


# AN INDIVIDUALISED, SCALABLE PROJECT-BASED LEARNING FRAMEWORK FOR STRUCTURE DESIGN COURSES ESTABLISHED IN A LARGE AEROSPACE STUDY PROGRAMME

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## Abstract

In this paper, a didactic tool is presented that allows for conducting highly individualised student projects for the education of engineers in large classes in academia and industry. Submissions, subsequent evaluations and personalised feedback are fully automatised. The successful application has been demonstrated in the scope of structural design courses at the Technical University of Munich.

**Keywords:** Project-Based Learning, Individualisation, Automatised Evaluation, Large Classes, Structure Design

## 1. Motivation

Project-based learning (PBL) refers to an inquiry-based teaching method in which students design and accomplish projects that address meaningful challenges. In systematic reviews [1, 2, 3] and in meta-analyses [4], PBL has been shown to significantly improve student learning outcomes, including academic achievement and thinking skills. Further, a positive impact on affective attitudes such as motivation and engagement was observed. This makes student projects an ideal approach for providing practically relevant hands-on exercises in the education of aerospace engineers.

Yet, conducting student projects on realistic tasks can be challenging, as the complexity and computational demands of design and analysis procedures in engineering are high. This is particularly the case for numerical simulation problems with extensive pre- and post-processing steps, as well as design tasks with ambiguous outcomes. A representative example of this type of advanced problems is the analysis of aircraft structures through Finite Element (FE) Analysis and the subsequent proof of strength and stability measures for certification.

The extent of a respective FE model of a large aircraft is illustrated in Figure 1.

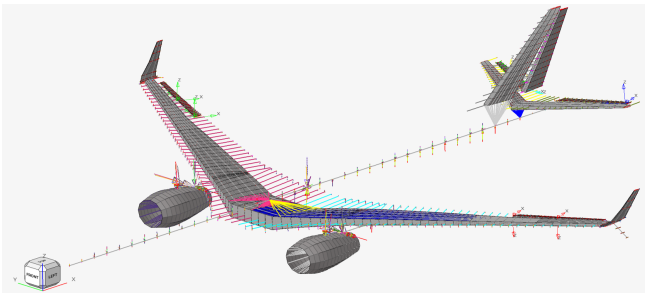


Figure 1 – FE model of the load-bearing structure of an airliner

Moreover, when conducting graded student projects in large classes with up to several hundred participants, such engineering topics can hardly be managed efficiently by manual evaluation. In addition, the independent student work and the exclusive use of permitted aids cannot be guaranteed in open-book projects lasting several weeks (particularly in light of recent advances in artificial intelligence tools). This counteracts the aforementioned benefits for learning effects.

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To approach these challenges and requirements, a novel, highly automatised student project framework has been developed, which is capable of:

- easy development of **arbitrary project tasks of scalable complexity**, compatible with any external computational tool,
- **detailed personalisation** of the project task inputs and their evaluation, supporting an independent execution of the task by each student,
- efficient handling of a **large number of participants**.

In the following, the didactic intentions and the concept of the project framework are presented. Finally, the successful application is then showcased in the scope of structural design courses in aerospace study programmes at bachelor's and master's level.

## 2. Didactic Strategy

The approach of this work follows a didactic strategy that aims at supporting students' learning processes through several complementary principles. The central elements are project-based learning, practical relevance, individualised tasks, feedback-oriented learning cycles, and digital support for scalable implementation. The underlying idea is to shift engineering education from a primarily knowledge-transfer-oriented paradigm towards a competence-oriented learning environment in which students actively apply, reflect, and extend their knowledge.

### 2.1 Project-Based Learning

Project-based learning (PBL) is a learner-centred educational approach in which students acquire knowledge and competencies by working on complex tasks or projects that address meaningful challenges. Unlike traditional instructional approaches, where knowledge is often presented independently from its application context, PBL integrates theoretical concepts with practical activities and requires learners to actively construct solutions. For higher education, PBL has been identified as a promising approach for supporting cognitive, behavioural, and affective learning outcomes. A systematic review by Guo et al. [5] shows that project-based learning supports not only the acquisition of disciplinary knowledge, but also the development of cognitive strategies, engagement, and professional skills. The authors emphasise that learning outcomes in PBL are frequently connected to authentic project products, reflection processes, and the demonstration of competence through practical artefacts.

Especially in engineering education, project-based approaches provide an effective connection between academic knowledge and professional practice. Modern engineering tasks are typically characterised by complexity, interdisciplinarity, incomplete information, and the necessity to consider multiple constraints simultaneously. Hagedorn et al. [6] argue that project-based engineering education supports the development of competencies required for modern engineering practice by exposing students to complex systems and realistic development processes instead of isolated knowledge units.

