The Cost of Maintaining Thermal Protection Systems

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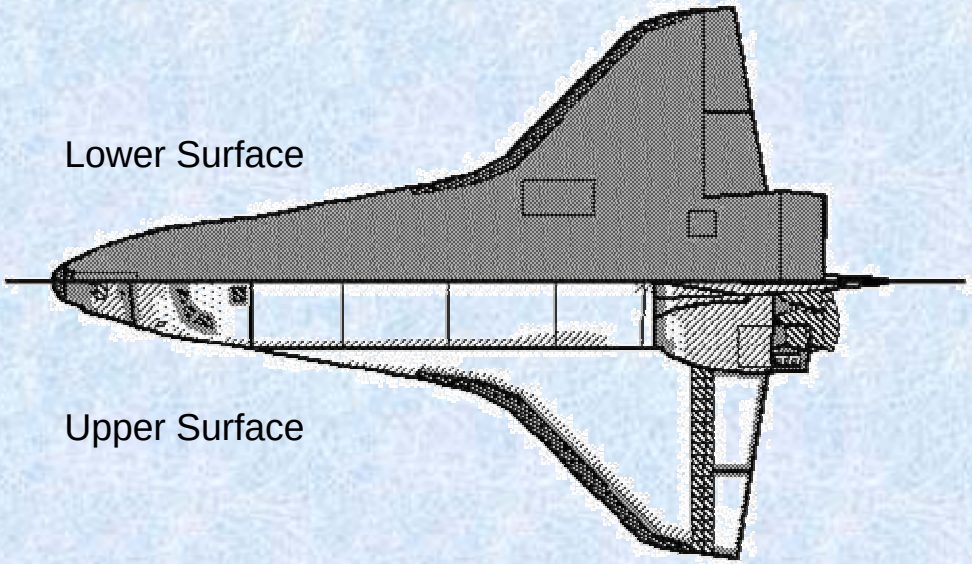
Agenda

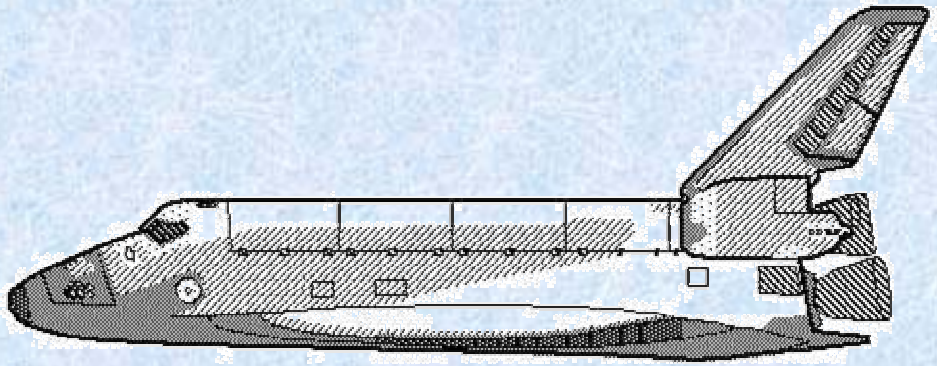
- **Background**
  - Design Overview
  - Maintenance Drivers
- **Factors Affecting Cost**
  - Materials
  - Access
  - Touch Time Labor
  - Costs per TPS Type
  - Off Line Support
- **Improvements To Reduce Cost**
  - Presently In-work
  - Future Necessities
- **Beyond Shuttle**

TPS Surfaces

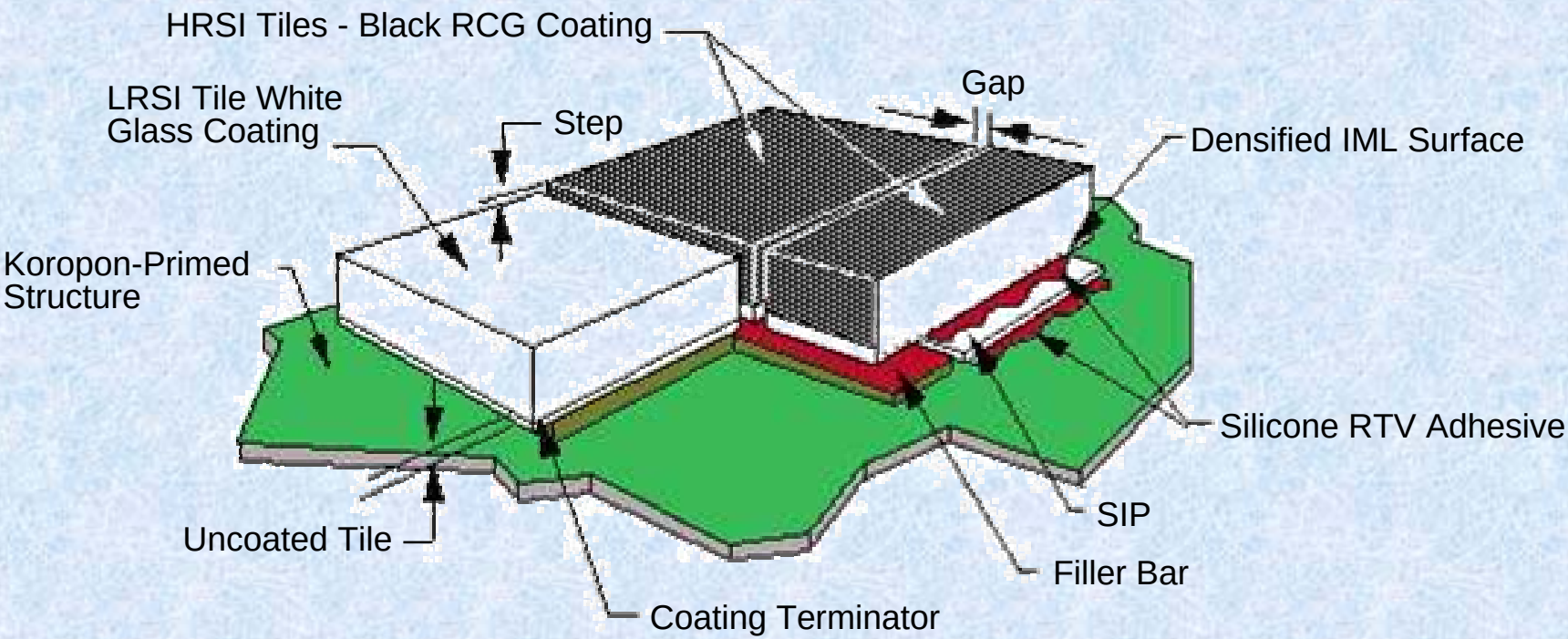


TPS Legend

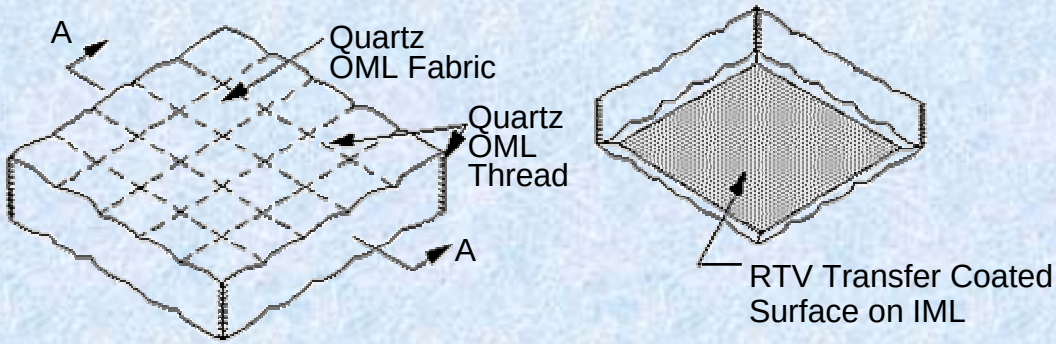
- HRSI (Black) Tiles
- LRSI (White) Tiles
- AFRSI Blankets
- FRSI
- RCC
- Glass
- Exposed Metallic Surfaces

