Gateway To Space

ASEN 1400 / ASTR 2500
My Name is...
\[ \frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} = 0 \]

\[ \sum_{k=1}^{n} k^2 = \frac{n(n + 1)(2n + 1)}{6} \]

\[ \frac{d}{dx} f(x) = \lim_{\Delta \to 0} \frac{f(x + \Delta) - f(x)}{\Delta} \]

\[ \cos x = \sum_{n=0}^{\infty} \frac{(-1)^n x^{2n}}{(2n)!} \]

\[ \int \tan(ax) \, dx = -\frac{1}{a} \ln |\cos(ax)| + c \]

\[ \int u \frac{dv}{dx} \, dx = uv - \int \frac{du}{dx} v \, dx \]

\[ \lim_{x \to c} \frac{f(x)}{g(x)} = \lim_{x \to c} \frac{f'(x)}{g'(x)} \]

\[ \lim_{x \to -\infty} \tan^{-1}(x) = -\frac{\pi}{2} \]
PID Control Law

- Proportional, Integral, Derivative (PID)
  - Used to control single axis

• One PID controller for each axis

\[
\omega_{\text{err}} = \text{rate error} \\
\theta_{\text{err}} = \text{attitude error} \\
\theta_{i_{\text{err}}} = \text{integrated attitude error}
\]
PID Control Law Response Times

- Zero Rate Gain = No Damping
- Small Rate Gain = Light Damping
- Large Rate Gain = Heavy Damping
"If you're really successful at bullshitting, it means you're not hanging around enough people smarter than you."

Neil deGrasse Tyson
November 2000 University of Colorado at Boulder

...Word!
Gateway To Space

ASEN 1400

Class #1

Colorado Space Grant Consortium
How was the first day?
How was the second day?
Today

- Lots of stuff about the class
- What to expect from this course
- Format for this course
  - “How to get an A”
- Introductions
- Pictures

First Day Checklist
So you know what you heard
Class Size
Who's Out There?
Who’s Out There?
Space Clip
What this class takes...
Wordle from Comments 2011 Class:
Wordle from Comments 2013 Class:
Wordle from Comments Fall 2014 Class:
What to expect...
What to Expect?

- What you imagine this class will be like...
What to Expect?

- What it is like…
What to Expect?

- What it is like…
What to Expect?

- What it is like...
What to Expect?

- What it is like…
What to Expect?

- What it is like…
Speaking of History…

What is it like…
What to Expect?

- 18th time teaching this course (1st spring since 2006)

- I have a unique teaching style
- I teach like I wish I had been taught
- Sense of humor
What to expect from this class:

- If you are not here because you want to be here, then leave…

- If you are here because you think this will be easier than GEEN 1400 (or some other class), then leave…

- If you are a slacker, then leave…

- But if you want to work hard and achieve something great…

  then please stay
The Class:

Learn the basics of atmospheric and space sciences, space exploration, spacecraft design, rocketry, and orbits.

Life Cycle of an Spacecraft Project

Design and Analysis

Earth to Mars:

Past Student Experiments:
- Atmospheric radiation levels
- Solar cell efficiency
- Atmospheric soundings
- Video imaging
- High altitude effects on roaches
- Digital sound recording of upper atmosphere
- Temperature studies
The Class:

Hear about the current research in space through lectures from industry
Launch a mini-satellite on a high altitude balloon that is designed and built by you and a team of students.
The Class:
The Class:
The Class:

- Interactive
- Interesting
- Applicable
- Fun
Team Video:

Team Video Fall 2012
Syllabus
Syllabus:

