MSc Track “Spaceflight”

R. Noomen, B.T.C. Zandbergen
March 16, 2020
Our Track and Profiles

- **Track**
  - Aerodynamics & Wind Energy
  - Flight Performance & Propulsion
  - Control & Operations
    - Control and Simulation
    - Air Traffic Management & Airports
    - Air Transport & Aerospace Operations
  - Space Flight
    - Space Engineering
    - Space Exploration
    - Design & Production of Composite Structures
    - Novel Aerospace Materials
    - Structural Integrity
    - Aerospace Structures & Computational Mechanics

- **Profile**
  - Aerodynamics
  - Wind Energy
  - Flight Performance & Propulsion
  - Control and Simulation
  - Air Traffic Management & Airports
  - Air Transport & Aerospace Operations
  - Space Engineering
  - Space Exploration
  - Design & Production of Composite Structures
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  - Structural Integrity
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Research Areas MSc “Spaceflight”

Space Engineering:
- Miniaturizing spacecraft
  - space propulsion
  - attitude determination and control
  - space instruments
- 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”
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/spacecraft (Systems) Engineering
- understand the concept that satellites are (part of) end-to-end systems
- develop the ability to work independently on a spaceflight-related engineering or research problem (international environment)
MSc Program

1st year
- q1: courses
- q2: courses
- q3: courses
- q4: internship (or: literature)

2nd year
- q1: literature (or: internship)
- q2: thesis
- q3: thesis
- q4: thesis
Program: Possible Extras

- Honours Track

(already discussed in general presentation)
MSc Program – Overview

Core courses

- ae4874I fundamentals of astrodynamics 4
- ae4890-11 planetary sciences I 4
- ae4S12 space systems engineering 3

- ae4010 research methodologies 2
- wm0324LR ethics and engineering for AE 3

total 16

Description of contents, scheduling, etcetera:
https://studiegids.tudelft.nl/
or
https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal
or
https://mytimetable.tudelft.nl
MSc Program – Overview (cnt’d)

“Space Engineering” profile courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ae4880</td>
<td>space instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>ae4S01</td>
<td>thermal rocket propulsion</td>
<td>4</td>
</tr>
<tr>
<td>ae4S01P</td>
<td>exercise thermal rocket propulsion</td>
<td>2</td>
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<tr>
<td>ae4S07</td>
<td>micropropulsion</td>
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</tr>
<tr>
<td>ae4S10</td>
<td>microsat engineering</td>
<td>4</td>
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<tr>
<td>ae4S15</td>
<td>space embedded systems</td>
<td>3</td>
</tr>
<tr>
<td>ae4S20</td>
<td>satellite thermal control</td>
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</table>

total at least 14 out of 24
MSc Program – Overview (cnt’d)

“Space Exploration” profile courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>ae4866</td>
<td>prop. and optim. in astrodynamics</td>
<td>4</td>
</tr>
<tr>
<td>ae4868</td>
<td>numerical astrodynamics</td>
<td>3</td>
</tr>
<tr>
<td>ae4870A</td>
<td>rocket motion</td>
<td>3</td>
</tr>
<tr>
<td>ae4870B</td>
<td>re-entry systems</td>
<td>3</td>
</tr>
<tr>
<td>ae4872</td>
<td>satellite orbit determination</td>
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<tr>
<td>ae4876-11</td>
<td>planetary sciences II</td>
<td>4</td>
</tr>
<tr>
<td>ae4878</td>
<td>mission geometry and orbit design</td>
<td>4</td>
</tr>
<tr>
<td>ae4880</td>
<td>space instrumentation</td>
<td>4</td>
</tr>
</tbody>
</table>

**total** at least 16 out of 31
MSc Program – Overview (cnt’d)

elective courses (1)

<table>
<thead>
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<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>ae4143</td>
<td>hypersonic aerodynamics</td>
<td>3</td>
</tr>
<tr>
<td>ae4313</td>
<td>spacecraft attitude dynamics &amp; control</td>
<td>3</td>
</tr>
<tr>
<td>ae4313P</td>
<td>spacecraft attitude dynamics &amp; control ex.</td>
<td>1</td>
</tr>
<tr>
<td>ae4499</td>
<td>space project (capita selecta)</td>
<td>4</td>
</tr>
<tr>
<td>ae4??</td>
<td>space design project</td>
<td>4</td>
</tr>
<tr>
<td>ae4889</td>
<td>special topics in astrodynamics</td>
<td>2</td>
</tr>
<tr>
<td>ae4S04</td>
<td>introduction thermal rocket propulsion</td>
<td>1</td>
</tr>
<tr>
<td>ae4S07</td>
<td>micro-propulsion</td>
<td>4</td>
</tr>
</tbody>
</table>

