AA 284a
Advanced Rocket Propulsion

Lecture 6
Launch Industry/Market

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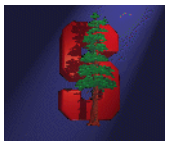
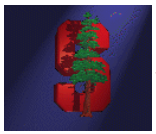


Launch Market

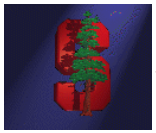
- Service of transporting payloads into earth orbit (or suborbital flight)
- Market segments
  - Destination Orbit
    - LEO, GEO, Suborbital
  - Customer
    - Commercial, Government
- Features of the market
  - High prices
  - High development costs/risks (non-contestable)
  - Government influence (regulations/subsidizing)
- Propulsion is the driving technology
  - For orbital systems more than 90% of the gross mass is propulsion
  - Airline like operations is highly unlikely in the near future



Launch Market Segments and Drivers

Segment	Driving Factor
Communications	Launch availability, new services, markets, players
Military	New missions, satellite lifetime
Positioning	New countries
Science/Technology	Cost, ease of access to space
Remote Sensing	Commercial success, regulation
Burial	Market interest
Manufacturing	Research success, cost, ease of access
Tourism	($<500/kg), reliability
Settlements	Cost, reliability
Waste Disposal	(<$1000/kg), Government approval
Mining	Mining rights, entrepreneurship
Earth Transport	($<200/kg), Reliability, noise
Entertainment	Entrepreneurship
Advertising	Market interest
Power Generation	Economic & technical viability
Novelties	Entrepreneurship

Wide Range of Potential Users



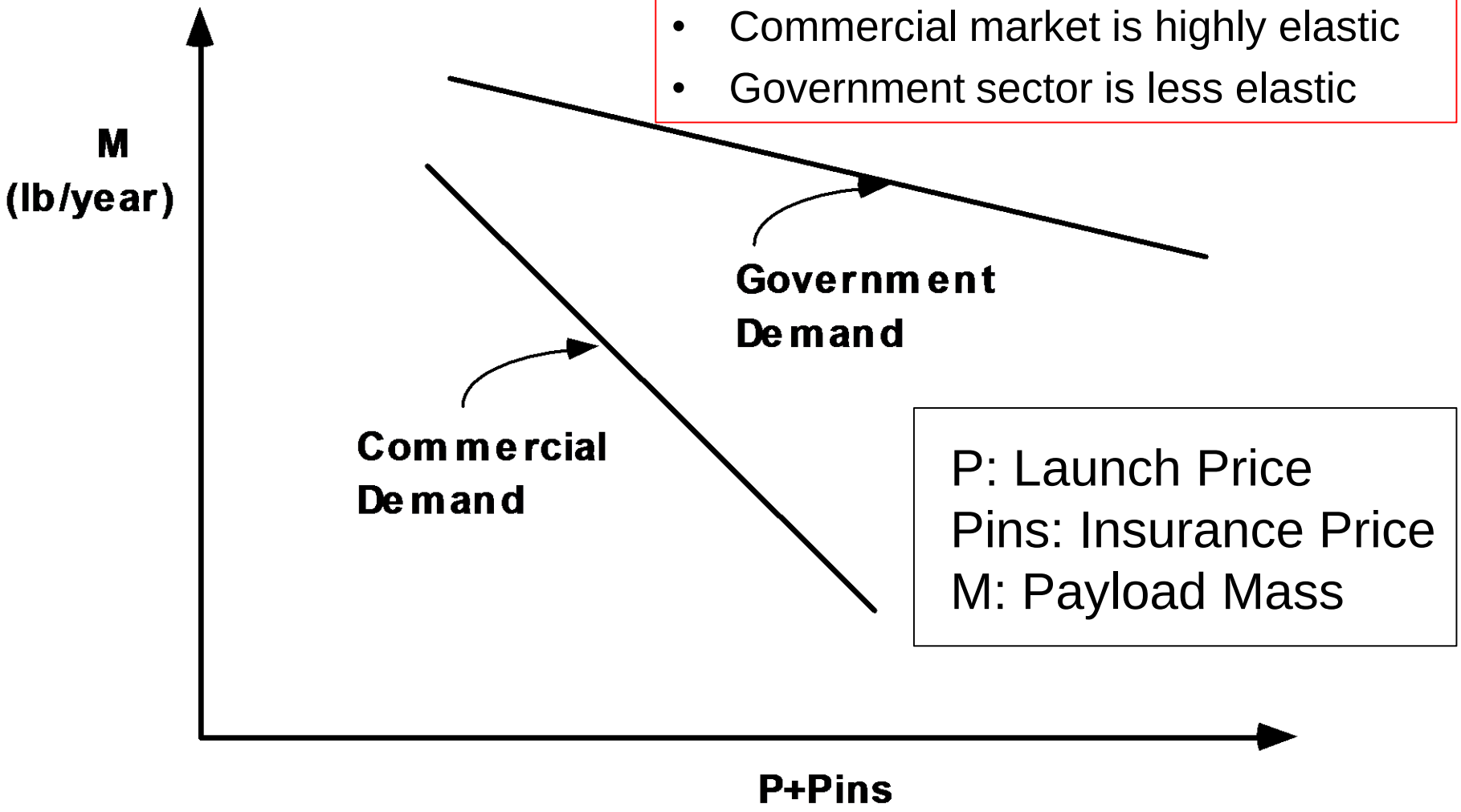
Launch Market - Sampling

Launch Vehicle	Country	Mass to LEO	Unit Cost, $/kg
Atlas V	US	9,000	14,000
Delta IV H	US	23,000	13,000
Falcon 9 v1	US	10,500	5,400
Titan IV	US	21,700	13,800
Ariene V ES	EU	21,000	10,500
VEGA	EU	1,500	15,600
Epsilon	Japan	1,200	32,000
Dnepr-1	Ukraine	3,700	3,800
Proton-M	Russia	21,600	4,300

Very Expensive Service

Launch Market-Economics

- Commercial market is highly elastic
- Government sector is less elastic



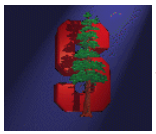
P: Launch Price
Pins: Insurance Price
M: Payload Mass

Launch Market-Oligopoly

- Government Demand: (political and strategic issues)

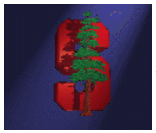
$$M_g = Cons.$$

- Commercial Market : Bertrand Model
- Customer Problem: $\min[p + p_{ins}]$
- Best cost and reliability combination wins.
- Monopoly ?
- Others also survive
    - Government market
    - Diversification of commercial customers (Reduce risks and keep players in market to pull prices down)



