location.

Impact map built from multiple trajectories from multiple release locations.

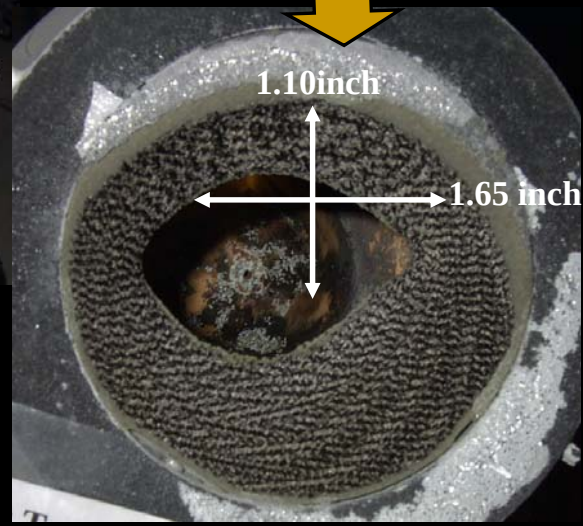


TPS Impact Tolerance Testing

Pre-Test Intermediate Slot (0.015 in) with Static Indention
¼ inch Dia. Frontside Damage

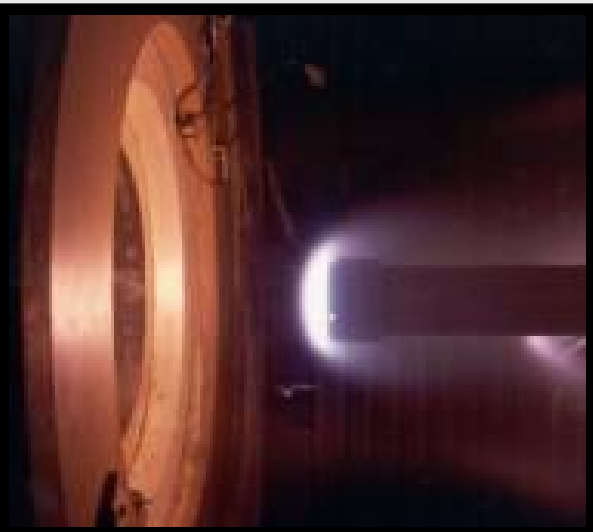


MLGD Thermal Barrier Test Article

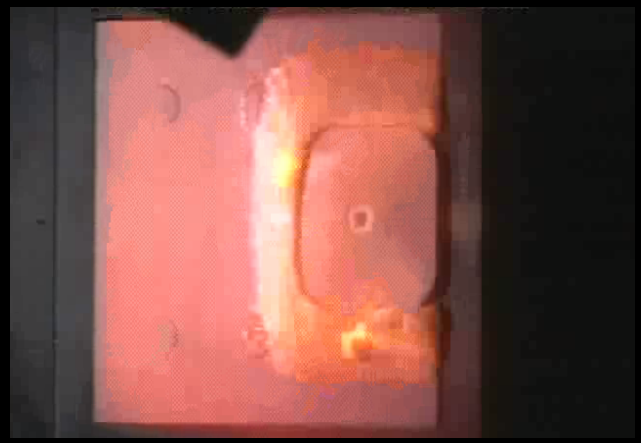


Frontside Post-Test View Intermediate Slot After 300s at 3000F & 148 psf

Impact Testing



Arc-Jet testing of RCC Plug Repair cover plate (2960º F)

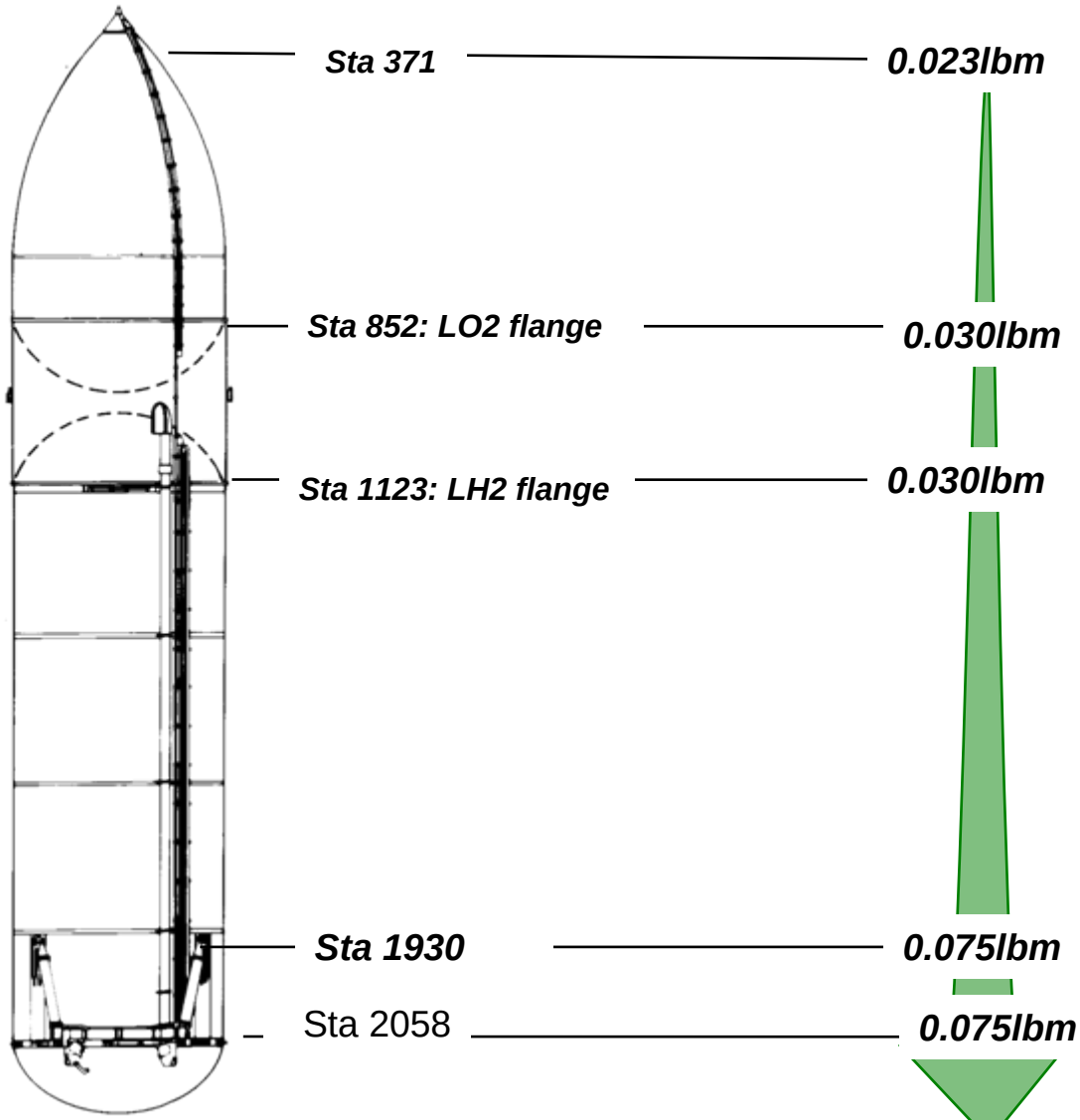


Arc-Jet testing of RCC Plug Repair sealant material (approx. 2800º F)

RCC Panel # 6 was tested on May 30, 2003.

