8C

N91-28202

UNITED TECHNOLOGIES PRATT&WHITNEY

CRYOGENIC UPPER STAGE PROPULSION

RL10 and Derivative Engines

Presented to:
Space Transportation Propulsion
Technology Symposium
Pennsylvania State University

June 1990

Presented by:
James R. Brown
Manager, Upper Stage Programs

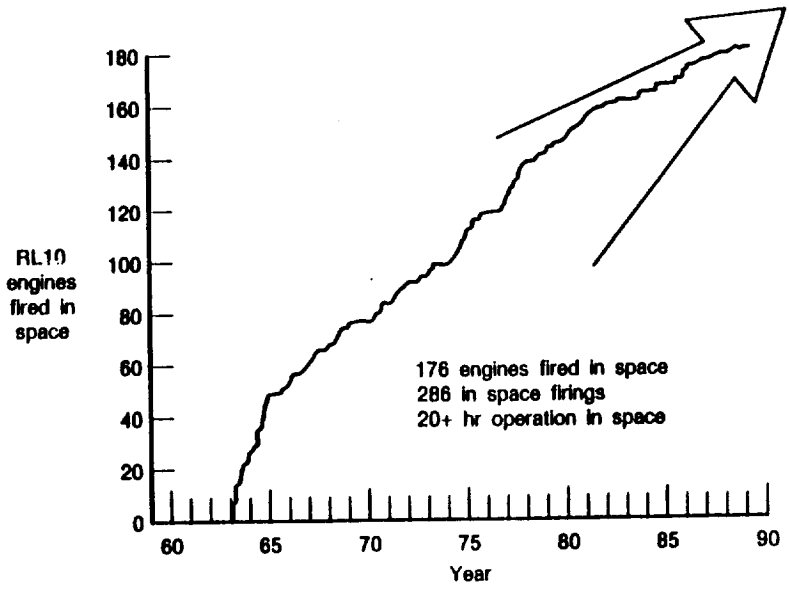
SPACE PROPULSION AND SYSTEMS
P. O. Box 109600
West Palm Beach, Florida 33410-9600

TOPICS

- Engine model history
- RL10 demonstrated capabilities
- RL10 derivative potential for SEI
- Summary

