Experimental Spaceplane (XS-1)

First Step Toward Reducing the Cost of Space Access by Orders of Magnitude

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Program Manager

Program Overview for NRC ASEB

16 October 2014

DARPA

ASEB Focus Questions for Reusable Launch Systems

- What are technically feasible approaches for transitioning to a launch system with reusable components?

- What are the near- and mid-term opportunities to demonstrate technologies and capabilities needed for launch vehicles with more reusable components?

- What approaches should be taken to overcome the development challenges associated with reusable boost propulsion systems?

XS-1 Approach to Transition to Reusable Launch

No apparent technical “showstoppers” preventing us from building reusability into launch systems today → philosophical approach is key.

Philosophical Approach being pursued by XS-1 Program:

1. Take distinct, but incremental steps
2. Set aggressive, but achievable goals
3. Design-in operability (“aircraft-like operations”) up front
4. Be open to the form of the solutions, don’t mandate technologies or approaches
5. Design for broad user segment, not exclusively Government/DoD

DC-X Paved the Way

'Ops Lab' procured on 2 year schedule, $70M

Flew 18 Aug 93 through 1996

DC-X/XA Demonstrated

Streamlined Management "Aircraft-like" O&M

- 26 hr turnaround time
- 2-3 hr call up/alert
- Small crews: 6 to 12
- Minimal facilities < $600K

"Aircraft-Like" Flight Ops

- Flight abort/engine out
- Incremental flight test
- All weather

Critical Technologies

20 Years Later …

- A robust commercial sector
- Spaceports proliferating
- Rapidly maturing tech
- Costs down 10-100X

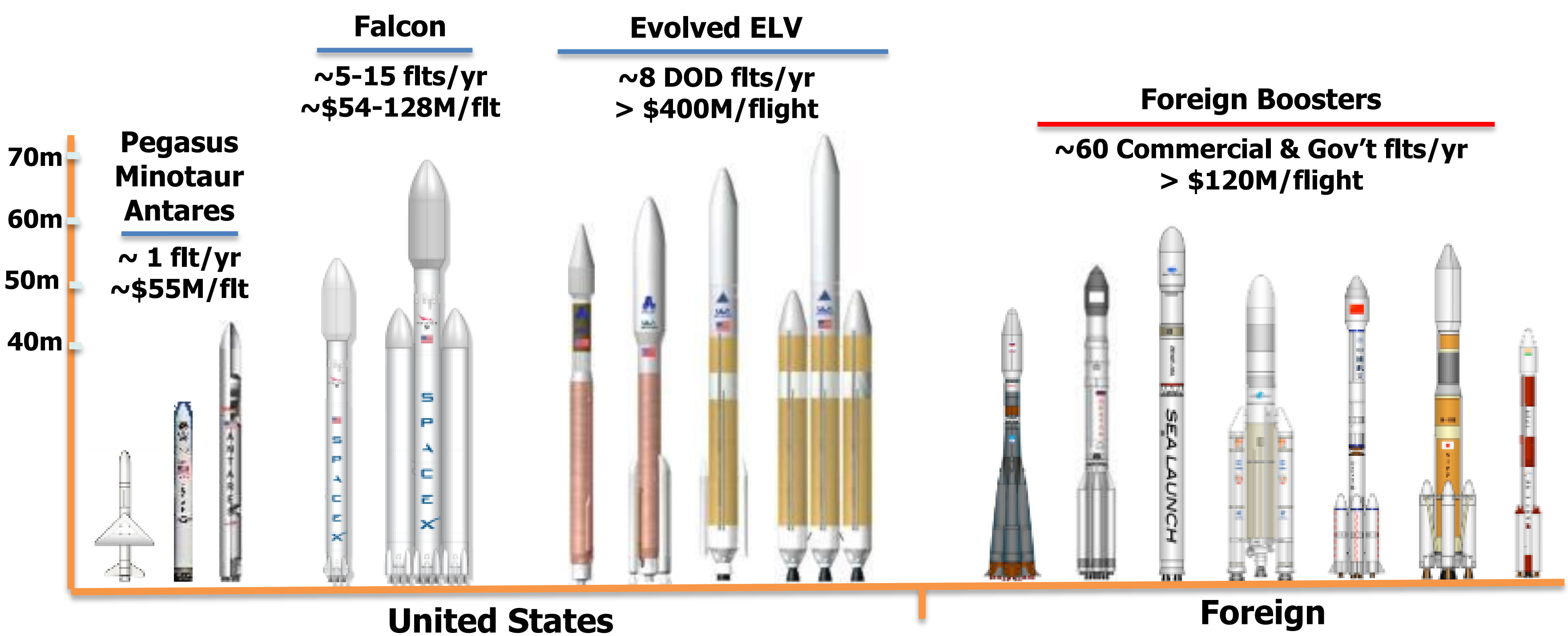
IN MEMORIAM

Thank You!

Dr. Bill Gaubatz

U.S. Launch – A Growing Problem

- DoD payloads launched on Evolved ELV at ~$3B/year & growing
- Small payloads launched at ~$50M on few remaining Minotaurs
- Foreign competitors lead commercial launch, once dominated by U.S.
- No surge capability, long call-up times, typically > 2 years
- Budgets continue to decline, threats to space and air assets growing



XS-1 Goals

Step One to Routine, Low Cost Access to Space

1. Break cycle of escalating space system costs

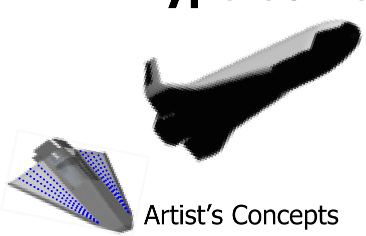
- Change how spacecraft are built
- Enable future space system architectures
- Leverage interests & capabilities of commercial sector

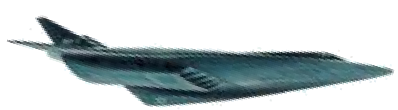
2. Provide affordable/routine space access; would fly in 2018

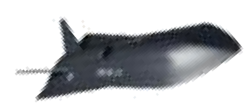
- **Responsive launch** → single smallsat or constellations for rapid employment
- **Disaggregation** → smaller spacecraft, flown more often & more survivable
- **Resilient** → ability to fight through contested & congested environments
- **Hypersonic testing** → platform for R&D of hypersonic systems & components

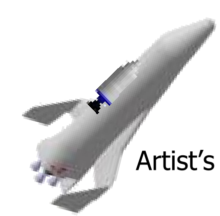
3. Enable advanced flight vehicles and strategic capabilities

- **Space sortie aircraft** → Global ISR, boost-glide, PTP transport
- **Hypersonic aircraft** → High-speed, thermally-robust technologies


Artist's Concepts


Artist's Concept


Artist's Concept


Artist's Concept

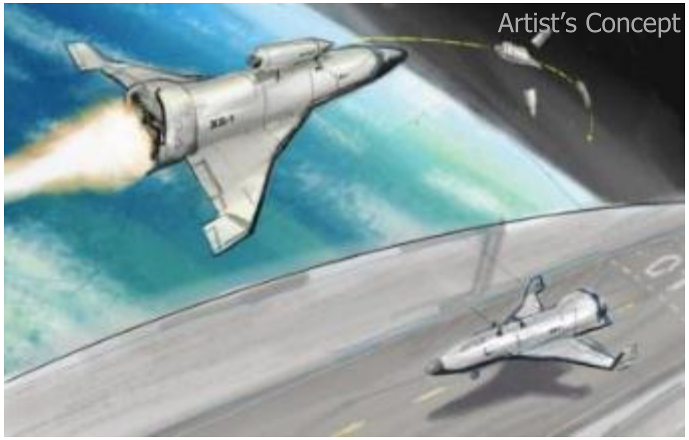
XS-1 Technical Objectives

- Reusable first stage
- Fly XS-1 10 times in 10 days
- Fly XS-1 to Mach 10+ at least once
- Launch demo payload to orbit
- Design for recurring cost ≤ 1/10 Minotaur IV

(< $5M/flight for 3,000 – 5,000 lbs to LEO at 10+ flts/yr)

