Course Goal

Not trying to make everyone who takes the course a systems engineer, but trying to give aerospace engineers a systems perspective.
Space Systems Engineering Course Overview

- NASA is motivated to have universities add Systems Engineering to undergraduate curriculum requirements.
- This course uses a space theme, but is applicable to engineering disciplines other than aerospace.
- This course is designed as a pre-requisite to the senior capstone design class or for Graduate Students. Many of the systems engineering tools and techniques are necessary for good system design.
- This course was developed and piloted at The University of Texas at Austin in the Department of Aerospace Engineering, 2008.

Introductions
- Instructor; Teaching Assistant
- Students, including their SE experience
- Review of Syllabus & Schedule (handouts)
- Grade - homework, exams, projects, readings
- Access to materials

Semester-long Reading Assignment (1/2)

- **Intent:** to further understand aspects of systems engineering through professional literature.
- **Select one book from list:**

<table>
<thead>
<tr>
<th>Book Title</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>An Introduction to General Systems Thinking</em></td>
<td>Gerald M. Weinberg</td>
</tr>
<tr>
<td><em>Design Paradigms: Case Histories of Error and Judgment in Engineering</em></td>
<td>Henry Petroski</td>
</tr>
<tr>
<td>(or alternative Petroski selection)</td>
<td></td>
</tr>
<tr>
<td><em>The Secret of Apollo</em></td>
<td>Stephen B. Johnson</td>
</tr>
<tr>
<td><em>Against the Gods: The Remarkable Story of Risk</em></td>
<td>Peter L. Bernstein</td>
</tr>
<tr>
<td><em>The Machine that Changed the World</em></td>
<td>J. Womack, D. Jones &amp; D. Roos</td>
</tr>
<tr>
<td><em>Space Systems Failures</em></td>
<td>D. Harland</td>
</tr>
<tr>
<td>The Columbia Accident Investigation Board Report, Volume 1, 2003</td>
<td></td>
</tr>
</tbody>
</table>

Note: All books available on Amazon.com
Semester-long Reading Assignment (2/2)

- Write a 5-7 page book report on the relevancy of the book to systems engineering.
- Questions to address in report:
  - What are the main points that the book is trying to get across from an engineer’s perspective?
  - How is the book relevant to learning/practicing systems engineering?
  - Were there any concepts in the book that should be included in the curriculum?
  - Did the author(s) do a good job explaining particular topics?
  - Did you learn anything?
  - Did you enjoy the book?
  - Take-away: what will you remember most from reading this book?
- At end of semester:
  - Turn in individual book report.
  - Conduct book discussion with your fellow readers.
  - Produce a consolidated list of pros and cons for including the book in the systems engineering curriculum.

Alternative Semester-long Assignment (1/2)

- Intent: to learn systems engineering lessons from previous space mission mishaps.
- Select one failure report from list:
  1. WIRE Mishap Investigation Board Report June 8, 1999
  2. Genesis
  3. CONTOUR Comet Nucleus Tour Mishap Investigation Board Report; May 31, 2003
  5. The NEAR Rendezvous Burn Anomaly of December 1998; November 1999
  10. Mars Climate Orbiter Mishap Investigation Board Report; November 10, 1999
  11. Lewis Spacecraft Mission Failure Investigation Board final report; February 12, 1998

Note: All failure reports available from the instructor.
Alternative Semester-long Assignment (2/2)

- Write a 5-7 page book report answering the following questions with respect to the mission failure report you selected.
- Questions to address in report:
  1. What systems engineering shortcomings were identified by the Mishap Investigation Board (MIB) as contributing factors to the mission failure? Do you agree?
  2. Where in the development lifecycle did these factors occur?
  3. As the lead systems engineer on a similar project what would you do to reduce the probability of similar problems?
- For additional background reading on space mission mishaps, refer to the following documents:
  - General Accounting Office Better Mechanisms Needed for Sharing Lessons Learned GAO-02-195 – identifies inadequate systems engineering as a contributing cause to most project failures.

Systems Thinkers ...

- See the whole picture
- See the forest and the trees
- View from different perspectives
- Look for interdependencies
- Understand different models
- Think long term
- “Go wide” in thinking about cause and effect relationships
- Think about potential benefits (opportunities) as well as about unintended consequences (risks)
- Focus on problem solving, not finding blame

With thanks from: Astronomy Picture of the Day; Apollo 17: Last on the Moon Credit: Apollo 17, NASA; scanned by Kipp Teague (http://antwrp.gsfc.nasa.gov/apod/ap021212.html)

Systems Thinking Playbook, Sweeney and Meadows; 1995
Interview with NASA Administrator, M. Griffin on “The True Challenge of Project Management”

Dr. Griffin continued that systems engineering and project management are opposite sides of the same coin. To talk about one without the other is flawed. The losses of Challenger and Columbia, the Hubble Space Telescope’s flawed optics, Mars Observer, Mars Climatology Observer ’99, Mars Polar Lander, Genesis - all of these programs’ issues were due to failures in program management and systems engineering. They all must be looked at as learning experiences, to learn as much from them as possible so we can repeat as few of them as possible.

