Experimental Spaceplane (XS-1)

Aiming to Reduce the Time to Space and Cost to Space by Orders of Magnitude

Mr. Jess Sponable, TTO Program Manager

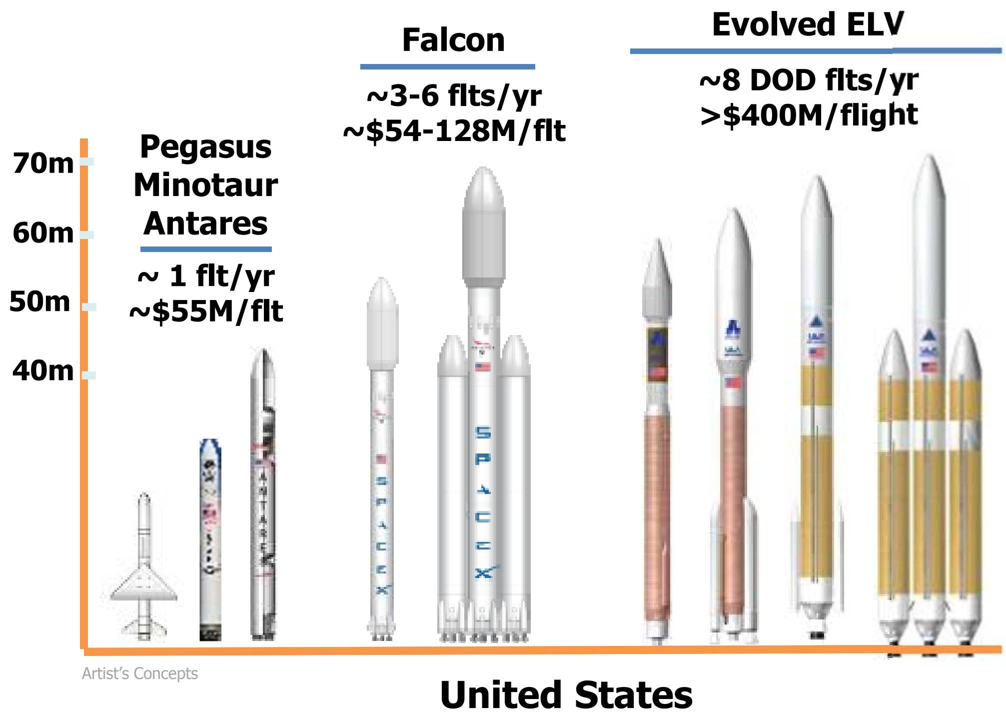
Program Overview

29 April 2016

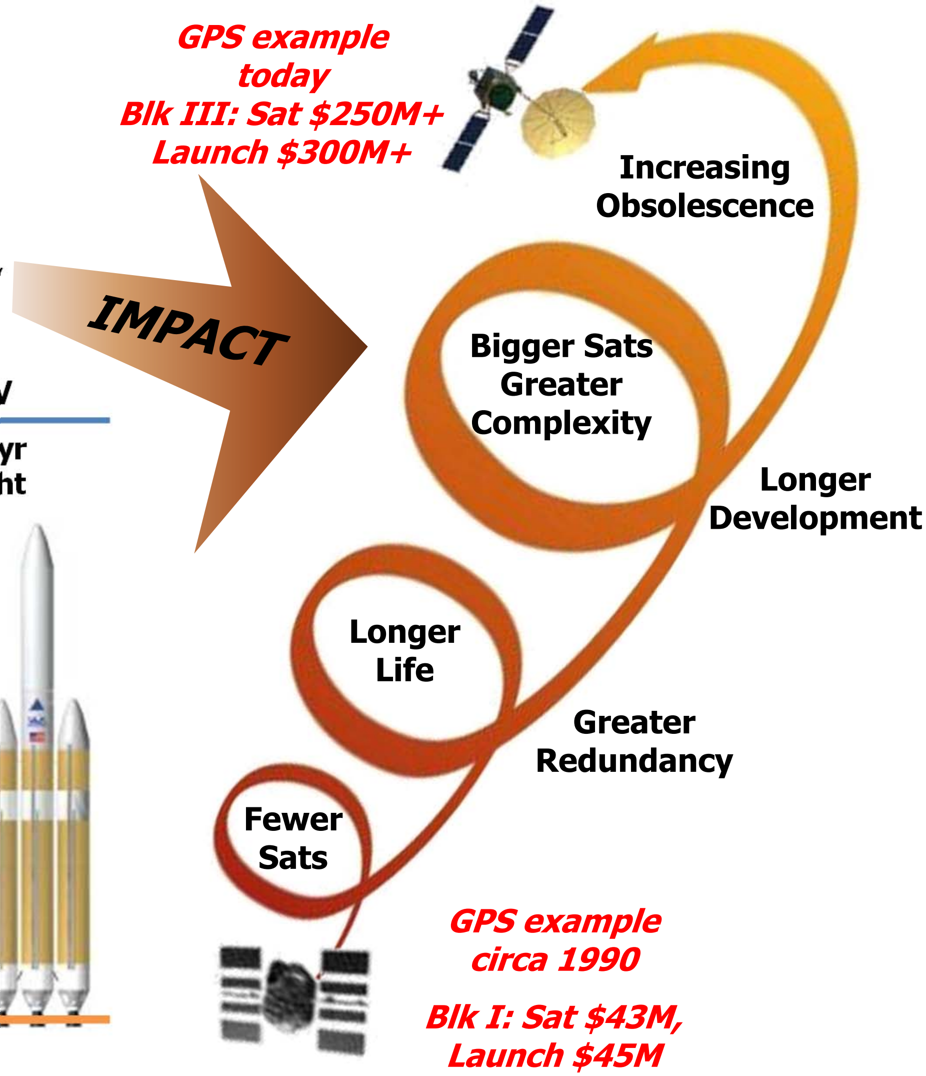
U.S. launch costs are a growing problem

Dramatic growth in U.S. launch costs since early 1990s…

- ✓ DoD launch >$3B/year & growing
- ✓ Small launch >$50M each
- ✓ Commercial launch fled overseas
- ✓ Launch costs are "tip of the iceberg"



…is driving much larger growth in space system costs



XS-1—what is it?

Reusable 1st stage, expendable upper stage

GOALS

1. Fly 10X in 10 days, no upper stage/payload
2. Design the objective system for >3,000-lb payload at <$5M/flight
3. Fly demo system one time with orbital payload >900 lbs

XS-1 goals

PRIORITIZED GOALS	OBJECTIVE	THRESHOLD
Design a reusable booster system with launch costs traceable to <$5M/flight[1,2]	Payload: ≥3,000 lbs to 90° inclination, 100 nmi circular (reference orbit)	Payload: ≥3,000 lbs to 28.5° inclination, 100 nmi circular (reference orbit)
Fly booster 10 times in 10 days[3]	Sequential calendar days	Allow for weather, range, & emergency delays
Demonstrate an immediate payload to orbit capability with cost traceability to the Operational System[2,4]	Payload: ≥1,500 lbs to 100 nm, 28.5° due east	Payload: ≥900 lbs to 100 nm, 28.5° due east
Enable routine, low-cost space access	Fly XS-1 to Mach 10+ at least once, and stage at high Mach to minimize the size and cost of the upper stage	Fly XS-1 to Mach 3+ at least once, with Mach 2+ staging of a low-cost upper stage

