Current Launch System Industrial Base

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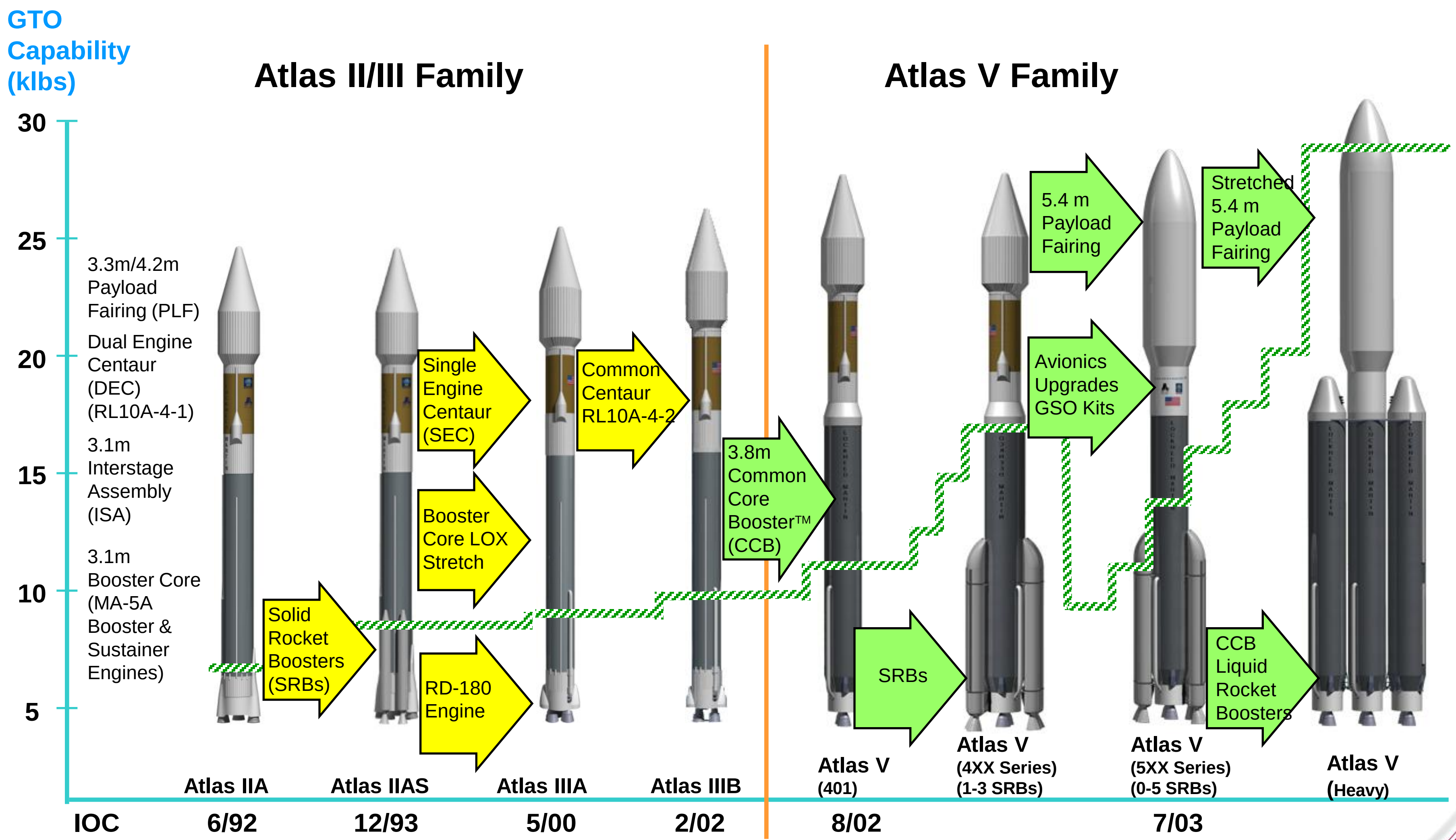
October 19, 2011

