

Space Shuttle Lessons Learned

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Thorpe - Space Shuttle Lessons
Learned

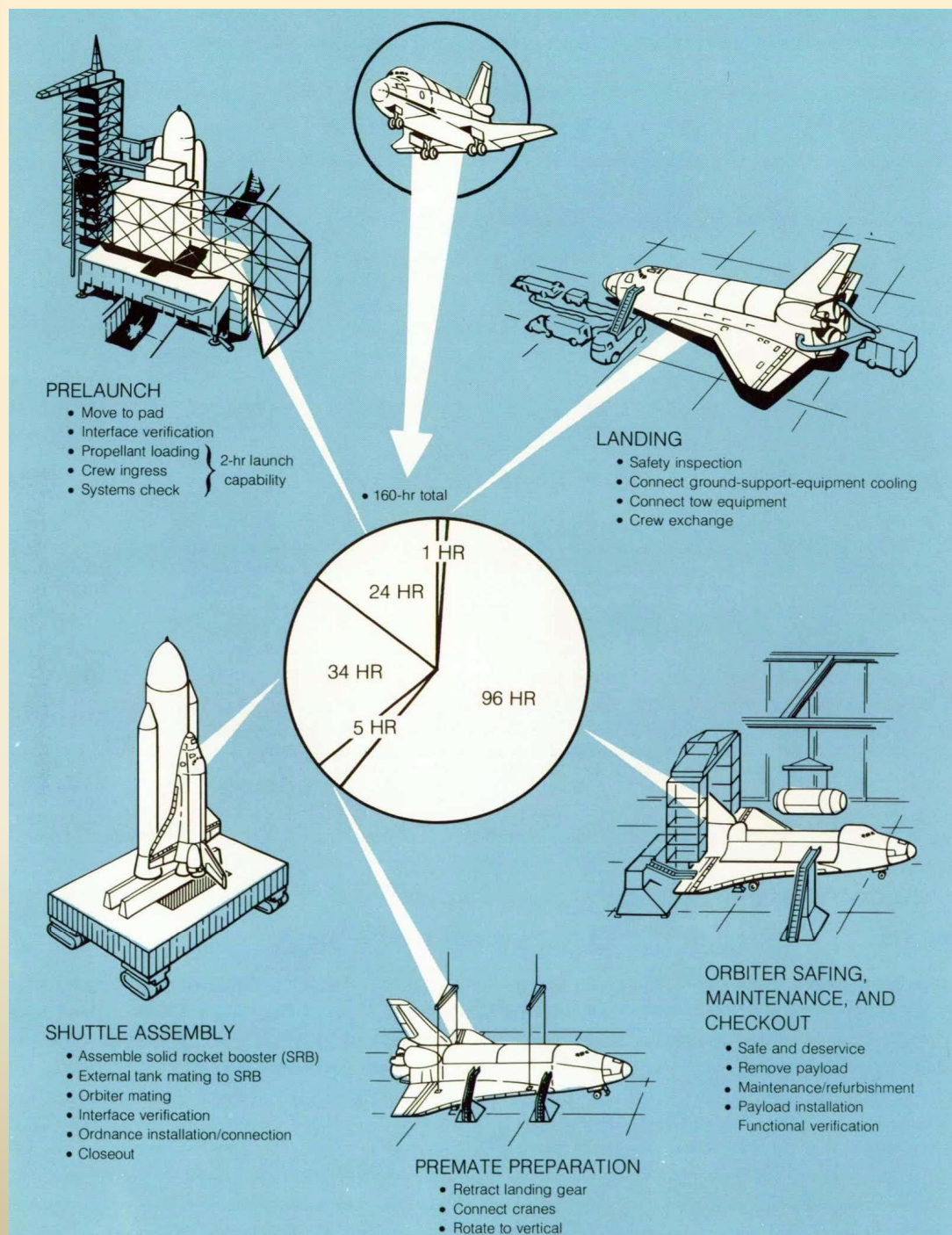
Not Necessarily a Lesson Learned from the Shuttle Program, but a good place to start

Either TVC actuator broke loose on engine, or it's a new integrity test of missile



160hr from Landing until Liftoff

Goal: 60 launches/year
40 launches from KSC
20 launches from VAFB



1 hour: Landing

- Remove crew (why remove?)
- Tow to VAB

96 hour: Orbiter Safing, Maintenance & Checkout

- Remove & Install Payload

5 hour: Premate Preparatn.

- Retract landing gear
- Rotate to vertical

34 hour: Shuttle Assembly

- Assemble SRB
- Mate ET & Orbiter
- Install Ordnances

24 hour: Prelaunch

- Move to Pad
- Propellant Loading
- Crew Ingress
- System Check

Lessons

#1: NASA never considered Space Shuttle a Space Station

If Space Shuttle could have stayed in orbit over
12 months why spend \$B on a space station



Why not spend the \$B
to modify Shuttle to
stay in orbit for months

#2a Greatest reason why Shuttle did not achieve cost savings

- **Tile** weighed 13,137 lb & repairs were conducted entire time vehicle was on ground, killing any chance of 40 missions/year. **Reduced flights/year was biggest driver to Shuttle not meeting its price targets to orbit.**
- Also, 4,800 lb of foam on ET so ice/frost wouldn't damage **tile**



2b: Fragile Thermal Protection System

Potential Materials we could use instead of tiles in 70's:

