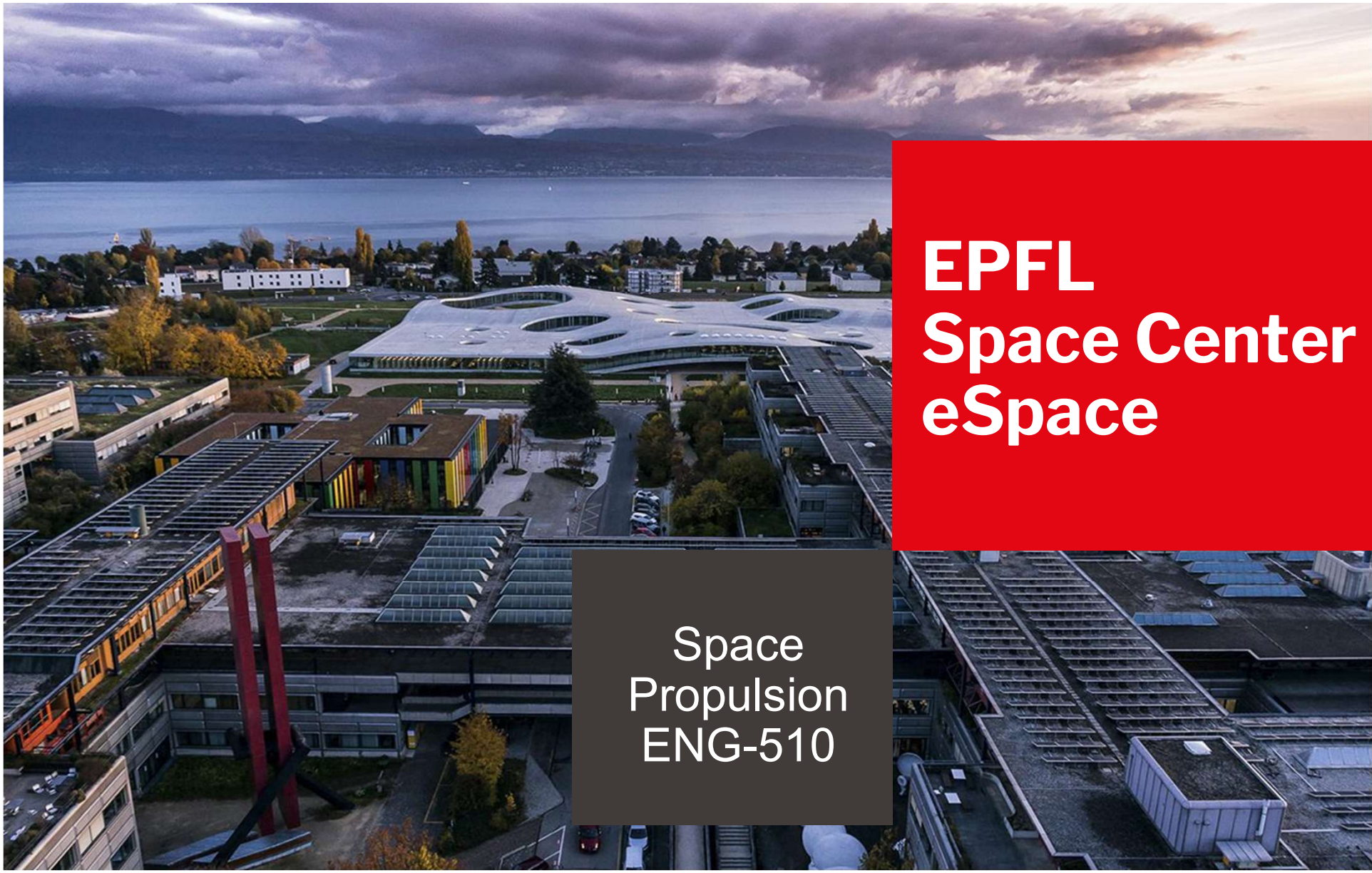

EPFL Space Center eSpace

Space Propulsion ENG-510

eSpace
EPFL Space Center

Space Propulsion ENG-510

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Lecture #1 Introduction & General Course Information