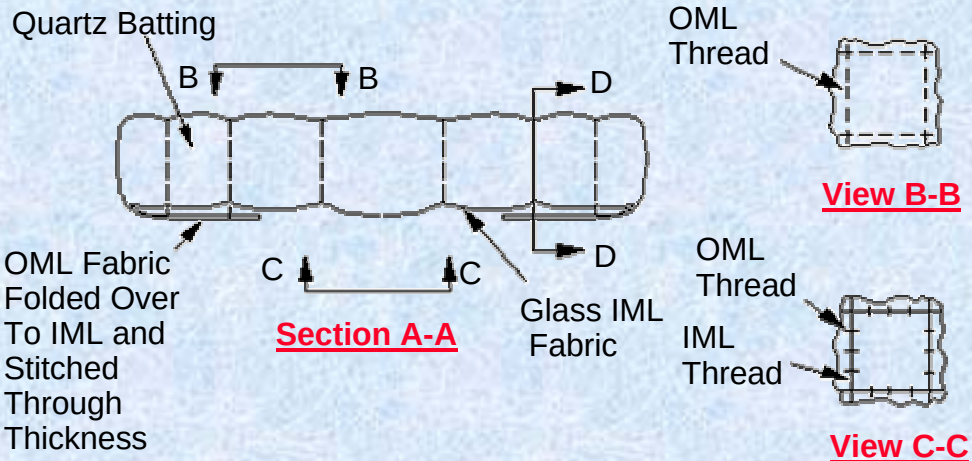


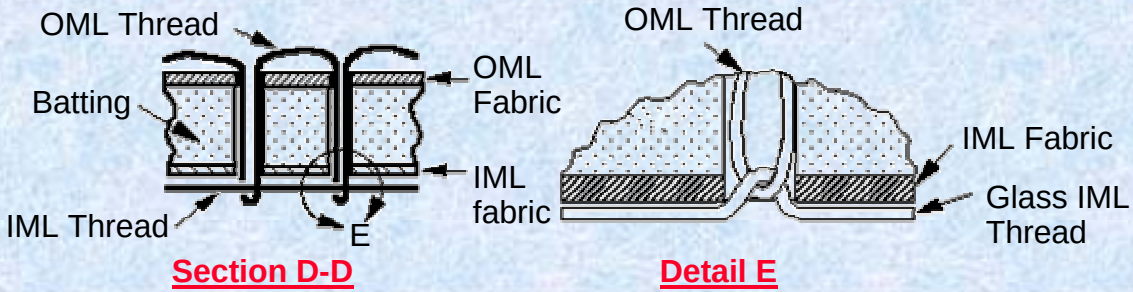
Tile Configuration



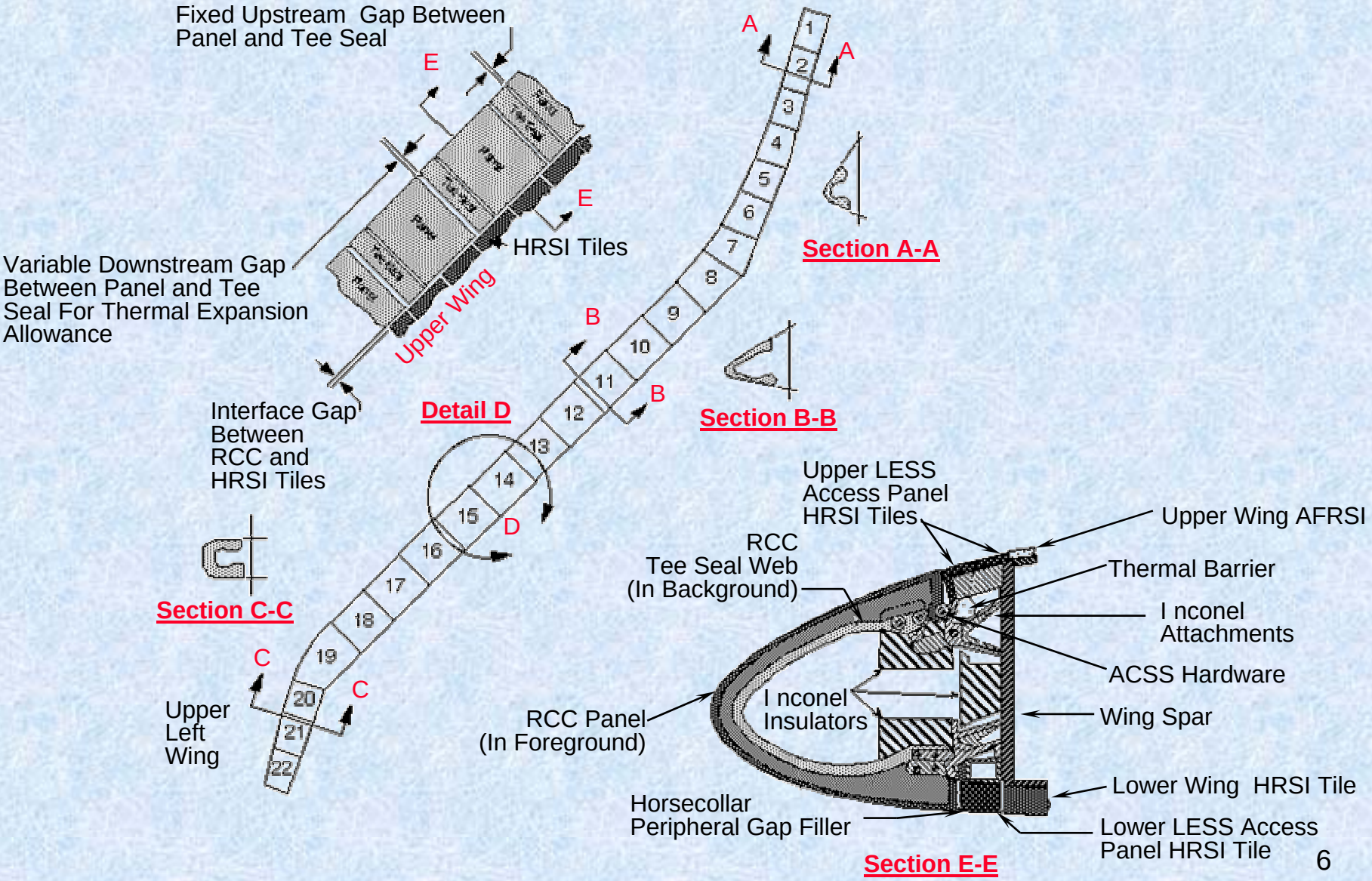
Fibrous Insulation Blankets



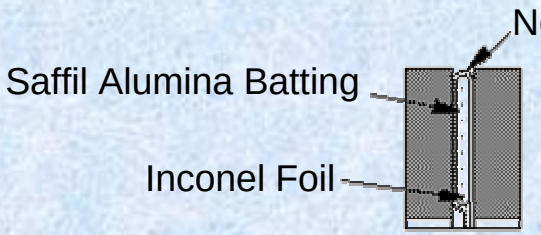




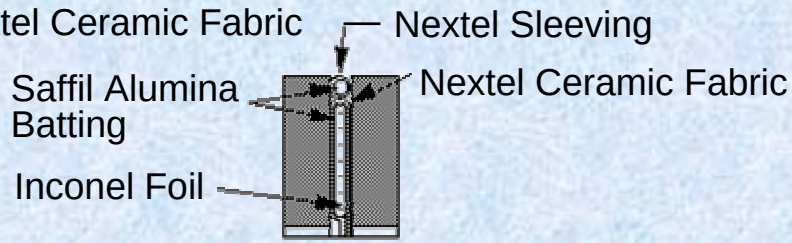
Leading Edge RCC



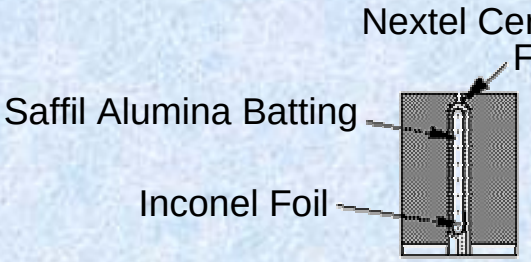
Gap Fillers



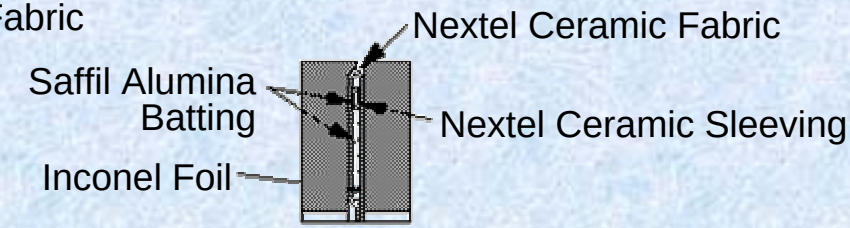
Pillow or Pad Type



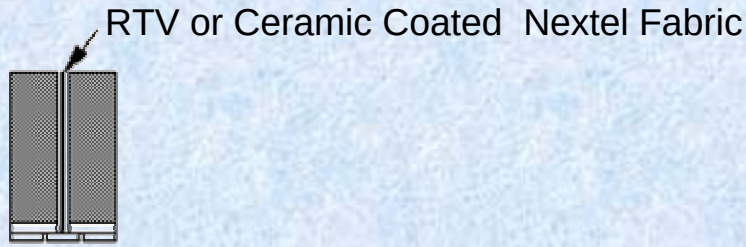
Pillow With Sleeving



Pillow Captive Type (Double Lip)



