Experimental Spaceplane (XS-1)

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

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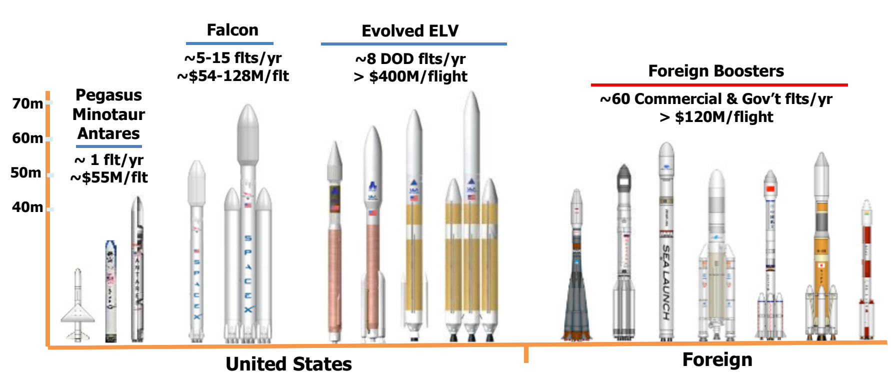
Program Manager

Program Overview for COMSTAC

16 September 2014

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



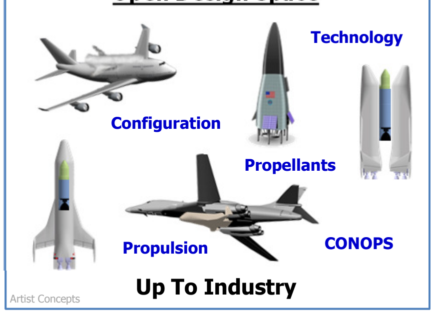
Experimental Spaceplane (XS-1)

Step One to Routine, Low Cost Access to Space

XS-1 Vision

- **Break cycle of escalating space system costs**
- **Aircraft-like operability enabling low cost, responsive access to space**
- **Accelerate introduction of hypersonic technologies and next generation aircraft**
- **Responsive platform for global reach national security and commercial applications**
- **Enable residual capability for responsive launch of 3,000 – 5,000 lb payloads**

Open Design Space



Up To Industry

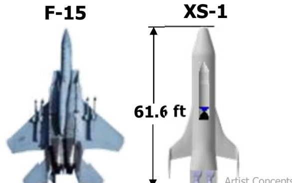
Technical objectives

- **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)

Notional Government Reference X-Plane

One of Many Possible Industry Solutions

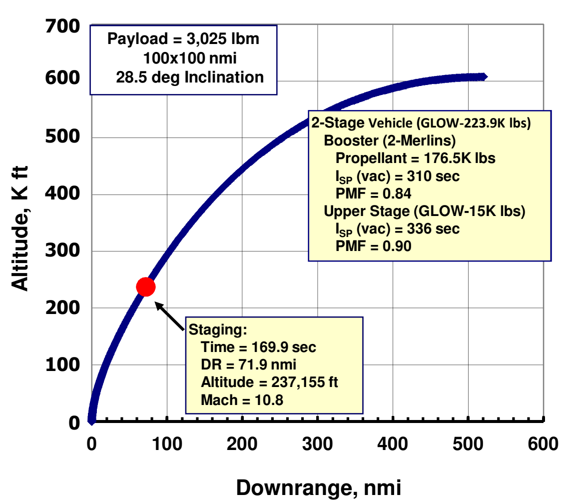


Booster	
Engine	2 Merlins
GLOW (K lbs)	223.9
MECO (K lbs)	47.4
Usable LOX/RP (K lbs)	176.5
Isp (vac)	310
Stage PMF	0.84
Upper Stage	
GLOW (lbs)	15.0
Isp (vac)	336
Stage PMF	0.9
Payload (K lbs)	3.0

Expendable stage ~5% of stack weight

Mach 10 staging with small upper stage (shown)

