MSc track “Spaceflight”

Ir. R. Noomen
August 25, 2017
Research Areas MSc “Spaceflight”

Space Engineering:
- Miniaturizing spacecraft
  - Attitude Determination and Control
  - Propulsion
  - Space instrumentation
  - Engineering of spacecraft
- Distributed space systems
  - Navigation and control
  - Disruptive concepts
  - On-orbit servicing

Space Exploration:
- Mission analysis, orbits and engineering
  - precise orbits and applications
  - space debris
  - transfer orbits
- Rockets, ascent and re-entry systems
- Planetary exploration and astronomy
Inflow in MSc “Spaceflight”

limited capacity for some themes!
Mission: To bundle and create expertise on Space for local, regional and global impact on research, education and valorization

Members: 5 faculties (LR, EWI, 3ME, CITG, TNW)

Education: Spaceflight Minor, new initiatives, more inter-faculty cooperation
Objectives of the Master
Educating all-round Aerospace Engineers

BSc
BROAD academic background, consolidated knowledge of the domain of aerospace ENGINEERING

Academic intellectual skills and attitudes to analyse, apply, synthesize, DESIGN

MSc
EXPERT view of aerospace engineering discipline, breadth is MSc Track
Detailed knowledge of one or more subdisciplines
Academic intellectual skills and attitudes to model, analyse, develop, RESEARCH, solve
Learning Objectives

• acquire a broad understanding of the theory of “spaceflight”

• acquire knowledge and skills in Space Mission Design

• develop skills in Space Systems Engineering

• understand the concept that satellites are end-to-end systems

• become familiar with satellite measurements and data processing

• develop the ability to work independently on a spaceflight-related engineering or research problem (international environment)
Programme: possible deviations

**Annotation Sustainable Development**
WM0939TU Engineering for Sustainable Development (5 EC – Q2)
10 EC dedicated electives, 4 may be included in the regular program
Final thesis work 6-8 EC extra on sustainability in addition to regular 42 EC.
Point of contact: Ir. Joris Melkert

**Annotation Entrepreneurship**
MoT9610 Basic Entrepreneurship course (5 EC – Q1)
  + MoT9612 Business Development Lab Short (5 EC – Q3)
5 EC dedicated electives, 4 may be included in the regular program
Final thesis work 6-8 EC extra on entrepreneurship in addition to regular 42 EC.
Point of contact: Ir. Joris Melkert

**Honours Track**
Individual program for excellent students
20 EC, on top of the regular program
(often) Not directly related to your track
Point of contact: Ir. Aldert Kamp
# MSc Program – Overview

## Core courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>ae4874I</td>
<td>astrodynamics I</td>
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<tr>
<td>ae4890-11</td>
<td>planetary sciences I</td>
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<tr>
<td>ae4S10</td>
<td>microsat engineering</td>
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<td>ae4S12</td>
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**Total:** 20
MSc Program – Overview (cnt’d)

“Space Engineering” profile courses

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<td>ae4S01P</td>
<td>exercise thermal rocket propulsion</td>
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<tr>
<td>ae4S06</td>
<td>spacecraft mechatronics</td>
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<td>ae4S06P</td>
<td>spacecraft mechatronics exercise</td>
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<td>ae4S12P</td>
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<td>ae4S20</td>
<td>satellite thermal control</td>
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**Total** 14 out of 20
MSc Program – Overview (cnt’d)

“Space Exploration” profile courses

<table>
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<td>ae4870B</td>
<td>re-entry systems</td>
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<td>ae4872</td>
<td>satellite orbit determination</td>
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<tr>
<td>ae4878</td>
<td>mission geometry and orbit design</td>
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| Total       |                                                  | 16      |
elective courses (1)

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<td>ae4313</td>
<td>spacecraft attitude dynamics &amp; control</td>
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<td>ae4499</td>
<td>space project (capita selecta)</td>
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<td>ae4866</td>
<td>prop. and optim. in astrodynamics</td>
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<td>ae4867</td>
<td>numerical astrodynamics</td>
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<td>ae4874II</td>
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<td>ae4876-11</td>
<td>planetary sciences II</td>
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<td>ae4S06P</td>
<td>exercise spacecraft mechatronics</td>
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</tr>
<tr>
<td>ae4S20</td>
<td>satellite thermal control</td>
<td>3</td>
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</tbody>
</table>