Pillow Captive Type (Single Lip)

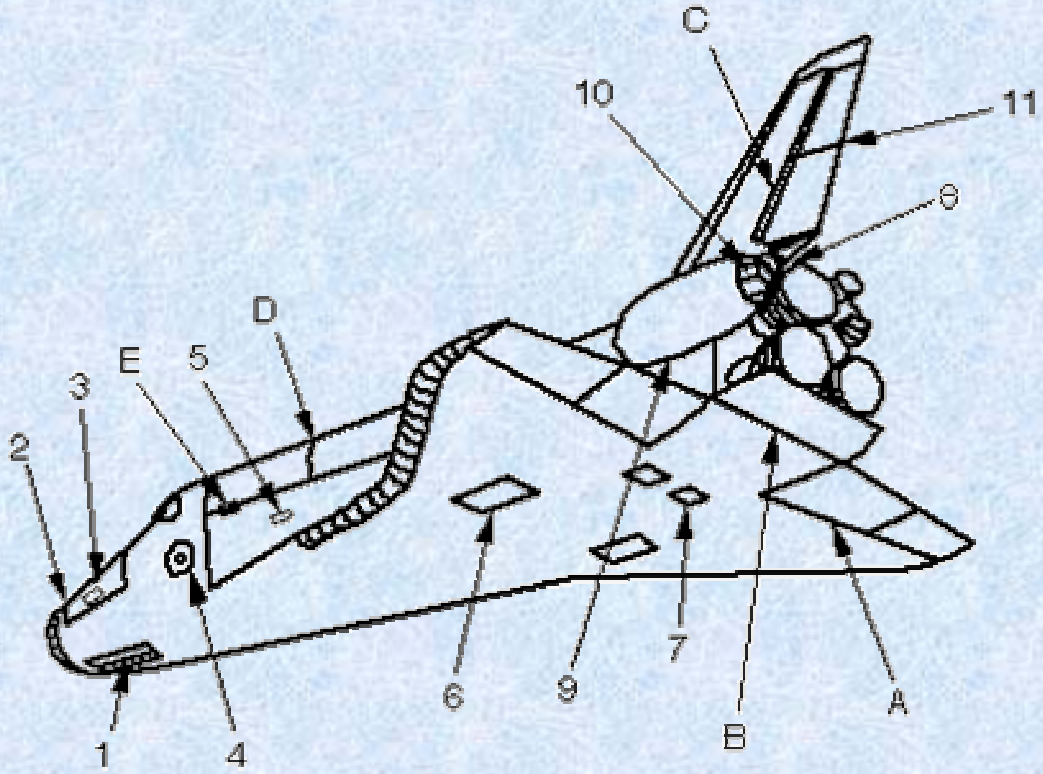


Ames Type

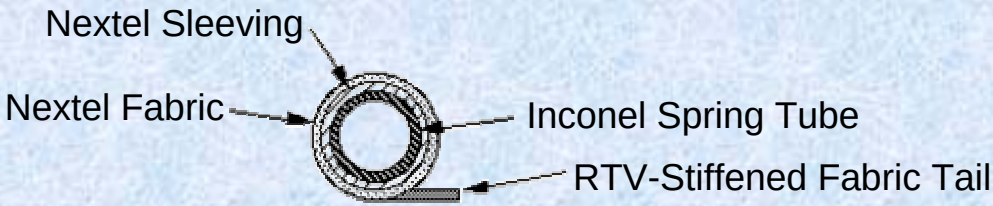
Thermal Barrier & Seal Locations

Thermal Barriers	
1	Nose Landing Gear Door
2	FRCS Module/Fuselage Interface
3	Forward RCS Thrusters
4	Crew Hatch
5	Vent Doors
6	Main Landing Gear Doors
7	External Tank Doors
8	Vertical Stabilizer/Fuselage Interface
9	OMS Pod/Fuselage Interface
10	OMS Pod RCS Thrusters
11	Rudder Speed Brake Split Line

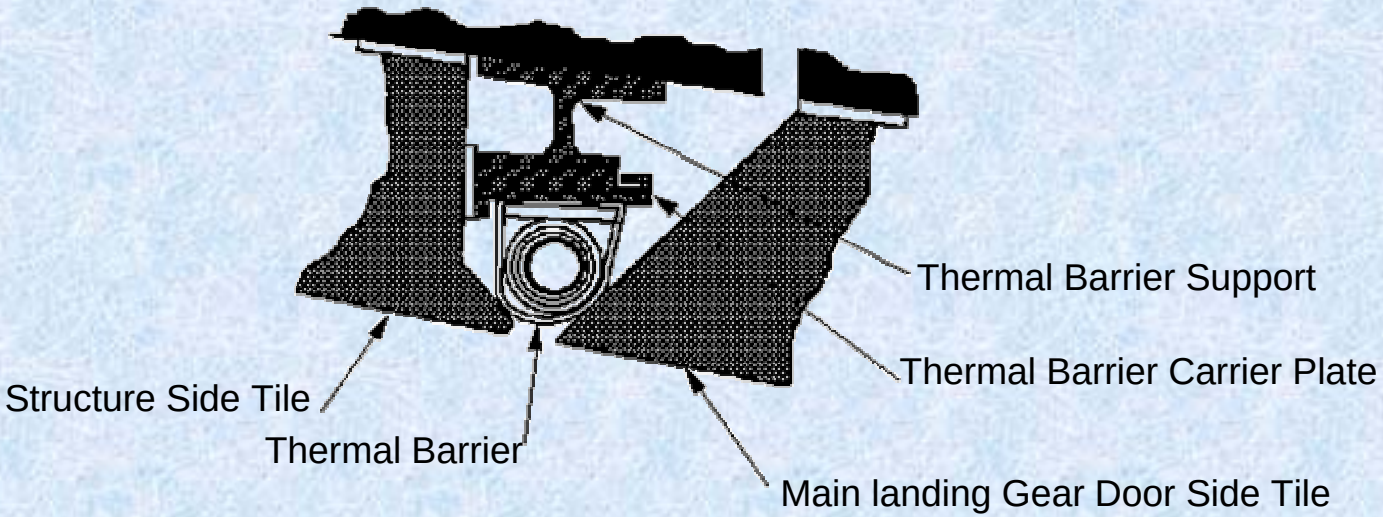
Aerothermal Seals	
A	Wing/Elevon
B	Aft Fuselage/Body Flap
C	Vertical Stabilizer/Rudder Speed Brake
D	Payload Bay Door Expansion Joints
E	Payload Bay Door Hinge Covers



