Gateway To Space

ASEN 1400 / ASTR 2500

Class #17

Colorado Space Grant Consortium
Today:

- Announcements

- One minute questions/answers

- Lecture on Launch Vehicles
Announcements:

- Hardware orders – make them ASAP
- Insulation – more has made it home
- Other items needed?
- Launch is 25 days away
- Time is still your enemy not your friend
- DD Rev A/B – Still haven’t read them
Announcements:

- HASP 2014 Meetings to start 8 AM M, W, or F the week of November 4th

- One meeting per week for one hour until fall break

- HASP 2013 Final Presentation and Report is 10:00 AM on November 22nd

- RocketSat-10 meetings will start after fall break

- Anyone not have their picture taken on “1st day?”
Announcements:
Team Heavyweight
Preliminary Design Review

Cameron Heppe
Andy Anderson, Liam Kolber, Caleb Quechler,
Brent Patton, Justin Cherry, Ryan Oels, Eric Selig
December 17, 2012
Announcements:

Team Valkyrie

Daniel Albert, James Brobst, Adam Heaton, Kirk Christiansen, April Olson, Noah Guimard, Kevin Tatebe, Chia-hsin
One Minute Report Questions:

- What other programs can we do with SG?

- How much time do projects like RS take up?

- If you're not a part of SG in one of the missions, what is the cost contribution you have to give on average for trips?

- Seeing RS9 does AES have a materials engineering disciple in for zero gravity research?
One Minute Report Questions:

- Would it be possible to do SG and active learning opportunity or is that too much?

- How people find time for these activities while they are in rigorous aerospace curriculum?

- Did cockroaches survive?

- Is RS the only RS team starting up this spring?

- Does RS know what the next mission will be?
One Minute Report Questions:

- Does the concept of operations have to be specific format?

- We had no idea what you wanted for the CONOPS!

- Can we get food on the way to/from the launch site?

- Do we get graded on how nicely we dress during presentations?
One Minute Report Questions:

- What happens to all the equipment after the class?
- Is DD Rev C due on Launch Day?
- When we turn in the BalloonSat post-launch, do we need to make a new structure?
Announcements:
Next Class...

Orbit and Mission Design
- Part 1

Mid Semester Team Evals

Colorado Space Grant Consortium
Concept of Liftoff

Colorado Space Grant Consortium
Concept of Liftoff

- What does liftoff mean?
- Newton’s 2\textsuperscript{nd} Law?
- \( F = m \times a \)
- How much do you weigh?
- How much thrust (F)?
- Off the ground but have to keep going
Before we get started...

In Class Exercise
Building a Rocket on Paper:

- Please wait, everyone will be opening your envelopes in a minute

- Not every rocket design will work...

- **YOU ARE A ROCKET ENGINEER:**
  You make $70,000.00 a year and you have a masters degree and drive a company Viper
Building a Rocket on Paper:

1.) Build a rocket with the right people. You will need…

- Payload Specialist
- Thruster Specialist
- Fuel Expert
- Structural Engineer
2.) Calculate total mass of your rocket, must include everything.

\[ \text{Total mass} = \text{mass of fuel} + \text{payload} + \text{structure} + \text{thrusters} \]
Building a Rocket on Paper:

3.) Calculate the thrust needed to lift your rocket off the launch pad

\[ \text{Needed thrust} = \text{total mass} \times \text{gravity} \]

\[ F = m \times a \, [\text{Newtons, N}] \]

1 N = 1 kg*m/s²
1 pound-force = 4.45 N
\( a = \text{gravity} = 10 \, m/s^2 \)
Building a Rocket on Paper:

4.) Calculate the total lift (thrust) capability of your rockets thrusters

5.) Does your structure support the total weight of the rocket?

6.) Do you lift off the ground or did you crash and burn?