Alternative would be Mach 5 staging with larger upper stage



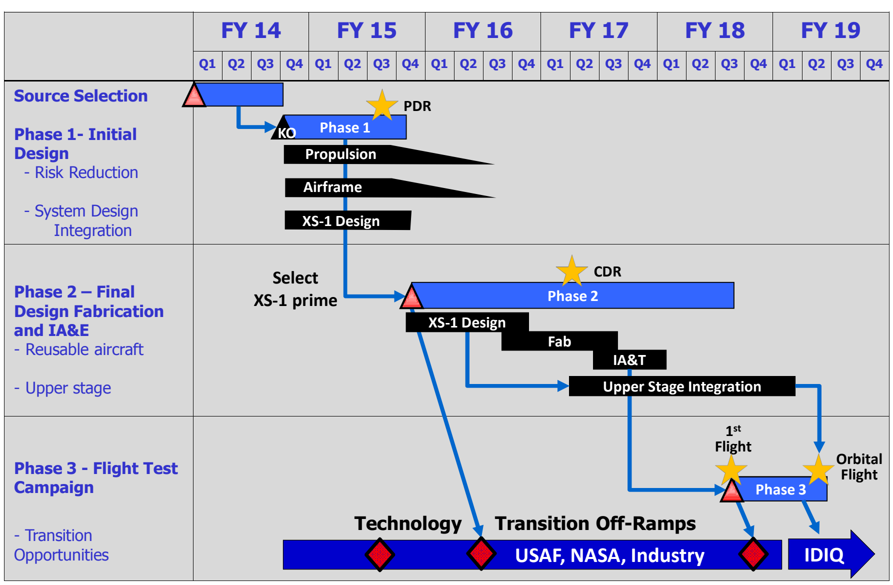
XS-1 Phase I Awards

- **Phase 1 system awards**
  - ✓ The Boeing Company working with Blue Origin
  - ✓ Northrop Grumman working with Virgin Galactic
  - ✓ Masten Space Systems working with XCOR

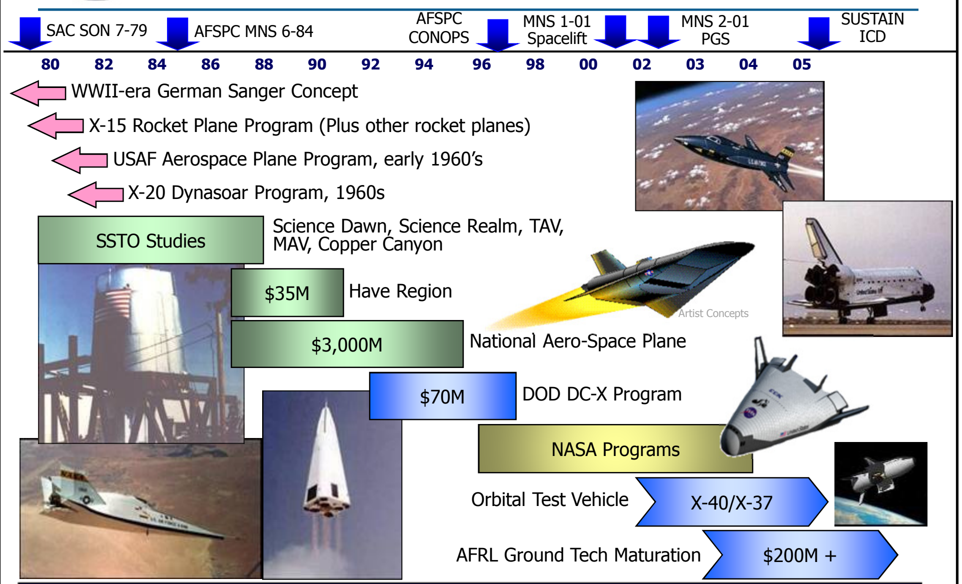


- **Technology awards/cooperative efforts**
  - ✓ Honeywell – Real-time abort trajectory generation
  - ✓ Gloyer-Taylor Labs – Composite cryogen tank fabrication and test
  - ✓ NASA Armstrong Flight Test Center – Fiber Optic Sensor System (FOSS)
  - ✓ SAS and LLNL – Ox Rich Staged Combustion / Next-Gen Rocket seedlings
  - ✓ ATK/COI – CMC Thermal Protection Systems
  - ✓ CCAT – Carbon Carbon Thermal Protection Systems
  - **Upcoming awards**
    - 2 Propulsion
    - 1 Comm / Space-Based Range Award

