16.842 Fundamentals of Systems Engineering

Prof. Olivier de Weck

TA: Maj. Jeremy Agte

16.899 Fundamentals of Systems Engineering
H (permanent number 16.842)
Prereq: Permission of Instructor
Units: 2-0-4
F1-3 in 33-418
Grading A-F

Register for 16.899 if taking the “full” 6-unit class and attending F1-3 Grading on A-F Letter scale

Introduction to the principles and methods of Systems Engineering. Lectures follow the "V"-model of Systems Engineering including needs identification, requirements formulation, concept generation and selection, trade studies, preliminary and detailed design, component and subsystem test and integration as well as functional testing and delivery and operations. …The class serves as preparation for the systems field exam in the Department of Aeronautics and Astronautics.
O. de Weck and guest lecturers

Students wishing to only participate in the journal club held on F2-3 should register under **16.980 Advanced Special Project** for 3 units

Register for 16.980 if taking only the journal club portion, 3-units, attending F2-3, Grading is Pass/Fail

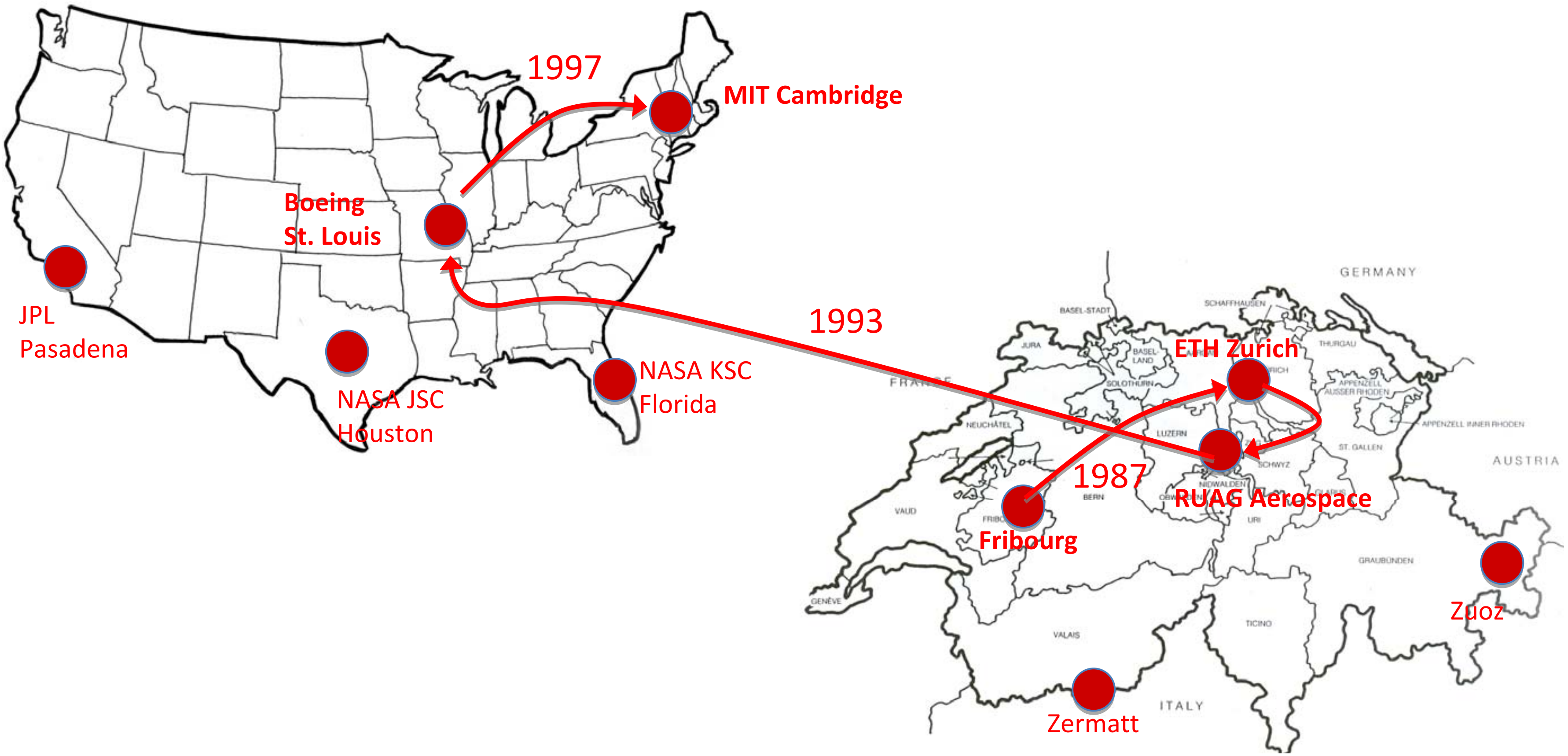
Agenda

- Introductions
  - "How I got hooked on Systems Engineering"
  - Student Introductions
- Syllabus
  - Motivation, Learning Objectives, Format, Grading
  - Schedule
  - Readings ("Journal Club")
- Systems Engineering Overview
  - NASA/SP-2007-6105 Handbook Perspective
  - Caveats

Personal Intro

- Olivier Ladislas de Weck
  - Dipl. Ing. Industrial Engineering – ETH Zurich 1992
  - 1993-1997 Engineering Program Manager Swiss F/A-18 Project, McDonnell Douglas, St. Louis
  - S.M. ’99 Ph.D. ’01 Aerospace Systems – MIT
  - Associate Professor – dual appointment AA and ESD, Associate Director ESD (since July 2008)
  - Research:
    - Systems Engineering for Changeability and Commonality
      - http://strategic.mit.edu
    - Space Logistics
      - http://spacelogistics.mit.edu