Link to footnotes

Open design space

Configuration

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

Artist's Concept

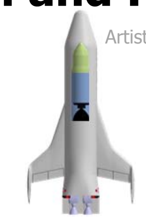
Artist's Concept

Artist's Concept

© XCOR Aerospace

Launch and Recovery

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



Artist's Concept

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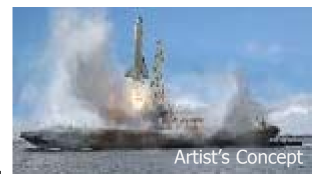
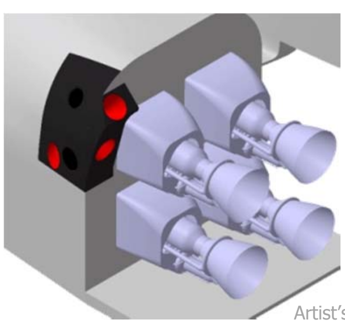


Artist's Concept

Artist's Concept

Propulsion

- The XS-1 program is seeking propulsion systems mature enough to support flight testing NLT 2020

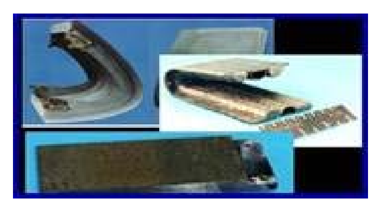


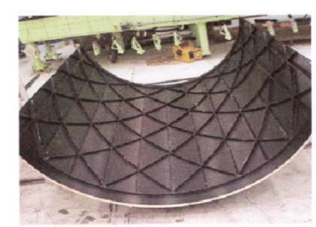
Artist's Concept

Artist's Concept

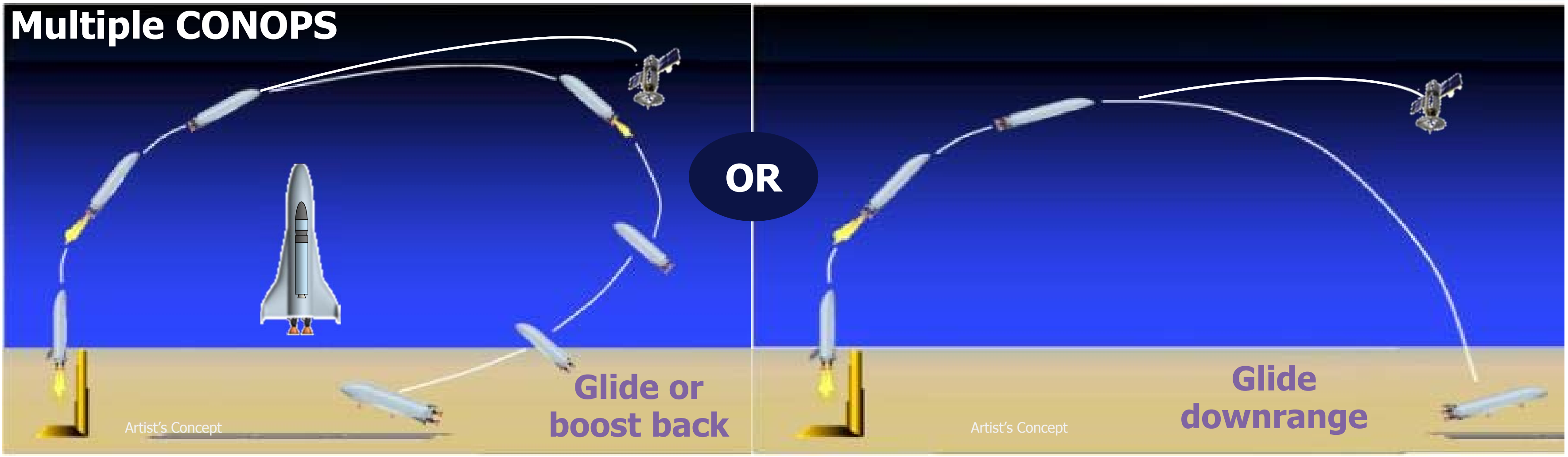
Thermal Protection Systems (TPS) and Structures

- Metallic
- Composite
- Hybrid
- Active
- Passive

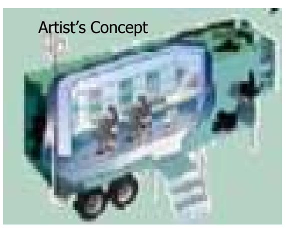




Design for "aircraft-like" ops tempo & cost



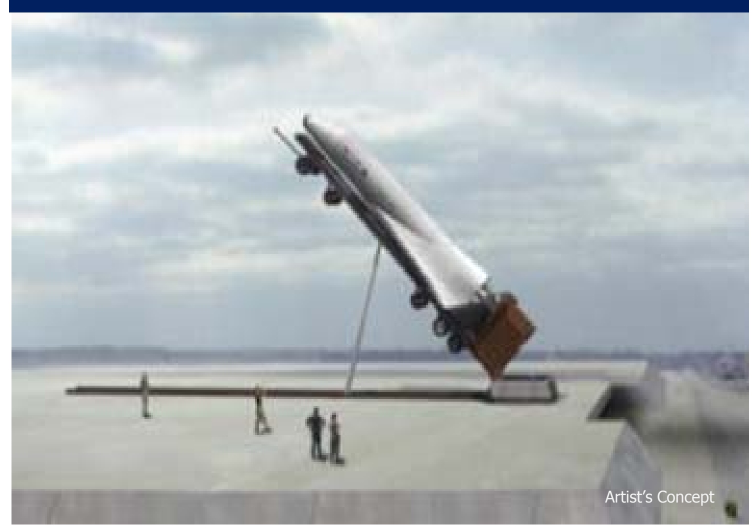
- **Design for Operability**



  - *Clean pad—rapid throughput*
  - *Flight ops control center with minimal crew size*
  - *Automated ops, propellant & fluid loading*

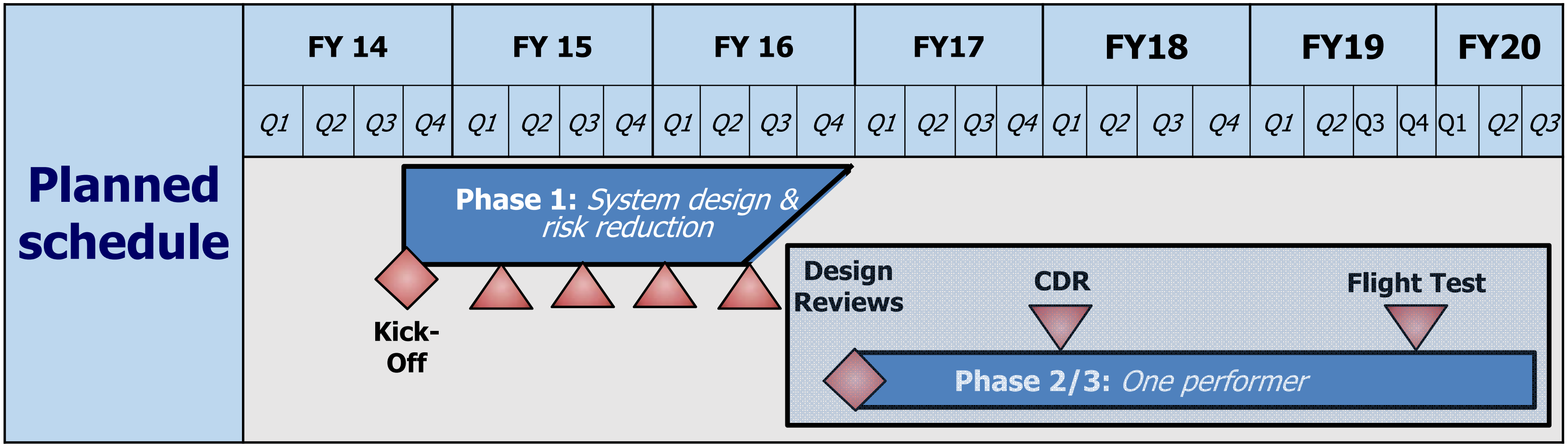
- **Design for Maintainability**
  - *Hangars, not specialized facilities*
  - *Standard aircraft GFE, interfaces, processes*
  - *Design for reliability, maintainability, support & availability and integrated systems health management*

