

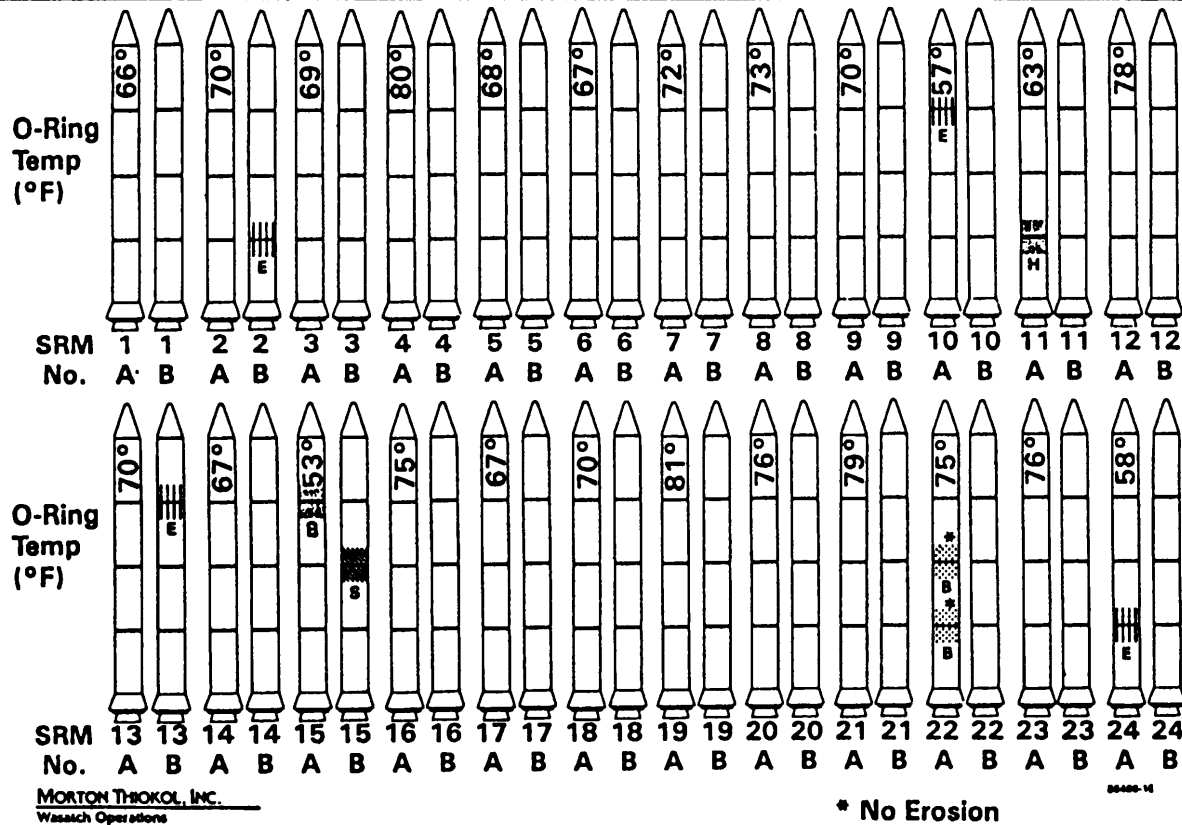
Launch and Entry Failures

- Atlas ICBM
- STS 51-L - Challenger
- STS 107 - Columbia
- AMROC SET-1



Review Slide - STS-51L L-1 FRR

History of O-Ring Damage in Field Joints (Cont)



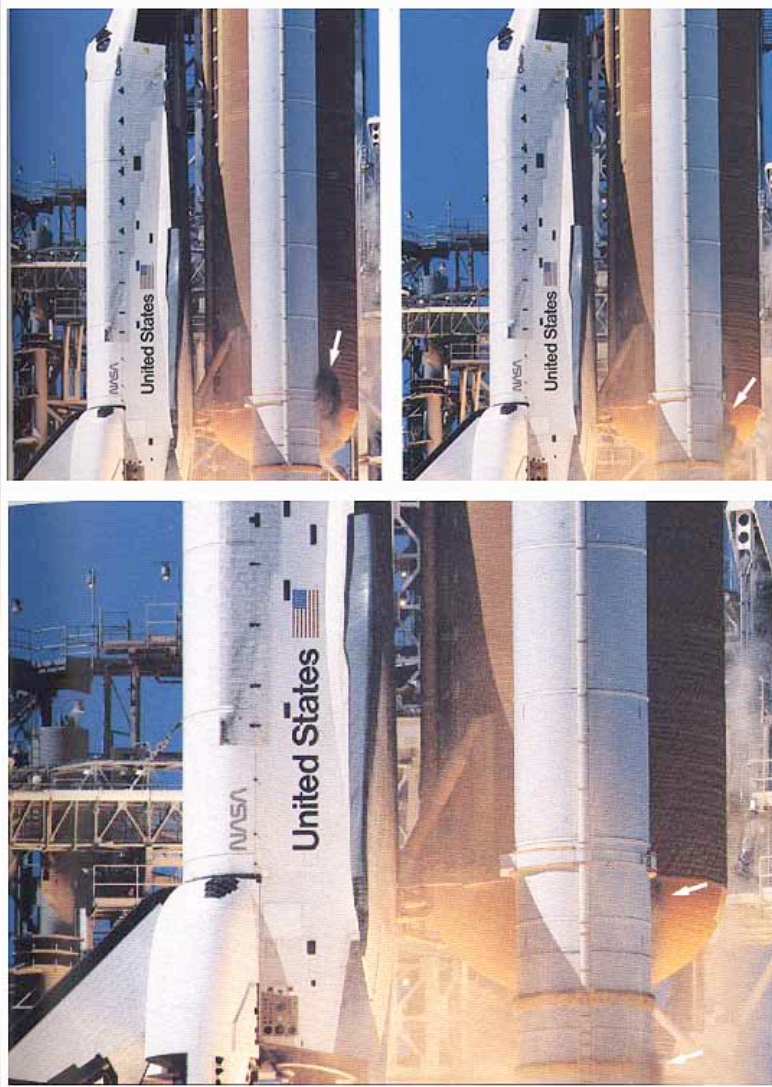
INFORMATION ON THIS PAGE WAS PREPARED TO SUPPORT AN ORAL PRESENTATION AND CANNOT BE CONSIDERED COMPLETE WITHOUT THE ORAL DISCUSSION

From Edward R. Tufte, Visual and Statistical Thinking: Displays of Evidence for Making Decisions
Graphics Press, 1997

