Experimental Spaceplane (XS-1)

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

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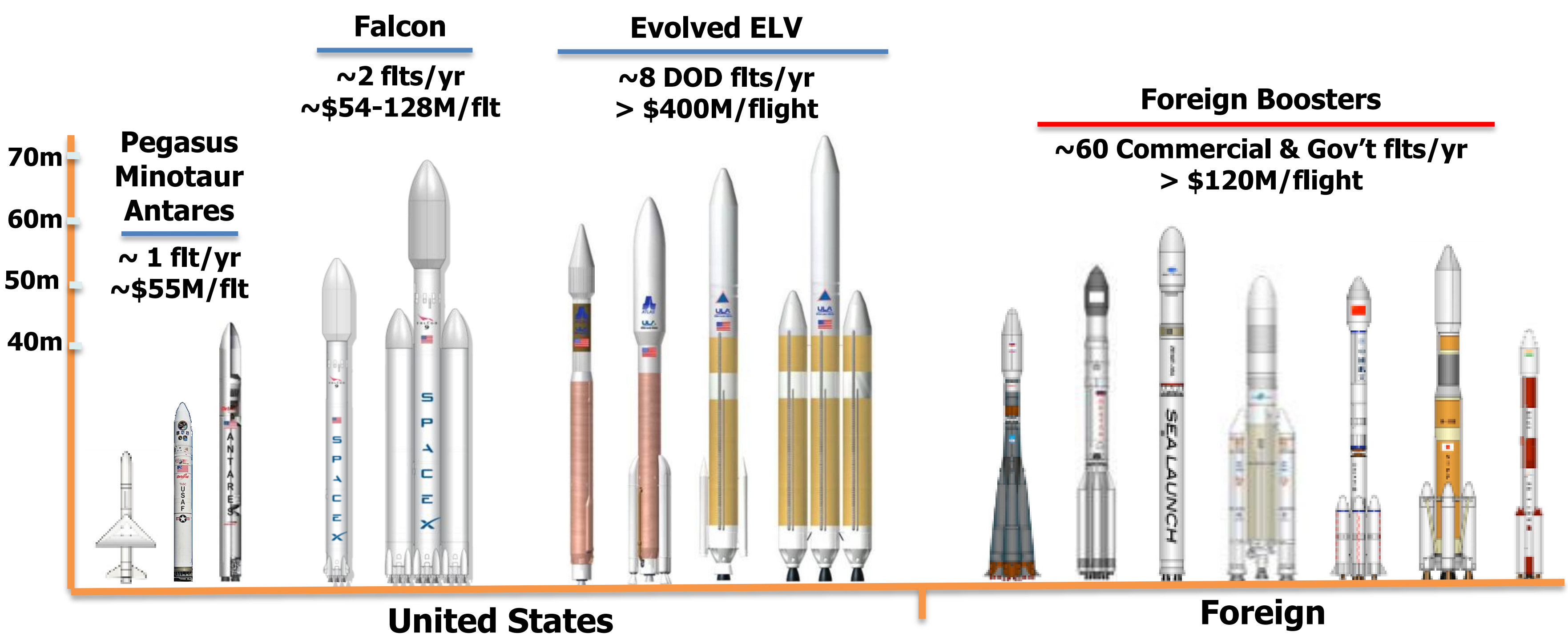
Program Overview

6 November 2013

DARPA

The Problem: Access to Space

- DoD payloads launched on Evolved ELV at ~$3B/year & growing
- Small payloads launched at ~$50M on few remaining Minotaurs
- No surge capability, long call-up times, typically > 2 years
- Budgets continue to decline
- Threats to space and air assets growing



Solution: Experimental Spaceplane (XS-1)

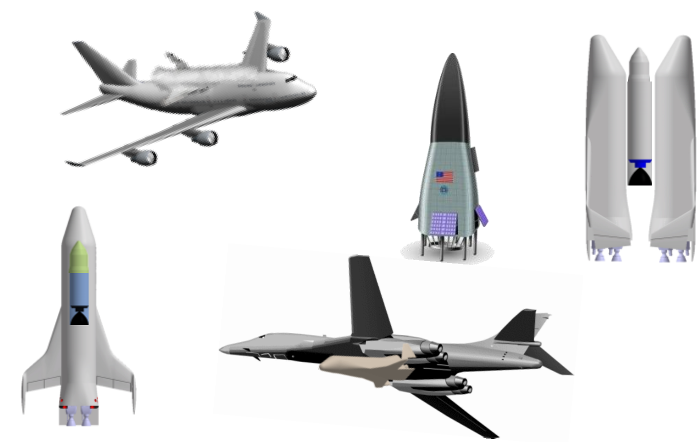
XS-1 Vision

- Break cycle of escalating space system costs
- Enable routine space access & hypersonic vehicles by integrating, testing, and maturing technologies and lean operations
- Provide capability for responsive launch of 3,000 – 5,000 lb payloads

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 – 5000 lbs to LEO at 10+ flts/yr)

Some Possible XS-1 Approaches



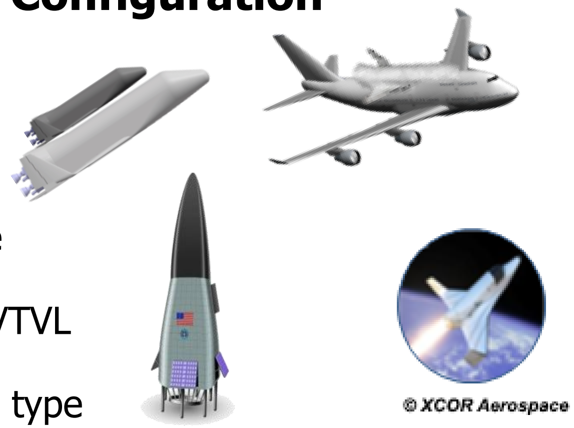
Artist Concepts

Objectives explained further in next session

Open Design Space

Configuration

- Winged
- Unwinged
- Payload carriage
- HTHL / VTHL / VTVL
- Stage count and type



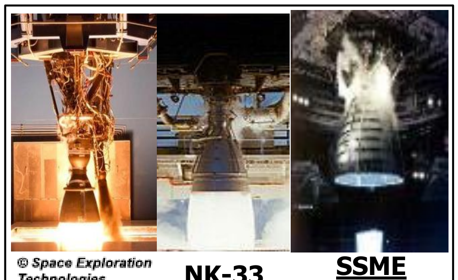
Artist Concepts

Launch and Recovery CONEMPs

- Ground launch
- Air launch
- Sea/barge launch
- Land downrange
- Return to launch site

