STS-1 FORWARD RCS OXIDIZER TANK SUBSYSTEM FAILURE ASSESSMENT

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2021 AIAA SciTech Forum and Expo
11-15 January 2021

STS-1 Forward RCS Oxidizer Tank Subsystem Failure Assessment

- Introduction
- Landing and post-flight inspection
- Launch and ignition overpressure (IOP)
- Orbiter reaction control system (RCS)
- Forward RCS (FRCS) module and oxidizer tank subsystem
- Loads, structural, and failure analyses
- Concluding remarks

The Crew, Young and Crippen

Landing at Edwards AFB - It Worked!

Orbiter Post-Flight Inspection

FLIGHT TEST PROBLEM REPORT NO. 58

Statement of problem:
Forward RCS oxidizer tank aft Z strut found deformed. scj 5/3/81

Discussion:
The forward RCS oxidizer aft Z strut failed in Euler buckling due to the lift-off dynamic response from the SRB overpressure. The forward and aft Z axis tank struts on both the fuel and the oxidizer tanks were replaced with struts reinforced by plies of boron/epoxy. The rod end diameter of the fuel tank struts was increased by 1/16 in. to be the same as the diameter of the ozidizer struts.

The base heat shield left and right struts were reinforced and replaced. All other large mass support systems were reassessed for positive margins.

Required date for resolution: CLOSED 7/22/81

Personnel assigned: E. W. Sandars/ES2 X-6156, R. J. Ward/WA3 X-4323

Action progress:
(blank)

Effect on subsequent missions:
None

Conclusions:
Z axis accelerations exceeded design limits due to SRB overpressure which resulted in deformation of the forward RCS oxidizer tank aft Z strut.

Corrective action:
Forward RCS struts were modified and replaced. Base heat shield left and right struts were reinforced and replaced. All large mass structures were analyzed and found to have positive margins of safety.

JSC Form 1143C (Dec 78) 230 NASA-JSC

STS-1 Orbiter Final Mission Report, JSC-17378, Aug. 1981

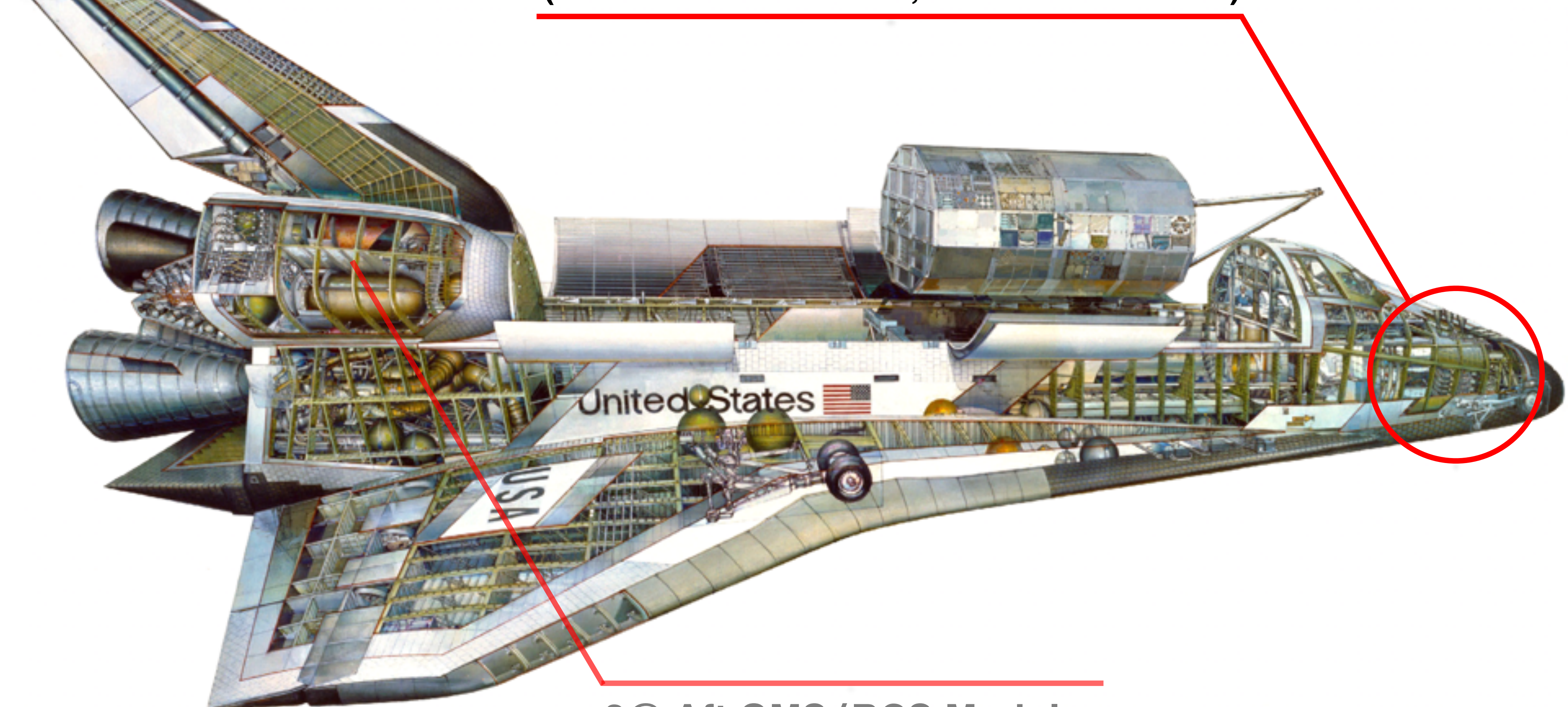
In-Flight Anomaly STS-1-V-58 (IFA Report V-58)