Brief information on your lecturer and the space propulsion course

eSpace
EPFL Space Center

Biography Markus Jäger

Biography:

- German (close to Lake of Constance), 54 years, married, 5 children (1 daughter [31 years], 4 sons [26, 24, 22 and 18]), 2 grand children [3 years 4 months and 10 months]) living in Bremen, Germany
- Fluent in German, English and French
- Spending time in running, beer brewing and traveling
- Interested in soccer (perhaps a bit more than interested…)

Biography Markus Jäger

Biography:

- Studies of Aerospace Engineering @ Technical University of Stuttgart + ENSICA Toulouse
- April 1998: Start @ Airbus Defence & Space in Bremen, Germany
- 2013: Working @ Airbus Defence & Space in Les Mureaux, France
- 2014 to 2020: Once again Airbus Defence & Space in Bremen
- January 2021 to April 2022: Working @ ArianeGroup in Lampoldshausen, Germany
- May 2022 to September 2023: Working @ The Exploration Company in Munich, Germany

Biography Markus Jäger

Biography:

- Since October 2023: Back @ Airbus Defence & Space in Bremen
- Since 2022: Lecture Space Propulsion @ EPFL, Lausanne, Switzerland (now season 4)
- Since 2024: Lecture Space Propulsion @ ETH, Zürich, Switzerland
- Distance studying on Personal & Organization and Business Administration within MBA course

Background & Motivation

Background:

- Propulsion engineer since the beginning in 1998
- Propulsion expert since September 2019 (but not anymore…)
- Chemical propulsion systems and electrical propulsion systems
- Storable propellant and cryogenic propellant
- Toxic and ‘greener’ propellants
- Engineering and testing
- Development and production
- Aerospace and aeronautics

Background & Motivation

Background:

- NASA and ESA
- Project manager + system engineering and modeling + analysis
- Prime contractor and Sub-contractor
- Global player and start-up
- System integrator and thruster designer

Background & Motivation

Background:

- Projects: EPS Perfo 2000, EPS Versatile, A5ES/ATV, VENUS, WOTAN, TBN Spaceplane, A5ME Upper Stage, Orion ESM, MSR-ERO RIT-2X Thruster, zeroE, Mission Possible, Mission Odysee, Starlab Commercial Space Station
- Business units: Launchers, Orbital Systems, Orbital Propulsion, Exploration (only Space)
- Responsibilities: Propulsion Engineer, System Engineer, Project Manager, Team Leader, Head of Department, Expert, Business Development, R&T + R&D engineer

Background & Motivation

Background:

