

Fundamentals of Systems Engineering

Prof. Olivier L. de Weck

Session 1

Systems Engineering Overview
Stakeholder Analysis

Class Parameters

- This class is an introduction to the **Fundamentals of Systems Engineering**, a “door opener” to this important and evolving field
- Ideal for graduate students (1st, 2nd year of masters program)
 - Some advanced undergraduates or returning professionals can also benefit
- Taught in format of a SPOC (Small Private Online Course)
 - All lectures are recorded and available online on webex
- At MIT: **16.842**, 6 units, taught in 9-057 and webex format
 - Serves as a core class in the Department of Aeronautics and Astronautics for students interested in the ‘systems tracks’ and doctoral qualifying exams
- At EPFL: **ENG-421**, 5 ECTS credits, taught in ODY-10020 and webex
 - Serves as one of the core classes in the new Minor in Systems Engineering



Agenda for Today

■ Introductions

- Personal Introductions
- Course Introduction, incl. Learning Objectives

■ Systems Engineering (SE) Overview

- A bit of history
- The “V”-Model
- SE Standards and Handbooks
- Challenges of current practice

■ Stakeholder Analysis

- Identifying Stakeholders
- CONOPS
- Stakeholder Value Network (SVN) Analysis

■ Assignment A1

- 2016 Cansat Competition, Team Formation etc...



Short Break

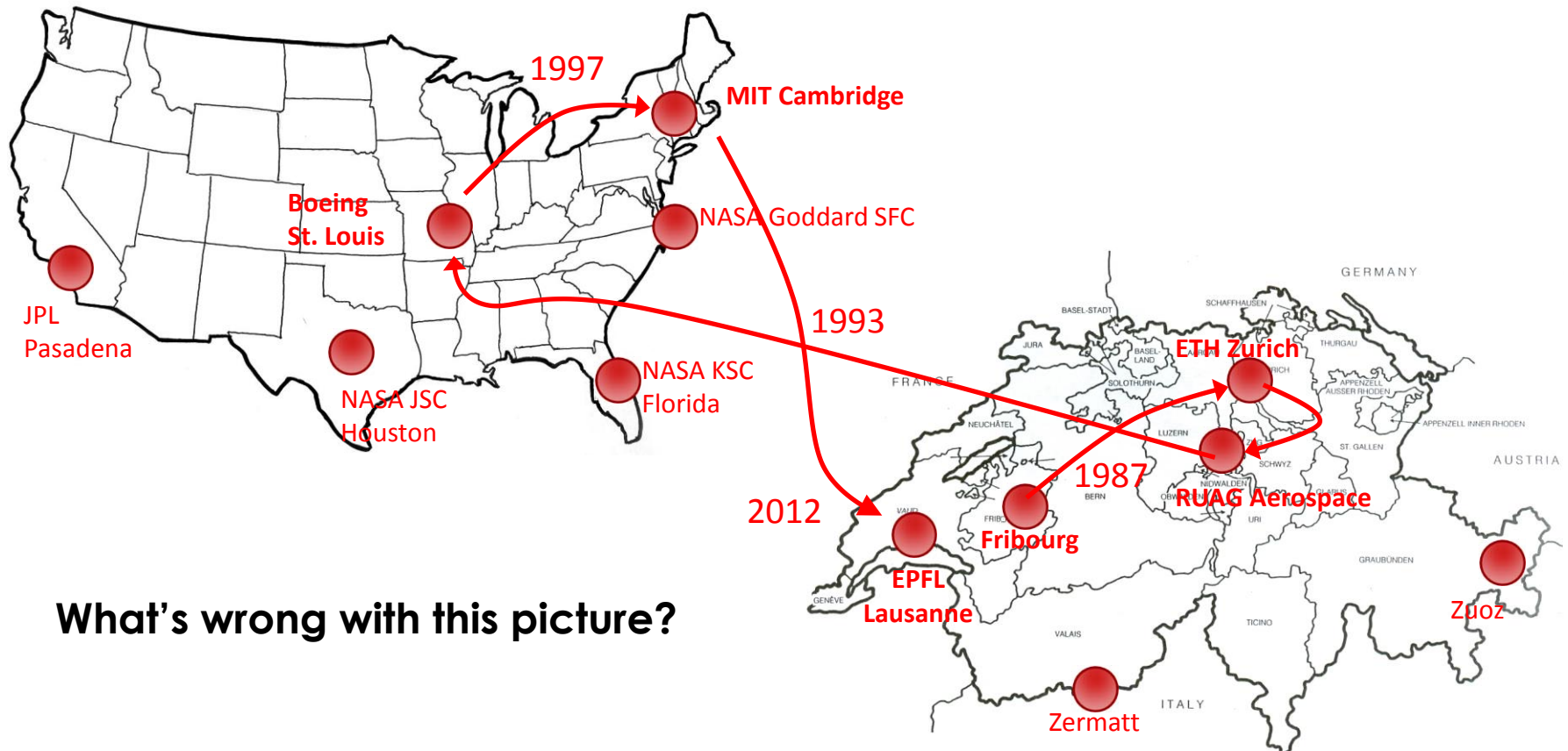
Personal Intro

■ Olivier de Weck

- Dipl. Ing. Industrial Engineering – ETH Zurich 1992
- 1993-1997 Engineering Program Manager Swiss F/A-18 Project, RUAG (formerly F+W Emmen)
- Liaison Engineer at McDonnell Douglas, St. Louis
- S.M.' 99 Ph.D.' 01 Aerospace Systems – MIT
- Visiting Researcher at NASA Goddard Spaceflight Center
- Professor – dual appointment Department of Aeronautics and Astronautics and Institute for Data, Systems, and Society (IDSS)
- Adjunct Professor at EPFL, since 2012
- Editor-in-Chief Journal *Systems Engineering* (since 2013)
- MIT Strategic Engineering Research Group:
 - <http://strategic.mit.edu>



A Transatlantic Journey ...



What's wrong with this picture?

F/A-18 Complex System Change

F/A-18 System Level Drawing

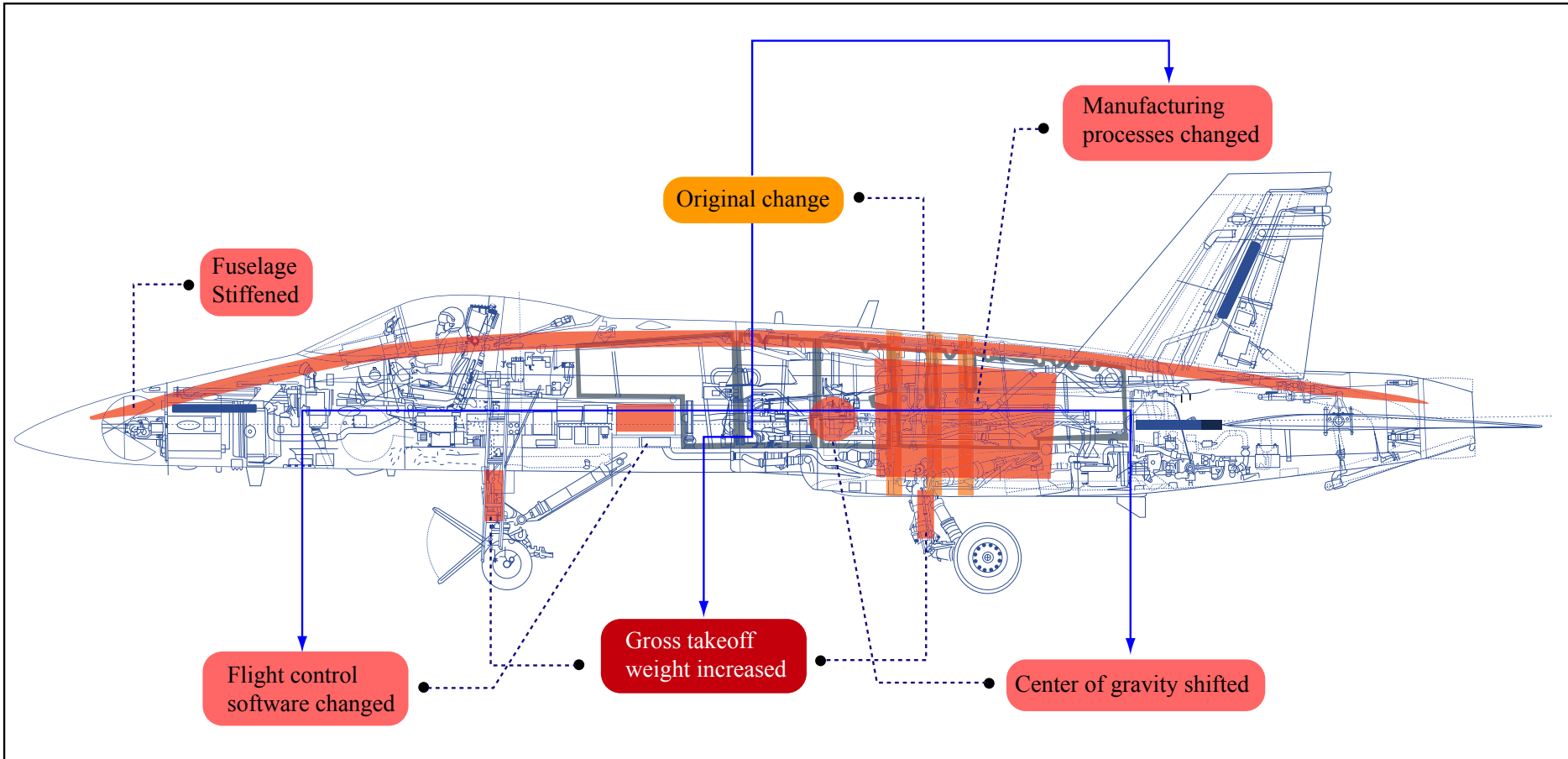
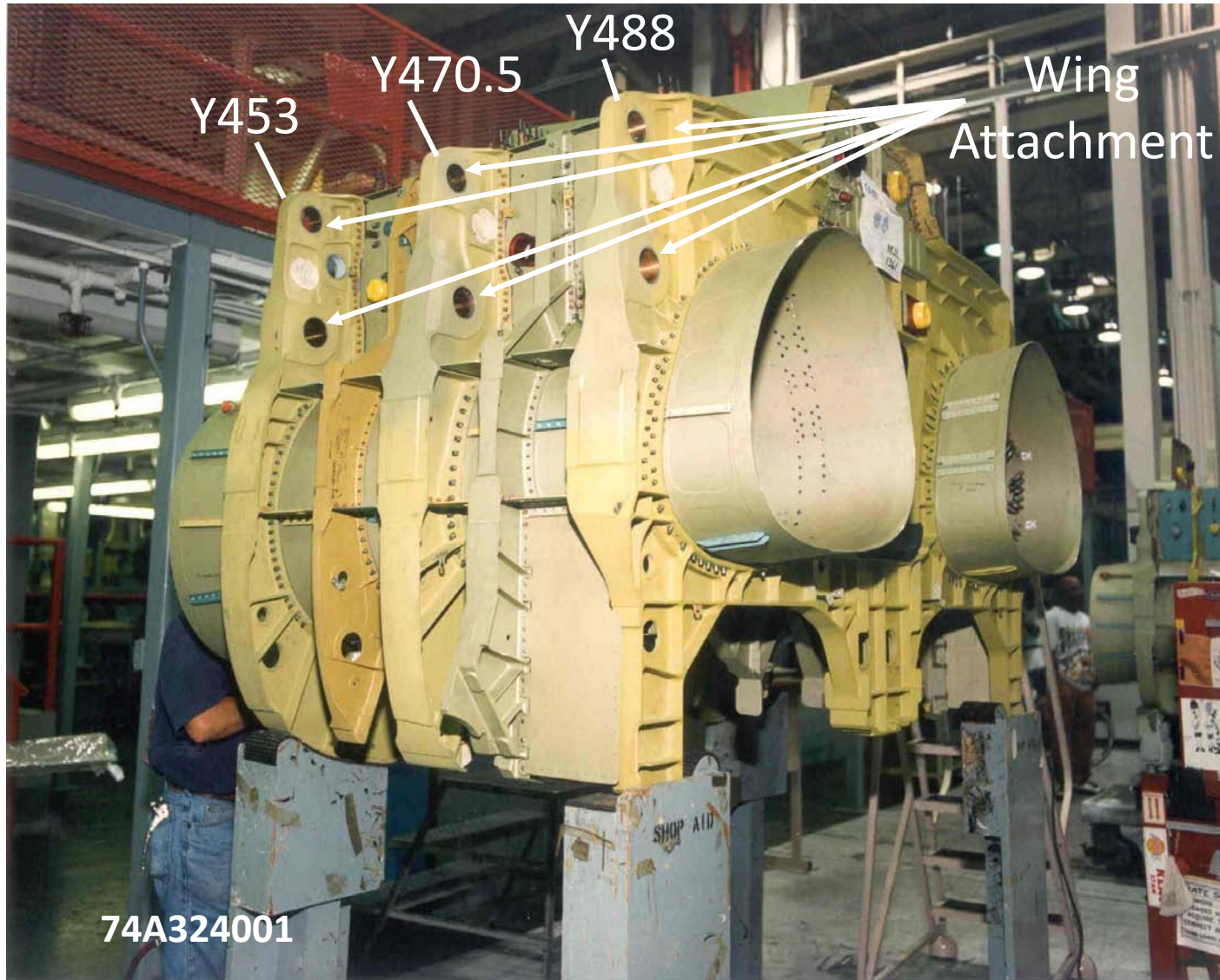


Image by MIT OpenCourseWare.

F/A-18 Center Barrel Section



Lessons Learned from Swiss F/A-18 Program

- High-performance aircraft are very complex internally ... propulsion, avionics, structures ...
- Changing requirements can have ripple effects because everything is tightly coupled
 - It is difficult to predict the totality of system interactions 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

And who are you ...?