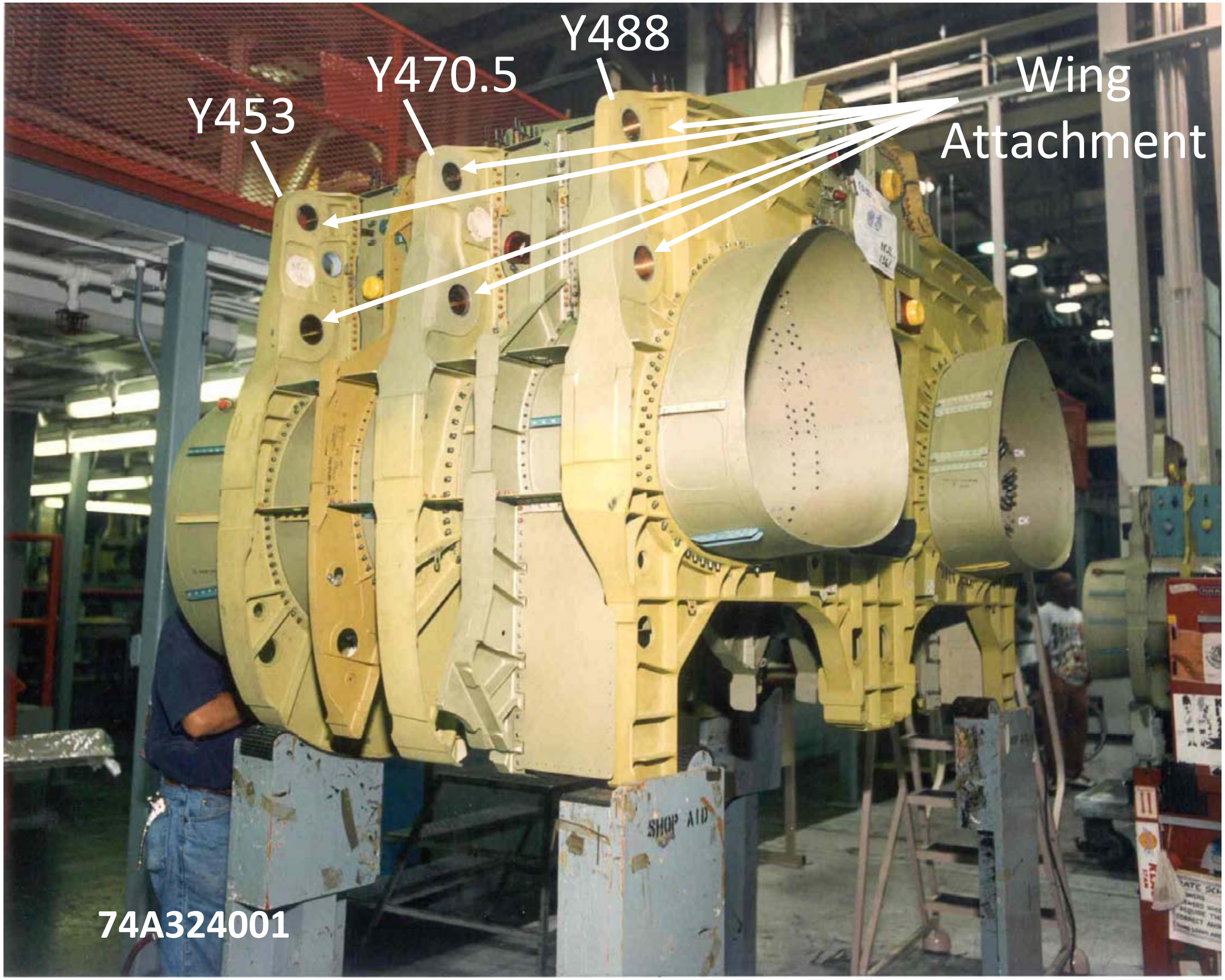
A Transatlantic Journey …



Or …. "How I got hooked on Systems Engineering"


104
VFA-103
104
AA

F/A-18 Center Barrel Section



F/A-18 Complex System Change

F/A-18 System Level Drawing

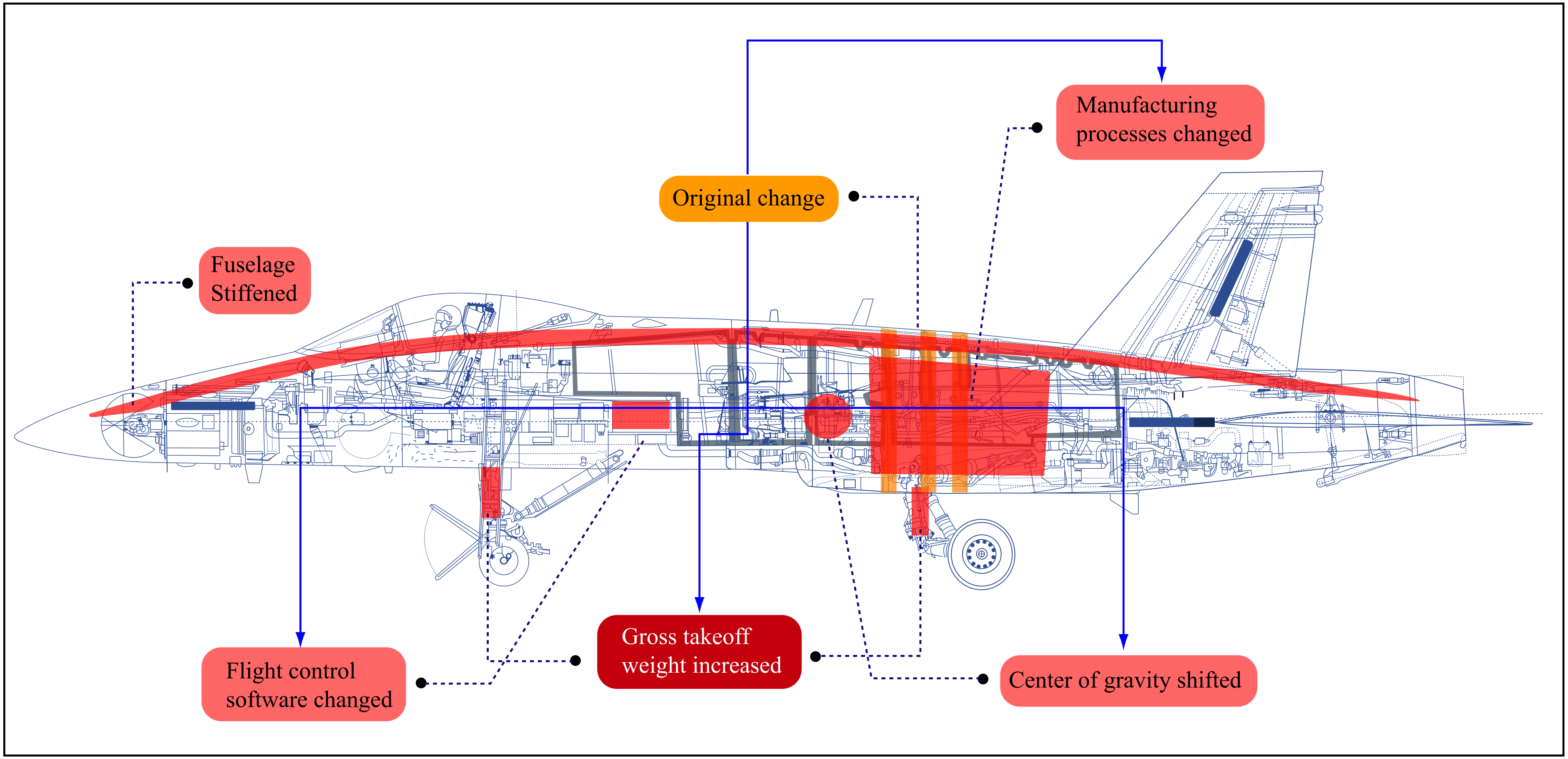


Image by MIT OpenCourseWare.