"***Forward RCS oxidizer tank aft Z strut found deformed.***"

"***The … strut failed in Euler buckling due the lift-off dynamic response from the SRB overpressure.***"

Orbiter Reaction Control System (RCS)

Forward RCS (FRCS) Module
(14@ 870 lbf thrusters; 2@ 24 lbf verniers)



2@ Aft OMS/RCS Modules
(each 12@ 870 lbf thrusters; 2@ 24 lbf verniers)

April 12, 1981 - Liftoff!

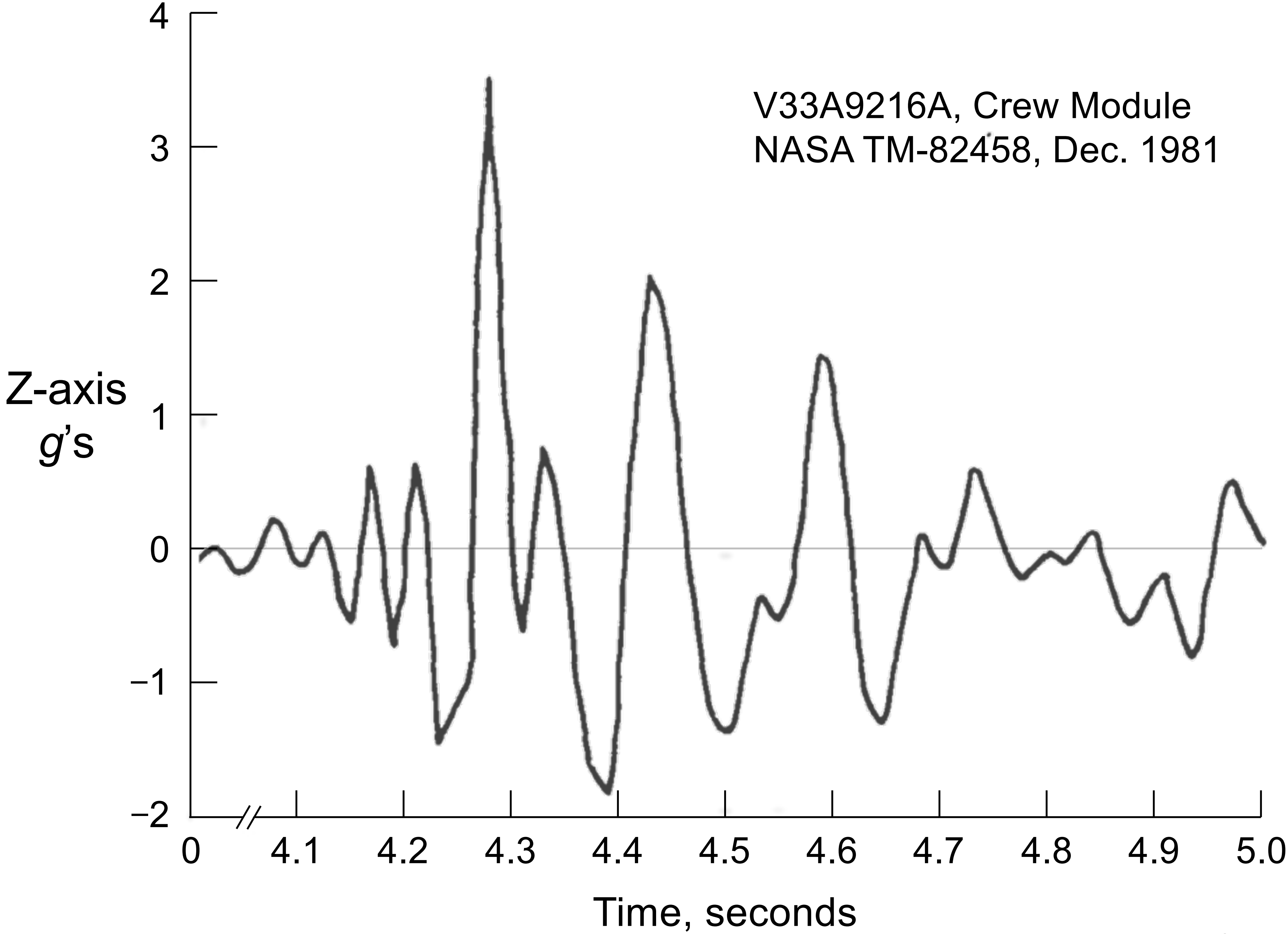
LC-39A Perimeter Camera Views

April 12, 1981 - Liftoff! (2)

Fixed Service Structure Camera Views

Ignition Overpressure (IOP)

- **At solid rocket booster (SRB) ignition, a strong transient IOP wave was generated**
- **SRB IOP environment was predicted pre-flight with analyses and scale-model testing**
- **Orbiter frequency response to IOP was greater than pre-flight predictions, exciting vehicle bending**
- **Peak Z (normal) accelerations of –2 *g* to +3.5 *g* were measured in Orbiter cockpit**
- **IOP caused other issues; aft heat shield and aerosurface acoustic loading at or near design limits**



V33A9216A, Crew Module
NASA TM-82458, Dec. 1981
Z-axis
g's
4
3
2
1
0
−1
−2
0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
Time, seconds

