# AERO96008 Aerospace Vehicle Design

Coursework Briefing Sheet
2021-22

## 1 Introduction

The design of aerospace vehicles is a complex, multidisciplinary endeavour. The Aerospace Vehicle Design module aims to offer students the opportunity to integrate and apply their prior knowledge and analytical skills to the design of an aircraft of conventional architecture, starting from only a simple set of operational requirements. It forms the basis upon which students can subsequently engage in the design of aerospace systems featuring less-conventional architectures in their Group Design Project.

The module delivery and assessment structure replicates the multi-stage approach and methods typically employed by vehicle design teams, increasingly narrowing the design space and increasing the level of detail, thus taking students through the complete life cycle of an aircraft design project.

Mirroring the environment within an actual design bureau, this will be a group exercise. Students will therefore work together to

- complete one iteration of the conceptual design for an aircraft to fulfil the brief provided,
- complete one iteration of the preliminary structural design and sizing of the primary structural parts of the aircraft; and
- complete the detailed design of and test a structural member to failure.

The project will be completed by groups of *six* students. Students may choose their groups at the beginning of the project through Blackboard. It is incumbent upon each group to organise themselves and split the work evenly and fairly. Guidance for a suggested, even, breakdown of work is provided in the following sections. The entirety of what you have been taught in this module and some independent reading are required to complete this exercise.

As this is not an individual piece of work, be aware that the success of the project depends on every team member contributing to the effort and delivering good quality work on time time. Remember that as you are dependent on the work of others, others depend on your work.

# 2 Design Brief

## 2.1 Conceptual Design

The conceptual design for a small business jet aircraft of conventional design must be produced. It should accommodate four passengers and their baggage in an appropriate seating layout, along with a crew of 2 pilots. No additional bulk cargo need be considered.

The design mission profile to be met is the following:

**0-1** Taxi & Takeoff

**1-2** Climb and accelerate to cruise

**2-3** Cruise for 2,500 km at Mach 0.75 and 40,000 ft amsl

**3-4** Descent to land

**4-5** Following missed approach climb and accelerate to alternate

**5-6** Cruise to alternate destination 370 km away at appropriate altitude & airspeed

**6-7** Loiter at 5,000 ft for 45 minutes at an appropriate airspeed

**7-8** Descent to land

**8-9** Landing & Taxi

The aircraft must comply with all FAR-25 regulations. It must be capable of operating from airports with a minimum runway length of 1.2 km at sea level, under ISA conditions. A reasonable approach speed for the type of aircraft should be chosen.

The aircraft should be capable of reaching a maximum speed of Mach 0.78 at cruise altitude and an absolute ceiling of 45,000 ft amsl at $V_x$. The cabin must further be pressurised to an altitude no higher than 8,000 ft.

Note that the use of NACA airfoils is strongly recommended for this coursework, given the amount of experimental information available for their performance characteristics. Alternate airfoils may be used only if you have complete sets of *reliable* data for their performance.

## 2.2 Preliminary Airframe Design

Having completed the conceptual design phase of your project, the key details of the aircraft should be sufficiently known to allow for the preliminary design of the airframe to be conducted. At this stage you must therefore complete an initial sizing of the primary structural parts of the aircraft, specifically the fuselage, wing and empennage structure. The secondary parts such as LE and TE components can be selected by reviewing similar aircraft. Stability and dynamic issues should not be considered in this part of the project.

In completing your preliminary sizing of the primary structure, the following assumptions can be made:

- All weight distributions should be known and can be used be used in the initial estimate of the Bending Moment, Shear Force and Torque along the each major structural member. The following load cases should be considered:
  - Symmetric flight at the ultimate load factor, evaluated at manoeuvre $V_A$ and dive $V_D$ speeds, to determine the structural loading of the wing, fuselage and tail structures at failure.
  - One Engine Inoperative condition. Assume a load acting at the aerodynamic centre of the vertical stabiliser such that the aircraft is directionally trimmed in case of single critical engine failure. This is an asymmetrical loading condition
  - Landing with front nose-off case. Hence the full aircraft load is supported the main UG only. You may ignore all aerodynamic loads.
- A trapezoidal or elliptic air load distribution (N/m) across the span of lifting surfaces may be assumed, as appropriate.
- A wing box can be designed with the 'flexural axis' line at the centre of the cross-section of the wing box for all aerodynamic structures.
- A single stringer type, with the pitch remaining constant throughout, may be assumed for each aerodynamic structural component of the empennage.
- The fuselage weight should be modelled as a simple load per unit length for the structure. If discrete information is known for cargo, weights, etc. this can be added as a further distributed weight along the fuselage.
- For the purpose of this preliminary study you may ignore the presence of windows and floor and focus only on the primary loading paths. Only qualitative considerations are required for fixings and joints.
- Any materials of your choice can be used but at least one of the empennage structures must be of composite construction.
- The wing structure should have a safe-life of 30,000 cycles. For this exercise, fatigue should not be considered for the remaining components