Lessons Learned

- High-Performance Aircraft are very complex internally … propulsion, avionics, structures …
- Changing requirements can have ripple effects because everything is tightly coupled
  - The totality of system interactions cannot be fully predicted ahead of time
- The "whole" system is much more than the air vehicle: logistics, training, incl. simulators etc..
- People matter a lot: contracts, culture, incentives ….

Personal Introductions

- Name
- Department Lab/Center Affiliation
- Previous Work or Projects
- Why are you interested in Systems Engineering?

Syllabus

- Motivation
  - Aerospace Systems deliver important functions to society … air transportation, defense, sensing, exploration …
  - Complex "machines" with thousands of unique parts and potentially millions of interactions
    - Many aerospace systems require 5-6 levels of decomposition to arrive at indivisible parts that cannot be taken "a-part"
  - Humans play an important role as designers, operators, beneficiaries, maintainers ….
  - Best Practices have emerged since the 1960's and are continuously evolving … documented in standards/handbooks
  - Limitations of "traditional" SE
    - System safety … Columbia and Challenger accidents
    - Designing for lifecycle … Iridium and Globalstar
    - Co-designing system and supply chain (e.g. Boeing 787 delays …)

System Complexity

Assume 7-tree [Miller 1956]

How many levels in drawing tree?

$$\#levels = \left\lceil \frac{\log(\#\ parts)}{\log(7)} \right\rceil$$

		~ #parts	#levels
• Screwdriver	(B&D)	3	1
• Roller Blades	(Bauer)	30	2
• Inkjet Printer	(HP)	300	3
• Copy Machine	(Xerox)	2,000	4
• Automobile	(GM)	10,000	5
• Airliner	(Boeing)	100,000	6

simple

complex

Source: Ulrich, K.T., Eppinger S.D. , Product Design and Development
Second Edition, McGraw Hill, 2nd edition, 2000, Exhibit 1-3

Learning Objectives

The students in this class will be able to …

- Enumerate and describe the most important **Systems Engineering standards and best practices**[1]
- Summarize the **key steps in the systems engineering process** starting with stakeholder analysis and ending with transitioning systems to operations
- Appreciate the **important role of humans** as beneficiaries, designers, operators and maintainers of aerospace systems
- Articulate the **limitations of the way that current systems engineering is** practiced in terms of dealing with complexity, lifecycle uncertainty and other factors
- **Apply some of the fundamental methods and tools** of systems engineering to some basic "toy" examples as a stepping stone to more complex and real world projects

[1] Our main "textbook" for the class will be the NASA Systems Engineering Handbook, NASA/TP-2007-6105, Rev 1. All students taking this class will have read the textbook in its entirety by the end of the term.

Additionally this class can serve as preparation for the AA Systems Field Exam

Class Format

- Four main elements
  - Lectures (60 min, convey key concepts)
    - Organized roughly along the "V" model of SE
  - Assignments
    - 7 assignments total, based mainly on past qualifying exam questions since 1999, should take ~ 2hrs each
  - Readings
    - Assigned weekly reading of sections from NASA Handbook
    - One or two journal/conference paper per week on advanced material that goes beyond traditional SE
      - Journal Club Format: 20 min prepared summary, followed by 40 min of open discussion
  - Design Competition
    - LEGO Mindstorms (NXT 2.0)
    - Voluntary at the end of semester, paired with social event
- Two quizzes
  - Mid-term (October 16, 2009)
  - End-of-term (December 4, 2009)
  - Quizzes will be administered online (surveymonkey.com) and are open book

V-Chart

Fall 2009

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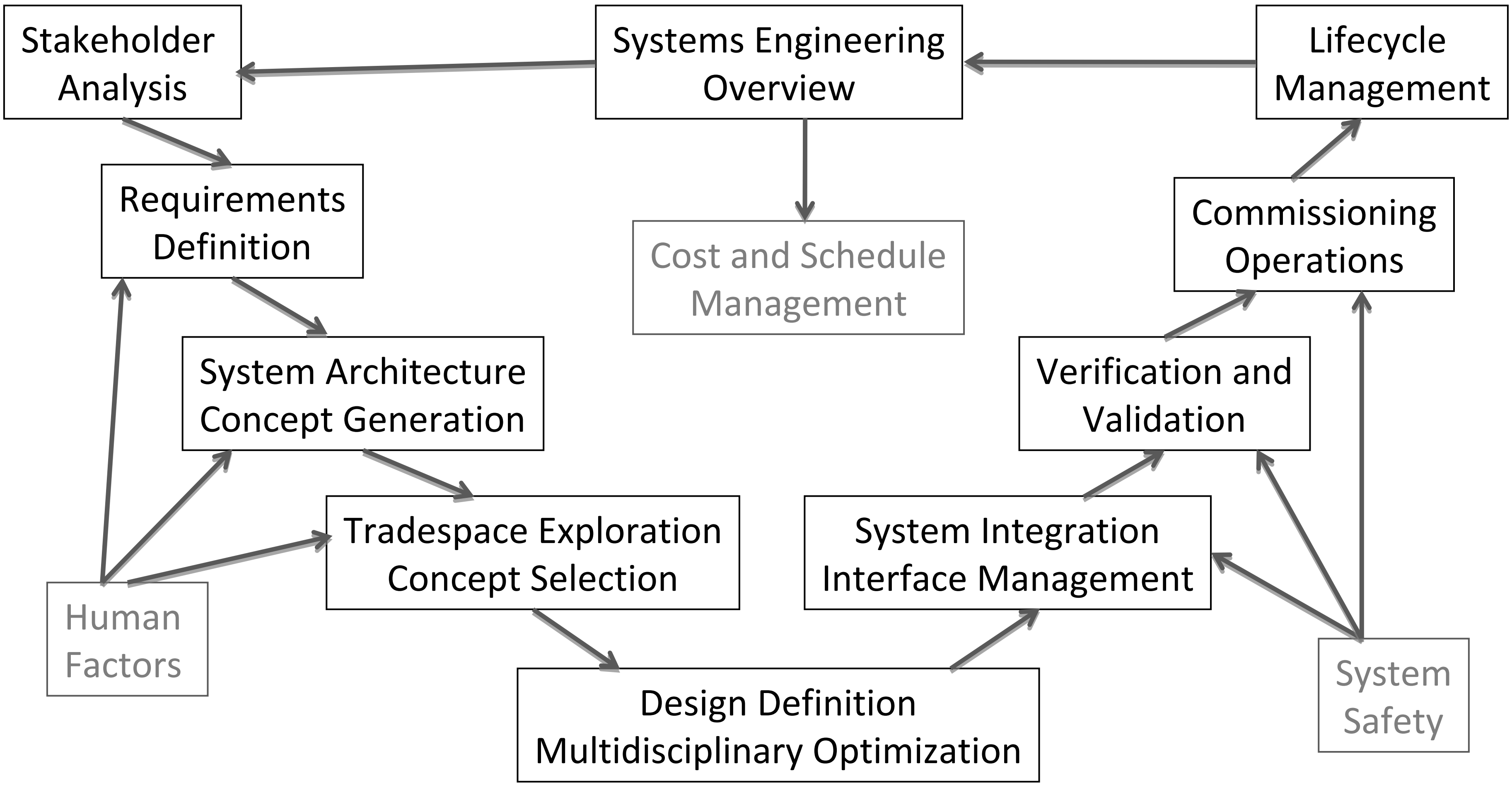


