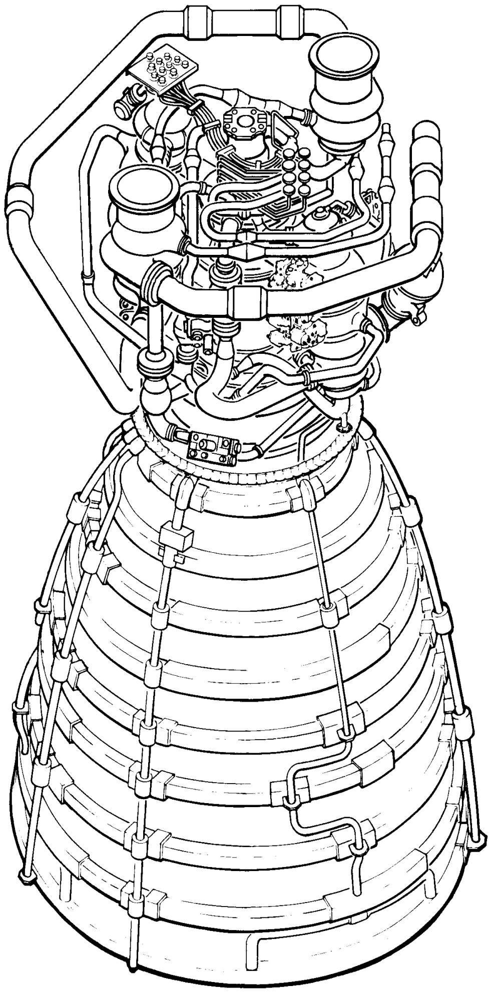


Atlantis STS-110

Space Shuttle Program

SSME Flight Readiness Review

March 26, 2002

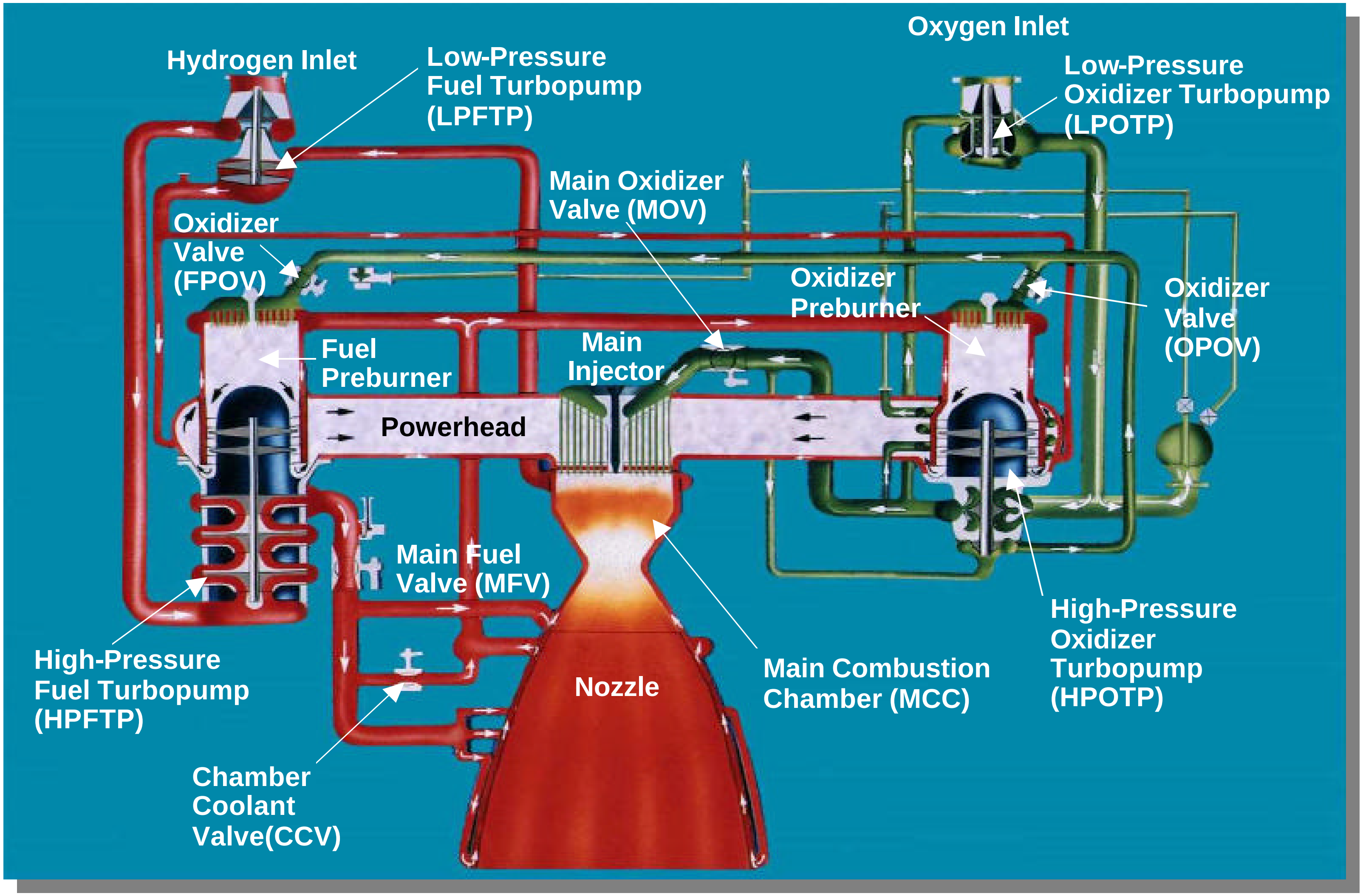
G. HOPSON
26 March 2002

Atlantis STS-110

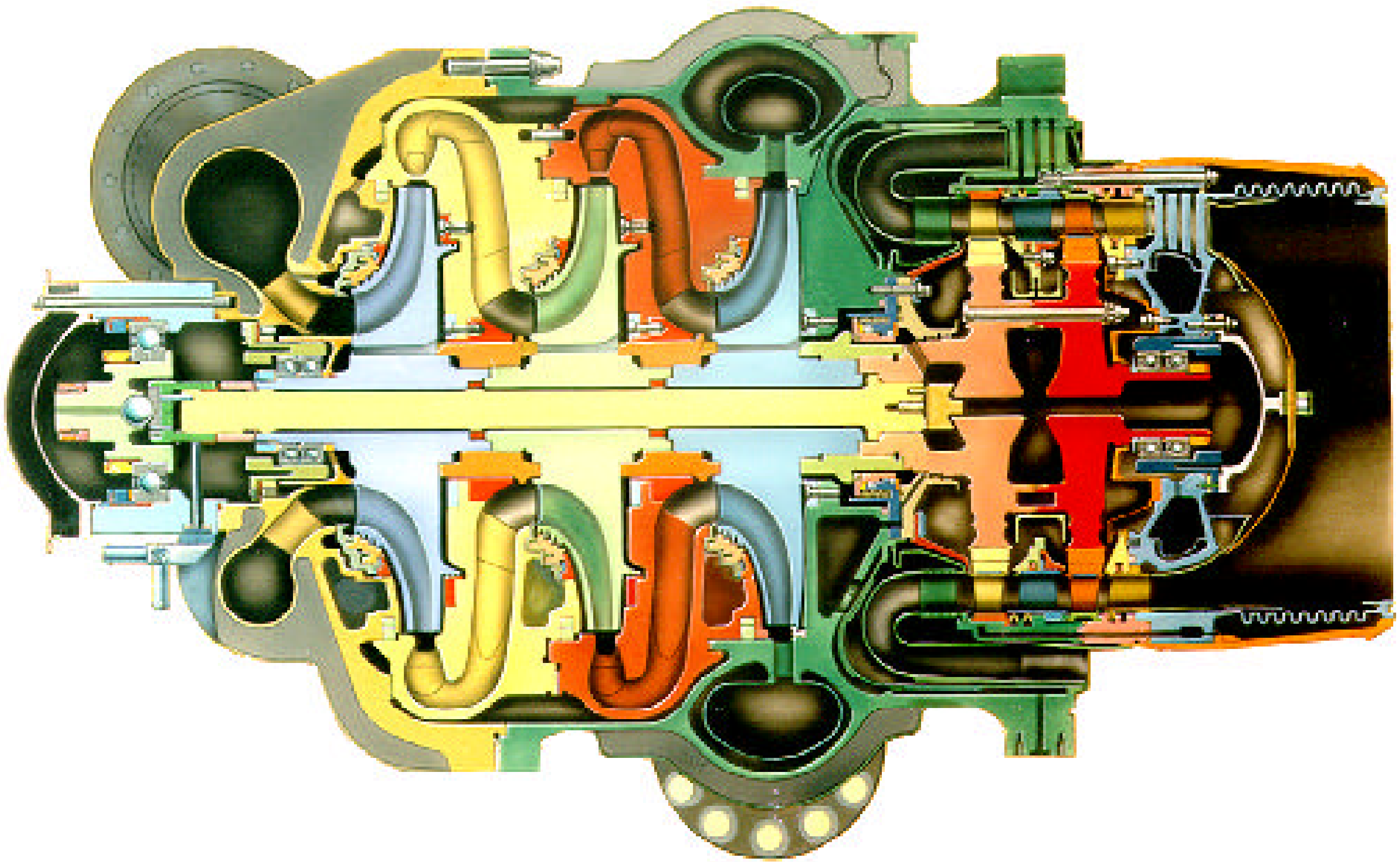
Agenda

- First Flight of a Block II SSME Cluster
- Major Components
- Engine Performance
- First Flight ECPs - None
- Special Topic
  - HPFTP Turbine Exit Diffuser Cracks
  - HPFTP Turbine Blade Shot Peen Process
- Problem Report and Material Review Reassessment
  - All dispositions evaluated and acceptable for flight