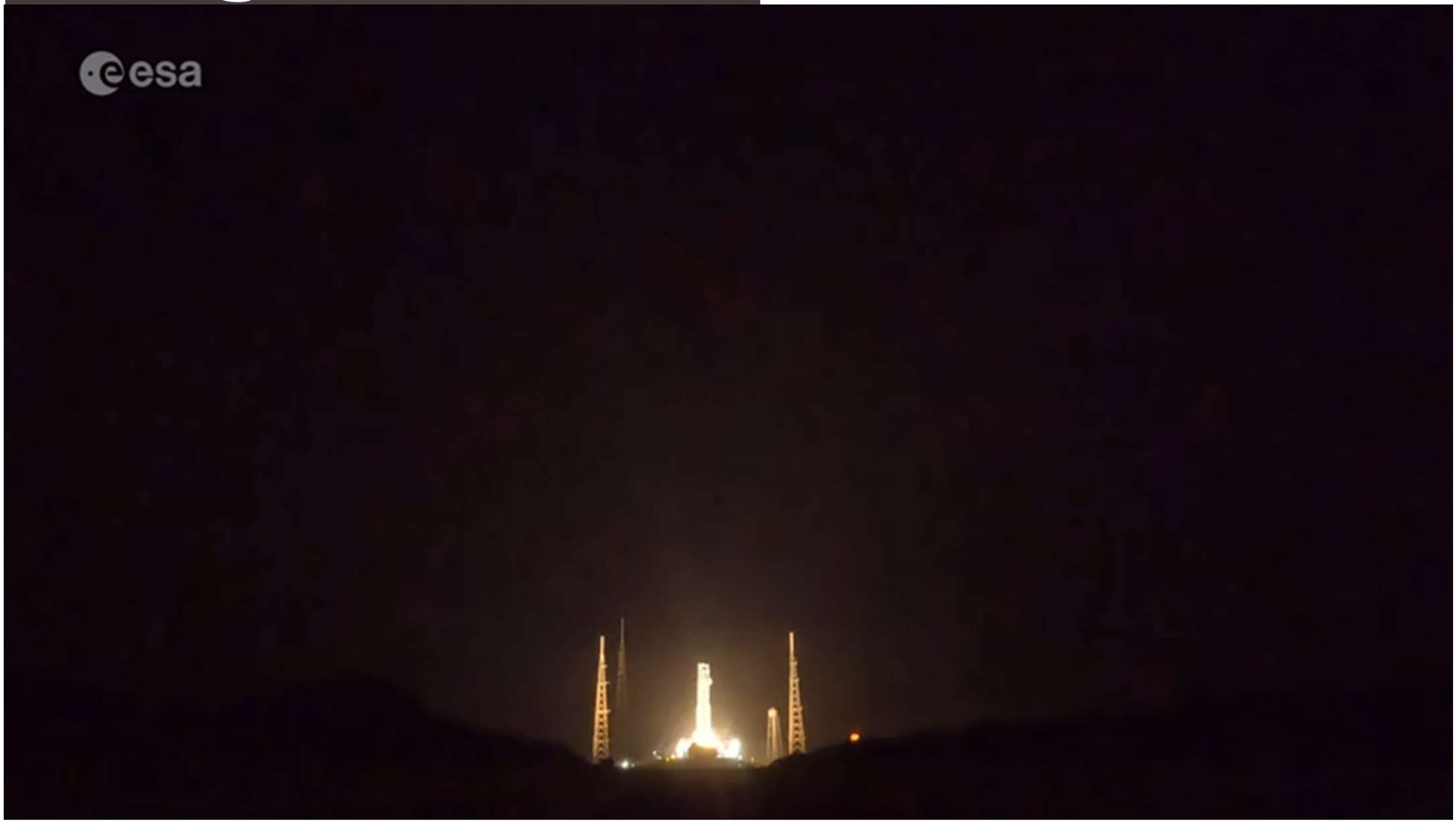
- International network: Chair of IAF Space Transportation Committee and member of IAF Propulsion Committee + IAF Space Traffic Management Committee
- Advisor to the ASTRAIOS project (Analysis of Skills, Training, Research and Innovation Opportunities in Space)

Background & Motivation

Background:

- Others:
  - Presentation in schools during World Space Week
  - Student internships
  - Student projects (2 @ EPFL during spring semester)
  - Master thesis (1 @ EPFL this year)
  - Organization of department events
  - Participation to reviews
  - Consulting / mentor for young professionals

Background &



Background & Motivation

Motivation:

- Son performed mechatronics university bachelor study @ OHB (4^{th} generation of engineers in our Family) now working for German space start-up Marble Imaging
- «I want to show students how fascinating the world of propulsion is»
- «I want to teach students how the space industry is currently working w.r.t. propulsion systems development and qualification»
- «I want to learn from the students: new ideas, new inspiration, new methods + tools, …»
- EPFL is a very viewed university with an incredible international set-up as well as diverse team

Space Propulsion Course Outline

Objectives:

- Main objective of the course is to provide an overview of space propulsion systems (and not only thrusters)
- Secondary objective of the course is to describe the basic design principles of propulsion systems

Space Propulsion Course Outline

Objectives:

- At the end of the course, the students will be able to:
  - Analyze propulsion system requirements
  - Plan a project in phases
  - Coordinate tasks between different engineering disciplines
  - Translate system requirements into subsystem requirements
  - Justify propulsion system selection
  - Identify principal propulsion system components
  - Discuss required performance characteristics

