Development of Reusable Engines

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Pratt & Whitney Space

6th International Symposium
Propulsion for Space Transportation of the XXIth Century

Premise of the Presentation

Evolutionary Design of Reusable Rocket Engines is the Key to Meeting RLV Propulsion Requirements of Safety, Reliability, and Cost

and in addition

International Partnering on Propulsion System Development can further lead to:

- ***Higher Product Safety & Reliability***
- ***Reduced Development Costs,***
- ***Lower Development Risks***

Typical Reusable Engine Requirements

Challenging Requirements call for an Innovative Approach

Vacuum Thrust Vacuum Isp Thrust/Weight (sl)	900k - 1,500k 325 - 340 sec 80 - 100	Large high pressure (>2500) staged combustion (closed cycle) engine (beyond current SOA in US)
Reliability Safety	.999 - .9999 .9999 - .99999	Inherently safe engine cycle and mature design with high performance Engine Health Management System
Prelaunch Prep Post Launch Turn Maintenance	< 1hr < 10 shifts 30 - 40 hrs/mission	Jet engine operations approach with high performance Engine Health Management System
Development cost	< $1,500M	Mature technologies to minimize development schedule, risks, costs.
Cost per flight	$200K - $100K	Inherently reliable engine coupled with streamline operations concept.

(2GRLV LOX/Kerosene Booster Engine Requirements)

Approach to Meeting Reusable Engine Requirements

The Reusable Engine 'Vision'

Our RLV Engine "Vision" is to provide a Rocket Engine for RLV applications, using appropriate advanced technologies, to achieve significant improvements in:

Safety,
Reliability,
Operability,
& Maintainability

If we Accomplish this, we believe that the low cost goals will follow -

Reusable Engine Safety Requirements

Safety and Reliability are considered the most Important and Dominate Attributes of the Reusable Engine ‘Vision’

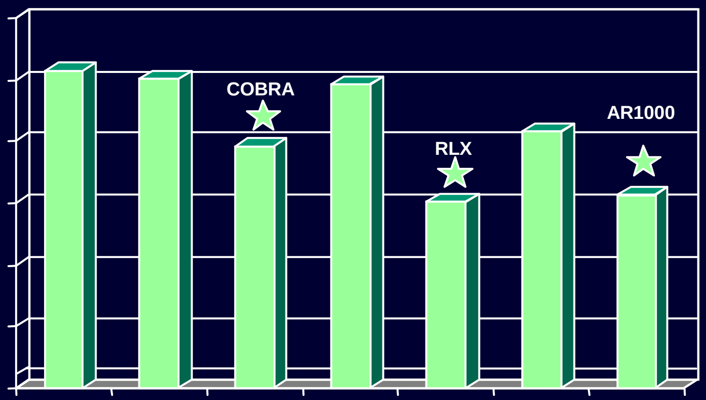
A Truly “Safe & Reliable” Engine will of necessity be Operable and Maintainable.

Future Reusable Engines must address <u>all</u> the Vision Attributes, but with Special Emphasis on Safety & Reliability

