Massachusetts Institute of Technology

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Fundamentals of Systems Engineering

Prof. Olivier L. de Weck

Session 7

Miscellaneous Topics

Outline for Today

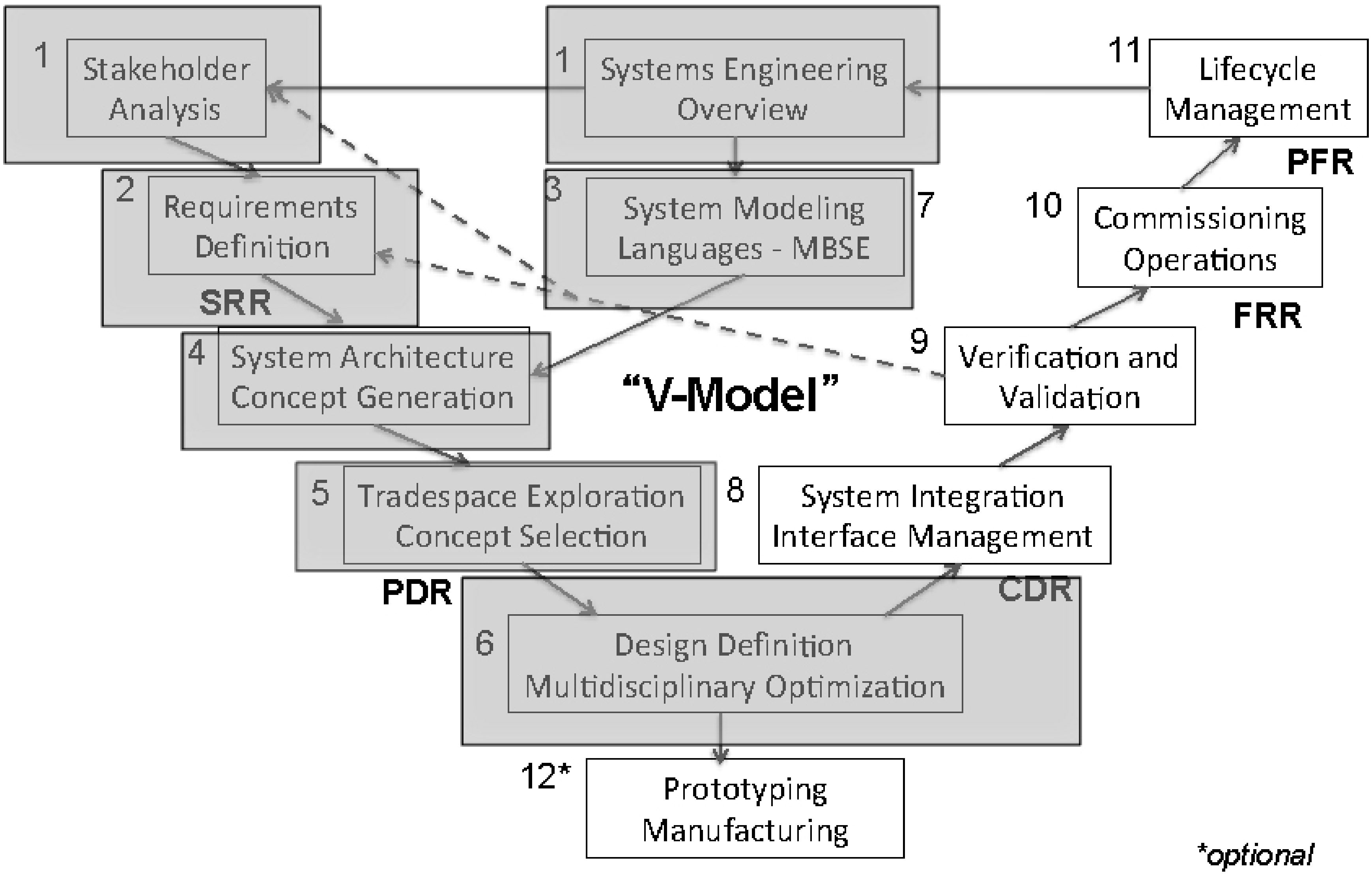
- General Status Update
- Go over Master Solution for Online Quiz
- Interactive Discussion with INCOSE Board of Directors (BoD)
- Octanis 1 Project Presentation

