1. Annotation

Course Description

The course introduces students to the fundamentals of systems engineering as an interdisciplinary approach and means to enable the realization of successful systems, as defined by the International Council of Systems Engineering.

The course covers the entire spectrum of the lifecycle management of a system, encompassing conceptual design, design, implementation, assembly-Integration and test (AIT), operations and disposal of systems.

Being a foundational course for the Space and Engineering Systems students of Skoltech, the course discusses many applications of systems engineering including some parts of space systems engineering. The course also discusses systems architecture principles.

The Systems Engineering course follows the systems engineering V-model as an educational guideline. The course includes a design project that is conducted throughout the term.

Course Prerequisites

There are no prerequisites for this course.

2. Structure and Content
<table>
<thead>
<tr>
<th>Course Academic Level</th>
<th>Master-level course suitable for PhD students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of ECTS credits</td>
<td>6</td>
</tr>
<tr>
<td>Topic</td>
<td>Summary of Topic</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Introduction to the course, overview of systems engineering phases, introduction of project</td>
<td>An introduction to systems engineering. It provides students an overview of the different phases of the lifecycle of a complex engineering system, tools and methods to scope projects</td>
</tr>
<tr>
<td>Stakeholders analysis, requirements definition</td>
<td>Stakeholder analysis and surveys used to define and analyse user needs; development of system requirements; Starting from user needs, this topic unfolds methods to formulate and manage requirements and provides a description of common pitfalls found in requirements definition, Project formulation</td>
</tr>
<tr>
<td>Managing complexity, System architecture</td>
<td>Approaches for the management of complexity in systems design, Principles of system architecture</td>
</tr>
<tr>
<td>Interface definition and analysis</td>
<td>Interface design and analysis, DSM, N2 diagrams, Discussion of system ilities and their importance in system design and lifecycle management.</td>
</tr>
<tr>
<td>Project management</td>
<td>Overview of main tools in project management, such as Gantt charts and PERT (Project Evaluation and Review Technique) analysis. Definition and discussion of critical paths and management approaches.</td>
</tr>
<tr>
<td>System and product modelling, MBSE</td>
<td>Overview of system modelling languages and of product modelling, analysis and simulation systems, Introduction to Model Based Systems Engineering</td>
</tr>
<tr>
<td>Concurrent engineering</td>
<td>An introduction to concurrent engineering, with comparison of alternative product development approaches such as the spiral and waterfall development models, including integrated product development processes</td>
</tr>
<tr>
<td>Assembly, integration, and testing.</td>
<td>Overview of assembly, integration, and testing (AIT) processes. Contextualization of AIT within the V-model of systems engineering.</td>
</tr>
<tr>
<td>Risk management</td>
<td>Tools to manage and assess risks. Different types of project risks. Risk matrices: likelihood and severity of risks.</td>
</tr>
<tr>
<td>Trade Space Exploration</td>
<td>Fundamental approaches of tradespace exploration as part of the lifecycle management process; application of tradespace exploration to support architecture formulation and selection in systems architecting problems; Formulation of a tradespace exploration model.</td>
</tr>
<tr>
<td>Verification and validation</td>
<td>Verification and validation of complex systems. Feedback loops in systems design and lifecycle management.</td>
</tr>
<tr>
<td>Operations &amp; disposal</td>
<td>An overview of the major processes in operations and disposal of complex systems. Concepts of operations and use case scenarios as tools to inform the definition and management of a system.</td>
</tr>
</tbody>
</table>
## 3. Assignments

<table>
<thead>
<tr>
<th>Assignment Type</th>
<th>Assignment Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Homework</strong></td>
<td>Per topics 1 and 2. PROBLEM SET 1 Space Mission Architecture and Lifecycle Models</td>
</tr>
</tbody>
</table>

**Part A – (50%) Individual**

**Lifecycle Models**

One of the goals of systems engineers is to tailor the lifecycle process to the system under design, and to the organization in which they operate. At the outset of new projects, your manager asks you to come up with a proposed lifecycle model and discuss it. Discuss and sketch proposed lifecycle models for the following systems:

- A large telecommunications satellite designed by a government space agency.
- Space instrumentation for small satellites developed by a New Space company (e.g. Planet Labs).
- iPhone apps developed by a Skoltech startup.

After discussing the individual cases, conduct a cross-cutting analysis across the three lifecycle models you developed.