Artist Concepts

Propulsion



Merlin Commercial Rocket

NK-33 Stockpiled Russian Rocket

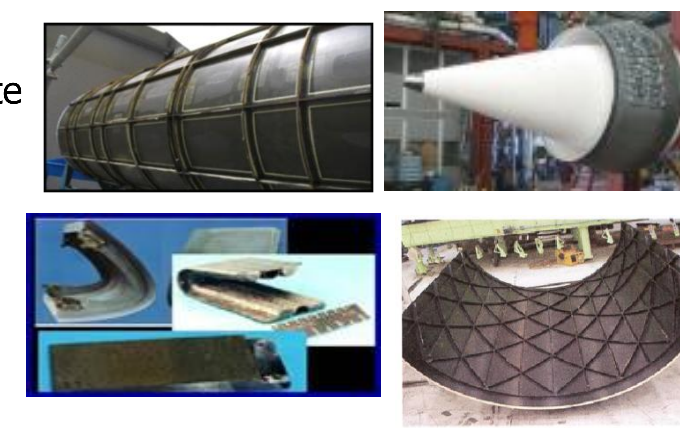
SSME Shuttle Engines

Traditional

Novel

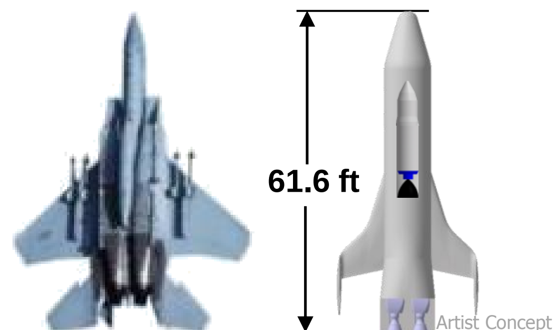
TPS and Structures

- Metallic
- Composite
- Hybrid
- Active
- Passive



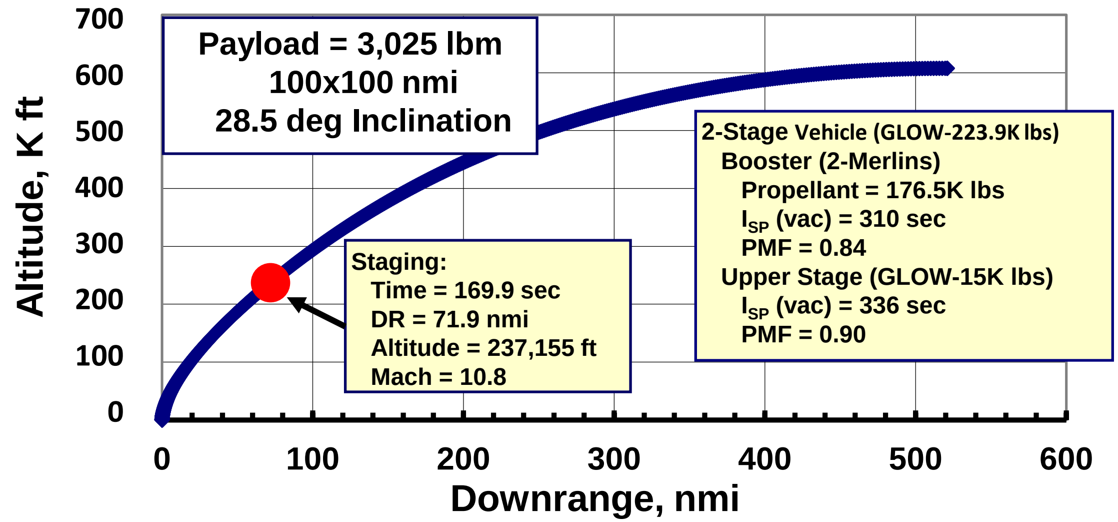
Gov't Reference X-Plane

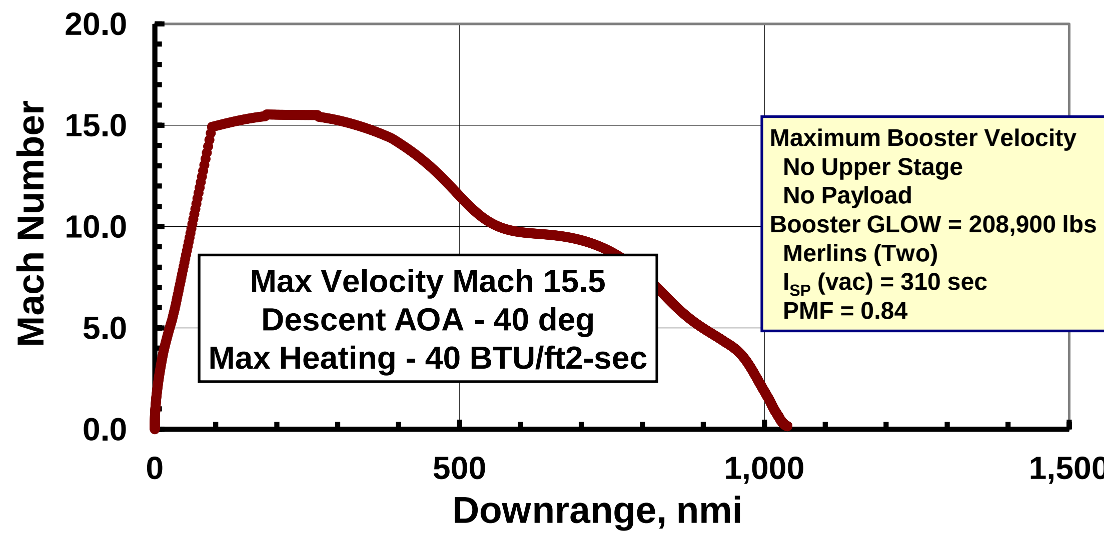
One of Many Possible Solutions



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 dry stack weight



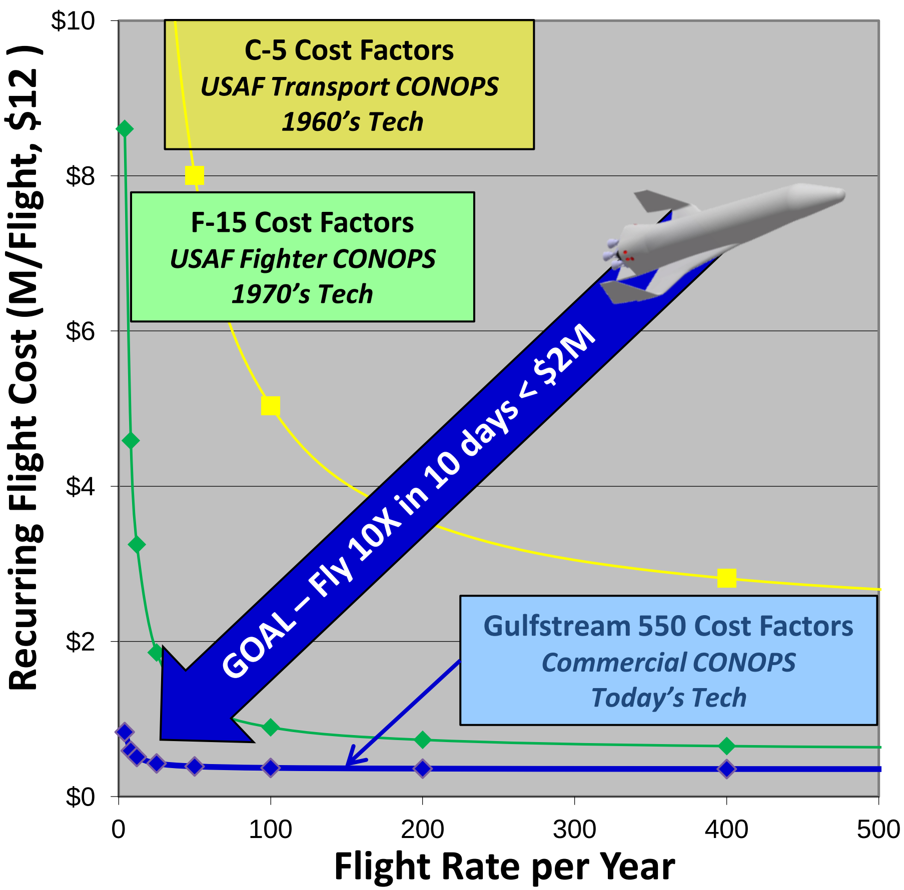


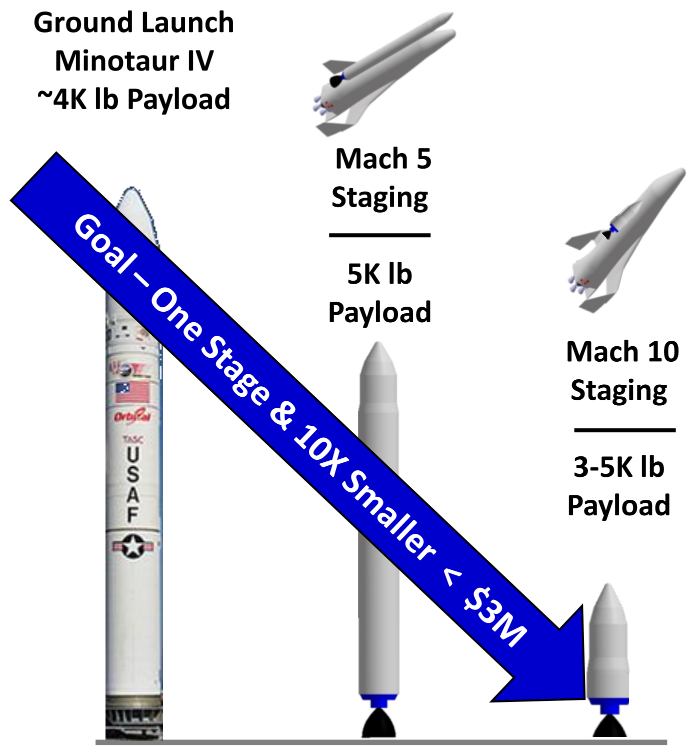
Using NK-33, air launch, two stage and/or scale-up → 5K lb payload

Addressing the Cost Equation

Aggressive and Achievable 10X Lower Recurring Flight Cost

Reusable Aircraft Cost + Expendable Hardware Cost





GLOW (K lbs)	190	67	15
No. Stages	4	2*	1*
Cost ($M)	~50	10	~1-2

* Configured as expendable upper stage

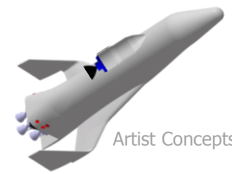
Artist Concepts

Tackle the tipping point < $5M/flight ($2M Ops + $3M Stage)

Why XS-1?