Clean-Pad CONOPS



Key driver is goal to fly 10X in 10 days

Planned schedule



Phase 2/3

Full and open solicitation

Contract award planned ~Oct 2016

Will use a Program Solicitation, so only Other Transaction (OT) proposals accepted

Public-private partnership

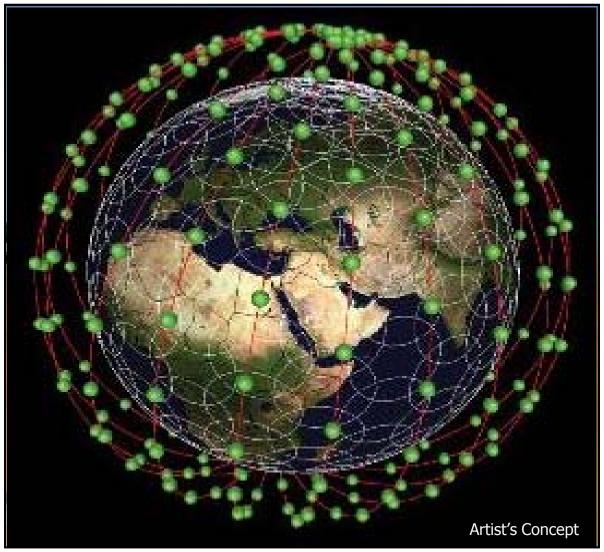
Experimental Spaceplane (XS-1) vision

Goal: Responsive & routine "aircraft-like" access to space
Fly 10X in 10 days

10 flights in 10 days would be a game-changer

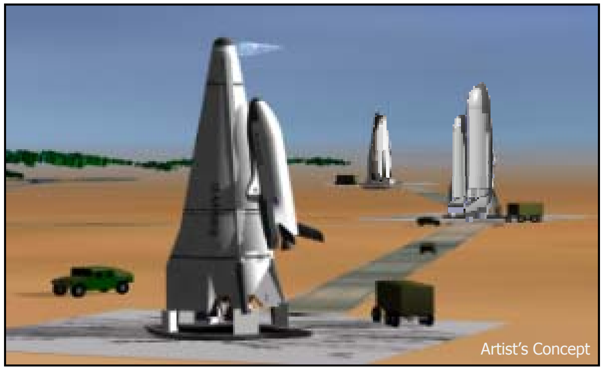
XS-1 would support rapid deployment and reconstitution of smallsat constellations

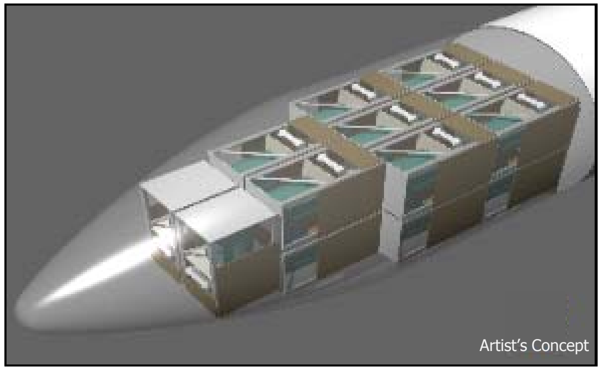
- Could launch 100 small satellites in 10 days for $50M
- Equivalent Delta Heavy launch would cost $500M
  - High risk to put all satellites on one launch



XS-1 would support more survivable disaggregated space architectures

Time to space is important for commercial entities and national security

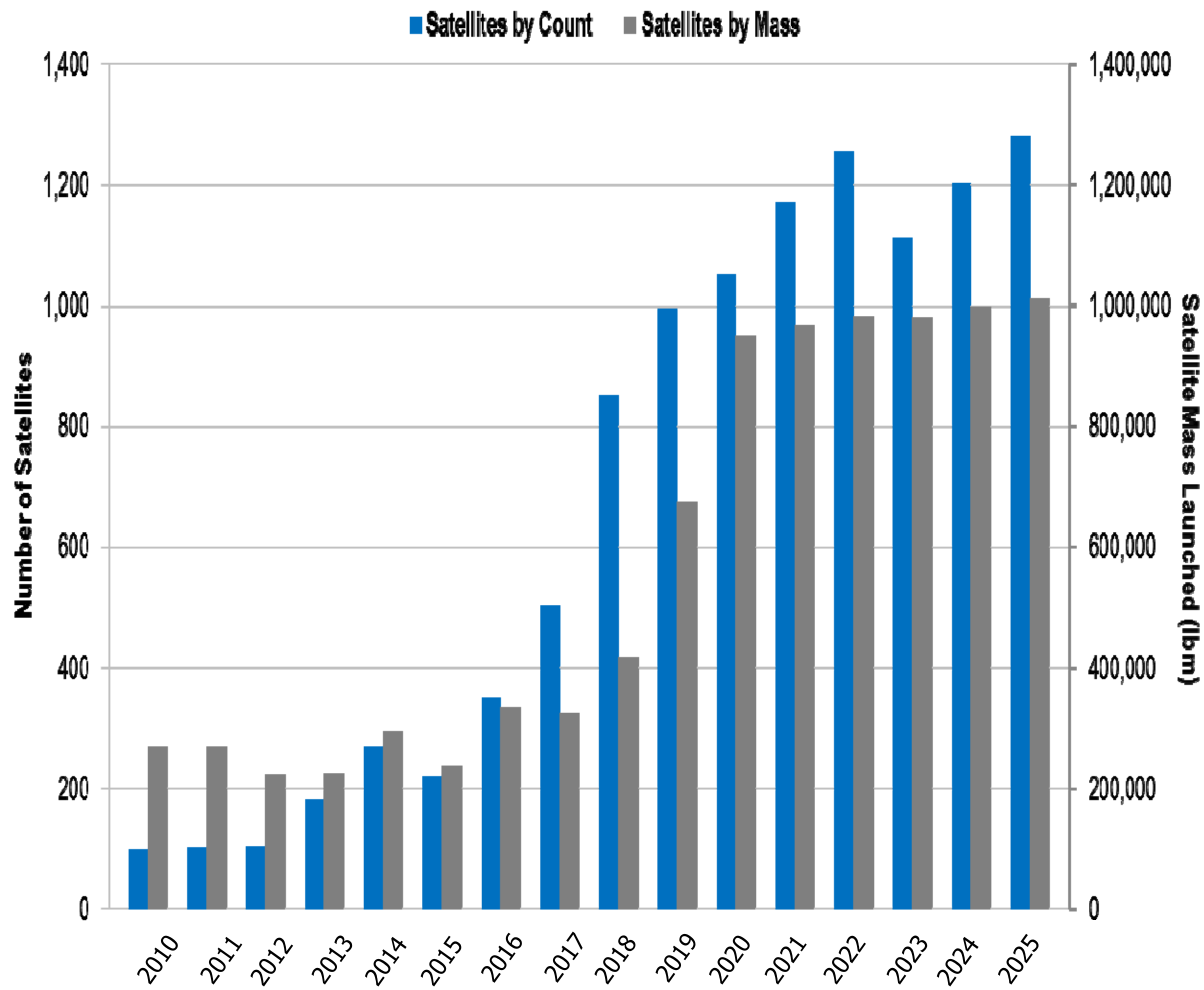




XS-1 would accelerate reusable space technology to aircraft-like tempos

Market projection today (potentially much larger)

- Significant market growth including **deployment and replenishment** from multiple **new commercial companies**
  - All satellites <10K lbs
  - Satellite mass only, upper stage not included
  - Graph captures full market potential but does not account for reality that some ventures are non-addressable or will fail
- Increased opportunity for U.S. launch providers due to **significant growth** in market share for domestic and friendly foreign systems



One study projecting large potential market—is it a bubble?

