Degree Program Documentation
Bachelor's Program Aerospace

Part A
TUM Department of Aerospace and Geodesy
Technical University of Munich

TUM Department of Aerospace and Geodesy
[12.01.2021]

General Information:

- Administrative responsibility: TUM Department of Aerospace and Geodesy
- Name of degree program: Aerospace
- Degree: Bachelor (B.Sc.)
- Standard duration of study: 6 semesters of enrollment
- Credits: 180 credit points (CP)
- Form of study: full time
- Admission: Aptitude assessment (EFV – Bachelor's)
- Start: Winter semester (WiSe) 2021/2022
- Language of Instruction: English
- Main Location: Garching, Ottobrunn
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Table of Contents

1 Degree Program Objectives

1.1 Purpose

The global aerospace industry is central to solving the challenges of mobility and communication in the information age. Topics around mobility, the measuring of changes to the earth's surface and the use of space in urban and rural environments, as well as innovation and data relevant to climate change are highly important to all societies. Ever smaller satellites surround our planet sending geo-information on all spatial and temporal dimensions – delivering the basis of data that we need to approach the most urgent questions of our time and developing new technological solutions. Questions of climate neutral and futuristic mobility concepts whose development and implementation are becoming more pressing all the time. Start-ups engaged in this work, which are offering innovative services and products, are booming. At the same time, world powers are competing once again in a race for dominance in space, economically, but also politically and militarily. With all these global and scientific-technological developments, the aerospace industry is already one of the most complex fields, especially considering its high demand regarding safety and certification.

The aerospace sector also acts as an important driver of innovation for the German economy, whether it be as a partner in the European Space Agency ESA in the development of the Galileo navigation system or of the Ariane 6 launch vehicle, or through engine designs that reduce the fuel consumption and emissions of aircraft. The number of people employed in the aerospace industry throughout Germany has risen significantly in recent years: from 100,700 in 2012 to 111,500 in 2018.[1] There is also no shortage of new growth areas, be it in the field of short-haul mobility (e.g. air taxis, drones) or in materials research (e.g. carbon composites) for use in aircraft and space travel.

Aerospace engineers are constantly working to test and challenge existing limits and prevailing solutions. Many areas of life have already been fundamentally changed by the influence of new technologies and innovations originating in the aerospace field. Further innovations will lead to marginal cost reductions, opening up new dimensions of mobility and communication on earth and the exploration and use of space. This will be accompanied by the development of new business models and value-added chains, the emergence of which the German economy cannot afford to miss.

The complexity of the industry will continue to increase due to increasing digitalization, the growing influence of virtual products, and the need for closer cooperation between different engineering disciplines. This will place additional demands on the next generation of engineers. This is why an education that focuses from the outset on interdisciplinarity, sustainability and the special challenges of technological frontiers from extreme material stress to maximum energy efficiency is an essential contribution to sustained innovation and economic power in the short term and to a

[1] Source: BDLI Branchendaten der Luft- und Raumfahrtindustrie 2018; https://www.bdli.de/sites/default/files/2019-05/Branchendaten2018.pdf (published 05.2019, accessed 12.08.2020)

society worth living in in the long term. We need aerospace engineers to develop sustainable and future-oriented technologies.

1.2 Strategic Significance

“Future Mobility” is one of the core challenges facing our society in the 21st century and it is therefore a big part of the TUM’s and the Department of Aerospace and Geodesy’s mission to help educate the next generation of engineers for this field. A special focus in the aerospace cluster is making sure that graduates will be able to contribute sustainable technological solutions through their work in the aerospace research and industry.

With the foundation of the Department of Aerospace and Geodesy on the new TUM campus Taufkirchen/Ottobrunn in 2019 the TUM with the support of the Bavarian government has taken a big step toward further improving the link between academia and industry in Munich and strengthening the triangle of aerospace expertise formed by Ottobrunn, Garching and Oberpfaffenhofen (see figure 1).

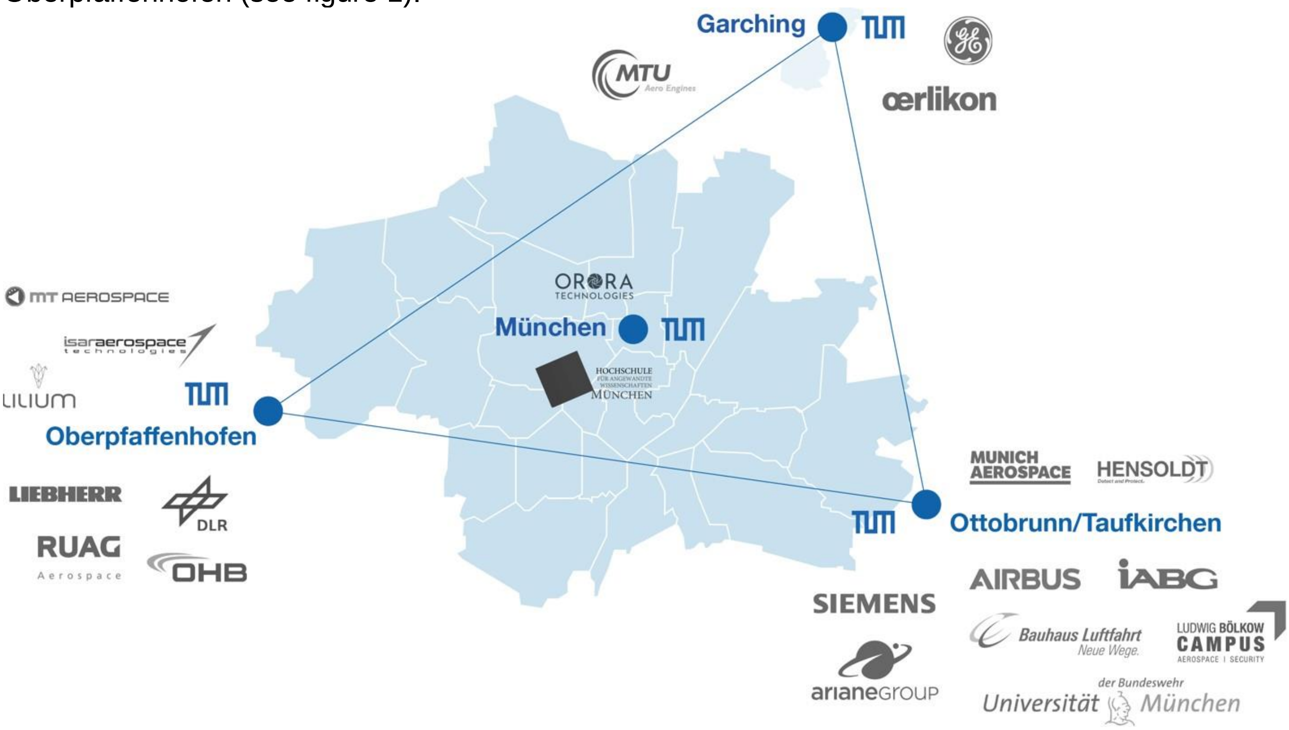

Figure 1 The triangle of aerospace research and industry of the Munich Metropolitan Area

A big range of university-affiliated and other research institutions in the wider Munich area create a network with perfect conditions to educate fresh talents. In cooperation with local and international companies – from highly innovative start-ups to leading players in the aerospace industry – students benefit from access to the direct practical application of their theoretical knowledge.