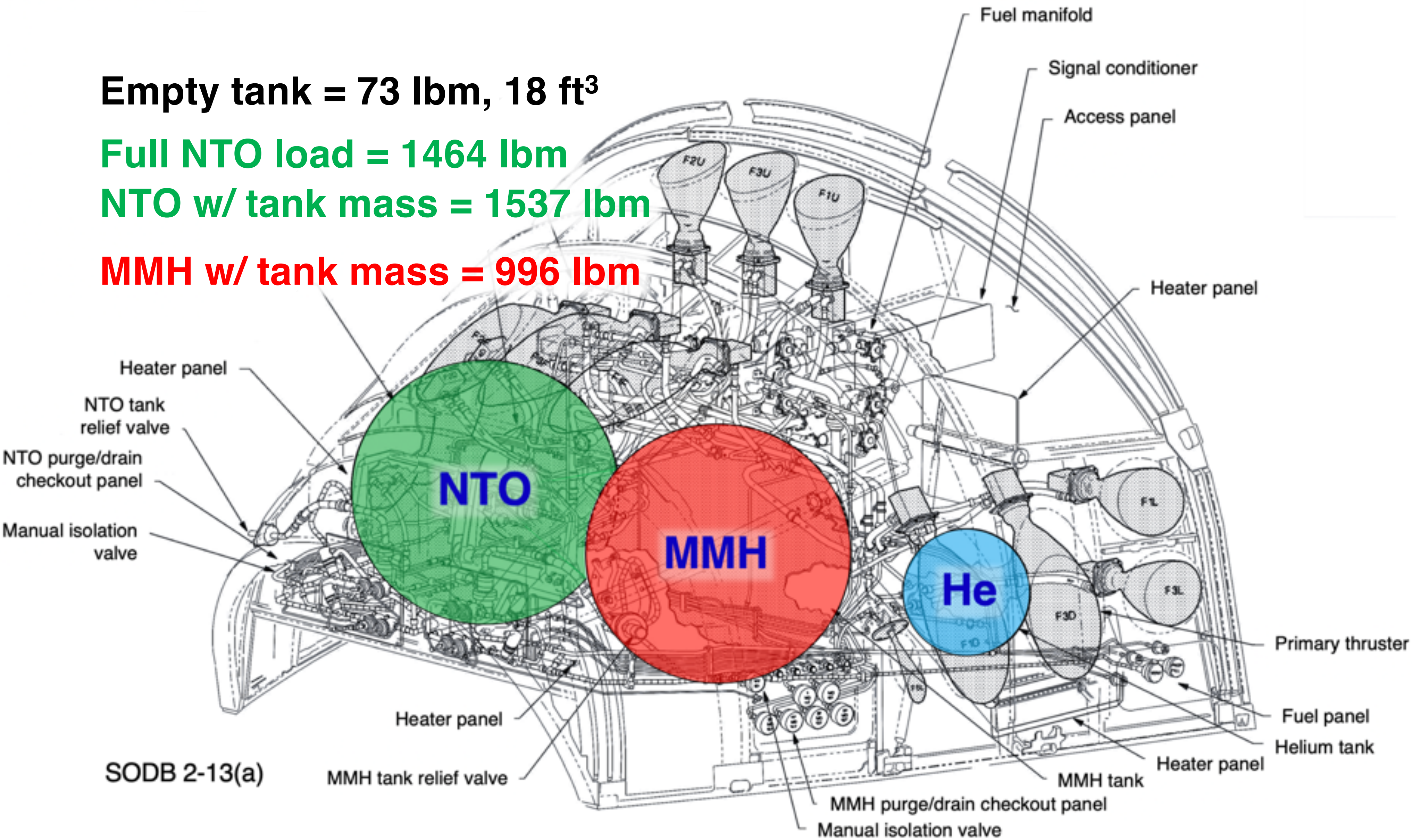
FRCS Module and Prop Tanks

Empty tank = 73 lbm, 18 ft^3

Full NTO load = 1464 lbm