Typical Thermal Barrier

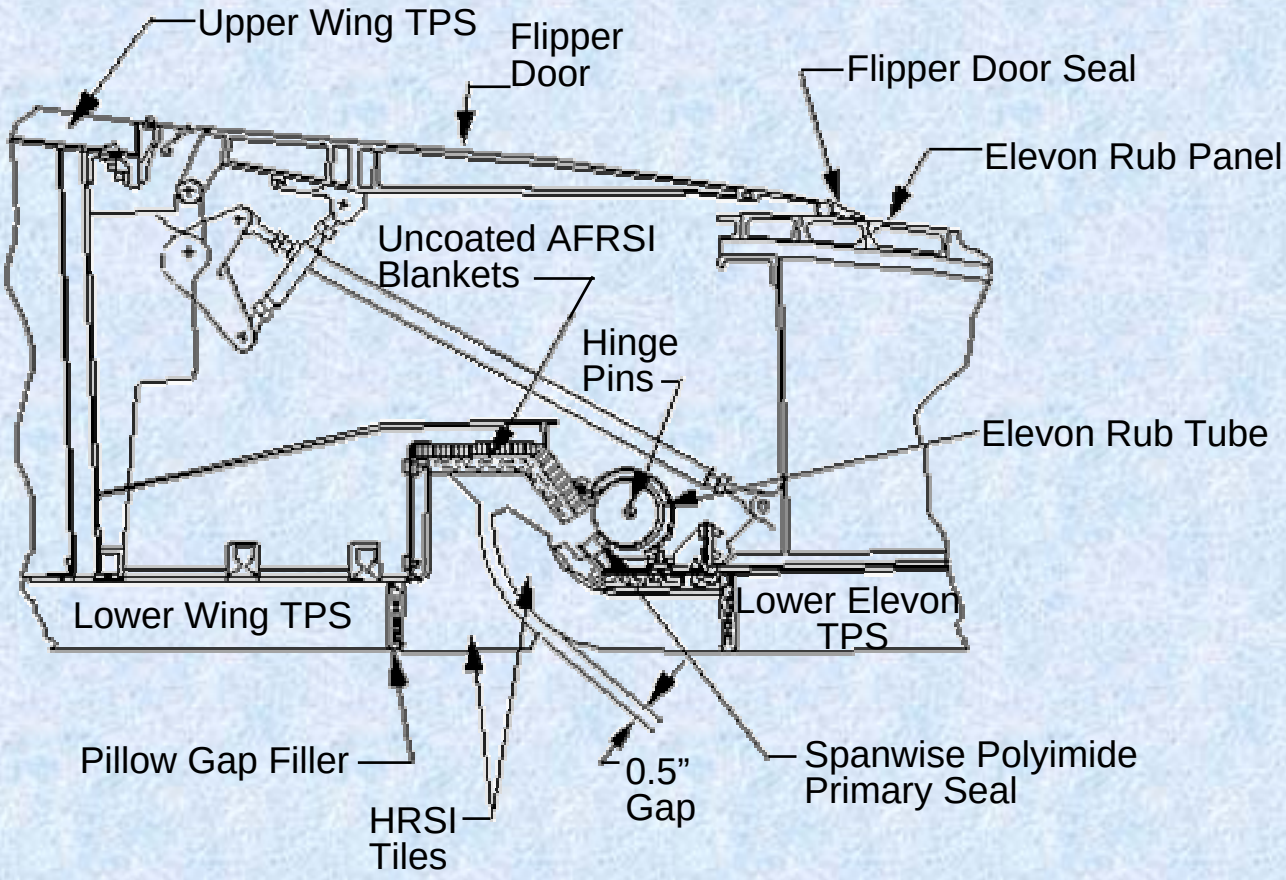


Typical Thermal Barrier Detail



Main Landing Gear Door Thermal Barrier

Elevon Cove Seal



Orbiter TPS

Average tiles damaged from flight requiring replacement	~20
Average tiles replaced per flow	~75
HRSI tiles on the Orbiter	~19,700 (9 lb), 525 (22 lb)
TUFI tiles on the Orbiter	306 (8 lb)
FRCI tiles on the Orbiter	2,950 (12 lb)
LRSI tiles on the Orbiter	725 (9 lb), 77 (12 lb)
FIB blanket area on the Orbiter	2,123 sq ft
FRSI sheet area on the Orbiter	2,024 sq ft

Flight Damage History

MISSION	IMPACTS > 1"	TOTAL IMPACTS
STS-41D/FL1	30	111
STS-51A/FLT2	20	87
STS-51C/FLT3	28	81
STS-51D/FLT4	46	152
STS-51G/FLT5	144	315
STS-51I/FLT6	33	141
STS-26R/FLT7	55	411
STS-29R/FLT8	23	132
STS-33R/FLT9	21	118
STS-31R/FLT10	14	63
STS-41/FLT11	16	76
STS-39/FLT12	16	237
STS-48/FLT13	25	182
STS-42/FLT14	44	209
STS-53/FLT15	23	240
STS-56/FLT16	36	156
STS-51/FLT17	18	154
STS-60/FLT18	15	106
STS-64/FLT19	19	150
STS-63/FLT20	14	125
STS-70/FLT21	9	127
STS-82/FLT22	18	103
STS-85/FLT23	6	102
STS-91/FLT24	50	198
STS-95/FLT25	45	187
OV-103 AVERAGE	**30.7**	**158.5**
FLEET AVERAGE	**31.1**	**149.2**

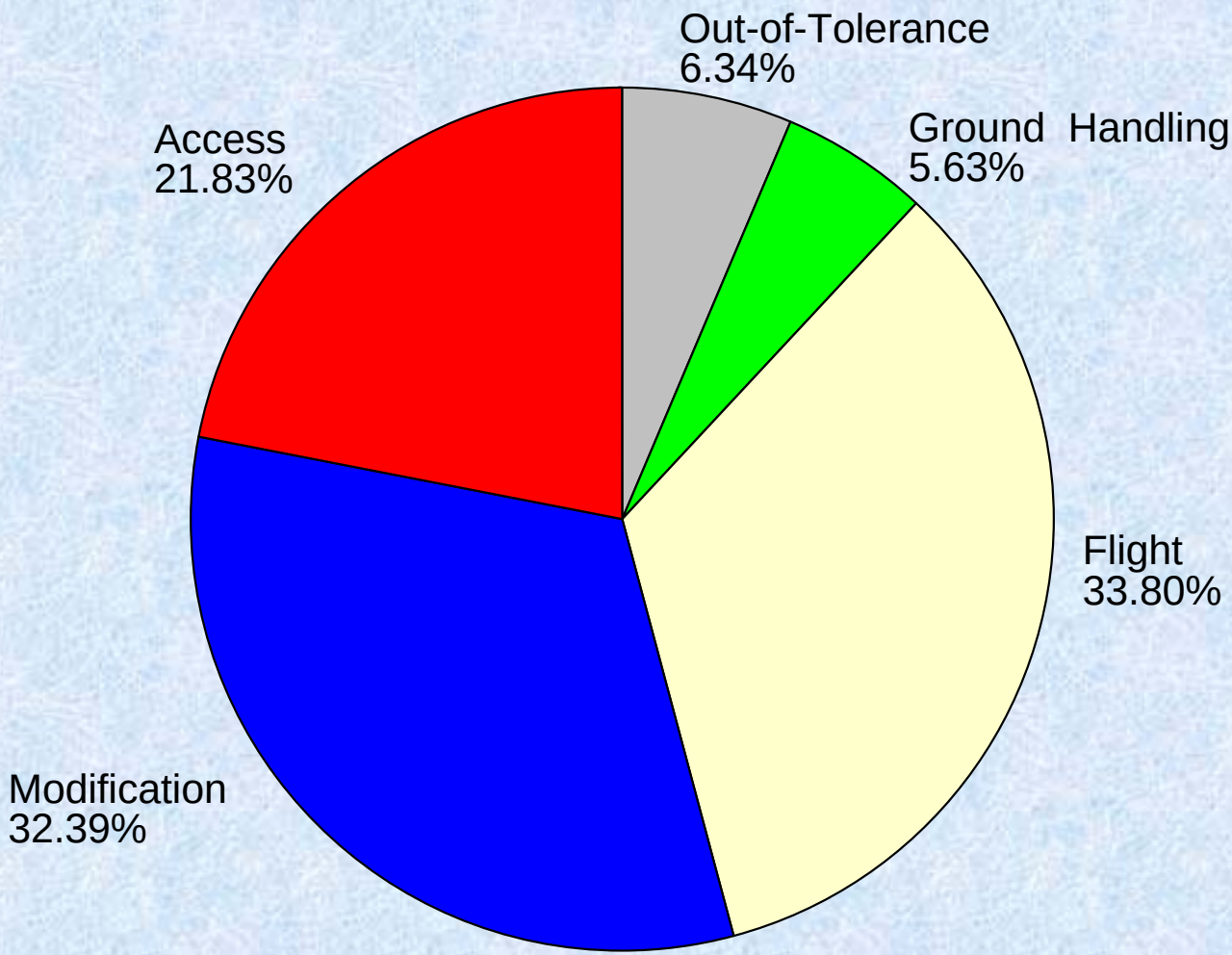
Materials Cost

Raw Materials*	$200k / Flight
Tile PU's	$137k / Flight
Consumables	$ 10k / Flight
Total	$347k / Flight