If we look at the state level, it becomes clear that Bavaria is one of the leading locations in Europe for aerospace industry and research. Multiple structural conditions positively contribute to this: Bavaria is a location for system companies, the equipment industry, technical service providers and scientific and training institutions and has a good aviation infrastructure. Bavaria covers almost all areas of the value chain: research, development, production, maintenance, repair and overhaul. The funding provided under the Bavarian “Cluster Offensive” also highlights the importance of aviation and aerospace for Bavaria. To ensure that this remains so in the future, there is a need for courses of study such as the "Aerospace" bachelor's degree.

The introduction of a bachelor's degree program "Aerospace" is therefore conceptualized as a consecutive study program which leads up to our already established master’s program “Aerospace”, providing the basis for further specialization at the master’s level. However, other Master’s programs within the Department of Aerospace and Geodesy will also welcome graduates of the Bachelor’s program Aerospace, such as the master’s program Earth Oriented Space Science and Technology (ESPACE) with its focus on educating future satellite application engineers (see Figure 2).

TUM Department of Aerospace and Geodesy						
Bachelor		Master				
Aerospace	Geodesy and Geoinformation Land Management (Partial Bachelor)	Aerospace	Geodesy and Geoinformation	Cartography	Earth Oriented Space Science and Technology	Land Management and Geospatial Science

Figure 2 Study programs at TUM Department of Aerospace and Geodesy

A large number of professorships, which broadly represent the aerospace industry, supports the bachelor’s program. The Department of Aerospace and Geodesy currently consists of 23 professorships and will grow to 50 professorships in the next few years. Within the framework of the considerable expansion of the professorships, the field of aeronautics as well as space will be clustered thematically. In the field of aeronautics, the range of topics spans the clusters "Airframe Technologies", "Transport Systems", “Novel Guidance and Control Solutions", "Advanced Flight Physics", and "Advanced Propulsion", each of which consists of 3 to 5 professorships. In the field of "Aerospace", clusters are being created with 3 to 5 professorships each in the areas of "Propulsion", "General Technologies and Robotics", "Exploration", and "Navigation and Communication".

In order to create and use additional synergies in research and teaching, the professors of aerospace at the TUM Department of Aerospace and Geodesy founded "Munich Aerospace" together with representatives of the Universität der Bundeswehr München (UniBW), the German Aerospace Center (DLR), and “Bauhaus Luftfahrt”. This association bundles university and non-university research, development and teaching in the field of aerospace on a common platform in Munich.

The teaching language in the bachelor’s degree program Aerospace is English, following the demand of the international character of the aerospace industry. This offer is also a contribution to the further internationalization of the TUM and in accordance with the goals of the Institutional Strategy of Excellence by attracting and forming international talents.

The combination of teaching and research is an essential foundation of the academic education at the Department of Aerospace and Geodesy. All professors of the department are proven experts in their fields and lead trend-setting research projects in the national and international environment. In many cases, research projects are carried out in close cooperation with industry. The close links with the Department of Mechanical Engineering and the Department of Civil, Geo and Environmental Engineering enable strong scientific exchange across department boundaries, which will lead to further alliances after the founding of the TUM School of Engineering and Design.

Current research results are integrated into teaching and students are given the opportunity to participate in projects in a variety of ways. The link between research and teaching is also evident at the bachelor's degree level through a special emphasis on research-oriented approaches in courses and independent student research achievements, for example in research practice and the master's thesis.

2 Qualification Profile

The qualification profile of graduates of the bachelor's program "Aerospace" meets the requirements of the German Qualifications Framework for Higher Education Qualifications (Higher Education Qualifications Framework - HQF) in accordance with the resolution of 16 February 2017 of the German Rectors' Conference and the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany. Following the HQF-guidelines, the qualification profile for the bachelor's program "Aerospace" can be defined on the basis of the requirements (i) Knowledge and Understanding, (ii) Use, Application and Generation of Knowledge, (iii) Communication and Cooperation and (iv) Scientific Self-Understanding/Professionalism. The formal aspects in accordance with HQF (admission requirements, duration, degree options) are described in Chapters 3 and 6 of this document as well as in the corresponding examination and study regulations (Fachprüfungs- und Studienordnung, FPSO).

<u>Knowledge and Understanding</u>

Graduates of the bachelor's program Aerospace are qualified aerospace engineers with a broad basis of knowledge in the fundamental disciplines of aerospace sciences comprising advanced mathematics, engineering mechanics, thermodynamics, informatics and electrical engineering as well as aerospace materials, structures, and systems. Based on those, the students gain an understanding for the special requirements and characteristics of the aerospace field like safety orientation or lightweight design. They have solid, domain specific knowledge of aerospace systems like aircraft, helicopters, launchers, satellites and aircraft/rocket propulsion systems. Additionally they have gained basics in several other fields such as design, modeling, simulation and the development process.

While there are overlaps with other engineering disciplines in the fundamental domains mentioned above, aerospace engineers acquire a distinctive profile by applying this knowledge to challenges from the aerospace field. These particular challenges include, but are not limited to:

- Safety and certification in a highly regulated environment with very high safety requirements
- Lightweight construction for highly loaded parts
- Design for hostile operational environments (extremes of temperature, speed, acceleration etc.)
- Design for high system reliability
- Economic and resource constraints in all phases from production to operation
- Human factors, since typical aerospace applications rely heavily on human-machine interactions from cockpits via air traffic control to remote control
- Global value chains and international cooperation at every stage of the life cycle of aerospace systems and operations

Aerospace graduates distinguish themselves from other mechanical engineers by their ability to name, analyze, design and implement engineering solutions, which account for these special challenges. In materials science, they know which materials to use for durability, heat resistance, structural integrity or flexibility, while in electrical engineering they are able to deal with issues of latency in long-distance communication into space and create contingent systems for extra safety in airplanes or spacecraft. They have a fundamental understanding of issues of the construction process over all stages from planning and design, calculation, to production conditions. Graduates know how to model uncertainty, factoring in its quantification and propagation, making sure to fulfil stringent requirements in varying environments.

