MSc Track “Spaceflight”

R. Noomen
March 14, 2018
Research Areas MSc “Spaceflight”

Space Engineering:

• Miniaturizing spacecraft
  ○ space propulsion
  ○ attitude determination and control
  ○ space instruments
  ○ engineering of small 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, re-entry systems and GNC
• Planetary exploration and astronomy
Inflow in MSc “Spaceflight”

limited capacity for some themes!
Department of spaceflight in
TU Delft SPACE INSTITUTE

Sensing from Space

Distributed Space Systems

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 (part of) 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)
MSc Program

1st year courses courses courses literature

2nd year internship thesis thesis thesis
Program: Possible Deviations

**Annotation Sustainable Development**
4 ECTS in electives of regular program, 11 ECTS extra-curricular
Final thesis to incorporate sustainability elements
Point of contact: Ir. Joris Melkert

**Annotation Entrepreneurship**
4 ECTS in electives of regular program, 13 ECTS extra-curricular
Final thesis to incorporate entrepreneurial elements
Point of contact: Ir. Joris Melkert

**Honours Track**
Individual program for excellent students
Internship, research or expert design project(s), courses, or combination
20 ECTS, 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 Name</th>
<th>Credits</th>
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</thead>
<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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<td>ae4S12</td>
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**Total**: 16
MSc Program – Overview (cnt’d)

“Space Engineering” profile courses

<table>
<thead>
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<tr>
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<tr>
<td>ae4S01</td>
<td>thermal rocket propulsion</td>
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<td>ae4S01P</td>
<td>exercise thermal rocket propulsion</td>
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<td>ae4S06</td>
<td>spacecraft mechatronics</td>
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<td>ae4S06P</td>
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<td>ae4S10</td>
<td>microsat engineering</td>
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<tr>
<td>ae4S20</td>
<td>satellite thermal control</td>
<td>3</td>
</tr>
<tr>
<td>ae4STBD</td>
<td>space embedded systems</td>
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</table>

total at least 14 out of 25
MSc Program – Overview (cnt’d)

“Space Exploration” profile courses

ae4866  prop. and optim. in astrodynamics  4
ae4867  numerical astrodynamics  2
ae4870A  rocket motion  3
ae4870B  re-entry systems  3
ae4872  satellite orbit determination  6
ae4876-11  planetary sciences II  4
ae4878  mission geometry and orbit design  4
ae4880  space instrumentation  4

total at least 16 out of 30
MSc Program – Overview (cnt’d)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<td>ae4313</td>
<td>spacecraft attitude dynamics &amp; control</td>
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<td>ae4447</td>
<td>aircraft performance optimization</td>
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<td>ae4499</td>
<td>space project (capita selecta)</td>
<td>4</td>
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<tr>
<td>ae4874II</td>
<td>astrodynamics II</td>
<td>4</td>
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<tr>
<td>ae4STBD</td>
<td>micro-propulsion</td>
<td>4</td>
</tr>
<tr>
<td>ae4STBD</td>
<td>introduction thermal rocket propulsion</td>
<td>1</td>
</tr>
</tbody>
</table>

AE499 space project (capita selecta): mandatory for MSc students profile “space engineering” w/o aerospace background. Quarter 1. register with B. Zandbergen
elective courses (2)

cie4601 physics of the Earth and atmosphere 5
et3604LR electronic circuits 3
me46060 eng. optimization: concept & applications 3
tw3720TU object oriented scientific program. C++ 3
wi4007TU Fourier and Laplace transformation 4
wi4019 non-linear differential equations 6
wi4460TU Monte-Carlo sim. of stochastic proc. I 3
wm1428-3 computational fluid dynamics 6

mm-mmm profile 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
• fourth quarter first MSc year
• 12 ECTS
Research in Second Year

- Internship
- Master thesis project
  - research related to ongoing programmes
  - 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
• www.lr.tudelft.nl/internship
• 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
  - space propulsion
  - attitude determination and control
  - space instruments
  - engineering of small 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, re-entry systems and GNC
- Planetary exploration and astronomy
<table>
<thead>
<tr>
<th>General subject</th>
<th>Supervisor(s)</th>
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<tr>
<td>Miniaturizing spacecraft</td>
<td>Zandbergen, Cervone</td>
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<tr>
<td>• Space propulsion</td>
<td>Kuiper, Guo, Fonod</td>
</tr>
<tr>
<td>• Attitude determination and control</td>
<td>Menicucci, Kuiper</td>
</tr>
<tr>
<td>• Space instruments</td>
<td>Bouwmeester</td>
</tr>
<tr>
<td>• Engineering of small spacecraft</td>
<td></td>
</tr>
<tr>
<td>Distributed space systems</td>
<td>Guo, Gill, Fonod</td>
</tr>
<tr>
<td>• Navigation and control</td>
<td></td>
</tr>
<tr>
<td>• Disruptive concepts</td>
<td></td>
</tr>
<tr>
<td>• On-orbit servicing</td>
<td></td>
</tr>
<tr>
<td>Mission analysis, orbits and engineering</td>
<td>Doornbos, Simons, Visser, Schrama, Naije</td>
</tr>
<tr>
<td>• Precise orbits and applications</td>
<td>Mooij, Doornbos, Noomen, Guo</td>
</tr>
<tr>
<td>• Space debris</td>
<td>Noomen, Cowan, Heiligers</td>
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<tr>
<td>• Transfer orbits</td>
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<tr>
<td>Rockets, re-entry systems and GNC</td>
<td>Mooij, Naeije, Zandbergen</td>
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<tr>
<td>Planetary exploration and astronomy</td>
<td>Schrama, Vermeersen, van der Wal, Stam, Brandl, Cazaux</td>
</tr>
</tbody>
</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