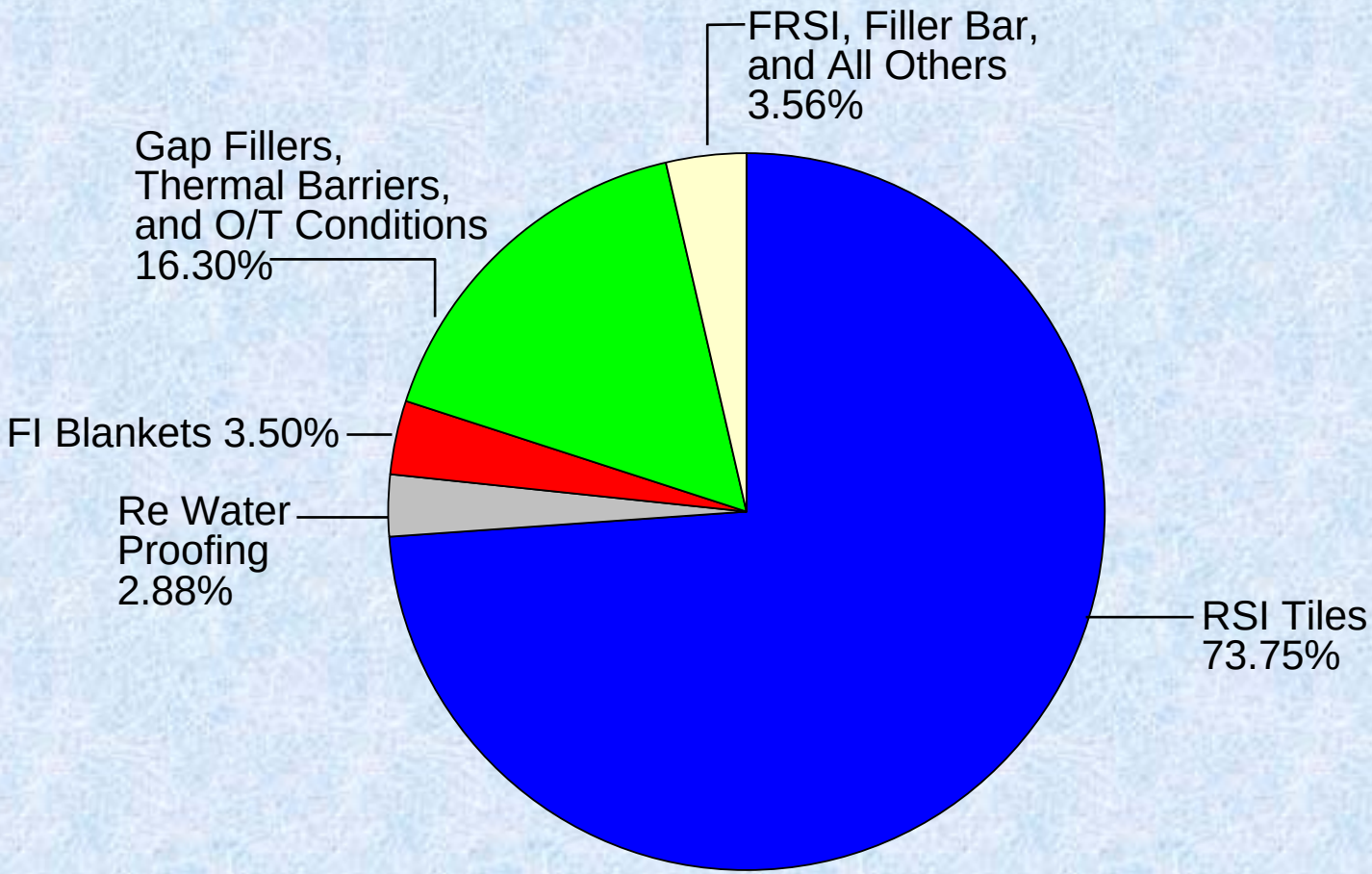
* TPSF = RTV'S, Threads, Fabrics, Coatings, etc.