1. Breaks cycle of escalating space system costs

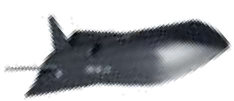
- Order of magnitude lower launch cost changes how spacecraft are built
- Enables new responsive & disaggregated architectures
- On path to affordable space

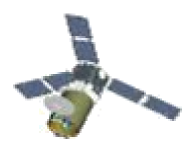


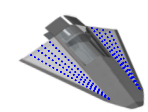
Artist Concepts

2. XS-1 enables new types of aircraft & test capabilities

- Space access aircraft → Global ISR and protection
- Affordable hypersonic aircraft → Low parts count & CTE structures/TPS
- Hypersonic testbed → boost-glide systems & hypersonics







Artist Concepts

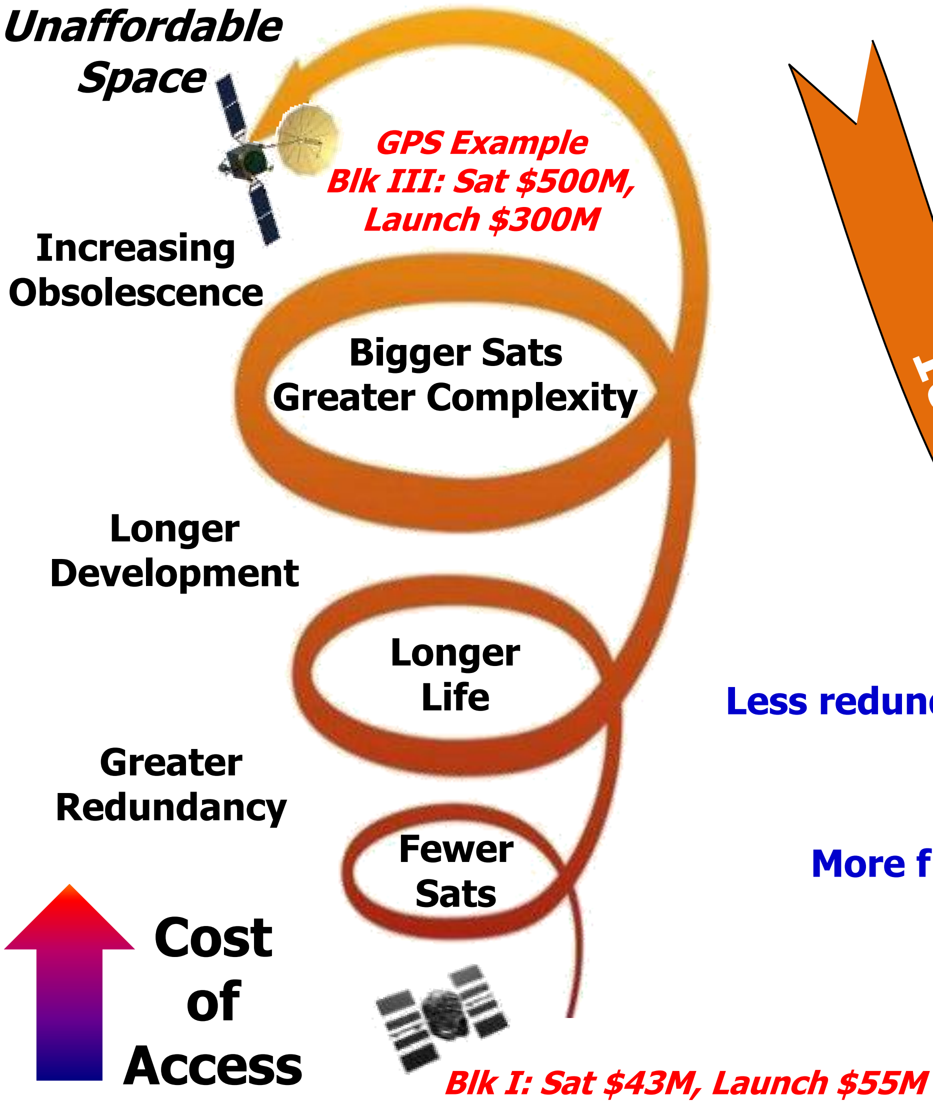
3. Enables ORS residual capability & disaggregation

- ORS Launch → single smallsat or constellations for rapid employment
- Modular launch (bi-mese) → captures AF missions, recaptures commercial market
- Disaggregation → of stage or satellite can capture AF, NRO & commercial missions

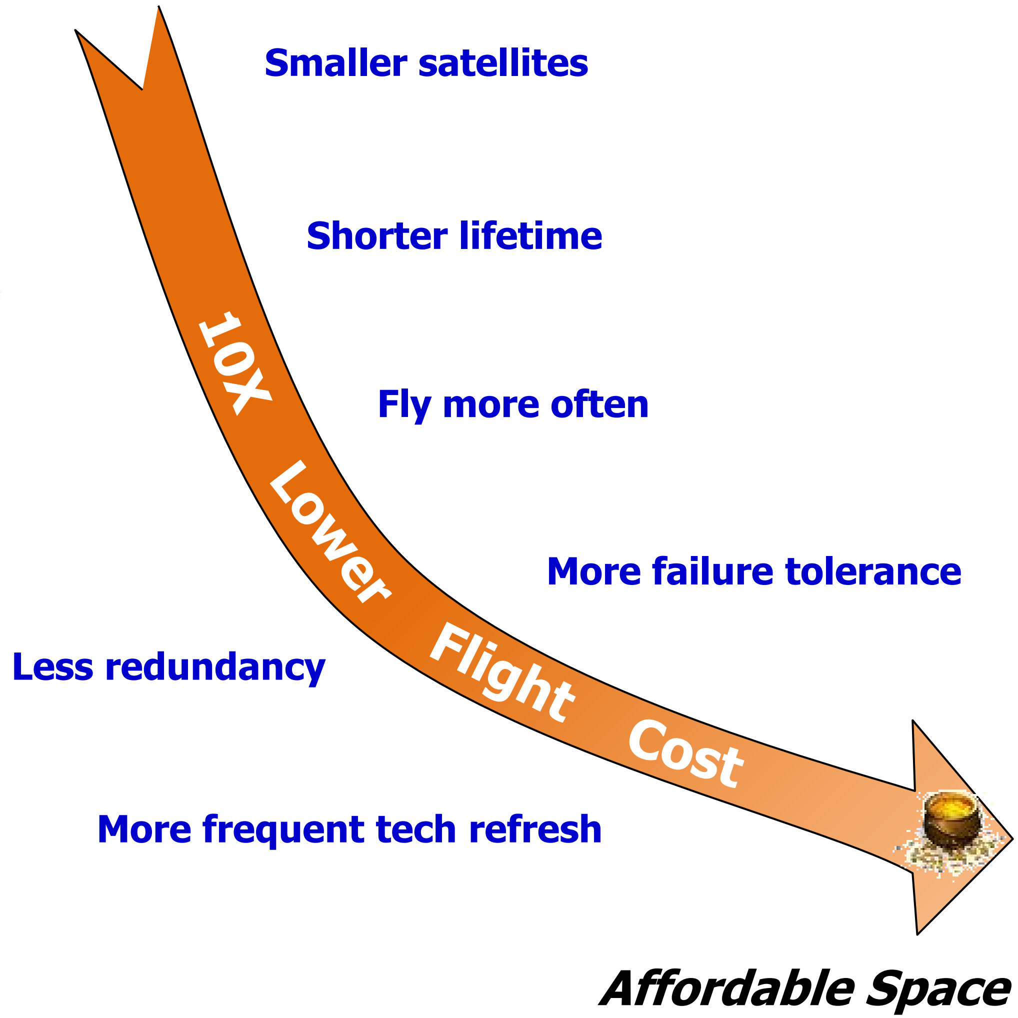
Key Goal: Break cycle of escalating space system cost