XS-1 Planned Schedule

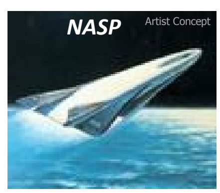


Long Spaceplane History



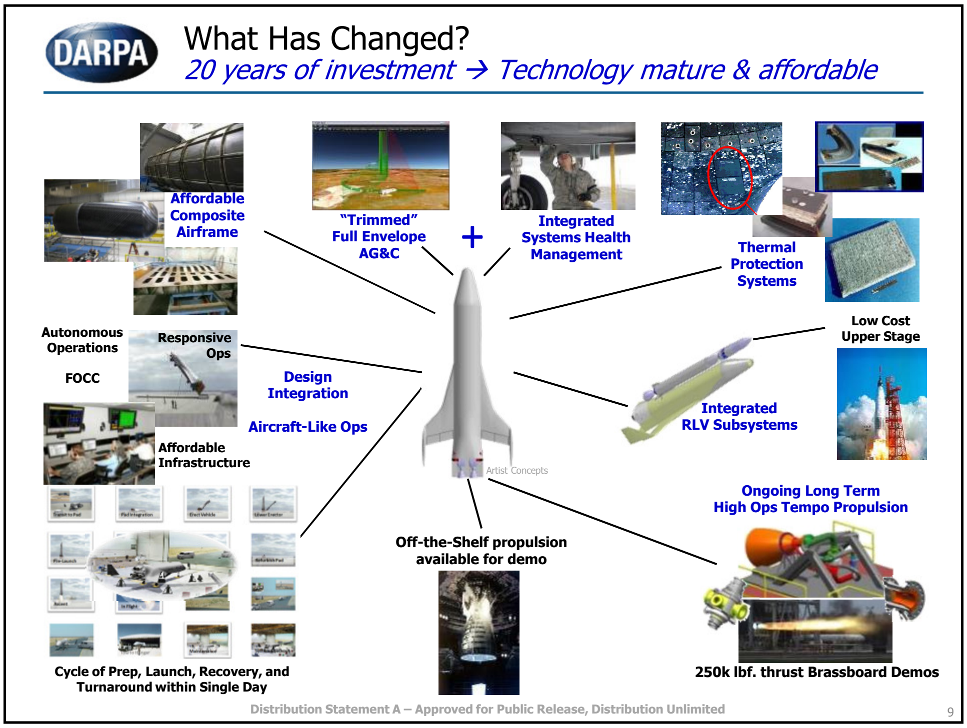
Long USAF Push for Aircraft-Like Access to Space

Legacy of Past Programs



	Space Shuttle	NASP	VentureStar
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

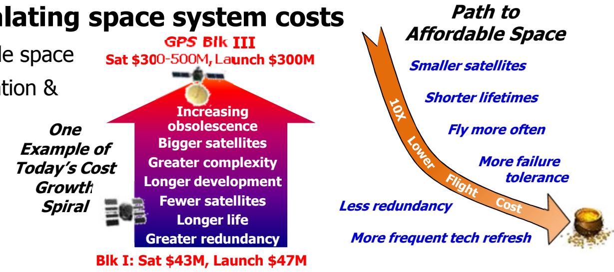
Past programs over-specified the problem (SSTO, scramjet, heavy lift, crewed, etc.) AND relied on immature designs and technology (TRL 2/3)



XS-1 Goals

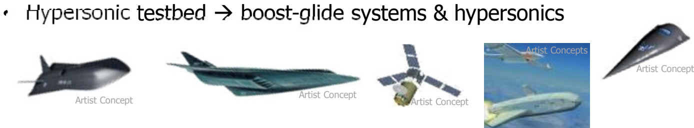
1. Break cycle of escalating space system costs

- Seeking path to affordable space
- Would enable disaggregation & resiliency strategies
- 10X lower launch cost changes how spacecraft are built



2. Enable 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



3. Enable residual capability

- ORS Launch → single smallsat or constellations for rapid employment
- Support growth options including near-term modular options

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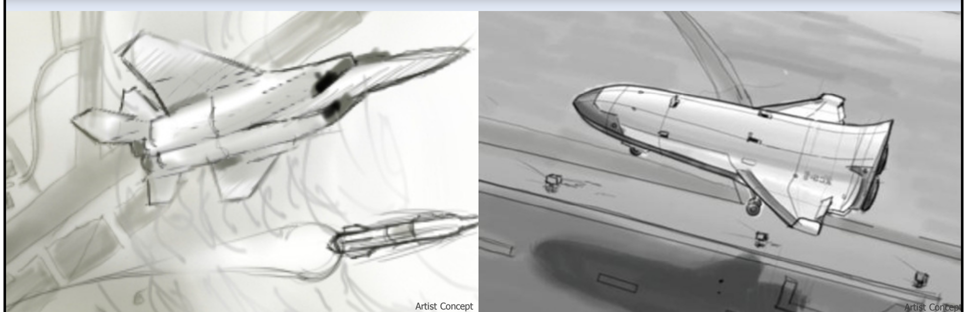
DARPA Leadership Perspective:
Attack the cost equation

Collectively the space portfolio is supporting responsiveness and cost reduction of launch through ground-based systems.