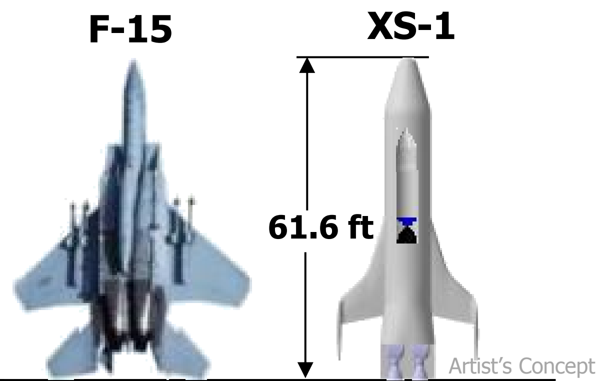
<u>Open Design Space, Industry Has Flexibility</u>

- Configuration
- Propellants
- CONOPS
- Materials
- Technologies
- Propulsion



Notional Government Reference X-Plane

One of Many Possible Industry Solutions

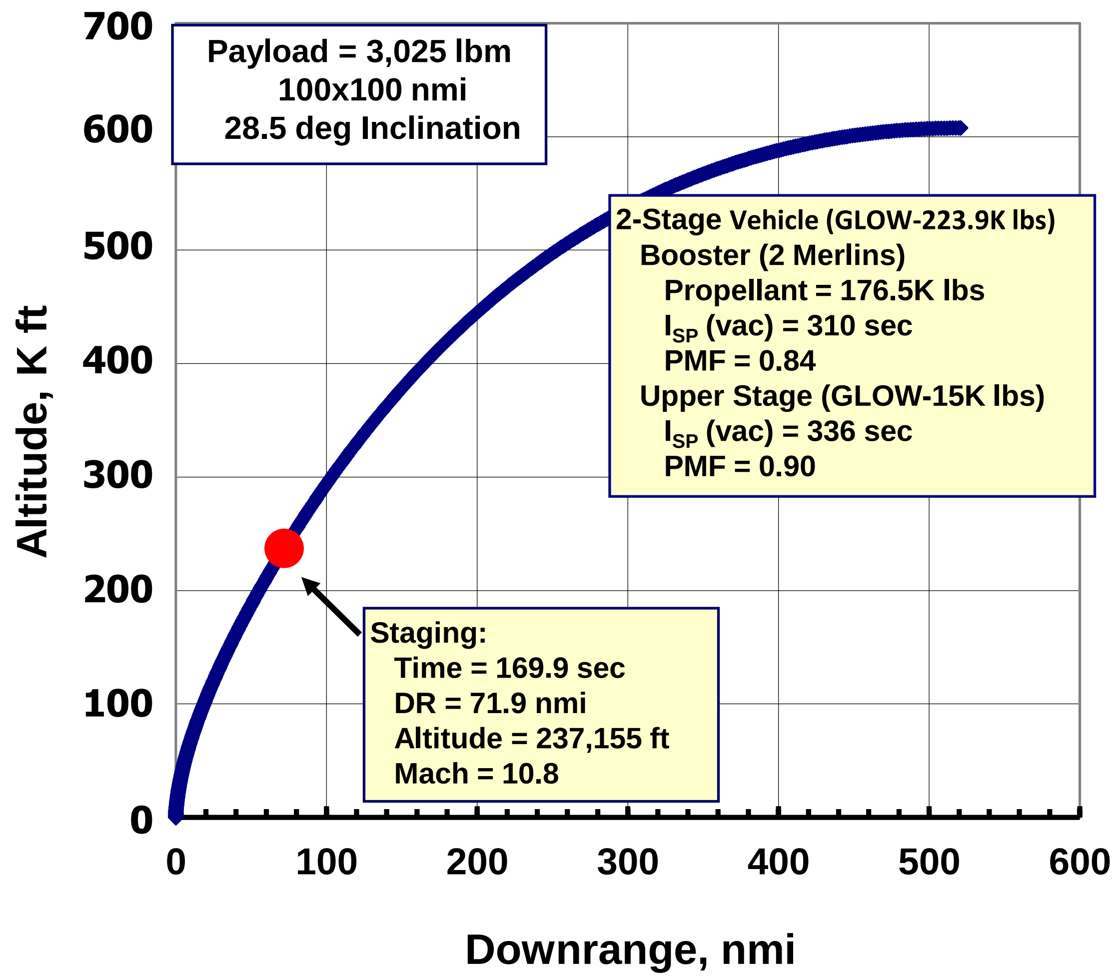


Booster	
Engine	2 Merlins
GLOW (K lbs)	223.9
MECO (K lbs)	47.4
Usable LOX/RP (K lbs)	176.5
Isp (vac)	310
Stage PMF	0.84
Upper Stage	
GLOW (lbs)	15.0
Isp (vac)	336
Stage PMF	0.9
Payload (K lbs)	3.0

Expendable stage ~5% of stack weight

Mach 10 staging with small upper stage (shown)

Alternatively, stage at lower speed with larger upper stage

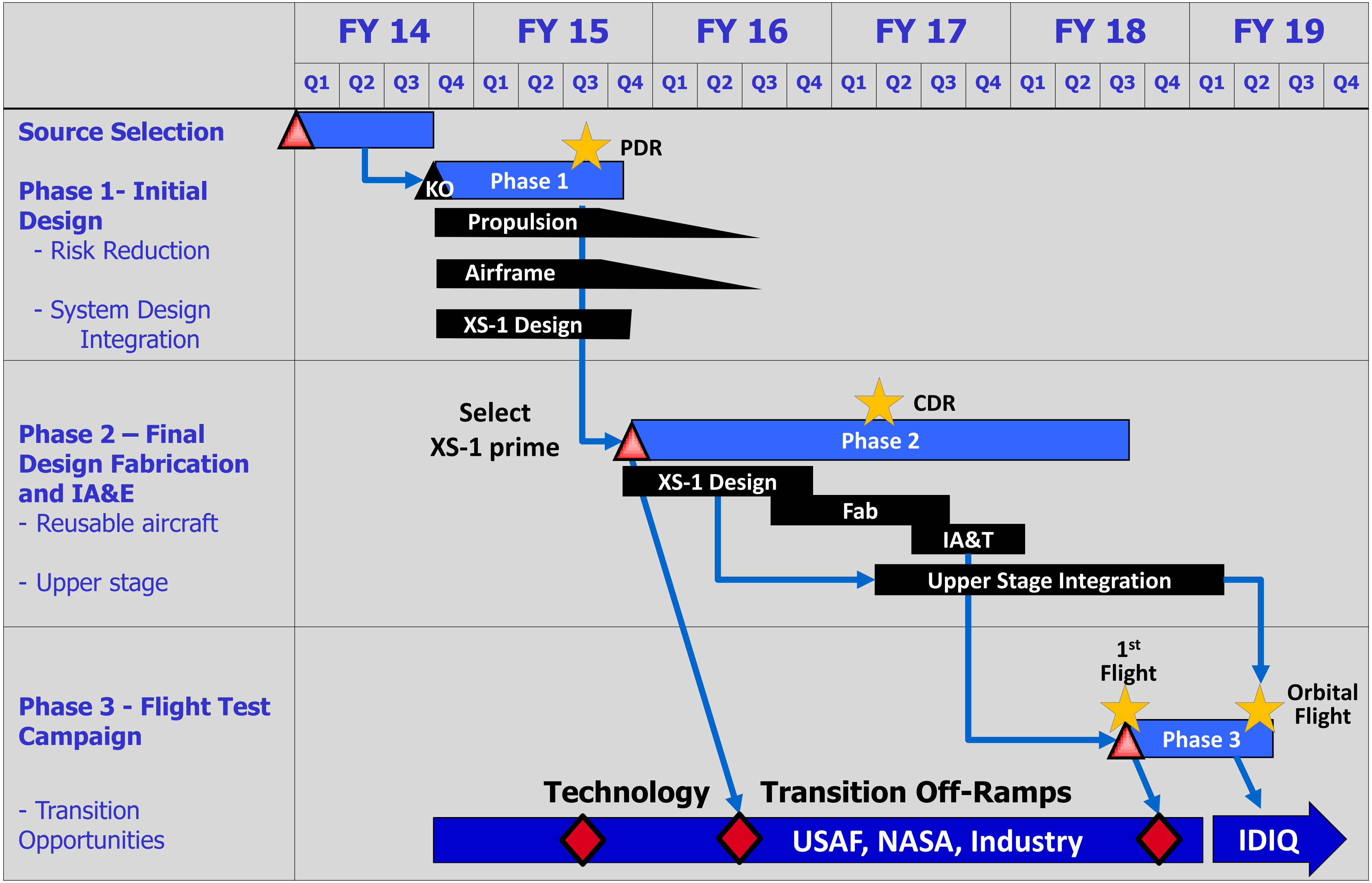


XS-1 Phase I Awards

- **Phase I system awards**
  - ✓ The Boeing Company working with Blue Origin
  - ✓ Northrop Grumman working with Virgin Galactic
  - ✓ Masten Space Systems working with XCOR