Consequently, project-based learning is particularly relevant for universities with an applied-science profile, where the transition between theoretical fundamentals and professional engineering practice is a central educational objective. In such environments, learning is not limited to understanding existing solutions but includes the ability to analyse problems, select appropriate methods, develop solutions, and evaluate engineering decisions.

The project-oriented learning concept further requires students to organise their own learning process. Rather than following predefined solution paths, students must independently acquire missing knowledge, plan their activities, and continuously evaluate their progress. This aspect is closely connected to self-directed learning approaches, where learners take responsibility for their own learning activities and become active participants in the learning process [7].

In the context of this work, a project refers to one or more large engineering challenges for a group of learners, in the form of one or more assignments. Figure 2 illustrates the workflow of one assignment

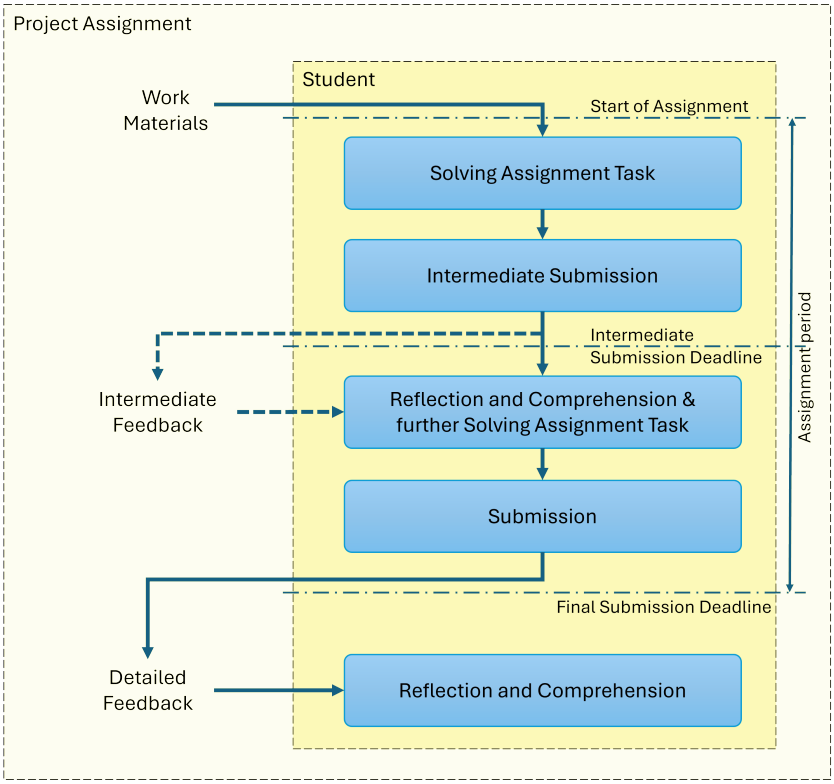



Figure 2 – Sequence of actions of a student during one assignment

from the perspective of an individual student. After receiving the assignment work materials, students independently work on the solution process, applying engineering methods, analysing results, and preparing their final submission. After submission, the results are evaluated and detailed individual feedback is provided to the student. Additional intermediate submissions can be arranged during the working period, displayed as an additional loop in Figure 2, to offer a brief intermediate feedback, serving as a checkpoint and hint.

Depending on the complexity of the task and the learning scenario, the period between receiving the materials and completing the final evaluation may extend over several weeks or months for each assignment. Students may work individually or collaboratively in groups. In both cases, the underlying learning principle remains identical: each student engages with the engineering problem through a personalised task configuration and therefore has to actively understand and apply the required methods.

## 2.2 Practical Relevancy

A fundamental element of the proposed didactic strategy is the creation of realistic engineering challenges with a level of complexity exceeding common textbook exercises. While conventional exercises often focus on applying a specific equation or procedure under clearly defined conditions, engineering practice requires dealing with open-ended problems including constraints, uncertainties, competing objectives, and interpretation of results.

Guo et al. [5] identify authenticity and meaningful project outcomes as important characteristics of effective project-based learning. According to their review, PBL differs from traditional learning settings by requiring students to produce and evaluate project artefacts rather than only demonstrating isolated knowledge.

In engineering education, this shift from isolated exercises towards realistic design challenges is particularly important. Hagedorn et al. [6] highlight that project-based engineering education enables students to address complex engineering systems and develop skills related to innovation, creativity, and interdisciplinary problem solving. A meta-analysis by Zhang and Ma [4], analysing experimental and quasi-experimental studies, reports significant positive effects of PBL on academic achievement, attitudes, and higher-order thinking skills. The effect was particularly pronounced in engineering

and technology subjects, where project-oriented approaches naturally correspond to the structure of professional tasks.
The proposed approach therefore transforms typical isolated exercises into engineering projects in which students must combine theoretical knowledge, numerical methods, modelling, and interpretation of technical results. For this, each assignment is designed as a realistic and demanding engineering problem whose relevance is apparent to the learner. The objective is not only to obtain a numerical result but to understand the engineering context in which this result has to be interpreted and used. Such authentic problem settings can increase intrinsic motivation and encourage students to invest the effort required for extended learning phases.

