MSc Track “Spaceflight”

R. Noomen, B.T.C. Zandbergen
March 12, 2019
Our Track and Profiles

Track
- Aerodynamics & Wind Energy
- Flight Performance & Propulsion
- Control & Operations
- Space Flight
- Aerospace Structures & Materials

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
- Novel Aerospace Materials
- Structural Integrity
- Aerospace Structures & Computational Mechanics
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

Make choice
- diversity of contents
- limitations in capacity
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 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: literature

2nd year
- q1: internship
- q2: thesis
- q3: thesis
- q4: thesis
Program: Possible Deviations

- Annotation Sustainable Development
- Annotation Entrepreneurship
- Honours Track

(already discussed in general presentation)
MSc Program – Overview

Core courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</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>ae4S12</td>
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<tr>
<td>ae4010</td>
<td>research methodologies</td>
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<tr>
<td>wm0324LR</td>
<td>ethics and engineering for AE</td>
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</table>

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>
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<td>ae4S01</td>
<td>thermal rocket propulsion</td>
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<td>ae4S15</td>
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<td>ae4S20</td>
<td>satellite thermal control</td>
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total at least 14 out of 20
“Space Exploration” profile courses

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<td>ae4868</td>
<td>numerical astrodynamics</td>
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<td>ae4870A</td>
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<td>ae4870B</td>
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<td>ae4872</td>
<td>satellite orbit determination</td>
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<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>
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</tr>
</tbody>
</table>

| Total       |                                                 | at least 16 out of 31 |


elective courses (1)

ae4143  hypersonic aerodynamics  3
ae4313  spacecraft attitude dynamics & control  3
ae4447  aircraft performance optimization  3
ae4499  space project (capita selecta)  4
ae4874II  astrodynamics II  4
ae4S04  introduction thermal rocket propulsion  1
ae4S07  micro-propulsion  4

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

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
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
Second MSc 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
- 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’: 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>
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<tbody>
<tr>
<td>Miniaturizing spacecraft</td>
<td>Cervone, Zandbergen, Botchu</td>
</tr>
<tr>
<td>Space propulsion</td>
<td>Kuiper, Guo, Bouwmeester, Fonod</td>
</tr>
<tr>
<td>Attitude determination and control</td>
<td>Kuiper, Menicucci</td>
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<tr>
<td>Space instruments</td>
<td></td>
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<tr>
<td>Distributed space systems</td>
<td>Guo, Gill, Fonod</td>
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<tr>
<td>Navigation and control</td>
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<tr>
<td>Disruptive concepts</td>
<td></td>
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<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</td>
</tr>
<tr>
<td>Precise orbits and applications</td>
<td>Mooij, 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, Brandl, Cazaux, Dirkx, Root</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.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-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
- 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

Stratos 2+, 21 km, 2015

Stratos 4, 100+ km
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)
**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 “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 include courses that are quite similar. Selecting one will do (no need to select them all).

<table>
<thead>
<tr>
<th>Course code</th>
<th>Course title</th>
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<td>ME46005</td>
<td>Physics and Measurement</td>
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<td>Q1/2</td>
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<tr>
<td>WM-490-40TU</td>
<td>Monte Carlo Methods</td>
<td>3</td>
<td>Q2</td>
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<tr>
<td>WM-490-40TU</td>
<td>Monte Carlo Simulation of stochastic Processes</td>
<td>3</td>
<td>Q1</td>
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<tr>
<td>CE4410</td>
<td>Probabilistic Design</td>
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<td>Q2</td>
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<td>AE4205</td>
<td>MDO for Aerospace Applications</td>
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<td>Eng. Optimization: Concept &amp; Applications</td>
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<td>ID4010</td>
<td>Design Theory and Methodology</td>
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<td>EE4378</td>
<td>Photovoltaic systems</td>
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<td>IN4310</td>
<td>Distributed Computer Systems</td>
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<td>Q3</td>
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<tr>
<td>ME45100</td>
<td>Fuel-cell systems</td>
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<td>AE4550</td>
<td>Aeronautics</td>
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<tr>
<td>AE4560P</td>
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<td>ET3604LR</td>
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<td>ME4560S</td>
<td>Equipment for Heat &amp; Mass transfer</td>
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<td>Space robotics</td>
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<td>Robotics Practical</td>
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<td>ME4660S</td>
<td>Optics</td>
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A more up to date list can be obtained from the profile coordinator Space Engineering
# Profile + electives “exploration” (not exhaustive)

<table>
<thead>
<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>x</td>
<td>x</td>
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<td>Mission geometry</td>
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<td>x^2</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>
<td>x</td>
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<td>Hypersonic aero</td>
<td>x^1</td>
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<td>Relativity (Leiden)</td>
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<tr>
<td>Physics Earth and atm.</td>
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<td>Adv. topics in analysis</td>
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<td></td>
<td></td>
<td></td>
<td>x^2</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
- ground station for cubesats
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
  - Solving the Thermal Challenges of Next-Generation CubeSats
  - H.S.B. Brouwer

- Design, manufacturing and characterisation of a water-fed CubeSat micro-reactor
  - Dondersteen
  - R.A.N. Puyck

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

- Design Optimization of Ground and Air-Launched Hybrid Rockets
  - Development of an Optimization Tool for Multi-Technology Rocket Launch Vehicle Design
  - Francisco Munawar
Recent Thesis Projects (cnt’d)

Impact of Satellite Fragmentations in GEO Graveyard Orbits
Master Thesis
L. Ruskin August 8, 2016

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

Optimisation Strategies for Galilean Moon Tours
Lars Hoving

Delft University of Technology
Thesis Opportunities
Thesis Opportunities (2)

Avionics based on mobile phone

Autonomous formation flying

Advanced micro-propulsion

Advanced ADCS

• and many many more ...
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**
  
  o talk to staff
  
  o choose profile
  

• **Apply**

  o formal application and registration through StudieLink
  

Points of Contact + Info

• Master Track coordinator  ir. R. Noomen (r.noomen@tudelft.nl; 9.20)

• Profile coordinator
  o Space Engineering : ir. B.T.C. Zandbergen (b.t.c.zandbergen@tudelft.nl; 8.10)
  o Space Exploration : ir. R. Noomen (9.20)

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

• Websites
  o http://www.lr.tudelft.nl/sf
  o https://www.tudelft.nl/studenten/faculteiten/Lr-studentenportal
  o https://mytimetable.tudelft.nl
  o http://mystudyplanning.tudelft.nl

• March 15, 17.30-20.00: informal meeting with staff (main hall AE)