SD2900 Fundamentals of Spaceflight, 7.5 credits

Course Handbook 2020

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Contents

About this course

Space technology plays a key role in modern society, enabling space exploration, Earth observation, telecommunication and navigation services, weather forecasting and much more. The purpose of this course is that you should develop a basic working knowledge in this field, so that you are well prepared for more advanced courses and are able to actively participate in a space related context. The course mainly focuses on your conceptual understanding and your abilities to tackle an engineering task, to communicate your results effectively and to interact with others.

Learning objectives

After completing course the student should be able to

1. Demonstrate broad knowledge and understanding of the scientific basis and proven experience in spaceflight, as well as insight into current research and development work.

2. Demonstrate basic methodology and understanding of spaceflight, including launcher dynamics, orbital mechanics, manoeuvres and relative motion in orbit.

3. Demonstrate the ability to critically, independently and creatively identify, formulate and manage a geocentric space mission with a holistic view.

4. Demonstrate the ability to analyse and critically evaluate various technical solutions for a geocentric space mission.

5. Demonstrate the ability to plan and, with adequate methods, carry out a feasibility study of a geocentric space mission within given frames and to evaluate this work.

6. Demonstrate the ability to critically and systematically integrate knowledge from previous courses in order to analyse, assess and deal with complex phenomena, problems and situations in spaceflight, even with limited information.

7. Demonstrate the ability to model, simulate, predict and evaluate spacecraft behaviour from launching to rendezvous with other spacecraft, even with limited information.

8. Demonstrate the ability to develop a geocentric space mission, including technical solutions, with regard to people's conditions and needs and society's goals for economic, social and ecologically sustainable development.

9. Demonstrate ability for teamwork and collaboration in culturally mixed groups.

10. Demonstrate ability to clearly present and discuss engineering conclusions and the knowledge and arguments behind them, in dialogue with different groups, orally and in writing, in international contexts.

11. Demonstrate the ability to make judgments with regard to relevant scientific, societal and ethical aspects when choosing technical solutions for a geocentric space mission.

12. Demonstrate insight into the opportunities and limitations of spaceflight, its role in society and people's responsibility for how it is used, including social and economic aspects as well as environmental and work environment aspects.

For the highest grades, the student should also be able to

13. Demonstrate in-depth methodology and understanding of spaceflight.

14. Demonstrate the ability to identify his or her need for additional knowledge in spaceflight.

Prerequisites

You should preferably have knowledge in calculus, linear algebra, numerical methods, mechanics and fluid mechanics. Experience of programming in Matlab is an advantage too.

Teachers

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Literature

The course is based on the third edition of the book *Spaceflight Dynamics* by William E. Wiesel [1]. The book will be used extensively in the course. One compendiums will be provided in electronic form, *How to Write a Paper* by Mike Ashby [3]. It is recommended that you purchase the course book from the Student Union Bookstore: Kårbokhandeln Drottning Kristinas väg 19, https://www.karbokhandeln.se.

Forum

The new KTH learning management system *Canvas* will be used in the course. Once registered to the course, you can access the spaceflight activity at

https://kth.instructure.com

using your KTH login. How to use the forum will be demonstrated in class.

Computer resources and Matlab

No dedicated computer resources are provided in the course. Instead, each team is expected to work out a feasible solution using available computers at campus or your own laptops. If you are not familiar with Matlab (an interactive system for doing numerical computations), it is recommended that you get familiar with it as soon as possible. It will be very useful in the project assignments in this course as well as in many other courses at KTH (and likely in your future career). Matlab will not be taught in class, but good material is available on-line[1]. You may also complete the course SD1105 Matlab (3 credits) by performing an individual assignment in Matlab. Please contact Ulf Carlsson (ulfc@kth.se) at the Engineering Mechanics Department for more information about this opportunity.

Teaching and learning

In this course, your learning will be facilitated by a peer learning approach similar to the one described in [4]. The objective is to enable a natural and creative learning environment that hopefully leads to a deeper learning experience and at the same time develops some of your personal and interpersonal skills. You will therefore be part of a learning team, formed by four or five students. Each learning team will meet several times per week to engage with the course material and collaborate on different project tasks. The learning team activities are central parts of the course, and are described in more detail in the following. The main task for you and your learning team is to engage with the content of each cycle in five successive ideal steps:

1. In the first step, you prepare yourself by reading the sections in the course textbook or lectures slides (if available) before the lecture and ideally carrying out some homework on-line in the system *Möbius* (accessed from *Canvas*). Based on this, you should also identify a main insight and a main difficulty that you would like to discuss with your learning team.

[1] https://www.mathworks.com/content/dam/mathworks/mathworks-dot-com/moler/intro.pdf

2. The second step is flipped classroom lecture by GT. The purpose of the lecturing is not to teach all the technical details in the book, but to emphasize principles and models through multiple choice questions with the Mentimeter software. The flipped classroom lectures constitute important formative feedback.

3. The third step is a 1–2-hour **discussion** with your learning team during a workshop. The ambition here is to have a fruitful discussion about the insights and difficulties that are brought to the meeting, e.g. from the flipped classroom lecture. It is suggested to start and end the meeting with a round that allows each team member to speak in turn. More on team organization, responsibilities and reporting later on.

   Very important: This session should focus on understanding of the principles and models currently dealt with. You should not only perform project work at the workshops!

4. The final step is a **project workshop** with your learning team. At times, GT will be present to provide some feedback and support during the workshops. Note, however, that this session alone will not be sufficient to carry out all the project work. You will have to meet and work on the project outside of class too.