AE4499 capita selecta: mandatory for MSc students profile “space engineering” w/o aerospace background.
Quarter 1. register with B. Zandbergen.
Optional for “space exploration” (quarter 1, still).
MSc Program – Overview (cnt’d)

**elective courses (2)**

<table>
<thead>
<tr>
<th>Code</th>
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<td>cie4601</td>
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<td>et3604LR</td>
<td>electronic circuits</td>
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<td>wb1440</td>
<td>eng. optimization: concept &amp; applications</td>
<td>3</td>
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<tr>
<td>wi4019</td>
<td>non-linear differential equations</td>
<td>6</td>
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<tr>
<td>wi4460TU</td>
<td>Monte-Carlo sim. of stochastic proc. I</td>
<td>3</td>
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<tr>
<td>wi4771TU</td>
<td>object oriented sci. programming with C++</td>
<td>3</td>
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</tbody>
</table>

**mm-mmm** mandatory courses of the other profile

**nn-nnn** other relevant AE/TUD courses

(or at other universities, e.g. Astronomy/Leiden)
Literature study

• Connected to MSc project
  – same topic
  – building theoretical knowledge
  – (some) practical aspects
  – selection of relevant topics and techniques
  – research question(s) + plan of attack

• Connected to courses
• 4th quarter 1st MSc year
• 12 ECTS
Research in second year

• Internship
• Master thesis project
  o research related to ongoing programmes
  o preceded by literature study on same topic
• Cooperation between sections “Astrodynamics and Space Missions” and “Space Systems Engineering”
Internship

• period of 12 weeks full-time
• exposure to real working environment
• “learn and explore” to acquire different skills than those taught in the courses and projects
• start organizing (international) internship well in advance; approximately 9 months before the start date
• internship coordinator: Mrs. Miranda van Haagen (room 2.10; open office Monday + Thursday 12.30-13.30 hrs)
• staff of Spaceflight track
• enroll on Brightspace AE5-050
• [website link]
• internship-ae@tudelft.nl
Internship/jobs: industry

and many many more....
Internship/jobs: academia

and many many more....
General remarks:

• main elements connected ideally

• choose before start of academic year (first lectures.....)

• Delft BSc student, BSc not completed: not allowed as an MSc student. Check weblink on the ‘Airport-AE’: http://studenten.tudelft.nl/index.php?id=104242

• non-EU students must achieve a minimum of 50% of study load every year (Modern Migration Policy Act)
Research Areas MSc “Spaceflight”

Space Engineering:
• Miniaturizing spacecraft
  o Attitude Determination and Control
  o Propulsion
  o Space instrumentation
  o Engineering of spacecraft
• Distributed space systems
  o Navigation and control
  o Disruptive concepts
  o On-orbit servicing

Space Exploration:
• Mission analysis, orbits and engineering
  o precise orbits and applications
  o space debris
  o transfer orbits
• Rockets, ascent and re-entry systems
• Planetary exploration and astronomy
## Research Themes

<table>
<thead>
<tr>
<th>General subject</th>
<th>Supervisor(s)</th>
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</thead>
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<tr>
<td>Miniaturizing spacecraft</td>
<td>Cervone, Zandbergen</td>
</tr>
<tr>
<td>• Space propulsion</td>
<td>Kuiper, Guo, Bouwmeester, Fonod</td>
</tr>
<tr>
<td>• Attitude determination and control</td>
<td>Speretta</td>
</tr>
<tr>
<td>• Communication and data systems</td>
<td>Kuiper, Menicucci</td>
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<tr>
<td>• Space instruments</td>
<td>Bouwmeester</td>
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<tr>
<td>• Engineering of small spacecraft</td>
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<tr>
<td>Distributed space systems</td>
<td>Guo, Gill</td>
</tr>
<tr>
<td>• Navigation and control</td>
<td></td>
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<tr>
<td>• Disruptive concepts</td>
<td></td>
</tr>
<tr>
<td>• On-orbit servicing</td>
<td></td>
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<tr>
<td>Mission analysis, orbits and engineering</td>
<td>Doornbos, Simons, Visser, Schrama, Naeije</td>
</tr>
<tr>
<td>• Precise orbits and applications</td>
<td>Mooij, Doornbos, Noomen, Guo</td>
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<tr>
<td>• Space debris</td>
<td>Noomen, Cowan, Heiligers</td>
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<tr>
<td>• Transfer orbits</td>
<td></td>
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<tr>
<td>Rockets, re-entry systems and GNC</td>
<td>Mooij, Naeije</td>
</tr>
<tr>
<td>Planetary exploration and astronomy</td>
<td>Schrama, Vermeersen, van der Wal, Stam,</td>
</tr>
<tr>
<td></td>
<td>Brandl, Cazaux</td>
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</table>
Research Themes (cnt’d)