General Status Update

Assignment	*Topic*	*Weight*
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%

The "V-Model" of Systems Engineering

16.842/ENG-421 Fundamentals of Systems Engineering



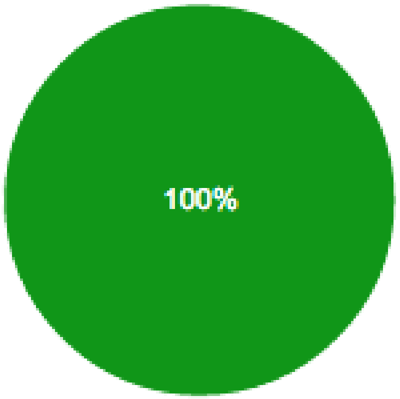
Numbers indicate the session # in this class

SE Mid-Term Exam

- 10 Questions, each worth 10 points
- Max 100 Points
- Open Book, Open Internet, Could use calculator, SE, Handbook PC etc…
- Individual Work (no collaboration or copying)
- Time estimate: 60-90 minutes (actual time ?)

Question 1

1. If a complex electro-mechanical system has 1850 individual unique part numbers, how many levels do you expect the drawing tree of that system to have?



1	0	0%
2	0	0%
3	0	0%
4	29	100%
5	0	0%
6	0	0%
7	0	0%
8	0	0%
more than 8	0	0%

Assume 7-tree [Miller 1956]

http://www.musanim.com/miller1956/

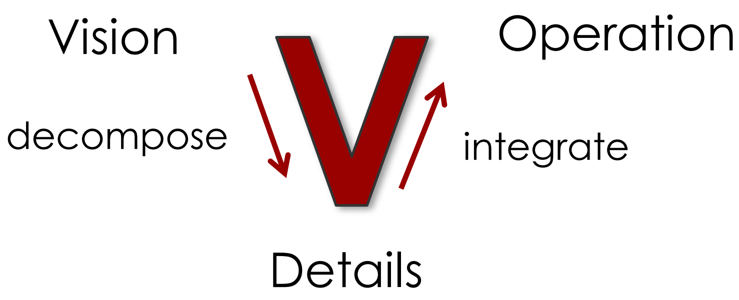
$$\#levels = \left\lceil \frac{\log(\#\,parts)}{\log(7)} \right\rceil$$

Question 2

- You are attending a cocktail party and tell a stranger that you took a class in Systems Engineering this term. She asks you "What is Systems Engineering?". What is your response?
- Sample responses
  - Systems Engineering represents a method, but also a mindset which enables the design, construction, operations and testing of a system in a successful way if done correctly. To exemplify in real life, *system engineering is like cooking a delicious cake*. The ingredients are either made by you or manufactured by a producer.
  - The woman's name is Cher and it turns out she's a singer. I explain to her, "Systems engineering is the optimal process for bringing an idea to reality with a combination of disciplines *that work in concert – just like all the instruments and vocals in your band combine to make beautiful music*. It isn't just about the design or the pieces that go into it; it is a process that lasts the entire life of the product.