3,742 lbs of RCC = RCC **>1,204 C**

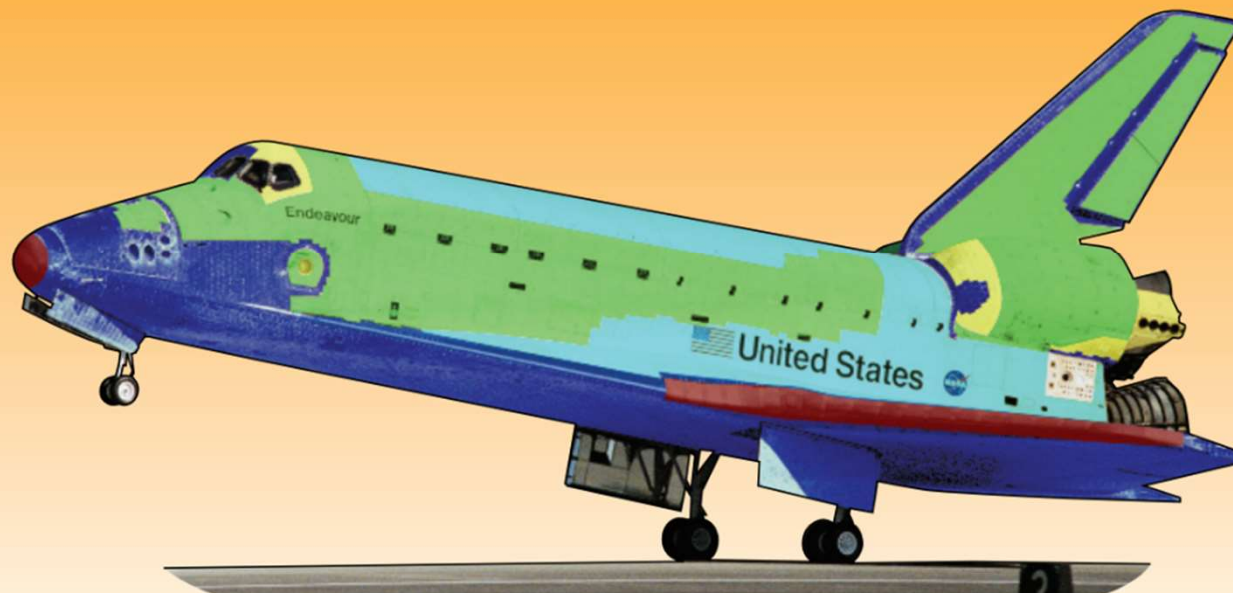
9,728 lbs of HRSI = 602A alloy **<1,204 C**

2,236 lbs of LRSI = 304 Stainless **< 800 C**

1,173 lbs of FRSI = titanium **< 500 C**

15% orbiter weight savings if refractory metals were used instead of aluminum Orbiter frame, but would require higher development cost.

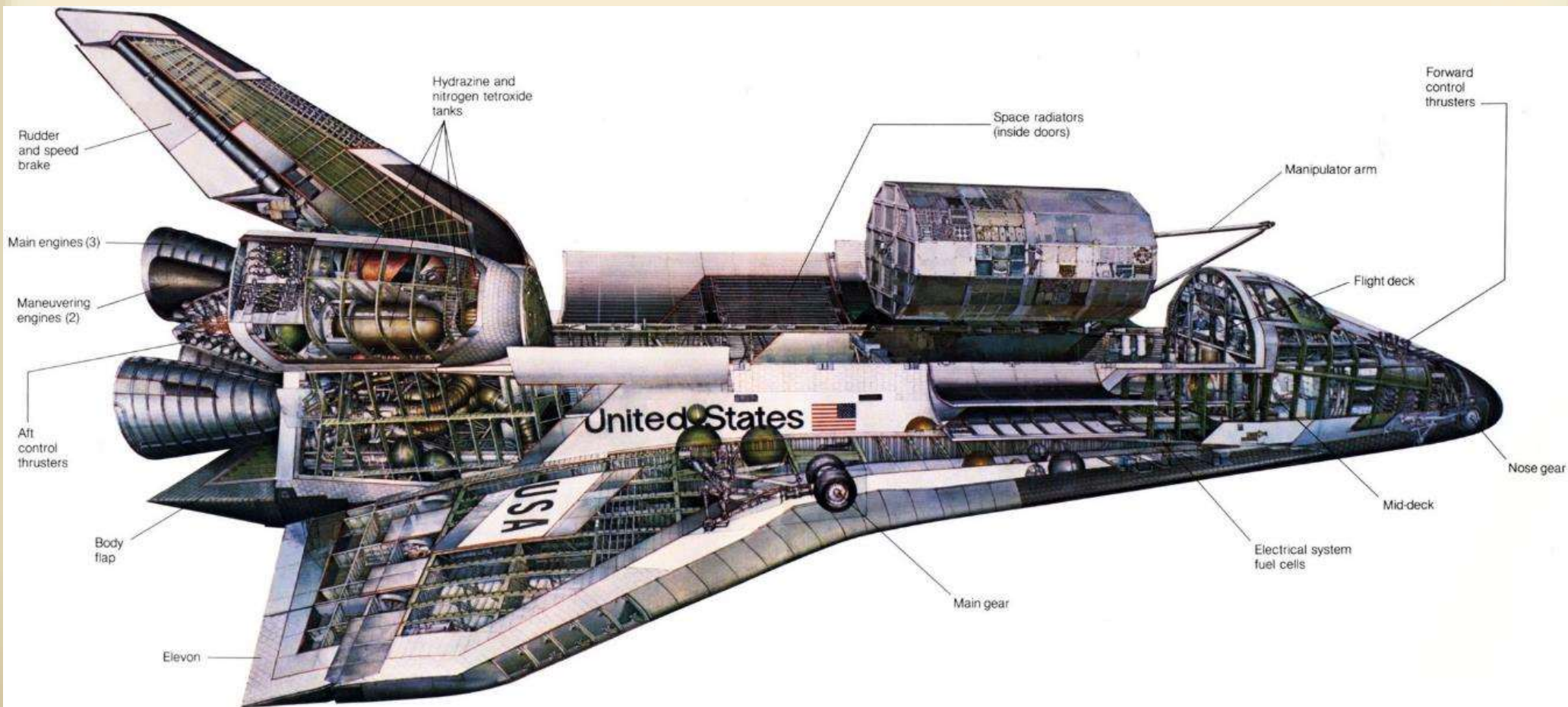
- Reinforced Carbon-Carbon Coating
- High-temperature Reusable Surface Insulation Tile
- Low-temperature Reusable Surface Insulation Tile
- Advanced Flexible Reusable Surface Insulation Blanket
- Flexible Reusable Surface Insulation Blanket