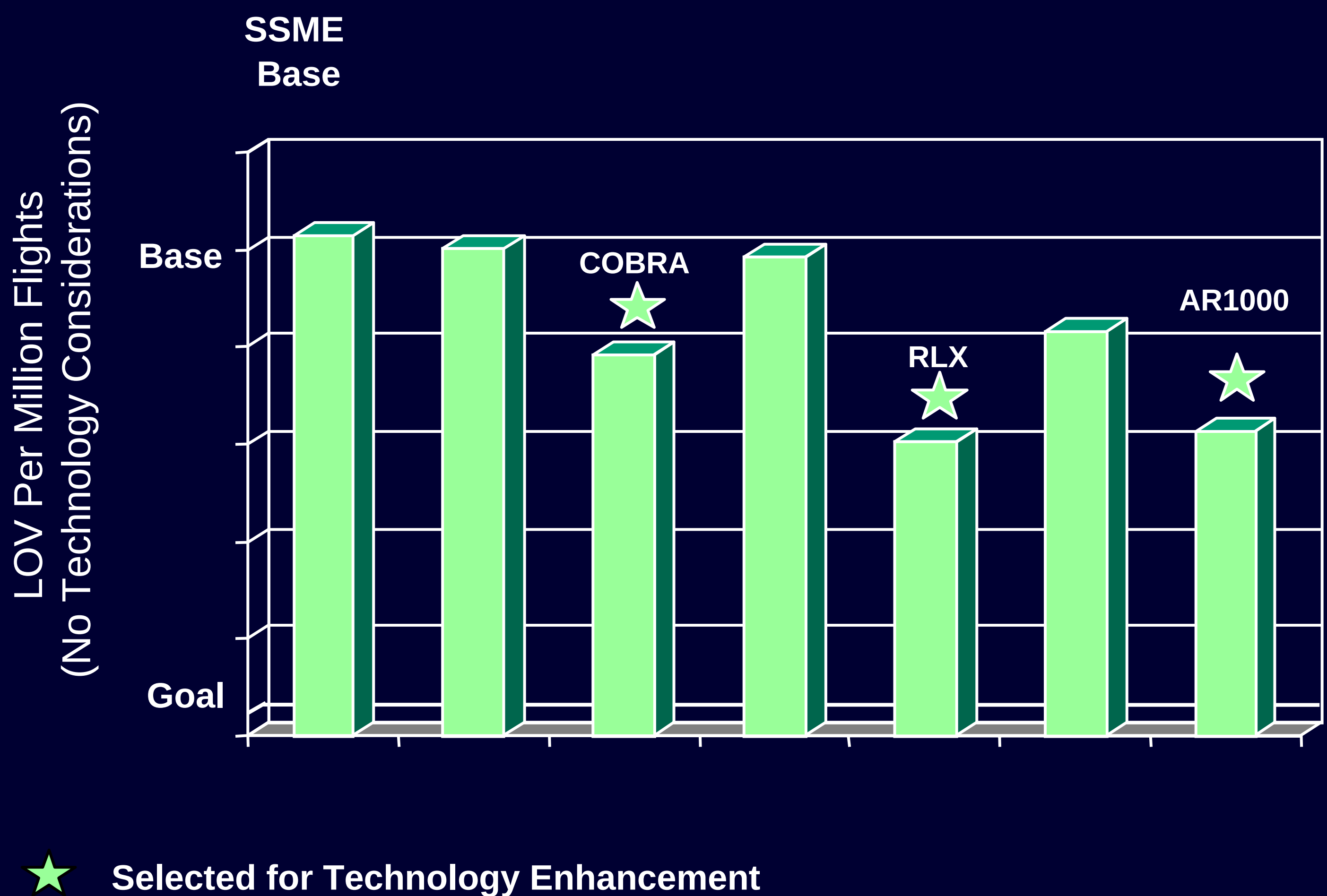
Achieving Engine Safety

Design for Safety

- Inherently Safe Cycle
- Graceful Failure Modes
- Simplex Components
- Redundant Systems
- Reduced Environments



COBRA (SBFRSC), RLX (SPLTEX), and AR1000 (SBORSC) Cycles were Selected Based On Inherent Cycle Safety



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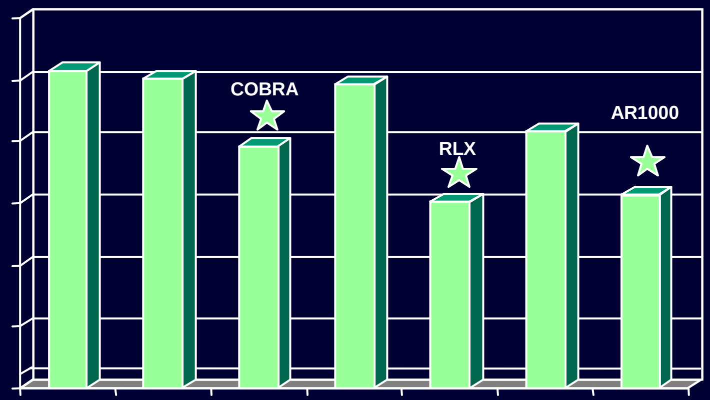

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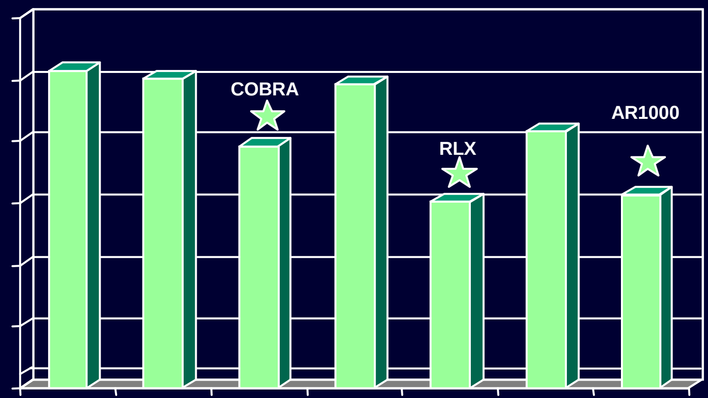
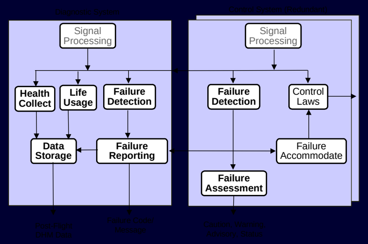


Technologies for Safety

- Advanced engine health monitoring
- Advanced materials
- Advanced design concepts