Grading

For those enrolled in the 6-unit course (registered under 16.899) the grading will occur on the letter scale A-F following standard MIT grading policy. The grade will be composed as follows:

Assignments (total of 7 assignments[1])	60%
Mid-Term and End-of-Term Quizzes	30%
Active Class Participation	10%
Total	**100%**

Students registering only for the 16.980 Advanced Individual Study (journal club) will be graded strictly on pass/fail. To obtain a passing grade students must present one paper and participate in at least 70% of the discussion sessions

[1] We will use the best six grades from the assignments, thus one assignment can be missed and students may still achieve a grade of A if they miss one assignment.

Schedule

- F1-3
- 33-418
- 12 Sessions
  - First today Sept 11, 2009
  - Last official session Dec 4, 2009
- Bakeoff session December 11, 2009
- See syllabus for details

References ("Journal Club")

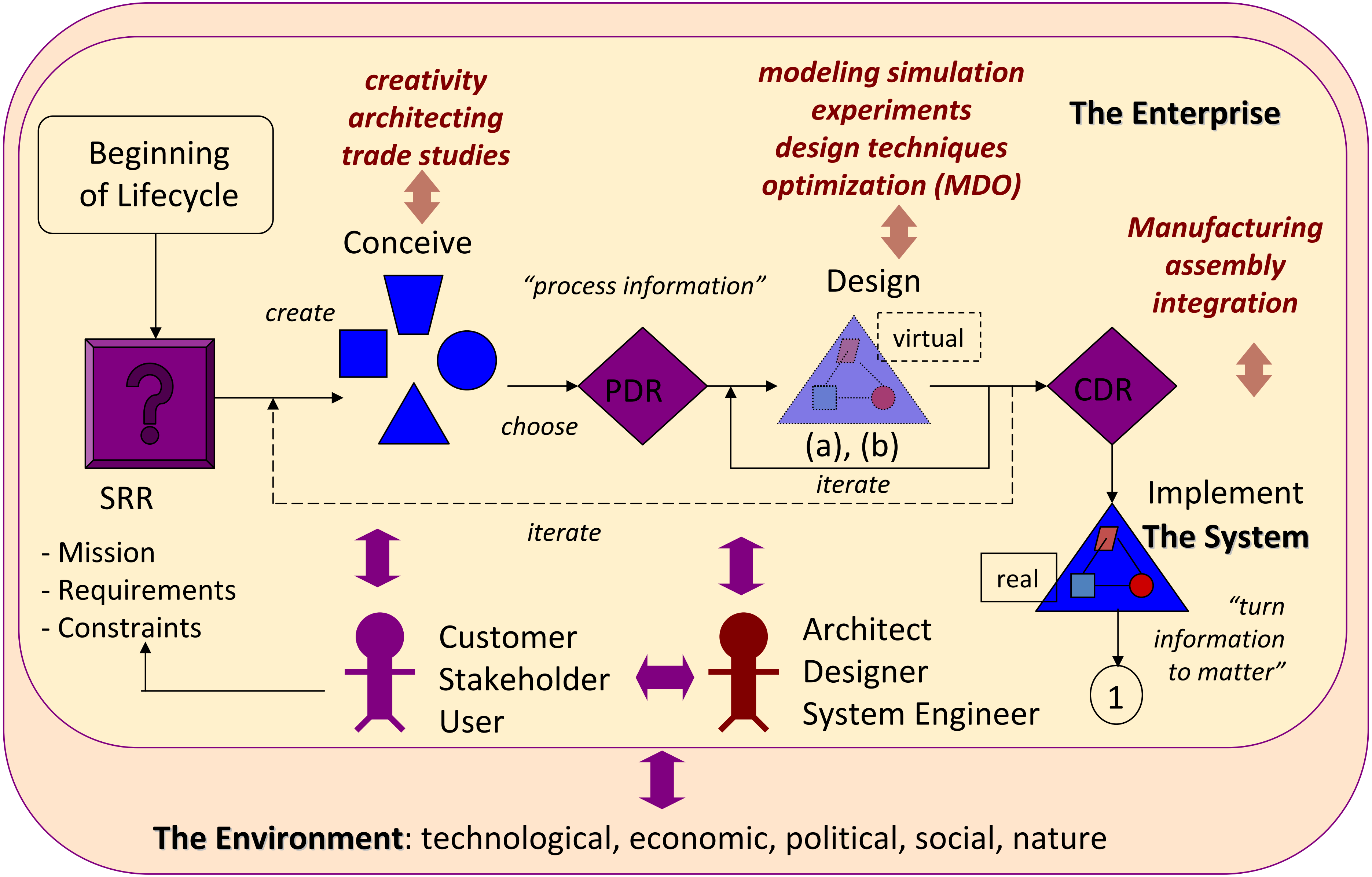
- Systems Engineering Standards
  - **NASA Systems Engineering Handbook, NASA/SP-2007-6105, Rev 1, Dec 2007**
  - INCOSE Systems Engineering Handbook, A Guide for System Lifecycle Processes and Activities, INCOSE-TP-2003-002-03, version 3, International Council on Systems Engineering (INCOSE), June 2006
  - ISO/IEC 15288:2008(E), IEEE Std 15288-2008, Second edition, 2008-02-01 Systems and software engineering — System life cycle processes, Ingénierie des systèmes et du logiciel — Processus du cycle de vie du système

