Space Shuttle Lessons Learned Knowledge Sharing Forum

KSC Learning Institute
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Introduction

- Space Shuttle is the most remarkable flying machine ever built. Be Proud. A great achievement
- The technical innovations for a reusable spacecraft were amazing and built on 20 years of previous spaceflight experience
- New technology maturation is always risky
- Fly, learn, understand, redesign is normal

Discovery Rollout for STS 133 September 2010

Better is the Enemy of Good Enough

- Adding software protection for low probability failures caused unintended failures in flight
- RMS enhanced runaway protection induced “brakes on” failure on STS-49 satellite capture attempt
- Lambert Guidance failure on STS-49 third rendezvous

Better is the Enemy of Good Enough

- 1987 EPA mandated CFC changes to ET foam manufacturing and spraying agent caused extensive ET insulation material and certification changes between 1987 and 1997.
- Varying degrees of foam shedding still occurred. STS 87 Nov 1997 had extensive intertank foam shedding traced to blowing agent change
- Ground Test Environment can not duplicate actual Flight Environment—aeroheating, pressure change, and ‘popcorn effect’ debris.
- Limited test data on TPS damage susceptibility to foam strikes. CRATER for tile. RCC BB impacts

Better is the Enemy of Good Enough

- SSME HPFTP temperature sensor redesign and 3 failures on first flight shut down one engine and nearly a second engine on STS 51F-19th Shuttle Mission July 1985
- Ground testing could not duplicate flight environment
- Flight Director decision -“limits to inhibit”- saved a mission and perhaps prevented a catastrophe

Flying with Design Deficiencies

- Continued flight success builds complacency and acceptance of the risk we think we completely understand--DANGER
- Why Danger?
- Computer Modeling does not always represent the Real World
- We often have incomplete test data
- It is easy to miss a critical parameter(s)

Computer Modeling Versus Real World

- SRB joint dynamic motion and O-Ring sealing
- SRB O-Ring tracking safety margin calculations
- ET Foam debris formation mechanisms
- ET Ascent debris transport mechanism and trajectories
- Crack Growth predictions in turbomachinery turbine blades

Incomplete Test Data and Missing Critical Parameters

- SRB O-Ring tracking in cold weather
- STS 51C Jan 1985 Experienced the worst blow-by seen to date in both nozzle joints and erosion and blow-by in two case joints. The calculated O-Ring temperature was 12 degrees C, the coldest prior to the loss of Challenger on STS-51-L in Jan 1986
- O-Ring leak check verification changes caused different erosion signatures
- We continued to see secondary O-Ring erosion on every flight thinking we understood the phenomena and risk
- We missed how critical cold O-Ring tracking was in a dynamically moving joint during the SRB ignition transient

Immediately after solid rocket motor ignition, dark smoke (arrows) swirled out between the right hand booster and the External Tank. The smoke's origin, behavior and duration was approximated by visual analysis and computer enhancement of film from five camera locations. Consensus: smoke was first discernible at .678 seconds Mission Elapsed Time in the vicinity of the right booster's aft field joint.