RL10 LIQUID HYDROGEN ROCKET ENGINE

- Perfect flight record - 100% reliable



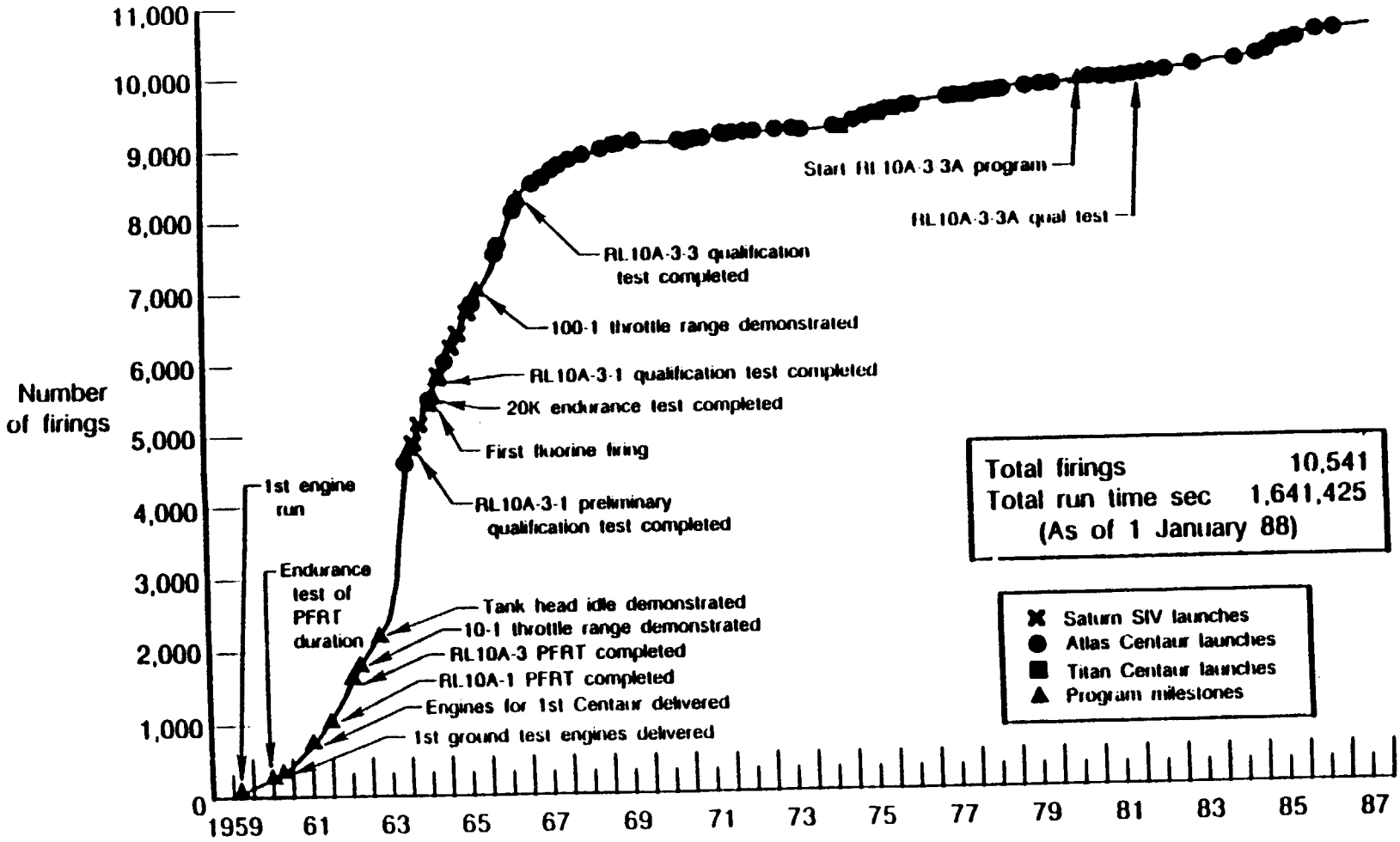
RL10A-3-3A ENGINE

Vacuum thrust, lb	16,500
Specific impulse, sec	444.4
Weight, lb	305
Mixture ratio	5:1
Chamber pressure, psia	475
Area ratio	61:1
Qual life, firings/hr	20/1.25

RL10 EVOLUTION

Model no.	A-1	A-3	A-3-1	A-3-3	A-3-3A	A-4
Vac thrust, lb	15,000	15,000	15,000	15,000	16,500	20,800
Chamber pressure, psia	300	300	300	395	475	578
Thrust/weight	50	50	50	50	54	57
Expansion ratio	40:1	40:1	40:1	57:1	61:1	84:1
I_{sp}, sec at 5.0 O/F (5.5)	424	429	433	442.4	444.4	(449.0)
Flight certification date	11/61	6/62	9/64	10/66	11/81	12/90

RL10 DEVELOPMENT HISTORY



RL10 EXPERIENCE

Demonstrated capability

- High ratio nozzle
- Durability
- Low thrust/throttling
- Higher thrust
- High mixture ratio
- Alternate propellants

HIGH AREA RATIO NOZZLE

- Extensive testing with 84 area ratio extensions
- Boilerplate 205 area ratio tested
- High area ratio contour primary nozzle tested
- Extending / retracting system under development

CONCEPT VERIFICATION 84 AREA RATIO NOZZLE TESTING

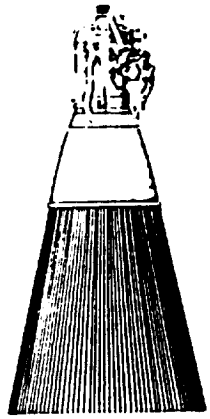
RL10 engine installed in E-6 test stand	Carbon/carbon nozzle during engine run
Carbon/carbon nozzles (2)	9,233 sec (69 firings)
Columbium nozzles (4)	5,392 sec (26 firings)
Total	14,625 sec (95 firings)

RL10 EXPERIENCE

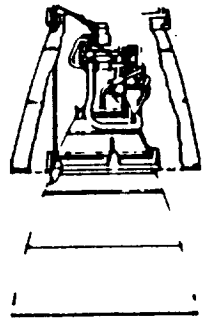
205 area ratio boilerplate nozzle results

RL10A-3-3

RL10A-3-3 with ε = 205 Nozzle Extension



Short RL10 Derivative 11B ε = 205

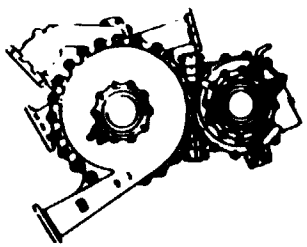


Δ Specific Impulse (ε = 57 to ε = 205)	20.9 sec @ O/F = 5.0 20.4 sec @ O/F = 6.0

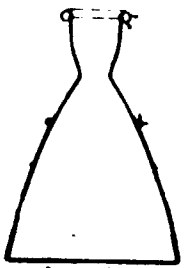
RL10 EXPERIENCE

Durability

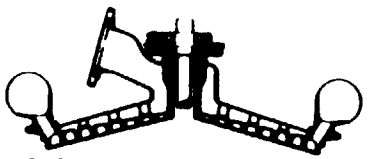
- Life potential greater than 5.0 hours, 200 firings at 15K thrust



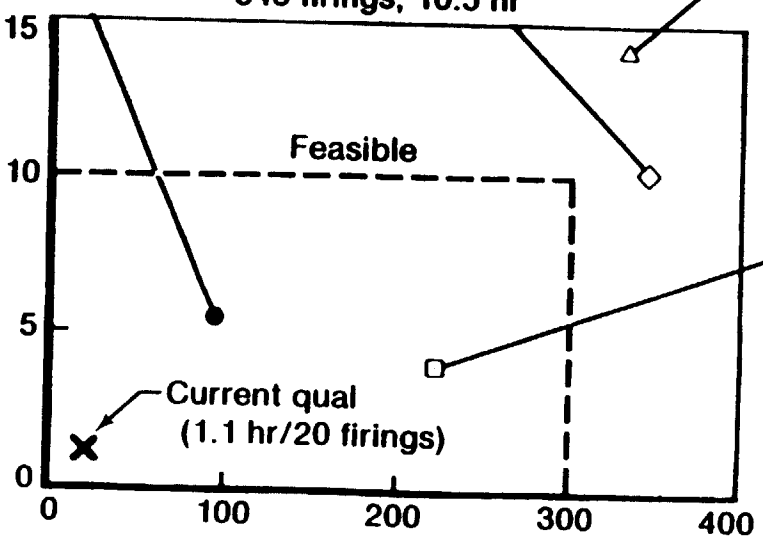
Turbopump assembly =
89 firings, 5.56 hr