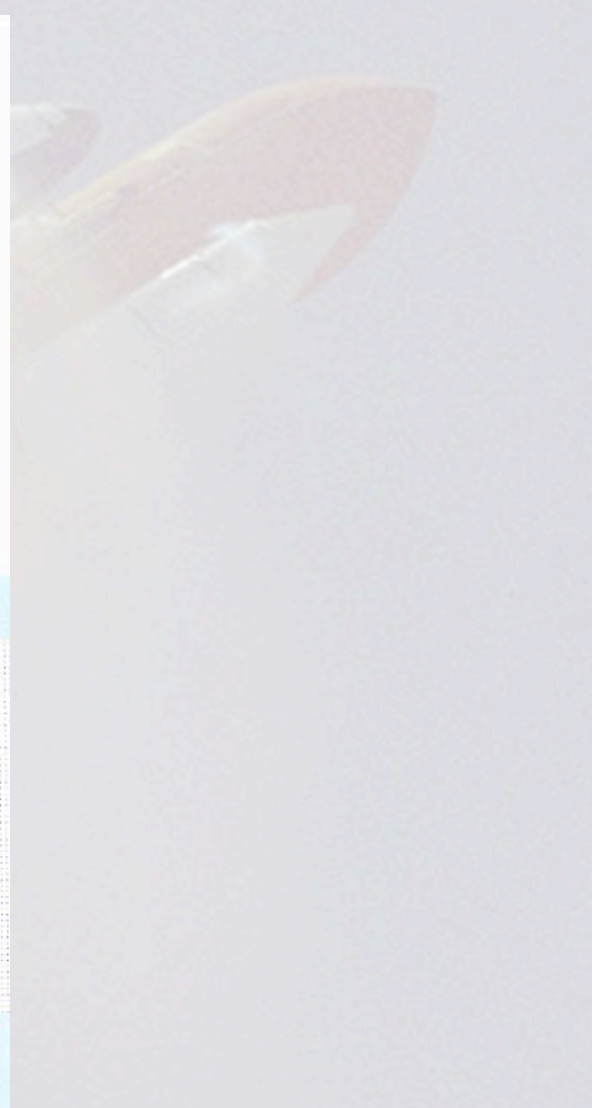
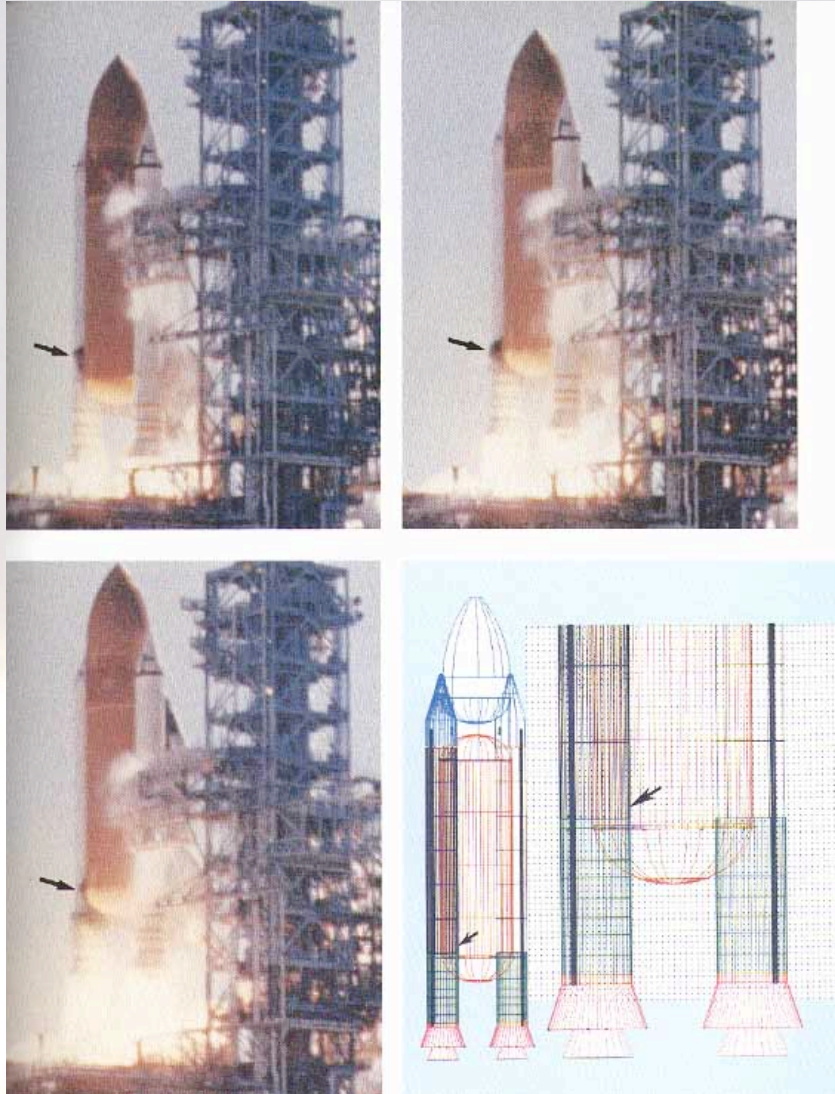


Black Smoke Plumes from Aft Field Joint

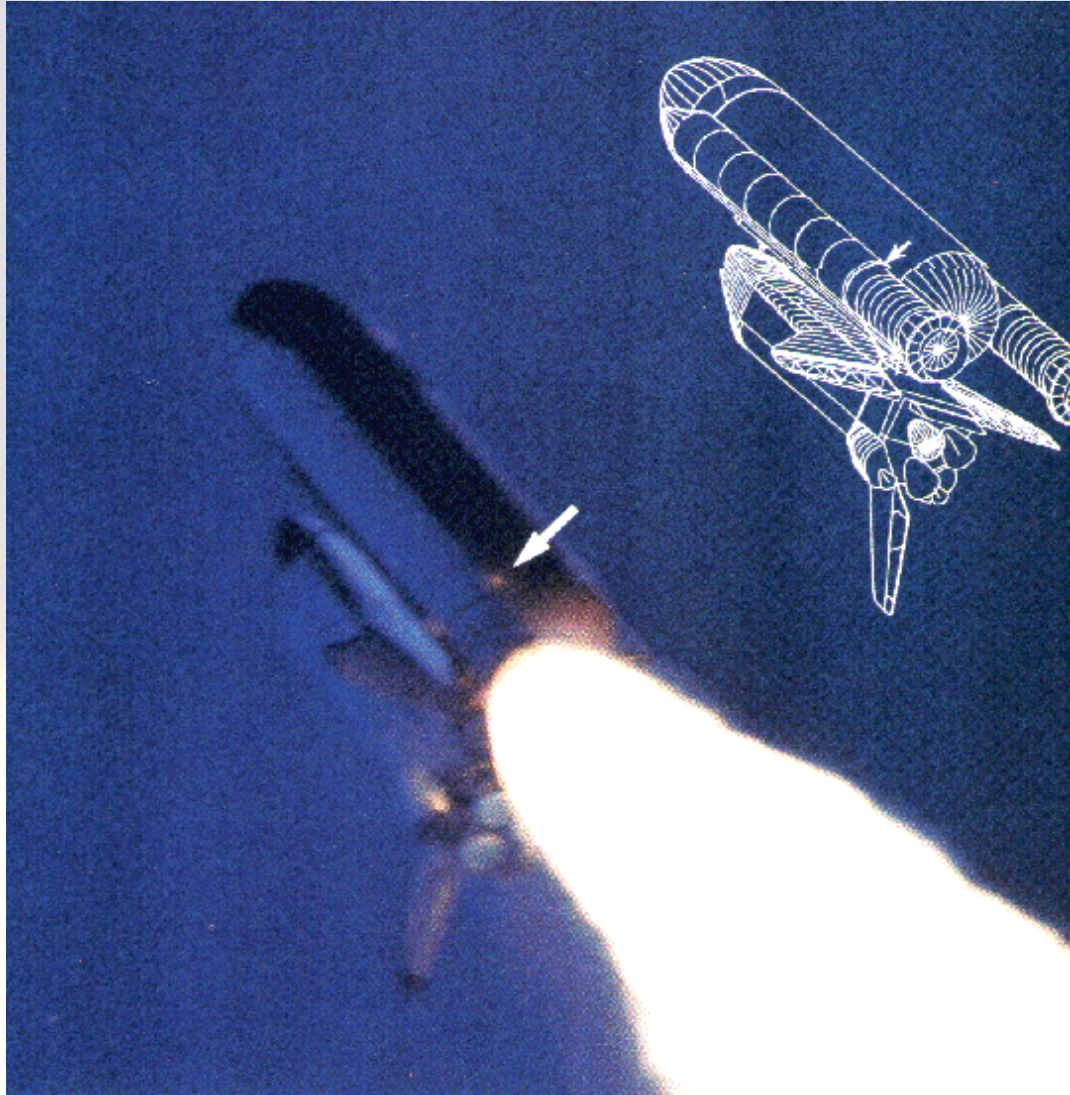




Photographic Evidence



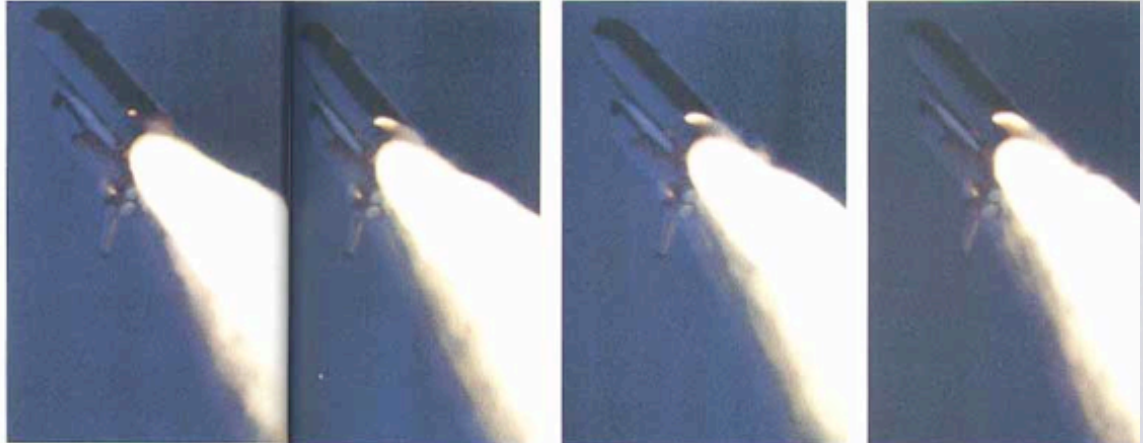
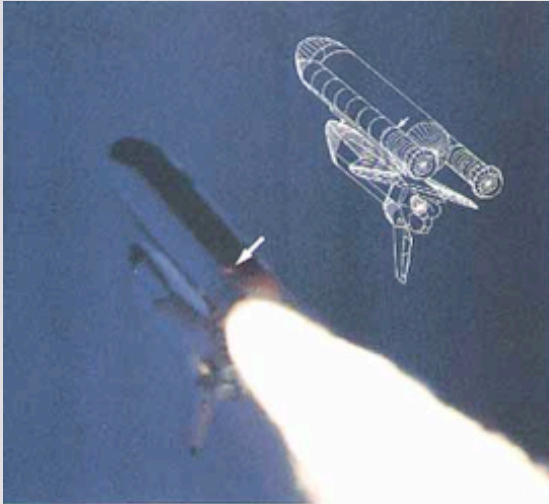
T+58 sec - Appearance of External



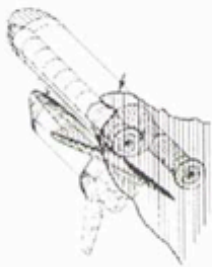
Flame Hitting Aft Attach Fixture and ET



Progression of SRB Burn-through



At 58.786 seconds, the first flicker of flame appeared. Flare visible above. It grew into a large plume and began to impinge on the External Tank at about 60 seconds. Flame is highlighted in the computer drawing between the right booster and the tank, as in the case of earlier smoke puffs. At far right (arrow), vapor is seen escaping from the apparently breached External Tank.