Based on this knowledge, B.Sc. Aerospace graduates are able to independently evaluate and solve practical engineering problems across the life cycle of different aerospace systems creating a solid basis for further specialization across the aerospace spectrum from research to industrial application and regulation.

Use, Application and Generation of Knowledge

To guarantee seamless applicability of aerospace knowledge, bachelor students learn to employ a broad range of methods used across all domains of the field. They describe and analyze engineering problems in abstract and mathematical terms and create practical solutions, e.g. by applying software tools to different parts of the life cycle, such as

- defining and understanding requirements,
- conceptual design, development of solution strategies, sizing and detailed design,
- modeling and simulation,
- computation (structural, fluid and aerodynamics, control),
- multi-domain implementation of Cyber-Physical Systems (CPS), combining mechanical, electrical, electronic, computational, hydraulic, and other elements,
- system integration,
- testing and experimentation,
- certification and quality management,
- production and assembly,
- operation and maintenance,
- recycling and disposal.

At all stages, bachelor graduates use software and other tools employed in the aerospace industry. Examples include Computer Aided Design (CAD), MATLAB™ and other programming languages, Finite Elements Method (FEM), Computational Fluid Dynamics (CFD), Product Lifecycle Management (PLM) Configuration Management, Regulation Management, and tools for visualization and animation.

Students gain a holistic understanding of integrated systems considering all relevant interactions between components and subsystems, various disciplines –from informatics and electrical engineering to mechanics and materials science–, as well as between different stakeholders of the process. Students learn to apply this holistic view to every step of the life cycle and take an interdisciplinary perspective on solving engineering problems. They are therefore ideally prepared to use the synergies of interdisciplinary cooperation to create novel solutions.

Due to the importance of safety and certification in the aerospace field the training of bachelor students puts an emphasis on quality management via the continuous generation of process artifacts and documentation to provide certification evidence, as well as the ability to conduct safety analysis. Students learn how to use stochastic and statistical methods, experimental design and testing of hypotheses to manage uncertainty and quality aspects to create fault tolerant systems that are resilient in demanding environments.

Graduates of the B.Sc. Aerospace have shown that they can combine theoretical knowledge from multiple disciplines with first-hand application.

Communication and Cooperation

The knowledge and skillful use of all relevant “tools of the trade” enables aerospace graduates to excel as members of international and multi-disciplinary teams. They have an understanding of different stakeholders and functions in the aerospace field. They have proven their ability to work on practical and applicable solutions in different work environments with diverse teams through industry internships and contact with professionals and researchers from different areas of the aerospace field. By gaining an overview of the industry and the whole product life cycle, they understand the necessary cooperation and project management involved in the planning, production, and operation of aerospace machines.

By looking at the big picture, they also situate the aerospace industry in the wider society and the political and economic environment, where engineering problems are the means to solve broader issues such as mobility, communication, international cooperation, or climate change. The focus on processes, resource efficiency, and safety prepares graduates to look for sustainable, economically, ecologically, and socially viable solutions to real-world problems.

They know how to communicate effectively in globally used English language terminology and profit from the international student cohort with which they interact throughout the program.

Scientific Self-Understanding/Professionalism

Aerospace graduates are capable of using their engineering knowledge, skills, and methods to analyze, evaluate, and design solutions to problems in the fields of aerospace and beyond. They take into consideration the technical, engineering, economic, ecological and regulatory aspects as well as the wider impacts of solutions they create. This also and specifically applies to the dual-use character of many aerospace technologies, where graduates are sensitive to the ethical implications of designing products that have both civil and military applications.

As required in the aerospace field, graduates are highly process-oriented and work in well-documented and safety-conscious ways as members of international and interdisciplinary teams. This approach helps them communicate and cooperate effectively with international professionals and researchers from multiple disciplines.

This training in abstract and process-oriented thinking starts at the stage of defining project requirements and gives graduates the ability to independently form hypotheses, define goals and critically reflect on the means and methods of achieving them. A comprehensive understanding of complex aerospace systems and their interactions, an intuitive sense for magnitudes and dimensions and strong engineering judgement capabilities come from the students’ experience with practical elements of the program. Mechanisms to assess the plausibility and feasibility of their own concepts are a very important skill that enable an internal critical feedback loop, the basis of continuous improvement. The focus on quality management and diligent process documentation leads students to constantly validate and verify their approach. They progress with diligence, an eye to quality and potential sources of errors, while conscious of factors of cost and scheduling for all stakeholders involved.

Through their choice in electives, students are able to orient themselves towards a master’s program, take on an independent role while doing group work, and start to define their individual professional and academic profile.

3 Target Groups

3.1 Target Audience

The bachelor's program Aerospace is an international undergraduate degree program, aimed at graduates of secondary education institutions as well as suitably qualified professionals with a particular interest in the subject of aerospace. Applicants must have a suitable university entrance qualification or a corresponding professional qualification and a deep interest in scientific and technical issues and their engineering perspectives. The bachelor's program is offered in English, thus taking into account the high degree of internationality in the aerospace industry. Both, national and international applicants are welcome.

3.2 Prerequisites

A basic understanding of scientific and technical contexts is required for admission to the degree program. In addition to mathematics, at least one other MINT (Mathematics, Informatics, Natural Science, Technology/Engineering) subject should have been taken by the end of the upper secondary school in which above-average grades can be demonstrated. An aptitude assessment procedure is in place to check for all necessary requirements as part of the application process.

In order to successfully continue their studies, applicants should be able to think in an interdisciplinary way at secondary school level and to recognize the methodological differences between the subject cultures of mathematics, engineering, and the natural sciences and to apply them independently later on. Furthermore, applicants should be able to learn and work out scientific theories and solutions independently.

Before students can start on their bachelor's thesis, they have to prove the completion of at least 14 weeks of internships in an aerospace-related or engineering company (manufacturing or engineering internships are recognized). It is recommended that applicants participate in several weeks of pre-study internships before starting the program, since it gives them the opportunity to gain initial insights into their future professional field and strengthens their decision to choose a course of study.

3.3 Target Numbers

As a general guideline, the Department of Aerospace and Geodesy expects a cohort size of about 300 students, so that in a few years about 900 students will be enrolled in the bachelor Aerospace. This estimation is based on the strong interest shown in the existing master's program Aerospace, which currently receives around 500 applications per semester with ca. 200 admissions. The Bachelor will be the first English-speaking Bachelor at the TUM and will set new standards in the recruitment of international applicants. The department continues its goal to increase the proportion of female students by offering programs like TUM Entdeckerinnen, specifically aimed at furthering the interest of female applicants in science and engineering.