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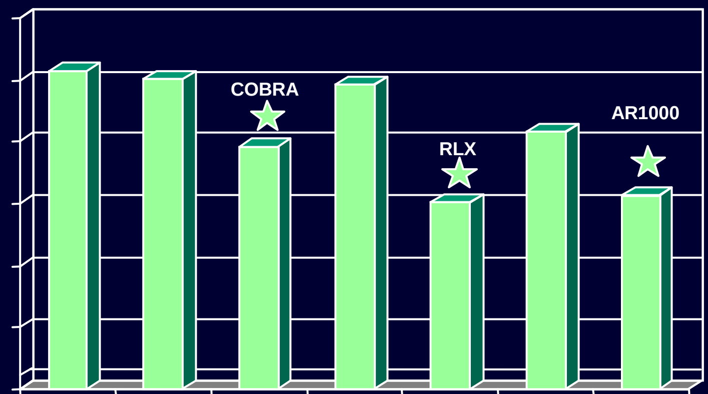

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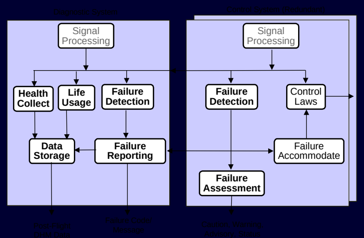
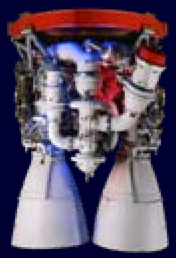


Maturity for Safety

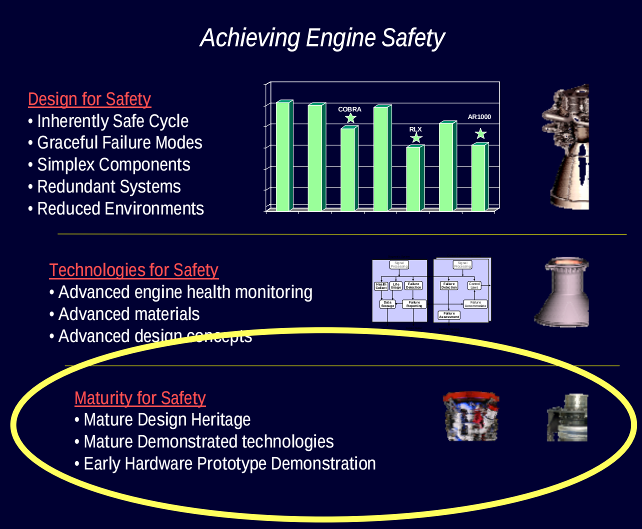
- Mature Design Heritage
- Mature Demonstrated technologies
- Early Hardware Prototype Demonstration



Evolution to Achieve Engine Safety

Evolution rather than New Design

Evolution of Design Builds on the Foundation and Heritage of Existing Successful Hardware



Evolution directly enables "Design Maturity", the third Element of Achieving Engine Safety

Evolution continues the maturity of core hardware designs while adding new technologies and design features to increase Safety.

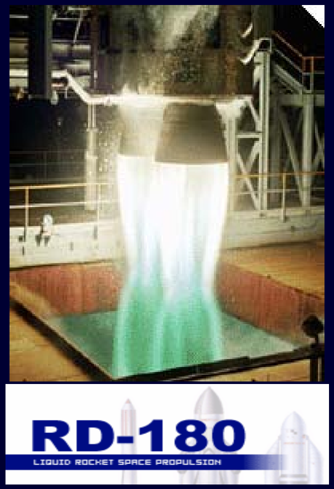
Evolution often allows "Early Testing" of an Evolved Engine Design using existing hardware, further enhancing the maturity of the engine.

Why International Cooperation & Partnership

- International team brings strengths from both partners - Broad International Experience Base
- International team brings diversified Technologies, Designs, Methods, and Engineering Culture
- International team brings resources from both Partners
- International team provide an opportunity for Alternate Sourcing
- International Market opens additional opportunity for Product Evolution (example: RD170 - RD180 - RD191)
- Resultant collaborative and evolved products allow reduced Development Costs, Schedule, and Risks
- Initiates Groundwork for International Product (i.e. RLV)

RD AMROSS

An Existing Successful Russian-American Rocket Engine Joint Venture



February 21, 2002
Maiden Atlas IIIB

May 24, 2000
Maiden Atlas IIIA

Who is RD AMROSS ?

A U.S. company (1997) Established for the Marketing and Sale of the RD-180 & Derivative Engines and Support Services.