The piece of foam impacted and resulted in a crack with no through penetration.

External Tank Debris Allowables



10/15/04 Update

Improved Ascent Imagery

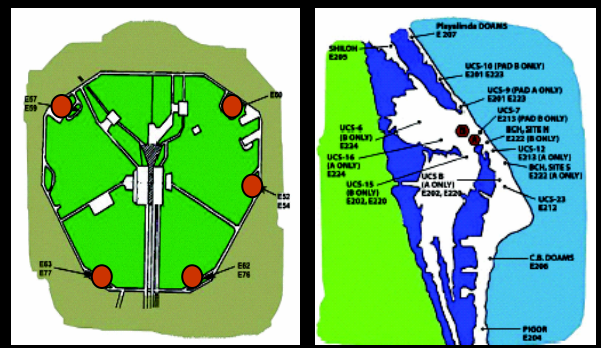
- Engineering data and debris detection on ascent improved by using integrated approach
- Additional Ground-Based trackers added and upgraded
- Aircraft-based imagery
- Digital cameras on External Tank, Solid Rocket Booster, and Orbiter improve real-time assessment
- Handheld crew cameras support added systems
- Radar tracking of debris

Proposed STS-114 Camera Locations

SRB Mounted Camera

ET Mounted Camera

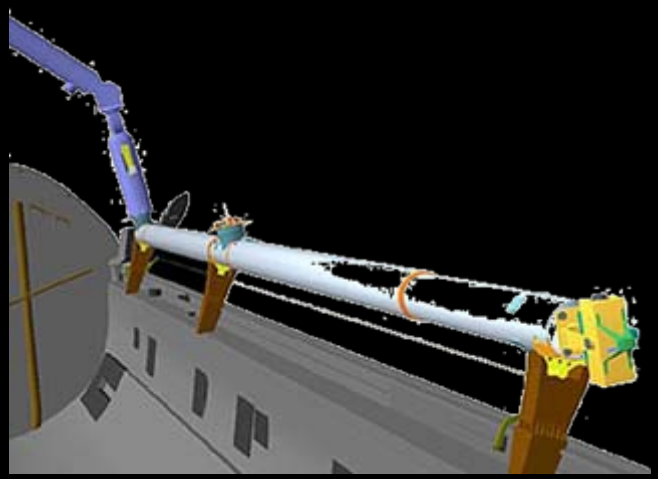
Ground Tracking



Short, Medium and Long-Range Trackers

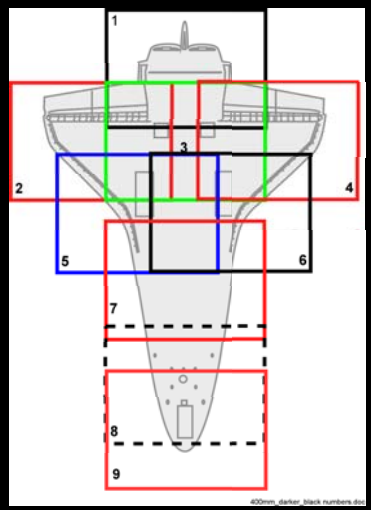
On-Orbit Inspection

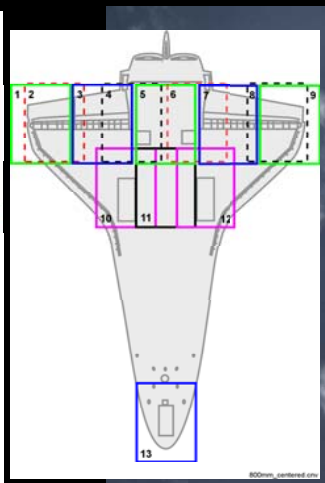
- New Orbiter Boom Sensor System for TPS inspection
- Attaches to the Shuttle's existing robotic arm
- Boom mounted laser imagers (LDRI and LCS)
- System compliments other RTF initiatives to understand TPS condition, including Wing Leading Edge Sensors and hand-held cameras
- Boom system currently on critical path