4 Demand Analysis

The German aerospace sector has been growing continuously from 100,700 in 2012 to 111,500 in 2018.[2] The air travel sector has taken a downturn due to the CoViD19 pandemic, but the aerospace industry as a whole is still growing. This causes a continued demand for well-trained aerospace engineers for areas from space-related technology, to aircraft (both civilian and military), and foundational research topics such as sustainable mobility and future communication.

The global aerospace industry has a steady demand for highly trained aerospace engineers with the qualification profile described above. Big new airplane projects in Asia and South America create a need for a large support network of suppliers that employ aerospace engineering graduates and work on an international scale. Many of these suppliers are German or have factories and subsidiaries in Germany due to its highly developed infrastructure and the high education level of the workforce.

Additionally, new kinds of air mobility are rapidly gaining momentum with developments in the fields of urban air mobility, drones for civil applications, electric aviation, and vertical air mobility. Graduates of the bachelor’s program aerospace fill a need for aerospace experts within this wider trend.

[2] Source: BDLI Branchendaten der Luft- und Raumfahrtindustrie 2018; https://www.bdli.de/sites/default/files/2019-05/Branchendaten2018.pdf (published 05.2019, accessed 12.08.2020)

5 Competition Analysis

5.1 External Competition Analysis

The bachelor's program Aerospace, particularly one completely taught in English, is in competition with very few universities within Germany. The only university to date that offers a specialized aerospace bachelor's program is the University of Stuttgart:

- **University of Stuttgart** „Luft- und Raumfahrttechnik“ (Aerospace Engineering): Marketed as the only (i.e. first) consecutive bachelor's program at a civilian university in Germany to focus on aerospace, this program offers a similar range of courses and content as the B.Sc. Aerospace at the TUM. The program is entirely in German and therefore does not compete for most international students without German language skills or German students interested in studying in English.

Other than the TUM and the University of Stuttgart, several German universities offer aerospace related master's programs that build on mechanical engineering or other engineering bachelor's programs. During the undergrad programs, many universities provide electives and focus areas with aerospace contents. Those universities are not in direct competition with our consecutive bachelor's program aerospace, but form part of German academic aerospace education (listed alphabetically by city):

- **RWTH Aachen University** “Transport Engineering and Mobility”: This bachelor's program includes elements of aerospace engineering next to other forms of mobility such as railway and road based systems.
- **Technical University Berlin** „Master of Space Engineering”: This master's program builds on a bachelor's program “Verkehrswesen” (Transportation) which includes some aerospace engineering electives.
- **Technical University Braunschweig** „Luft- und Raumfahrt“: Students are offered an orientation towards the Aerospace master's program through their choice of electives at the bachelor's level.
- **Universität Bremen** „Space Sciences and Technologies” (bachelor and master): As part of the physics/electrical engineering department this program specializes in “Physics for Space Observation” and “Information Technologies for Space” and does not include content about airplanes, helicopters, or other engineering subjects.
- **Technical University Darmstadt** „Schwerpunkt Luftverkehr” (Aviation@TU Darmstadt): This is not a full-fledged bachelor's program, but rather a focus area with a wide choice of courses in aviation and air traffic that can be selected by students from variety of different backgrounds.
- **Technical University Dresden** “Luft- und Raumfahrttechnik” (Aerospace Engineering): Aerospace is one of eight focus areas during a bachelor in mechanical engineering.

- **Technical University Hamburg** „Aircraft Systems Engineering“: The master program builds on the bachelor program in Mechanical Engineering focusing on modern air transport and aircraft design. It does not cover space technology.
- **Karlsruhe Institute of Technology** “Ausrüstungssysteme der Luft- und Raumfahrt“ (master’s focus area only): Specialized in information technology and electrical engineering for aerospace application.
- **Universität der Bundeswehr München** „Aeronautical Engineering“: A bachelor program following the German model of a dual study program with a 4,5 year duration in German and English, which is exclusively offered to students currently in the German military service. It incorporates practical professional education for pilots into the study program and offers the possibility to choose a technical or management specialization.

Since aerospace is an international field of study catering to a global industry, the TUM is in competition with some other high profile European universities that offer similar programs at the undergraduate level. There are distinguishing properties in our bachelor’s program, such as short duration (3 years), mode of teaching (electives, practical courses), attractive partners in industry (Airbus, iABG, DLR, Siemens, Hensoldt, arianeGroup etc.), as well as an extant consecutive master’s program at the same university, all of which give the B.Sc. Aerospace at the TUM an edge versus many of its competitors:

- **TU Delft** “Aerospace Engineering” (The Netherlands): TU Delft offers a comparable program and stands in direct competition to the TUM’s B.Sc. Aerospace. Like the TUM, it offers a master’s program “Aerospace”. The teaching language is English.
- **University of Glasgow (Great Britain)** “Aeronautical Engineering”: This degree program can be completed after 4 years with the title Bachelor of Engineering (BEng) or after 5 years with the title Master of Engineering (MEng).
- **Imperial College London (Great Britain)** “Aeronautical Engineering”: ICL offers a BEng degree of 3 years and a MEng degree of 4 years. They are comparable in content. The M.Sc. program “Aeronautical Engineering” is currently (end of 2020) still in development.
- **Universidad Carlos III de Madrid (Spain)** “Aerospace Engineering”: This English language bachelor’s program with a duration of 4 years is comparable in content, but adds another year for practical training and internships before graduation.
- **Universidad Politécnica de Madrid (Spain)** “Aerospace Engineering”: UPM offers internationally recognized Spanish language aerospace programs. The 4-year undergraduate degree offers specializations in Aerospace Vehicles, Aerospace Propulsion, Aerospace Sciences and Technologies, Airports and Air Transport, and Navigation and Aerospace Systems. There are three masters programs to specialize further in Aeronautical Engineering, Space Systems, or Air Transport Systems.
- **University of Southhampton (Great Britain)** “Aeronautics and Astronautics”: There are both a BEng (3 years) program with comparable contents to B.Sc. Aerospace at the TUM and multiple MEng (4 years) degree programs in the Aerospace field with

different specializations during the 4th year. There is a master "Aeronautical Engineering" offered in English with a capacity of 45 students (TUM: ca. 200).