#3a: Vehicle was underpowered

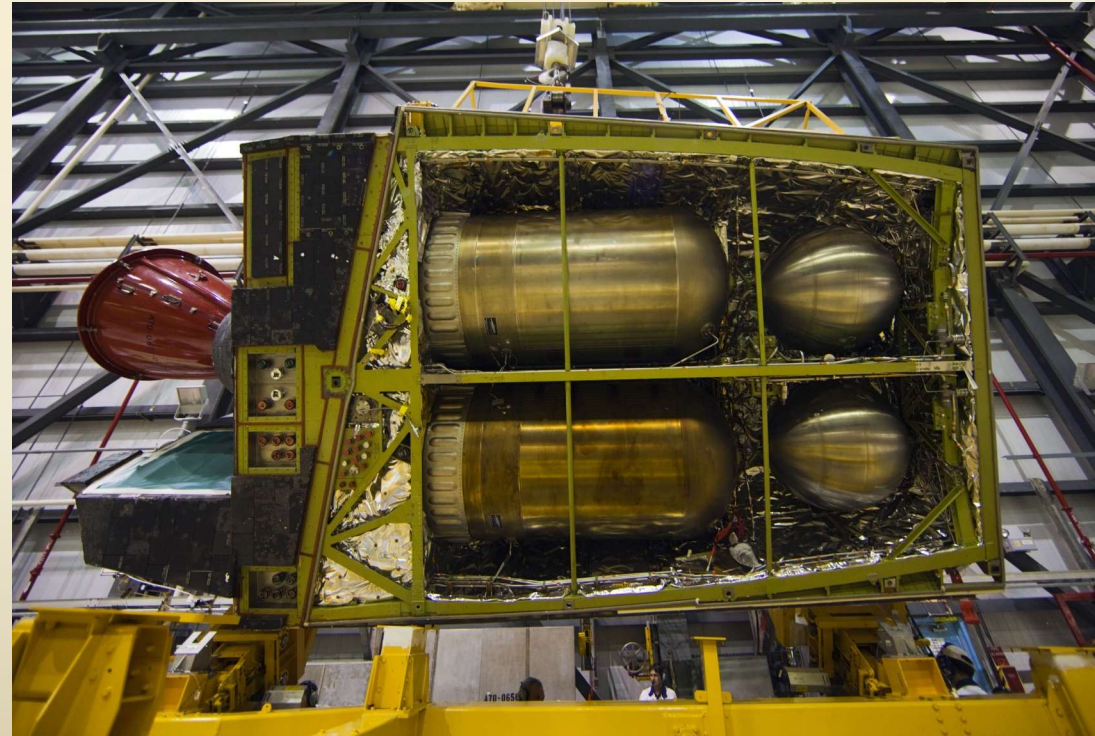
To meet requirements of 8 passengers with 65,000 lbs to LEO; **VEHICLE NEEDED MORE IMPULSE!**

Obtained by: larger ET, more SRB segments, using OMS before MECO, and/or a 4th SSME



3b: fluids were not integrated

- OMS should have used same LOX/LH2 as SSME and fuel cells for less weight & complexity
- 5,400 lb of LOX/LH2 left (wasted) in MPS after MECO
- OMS could have been ignited before MECO for extra impulse during ascent



#3c: SSME operated 104%⁺

- B/C vehicle was undersized, SSME's were operated beyond design
- Which required **removal/inspection after every launch**