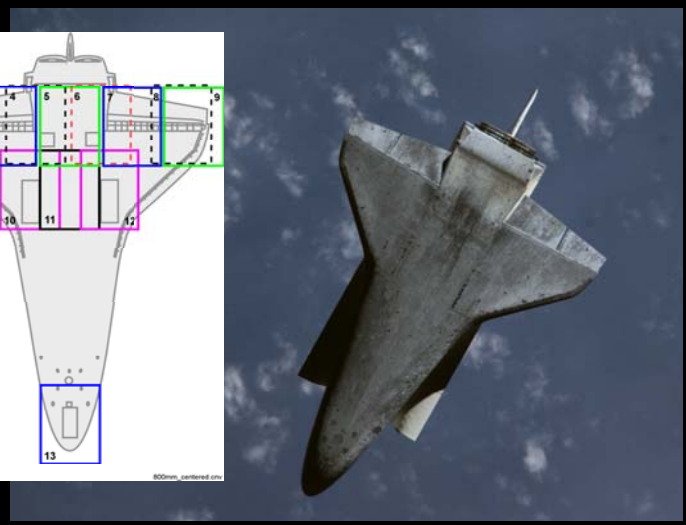


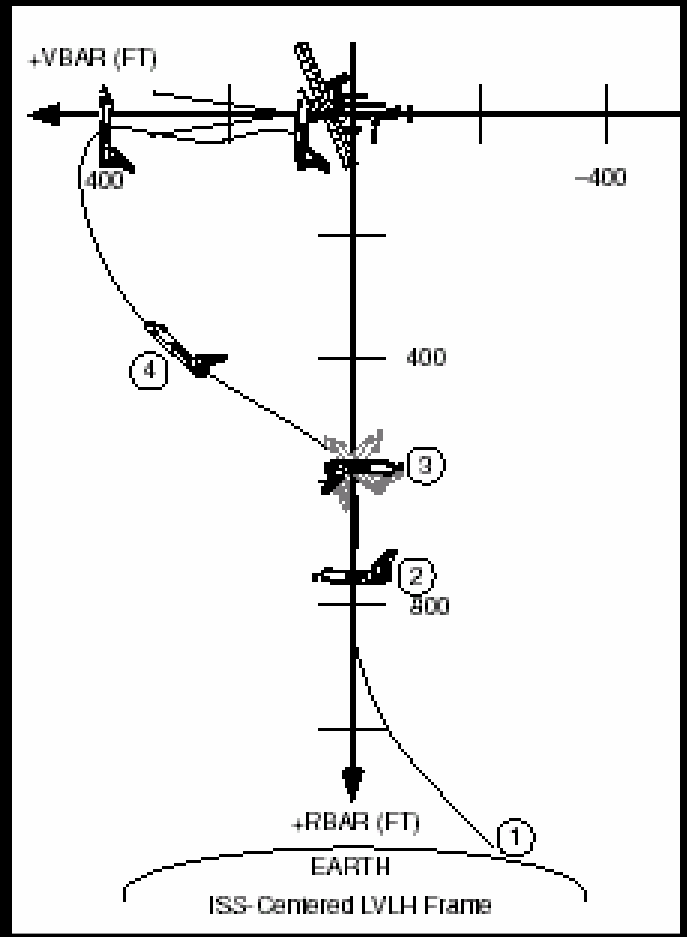
On-Orbit Inspection

- Various techniques being considered
- Techniques for conducting inspection at ISS under study
- ISS crew with on-board cameras may provide additional Space Shuttle TPS evaluation
- Evaluating use of Space Shuttle and ISS robotic arms to facilitate 100% TPS inspection capability









Orbiter Pitch-Around for Inspection and approach to International Space Station

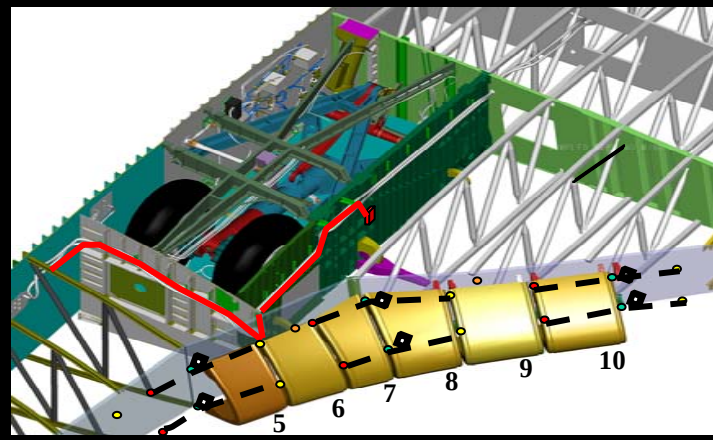
Wing Leading Edge (WLE) Sensors

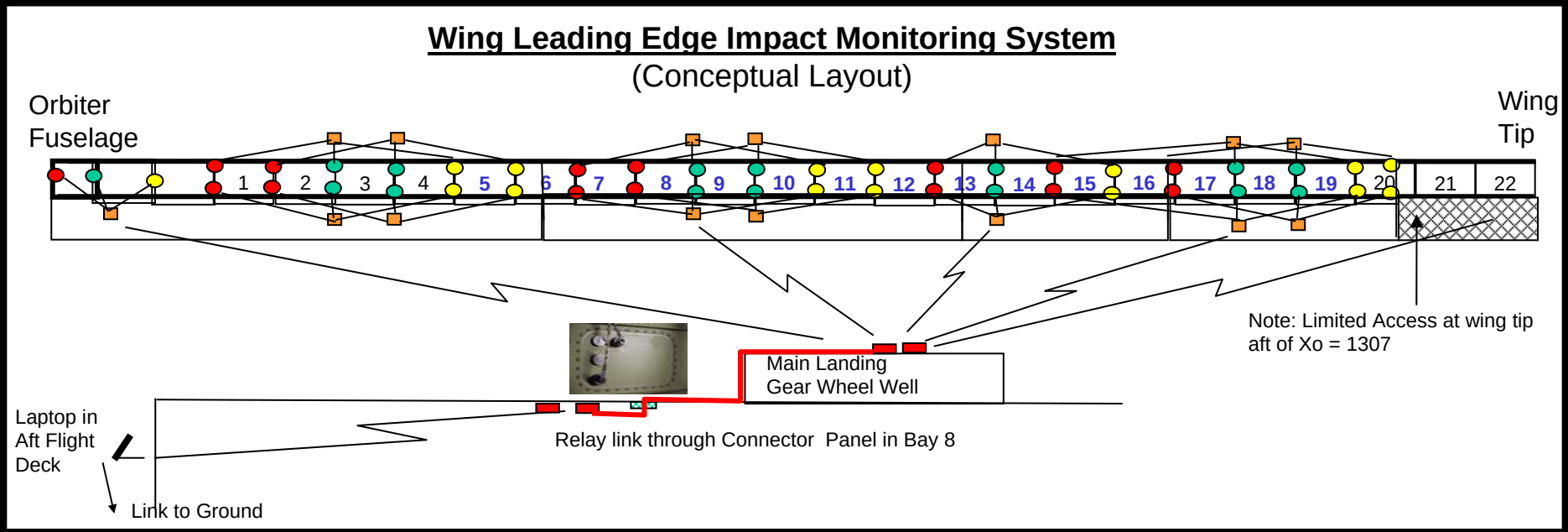
Function

- Additional means of impact detection; proposed instrumentation *downlinks* WLE impact information

Plan

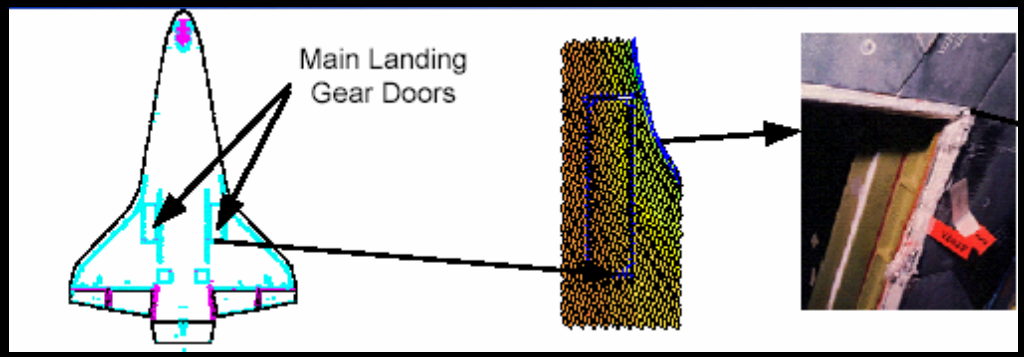
- Sensor units in each wing on the top and bottom of each RCC panel
  - 66 accelerometers & 22 temperature sensors per wing
- Provide relay to flight deck laptop computer for download
- Ready for use on STS-114