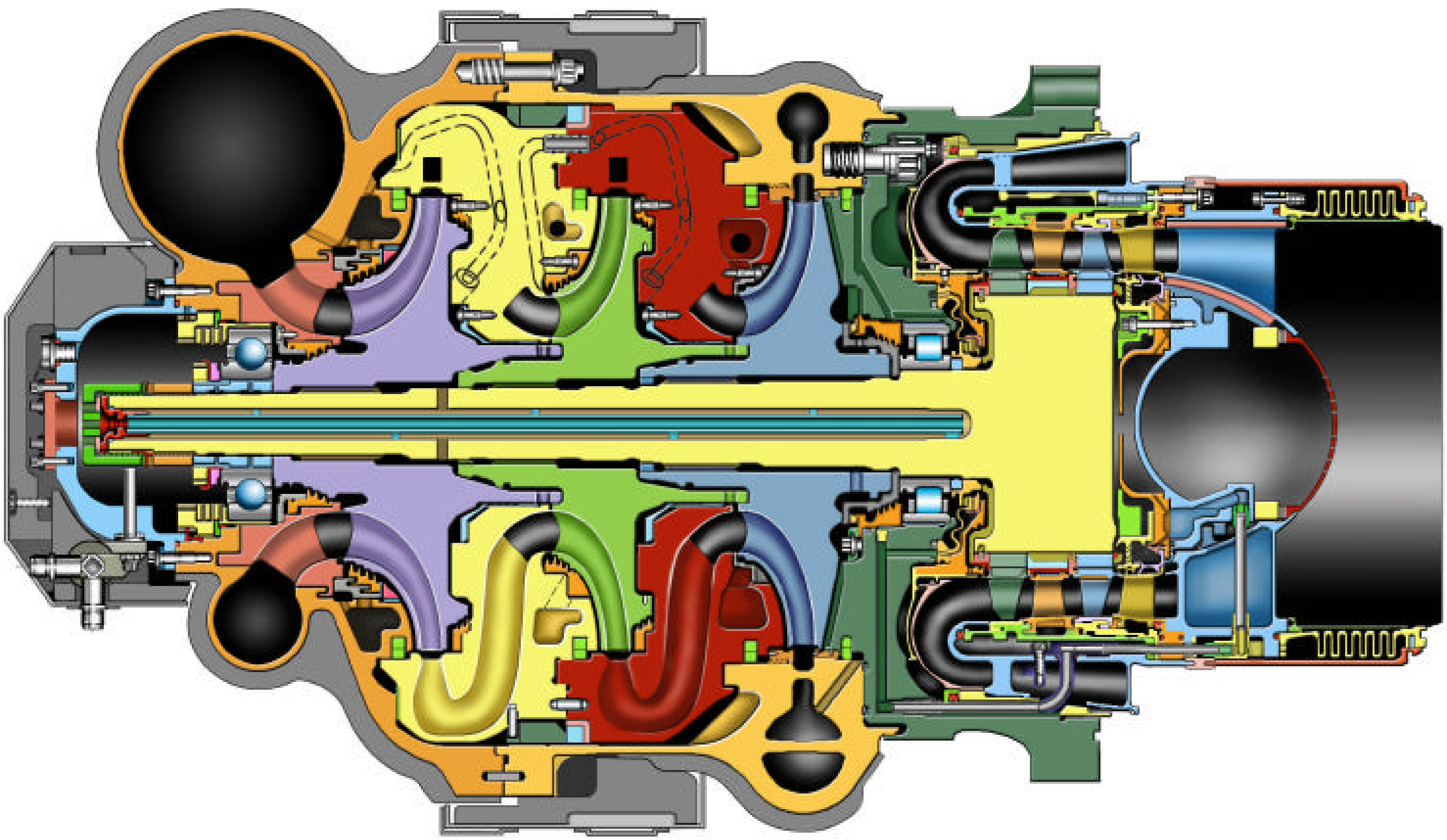
SSME Propellant Flow Schematic



BLOCK I HPFTP



BLOCK II HPFTP



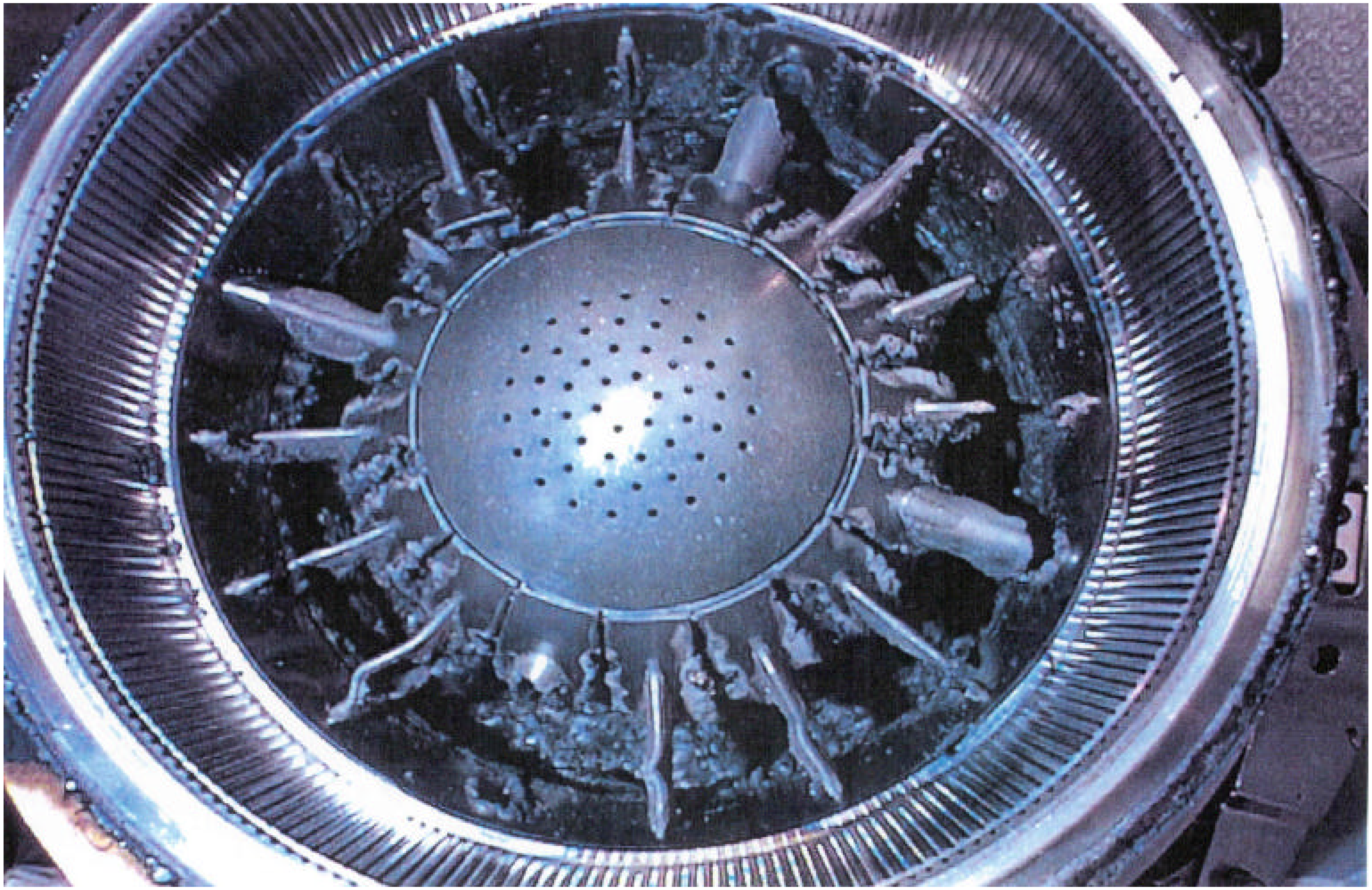
PRINCIPAL CAUSES OF PUMP DAMAGE