NTO w/ tank mass = 1537 lbm

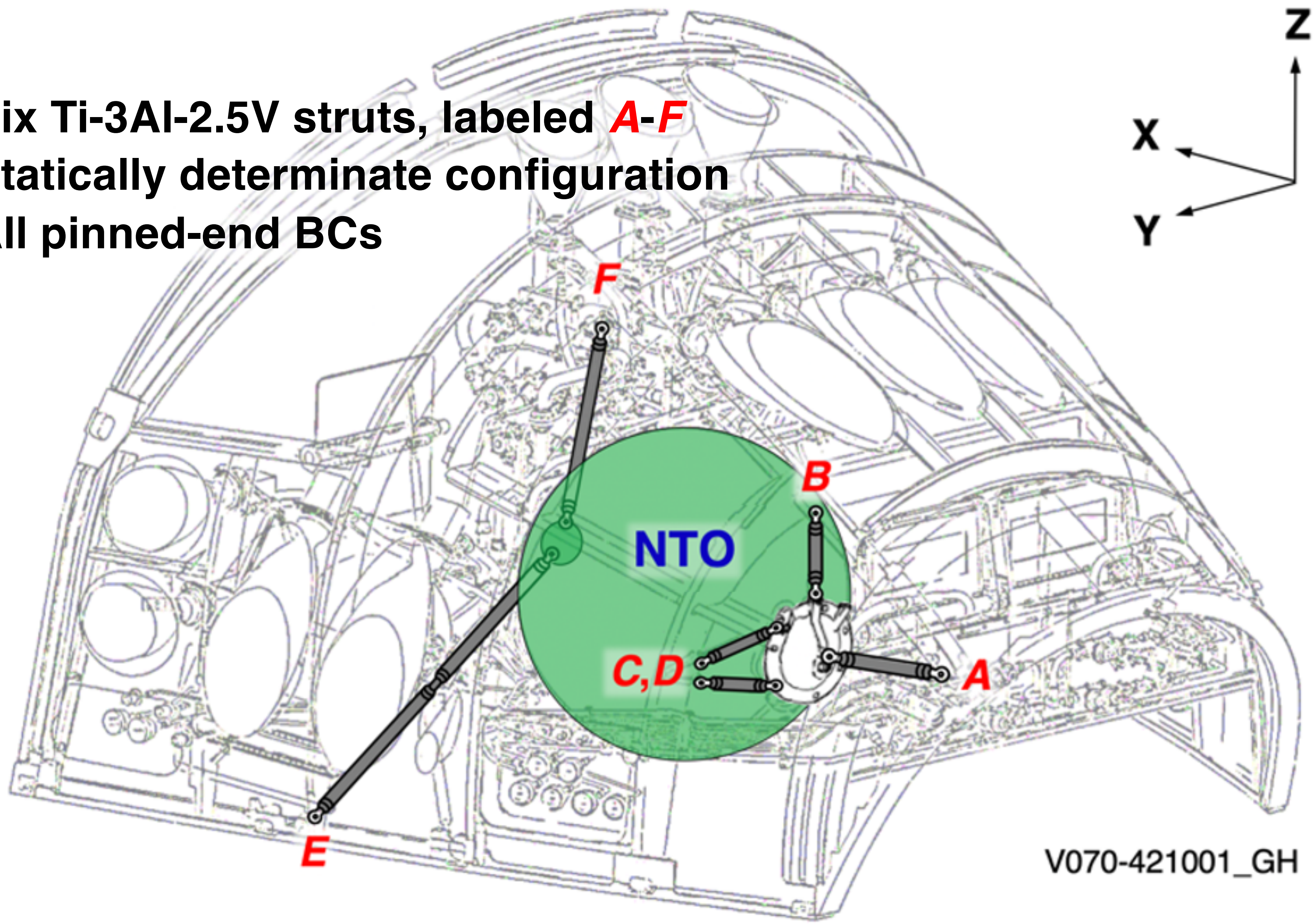
MMH w/ tank mass = 996 lbm



SODB 2-13(a)

FRCS Oxidizer Tank Subsystem