## 2.3 Individualisation of Tasks

Conventional engineering exercises in academic teaching are often designed around a limited number of predefined problems. While this approach enables efficient organisation of courses, it also contains the risk that students may primarily reproduce known solution procedures or exchange solutions without developing a deeper understanding of the underlying principles. Individualised assignments address this limitation by creating unique learning situations for each learner. Even small variations in parameters, boundary conditions or system configurations require students to actively analyse the problem and transfer their knowledge instead of following a fixed scheme. This approach supports the development of independent engineering competence. Students are required to plan their activities, select suitable methods, evaluate intermediate results, and justify their decisions. Consequently, the focus shifts from obtaining a correct numerical result towards understanding the complete engineering process.
The importance of learner-centred and self-directed approaches in project-based learning is emphasised by Brundiers and Wiek [8]. Their analysis of problem- and project-based learning courses highlights that effective PBL settings require students to actively engage with authentic problems, take responsibility for their learning process, and develop competencies through independent investigation. Similarly, Žerovnik and Nančovska Šerbec [9] identify several important design principles for project-based learning in higher education. Among these principles are authenticity, student activity and continuous inquiry. Individualised tasks directly support these principles by ensuring that every learner has to engage with a relevant engineering challenge.

## 2.4 Feedback and Reflection

In addition to realistic and individualised tasks, continuous feedback is a central element of the proposed learning strategy. In complex engineering projects, feedback is not only required for grading but represents an essential mechanism for learning and competence development. Students working on open engineering problems must be able to recognise misconceptions, evaluate their assumptions, and improve their solutions. Without feedback, incorrect approaches may remain unnoticed for long periods, reducing the effectiveness of the learning process. Project-based learning naturally creates opportunities for reflection because students have to evaluate their own work, interpret results, and compare different solution strategies.
This learning process corresponds to the experiential learning cycle described by Kolb [10], in which learning emerges through a continuous sequence of concrete experience, reflective observation, abstract conceptualisation, and active experimentation. The proposed project workflow follows this principle by requiring students to apply engineering concepts, analyse the obtained results, reflect on deviations, and improve their approach in subsequent iterations. Guo et al. [5] report that reflection activities, self-assessment, observation, and feedback processes are frequently used instruments for measuring and supporting learning outcomes in PBL environments.
The proposed approach integrates feedback directly into the assignment cycle. After submission, students receive an evaluation of their work including detailed information about errors and deviations, which allows the learner to evaluate the obtained results, identify error sources and weaknesses in the solution process, and improve the understanding of the underlying engineering concepts. This reduces the temporal distance between performing an engineering activity and reflecting on its quality. Depending on the learning objectives and complexity of the assignment, the workflow can additionally include intermediate submissions during the working period, as shown as an additional loop

in Figure 2. These intermediate checkpoints enable the provision of preliminary feedback at earlier stages of the learning process. In contrast to the final evaluation, this intermediate feedback is intentionally focused on guiding the student's current progress and supporting the continuation of the solution process, rather than providing a complete analysis of the submitted work. This enables students to reflect on their approach while actively working on the assignment and further supports an iterative learning process.
Such immediate feedback supports formative assessment principles, where assessment activities are used to improve learning rather than only to judge performance. This distinction between assessment of learning and assessment for learning is central to formative assessment. Black and Wiliam [11] demonstrated that feedback processes integrated into learning activities can significantly support student progress by enabling learners to recognise gaps between their current understanding and the intended learning objectives. Especially in engineering education, where complex calculations and modelling procedures are involved, rapid feedback helps students to connect theoretical concepts with their practical application.

### 2.5 Automatisation and Scalability

Targeting all aforementioned aspects when conducting projects can be labour-intensive for lecturers and even become impossible as the number of participants increases. The complete sequence shown in subsection 3.1 has to be processed repeatedly for every student for every assignment. A solution for handling the teaching workload with limited capacities, while still maintaining the educational quality for large academic courses in particular in the field of engineering sciences, is consequent digitalisation and automatisation of the assignment procedures. The applicability is thereby technically not limited by the course size and easily scales to groups of hundreds of students. The steps covered by the automatisation in this work are marked in Figure 2.
Automatisation not only enables a detailed individualisation efficiently, but also allows for a complexity of the assignment problems, which is only limited by the computational resources of the teachers and students. In addition, automatisation helps to accelerate the process of providing students with detailed feedback, minimising the temporal distance to the work on the assignment task and thereby the student's initial reasoning. Important to say, the automatisation is not intended to replace personal interaction between students and instructors. Instead, it reduces repetitive evaluation tasks and allows instructors to invest more time in higher-level mentoring, discussion, and support for individual learning difficulties.