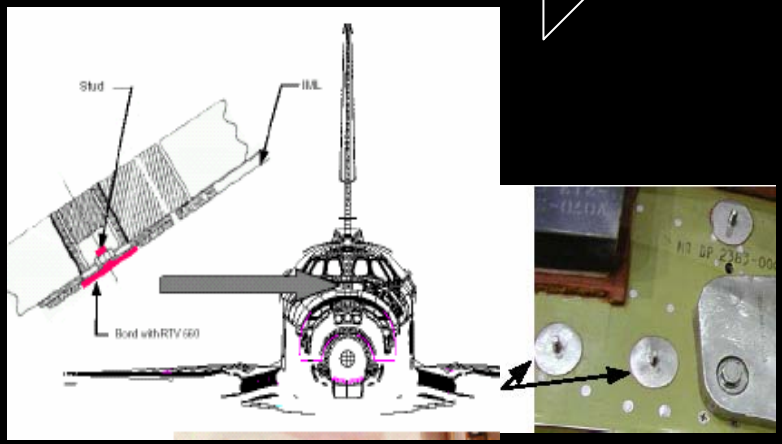




Orbiter Hardening

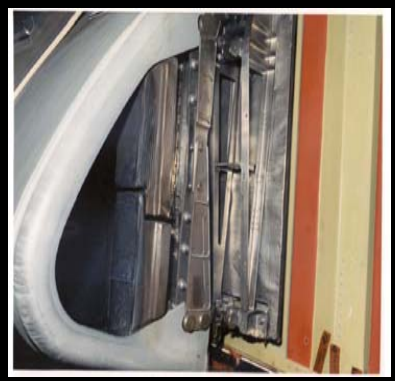
Main Landing Gear Door (MLGD) Corner Void filled with bonded ceramic insulation

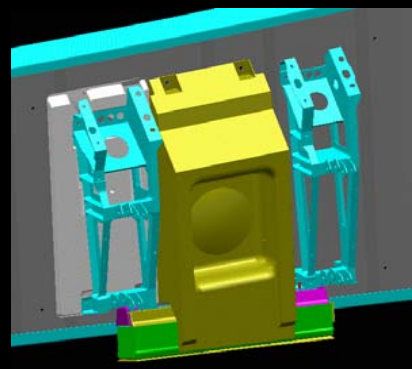




Forward RCS Carrier Panel Redesign replaces bonded studs with riveted studs

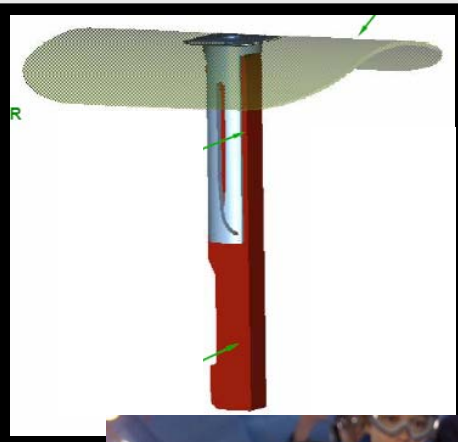
Unprotected lower wing spar areas redesigned by adding additional insulation and flow restrictors

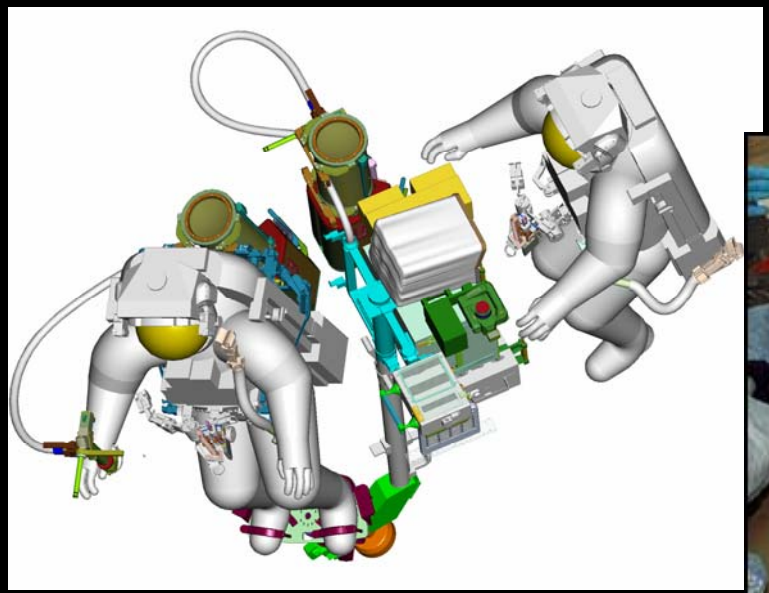




On-Orbit Repair

- Tile repair concept well-defined; cure in-place ablator (CIPA) and application tools in development
- RCC crack and small hole repair tools in development
- First flight to demonstrate TPS repair capabilities