Airborne **L**aunch **A**ssist **S**pace **A**ccess (ALASA) aims to enable responsive launch of 100 lb payloads from existing globally distributed airfields to enable next-generation tactical missions

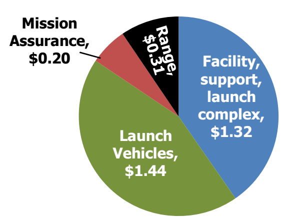
The E**x**perimental **S**paceplane (XS-1) reusable vehicle capability would extend this capability to 3,000 lb payloads with "aircraft-like" access to space at 10X lower costs



All images are artist's concept

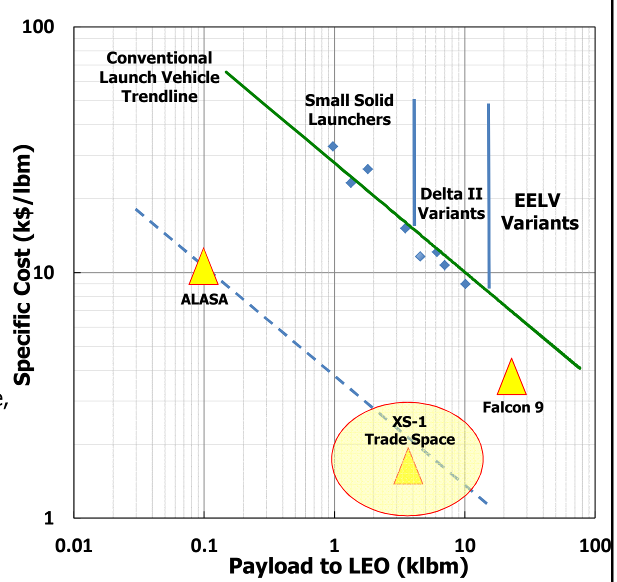
Challenges to Achieving Lower Cost
XS-1 would complement heavy Falcon & EELV payloads

ELV Launch Cost Breakdown



Technical Challenges

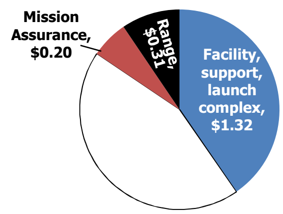
- Design and system integration enabling "aircraft-like" operations
- Light weight/high energy airframe, high propellant mass fraction
- Durable thermal structures/ protection, -300°F to +3,000°F
- Reusable, long life & affordable propulsion



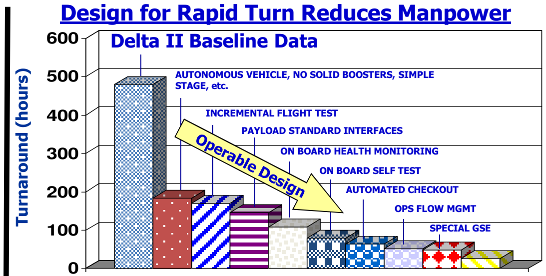
Note: Data extracted from FY12 PE/BPAC data, Excludes AFSPC payroll at launch sites and base O&M

Goal: Design and System Integration

Enable "aircraft-like" operations

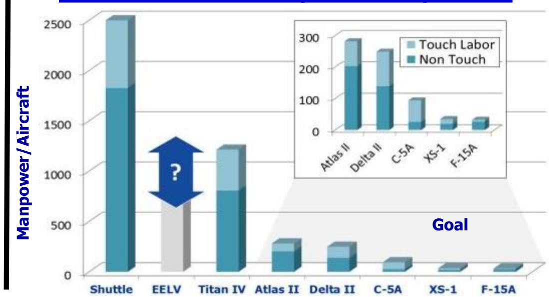


Design for Rapid Turn Reduces Manpower



Few Facilities, Small Crew Size

Launch Site/Base Manpower Comparisons



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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*