Original SRB Field Joint Design

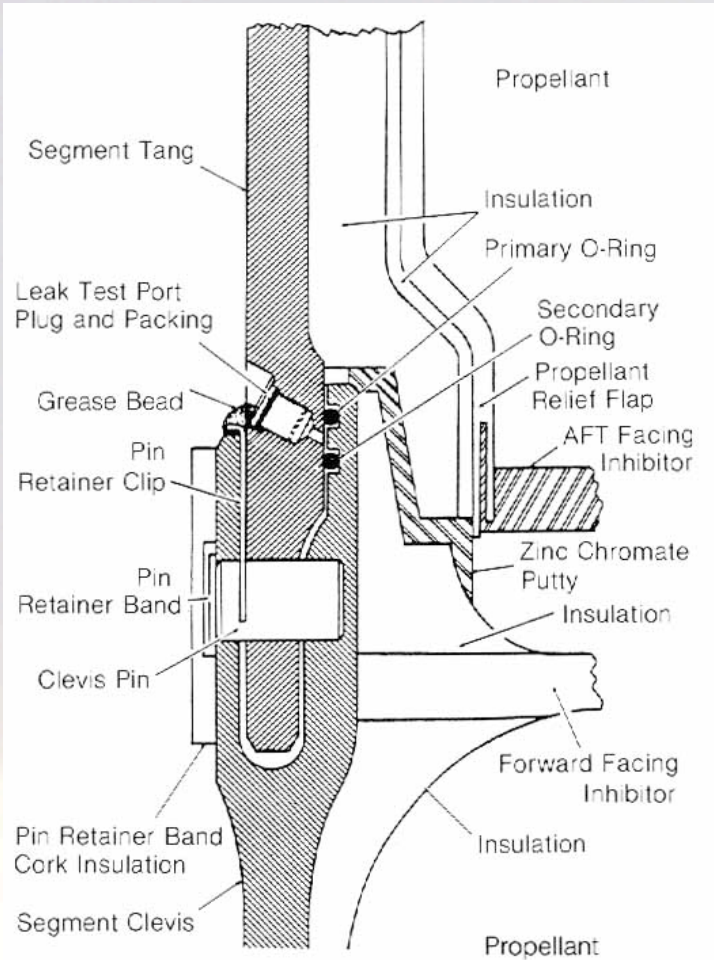
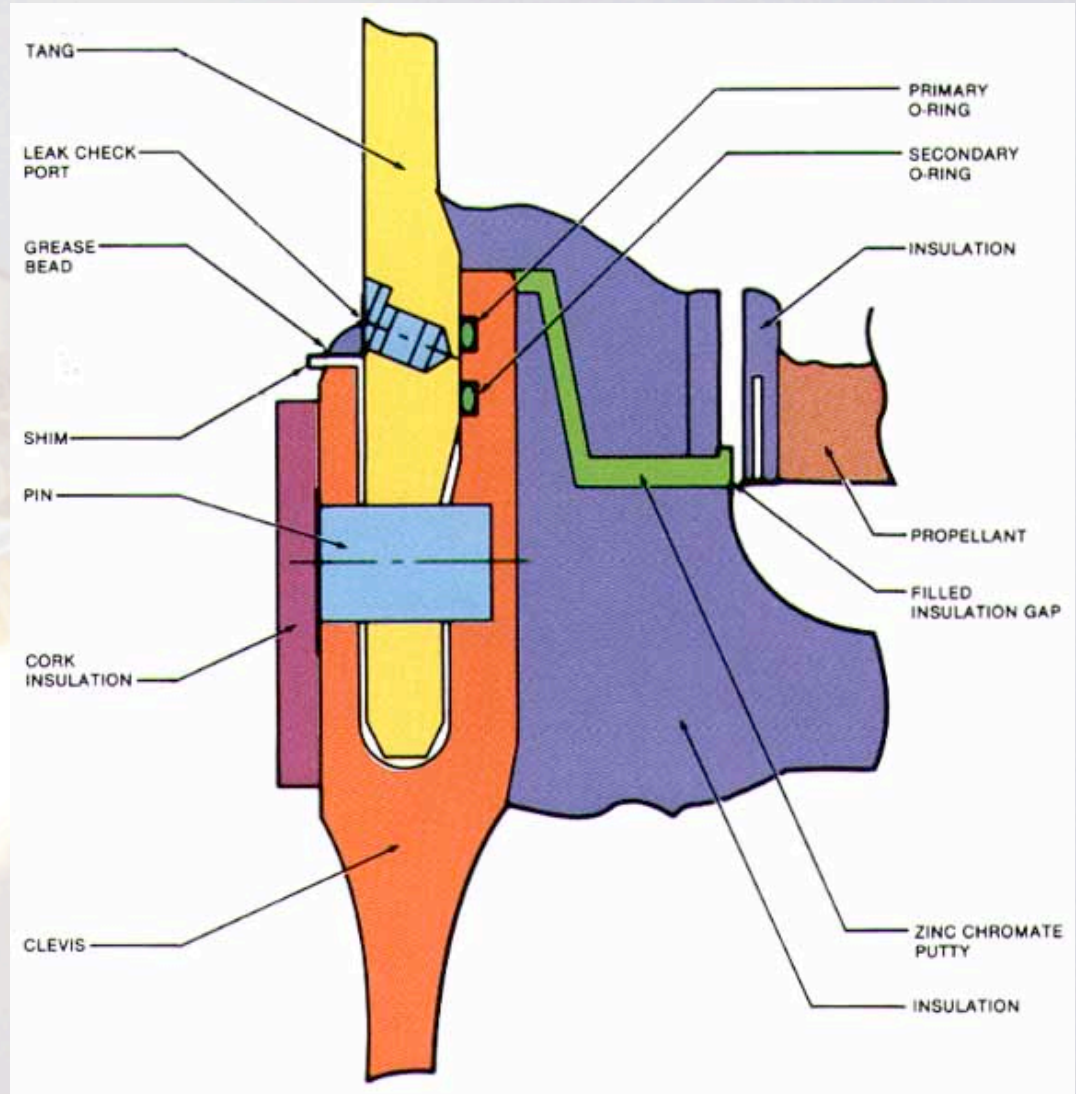
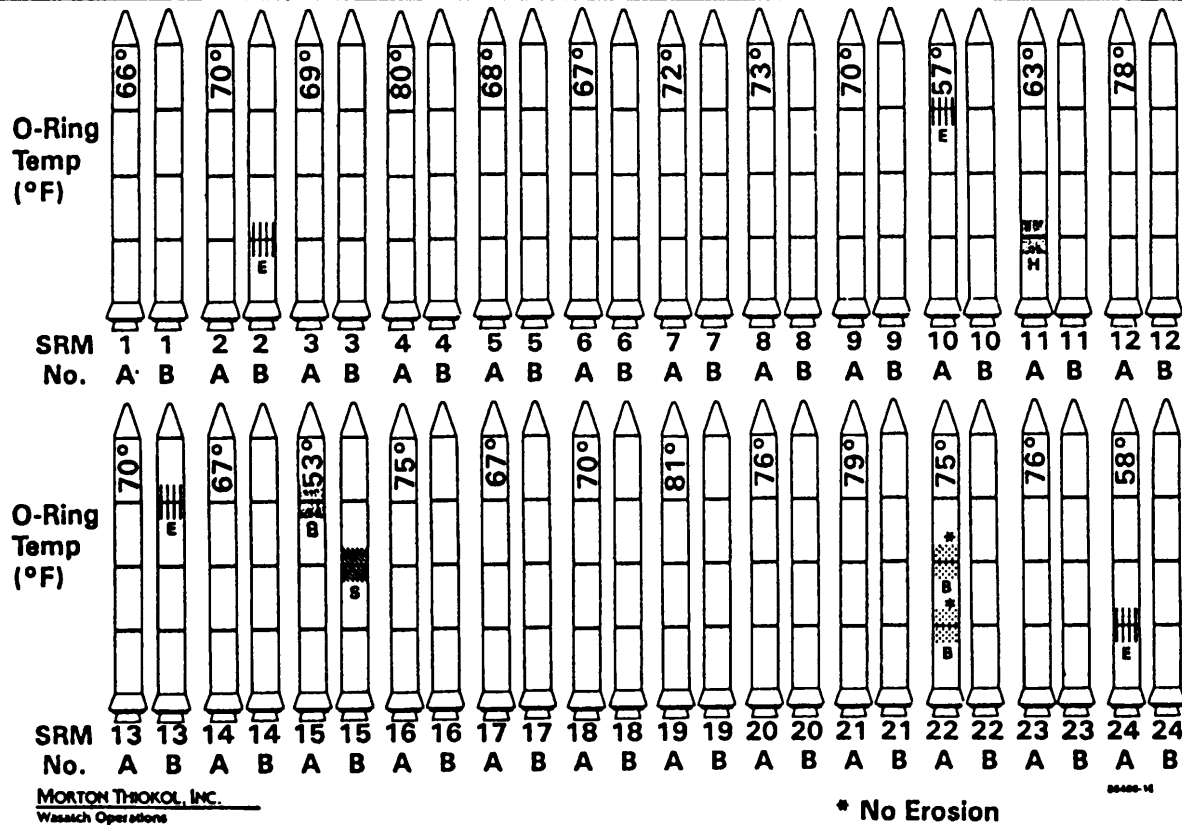