- High Oxygen to Fuel Ratio
- Foreign Object Damage

Blade Cracking Failure – 7/1/96

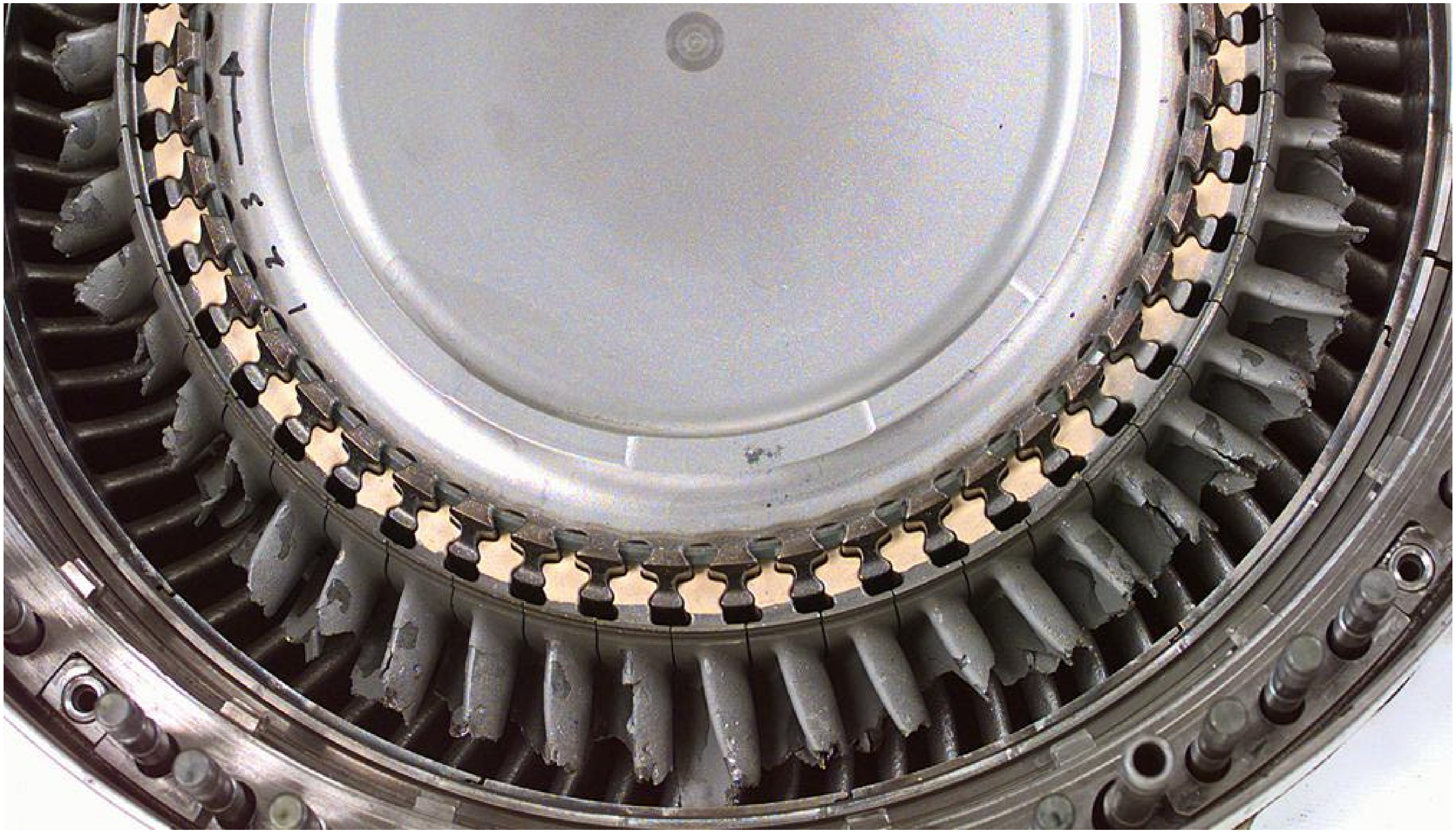
Damaged Turbine Blades (8-1a)