RDAMROSS

American - Russian Rocket Engine Joint Venture

50% Owner

50% Owner

Pratt & Whitney Space Propulsion

NPO Energomash

NPO ENERGOMASH

- Premier Upper Stage Engine Company
- Turbopump developer & producer for SSME
- Funding source for RD-180 development
- RD-180 integration and launch support services
- U.S. Co-Production source for the RD-180

- Premier LOX/Kerosene Rocket Engine Company
- Rich Engine Development & Evolution Heritage
- Designer & Developer of the RD-180
- RD-180 Production for Atlas launch vehicles
- RD-180 integration and launch support services

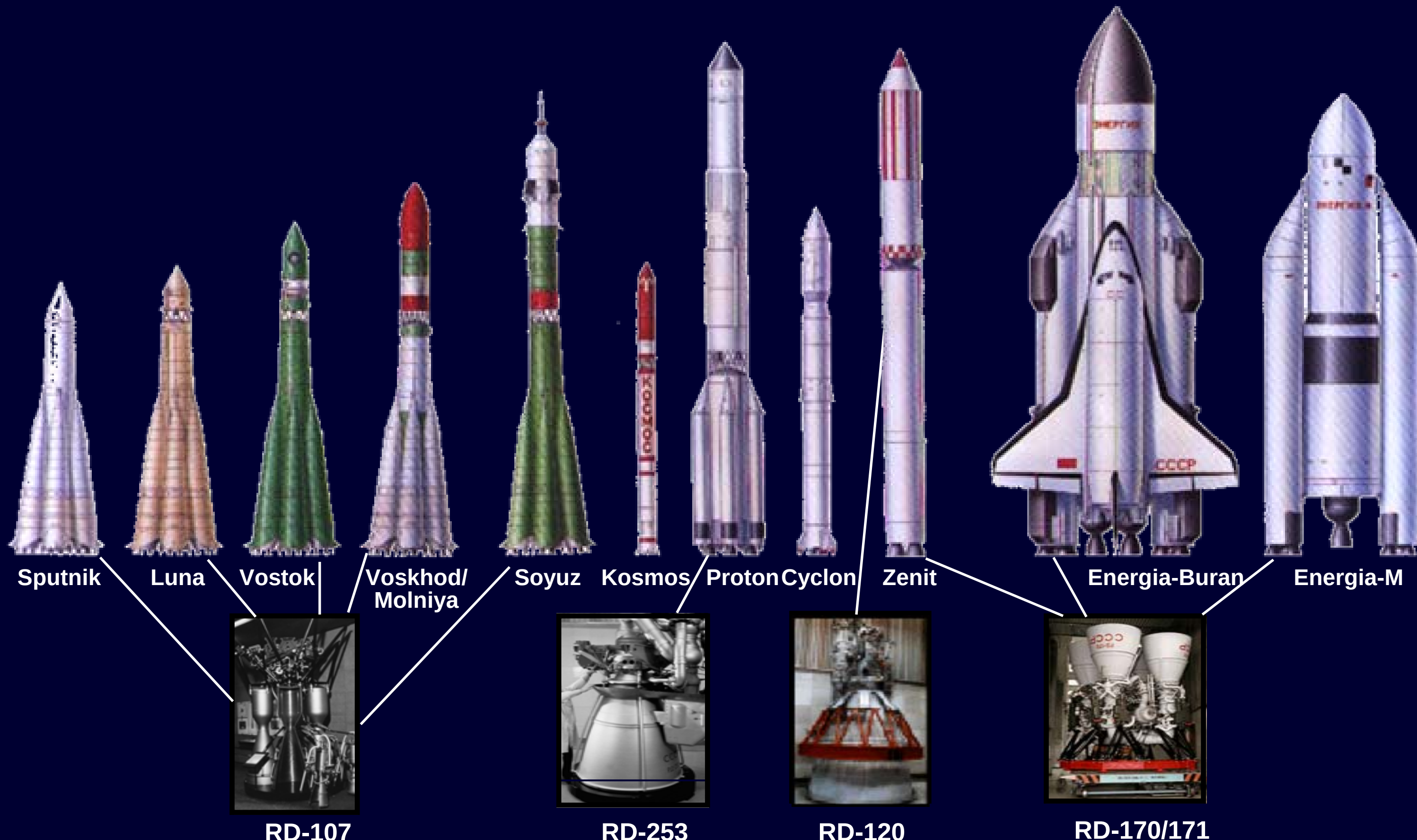
RD-180 Background Information

- RD-180 Engine originally pursued in early 1990's by General Dynamics for Atlas
- General Dynamics merged with Martin Marietta, and later became Lockheed Martin in 1995. Competitions held to upgrade Atlas booster propulsion.
- In 1995, Lockheed Martin selected the team of NPO EM and P&W to develop the RD-180 for the Atlas IIAR (now Atlas III) and eventually for the EELV Atlas V
- In early 1997, RD AMROSS was formed to formally establish production and sell flight engines and launch services to Lockheed Martin.
- A phased development and certification program is now near completion which certifies the RD-180 for use on the Atlas III, Atlas V MLV, Atlas V HLV strap-on LRBs and the Atlas V HLV Core

The Russian-American cooperation to rapidly develop, certify and field the RD-180 booster engine is unprecedented.