- **Technology awards/cooperative efforts**
  - ✓ Honeywell – Real-time Abort Trajectory Generation
  - ✓ Gloyer-Taylor Labs – Composite Cryogen Tank Fabrication and Test
  - ✓ NASA Armstrong Flight Test Center – Fiber Optic Sensor System (FOSS)
  - ✓ SAS and LLNL – Ox-Rich Staged Combustion / Next-Gen Rocket seedlings
  - ✓ ATK/COI – CMC Thermal Protection Systems
  - ✓ C-CAT – Advanced Carbon-Carbon Thermal Protection Systems
  - ✓ Orbitec – Vortex Combustion Rocket Thrust Chamber Scale-Up and Fabrication
  - ✓ Aerojet Rocketdyne – Additively Manufactured Regen-Cooled Thrust Chamber
  - **Upcoming:** 1 Comm / Space-Based Range Award

XS-1 Planned Schedule



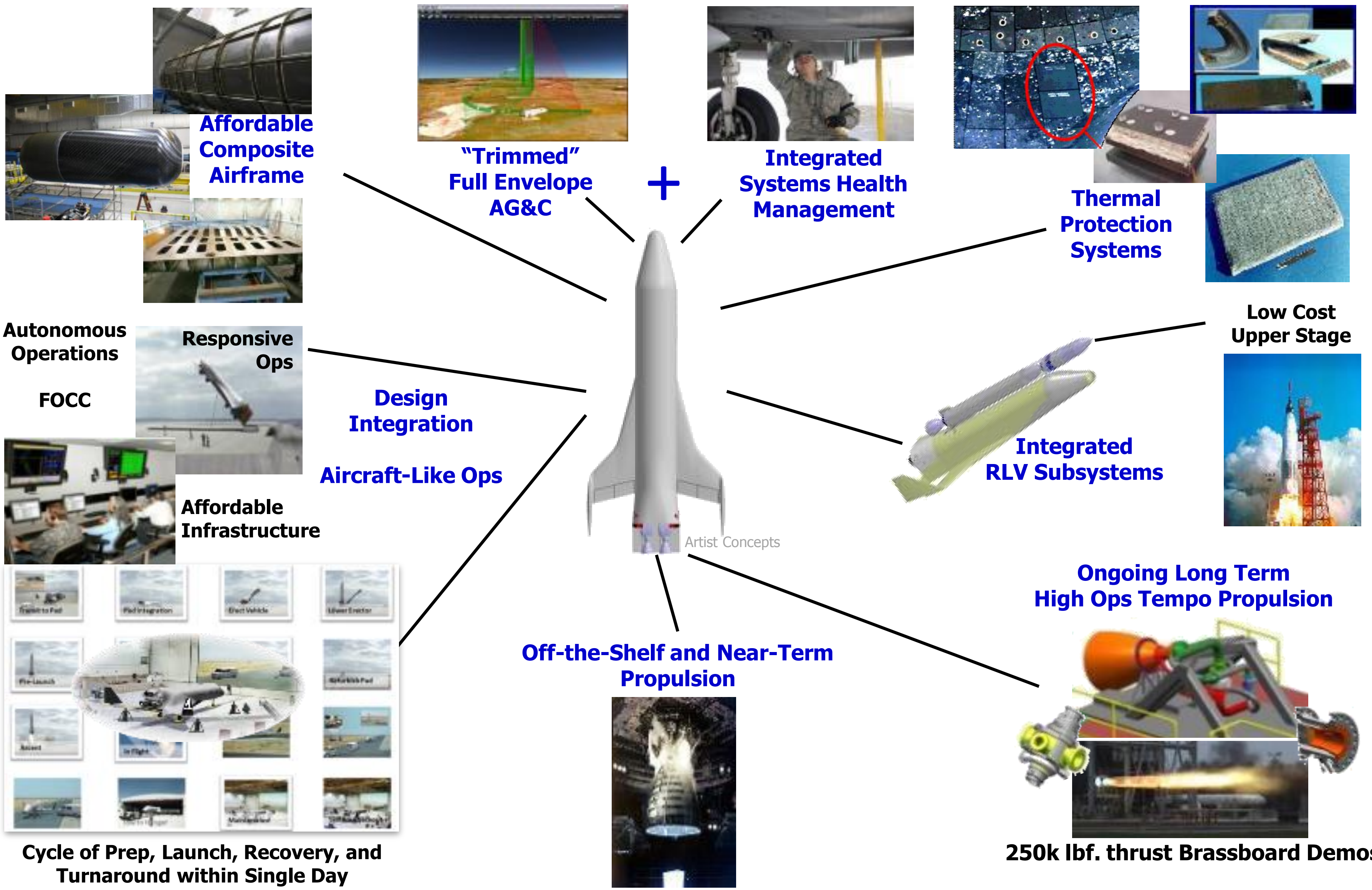
Legacy of Past Programs

Initial Goals (requirements)	**NASA human rated** **Payload – 65K lbs**	**AF crewed** **Payload < 10K lbs** **SSTO, scramjet powered** **Aircraft-like ops, fast turn**	**NASA human rated** **Payload - 65K lbs** **SSTO, rocket powered** **Aircraft-like ops, fast turn**
Technology (at start)	**TRL ~3 <u>and</u> immature design** **New LOX/LH_2 SSME** **Unproven materials/TPS** **Toxic OMS/RCS, etc.** **1960s/1970s technology**	**TRL ~2 <u>and</u> immature design** **New LS/RAM/SCRAM/rocket** **New materials/structures** **New LOX/LH_2 tanks** **New hot structure TPS, etc**	**TRL ~3 <u>and</u> immature design** **Mod LOX/LH_2 aerospike rocket** **New composite structures** **New metallic TPS** **New LOX/H2 tanks, etc.**
Approach	**Expendable launch (SRB, ET)** **Operational after 4 flights** **Evolved to "space station"**	**X-Plane first** **Incremental flight test**	**X-Plane first** **Incremental flight test**
Outcome	**Successful flights** **Very expensive with ground "standing army"**	**Never flew** **Design never closed** **Technology not available**	**Never flew** **Design never closed** **Technology not available**

Past programs over-specified the problem (SSTO, scramjet, heavy lift, crewed, etc.) AND relied on immature designs and technology (TRL 2/3)

What Has Changed?