Nozzle Tube Rupture - 8/27/97



Damaged Turbine - SSME 0524

Foreign Object Obstruction in Fuel Preburner - 6/16/00

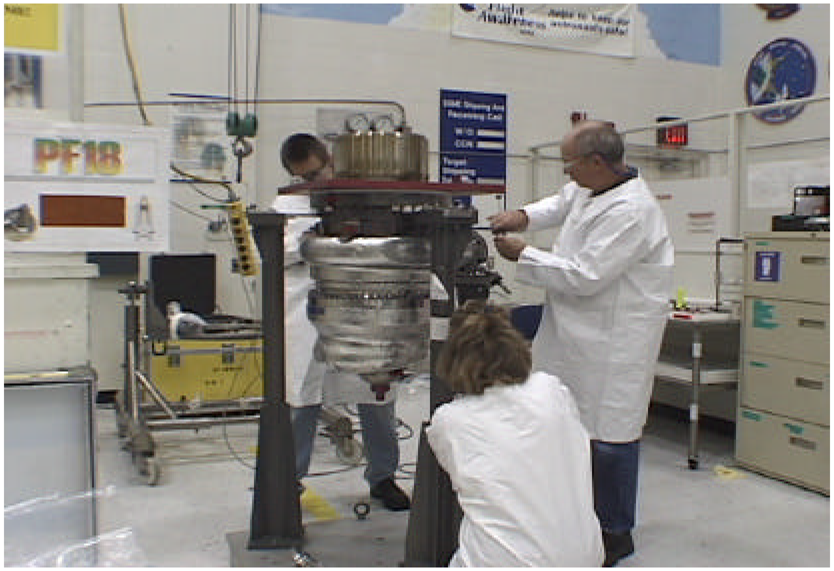


Damaged Turbine - SSME 0523

Block II HPFTP Deployment

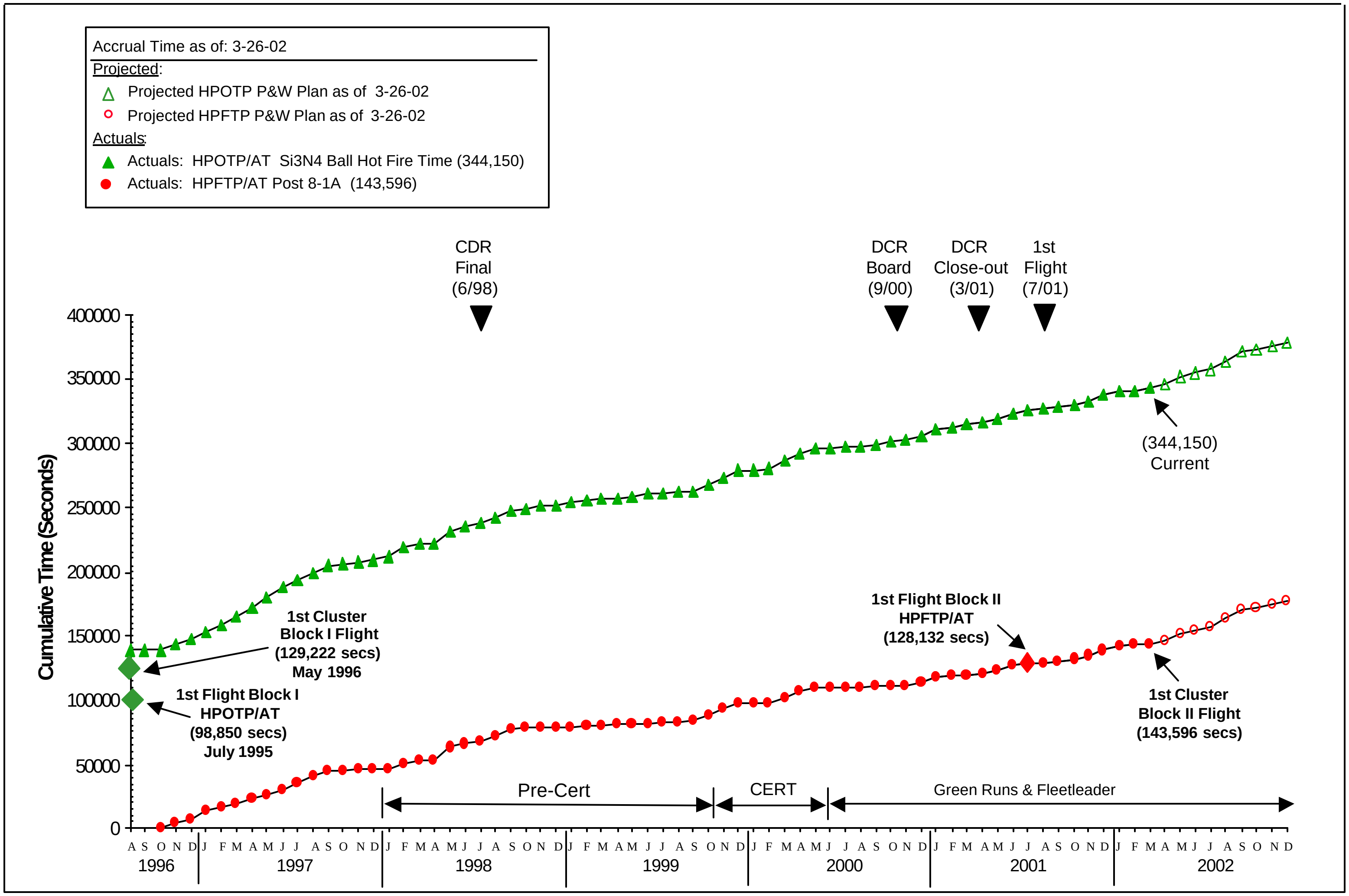
Deliveries Support Block II SSME Implementation

- 13 Block II HPFTPs completed manufacturing and now delivered
  - Production rate > 1 unit / month since first flight in July 2001 (STS-104)
- 12 Units completed successful Green Run Acceptance Tests at SSC
  - Timely test support expediting flow to KSC
- Total of 19 units will be completed through manufacturing by September
  - HPFTPs support full Block II SSME implementation beginning with STS-110