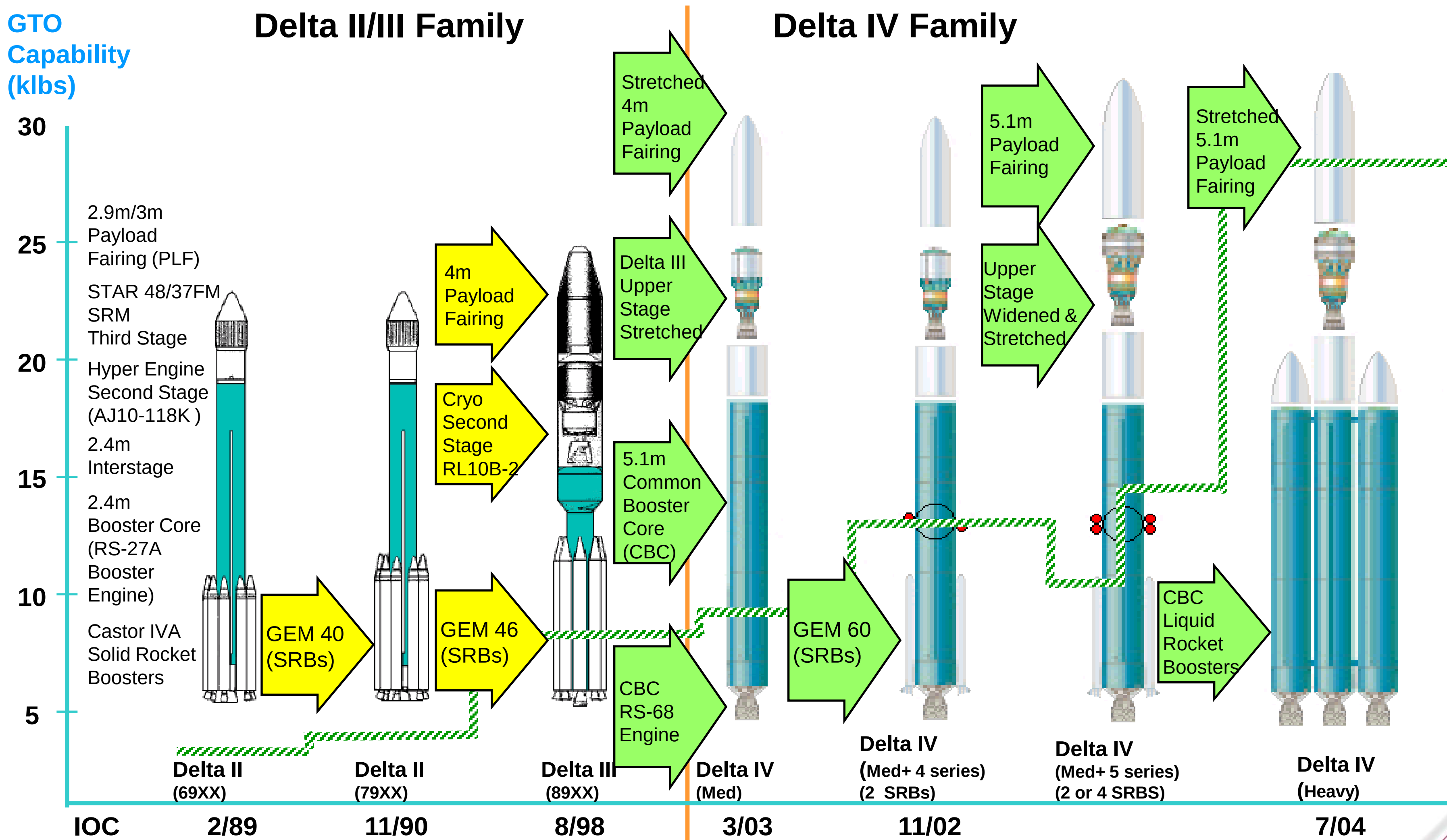
Agenda

- EELV Launch Systems and Industrial Base
- Rocket Propulsion Industrial Base

Atlas V Evolution



Delta IV Evolution



EELV Industrial Base

- As EELV's anchor tenant, NSS must provide a *steady production rate*, decoupled from launch manifest, to *establish a healthy industrial base*
  - *Launch industrial base is shrinking due to decreased market; exacerbated by current USG buying practices*

- Solution: *steady production rate* provides *long-term, focused*, and well-defined *commitment to industry*
  - *Removes uncertainty from program and retains capacity*
  - *Preserves capability for next generation space launch*

EELV Industrial Base (Cont'd)