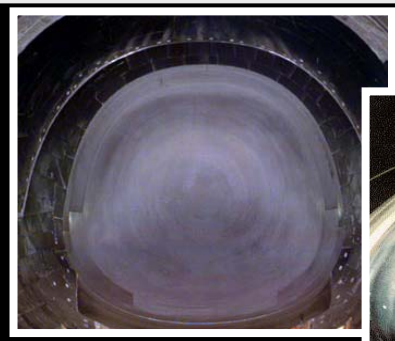


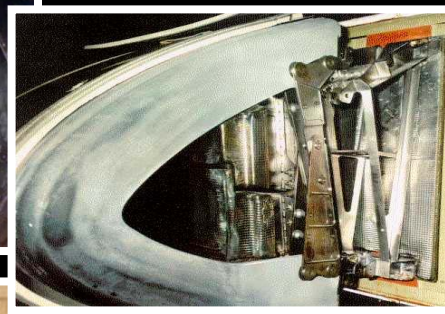
On-Orbit Repair

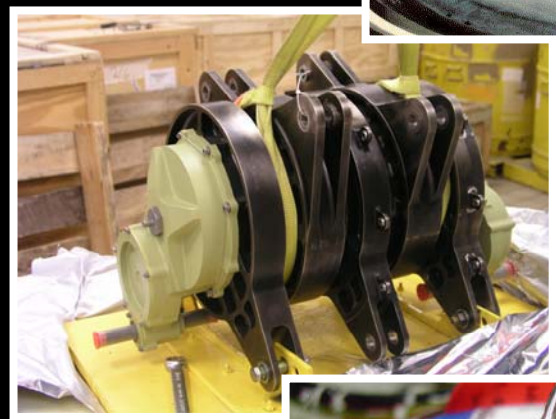
Crew Training in Zero G Aircraft

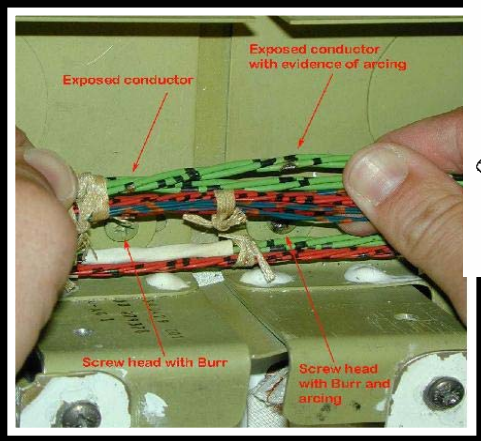
Orbiter Processing for Return To Flight

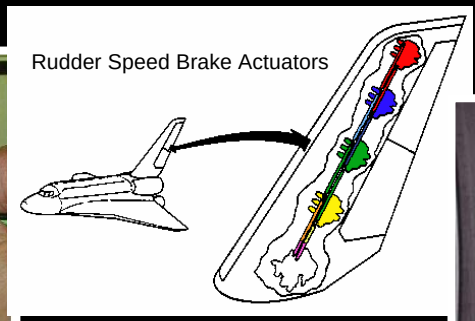
- RCC inspection/re-installation on-track
  - OV-103 RCC closeouts complete in Nov
  - OV-104 RCC closeouts complete in Aug
- Residual tile work from OV-103 OMM continues
  - 10-20 tiles installed each week
  - Completion targeted for November
- Challenges Ahead
  - Rudder Speed Brake re-installation
  - Flowliner cracks
  - Overall Integrated System Mission Processing
  - TPS work post-Hurricane Jeanne



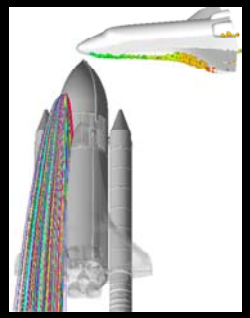








Return to Flight Rationale



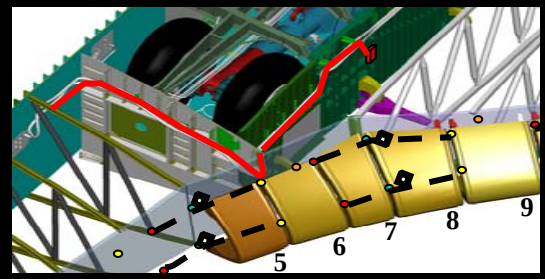
Primary Hazard Control

I
Elimination of Critical Debris

Warning Devices

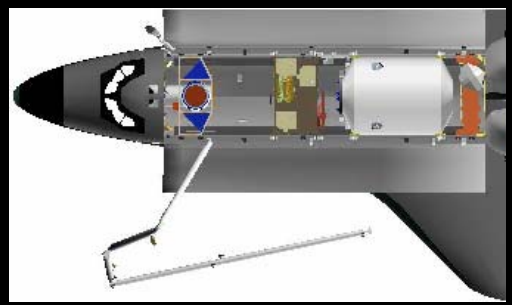
II
Impact Detection During Ascent

III
On-Orbit Debris Impact/Damage Detection



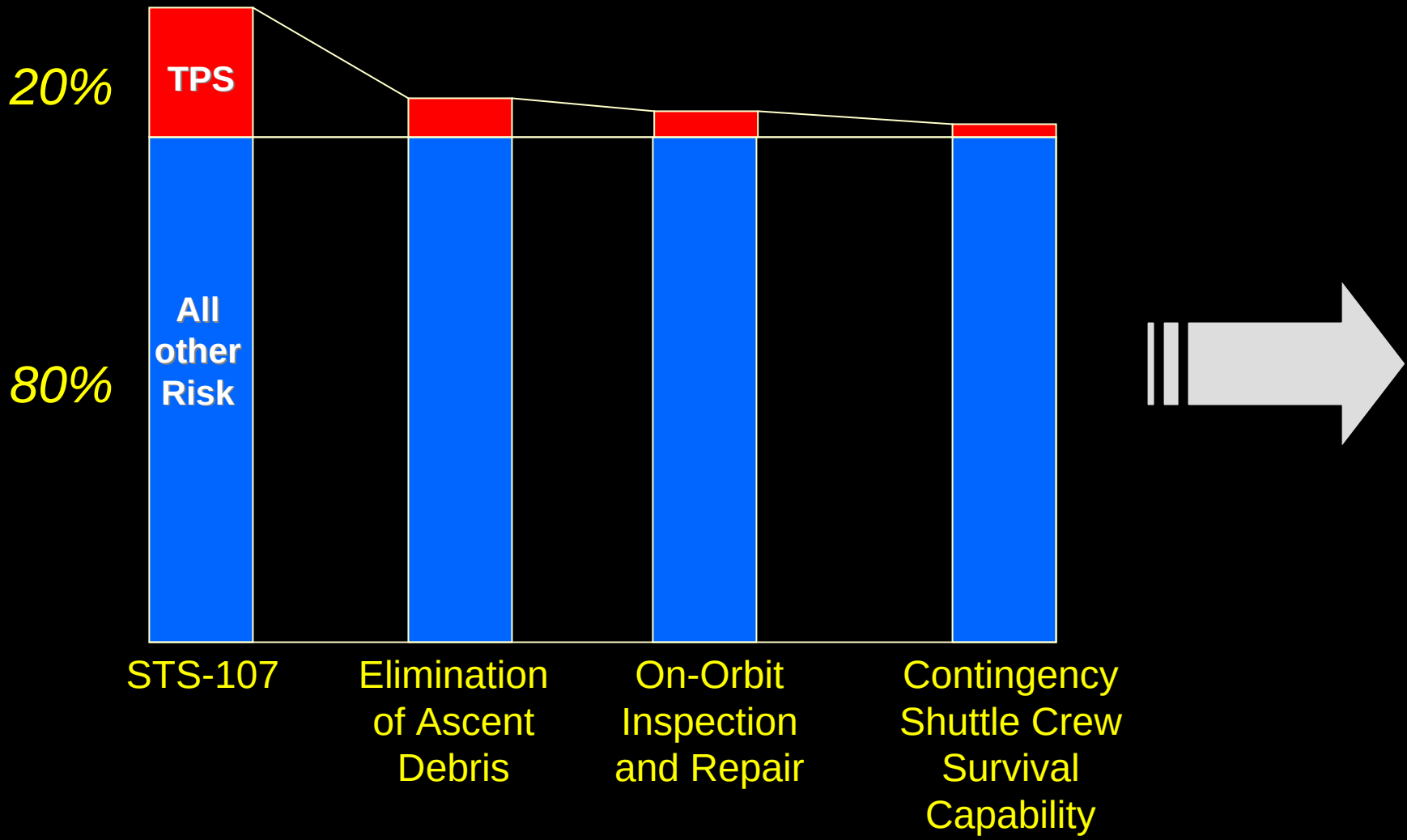
Special Procedures

IV
On-Orbit TPS Repair (Tile & RCC)