Block II Demonstrated Hot-Fire Experience

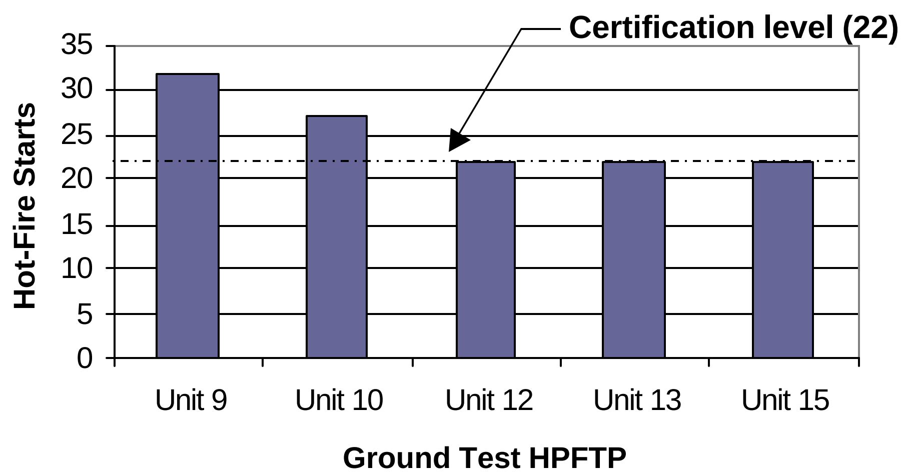
HPFTP / HPOTP Cumulative Hot-Fire Time



Block II HPFTP Test Experience

Ground Test Program at SSC Adding Maturity

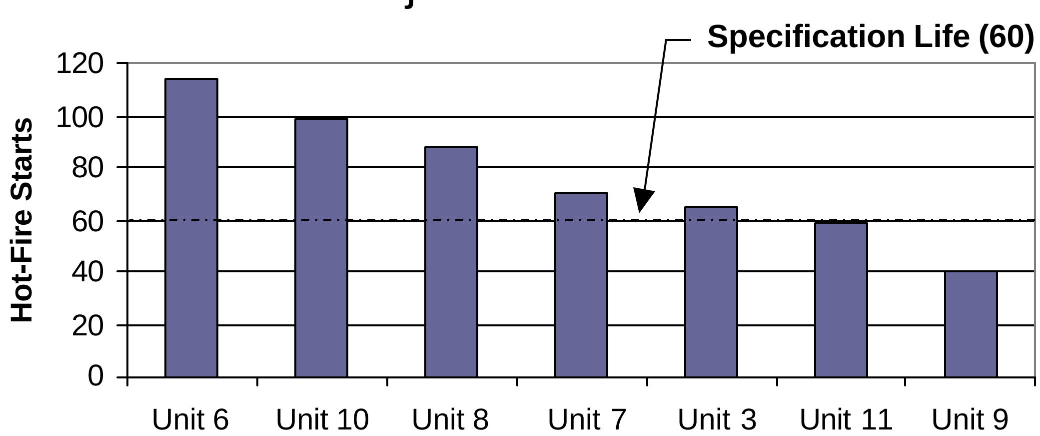
- Accrued ground / flight hot-fire experience is now 251 starts / 143,596 seconds
  - 24 starts / 15,464 seconds added since introduction on STS-104, equivalent to Certification Test Series
- HPFTP hot-fire accrual is comparable to HPOTP test time of 268 starts / 129,222 seconds at full cluster introduction of Block I SSME in May 1996 (STS-77)
- 5 Block II HPFTP units at or above Certification hot-fire accumulation of 22 starts



HPOTP Meeting All Operational Objectives

Ready to Initiate First Service Interval O&R Return

- HPOTPs in service since July 1995 and have supported 30 missions
  - Complete implementation accomplished with STS-91 in June 1998
  - Hot-fire accrual in ground test and flight now at 669 starts / 344,150 seconds
- 5 HPOTP ground test units have hot-fire accrual exceeding specification life of 60 missions
- Unit 8015 accumulated 11th start on STS-109; will return for first service interval O&R in April / May
  - Unit delivered May 1995 and flew January 1996. Unit returns after 6 years of operational service without major maintenance.



Atlantis STS-110

SSME Major Components

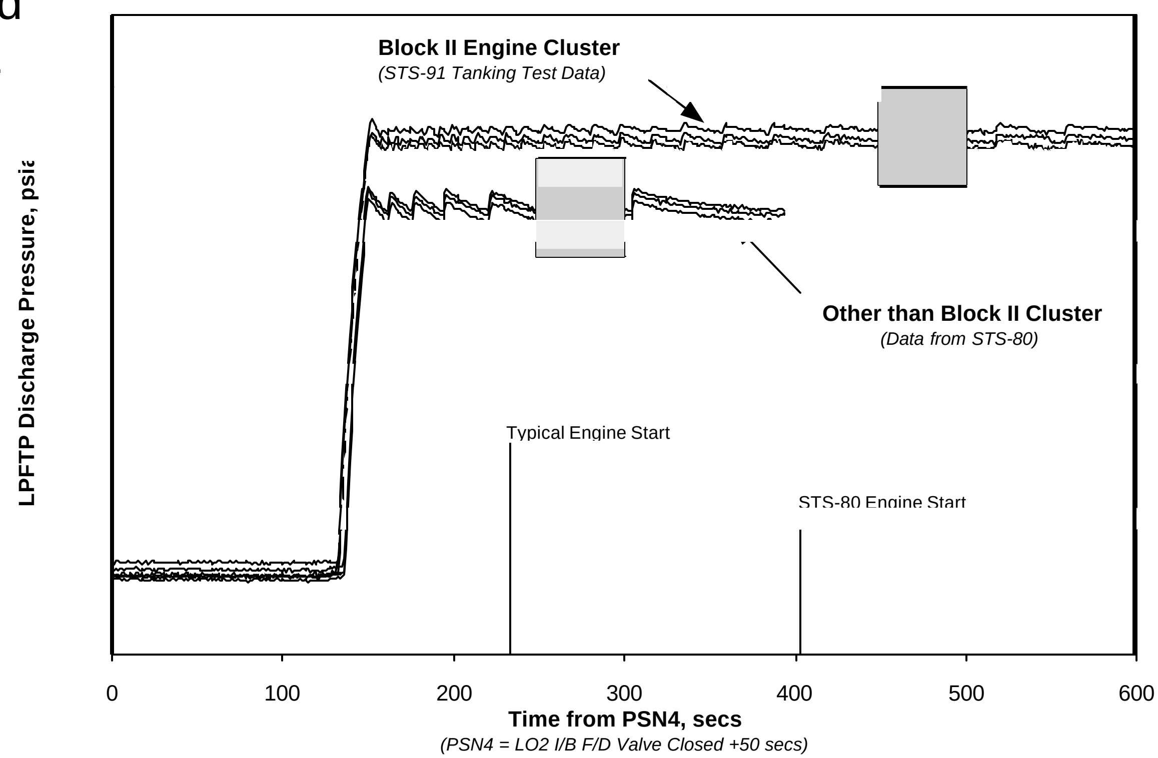
Engine	ME-1 / 2048 *Block II*	ME-2 / 2051 *Block II*	ME-3 / 2045 *Block II*
Last Hot-Fire	**902-809**	**STS-104**	**STS-105**
Powerhead	6021	6018	6008
Main Injector	6015	2035	4026
MCC	6012	6022	6008
Nozzle	4026	4024 (1)	2031
Controller	F45	F58	F34
HPFTP	8019	8016	8022R1 (1)
LPFTP	4207	6005	6003
HPOTP	8019R1	8029	8023R1
LPOTP	2236	6003	4506

(1) Changes from last hot-fire.