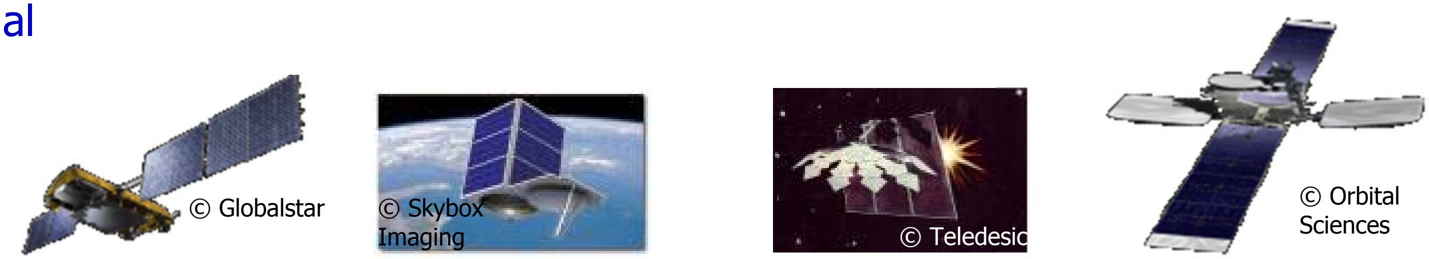
Source: Dr. John Bradford, Spaceworks

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 and future markets for transition when developing XS-1 designs!

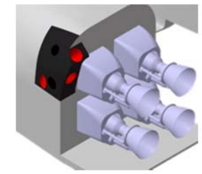
Today, technical readiness is high (~ TRL 5)

Artist's Concept

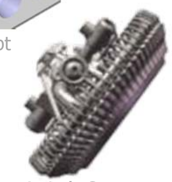
"Aircraft-Like" operations

- Reliable, maintainable, supportable, ***minimum manpower***
- Incremental flight test, like aircraft
- Flexible basing—inland and coast—CONUS and overseas

Robust Propulsion



Artist's Concept



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- Long-life, reusable engines
- Cost & operability conducive cycles vs performance
- **Demonstrated *robust engines*** and technologies

Artist's Concept

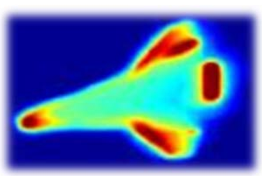
Long-life airframe & structures

- Hundreds of $M Air Force and NASA investment in composite airframe technologies
- Reusable ***composite cryotanks*** extensively tested, full scale testing in progress

Emerging commercial sector

Artist's Concept

- Technology has downsized spacecraft
- ***Many new satellites & constellations***
- Private sector has reusable and expendable launch vehicles



Aero-thermodynamics

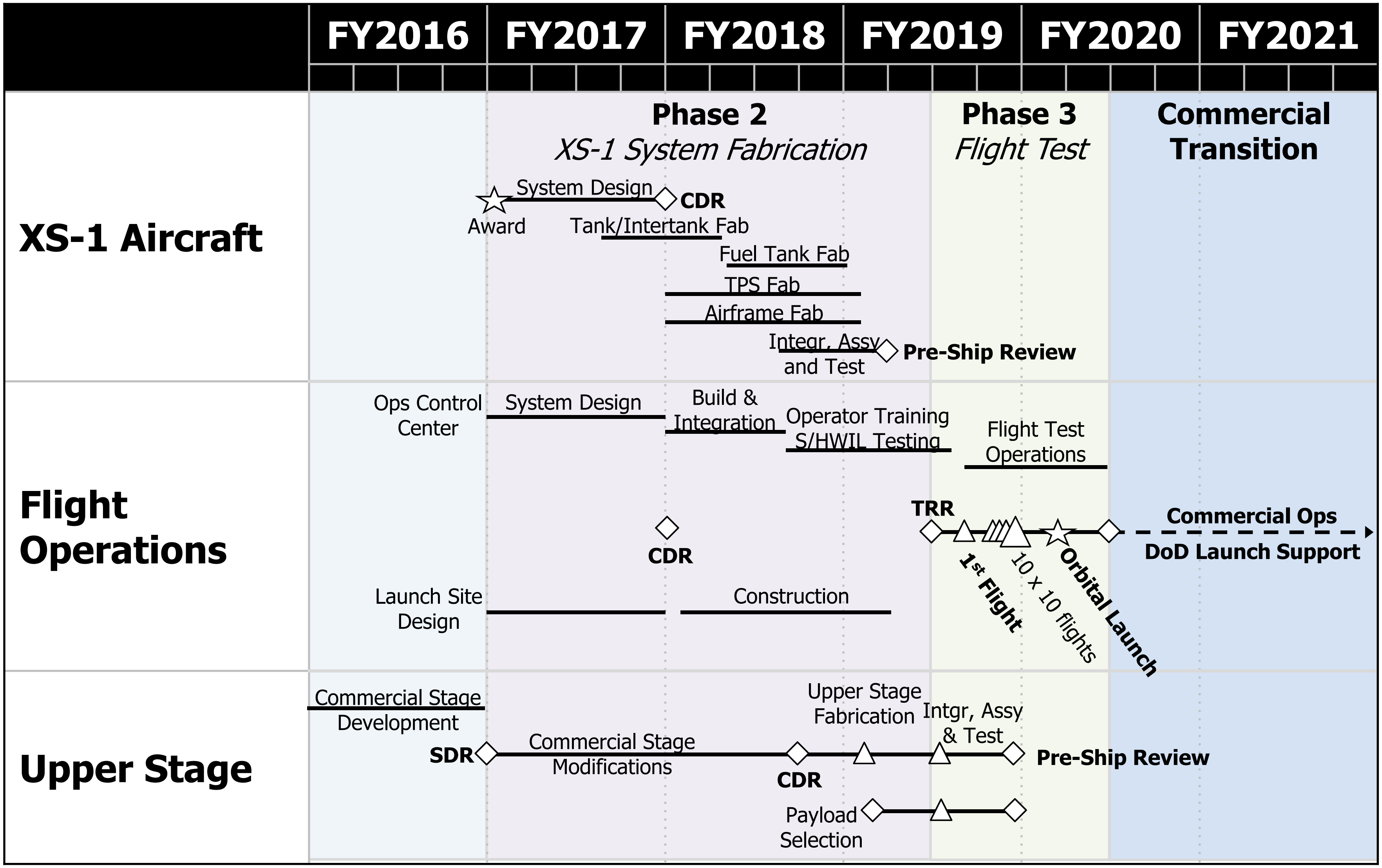
- Plethora of modeling, simulation and design tools driven by PC
- Thermal environment far less stressing than Space Shuttle
- ***Many advanced thermal protection options***

Low-cost expendable upper stage

- ***Emerging private-sector options***
- Many options: Firefly, Rocket Lab, Ventions, Virgin Galactic, etc.
- Minimize number of stages, parts count, complexity, dry weight and cost

Artist's Concepts

Conceptual schedule



Program solicitation information

- DARPA's XS-1 Phase 2/3 solicitation expects to request proposals and plans to make an award to one performer
- The proposed design should be ready for flight test within DARPA's schedule and budget
- A solicitation for XS-1 Phase 2/3 will request key technical information both to help the offeror develop their proposal and to ensure sufficient detail exists to justify an award:
  - A Vehicle Overview Document (VOD) establishing key parameters and a top-level framework to identify the status of a proposed XS-1 design
  - A technical proposal volume that includes information requested for a System Design Document (SDD), a future deliverable
  - A Technical Maturation Plan (TMP) that identifies the risk reduction approach enabling flight test initiation no later than FY2020

Vehicle Overview Document (VOD) and System Design Document (SDD)

- A VOD identifies key design details of interest to the Government and is intended to facilitate and simplify tracking of design progress
- Some information planned to be incorporated in the VOD include:
  - Booster characteristics
  - Mission performance parameters
  - Operational labor and timing
  - Additional technical performance measures
  - Etc.