Launch Market- Current Trends (Not Predictions)

- Commercial:
  - GEO satellites are getting bigger/heavier and more capable
  - Heavy launchers are trying to keep up with the weight increase of the satellites by improving performance
  - LEO satellites are getting smaller/lighter
- DoD:
  - Small payload, rapid access, affordable (?)
- NASA
  - After shuttle transition to Aries launch vehicle family
- Potential new commercial market
  - A market for very/small inexpensive satellites is expected to blossom when the really affordable launch capability becomes available



Small Launch Vehicle Data

Launcher	Payload*, kg	Cost#, M$	Cost/Payload, $/kg	Reliability
US Launchers				
Pegasus XL	190	20.0	105,263	34/39
Minotaur	317	19.0	59,936	7/7
Taurus	660	36.0	54,546	6/7
EU Launchers				
Vega	1,395	20.0	14,337	0/0
Russian Launchers				
Dnepr	300	10.0	33,333	9/10
Kosmos	775	12.0	15,484	422/448
Start	167	9.0	53,892	6/6
Strela	700	20.0	28,571	1/1
Others				
Long March 2	1,600	23.0	14,375	22/22
PSLV	900	15.0	16,667	4/7

*Sunsynchronous Orbit: 800 km, 98.7º

#FY02 Values

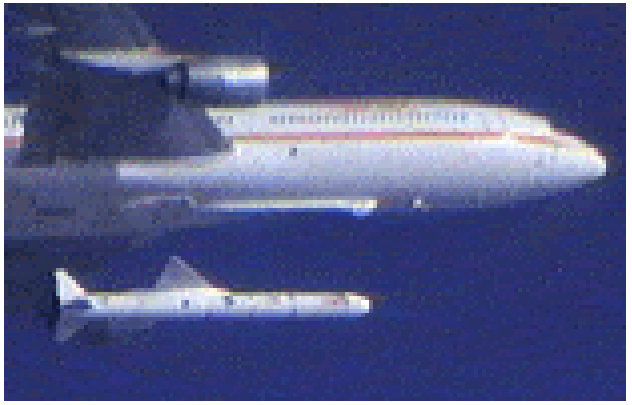
PegasusXL Launch Vehicle

ORBITAL Sciences

Air Launched (L1011): Dropped at 39 kft

Propulsion System:

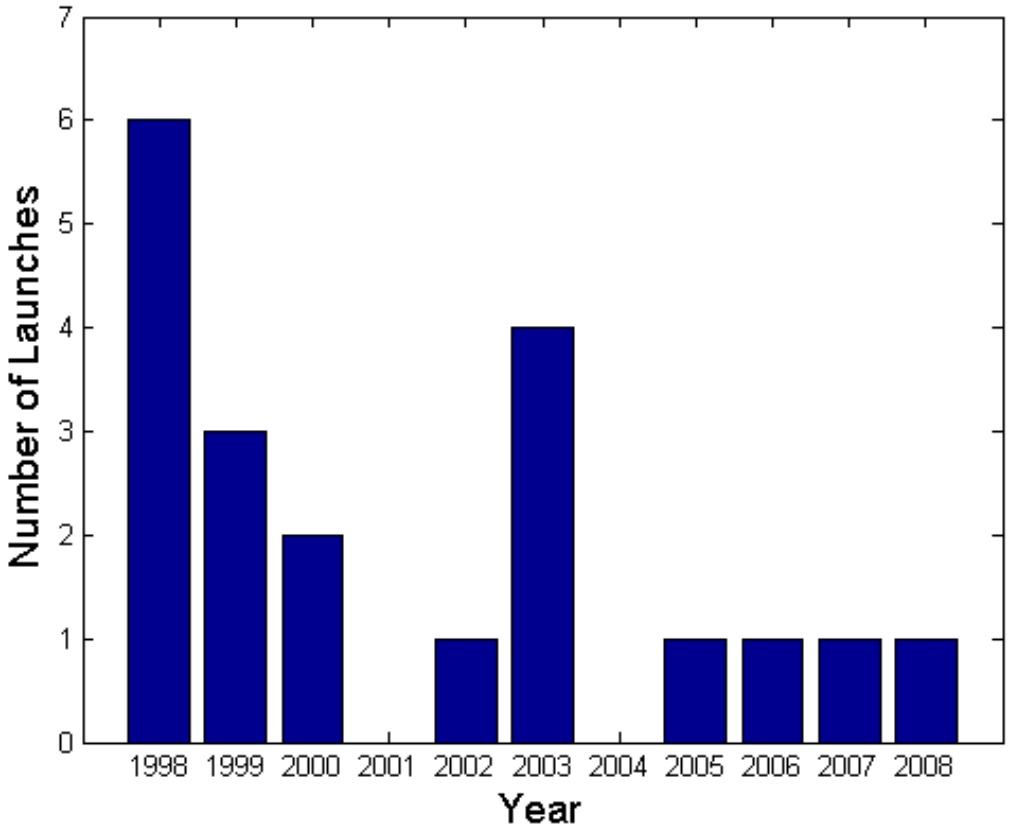
- Stage 1: 50SXL (Solid – Alliant Techsystems)
- Stage 2: 50XL (Solid – Alliant Techsystems)
- Stage 3: 38 (Solid – Alliant Techsystems)
- Stage 4: HAPS (Hydrazine monoprop. – Aerojet)



Reasons for high recurring cost:

- Expensive propulsion system
- Air platform/low launch frequency

PegasusXL Launch Vehicle



Number of launches decreased in time

Presently average is one launch a year

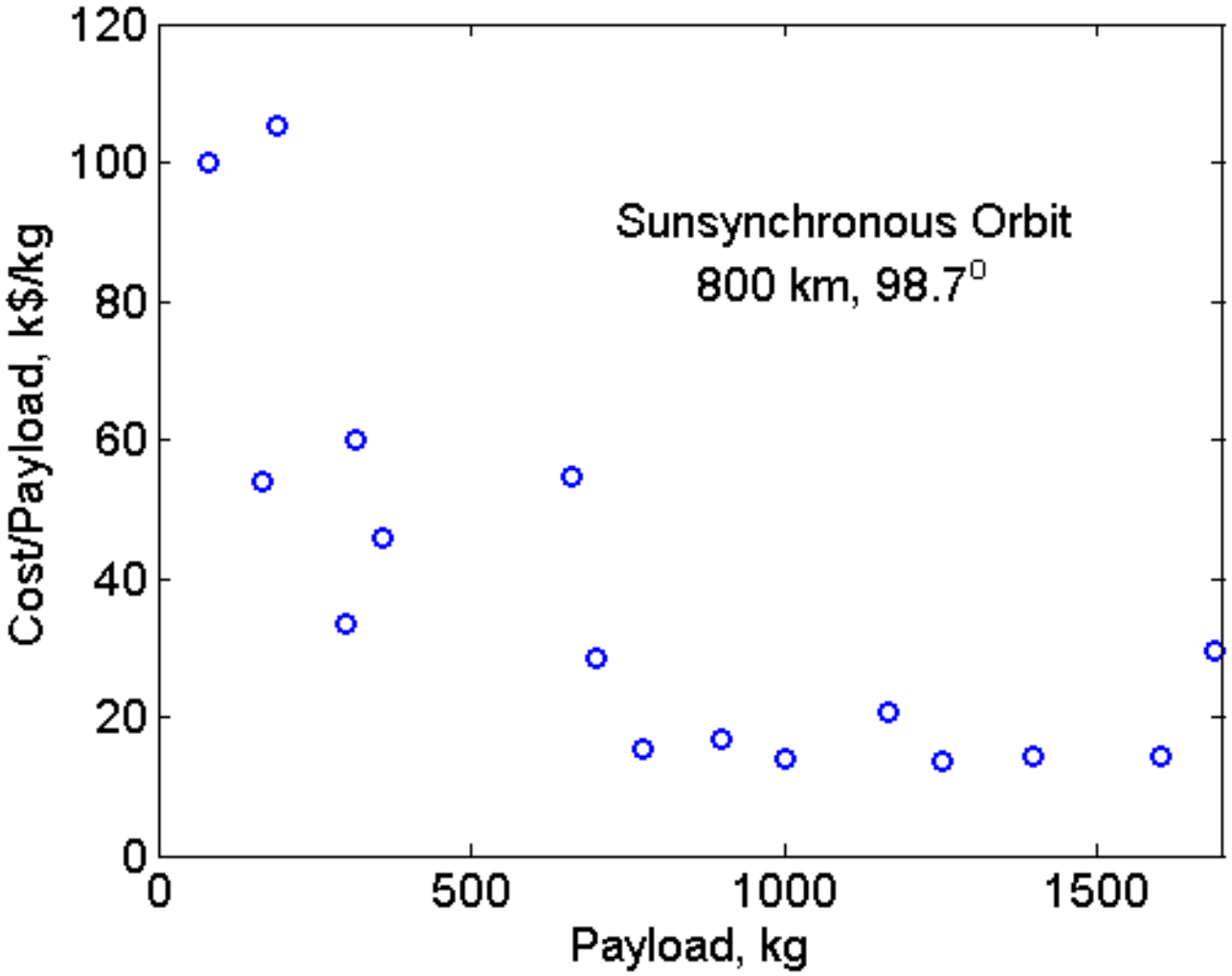
Dilemma of Launch Business

- High launch costs limit the demand
- Low launch frequency increase the cost

This cycle can **NOT** be broken with current propulsion technologies (improvements have been gradual since 1970's)

Disruptive propulsion technologies are needed

Small Launch Vehicle Data

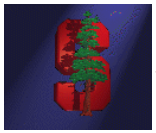


Launch Market- Recent or Current Programs

- Small LV- DoD Funded:
  - ALASA (DARPA): Failed!
    - Payload of 45 kg to LEO
    - Air launch – F15
    - N2O/HC mixture as propellant
  - SWORDS (Army): Failed!
    - Small launch vehicle
    - All liquid (Methane/LOX)
- Large Commercial:
  - Orbital market (primary ones):
    - SpaceX (LOX/Kerosene liquids)
    - Blue Origin (LOX/NG and LOX/H2)
  - Suborbital market:
    - Virgin Galactic (N_2O base hybrid propulsion)
    - Blue Origin (LOX/NG)

Launch Market- Other Small Orbital Programs

- Generation Orbit: GOLauncher 2
  - 40 kg to LEO
  - Solid Propulsion
  - Air Launch
- Virgin Galactic: LauncherOne
  - 300 kg to SSO
  - LOX/Kerosene
  - Air Launch
- Rocket Labs: Electron
  - 150 kg to SSO (500 km)
  - LOX/Kerosene
  - Electric pump fed
  - Composite LOX tank
  - 3D manufacturing
- Nammo Raufoss: North Star
  - 10 kg to 650 km polar
  - H2O2 hybrid



Launch Market- Why Sub Orbital ?

Orbital

- Three passengers
- Delta V=7.5 km/sec
- Vehicle Mass: 13,000 kg
- 90% propellant
- Air launch is difficult
- Vertical lift off
- Performance is critical
- Sophisticated reentry (TPS)
- Complex life support system
- Dangerous ride
- Man rating would be very difficult if not impossible
- Very high price (currently $20 Million)

Sub-Orbital

- Three passengers
- Delta V=2.5 km/sec
- Vehicle Mass: 1,600 kg
- 60% propellant
- Can use air launch
- Horizontal lift off
- Performance is not critical
- Simple reentry system
- Simple life support system
- Relatively benign ride
- Man rating is a lot easier
- Potentially low price ($30,000 to $100,000 per ticket)

Exciting Times: Commercial Space

Near Space Experiences

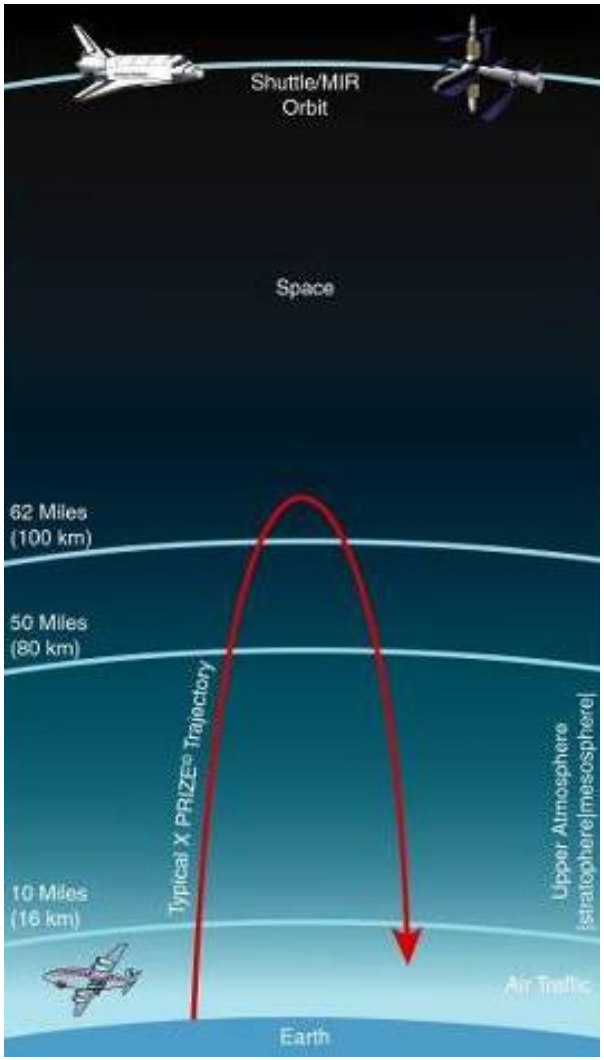
Zero-G, high altitude balloon, supersonic jets