The described process can be interpreted in terms of an experiential learning cycle that stimulates learning through experience, reflection, conceptualization and active experimentation [4]. Different people have different learning styles. Some learn from lectures, others from reading, discussing, solving problems or from case studies. This course is designed to offer various opportunities for learning, with less lectures and more discussions and project work as a result. Another benefit of this approach is that you (to some extent) can influence the focus of the course. With this follows a responsibility for your own learning. Your home team has to consider that all the material in the book cannot be treated in class and you have to agree on what is the most essential to bring up. GT and the guest lecturers will mainly provide structure, coaching and expertise to the process to support your learning.

The technical work in the course mainly consists of a project assignment. The ambition is to offer a challenge that is related to a topic of current interest in the space community. It is also possible to explore a topic of your own; as long as the corresponding learning objective can be reached (the same grading criteria will apply). This means that the focus of the course can differ somewhat from one year to the next, and between different teams. From a learning point of view, the project work allows for training of engineering as well as personal and interpersonal skills, and is thus a very important part of the course. The project assignment(s) will be handed out separately. There will also be additional feedback and inspiration in the form of guest lectures, some of them related to the project assignment and some of a more general character.

Program

The bulk of the course is based on **Chapters 1, 2, 3, 7, 8 and 9** in Spaceflight Dynamics by William Wiesel. All of it is relevant and interesting reading. However, some sections are emphasized in order to keep the course focused, see Table 1. You must work out solutions to the problems on the on-line system *Möbius* (accessed from *Canvas*). This will be particularly fruitful if other team members work on the same problems (you can then compare and discuss the results).

Table 1: Content of the modules.

Topic	Readings	Problems
Rocket performance	1.1−1.2, 7.1−7.4, 7.8	Möbius
Rocket dynamics	1.3-1.5, 1.7, 7.9−7.10, 9.1−9.2, Ashby	Möbius
Orbital mechanics	1.9−1.10, 2.1−2.5, 2.7, 2.9, 9.3−9.9*	Möbius
Satellite operations	3	Möbius
Reentry dynamics	8 + additional literature	Elective
Clean Space	Additional literature	Elective

*Sections 9.3-9.9 can be read briefly as an orientation.

The overview lectures, guest lectures, learning team sessions, class seminars and project workshops will take place according to the schedule (*Syllabus* in *Canvas*).

Formalities

To be approved at the course (grade E) you are expected to

1. Participate in the teamwork activities by carrying out preparatory homework, participating in the discussions, and sharing your team's responsibilities,

2. Contribute to an approved project work, that is presented by your team in a written paper and at a student conference, respectively, and

3. Show that you have acquired adequate theoretical skills in spaceflight dynamics according to the grading criteria.

Accordingly, the criteria in Tables 4−8 will be used to settle your course grade based on

1. If you have been active or passive in the project work (checked by peer evaluation),

2. The quality of your team's project work (according to detailed criteria),

3. Your results at the online *Möbius* homeworks,

4. Your result at an online concepts test and optional oral concepts test,

5. Your result at an optional oral dissertation.

A simple point system is used to make the grading system as clear as possible. For the individual parts (the concepts tests and the oral dissertation) the result "not approved" gives 0 points, "approved" gives 1 point and "approved with honors" gives 2 points. So, maximum 4 points in total for the individual parts. An "approved" project work (technical work in the paper as well as presentation) is required to pass the course. An approved project, both written paper and presentation, will give 1 point to each team member. A project with "approved with honors" for both the paper and presentation part, will give 2 point each to all team members. If one of the parts, technical or presentation, is awarded "approved" the final grade on the project will be "approved", i.e. 1 point per team member. So, maximum 2 points per team member depending on the quality of the project work. In order to make the grading as fair as possible, the different points are added and the course grade is set according to Table 2.

Table 2: Course grade depending on total points.

Points	Grade	Meaning
6	A	Excellent
5	B	Very good
4	C	Good
3	D	Satisfactory
2	E	Sufficient (see below)

In addition, the following criteria apply:

- At least two individual points (from online concepts test and Project) are required for the pass grade E.

- The result "approved with honors" is reserved for original work. If some aspect of the project work is "not approved" in the first iteration your team has to perform additional work in order to satisfy the criteria of the "approved" level.

- If the peer evaluation indicates that you have not contributed in the project work, you may get a lower final grade. This outcome is treated on a case-by-case basis, and depends on the actual circumstances.

- If there is no doubt that you have been passive in the project work you will receive the final grade F (regardless of your individual grade). If you have not participated actively in the project work, you can obviously not reach the corresponding learning objectives. This outcome is treated on a case-by-case basis, and depends on the actual circumstances.

- The given grades A−E and F are final, it is not possible to re-take an exam, etc. in order to obtain a higher course grade.

Table 3 summarizes the grading in the course.

Table 3: How to achieve "grade points"

Points	Examination	Condition
1	Online concepts test	*Möbius* problems on Pass/Approved level completed before online concepts test
1	Oral concepts test	*Möbius* problems on Honors level completed before oral concepts test
1−2	Project work	
1−2	Oral dissertation	

The message of the given criteria is simple: focus on the course activities and to learn from them. Once you reach the learning objectives, you will be approved and get a fair grade. Just like that. If you have a high ambition in the course the following advice is very useful: the best possible way to prepare for the exams is to participate in the learning team discussions. Or, as stated in a saying: to teach is to learn twice. If you help your home team to understand different matters, you will at the same time improve yourself and obtain even better results in the course. In summary: you should only take this course if you want to learn something. Get involved in the home team activities, have fun and learn a lot. By the way, you will get some points for your effort (and a grade too!).

Teamwork

In this course you will be part of a cross-cultural team of four or five students. As described in the section about teaching and learning, you will for example meet on a weekly basis to discuss the content of the current learning cycle. But you will also work on a project task together. The project work will require a number of different competencies, such as management of the work; searching for relevant information; developing a feasible approach to the problem; performing numerical analysis in Matlab; writing a paper or preparing an oral presentation.