## 3. Implementation of the Project Framework

Translating the above-mentioned didactic ambitions into practice, a highly automatised programmed framework is created. This framework is designed to realise student projects that systematically align with the outlined objectives, while providing a customisable programme architecture, which allows application in any academic teaching subject that is suitable for assignment submissions in digital form. It is implemented in the widely used programming language Python to ensure high accessibility and compatibility. In the following subsections, the general project workflow is described from a teacher's perspective. All essential steps are explained in detail subsequently.

### 3.1 Assignment Procedure

An assignment represents an isolated task of a project and for one assignment the project framework follows a predefined sequence. This sequence determines the administrative and technical work on the instructor's side, but should not affect or limit the creative design of the problem to be solved by the students. The flowchart in Figure 3 illustrates this sequence and outlines the actions of both teachers and students during one assignment, connected by arrows indicating the flow of information, data and files.

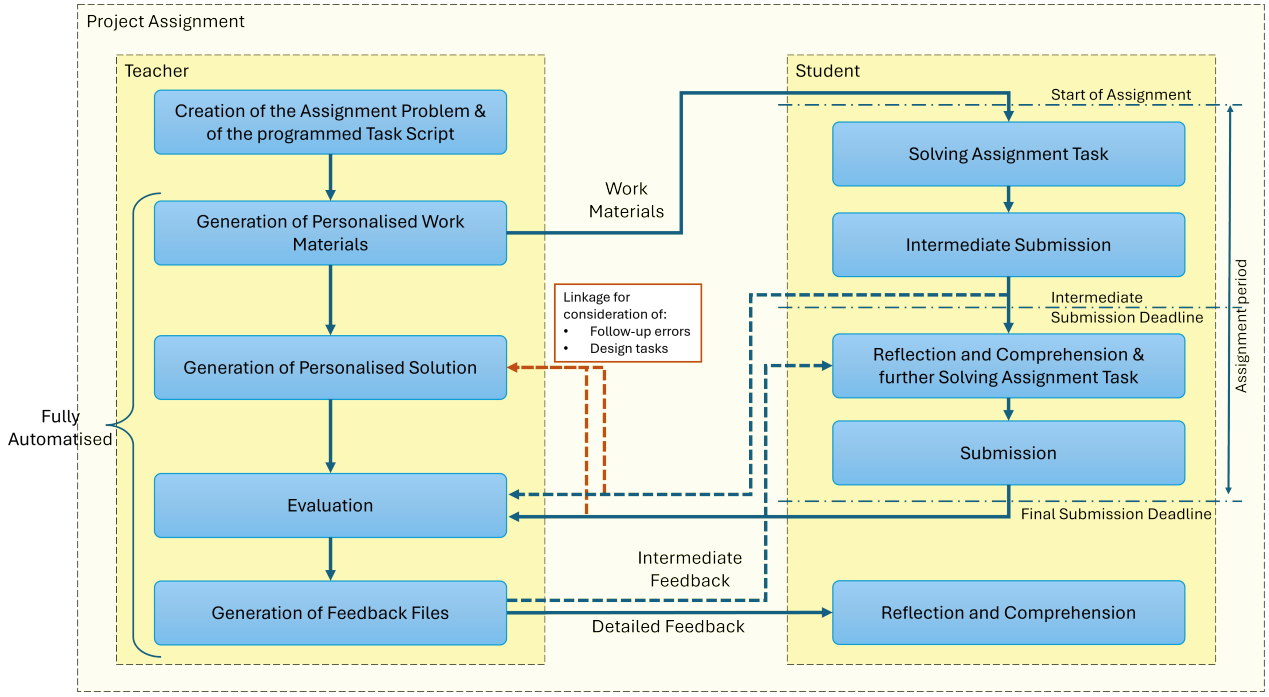



Figure 3 – Sequence of actions for teachers and students during one project assignment

Prior to an assignment period, the teacher develops a problem statement considering the aspects in subsection 2.2. All required solution steps for solving the task, as well as the settings specific to this task, are represented in the framework by means of a programmed script (see subsection 3.2). Subsequently, a personalised set of work materials is generated automatically (see subsection 3.3) and distributed to the students. After working on the task, the students prepare their results for submission (see subsection 3.5) and return them to the teacher before a fixed deadline. All submissions are then read, processed, evaluated and graded automatically (see subsection 3.6). Finally, the students receive feedback files including hints for the intermediate submission and including the complete solution and evaluation for the final submission.

All processes on the instructor's side in Figure 3 must be iterated over all participating students. To decrease computational time for large classes, the processes are parallelised in the framework using the "concurrent.futures" Python module [12]. The framework accepts assignment periods to overlap time-wise, if their task content is independent from one another. At the end of the project when the last assignment is finished, the grades of all assignments are combined to an overall project grade according to a predefined weighting scheme.