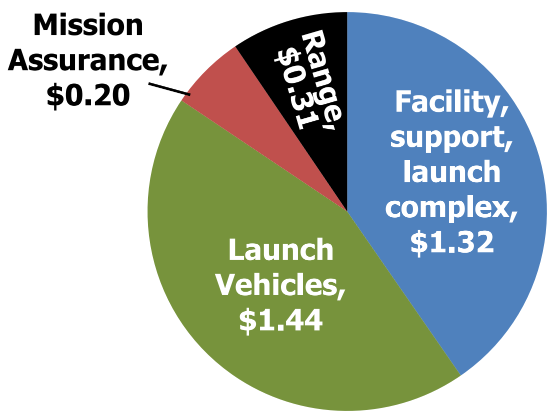
20 years of investment → Technology mature & affordable

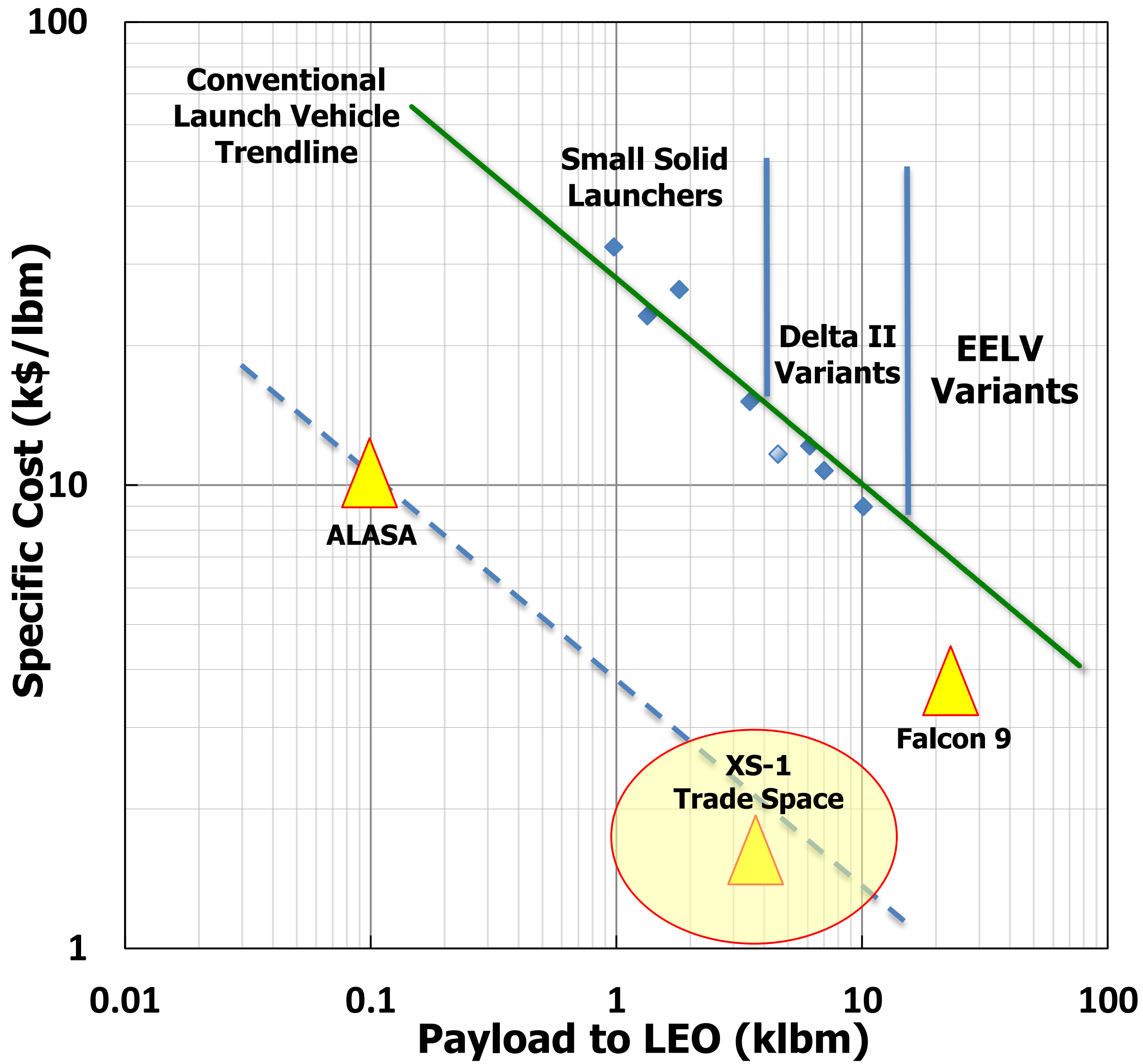


Challenges to Achieving Lower Cost

XS-1 would complement heavy Falcon & EELV payloads

ELV Launch Cost Breakdown





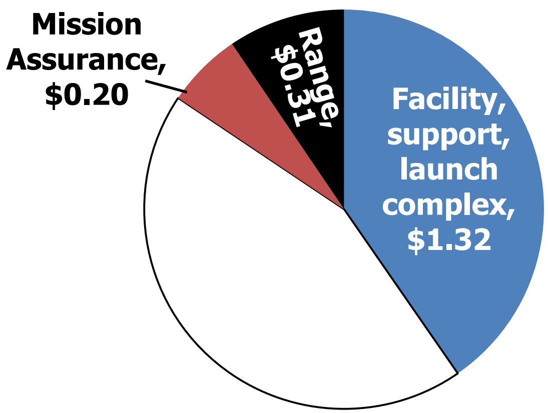
Technical Challenges

- Design and system integration enabling "aircraft-like" operations
- Light weight/highly-integrated airframe, high propellant mass fraction
- Durable thermal structures/ protection, -300ºF to +3,000ºF
- Reusable, long life & affordable propulsion

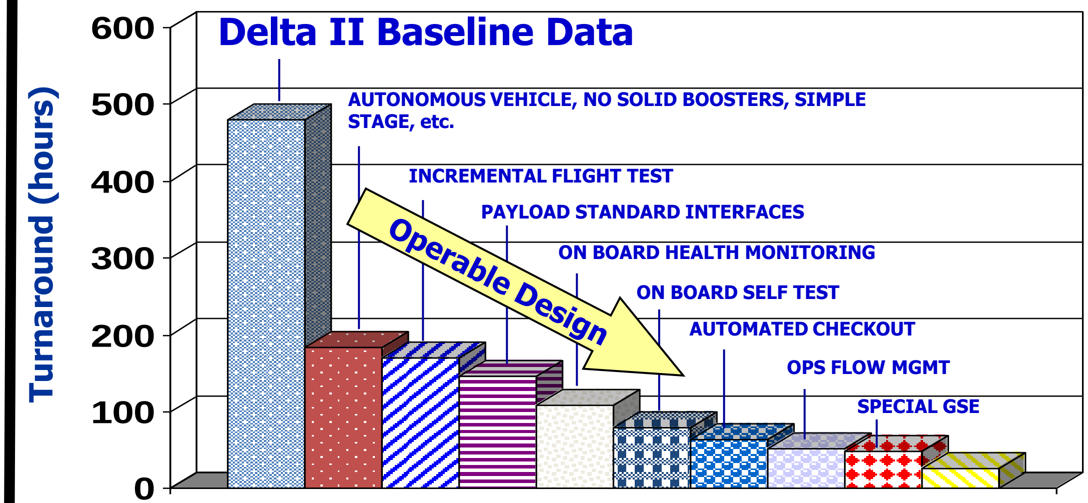
Note: Data extracted from FY12 PE/BPAC data, Excludes AFSPC payroll at launch sites and base O&M