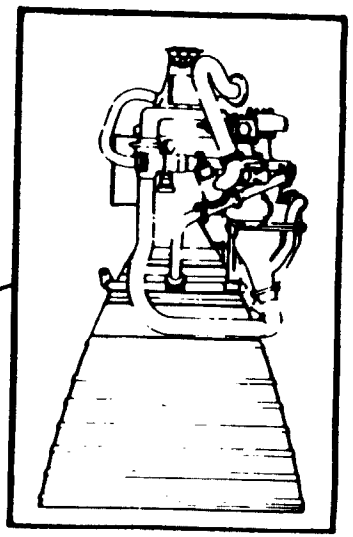
Thrust chamber high time =
345 firings, 10.5 hr



Injector high time =
337 firings, 14.4 hr



Increased life capability



Engine high time for one build = 223 firings, 4.0 hr
86 engines have exceeded 3600 sec in a single build

RL10 EXPERIENCE

Durability

- Rubbing carbon seal life limit on turbo machinery
  - Function of velocity - proportional to speed
  - Gears may be limit above 25K thrust
- Chamber low cycle fatigue limit on number of firings
  - Most severe strain during start transient

RL10 EXPERIENCE

Low Thrust

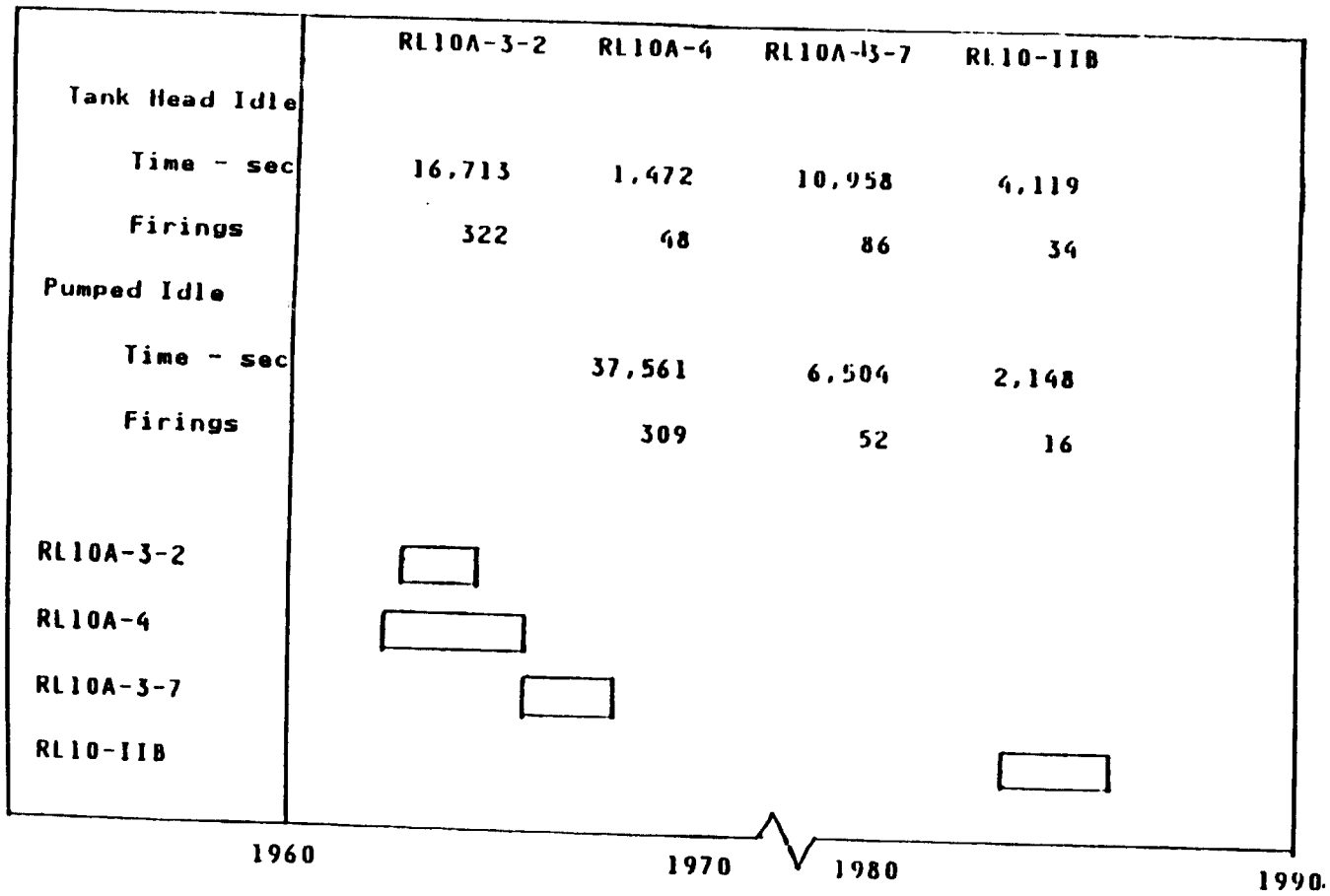
1960's Testing
* Full Throttling
* Complex Controls
* High Loss Injector