Figure 14
Solid Rocket Motor cross section shows positions of tang, clevis and O-rings. Putty lines the joint on the side toward the propellant.



The Slide That Was Presented

History of O-Ring Damage in Field Joints (Cont)



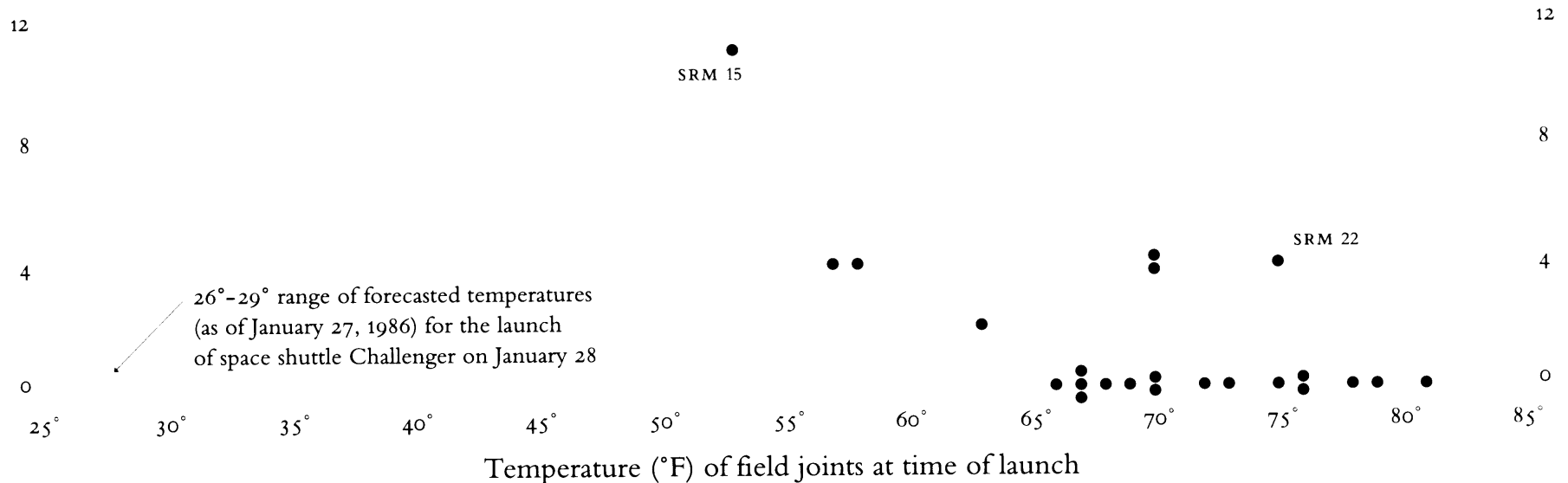
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Graphics Press, 1997



The Slide That Should Have Been...

O-ring damage index, each launch



From Edward R. Tufte, *Visual and Statistical Thinking: Displays of Evidence for Making Decisions*
Graphics Press, 1997



Clearance Effects on O-Ring Seating

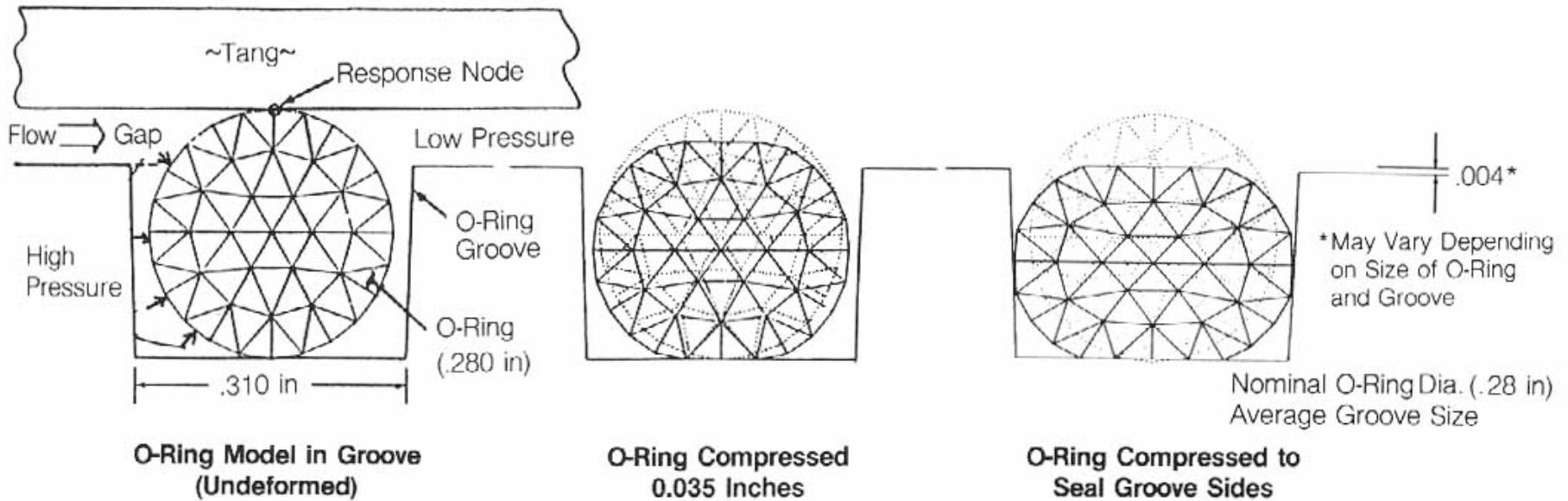


Figure 18
Drawings show how progressive reduction of gap between tang and clevis can inhibit and eventually block motor cavity's high-pressure flow from getting behind O-ring.



Dynamic Motion of O-Ring Seals

Pressurized Joint Deflection

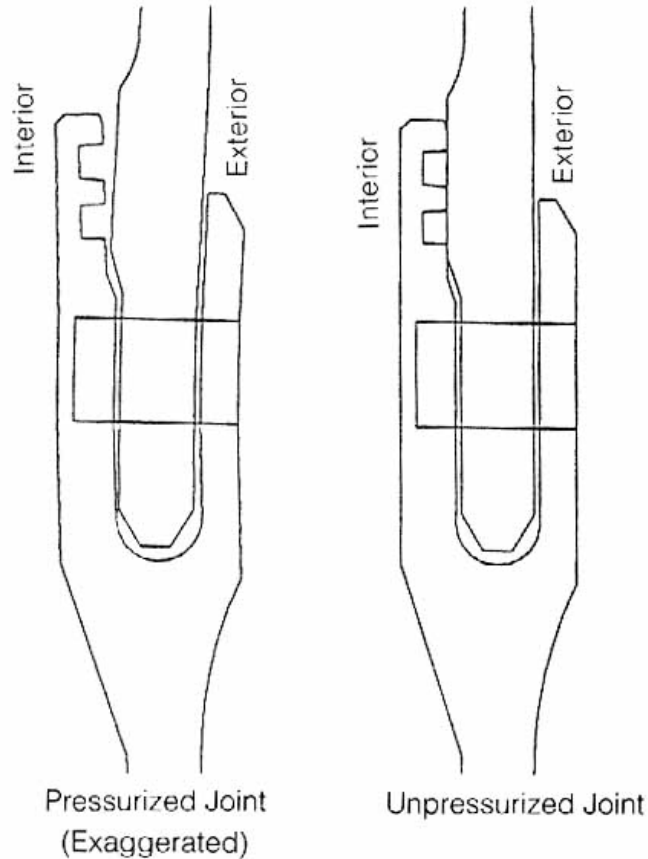


Figure 16
Drawings show how tang/clevis joint deflects during pressurization to open gap at location of O-ring slots. Inside of motor case and propellant are to left in sketches.