- An SDD is a complement to the VOD providing greater depth as well as additional contextual information, such as design philosophy, rationale, maturity, and fidelity

- Some information planned to be incorporated in the SDD include:
  - System requirements and traceability
  - Flight systems configuration
  - Detailed flight system mass properties
  - Aerodynamics and aerothermodynamics
  - Etc.

Commercialization of XS-1

- DARPA's goal is to directly transition the XS-1 to the commercial sector
- To facilitate commercialization, DARPA wants to transfer title of the XS-1 vehicle to industry…

…but industry needs to offer a plan that provides "consideration in kind" justifying transfer of title

- Proposals should address commercialization planning elements such as:
  - Proposer's understanding of current and projected demand by key market segment
  - Understanding of core customer needs by market segment and how they plan to address them
  - Expected business model and partnerships
  - ROI calculations associated with that business model
  - Competitive analysis of existing vehicles and expected future vehicles
  - Description of business model's robustness to key market uncertainties
  - A top-level transition plan outlining additional activities needed to establish a commercial business, timeline associated with each and how those activities fit within the Proposer's Gate Review process

Efficient management is essential

DARPA will manage XS-1 as a "fast track" program—can industry?

Management Approach	
I	Agree to clearly defined program objectives in advance
II	Single manager under one agency
III	Small government and contractor program offices
IV	Build competitive hardware, not paper
V	Focus on key demonstrations, not everything
VI	Streamlined documentation and reviews
VII	Contractor integrates and tests prototype
VIII	Develop minimum realistic funding profiles
IX	Track cost/schedule in near real time
X	Mutual trust essential

A Teams Only!

Streamline Your Processes!

Be Efficient & Safe!

Challenge to industry:

Follow through to affordable flying hardware!

Pick the right program manager & right team

- Should understand technology and system trades
- Tailored systems engineering process key to success
  - Operative word is “tailored” to achieve min. cost demonstration
- Should implement program objectives as honest broker
- Program success should be more important than next promotion
- Requires ability to make decisions
  - At the right time, and
  - At the right level (push responsibility to lowest level)
- Program manager should personally approve all costs in advance/real time AND share information with Gov’t counterpart
- Pick program manger for life of program
- Minimize personnel turnover

Open communication and cooperation is essential

Government and contractor PMs should interactively share all program information, critical decisions and risks

Government must trust contractor

- To do its job and test/fly hardware
- By not second-guessing every contractor decision

Contractor must trust government

- To provide stable programmatic direction
- Not to drive cost/schedule with unreasonable demands

Build a joint program team philosophy and esprit de corps

- Think: Team, team, team… anyone can, <u>we do</u>

Allows empowered government and contractor team to push ahead decisively and succeed or fail together

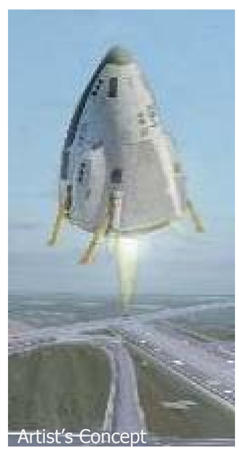
Summary

Highlights

- DoD launch costs are growing, commercial markets are proliferating
- XS-1 seeks to provide new, game-changing capabilities through order-of-magnitude lower costs
- XS-1 aims to leverage emerging suborbital and launch technology & entrepreneurs
- XS-1 intends to transition to industry to create sustainable, competitive launch service

XS-1 program seeks to be an agent for change …

… DARPA is open to innovative industry proposals



Final thought: Just do it!

From the October 9th, 1903 edition of The New York Times:

"[A] flying machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanicians in from one million to ten million years."

From Orville Wright's diary October 9th, 1903:

"We started assembly today."

DARPA

www.darpa.mil

XS-1 requirements – notes

[1]The full system (reusable and expendable components) capable of launching these payload masses will be referred to as the "Operational System". This must include performance capabilities for the booster and upper stage, whether reusable or expendable.

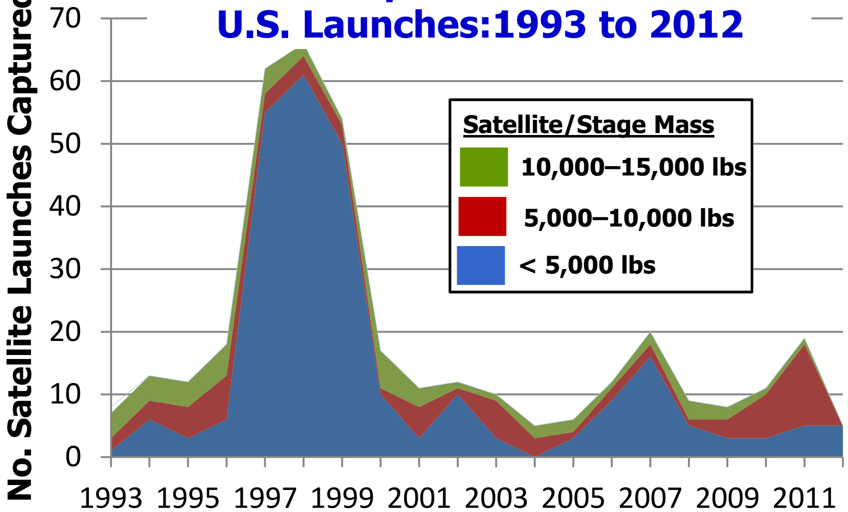
[2]Showing traceability requires rigorous tracking of both recurring and non-recurring costs. These must be incorporated into a cost model which includes flight rates, learning curve efficiencies, demonstrated versus Operational System capabilities, required R&D, and amortization. Under the cost model assumptions, the number of flights and the annual flight rate required to achieve the flight cost goal (can assume BY 2016$) must be identified. The cost model traceability must include both the booster and upper stage for the Operational System capability. This requires assessments/assumptions for low to medium risk upper stage availability. Section 4.1.4 explains how the per-flight costs are to be addressed in any proposal to this solicitation.

[3]The Goal is for the 10 flights to be accomplished at any time during a 10 consecutive day period. If range delays are incurred when the vehicle is fully flight-ready, the delays will not be counted against the performance of this goal. The Threshold for this goal will be met if, after subtracting range, weather, and emergency delays, 10 flights have taken place within a net period of 10 calendar days. The flight campaign may consist of 10+ flights and should be representative of the operational system flight envelope for altitude, dynamic pressure, and Mach number.

[4]Smaller demonstration payloads to alternative altitude and inclination orbits of equivalent energy states are acceptable.

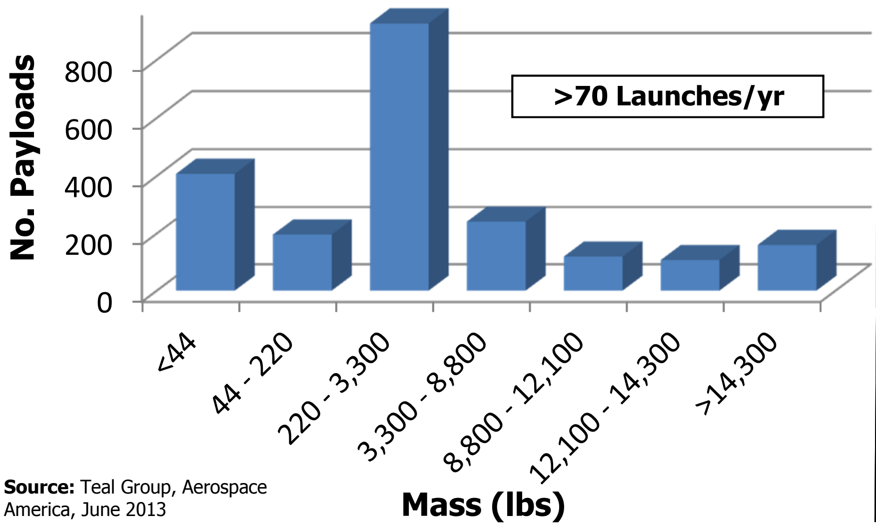
Market projection, Nov 2013: Responsive launch of 3K- to 5K-lb payloads

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.