Other leading Aerospace universities do not offer bachelor's programs, but are part of the academic aerospace environment in Europe:

- **Université Fédérale Toulouse Midi-Pyrénées/ ISAE Supaero (France)** "Aerospace Engineering": ISAE Supaero does not offer bachelor's programs. The master's program is in a partnership (double degree) with the TUM's master Aerospace.
- **KTH Stockholm (Sweden)** "MSc Aerospace Engineering": KTH offers only one English language undergraduate program in "Information and Communication Technology".
- **Technion – Israel Institute of Technology (Israel)** offers undergraduate and graduate studies at its Faculty of Aerospace Engineering: Course catalogues and curriculum for undergraduate studies are exclusively available in Hebrew.
- **University of Pisa (Italy)** "Master of Science in Space Engineering": The university does not offer English language undergraduate programs in engineering.
- **Cranfield University (Great Britain)** does not offer bachelor's degrees, but several post-graduate i.e. master's level degree programs, such as "Aerospace Computational Engineering", "Aerospace Dynamics", "Aerospace Manufacturing", Aerospace Materials", "Aerospace Vehicle Design", and "Aircraft Engineering".

As the Shanghai Ranking 2020[3] confirms, the TUM is the only German university to reach the top 50 universities globally for Aerospace Engineering. This is due to the high profile of the master's program Aerospace, but surely contributes to attracting interested students for the bachelor's program as well. Outside of Europe the TUM is in mainly competition with many high-profile Chinese and US-American universities, with some examples listed below. However, besides the quality of education students consider multiple other factors when choosing their alma mater, such as tuition fees, cost of living, language barriers, or the ease of applying and receiving a student visa. In the top group for aerospace education, these other factors often make the difference in students' decision, where to study. Some of the TUM's main competitors in the Aerospace field are (in alphabetical order by city):

- **University of Michigan-Ann Arbor (USA)** "Aerospace Engineering": The program requires a first semester of general engineering courses to be taken before admission for a major in Aerospace Engineering. The degree program does usually last 4 years (8 terms) with a possible specialization in Aero- or Astronautics.
- **Beihang University (China)** "Aircraft Engineering", "Flight Technology", "Vehicle Design and Engineering (Aerospace Engineering)": The School of Aeronautic Science and Engineering (ASE) offers a wide range of Aerospace education, both in English and Mandarin Chinese. The university also offers several master's programs such as

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[3] http://www.shanghairanking.com/Shanghairanking-Subject-Rankings/aerospace-engineering.html (2020-09-25)

"Aerospace Engineering", "Aeronautical Engineering", "Aircraft Design", and "Manufacturing Engineering of Aerospace" among others.

- **Beijing Institute of Technology (China)** "Aerospace Engineering": A complete undergraduate program at the School of Aerospace Engineering, with a consecutive master's program.
- **Caltech (Pasadena, USA)** "Astrophysics": The California Institute of Technology offers several undergraduate majors in fields that can be combined with a minor in Aerospace Engineering, such as Astrophysics, mechanical Engineering, Materials Science, Electrical Engineering as well as Control and Dynamical Systems to name a few. There is no dedicated major at the bachelor's level in Aerospace Engineering.
- **Texas A&M University (College Station, USA)** "Aerospace Engineering": All undergraduate degree programs at A&M's School of Engineering share the first year of courses, with an additional three years of specialized aerospace content for students majoring in Aerospace Engineering.
- **Georgia Tech (Atlanta, USA)** "Aerospace Engineering": The Georgia Institute of Technology offers both an undergraduate and a graduate program in Aerospace Engineering.
- **Harbin Institute of Technology (China)** "School of Astronautics": The HIT offers 10 astronautic-related undergraduate majors spanning 6 primary disciplines and 15 subordinate disciplines as well as a wide range of graduate programs, however, no aerospace specialized programs are offered in English. It does not offer a similar choice for *aero*nautics.
- **MIT (Cambridge, USA)** "Aerospace Engineering": The two B.Sc. programs "Aerospace Engineering" and "Engineering" at The Massachusetts Institute of Technology AeroAstro offer both a more focused and a more flexible study plan for aerospace undergraduate students. The master's programs offer a variety of 12 specializations like Aerospace Computational Engineering to Humans in Aerospace.
- **Moscow Aviation Institute (Russia)**: MAI offers four international English-medium bachelor's degree programs ("Aircraft Engineering", "Spacecraft Engineering" "Control Systems and Computer Science in Engineering", "Propulsion Engineering") each lasting 4 years with a tuition cost of 6000 US dollars per year.
- **Nanjing University of Aeronautics and Astronautics (China)** "Aeronautical engineering" and "Aircraft Maintenance Engineering": NUAA is nationally ranked first in Aeronautical Engineering studies with a comprehensive and internationally regarded 4-year program (B.Eng.) also taught in English.
- **Northwestern Polytechnical University (Xi'ian, China)** "Aerospace Engineering" and "Astronautics Engineering": The schools Aeronautics and Astronautics at NPU offer 9 undergraduate programs of 4 years and 13 post-graduate programs between them. Two undergraduate programs are offered in English.

5.2 Internal Competition Analysis

Inside the TUM, the B.Sc. program Aerospace has some overlap with the bachelor's programs Mechanical Engineering at the Department of Mechanical Engineering as well as Engineering Science at the Munich School of Engineering. Some of the distinguishing characteristics are listed below:

- Neither of the other bachelor's programs is taught exclusively in English. This obstacle deters a big potential group of prospective international students that do not know enough German for admission to a (partly) German language program. The bachelor program Aerospace is therefore adding this group to the potential pool of applicants.
- The bachelor program Mechanical Engineering includes some aerospace applications in its specializations to enable graduates to apply for the master's program Aerospace. However, as mentioned above in the qualification profile, aerospace engineers have a much more specialized profile. By putting less focus on areas less relevant for aerospace (gears, transmissions, lubrication, etc.), the dedicated Aerospace program allows a stronger focus on core disciplines (e.g. fluid physics, light weight construction, thermodynamics, safety and certification).
- The bachelor program Engineering Science at the Munich School of Engineering is an intensive program of 210 ECTS credits spanning all domains of engineering with a wide basic education in physics and chemistry, mechanical and electrical engineering, as well as informatics. Specializations through an especially broad elective catalogue allow graduates of this program to prepare for master's programs as varied as Applied and Engineering Physics, Computational Mechanics, Mechanical Engineering, Electrical Engineering, *or* Aerospace. The aerospace program therefore allows students to focus on aerospace applications much more quickly, while the B.Sc. Engineering Science trains engineers for academic research in interdisciplinary fields by offering fundamentals of multiple domains and postponing all specializations to the elective catalogue in the 5th and 6th semester.

As part of the continuing expansion of the Department of Aerospace and Geodesy with a new campus in Ottobrunn and many new professors and lecturers in the coming years, the expertise and research potential for aerospace topics at the TUM is constantly growing. A consecutive bachelor's program Aerospace is a logical addition to the Department's and the TUM's profile.