Space Propulsion Course Outline

Content:

- **Part 1 – Introduction in Spacecrafts + Mission Design -** Short highlights of spacecraft design including overview on subsystems
- **Part 2 – Introduction in Propulsion Systems -** Brief overview on space propulsion systems considering also:
  - Design Guidelines for Propulsion Systems - Main design principles (basic performance equations) for propulsion systems considering different mission objectives
  - Propulsion System Architecture - Description of propulsion subassemblies needed for the different propulsion systems like pressurization system
  - Propulsion System Components - Description of basic equipment needed for the different propulsion systems like pressure regulator

Space Propulsion Course Outline

Content:

- **Part 3 – Non-classical Propulsion Systems -** Short introduction on non-classical space propulsion systems like solar sails, tethers, …
- **Part 4 – Future Aspects of Propulsion Systems -** Introduction in future evolution of propulsion systems as well as overview of current investigations on new propulsion systems
- **Part 5 – Special session -** Special session with external TBD guest

Space Propulsion Course Outline

Assessment Method:

- Oral examination (50 %)
- Bi-weekly exercises (25 %)
  - 20 % structure of the paper
  - 30 % consideration of course presentation
  - 50 % content of exercise
- Project group work evaluation (25 %)
  - 20 % Vertical lift-off + flight
  - 20 % Safe core stage landing with parachute
  - 20 % Available launcher performance prediction + below 200 m + flight result
  - 20 % Safe operations on ground
  - 20 % Booster separation

Space Propulsion Course Outline

Bibliography:

- Space Propulsion Analysis and Design (Humble, Henry & Larson, Space Technology Series)
  No ebook available, but one print edition is now on order by library
- Rocket and Spacecraft Propulsion (Turner, Martin J. L., Springer)
  No ebook available, but one print edition is now on order by library
- Fundamentals of Electric Propulsion: Ion and Hall Thrusters (Dan M. Goebel, I. Katz, Wiley)
  Ebook available on BEAST or with this link https://ebookcentral.proquest.com/lib/epflch/detail.action?docID=413081 and print edition on order by library

Space Propulsion Course Outline

Communication:

- Contact information:
  - You can contact me by mail or on my mobile phone @ any time
  - My responsiveness will be limited during normal working days (as then main focus is given on my activities @ Airbus DS)
  - I will be present @ EPFL after the courses for discussion / exchanges

Space Propulsion Course Outline

Schedule (as shown on Moodle):

- More or less every 2nd Tuesday starting on 18th of February
  - Course # 1: 18.2.2025 @ 9:15 to 11 am lecture + exercise
  - Project exercise # 1: 25.2.2025 between 9 to 10:30 am
  - Course # 2: 4.3.2025 @ 9:15 to 11 am lecture + exercise
  - Project exercise # 2: 11.3.2025 between 9 to 10:30 am
  - Course # 3: 18.3.2025 @ 9:15 to 11 am lecture + exercise
  - Project exercise # 3: 25.3.2025 between 9 to 10:30 am
  - Course # 4: 1.4.2025 @ 9:15 to 11 am lecture + exercise
  - Course # 5: 8.4.2025 @ 9:15 to 11 am lecture + exercise
  - Project exercise # 4: 15.4.2025 between 9 to 10:30 am

Space Propulsion Course Outline

Schedule (as shown on Moodle):

- More or less every 2nd Tuesday starting on 18th of February
  - Easter break
  - Project exercise # 5: 29.4.2025 between 9 to 10:30 am
  - Course # 6: 6.5.2025 @ 9:15 to 11 am lecture + exercise
  - Trial launch: 13.5.2025 @ 9 am TBC
  - Course # 7: 20.5.2025 @ 9:15 to 11 am lecture (information on oral exam will be given)
  - Launch event: 27.5.2025 @ 9 am TBC
  - Oral exam: 3. + 4.7.2025 TBC

Space Propulsion Course Outline

Logistics:

- Course Material:
  - Handout for each lecture in *.pptx and *.pdf formats
  - Available on Moodle on course day (Actual files from last year will still be modified
  - No paper hand-out