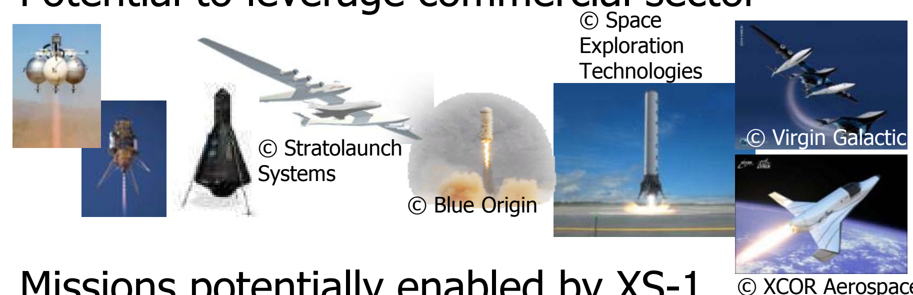
Worldwide Projected Payloads: 2013 to 2022



Source: 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

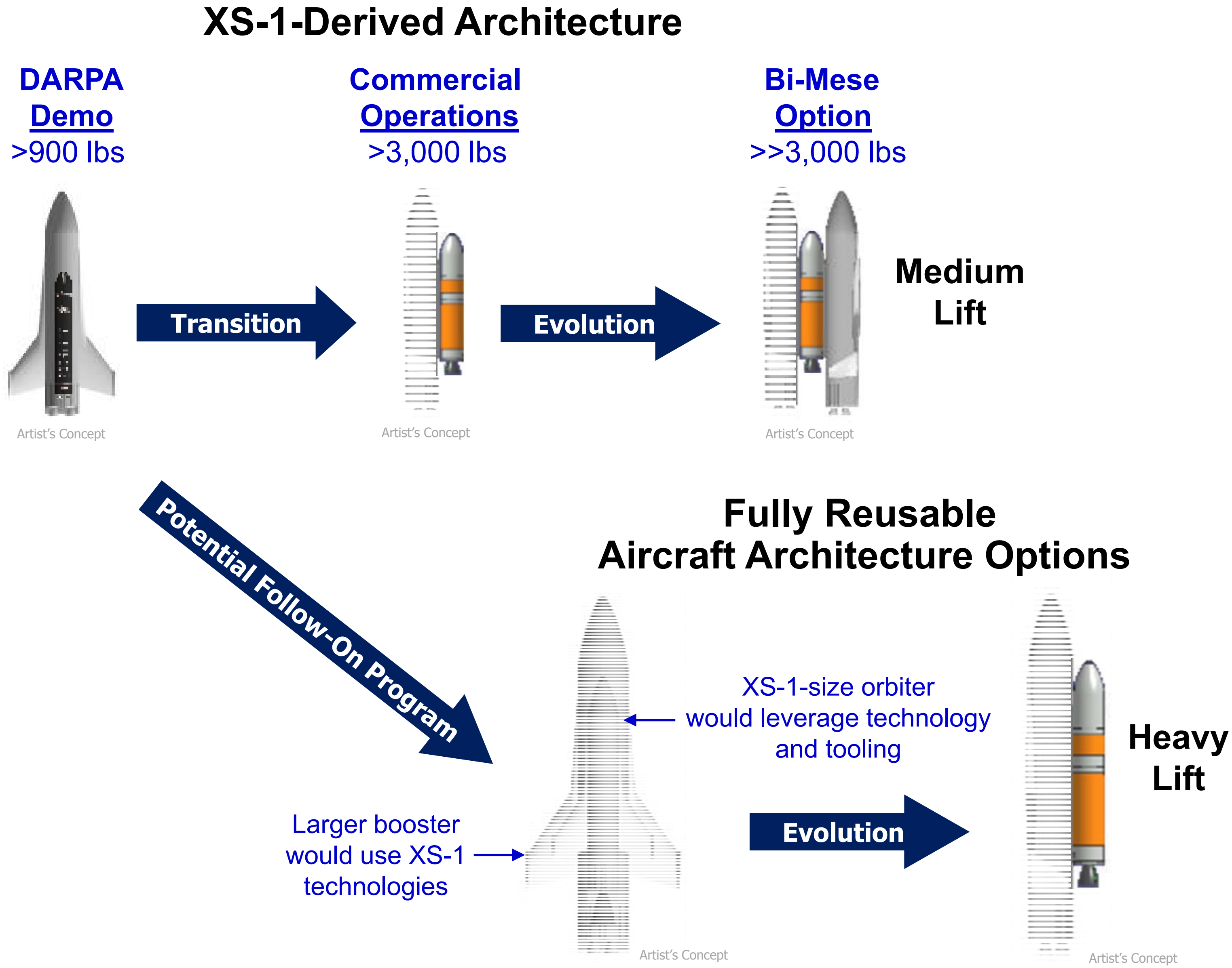


- Missions potentially enabled by XS-1
  - USAF ORS & "disaggregated" satellites
  - Recapture commercial launch

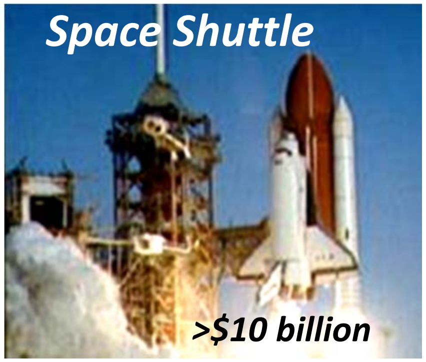
➔ Historical avg of 3-5 launches/yr at 5,000 lbs

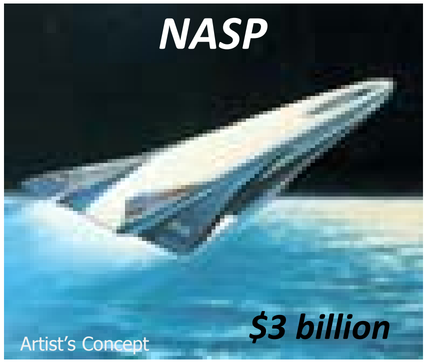
➔ Projected market much higher

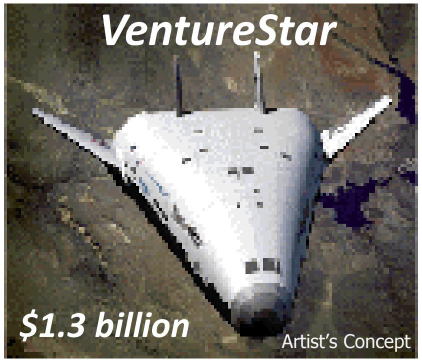
Gov't baseline vehicle could also enable other capabilities