6 Program Structure

The standard duration of the bachelor study program is 6 semesters with courses starting each winter term. The program comprises the following elements:

Modules	**Credits (ECTS)**
Required modules (2 fundamental modules, 18 basic modules)	109
Electives - 5 Engineering electives (25 ECTS) - 2 Aerospace Lab Courses (9 ECTS) - 2 Supplementary Courses (6 ECTS)	40
Introductory courses and project weeks	11
Internship	8
Bachelor's Thesis	12
Total	**180**

The balanced workload for each semester demands the equivalent of roughly 30 ECTS credits while not exceeding six exams per semester. Students are free to take additional courses from the extensive electives catalogue or the choice of supplementary modules.

All course offerings are in English with students allowed to choose German for papers or exams with the examiner's permission.

The majority of modules are offered by chairs and professorships at the Department of Aerospace and Geodesy. Additional courses are offered in cooperation with the Department of Mechanical Engineering, the Department of Mathematics, or the Department of Electrical and Computer Engineering. Those departments also offer additional engineering electives and supplementary courses allowing students to choose from TUM's wide array of technical and engineering modules when focusing on an area of interest.

The main teaching format of frontal lectures is complemented by exercises in smaller groups, including optional tutorials, practical courses, project weeks, an internship and engineering projects. Two introductory courses give students a chance to become familiar with the professional profile of aerospace engineers as well as the aerospace applications in geodesy. At the end of the program, students prove their qualification for independent scientific work by writing a Bachelor's Thesis.

6.1 Curriculum Overview

1 Semester (Winter)	2 Semester (Summer)	3 Semester (Winter)	4 Semester (Summer)	5 Semester (Winter)	6 Semester (Summer)
Introduction into Aerospace 3	Advanced Mathematics II 6	Introduction into Geodesy 3	System Elective 5	Engineering Project / Project week 5	Elective II 5
Advanced Mathematics I 7	Engineering Mechanics II 5	Advanced Mathematics III 6	Heat Transfer 5	Modeling Elective 5	Elective III 5
Engineering Mechanics I 6	Thermodynamics I 5	Engineering Mechanics III 5	Fluid Mechanics II 5	Elective I 5	Aerospace Lab Course II 4
Electrical Engineering (1) 3	Electrical Engineering (2) 5	Thermodynamics II 5	Aerospace Structures and Elements (2) 5	Aerospace Lab Course I (overall system, Airplane, Heli, Engine, Space) 5	Supplementary Course II 3
Aerospace Material Science and Processing (1) 4	Aerospace Material Science and Processing (2) 4	Fluid Mechanics I 6	Control Theory 5	Supplementary Course I 3	Bachelor's Thesis 12
CAD/TD for Aerospace Engineers 3	Engineering Computer Science II 5	Aerospace Structures and Elements (1) 4	Test, Analysis and Simulation 5	Engineering Internship 8	
Engineering Computer Science I 5					
Summe 31	Summe 30	Summe 29	Summe 30	Summe 31	Summe 29

Figure 3 Bachelor Aerospace Curriculum (size of cell represents amount of workload in ECTS per semester)

Please note: "Aerospace Material Science and Processing" and "Aerospace Structures and Elements" each span 2 semesters; credits are conferred after completion of the exam at the end of the second semester.

1st Semester (Winter)		2nd Semester (Summer)		3rd Semester (Winter)		4th Semester (Summer)		5th Semester (Winter)		6th Semester (Summer)	
Advanced Mathematics I	7	Advanced Mathematics II	6	Advanced Mathematics III	6	System Elective	5	Modeling Elective	5	Free Elective	5
Engineering Mechanics I	6	Engineering Mechanics II	5	Engineering Mechanics III	5	Test, Analysis and Simulation	5	Additional Engineering Elective	5	Additional Engineering Elective	5
Electrical Engineering (1)	>	Electrical Engineering (2)	8	Thermodynamics II	5	Heat Transfer	5	Aerospace Lab Course I	5	Aerospace Lab Course II	4
Aerospace Material Science and Processing (1)	>	Aerospace Material Science and Processing (2)	8	Aerospace Structures and Elements (1)	>	Aerospace Structures and Elements (2)	9	Supplementary Course I	3	Supplementary Course II	3
Engineering Computer Science I	5	Engineering Computer Science II	5	Fluid Mechanics I	6	Fluid Mechanics II	5	Engineering Internship	8	Bachelor's Thesis	12
CAD/TD for Aerospace Engineers	3	Thermodynamics I	5	Introduction into Geodesy	3	Control Theory	5	Engineering Project / Project Week	5		
Introduction into Aerospace	3										
Sum of Credits (semester)	24	Sum of Credits (semester)	37	Sum of Credits (semester)	25	Sum of Credits (semester)	34	Sum of Credits (semester)	31	Sum of Credits (semester)	29
Examinations	6	Examinations	6	Examinations	6	Examinations	6	Examinations	6	Examinations	6

Figure 4 Bachelor Aerospace Curriculum (cells represent modules, sum of credits per module, examinations per semester)