Space Propulsion Course Outline

Logistics:

- Course will use moodle:
  - Electronic learning environment selected by EPFL
  - http://moodle.epfl.ch
  - Principal course materials will be available on the moodle web site
  - Login using your GASPAR username and password
  - Click «all courses»
  - Click «STI»
  - Click «Space Propulsion»
  - http://moodle.epfl.ch/course/view.php?id=16944

Space Propulsion Course Outline

Lecture Exercise:

- Ice-breaker
- Mission analysis
- Propulsion system budgets
- Thruster design

Space Propulsion Course Outline

Staff:

- Lecturer – Markus Jäger (markus.jager@epfl.ch)
- Assistant – Florent Gaspoz (florent.gaspoz@epfl.ch)
- Secretary – Candice Norhadian (candice.Norhadian@epfl.ch)

Project Outline

Project Group Work Description:

- The general objective of the project is the practical application of the course content

Project Outline

Project Group Work Description:

- Development of a single stage launcher, i.e. one core stage + two boosters
- Core stage propulsion shall be based on liquid pneumatical propulsion (i.e. Water + GN2 gas pressure)
- Launcher core stage shall have parachute(s) for recovery
- Booster shall be launched with core stage and separated (after propellant run-out) without mandatory safe landing on ground
- Generic launch pad will be defined