1980's Testing
* Stepped Thrust Levels
* Simple Controls
* Gox Heat Exchanger

RL10 EXPERIENCE

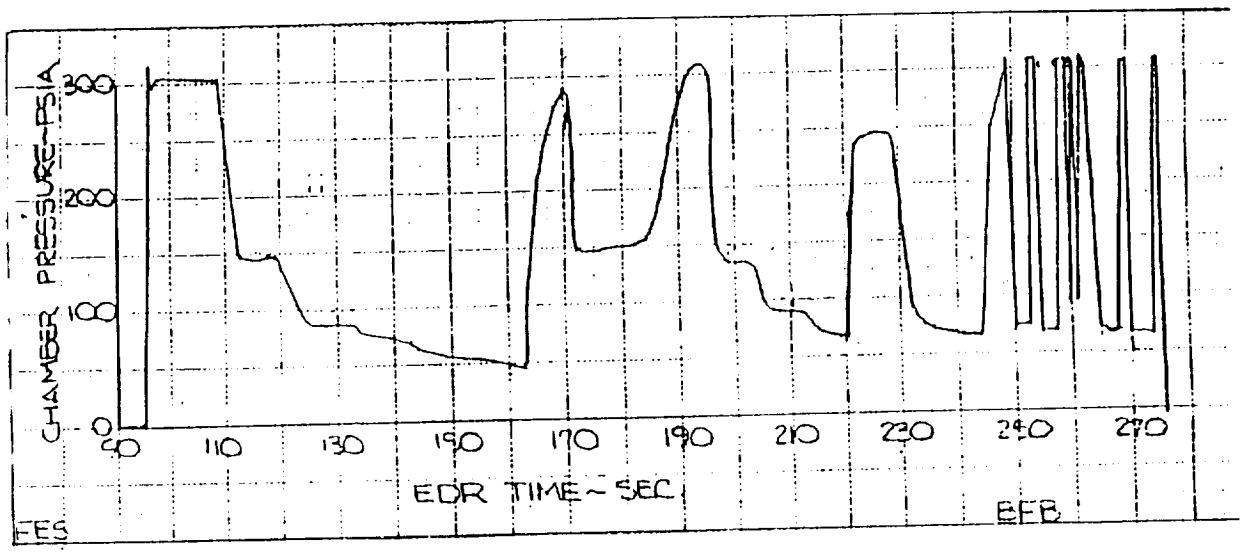
RL10 low thrust summary

	RL10A-3-2	RL10A-4	RL10A-3-7	RL10-IIB
Tank Head Idle				
Time - sec	16,713	1,472	10,958	4,119
Firings	322	48	86	34
Pumped Idle				
Time - sec		37,561	6,504	2,148
Firings		309	52	16