**Part B – (50%) Teamwork**

Throughout this course you will design, assemble, integrate, test, and fly a stratospheric balloon. You will interface with student colleagues that proposed payloads to be hosted and flown on the balloons, in addition to your own mission payloads.

Propose and describe the architecture for your balloon mission and its main elements. Tailor and discuss a lifecycle development model for the mission.

<table>
<thead>
<tr>
<th>Problem Set</th>
<th>Per topics 3 and 4. PROBLEM SET 2 Architecture Representation and Managing Complexity</th>
</tr>
</thead>
</table>

**Part A – (50%) Individual**

1. Consider the academic degree you are pursuing at Skoltech (courses, research, E&I experience, internships, and so forth) as a complex system. Represent your program structure using a Product Breakdown Structure (PBS), and represent the work required to complete your program using a Work Breakdown Structure (WBS).

Discuss the relations between your academic program (considered as a system) and its PBS and WBS.

2. Consider Skoltech as a complex system. Identify the main elements of the university, functions, and interfaces and represent them using OPM diagrams. Represent the interfaces between all the elements of the architecture of Skoltech using a N2 diagram.

**Part B – (50%) Teamwork**

Work in teams and use the appropriate SysML diagrams to build a full system model of your balloon project, following the simplified MBSE approach illustrated in Lecture 3. Structure the SysML model as you deem appropriate.

You may use any tool of your choice to create the diagrams. An open source tool that is free for download is called Modelio and you can download it at www.modelio.org. A popular commercial software for SysML modeling is MagicDraw (including its SysML plugin). A free trial of MagicDraw is available for 6-month use, but is limited with maximum 25 instances per element type.
| Problem Set | Per topics 5 and 6.  
PROBLEM SET 3  
Operations, Disposal, and Risk Management |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Part A – (50%) Individual</td>
<td></td>
</tr>
</tbody>
</table>
| 1. Last week you represented the structure of your degree program at Skoltech using Product Breakdown Structures and Work Breakdown Structures. Starting from those diagrams, represent the processes required to fulfill your degree requirements as a concept of operations (ConOps), using an Extended Functional Flow Block Diagram (EFFBD).  
2. Identify and classify sources of risk for your degree program. Draw a risk matrix for your degree program and describe a mitigation plan for the risks you identified. |
| Part B – (50%) Teamwork (to be submitted as Individual for this time) |
| 1. Work in teams and use Functional Flow Block Diagrams (FFBDs) or Extended Functional Flow Block Diagrams (EFFBDs) to represent the Concept of Operations of your balloon project. Make sure this new representation is coherent with the behavior diagram (BD) you developed for Problem Set 2. Make a choice of which diagram (FFBD/EFFBD versus BD) you are going to maintain and update from now on and describe the rationale of your choice.  
2. Work in teams to identify and classify sources of risk for your balloon project. Refer to the risk categories discussed on the NASA Systems Engineering Handbook. Write a Risk Management Plan (RMP) describing each risk you identified, and its corresponding mitigation strategy. Classify risks using a Risk Matrix. |
| Problem Set | Per topics 7 and 8.  
PROBLEM SET 4  
AIT and V&V |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Part A – (50%) Individual</td>
<td></td>
</tr>
<tr>
<td>Propose and describe a process to optimize AIT and V&amp;V processes for a complex system. Define the metrics for which you are optimizing the processes and describe how would you apply your proposed process to optimize AIT and V&amp;V of a large satellite system development process.</td>
<td></td>
</tr>
<tr>
<td>Part B – (50%) Teamwork</td>
<td></td>
</tr>
<tr>
<td>Draft an Integration Strategy Document (ISD), Interface Control Documents (ICD), Test Procedures Document (TPD), and Verification and Validation Document (VVD) for your project.</td>
<td></td>
</tr>
</tbody>
</table>
**Problem Set**

Set Per topics 9 - 11.

**PROBLEM SET 5**

Project Management

Part A – (50%) Individual

Find the Earliest Finish for the following project (same example as illustrated in class) and describe in detail the steps you have taken to come to the answer.

Part B – (50%) Teamwork

1. Develop a Project Management Plan for your project. Find the critical path and the most important project management indicators as discussed in class.
2. Draft a second iteration of the Integration Strategy Document (ISD), Interface Control Documents (ICD), Test Procedures Document (TPD), and Verification and Validation Document (VVD) for your project, incorporating the feedback you will receive and the lessons learnt during class and design sessions. (be proactive – if you did not receive enough feedback, come and ask!)