AE4?? Space design project: Depends on availability of projects. Projects will be communicated early September.
## MSc Program – Overview (cnt’d)

**elective courses (2)**

<table>
<thead>
<tr>
<th>Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>cie4601</td>
<td>physics of the Earth and atmosphere</td>
<td>5</td>
</tr>
<tr>
<td>et3604LR</td>
<td>electronic circuits</td>
<td>3</td>
</tr>
<tr>
<td>me46060</td>
<td>eng. optimization: concept &amp; applications</td>
<td>3</td>
</tr>
<tr>
<td>me46095</td>
<td>multiphysics modelling using COMSOL</td>
<td>4</td>
</tr>
<tr>
<td>tw3720TU</td>
<td>object oriented scientific program. C++</td>
<td>3</td>
</tr>
<tr>
<td>wi4007TU</td>
<td>Fourier and Laplace transformation</td>
<td>4</td>
</tr>
<tr>
<td>wi4011-17</td>
<td>computational fluid dynamics</td>
<td>6</td>
</tr>
<tr>
<td>wi4019</td>
<td>non-linear differential equations</td>
<td>6</td>
</tr>
<tr>
<td>wi4525TU</td>
<td>Monte-Carlo sim. and stochastic proc.</td>
<td>5</td>
</tr>
</tbody>
</table>

**mm-mmm**  profile courses of the other profile  
**nn-nnn**  other relevant AE/TUD courses  
(or at other universities, e.g. Astronomy/Leiden)
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 AE5050
• internship-ae@tudelft.nl
Internship/jobs: Industry

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

and many many more....
Second MSc Year

- Literature study
- 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”
- Cooperation between track “Spaceflight” and other tracks
Literature Study

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

• connected to courses
• First quarter second MSc year (fourth quarter first MSc year)
• 12 ECTS
General Remarks

• main elements connected ideally

• choose profile and courses before start of academic year (first lectures.....)
  o theme(s)

• switching between profiles difficult

• Delft BSc student, BSc not completed: not allowed as an MSc student. Check weblink on the ‘Airport-AE’: [https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal/onderwijs/master/application](https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal/onderwijs/master/application)

• non-EU students must achieve a minimum of 50% of study load every year (Modern Migration Policy Act)

(part of contents already given in general presentation)
Research Areas MSc “Spaceflight”

Space Engineering:
- Miniaturizing spacecraft
  - space propulsion
  - attitude determination and control
  - space instruments
- 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
# Research Themes

<table>
<thead>
<tr>
<th>General subject</th>
<th>Supervisor(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miniaturizing spacecraft</td>
<td>Cervone, Zandbergen, Botchu Kuiper, Guo, Bouwmeester Kuiper, Menicucci, Speretta</td>
</tr>
<tr>
<td>Space propulsion</td>
<td></td>
</tr>
<tr>
<td>Attitude determination and control</td>
<td></td>
</tr>
<tr>
<td>Space instruments</td>
<td></td>
</tr>
<tr>
<td>Distributed space systems</td>
<td>Guo, Speretta, Gill</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>Simons, Visser, Schrama, Naeije, Dirkx, Van den IJssel, Siemes, Mooij, Noomen, Guo, Noomen, Cowan, Heiligers</td>
</tr>
<tr>
<td>Precise orbits and applications</td>
<td></td>
</tr>
<tr>
<td>Space debris</td>
<td></td>
</tr>
<tr>
<td>Transfer orbits</td>
<td>Mooij, Naeije</td>
</tr>
<tr>
<td>Rockets, re-entry systems and GNC</td>
<td></td>
</tr>
</tbody>
</table>
| Planetary exploration and astronomy                  | Schrama, Vermeersen, Van der Wal, Stam, Brandl, Cazaux, Dirkx, Root
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.government.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
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-PQ

- Miniaturized bus
- Active attitude control
- Thermal payload
- GPS receiver
- Laser retro-reflectors
- Low-frequency radio

Launch Q4 2020
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
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.
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
- optimization
- solar sailing
- orbit and constellation design
- interplanetary trajectories
- low-thrust orbits
- rendezvous and docking
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
Electives “space engineering”

In this table some potential elective courses are given that can be selected as part of the profile Space Engineering (see brochure for a description of this profile). Courses are given grouped according to a number of categories including general, design and engineering optimization, electronics/power/computer engineering, micro-technology, propulsion, vehicle engineering and distributed systems. The table may sometimes give courses that are quite similar. Selecting one will do (no need to select the other).
Profile + electives “exploration” (not exhaustive)