Naturally, different team members will bring different knowledge and skills to the table. In this course, you are encouraged to exploit these competencies in the way you think it will benefit the project the most. It is perfectly all right to split the work based on your weaknesses and strengths, as long as everybody contributes in an active and meaningful way, and that everybody can account for most of the work performed by the other team members. In this way, it is hoped that the project work will become a more inclusive and joyful experience.

The home teams will be formed by GT. To give the teamwork some structure, two of the team members will act as chairperson and secretary. A new chairperson and secretary will be appointed in each cycle, so that all team members are given opportunity to practice in these positions.

Table 4: Criteria for the technical part of the project work.

Results	Criterion
Honors	Your technical work is based on correct principles and has a creative and investigative character. Due to this, elements of more advanced/accurate modeling and/or value-adding research are typically present. Overall, your technical work is focused and relevant in relation to the project description. Assumptions and approximations that underlie the theoretical models are clearly accounted for. Your engineering solutions are credible from an implementation point of view, and your computational results make engineering sense.
Approved	Your technical work is based on correct principles but has a somewhat restrained character. Due to this, elements of more simple/crude modeling and/or a shallow treatment of some relevant aspect of the mission are typically present. Overall, most of your technical work is focused and relevant in relation to the project description. Your engineering solutions are reasonably credible from an implementation point of view, and your computational results make engineering sense subject to the assumptions made.
Not approved	Your project work does not meet the given criteria for approval in one or several aspects. For example, your work may be based on principles or models that are not correct or applicable in the present context, or your results do not make engineering sense.

Table 5: Grading criteria for presentation part of the project work.

Results	Criterion
Honors	Your approach, results and conclusions are presented in a complete, concise, coherent and well-structured engineering paper that clearly meets the professional standard that is communicated in Ashby [3]. The review criteria in Table 8, as well as relevant peer feedback, have clearly been taken into consideration when preparing the final version of the paper. Your presentation at the project conference is characterized by a distinct and appealing layout, an evident structure and a proper amount of clearly visible information that is delivered on time.
Approved	Your approach, results and conclusions are presented in a complete and well-structured engineering paper that in most aspects meets the professional standard that is communicated in Ashby [3]. The review criteria in Table 7, as well as relevant peer feedback, have been taken into account when preparing the final version of the paper, but perhaps only to some extent. Your oral presentation at the project conference is characterized by an adequate layout, a suitable structure and a reasonable amount of information that is delivered on time.
Not approved	The presentation of your project work does not meet the given criteria for approval in one or several aspects. For example, some vital part of the paper is missing, such as the abstract, the introduction, separate conclusions or references.

Chairperson

The main responsibilities for the chairperson are to:

- Initiate the meeting with a round so that everybody is allowed to speak,
- If necessary, pass the word around during the discussion,
- Bring the discussion back on track if too much time are spent on a minor issue,
- Make sure that the team agrees on one main insight and one main difficulty to be reported in the minutes of the meeting (see below),
- Conclude the meeting with final round.

Secretary

The main responsibilities for the secretary are to:

- Take notes during the session, and

- **Write a set of meeting minutes in the Meeting Minutes log book immediately after the meeting.**

The meeting minutes can be very brief, but should at least cover today's date, the name of the home team, meeting participants, a short summary of the discussion in the home team, the team's main insight and difficulty, and a note on the next meeting. **Please use the following lines as a template for the meeting minutes, and write them in plain text directly in the log book:**

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TITLE FIELD:

The Astronauts - September 4

ENTRY FIELD:
Present:
Valentina Teresjkova (chairperson)
Christer Fuglesang (secretary)
Neil Armstrong
Jurij Gagarin

Absent:
Buzz Aldrin (alien virus)

Main discussion:
At this first meeting we first introduced ourselves to one
another, and briefly shared our experiences of group work. We
then started the meeting with a round where we in turn presented
our impressions of the reading. The discussion that followed
focused on the derivations and meaning of the thrust and rocket
equations, respectively. The physical significance of the
specific impulse, the effective exhaust velocity, and the
various mass and structural ratios were discussed as well. We
then agreed on what we considered to be the main insight and
main difficulty of this learning cycle. The session was concluded
with another round to summarize our impressions. Overall, it was
a good discussion.

Main insight:
That it is only the initial and final mass of the propellant
that determines the dV (for a given Isp), but that a different
burn rate will result in a different acceleration profile.

Main difficulty:
We could not quite understand why the mass flow rate dm/dt of
the propellant can be assumed to be constant in the derivation
of the thrust equation.

Next meeting:
Date: September 9
Time: 10.15
Chairperson: Christer Fuglesang
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`Secretary: Neil Armstrong`

Table 6: Grading criteria for the online and oral concepts tests.

Results	Criterion
Honors (oral test)	You are able to apply fundamental principles in order to explain the governing dynamics of spaceflight, with emphasis on rocket dynamics and basic orbital mechanics.
Approved (online test)	You are able to apply fundamental principles in order to explain the governing dynamics of spaceflight, with emphasis on rocket dynamics. You show this by having more than 1/2 correct answers on the online concepts test.
Not approved (online test)	You are not able to apply fundamental principles in order to explain the governing dynamics of spaceflight. You obtain this result by having equal to or less than 1/2 correct answers on the online concepts test.

The first meeting

At the first meeting, you will mainly get acquainted with your team, share some experiences and agree on a set of ground rules for your teamwork. It is suggested that you start the meeting by introducing yourself to one another, and perhaps share some thoughts about the course. Be sure to acknowledge the chairperson and secretary of the meeting, and that you are all familiar with their responsibilities.

Your different cultural backgrounds and experiences can lead to different assumptions and expectations in the teamwork (at least initially). In turn, this can give rise to cultural clashes and conflicts that occur just because we are not aware of our differences [6]. In this course we will try to improve our awareness of cultural differences in a supportive and friendly environment. Please consider the following questions:

- Do you have any joyful of painful teamwork experiences (mono-cultural or cross-cultural) that the team can learn from?