Mostly available right now

Relatively affordable at $5,000 - $25,000

Coming in 2016
$150,000

Suborbital Space Flight



A first step to:

Low-Cost and Reliable Access to Space

Characteristics:

- Easier mission (lower deltaV)
- Larger margins/Lower risk
- Reasonable cost
- Frequent flight rate
- Low G loading
- Human rating
- Quick turnaround
- Payload / user friendly

Suborbital Competition

SpaceShipTwo ©Virgin Galactic

LynX ©XCOR

New Shepard ©Blue Origin

Hyperion ©Armadillo Aerospace

RocketplaneXP ©Rocketplane

TBN ©EADS Astrium

Xaero©Masten Space Systems

Suborbital Players - Winged

Virgin Galactic - APPROACH
SpaceShipTwo is a vehicle system developed by Scaled Composites. The vehicle is air launched with a hybrid rocket powered second stage. The vehicle carries six spaceflight participants. Re-entry is managed by a unique feathering flight control surface.

XCOR – APPROACH
XCOR is developing a single-stage winged HTHL suborbital vehicle powered by bi-propellant rocket engines to perform in aircraft-like operations, capable of flying four times a day with turnaround time between flights as short as two hours.

Virgin Galactic

- *Virgin Galactic has recently started powered flight testing*
- *Commercial flights will follow soon*
- *SpaceShipTwo utilizes a hybrid rocket system*
- *Hybrid motors will be used in large numbers*

- *SpaceShipTwo's hybrid is a classical system based on*
  - *N2O oxidizer*
  - *Rubber based fuel*
- *First power flight has been completed*
  - *A short burn but successful test*
- *Longer burn flights will take place in the near future*

Suborbital Players - Vertical

Blue Origin – APPROACH

Blue Origin is focused on developing rocket-powered Vertical Takeoff and Vertical Landing (VTVL) vehicles for access to suborbital and orbital space. In addition to human spaceflight, it will also provide researchers the capability to fly experiments into space.

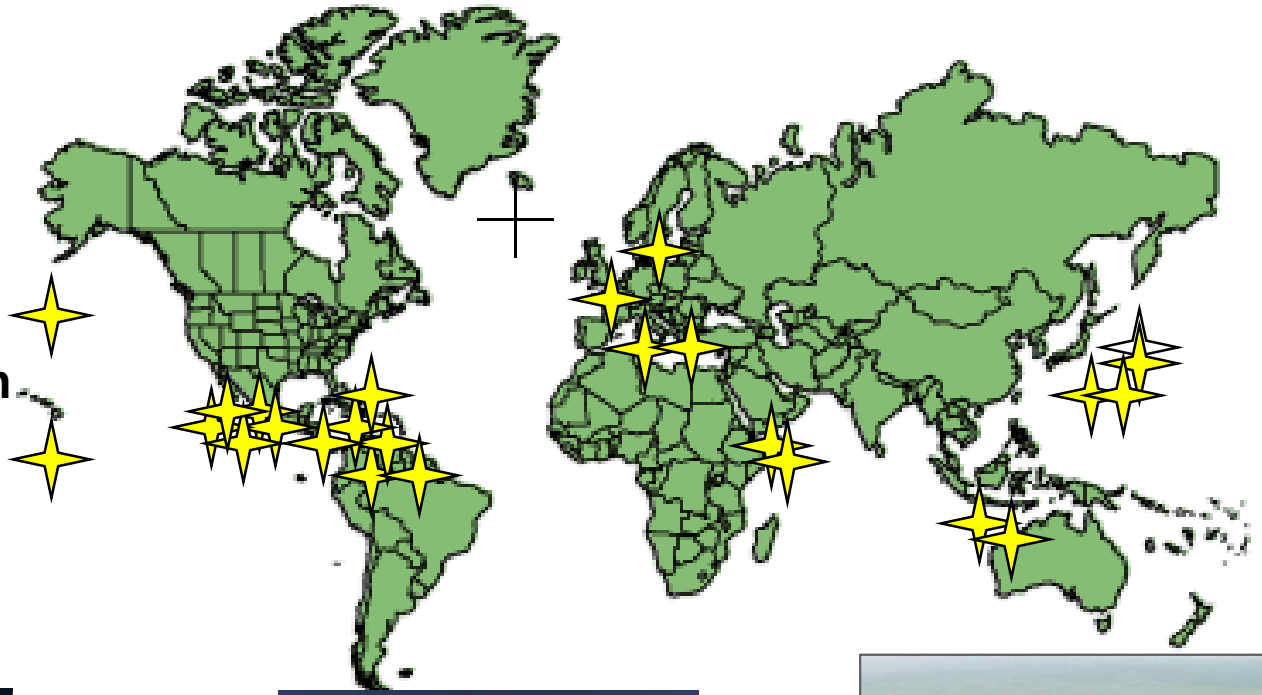
SpaceX - APPROACH

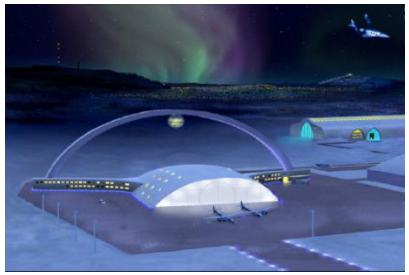
The Grasshopper is an SRLV consisting of a Falcon 9 First Stage tank, a Merlin 1D engine, four steel landing legs, and a steel support structure. The vehicle is currently undergoing incremental altitude flight tests. The test program involves phases for takeoff, flight, and landing, and flights both below and within controlled airspace

Spaceports Around the World

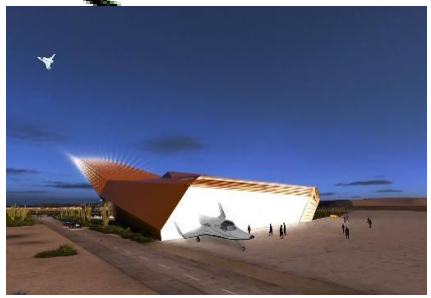
SPACEPORTS - Sites dedicated to launching orbital or suborbital vehicles into space