7.) Could you lift off the surface of the moon?  
   \[ g_{\text{moon}} = \frac{1}{6} \cdot g_{\text{earth}} \]
Ion Engine:

Max Thrust = 200 N
Engine/Fuel Mass = 9,000 kg (90,000 N)
Max Thrust (minus Engine/Mass) = -82,000 N
Remaining Mass = -8,200 kg

<table>
<thead>
<tr>
<th>Material</th>
<th>Ashes (2 kg)</th>
<th>Professor (180 kg)</th>
<th>Stamps (2K kg)</th>
<th>Water (20K kg)</th>
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</table>
**Cold Gas Engine:**

Max Thrust = 22,000 N  
Engine/Fuel Mass = 1,700 kg (17,000 N)  
Max Thrust (minus Engine/Mass) = 5,000 N  
Remaining Mass = 500 kg

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Propane Engine:

Max Thrust = 100,000 N
Engine/Fuel Mass = 8,000 kg (80,000 N)
Max Thrust (minus Engine/Mass) = 20,000 N
Remaining Mass = 2,000 kg

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Liquid Engine:

Max Thrust = 1,500,000 N
Engine/Fuel Mass = 103,000 kg (1,030,000 N)
Max Thrust (minus Engine/Mass) = 470,000 N
Remaining Mass = 47,000 kg

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</table>
### Solid Engine:

**Max Thrust**  
= 3,000,000 N

**Engine/Fuel Mass**  
= 52,000 kg (520,000 N)

**Max Thrust (minus Engine/Mass)**  
= 2,480,000 N

**Remaining Mass**  
= 248,000 kg

<table>
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Launch Vehicles

Past, Present, Future & Sci-Fi Future
Outline:

- Background & Rocket Types
- Past
- Present
- Future
- Sci-Fi Future
Objectives:

- Become familiar with past and present launch vehicles
- Learn the major companies

- **Rocket Classes**
  - Small Lift: < 2,000 kg
  - Medium Lift: 2,000 – 20,000 kg
  - Heavy Lift: 20,000 – 50,000 kg
  - Super Heavy Lift: > 50,000 kg
Background:

- **Thrust** = the force that moves (lb, N)

- **Impulse** = force over period of time

- **Specific Impulse** = Isp = ratio of impulse to fuel used

- Higher Isp usually indicates low thrust but very little fuel used

- Will learn more in Propulsion Lecture

- Rocket Types include: **Solid, liquid, hybrid**
Human Rating Requirements

System Safety
- Fault tolerance to system or crew errors
- Caution & Warning systems
- Ready access to emergency equipment

Crew/Human Control of the System
- On board and remote monitoring and control
- Manual flight capability with adequate handling

Crew Survival/Aborts
- Prelaunch – Unassisted crew egress from the launch pad
- Powered flight: Loss of all propulsion or attitude control
- Abort initiation: Auto, crew, or ground
Types of Rockets
Types of Rockets

Model Rockets (Estes)
Types of Rockets

High Altitude/Amateur Rockets
Types of Rockets

Suborbital/Sounding Rockets
Types of Rockets

Orbital Rockets
Types of Rockets:
Past
Past:

Jupiter C (1956-1957)

- Thrust: 334,000 N (75,090 lb)
- Fueled Weight: 29,030 kg
- Payload to Orbit: 9 kg LEO (14 kg)

# of Flights: 6, 4 successful

Explorer I
Past/Present:

**Scout (1961-1994)**

- **Thrust:** 464,700 N (104,500 lb)
- **Fueled Weight:** 21,750 kg
- **Payload to Orbit:** 270 kg LEO
- **# of Flights:** 188, 105 successful
Past:

**Mercury Redstone (1960-1961)**

- **Thrust:** 347,000 N (78,000 lb)
- **Fueled Weight:** Not Found kg
- **Payload to Orbit:** 9 kg LEO (Suborbital)
- **# of Flights:** 6, 5 successful

First US manned rocket
Chimp “Ham”, Shepard, and Grissom
Past:

Saturn V

<table>
<thead>
<tr>
<th>Thrust:</th>
<th>34,500,000 N (7,760,000 lb)</th>
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<tbody>
<tr>
<td>Fueled Weight:</td>
<td>2,910,000 kg</td>
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<tr>
<td>Payload to Orbit:</td>
<td>127,000 kg LEO</td>
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<tr>
<td>Launches:</td>
<td>11/11</td>
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</table>

7 manned moon landings
Past:
Can it be built today? **Not really…**

According to Prof. Jesco von Puttkamer, Program Manager of Future Planning at NASA in 1999…

- The blue prints still exist, however only on microfilm.