- Can you spot any interesting trends in the results of the questionnaire? What conclusions can you draw from these?

- How can we develop a "cultural repair" perspective? This means to develop an understanding and acceptance of other cultures (which is different from knowing everything about them!), in order to learn strategies for managing diversity in a sensitive way [6].

It can also be very helpful to agree on a set of ground rules for your teamwork through a "contract" or "agreement". You may pick and choose from these rules or, even better, draw up your own list. However, one ground rule should be included for all teams (based on feedback from previous students):

- **During team sessions, *all* communication must be in English.**

A short summary of your discussion and a bullet list with your main observations, conclusions and ideas should be documented in your first set of meeting minutes in the log book. Your ground rules should be included in the contract you will sign at the end of the first week!

Towards the end of a "regular" team discussion (where you will focus on theory and conceptual understanding), you should not forget to allow time for a final round and to agree on your team's main insight and main difficulty in the learning cycle. Note that the main insight/difficulty should preferably be related to the principles and concepts that are discussed in course (in order to keep focus).

Project

In order to train some of your engineering as well as personal and interpersonal skills, you and your team will be engaged in a rather challenging project work in the course. To make the project task as interesting and relevant as possible, it is typically related to a "hot" topic in the space community. The problem formulation is intentionally open-ended to allow for elements of creativity and exploration. Initially, it is therefore critical that your team agrees on a manageable scope in order to meet the main objectives within the given time frame. It is also important to note that the project concerns a feasibility study on the conceptual level. Consequently, you should focus on the overall sizing, mass budget, ΔV budget, etc. of the system/vehicle/mission, rather than detailed design and drawings of hardware (unless you have the time and skills, etc.).

It is strongly recommended that you survey the knowledge and skills that you possess in the team, and create a first model/mission based on that. What type of model can you reasonably develop based on your capabilities and the time that you are willing to invest? Will the planned outcome meet the criteria for an approved project in Table 4? If everything works out and if you have time: how can the model be improved?

The result of the project work should be presented orally at a project seminar and in the form of a short engineering paper, respectively. To support you in this process, some emphasis will be put on project management in the beginning of the course. You will begin this work on your own in the first learning cycle, and then get more input during the second cycle. In the beginning of the third learning cycle you should hand in a Work Breakdown Structure (WBS) that will allow for planning and feedback in an early phase of the project (we will discuss this during the guest lecture on project management).

The WBS should be labeled as "yourteam-wbs.pdf" (for example "darthvader-wbs.pdf") and uploaded in pdf format in *Canvas* no later than the agreed deadline.

Paper

As mentioned above, the results of the project should be presented in the form of a short engineering paper. The paper should be written in English and include a title, the names and a KTH address of the authors (see the sample papers), an abstract, an introduction, suitable sections for the technical part, and separate conclusions and references. The length of the paper must not exceed 10 pages (including everythin, e.g. list of references and appendices), using the IEEE paper template. The paper must also have a section "Division of work between authors" that accounts for the contributions of each team member to the project work. For example:

> **Valentina Teresjkova** posed the equations of motion in a form suitable for numerical integration, implemented the result in Matlab and performed the numerical computations. She also wrote parts of the paper, in particular the section about the results of the numerical analysis and the conclusions.

To support you and your team in this effort, references are provided. The most important is a very good text by Ashby [3] about how to write a paper. In addition, a few sample papers from previous work in the course is provided. When writing the paper, it is also useful to consider the criteria in Table 8 and the separate detailed check list and evaluation criteria.

A good paper is rarely written overnight. On the contrary, it is typically a result of an iterative process taking successive feedback into account over several days or sometimes even weeks. It is therefore important to start writing at an early stage of the project. This will also allow for early feedback on your work, that can be used to improve the paper as well as the technical work. You will therefore write three successive versions of the paper as described in the following.

Concept sheet

Following the advice given in Ashby [3], the first version of the paper is equivalent to Ashby's "Concept Sheet". This is in accordance with the golden rule of writing: think first, then write. There is no point in writing a lot of text and equations, producing figures and graphs, etc. before your technical results have converged. But to identify the content that you really need from a concept sheet can save you a lot of time and effort and at the same time improve quality. This is essentially a Work Breakdown Structure applied to your writing process. This version will be reviewed by GT, in order to provide some early feedback.

The concept sheet of the paper (Note: only 1 A4 page) should be labeled as "yourteam-concepts-sheet.pdf" (for example lostinspace-concepts-sheet.pdf) and uploaded in pdf format in *Canvas* no later than the agreed deadline.

Draft version

The draft version of your paper should be as complete as possible and reflect what you have in mind for the final version. Again, this will allow for more relevant feedback that you can use to improve the paper until the final version. This version will be exposed to a peer review process, where two different teams review each other's papers and provide written and oral feedback to each other (more on the peer review below).

The draft version of the paper should be labeled as "yourteam-draft-paper.pdf". (for example "lostinspace-draft-paper.pdf") and uploaded in pdf format in *Canvas* no later than the agreed deadline.

Peer review

The home teams will be utilized to perform a peer review of the second version of the paper. This exercise aims at improving your ability to write a paper, to review engineering work, and to give constructive feedback. Of course, the peer review is also meant to stimulate further insight and learning about spaceflight dynamics.

First step

The first step of this process is an individual review of the paper that has been assigned to your team (it will be available in your team's documents folder in *Canvas*). First review the paper on your own using the evaluation criteria, Table 7. Then write a short feedback with reference to the given criteria, telling what strengths and possible areas of improvement the paper have from an engineering as well as writing point of view. It is suggested that you use the provided peer review form (also available in *Canvas*) to summarize your feedback.