- **10 Non-federal US Spaceports**
- **Sweden**
- **Singapore**
- **UAE**
- **Abu Dhabi**
- **Spain**
- **Hokkaido, Japan**
- **Curacao**
- **Korea**
- **Ibaraki, Japan**
- **Malaysia**





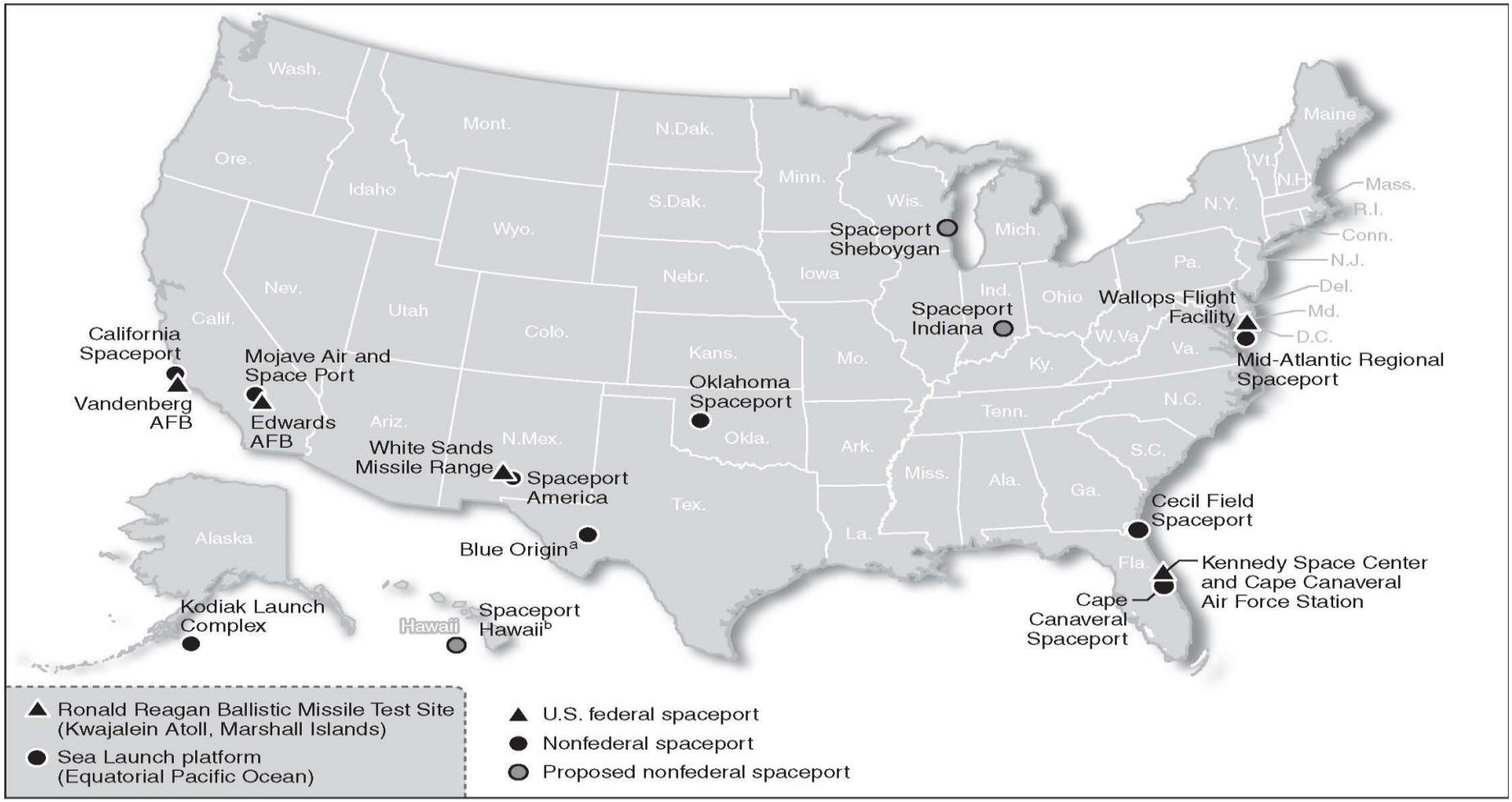
Spaceport Sweden© Spaceport Sweden



Caribbean Spaceport © SXC

Singapore © Space Adventures

Spaceports - USA



Sources: FAA and GAO.

Spaceports - USA

Spaceport America is the world's first purpose built commercial spaceport and is managed by the New Mexico Spaceport Authority.

- Main terminal hangar will be able to house two Virgin Galactic WhiteKnightTwo aircraft and five SS2 spacecraft. Virgin Galactic's commercial flights will launch from Spaceport America after successful completion of its final test program and licensing of the space launch system by the FAA.
- The spaceport has already hosted 12 flight tests by vertical launch customers, including Lockheed Martin, Armadillo Aerospace, and Moog-FTS.

US Commercial Orbital Launchers

Operator	Vehicle	Year of First Launch	Total Launches	Active Launch Sites	Mass to GTO kg (lb)	Mass to LEO kg (lb)	Mass to SSO kg (lb)
Orbital Sciences Corp.	Antares	2013	1	MARS	--	6,120 (13,492)	4,500 (9,920)
Orbital Sciences Corp.	Pegasus XL	1994	31	CCAFS, Kwajalein, VAFB, WFF	--	475 (1,045)	325 (715)
Orbital Sciences Corp.	Taurus	1994	9	VAFB	--	1,160 (2,552)	1,600 (3,520)
SpaceX	Falcon 9	2010	4	CCAFS	4,850 (10,692)	13,150 (28,991)	--
United Launch Alliance	Atlas V	2002	34	CCAFS, VAFB	2,690-6,860 (5,930-15,120)	8,123-18,814 (17,908-41,478)	6,424-15,179 (14,163-33,464)
United Launch Alliance	Delta IV	2002	21	CCAFS, VAFB	4,541-13,399 (10,012-29,540)	9,390-22,977 (20,702-50,656)	7,746-21,556 (17,078-47,522)
UH, Sandia, Aerojet	Super Strypi	2013	0	Barking Sands	--	200 (441)	--

Ref: "The Annual Compendium of Commercial Space Transportation: 2012" FAA AST, February 2013.