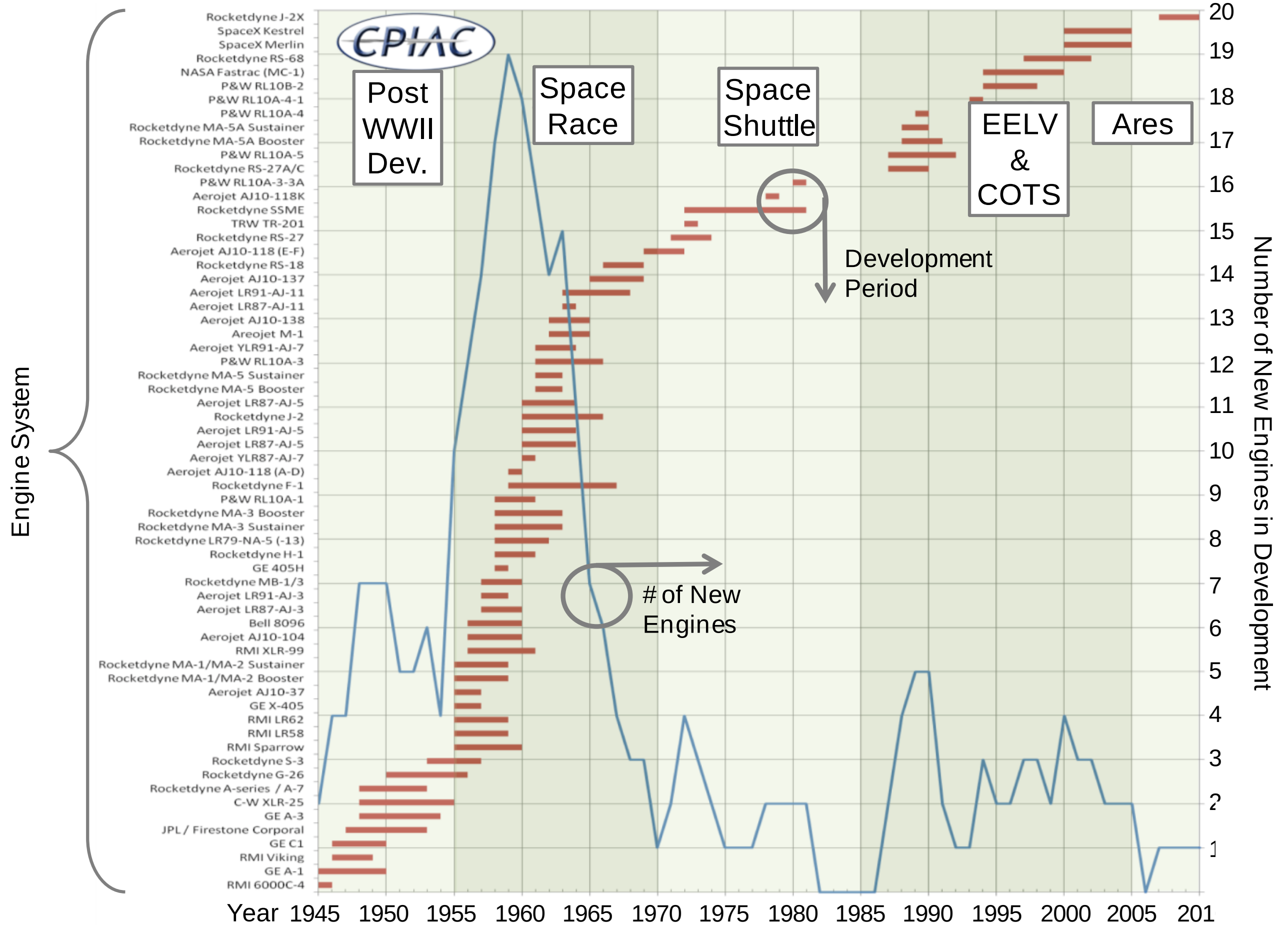
- *Rate is the key factor* that keeps prime and sub production from going dark, increasing costs/risks
  - *Detailed analysis with ULA, PWR, ATK, Aerojet*
  - *Restart / recertification cost and effort significant*
- Keystone of new EELV approach is *annual minimum production rate of 8 cores*
  - *4 Atlas, 4 Delta -- 5 USAF / 3 NRO / year commitment*
- Steady production achieved through Block Buys
  - *"Block" = Annual Production Rate X Defined Duration*

Production Rate Commitment Critical To Industrial Base Health and EELV Program Stability

U.S. Rocket Engine Development

1945-2010

- Today, there are no new engine development programs in the U.S.