10X Cost Reduction Would Enable Many Benefits

Space Systems Cost Spiral

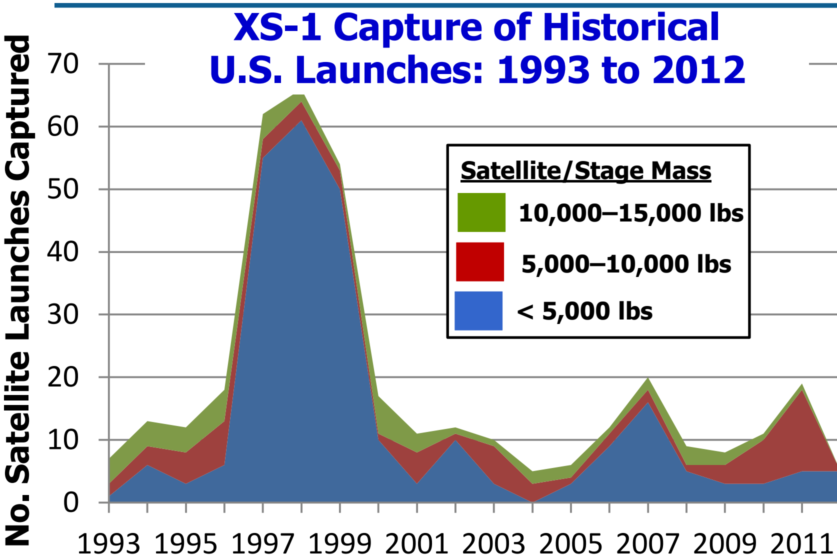


Invert the Cost Equation



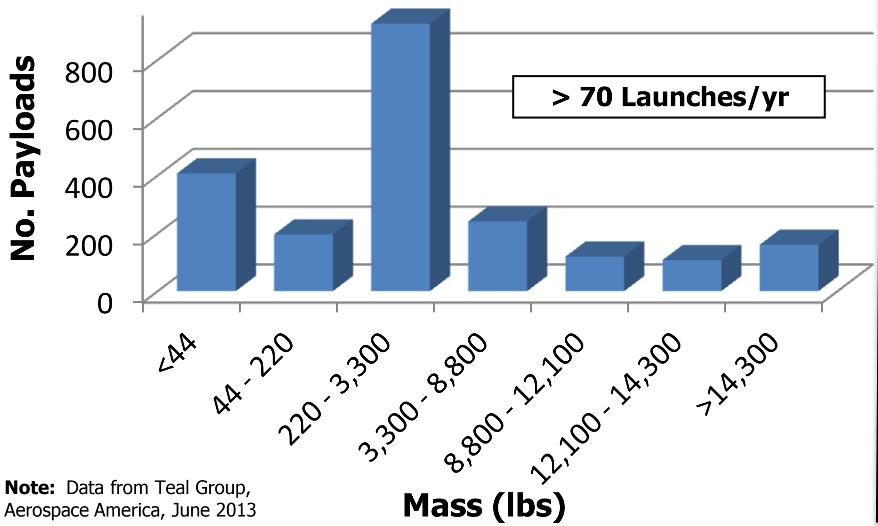
XS-1 Market #1 (DOD) and #2 (Commercial)

Responsive launch of 3 to 5K lb payloads



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 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

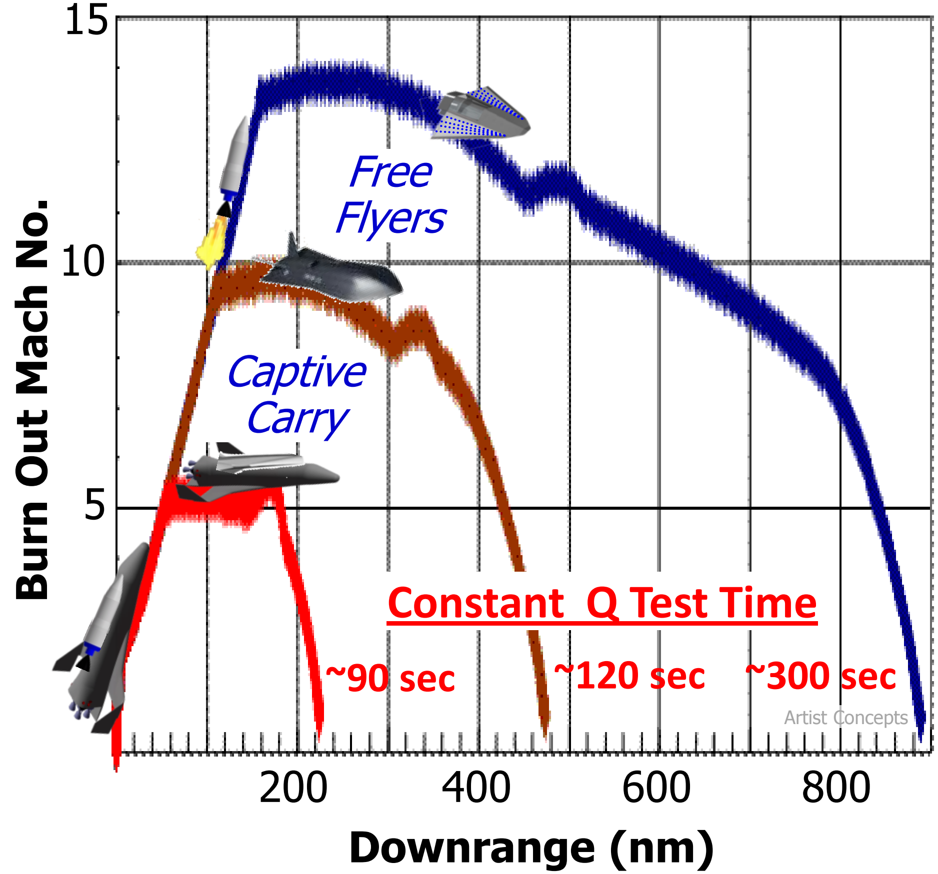
XS-1 Market #3

Hypersonic Testbed

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 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



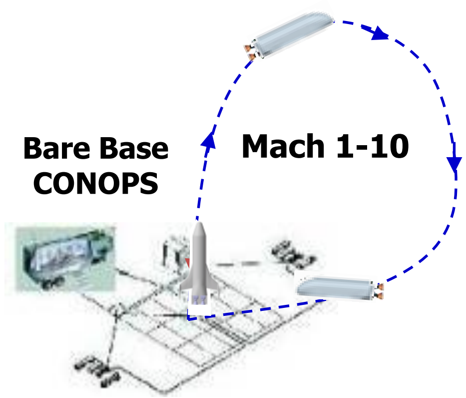
Projected Cost of Flight Test < Many (Not All) Ground Tests

Test of component & systems ♦ RAM/SCRAM/turbine ♦ Boost-glide vehicles

XS-1 Future Markets: #4, #5, etc.

Technology scaleable to future capability

Proposed XS-1 Program

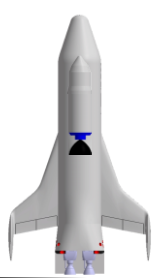


Flight Test

Build

F-15
(Size Ref)

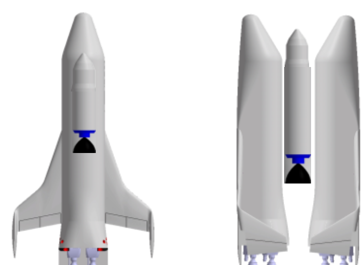
XS-1



Demonstrate

Payload to LEO

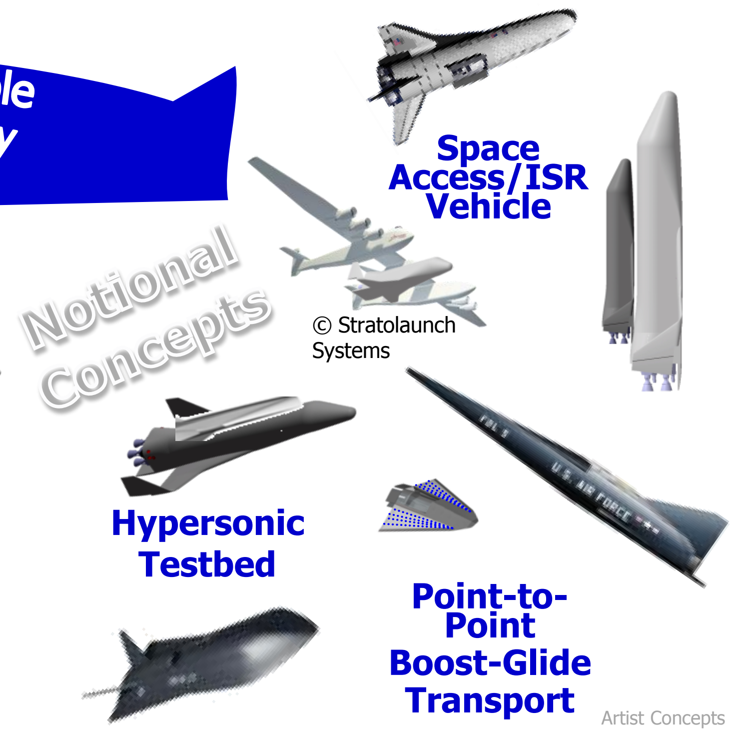
Scalable/Traceable to Future Capability



Near Term Transition Options

Commercial Capability

Commercial Launch for ORS, AF & Intel



Many Transition Options

Aircraft-Like operability

National security global reach architectures

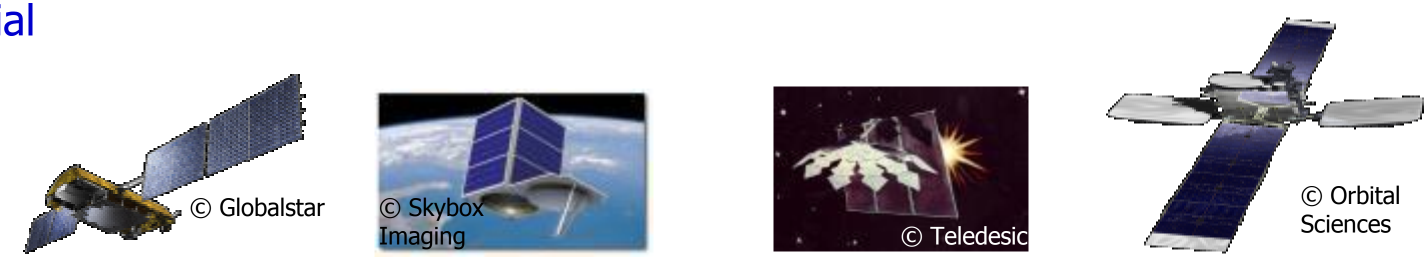
Enable AFSPC Full Spectrum Launch Capability