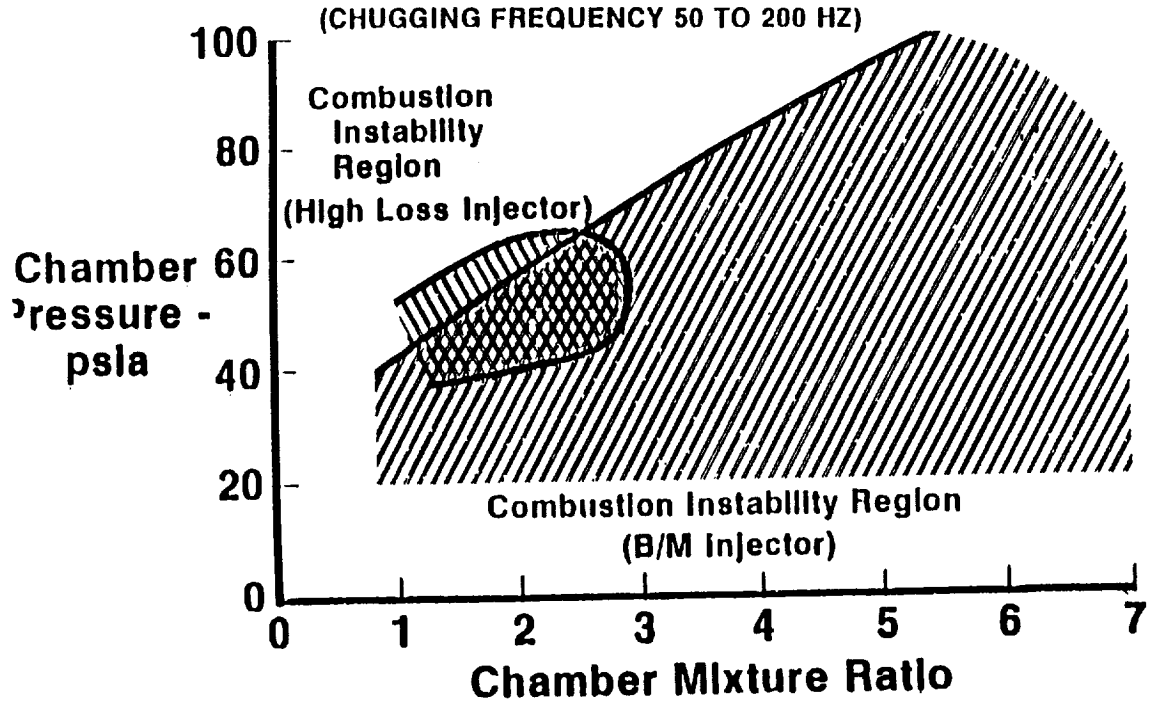
RL10 EXPERIENCE

Typical RL10A-4 throttling test



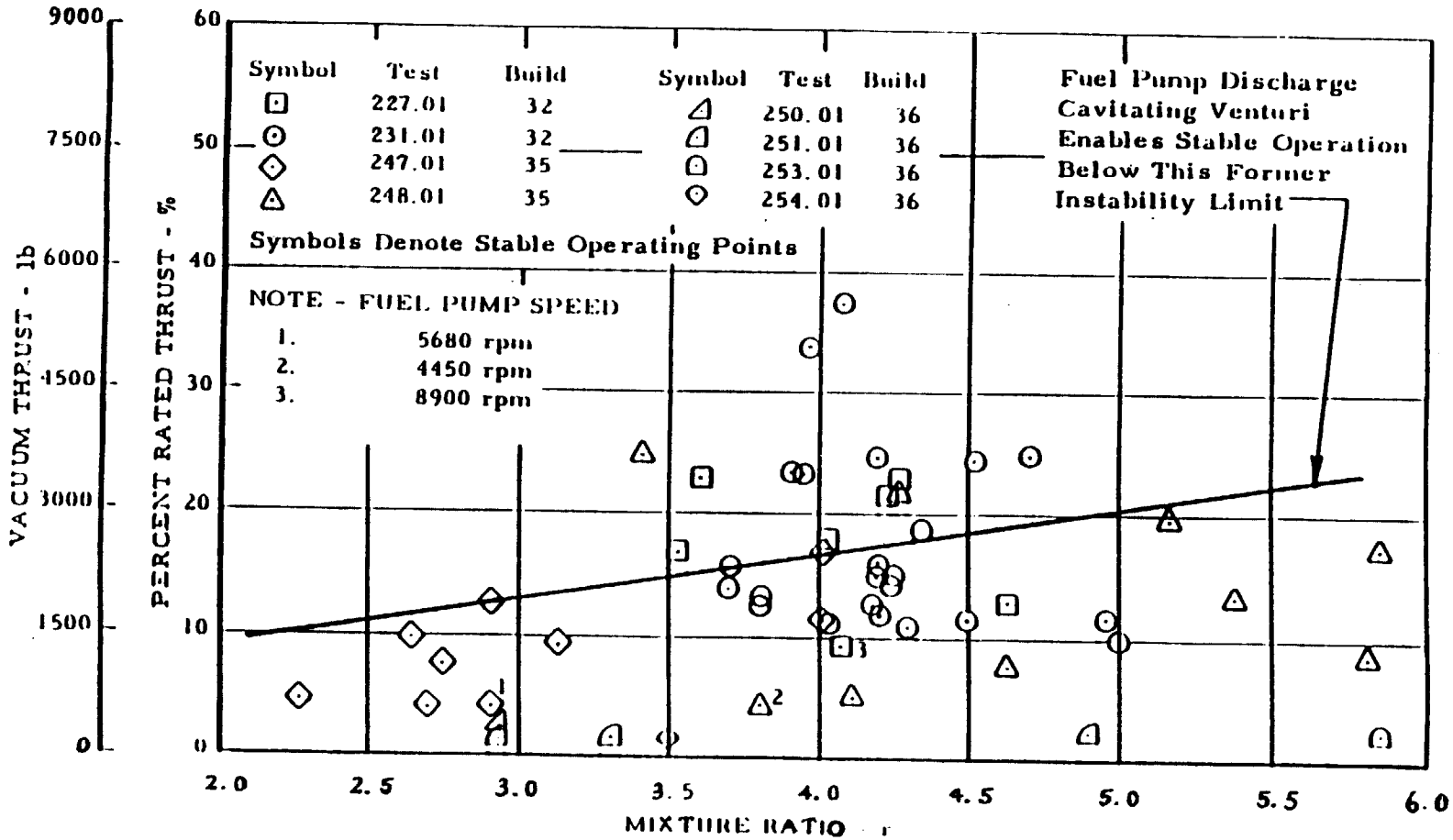
RL10 EXPERIENCE

RL10 combustor instability characteristics

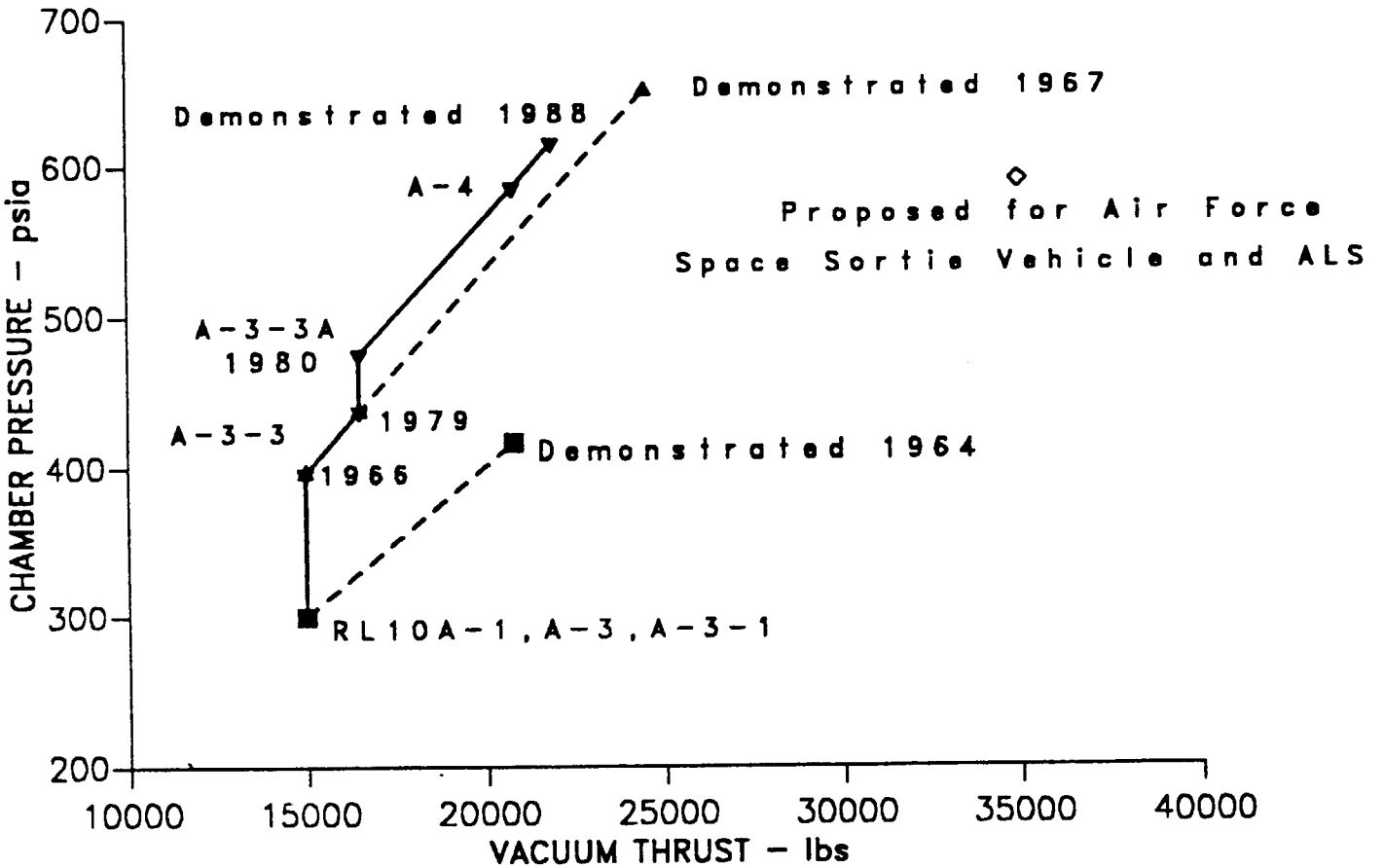