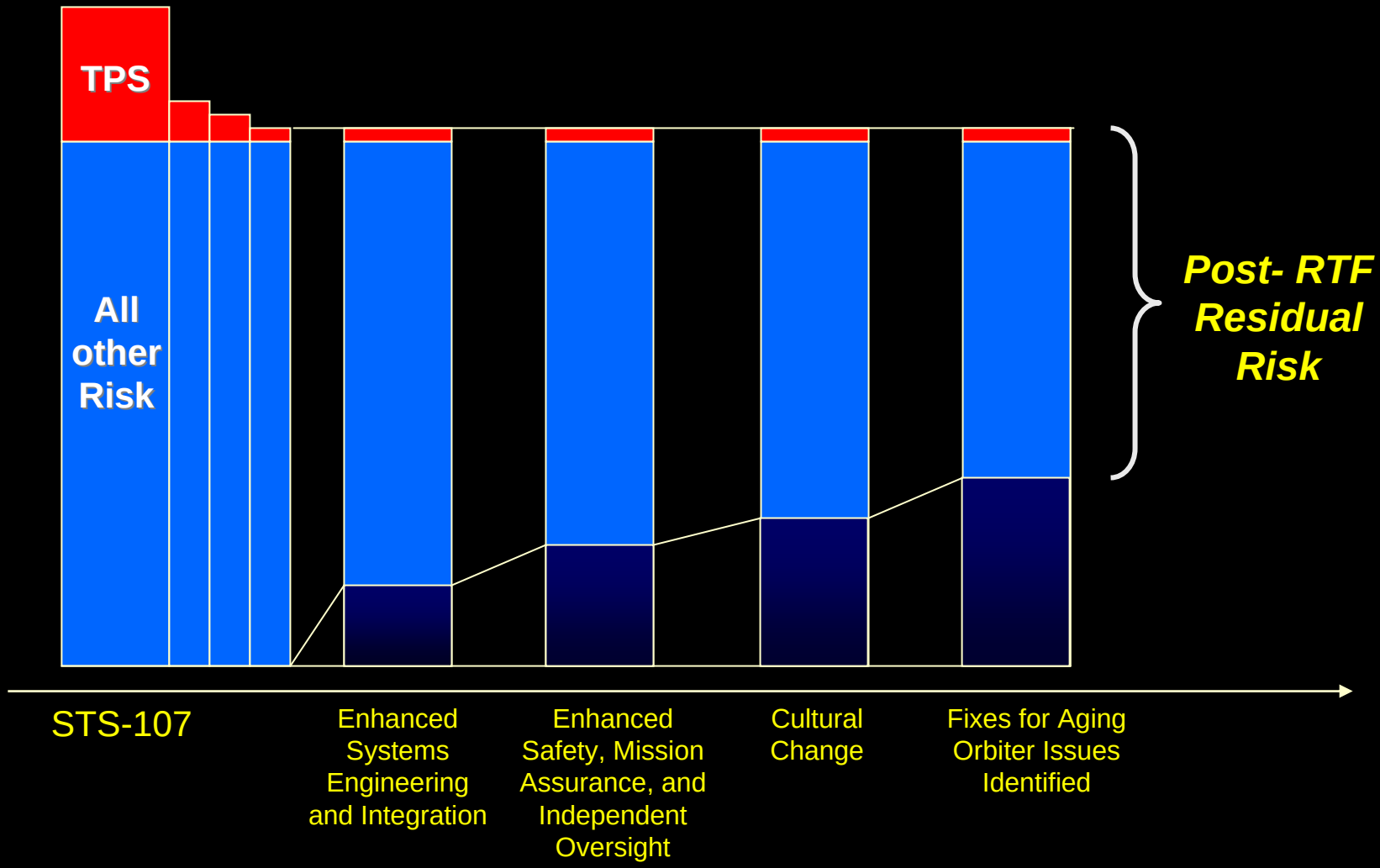


V
Crew Rescue

Space Shuttle Risk of Loss Vehicle and Crew



Space Shuttle Risk of Loss Vehicle and Crew



Why is it so hard?

Why is it so hard?

Why does it cost so much?

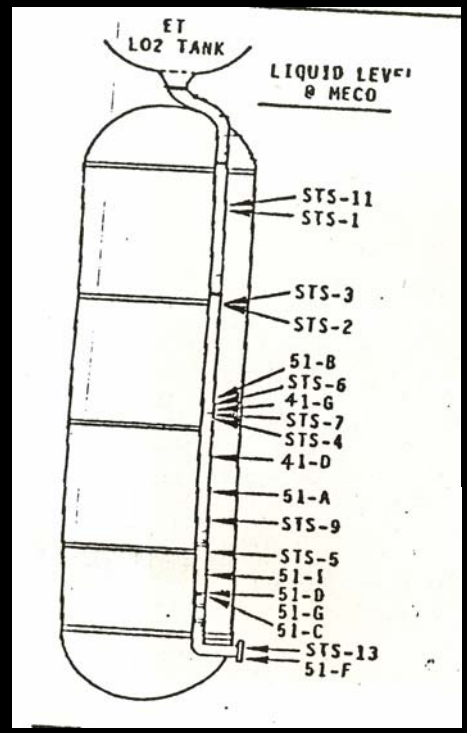
Compare space travel within aviation - compare the Space Shuttle to a Boeing 737

Comparison of the Space Shuttle to a Boeing 737

122 feet	***Length***	138 feet
78 feet	***Wingspan***	112 feet
173,500 – Orbiter 623,500 LBS - Orbiter + ET + SRB	***Empty (dry) weight***	93,680 LBS
April 12, 1981	***First flight***	B737-100 April 9, 1967 (-900 Nov 20, 1997)
To low earth orbit: 56,000 LBS (including crew of 7 & provisions)	***Payload***	52,500 LBS Crew of 2 + 189 Passengers
3,821,000 LBS	***Fuel***	6,875 US GAL = 55,000 LBS

Comparison of the Space Shuttle to a Boeing 737

- B737 max takeoff weight 174,200 lbs
  - 31% is fuel
  - 54% is vehicle
  - 30% is payload (passengers, crew, baggage)
  - FAA required fuel reserve: 45 minutes loiter plus divert
- Total Shuttle vehicle weight at liftoff: 4.5 million lbs
  - 85% is propellant
  - 14% is vehicle structure
  - 1.3% is payload and crew
  - Propellant reserve at MECO---2,300 lbs = 0.060%