11 - Lecture
08 - Guest
10 - Teams
07 - Reviews
07 - Extra
15 - Attention
<table>
<thead>
<tr>
<th>Class #</th>
<th>Date</th>
<th>Day</th>
<th>DTL</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>01-13-15</td>
<td>T</td>
<td>88</td>
<td>Class Introduction and Pictures (So starts the rollercoaster)</td>
</tr>
<tr>
<td>2</td>
<td>01-15-15</td>
<td>R</td>
<td>86</td>
<td>Spacecraft Overview – (Compressed)</td>
</tr>
<tr>
<td>3</td>
<td>01-20-15</td>
<td>T</td>
<td>81</td>
<td>BalloonSat Overview + Request for Proposals: Functional Block Diagrams, Design Documents</td>
</tr>
<tr>
<td>4</td>
<td>01-22-15</td>
<td>R</td>
<td>79</td>
<td>HANDS-ON: Team Forming + Team Activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>PROPOSAL Assigned (18 days)</strong></td>
</tr>
<tr>
<td>5</td>
<td>01-27-15</td>
<td>T</td>
<td>74</td>
<td>Guest Lecture – “Solar System Exploration Missions”</td>
</tr>
<tr>
<td>6</td>
<td>01-29-15</td>
<td>R</td>
<td>72</td>
<td>HANDS-ON: Soldering 101 (Build and Blink)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>Arduino’s distributed to teams today for HW 04</em></td>
</tr>
<tr>
<td>7</td>
<td>02-03-15</td>
<td>T</td>
<td>67</td>
<td>REVIEWS: Conceptual Design Review (CoDR)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>4 minute presentations &amp; 5 minutes of Q/A</em></td>
</tr>
<tr>
<td>8</td>
<td>02-05-15</td>
<td>R</td>
<td>65</td>
<td>HANDS-ON: Arduino – Part I (Type and Blink):</td>
</tr>
<tr>
<td>x1</td>
<td>02-09-15</td>
<td>M</td>
<td>61</td>
<td><strong>PROPOSALS DUE 8:00 AM</strong></td>
</tr>
<tr>
<td>9</td>
<td>02-10-15</td>
<td>T</td>
<td>60</td>
<td>HANDS-ON: Arduino – Part II (Analog Sensors):</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>After lecture intro, some team members may leave to work on other aspects of the project but must report back to room at end of class</em></td>
</tr>
<tr>
<td>10</td>
<td>02-12-15</td>
<td>R</td>
<td>58</td>
<td>HANDS-ON: Arduino – Part III (More Sensors):</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>After lecture intro, some team members may leave to work on other aspects of the project but must report back to room at end of class</em></td>
</tr>
<tr>
<td>x2</td>
<td>02-12-15</td>
<td>R</td>
<td>58</td>
<td>HANDS-ON: Arduino – Part IV (Memory):</td>
</tr>
<tr>
<td></td>
<td>6 – 9 PM</td>
<td></td>
<td></td>
<td><em>Team representatives required to attend</em></td>
</tr>
<tr>
<td>x3</td>
<td>02-13-15</td>
<td>F</td>
<td>57</td>
<td>&gt;&gt;&gt;&gt; Authority To Proceed (ATP) by appointment with Chris &lt;&lt;&lt;&lt;</td>
</tr>
<tr>
<td>Week</td>
<td>Date</td>
<td>Day</td>
<td>Time</td>
<td>Topic</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>-----</td>
<td>------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>11</td>
<td>02-17-15</td>
<td>T</td>
<td>53</td>
<td>Requirements Flow Down Process + HASP 2014 Team</td>
</tr>
<tr>
<td>12</td>
<td>02-19-15</td>
<td>R</td>
<td>51</td>
<td>Guest Lecture – “Systems Engineering”</td>
</tr>
<tr>
<td>13</td>
<td>02-24-15</td>
<td>T</td>
<td>46</td>
<td>Guest Lecture – “Spacecraft Structures”</td>
</tr>
<tr>
<td></td>
<td>[WEB]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>02-26-15</td>
<td>R</td>
<td>44</td>
<td>Guest Lecture – “Spacecraft Propulsion”</td>
</tr>
<tr>
<td></td>
<td>[WEB]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>03-03-15</td>
<td>T</td>
<td>39</td>
<td>REVIEWS: Preliminary Design Review (PDR)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;6 minute presentations &amp; 1 minute of Q/A&gt;</td>
</tr>
<tr>
<td>16</td>
<td>03-05-15</td>
<td>R</td>
<td>37</td>
<td>Rocket History</td>
</tr>
<tr>
