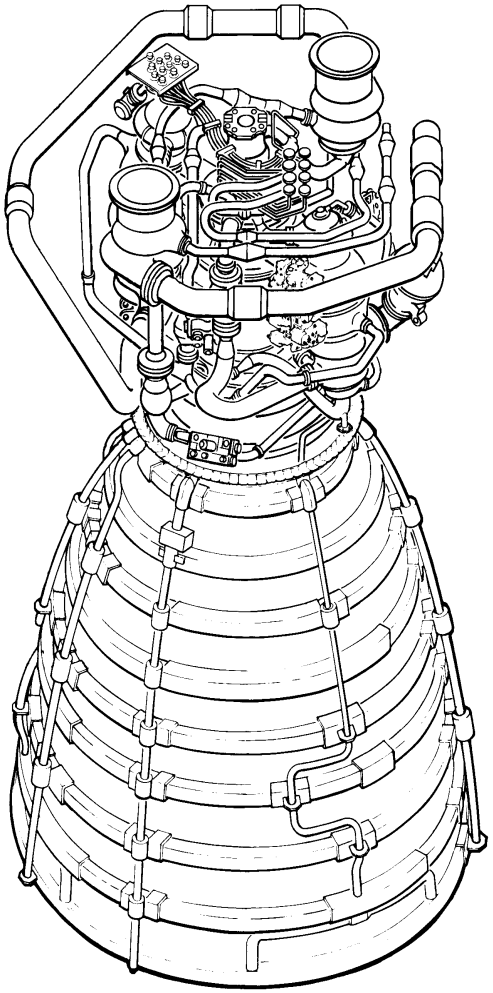

Atlantis STS-112

Space Shuttle Program

SSME Flight Readiness Review

September 17, 2002

G. HOPSON
17 September 2002

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Agenda

- **Major Components**
- **Engine Performance**

Special Topic

- **HPOTP Knife Edge Seal Fracture**

- **Material Review Reassessment**

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SSME Major Components

Engine	ME-1 / 2048 *Block II*	ME-2 / 2051 *Block II*	ME-3 / 2047 *Block II*
Last Hot-Fire	**STS-110**	**STS-110**	**STS-109**
Powerhead	6021	6018	6016
Main Injector	6015	2035	4027
MCC	6012	6022	6011
Nozzle	4026	4024	4027
Controller	F45	F58	F63
HPFTP	8019	8016	8118 (1)
LPFTP	6102R1 (1)	6005	2225
HPOTP	8019R1	8029	8024
LPOTP	2236	6003	2230

(1) Changes after last hot-fire.

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Predicted SSME Ignition Confirm Margins

Parameter	Margin Sigma		
	ME-1 (2048)	ME-2 (2051)	ME-3 (2047)
HPFTP Minimum Speed	4.8	3.6	5.5
Min/Max Ignition Pc	5.0	5.3	5.1
Antiflood Valve Min Open	25.8	24.6	25.0
HPFTP Max Turbine Temperature	4.4	5.5	4.6
HPOTP Max Turbine Temperature	7.6	4.6	5.4
HPOTP Min Turbine Temperature	7.1	7.9	9.6
Preburner Max Purge Pressure	29.2	29.7	30.6
POGO GOX Min/Max Pressure	3.2	4.1	3.4

[ ] Less than 3 sigma margin

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Predicted SSME Performance at 104.5% P.L.

At Engine Start + 200 seconds

Parameter	ME-1 (2048)	ME-2 (2051)	ME-3 (2047)
HPFT Disch Temp A, Deg R	1.0	-1.6	-0.3
HPFT Disch Temp B, Deg R	1.2	-0.6	-0.1
HPOT Disch Temp A, Deg R	-1.4	1.2	-0.3
HPOT Disch Temp B, Deg R	-1.1	0.7	-0.7
HEX Interface Temp, Deg R	-0.8	0.9	-0.3
HPFTP Speed, rpm	0.3	0.0	0.5
LPFTP Speed, rpm	1.4	0.4	-0.3
HPOTP Speed, rpm	-0.2	1.0	-0.1
LPOTP Speed, rpm	-0.8	1.4	0.0
OPOV Position, %	-0.5	-0.5	-1.4
FPOV Position, %	-0.6	-0.5	**a** [-2.2]
PBP Disch Pressure, psia	-0.5	0.8	-1.1
HPFTP Disch Pressure, psia	1.1	-1.2	0.0
HPOTP Disch Pressure, psia	-0.6	-0.5	-1.3
HPFTP U/N	8019	8016	* 8118
LPFTP U/N	* 6102R1	6005	2225
HPOTP U/N	8019R1	8029	8024
LPOTP U/N	2236	6003	2230

***** Change since last acceptance test or flight

[ ] Exceeds database two sigma

a High HPFP efficiency; consistent with engine history

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Predicted Redline Margins at 104.5% P.L.