### 2.3 Detailed Component Design

Having sized and optimised the primary structure in the preliminary design phase, an aircraft design project moves into the detailed design phase. For structural design engineers this involves designing individual components and optimising them for minimum weight and/or cost subject to manufacturing constraints.

The component you will be designing and testing is part of your aircraft's flap extension mechanism, functioning in a manner seen in Figure 1. The component will be milled from a 1/4 inch thick plate of 6082-T6 aluminium alloy. Figure 3 illustrates the dimensions of the blank, which can be machined to your own design, via cut-outs, holes, etc. Material may be removed in any way you wish, subject to following manufacturing constraints:

- Minimum for all internal radii must be 4.00 mm.
- Minimum for any internal cut-out radii must be 4.00 mm.

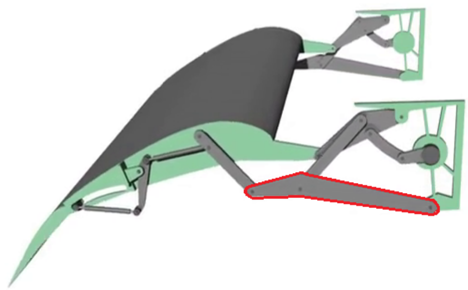

Figure 1: Illustration of a flap extension mechanism with component to be designed highlighted in red

- Minimum internal distance to any free edge 3.5 mm.
- Minimum internal strut width 3.5 mm.
- There is a 30.00 mm diameter safe area around the loading and supporting holes (shown in Figure 3). This area cannot be removed in your design.
- No taper in thickness is possible.
- All removal of material must be through the entire thickness of the blank, i.e. no webs can be machined.

Simulating the loading conditions likely to be encountered within the flap assembly, the beam type structure is required to carry a vertical load that is eccentrically applied to the middle hole only, as seen in Figure 2 ,via a supporting bracket. The load is applied through the mid-thickness of the bracket, via a screw jack connected to the structure by means of a universal bearing. The structure will be loaded via a 10mm diameter pin; however, the load is transferred via a set of 18mm diameter collars fitted through the hole and either side of the Aluminium panel. The load pin can rotate out of the plane by a small amount. The two outer holes are used to support the beam structure. Linear bearings are only available on one side, creating a rolling support as seen in Figure 2.

The structure should be designed to carry a LIMIT LOAD = 6.5 kN and should not deflect more than 5 mm at LIMIT LOAD. The deflection will be measured in a vertical direction directly in line with the load. An allowance will be made for slack in the bearings and supports. This information will be given to students at the test session. In line with standard aerospace safety factor use, the structure should be designed to carry an ULTIMATE LOAD =1.5 $\times$ LIMIT LOAD prior to failure.

As a group, your are therefore required to design and test one concept for the structural component in question that maximises the merit function $\eta$ defined by equation (1), based on which the performance of your design will be judged.

$$\eta = \frac{LOAD}{MASS} \tag{1}$$

where the $LOAD$ is the maximum load achieved prior to failure of the structure (by structural failure or excessive deflection) and may be no larger than the design ULTIMATE

LOAD.

The analysis must involve some degree of Finite Element Analysis, using packages such as Abaqus or Simulia (available through the 3DEXPERIENCE platform). Remember that when presenting FEA studies, the validation of the tools using analytical solutions to check mesh density and accuracy should be reported. Your approach to the design and analysis, as well as your performance predictions should be presented and discussed in the report described in section 3.2.