Transition Path Requires Proactive Industry

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

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

- Commercial
- Military
- Civil

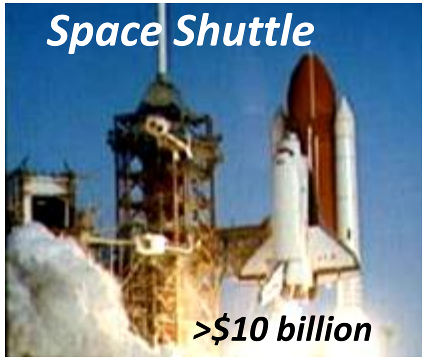


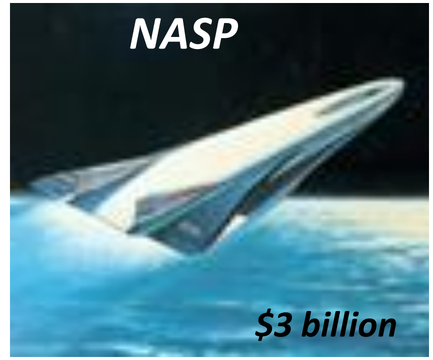
✓ **Emerging DOD requirements for disaggregation & resiliency**

- **Disaggregation:** downsize spacecraft for routine, responsive & affordable launch
- **Resiliency:** ability to fight through contested & congested environments

Consider Near-Term (#1 - #3) and Future (#4 - #5) Markets for transition when developing XS-1 designs!

Legacy of Past Programs



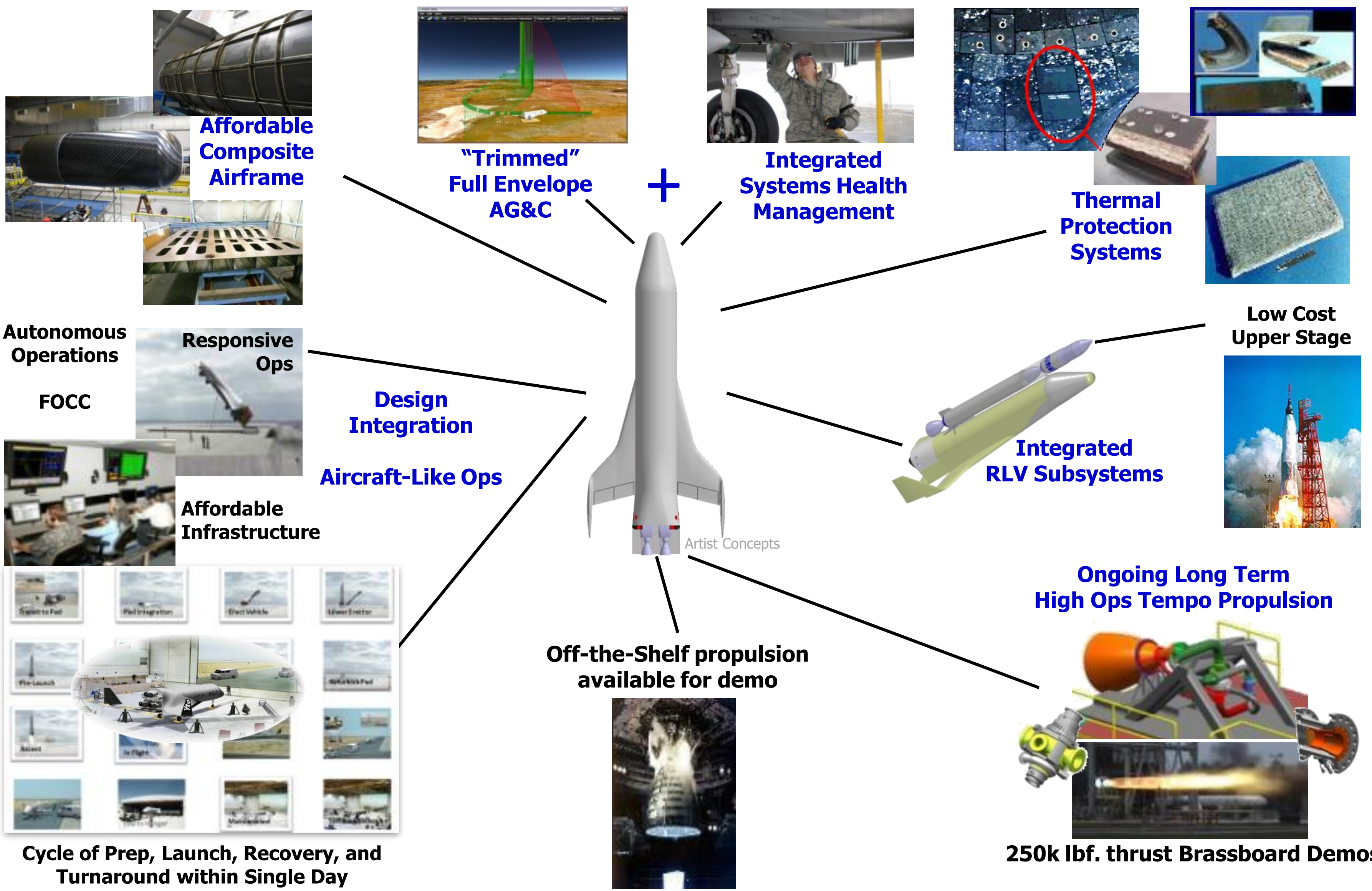


Initial Goals (requirements)	**NASA human rated** **Payload – 65K lbs** **$10M per flight**	**AF crewed** **Payload < 10K lbs** **SSTO, scramjet powered** **Aircraft-like ops, fast turn**	**NASA human rated** **Payload - 65K lbs** **SSTO, rocket powered** **Aircraft-like ops, fast turn**
Technology (at 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?

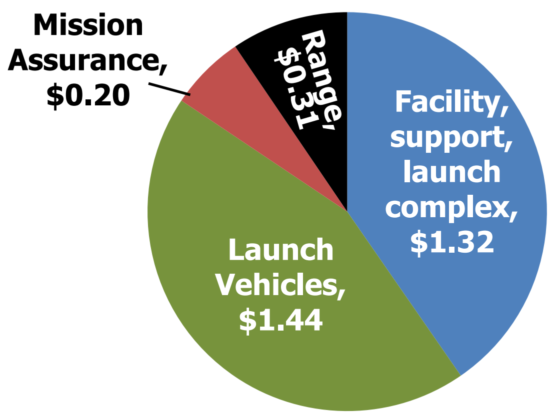
20 years of investment → Technology mature & affordable