Goal: Design and System Integration

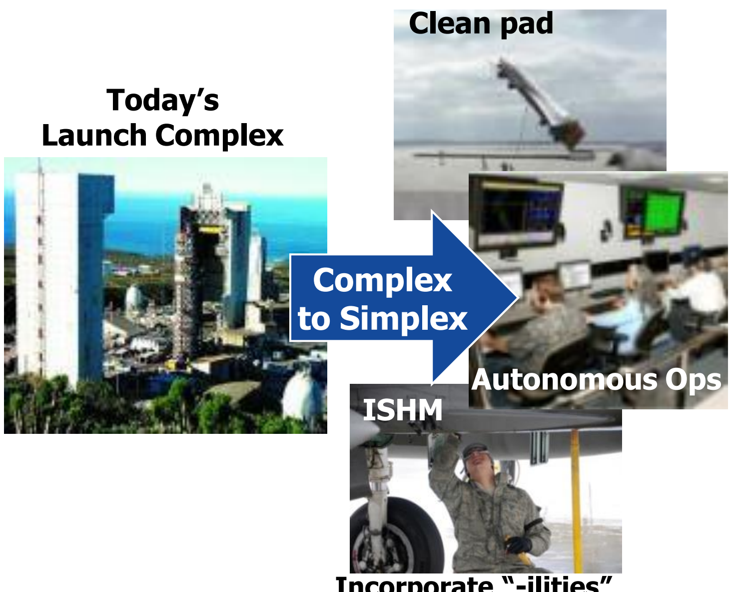
Enable "aircraft-like" operations



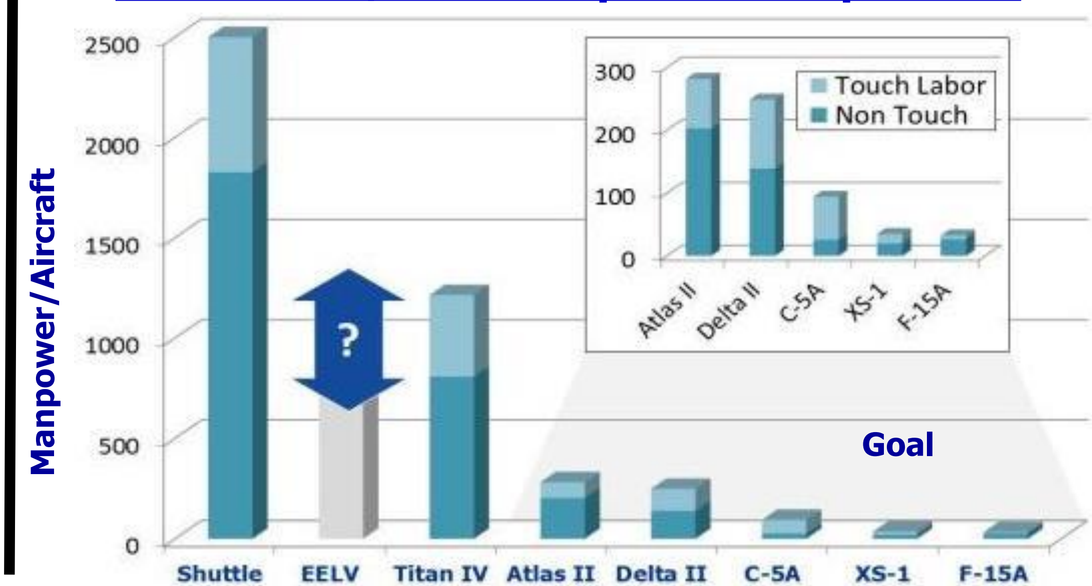
Design for Rapid Turn Reduces Manpower



Few Facilities, Small Crew Size



Launch Site/Base Manpower Comparisons



Goal: Design Integration

"Clean Pad" Aircraft-Like Operations

- **Aircraft-like CONOPS**
  - *Clean pad - rapid throughput*
  - *Ops Control Center – like aircraft*
  - *Containerized payloads*
- **Aircraft GSE/Facilities where practical**
  - *Hangars, not specialized buildings*
  - *Standard interfaces/processes*
  - *Automated ops, propellant & fluid loading*

CLEAN PAD CONOPS
Rapid Throughput, < 24 hrs on pad

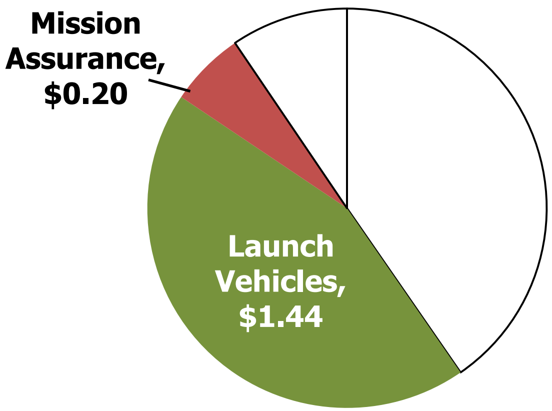
OPS CONTROL CENTER
Small 3 Person Ops Crew Size

Flight Manager (FM) | **Deputy FM** | **Crew Chief**

- **Integrated Systems Health Management**
  - *Determine real-time system health*
  - *Integrate with Adaptive G&C*
  - *Enable reliable, rapid turnaround aircraft*
- **Leverage high ops tempo investments**
  - ***ALASA** – Autonomous Flight Termination System*
  - ***ALASA** – Rangeless range, space based command, control & data acquisition*
  - *Adaptive GN&C – safe, reliable recovery/abort*

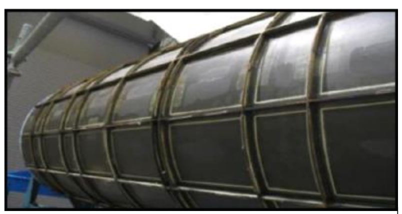
Goal: Highly-Integrated, Low-Complexity Airframe

High Propellant Mass Fraction (PMF)

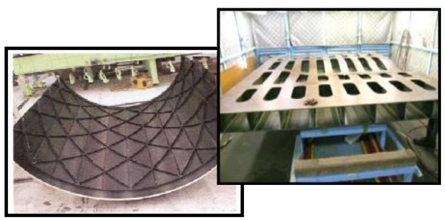


Affordable Structure

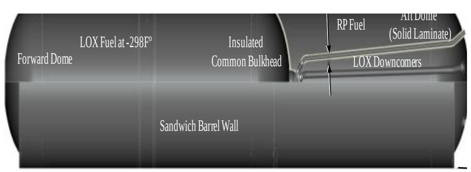
Composite Structures Can Reduce Weight ~30%



USAF Monocoque Tank in Test

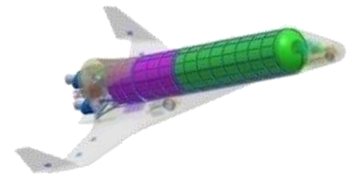


NASA Open-Core Tank in Fabrication



Tank/Structure Integration

- ✓ **Integral load bearing structure**



- ✓ **High PMF key to performance**

$$\Delta V = I_{SP} * g * \ln\left(\frac{1}{1 - PMF}\right)$$

- ✓ **10X fewer parts & lower cost**

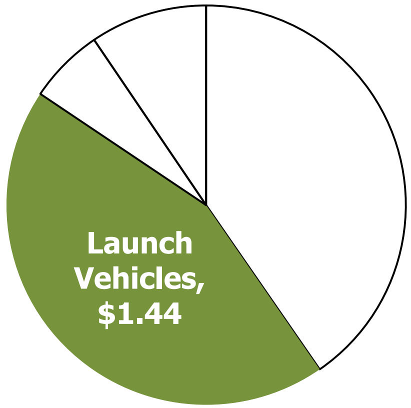
- ✓ **Reusable vehicle cost would be amortized rapidly …**

$$\left(\frac{\text{Unit Cost}}{\text{No. Flights}}\right)$$

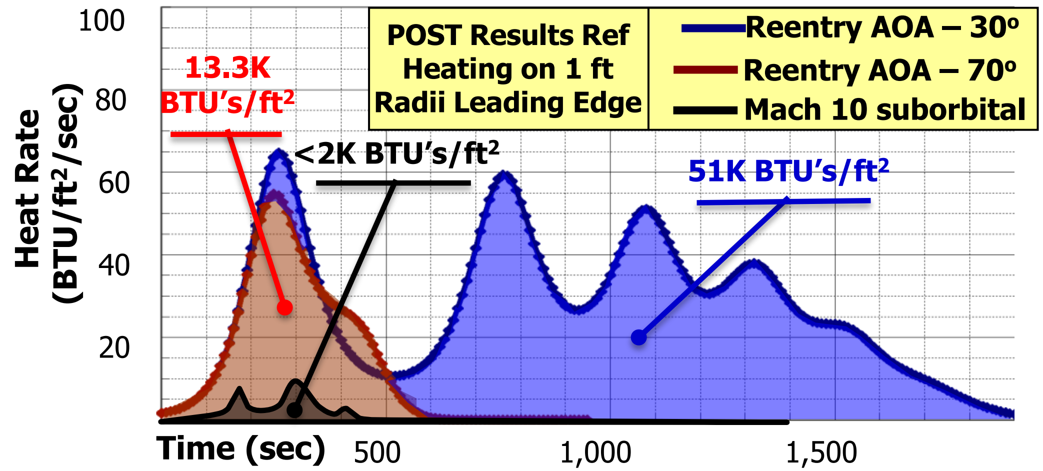
Design tank / airframe structure to enable high PMF/ΔV

Goal: Durable Thermal Structures / Protection

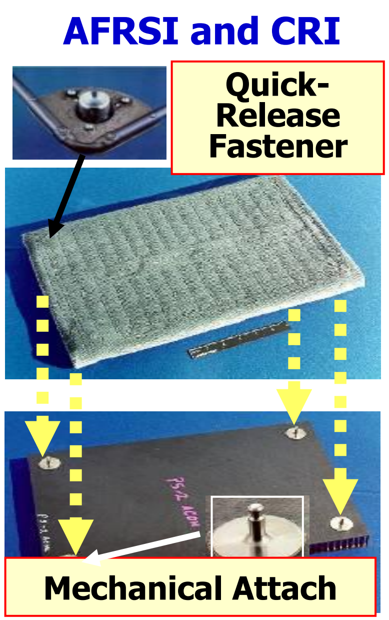
-300 °F to +3,000 °F

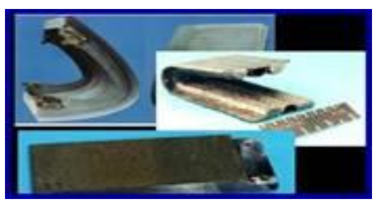


How you design & fly is key!