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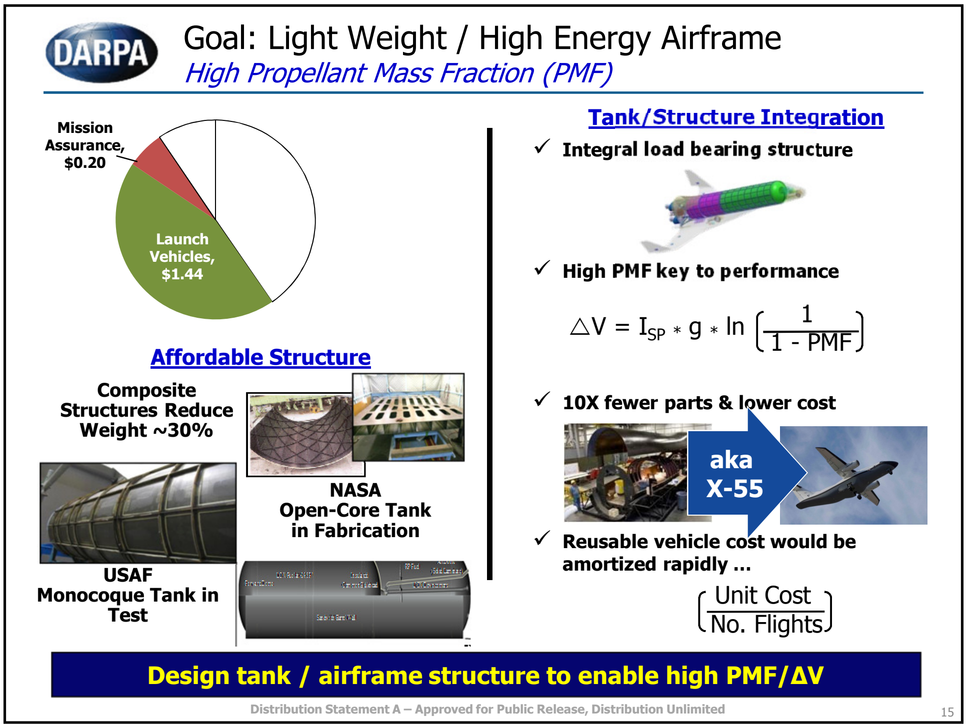
DARPA
Goal: Light Weight / High Energy Airframe
High Propellant Mass Fraction (PMF)
Mission Assurance, $0.20
Launch Vehicles, $1.44
Affordable Structure
Composite Structures Reduce Weight ~30%
NASA Open-Core Tank in Fabrication
USAF Monocoque Tank in Test
Tank/Structure Integration
✓ Integral load bearing structure
✓ High PMF key to performance
$\triangle V = I_{SP} * g * \ln\left(\frac{1}{1 - PMF}\right)$
✓ 10X fewer parts & lower cost
aka X-55
✓ 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
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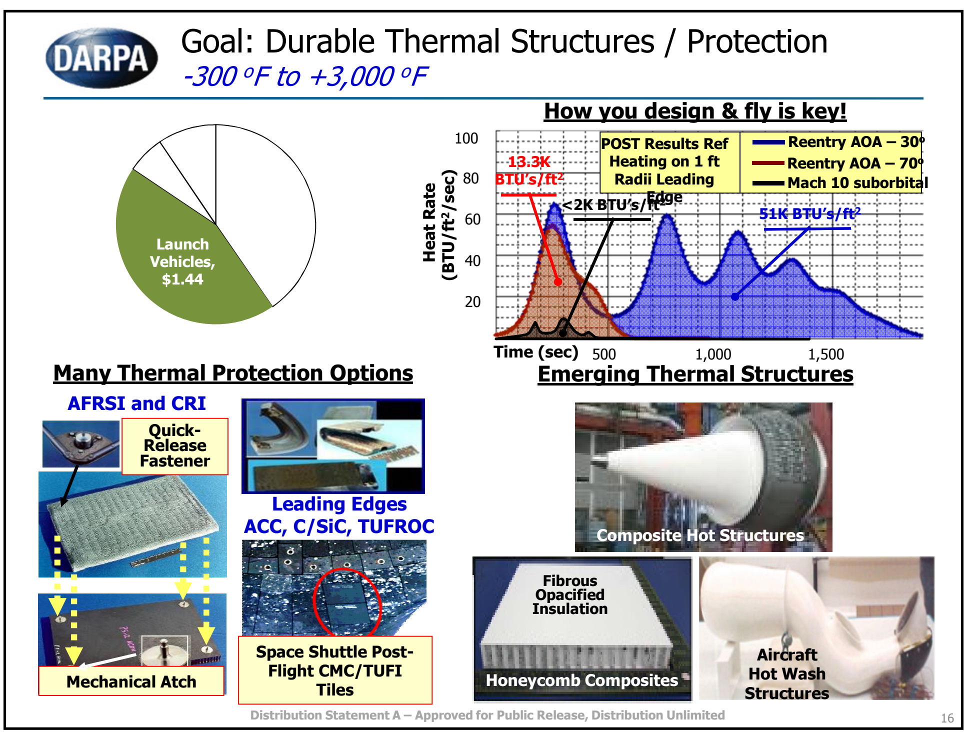
DARPA
Goal: Durable Thermal Structures / Protection
-300 °F to +3,000 °F
Launch Vehicles, $1.44
How you design & fly is key!
POST Results Ref Heating on 1 ft Radii Leading Edge
Reentry AOA – 30°
Reentry AOA – 70°
Mach 10 suborbital
13.3K BTU's/ft²
<2K BTU's/ft²
51K BTU's/ft²
Heat Rate (BTU/ft²/sec)
100
80
60
40
20
Time (sec) 500 1,000 1,500
Many Thermal Protection Options
AFRSI and CRI
Quick-Release Fastener
Mechanical Atch
Leading Edges ACC, C/SiC, TUFROC
Space Shuttle Post-Flight CMC/TUFI Tiles
Emerging Thermal Structures
Composite Hot Structures
Fibrous Opacified Insulation
Honeycomb Composites
Aircraft Hot Wash Structures
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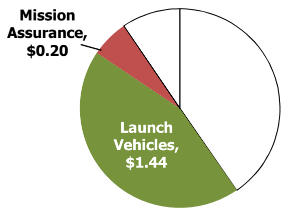
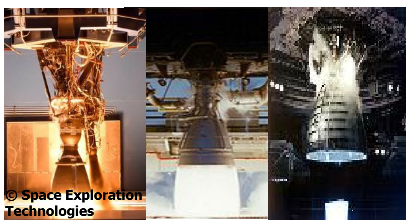
Goal: Reusable, Long Life and Affordable Propulsion