Work Access

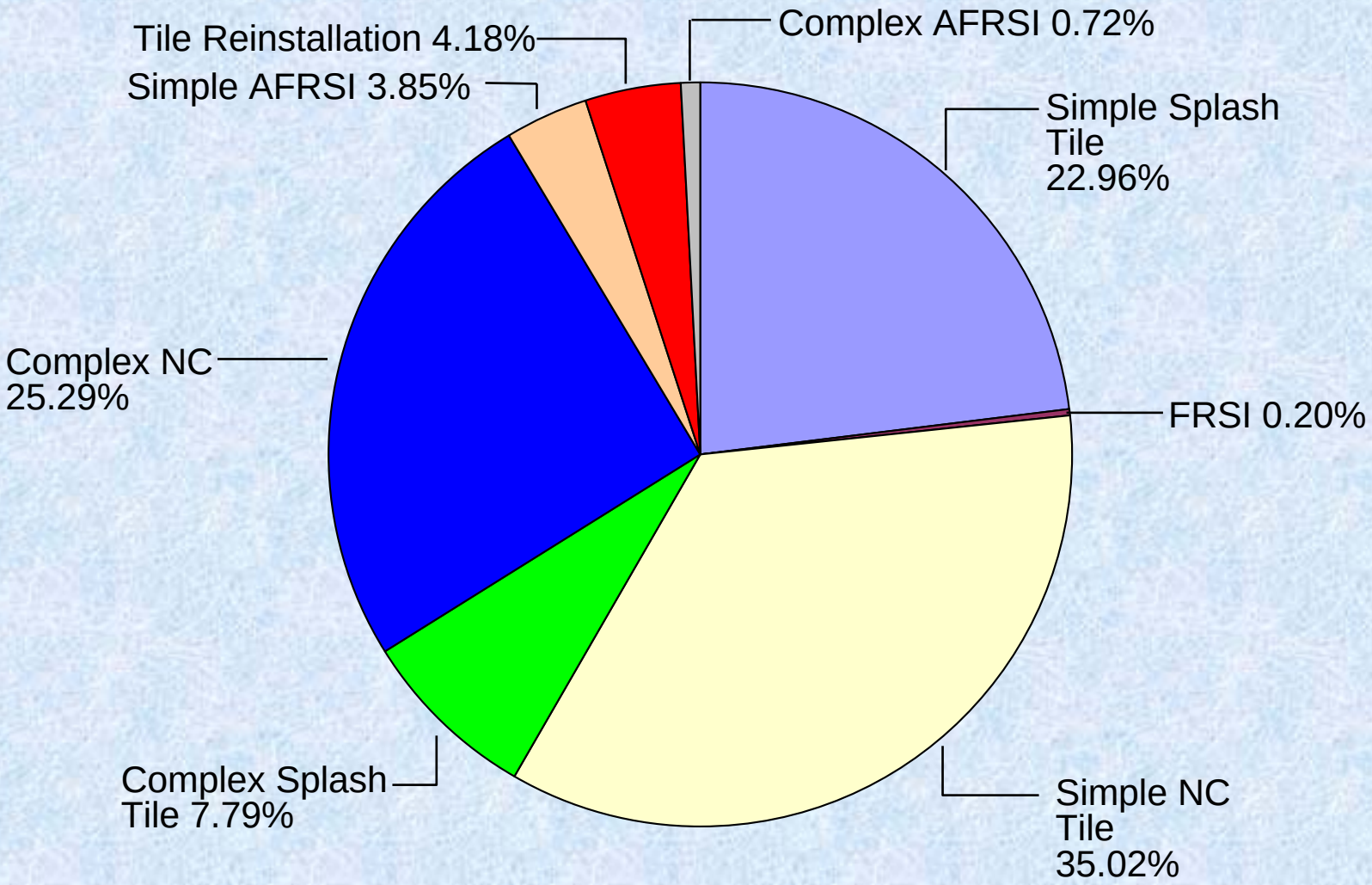
Causes for R&R



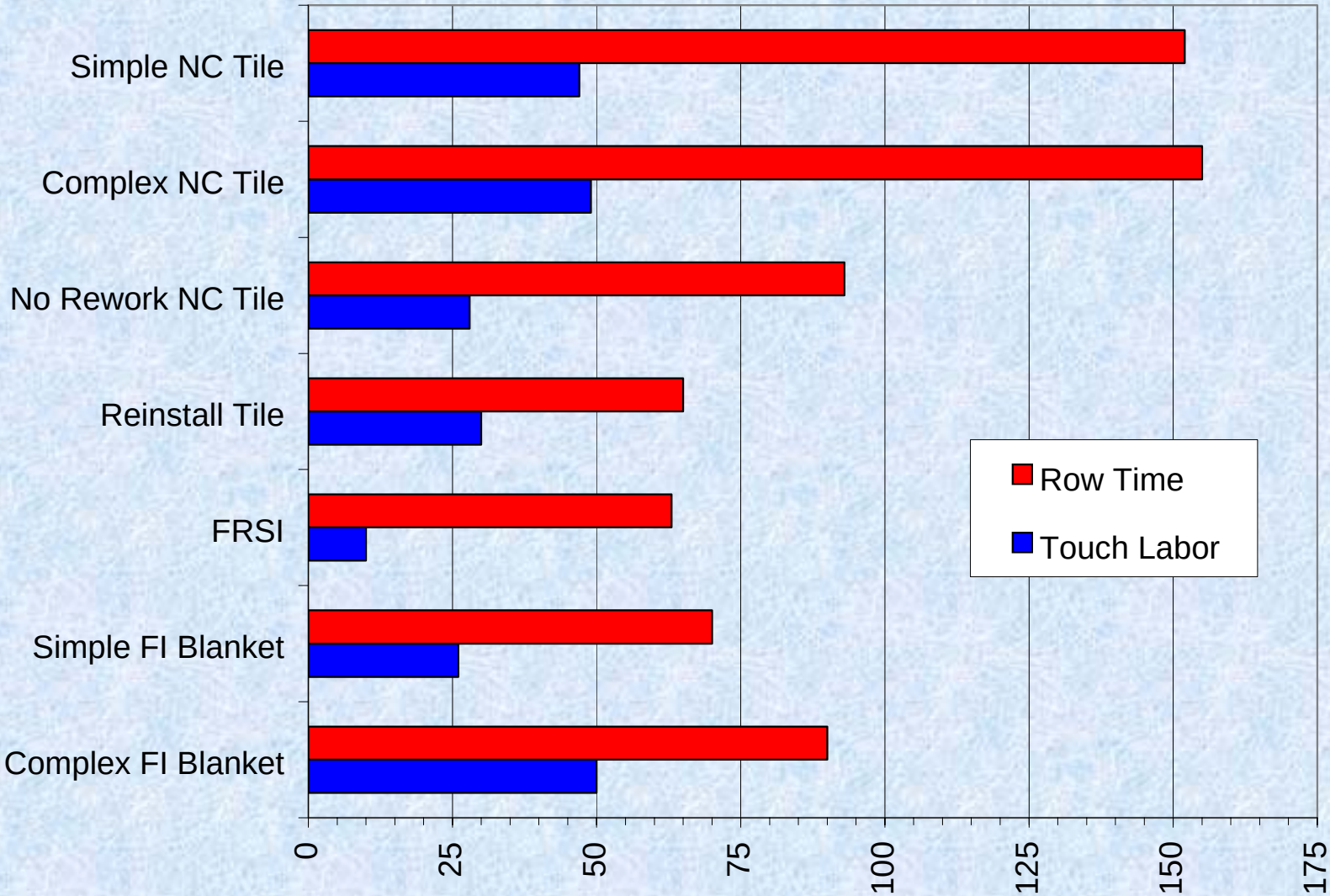
TPS Discrepancies



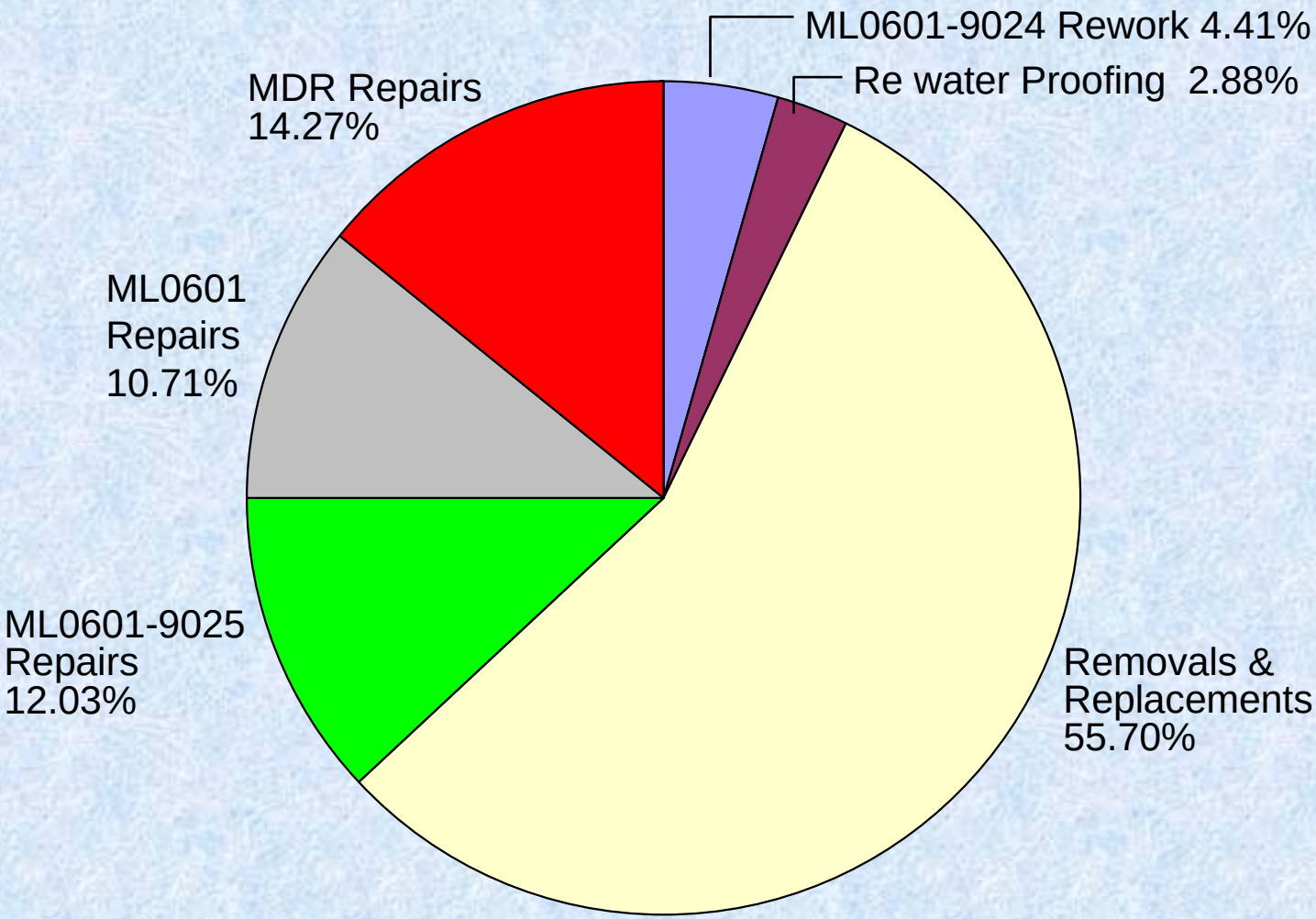
Work Load for Component R&R



Labor Hours per Type