Atlantis STS-110

Block II SSME Engine Ready Limit Change

- **SSME Pre-Start LCC changed for Block II prior to STS-104**
  - LPFTP Disch Pressure Engine Ready limits changed to accommodate higher LH2 Inlet Pressure for Block II Clusters
    - Higher pressure demonstrated on STS 91 tanking test
    - STS-110 will be the first flight use of the new limits



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Predicted SSME Ignition Confirm Margins

Parameter	Margin Sigma		
	ME-1 (2048)	ME-2 (2051)	ME-3 (2045)
HPFTP Minimum Speed	3.5	**a [2.9]**	5.3
Min/Max Ignition Pc	3.6	3.6	3.1
Antiflood Valve Min Open	25.8	25.8	26.2
HPFTP Max Turbine Temp	4.5	5.0	4.4
HPOTP Max Turbine Temp	7.2	4.7	9.1
HPOTP Min Turbine Temp	7.0	8.4	7.0
Preburner Max Purge Pressure	28.8	29.0	29.3
POGO GOX Min/Max Pressure	3.0	4.1	4.1

[ ] Less than 3 sigma margin

a 3.8 sigma when adjusted for effects of high LH2 Inlet Pressure

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Predicted SSME Performance at 104.5% P.L.

At Engine Start + 200 seconds
(MR = 6.032, OPI = 69 psia, FPI = 28 psia)

Parameter	ME-1 (2048) Sigma	ME-2 (2051) Sigma	ME-3 (2045) Sigma
HPFT Disch Temp A, Deg R	-0.9	-2.0	-0.4
HPFT Disch Temp B, Deg R	0.5	**a [-2.3]**	-0.1
HPOT Disch Temp A, Deg R	-1.5	0.7	**b[-2.5]**
HPOT Disch Temp B, Deg R	-0.6	1.1	-1.9
HEX Interface Temp, Deg R	-0.8	1.0	-1.3
HPFTP Speed, rpm	-2.0	-1.9	-1.4
LPFTP Speed, rpm	0.9	0.5	-0.9
HPOTP Speed, rpm	0.3	1.6	0.3
LPOTP Speed, rpm	-0.6	1.6	0.8
OPOV Position, %	-0.1	-0.6	0.9
FPOV Position, %	-1.0	-1.0	0.0
PBP Disch Pressure, psia	0.5	1.5	1.1
HPFTP Disch Pressure, psia	-1.7	-1.8	-2.0
HPOTP Disch Pressure, psia	0.5	0.1	0.5
HPFTP U/N	8019	8016	* 8022R1
LPFTP U/N	4207	6005	6003
HPOTP U/N	8019R1	8029	8023R1
LPOTP U/N	2236	6003	4506

***** Change since last hotfire
[ ] Exceeds database two sigma
a Result of high performing HPFTP
b Effect of low HPFT turbine efficiency

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26 March 2002

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Predicted Redline Margins at 104.5% P.L.

Parameter	Margin Sigma		
	ME-1	ME-2	ME-3
HPFT Discharge Temp ChA, Deg R	6.3	7.2	5.8
HPFT Discharge Temp ChB, Deg R	5.1	7.6	5.6
HPOT Discharge Temp ChA, Deg R	8.1	6.6	8.8
HPOT Discharge Temp ChB, Deg R	9.3	7.8	10.2
HPOT Discharge Temp ChA, Deg R	5.7	6.2	4.8
HPOT Discharge Temp ChB, Deg R	6.4	6.6	4.5
HPOTP IMSL Purge Pr, psia	4.3	4.9	5.6
Low MCC Pc, psid			
Command-ChA Avg	21.1	21.7	21.2
Command-ChB Avg	24.1	25.5	25.2
FASCOS			
HPFTP (16 GRMS)	6.8	8.2	8.2
HPOTP (11 GRMS)	33.5	34.4	34.4

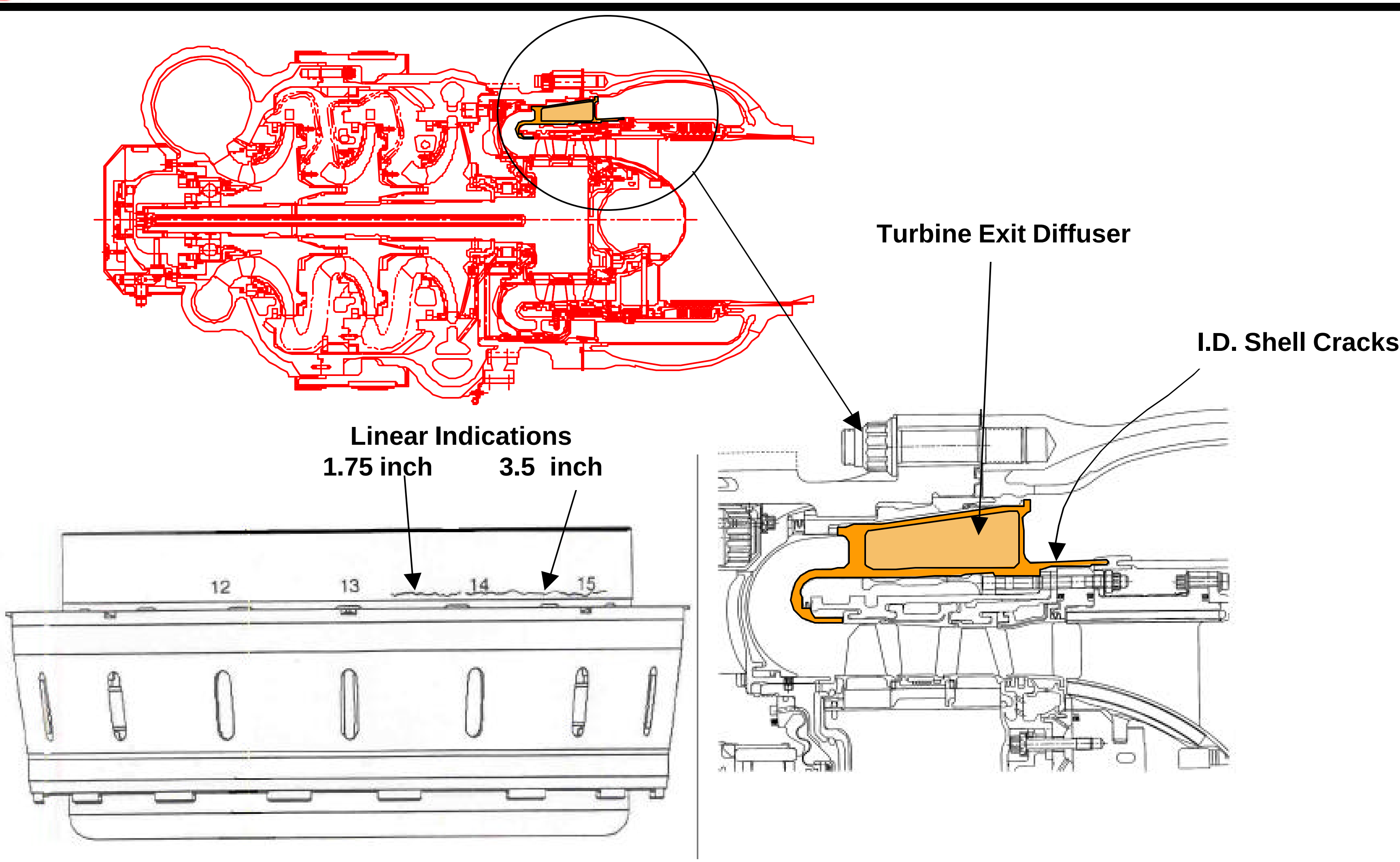
Block II HPFTP Turbine Exit Diffuser

I.D. Shell Cracks

- **Issue**
  - Cracking of the Turbine Exit Diffuser (TED) may result in turbine bypass
- **Background**
  - Circumferential cracks up to 3.7 inches long found on TED I.D. shell (flowpath side)
    - First occurrence at this location
    - Cracks appear to be through wall
  - Cracks found during FPI disassembly inspections of HPFTP 8210R1
    - TED accumulated 33 starts/ 20,881 seconds
      - 4683 seconds at 109% RPL
      - Six - 1000 second extended duration tests
    - TED continued to operate acceptably with no notable performance or structural issues