**Project**

Final project

Students have to produce a design report and a presentation to be delivered to faculty, invited industry experts, and researchers.

During the presentation, students are asked questions and are asked to defend their systems engineering choices and justify their decisions in light of the architectural tradeoffs encountered during the design exercise. The design report is graded by the course instructor whom verifies the achievement of the learning objectives of the course by the students.

Examples of design projects include:

1. System design process improvement with clustering techniques
2. System modeling of organizational processes
3. Design of a fractionated satellite system for Earth Observation
4. Design of a Synthetic Radar Aperture payload for small satellite systems.
5. Requirements management through systematic approaches
6. Collaborative design methodology evaluation
7. Systems of systems architecture study

### 4. Grading

<table>
<thead>
<tr>
<th>Type of Assessment</th>
<th>Graded</th>
</tr>
</thead>
</table>

**Grade Structure**

<table>
<thead>
<tr>
<th>Activity Type</th>
<th>Activity weight, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homework Assignments</td>
<td>40</td>
</tr>
<tr>
<td>Final Project</td>
<td>30</td>
</tr>
<tr>
<td>Presentation</td>
<td>20</td>
</tr>
<tr>
<td>Attendance</td>
<td>10</td>
</tr>
</tbody>
</table>

**Grading Scale**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A:</td>
<td>86</td>
</tr>
<tr>
<td>B:</td>
<td>76</td>
</tr>
</tbody>
</table>
5. Basic Information

Course Stream | Science, Technology and Engineering (STE)
Course Term (in context of Academic Year) | Term 2
Course Delivery Frequency | Every year

Students of Which Programs do You Recommend to Consider this Course as an Elective?

<table>
<thead>
<tr>
<th>Masters Programs</th>
<th>PhD Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Manufacturing Technologies</td>
<td>Computational and Data Science and Engineering</td>
</tr>
<tr>
<td>Energy Systems</td>
<td>Engineering Systems</td>
</tr>
<tr>
<td>Petroleum Engineering</td>
<td>Petroleum Engineering</td>
</tr>
<tr>
<td>All Master Programs</td>
<td></td>
</tr>
</tbody>
</table>

Course Tags | Engineering

6. Textbooks and Internet Resources

<table>
<thead>
<tr>
<th>Required Textbooks</th>
<th>ISBN-13 (or ISBN-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>INCOSE Systems Engineering Handbook</td>
<td>9781118999400</td>
</tr>
</tbody>
</table>
Web-resources (links) | Description
--- | ---
Springer [www.springer.com](http://www.springer.com) | 
State Public Scientific and Technical Library of Russia [http://www.gpntb.ru](http://www.gpntb.ru) | 

### 7. Facilities

**Equipment**
- Audience: 421, 422, 423, 424, 425, 402, 403, 404 (computer class), 407, 408.
- Syllabus documents and materials on the topics of discipline.
- The library, including electronic publications.
- Access to the Internet through a computer class and Wi-Fi network of the institute.

**Software**
- MATLAB
- MagicDraw

### 8. Learning Outcomes

**Knowledge**
- Design and tailor a lifecycle of a system, with particular emphasis on space projects.

**Skill**
- Identify the main architectural elements of the space mission and its main stakeholders.
- Design a systems engineering management plan for a complex system.
- Conduct tradeoff analysis and simple systems architecture studies during the early stages of a design project.
- Known the state of the art of systems engineering research from relevant literature sources and identify new areas of investigation in the field.
<table>
<thead>
<tr>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure and conduct team work towards the development of complex engineering systems.</td>
</tr>
</tbody>
</table>

### 9. Assessment Criteria

#### Input or Upload Example(s) of Assignment 1:

<table>
<thead>
<tr>
<th>Select Assignment 1 Type</th>
<th>Problem Set</th>
</tr>
</thead>
</table>
| **Input Example(s) of Assignment 1 (preferable)** | PROBLEM SET 1  
  Space Mission Architecture and Lifecycle Models |
PROBLEM SET 1
Space Mission Architecture and Lifecycle Models

Part A – (50%) Individual
Space Missions Architecture
1. Take a space mission of your choice (you can browse Google for information) and describe the main elements of the mission's architecture? (e.g. : launch segment, space segment, ground segment). Next, answer to the following questions:
   1) What were the mission objectives?
   2) What was the cost of the mission?
   3) How many years it took to develop the mission?
   4) Was the mission successful?