Second step

In the second step of the process, you should bring your peer review form to a home team session. At this session, your team should discuss the quality of the different aspects of the paper (technical work, content, style and overall impression) and upload a summary of the most relevant feedback in *Canvas*. In order to make the feedback more effective, try to avoid being too detailed and to provide constructive advice for improvement (example: instead of writing that the abstract is just crap, explain what the purpose of the abstract is or provide a reference that explains this). To give constructive feedback is not necessarily an easy task [2], but the basic principle (according to GT) is: instead of just pointing out all negative aspects of the work, first highlight the good aspects of it and then deliver the bad news as suggestions for improvement (in a gentle manner).

The written feedback should be structured according to the given criteria (technical work, content and style), and uploaded in pdf format in *Canvas* no later than the agreed deadline. Please label your documents according to "yourteam-review-of-otherteam.pdf" (for example "lostinspace-review-of-darthvader.pdf"). Note that the quality of the provided feedback will be considered in the review of the overall project work (it is a team responsibility).

Table 7: Criteria for the review of your paper.

Technical work
Are all major aspects of the project description treated? Is there a valid reasoning used, and does it show an apparent understanding and grasp of the subject? Does the work even show some originality and imagination? Are conditions, approximations and assumptions clearly stated? Are governing equations included, and are they valid for this problem? Are appropriate methods used for solving the equations, and are they suitably explained? Does the technical work appear to be correct, or at least reasonable? If some results are obviously not realistic, have the author commented on this? Are the validity and accuracy of the results motivated? Are an appropriate number of figures used when presenting numerical or experimental results? Are the conclusions reasonable and relevant in relation to the project description?
Content
Is the title meaningful and brief? Does the abstract cover the motive, method, key results and main conclusions of the work? Does the introduction communicate why the topic is interesting or important, who have contributed what in the past, and the purpose of the present paper (alternatively, a historical background and/or important applications of the technology)? Does the paper have an apparent and natural structure that helps the reader to keep track? Are theory/methods and results presented in separate sections? Are the section headings meaningful and brief? Is the content relevant and concise, or can some parts even be omitted without losing quality? Does the level of detail stand in reasonable proportion to the results and conclusions that are reported? Are the most important results drawn together in a separate section with conclusions? Finally, are sources of previous work, theories, methods or data cited in a concluding list of references?

Style
Is the paper written in commendable English and does it present the material in a clear and apparent form? Does the introduction have a good first sentence? Is the spelling correct? Are figures and tables clear, easy to read and properly integrated in the text? Are figure and table captions meaningful and brief? In graphs: are axes properly labeled, units well defined and a readable font size used? Are equations suitably formatted and properly presented in the text? Are all properties in the equations defined in the text? Are pages, figures, tables and equations numbered? Is the list of references complete and properly used in the text?
Overall impression
What is your overall impression of the paper? What was the main point that the authors tried to convey? What did you like the most about the paper? What did you like the least? If the authors have additional time to work on the paper, what would you mainly recommend them to improve?

Third step

Finally, you will have a meeting with your partner team in order to explicate and discuss your different reviews (your review of their paper, and their review of your paper, respectively). Of course, this is also a good opportunity to discuss the project work as such. There is no particular agenda or organization for this exchange of feedback; this is something that you need to agree upon in the beginning of your meeting. It is, however, expected that you give each other *constructive* feedback in a gentle and respectful manner.

Conference

The project results should also be presented orally at a concluding student conference. At this conference, your team is expected to present a short background to the project, the main aspects that you have identified and addressed, the main assumptions and approximations that your approach is based on, and your main results and conclusions. Further, each team will be responsible for providing oral feedback to another team.

Structure and practicalities

At the conference, a 25 minutes slot is given to each team; 15 minutes, is dedicated to the presentation. The remaining 10 minutes are used for questions (3 minutes), preparation of feedback (5 minutes) and oral feedback (2 minutes). At the same time as the feedback is being prepared, the team that is up next must get ready to present. Note that this is a tight schedule, and that you must be well prepared and on time if this day will work out as planned.

The schedule for the conference will be handed out separately, telling when you are expected to present and give feedback, respectively. The conference will be divided into four sessions with four teams in each session. You must participate at the session in which your team is presenting, but you are allowed to participate at other sessions too (as audience). However, you are not allowed to enter or leave the room during a presentation. You must be in time when a presentation starts, and cannot leave the room until after the questions. At all times, you must enter or leave the room quietly.

Regarding who should present at the conference, your team has two options:

1. One team member gives the whole presentation. If you choose this option, the presenter will be chosen arbitrarily by GT at the conference. Thus, all members must prepare to give the whole presentation.

2. Two team members share the presentation equally. The team can select one presenter in advance, but the partner will be chosen arbitrarily by GT at the conference. Thus, all members must prepare to give half of the presentation.

Some teams will have listened to other teams' presentations before their own, and may therefore have gained some new insights about the project. This is of course a very desirable outcome of the conference, but it is important that you deliver your presentation just the way you planned it (without references to the other teams). Each team should be given equal opportunity to present their results, regardless of the conference schedule.

It is strongly recommended that you bring your own laptop with a properly working presentation. This usually works the best, because you then know that your presentation is compatible with the software. Although a backup laptop will be available at the conference, the likelihood of failure is higher using this option. Bring your presentation **in pdf format** on a USB memory stick if you intend to use the backup laptop. **Before each session, it will be possible to test that your presentation is working properly on your own laptop.**

About your presentation

To give an oral presentation is of course different from writing a paper. While the format of a paper is well defined and perhaps a bit dull, an oral presentation can be more colorful and entertaining. The challenge is to exploit the visual aids to amplify and "sell" your message to the audience, instead of (as in the worst case) making it drown in an ocean of visual impressions. To give a good oral presentation is not easy, and typically requires a lot of practice. In this course, we will start simple and try to learn as much as possible from each other when preparing and giving the presentations. In fact, a successful presentation relies a lot on thorough preparation. The actual delivery is of course important too, but is in fact only a part of it.