## 3.2 Task Script

All operations for solving the assignment problem are implemented by the teacher within a programmed script with a predefined input, output and code structure. This adaptable script is directly imported into the fixed framework and executed for generating the personalised work materials and solutions. This approach facilitates maximum flexibility and enables access to any external programming tool. For instance, various mathematical and scientific libraries, as well as numerical solvers can easily be imported or called, as demonstrated in section 4.
Furthermore, the code architecture of the framework allows for setting up a pipeline, which returns data from the students' submissions for usage in the task script. Thereby a consideration of the students' work in the generation of the personalised solutions is achieved (depicted by the red dashed arrows in Figure 3). This allows to realise design tasks with open outcomes, as later shown in section 4., when calculations are performed on simulation models arbitrarily modified by each student during their work.

## 3.3 Personalised Work Materials

Complementary to the task script logic (subsection 3.2), personalised assignment instructions and submission templates are generated automatically for each student. The personalisation is performed based on unique student data, such as the student ID. Each submission template contains individualised input values for the task and provides designated fields for all result values requested in the assignment instructions. The teacher predefines a realistic range for all variable, personalised input parameters, allocated to the task script in JavaScript Object Notation (JSON) format.
A comma-separated value (CSV) tabular format was chosen for the submission templates to ensure high adaptability. This allows not only single integer, float and string values, but also lists, vectors and matrices to be easily submitted within a single file. A brief excerpt from the header of an empty submission template is shown in Figure 4 (left), with individualised input values marked in orange and fields to be filled by the student marked in yellow. Furthermore, the framework also supports calling any external algorithm for generating additional individualised input, e.g. simulation models as shown in section 4.

| Project - Summer Semester 2026 - Assignment 2 | | | | |
|---|---|---|---|---|
| student ID | 051848 | | | |
| name | Otto | | | |
| surname | Lilienthal | | | |
| | | | | |
| Personalised Input Values | | | | |
| E-modulus_avg | 70995.3 | | | |
| E-modulus_B-basis | 64954.57 | | | |
| Yield strength (t/c) | 490 | | | |
| Ultimate strength (t/c) | 530 | | | |
| Load scale factor 1 | 1.46 | | | |
| Load scale factor 2 | 1.46 | | | |
| limit model mass [kg] | 28.444 | | | |
| | | | | |
| cross-section dimensions and element offsets [mm] | | | | |
| panel ID | t_new | offset | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| | | | | |
| stringer ID | h_web,new(DIM1) | t_new(DIM2) | w_flange,top,new(DIM3) | |
| 1 | | | | |
| 2 | | | | |
| | | | | |
| new model mass [kg] | | | | |
| | | | | |
| | | | | |
| Strength analysis | | | | |
| LC1 | | | LC2 | |
| element ID | RF_strength | | element ID | RF_strength |
| 1 | | | 1 | |
| 2 | | | 2 | |
| 3 | | | 3 | |
| 4 | | | 4 | |
| 5 | | | 5 | |
| 6 | | | 6 | |
| 7 | | | 7 | |
| 8 | | | 8 | |
| 9 | | | 9 | |
| 10 | | | 10 | |
| 11 | | | 11 | |
| 12 | | | 12 | |
| 13 | | | 13 | |
| 14 | | | 14 | |

| Project - Summer Semester 2026 - Assignment 2 | | | | |
|---|---|---|---|---|
| student ID | 051848 | | | |
| name | Otto | | | |
| surname | Lilienthal | | | |
| | | | | |
| Personalised Input Values | | | | |
| E-modulus_avg | 70995.3 | | | |
| E-modulus_B-basis | 64954.57 | | | |
| Yield strength (t/c) | 490 | | | |
| Ultimate strength (t/c) | 530 | | | |
| Load scale factor 1 | 1.46 | | | |
| Load scale factor 2 | 1.46 | | | |
| limit model mass [kg] | 28.444 | | | |
| | | | | |
| cross-section dimensions and element offsets [mm] | | | | |
| panel ID | t_new | offset | | |
| 1 | 4.8 | 2.4 | | |
| 2 | 5.0 | 2.5 | | |
| 3 | 5.0 | 2.5 | | |
| | | | | |
| stringer ID | h_web,new(DIM1) | t_new(DIM2) | w_flange,top,new(DIM3) | |
| 1 | 40.0 | 2.0 | 35.0 | |
| 2 | 40.0 | 2.0 | 35.0 | |
| | | | | |
| new model mass [kg] | 25.63245 | | | |
| | | | | |
| | | | | |
| Strength analysis | | | | |
| LC1 | | | LC2 | |
| element ID | RF_strength | | element ID | RF_strength |
| 1 | 4.89500694437401 | | 1 | 5.5084662790324 |
| 2 | 4.04287005693402 | | 2 | 4.740364304979 |
| 3 | 4.22253962838058 | | 3 | 4.88237957174459 |
| 4 | 3.87870783090081 | | 4 | 4.35051623995006 |
| 5 | 3.89878020482203 | | 5 | 4.64828597358525 |
| 6 | 3.63875579102748 | | 6 | 4.22217926279806 |
| 7 | 4.14512239861949 | | 7 | 4.49884414308353 |
| 8 | 3.85240085385107 | | 8 | 4.45920927272441 |
| 9 | 3.52621621899826 | | 9 | 4.14576862192606 |
| 10 | 4.43377120271731 | | 10 | 4.63321987661063 |
| 11 | 4.15170608080298 | | 11 | 4.82311073075911 |
| 12 | 3.23304223832552 | | 12 | 3.78345436597763 |
| 13 | 3.6883340924705 | | 13 | 3.93742065028171 |
| 14 | 3.72089537816924 | | 14 | 4.12274375423678 |