- Selected Conference and Journal Articles
  - Topically synchronized with lectures
  - Explore beyond traditional SE
  - Journals: Systems Engineering, Journal of Spacecraft and Rockets ….
  - MIT Centric

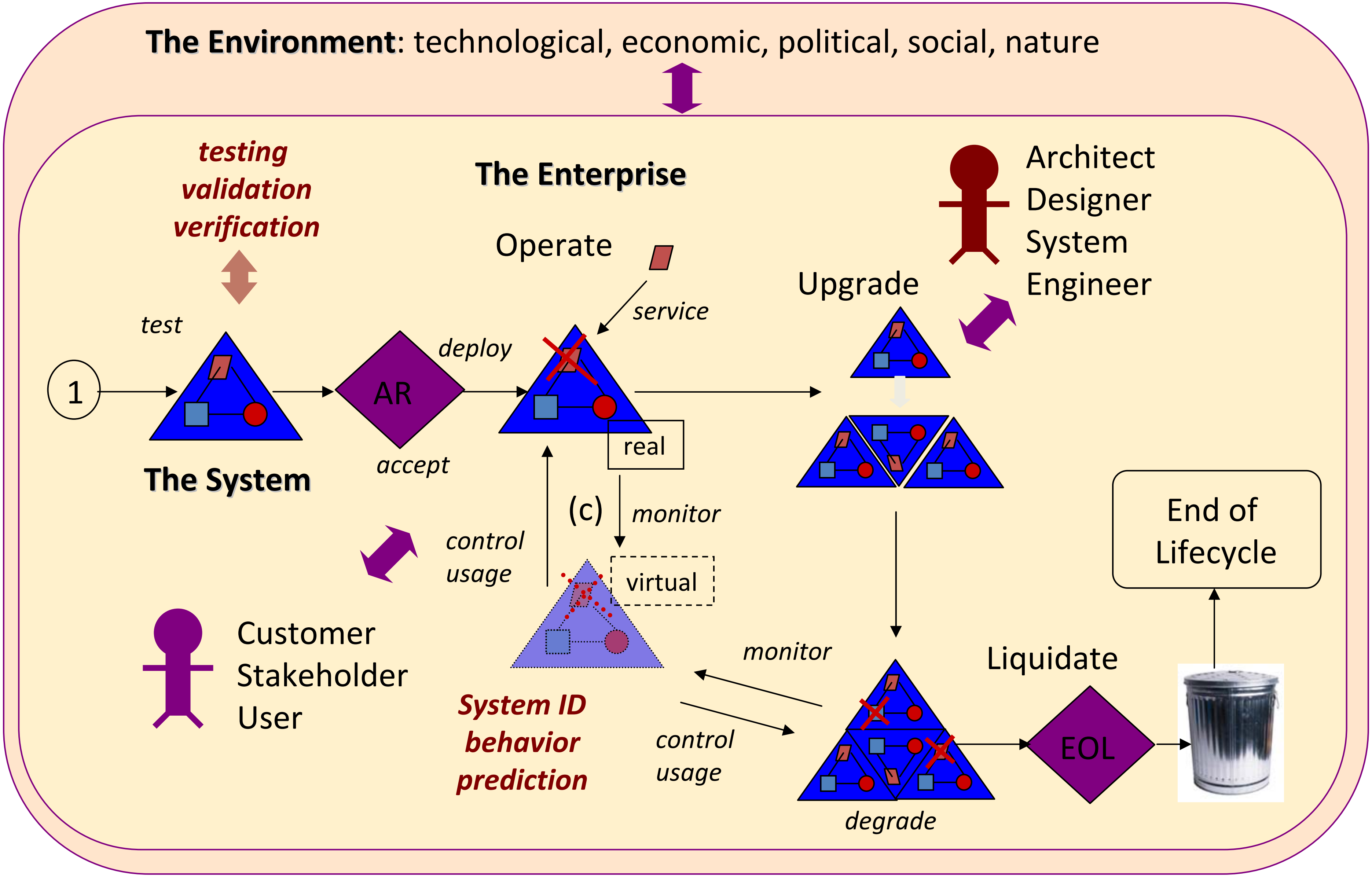
These are suggestions based on my best knowledge/experience. Feel free to make additional suggestions

Systems Engineering Overview

de Weck's framework for Systems Engineering Part (1)
Conception, Design, Implementation



de Weck's framework for Systems Engineering Part (2)
Operate, Upgrade, Liquidate



NASA Version of SE

Requirements

Agency

NASA Policy Directives (NPD)
NASA Procedural Requirements (NPR)
- NPD 7120.4 Program/Project Management
- NPR 7120.5D Program/Project Management
- NPR 7150.2 Software Eng. Req.
- NPR 8000.4 Risk Management
- **NPR 7123.1A Systems Engineering**
- Mandatory Standards
- etc.

Center

Center Policy Directives
Center Procedural Requirements
Center Work Instruction

Guidance

Agency

NASA Handbooks
- **NASA/SP-2007-6105 Systems Eng. Handbook**
- etc.

Center

Center Handbooks

Purpose of the NPR 7123.1A

- To clearly articulate and establish the requirements on the implementing organization for performing, supporting and evaluating systems engineering.
  - **Systems engineering is a logical systems approach performed by multidisciplinary teams to engineer and integrate NASA's systems to ensure NASA products meet customer's needs.**
  - This systems approach is applied to all elements of a system and all hierarchical levels of a system over the complete project life- cycle.