- **Briefly introduce yourself**
 - Name
 - Department or Lab Affiliation
 - Any prior experience with Systems Engineering ?
 - Name one thing you want to learn in this class
- Try to keep it to 30 seconds or less

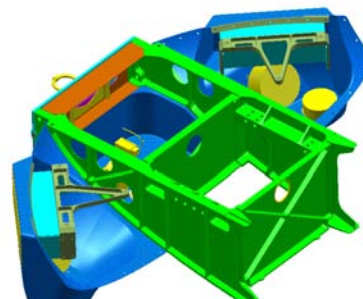
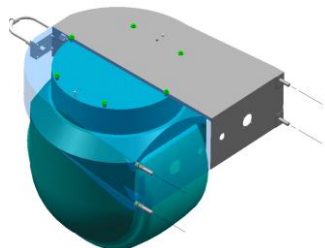
Motivation for this class

- 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 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** ... recent SpaceX Falcon 9 launch failure
 - **Typical program cost and schedule overruns** ... Boeing Dreamliner 787 delays ...
- Systems Engineering is also penetrating in other industries
 - Automobiles, Software, Medical Devices

Example: FLIR System for Aircraft

FLIR = Forward Looking Infrared

The FLIR System AN/AAQ-22 Star SAFIRE electro-optical/infrared sensor has been designed to provide full digital high-definition (1280x720) video compliant with US and NATO specifications.



L-3: Adds/Removes Hardware & Details

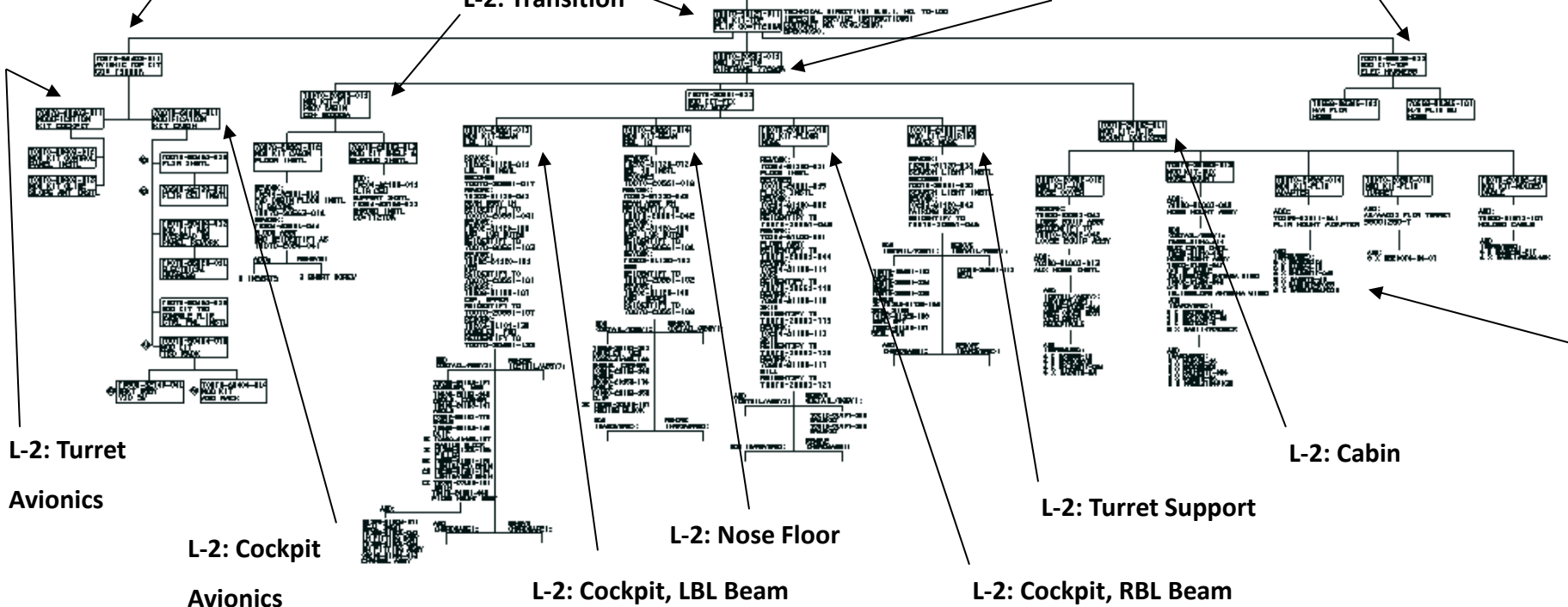
L0: Top Kit Collector

L-1: Avionics Sub Kit

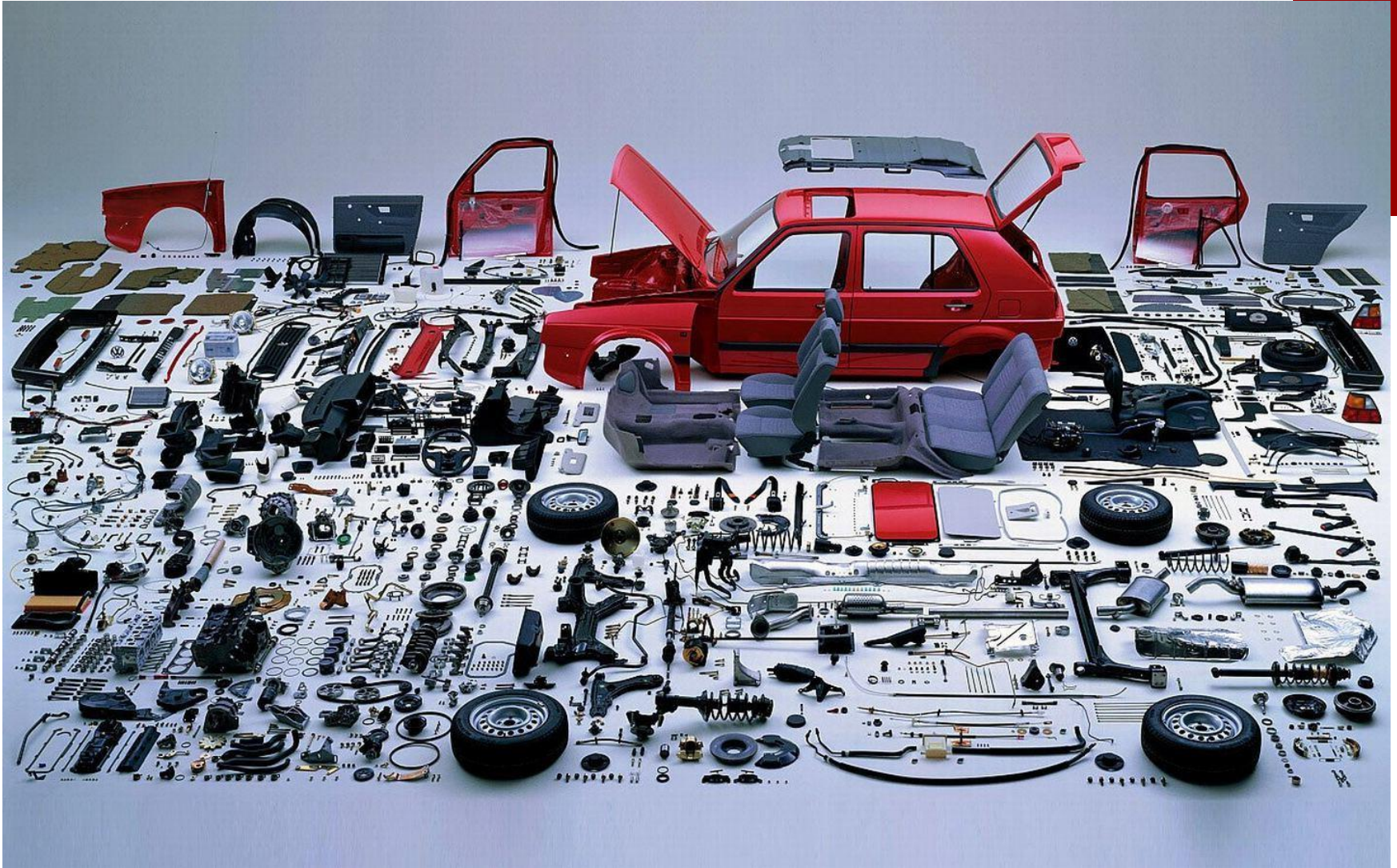
L-2: Transition

L-1: Elec Harness Sub Kit

L-1: Airframe Sub Kit



Why do we need system decomposition?



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Image Source: <http://www.teslamotorsclub.com/showthread.php/29692-How-many-moving-parts-in-a-Model-S/page3>

Concept Question 1


- How many levels of decomposition (depth of drawing tree) do we need to describe the car shown in the previous picture?
 - 1
 - 2
 - 3
 - 4
 - 5
 - 6
 - >6
 - This question does not make sense to me

■ Answer Concept Question 1
(see supplemental files)

System Complexity

Assume 7-tree [Miller 1956]
<http://www.musanim.com/miller1956/>

How many levels in drawing tree? $\#levels = \left\lceil \frac{\log(\# parts)}{\log(7)} \right\rceil$

		\sim #parts	#levels	
■ Screwdriver	(B&D)	3	1	simple
■ 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	

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

Learning Objectives

Participants in this class will be able to ...

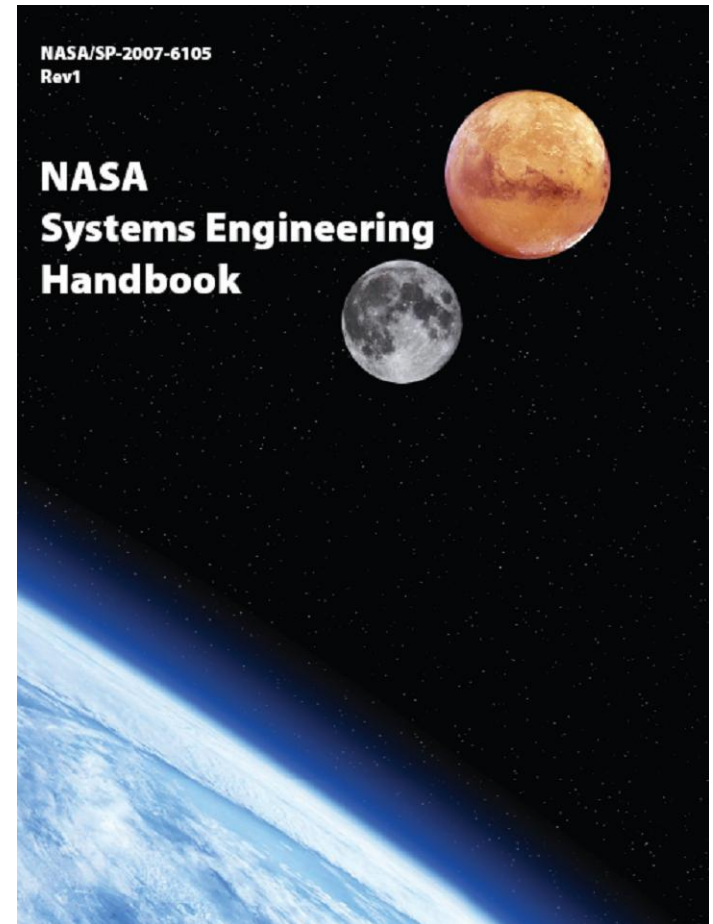
- SE1: Describe the most important **Systems Engineering standards and best practices** as well as newly emerging approaches^[1]
- SE2: Structure the **key steps in the systems engineering process** starting with stakeholder analysis and ending with transitioning systems to operations
- SE3: Analyze the **important role of humans** as beneficiaries, designers, operators and maintainers of aerospace and other systems
- SE4: Characterize the **limitations of the way that current systems engineering is** practiced in terms of dealing with complexity, lifecycle uncertainty and other factors
- SE5: **Apply some of the fundamental methods and tools** of systems engineering to a 'simple' cyber-electro-mechanical system 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 participants will receive a copy of the handbook.**

Note: This class is not an explicit preparation for CSEP Certification

NASA/SP-2007- 6105 Rev 1

- “Bible” for Systems Engineering at NASA
- 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”
- 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



Class Format – 5 major elements

Lectures

- 12 Lectures total (2h each)
- Follow roughly the “V-Model”

Assignments

- Team-based (5 people)
- 5 Assignments total (~ 2 weeks duration for each)
- Create a “PDR”-Level Design

Design Competition

- Top 3 Teams at each school will qualify for the 2016 Cansat Competition

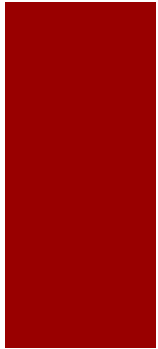
Readings

- Pre-Readings based on sections of NASA SE Handbook, see syllabus for details
- Post-Readings are 1-2 journal or conference papers on topic
- Expect to read about 30-40 pages per week

Exams

- Online Quiz
- Oral Exam (20' per student)
 - Based on 2-page reflective memo

Grading Scheme



- Group Assignments A1-A4 (total of 4) 50%
 - 12.5% each
- Group Assignment A5 (PDR presentation) 20%
- Online Quiz 10%
- Oral Exam (incl. 2-page reflective memo) 10%
- Active Class Participation* 10%
- Total 100%

EPFL Scale	6	5.5	5	4.5	4	3.5	3	2.5	2	1.5	1	NA
Northern America Scale	A	A-	B	B-	C	C-	D	F	F	F	F	Absent
ECTS Scale	A	B	C	D	E	F	F	F	F	F	F	Absent

*Measured based on concepts question responses, class attendance and in-class contributions.

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 - The “V”-Model
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A bit of SE History

- Systems Engineering has been informally practiced since antiquity
 - Great Wall of China, Egyptian Pyramids, Roman Aqueducts
 - Mainly a “workforce” problem to build large infrastructures
- The term “**Systems Engineering**” can be traced back to Bell Labs (1940s)
 - https://en.wikipedia.org/wiki/Bell_Labs
 - Beginning of new methods to better handle complexity
- Formal Systems Engineering really started after WWII
 - 1950’s and 1960s: Cold War, Apollo Lunar Program, ICBMs etc...
 - Complex Engineering Systems: Air Traffic Control, High Speed Rail, Nuclear ..
 - Mainly (paper) document-based: requirements, specifications, test plans etc...
- Early Pioneers
 - Arthur D. Hall, Kelly Johnson, Simon Ramo, Eberhard Rechtin, Andrew Sage, Margaret Hamilton, and others
- 1995 Founding of International Council for Systems Engineering (INCOSE)
- Since ~2000: Development of new Model-Based-Systems-Engineering (MBSE). Need to accelerate SE and better handle complexity



Simon Ramo

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How would you define Systems Engineering?

- **Turn to your neighbor** and discuss for about **5 minutes**:
 - What is your definition of Systems Engineering?
 - Can you agree amongst yourselves?
 - What are the key elements of a definition?