<td>17</td>
<td>03-10-15</td>
<td>T</td>
<td>32</td>
<td>Launch Vehicles</td>
</tr>
<tr>
<td>18</td>
<td>03-12-15</td>
<td>R</td>
<td>30</td>
<td>Orbits and Mission Design – Part I</td>
</tr>
<tr>
<td>19</td>
<td>03-17-15</td>
<td>T</td>
<td>25</td>
<td>Orbits and Mission Design – Part II</td>
</tr>
<tr>
<td>20</td>
<td>03-19-15</td>
<td>R</td>
<td>23</td>
<td>HANDS-ON: In-Class Team Time – Bring hardware and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>questions. Chris will be walking the room and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>inspecting payloads</td>
</tr>
<tr>
<td>20</td>
<td>03-23-15</td>
<td>T-R</td>
<td>18</td>
<td>Spring Break – NO CLASSES – Spring Break</td>
</tr>
<tr>
<td></td>
<td>03-27-15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>03-31-15</td>
<td>T</td>
<td>11</td>
<td>HANDS-ON - In-Class Mission Simulation Test (ON for</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>the whole class) If Time = Spider</td>
</tr>
<tr>
<td>22</td>
<td>04-02-15</td>
<td>R</td>
<td>09</td>
<td>Guest Lecture – “Spacecraft Attitude Determination</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>and Control”</td>
</tr>
<tr>
<td>Day</td>
<td>Date</td>
<td>Day</td>
<td>Time</td>
<td>Activity</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>-----</td>
<td>------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>23</td>
<td>04-07-15</td>
<td>T</td>
<td>04</td>
<td>REVIEWS: Launch Readiness Review (LRR)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;4 minute presentations &amp; 4 minutes of Q/A</td>
</tr>
<tr>
<td>24</td>
<td>04-09-15</td>
<td>R</td>
<td>02</td>
<td>Launch Logistics</td>
</tr>
<tr>
<td>24</td>
<td>04-09-15</td>
<td>F</td>
<td>01</td>
<td>Final BalloonSat Weigh-in and TURN IN</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>By appointment 8:00 AM to 2:00 PM @ Chris’s Office DLC 270A</td>
</tr>
<tr>
<td>24</td>
<td>04-11-15</td>
<td>SAT</td>
<td>00</td>
<td>Launch Day @ 6:50 AM @ Windsor, Colorado</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Leave Boulder at 4:45 AM!)</td>
</tr>
<tr>
<td>25</td>
<td>04-14-15</td>
<td>T</td>
<td>+3</td>
<td>Guest Lecture – “Spacecraft Power” and Career Advice</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ Launch Recap and Report and Data Analysis Guidance</td>
</tr>
<tr>
<td>26</td>
<td>04-16-15</td>
<td>R</td>
<td>+5</td>
<td>REVIEWS: Quick Look Post Launch Presentation</td>
</tr>
<tr>
<td>27</td>
<td>04-21-15</td>
<td>T</td>
<td>+10</td>
<td>Guest Lecture – “Have You Been To Mars?”</td>
</tr>
<tr>
<td>29</td>
<td>04-28-15</td>
<td>T</td>
<td>+17</td>
<td>Space Grant Opportunities, Class Survey, and Team Videos</td>
</tr>
<tr>
<td>29</td>
<td>04-28-15</td>
<td>SAT</td>
<td>+14</td>
<td>REVIEWS: ITLL Design Expo (9:00 AM – 4:00 PM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Open to the general public from 12:30 to 3:00 PM</td>
</tr>
<tr>
<td>30</td>
<td>04-30-15</td>
<td>R</td>
<td>+19</td>
<td>Final Class – Review and Discussion + Final Team Evaluations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bring all hardware</td>
</tr>
<tr>
<td>31</td>
<td>05-05-15</td>
<td>T</td>
<td>+23</td>
<td>REVIEWS: Community Service Activity Presentations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ Extra Credit Final Exam (time permitting)</td>
</tr>
</tbody>
</table>
NOTES: All “DUE” items are due electronically via email at Prof.Koehler@gmail.com by class time unless otherwise stated above. Items submitted after class begins or past the specified time, will be late and subject to grade penalty. Files must be emailable or brought to Chris on USB driver before time due.