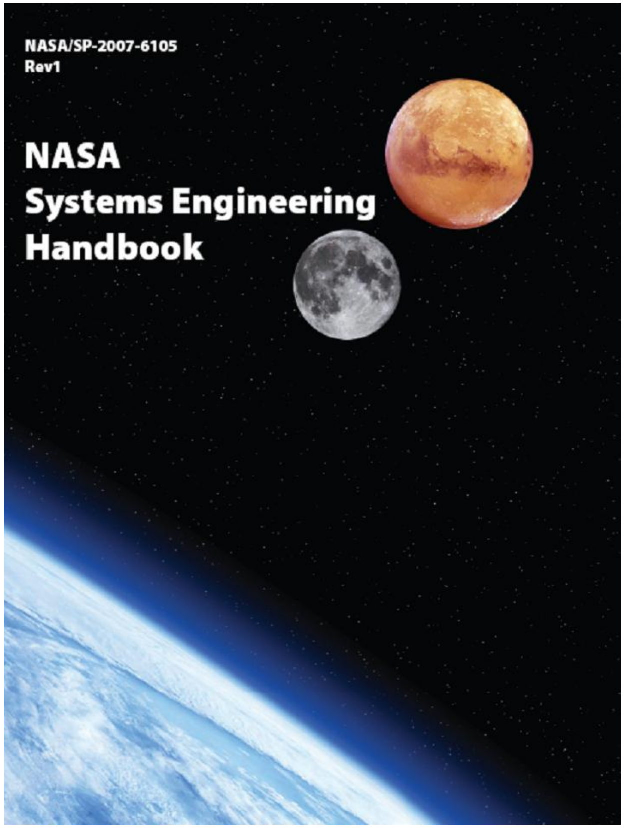
NASA/SP-2007- 6105 Rev 1

- Makes The Bridge From "Typical" Guidance Back To NASA Systems Engineering Process (NPR 7123.1)
  - Guidance From Practitioners
    - Written by practitioners for practitioners
  - "How" Vs "What"
  - Fills Gaps

- Updates The Guidance from SP-6105 (basic)
  - Updates The Practice/Methodology from 1995

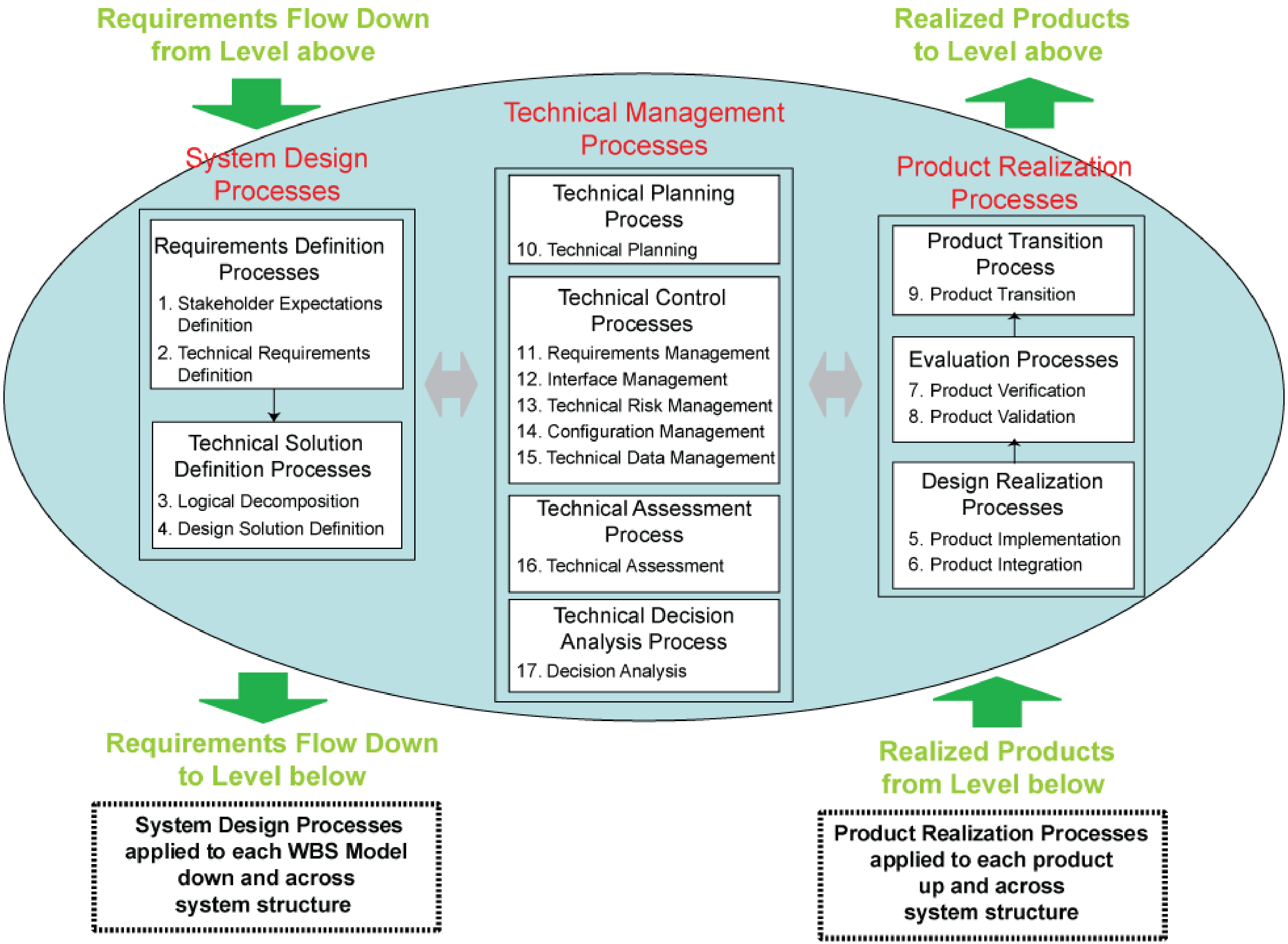
- Provides Top-level Guidance for Systems Engineering Best Practices; It Is Not Intended In Any Way To Be A Directive