Similar to a paper, the structure of a technical presentation is characterized by a background, problem definition, approach, results and conclusions. Typically, you start out with a slide that contains the title of the work, the authors, the date and the particular event (the name of the conference). Then, it is common to give the audience an overview of the talk in the form of an outline (that may be re-visited or visible during the presentation). From there on, it is more individual, but most conference presentations are concluded with a slide that summarizes the main conclusions. An acknowledgment is sometimes included, but references are not.

At present, GT has not been able to find an equally good (and to the point) reference for preparing and giving an oral presentation as the one by Ashby for writing a paper [3]. Note, however, that the usefulness of the advice strongly depends on the context (how much time you have, the purpose of the presentation, the audience, etc.). In addition, you may consider the following advice:

- The "Concept Sheet" proposed by Ashby for writing a paper can also be applied to presentations. Meaning: first think about what you should present and why, then prepare the presentation. This can save you a lot of time and at the same time improve the quality of your presentation.

- Be sure that the information on the slides is clearly visible to the audience (also those sitting in the back). For example, this means that you must use an appropriate font size when writing text.

- Try to limit the amount of information on the slides as much as possible, and use the slides to help you keep track of where you are, what you intend to say, and where you are going.

- Do not include any information whatsoever on the slides that you do not intend to mention or use in some way. If you do not use the information, you can obviously remove it and make the presentation even more to the point.

- Try your best to speak loud and clear to the audience and not to the computer or the presentation. This is obvious, but is in fact quite difficult to remember once the presentation is running and you are (naturally) a bit stressed.

- Carefully plan how you intend to start and end the presentation, respectively. This is very often forgotten, and can for example leave an unnecessary atmosphere of uncertainty in the room (which reduces the overall impression, because the end of the presentation is the part that the audience has in fresh mind).

Giving oral feedback

As mentioned above, your team will be responsible for providing feedback to another team. A feedback form is provided for this purpose (available in *Canvas* and a printed copies at the conference). Three main aspects will be considered: the technical work, the slides and the oral delivery. To improve the quality of the feedback, it is suggested that different members focus on different aspects. Since you are at least four members you may, for example, have redundant monitoring of the technical work (that is likely the most difficult aspect to review). The feedback form is composed of a number of positive attributes that you can check during the presentation, as well as some room for comments. You are also expected to indicate your overall impression. In your opinion, is it a "not approved", "approved" or "approved with honors" type of work that the other team has accomplished?

After the presentation and questions, your team has about five minutes to share your opinions on the other team's work and prepare a short oral feedback. The feedback should be given on behalf of your team: rather use "we think..." than "I think..." when delivering the feedback. It suggested that one member begin by thanking the speakers for an interesting presentation (or using another suitable descriptor: entertaining, inspiring, etc.). Then, three different members give feedback on one main aspect each. Finally, yet another member concludes the feedback by summarizing your overall impression.

Peer evaluation

Previous students have in the course evaluations asked for peer evaluations of the project work. This will be introduced this year and is intended to prevent "free-loading" and to guide each student in a better way. In order to implement the evaluation criteria, a mid-term session with open evaluations will be performed. The final peer evaluation will be closed. For complete details, see the separate evaluation criteria.

Online concepts test and oral concepts test

The compulsory online concepts test is an individual open book exam in Canvas. No collaboration is allowed. The test is typically composed of 7 multiple choice type of conceptual problems. You must have 4 correct answers to pass the online concepts test. Note that you must complete all the Möbius homeworks on Pass/Approved level before the online concepts test.

The optional oral concepts test to get higher grades is also focused on conceptual understanding and back-of-the-envelope-calculations. Note that you must complete all the Möbius homeworks on Honors level before you can sign up for the optional oral concepts test.

Based on the compulsory preparatory homeworks in Möbius, your conceptual understanding of the following topics is typically emphasized in the test:

- Rocket thrust,
- Specific impulse,
- The rocket equation,
- Motion of single- and multistage rockets in force-free space,
- Impact of gravity and drag on the burnout speed of a sounding rocket,
- The gravity law,
- Equations of motion for an Earth satellite,
- Conservation of energy and angular momentum,
- Impulsive orbital transfers,
- The classical orbital elements and properties of elliptic orbits, and
- Close proximity relative motion due to impulsive maneuvers.

Oral dissertation

The course is concluded with an optional oral dissertation with emphasis on the ability to derive and explain more advanced elements of spaceflight dynamics. The oral dissertation is meant to be an opportunity for you to show what you have learnt about the advanced topics in the course; launcher dynamics, two-body orbital mechanics, low thrust orbital transfers and relative orbital motion, respectively. Therefore, the oral dissertation does not have the traditional format of a teacher asking questions and a student answering them. Instead, you will perform an oral dissertation with two other students and GT listening. At the dissertation, you have 15 minutes at your disposal to demonstrate that you have reached the second learning objective of the course, and to what extent in relation to the grading criteria (a whiteboard and a pen will be available). You have two options:

1. To select one of the advanced topics and focus on this particular one as presented in the Wiesel book and in the overview lectures. This means that you only have work with this particular topic when you prepare for the oral dissertation, the one that you find the most interesting yourself. This will be sufficient to satisfy the criteria for "Approved" at the oral dissertation in Table 8, but not "Approved with honors".

2. To accept the ultimate challenge in the course and investigate and synthesize a chosen subject matter a little more on your own. To make the chosen subject matter your own, and to feel it (either you do or you don't, and only you can feel this). For example, you may

investigate the following subjects in more detail: modeling and impact of earth oblateness on the two-body problem, more realistic pitch dynamics in the equations of motion for a launcher, how the different mathematical models are related to each other (what is the relation between the gravity turn equations and the two-body equations), gravity assisted maneuvers for a spacecraft, Lagrangian points, etc. Such an effort will make it possible to satisfy the criteria for "Approved with honors" in Table 6, but only if the given criteria are met at the oral dissertation (otherwise the "Approved" level will apply, of course). More examples of suitable topics for the oral dissertation will be provided in the preparation lecture.