Many Thermal Protection Options

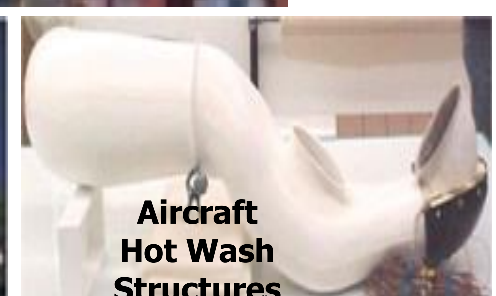




Leading Edges ACC, C/SiC, TUFROC

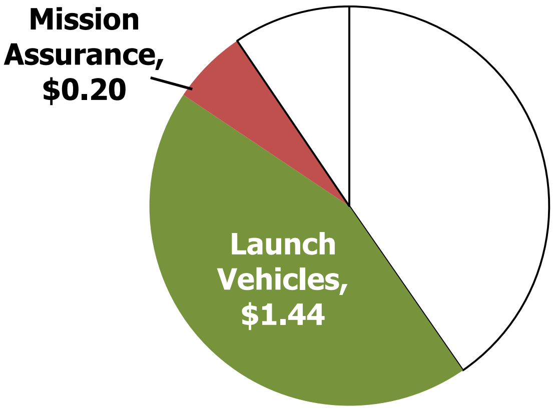
Space Shuttle Post-Flight CMC/TUFI Tiles

Emerging Thermal Structures



Goal: Reusable, Long Life and Affordable Propulsion

Multiple Options – Design Integration Challenge

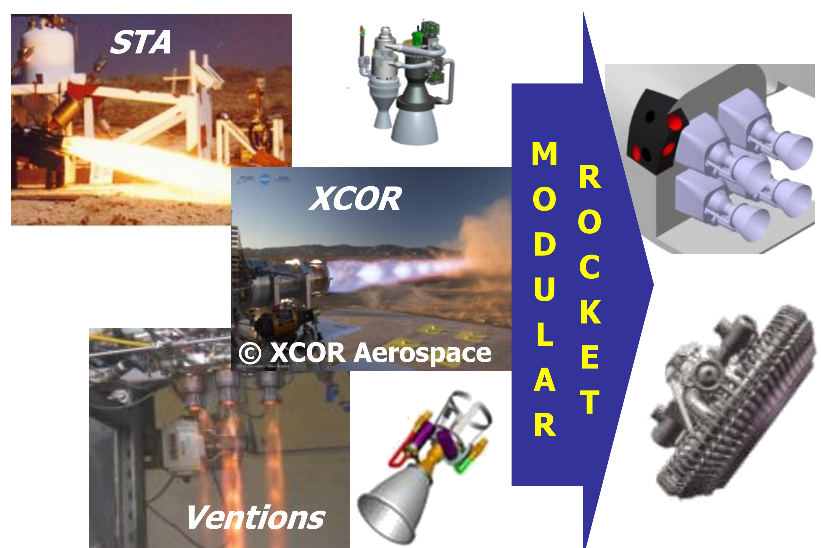


- ✓ **Use existing and near-term propulsion technologies, emphasizing:**
  - **Long life, rapid call up/turnaround**
  - **High reliability**
- ✓ **Design as Line Replaceable Unit**
  - **Rapid remove and replace**
  - **Support high ops tempo flight rate**
- ✓ **Leverage commercial sector developments**

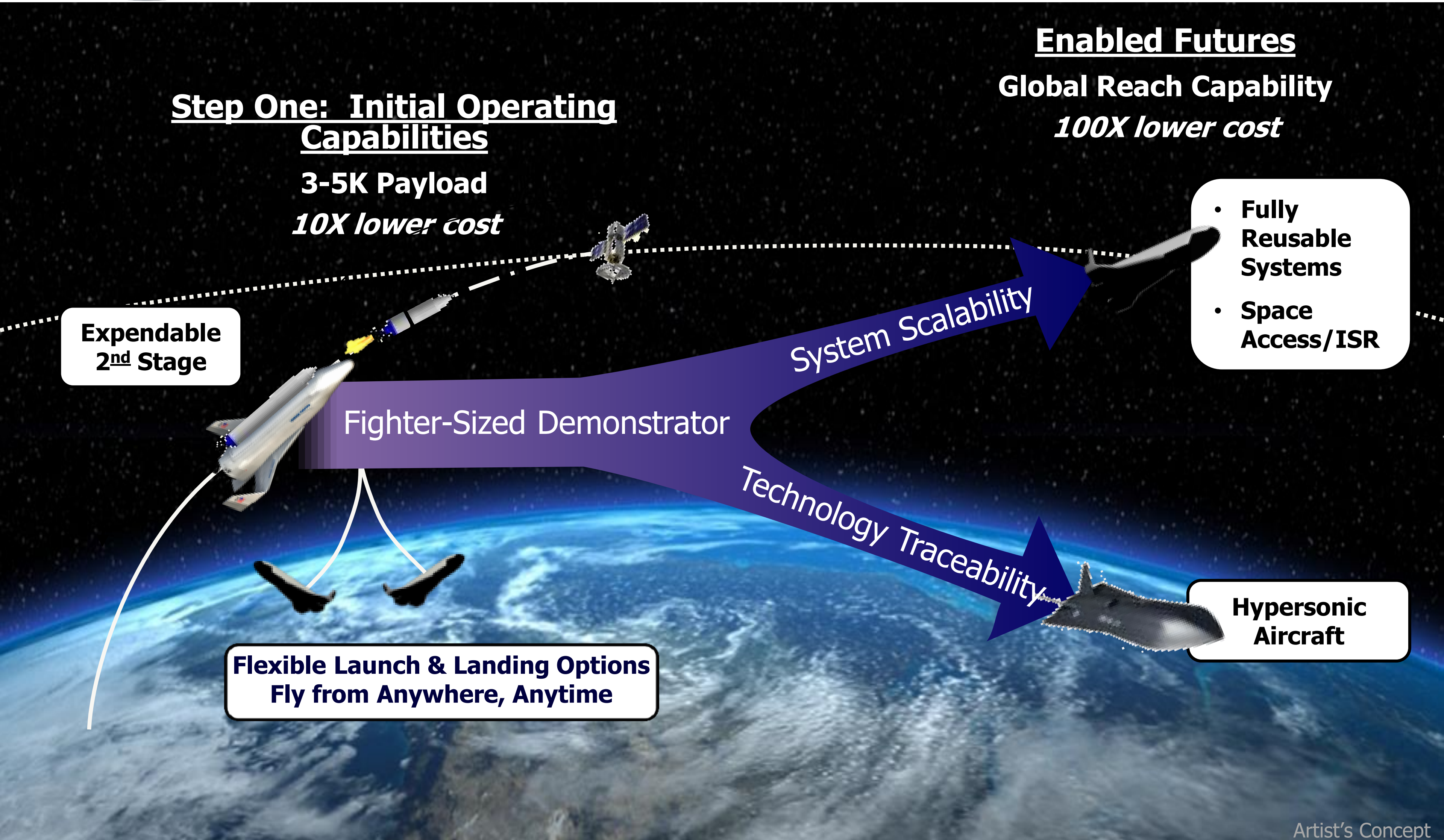
Multiple Propulsion Options

Merlin Commercial Rocket

Bantam Family of Rockets

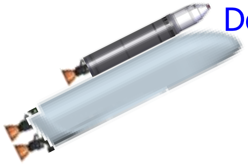


XS-1 Aims to Enable Future Capabilities



Would deliver affordable, routine space access - On path to global reach capability