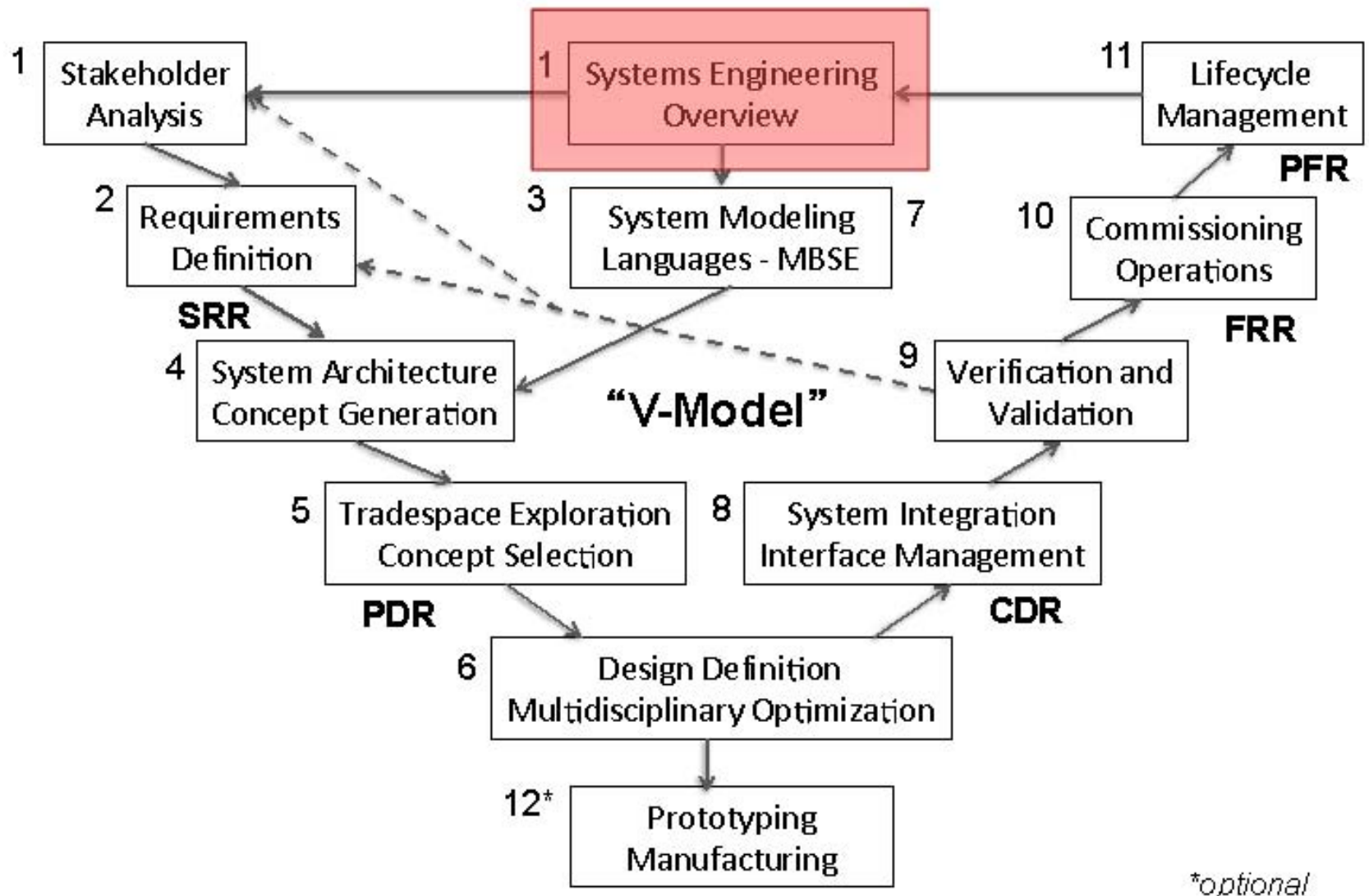
- We will sample after about 5 minutes !

Some Definitions of SE

- "System engineering is a robust approach to the design, creation, and operation of systems. In simple terms, the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals."— NASA Systems Engineering Handbook, 1995.
- "An interdisciplinary approach and means to enable the realization of successful systems"— INCOSE handbook, 2004
- More recently the scope of SE has broadened:
 - Design of Enterprises, Infrastructure Networks etc...

The famous “V-Model” of Systems Engineering

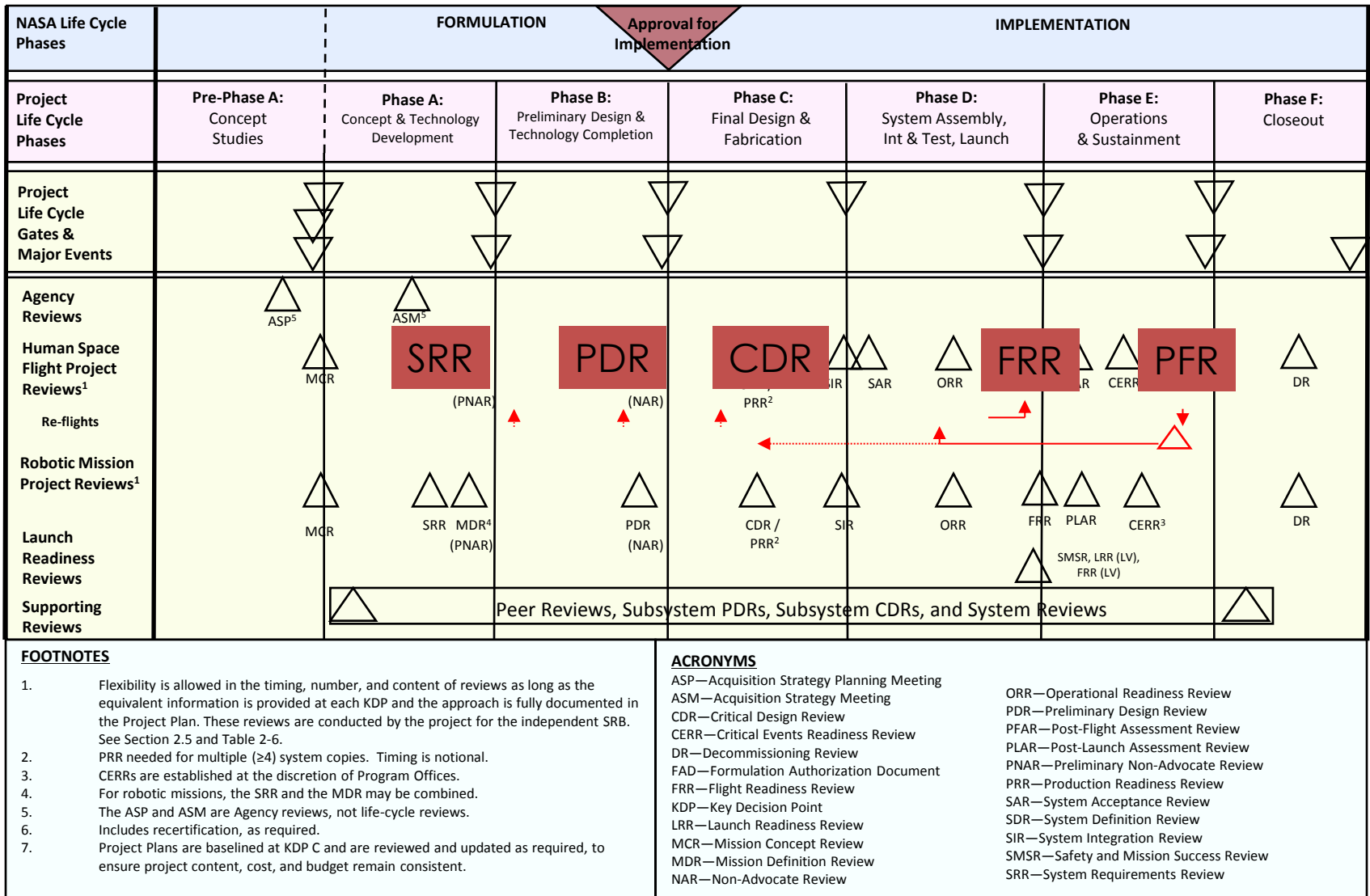
16.842/ENG-421 Fundamentals of Systems Engineering



**optional*

Numbers indicate the session # in this class

NASA Program & Project Lifecycle



SE Standards and Handbooks

■ Systems Engineering Standards

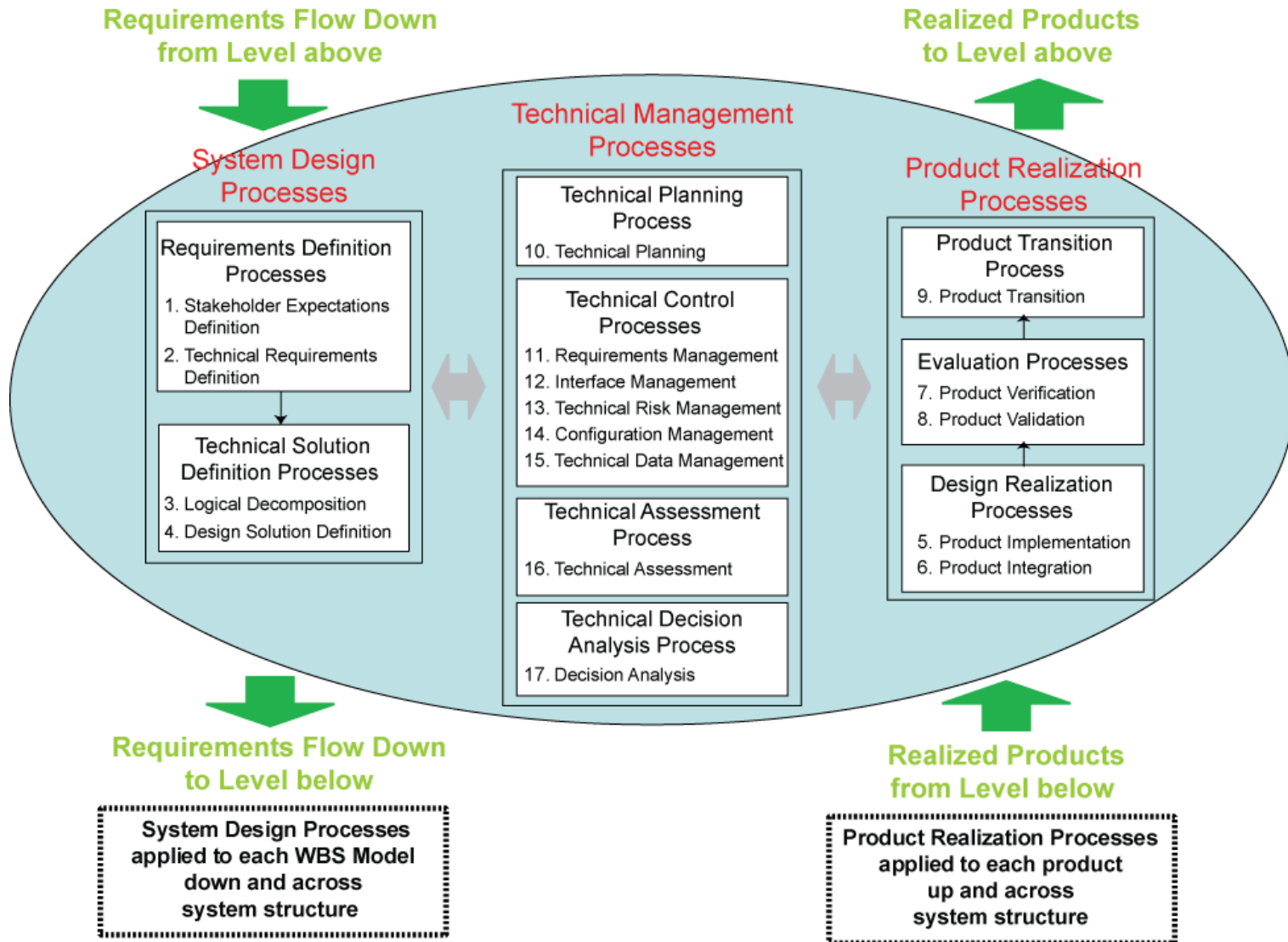
1. **NASA Systems Engineering Handbook**, NASA/SP-2007-6105, Rev 1, Dec 2007
2. **INCOSE Systems Engineering Handbook**, A Guide for System Lifecycle Processes and Activities, INCOSE-TP-2003-002-03, version 3, International Council on Systems Engineering (INCOSE), June 2006 – version 4 was just issued in July 2015
3. **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 – May 2015 edition
4. **ECSS-E-10A** – European Systems Engineering Standard, <http://www.ecss.nl/>

■ Selected Conference and Journal Articles (in “Readings” folder)