Comparison of the Space Shuttle to a Boeing 737

17,500 MPH (M=25 at 400,000 feet)	***Max operating speed***	M 0.82
Zero payload 600 N. Miles (3,600,000 feet)	***Max certified altitude***	41,000 feet
Average Trip Distance 4 Million miles (14 days)	***Range***	3,158 statute miles (6 hours)
6,750,000 pounds	***Takeoff thrust***	2CFM56-7B26 engines 26,300 pounds

Energy for Spacecraft vs. Aircraft

Typical commercial airline cruise: 30,000 ft (5 N.MI.) at 500 MPH
Orbital spacecraft minimum: 100 N. MI. at 17,500 MPH

$$E = PE + KE = m\ h\ g_c + \tfrac{1}{2}\ m\ v^2$$

Energy = Mass X Altitude X Gc + ½ Mass X Velocity Squared

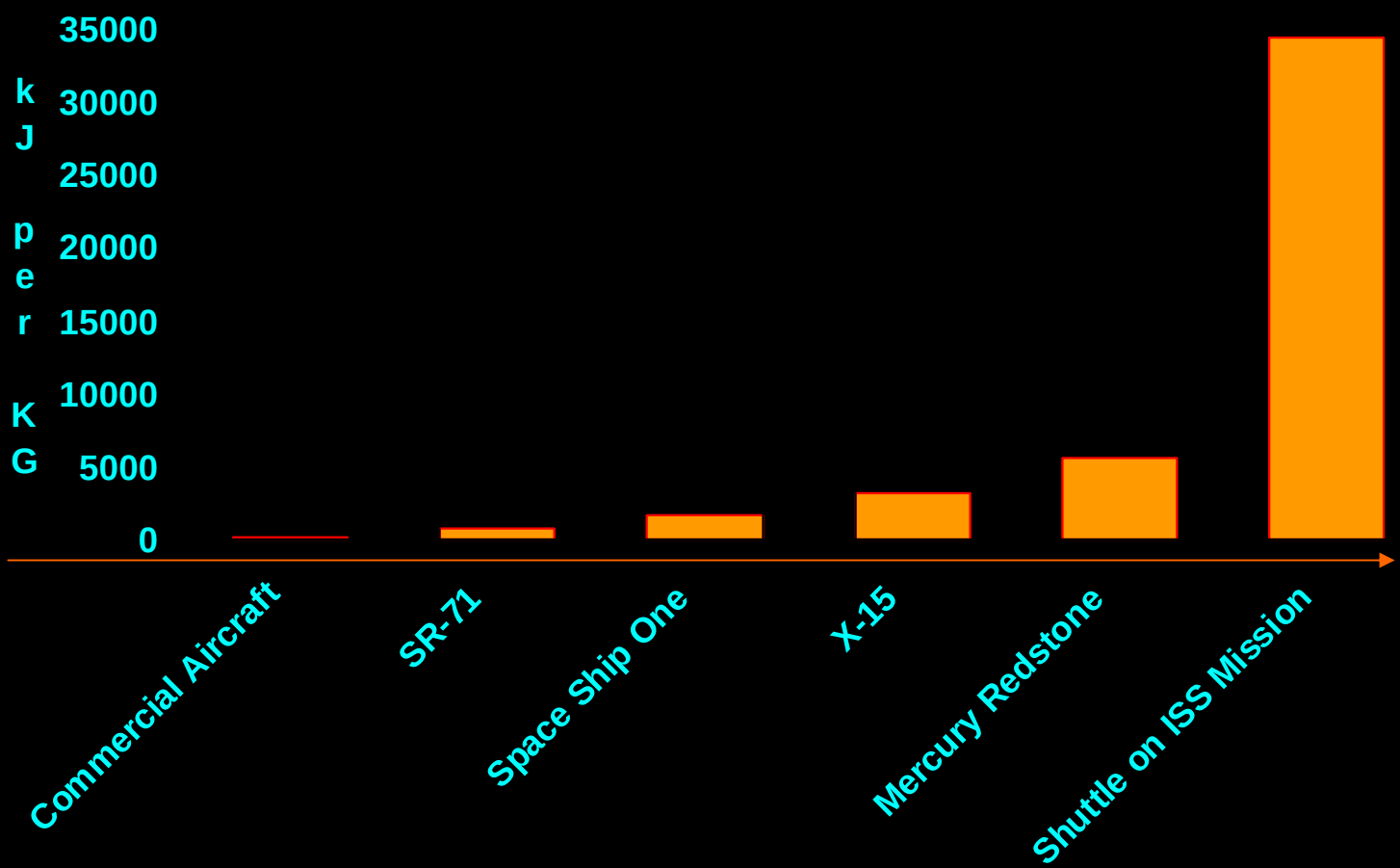
FOR THE SAME MASS

- Altitude difference: 20 times greater (5 miles vs. 100 miles)
- Potential energy difference: 20 times greater

- Velocity difference squared is $(17{,}500)^2 / (500)^2$
- Kinetic energy difference: 1000 times greater