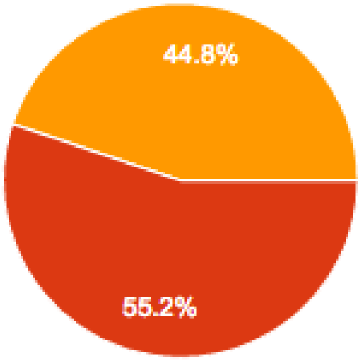
Question 3 – V-Model

- The V model is a graphical representation of the entire lifecycle of a system. It shows major review milestones and what stage the project should be in for each review. The left side of the V is the design of the system, including requirements definition and concept selection. The right side of the V is fabrication, integration, and test.
- …Requirements on the left directly affect the right side of the flow. If requirements change, a system won't pass V&V and will have to get through more iterations on the concept. If a system is found deficient in V&V, this can directly affect the left side of the 'V', where requirements waivers may have to be issued, or requirements changes may even be made. …



Question 4

4. What is the most important aspect of systems engineering that the "V" model does not show explicitly?

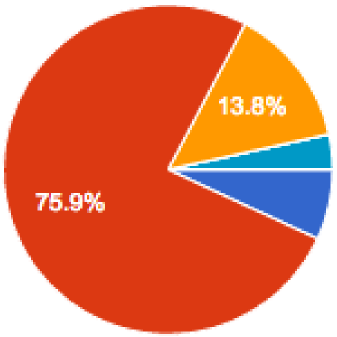


Requirements elicitation	**0**	0%
Iterative nature of design	**16**	55.2%
Possibility of schedule and cost overruns	**13**	44.8%
Need for systems integration	**0**	0%
Handoff to operations	**0**	0%

OK both correct.

Questions 5 and 6

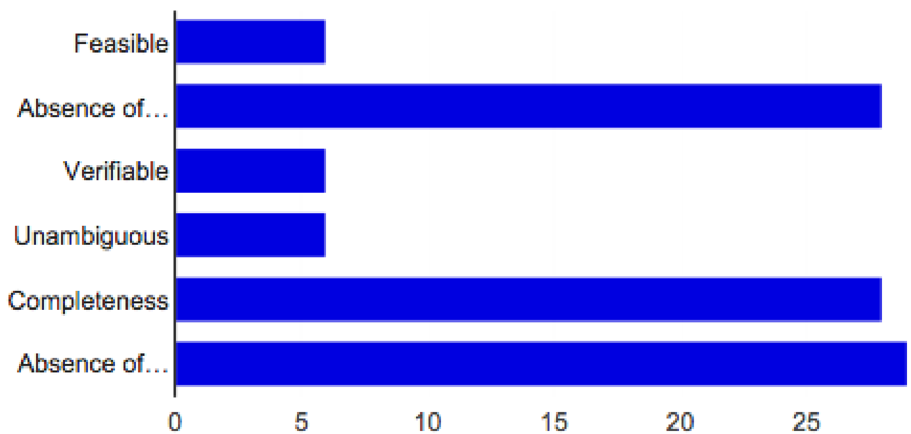
5. At which of the following milestones should the main concept (architecture) of a system have been selected?



SRR	**2**	6.9%
PDR	**22**	75.9%
CDR	**4**	13.8%
AR	**0**	0%
IOC	**0**	0%
Other	**1**	3.4%

PDR is correct.

6. Which of the following are attributes that a set of system requirements should meet?



Feasible	**6**	20.7%	
Absence of Redundancy	**28**	96.6%	√
Verifiable	**6**	20.7%	
Unambiguous	**6**	20.7%	
Completeness	**28**	96.6%	√
Absence of Conflicts	**29**	100%	√