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**

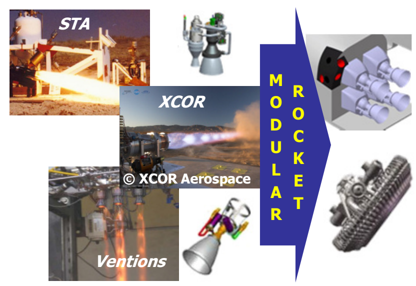
Multiple Affordable Propulsion Options



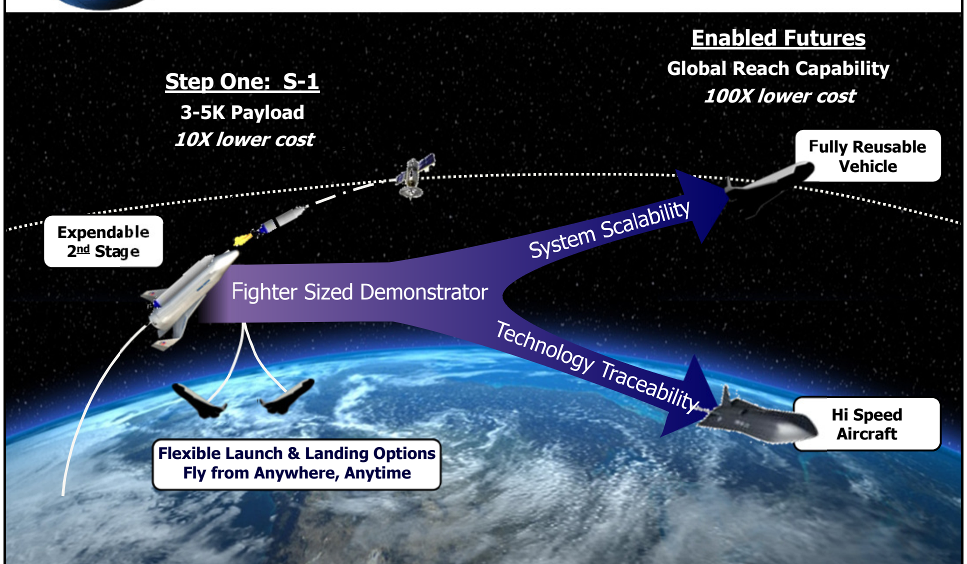
Merlin Commercial Rocket

NK-33 Stockpiled Russian Rocket

SSME Space Shuttle Engines

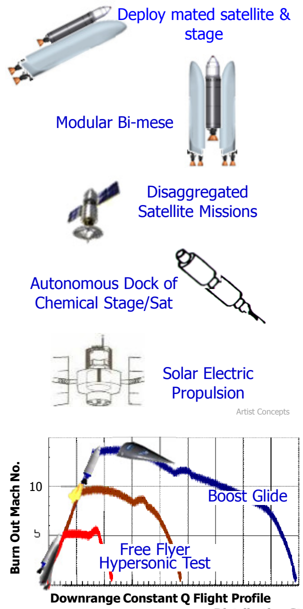


OV-1 Derived Capabilities



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

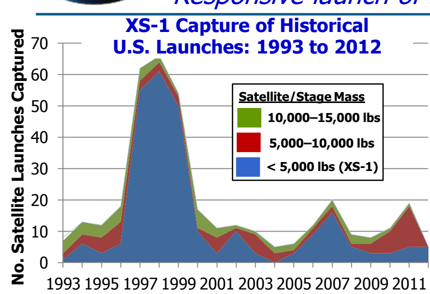
XS-1 Capabilities Would Evolve Over Time



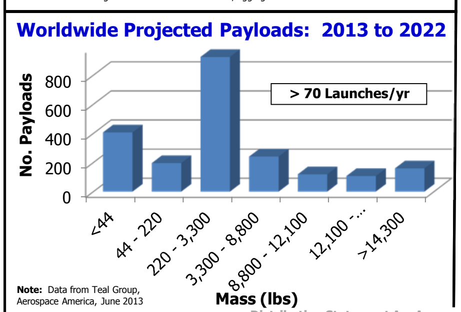
- **Core capability > 3,000 lbs to LEO**
  - ✓ Option: Grow capability with modular launch
- **Payload disaggregation could shrink sizes**
  - ✓ Downsize & modernize payloads
  - ✓ Single payload siimplified spacecraft
- **Stage disaggregation would grow effective payload**
  - ✓ Launch satellite payloads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

Potential XS-1 DOD and Commercial Satellite Markets

Responsive launch of 3 to 5K lb payloads



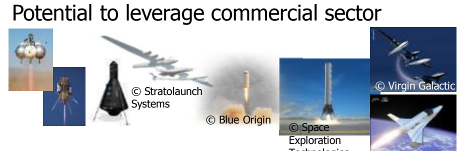
Note: All satellites launched on U.S. boosters. U.S. satellites launched on foreign boosters. Excludes classified & crewed flights. Counts satellites >1K lbs, aggregates smaller satellites.