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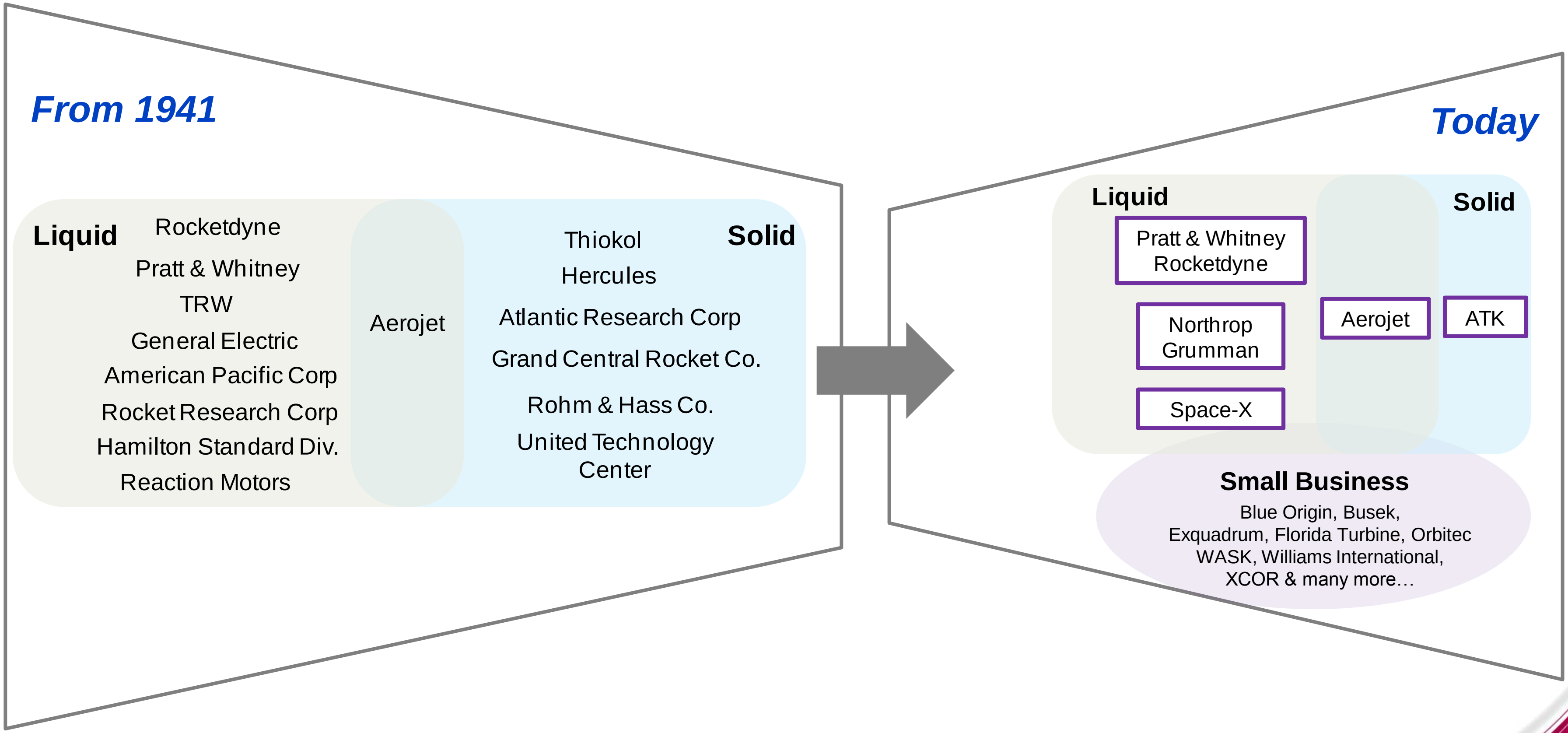
U.S. Rocket Propulsion Industry

Evolution

- Since 1941, more than a dozen U.S. companies had been involved in rocket propulsion business
- Only a few major U.S. companies are active today, however various new commercial space entities are emerging



Liquid Rocket Engines

"State of the Industry:"