- All the subcontractors and suppliers are no longer around.

- The technology is old. We can build much smaller and lighter rockets today.
Past:

Lockheed Martin

Thrust: 4,800,000 N
(1,080,000 lb)

Fueled Weight: 860,000 kg

Payload to Orbit: 21,645 kg LEO

Cost per launch: $250,000,000

Cost per kg: $11,500

# Launches: 35, 32 successful

Last Launch: 2005
Past:

Falcon 1 (Space-X)

- Thrust: 454,000 N
- Fueled Weight: 38,555 kg
- Payload to Orbit: 570 kg LEO
- Cost per launch: $7,000,000
- Cost per kg: $12,280
- Launches: 5/2

First flight March 2006, retired 2010

To be replaced with Falcon 1e (1010 kg to LEO), current status uncertain.
**Past:**

**Space Shuttle**

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<th>Description</th>
<th>Value</th>
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<td>Thrust</td>
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<td>2,040,000 kg</td>
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<td>Payload to Orbit</td>
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</table>
Past:

Energia (Russia)

Thrust: 34,800,000 N
(7,820,000 lb)
Fueled Weight: 2,400,000 kg
Payload to Orbit: 90,000 kg LEO
Cost per launch: $764,000,000?
Cost per kg: $Not Known
Past:

Buran “Snowstorm” (Russia)

First and only launch
November 15, 1988

No one on board
- Life support not tested
- CRT’s did not have software

Only 2 orbits
- This was limited because of computer memory

Landed by autopilot
Past:

Aero Buran was test unit

Had 24 test flights

3 others were being built
- Pitchka (Little Bird)
- Baikal (Typhoon)

All dismantled in 1995
Past:
Present/Past:
Past:
Present:

<table>
<thead>
<tr>
<th>United States</th>
<th>Foreign</th>
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<tbody>
<tr>
<td>- Atlas</td>
<td>- France (Ariane)</td>
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<td>- Delta</td>
<td>- Japan (H-series)</td>
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<tr>
<td>- Pegasus</td>
<td>- India (PSLV)</td>
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<td>- Taurus</td>
<td>- China (Long March)</td>
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<tr>
<td>- Falcon</td>
<td>- Russia (Proton, Sea Launch, Soyuz)</td>
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<td>- Antares</td>
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</table>
Present:

Atlas V (2002 – Present)
Lockheed Martin/ULA

Thrust: 8,590,000 N (1,900,000 lb)
Fueled Weight: 546,700 kg
Payload to Orbit: 10-19,000 kg LEO
Cost per launch: $138,000,000
Cost per kg: $9,000
Launches: 27, 1 partial failure

Notable payloads:
Mars Reconnaissance Orbiter
Juno
Present:

**Delta II (1989 – Present)**

Boeing/ULA

- **Thrust:** 2,630,000 N (591,000 lb)
- **Fueled Weight:** 230,000 kg
- **Payload to Orbit:** 5045 kg LEO
- **Cost per launch:** $60,000,000
- **Cost per kg:** $11,892

**Notable Payloads:**
- Mars Rovers
- GRAIL
Present:

Delta IV

Height 63 - 77.2 m (206 - 253.2 ft)
Diameter 5 m (16.4 ft)
Mass 249,500 - 733,400 kg (550,000 - 1,616,800 lb)
Capacity
Payload to LEO 8,600 - 25,800 kg (18,900 - 56,800 lb)
Payload to GTO 4,300-12,980 (9,480-28,620 lb)
Cost per launch: $160,000,000
Present:

Delta IV Heavy

Thrust: 8,896,443 N
Fueled Weight: 733,000kg
Payload to Orbit: 23,000kg LEO
Cost per launch: $254,000,000
Cost per kg: $11,000
Launches: 5/4
First Launch: Dec 2004

Possible launcher for MPCV
(Formerly Orion)
Present:
### Present:

**Pegasus**

Orbital

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<td>Cost per kg:</td>
<td>$19,800</td>
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Launches: 40/35
Present:
Taurus (XL) (1994 – Present)
Orbital

- Thrust: 1,606,000 N
- Fueled Weight: 73,000 kg
- Payload to Orbit: 1,320 kg LEO
- Cost per launch: $24,000,000
- Cost per kg: $16,000

Launches: 9/6
Present:

**Antares (2013)**
Orbital, Wallops

Thrust: 3,265,000 N
Payload to Orbit: 1,320 kg LEO
Cost per launch: $?
Cost per kg: $?