Block II HPFTP Turbine Exit Diffuser

I.D. Shell Cracks



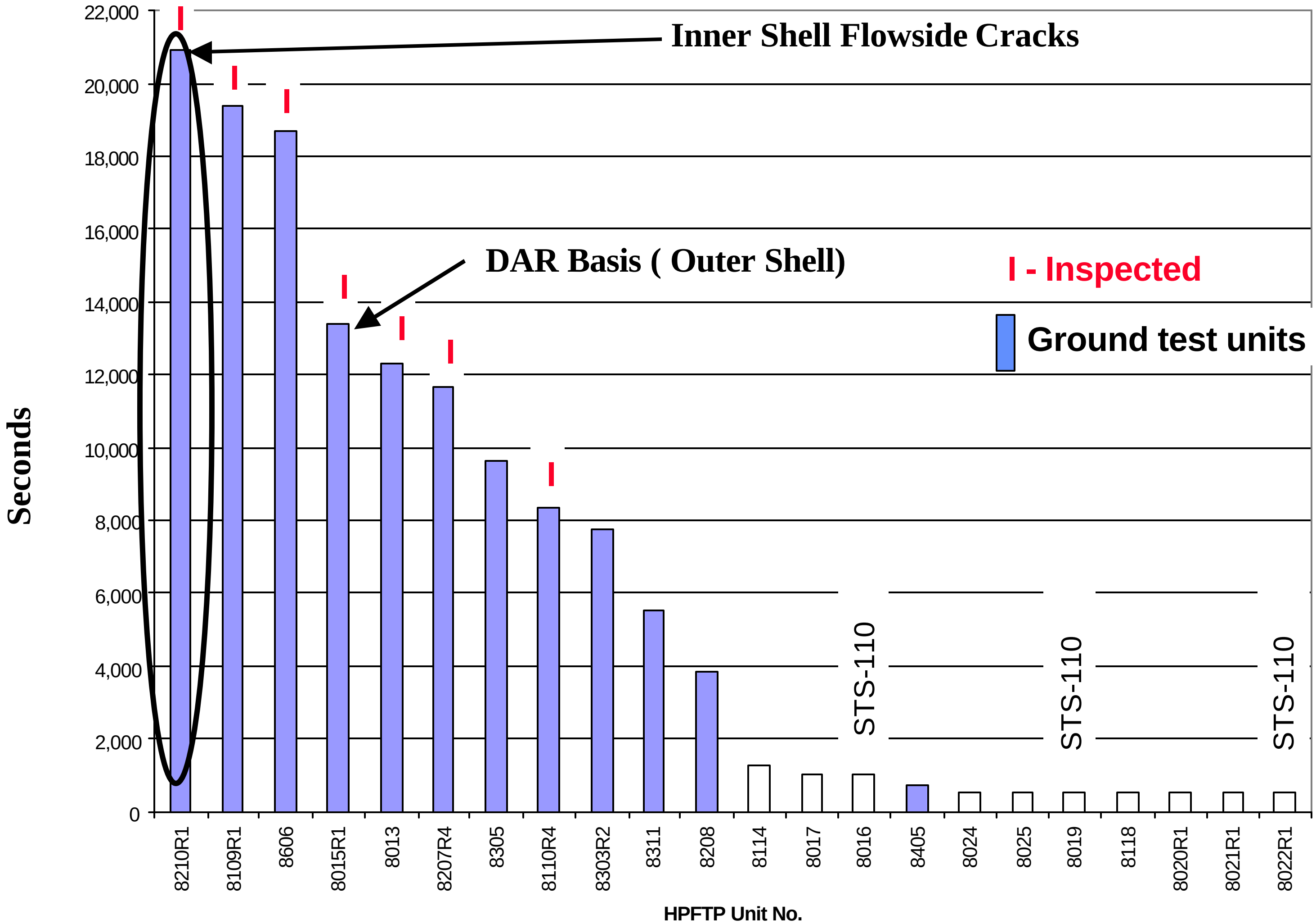
Block II HPFTP Turbine Exit Diffuser

I.D. Shell Cracks

- **Investigation**
  - Cracked TED used in HPFTP 8012 (Certification) for 22 starts/ 12,161 seconds
    - No I.D. shell cracks noted
  - DAR requires inspection at 5 starts/ 3351 seconds
    - Cracking on TED from HPFTP 8015R1
      - Different location- Outer Shell
  - Highest time flight unit (8016) has 2 starts /1032 seconds
    - Will have accumulated 8.6% of cracked unit total time after its next flight
    - Will have accumulated 9.1% of cracked unit total starts after its next flight

Block II HPFTP Turbine Exit Diffuser

I.D. Shell Cracks



Block II HPFTP Turbine Exit Diffuser

I.D. Shell Cracks

- **Flight Rationale**
  - Flight units maintain large margin over cracked unit
    - Will have accumulated 9% of cracked unit experience after its next flight
  - Extensive operational experience with no significant performance or structural issues