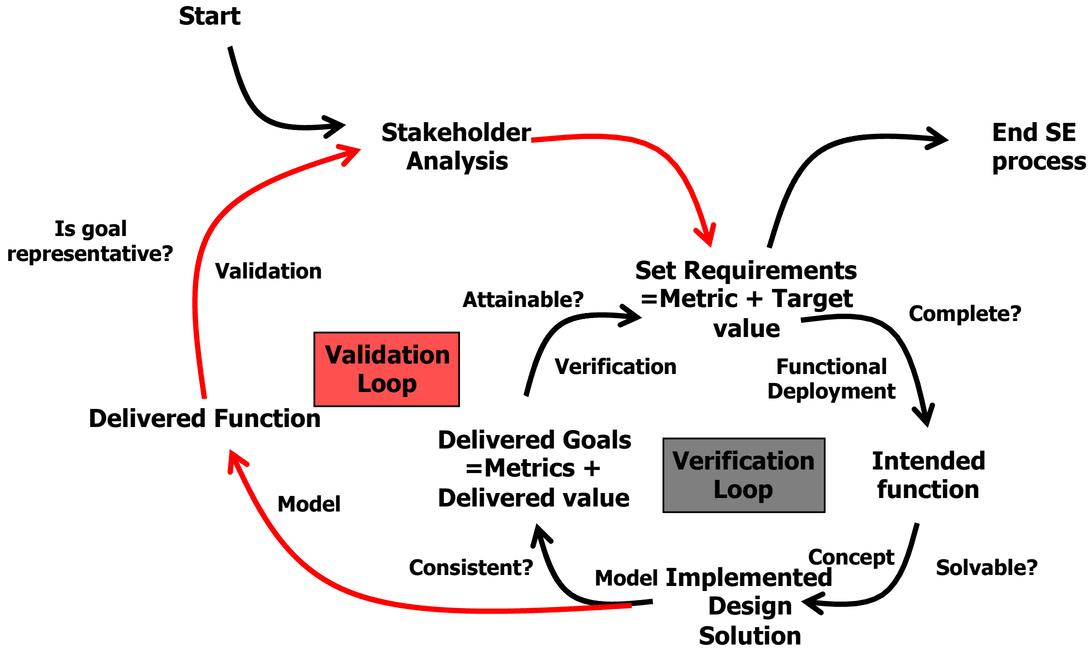
Question 7

7. What is the distinction between Verification and Validation in Systems Engineering?

The objectives of the verification and the validation are different. Verification uses performance tests, analysis, inspection or demonstration to the proof of compliance with requirements. Validation observes the accomplishment of the purpose and stakeholder's expectations with the same processes. Verification can be performed at different stages of the product life cycle and uses all documentation to establish the configuration baseline of the product for eventual later modifications. Validation checks the effectiveness and suitability of the product for operation, using its concept to perform tests in realistic conditions. The systems engineer manages the use of verification and validation to check products' conformance with requirements.

Verification: Did you satisfy requirements as written?

Validation: Did you satisfy the stakeholders and deliver the expected value to them?



Question 8

- Question 8 – Rocket Equation

$$\Delta v = g_o I_{sp} \ln\left(\frac{m_o}{m_1}\right)$$

$$m_o = (1+\alpha)(m_f + m_p)$$

$$m_1 = \alpha(m_f + m_p)$$

- Single Stage to Orbit (SSTO)
  - ΔV – change in velocity = 11,200 [m/s]
  - g_o – gravitational acceleration = 9.81 [m/s^2]
  - I_{sp} – specific impulse = 440 [s]
  - m_o – initial mass [kg]
  - m_1 – final mass [kg]
  - m_f – fuel mass [kg]
  - m_p – payload mass [kg]
  - α – structural mass fraction – 0.1

$$\frac{\Delta v}{g_o I_{sp}} \le \ln\left(\frac{1+\alpha}{\alpha}\right)$$

LHS = 2.59 **RHS = 2.398**

Infeasible Requirement !

What would mass fraction have to be
To make it feasible ? → $\alpha < 0.08$

We’ve tried before and failed:

- Lockheed Martin X33
  - SSTO Reusable Launch Vehicle Demonstrator
  - Target Mass m_o=130,000 kg, mass fraction α =0.1
  - Propellant: LOX / LH2 ~ I_{sp}=440sec
  - Fatal failure of LH2 composite fuel tanks
  - NASA canceled project in 2001 after spending $1,279 Million

The **Lockheed Martin X-33** was an unmanned, sub-scale technology demonstrator suborbital spaceplane developed in the 1990s under the U.S. government-funded Space Launch Initiative program. The X-33 was a technology demonstrator for the VentureStar orbital spaceplane, which was planned to be a next-generation, commercially operated reusable launch vehicle. The X-33 would flight-test a range of technologies that NASA believed it needed for single-stage-to-orbit reusable launch vehicles (SSTO RLVs), such as metallic thermal protection systems, composite cryogenic fuel tanks for liquid hydrogen, the aerospike engine, autonomous (unmanned) flight control, rapid flight turn-around times through streamlined operations, and its lifting body aerodynamics.