RL10 EXPERIENCE

Stable throttling to less than 2%



RL10 UPRATING HISTORY



RL10 EXPERIENCE

High mixture ratio summary

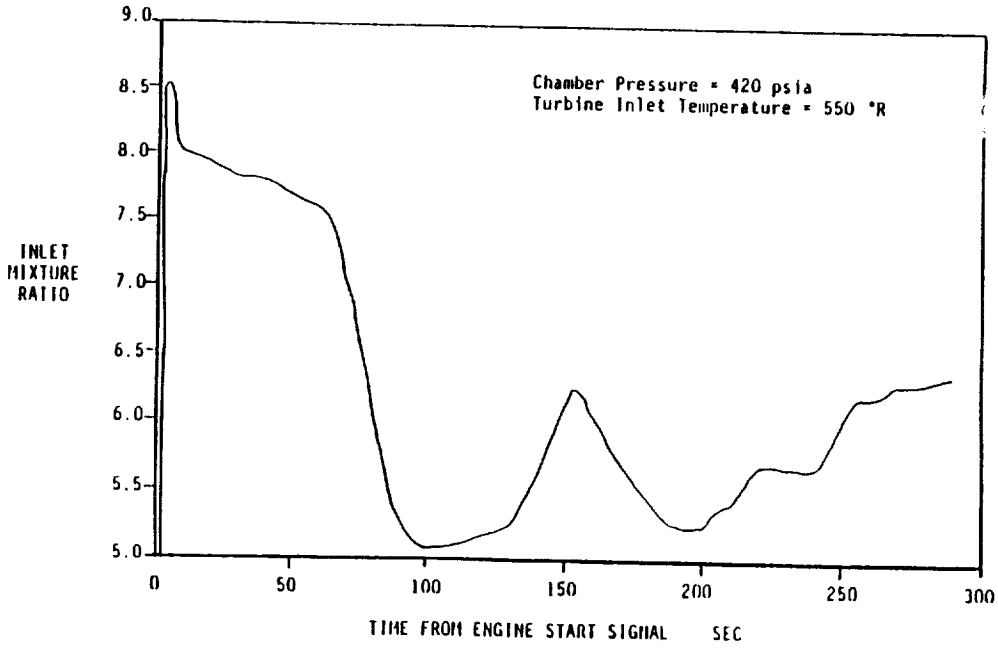
- 250 sec greater than 7.0 O/F - - 7 engines - -
- One run up to 13.5 O/F