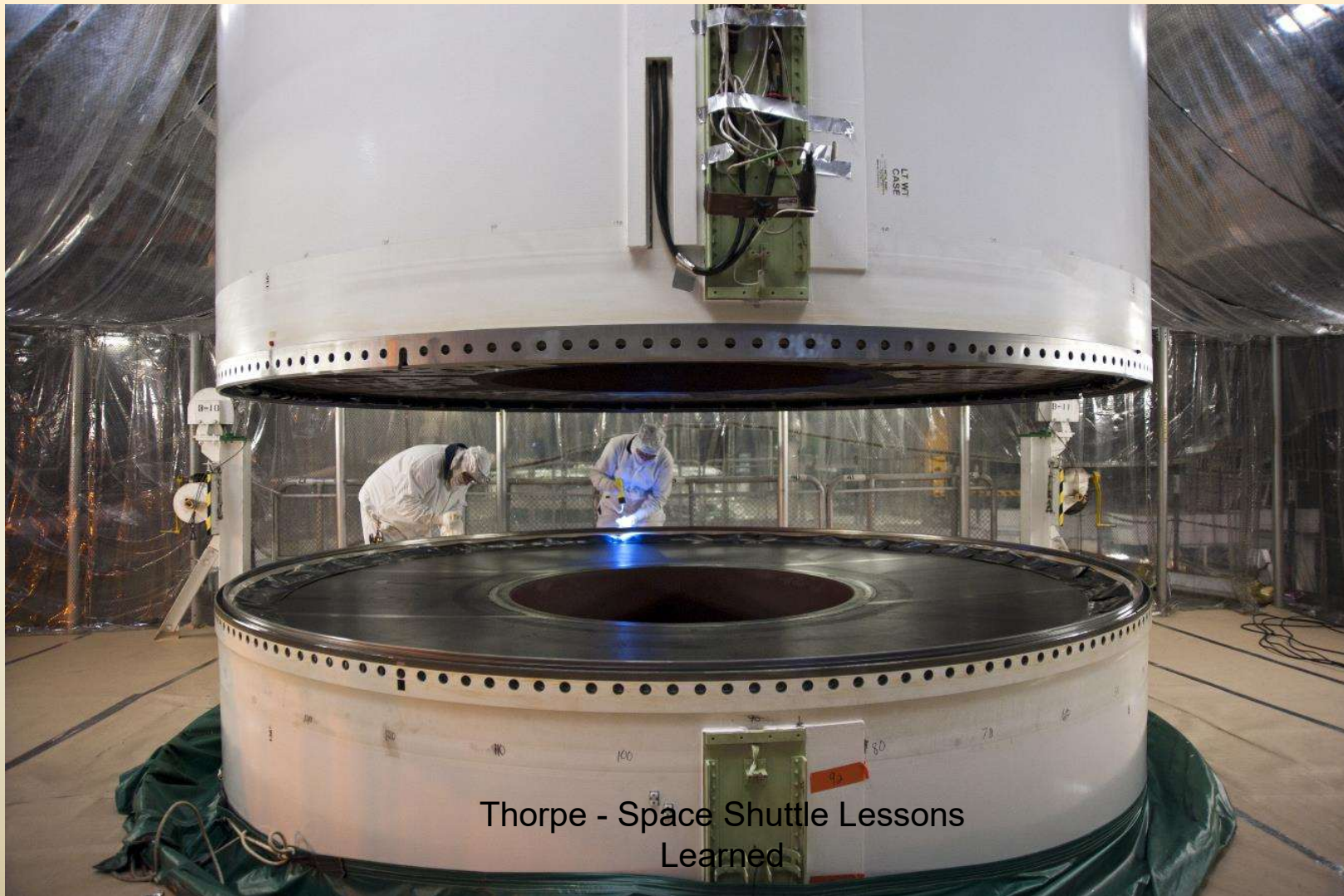
FAA estimates one **aircraft engine** failure / 375,000 flight hours
(one jet engine failure for every ~43 years of continuous flight time)