NPO Energomash Experience

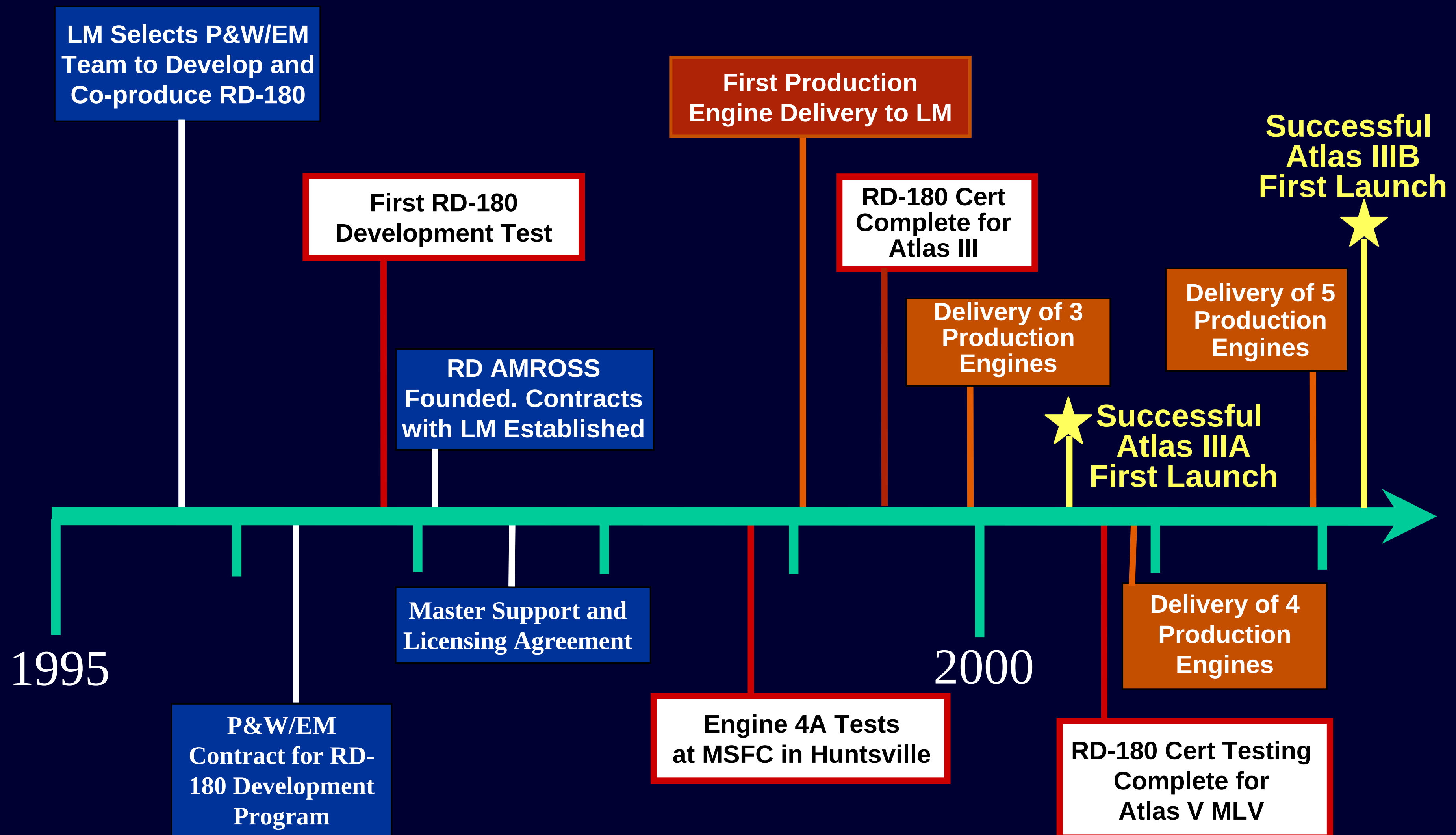
More than 2,300 launches made using more than 11,000 engines