  - - 5.0 to 13,5 in 35 sec
- One run over 7.5 O/F more than 60 sec

NO ENGINE DAMAGE FROM HIGH O/F OPERATIONII

RL10 EXPERIENCE

Stoichiometric mixture ratio demonstrated



RL10 EXPERIENCE

Alternate Propellants

FLOX/CH4 9 Tests 120 Sec 11K Thrust

O2/C3H8 23 Tests 106 Sec 14K Thrust

F2/H2 29 Tests 1757 Sec 21K Thrust

RL10 CAPABILITY

Space initiative space propulsion requirements

- Throttling
- High performance
- Reusable
- Space based
- Man rated

RL10 CAPABILITY

Throttling

Throttling engine testing 1963 through 1965 (under MSFC contract) most applicable

- 309 Tests
- 37,561 Seconds
- Demonstrated stable, continuous throttling down to 2% thrust
- Solved oxidizer chugging stability and fuel system stability problems

RL10 CAPABILITY

Specific modifications for continuous throttling

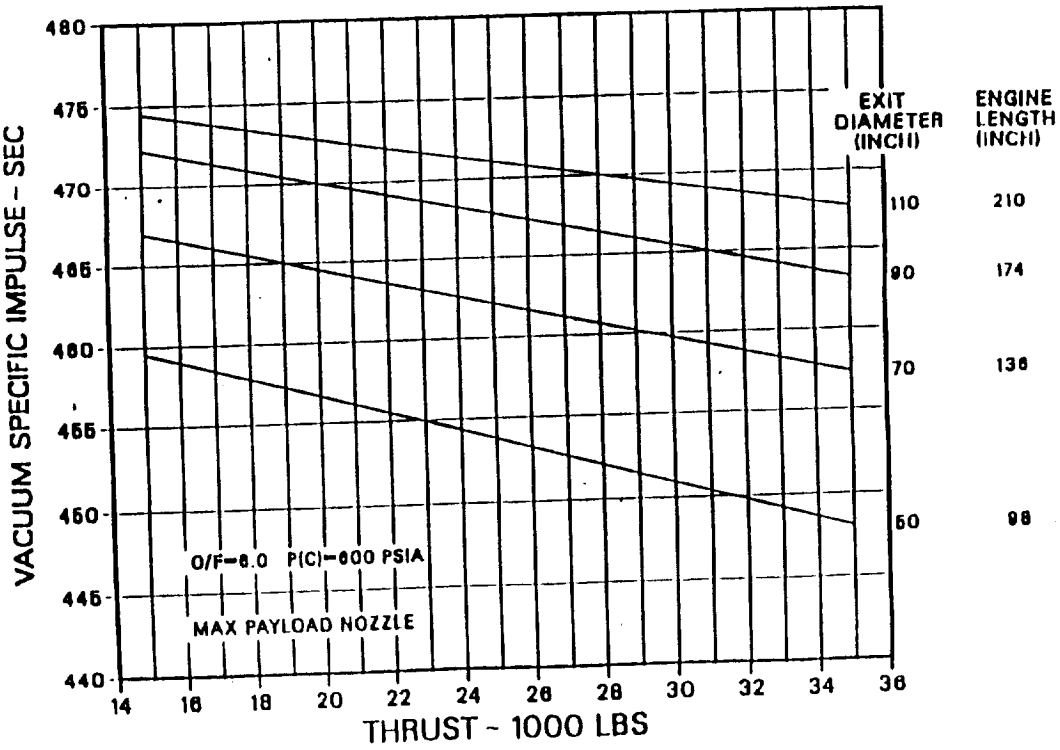
- Control valves
  - Fuel control (turbine bypass)
  - Oxidizer control
  - Cavitating venturi
- Scheduler (controller)
- Idler gear ratio (from 2.5 to 2.13)
- High loss injector

RL10 CAPABILITY

High performance

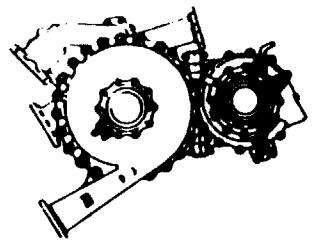
- High area ratio nozzle
  - Extensive testing 84 area ratio extensions
  - Boilerplate 205 area ratio tested
  - Extending/retracting system under development
- Impulse potential > 470 sec
- Available impulse dependent on envelope constraints