Turbopump output
pressure = 8,000 psi

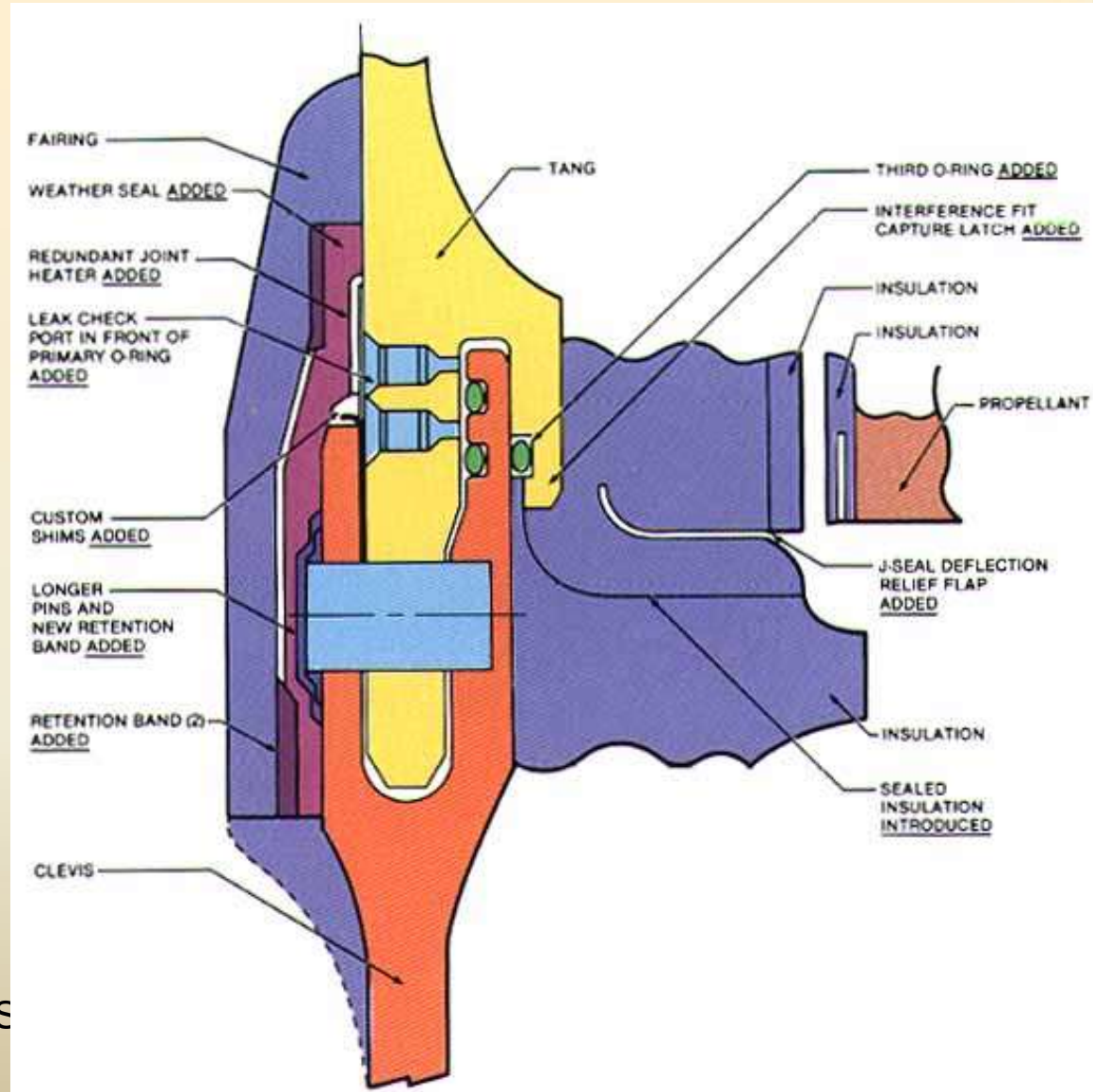
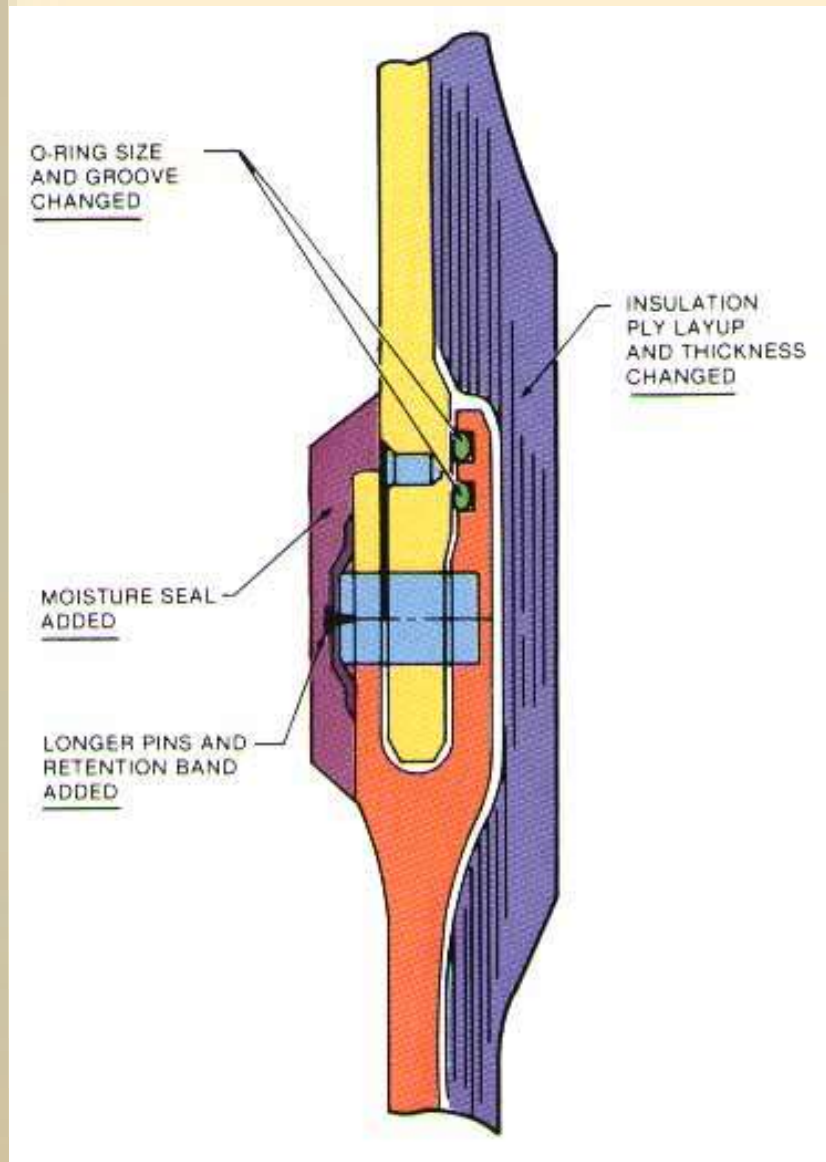
#4a: SRB designers allowed 4" gap between segments

which exposed joint hardware to combustion gases
(Couldn't a Zinc Chromate paste fill the gap?)