Project Outline

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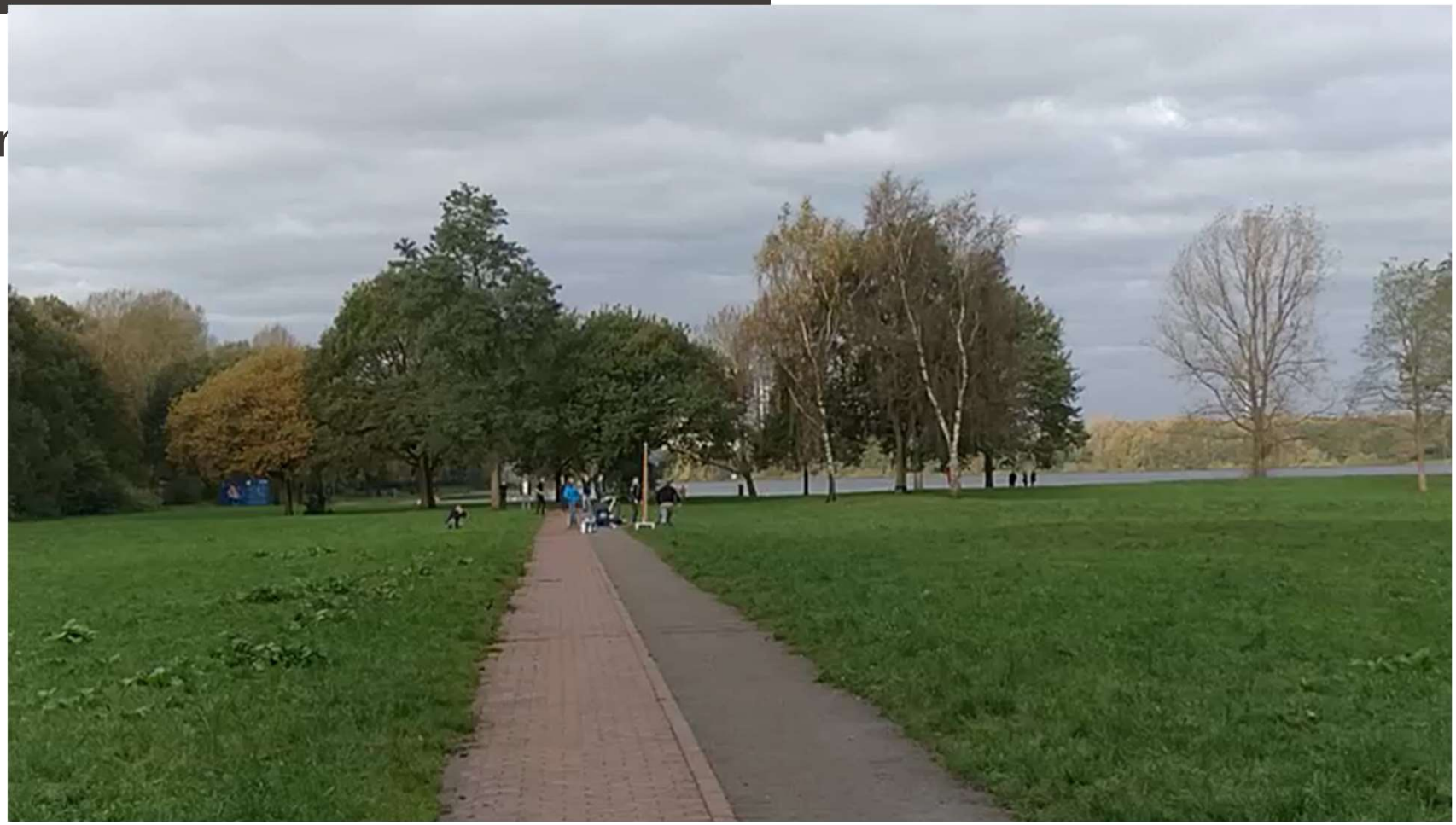
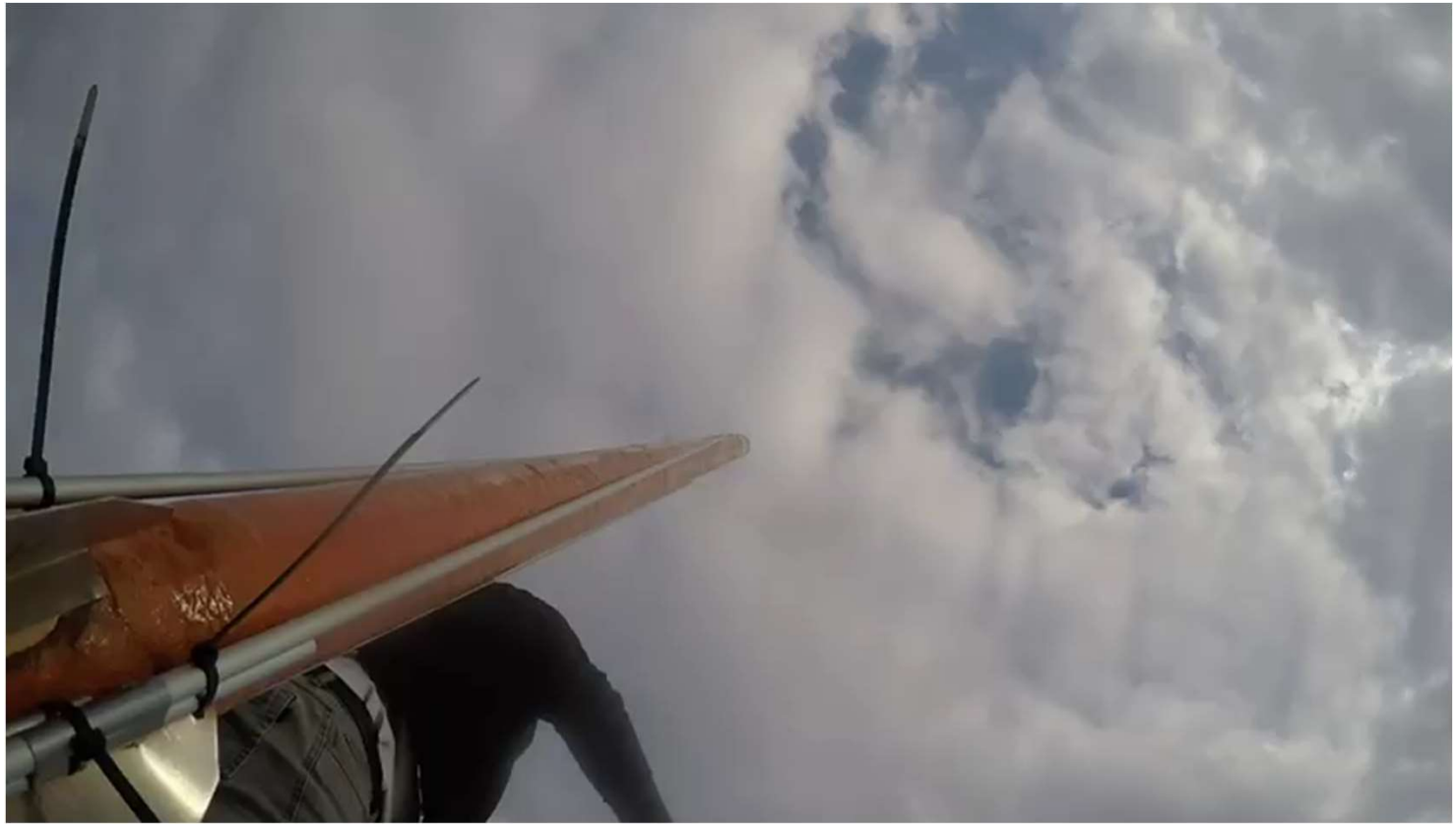