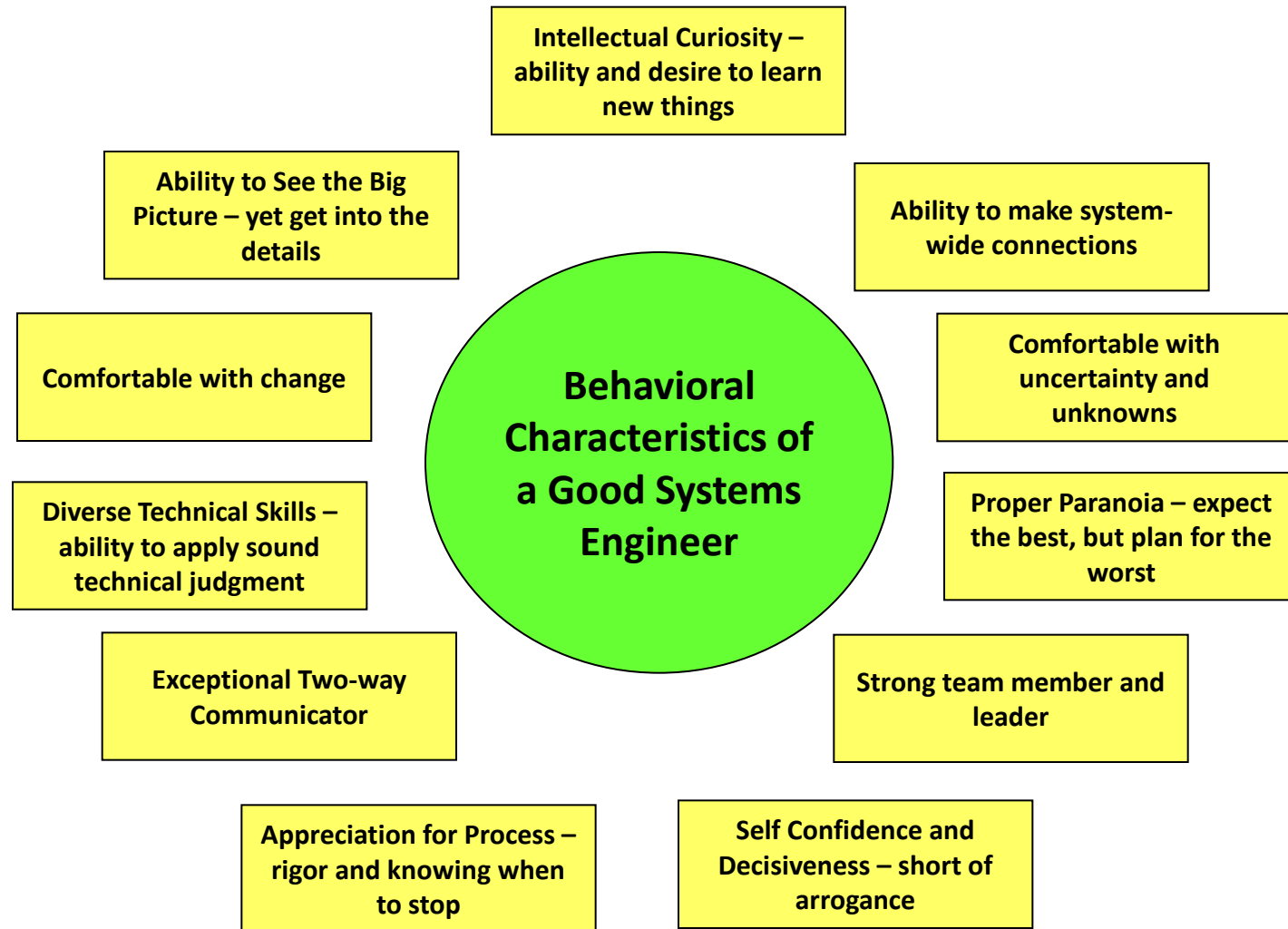
- Explore beyond traditional SE
- Somewhat MIT-centric

These are suggestions based on my best knowledge/experience. Feel free to make additional suggestions as the literature in SE is growing fast.

The NASA Systems Engineering “Engine”



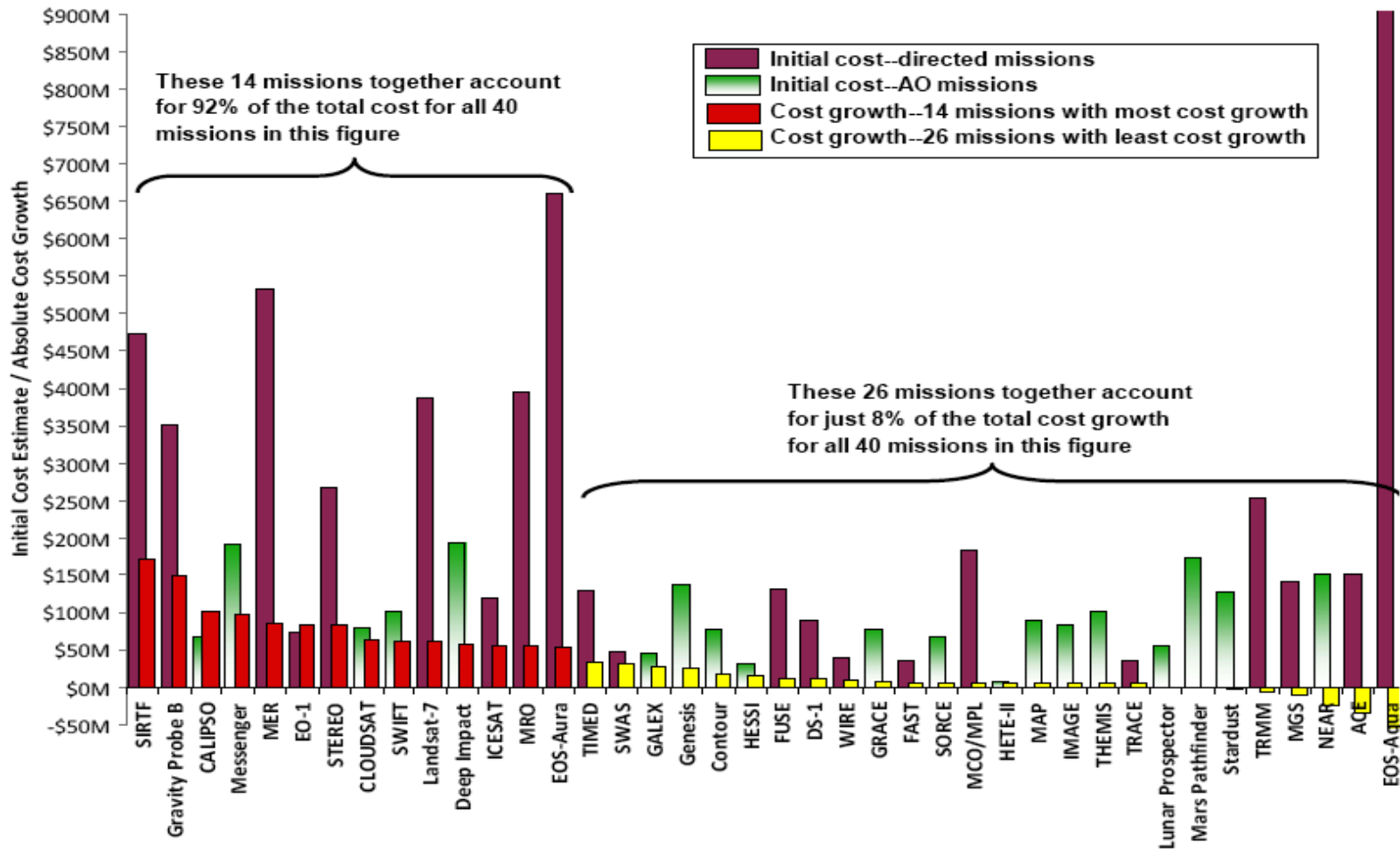
Gentry Lee's Critical Behavioral Characteristics of a Good Systems Engineer



Challenges of current practice ...

- NASA and other formal Systems Engineering processes are very helpful and valuable, but ...
 - Assume mostly “clean sheet” design, but many real projects are modifications of previous systems
 - How to do “redesign”, use legacy or COTS 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” or “stagegate” process suggests
 - See recent NRC Study on Cost and Schedule Growth in NASA’ s Earth and Space Science Missions in which I participated (see next chart).
 - Etc...etc..

Ranking of 40 NASA science missions in terms of absolute cost growth in excess of reserves



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Sega R., de Weck O.L., et al. "Controlling Cost Growth of NASA Earth and Space Science Missions" By Committee on Cost Growth in NASA Earth and Space Science Missions, National Research Council (NRC) of the National Academy of Sciences, ISBN-13: 978-0-309-15737, Washington .D.C., July 2010

Agenda for Today

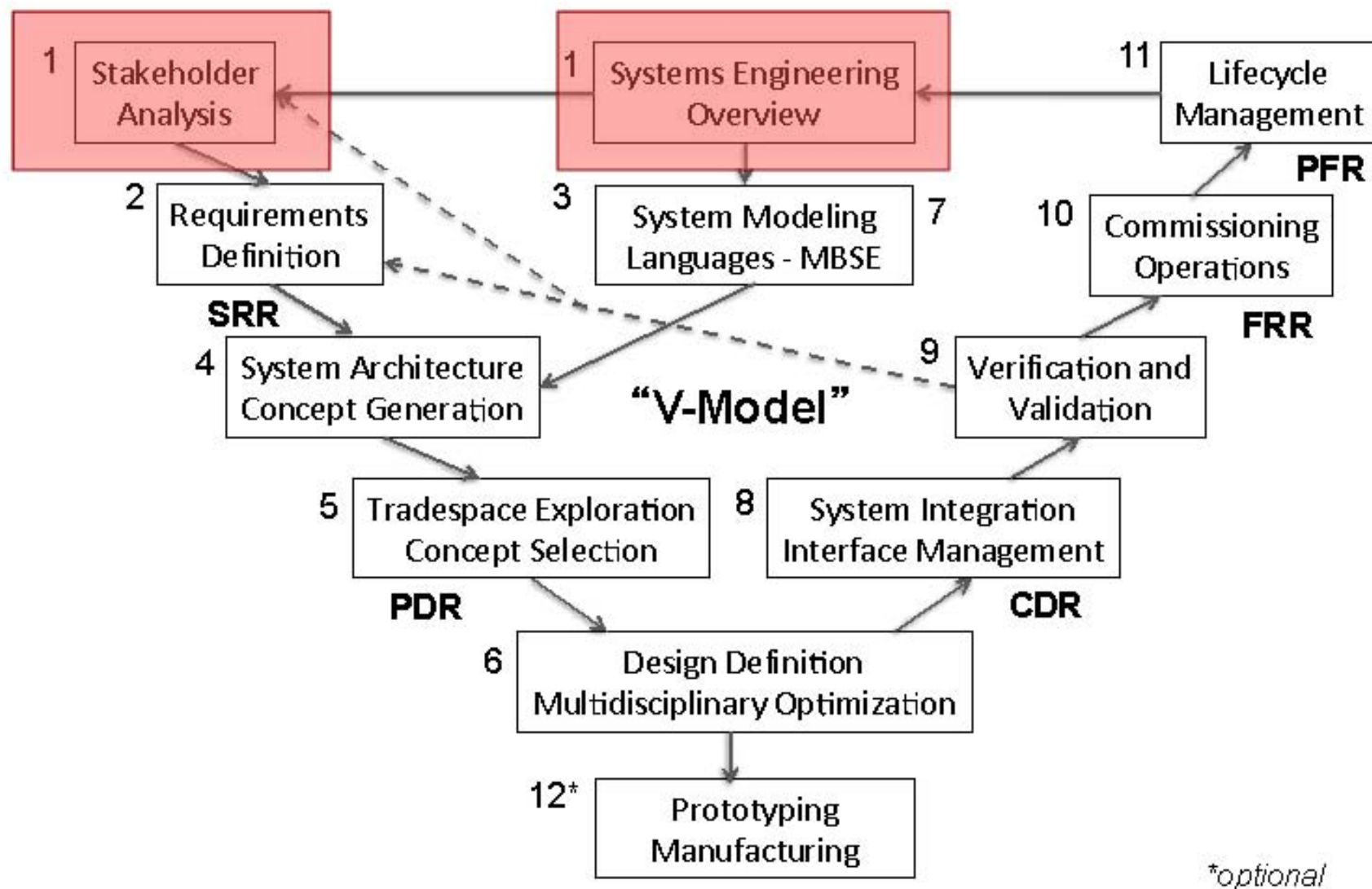
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Short Break

The famous “V-Model” of Systems Engineering

16.842/ENG-421 Fundamentals of Systems Engineering



Numbers indicate the session # in this class

Concept Question 2

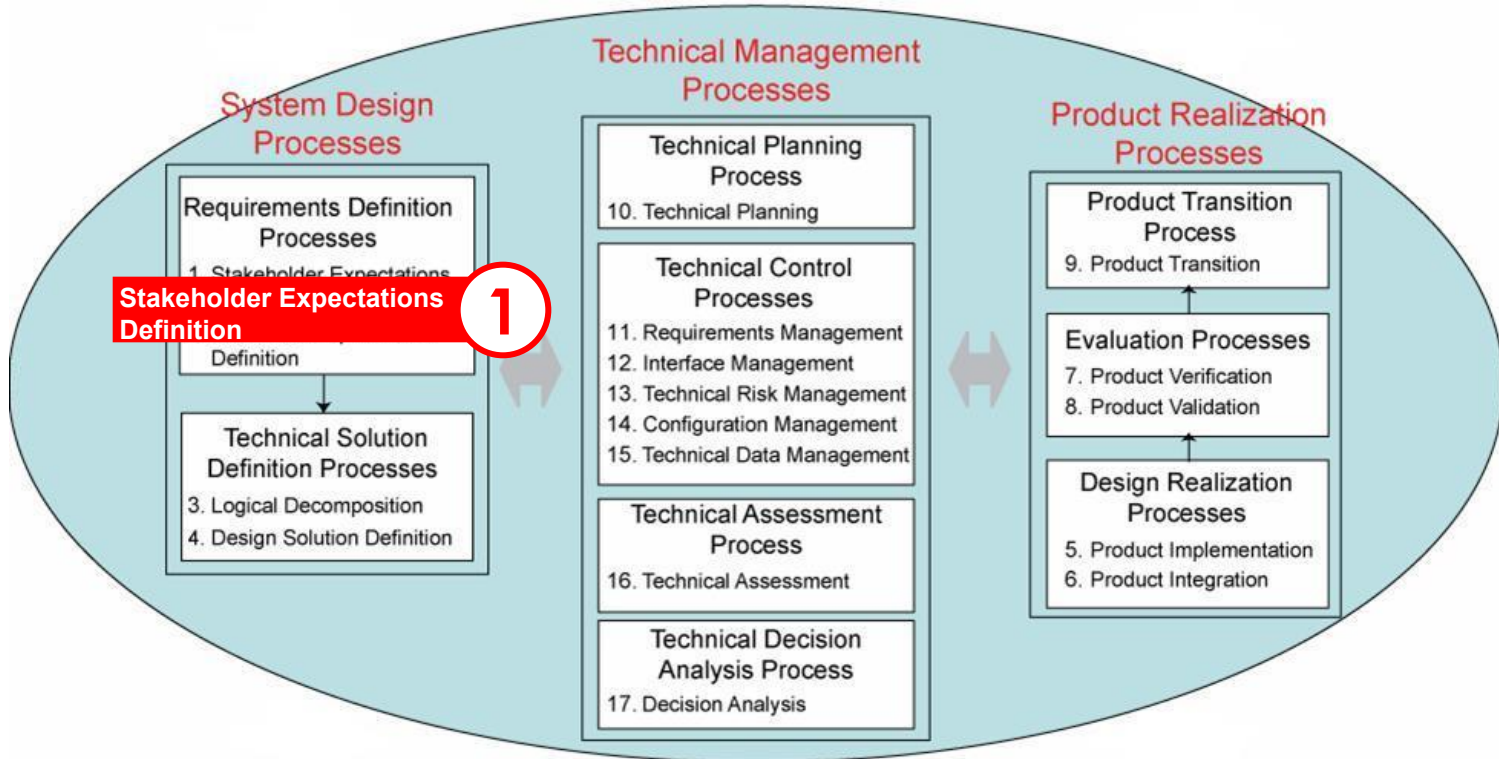
- Before rushing to propose or design something we need to spend considerable amount of time **engaging with stakeholders**, Why?
- Pick what you think is the most important reason
 - Because they have the funds
 - Because we need to understand their needs first
 - Who is my competition?
 - Need to understand regulations and laws
 - Other

■ Answer Concept Question 2
(see supplemental files)

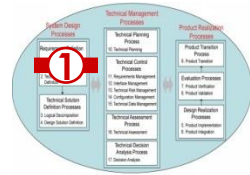
NASA view of stakeholder process



Stakeholder Expectations Definition Process

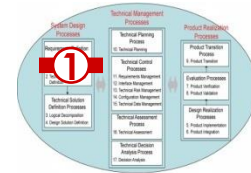


Who is a Stakeholder?