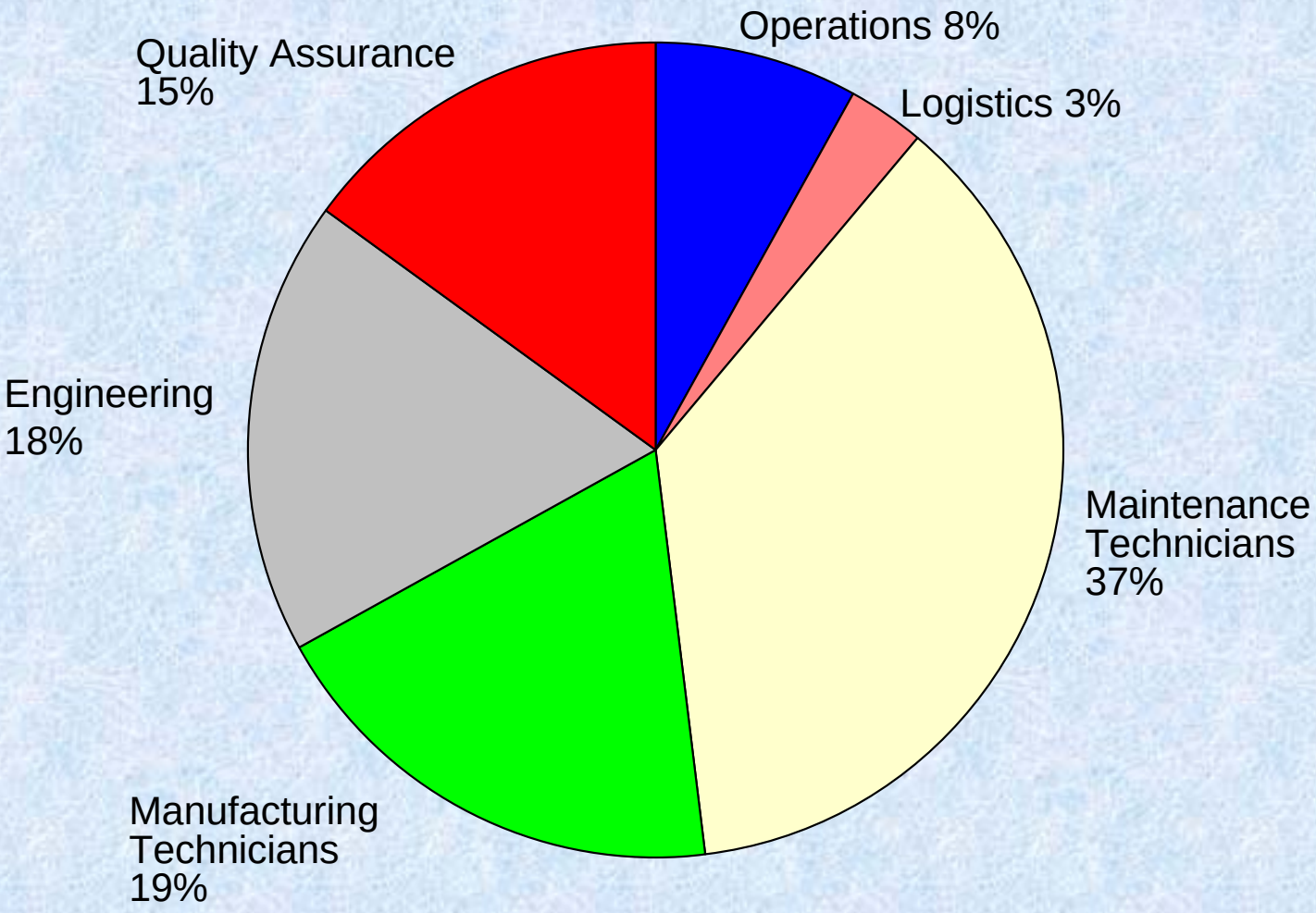
Tech Labor Breakdown



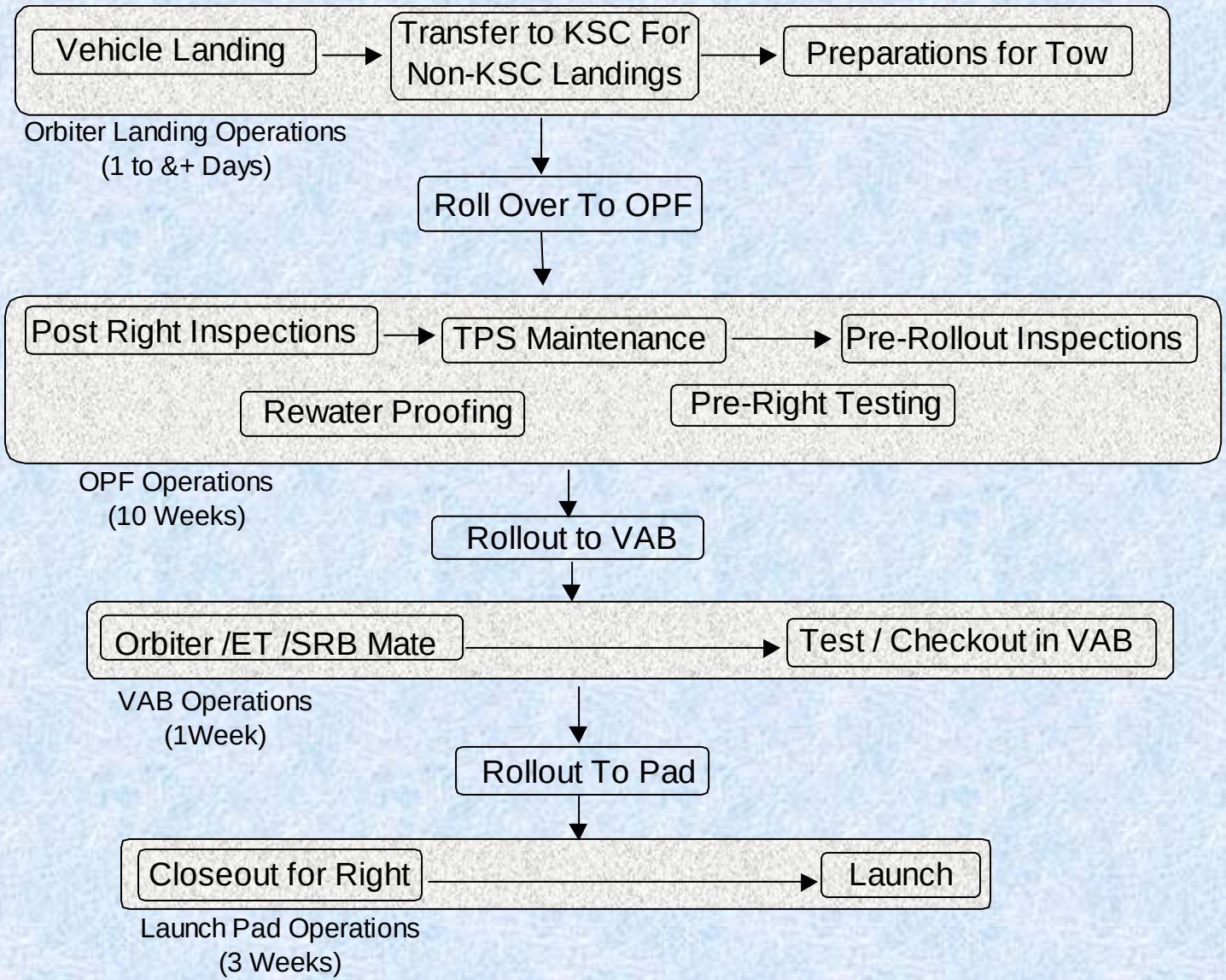
Labor Touch Time per TPS Type

- Tile = 2.27 hours/sq.ft.
- FIB = 0.16 hours/sq.ft.
- FRSI = 0.02 hours/sq.ft.
- ET SOFI = 0.70 hours/sq.ft.