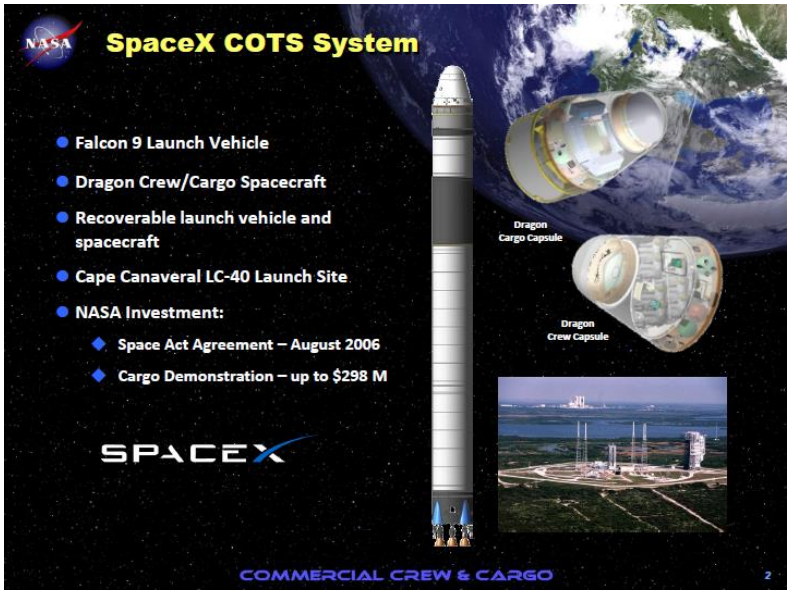
NASA COTS Program

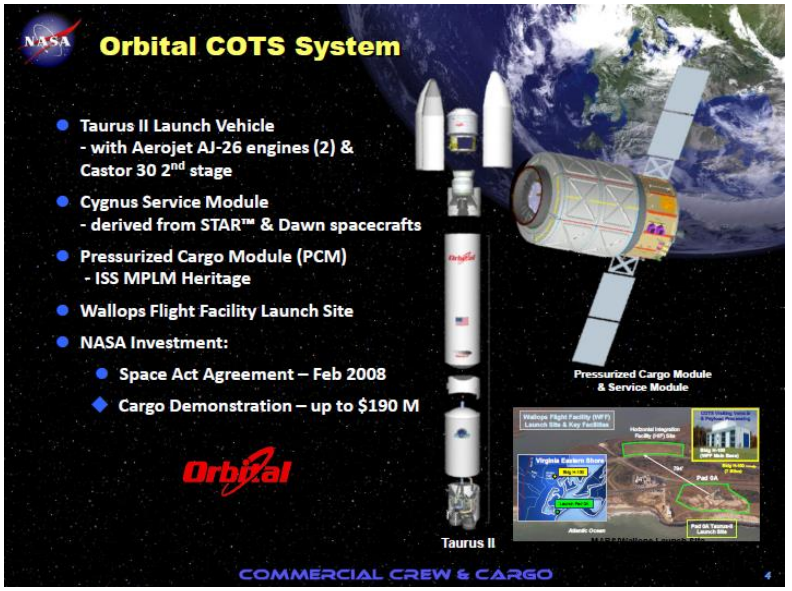
Open Competition

Milestone System – pay for performance - $700 million in NASA funds

“Skin in the Game” – private investment along with government funding

Transition to Commercial Resupply Service contracts after successful demonstrations - $3.5 billion in business over five years





NASA Commercial Crew Program

Same Business Model as COTS – over $1.1 billion in total NASA development funding over 4 competitive phases

Maintain Competition AND Maintain Safety Standards

Purchase Flight Services after Successful Demos

Encourage Commercial Human Spaceflight Business Development & Applications

Boeing CST-100

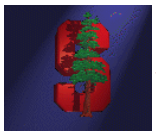
SpaceX Dragon

NASA Commercial Cargo and Crew Programs Funding

Series of NASA funded programs to supply the International Space Station with crew & cargo following Shuttle retirement.

Significant investment of financial and technical resources in private sector to develop and demonstrate safe, reliable, and cost-effective space transportation capabilities.

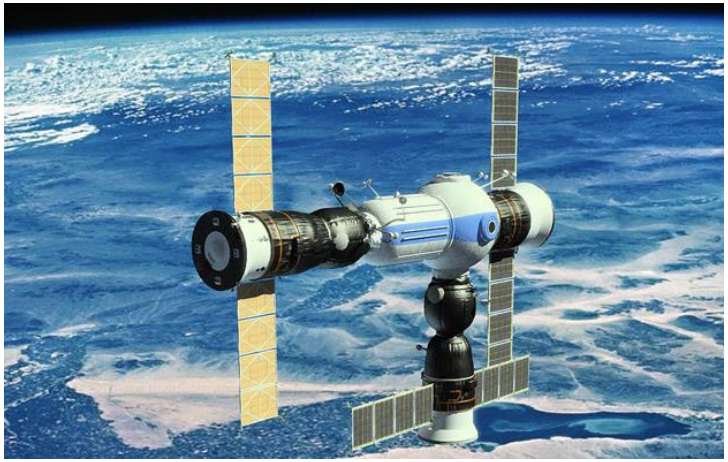
Commercial Cargo Program	**Program Years**	**Funding**
Commercial Orbital Transportation Services (COTS)	2006 - 2012	$800M
ISS Commercial Resupply Services (CRS)	2011 - 2016	$3.5B
Commercial Crew Program	**Program Years**	**Funding**
Commercial Crew Development (phase 1)	2010 - 2011	$50M
Commercial Crew Development (phase 2)	2011 - 2012	$270M
Commercial Crew Integrated Capability (phase 3)	2012 - 2014	$1.1B



Commercial Space Facilities

Galactic Suite

Promote private access to space



Bigelow Aerospace

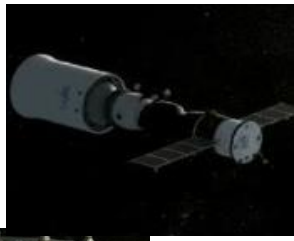
$500 million private investment
Affordable option for space flight
Launched prototype expandable space habitat
Building an extension to ISS (BEAM)

RSC Energia/Orbital Technologies

First commercial space station

Beyond LEO - Lunar

Google Lunar X Prize Competition
- $20 million for the winner
- More than 20 teams from around the world
- 2015 Deadline for landing a lunar rover



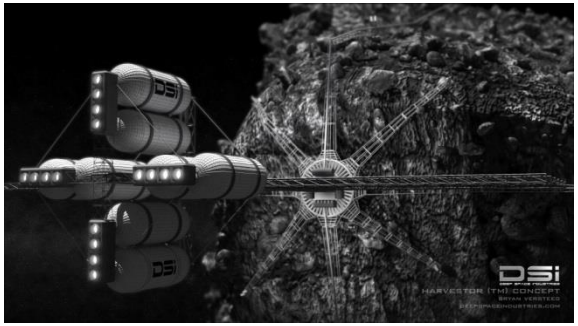
Space Adventures Lunar Flyby
- About $300 million mission cost – 2 customer seats (1 sold already)