EFFECT OF THRUST LEVEL ON PERFORMANCE

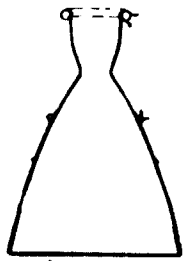


RL10 CAPABILITY
Reusable

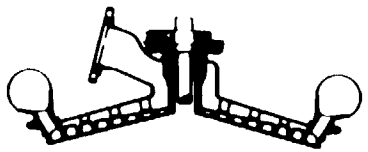
- Life potenital greater than 5.0 hours, 200 firings



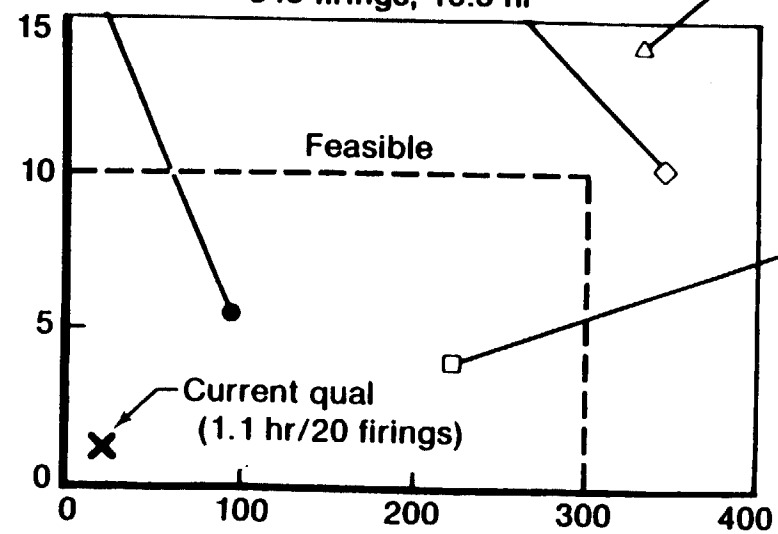
Turbopump assembly =
89 firings, 5.56 hr



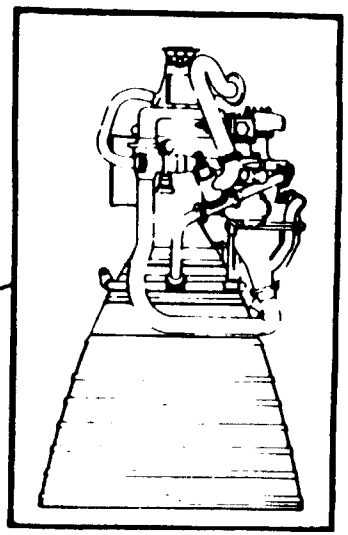
Thrust chamber high time =
345 firings, 10.5 hr



Injector high time =
337 firings, 14.4 hr



Increased life capability



Engine high time for one build = 223 firings, 4.0 hr
86 engines have exceeded 3600 sec in a single build

MAN-RATING

- High reliability
- Noncatastrophic failure modes
- Redundant components and/or engine out

RL10 CAPABILITY

Man-rated

- RL10 has high demonstrated reliability
  (0.9984 @ 90% confidence level)
- RL10 has benign failure modes
  (Current base model - RL10A-3-3 has > 3,800 tests
  over 25 years with no catastrophic engine failures)
- With engine-out capability, RL10 propulsion system would have very high reliability and safety

SPACE-BASING

- Minimal maintenance needed
- Health monitoring provided
- Easy engine change-out capable
- Long space exposure compatible

RL10 CAPABILITY

Space based

- Only minor maintenance practical in space environment
- Removal of entire engine most likely solution for problem
- RL10 could be modified to facilitate engine changeout
- RL10 well characterized for health diagnostic purposes
- RL10 has demonstrated reusability in space (7 firings on single mission)

SUMMARY

THE RL10 IS NOT DESIGNED TO BE

- A high pressure engine
- A small envelope engine
- Inherently redundant

AN RL10 DERIVATIVE IS . . .

- Based on in-depth studies/hardware demonstrations
- Low maximum system pressures
- Low program risk
- Near-term available
- Highly reliable due to its simplicity/low pressure
- Well characterized and understood (large data base)
- Turbo machinery configured for full throttling
- Failure tolerant
- Multiple start capability

RL10 DERIVATIVE
Options

- Deep continuous throttling
- Extended operational life
- High area ratio nozzle
- Higher thrust
- Higher mixture ratio
- H_2 and/or O_2 tank pressurization
- Tank head idle
- Health monitoring
- Quick/smart disconnects

RL10 DERIVATIVE OPTION RANGES

	RL10A-4 (New)	RL10 Derivative	
		B Family	C Family
Thrust lbs	20,800	15,000 to 22,000	25,000 to 35,000
Nominal mixture ratio	5 5	4 0 to 12.0	
Area ratio	84	up to 600+	
Thrust positions	Full thrust	Multi position or continuous deep throttling	
TBO, firings	15	60+	
HRS	0.8	2+	
Tank pressurization	H_2	H_2 and/or O_2	
Engine conditioning	Dump	Dump or THI	

RL10 CAPABILITY

Summary

- RL10 reliability record unmatched
- Throttling capability demonstrated
- Durability potential demonstrated
- RL10 has demonstrated many capabilities required for space initiative propulsion

PRESENTATION 1.2.4

SATELLITE/SPACECRAFT PROPULSION