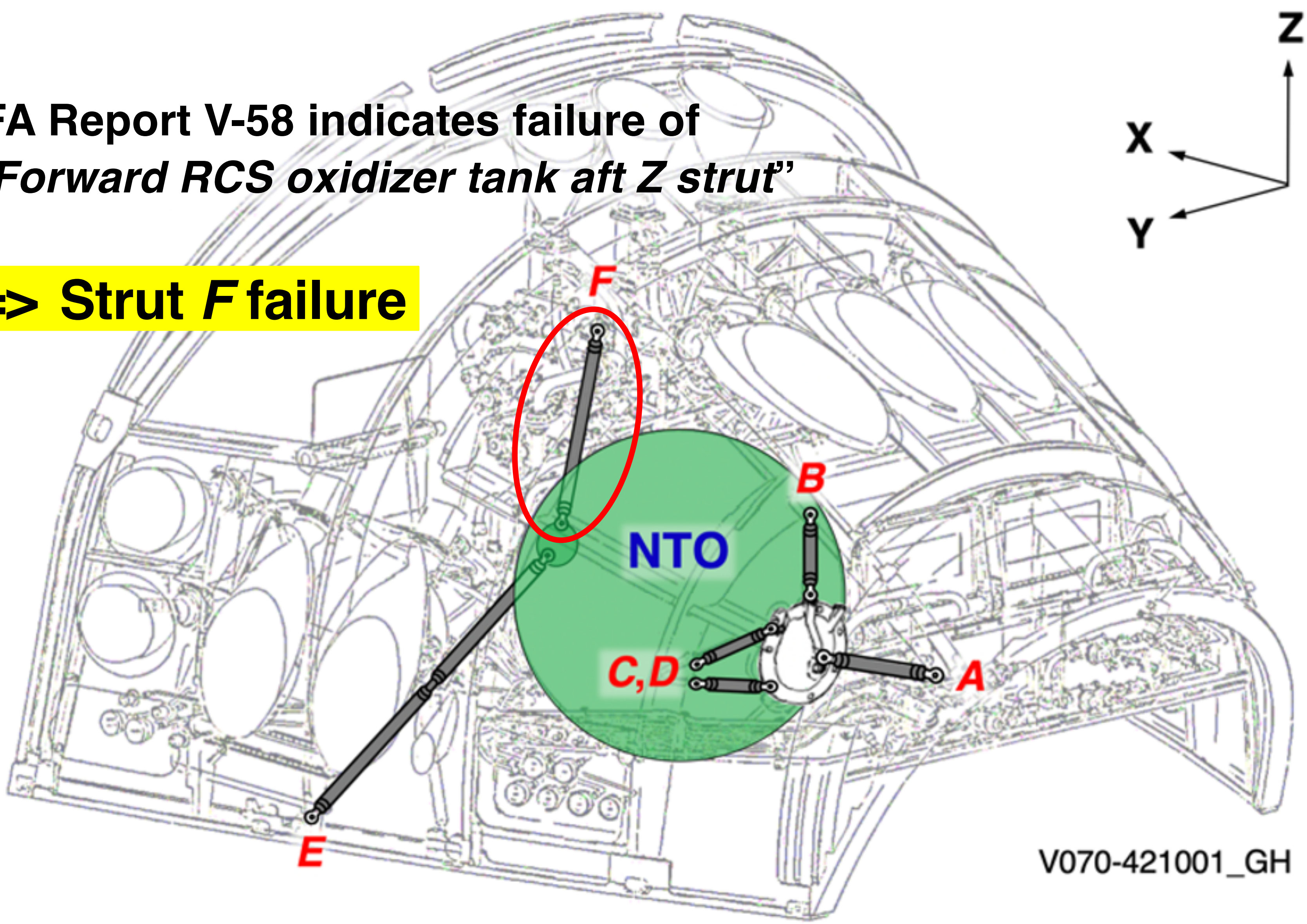
Six Ti-3Al-2.5V struts, labeled *A*-*F*
Statically determinate configuration
All pinned-end BCs