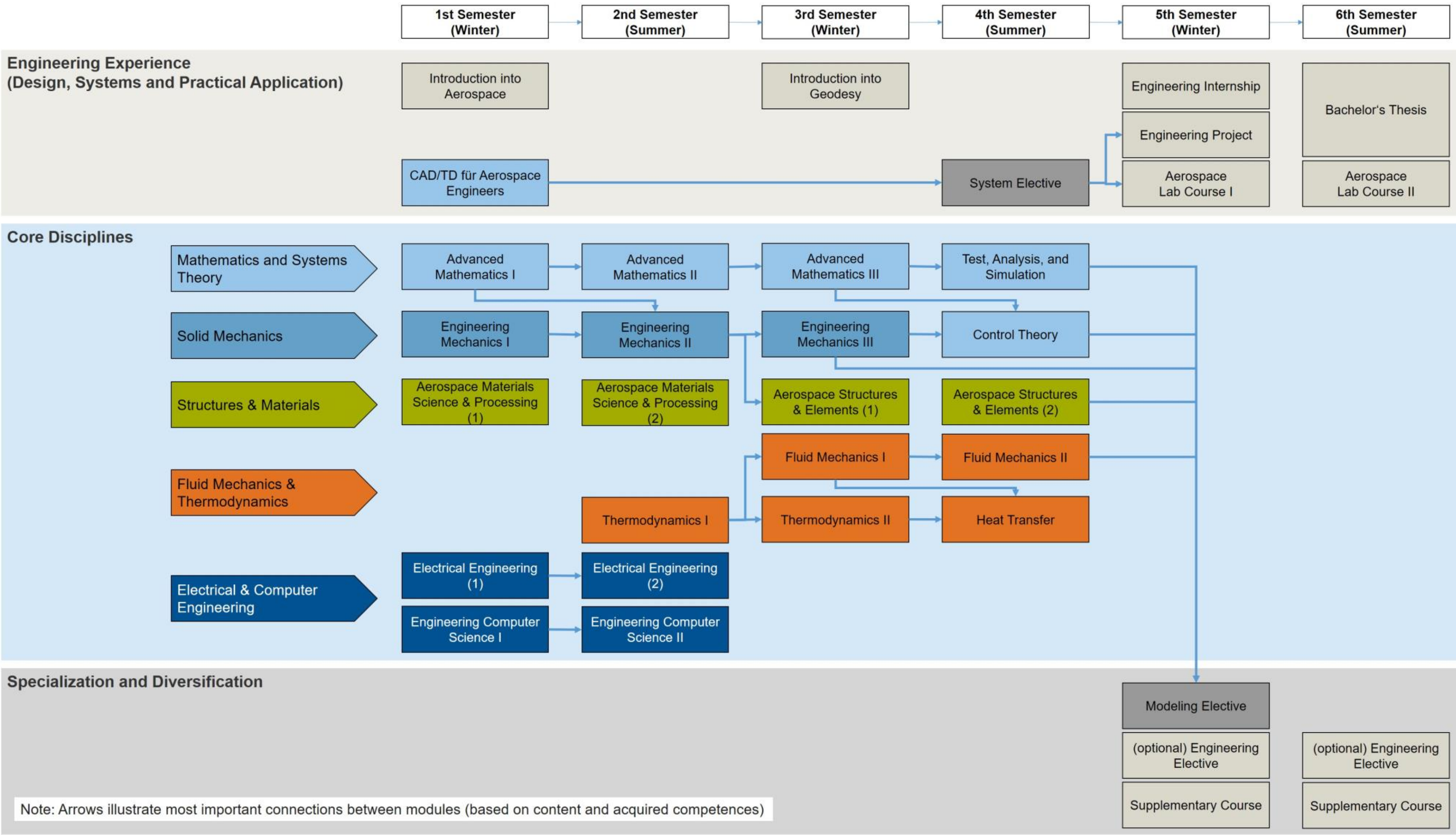

Figure 5 Bachelor Aerospace Competence Flowchart (read left to right from 1st to 6th semester)

General concept

To enable students to gain the holistic understanding of integrated systems and all relevant core domains of aerospace as described in the qualification profile, the curriculum covers the following five main areas of aerospace expertise:

- Structures and Materials
- Fluid- and Aerodynamics
- Integrated Systems (e.g. airplane, helicopter, rocket, satellite, drone, engine)
- Dynamics and Control (e.g. flight mechanics, helicopter dynamics, orbital dynamics)
- Propulsion (e.g. internal combustion engines with propeller, turbomachinery, rocket propulsion, electric propulsion)

The required modules of the curriculum represent the first two areas, whereas the other three areas are covered by electives. The balance between required modules and electives makes sure that they complete modules from at least four of these areas and have basic knowledge in all of them. This general idea and the interconnection between the different domains is visualized in Figure 5 in a competence flowchart.

Frontloading of Fundamentals and Basics

The program structure concentrates all *required modules* in the first four of the six study semesters. This early preparation of students with *basics* across all domains enables students to make connections across disciplines and start applying their knowledge in group projects and their internship much sooner than in classical engineering degrees, where other fundamental disciplines occupy more space in the curriculum. This "frontloading" pays dividends in later semesters by allowing a more domain specific content-based foundation. As can be seen from figure 4, almost all basics continue in subsequent semesters forming chains of steady build-up and knowledge creation in the following domains:

- Mathematics (Advanced Mathematics I, II, III)
- Engineering Mechanics (Fundamentals, Continuum Mechanics, Dynamics)
- Electrical Engineering (I, II)
- Informatics (Engineering Computer Science I, II)
- Thermodynamics (Thermodynamics I and II, Heat Transfer)
- Fluid Mechanics (I, II)
- Material Science (one module over two semesters)
- Aerospace Structures and Elements (one module over two semesters)

In the first semester, the modules Advanced Mathematics I and Engineering Mechanics I are called *fundamentals*, because students have to complete these exams within their first year of studies. This ensures that students who have not been able to fulfil the expectations in these subjects get early feedback and additional pressure, so they are not overtaken by the demands of later semesters. Early feedback can mean a re-evaluation for some, but can re-affirm others and give them a solid basis for the next semesters.

Students learn in the first four semesters to understand, calculate and design all aspects of aircraft or spacecraft. Measuring and calculating (Advanced Mathematics, Mechanical Engineering) lightweight construction (Aerospace Material Science and Processing), cyber-physical systems and control (Electrical Engineering, Control Theory), programming and information technology (Engineering Computer Science), design and technical drawings (CAD/TD for Aerospace Engineers).

The module Engineering Computer Science I focuses on students understanding of software and programming (MatLab™, C, C++). Computer aided Design and Technical Drawing for Aerospace Engineers introduces essential software tools like CAD (e.g. CATIA, Inventor) to students early on, which they will continue to need in following semesters in the modules Material Science and Processing, and Aerospace Structures and Elements.

This early scientific foundation in multiple domains, and knowledge of the necessary software and mathematical tools, make it possible to start more complex, advanced domain tailored courses like Thermodynamics (2nd and 3rd semester) and Fluid Mechanics (3rd and 4th semester) earlier than comparable bachelor's programs. Through a combination of lectures with frontal yet interactive teaching with frequent exercises in bigger and smaller groups, tutorials and projects, both theory and practice balance out in this phase.

Development of individual interests through electives

Building step-by-step on this foundation of required modules, students gain clear, all-round knowledge of structural (e.g. materials, mechanical) and fluid (e.g. fluid dynamics, thermodynamics, heat transfer) aspects of aerospace, as well as some basics from contributing domains (informatics, electrical engineering, control) so by the 4th semester, they are able to choose from their first elective catalogue.

The System Elective in the 4th semester gives students a choice to focus on one particular type of flight system: helicopters, aircraft, spacecraft, or propulsion systems. In the 5th semester, the Modeling Elective offers another possibility to choose: Computational Aerodynamics, Computational Solid Mechanics in Aerospace, Dynamic simulation for vehicles, machines, and mechanisms, as well as System Theory and Modeling.