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#4b Requiring combustion gases to seat Crit 1 (not Crit1R) hardware in 0.6 second is “foolish”

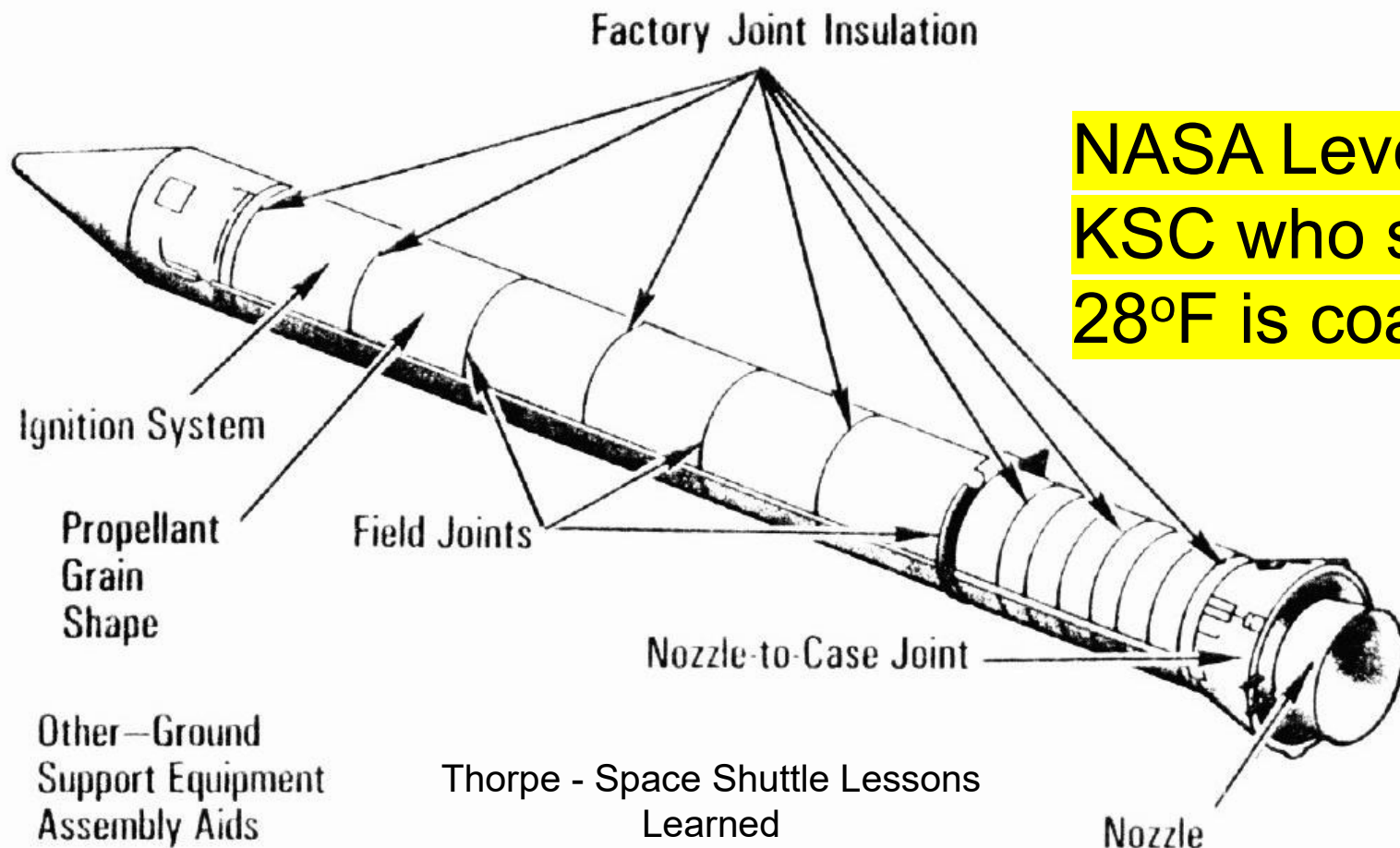


#4c It was NOT TOO COLD TO LAUNCH!

SRB contractor failed to meet LCC requirements 28°F

They thought requirement was 53°F. (It's in their book!)

7 of 8 Field Joints did not leak & those joints saw same temp & press during the same ill-fated launch of Challenger. There were O-ring erosion & blowbys during launches at 75°F