- Adds Additional Special Topics
  - Tools
  - NEPA
  - Human Factors

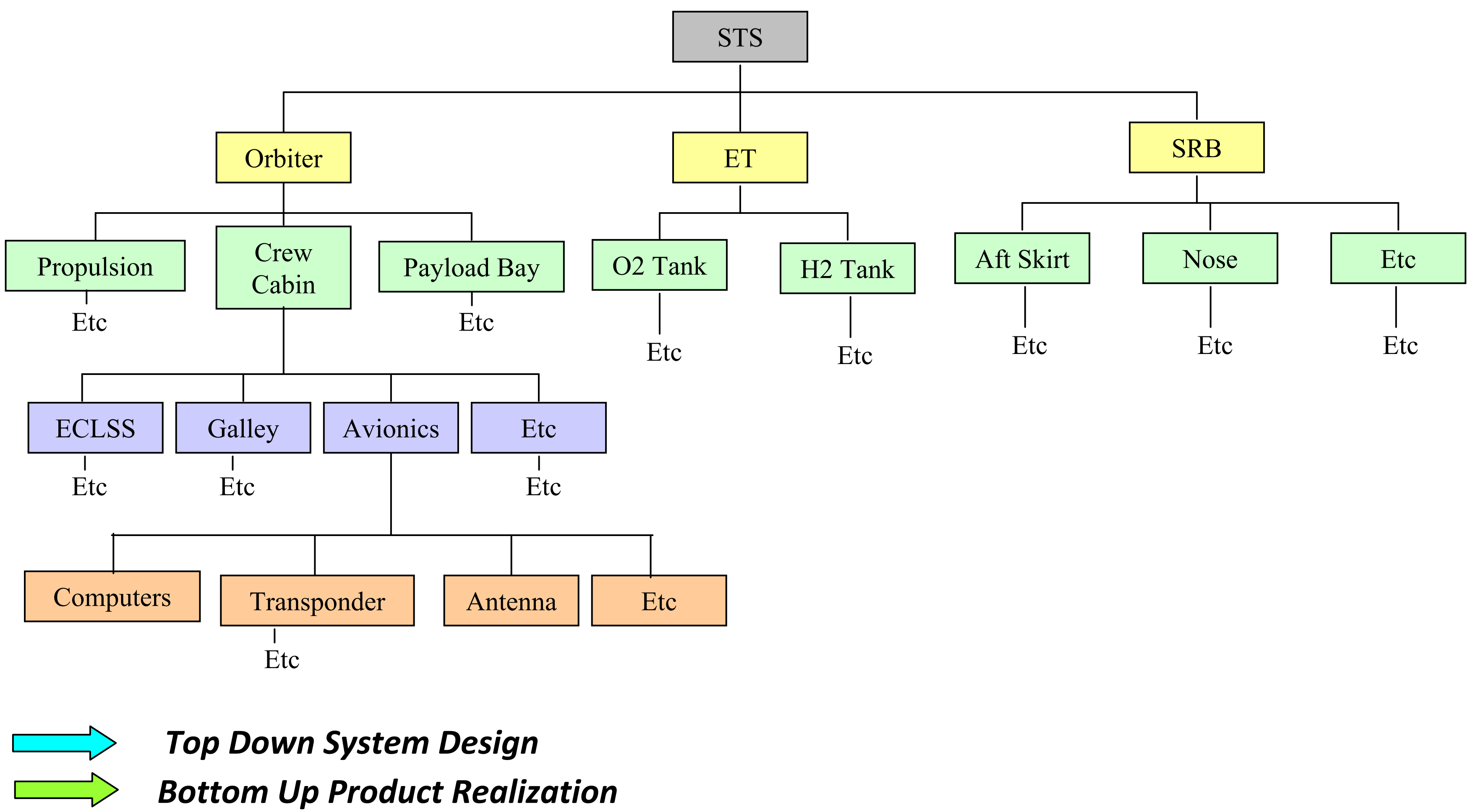


Common Technical Processes

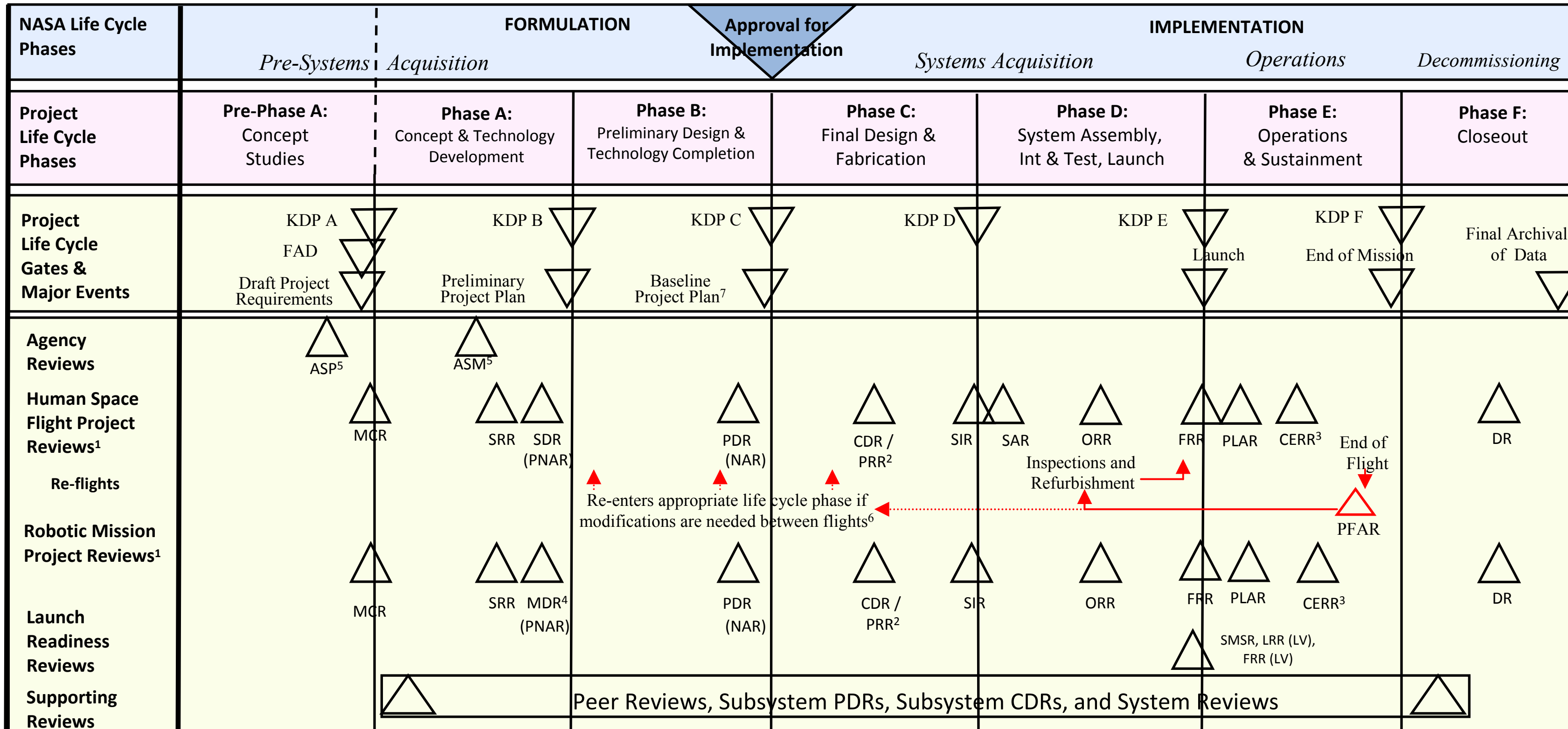
"SE Engine"