Legacy of past programs





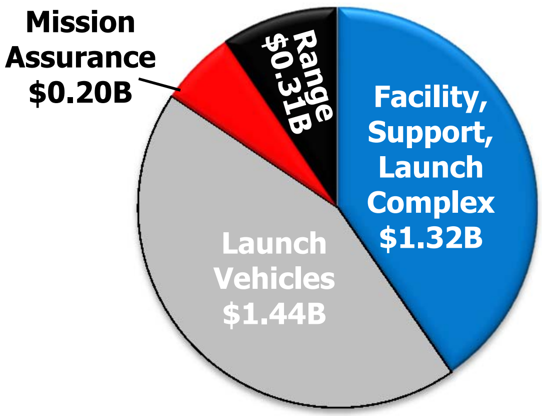


	Space Shuttle	NASP	VentureStar
Initial Goals (requirements)	NASA human-rated Payload—65K lbs $10M per flight	AF crewed Payload <10K lbs SSTO, scramjet-powered Aircraft-like ops, fast turn	NASA human-rated Payload—65K lbs SSTO, rocket-powered Aircraft-like ops, fast turn
Technology (at start)	TRL ~3 and immature design New LOX/LH_2 SSME Unproven materials/TPS Toxic OMS/RCS, etc. 1960s/1970s technology	TRL ~2 and immature design New LS/RAM/SCRAM/rocket New materials/structures New LOX/LH_2 tanks New hot structure TPS, etc.	TRL ~3 and 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)

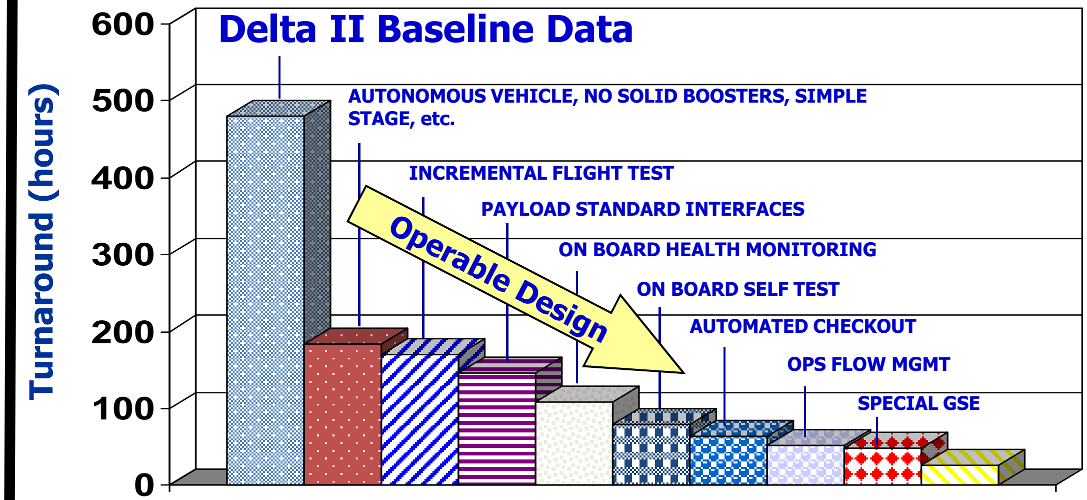
Design and system integration to enable “aircraft-like” operations

EELV Launch Cost Breakdown

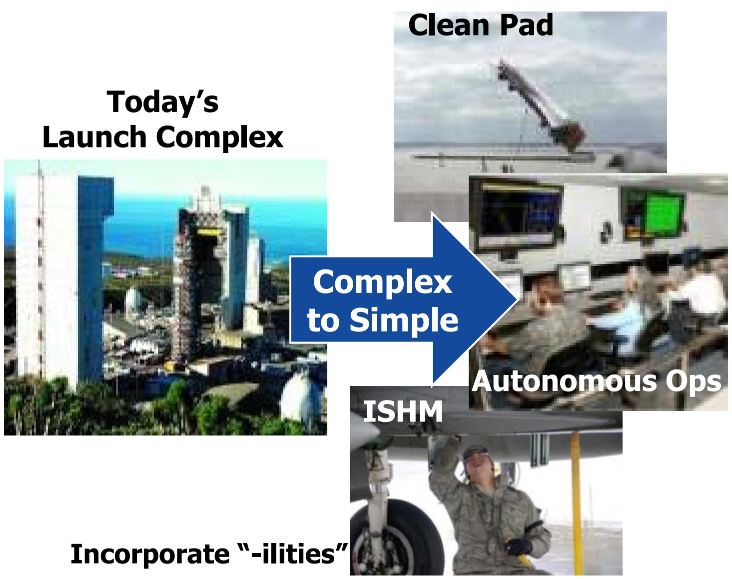


Source: President’s Budget Request FY 2012

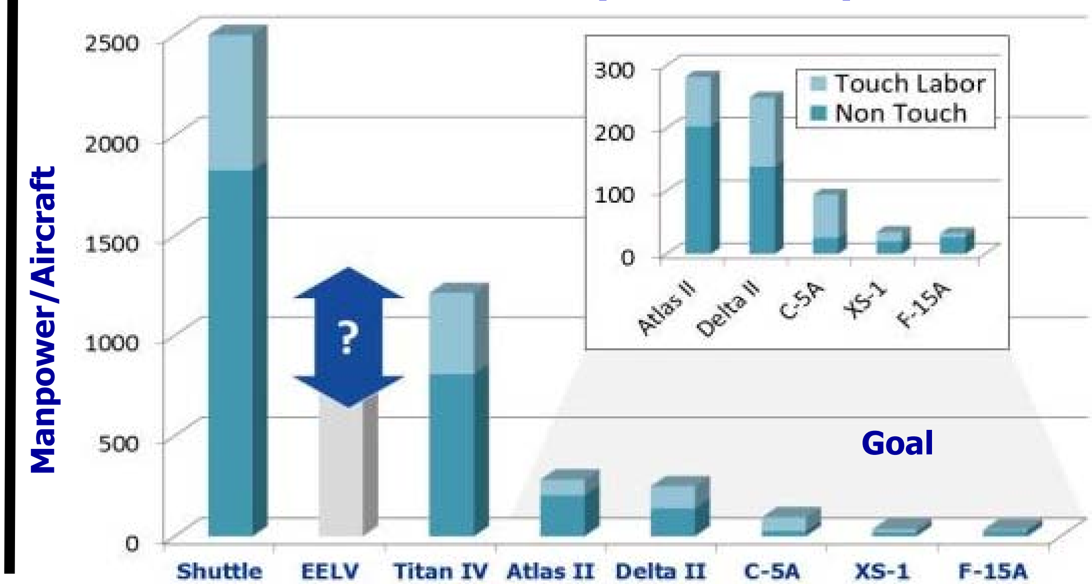
Design for Rapid Turn Reduces Manpower



Few Facilities, Small Crew Size



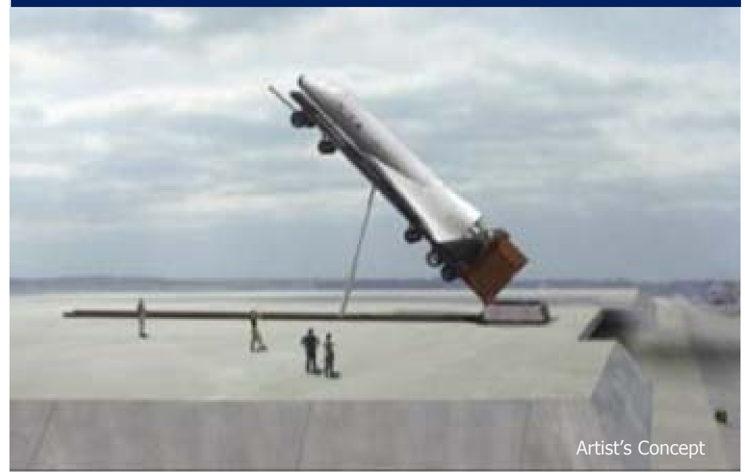
Launch Site/Base Manpower Comparisons



Design integration for "clean pad" aircraft-like operations

- **Aircraft-like CONOPS**
  - Clean pad—rapid throughput
  - Ops Control Center—like aircraft
  - Containerized payloads
- **Aircraft ground support equipment (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