https://www.govtment.nl/topics/secondary-vocational-education-mbo-and-higher-education/contents/exemption-certain-engineering-or-nuclear-related-courses-of-study
Spacecraft Design and Analysis

ADCS modes

De-tumbling of S/C

Switch mechanisms:
- Automatic
- Automatic tumbling too fast
- Conditional switch
- OBC commanded switch
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
GPS Tracking of Space Missions

Topics:
• precise orbit determination
• gravity field determination
• surface force modeling
• atmosphere research
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
Tracking of Space Missions

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

TU Delft
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
Planetary Exploration and Astronomy

Topics:

• deep space tracking
• orbit analysis
• tidal deformation
• gravity field
• polar motion
• internal structure
• atmosphere
• conditions for life
• water
• ring systems
• …..

Using spacecraft around planets, moons and asteroids
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)
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 “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>
<th>Course code</th>
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<td>Monte Carlo Methods</td>
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<td>Probabilistic Design</td>
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<td>Q2</td>
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<tr>
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<td>ME460601440</td>
<td>Eng. Optimization 1: Concept &amp; Applications</td>
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<td>Q4</td>
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<td>ID4010</td>
<td>Design Theory and Methodology</td>
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<td>SPM5520</td>
<td>Engineering optimization in energy and industry</td>
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<td>Electronics/Power/Computer engineering</td>
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<tr>
<td>ET4366SET</td>
<td>Electrical Power Engineering</td>
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<tr>
<td>ET4378</td>
<td>Photovoltaic systems</td>
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<td>Q1/2</td>
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<td>IN4391</td>
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<td>ME45100</td>
<td>Fuel-cell systems</td>
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<td>Q1</td>
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<td>Q3</td>
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<td>AP3392</td>
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Profile + electives “exploration” (not exhaustive)

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<tr>
<th>Course</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>thermal rocket prop.</td>
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<td>s/c att. dyn &amp; control</td>
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<td>hypersonic aero</td>
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<td>relativity (Leiden)</td>
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<td>physics Earth and atm.</td>
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<tr>
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<td></td>
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<td>x²</td>
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</table>

1: choose two out of three. 2: choose one
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 Addressing the Thermal Challenges of Next Generation CubeSats

H.S.B. Brouwer

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

Dondersteen

R.M.A. Pooyck

Regenerative cooling analysis of oxygen/methane rocket engines

Luka Denyes

Design Optimization of Ground and Air-Launched Hybrid Rockets

Development of an Optimization Tool for Multi-Technology Rocket Launch Vehicle Design

Francisco Miranda
Recent Thesis Projects (cnt’d)

- **Impact of Satellite Fragmentations in GEO Graveyard Orbits**
  - MSc Thesis
  - L. Ruskin
  - August 9, 2018

- **Statistical Impact Prediction of Space Debris**
  - The Uncertainty Propagation Approach
  - R. Hoogendoorn

- **Optimisation Strategies for Galilean Moon Tours**
  - Lars Hoving
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
- Generalise 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

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

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AE Graduation Project
MSc Thesis Kick-off Form

MSc Thesis Kick-off Form (AE 2)
Master Aerospace Engineering

This form must be submitted at the start of your Thesis Project. Only fully completed digital forms can be taken into account. Send this form to OSA-LR@tudelft.nl

Note: A candidate may not start the thesis before having successfully completed the BSc programme and the first year of the MSc programme (art 10.2 Implementation Regulations)

Name student: ________________________________
Student number: _______________________________
E-mail: _____________________________________
(mobile) phone number: _________________________
Start MSc programme (month/year): ______________
Start date thesis: _______________________________

Thesis/Research is related to nuclear proliferation: [ ] yes [ ] no
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, 2018 *
- Have discussion with staff
- 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 (form AE2)
- Alterations in course list possible (form AE4)


Also: [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
  – Space Engineering : ir. B.T.C. Zandbergen (8.10)
  – Space Exploration : ir. R. Noomen (9.20)

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

• Website
  • http://www.lr.tudelft.nl/sf
  • http://studenten.tudelft.nl/informatie/faculteitspecifiek/lr/ae-airport

• March 22, 17.30-20.00: informal meeting with staff
  (main hall AE)