Failures of its 21-meter wingspan and multi-lobed, composite material fuel cells during pressure testing ultimately led to the withdrawal of federal support for the program in early 2001. Lockheed Martin has conducted unrelated testing, and has had a single success after a string of failures as recently as 2009 using a 2-meter scale model.[3]

X-33

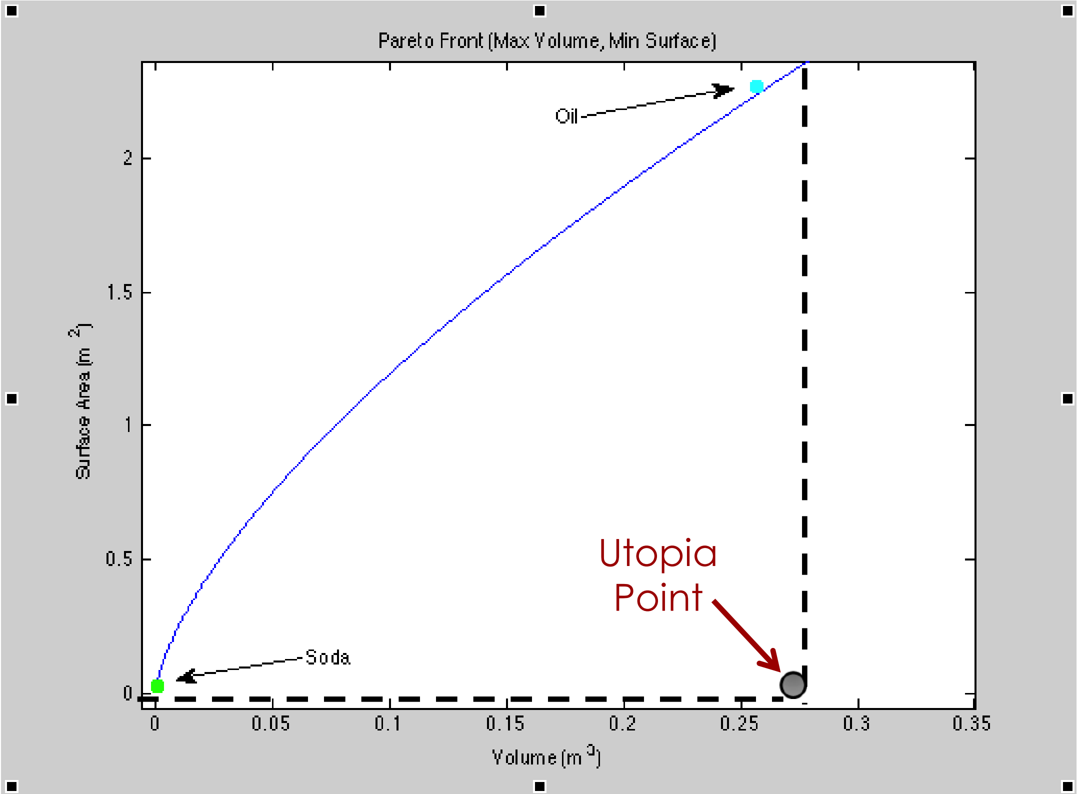
Simulated in-flight view of the X-33

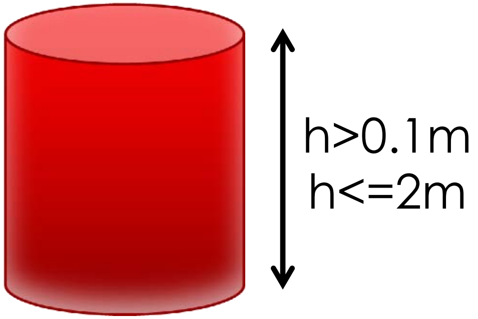
I am sure we will try again at some point !