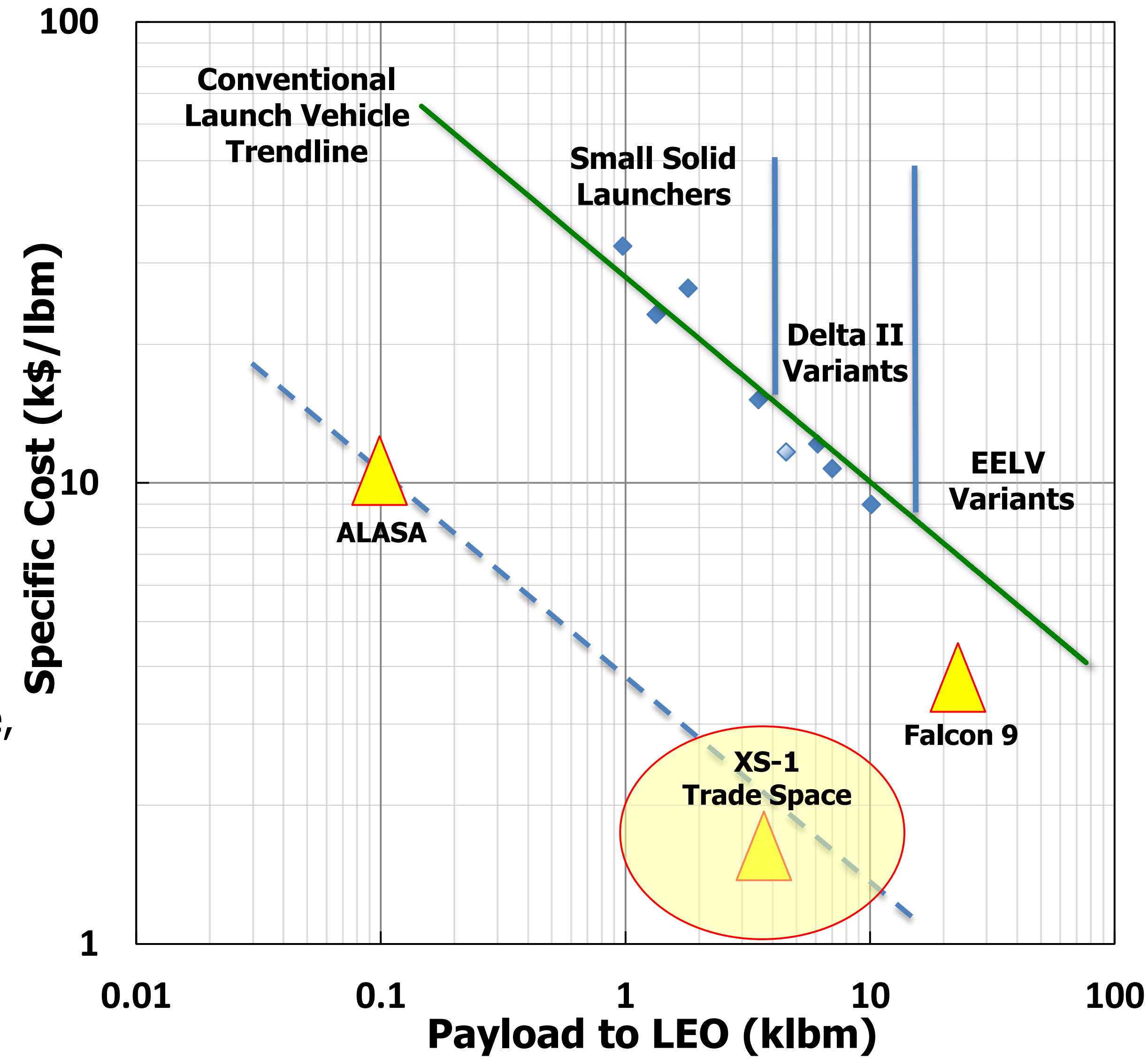


Challenges to Achieving Lower Cost

Complements heavy Falcon & EELV payloads – does not compete

ELV Launch Cost Breakdown





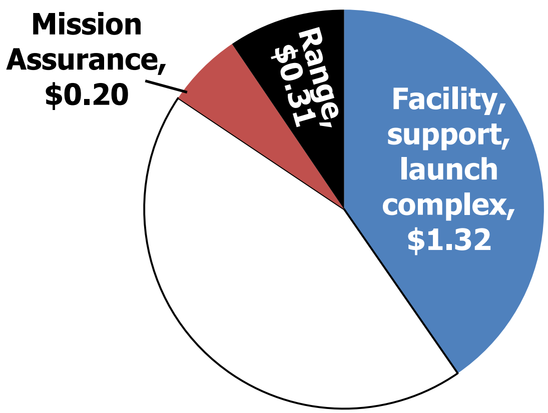
Technical Challenges

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

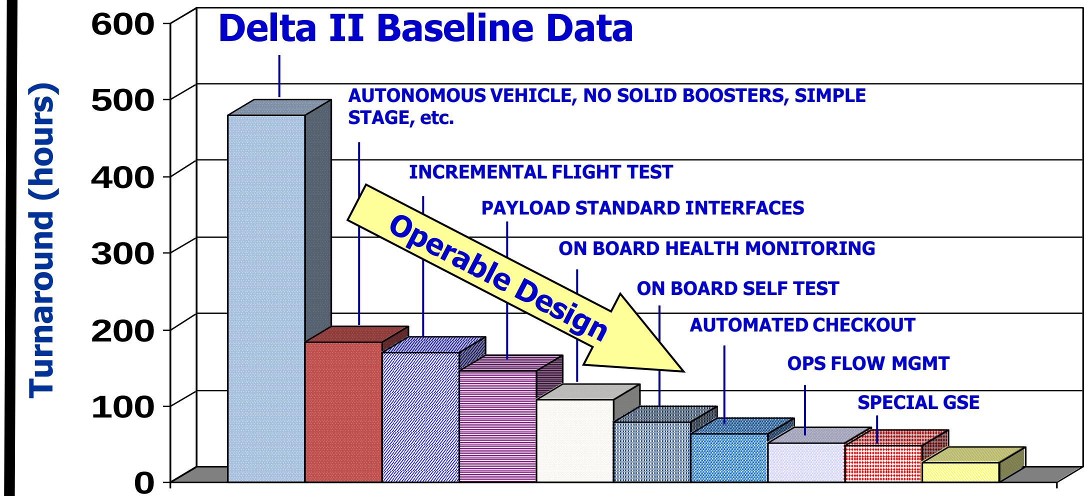
Note: Data extracted from FY12 PE/BPAC data, Excludes AFSPC payroll at launch sites and base O&M

Design and System Integration

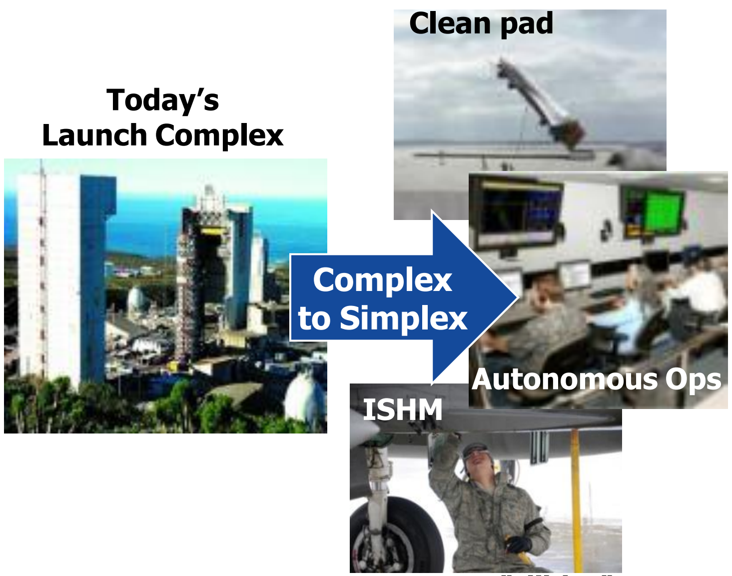
Enable "aircraft-like" operations



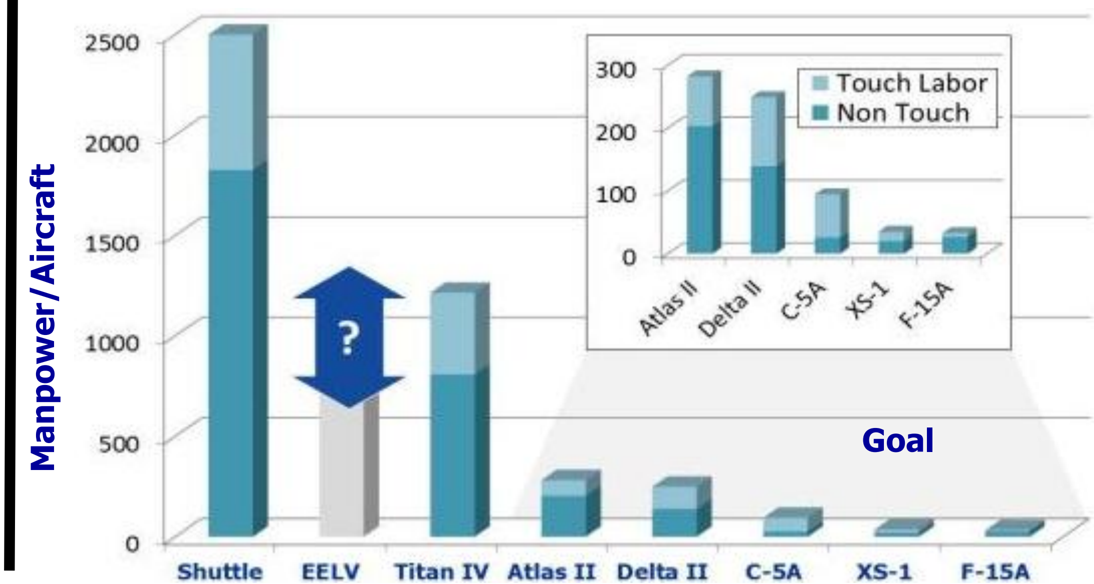
Design for Rapid Turn Reduces Manpower



Few Facilities, Small Crew Size



Launch Site/Base Manpower Comparisons



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

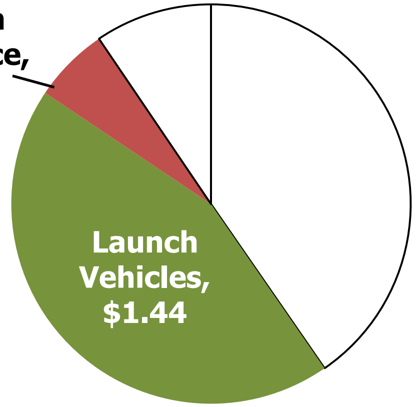
OPS CONTROL CENTER
Small 3 Person Ops Crew Size