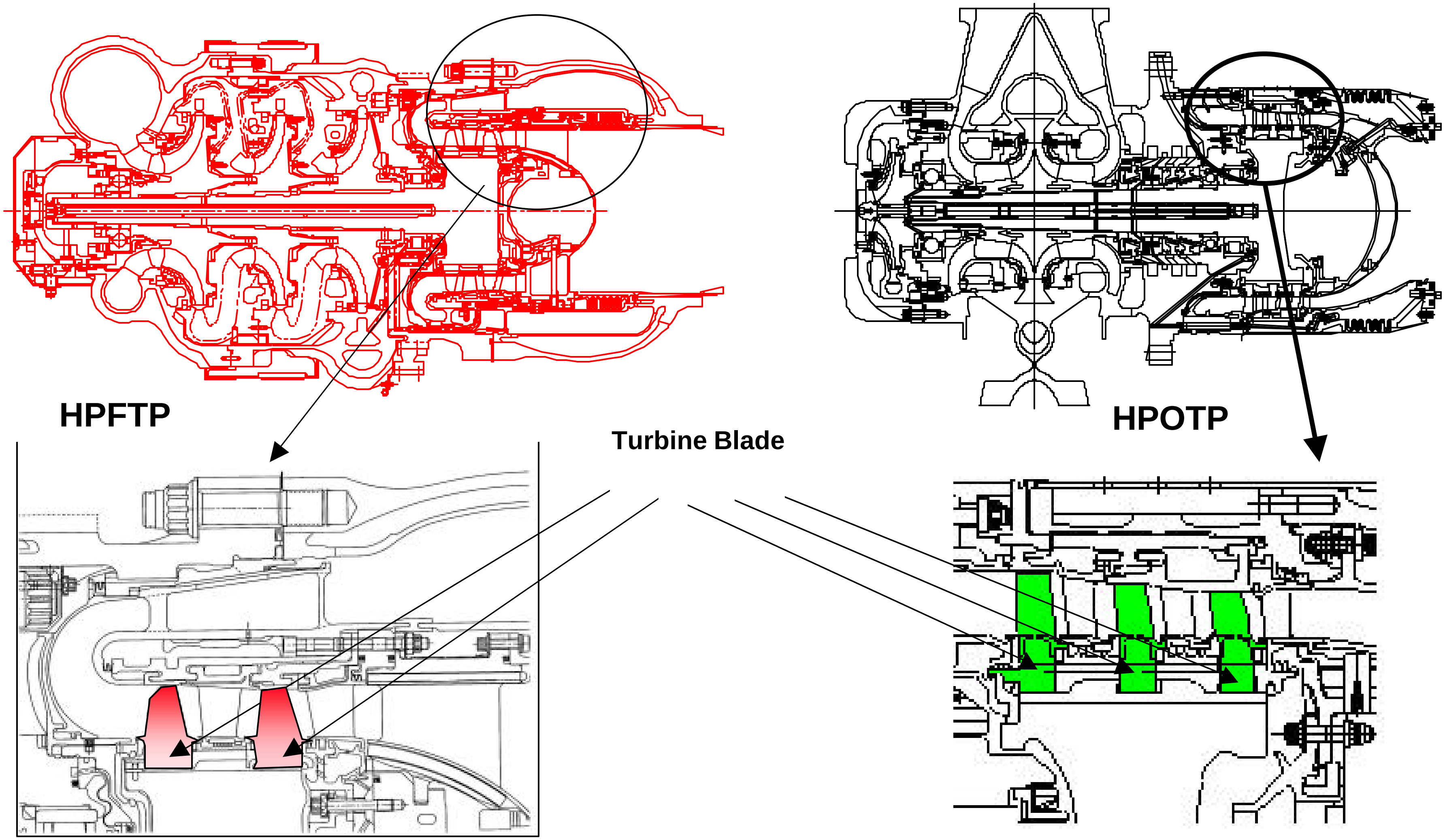
Block II HPFTP/HPOTP Turbine Blade

Shot Peen Process

- **Issue**
  - HPFTP turbine blades shot peened without formal Engineering Source Approval (ESA) process control
  - HPOTP turbine blades shot peened with unapproved shot media
- **Background**
  - Turbine blade shot peened by sub-tier supplier - Impact Finishers
  - Audit of HPFTP blades revealed no P&W approved shot peening set-up process sheets
    - ESA granted shot peen process approval of prime supplier without requisite shot peen process sheet review and approval at sub-tier supplier
    - Current shot peening supplier has processed all production turbopump blades (certification/flight)

Block II HPFTP/HPOTP Turbine Blade

Shot Peen Process



Block II HPFTP/HPOTP Turbine Blade

Shot Peen Process

- **Background (Continued)**
  - Shot peen supplier has ESA for numerous additional parts
    - Formal process control sheets exist
    - Review of HPOTP blades revealed a change to the shot peen media without ESA approval
  - Shot peening imparts a compressive residual surface stress and improves fatigue capability
    - Not quantified or used in structural/dynamic analysis
  - Process parameters ensure two end item control characteristics
    - Peen Intensity (residual compressive stress)
    - Peen coverage (adequate coverage to critical blade features)

Block II HPFTP/HPOTP Turbine Blade

Shot Peen Process

- **Investigation- HPFTP Blades**
  - Peen intensity and coverage verified by inspection of blades and test strips
    - Peen intensity
      - All test strip data reviewed and acceptable
      - Visual re-inspection of blade surfaces from representative lots reveal constant peen intensity
      - Laboratory evaluation of blades from representative lots show consistent peen intensity throughout program
    - Peen coverage
      - Visual blade inspection documented by shot peen supplier, machining supplier (prime subcontractor), and Pratt & Whitney
      - Personnel Interviews verified that peen nozzles properly aligned
      - Test strips and blades from representative lots re-inspected with no anomalies

Block II HPFTP/HPOTP Turbine Blade

Shot Peen Process

First Stage Blade

Category (shading)	Cert/Dev		Cert/Dev	Cert/Dev/Flt		Cert/Dev/Flt	Cert/Dev/Flt	Cert/Dev/Flt	Cert/Dev/Flt	Cert/Dev/Flt	Cert/Dev/Flt	Flight	Flight	Flight	Flight	Flight	Flight
Reverified Test Strip Intensity	X	X	X	X	X	X	X	X	X*	X*	X*	X	X	X	X	X	X*
Reverified Test Strip Coverage	X	X	X	X	X		X	X	X	X	X				X	X	X
Laboratory Intensity Analysis	X		X							X	X					X	
Surface Finish									X	X	X						
Visual of a Sample Blade	X		X	X		X			X	X	X	X	X	X	X	X	
STS-110 Blades						STS-110			STS-110	STS-110	STS-110	STS-110	STS-110	STS-110			

Lot Date
Lot No. →

X* - Re-measured Test strip

Second Stage Blade

Category (shading)	Cert/Dev	Cert/Dev	Cert/Dev	Flight		Cert/Dev				Flight	Flight	Flight	Flight	Flight	Flight	Flight	Flight	Flight			Flight	
Reverified Test Strip Intensity	X	X	X	X*	X	X	X	X	X	X*	X*	X	X	X	X*	X*	X*	X	X	X	X	X*
Reverified Test Strip Coverage				X	X	X	X	X	X	X	X			X	X	X	X		X		X	X
Laboratory Intensity Analysis									X		X		X		X		X					
Surface Finish				X						X	X				X	X	X					
Visual of a Sample Blade	X	X		X	X		X		X	X	X	X	X	X	X	X	X	X				
STS-110 Blades				STS-110						STS-110	STS-110	STS-110			STS-110	STS-110	STS-110					

Lot Date
Lot No. →

Cert/Dev | Cert/Dev/Flt | Flight | STS-110 Blades

G. HOPSON
26 March 2002

Block II HPFTP/HPOTP Turbine Blade

Shot Peen Process

- **Investigation- HPOTP Blades**
  - Process control sheets exist for all HPOTP Blades
  - Shot peen media type recorded
  - Supplier changed media in 1995
    - Did not obtain ESA approval
  - Peening intensity and coverage verified for both shot media
  - Sufficient development test experience for both media
    - No out of family conditions post hot fire

Block II HPFTP/HPOTP Turbine Blade

Shot Peen Process

- **Flight Rationale - HPFTP blades**
  - Flight blades have been shot peened with the same process as development and certification blades
    - Peening intensity is verified by test strip deflections
    - Shot peen coverage has been verified by inspection of blades and test strips
  - Extensive hot fire experience with no performance or out of family conditions

- **Flight Rationale - HPOTP blades**
  - Peening intensity and coverage verified for both shot media
  - Significant development test experience for both media
    - No out of family conditions

Atlantis STS-110

SSME Certification of Flight Readiness

- **Flight Readiness Review CoFR Exception**
  - One Exception
    - UCR A034462 – High Pressure Fuel Turbopump (HPFTP) contamination

Atlantis STS-110
SSME Readiness Statement

- **The Atlantis Main Engines are in a ready condition for STS-110**

G.D. Hopson	**J. S. Paulsen**
Manager	**Program Manager**
SSME Project	**Space Shuttle Main Engine**