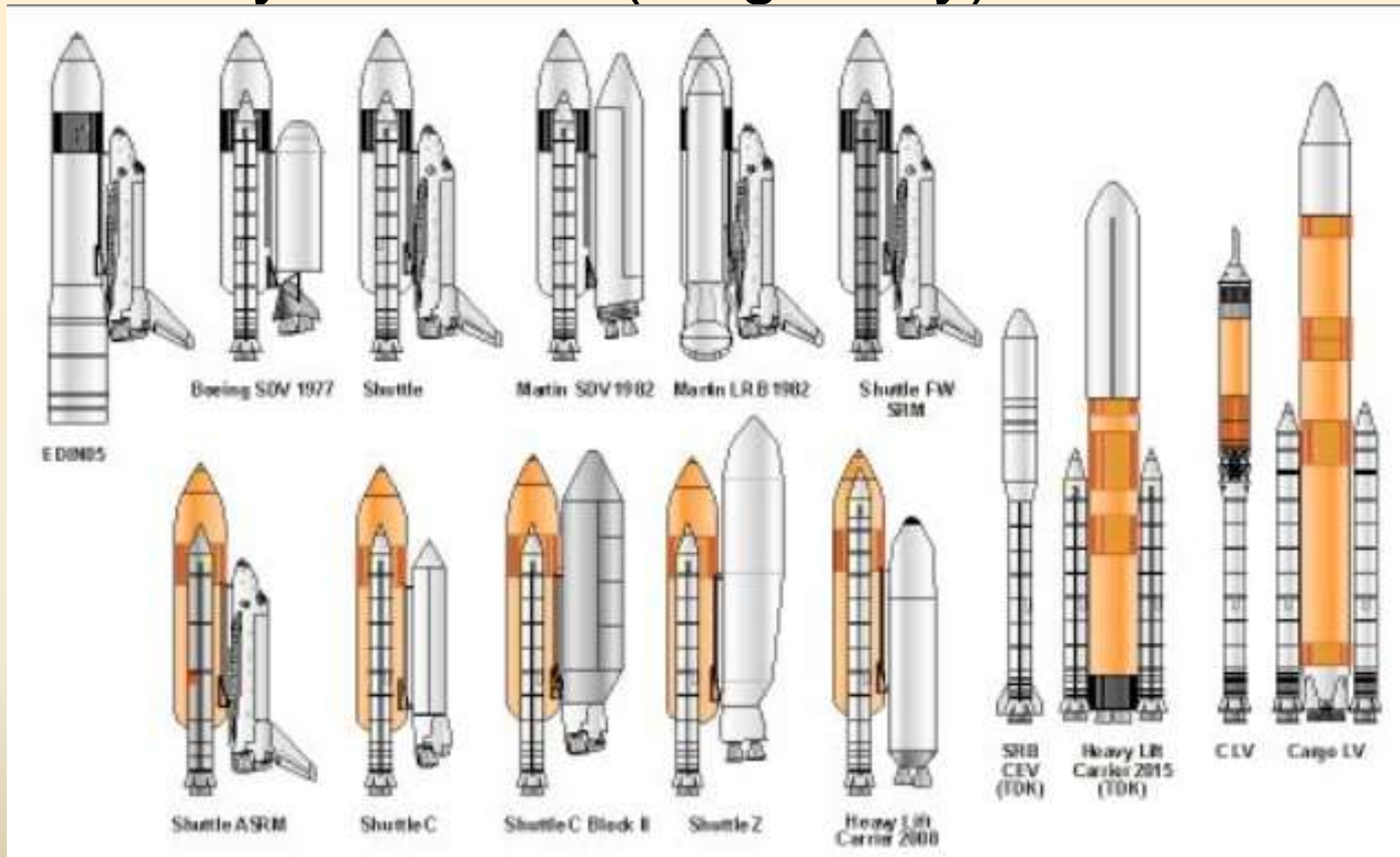


NASA Level 1 for
KSC who set
28°F is coauthor

#5: Same vehicle flown for 30 yrs

To reduce costs – fly often!!!

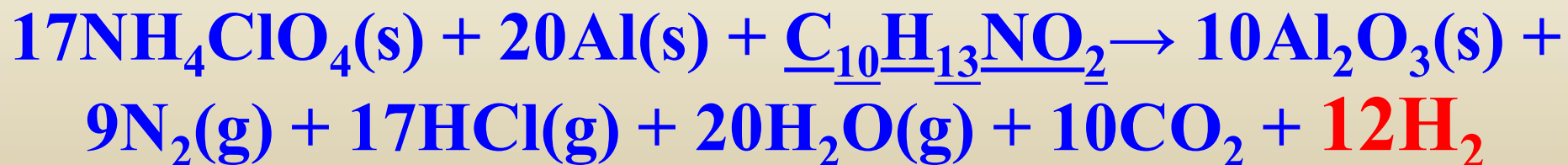
- * Fly smaller orbiters w/12 passengers & no cargo
- * Fly Shuttle-C (cargo only) vehicles



Shuttle Evolution
Improvements suggested to the shuttle derived from the design as flown.
Credit: © Mark Wade

#6a SRB propellant produces free Hydrogen that detonates

% of chemicals	Propellants	Chemical Formula	Weight (lbs.)
69.60%	ammonium perchlorate (oxidizer)	NH ₄ ClO ₄ (s)	765,600
16.00%	aluminum (fuel)	Al(s)	176,000
12.04%	polybutadiene acrylonitrile (PBAN) polymer (rubber binder & secondary fuel)		132,440
1.96%	epoxy curing agent (1.96%)		21,560
0.40%	iron oxide (a catalyst)	C ₁₀ H ₁₃ NO ₂	4,400
% of chemicals	COMBUSTION PRODUCTS	Chemical Formula	Weight (lbs.)
37.70%	Aluminum Oxide	Al ₂ O ₃ (s)	414,700
22.80%	Hydrochloride Acid	HCl(g)	250,800
16.20%	Carbon Dioxide	CO ₂	178,200
13.50%	Steam	H ₂ O(g)	148,500
9.20%	Nitrogen gas	N ₂ (g)	101,200
0.90%	Free Hydrogen gas	H ₂	9,900
0.40%	iron oxide (a catalyst)	C ₁₀ H ₁₃ NO ₂	4,400