When you arrive to the oral dissertation you are expected to tell before the start of your presentation which option you have selected, i.e. Approved or Approved with honors, and which topic you will present. Before your presentation you will be given 15 minutes to prepare yourself by, for example, writing some notes for the presentation. You are thus not allowed to use a pre-written set of notes, but are expected to know the stuff well enough to tell your own story about it. Each presentation will be followed by a 10 minutes discussion, where the presenter should be able to answer questions from the audience, i.e. fellow students. By asking relevant and insightful questions and participating in the discussion that follows, each participant will thus be able to show that the different topics are well understood. GT will intervene and ask questions if necessary. In order to document each participant's contributions at the dissertation, GT will take notes during the session. Finally, GT will summarize his impression and inform the participants about their result according to the grading criteria. In total, the session with three students will take about 1 hour and 30 minutes. In order to distribute your workload, it is strongly recommended that you prepare your dissertation successively in the course. In 15 minutes, you will not be able to present more than a couple of handwritten pages of text and equations (and the 15 minutes limit will be strongly enforced at the oral exam!). The challenge is thus to present the chosen subject matter in a coherent and well-reasoned manner, and at some point(s) demonstrate the depth of your skills. You should thus prepare a presentation that you feel comfortable with, so that it reflects your own ambition at the dissertation. Again, the dissertation is meant to be an opportunity for you to show what you have learned.

The place of the oral dissertation will be announced later. Please respect the slot that you have been assigned (the schedule will be available in *Canvas*) and show up on time!

Table 8: Grading criteria for oral dissertation. The mathematical models that are emphasized in the course are those of launcher trajectories, two-body orbital mechanics, relative orbital motion and low-thrust orbit transfer, respectively.

Results	Criterion
Honors	You are able to derive, relate and/or develop the mathematical models of spaceflight dynamics that are treated in the course, and thus show a willingness and ability to investigate and synthesize the subject matter on your own. Your presentation at the oral dissertation is on time, almost invariable clear, coherent and well-reasoned, and constitutes a personal account of the chosen subject matter. Premises in terms of fundamental principles and assumptions that underlie your argumentation are clearly stated, and properly posed questions are answered in a straight and aware manner. You participate actively during the session by paying attention to the other candidates' presentations and by asking relevant and well-reasoned questions.
Approved	You are able to derive and explain the main characteristics of at least one of the mathematical models of spaceflight dynamics that are emphasized in the course (a topic that you prefer). Your presentation at the oral dissertation is

	clear and coherent in most parts, and treats the chosen subject matter in an intelligible manner. Premises in terms of fundamental principles and assumptions that underlie your argumentation are typically but not always stated, and most of the properly posed questions are answered in an adequate manner. You participate actively during the session by paying attention to the other candidates' presentations and by asking relevant questions.
Not approved	Your effort at the oral dissertation does not meet the given criteria for approval in one or several aspects. For example, you may not be able to explain how a particular mathematical model originates from fundamental principles, or are unable to answer properly posed questions in an adequate manner.

Preparatory homework

Note that the homework described below defines a baseline that is meant to help you to focus on the most essential aspects of the course. You are strongly encouraged to read additional sections in the book (the whole book is relevant and interesting). Note that it is mandatory to solve the Pass/Approved level homeworks problems in the system *Möbius*. It will be particularly fruitful if you do this in collaboration with your team or other course participants.

Rocket performance

- **Main focus**: thrust equation, specific impulse, rocket equation, single- and multistage performance, rocket motion in free space.
- Read sections 1.1−1.2, 7.1−7.4 and 7.8 in the book.
- Derive the equation of motion for a rocket in free space using the momentum principle.
- Based on this result, define and explain the thrust equation.
- Define and explain the physical significance of I_{sp}.
- Derive and explain the rocket equation.
- Explain the basic principle of rocket staging.
- Derive an expression for the burnout velocity of a serial multistage rocket by defining suitable mass ratios for the different stages.
- Explain the characteristics of an optimal multistage rocket, assuming that each stage uses the same propulsion and structures technology.
- Prepare for the home team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.
- Assuming a structural technology defined by ε and a propulsion technology defined by I_{sp}, derive expressions for m_s and m_p of a booster that can accelerate a payload with mass m_* from rest to a burnout velocity V_*.
- Solve a couple of problems in the book, preferably selected by your learning team.

Rocket dynamics

- **Main focus**: the atmosphere, impact of gravity and drag on burnout speed, equations of motion in two dimensions, the local-horizon frame, decomposition of acceleration vector, gravity turn trajectories.
- Read sections 1.3−1.5, 1.7, 7.9−7.10 and 9.1−9.2 in Wiesel (the theory sections in Chapter 1 mainly serve as a background to the round Earth reference frame used in section 7.10).

It is also time to start reading the text “How to write a paper” by Mike Ashby (available in *Canvas*).

- Derive the hydrostatic equation and show that the air density will depend exponentially on the altitude if the atmosphere is assumed to be isothermal. Explain how gravity and drag influence the thrust program of a sounding rocket.
- Explain how the inertial acceleration vector can be decomposed into components along and transversal to the velocity vector (using the speed $V(t)$ and the flight path angle $\gamma(t)$ as degrees of freedom).
- Use this result to pose the equations of motion for a gravity turn trajectory in state-space form, and use these to explain the main characteristics of the dynamics (a flat-Earth treatment is sufficient here). What is the main advantage of a gravity turn trajectory?
- Explain how a round-Earth perspective can be taking into account using the local-horizon frame, and how the corresponding equations of motion differ compared to the flat-Earth case.
- Prepare for the home team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.
- Solve a couple of problems in the book, preferably selected by your learning team.
- **Advanced level**: carefully review the theory of gravity turn trajectories, with focus on the criteria for the oral dissertation.