**NOTE:**

Students doing an MSc thesis project on

- guidance, navigation & control
- re-entry
- hypersonics
- rocket motion + DARE-related

must get a permit from the Ministry of Education, Culture and Science ("OCW") before the official start of the MSc thesis project

Spacecraft Design and Analysis

ADCS modes

De-tumbling of S/C
Spacecraft Design and Analysis (cnt’d)

PocketQube (PQ)

3U-CubeSat
Miniaturizing Spacecraft Technologies

- Micro reaction wheel
- Micro sun sensor
- 3-axis magnetic control board
Miniaturizing S/C Technologies (cnt’d)
Small Satellite Integration and Testing
Space instrumentation

Sensing from Space

Developing smaller and smaller camera’s with ever improving performance !!
Flying the Technologies: Delfi-n3Xt

**Active attitude control**  
(TU Delft)

**Micro propulsion**  
(TNO, TU Delft, UTwente)

**Innovative CubeSat radio**  
(ISIS)

**Amorphous Silicon solar cells**  
(DIMES)

**Smart power management**  
(SystematIC Design)

**High data-rate link**  
(TU Delft)

Launched Nov 2013
Distributed Space Systems

- Miniaturized inter-satellite communication and ranging
- Cooperative control of spacecraft
- Multi-agent based control using mobile phone
- Innovative systems engineering methods
- Autonomous Formation Flying (AFF) testbeds
- Collision avoidance, Active Debris Removal

Ground-based testbed

Air-based testbed (next step)
Autonomous FF Testbed

- Typical FF testbed is expensive to build and maintain
- A low-cost FF testbed consisting of multiple robots is developed by SSE
- A first robot is already available, but more are to be developed and integrated
- Enabling technologies for distributed space systems will be validated on the testbed before going to space
- Go to YouTube to have a first look!

http://www.youtube.com/watch?v=FWV9ee0hddo&hd=1
Precise Orbits and Applications

(see next sheets)
GPS Tracking of Space Missions

Topics:

- precise orbit determination
- gravity field determination
- surface force modelling
Radar Altimetry Missions

Topics:

• dynamic sea surface topography (sea level above geoid)
• mean sea surface and vertical deflections
• ocean tides
• waves and wind
• ice topography
• tsunami detection
• earthquake observation
Atmosphere at Satellite Altitude

Swarm

GOCE
Topics:

- development of ground station
- processing data
- orbit determination of Delfi-C3, Delfi-n3Xt, other s/c
Space Debris
Transfer Orbits

Topics:

- orbit modeling and computation
- orbit and constellation design
- interplanetary trajectories
- low-thrust orbits
- rendezvous and docking
- orbit optimization
- solar sailing
Rockets, Re-entry Systems and GNC

Optimization of ascent trajectories

Re-entry trajectories towards Earth surface

Planetary Entry & Descent

Vehicle Shape Optimization
not because it is easy, but because it is hard,
because that goal will serve to organize and measure the best of
our energies and skills,

J.F.Kennedy

Stratos 2+, 21 km, 2015

Stratos 3, 100+ km
Planetary Exploration and Astronomy

Topics:

- deep space tracking
- orbit analysis
- tidal deformation
- gravity field
- polar motion
- internal structure
- atmosphere
- conditions for life…
- …..

Using spacecraft around planets, moons and asteroids
Planetary Exploration and Astronomy (cnt’d)

Jovian moon Europa: water?
Planetary Exploration and Astronomy (cnt’d)

Astronomical research:
• Starburst Galaxies
• Massive Star Formation
• Exoplanets

Instrumentation for JWST:
MIRI (testing, science)

Instrumentation for E-ELT:
METIS (design, construction, testing)

Optical components:
Immersed gratings, cryogenic chopper, active mirror (concept, testing)
Planetary Exploration and Astronomy (cnt’d)

Laser Ranging as part of EU FP7 Project ESPACE
(European Satellite PArtnership for Computing Ephemerides - ROB, TUB, JIVE, TUD, CNES, DLR and IMCCE)

The near future: concept of a laser transponder link between an observatory on Earth and a laser terminal on Phobos.