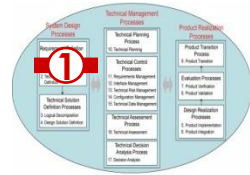
- A group or an individual who is **affected by** or is in some way **accountable** for the outcome of an undertaking
- Stakeholders can be classified as:
 - **Customers** – An organization or individual that has **requested** a product and will **receive** the product to be delivered. Examples:
 - An end user of the product
 - The acquiring agent for the end user
 - The requestor of the work product from a technical effort
 - **Other interested parties** who provide broad overarching **constraints** within which the customers' needs must be achieved, or who **have influence** on success of the system. Examples:
 - Those affected by the resulting product
 - Those affected by the manner in which the product is realized or used
 - Those who have a responsibility for providing life-cycle support services (e.g. design, manufacturing, operations, maintenance)

Examples of Stakeholders



Relative to Org	Stakeholder	Typical Expectations
External	Customer	Expected level of product quality, delivered on time, affordable, life cycle support & services
	Subcontractors/vendors	Well defined requirements
	Local, State, National Public	Products must not contaminate the environment
Internal	Org Management	Internal Commitments met (cost, schedule), good status provided, compliance with org policies, directives and procedures
	PM	Expected technical work products delivered on time and can be used for decision making
	Technical Team members	clear tasks, job security, rewards, teamwork
	Functional Organizations (e.g., test)	Test support products available, clear test requirements, recognition for project help

Concept of Operations (CONOPS)



- One of the major outputs for **capturing** stakeholder expectations is the Concept of Operations or “**ConOps**”
- The ConOps is an important **component** in capturing expectations, forming requirements and developing the architecture of a project or system
- Should be addressed early in the project
- Thinking through the ConOps and use cases often **reveals** requirements and functions that might be otherwise **overlooked**

Example CONOPS: Lunar Design Reference Mission

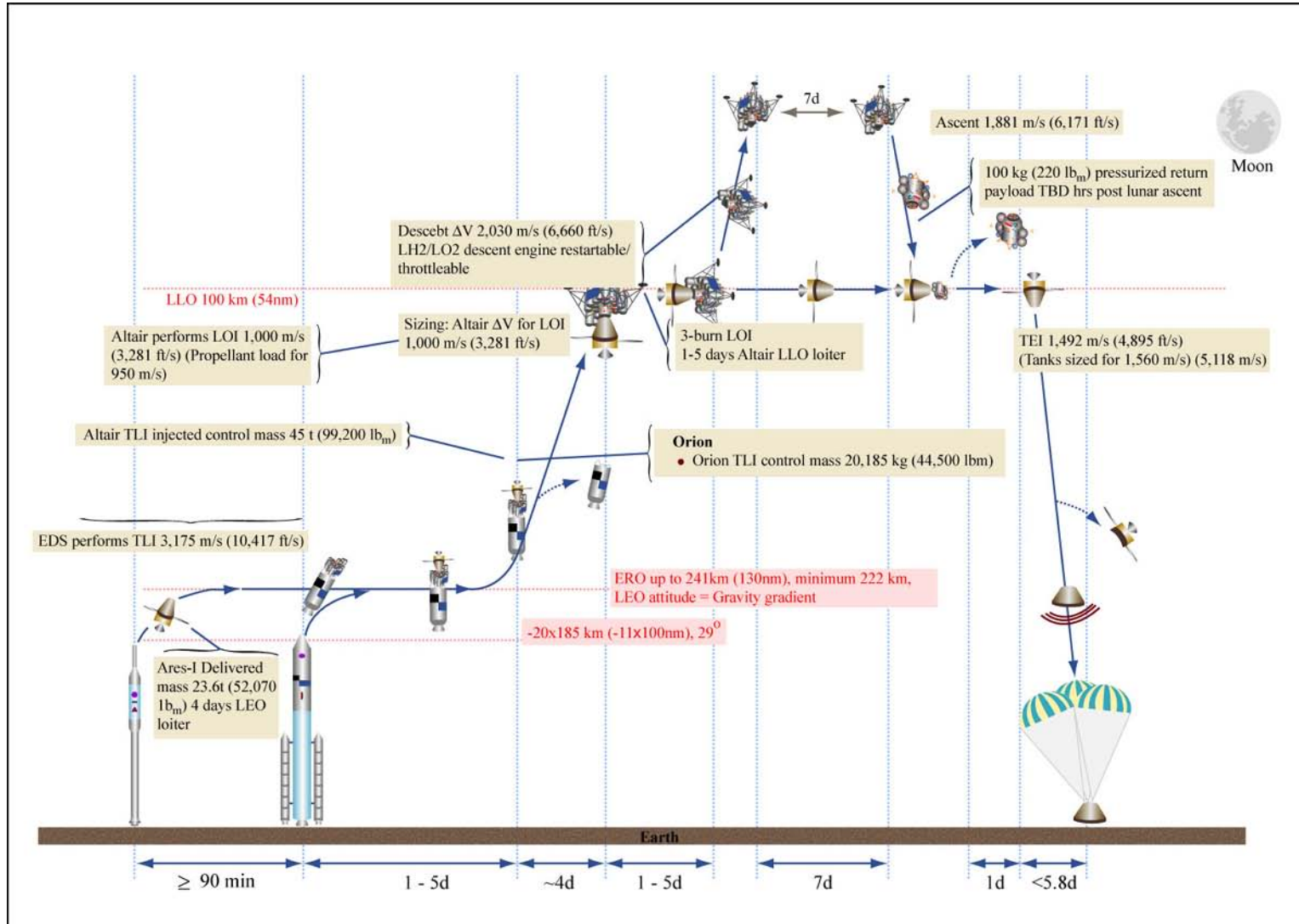
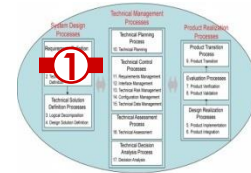
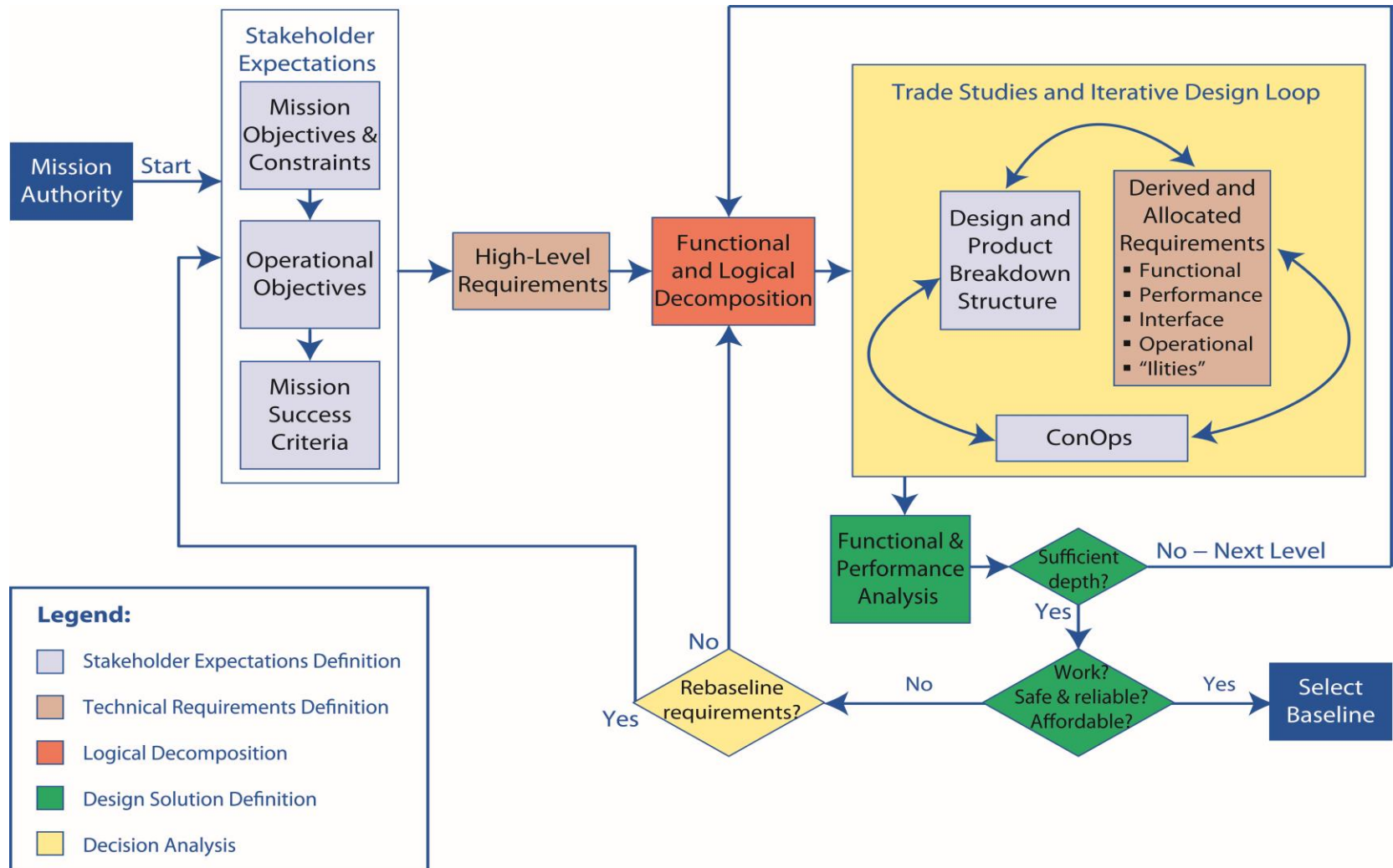
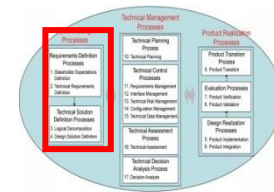


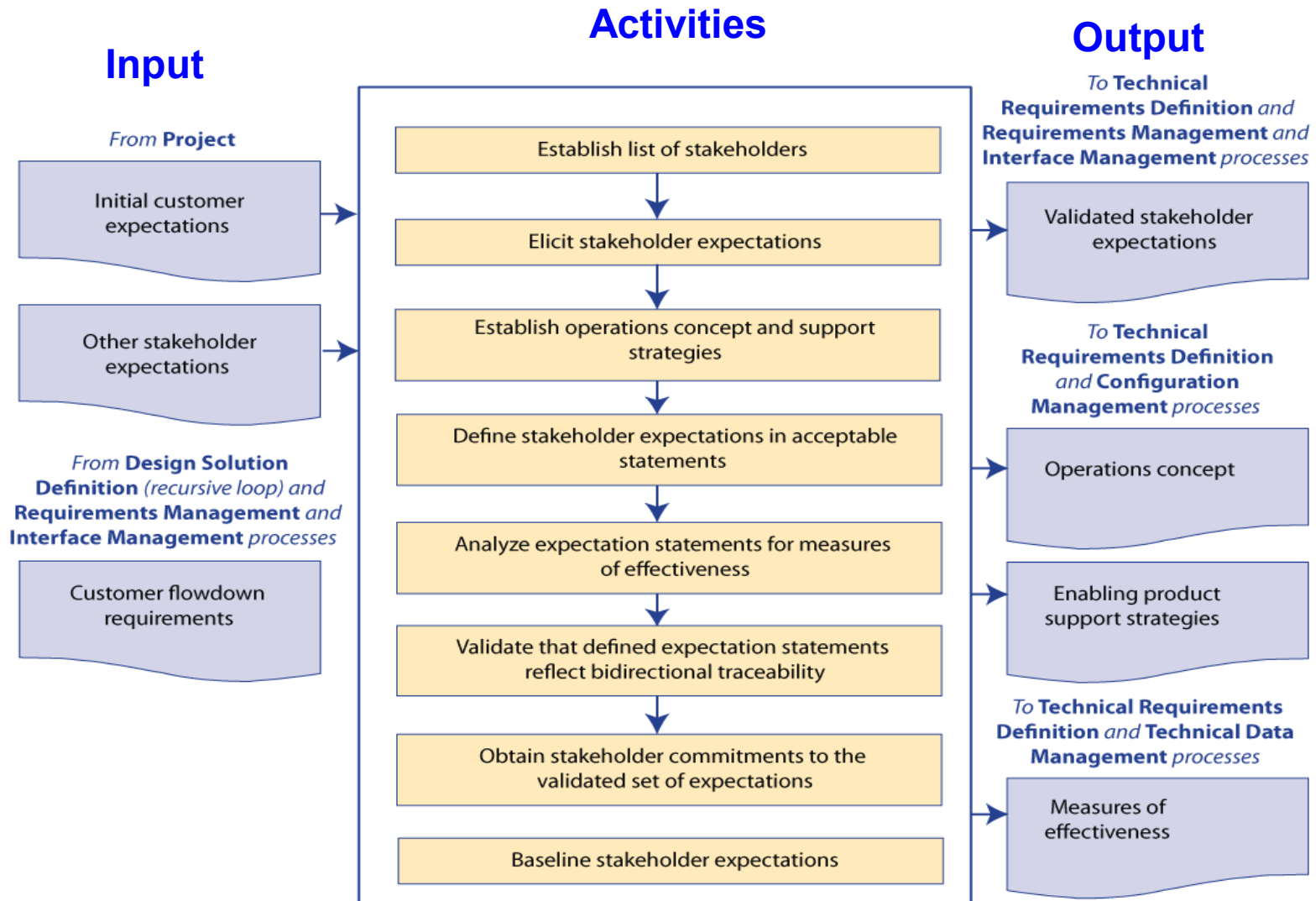
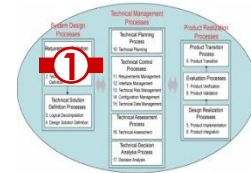
Image by MIT OpenCourseWare.