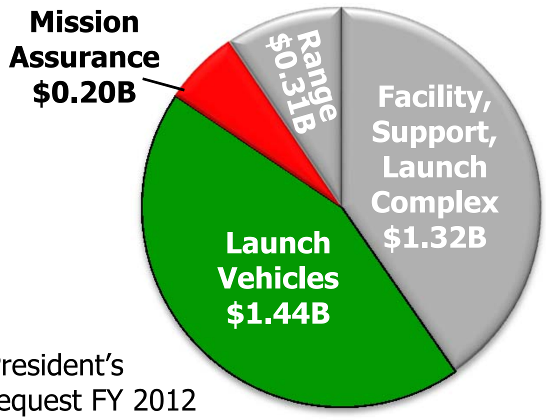
OPS CONTROL CENTER
Small 3-Person Ops Crew Size

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

- **Integrated Systems Health Management**
  - Determine real-time system health
  - Integrate with adaptive guidance, navigation & control (GN&C)
  - Enable reliable, rapid turnaround of aircraft
- **Leverage high-ops-tempo investments**
  - Airborne Launch Assist Space Access (ALASA)
    - Autonomous Flight Termination System
    - Rangeless range, space-based command, control & data acquisition
  - Adaptive GN&C—safe, reliable recovery/abort

Lightweight/high-energy airframe with high propellant mass fraction (PMF)

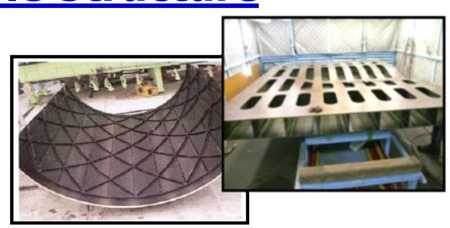
EELV Launch Cost Breakdown



Source: President's Budget Request FY 2012

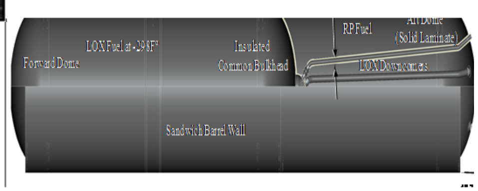
Affordable Structure

Composite Structures Reduce Weight ~30%



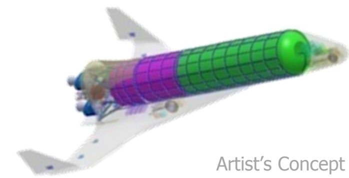
NASA Open-Core Tank in Fabrication

USAF Monocoque Tank in Test



Tank/Structure Integration

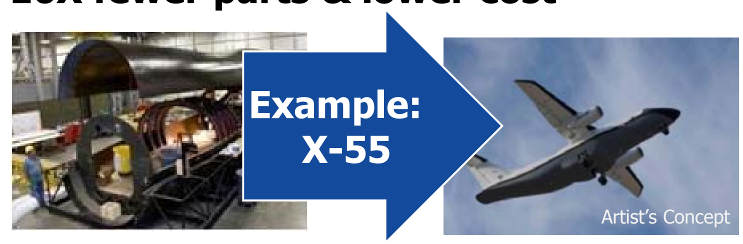
- ✓ **Integral load-bearing structure**



- ✓ **High PMF key to performance**

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

- ✓ **10X fewer parts & lower cost**



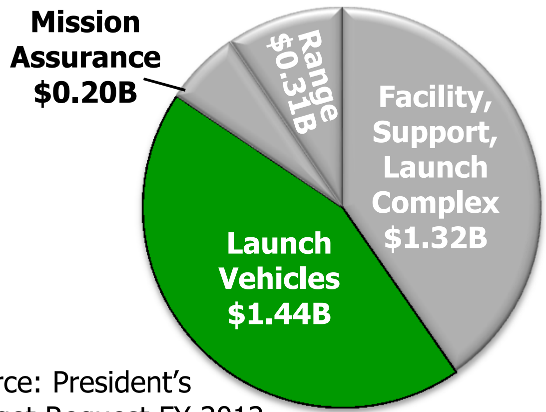
- ✓ **Reusable vehicle cost is amortized rapidly…**

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

Design tank/airframe structure to enable high PMF/ΔV

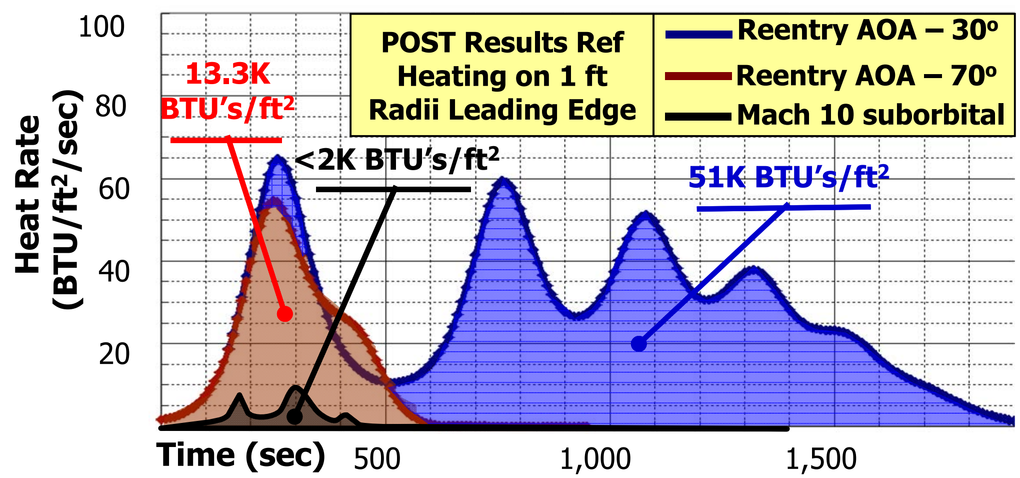
Durable thermal structures/protection from -300 °F to +3,000 °F

EELV Launch Cost Breakdown



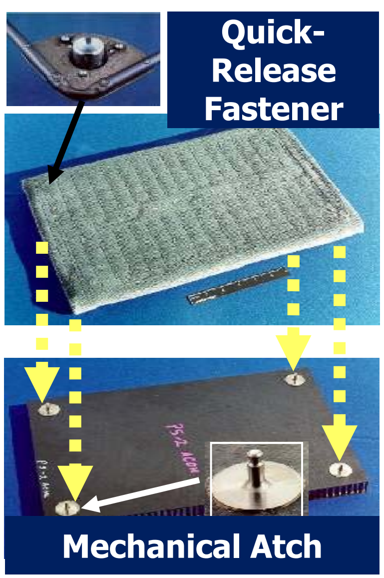
Source: President's Budget Request FY 2012

How You Design & Fly Is Key!



Many Thermal Protection Options

AFRSI and CRI

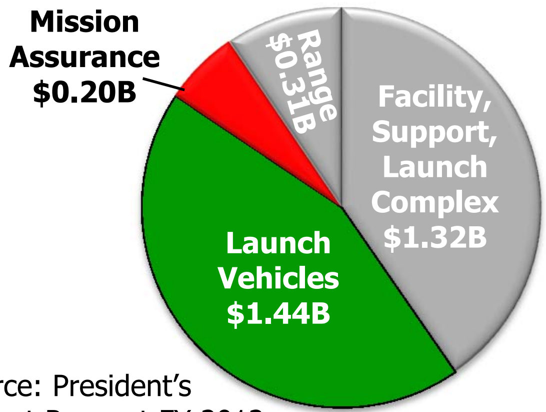


Leading Edges ACC, C/SiC, TUFROC

Emerging Thermal Structures

Reusable, long-life and affordable propulsion poses design integration challenges

EELV Launch Cost Breakdown



Source: President's Budget Request FY 2012

- ✓ **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 removal and replacement**
  - **Support high-ops-tempo flight rate**

Multiple Affordable Propulsion Options

Merlin
Commercial Rocket

NK-33
Stockpiled Russian Rocket

SSME
Space Shuttle Engines