SRB burn thru

Challenger explosion

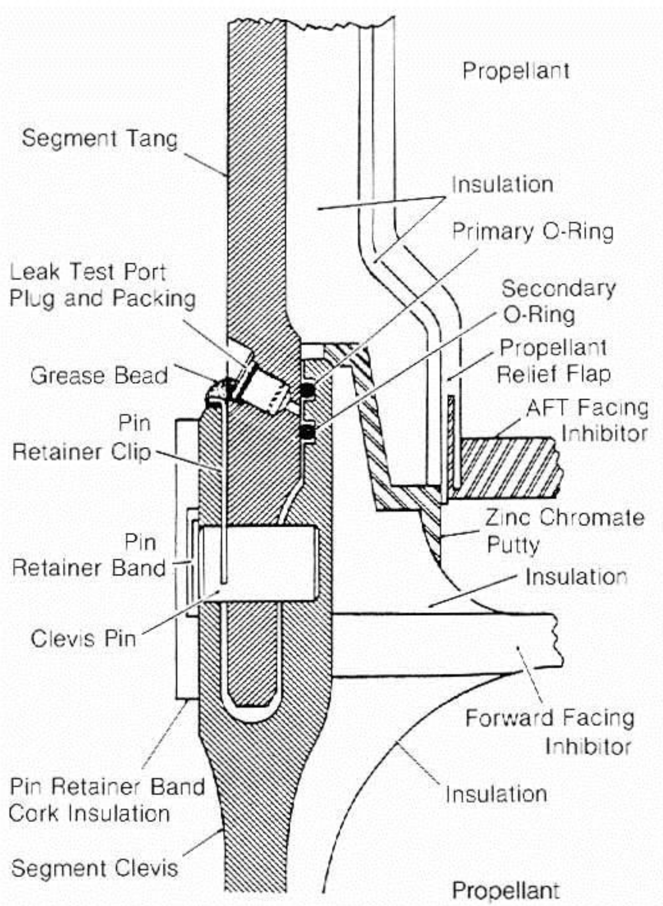
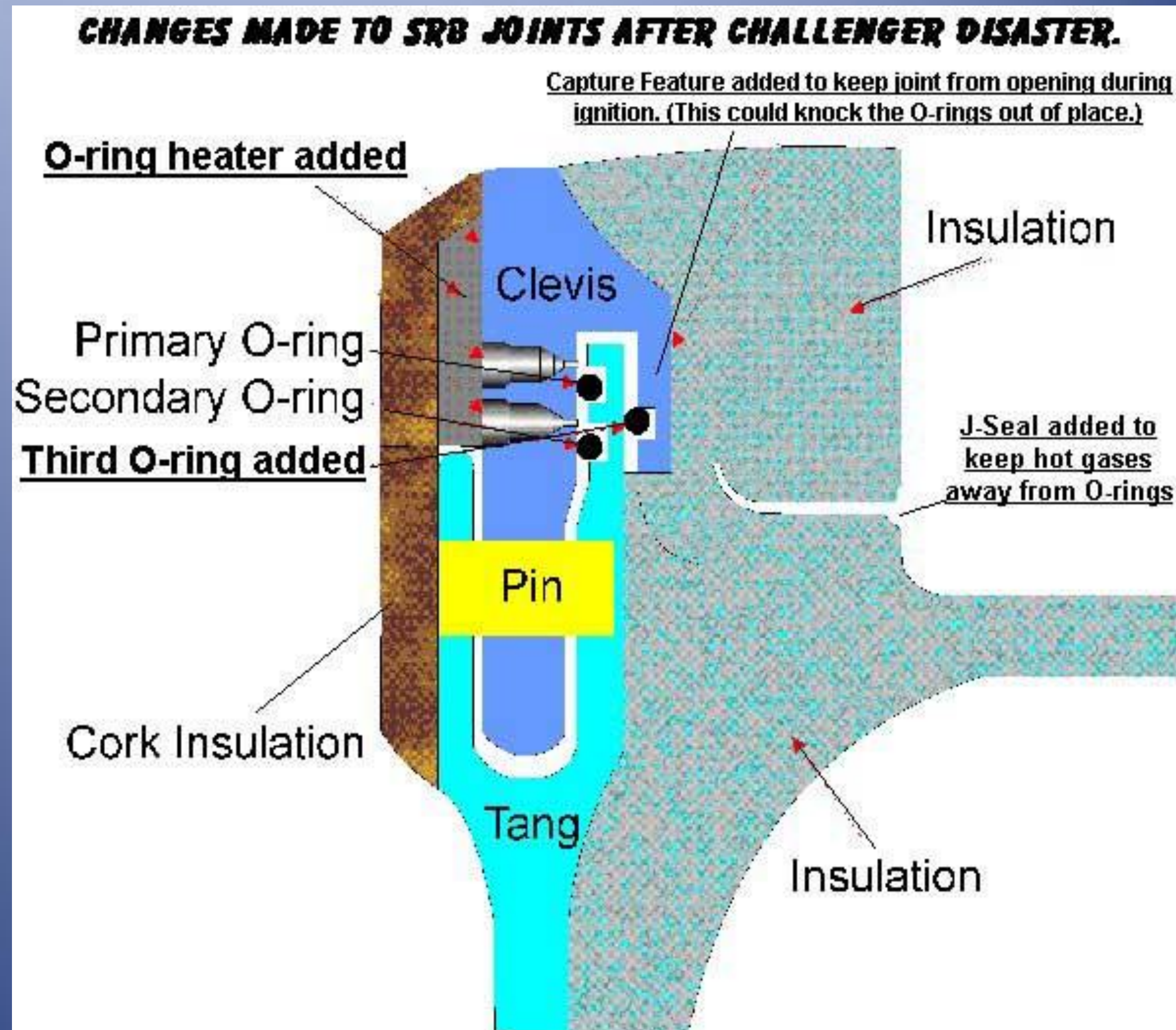