As part of their professional profile, aerospace engineers need to know about all domains of the aerospace field, conveyed through basic modules for solid mechanics, electrical, computational, fluid engineering, and thermodynamics. The electives allow students to specify and round out their individual profiles by requiring them to make a choice from the systems, modeling and other optional engineering electives (list of selected modules from multiple TUM engineering departments). These elective catalogues cover at least two out of three subject areas: integrated system, dynamics and control, propulsion. Depending on the individual choice, this leaves two more electives for students to focus more in-depth on their specific area of interest.

These electives give students the possibility to start orienting themselves in a particular direction to prepare for a master's degree in their individual interest, or to pursue a professional profile in a particular field of expertise. With the smaller supplementary modules, they can even sharpen their profile away from a general direction to dive deeper into a subject of their individual interest.

One elective is completely free of content constraints to enable students to add modules from the TUM's offers across all departments, for example at the Language Center or the Munich Center for

Technology in Society. Course include transdisciplinary skills (e.g. languages, project management), soft skills (e.g. presentation, intercultural competence, teamwork) and other subject areas such as the social sciences or philosophy (e.g. Ethics and Responsibility, Politics for Rocket Scientists). Students are explicitly encouraged to pick modules outside of the engineering subject matter and pick up general skills and perspectives from other disciplines.

The more flexible structure of the last two semesters also enables students to go abroad and transfer credits from another university, for example by taking advantage of an ERASMUS scholarship or as part of the TUM exchange program.

Focus on Aerospace specific examples

Across the whole curriculum, students are immersed in an aerospace-specific learning experience. Starting with the 1st semester, the lecture „Introduction to Aerospace" allows students to identify, which professional areas may be of special interest to them by introducing practitioners from the aerospace industry along with researchers in different aerospace fields. It also makes sure that first-year students already start working and thinking with dedicated examples specific to the aerospace field. Since lecturers at chairs within the Department of Aerospace and Geodesy are responsible for most modules, the research examples and subjects of their teaching are usually centered on aerospace projects. This helps students to connect to their aerospace discipline and its specific set of challenges, even when learning about general engineering domains like Thermodynamics, Fluid Dynamics, Control Theory, Informatics and Electrical Engineering.

Practical application and building professional self-confidence

Throughout the program, students come into contact with each other as well as with the practical applications of the theory through group work and projects. The Introduction to Aerospace in the first semester, the Introduction to Geodesy in the third semester, and the dedicated Engineering Project in the fifth semester all offer students a possibility to take part in project weeks, which are an innovative way to foster interdisciplinary practical cooperation between students of multiple degree programs across the TUM.

To prepare students both for professional work in academic and industry positions, they have to complete an internship in their 5th semester as well as two Aerospace lab courses, the first one of which is offered by the Department of Aerospace and Geodesy and the second one is a free choice between practical courses from all engineering departments at the TUM.

A wide variety of student initiatives with successful teams gives further opportunities to engage with practical applications through competitions and building prototypes. Students at the TUM build everything from planes (AKAFlieg), satellites (WARR, MOVE projects), to Hyperloop pods, competing in international competitions and networking with industry professionals.

Finally yet importantly, the English teaching language means that students can expect a highly international cohort, which is the optimal preparation for an international professional environment with global links that come together in Munich.

Several organizations make sure that students have the possibility to meet and exchange ideas with industry professionals. Using case studies and guest lectures by researchers and professionals, students are challenged to put their own solutions to the test and develop a critical and practical understanding of their potential role in the aerospace field.

7 Organization and Coordination

The Bachelor's program Aerospace is offered by the department of Aerospace and Geodesy. The Department's lecturers also offer the majority of both required and elective modules for the program. The Department of Mathematics, the Department of Mechanical Engineering, and the Department of Electrical Engineering contribute additional modules.

The Aerospace program is part of the system accreditation process of the TUM, which ensures that the program complies with the TUM standards of teaching quality. Part of this quality management process are regular quality management circle, student evaluations, and regular reviews of feedback for the program.

An aptitude assessment committee conducts the admission's procedure to the program and is formally responsible for the selection and admission of students. The program coordinator at the Academic Programs Office supports the committee.

The following administrative tasks are performed partly by the TUM Center for Study and Teaching (TUM CST) and its administrative units, partly by offices in the schools or departments:

Student Advising:	Student Advising and Information Services (TUM CST) Email: studium@tum.de Phone: +49 (0)89 289 22245 Provides information and advising for prospective and current students (via hotline/service desk)
Departmental Student Advising:	studiendekanat@lrg.tum.de
Academic Programs Office	studiendekanat@lrg.tum.de
Study Abroad Advising/Internationalization:	TUM-wide: TUM Global & Alumni Office internationalcenter@tum.de Departmental: Mr. Daniel Hartenstein, M.A.; daniel.hartenstein@tum.de
Gender Equality Officer:	TUM-wide: Dr. Eva Sandmann sandmann@tum.de, Tel. +49 (0)89 289 22335 Departmental: Prof. Martin Werner
Advising – Barrier-Free Education:	TUM-wide: Service Office for Disabled and Chronically Ill Students (TUM CST), Email: Handicap@zv.tum.de Phone: +49 (0)89 289 22737 Departmental: studiendekanat@lrg.tum.de

Admissions and Enrollment:	Admissions and Enrollment (TUM CST) Email: studium@tum.de Phone: +49 (0)89 289 22245 Admissions, enrollment, Student Card, leaves of absence, student fees payment, withdrawal
Aptitude Assessment (EFV):	TUM-wide: Admissions and Enrollment (TUM CST) Departmental: studiendekanat@lrg.tum.de
Semester Fees and Scholarships:	Fees and Scholarships (TUM CST), Email: beitragsmanagement@zv.tum.de
Examination Office:	Central Examination Office (TUM CST), Campus Munich Graduation documents, notifications of examination results, preliminary degree certificates
Departmental Examination Office:	Mr. Daniel Hartenstein, M.A., Ms. Isabelle Canchila Acuña studiendekanat@lrg.tum.de
Examination Board:	Examination Board Aerospace
Quality Management – Academic and Student Affairs:	TUM-wide: Study and Teaching – Quality Management (TUM CST), https://www.lehren.tum.de/startseite/team-cst/ Departmental: Dr. Robert Graner; E-Mail: robert.graner@tum.de (QM Circle, Course Evaluations, Module Management) Dean of Studies: Mr. Prof. Dr. Klaus Drechsler

8 Enhancement Measures

The program is part of the TUM's system accreditation and quality management process. It therefore uses regular course evaluations, student feedback meetings, and quality circles with students as well as regular involvement of professionals from research and industry from outside the TUM to look for potential improvements and further development of the degree program.

The lecturers as well as the administration at the Academic Programs Office of the Department of Aerospace and Geodesy are in close and frequent contact with the student body representatives to fix issues that arise throughout each semester.