Figure 4 – Excerpts from an empty submission template (on the left) and a template filled with the student's results (on the right).

## 3.4 Personalised Solution

According to the equations, imported solvers or libraries implemented in the task script (subsection 3.2), as well as the problem-dependent individualised task input, the solution is calculated for every student. The only requirement for the data format of the solution is that it can be read and written digitally. This solution later serves as a reference for the evaluation of the submitted results. As mentioned above, in case required by the problem setup, it is possible to take into account the students' submissions in the generation of the corresponding solutions. One instance in which this is crucial is the consideration of consequential follow-up errors made by the student in their calculations. By this, the reference solution could be based on incorrect intermediate values from the respective student.

## 3.5 Submission

After completing the work on an assignment, the project participants insert their results in the submission template, indicated by the yellow fields in Figure 4 (right) and submit their work. In addition to the CSV template, submissions can optionally contain any other file types defined as output in the task

script. To avoid issues regarding the correct format of the submitted files and their content, a simple validation software is provided for the students to ensure compliance with the desired format. File transfer to the teacher can be managed via email or via any web-based teaching platform, as mentioned in section 4. The framework automatically assigns the files belonging to each student based on their personal data detected in the file names and file content, such as ID and name. Thereafter, the submissions are directly parsed into the same format as the respective reference solution defined in the task script to enable a seamless evaluation.

### 3.6 Evaluation and Feedback

The evaluation of an assignment is performed by comparing the student's submission with the correct solution calculated by the task script. Integer and float values are evaluated based on the relative deviation and graded according to a predefined tolerance. String values, such as "option A", "option B", "Yes", "No" are checked for similarity and minor deviations can be tolerated if desired.
As the final step of one assignment, all students receive personalised feedback provided as a marked version of the filled submission template (see Figure 5 on the left), as well as the final solution in the form of the correctly filled template (on the right). Optionally, any additional output from the task script, such as simulation results, can also be returned.

| Project - Summer Semester 2026 - Assignment 2 | | | --- Feedback --- | --> Total Grade: 97.0% <-- | | |
|---|---|---|---|---|---|---|
| student ID | 051848 | | | | | |
| name | Otto | | | | | |
| surname | Lilienthal | | | | | |
| | | | | | | |
| Personalised Input Values | | | | | | |
| E-modulus_avg | 70995.3 | | | | | |
| E-modulus_B-basis | 64954.57 | | | | | |
| Yield strength (t/c) | 490 | | | | | |
| Ultimate strength (t/c) | 530 | | | | | |
| Load scale factor 1 | 1.46 | | | | | |
| Load scale factor 2 | 1.46 | | | | | |
| limit model mass [kg] | 28.444 | | | | | |
| | | | | | | |
| cross-section dimensions and element offsets [mm] | | | | | | |
| panel ID | t_new | | offset | | | |
| 1 | 4.8 | True | 2.4 | True | | |
| 2 | 5.0 | True | 2.5 | True | | |
| 3 | 5.0 | True | 2.5 | True | | |
| | | | | | | |
| stringer ID | h_web,new(DIM1) | | t_new(DIM2) | | w_flange,top,new(DIM3) | |
| 1 | 40.0 | True | 2.0 | True | 35.0 | True |
| 2 | 40.0 | True | 2.0 | True | 35.0 | True |
| | | | | | | |
| new model mass [kg] | 25.63245 | True | mass requirement fulfilled: | | True | |
| | | | | | | |
| | | | | | | |
| Strength analysis | | | | | | |
| LC1 | | | | LC2 | | |
| element ID | RF_strength | | | element ID | RF_strength | |
| 1 | 4.89500694437401 | True | | 1 | 5.50846627903247 | False |
| 2 | 4.04287005693402 | False | | 2 | 4.74036430497982 | False |
| 3 | 4.22253962838058 | False | | 3 | 4.88237957174459 | False |
| 4 | 3.87870783090081 | True | | 4 | 4.35051623995006 | False |
| 5 | 3.89878020482203 | False | | 5 | 4.64828597358525 | False |
| 6 | 3.63875579102748 | True | | 6 | 4.22217926279806 | False |
| 7 | 4.14512239861949 | True | | 7 | 4.49884414308353 | True |
| 8 | 3.85240085385107 | True | | 8 | 4.45920927272441 | True |
| 9 | 3.52621621899826 | True | | 9 | 4.14576862192606 | True |
| 10 | 4.43377120271731 | True | | 10 | 4.63321987661063 | True |
| 11 | 4.15170608080298 | True | | 11 | 4.82311073075911 | False |
| 12 | 3.23304223832552 | True | | 12 | 3.78345436597763 | False |
| 13 | 3.6883340924705 | True | | 13 | 3.93742065028171 | True |
| 14 | 3.72089537816924 | True | | 14 | 4.12274375423678 | True |