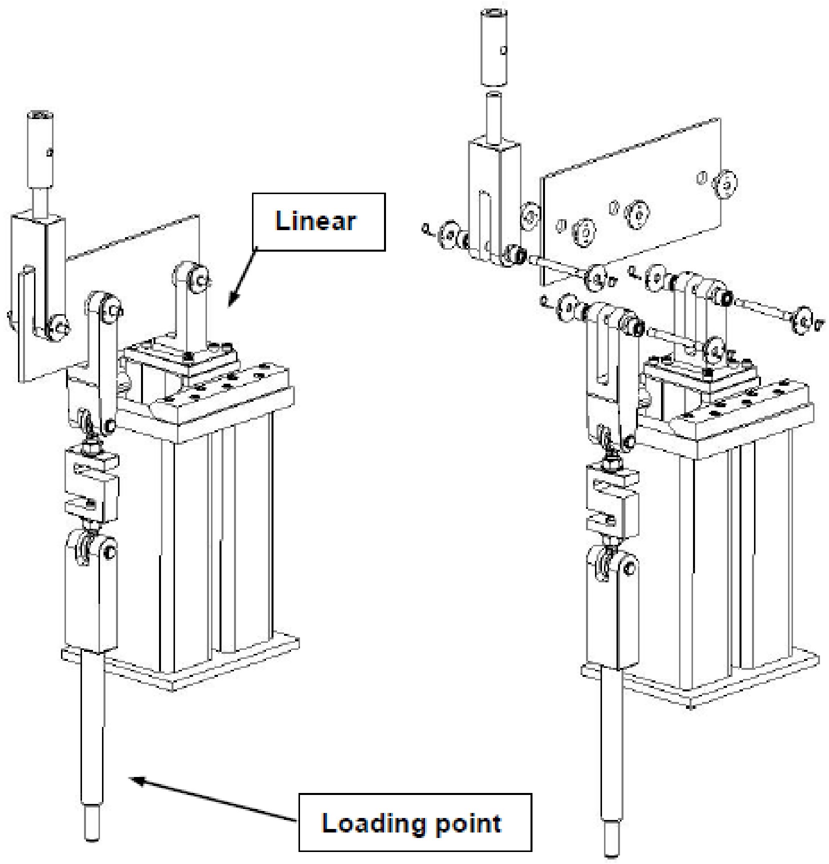


Figure 2: Schematic of the test rig

# 3 Assessment

The group's work will be assessed through three distinct submissions. These are

- **Initial Sizing Poster (15%)** Poster providing a basis for a presentation of the Baseline Design and Initial Sizing of the aircraft
- **Conceptual Design Report (35%)** Group report detailing the conceptual design of the aircraft and discussing the quality of the resulting design
- **Preliminary and Detailed Airframe Design Report (40%)** Group report detailing the design of (i) the primary structural components of the aircraft and (ii) the detailed design of a structural element from the aircraft's flap assembly.

A further 10% will be awarded for the performance of the structural component following testing, calculated from the group's ranking based on their achieved merit function.

You should further keep in mind that aircraft and airframe design is not just about effectively using a number of equations/methods but also making informed design decisions and being able to justify them. In addition to any quantitative results, your submissions should therefore also present your design decisions and any assumptions made should be highlighted and discussed where necessary.

## 3.1 Conceptual Design Stage

Your work on the conceptual design of the aircraft will be submitted for assessment in the form of an interim group poster and a final group report. Each submission is further explained below.

**Conceptual Design - Poster Presentation (15%)**

This poster session is meant to cover the early stages of the design process, reporting on the results of the initial sizing process. Your results should be presented on a single side of A1 size paper. Your poster should provide the audience with key information and results, in a well organized and visually pleasing manner. It should serve as a basis upon which you can effectively present the rationale behind your chosen baseline configuration, the calculated aircraft weights and the design point you chose.

This year's poster session will be held online. In addition to their poster, each group will therefore be required to submit a 5-minute long, pre-recorded presentation of their poster. During the scheduled poster sessions, which the entire class can join, each assessor will playback each group's poster presentation, ask the group follow-on questions, and provide oral feedback.

This poster session will account for 15% of your grade for this module. Your group mark will stem from the following categories.

- **Baseline Configuration:** Quality & presentation of solution and reasoning behind presented choices [20%]
- **Initial Weight Sizing:** Quality of assumptions made; consideration of operational environment; use of available methods; accuracy of results; discussion of their validity [25%]

- **Initial Wing & Thrust Sizing:** Completeness, correctness and quality of constraint diagrams; reasoning behind design point selection [35%]:
- **Overall Quality of Poster** [20%]

**Conceptual Design - Group Report (35%)**

This group report is meant to build on the results presented in the poster, following the feedback received during the session, and cover the remainder of the conceptual design process. The results for the following parts of the design process should be presented and discussed.