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*

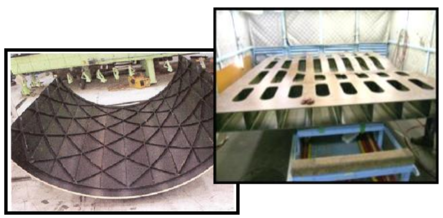
Light Weight / High Energy Airframe

High Propellant Mass Fraction (PMF)



Affordable Structure

Composite Structures Reduce Weight ~30%

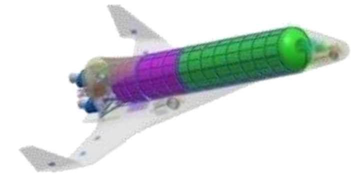


NASA Open-Core Tank in Fabrication

USAF Monocoque Tank in Test

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**

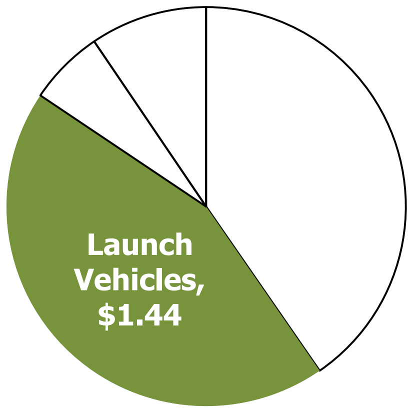
- ✓ **Reusable vehicle cost is amortized rapidly …**

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

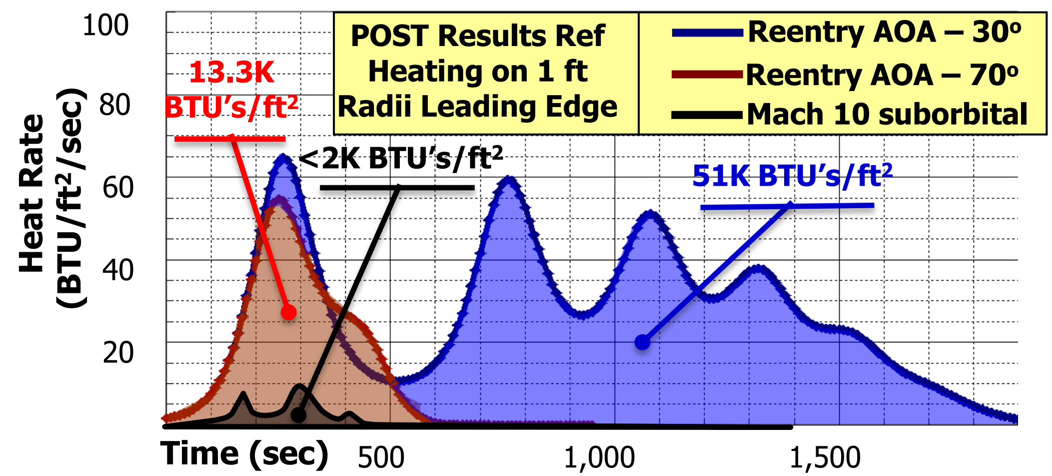
Design tank / airframe structure to enable high PMF/ΔV

Durable Thermal Structures / Protection

-300 °F to +3,000 °F

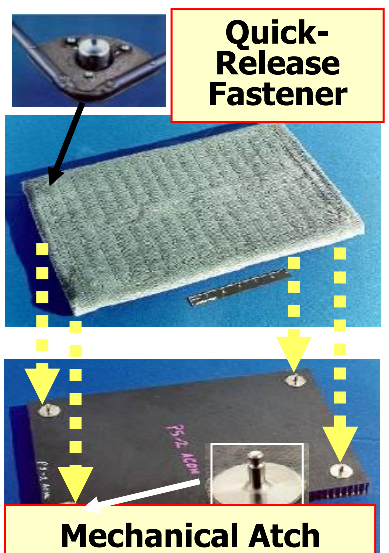


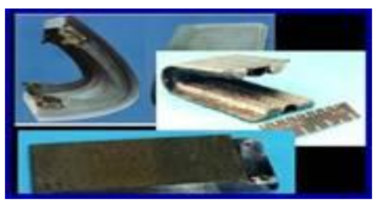
How you design & fly is key!



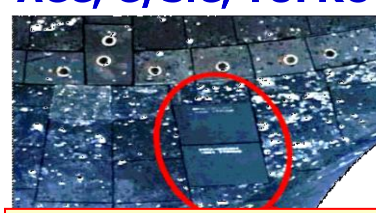
Many Thermal Protection Options

AFRSI and CRI



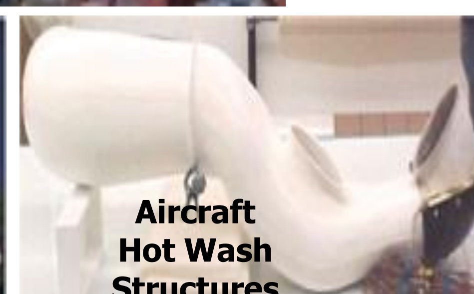


Leading Edges
ACC, C/SiC, TUFROC



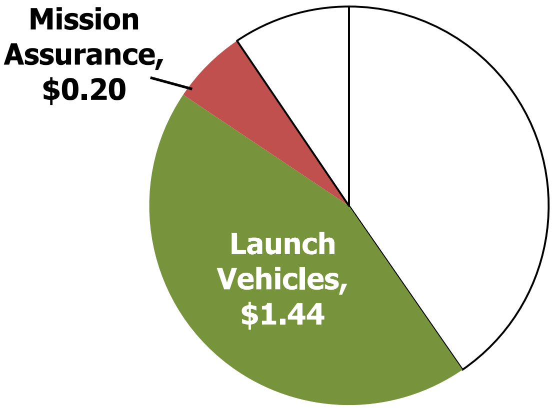
Space Shuttle Post-Flight CMC/TUFI Tiles

Emerging Thermal Structures



Reusable, Long Life and Affordable Propulsion

Multiple Options – Design Integration Challenge



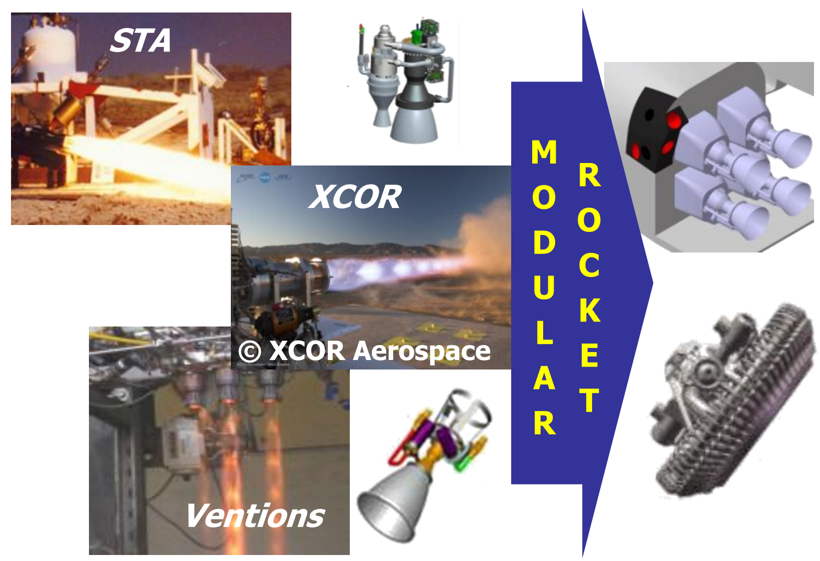
- ✓ **Use existing propulsion with mods for**
  - **Long life … rapid call up/turnaround … deep throttle**
  - **High reliability … historically, most launch failures caused by propulsion**
- ✓ **Design as Line Replaceable Unit**
  - **Rapid remove and replace**
  - **Support high ops tempo flight rate**