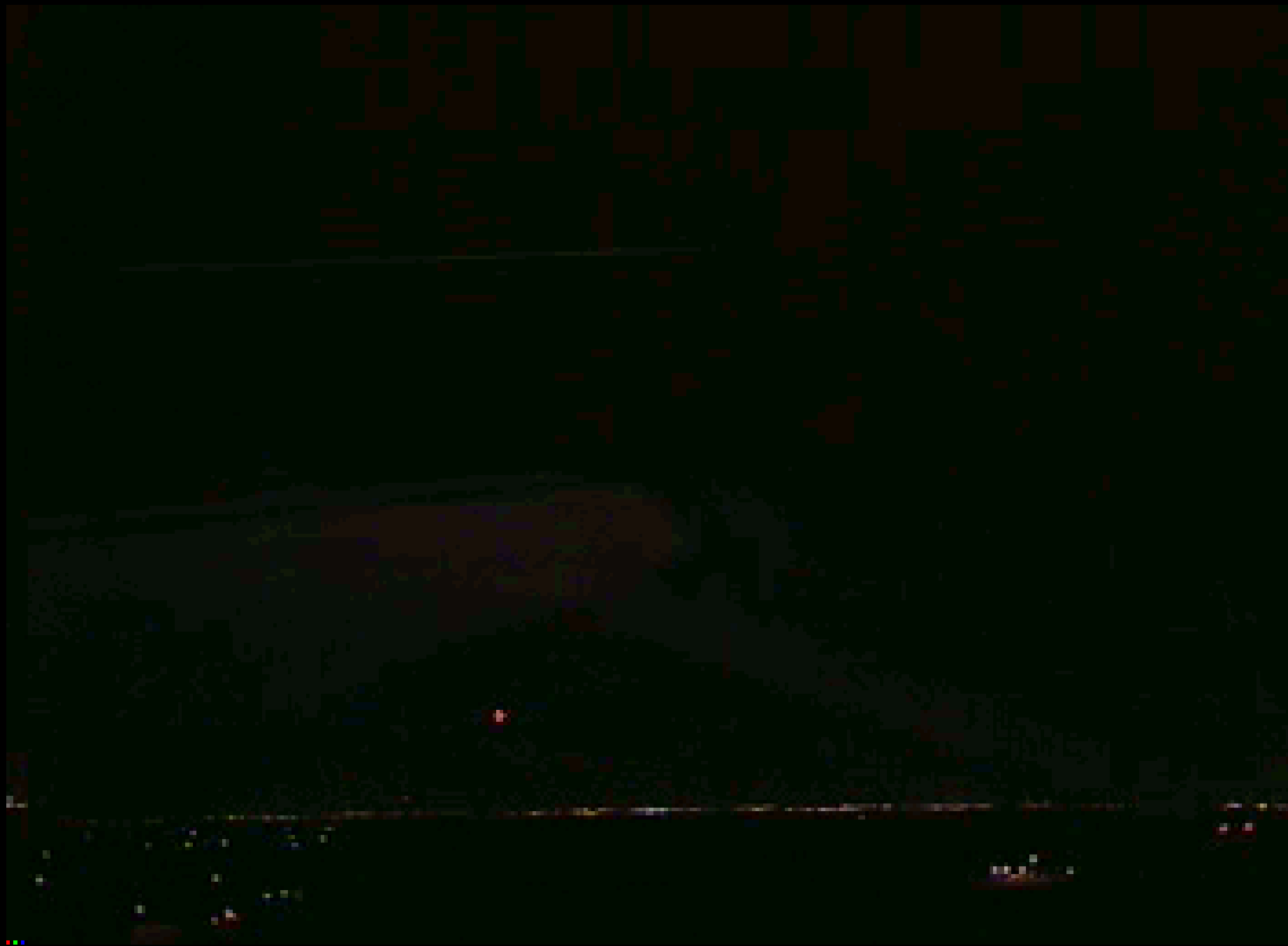
If it was easy, everyone would be doing it!

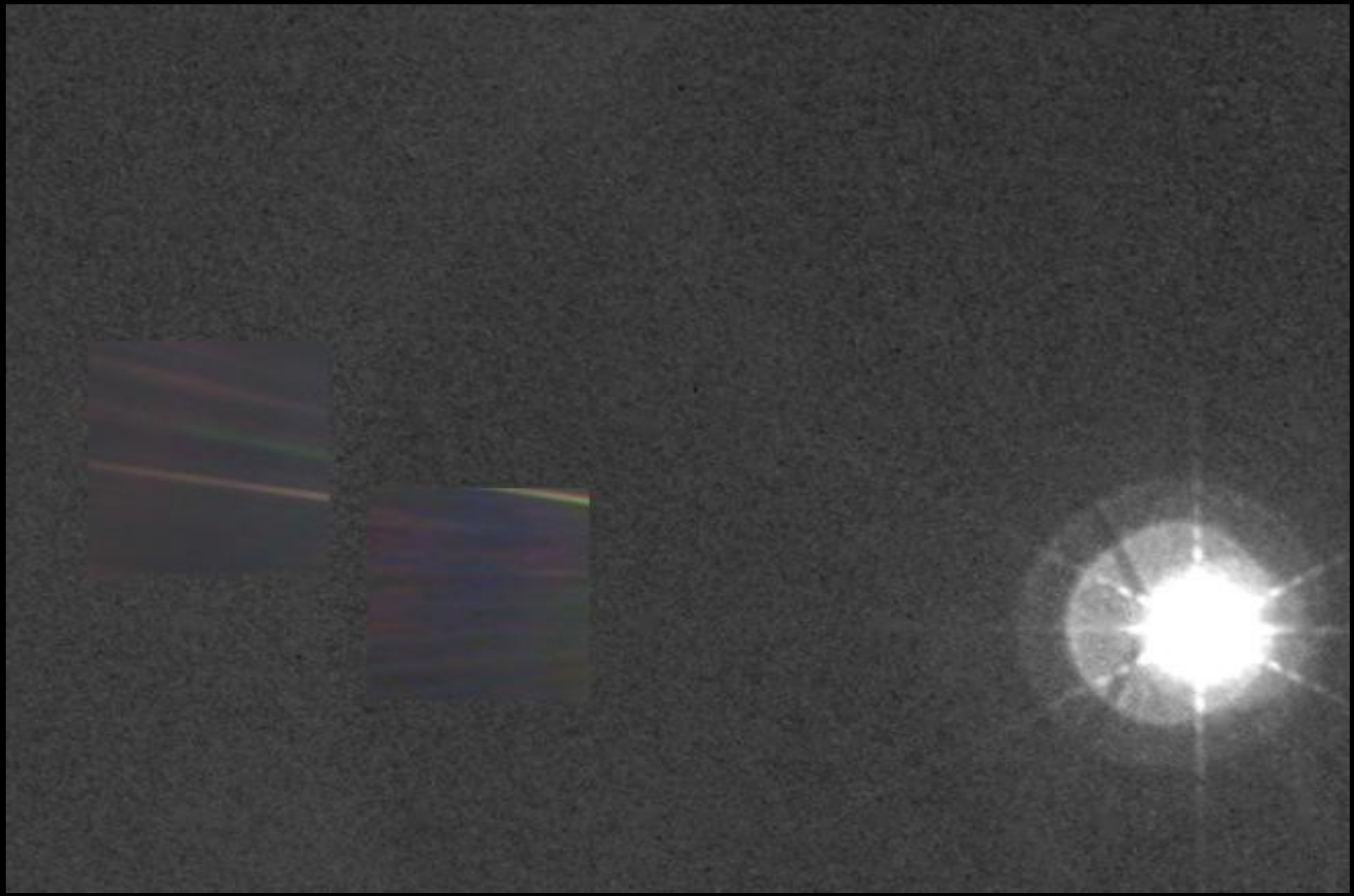
Launch Energy



What About Re-Entry?

- The Law of Conservation of Energy
  - Everything that goes into putting the Space Shuttle into orbit (4 million pounds of high energy chemicals), must be removed during re-entry
- Orbital velocity is approximately 25,600 FPS
- De-orbit burn changes velocity by approximately 300 FPS
- Main gear touchdown to wheel stop - brakes, drag chute, speed brakes - remove approximately 300 FPS
- 25,000 FPS = 98% of the velocity = 99.96% of the kinetic energy – removed by air friction alone
- 100% of the potential energy removal is accomplished by air friction



Exploration is expensive, dangerous, and risky…. So why should we explore?

The rewards are worth the risk !