Right Hand SRM Aft Field Joint Primary And Secondary Delta Gap Opening

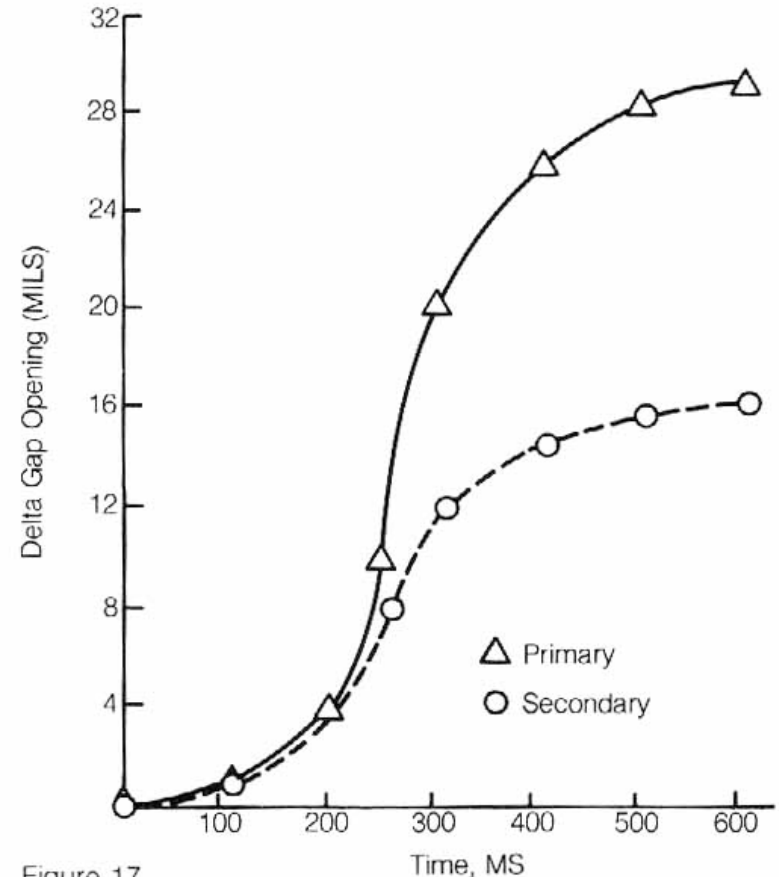
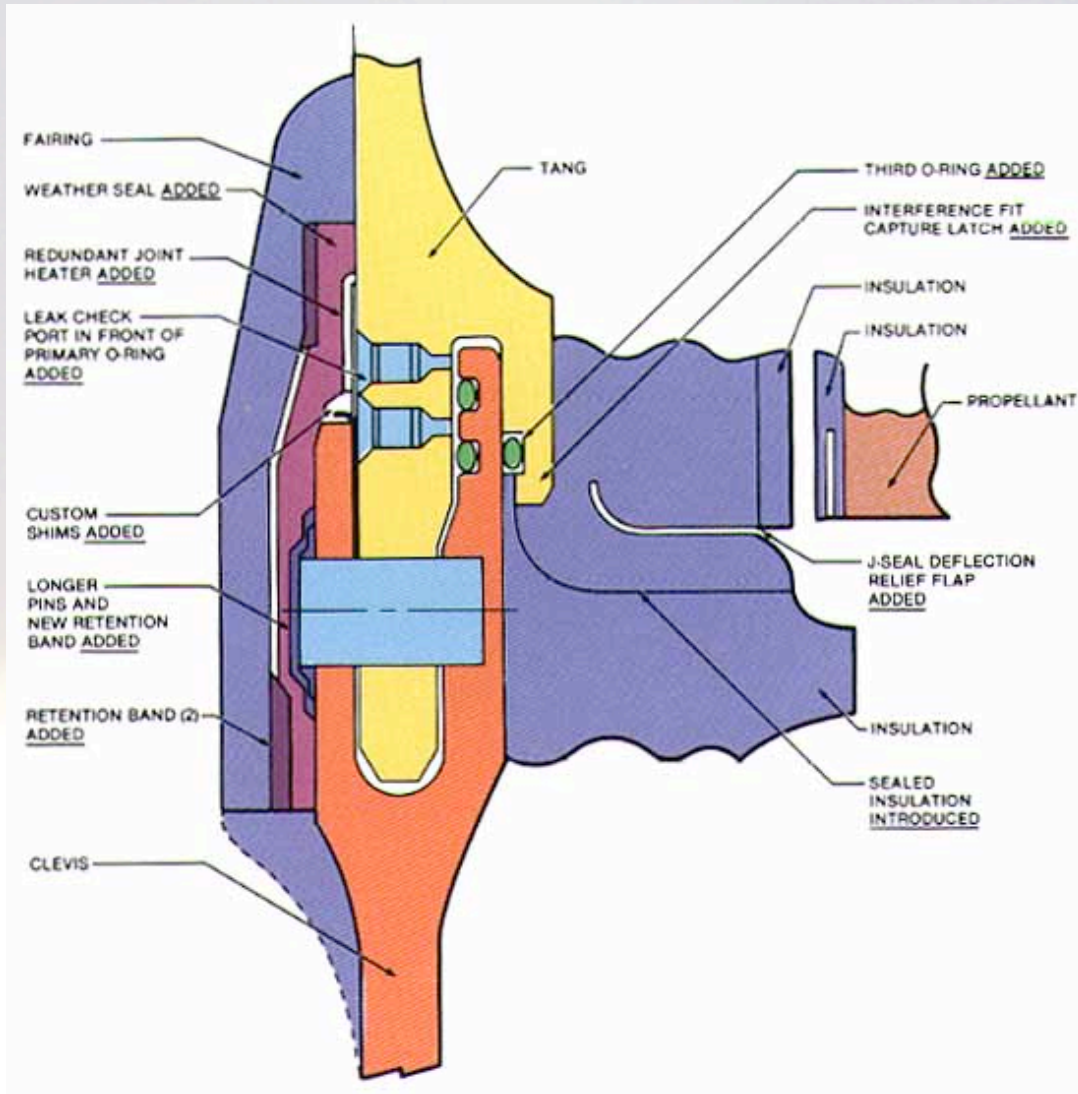


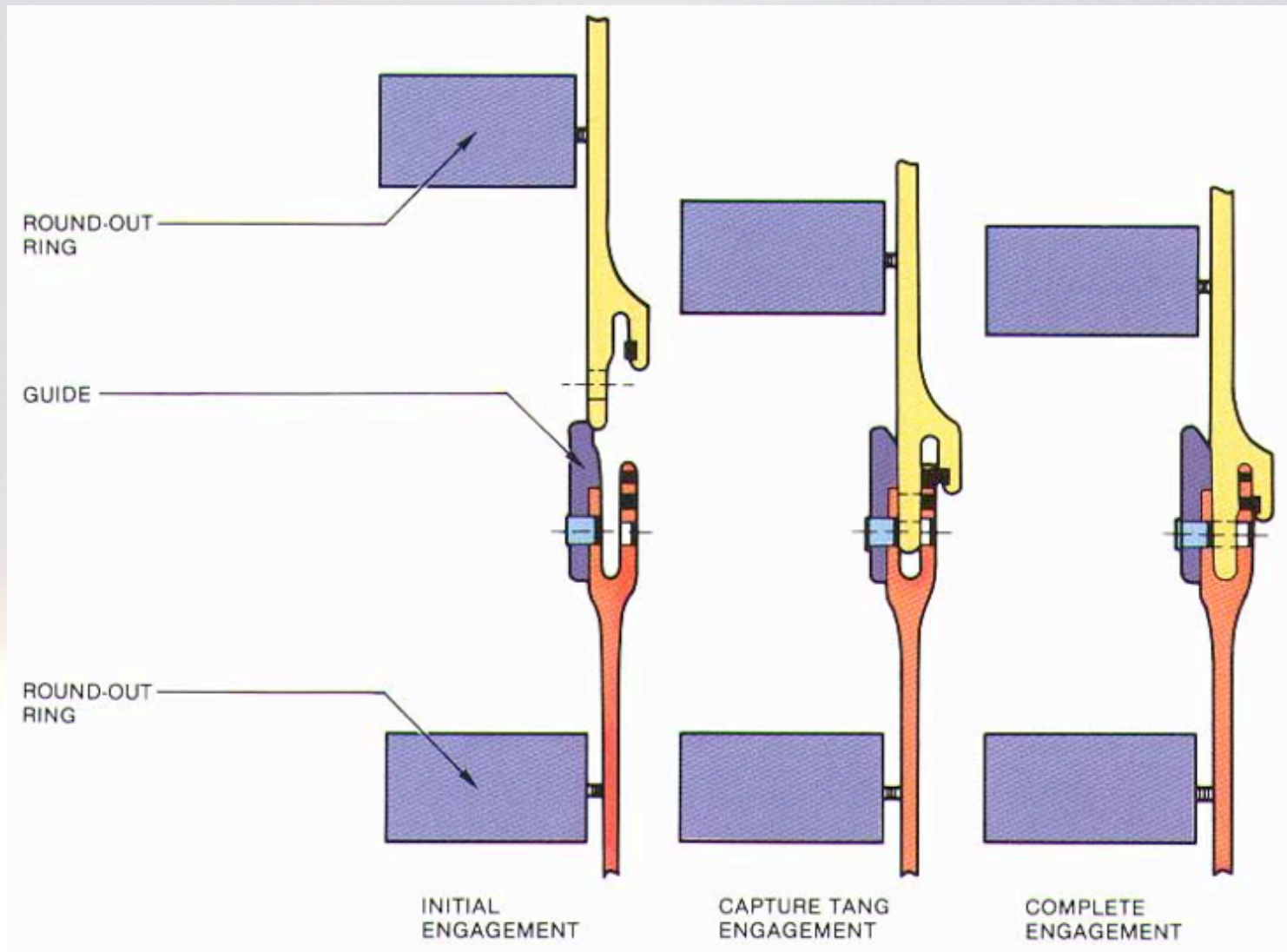
Figure 17
Graph plots changes in right booster's aft field joint primary and secondary gap openings. Horizontal scale is time in milliseconds from ignition.