Top-Down Bottom-Up Approach



Program & Project Life Cycles



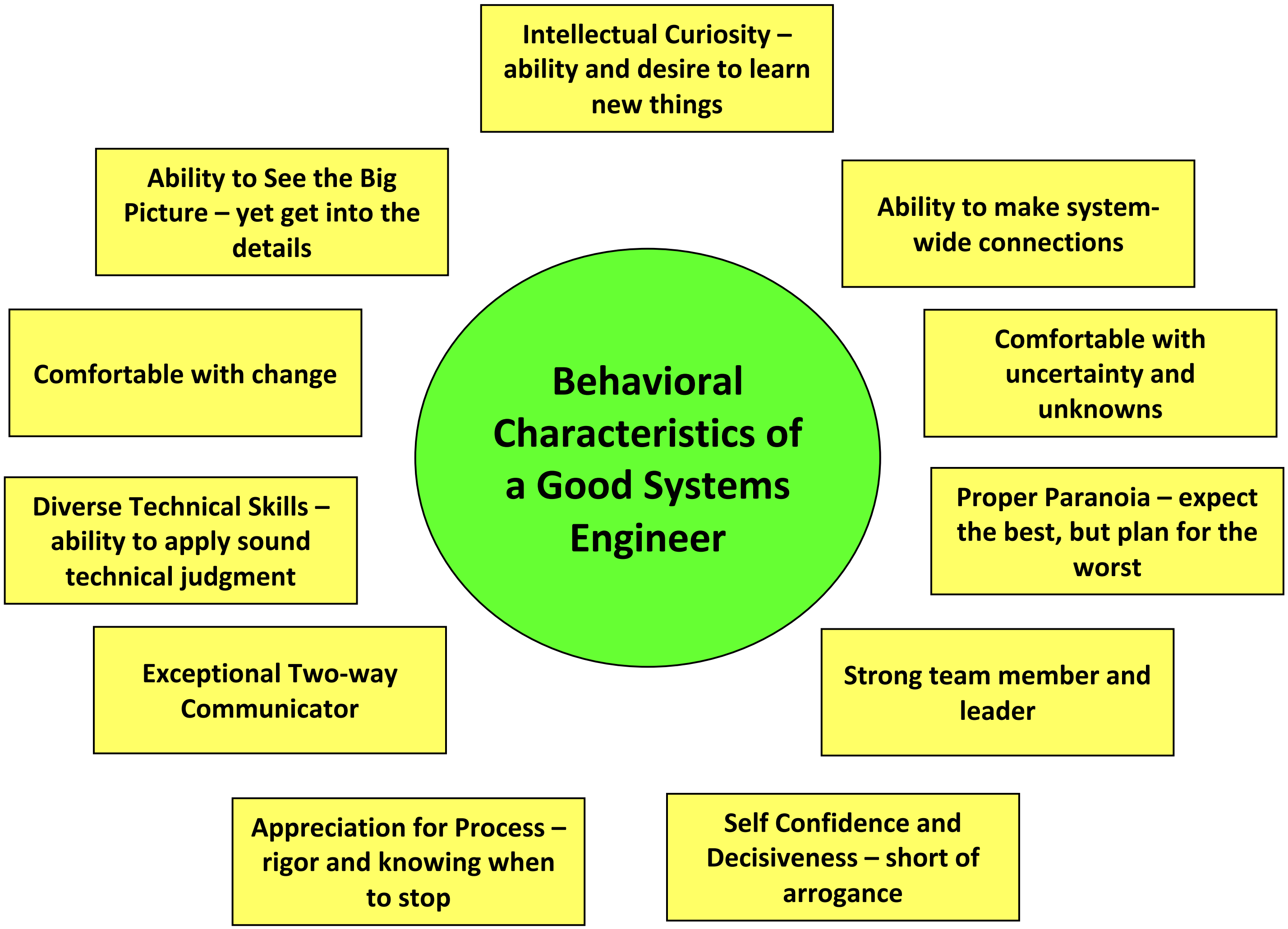
FOOTNOTES

1. Flexibility is allowed in the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan. These reviews are conducted by the project for the independent SRB. See Section 2.5 and Table 2-6.
2. PRR needed for multiple (≥4) system copies. Timing is notional.
3. CERRs are established at the discretion of Program Offices.
4. For robotic missions, the SRR and the MDR may be combined.
5. The ASP and ASM are Agency reviews, not life-cycle reviews.
6. Includes recertification, as required.
7. Project Plans are baselined at KDP C and are reviewed and updated as required, to ensure project content, cost, and budget remain consistent.

ACRONYMS

ASP—Acquisition Strategy Planning Meeting
ASM—Acquisition Strategy Meeting
CDR—Critical Design Review
CERR—Critical Events Readiness Review
DR—Decommissioning Review
FAD—Formulation Authorization Document
FRR—Flight Readiness Review
KDP—Key Decision Point
LRR—Launch Readiness Review
MCR—Mission Concept Review
MDR—Mission Definition Review
NAR—Non-Advocate Review
ORR—Operational Readiness Review
PDR—Preliminary Design Review
PFAR—Post-Flight Assessment Review
PLAR—Post-Launch Assessment Review
PNAR—Preliminary Non-Advocate Review
PRR—Production Readiness Review
SAR—System Acceptance Review
SDR—System Definition Review
SIR—System Integration Review
SMSR—Safety and Mission Success Review
SRR—System Requirements Review

Gentry Lee's Critical Behaviors of Systems Engineering*



Caveats

- NASA Systems Engineering processes are very helpful and valuable, but …
  - Assume mostly “clean sheet” design, but many real projects are modifications of previous systems
    - How do “redesign”, use legacy components etc…?
  - Assume that system/mission requirements and stakeholder needs are known and stable over time, but in reality they change with new administrations
    - Impact of externalities (e.g. policy) is underrepresented
  - Effect of design iterations and rework on budgets and project outcomes is more important than the linear “waterfall” process suggests
  - Etc…etc..
  - We will explore some of the responses to the caveats in the journal club section of the class.

Questions?

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