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

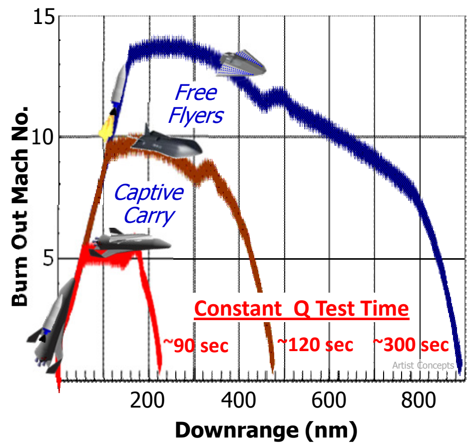
➔ Projected market much higher

XS-1 Could Facilitate Next Gen 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

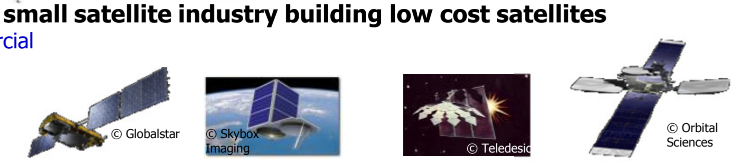


Projected Cost of Flight Test < Many (Not All) Ground Tests
Test of component/systems ♦ RAM/SCRAM/turbine ♦ Boost-glide vehicles

XS-1 Transition Path Would Require Proactive Industry

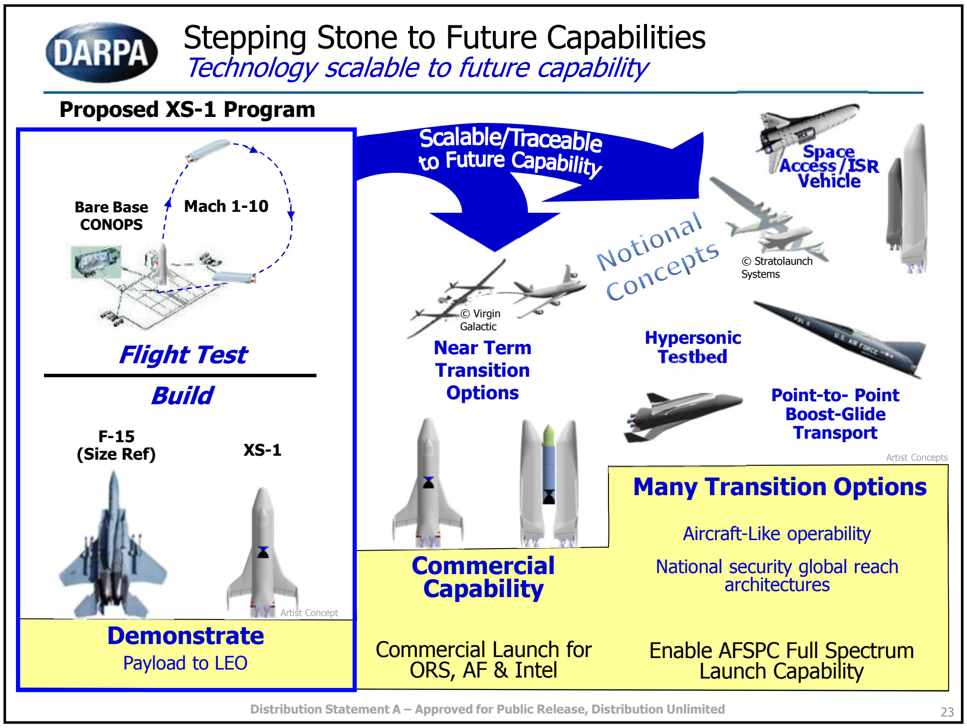
✓ **Robust DOD and commercial launch industry with ideas**