Redesigned SRB Field Joint



Revised SRB Assembly Technique



Columbia Launch - STS-107



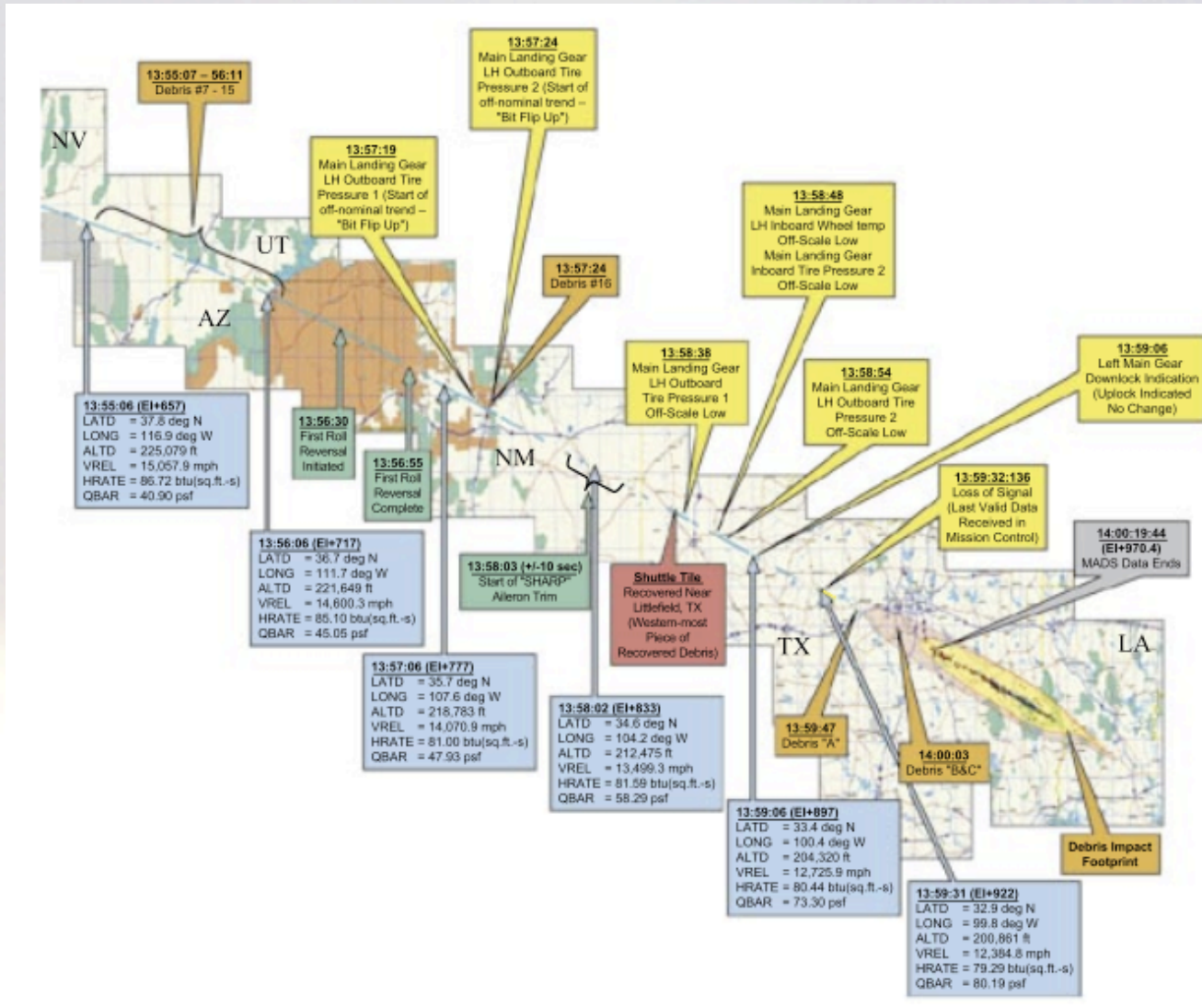
L+81.9 sec



In-Flight Breakup



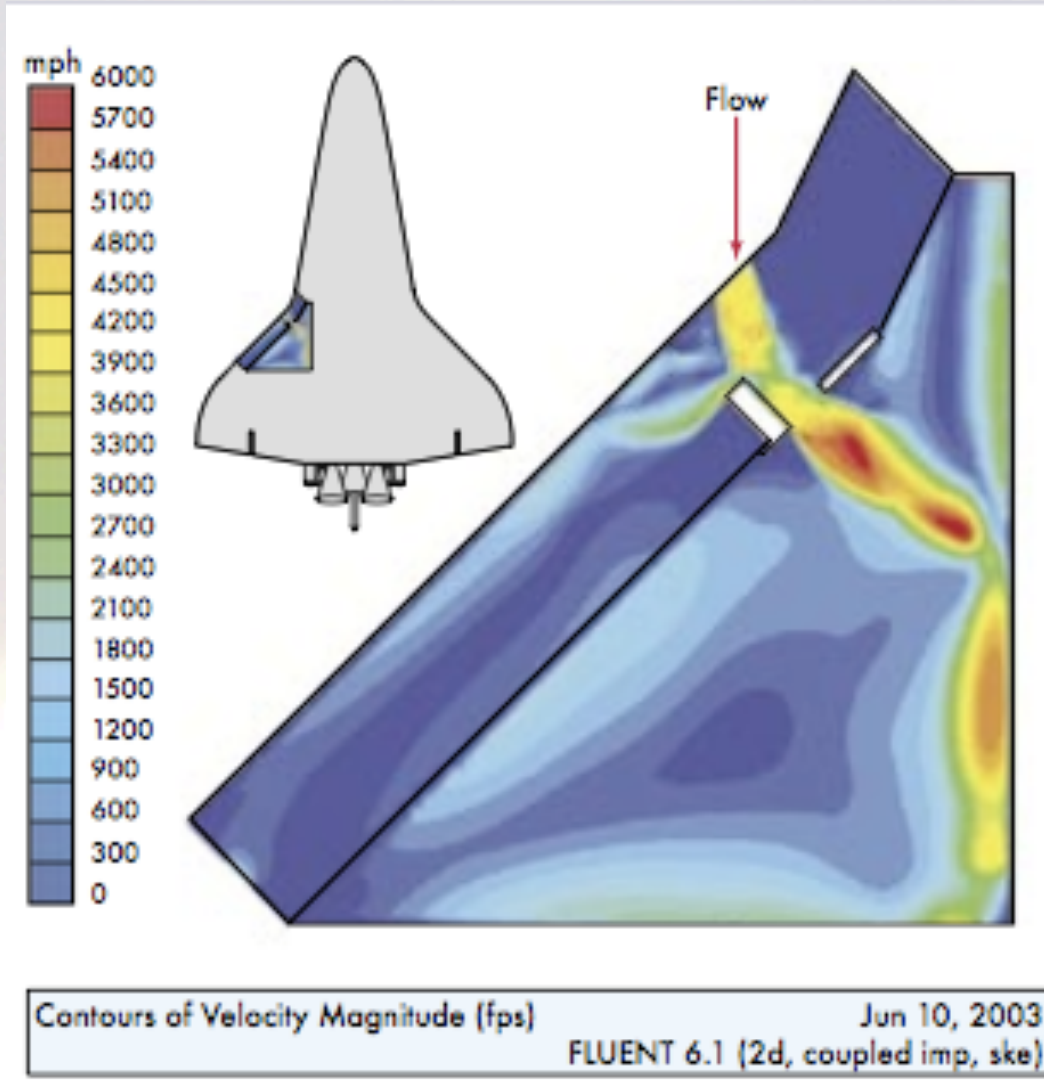
Events Along Flight Path



Columbia Debris Reconstruction

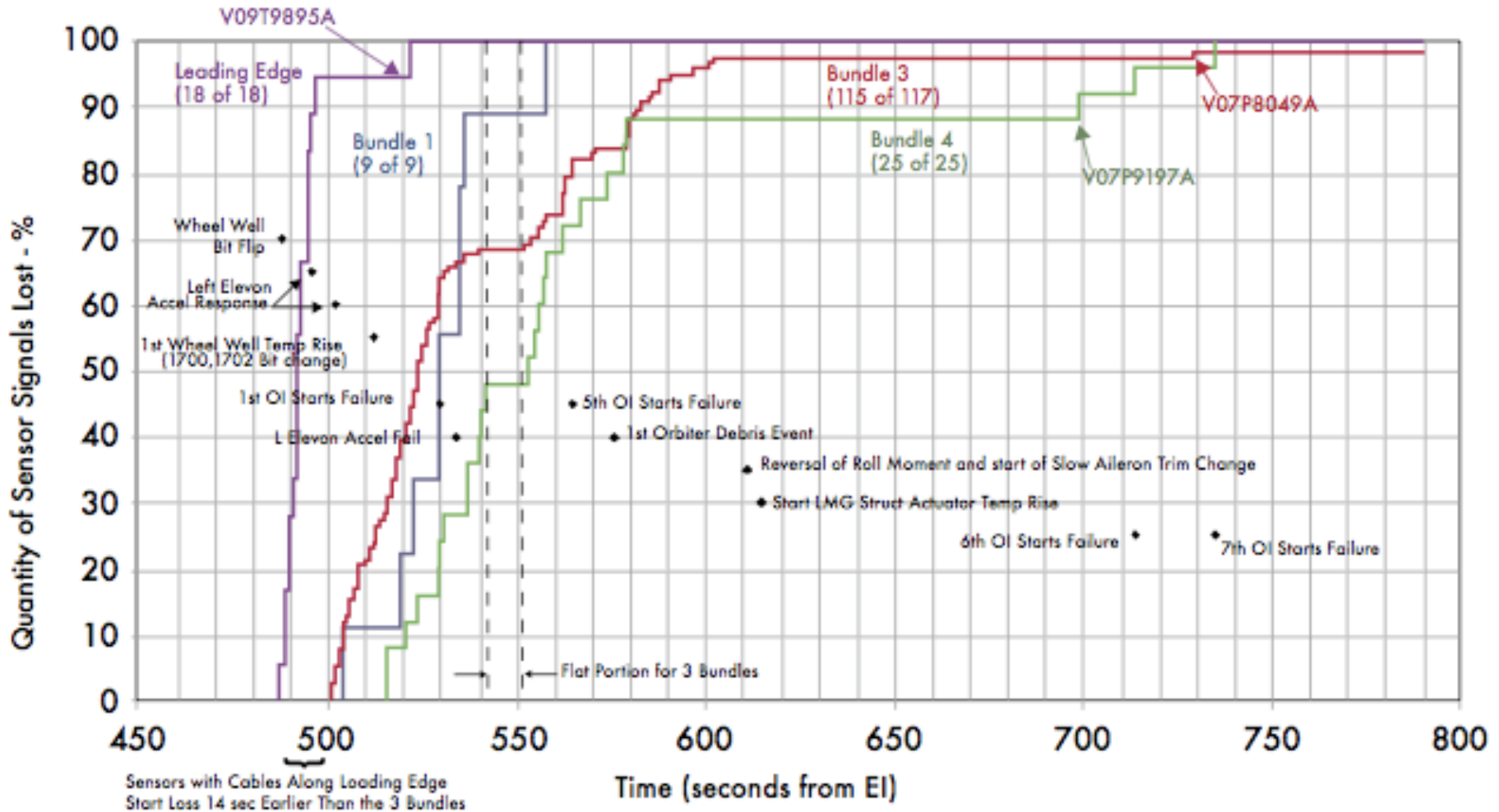


CFD Analysis of Internal Airflow

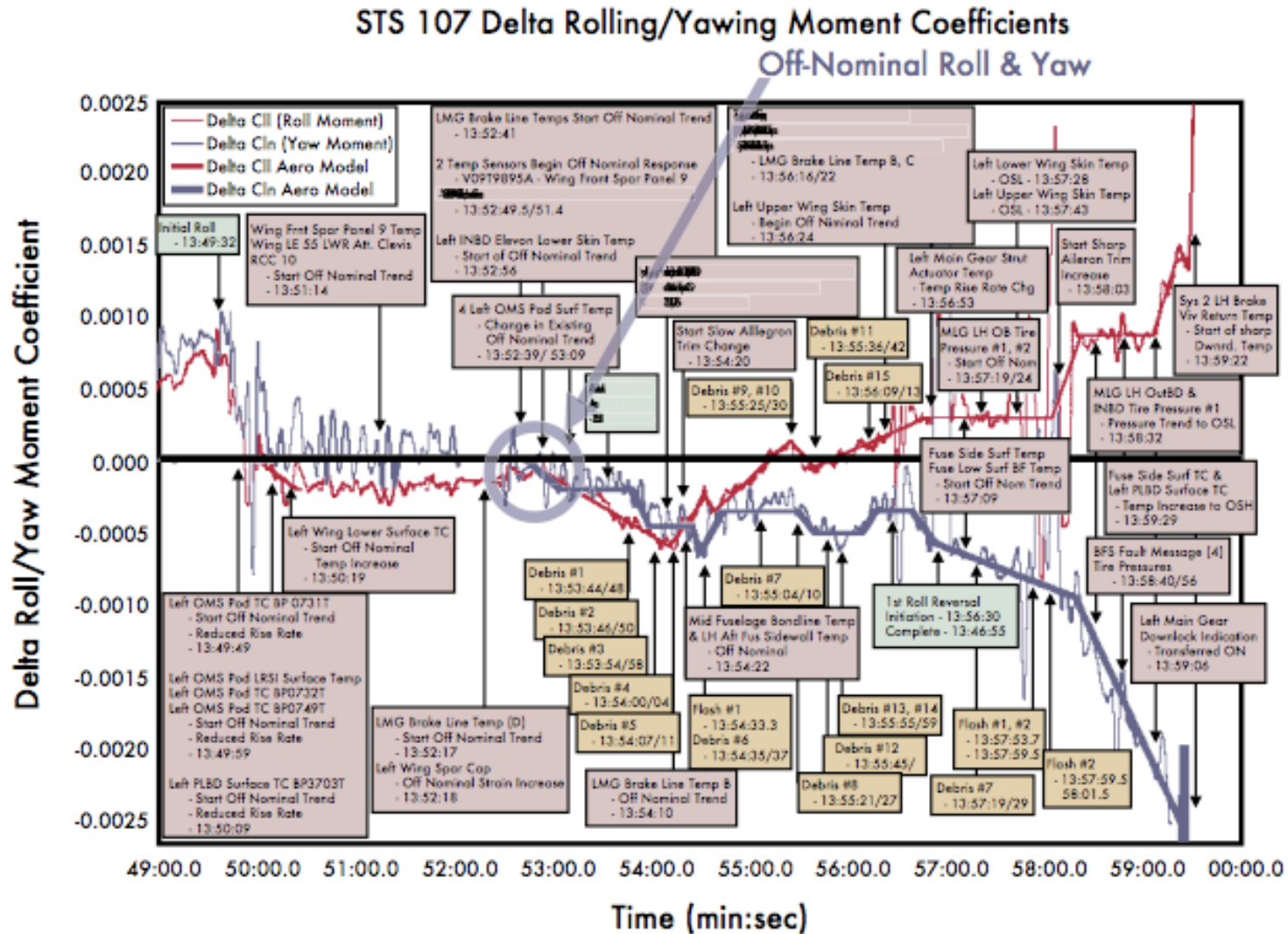