- Limited recent U.S. liquid rocket engine development
  - *RS-68 and Merlin – Designed to focus on reducing production recurring costs*
  - *J-2X is completing development*
  - *RL10 (A-4-2, B-2) – multiple performance enhancements, reduced overall design margins*
    - 50-year-old craftsman-based manufacturing
    - Limited growth opportunity without major redesign
  - *RD-180 – Produced in Russia with insight from the US companies*
  - *AJ26 – Americanization of Russian NK33*
  - *SSME – Last NASA funded development effort resulting in steady production*
  - *DoD Integrated High Payoff Rocket Propulsion Technology (IHPRPT), funded ~$200M over last 15 years -- technology focused only*
- New commercial space companies entering the market
  - *SpaceX, OSC, Blue Origin, Virgin Galactic, Sierra Nevada, etc…*
  - *Potentially "disruptive" to current access to space cost model*
  - *Still building maturity required for critical high value payloads*
  - *Long term market demand is uncertain*

Operational Liquid Engines in U.S.

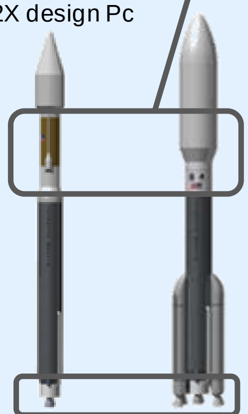
Today

	Atlas V	Delta IV	Space Shuttle	Falcon
Developer:				Commercial (Space-X)

Atlas V

RL10A-4-2
(LOX/LH2, 22k lbf)

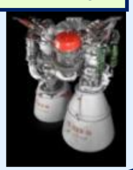
- First flown in 1963
- Currently flying at 2X design Pc



(400 Series) (500 Series)

RD-180
(LOX/RP, 860k lbf SL)

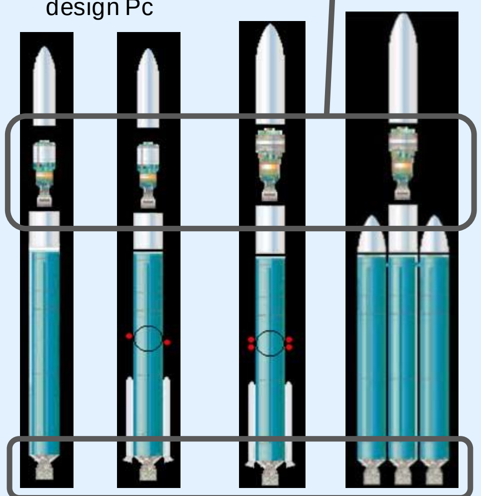
- First flown in 2002
- Russian made



Delta IV

RL10B-2
(LOX/LH2, 25k lbf)

- First flown in 1963
- Currently flying at 2X design Pc



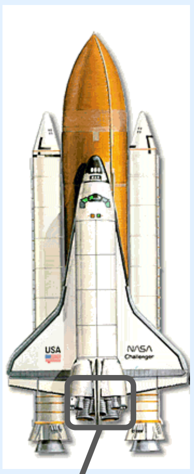
(Med) (Med+ 4m) (Med+ 5m) (Heavy)

RS-68
(LOX/LH2, 656k lbf SL)

- First flown in 2002
- RS-68A upgrade design certification completed in 2011

Space Shuttle

RETIRED (2011)



SSME (3X)
(LOX/LH2, 408k lbf SL)

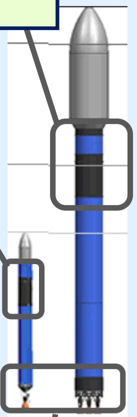
- First flown in 1981
- Retired in 2011

Falcon

NEW ENTRANT

Merlin (1X)
(LOX/RP, High Expansion Nozzle)

Kestrel
(LOX/RP, 6k lbf)



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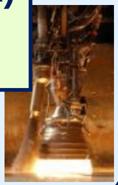
Merlin (1X/9X)
(LOX/RP, 115-125k lbf SL)



- First successful flight in 2008 (Falcon 1)

Delta II retiring after 2 NASA missions

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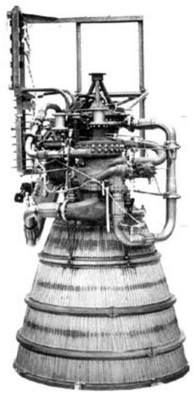
LOX/LH2 Upper Stage Engines

World's 1st Hydrogen Engine & Its Evolution

Engine Qualification Year

	1961	**1963**	**1966**	**1967**	**1985**	**1991**	**1994**	**1998**	**1999**	**2000**
Model	**A-1**	**A-3**	**A-3-1**	**A-3-3**	**A-3-3A**	**A-4**	**A-4-1**	**B-2**	**A-4-1A**	**A-4-2**