- Wing design
- High lift device selection & sizing

- Fuselage design & sizing
- Structural layout
- Aircraft system layout design
- Weight & balance predictions

- Powerplant selection, installation & integration
- Undercarriage design

- Aerodynamics Analysis - Wing Lift
- Aerodynamic analysis - Tail Lift
- Aerodynamics Analysis - Drag Estimation

- Tailplane sizing & design
- Static stability & trim analysis

- Control surface design
- Performance estimation

Note the grouping above indicates the suggested breakdown of roles/workload within a group and not the order in which topics should be presented for a coherent and well presented report. Your conceptual design report should include a 3-view drawing of your aircraft, submitted as an appendix. Any other supporting information may also be submitted as an appendix but will not count towards your grade.

Each group must additionally populate the provided `.csv` file with key design parameters for their aircraft and submit through Blackboard.

This group report will account for 35% of your module grade and should be no longer than 40 pages in total. The final report will be marked based on the following criteria:

- **Technical Solution:** Use of appropriate methodologies and assumptions; completeness and correctness of presented results [40%]
- **Justification & Discussion:** Justification of design decisions and assumptions made; discussion of quality of resulting prediction/results [25%]
- **Originality** [10%]:
- **Discussion of Overall Design** Being able to reflect on the quality of your design is key. Your report should therefore end with a section discussing how the final design performs relative to the design specification, identifying any issues and their origins, and most importantly identifying what changes must be implemented in the next design iteration to improve it. This is an opportunity to demonstrate your understanding of the overall aircraft design process and the tradeoffs involved in it [15%]

- **Presentation** Overall presentation of the report/results; quality of 3-view drawings [10%]

Oral feedback on the work presented in your report (in the form of a recording) will be provided ahead of the next opportunity for students to utilise it, i.e. prior to the Group Design Project.

**Conceptual Design - Design Review**

Each group will be given the opportunity to hold a 30-minute design review with one of the course lecturers during weeks 8 and 9 to receive formative feedback on their work. Groups will be able to sign up to one of the available sessions through Calendly[1]. No sessions other than those made available through this portal may be organised. It is up to each group and its members to collectively identify which aspects of their design they would like to discuss and receive feedback on. It is highly recommended that you come to these sessions with a significant portion of your design completed so as to get the most out of them.

## 3.2 Preliminary & Detailed Design Stages

**Preliminary & Detailed Design Group Report (40%)**

Each group's work in completing the preliminary sizing of their aircraft's airframe and the detailed design of the flap mechanism structural component will be reported in a single, combined design report, no longer than 50 pages.

In your report you should

- Present an initial review of relevant designs and options, identify the design procedures adopted and final design.
- Provide all key dimensions and clearly indicate assumptions made in the calculations.
- Illustrate your proposals by means of a suitable sketch.
- Present Finite Element analysis results in an appropriate way.
- Reflect on the final quality of your design and highlight future steps in the design process.

Remember that you are required to demonstrate an Engineering Designers awareness of the dual role of Analysis, Synthesis and Evaluation. The engineering solution you present must be defensible and your design proposal should be communicated in a manner befitting a Engineering Designer. Furthermore detailed equations can be scanned and presented in appendixes; only key equations need be placed in the main text.

It is up to each group to determine how to best distribute the work among their group members, however all group members should collaborate to review each other's work, contribute to each other's work offering ideas, and ensure that design decisions made are congruous.

The report will be marked based on the following criteria:

[1] `https://calendly.com/ic-avd/30min`

- **Technical Solution:** Use of appropriate methodologies and assumptions; completeness and correctness of presented results [35%]
- **Justification & Discussion:** Justification of design decisions and assumptions made; discussion of quality of resulting prediction/results [35%]
- **Originality** [20%]:
- **Presentation** Overall presentation of the report/results; quality of engineering drawings [10%]

**Manufacturing Drawings**

To allow the workshop to manufacture the flap assembly structural component you designed, each team must submit

- a 2D drawing of their part in 2D `.dxf` format, and
- their 3D part in `.stp` file format.

To avoid issues in manufacturing, please ensure that both your CAD file (`.stp`) and drawing (2D `.dxf`) are in the correct units (millimetres).

**Structural Testing Performance (10%)**

Following testing of your structure, the merit function for your structure will be estimated using equation (1) and teams will be ranked from highest to lowest scoring. Marks for the structural testing performance will be awarded based on your team's position in the scoreboard, with the top team awarded 100% and the lowest scoring team awarded 40%. Groups that do not submit a design for manufacture will be awarded zero marks.

**Preliminary Structural Design Review**

Each group will be given the opportunity to hold a 30-minute design review with one of the course lecturers during week 22 to receive formative feedback on their work. Information on how to book your session will be provided closer to the time. No sessions other than those made available through this portal may be organised. It is up to each group and its members to collectively identify which aspects of their design they would like to discuss and receive feedback on. It is highly recommended that you come to these sessions with a significant portion of your design completed so as to get the most out of them.