Project Outline



Project Outline

Project Group Work Description:

- Objectives / Requirements:
  - Vertical lift-off
  - Safe core stage landing with parachute
  - Available launcher performance prediction + maximal orbit altitude shall be below 200 m
  - Safe operations on ground
  - Booster separation

Project Outline

Project Group Set-up:

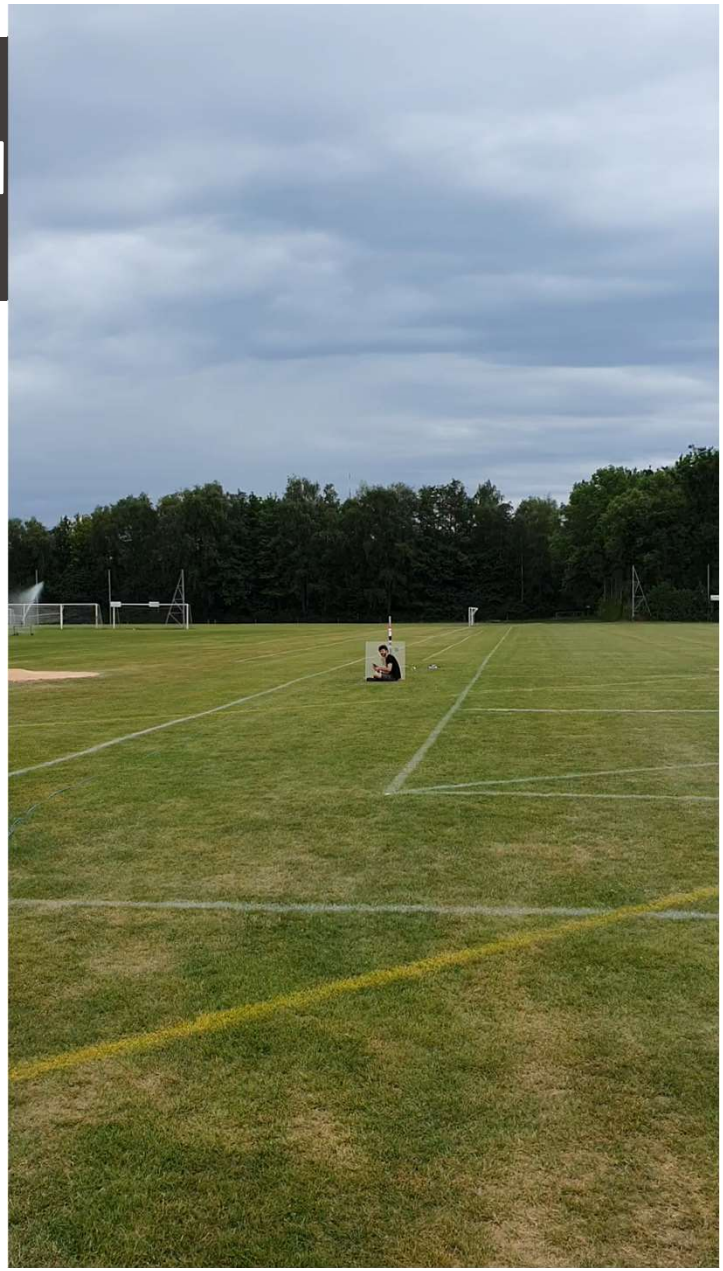
- 5 Students per Group (as example):
  - Launcher System (Technical coherence, requirement engineering)
  - Core Stage (Propulsion, mechanical engineering) + Functional Analysis (Modeling, performance prediction)
  - Recovery System (Software, electrical engineering, mechanism)
  - Ground System I/F (Interface management, mechanism, certification)
  - Booster Integration + Separation