RL10A-1
- 15k lbf
- Pc=300 psia
- Isp = 422 s

RL10A-3
- 15k lbf
- Pc=300 psia
- Isp = 427 s

RL10A-3-3A
- 16.5k lbf
- Pc=475 psia
- Isp = 444.4 s

RL10B-2
- 24.7k lbf
- Pc=640 psia
- Isp = 464 s

(Delta IV)

RL10A-4-2
- 22.3k lbf
- Pc=610 psia
- Isp = 451 s

(Atlas V)

The World's 1st "Qualified" LOX/LH2 Engine

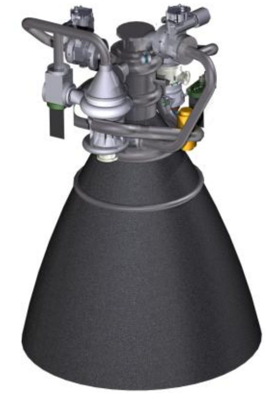
The World's 1st "Flown" LOX/LH2 Engine

- Successive increases in performance over 50 years (running at 2X design Pc)

Next Generation Engine (NGE)

Overview

- USAF considering an LOX/LH2 alternative engine to replace aging RL10
  - *Request for Information posted September 2010*
- NGE Objectives
  - *Modern manufacturing techniques & materials*
  - *Increased designed-in reliability and performance margins*
  - *Sustainable and low cost*
- Creates interagency partnership opportunity
  - *Incorporates NSS & NASA requirements*
  - *Captures emerging commercial needs*
- Leverage advanced design tools & technologies matured by AFRL/NASA technology investment
  - *e.g. AFRL Upper Stage Engine Technology (USET)*
- Creates open competition
  - *Bolster U.S. liquid propulsion industrial base capability*



Top-level Technical Requirements

Thrust (vacuum)	30klbfs
Isp (vacuum)	465 seconds or greater
Nozzle	Fixed (preferred, but not required)
Restartable	Minimum of 4 flight starts
Life expectancy	3000 seconds or greater
Reusable	Not required
Mixture Ratio	Adjustable during operation
Length (gimbal to nozzle exit)	NTE 90 inches
Exit Diameter	NTE 73 inches (desired)
Threshold Reliability	0.9990 or greater

NGE serves critical need for modern, reliable, cost effective engine, sustainment of industrial base and U.S. leadership in propulsion technology

Lessons Learned

Launch Failures

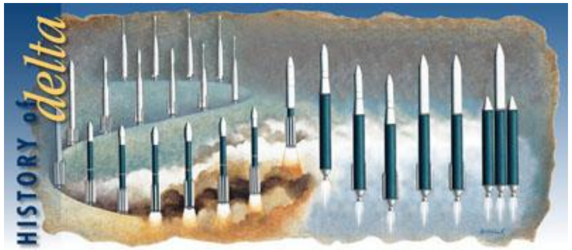
- In past 50 years, propulsion enabled ballistic and spacelift capabilities
  - *Powered first US ICBMs*
  - *Evolved into space launch vehicle systems*
  - *Continuous improvements in performance, reliability, operability*
- Historically, more than 40% of all launch vehicle failures caused by propulsion subsystem malfunctions (#1 contributor)*

Launch Vehicle Subsystem Failures (2010-9-30)

by Tomei, E. J., & Chang, I.-S., Aerospace

Functional Subsystem	U.S. LV	Non-U.S. LV	World LV	% Failure
Propulsion	70	104	174	40.00
Unknown	5	90	95	21.84
Guidance, Navigation, and Control	25	23	48	11.03
Separation	23	16	39	8.97
Thrust Vector and Attitude Control	23	16	39	8.97
Structures	10	9	19	4.37
Electrical Power Distribution and Control	10	5	15	3.45
Tracking and Flight Safety	3	0	3	0.69
Command and Control	0	1	1	0.23
Environmental Protection	1	0	1	0.23
Telemetry	0	1	1	0.23
Total	**170**	**265**	**435**	**100.00**

- A launch failure incurs the loss of not only expensive hardware (launch vehicles/satellites), but extremely high recovery cost



Improving propulsion subsystem reliability is critical to mitigating future launch failures