Orbital mechanics

- **Main focus**: Newton’s law of gravity, equations of motion for the two-body problem, conservation of energy and angular momentum, characteristics of the orbital and trajectory solutions and how to write a paper.
- Read the remainder of chapter 9 as an orientation about “space as a place”. You may distribute this reading over this cycle and the next. Then read sections 1.9−10 about energy and angular momentum for one particle. If you have time, 1.11−14 are also relevant. Next, sections 2.1−2.5 about the two-body problem are important, as well as section 2.7. The rest of chapter 2 is also relevant but you should at least read 2.9 (because it's interesting). You should also finish the text by Mike Ashby during this cycle.
- Pose and explain Newton's law of gravity.
- Pose the equations of motion for the two-body problem and show that the center of mass of the system moves in a straight line at constant velocity.
- Derive the relative equations of motion for the two-body problem and define the different parameters.
- Show that the specific energy and angular momentum of a satellite are conserved. Explain the physical significance of these results.
- Review the derivation of the orbit equation (2.29), and describe the different orbits and trajectories that it can represent (the conic sections).
- Review the derivation of the total energy (2.36) and the period (2.37) of a closed orbit.
- Explain the purpose, outline and content of a scientific/engineering paper.
- Prepare for the home team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.
- Solve a couple of problems in the book, preferably selected by your learning team.
- **Advanced level**: carefully review the theory of two-body orbital mechanics, with focus on the criteria for the oral dissertation.

Earth satellite operations

- **Main focus:** transfers between two co-planar circular orbits, inclination change maneuvers, launch to rendezvous, relative motion from a two-body perspective, low-thrust orbit transfer and lifetime decay.
- Read chapter 3 in Wiesel, and the remainder of chapter 9 (if you have not completed it). Sections 3.1−3.3 are central and straightforward. In section 3.4 you should understand the ground trace and why a launch to a certain orbit plane can only occur twice a day. In section 3.5 the main challenge is to understand the dynamics in the different perturbation coordinates using a two-body interpretation of the relative motion. Sections 3.6−3.8 are also relevant, review the derivations and the significance of the results (note that 3.7 is quite difficult to understand due to a too compact presentation).
- Derive the ΔV's for a Hohmann transfer between two circular orbits using results from the two-body problem.
- Derive the ΔV required for a pure inclination change Δi. Use the result to explain why an inclination-change maneuver is so expensive.
- Explain what a ground trace is and why a launch to a certain orbit plane can only occur twice a day.
- Explain the dynamics of the relative motion between a target in circular orbit and an orbiter in a 'close' elliptical orbit.
- Review the approach that is used to perform analysis of decay lifetime and low thrust orbit transfers, respectively.
- Can you explain how the Earth's equatorial bulge can produce the orbital perturbations represented by (3.53) and (3.54)?
- Explain the characteristics of a sun-synchronous orbit.
- Prepare for the home team discussion by writing down the main insight you have gained and the main difficulty you have encountered in your homework.
- Solve a couple of problems in the book, preferably selected by your learning team.
- **Advanced level:** carefully review the theory of relative orbital motion and low thrust orbital transfer, respectively, with focus on the criteria for the oral dissertation.

Reentry dynamics

- **Main focus:** reentry dynamics, pros and cons of different types of reentry, thermal protection systems.
- Read chapter 8 in Wiesel.
- For the steep ballistics reentry, section 8.2, explain the relations for the maximum aerodynamic deceleration of the spacecraft and its terminal speed approximation.
- For the ballistic orbital reentry, section 8.3, explain why the maximum deceleration is approximately 8.3g at a speed of 3.3 km/s, independent of the vehicle's drag coefficient.
- Explain the principles and advantages of skip and double dip reentries, sections 8.4 and 8.5.
- Explain the principles and advantages of aerobraking, section 8.6.
- The Space Shuttle used lifting body reentry, section 8.7, and several designs for reusable launch vehicles are considering similar designs, e.g. the Dream Chaser. Explain the advantages and disadvantages of lifting body reentry and discuss the frictional heating on the spacecraft.

- Describe the various thermal protection systems used in the design of reentry vehicles and the concept of reentry corridor.

Clean space

- **Main focus:** ESA's Clean Space Initiative for a sustainable space.
- Read recommended literature on Canvas.
- Explain and discuss the eco.Design initiative: launch vehicles' effect on the atmosphere, environmental regulations in the space sector, life cycle assessment and available technology for "greener" space activities. Go through and highlight critical steps of the road map for the eco.Design initiative.
- Explain and discuss the CleanSat initiative: reducing mass from high density debris regions, end-of-life reentry technologies, end-of-life passivation, design for demise and space debris modelling.
- Describe the phases of the active space debris removal mission, e.deorbit: rendezvous, capture and reentry. Discuss the required technologies for each of these phases and their current Technology Readiness Levels and the roadmap for the e.deorbit mission.

Support for students with permanent learning disabilities

Students with documented permanent learning disabilities shall contact the examiner to get the decision of approved support according to the new codes (R- and P-support).

References

[1] Wiesel, W. E., *Spaceflight Dynamics*, 3rd edition, Aphelion Press, 2010.

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[3] Ashby, M., "How to Write a Paper", 6th edition, Engineering Department, University of Cambridge, Cambridge, 2005.

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[5] Mazur, E., *Peer Instruction — A User's Manual*, Prentice Hall Series in Educational Innovation, 1996.

[6] Carroll, J., and Ryan, J., editors, *Teaching International Students - Improving Learning for All*, Routlegde, 2005.