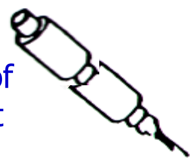
XS-1 Capabilities Would Evolve Over Time



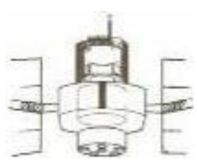
Deploy mated satellite & stage

Modular Bi-mese

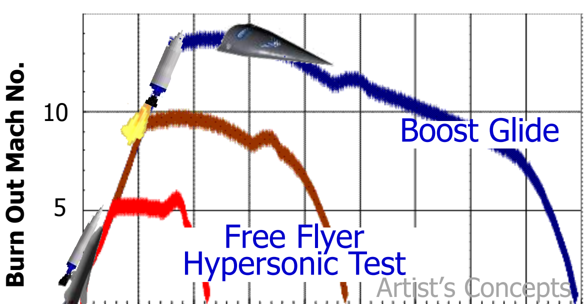
Disaggregated Satellite Missions



Autonomous Dock of Chemical Stage/Sat



Solar Electric Propulsion



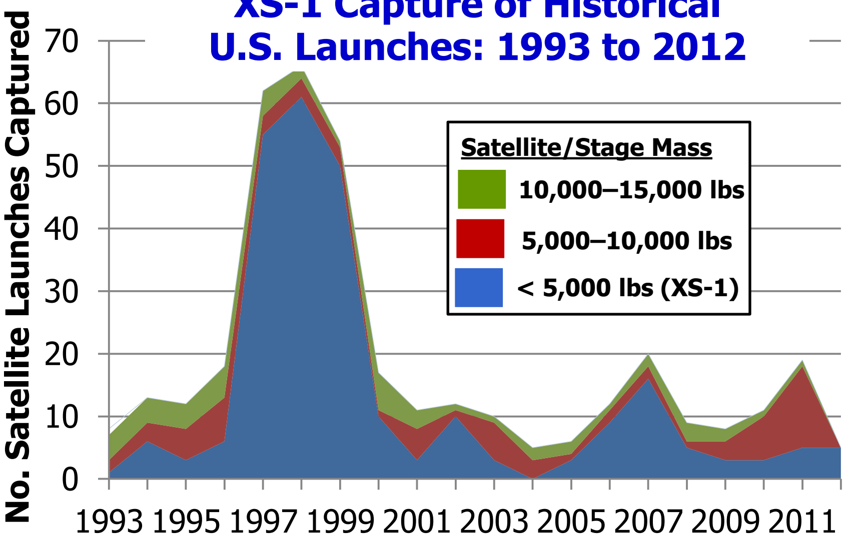
Downrange Constant Q Flight Profile

- **Core capability ≥ 3,000 lbs to LEO**
  - ✓ Option: Grow capability with modular launch
- **Payload disaggregation could shrink sizes**
  - ✓ Downsize & modernize payloads
  - ✓ Single payload simplified spacecraft
- **Stage disaggregation would grow effective payload**
  - ✓ Launch satellite payloads separately
    - ✓ Dock stage on-orbit with satellite
- **Grow launch markets**
  - Capture / recapture commercial launch
  - Enable new military / ORS capabilities
  - Growth versions could enable full spectrum AFSPC launch capability
  - Hypersonic testing / release of free-flyers

Potential XS-1 DoD and Commercial Satellite Markets

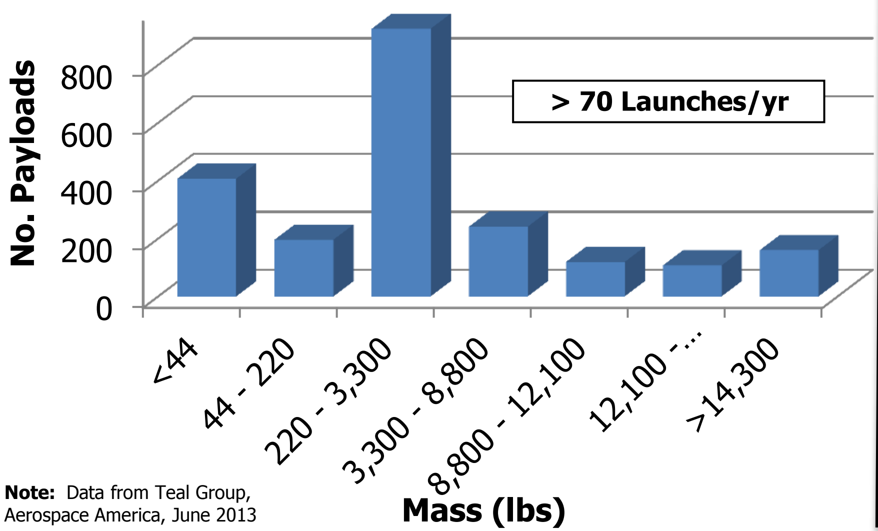
Responsive launch of 3 to 5K lb payloads

XS-1 Capture of Historical U.S. Launches: 1993 to 2012



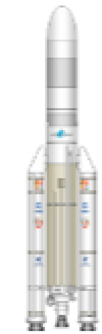
Note: All satellites launched on U.S. boosters. U.S. satellites launched on foreign boosters. Excludes classified & crewed flights. Counts satellites >1K lbs, aggregates smaller satellites.

Worldwide Projected Payloads: 2013 to 2022



Note: Data from Teal Group, Aerospace America, June 2013

- '97-'99 spike due to Iridium and Globalstar
- Lost commercial opportunities
  - Commercial launch migrated overseas
    … $Billions in lost revenue
    … Grew cost of DOD launch
  - New constellations hard to finance
    … Teledesic



- Potential to leverage commercial sector

- Missions potentially enabled by XS-1
  - USAF ORS & "disaggregated" satellites
  - Recapture commercial launch

➔ Historical avg of 3-5 launches/yr at 5,000 lbs

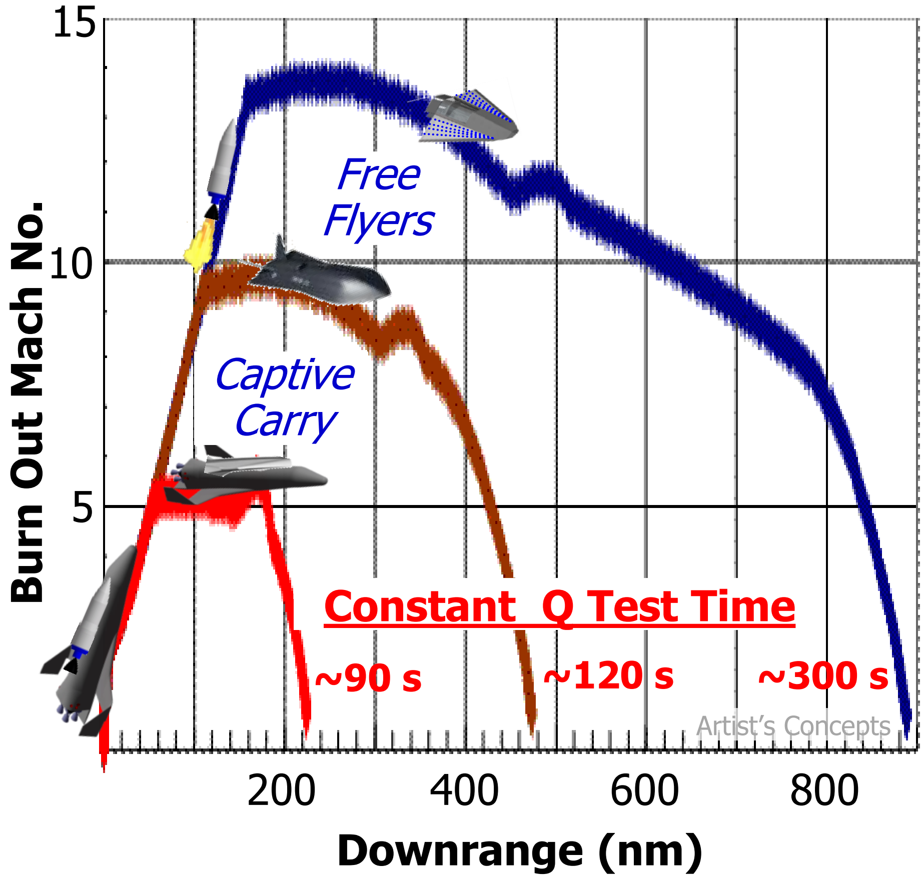
➔ Projected market much higher

XS-1 Could Facilitate Next-Generation Hypersonics

Multiple Test Options

- Captive carry experiments
  - May Limit Q and thermal testing
  - Propulsion (RAM/SCRAM/Turbine)
  - Airframe/Structures
  - Thermal Protection
- Release free-flyer experiments
  - Unpowered constant Q reentry
    - Long test time vs. ground test
    - Aerodynamic & thermal test
    - Laminar flow/boundary layer transition
    - Controls/avionics
  - Powered test vehicle
    - Longer flight tests
    - Useful test data limited only by scale and cost