Solid and liquid
Launches: 0
**Present:**

**Falcon 9 (Space-X)**

- **Thrust:** 5,000,000 N
- **Fueled Weight:** 333,400 kg
- **Payload to Orbit:** 13,150 kg LEO
- **Cost per launch:** $60,000,000
- **Cost per kg:** $5700
- **Launches:** 3/4
- **Nov 30 ‘11, Dragon RNDZ ISS**
**Dragon (Space X)**

- Fully autonomous rendezvous and docking with manual override capability in crewed configuration
- Pressurized Cargo/Crew capacity of >2500 kg and 14 cubic meters
- Down-cargo capability (equal to up-cargo)
Dragon:

- Launches on Falcon 9
- Supports up to 7 passengers in Crew configuration
- Designed for water landing under parachute for ocean recovery
**Present:**

Ariane 5 (France) (1996 – present)

| Thrust:       | 11,400,000 N                                      |
|              | (2,560,000 lb)                                    |
| Fueled Weight:| 737,000 kg                                       |
| Payload to Orbit: | 16-21,000 kg LEO                  |
| Cost per launch:  | $120,000,000                                    |
| Cost per kg:    | $6,400                                           |
| Launches:      | 60/56                                            |
Present:

H-2A, H-2B (Japan)

Thrust: 3,959,200 N
        (890,060 lb)
Fueled Weight: 260,000 kg
Payload to Orbit: 10,500 kg LEO
Cost per launch: $190,000,000
Cost per kg: $18,095
H-2B Launches: 2/2
H-2A Launches: 19/18
Present:
**Present:**

**Long March CZ-2F (China)**

<table>
<thead>
<tr>
<th><strong>Thrust:</strong></th>
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<td>(1,331,000 lb)</td>
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<tr>
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Yang Liwei
Present:

Sea Launch/Zenit

Thrust:
8,180,000 N

Fueled Weight:
450,000 kg

Payload to LEO:
13,740 kg

Cost per launch:
$100,000,000

Cost per kg:
$7,300

Launches:
31/28
Present:

Proton-M Enhanced (Russia)

- Thrust: 10,000,000 N
- Fueled Weight: 712,800 kg
- Payload to Orbit: 20,000 kg LEO
- Cost per launch: $100,000,000
- Cost per kg: $4500
- First Flight: 2007

Proton rocket family dates back to 1965, ~340 launches total
Present:
Soyuz:

(Russia)

Soyuz-U (cargo)
Soyuz-FG (crew)

Thrust: 10,000,000 N
Fueled Weight: 313,000 kg
Payload to Orbit: 6,900 kg LEO
Launches: 745/724

Soyuz also refers to crew capsule
<table>
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<tr>
<td><strong>Polar Satellite Launch Vehicle</strong></td>
<td><strong>(India)</strong></td>
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<tr>
<td>Thrust:</td>
<td>500,000 N</td>
</tr>
<tr>
<td>Fueled Weight:</td>
<td>294,000 kg</td>
</tr>
<tr>
<td>Payload to Orbit:</td>
<td>3,250 kg LEO</td>
</tr>
<tr>
<td>Cost per launch:</td>
<td>$17,000,000</td>
</tr>
<tr>
<td>Cost per kg:</td>
<td>$5200</td>
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<tr>
<td>Launches:</td>
<td>19/17</td>
</tr>
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<td>First Flight:</td>
<td>1993</td>
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</table>
Worldwide launch schedule

October 7, 2011 - A regularly updated listing of planned missions from spaceports around the globe. Dates and times are given in Greenwich Mean Time. "NET" stands for no earlier than. "TBD" means to be determined. Recent updates appear in red type. Please send any corrections, additions or updates by e-mail to: sclark@spaceflightnow.com