#6b SSME's were also dumping H2

120 lb/sec of free hydrogen dumped / 3 engines

Engines operate at 6:1, but Stoichiometric is 8:1

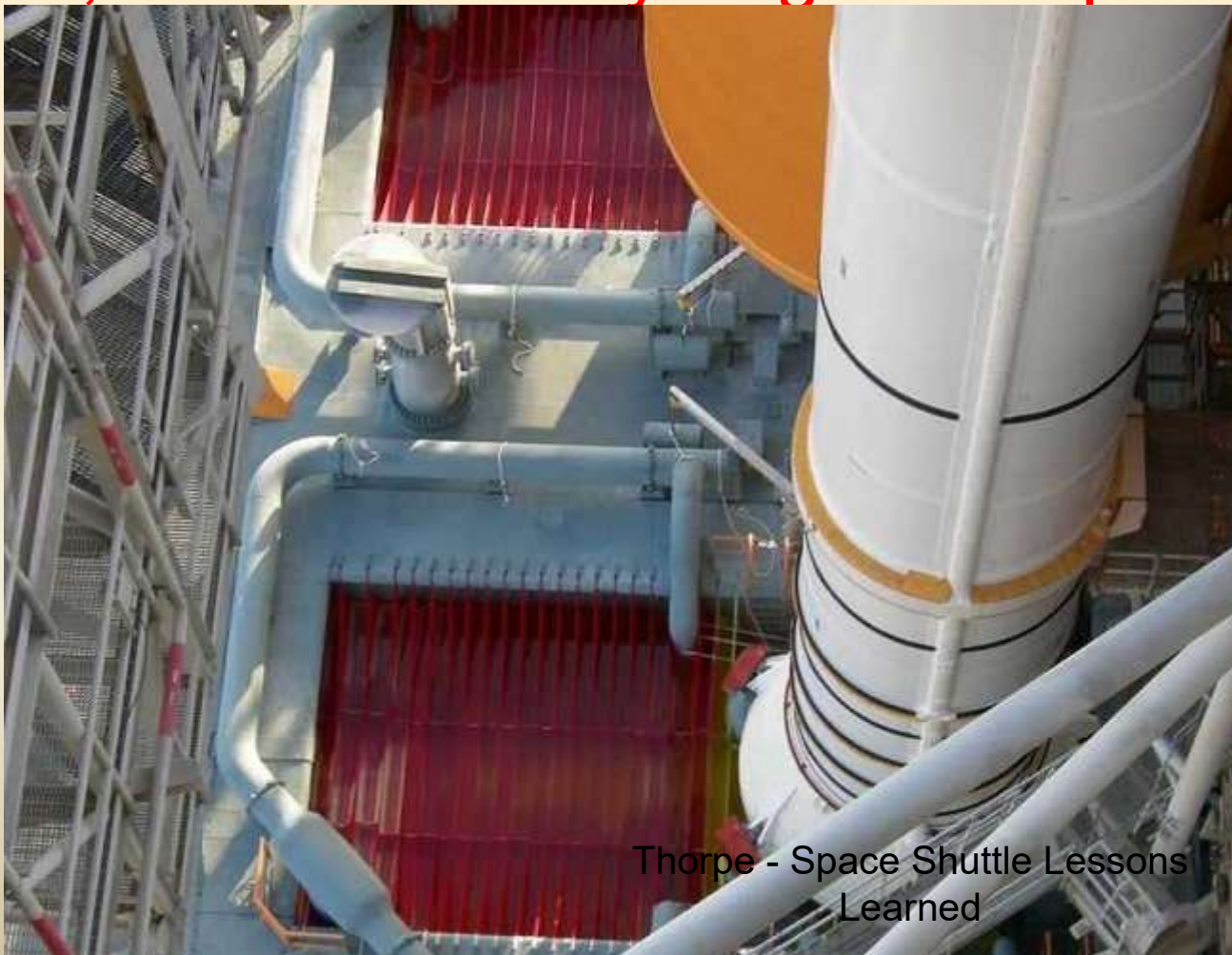


- Each SSME's (RS-25 engines) produced 418,000 lb of thrust on flowrate of 1,134.26 lb/sec.
- 6.03:1 oxidizer to fuel ratio
 - 161.3 lb/sec of LH2
 - 972.9 lb/sec of LOX
- But stoichiometric for LOX-LH2 is 8:1, so 972.9 lb/sec of LOX only burns 121.6 lb/sec of LH2

#6c To reduce effects of H2 detonation on Orbiter:

Sound Suppression Water Bags were installed in flame trench before every launch

~3,000 lb of free hydrogen dumped into flame trench



Free Hydrogen Released
162 lb/sec both SRB's
120 lb/sec from 3 SSME

Time for shuttle to clear
tower:

8 seconds SRB &
14 seconds for SSME's

#6d: Lesson NOT Learned

NASA still didn't consider amount of available free hydrogen by 4 SSME's (not 3) & larger SRB's; resulting in damage to MLP during 1st flight of Artemis in 2022



Conclusions

- Achievement of original goal will require changing our focus to design for operability and productivity, not only performance and minimum weight, and will require the development of several new technologies.
- Facilities associated with complex interfaces and service requirements must be clearly understood with major emphasis in the design process.
- Use of fancy ceramic tiles doesn't mean it should take place of plain old high temperature - refractory metals.
- Ambient temperature is not the only factor in the failure of SRB O-rings, other functions including erosion and blow out must be fully understood
- Airplane-like-Orbiter without Airplane-like Operations is economically unsustainable.
- LAUNCH THE ROCKET! LIVE IN THE ROCKET! LAND IN THE ROCKET! RETURN THE ROCKET! FLY THE ROCKET AGAIN!

QUESTIONS & COMMENTS