✓ **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


DARPA
Stepping Stone to Future Capabilities
Technology scalable to future capability
Proposed XS-1 Program
Bare Base CONOPS
Mach 1-10
Flight Test
Build
F-15 (Size Ref)
XS-1
Artist Concept
Demonstrate
Payload to LEO
Scalable/Traceable to Future Capability
Notional Concepts
© Virgin Galactic
Near Term Transition Options
Space Access/ISR Vehicle
© Stratolaunch Systems
Hypersonic Testbed
Point-to- Point Boost-Glide Transport
Artist Concepts
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
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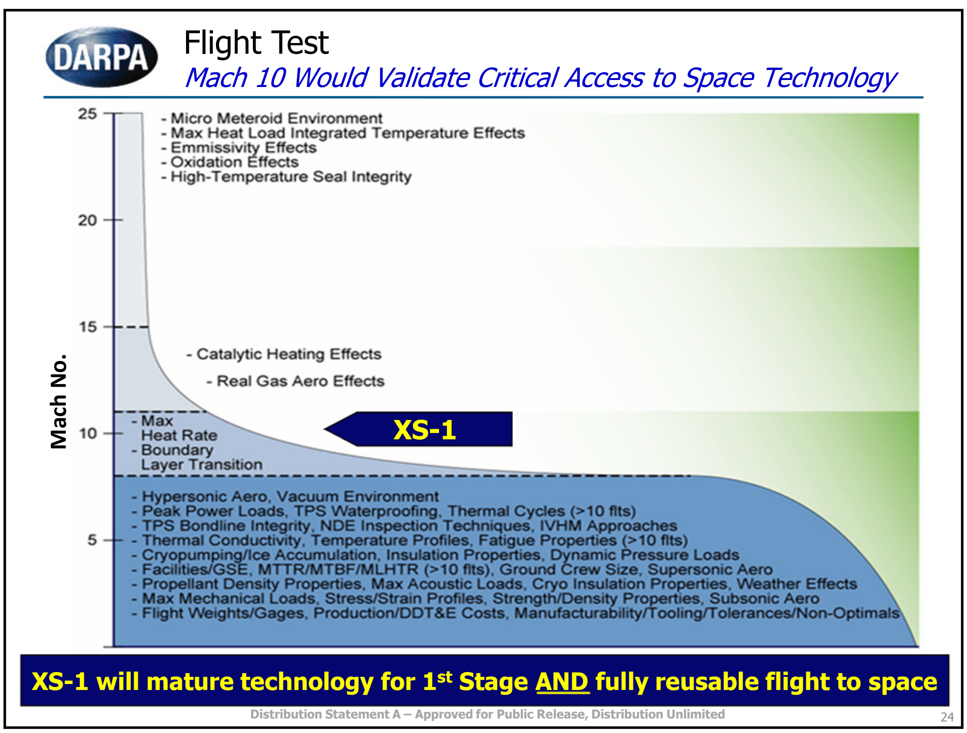
DARPA
Flight Test
Mach 10 Would Validate Critical Access to Space Technology
Mach No.
25
20
15
10
5
- Micro Meteroid Environment
- Max Heat Load Integrated Temperature Effects
- Emmissivity Effects
- Oxidation Effects
- High-Temperature Seal Integrity
- Catalytic Heating Effects
- Real Gas Aero Effects
- Max Heat Rate
- Boundary Layer Transition
XS-1
- Hypersonic Aero, Vacuum Environment
- Peak Power Loads, TPS Waterproofing, Thermal Cycles (>10 flts)
- TPS Bondline Integrity, NDE Inspection Techniques, IVHM Approaches
- Thermal Conductivity, Temperature Profiles, Fatigue Properties (>10 flts)
- Cryopumping/Ice Accumulation, Insulation Properties, Dynamic Pressure Loads
- Facilities/GSE, MTTR/MTBF/MLHTR (>10 flts), Ground Crew Size, Supersonic Aero
- Propellant Density Properties, Max Acoustic Loads, Cryo Insulation Properties, Weather Effects
- Max Mechanical Loads, Stress/Strain Profiles, Strength/Density Properties, Subsonic Aero
- Flight Weights/Gages, Production/DDT&E Costs, Manufacturability/Tooling/Tolerances/Non-Optimals
XS-1 will mature technology for 1st Stage AND fully reusable flight to space
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XS-1 Seeks to …

- Push Mach capability well beyond suborbital tourism
- Engage FAA-DOD-Industry teams to establish safe standards of practice for new launch systems
- Leverage commercial sector technology (Blue Origin, Virgin Galactic, XCOR, etc.)
- Transition vendor/subcontractor technology to commercial sector
- Transition some system prime technology to commercial sector
- Transition launch capability to commercial sector
- Explore new missions like hypersonic testing and point-to-point transport
- Enable more affordable launch expanding satellite opportunities
- Serve as a step to fully reusable access to space technologies

Trailblaze next generation commercial space …
… technology, flight envelope, regulatory, new markets, etc.

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 could be an agent for change …
… DARPA open to innovative industry proposals

Several Notional Concepts

www.darpa.mil