So how do we teach the big picture concept? If all agree that the ability to operate at the big picture level is really important, how do we teach it? Dr. Griffin said we can identify the trait, see it in certain young engineers. If we conclude that it is a skill you can’t teach, look for those who have it and use them. I am reminded of the idea that you can learn to play the piano, but if you don’t have the innate skill it will always be forced, not natural. We need to play to our strengths and play up other’s strengths as well. It wasn’t so long ago that systems engineering wasn’t even considered a formal discipline. Today, there is a body of knowledge devoted to systems engineering and program management. They have been formalized and can be taught. You may not be able to teach how to see the big picture, but you can teach the tools and skills to people to facilitate seeing it.

Dr. Griffin identified several things that are disquieting or in his words “scary” with respect to systems engineering and program management. Sometimes there is a failure to understand the systems engineering is the final gate of “the general ship of engineering.” If the lead systems engineer misses something, odds are that the program manager is not going to catch it, nor should it be his job to do so. Systems engineering cannot be only a set of tools and processes for ensuring that all the system interface requirements are met. They are components of it, but to lose sight of the big picture is a failure of systems engineering. Systems engineering is about asking the right questions, not so much having the answers to all the questions. It is about minimizing the unintended consequences of a design.

The Need for Systems Thinking

“Problems cannot be solved by the same level of thinking that created them.”  
Albert Einstein
**Back-up**

*Note:* Depending on how much time is spent on the course overview information, including the syllabus and schedule, more slides and discussion can be added on the general topic of systems thinking. There are a number of slides included in the back-up that can be pulled forward into the body of the lecture.

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### Characteristics of Engineers with High Capacity for Systems Thinking

<table>
<thead>
<tr>
<th>Rank</th>
<th>Characteristic</th>
<th>Questionnaire N= 276</th>
<th>Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Score (1-5 scale)</td>
<td>Frequency</td>
</tr>
<tr>
<td>1</td>
<td>Understanding the whole system and seeing the big picture</td>
<td>4.23</td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td>Understanding interconnections; closed loop thinking</td>
<td>4.22</td>
<td>43</td>
</tr>
<tr>
<td>3</td>
<td>Understanding system synergy</td>
<td>4.32</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>Understanding the system from multiple perspectives</td>
<td>4.26</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>Think creatively</td>
<td>4.24</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Understanding systems without getting stuck on details; tolerances for ambiguity and uncertainty</td>
<td>4.25</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>Understanding the implications of proposed change</td>
<td>3.85</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>Understanding a new system/concept immediately upon presentation</td>
<td>3.74</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>Understanding analogies and parallelism between systems</td>
<td>3.74</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>Understanding limits to growth</td>
<td>3.74</td>
<td>8</td>
</tr>
</tbody>
</table>

Ref: "Knowledge, Abilities, Cognitive Characteristics and Behavior Competencies of Engineers with High Capacity for Engineering Systems Thinking", Moti Frank, Systems Engineering, Volume 9, Number 2, Summer 2006
Systems Thinking – *Why is it Important?*

“Problems cannot be solved by the same level of thinking that created them.”
Albert Einstein

To comprehend and manage the requirements, and to develop the solution, we have to understand how it fits into the larger system of which it is a part.

When our response to opportunities and challenges is fragmented, the results are often insufficient or short sighted.

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**Systems Thinking – Hierarchy**

*Why is it Important?*

“Never forget that the system being addressed by one group of engineers is the subsystem of another group and the super-system of yet a third group.”


As systems engineers we must consider products above, peer products, and subordinate products.
Include an example for systems thinking…
What is the system? Can always use the Shuttle.

Systems Thinking Example

Think of the Space Shuttle, i.e., the Space Transportation System (STS)...how would you define the system?
Hierarchical Relationships for Systems of Interest

Enabling Systems, or together can be thought of as a System of Systems

A Satellite with Three Enabling Systems
Hierarchical Relationships for Enabling Systems

System of Interest

Program

Project

Enabling Systems

Enabling Systems

Enabling Systems

Assembly

Assembly

Subsystem

Subsystem

Systems engineering focus must include all aspects of the environment in which the system of interest operates.

What Does “Systems Thinking” Involve?

- Understanding the system requirements regardless of the position of one’s product in the system decomposition hierarchy
- Assessing the impact of system requirements on the subsystem for which one is responsible
- Assessing the impact of subsystem constraints on the system
- Assessing the impact of the subsystem’s requirements on lower level products before selecting a subsystem concept
Techniques That Promote Systems Thinking

Validation Planning and Solution Requirements

Early determination of the customer validation approach often clarifies requirements. Verification planning at concept development often eliminates flawed concepts that lead to failure.

Concurrent Engineering

Concurrent product and process development where all phases of the product life cycle and all stakeholders need to be considered at the outset and throughout the project cycle.

Discovery and Analysis

Ensure all needs are considered through stakeholder involvement, identification of alternate solutions and rigorous analysis to define the best solution.