| Project - Summer Semester 2026 - Assignment 2 | | | --- Solution --- | |
|---|---|---|---|---|
| student ID | 051848 | | | |
| name | Otto | | | |
| surname | Lilienthal | | | |
| | | | | |
| Personalised Input Values | | | | |
| E-modulus_avg | 70995.3 | | | |
| E-modulus_B-basis | 64954.57 | | | |
| Yield strength (t/c) | 490 | | | |
| Ultimate strength (t/c) | 530 | | | |
| Load scale factor 1 | 1.46 | | | |
| Load scale factor 2 | 1.46 | | | |
| limit model mass [kg] | 28.444 | | | |
| | | | | |
| cross-section dimensions and element offsets [mm] | | | | |
| panel ID | t_new | offset | | |
| 1 | 4.8 | 2.4 | | |
| 2 | 5.0 | 2.5 | | |
| 3 | 5.0 | 2.5 | | |
| | | | | |
| stringer ID | h_web,new(DIM1) | t_new(DIM2) | w_flange,top,new(DIM3) | |
| 1 | 40.0 | 2.0 | 35.0 | |
| 2 | 40.0 | 2.0 | 35.0 | |
| | | | | |
| new model mass [kg] | 25.63245 | | | |
| | | | | |
| | | | | |
| Strength analysis | | | | |
| LC1 | | | LC2 | |
| element ID | RF_strength | | element ID | RF_strength |
| 1 | 4.89500694437401 | | 1 | 1.75393907654378 |
| 2 | 2.42526380903523 | | 2 | 2.9667172946534 |
| 3 | 1.90763146842856 | | 3 | 1.61288288340486 |
| 4 | 3.87870783090081 | | 4 | 1.27873720736249 |
| 5 | 3.5321318534408 | | 5 | 1.55712450438862 |
| 6 | 3.63875579102748 | | 6 | 1.24476438568966 |
| 7 | 4.14512239861949 | | 7 | 4.49884414308353 |
| 8 | 3.85240085385107 | | 8 | 4.45920927272441 |
| 9 | 3.52621621899826 | | 9 | 4.14576862192606 |
| 10 | 4.43377120271731 | | 10 | 4.63321987661063 |
| 11 | 4.15170608080298 | | 11 | 2.03804932098505 |
| 12 | 3.23304223832552 | | 12 | 2.31147528141286 |
| 13 | 3.6883340924705 | | 13 | 3.93742065028171 |
| 14 | 3.72089537816924 | | 14 | 4.12274375423678 |

Figure 5 – Excerpts from a template filled with a student's results and the automatic evaluation feedback (on the left) and the final solution (on the right).

For the intermediate submission the informative value of the feedback is intentionally lowered by withholding the final solution and e.g. excluding the evaluation of certain entries.

## 4. Application in Structural Design Courses

### 4.1 Project Setup

Over the course of several semesters, the project framework has been applied in aerospace structure design classes in bachelor's and master's aerospace programmes at the Technical University Munich, with class sizes of up to 400 participants. All assignments covered complex structural analysis problems, as mentioned in the introduction, and were conducted over several weeks each, filling one academic semester. To adapt the task calculations to the limited computational power of students' personal computers, model sizes were reduced to a so-called superpanel, defined as a section of the stiffened outer skin of an aircraft wing between two adjacent ribs and spars, illustrated in Figure 6. Based on a complete model parametrisation, individualised FE models were created using pyNastran [13], a Python interface for the Nastran FE solver input format. The underlying structural parametrisation was inspired by the Common Parametric Aircraft Configuration Schema (CPACS) [14]. The