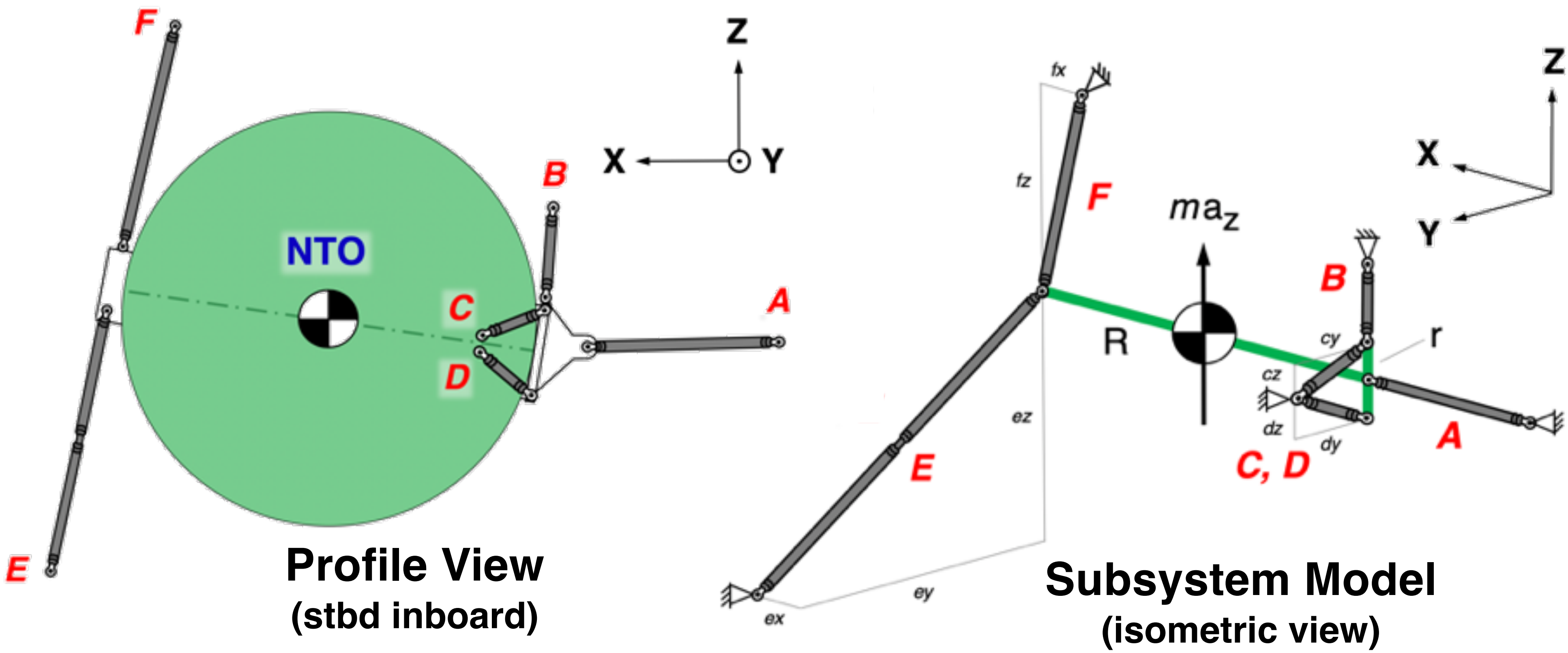
FRCS Oxidizer Tank Subsystem (2)

IFA Report V-58 indicates failure of "*Forward RCS oxidizer tank aft Z strut*"