Multiple Affordable Propulsion Options

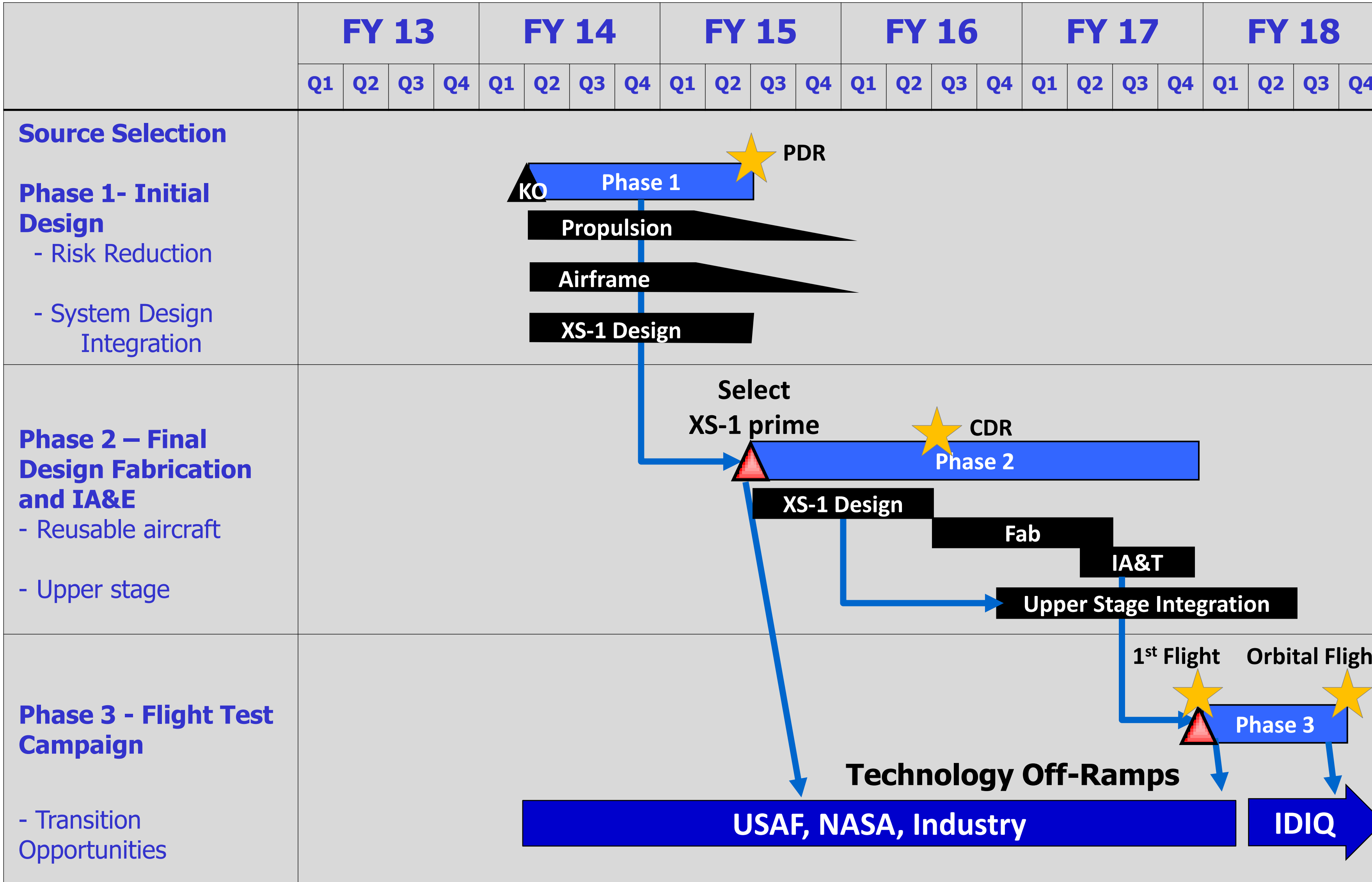
Merlin
Commercial Rocket

NK-33
Stockpiled Russian Rocket

SSME
Space Shuttle Engines



Anticipated Way Ahead



Summary

Highlights

- New era – Launch costs growing, budgets declining and threats proliferating
- Disruptive – Order of magnitude lower cost → new game changing capabilities
- Leverage – Emerging suborbital and launch technology & entrepreneurs
- Transition – Industry leads, many paths forward → Commercial, DoD, civil

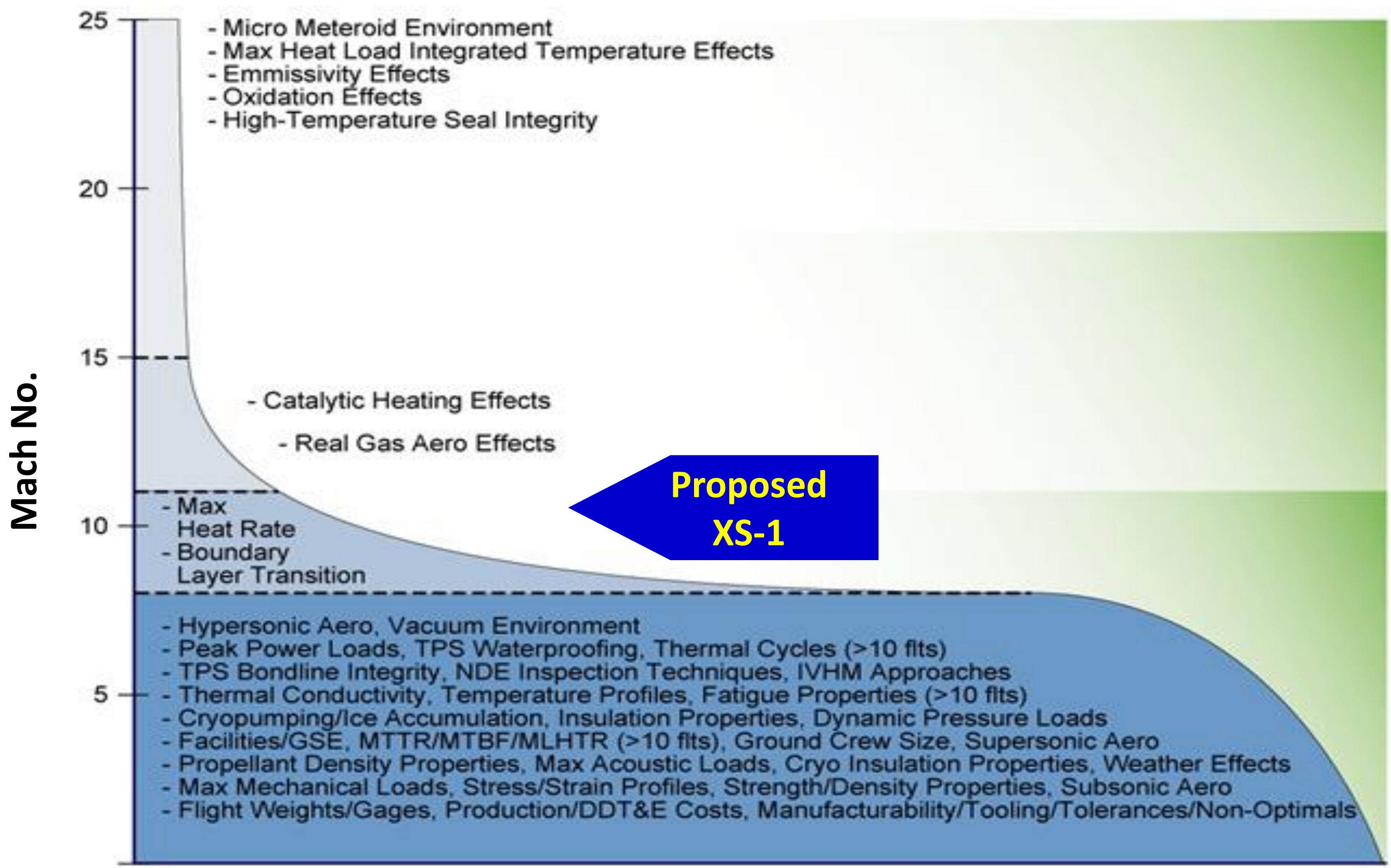
XS-1 program can be agent for change …

… DARPA open to innovative industry proposals

Several Notional Concepts

Flight Test

Mach 10 Validates Critical Technology



Technology Requirements Demonstrated

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