Relationships among the upstream System Design Processes

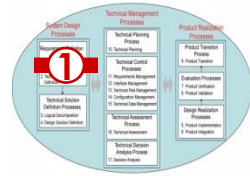


SP-2007-6105, Figure 4.0-1

Stakeholder Expectations Definition - Best Practice Process Flow Diagram



What are the Benefits of the Stakeholder Expectations Process?



- Build a system that meets customers' **expectations**
 - Operators requirements
 - Support from Congress and Public
- Build a system that can be **tested, operated** and **maintained**
- Ensure Stakeholder **commitments** are obtained and realized.

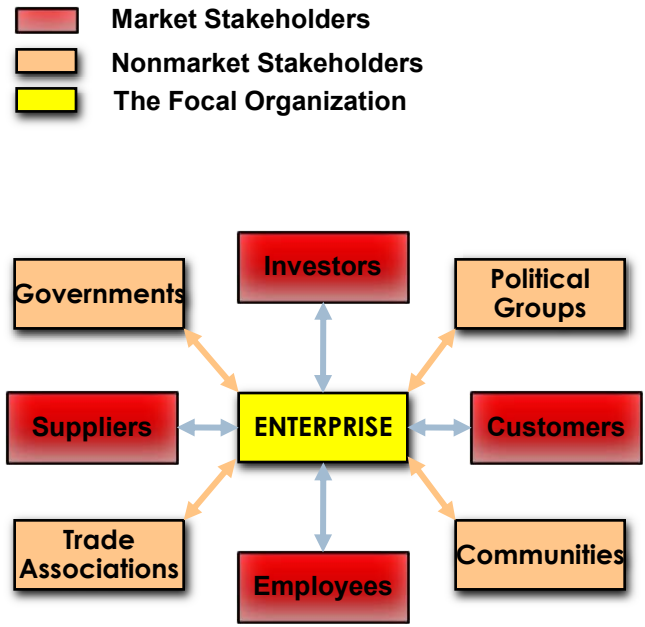
Stakeholder Value Network (SVN) Modeling

Most stakeholder models only focus on a single focal organization and ignore the indirect relationships amongst other stakeholders. This can lead to project failures if not recognized. Stakeholder Value Network (SVN) models attempt to capture these 2nd order effects and value loops.

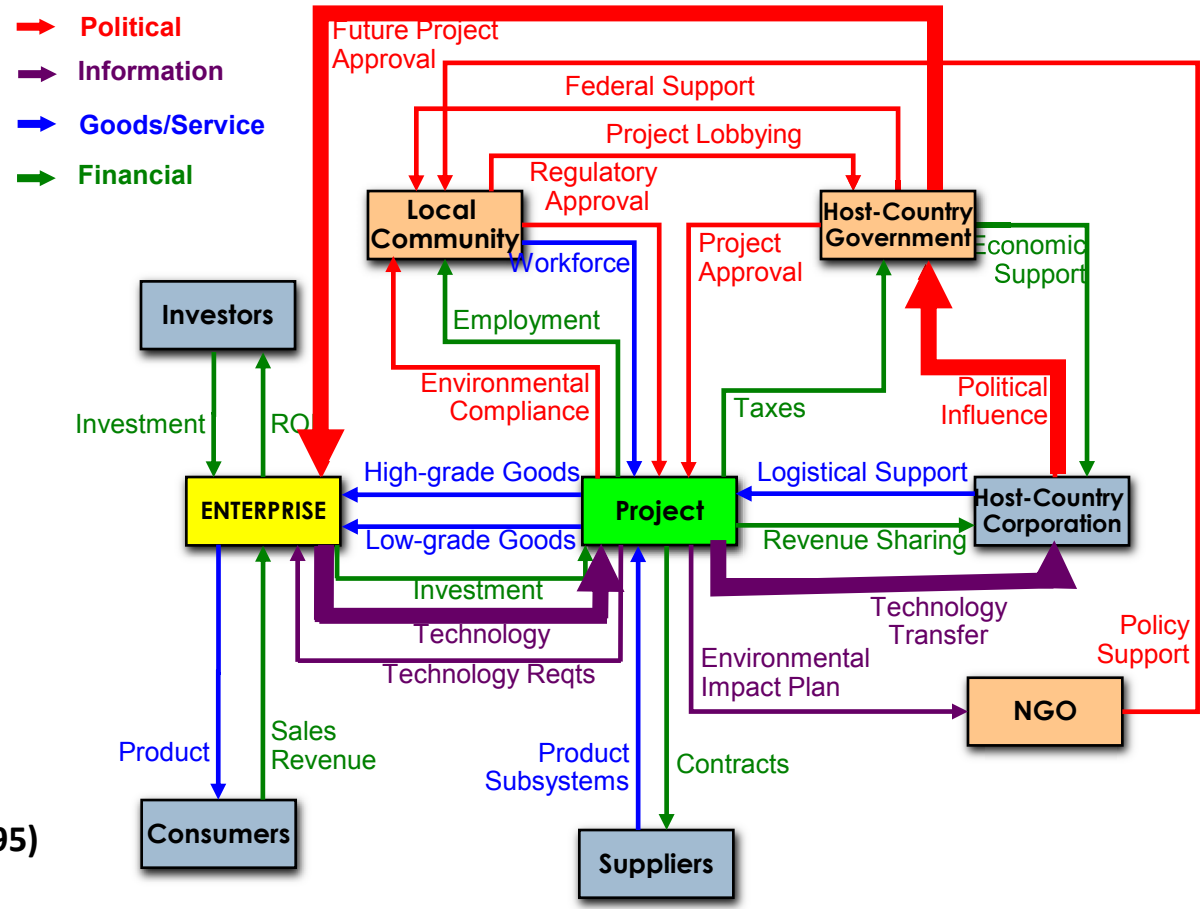
Based on the PhD Thesis of Dr. Wen Feng

Reading [1d] summarizes this approach: Feng W., Crawley E.F., de Weck O.L., Keller R., Robins R., “Dependency Structure Matrix Modeling for Stakeholder Value Networks”, 12th International Dependency and Structure Modeling Conference, DSM’10, Cambridge, UK, 22-23 July 2010 on

Introduction: "Hub-and-Spoke" Model and Value Network



"Hub-and-Spoke" Stakeholder Model
(Adapted from Donaldson and Preston, 1995)



Stakeholder Value Network
(Feng, Cameron, and Crawley, 2008)

Figure 3 in Wen Feng; Edward F. Crawley; Olivier de Weck; Rene Keller; Bob Robinson. "Dependency structure matrix modelling for stakeholder value networks". Proceedings of the 12th International DSM Conference, Cambridge, UK, 22.-23.07. 3-16.DSM 2010. CC by-nc-sa 3.0.

Motivation

■ Indirect Relationships:

- Understand the impact of both direct and indirect relationships between stakeholders on the success of large projects.

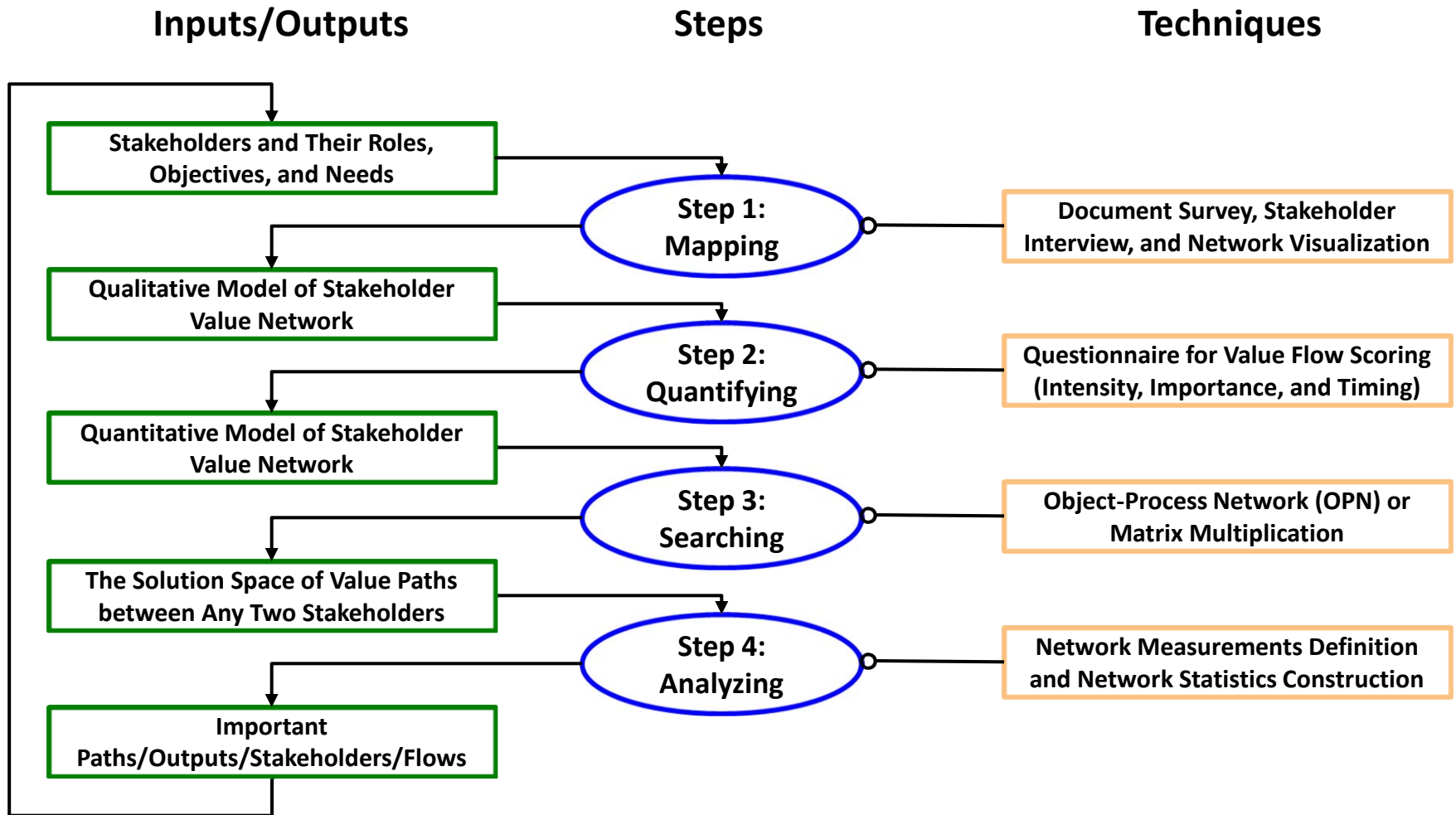
■ Strategies with Reduced Complexity:

- Apply such an understanding to inform decisions on stakeholder management strategies in a positive way and with reduced complexity.

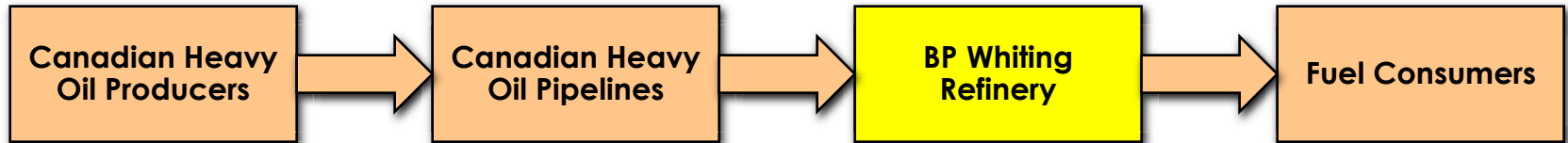
■ Communication Platform:

- Build a common platform for engineering, external affairs, and management within a project to consistently communicate important information about stakeholders.

SVN Methodology



A Case Study from the Oil & Gas Industry



■ BP Whiting Refinery Modernization Project

- **Whiting Refinery:** located in northwest Indiana, with more than 100-year history;
- **Modernization Project:** 2007-2012, \$3.8 billion, + 1.7-million-gallon gasoline/day;
- **Stakeholder Support:** new water permits for increased discharge of ammonia and suspended solids, issued by Indiana Department of Environmental Management (IDEM) and EPA;
- **Stakeholder Opposition:** an unanticipated firestorm of protest from Public Media (Chicago Tribune, Chicago Sun-Times, etc.) and Local Public (in Illinois), concerning water permitting;
- **BP finally promised to keep the lower discharge limits**
- **Managers' initial Mental Model for Stakeholder Importance:** Indiana State Government (IDEM) and U.S. Federal Government (EPA) are the most important stakeholders.