Latest changes:
9/20: Ariane 5 scrubbed; Adding window for Sea Launch/Atlantic Bird 7; Adding window for Minotaur 4/TacSat 4
9/22: Sea Launch/Atlantic Bird 7 delayed; Adding timeframe for Long March 2F/Tiangong 1; Adding time for Proton/QuetzSat 1
9/24: Updating launch times for Progress 45P, Soyuz 28S and Soyuz 29S
9/26: Long March 2F/Tiangong 1 delayed; Soyuz/Globalstar delayed
9/28: Adding time for Long March 2F/Tiangong 1
9/29: Adding time for Soyuz/Glonass; Adding date for Zenit/Intelsat 18; Proton/Glonass delayed
9/30: Adding Proton/SES 4 launch
10/04: Land Launch/Intelsat 18 scrubbed; Delta/NPP delayed; Adding date for Long March/W3C
10/05: Adding date for Proton/ViaSat 1
10/08: Adding time for PSLV/Mega-Tropiques; Adding Long March 2F/Shenzhou 8; Next Falcon 9 delayed; Taurus 2 demo delayed; Progress 46P delayed; Adding date for Atlas 5/AEHF 2

Launch Log

Final Shuttle Mission Patch
Free shipping to U.S. addresses!
The crew emblem for the final space shuttle mission is now available in our store! Atlantis is scheduled for launch in June.
- U.S. STORE
- WORLDWIDE STORE
Future
Falcon 1e:

- Length: 24.7m (81 ft)
- Width: 1.7 m (5.5 ft)
- Mass: 38,180 kg (77 klbs)
- Thrust on liftoff:
  - 512 kN (115 klbf)

Falcon 1 (5/2) with modified 1st stage.
Falcon Heavy:

- Thrust: 17,000,000 N
- Weight: 1,400,000 kg
- Payload LEO: 53,000 kg
- Launch cost: $125,000,000
- Cost per kg: $2300!
- First Flight: 2012, planned
Future:

**Vega (ESA)**

- Thrust: 3,040,000 N
- Fueled Weight: 124,300 kg
- Payload to Orbit: 1,500 kg LEO
- First Flight: Planned Jan 2012

Development began 1998
Building on a Foundation of Proven Technologies

Launch Vehicle Comparisons

**Space Shuttle**
- Height: 184.2 ft
- Gross Liftoff Mass: 4.5M lb
- 55k lbm to LEO

**Ares I**
- Height: 321 ft
- Gross Liftoff Mass: 2.0M lb
- 48k lbm to LEO

**Ares V**
- Height: 358 ft
- Gross Liftoff Mass: 7.3M lb
- 117k lbm to TLI
- 144k lbm to TLI in Dual-Launch Mode with Ares I
- 290k lbm to LEO

**Saturn V**
- Height: 364 ft
- Gross Liftoff Mass: 6.5M lb
- 99k lbm to TLI
- 262k lbm to LEO

**Orion CEV**
- Upper Stage (1 J-2X)
- 280k lb LOx/LH₂

**Core Stage**
- (5 RS-68 Engines)
- 3.1M lb LOx/LH₂

**Upper Stage**
- (1 J-2X)
- 499k lb LOx/LH₂

**Lunar Lander**
- 240k lb LOx/LH₂

**Earth Departure Stage (EDS)**
- (1 J-2X)
- 1M lb LOx/LH₂

**5-Segment Reusable Solid Rocket Booster (RSRB)**
- Two 5-Segment RSRBs

**S-IVB**
- (1 J-2 engine)
- 240k lb LOx/LH₂

**S-II**
- (5 J-2 engines)
- 1M lb LOx/LH₂

**S-IC**
- (5 F-1 engines)
- 3.9M lb LOx/RP
**Future:**

**Space Launch System (SLS)**

Congressionally mandated, 2010
Mission “Explore deep space and provide NASA-owned access to ISS”