NPO Energomash has provided booster propulsion for these Russian launch vehicles

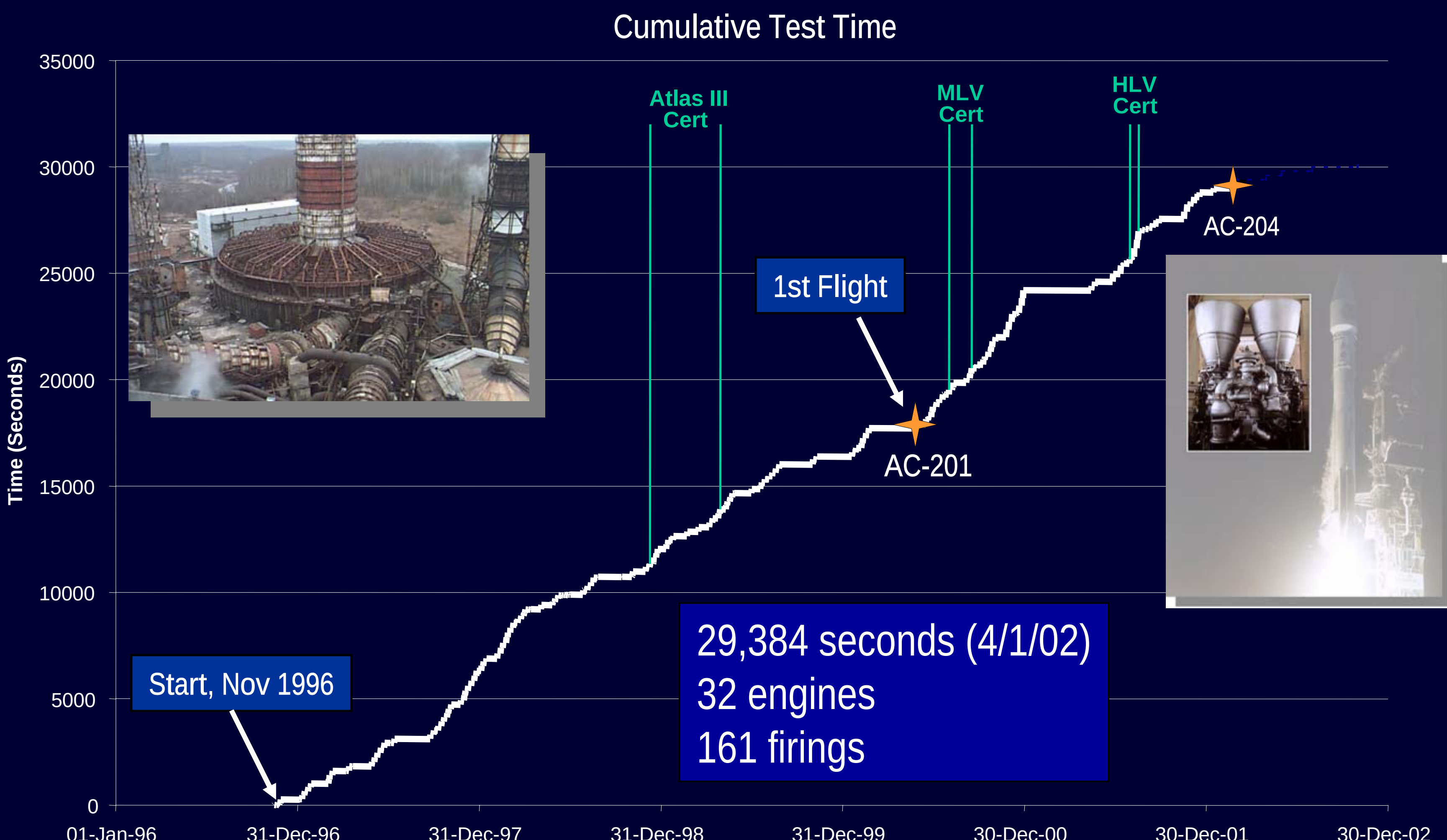
RD-180 Program Timeline

Swift Timeline For Key Agreements, Events And Successes Demonstrates Fast Schedule with Low Risks



RD-180 Test Time Accumulation

Consistent Swift Progress Toward Engine Maturity and Demonstrated Reliability



Russian LOX/Kerosene Technology

The Case for Russian Collaboration on LOX/Kerosene Engine Development for RLV's

- Russian Technology in *LOX/Kerosene* is State of the Art (TRL9)
  - Highest Chamber Pressure of any Booster Engine
  - GOX-Rich Staged Combustion
  - Stable Combustion in Preburner and Main Chamber
  - GOX-Rich/Compatible Turbine Drive
  - No Coking
  - No Chamber Blanching
  - Proven Turbomachinery Design
- No Comparable "US Based" LOX/Kerosene Technology
- Enables "Evolved" rather than "Clean Sheet" design
- Precedent of successful collaboration on the RD-180 program

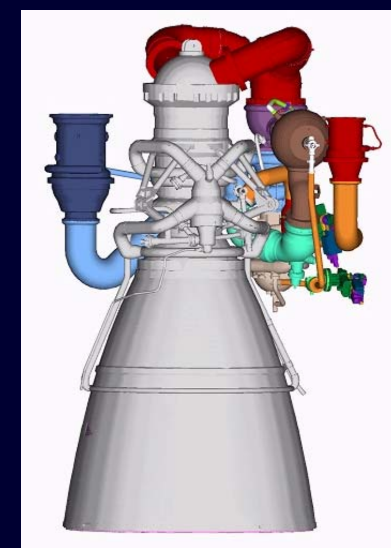
2GRLV LOX/RP Design Approach

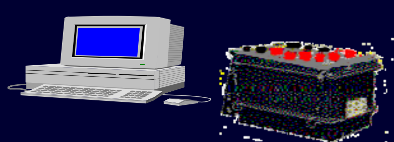
Russian RD-180 Heritage
Engine System Design
Component Designs
Technologies
Devel/Prototype Hardware