Bigelow Commercial Lunar Base
- Lunar habitat assembled in LEO and landed in one piece
- Utilizes proprietary inflatable habitat technologies
- PPP with NASA – Phase 1 study underway now

Golden Spike
- Private company
- Affordable lunar orbital or surface exploration

Shackleton Energy Company
- $ Multi-billion private equity financing – 10 year development plan
- Lunar ice resource extraction & processing
- Propellant depot business model

Beyond LEO - Asteroids

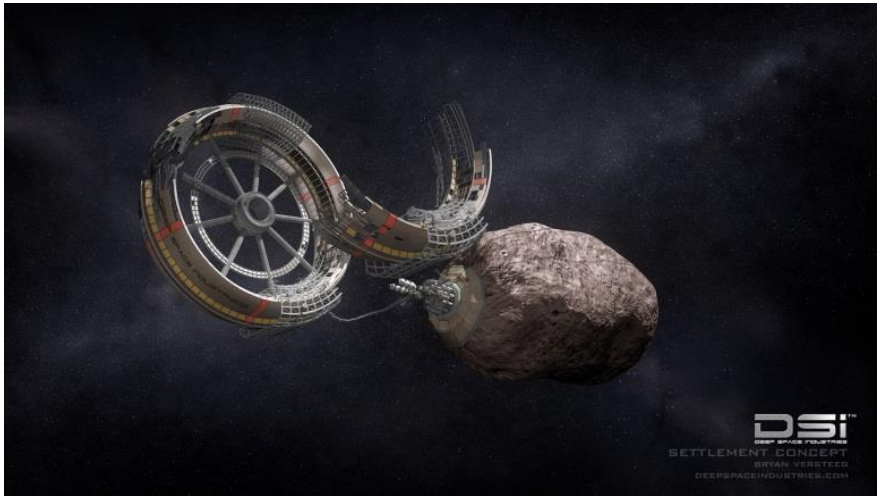


Planetary Resources

- Asteroid mining
- Robotic missions
- Reduce cost by constraining scope and simplicity
- Credible team

Deep Space Industries

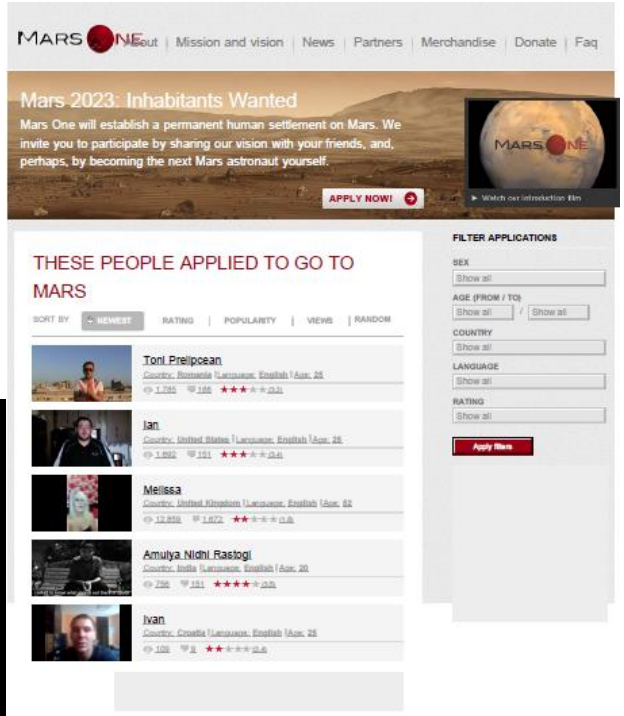
- Harvesting the resources of space
- Credible team



Beyond LEO - Mars

Inspiration Mars

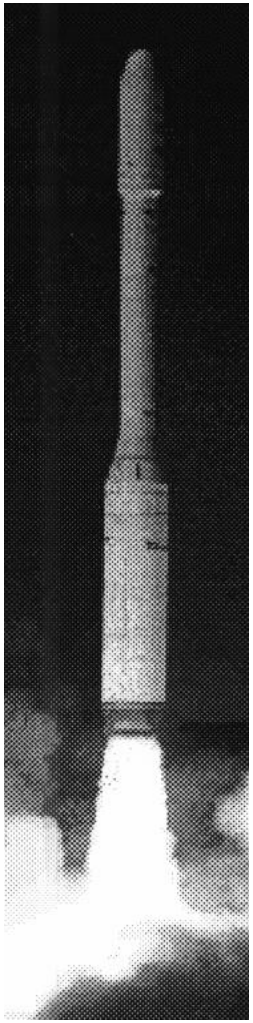
- Nonprofit organization
- Generate knowledge, experience and momentum for future space exploration
- Credible partners



Mars One

- Private company
- Permanent human settlement on Mars
- SpaceX Falcon Heavy

Taurus Launch Vehicle



- Country: USA
- Four-stage
- Totally expendable
- LEO Payload: 1,363 kg
- Total Mass: 73,030 kg

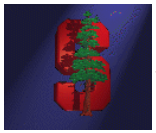
Taurus-Propulsion

Stage 1:(solid)
- Castor 120
- Isp(sl): 229 sec
- Burn time: 83 sec

Stage 2:(solid)
- Peg-1
- Isp(sl): 180 sec
- Burn time: 72 sec

Stage 2:(solid)
- Peg-2
- Isp(vac): 292 sec
- Burn time: 73 sec

Stage 4:(solid)
- Peg-3
- Isp(vac): 293 sec
- Burn time: 65 sec



Pegasus Launch Vehicle

Country: USA

Four-stage, Totally expandable

LEO Payload: 375 kg, Total Mass: 19,000 kg

Pegasus-Propulsion

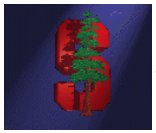
Stage 0:
- L-1011 (Isp=9900 sec)

Stage 1:(solid)
- Peg-1
- Isp(sl): 180 sec
- Burn time: 72 sec

Stage 2:(solid)
- Peg-2
- Isp(vac): 292 sec
- Burn time: 73 sec

Stage 3:(solid)
- Peg-3
- Isp(vac): 293 sec
- Burn time: 65 sec

Stage 4: (Liquid)
- MR-107 (NH4)
- Isp(vac): 236 sec
- Burn time: 65 sec



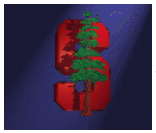
Ariene 5 Launch Vehicle

- Country: France
- Three-stage
- Totally expandable
- LEO Payload: 18,000 kg
- Total Mass: 737,000 kg