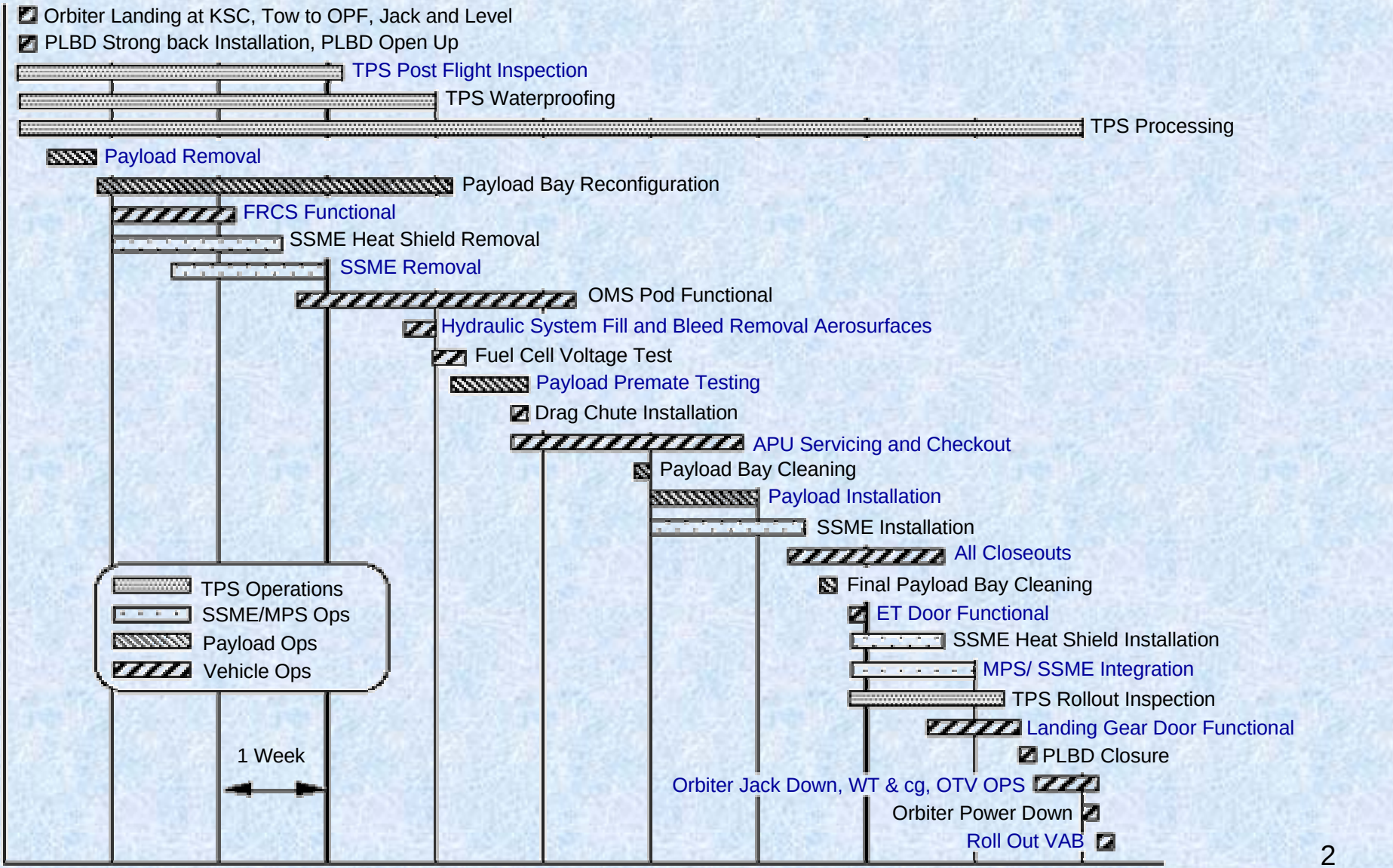
Discipline Comparison



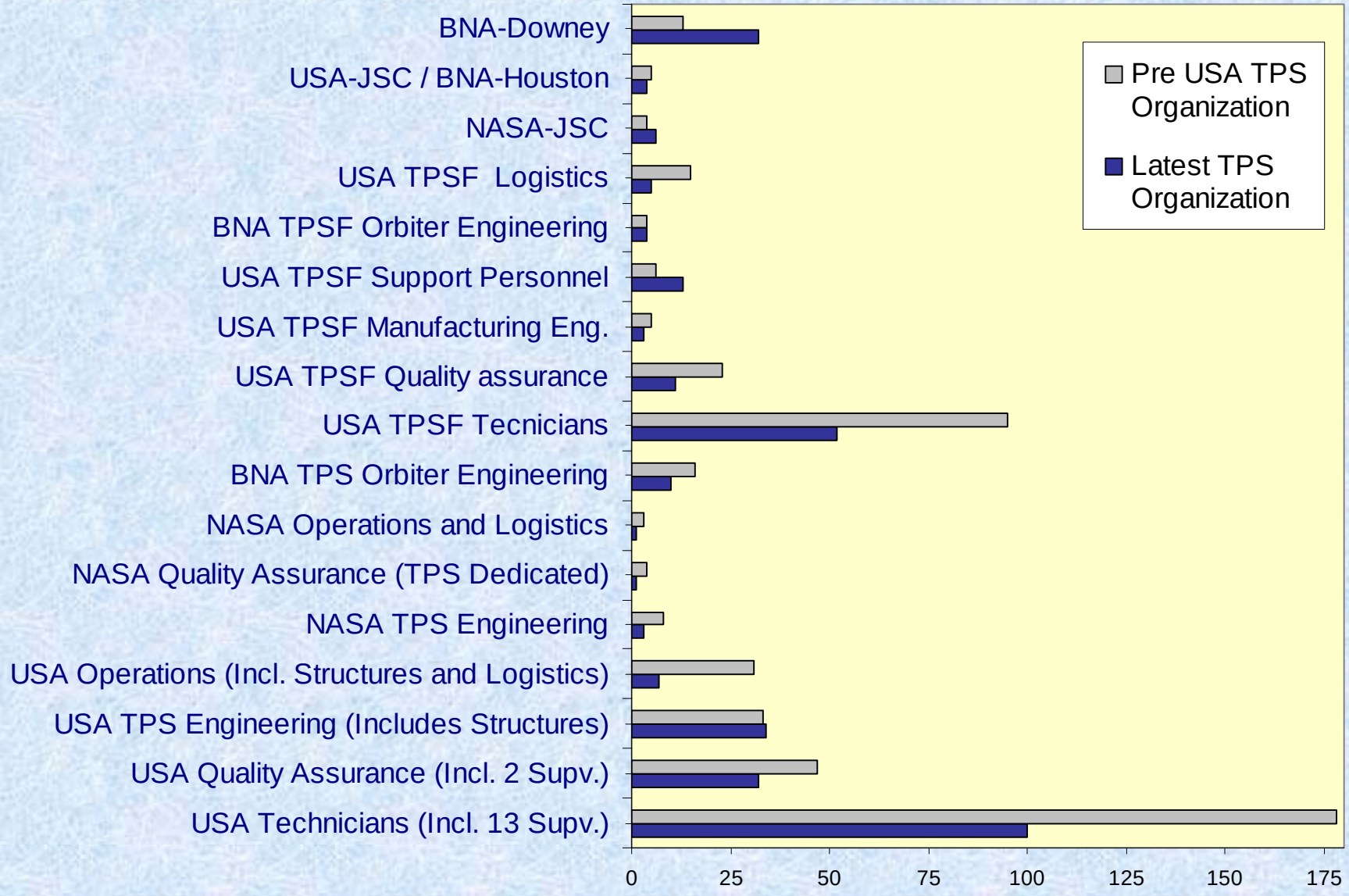
Orbiter Processing at KSC



OPF Processing



TPS Workforce



Past TPS Organization

TPS Organization	Personnel
SPC Technicians (Incl. 13 Supv.)	178
SPC Quality Assurance (Incl. 2 Supv.)	47
SPC TPS Engineering	33
SPC Operations	31
NASA TPS Engineering	8
NASA Quality Assurance (TPS Dedicated)	4
NASA Operations and Logistics	3
Rockwell TPS Orbiter Engineering	16
Rockwell TPSF Tecnicians	95
Rockwell TPSF Quality assurance	23
Rockwell TPSF Manufacturing Eng.	5
Rockwell TPSF Support Personnel	6
Rockwell TPSF Orbiter Engineering	4
Rockwell TPSF Logistics	15
NASA-JSC	4
Rockwell-Houston	5
Rockwell-Downey	13
Total TPS Workforce	**490**

Present TPS Organization

TPS Organization	Personnel
USA Technicians (Including 13 Supervisors)	100
USA Quality Assurance (Incl. 2 Supv.)	32
USA TPS Engineering (Includes Structures)	34
USA Operations (Includes Structures and Logistics)	7
NASA TPS Engineering	3
NASA Quality Assurance (TPS Dedicated)	1
NASA Operations and Logistics	1
BNA TPS Orbiter Engineering	10
USA TPSF Tecnicians	52
USA TPSF Quality assurance	11
USA TPSF Manufacturing Eng.	3
USA TPSF Support Personnel	13
BNA TPSF Orbiter Engineering	4
USA TPSF Logistics	5
NASA-JSC	6
USA-JSC	3
BNA-Houston	1
BNA-Downey	32
Total TPS Workforce	**318**

Improvements To Reduce Cost

Presently In-work

- Processing Reductions
- Less Toxic Re-Waterproofing
- Surface Defect Analyzer

Future Improvements

- White TUFI
- Ceramic Captive G/F
- Thermal Barrier Improvements

Beyond Shuttle

- Internal Vehicle Health Monitoring
- RF replaces Ground Connections
- No Penetrations
- No Windows
- Self Healing TPS