2GRLV Requirements

- Convert to Single Chamber
- Scale to Thrust Class
- Adjust & Optimize the Cycle
- Insert Life, Reliability, Operability, and EHMS Enhancements
- All US Produced

"AR1000"
US Designed and Produced RD-180 Derivative

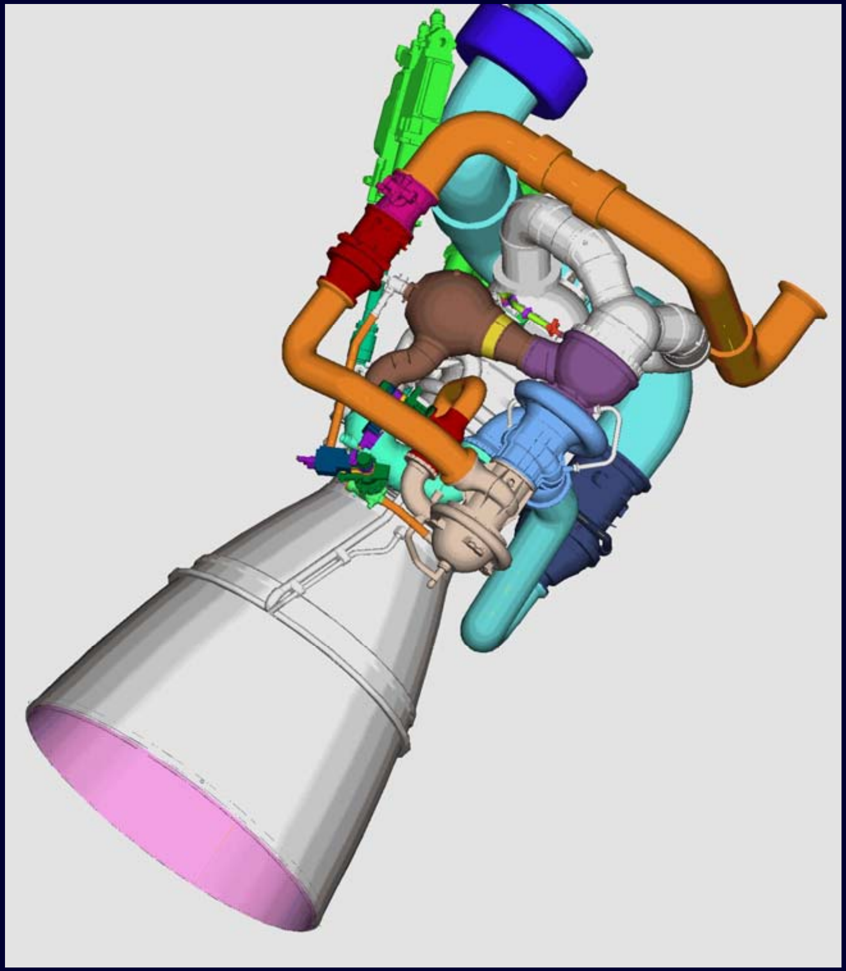




P&W Space-Jets Heritage
Systems Engineering
Operability Design Methods
Reliability Design Methods
Engine Health Management

The AR1000 LOX/Kerosene Engine

Developed through Evolution from Russian RD-180 Point of Departure



- Based on RD-180 Heritage Designs and Technologies
- P&W designed Engine
- Single Thrust Chamber design
- Single Preburner
- Single Shaft Turbopump
- Scaled to thrust class (.9-1.5M)
- Manufactured in U.S.
- Reusable - Operable - Safe
- Integrated Engine Controller and Engine Health Management Sys
- TVC (Fuel-draulics or EMAs)

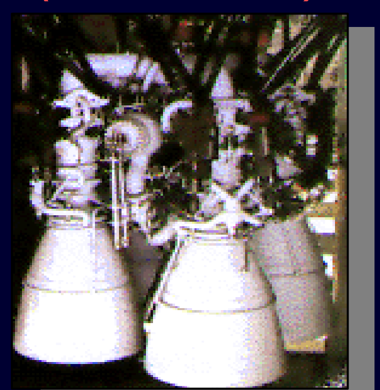
Design through "Evolution"

RD-180 Heritage

- RD-180 derived from the NPO EM designed RD-170 (man-rated, reusable)
- RD-170 component designs accumulated more than 900 tests and 100,000 seconds of test time
- RD-180 has 70% common hardware, 30% scaled hardware from RD-170
- Oxidizer rich staged combustion provides highest performance for LOX/kerosene engines
- High chamber pressure for high performance