Parameter	Margin Sigma		
	ME-1 (2048)	ME-2 (2051)	ME-3 (2047)
HPFT Discharge Temp ChA, Deg R	5.8	7.8	6.9
HPFT Discharge Temp ChB, Deg R	5.6	6.8	6.5
HPOT Discharge Temp ChA, Deg R	8.1	6.5	7.5
HPOT Discharge Temp ChB, Deg R	9.3	7.9	9.0
HPOT Discharge Temp ChA, Deg R	4.9	6.5	5.5
HPOT Discharge Temp ChB, Deg R	5.5	6.7	5.6
HPOTP IMSL Purge Pr, psia	3.8	4.9	6.9
Low MCC Pc, psid			
Command-ChA Avg	22.0	22.7	21.1
Command-ChB Avg	25.2	26.4	25.4
FASCOS			
HPFTP	7.8	8.2	8.9
HPOTP	34.4	35.3	35.3

HPOTP Turbine Outlet (Inboard) Seal

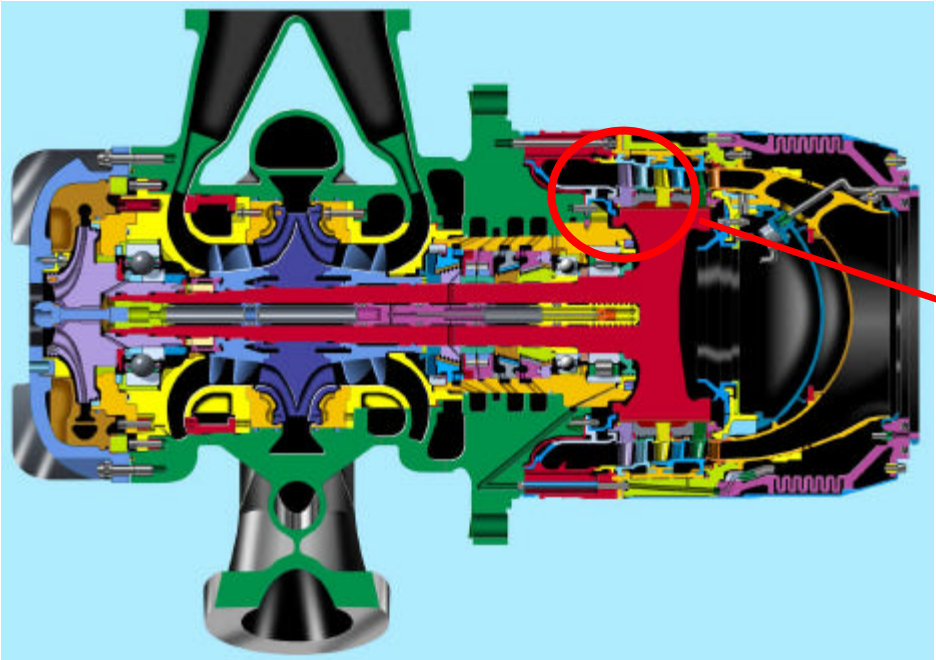
Knife Edge Fracture

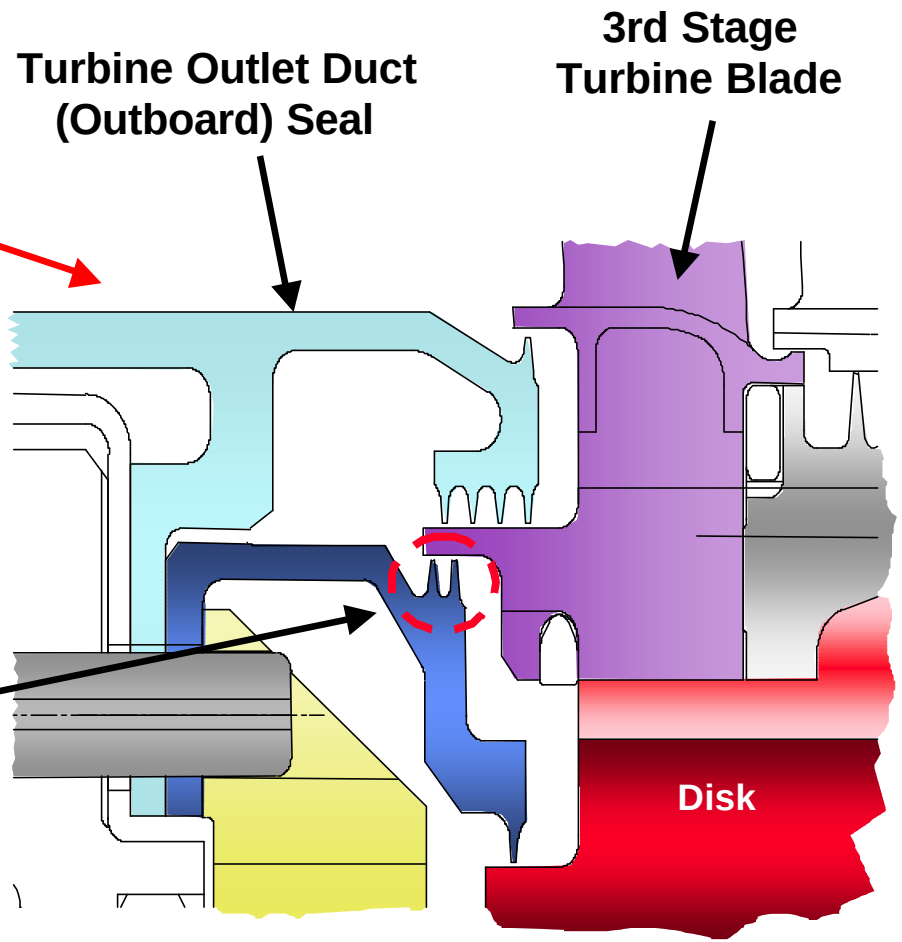
- **Issue**
  - Engine performance and FOD concerns due to fracture of turbine outlet seal knife edge

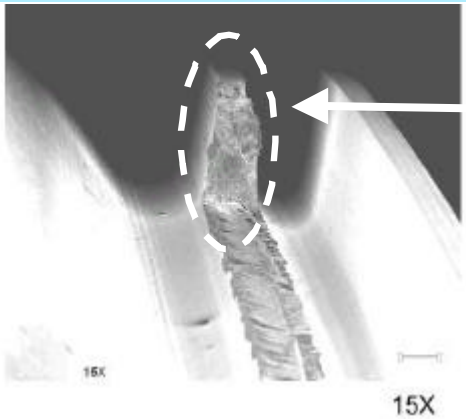
- **Background**
  - Turbine outlet seal is part of multi-knife edge seal configuration
    - Regulates HPOTP turbine coolant distribution
  - Cracks and missing material found in seal knife edge during scheduled overhaul (HPOTP 8014R2)
    - Downstream knife edge had three locations of missing material (0.5” - 3.4” circumferential length)
  - Adjacent and downstream components had minimal damage
  - First occurrence of seal damage in HPOTP program history