<table>
<thead>
<tr>
<th>elective</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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</thead>
<tbody>
<tr>
<td>prop. + optim.</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>rocket motion</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>re-entry systems</td>
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<td></td>
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<td>x</td>
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<td>satellite orbit det.</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>planetary sciences II</td>
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<td>x</td>
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<tr>
<td>mission geometry</td>
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<td>x</td>
<td>x</td>
<td>x</td>
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<td>space instrumentation</td>
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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>x</td>
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<td>hypersonic aero</td>
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<td>relativity (Leiden)</td>
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<tr>
<td>adv. topics in analysis</td>
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<td>x</td>
</tr>
</tbody>
</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
- ground station for cubesats
Recent Thesis Projects

- **Guidance and Control of a Spacecraft Swarm with Limited Knowledge**
  - A. Ripoll Sanchez

- **GNSS-Reflectometry Target Detection**
  - Juan José Blasco Burguillos

- **Design, manufacturing and characterisation of a water fed CubeSat micro-resistojet**
  - R.M.A. Poerk

- **Thermal Modelling & Analysis of the Deployable Space Telescope**
  - T.T.D. van Wees

[https://repository.tudelft.nl](https://repository.tudelft.nl)
Recent Thesis Projects (cnt’d)

- **Optimisation Strategies for Galilean Moon Tours**
  - By Lars Hoving
  - Low-Thrust Multiple Gravity-Assist Trajectory Design for GTOC6
  - Delft University of Technology

- **Impact of Satellite Fragmentations in GEO Graveyard Orbits**
  - By L. Boelen
  - MSc Thesis
  - August 9, 2016

- **Statistical Impact Prediction of Space Debris**
  - By R. Hoogendoorn
  - The Uncertainty Propagation Approach
Thesis Opportunities
Thesis Opportunities (2)

Small satellites

Advanced micro-propulsion

Advanced ADCS

Autonomous formation flying

• and many many more ...
Space-related Opportunities at Other Tracks: AWE

Launcher aerodynamics

Re-entry aerodynamics

High speed propulsion systems
Space-related Opportunities at Other Tracks: C&O

Course+practical “Space Attitude Dynamics and Control”

Example projects:
• controlling space vehicles
• remote control (from Earth) of a robot arm on the ISS
• control of space robots
• human-machine interaction

[Biggs, 2013]

[space.com, 2020]
Space-related Opportunities at Other Tracks: ASM

Design, Development and Verification of Spacecraft and Launcher Structures
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!
Getting started

- Select
  - talk to staff
  - choose profile

- Apply
  - formal application and registration through StudieLink

After application:
• Requirements check by Selection Committee
• Non-EU/EFTA at non-Dutch university have limited inflow capacity

If passed:
• Weighted lottery
  o based on match prior program (i.e. not individual performance): knowledge, skills and attitude
  o weight 3 for BSc AE and bridging program AE at TU Delft
  o weight 2 for BSc AE elsewhere and other BSc at Dutch universities
  o weight 1 for all other
• Results communicated to applicants (due date May 10, 2020)
• Option to enroll in alternative MSc track AE (deadline May 30, 2020)
• Waiting list (provided BSc completed on August 15)
• No opportunity to start in February 2021
Points of Contact + Info

- **Master Track coordinator**  
  ir. R. Noomen ([r.noomen@tudelft.nl](mailto:r.noomen@tudelft.nl); 9.20)

- **Profile coordinator**
  - Space Engineering: ir. B.T.C. Zandbergen ([b.t.c.zandbergen@tudelft.nl](mailto:b.t.c.zandbergen@tudelft.nl); 8.10)
  - Space Exploration: ir. R. Noomen (9.20)

- **Secretaries**
  - Space Engineering: Mrs. D.M.S. van der Sande ([d.m.s.vandersande@tudelft.nl](mailto:d.m.s.vandersande@tudelft.nl); 8.14)
  - Space Exploration: Mrs. R. van Wingaarden ([n.vanwingaarden@tudelft.nl](mailto:n.vanwingaarden@tudelft.nl); 9.12)

- **Websites**
  - [http://www.lr.tudelft.nl/sf](http://www.lr.tudelft.nl/sf)
  - [https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal](https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal)
  - [https://mytimetable.tudelft.nl](https://mytimetable.tudelft.nl)
  - [http://mystudyplanning.tudelft.nl](http://mystudyplanning.tudelft.nl)