RD-180
(0.9M lb thrust)

RD-170
(1.8M lb thrust)

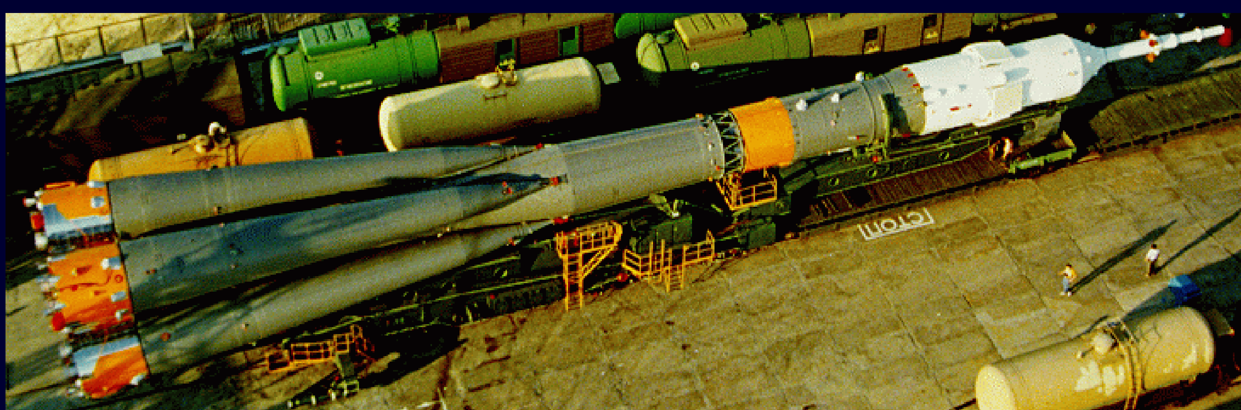


Energia/Buran

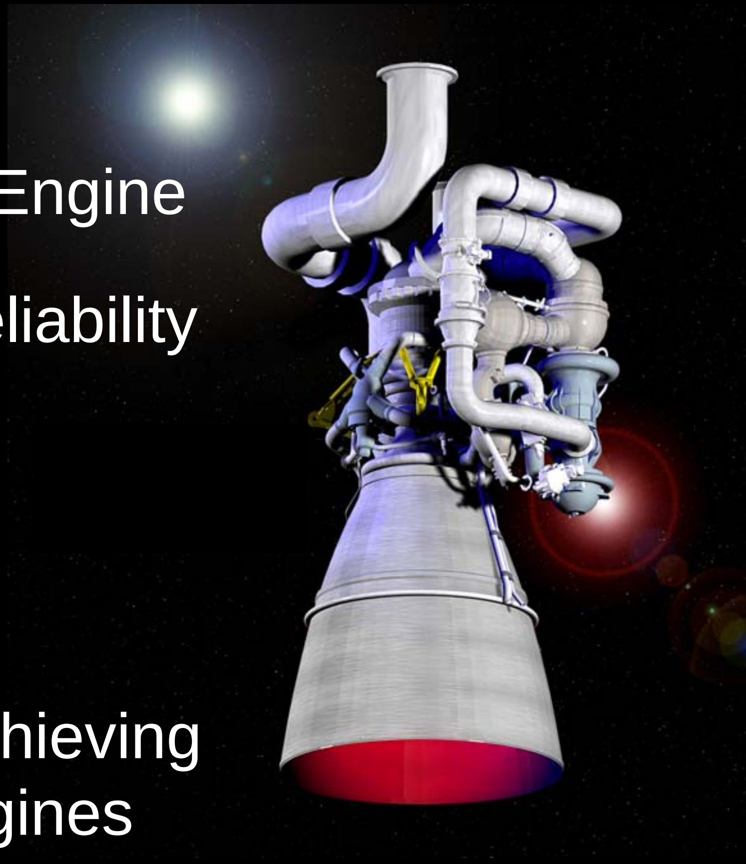
AR1000 Operability Approach

Builds on lessons learned from extensive launch experience

- **Minimal on pad checkout (Russian Philosophy)**
- **Redundant, robust critical instrumentation**
- **Spherical seals eliminate cryogenic leaks**
- **All electric Engine - EMA Actuators**
- **Jet Engine operability design heritage insertion**
- **Low thrust checkout prior to launch commit**
- **40-100% throttability**



Conclusions



- Safety is the most important RLV requirement for the Reusable Rocket Engine

- Three Elements to meet Safety & Reliability
  - Design for Safety
  - Technologies for Safety
  - Maturity for Safety

- Rocket Engine Evolution is key to achieving the Maturity required by Reusable Engines

- International Cooperation & Partnering allows many more Opportunities for Design Evolution → Maturity → Safety