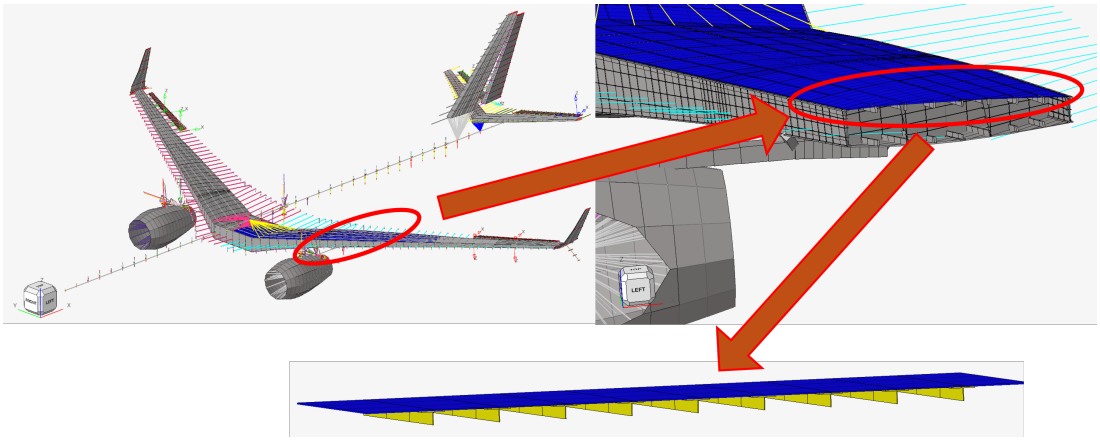


Figure 6 – Example of the FE model used: An isolated superpanel in the cross-sectional view of an aircraft wing structure

individualisation was implemented by a simple linear scaling of task input and model parameters based on the student ID number and a fixed algorithm to ensure reproducible generation of work materials. The tasks included the strength analysis, as well as the stability analysis of all sub-panels and stiffeners of the provided model, considering both isotropic metal and fibre composite designs in several quasi-static load-cases. Furthermore, in design tasks the participants were asked to redesign the FE model to satisfy prescribed mass constraints, which involved the integration of the submitted modified model version in the solution generation by the teachers, as explained in subsection 3.2. The reference solutions were generated using the commercial FE solver Altair Optistruct [15] and an external chair-owned structural analysis tool, both called from the task script for calculation of all requested values.
The online teaching platform Moodle [16] was used for distributing work materials and collecting submissions efficiently. As the file format and content format is crucial for the submitted files to be automatically registered and parsed, a web-based application for checking the files prior to submission was provided to the students. This application is fed on the back-end with the current assignment data to check the files according to the individualised templates.
All assignments were guided by weekly tutor sessions, supervised by a group of tutors providing personal support during the work. This was complemented by an online forum on the Moodle platform for open discussions and direct answers by the teachers visible to all students.

## 4.2 Results

As a result of introducing this project mode into the teaching concept of aerospace structure related courses, the authors of this work observed increased student engagement and indications of improved exam performance. A significant increase of participation was noticeable continuously during the semester in terms of detailed questioning and discussion in the regular course lectures and exercises. According to the personal response of the participants the projects were perceived as demanding, yet engaging due to the practical character of the problems.
Further aspects noticed during the conduction and worth mentioning are listed below:

- Providing not just one, but several intermediate feedback loops lead to a trial-and-error approach of a proportion of the participants and was thereby counteracting the initial didactic intention being further contributing to a guided learning process.
- Despite the strong personalisation of the project tasks, there is the risk of students' calculation scripts being copied and reused from previous semesters in the following courses, in case the task content is not varied sufficiently. A future challenge will be to prevent this, by introducing deliberate task modification for every new course.
- The larger the number of participants is, the more crucial it becomes to communicate all requirements for the submissions clearly, precisely and even repetitively, to guarantee a seamless

procedure of the project assignments.

- Particularly in the case of involving FE analyses the implemented parallelisation procedure described in subsection 3.1 implies a significant decrease of the run time for the creation of the assignment solutions for all students (from several hours to less than 15 minutes for the used computational infrastructure and settings).

## 5. Conclusion and Outlook

Project-based learning enables the integration of theoretical engineering knowledge with authentic application contexts, supporting the development of professional competencies through practical problem solving. In the presented project framework a high level of automatisation is utilised, which is not considered a replacement for didactic interaction but as an instrument to make high-quality project-based learning feasible for large student cohorts. By reducing administrative and repetitive tasks, instructors can focus their time on activities with high educational value, such as individual guidance, discussion, and mentoring.
An overall convincing experience was gained in the application in aerospace structure design courses. Though the presented observations are based primarily on teaching experience and course feedback and not on a controlled pedagogical study. To increase the variety and complexity of the individualised models even further, an extensive usage of the CPACS parametrisation is planned. Furthermore, refinements of the teachers and students user interface can simplify the access and handling of the project framework. As the framework is not restricted to one specific subject area, consequently, the introduction into courses of other disciplines, as well as into an industrial scope is a future step.

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Additional tools such as MSOffice, VSCode, Copilot, DeepL and ShareLateX were used in this work.