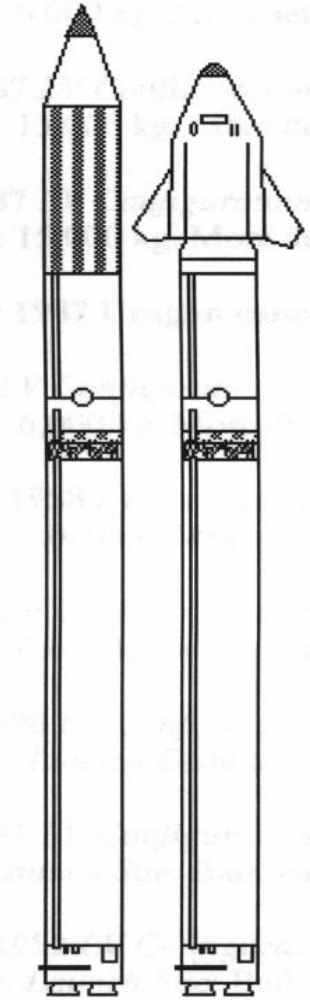
Stage 0:(solid)
- P230 (HTPB)
- Isp(sl): 259 sec
- Burn time: 123 sec

Stage 1:(liquid)
- Vulcain (Lox/LH2)
- Isp(sl): 310 sec
- Burn time: 605 sec
- C. Pres: 1,450 psi

Stage 2:(liquid)
- L7 (N_2O_4/MMH)
- Isp(vac): 320 sec
- Burn time: 810 sec
- C. Pressure: 218 psi

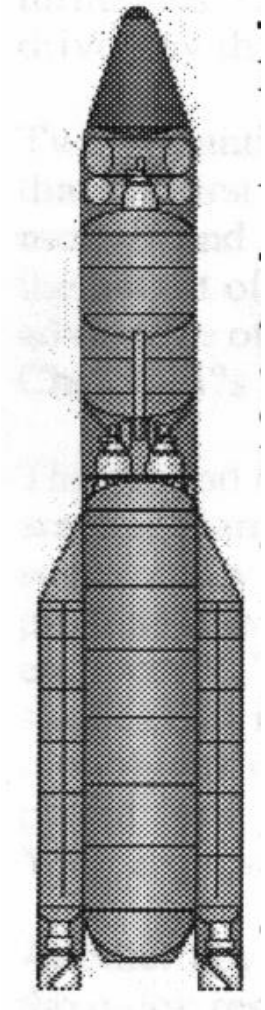


Zenit Launch Vehicle (Used by Boeing, Sea Launch)



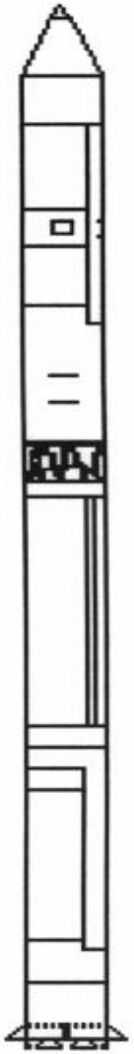
- Country: Russia
- Three-stage
- Totally expandable
- LEO Payload: 13,740 kg
- Total Mass: 478,390 kg
- Success Rate: 55/64
- Stage 1:(liquid)
  - 11D520 (lox/kerosene)
  - Isp(sl): 311 sec
  - Burn time: 150 sec
  - C. Pressure:
- Stage 2:(liquid)
  - 11D123 (lox/kerosene)
  - Isp(sl): 349 sec
  - Burn time: 315 sec
  - C. Pres: 2364 psi
- Stage 3:(liquid)
  - 11D58Z (lox/kerosene)
  - Isp(sl): 349 sec
  - Burn time: 660 sec
  - C. Pressure: 1124 psi

Proton Launch Vehicle



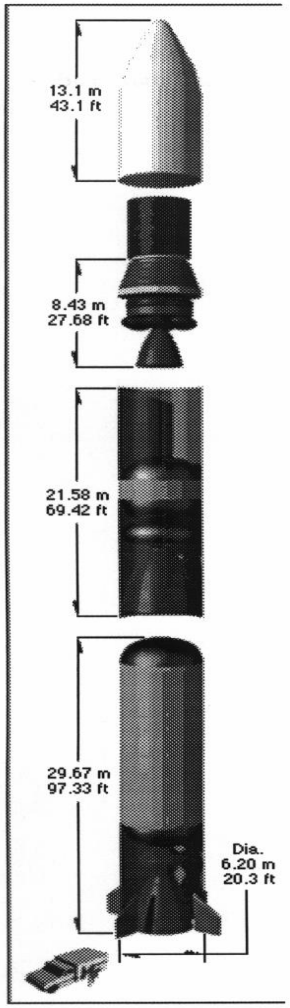
- Country: Russia
- Two-stage
- Totally expandable
- LEO Payload: 8,400 kg
- Total Mass: 595,490 kg
- Success Rate: 293/334
- Stage 1:(liquid)
  - 11D48 (N_2O_4/UDMH)
  - Isp(sl): 267 sec
  - Burn time: 124 sec
  - C. Pressure: 2130 psi
- Stage 2:(liquid)
  - 8D411K (N_2O_4/UDMH)
  - Isp(sl): 325 sec
  - Burn time: 160 sec

Kosmos Launch Vehicle



- Country: Russia
- Two-stage
- Totally expendable
- LEO Payload: 1,400 kg
- Total Mass: 107,500 kg
- Success Rate: 422/448
- Propulsion:
- Stage 1:(liquid)
  - 11D614 (N_2O_4/UDMH)
  - Isp(sl): 248 sec
  - Burn time: 130 sec
- Stage 2:(liquid)
  - 11D49 (N_2O_4/UDMH)
  - Isp(sl): 303 sec
  - Burn time: 375 sec

BEAL BA-2 (Failed Program)



- EELV, 3 stages
- Composite tanks and vehicle
- Payload to LEO: 17,000 kg
- Stage 1 and 2: kerosene/H2O2
- Helium pressurization system
- Total mass: 950,000 kg

Kistler Aerospace - K1 (Failed Program)

- Two-stage, totally reusable
- Uses N1 Russian engines
- Recovery: parachutes and airbags
- Development cost: $ 500 million
- Total mass: 363,400 kg
- LEO Payload: 4500 kg
- Launch Price (est): $ 17 million ($97)
- Success Rate: NA