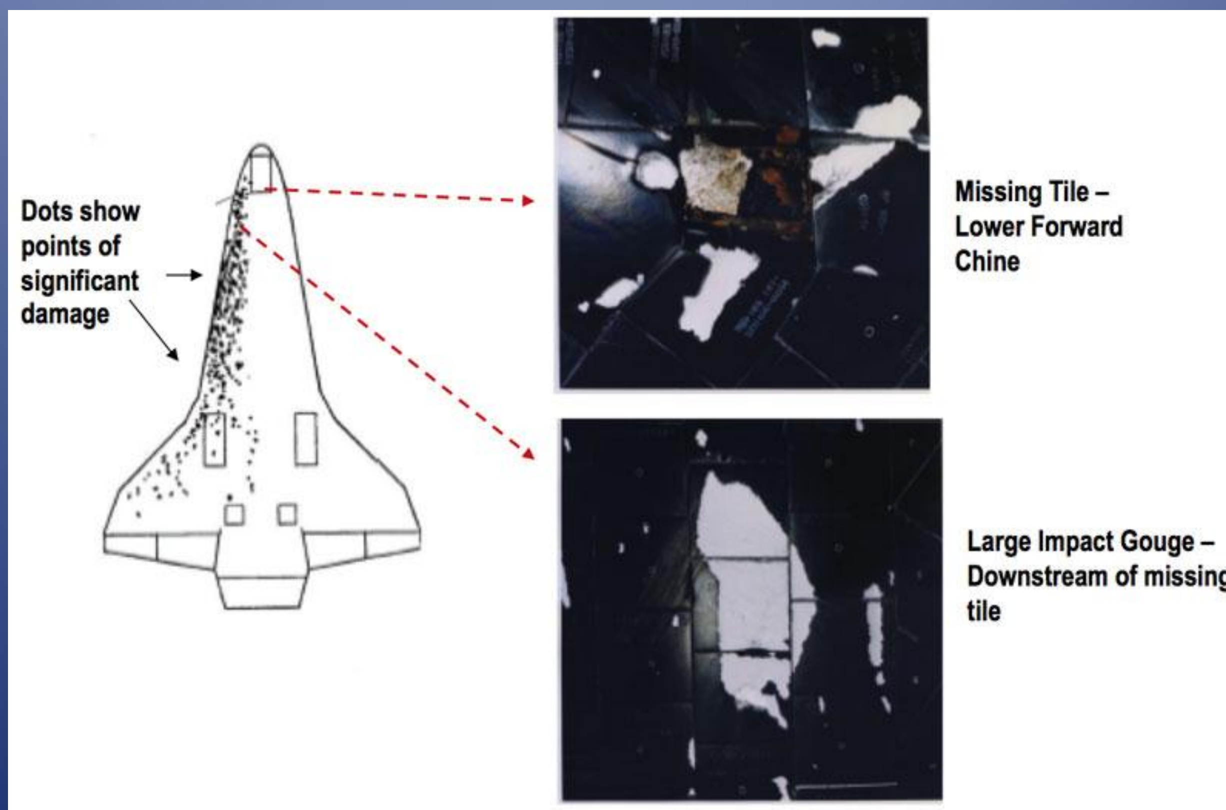
Figure 14
Solid Rocket Motor cross section shows positions of tang, clevis and O-rings. Putty lines the joint on the side toward the propellant.