### 3.3 Peer Assessment

To ensure the contribution of each team member towards the success of the project is fairly rewarded, the grades stemming from the two report submissions will be partially weighted to reflect peer assessment of individual group members' contribution. To this end all group members will be asked to complete two self and peer assessments, providing feedback on their own and their colleagues' perceived contribution towards the success of their group's project and support said assessment, for (i) the conceptual design phase and (ii) the preliminary and detailed design phases.

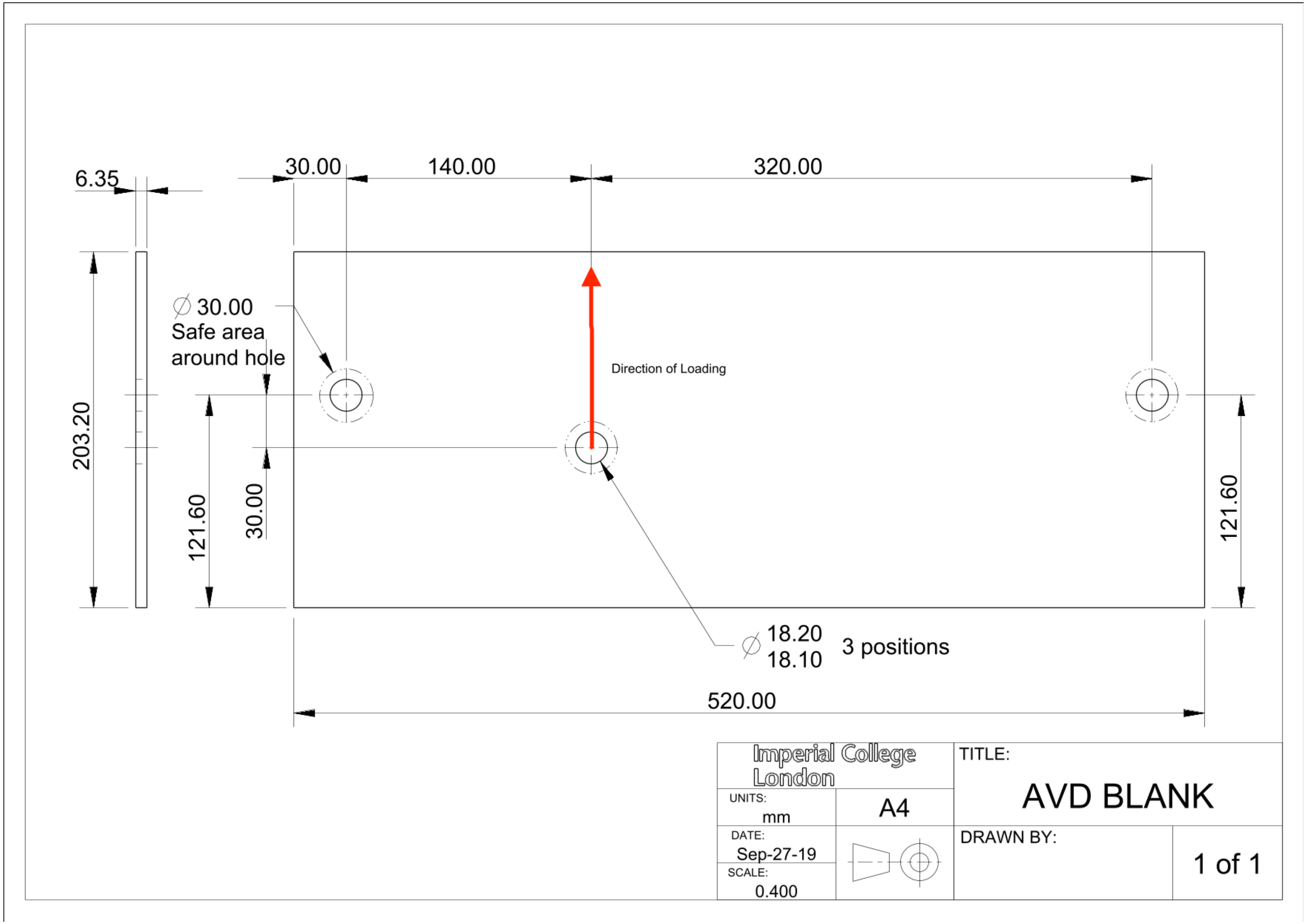


Figure 3: Engineering drawing of the blank to be machined (not to scale)