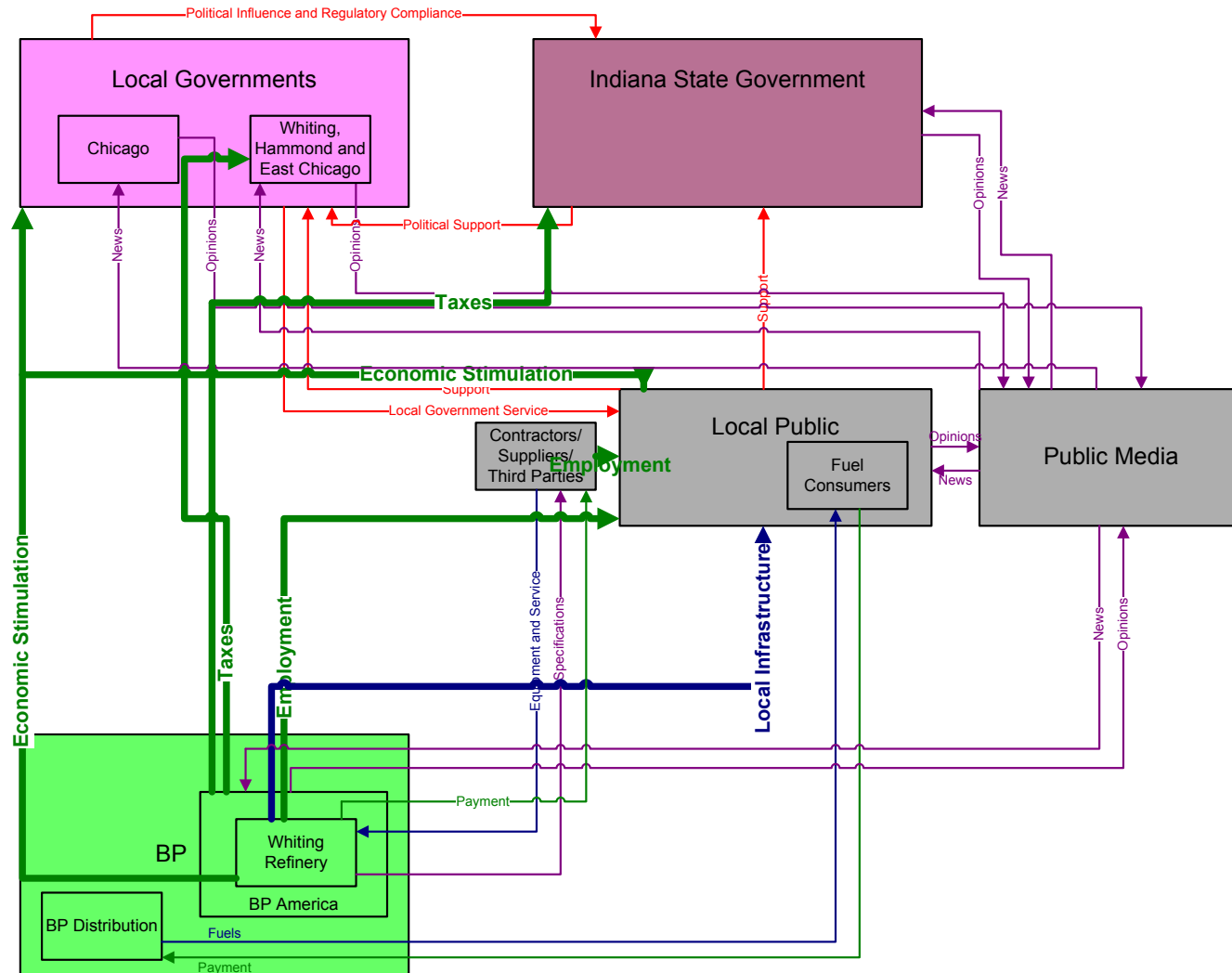
BP Whiting Refinery Modernization Project (WRMP)



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Issue 1: Local Economic Stimulation

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Issue 1: Local Economic Stimulation

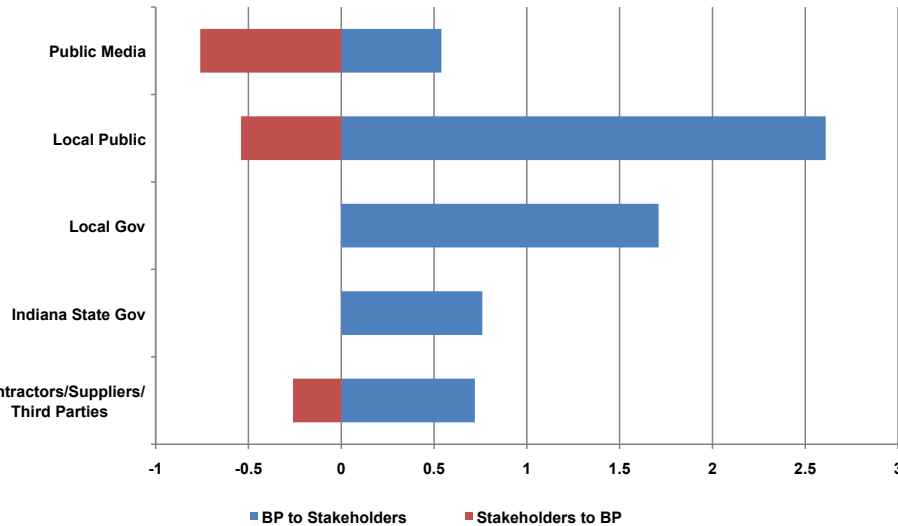
– 6 Stakeholders and 26 Value Flows

To Stakeholder	Value Flow	From Stakeholder	Questionnaire Ranking	WVFO (BP-Centered)
BP	Equipment and Service	Contractors/Suppliers/Third Parties	0.26	0.000
	Payment	Local Public	0.54	0.001
	News	Public Media	0.76	0.050
Local Gov	Economic Stimulation	BP	0.95	0.019
	Taxes	BP	0.76	0.013
	Political Support	Indiana State Gov	0.51	0.019
	Support	Local Public	0.95	0.007
	News	Public Media	0.51	0.002
Indiana State Gov	Taxes	BP	0.76	0.010
	Political Influence	Local Gov	0.22	0.008
	Regulatory Compliance	Local Gov	0.22	0.007
	Support	Local Public	0.76	0.029
	News	Public Media	0.76	0.016
Contractors/Suppliers/Third Parties	Payment	BP	0.36	0.003
	Specifications	BP	0.36	0.000
Local Public	Economic Stimulation	BP	0.95	0.029
	Employment	BP	0.54	0.017
	Fuels	BP	0.76	0.024
	Local Infrastructure	BP	0.36	0.011
	Employment	Contractors/Suppliers/Third Parties	0.22	0.002
	Local Gov Service	Local Gov	0.95	0.010
	News	Public Media	0.76	0.022
Public Media	Opinions	BP	0.54	0.008
	Opinions	Indiana State Gov	0.76	0.036
	Opinions	Local Gov	0.76	0.043
	Opinions	Local Public	0.76	0.027

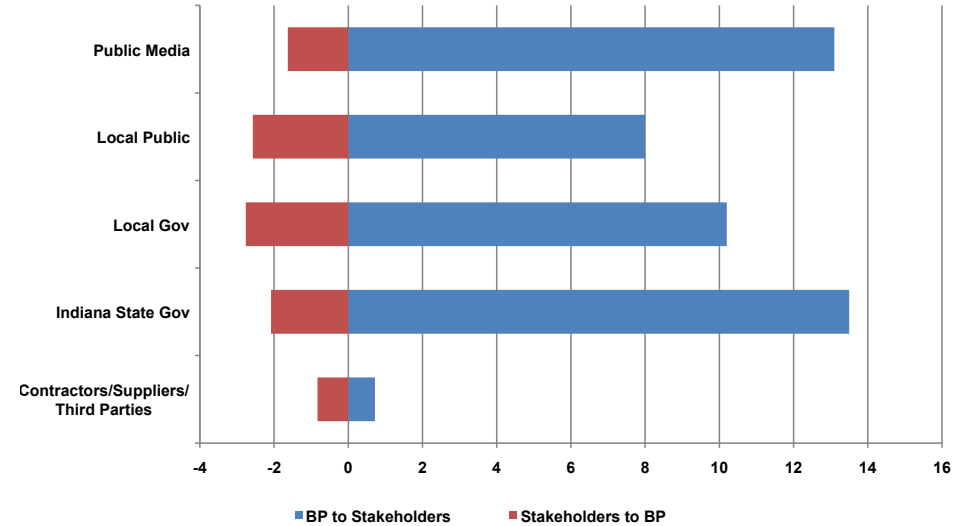
Issue 1: Local Economic Stimulation

– Stakeholder Balance

Hub-and-Spoke: Direct Transaction Value in the Map of Issue 1

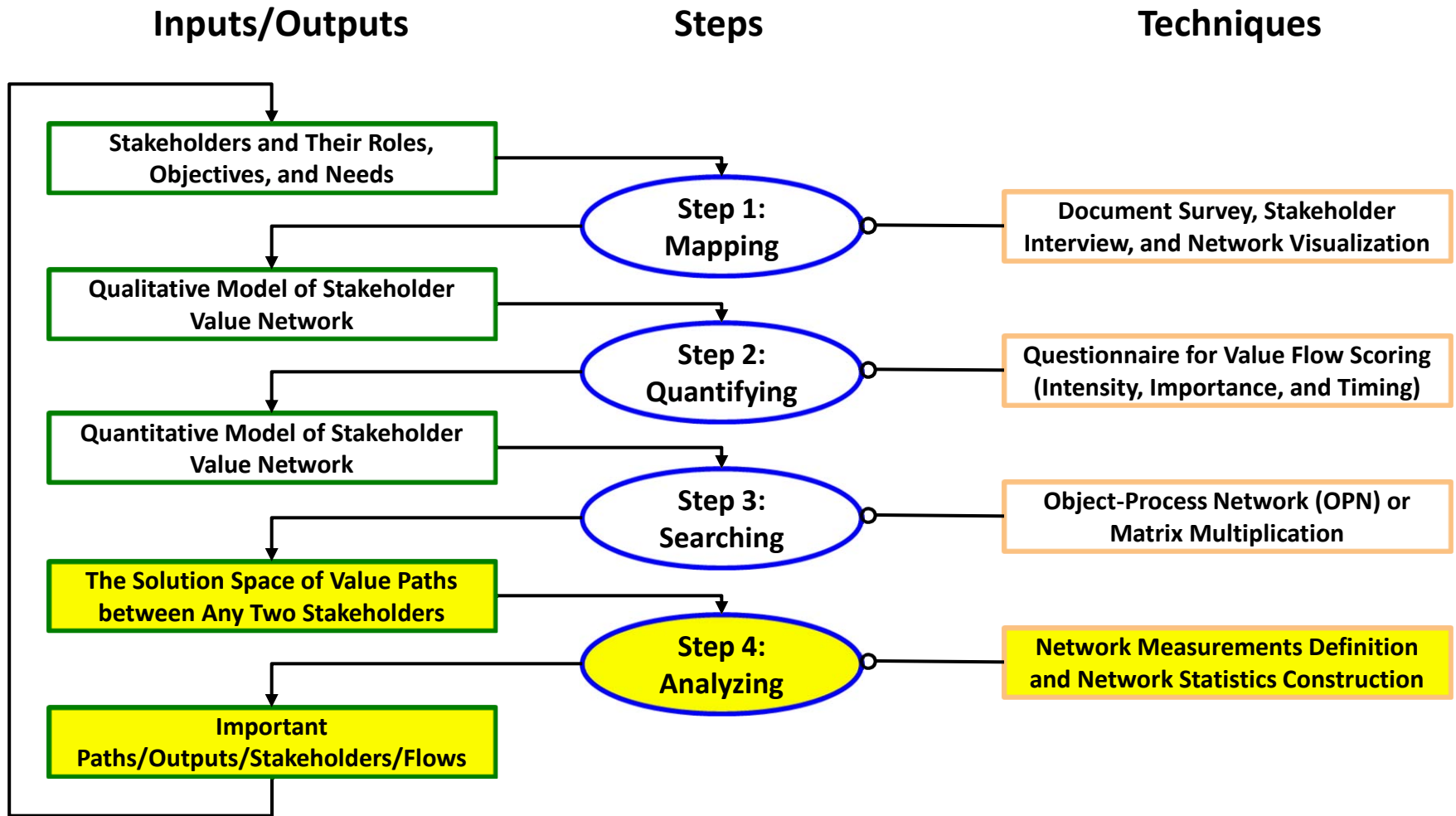


Network: Direct and Indirect Transaction Value in the Map of Issue 1



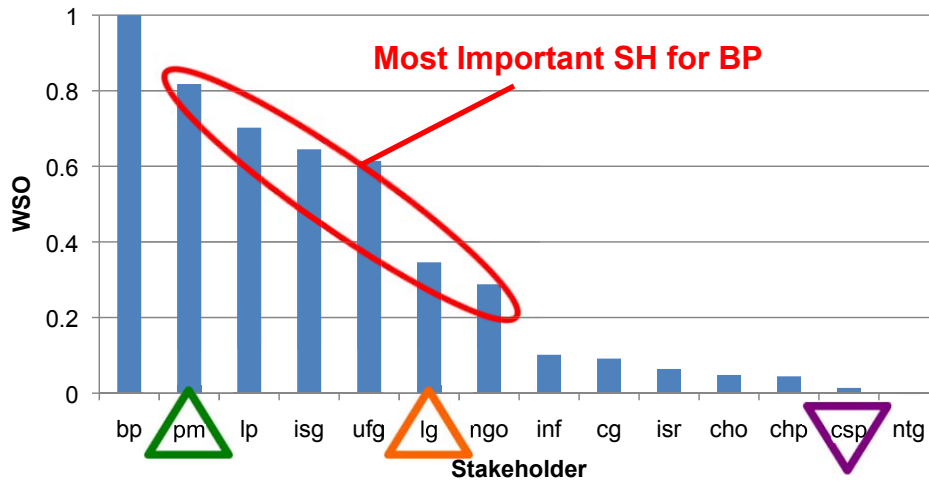
- **Definition 1:** Blue Bars represents the total transaction value from BP to Stakeholders, while Red Bar represents the total transaction value from Stakeholders to BP;
- **Definition 2:** The Left Graph shows the value of Direct transactions between BP and Stakeholders in the Hub-and-Spoke model, while the Right Graph shows the value of both Direct and Indirect transactions between BP and Stakeholders in the Stakeholder Value Network model;
- **Implication 1:** For a specific balance where Blue Bar is longer than Red Bar, BP is more powerful than the Stakeholder because BP provides more value to the Stakeholder than the Stakeholder provides to BP, vice versa;
- **Implication 2:** From the Hub-and-Spoke model to the Network model, the scale of transaction value generally becomes much larger because of the inclusion of Indirect transactions;
- **Implication 3:** All the Stakeholder Balance comparisons are under a specific Issue (Local Economic Stimulation, General Economic Performance, Local Environmental Protection, or National Energy Security) and based on a specific model (Hub-and-Spoke or Network).