Precision laser ranging to Phobos could measure the distance between an observatory on Earth and a terminal on the surface of Phobos to an accuracy of 1 mm in less than 5 min of integration time.
## Electives (not exhaustive)

<table>
<thead>
<tr>
<th>Engineering</th>
<th>Rockets, re-entry, GNC</th>
<th>Precise orbits</th>
<th>Space debris</th>
<th>Transfer orbits</th>
<th>Planetary expl. &amp; astr.</th>
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<td>x</td>
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<td>hypersonic aero</td>
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<td>space instrumentation</td>
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<td></td>
<td></td>
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<td>x²</td>
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</table>

1: choose two out of three. 2: choose one
Electives space engineering

Elective courses (version 2016)

In the next table, some electives are given for design, power engineering, micro-technology, propulsion, vehicle engineering and distributed systems. Table may give multiple courses, but in most cases selecting one will do.

<table>
<thead>
<tr>
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<tr>
<td>WI3425TU</td>
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<td>CIE4130</td>
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<td>Q4</td>
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<td>Electronics/Power/Computer engineering</td>
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<td>Photovoltaic systems</td>
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<td>ME45100</td>
<td>Fuel-cell systems</td>
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<td>Q4</td>
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<td>Avionics and Operations</td>
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<td>AP3181 D</td>
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<td>Q3</td>
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<td>AAE4313P</td>
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<td>Q3</td>
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<td>Hypersonic aerodynamics</td>
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<td>AAE465M003</td>
<td>Linear modelling (incl. FEM)</td>
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<td>WBB3168</td>
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<td>ME41020</td>
<td>Space robotics</td>
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<td>ME41025</td>
<td>Robotics Practical</td>
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<td>ADFS &amp; Space Instrumentation</td>
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<td>Q3</td>
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<tr>
<td>AAE4313P</td>
<td>Spacecraft attitude dynamics &amp; control exercise</td>
<td>3</td>
<td>Q3</td>
</tr>
<tr>
<td>ET3604LR</td>
<td>Electronic Circuits (BSc)</td>
<td>3</td>
<td>Q1</td>
</tr>
<tr>
<td>AAE4520</td>
<td>Satellite thermal control</td>
<td>3</td>
<td>Q1</td>
</tr>
<tr>
<td>AP33392</td>
<td>Geometrical optics</td>
<td>4</td>
<td>Q4</td>
</tr>
</tbody>
</table>
Facilities

- clean room for small satellite integration and testing
- powerful computing facilities and advanced software (Tudat)
- formation-flying laboratory (TBC)
- (access to data of) many operational satellites
- member of DIMES and Robotics Institute
- network of continuously operating GPS receivers
Recent Thesis Projects

- **Improvement and validation of test stand performance for novel micropropulsion systems**
  
  **E.H.W. Jansen**

- **Performance Characterization of Water Heat Pipes and their Application in CubeSats**
  
  **H.S.B. Brouwer**

- **Design, manufacturing and characterisation of a water-fed CubeSat micro-resistojet**
  
  **Dondersteen**

- **Regenerative cooling analysis of oxygen/methane rocket engines**
  
  **Luka Denies**

- **Design Optimization of Ground and Air-Launched Hybrid Rockets**
  
  **Francisco Miranda**
Recent Thesis Projects (cnt’d)

- **Lars Hoving**
  - Optimisation Strategies for Galilean Moon Tours
  - Delft University of Technology

- **R. Hoogendoorn**
  - Statistical Impact Prediction of Space Debris: The Uncertainty Propagation Approach
  - Delft University of Technology

- **L. Rubin**
  - Impact of Satellite Fragmentations in GEO Graveyard Orbits
  - MSc Thesis, August 9, 2010
  - Delft University of Technology
Thesis Opportunities
Thesis Opportunities (2)