Project Outline

Project Group Support:

- General objective of the project is the practical application of the theoretical course content
- Bi-weekly exercises will guide through / support project activities
- Assessment feedback on exercises is given on days w/o course (i.e. every 2nd Tuesday) per group (~ 15 min zoom meeting per group)
- Weekly group exchanges are recommended to respect schedule
- Practical fulfilment of requirements is expected
- Generic test bench will be defined + provided
- Interface document will be prepared (final version on March 4)

Project Ou



Project Outline

Exercise Description:

- Exercise # 1 (due date on 23.2.2025): Organize your project
  - 1-pager with description of your project organization in terms of participants + roles
  - Definition of first level of H/W needed
  - Identification of functions to be fulfilled
  - Description of the different mission phases
  - Identification of main requirements and verifications to be performed
  - Preparation of schedule with short description of main tasks
- Evaluation on 25.2.2025

Project Outline

Exercise Description:

- Exercise # 2 (due date on 9.3.2025): Define Ground I/F
  - 1-pager with definition of need w.r.t. Ground Support Equipment I/F
  - How many stages / bottles are used (size of rocket)?
  - Which pressure level is required?
  - Which Water mass is considered?
  - How is the filling with Water planned and when (on the launch pad)?
  - Is there a need for a launch tower?
  - Is a pressure measurement information needed?
  - Which electrical equipment is needed?
  - Specific needs for payload?
- Evaluation on 11.3.2025

Project Outline

Exercise Description:

- Exercise # 3 (due date on 23.3.2025): Performance Analysis
  - 1-pager with the performance analysis of your Water rocket including theoretical description of the equations involved
  - Presentation of analysis results including graphs like altitude over time, speed over time, mass over time, pressure over time
  - Description of payload separation system + performance
- Evaluation on 25.3.2025

Project Outline

Exercise Description:

- Exercise # 4 (due date on 13.4.2025): Verification Plan
  - 1-pager with description how the main requirements will be verified like parachute deployment, safe-landing (maximal speed during landing), maximal altitude below 200 m, vertical lift-off, payload separation
  - Description of verification by test, by analysis, by review of documents or by demonstration during assembly
  - Main focus shall be put on safety, redundancy and parachute deployment
  - It shall be described, how the system can be checked prior to launch of the complete rocket
- Evaluation on 15.4.2025

Project Outline

Exercise Description:

- Exercise # 5 (due date on 27.4.2025): Qualification Review
  - Final report (5 pages) with description of the Water rocket (Description of all products used, fluidical architecture, electrical architecture, mass budget, propellant budget, pressure budget, launch phases, verifications performed)
- Evaluation on 29.4.2025

Project Outline

Exercise Description:

- Exercise # 6 (due date on 13.5.2025): Trial launch
- Evaluation on 20.5.2025 (after lecture)
- Launch event on 27.5.2025

Potential Special Events

Proposals:

- In May:
  - Visit of EPFL rocket team test facility
- In May:
  - External lecturer with highlight lecture
  - Any suggestions / interests based my background?

Student Feedback

What are your expectations?

- Roundtable:
  - Presentation of students (e.g. your experience with propulsion [member of the EPFL rocket team, others …])
  - Questions on course, project
  - Feedback
  - Main interest w.r.t. space propulsion
  - Expectation from course
  - AoB