HPOTP Turbine Outlet (Inboard) Seal

Component Location



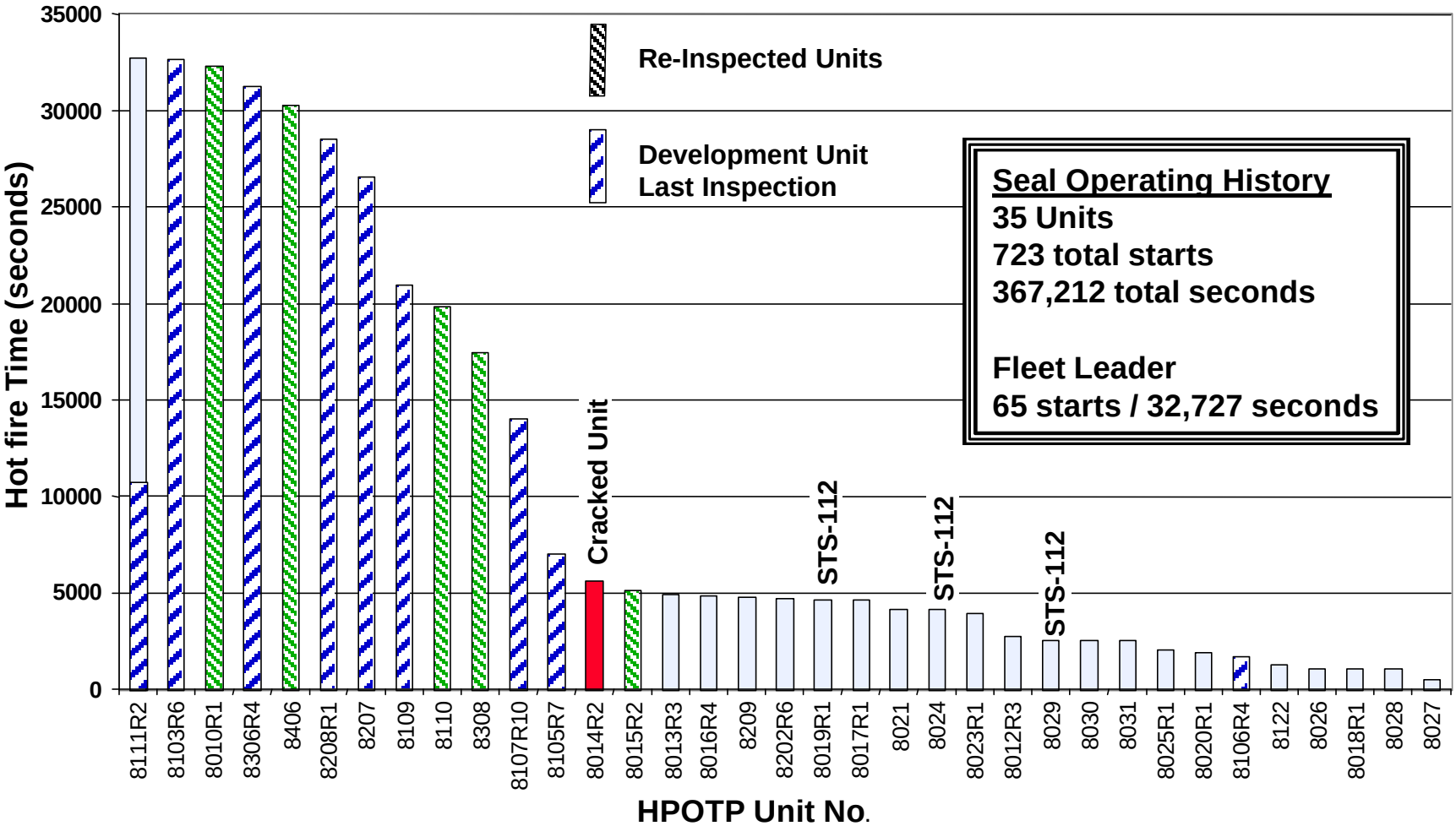




Turbine Outlet
(Inboard) Seal
Cracked Knife Edge /
Missing Material

HPOTP Turbine Outlet (Inboard) Seal

Hot Fire Operating History



HPOTP Turbine Outlet (Inboard) Seal

Knife Edge Fracture – Materials Analyses

- **High cycle fatigue cracking mechanism**
  - Multiple initiation sites on downstream side of knife edge root
- **SEM analysis shows additional crack locations (~ .002” in length)**
  - Both upstream and downstream sides of both knife edges
- **Material characteristics nominal**
- **Shallow surface pitting found under high magnification**
  - Coincident with area of cracking
  - Cause unknown / Role in cracking under investigation
- **High time seal manufactured at the time of cracked seal inspected with no cracks found**
  - Some minor pitting

HPOTP Turbine Outlet (Inboard) Seal

Knife Edge Fracture – In Field Performance

- **Hot Fire Operation**
  - Nominal during the entire service life
    - 11 starts / 5,644 seconds (including 10 flights)
    - No significant or abnormal temperature variations
- **Post Flight Inspections**
  - Nominal with the exception of high torque reported after the seventh hot fire - STS-99
    - Attributed to roller bearing skewing

HPOTP Turbine Outlet (Inboard) Seal

Knife Edge Fracture - Analysis

- **Performance and structural margins acceptable for worst case conditions**
  - Assumes both knife edges completely missing and increased clearances for downstream seals
    - Operating temps within previous Block I experience
    - Greater than 3 sigma margin to turbine discharge redline
      - 109% max operating conditions
- **FOD assessment shows adequate margin**
  - Maximum dislodged particle below critical impact mass for HPOTP turbine blades and heat exchanger
    - Most likely scenario is pieces ground up with minimal individual particle mass escaping into flow stream

HPOTP Turbine Outlet (Inboard) Seal

Knife Edge Fracture

- **STS-112 Flight Rationale**
  - Worst case analysis shows acceptable engine performance and structural margins with fractured turbine outlet seal
  - Worst case particle size is less than the critical impact mass for downstream components
  - STS-112 units have had no rotor torque or performance anomalies

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Material Review and Problem Report Reassessment

- **All Material Reviews and Problem Reports Reassessed**
  - Encompasses entire part / component histories
    - Fabrication
    - Assembly
    - Test
    - Flight
    - Recycle
  - Verified proper dispositions in light of current program sensitivities, knowledge and experience

- **All dispositions evaluated and judged acceptable for flight**

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SSME Certification of Flight Readiness

- **CoFR Exceptions**
  - None

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SSME Readiness Statement

- **The Atlantis Main Engines are in a ready condition for STS-112**

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Program Manager
Space Shuttle Main Engine