Avionics based on mobile phone

Advanced micro-propulsion

Advanced ADCS

Autonomous formation flying

And many more ...
MSc thesis planning

- Explore problem area
- Scrutinize initial problem statement
- Generalize problem
- Identify relevant literatures
- Develop research question + sub-questions
- Determine research methodology
- Establish project planning (work breakdown structure + Gantt chart)
- For Kick-off meeting: report on all of the above in kick-off report and prepare presentation

- Incorporate Kick-off comments
  - Do what you set out to do
  - Purpose mid-term meeting; assess work done so far & project management
  - Thus, submit two documents:
    1. draft thesis with work done so far + clear structure
    2. brief mid-term report outlining project management issues, e.g., deviations & challenges to KO and (revised) planning to end of project
  - Present the above during Mid-term focusing both on content and process

- Incorporate MT comments
  - Include verification & validation of your work
  - Finish your work
  - Prepare draft report

- Write thesis
  - Reflect on your work
  - (Have you answered your research question?)
  - Write executive summary of your work

- * Only allowed AFTER a positive Green light review

- AE Graduation Project

- Have you handed in your internship report?
- ± 4 – 6 w
- ± 2 – 3 months
- ± 2 – 3 months
- 3 months
- 7 months
- Graduation day

By Frans van der Zwaal, 17th December 2013, ex 14
# MSc thesis entrance permit

<table>
<thead>
<tr>
<th>Completed BSc</th>
<th>Completed Internship</th>
<th>Completed MSc courses</th>
<th>Completed Bridging Class</th>
<th>Completed Lit study/MOP</th>
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</thead>
<tbody>
<tr>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
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</table>

## Planning

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Week (approx)</th>
<th>Fill in the (planned) dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of project</td>
<td>Week 1</td>
<td></td>
</tr>
<tr>
<td>Kick off session</td>
<td>Week 4-6</td>
<td></td>
</tr>
<tr>
<td>Mid term review (optional)</td>
<td>Week 17</td>
<td></td>
</tr>
<tr>
<td>Greenlight review (optional)</td>
<td>Week 25</td>
<td></td>
</tr>
<tr>
<td>Expected Graduation</td>
<td>Week 30</td>
<td></td>
</tr>
</tbody>
</table>
Studying abroad

- PEGASUS, ERASMUS university networks
- other universities also possible

- elective courses only
- Honours Track completely
- literature survey
- internship
- MSc thesis

only after approval by AE supervisor!
Planning your MSc study

- Select MSc Track
- Complete “Application Form MSc Track” (including letter of motivation), and submit to Education and Student Affairs before (for Delft BSc students) May 1 *
- Have discussion with Track Coordinator
- Orient on your theme(s) of your liking
- Select preferential one(s)
- Select courses (together with theme supervisor)
- Complete electronic “MSc Track Registration form” **
- Have course list checked by Profile Coordinator
- Have course list checked by Track Coordinator
- TC submits course list to student administration
- First year: courses + literature study
- Second year: internship + MSc thesis project
- Alterations in course list possible


** [www.lr.tudelft.nl/ae-airport](http://www.lr.tudelft.nl/ae-airport) > Practical information > Forms
Elisabetta, Vidhya, Jiun, Jeannette, Samiksha, Pieter, Eberhard, Barry, Alessandra, Marc, Erwin, Daphne, Dominic, Bert, Jasper, EJO, Hans, Kevin, Sevket, José, Ron, Jian, Eelco, Angelo, Chris, Wouter, Prem, Stefano, Bernhard
Points of contact

• Master Track coordinator  ir. R. Noomen (9.20)

• Profile coordinator
  o Space Engineering : ir. B.T.C. Zandbergen (8.10)
  o Space Exploration : ir. R. Noomen (9.20)

• Secretaries
  o Space Engineering: Mrs. D.M.S. van der Sande (8.14)
  o Space Exploration: Mrs. R. van Wingaarden (9.12)

• Website
  o [http://www.lr.tudelft.nl/sf](http://www.lr.tudelft.nl/sf)
  o [http://studenten.tudelft.nl/informatie/faculteitspecifiek/lr/ae-airport](http://studenten.tudelft.nl/informatie/faculteitspecifiek/lr/ae-airport)

• Friday September 1
  o 16.00-17.10: presentations by current MSc students (room B)
  o 17.10-19.00: BBQ (field behind Fellowship)