Failure Rates of Sensor Wiring Bundles

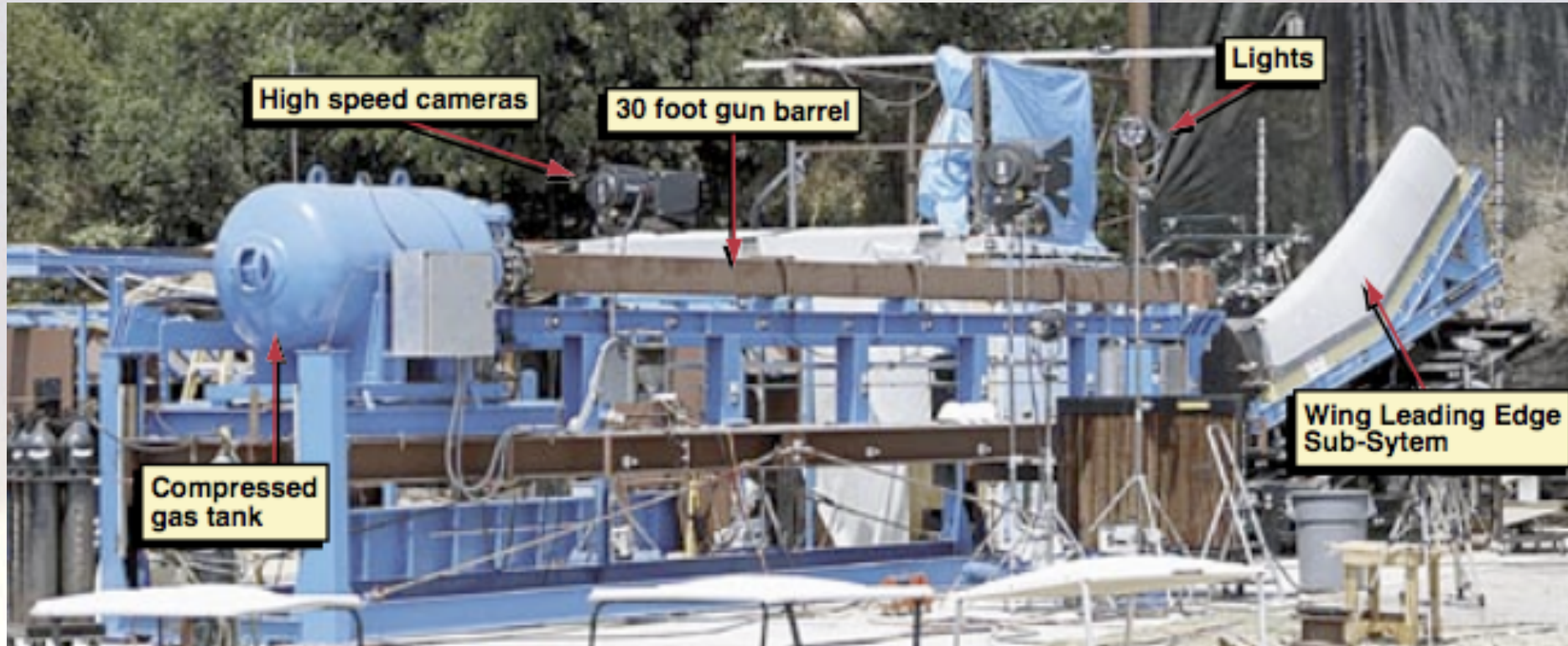
Percent Loss of Sensor Signals Versus Time In Left Wing and Wing Leading Edge Wire Bundles



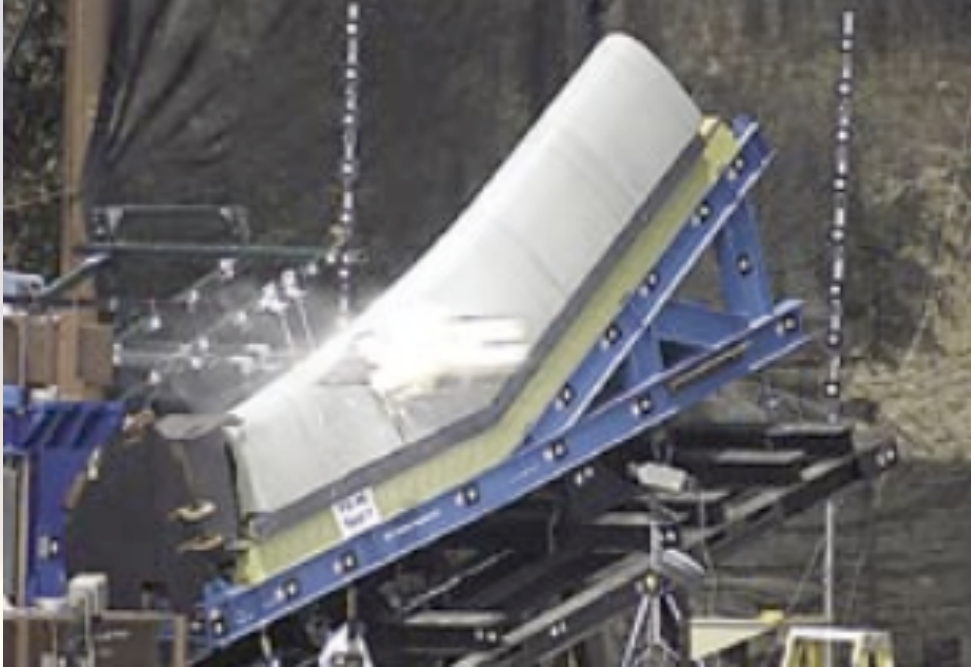
Divergence of Roll/Yaw Angles



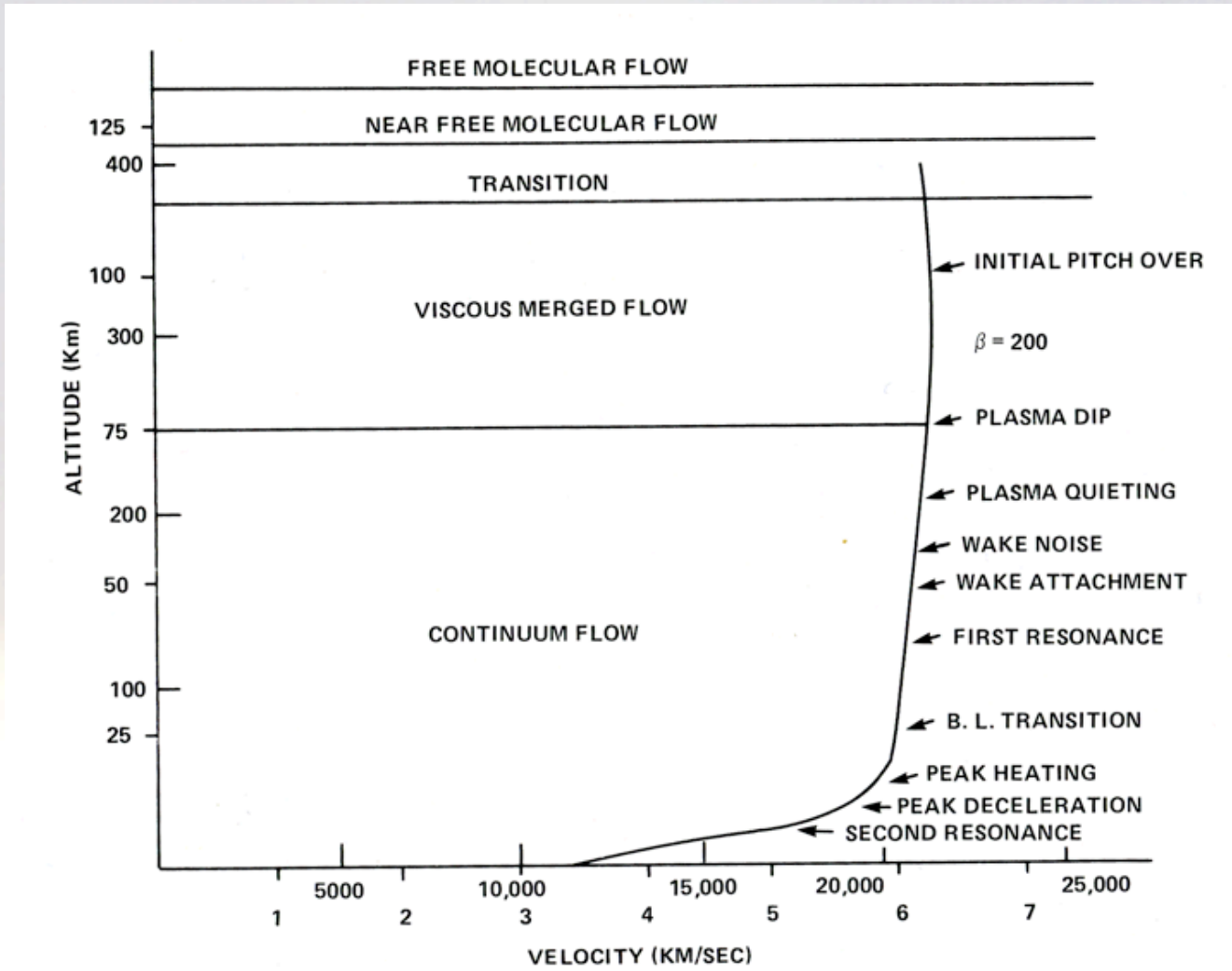
High-Velocity Impact Testing of RCC



Results of Impact Tests on RCC



Entry Flow Regimes



ref: Frank J. Regan, Reentry Vehicle Dynamics AIAA Education Series, NY, NY 1984



October 5, 1989 - T+2 sec



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Launch and Entry Failures
ENAE 791 - Launch and Entry Vehicle Design

October 6, 1989 - Aftermath



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Launch and Entry Failures
ENAE 791 - Launch and Entry Vehicle Design