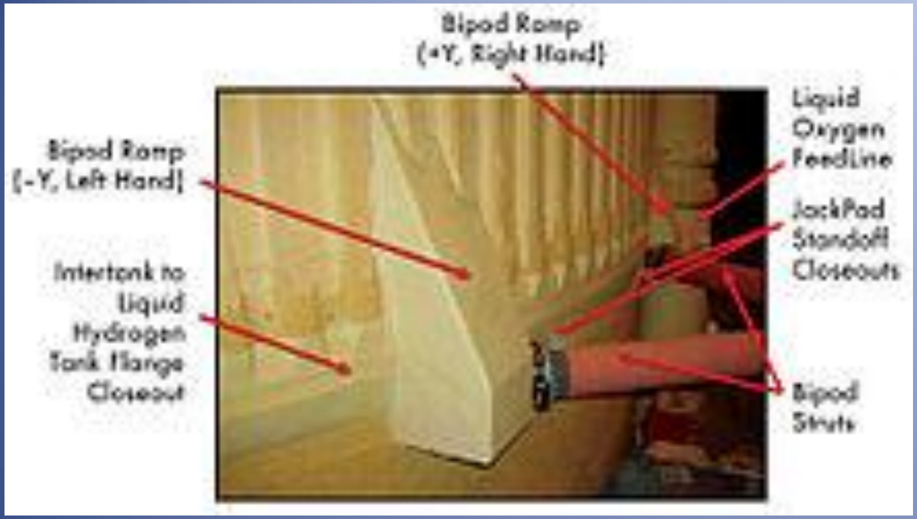


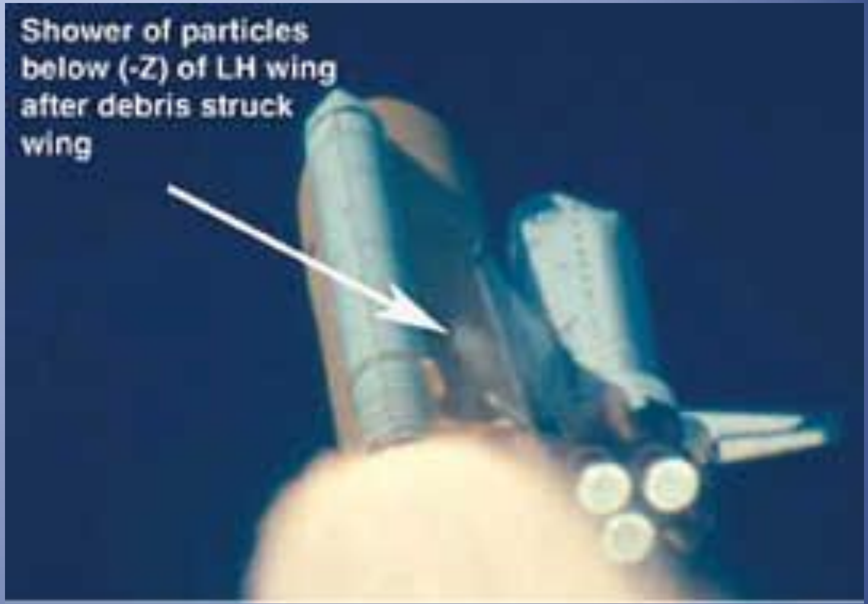
Incomplete Test Data and Missing Critical Parameters

- No Large ET Foam Strike testing on leading edge RCC panels or critical TPS locations. Flight Experience was our data base
- STS 27 Dec 88 at T+85 seconds a large piece of debris struck the shuttle. Traced to RSRB MSA-1 ablator loss. The orbiter took 707 hits, 298 greater than an 2.4 cm in size. One tile was knocked off, but behind it was a thick plate covering the L-band antenna that prevented a burn-through.
- We continued flying with large ET intertank and bipod area foam loss causing Orbiter Tile damage-STS 32,50,52, 62,87,112 . Deemed not a safety of flight issue, but a maintenance repair issue.
- STS 107 Jan 2003 left wing RCC panel struck and ruptured by large ET foam piece at T+82 seconds
- We missed aerodynamic transport trajectories and lethality of rapidly decelerating foam striking the wing leading edge RCC panels or critical tile locations.


United States


Dots show points of significant damage
Missing Tile – Lower Forward Chine
Large Impact Gouge – Downstream of missing tile





RCC panel foam impact test

Expect a Conservative Reaction to Failure

- Proper balance is difficult to achieve. Human nature wants tighter limits.
- Post Challenger ultra-conservative launch commit criteria (LCC) caused launch scrubs and high waiver activity.
- SSME start limit LCC were tightened resulting in launch scrubs and pad aborts
- worst-on-worst dispersions for QAlpha and QBeta squatcheloids made very conservative ascent load limits resulting in scrubs for winds aloft and multiple load indicator waivers.

Flight Experience leads to needed improvements

- Two GPC failures on STS-9 due to generic age related dendrite growth on computer boards solved by AP101B GPC upgrade
- STS-9 APU fuel line cracks/hydrazine leak and APU turbine blade cracks initiates IAPU safety enhancements
- Redesigned Pratt and Whitney SSME HPFTP and HPOTP provides significant safety margin improvements
- Haines IMU upgrade solves life issues and improves performance.

Summary

- Flying with design deficiencies you think you understand completely requires extreme caution. Challenge the test data and modeling. Have a healthy skepticism. Be highly aware of success induced complacency
- Deciding between necessary redesigns and ‘better is the enemy of good enough’ improvements is difficult. Quantitative risk assessment of before and after change is vital