=> Strut *F* failure



NTO Tank Subsystem Analysis Model



Profile View
(stbd inboard)

Subsystem Model
(isometric view)

- **Rigid tank and FRCS module structures**
- **Statically determinate => Solve equilibrium for individual strut forces P_i, $i = A, \ldots F$**
- **Calculate $P_F = -ma_Z/(2fz)$, $P_B = P_F fz$**

IFA Report V-58

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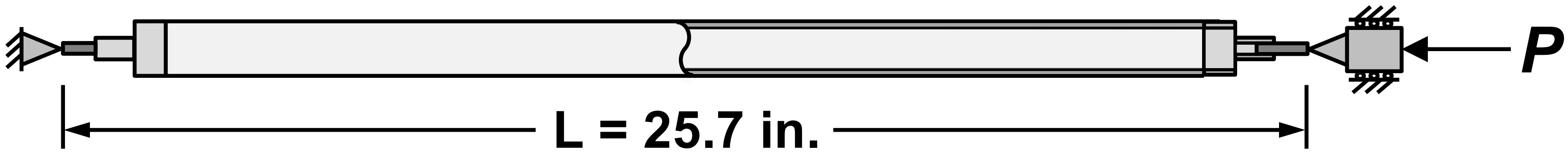
NTO Strut *F* Structural Analysis

- **Simplified strut analysis model developed**
  - **Actual dimensions; D = 1.25 in., T = 0.026 in.**
  - **Strut A, I; modified for end fittings**
  - **No geometric imperfections, pinned ends**
  - **Ti-3Al-2.5V mat'l prop's; E, σ_{cy}**



Strut Analysis Model

- **Calculate Euler buckling load for slender strut**

  $P_{euler} = -4242$ **lbf**

- **Static $a_Z = +5.37\ g$ required for buckling**

- **Euler buckling is elastic behavior**

  => No lateral deflection for $P < P_{euler}$

IFA Report V-58 (2)

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NTO Strut *F* Structural Analysis (2)

- **Strut deformation noted post-flight**
  => Material yield in deep postbuckling

- **Calculate bending moment for first yield at mid-span, M_{yield} = 2500 lbf-in.**

- **Compute strain energies required for**
  - **Euler buckling, U_{buck} = 133 lbf-in.**
  - **Bending to yield, U_{bend} = 141 lbf-in.**

- **Estimate min. dynamic amplification factor**
  $(U_{buck} + U_{bend}) / U_{buck}$ = **DAF = 2.06**

- **Equivalent loading to buckle and yield Strut *F***

$$F_{equiv} = -1537 \text{ lbm} \times 5.37\, g \times 2.06$$
$$= -17{,}002 \text{ lbf}$$

FRCS Strut Failure Analyses

- For NTO tank Strut *B*, $P_{johns} = -10{,}947$ lbf
  - Calculate $U_{johns} < U_{buck} + U_{bend}$ (for Strut *F*)

    => **Possible NTO Strut *B* failure**

- Calculate Strut *B* force under static a_Z
  - $P_B = -1537$ lbm x 5.37 $g/2 = -4127$ lbf
  - Estimate max. DAF = 2.65 (10,947 / 4127)

- Now consider failure of MMH tank Strut *F*
  - $P_F = -996$ lbm x 5.37 $g/(2\,fz)$ x 2.06

    $= -5665$ lbf $< P_{euler}$ (–4242 lbf)

    => **Possible MMH Strut *F* failure**

- No corroborating evidence observed on these struts (still elastic)

- MMH tank Strut *B* failure discounted

FRCS Strut Failure Analyses

- For NTO tank Strut *B*, $P_{johns} = -10{,}947$ lbf
  - Calculate $U_{johns} < U_{buck} + U_{bend}$ (for Strut *F*)

  => Possible NTO Strut *B* failure

- Calculate Strut *B* force under static [illegible]
  - $P_B = -1537$ lbm x 5.37 g / 2 = –4127 lbf
  - Estimate max. DAF = 2.65 (10,947 / 4127)

PLAUSIBLE

- Now consider failure of MMH tank Strut *F*
  - $P_F = -996$ lbm x 5.6[illegible] g / (2 fz) x 2.06

    = –5665 lbf < P_{euler} (–4242 lbf)