2. Research and report the annual budgets of ESA, NASA, and Roscosmos for 2013, and compare with the revenues of one representative company for each of the following sectors: a) IT, b) Energy, c) Biomed, d) Nuclear.

Lifecycle Models
One of the goals of systems engineers is to tailor the lifecycle process to the system under design, and to the organization in which they operate. At the outset of new projects, your manager asks you to come up with a proposed lifecycle model and discuss it. Discuss and sketch proposed lifecycle models for the following systems:
- A large telecommunications satellite designed by a government space agency.
- Space instrumentation for small satellites developed by a New Space company (e.g. Planet Labs).
- iPhone apps developed by a Skoltech startup.

After discussing the individual cases, conduct a cross-cutting analysis across the three lifecycle models you developed.

Part B – (50%) Teamwork (to be submitted as Individual for this time)
Throughout this course you will design, assemble, integrate, test, and fly a stratospheric balloon. You will interface with student colleagues that proposed payloads to be hosted and flown on the balloons, in addition to your own mission payloads.
Propose and describe the architecture for your balloon mission and its main elements. Tailor and discuss a lifecycle development model for the mission.
Part A – (50%) Individual

1. Consider the academic degree you are pursuing at Skoltech (courses, research, E&I experience, internships, and so forth) as a complex system. Represent your program structure using a Product Breakdown Structure (PBS), and represent the work required to complete your program using a Work Breakdown Structure (WBS). Discuss the relations between your academic program (considered as a system) and its PBS and WBS.

2. Consider Skoltech as a complex system. Identify the main elements of the university, functions, and interfaces and represent them using OPM diagrams. Represent the interfaces between all the elements of the architecture of Skoltech using a N2 diagram.

Part B – (50%) Teamwork

Work in teams and use the appropriate SysML diagrams to build a full system model of your balloon project, following the simplified MBSE approach illustrated in Lecture 3. Structure the SysML model as you deem appropriate.

You may use any tool of your choice to create the diagrams. An open source tool that is free for download is called Modelio and you can download it at www.modelio.org. A popular commercial software for SysML modeling is MagicDraw (including its SysML plugin). A free trial of MagicDraw is available for 6-month use, but is limited with maximum 25 instances per element type.

Input or Upload Example(s) of Assignment 3:

Select Assignment 3 Type

- Problem Set

Input Example(s) of Assignment 3 (preferable)

- PROBLEM SET 3
  Operations, Disposal, and Risk Management

Assessment Criteria for Assignment 3
Part A – (50%) Individual

1. Last week you represented the structure of your degree program at Skoltech using Product Breakdown Structures and Work Breakdown Structures. Starting from those diagrams, represent the processes required to fulfill your degree requirements as a concept of operations (ConOps), using an Extended Functional Flow Block Diagram (EFFBD).

2. Identify and classify sources of risk for your degree program. Draw a risk matrix for your degree program and describe a mitigation plan for the risks you identified.

Part B – (50%) Teamwork (to be submitted as Individual for this time)

1. Work in teams and use Functional Flow Block Diagrams (FFBDs) or Extended Functional Flow Block Diagrams (EFFBDs) to represent the Concept of Operations of your balloon project. Make sure this new representation is coherent with the behavior diagram (BD) you developed for Problem Set 2. Make a choice of which diagram (FFBD/EFFBD versus BD) you are going to maintain and update from now on and describe the rationale of your choice.

2. Work in teams to identify and classify sources of risk for your balloon project. Refer to the risk categories discussed on the NASA Systems Engineering Handbook. Write a Risk Management Plan (RMP) describing each risk you identified, and its corresponding mitigation strategy. Classify risks using a Risk Matrix.
PROBLEM SET 5
Project Management

Assessment Criteria for Assignment 5

Part A – (50%) Individual
Find the Earliest Finish for the following project (same example as illustrated in class) and describe in detail the steps you have taken to come to the answer.

Part B – (50%) Teamwork

1. Develop a Project Management Plan for your project. Find the critical path and the most important project management indicators as discussed in class.
2. Draft a second iteration of the Integration Strategy Document (ISD), Interface Control Documents (ICD), Test Procedures Document (TPD), and Verification and Validation Document (VVD) for your project, incorporating the feedback you will receive and the lessons learnt during class and design sessions. (be proactive – if you did not receive enough feedback, come and ask!)

10. Additional Notes