BP WRMP Case: Step 4 – Analyzing

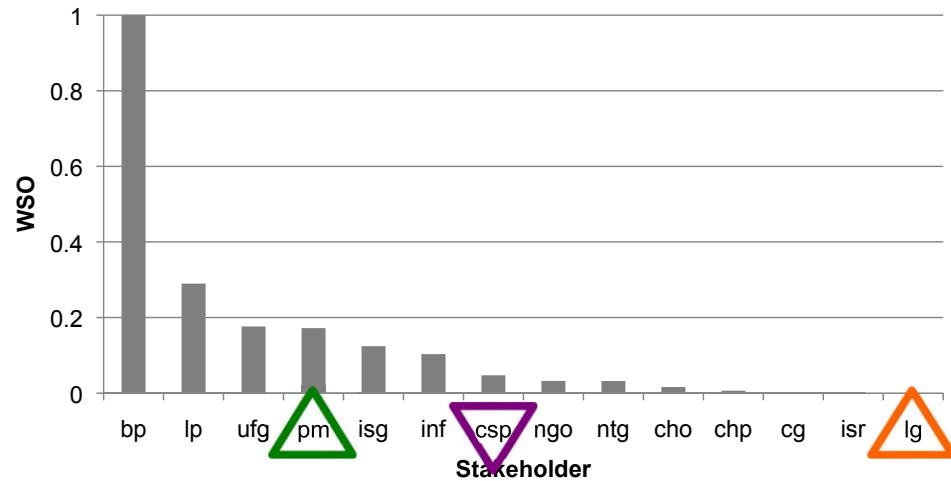


BP Whiting Case: Insight – Important Stakeholders

WSO in the Stakeholder Value Network (5039 Paths)

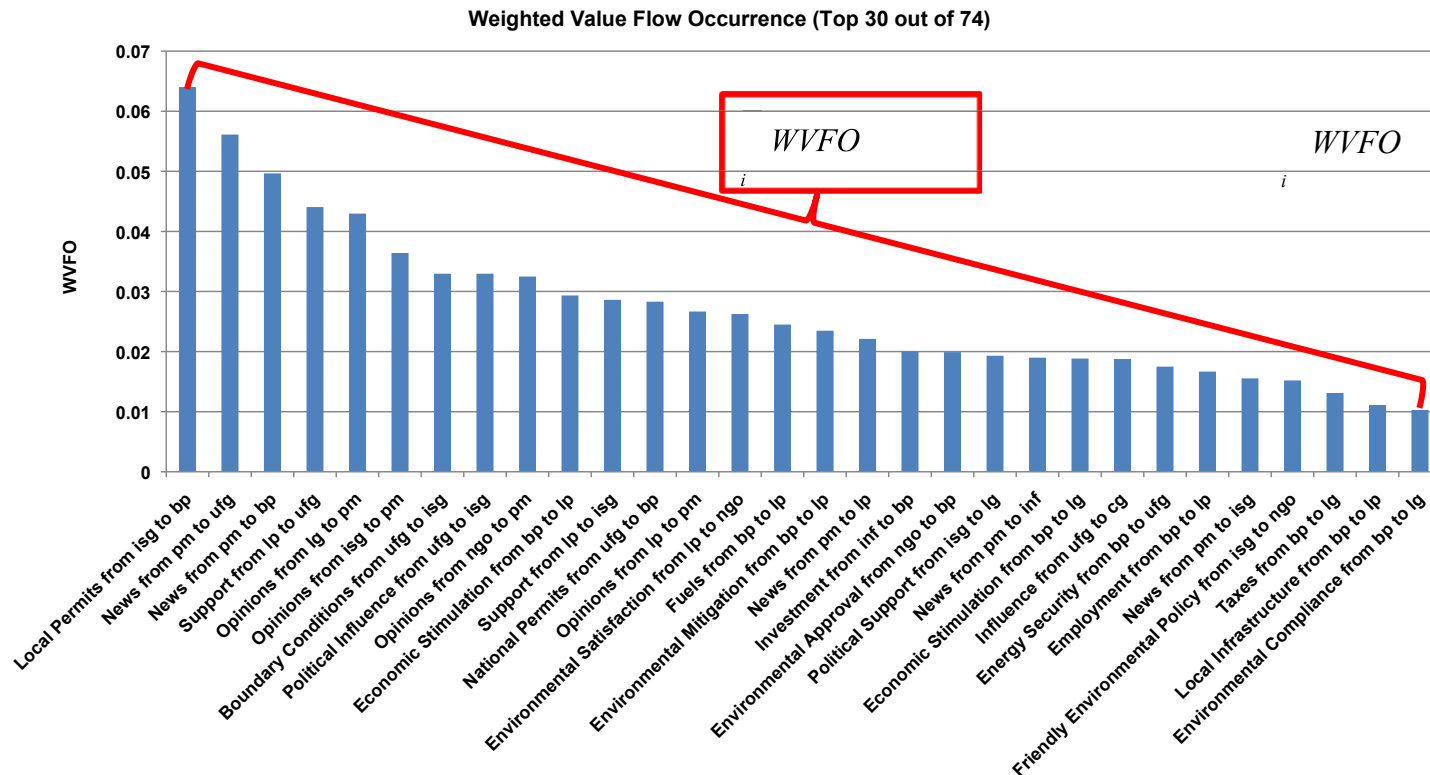


WSO in the "Hub-and-Spoke" Model (20 Paths)



- Weighted Stakeholder Occurrence (WSO) =
$$\frac{\text{Score Sum of the Value Paths Containing a Specific Stakeholder}}{\text{Score Sum of All the Value Paths for a Focal Organization}}$$
- **WSO** identifies **the most important stakeholders** who have the most effect on BP's project
- **Comparison 1 (with BP Managers' initial Mental Model):** Public Media (pm) and Local Public (lp) are the two most important stakeholders for BP, which have been confirmed by the later facts but ignored in managers' mental model at the beginning.
- **Comparison 2 (with the "Hub-and-Spoke" Model):** the Value Network model is closer to the later facts on important stakeholders, through considering the indirect stakeholder relationships.

BP Whiting Case: Insight– Important Value Flows



■ Weighted Value Flow Occurrence (WVFO) =

$$\frac{\text{Score Sum of the Value Paths Containing a Specific Value Flow}}{\text{Sum (Score Sum of the Value Paths Containing a Specific Value Flow)}}$$

- **WVFO** (and WSO) can be used as the guidance to build a smaller Stakeholder Value Network consisting of **the most important value flows** (between the most important stakeholders) to **reduce network complexity**.

Conclusions Stakeholder Value Networks (SVN)

- **Framework:** to understand the qualitative/quantitative impacts of indirect relationships between stakeholders on the success of large projects;
- **Reduced Complexity:** highlighting the important stakeholders (WSO) and the important value flows (WVFO), which can be used to construct a smaller model for more detailed analysis;
- **Strategic Insights:** identifying the critical value paths to engage stakeholders and prioritizing the high-leverage project outputs to allocate resources;
- **Transparent, Collaborative, and Alive Platform:** for different teams in a project (and for different stakeholders) to share important knowledge that is otherwise difficult to express or communicate.

Agenda for Today

- Introductions
 - Personal Introductions
 - Course Introduction, incl. Learning Objectives
- Systems Engineering (SE) Overview
 - A bit of history
 - The “V”-Model
 - SE Standards and Handbooks
 - Challenges of current practice
- Stakeholder Analysis
 - Identifying Stakeholders
 - CONOPS
 - Stakeholder Value Network (SVN) Analysis
- **Assignment A1**
 - 2016 CanSat Competition, Team Formation etc...

Assignments in this class

<i>Assignment</i>	<i>Topic</i>	<i>Weight</i>
A1 (group)	Team Formation, Definitions, Stakeholders, Concept of Operations (CONOPS)	12.5%
A2 (group)	Requirements Definition and Analysis Margins Allocation	12.5%
A3 (group)	System Architecture, Concept Generation	12.5%
A4 (group)	Tradespace Exploration, Concept Selection	12.5%
A5 (group)	Preliminary Design Review (PDR) Package and Presentation	20%
Quiz (individual)	Written online quiz	10%
Oral Exam (individual)	20' Oral Exam with Instructor 2-page reflective memorandum	10%

2016 CanSat competition overview

- **Design-build-fly** competition, provides teams with opportunity to experience the design lifecycle of an aerospace system
 - Competition reflects typical aerospace program on a small scale
 - Competition includes all aspects of an aerospace program from preliminary design review (PDR) to post-mission review
- Competition organized by American Astronautical Society (AAS) and American Institute of Aeronautics and Astronautics (AIAA) in Burkhett, Texas
- In this class:
 - Students form teams of 5
 - Over the course of the semester, teams prepare the **PDR-level design**
 - Internal PDR will be conducted to determine teams ranking
 - Top 3 teams from MIT and EPFL (6 teams in total) can apply to the competition

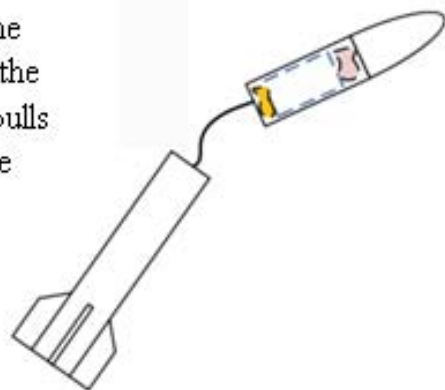
CanSat mission overview

- Mission simulates a sensor payload travelling through a planetary atmosphere, sampling it during flight
- Overall CanSat system has 2 components:
 - **Glider:**
 - Samples air temperature and pressure at 1Hz and transmits it to the ground station
 - Records and transmit glider position and velocity data
 - Takes pictures when requested by ground
 - **Re-entry container:**
 - Protects the glider during the rocket deployment phase
 - Provides stable, less forceful release environment.
- Mission requirements given in the competition guide, uploaded on Stellar

CanSat CONOPS description

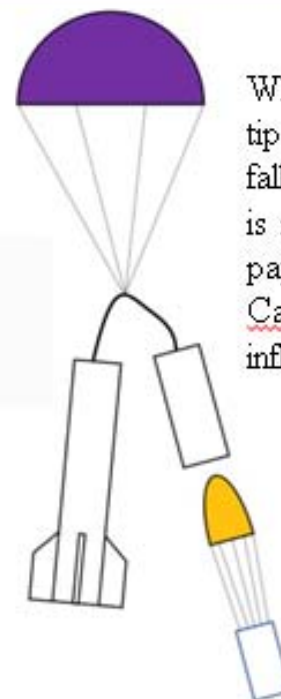
The payload and nose cone section are separated from the rocket. During this process, the shock chord between them pulls the rocket parachute from the rocket.

2.



When the front section tips over, the nose cone falls off and the CanSat is released from the payload section. CanSat's parachute now inflates over it.

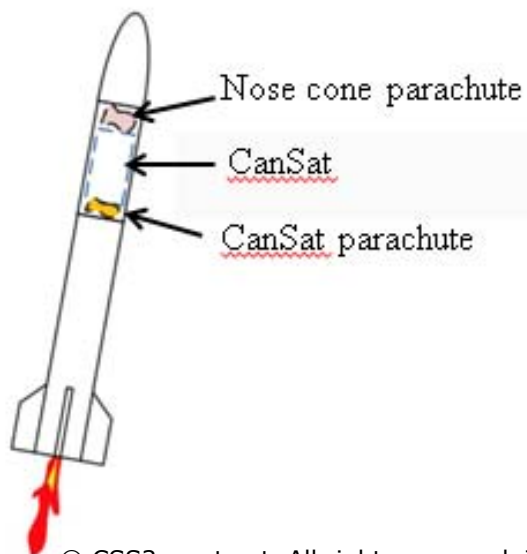
3.



CanSat rests on its parachute.

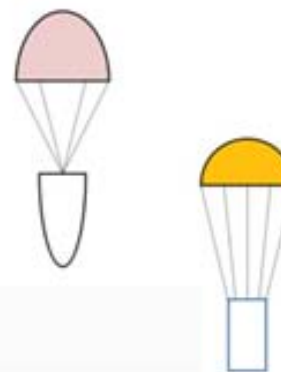
The nose cone parachute rests on the bottom of the CanSat.

1.



4.

The CanSat, nose cone and rocket descend under parachutes.



Additional details

- Teams shall be formed among students from the same school
 - Five students per team
 - Let your TA know if you need help with team formation
 - Mixed teams (MIT/EPFL) require instructor permission
- CanSat competition registration deadline
 - Registration fee \$100 sponsored by Prof. de Weck
 - CanSat building costs – max \$1000, need to be fundraised by student teams participating in the competition (after this class)
- Class will have an internal PDR
 - Will provide team rankings before the competition registration deadline

PDR package contents

- PDR is a “multi-disciplined technical review to ensure that the system under review can proceed into detailed design and can meet the stated performance requirements within cost (program budget), schedule (program schedule), risk and other system constraints”
- CanSat teams shall demonstrate:
 - Understanding of the CanSat mission requirements
 - Allocation and derivation of system and subsystem requirements
 - Definition of CanSat concept of operations (**CONOPS**)
 - Overview of preliminary design that meets requirements
 - Results of, or identification of, necessary trades to support preliminary design
 - Results of, or identification of, necessary prototyping or testing efforts necessary to support of finalize the preliminary design
 - Preliminary budget
 - Detailed development schedule

Assignment A1 Summary

- Assigned in Session 1
- Due 2 weeks from Session 1
- Four parts:
 - 1. Team Formation – Teams of ideally 5 students (20%)
 - Teams members should be from one school, MIT or EPFL; mixed teams require permission but are not impossible
 - 2. SE Definitions (20%)
 - 3. Stakeholder Analysis (30%)
 - 4. Refined CONOPS for CanSat 2015 (30%)
- Assignment is worth 12.5% (1/8) of your grade
- One writeup per team needs to be sent as “A1_Team#_2015.pdf”

Session 1 Summary

- Aerospace vehicles and other systems are becoming more complex and need at least 3-4 layers of decomposition (“magic” number 7)
- “V”-Model of Systems Engineering is the classic approach
 - Start with Stakeholder Analysis all the way to operations and Lifecycle Management
 - Importance of stage gates (‘milestones’): SRR, PDR, CDR, FRR, PFR
- Several standards exist that codify how SE should be done (NASA, INCOSE, ISO ...)
- Systems Engineering is far from perfect today
 - Latest trend is Model-Based Systems Engineering (MBSE), accidents and overruns still happen
- Stakeholder Analysis is always the first step
 - Identify who are the key stakeholders
 - Determine their needs and CONOPS
 - Stakeholder Value Network (SVN) analysis allows ranking stakeholders, value flows and provides a quantitative basis for stakeholder management
- **Next Friday: Session 2 Requirements Definition**

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16.842 Fundamentals of Systems Engineering
Fall 2015

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