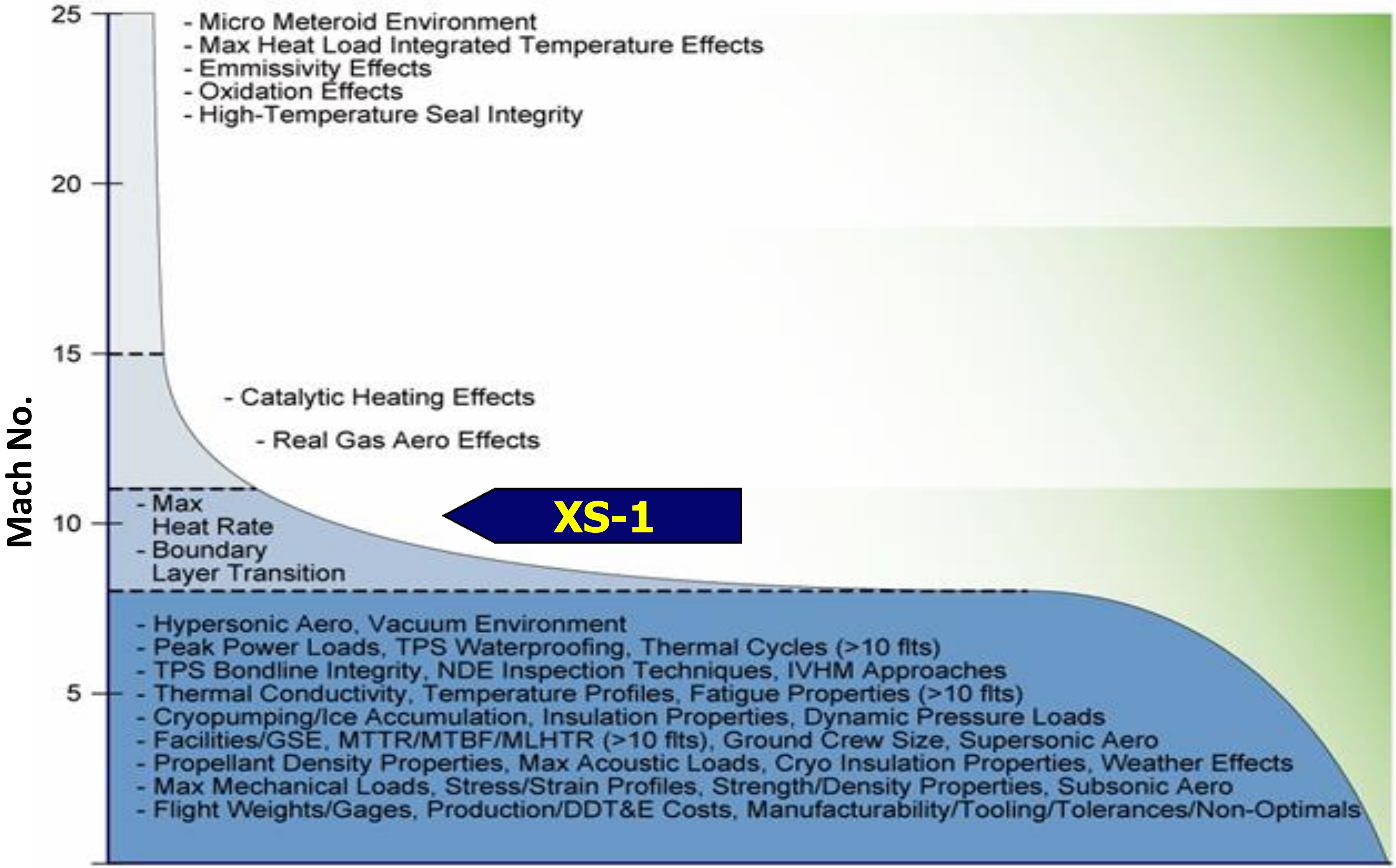
Constant Q Unpowered Glide from Engine Burn Out



Projected Cost of Flight Test < Many (Not All) Ground Tests
Test of component/systems ♦ RAM/SCRAM/turbine ♦ Boost-glide vehicles

Flight Test

Mach 10 Would Validate Critical Space Access Technology



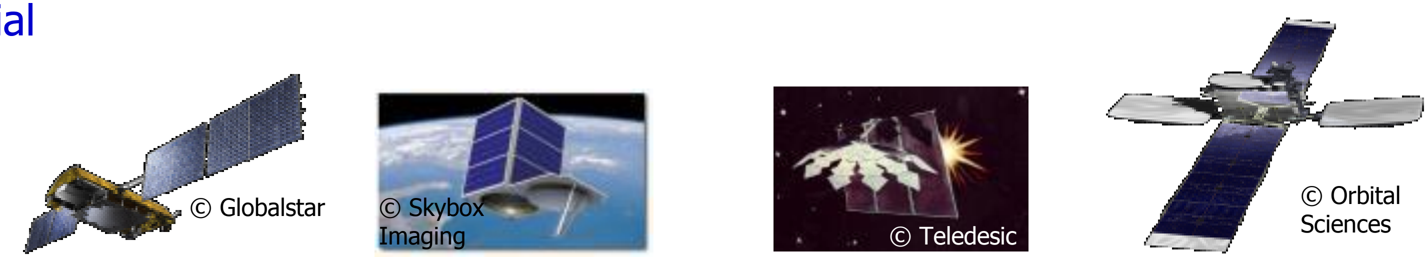
XS-1 would mature technology for 1st Stage and fully reusable flight to space

XS-1 Transition Path Would Require Proactive Industry

✓ **Robust DOD and commercial launch industry with ideas**

✓ **Growing small satellite industry building low-cost satellites**

- Commercial
- Military
- Civil



✓ **Emerging DOD requirements for disaggregation & resiliency**

- **Disaggregation:** downsize spacecraft for routine, responsive & affordable launch
- **Resiliency:** ability to operate in the harsh space environment

Industry Would Lead Commercial and Military Transition Options

Synopsis: Answers to Focus Questions

- What are technically feasible approaches for transitioning to a launch system with reusable components?
  - XS-1 program pursuing 3 prime contractor approaches, all different
  - Reusable 1st Stage, Expendable 2nd Stage
- What are the near- and mid-term opportunities to demonstrate technologies and capabilities needed for launch vehicles with more reusable components?
  - XS-1 program would be a near-term opportunity
  - Aggressive goals ensure technology would feed commercial RLV concepts
  - Stepping stone to fully reusable vehicles in future
- What approaches should be taken to overcome the development challenges associated with reusable boost propulsion systems?
  - XS-1 program is leveraging private sector engine technology
  - Advanced engine technology helpful, emphasize both operability <u>and</u> I_{SP}

Summary

XS-1 seeks to:

- Address growing launch costs in an era of declining budgets
- Lower operating costs to enable new, game-changing capabilities
- Leverage emerging commercial launch technology & entrepreneurs
- Demonstrate technology for transition to government and commercial users

XS-1 aims to create a new paradigm for more routine, responsive and affordable space operations.

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