All Subject lines of each email submitted for this class must follow the naming convention below:
Homework = “HW XX Lastname FirstInitial” Example = HW 01 Armstrong N (Attachments shall be in MS Word)
Team Documents = “DD rev Team Number” Example = DD C Team 04 (Attachments shall be in MS Word)
Team Presentations = “Review Team Number” Example = CDR Team 04 (Attachments shall be in MS PowerPoint)
Failure to use this naming convention will result in your email be deleted by a SPAM filter and may result in no credit or late penalties.

1 Minute Reports are DUE each day at the end of class. Please use your assigned number and printed form for proper credit. Attendance will be taken during each lecture. It is your responsibility to find and sign the attendance sheet before the end of class. If you need anything, please send an email with the word “HELP” in the subject. Email will be routed to the top of my email inbox.

<table>
<thead>
<tr>
<th>Individual Points/Grade Percentage</th>
<th>Team Points/Grade Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% Attendance (30) &amp; 1 Minute Reports (30)</td>
<td>10% Team Proposal</td>
</tr>
<tr>
<td>15% Homework 1-8,10 (10%) + 9 (5%)</td>
<td>13% Team Presentations (4)</td>
</tr>
<tr>
<td>05% Spatial Visualization Test (Must pass to get 5%)</td>
<td>10% Team Design Document (2 Revs)</td>
</tr>
<tr>
<td>05% Community Service and Presentation</td>
<td>02% Design Expo</td>
</tr>
<tr>
<td>15% Individual Contributions &amp; Participation on Team</td>
<td>15% Final Presentation and Final Report</td>
</tr>
<tr>
<td>50% Subtotal (You)</td>
<td>50% Subtotal (Team)</td>
</tr>
</tbody>
</table>

50% + 50% = 100%
How to get an A?
How to get an A:

“Everyone starts out with an A”

You have to try really hard to get anything lower than C-

Not in the business of giving bad grades…

…But you get the grade you earn

Please, Please, Don’t Cheat
Spring 2006 – Fall 2014 Grades
568 Students
How to get an A:

Grades are based on a normal 100 point scale

No curve

Team project and participation are based on your team evaluation and instructor evaluation

Feedback may be slow

Grader – Crawford Leeds
Fall 2011
How to get an A:

Grade Breakdown

<table>
<thead>
<tr>
<th>Individual Points/Grade Percentage</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attendance (30) &amp; 1 Minute Reports (30)</td>
<td>10%</td>
</tr>
<tr>
<td>Homework 1-8,10 (10%) + 9 (5%)</td>
<td>15%</td>
</tr>
<tr>
<td>Spatial Visualization Test (Must pass to get 5%)</td>
<td>05%</td>
</tr>
<tr>
<td>Community Service and Presentation</td>
<td>05%</td>
</tr>
<tr>
<td>Individual Contributions &amp; Participation on Team</td>
<td>15%</td>
</tr>
<tr>
<td>Subtotal (You)</td>
<td>50%</td>
</tr>
</tbody>
</table>
### How to get an A:

#### Grade Breakdown

<table>
<thead>
<tr>
<th>Team Points</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Proposal</td>
<td>10%</td>
</tr>
<tr>
<td>Team Presentations (4)</td>
<td>13%</td>
</tr>
<tr>
<td>Team Design Documents (2 Revs)</td>
<td>10%</td>
</tr>
<tr>
<td>Design Expo</td>
<td>02%</td>
</tr>
<tr>
<td>Final Presentation and Final Report</td>
<td>15%</td>
</tr>
<tr>
<td>Subtotal (TEAM)</td>
<td>50%</td>
</tr>
</tbody>
</table>
How to get an A:

Grade Breakdown

50% You + 50% Team = 100%
Homework
Homework:

Submit via email

- Subject should be in this format
  “HW XX Lastname Firstinitial”

- Send all items to Prof.Koehler@gmail.com

- Get from Website

First Homework is...
ASEN 1400 - Spring 2015

Taught as part of the Colorado Space Grant student experience and funded by the Department of Aerospace Engineering Sciences at the University of Colorado at Boulder.
The Book(s)
Miscellaneous:

**Book(s) for course**

- Typical engineering book cost
  - $100, $90, $80, $70

**This Book...**

- $10.86
- *Rocket Boys*
  Homer Hickam

**Also... Set aside $25 for batteries and dry ice**
**Miscellaneous:**

**Book(s) for course**

**This Book...**
- $14.69
- *Moon Lander – How we developed the Apollo Lunar Lander*
- *Thomas J. Kelly*

**Also... Set aside $25 for batteries**
Attendance:

- *Your responsibility to sign the attendance sheet every class*

- *Don’t sign for friends*

- *Sick, stay away but send email*

- *Gone for other reasons, must get approved before event, not after*

- *Be on-time*

- *Plan on being here for the full class (75 minutes)*
1 Minute Reports:

- Everyone has a unique number

- Use your uniquely numbered sheet each class

- Turn in at end of class

- Must be this format and not your own “I forget my forms” paper

Please Print/Write clearly

- I read each of them

- Great feedback as the class goes forward
1 Minute Report:

Name: 
Date: 
Lecture Title:

1. Key points of today’s lecture?

2. What wasn’t clear and/or what questions do you wish you had asked?

3. What personal contributions have you made to your team this week?

4. What grade would you give today’s lecture?

5. Other comments, concerns, or suggestions?
Community Service Activity
Community Service:

- Everyone must do a community service activity

- Not something you are doing for any other class/club/organization (i.e. NEW)

- Preferred if it is related to this class, your college major, or your interest in space

- Activity must last a minimum of 2 hours

- Form is on the class website and must be approved before completed
Community Service:

- Assigned: 01-13-15
- Approval Due: 03-17-15
- Completed: 05-05-15
- Form Submit: 05-05-15
- Presentation Due: 05-05-15 @ 12 PM

60 second presentation that summarizes your service project by using the template on the website. Presentations will be given at the Final Exam.
Community Service Approval (must be completed and signed before activity)

Description of planned activity:

Proposed date and location of activity: _______________ Date _______________ Location

Approved by ___________________ on _______________

(Chris Koehler)
**Community Service Completion**

Description of how the actual activity went:

Actual date __________ and location _________________________ of activity:

Number of those affected through your activity? _______________________

Point of Contact of the activity: ________________________________

Point of Contact signature: ________________________________

Point of Contact email and/or phone number: _______________________

Signature of student performing the activity: _______________________

Attach picture(s) of you doing the actual activity: _______________________


Community Service:
Spatial Visualization Test
Spatial Visualization Testing

- Everyone must take test and pass to get 5%

- Due by January 22nd, 2015

- Workshops if you don’t pass plus a chance to retake
Guest Speakers
Guest Speakers:

- Be attentive and present
- Applaud
- Thank you letters
- Ask questions
Miscellaneous
Miscellaneous:

- Respectful class participation
  - Phones, laptops, noises, footprint (stuff), etc.

- Notes – Take them

- Communications via email and this class

- Office hours 12:15 – 1:15 T & Th and by appointment

- I am busy but always approachable

- Where to Find Me… DLC 270A
Questions?
Introductions
Who is this Guy?
- WHO HAS NOT SEEN STAR WARS, EPISODE IV (1977)?
What Experience Do You Have?

Intern at Ball
summer of 1991

Worked with
Bob Poley

Worked on
RADARSAT
Who is this Guy?

Graduated from CU in December 1992 with B.S. in Aerospace Engineering

Graduated from CU in December 1994 with M.S. in Mechanical Engineering
What Did You Do After College?

Worked at Lockheed Martin from March 1995 until May 2000
What Did You Do At Martin?

- Classified satellite
- 1,000 people on program
- Youngest
- Reaction Control System
  Mechanical Design Lead
- Design done in IDEAS
- Released over 100 engineering drawings

- Supervised manufacture, assembly, integration and test for 5 satellite builds
- Last two years, Mechanical Design Lead for the Antenna systems
What Did You Do At Martin?

- Also worked on Stardust and Genesis

- Worked with many different disciplines and people
Why Did You Leave?

- Many reasons

1. Coming back here was a great opportunity

2. Pictures on the wall

3. Mentor

4. Change
Why Did You Leave?
Vision:

Providing a diverse group of Colorado students with experiences in space to prepare them for our Nation’s future space programs

COSGC = Workforce Development
Start Here…

Student Training and Management
Weaknesses:
RocketSat IV:
- Highest greenhouse gas measurement
- The tubing is vacated at apogee
- Air is forced into the tube, compresses, and remains in the order that it was sampled
- Sample is analyzed using laser analyzer after the flight
Who is this Guy?
Who is this Guy?

I love space…

And with the help of students…
- 10 large satellites
- 8 small satellites
- 166 rocket payloads
- 1080 BalloonSats
Who is this Guy?

I love to laugh

DEATH
The world’s leading cause of death
Who is this Guy?

I love to laugh
Who is this Guy?

I do crazy things
I love to read

Who is this Guy?
Who is this Guy?

I brew Kombucha

How the contents develop during the course of the fermentation process is very clearly seen in the results of Dr Jürgen Reise’s investigations. (From Deutsche Lebensmittelrundschau (German Food Review), 83rd year, No.9, 1987, with kind permission of the publisher and author.)

Substances contained in Kombucha made from black tea:

- lactic acid
- gluonic acid
- acetic acid
- ethanol
- glucose
- pH value
Who is this Guy?

I love to play video games
Who is this Guy?

I love to play guitar
Why Did You Leave?
Why Did You Leave?
Al Worden, Apollo 15
Why Did You Leave?

Harrison Schmitt, Apollo 17
## Who is this Guy?

| 44 | My age |
| 33 | The age I feel |
| 7  | Hours I get to sleep a night |
| 40 | Hours I get to sleep a week |
| 55 | Average number hours I work a week |
| 6  | Hours per week I am paid to teach this course |
| 17 | Average hours per week I actually spend on class |
| 18 | Times I have taught this course |
| 134| Emails I get each day |
| 30 | Emails I respond to each day |
| 1  | Me |
| 48 | You |
So why are you here?
Why You Are Here:

- You want to get a good job after college
- Good School
- Good Grades
- Good Experience

- This course and Space Grant gets you all three

- Unique point in your life
Space in Colorado:

3rd largest aerospace economy

169,810 employed at over 400 companies with $3.2 billion in payroll

3rd in the nation with $1.8 billion in NASA contracts
Final Word

You’ll Never...
Next Time:

Spacecraft Overview
Pictures?