https://en.wikipedia.org/wiki/Lockheed_Martin_X-33

Question 9

- Design a Pareto-optimal beverage / oil can





r/h>1/4
r<=2m

$$V = \pi r^2 h$$

$$A = 2\pi r^2 + 2\pi r h$$

9. Determine the optimal height and radius of a closed-end cylinder necessary to simultaneously maximize the volume and minimize the surface area of the cylinder. This is a typical problem in the design of beverage or liquid containers. Assume that the cylinder has negligible thickness. The height of the cylinder must be at least 0.1 meters, and the radius must be at least one-fourth the height. Neither the height nor the radius should be greater than 2.0 meters. Calculate and plot the Pareto frontier in the volume versus surface area objective space. Indicate the location of the Utopia point. The dimensions of a typical aluminum can containing soda such as Coca Cola are 4.8 inches high with a diameter of approximately 2.5 inches. The dimensions of a standard 55 US gallon (~208 liter) barrel of oil are approximately 880 mm tall with a diameter just under 610 mm. Are the aluminum soda can and the oil barrel Pareto optimal? Comment on your findings.

Question 10 – VW Emissions Scandal

10. Read the following Wikipedia article about the recent VW emissions scandal: https://en.wikipedia.org/wiki/Volkswagen_emissions_scandal. Then write a 300-500 word essay about what you think went wrong from a Systems Engineering perspective. Use key terms and concepts we covered in class so far to support your arguments.

Emission standards [edit]

The VW and Audi cars identified as violators had been certified to meet either the US EPA Tier 2 / Bin 5 emissions standard or the California LEV-II ULEV standard.[54] Either standard requires that nitrogen oxide emissions not exceed 0.043 grams per kilometre (0.07 g/mi) for engines at full useful life which is defined as either 190,000 kilometres (120,000 mi) or 240,000 kilometres (150,000 mi) depending on the vehicle and optional certification choices.[55][56]

This standard for nitrogen oxide emissions is among the most stringent in the world. For comparison, the contemporary European standards known as Euro 5 (2008 "EU5 compliant",[3] 2009[5]–2014 models) and Euro 6 (2015 models) only limit nitrogen oxide emissions to 0.18 grams per kilometre (0.29 g/mi) and 0.08 grams per kilometre (0.13 g/mi) respectively.[57][56] Defeat devices are forbidden in the EU.[58] The use of a defeat device is subject to a penalty.[57]

NO_x numbers for VW Passat and Jetta[13] See note

Car	EPA (USA)			Euro5			Euro6			Comment
	Limit	Dyno	WVU measurement	Limit	Register	Measurement 2011	Limit	Register	Measurement 201x	
Vehicle A [Volkswagen Jetta[59]]	0.043 g/km	0.022 g/km	0.61-1.5 g/km	0.18 g/km[57]		0.62 ± 0.19 g/km[39]	0.08 g/km[57]			lean-NO_x trap (LNT) (Vehicle A)
Vehicle B [Volkswagen Passat[59]]	0.043 g/km	0.016 g/km	0.34-0.67 g/km			0.62 ± 0.19 g/km				urea-based selective catalytic reduction (SCR) system (Vehicle B)

Cheat to meet requirements (verification NO_x tests), failed validation

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International Council on Systems Engineering

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INCOSE

Board Meeting
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Stevens Institute of Technology

Octanis 1 Project

- Design, Manufacturing and Deployment of a rover for extreme environments (e.g. Antarctica)
- Presented by Raffael Fabian Tschui
- Look for the Systems Engineering challenges in the project

octanis

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