Planned LEO payload capability:
70,000 – 129,000 kgs

Test flight 2017
1st crewed flight 2021

Based on Shuttle and Ares programs
Future: Liberty

ATK and Astrium

Based on Shuttle/Ares boosters and Ariane 5 upper stage

Not selected for Commercial Crew Development (CCDev), but is still in work

Planned LEO payload: 22,000 kg
Future: Dream Chaser

CU highly involved
- Displays, controls, human rating

7 crew members to ISS

Planned launch vehicle: ULA Atlas V
(must man-rate)

Based on HL-20 lifting body

Drop tests planned Summer 2012 on WhiteKnightTwo

Runway landing, 1.5 g
(Soyuz ~5 g)
Future: Dream Chaser
Future: CST-100 (Boeing)

(C)rew (S)pace (T)ransportation, 100 km is considered the boundary of space
Larger than Apollo capsule, smaller than MPCV
Atlas 5 planned launcher
Possibly operational by 2015
Future: New Shepard (Blue Origin)

Based off DARPA/McDonald Douglas’ DC-X

Vertical takeoff and landing

Suborbital tourism/research (100km alt, 10 min)

August 2011, test vehicle failure at mach 1.2, 45k ft

“Flight instability, range safety terminated thrust”

NASA’s commercial crew development:

- Awarded Launch Abort System contract
- Working on crew capsule with own funds
Future: SpaceShipTwo

Virgin Galactic and Scaled Composites

SpaceShipOne won the Ansari-X prize in 2004

SpaceShipTwo

• Six passenger
• Launches off WhiteKnightTwo at 50,000 ft
• Hybrid motor
Future: Spaceport America
Future: Spaceport America
Future:

When Can I Go?

The first flights are planned to begin in 2008. We are now starting to take reservations and deposit commitments for the first year of operations. The ticket price has been set at US$200,000 and the minimum, fully refundable deposit to secure your spaceship seat is US$20,000.

If you're ready to talk to us about making a firm reservation and paying a deposit, or would just like to be kept up to date with the Virgin Galactic space tourism programme, fill in the form below.

*Mandatory fields are marked with *

*Email address:  
*Type email address again to confirm:  
Title:  Mr  
*First Name:  
*Surname:  

*Would you consider putting down a deposit for a ride when we’re ready for you to do so?  

Market Research - If you are happy for us to contact you for research purposes, tick this box.
Future/Present: X-37

- Unmanned, classified
- Launches on Atlas V
- 2 Flights
  - April – Dec 2010
  - March 2011 - ?
Future/Past:

- X-33
- VentureStar
Future:

“Maglev Launch

(Magnetic Levitation)

Accelerate horizontally

Less on board propellant

Less weight
Future/Past:

- Crew Return Vehicle
- X-38
Future/Past:
Sci-Fi Future
Sci-Fi Future:

- Plasma Rocket
Sci-Fi Future:

- Anti-matter
Sci-Fi Future:
Sci-Fi Future:

- Boussard Ramjet Fusion Propulsion
Sci-Fi Future:

- Electrodynamic Tether
Sci-Fi Future:

- Jovian Electrodynamic Tether
Sci-Fi Future:

- Beamed Energy Propulsion
Sci-Fi Future:

- Plasma Rocket
**Sci-Fi Future:**

**Space Elevator**
- Konstantin Tsiolkovsky (Eiffel Tower)
- Arthur C. Clark (The Fountains of Paradise)

- Five Critical Technologies (Source: MSFC Study)
  - High Strength Materials
  - Tension Structures
  - Compression Structures
  - EM Propulsion
  - Supporting Infrastructure

- May Lower Launch Costs to <$10/kg!
Sci-Fi Future:

Space Elevator
Sci-Fi Future:

Getting to the moon

A Reach Earth’s Orbit
- Travel by current rocket technology at $5K - $20K per pound

B Reach “Lifport”
- Move cargo by rocket at modest cost

C Reach the Moon
- Cheap & reliable long-haul to and from the moon with a solar powered elevator; built with a ribbon anchored in earth’s gravity well.

Lunar elevator provides cheap and reliable access to the moon. This is because it eliminates the vast rocket fuel costs involved in braking on the way to the moon, and lifting off on the way back.