  => Possible MMH Strut *F* failure

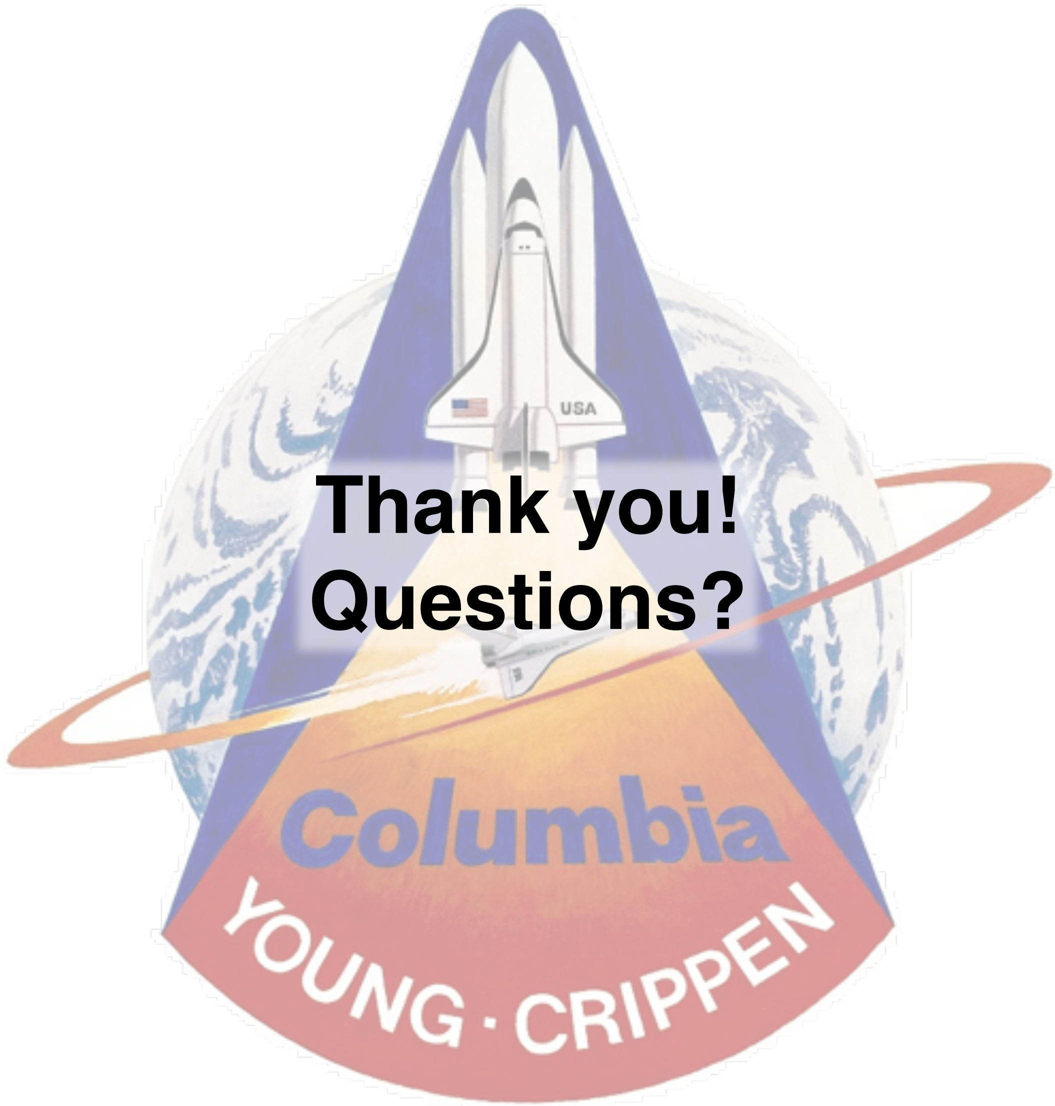
- No corroborating evidence observed on these struts (still elastic)

- MMH tank Strut *B* failure discounted

Concluding Remarks

- **Forward RCS NTO tank Strut *F* material failure noted in STS-1 post-flight inspection**
- **Analyses of Strut *F* failure performed for Euler buckling, followed by elastic bending, then material yielding**
- **Further analyses suggest possible elastic failures of NTO Strut *B* and MMH tank Strut *F***
- **Mitigations on STS-2 and subsequent flights**
  - **Boron-epoxy strips bonded to all Struts *B* and *F* for added strength and stiffness**
  - **Root-cause IOP reduced with increased pad water suppression/injection**

“*We Just Became Infinitely Smarter*”



Thank you!
Questions?