Minor Module Aircraft Engineering (2015000050)

Conceptual design of a climate neutral regional airliner

Introduction

The aim of this project is to apply the knowledge gained during the courses of the module Aircraft Engineering. To complete the assignment, you will have to work in groups of 6 to 7 students to produce a short report as well as a presentation. In the first section of this document, you will find the assignment description. The second section will focus on some organizational aspects of the assignment, such as method of grading and required report content.

1: The assignment

1.1: Context

You and your fellow group members have been hired by Twente In The Air Netherlands (TITAN), a leading design bureau specialized to perform conceptual design studies for airplane manufacturers. The European airplane manufacturer Airbus has requested your assistance in the conceptual design of a new airplane. This airplane is to be developed either by Airbus itself or by Airbus' French-Italian subsidiary, ATR. If TITAN succeeds in creating a conceptual design which meets the standards of Airbus, TITAN is entitled to 1% of the sale price of every airplane sold. Additionally, if the airplane manufacturer is satisfied with the performance of TITAN, Airbus will consider granting TITAN more work in the future. Should Airbus decline the conceptual design, TITAN will not be allowed to sell the design to competing manufacturers. So, there is a lot at stake for TITAN.
The board of TITAN has established several design teams who each are to separately create a conceptual design. The best design will be presented to Airbus. These teams may be involved in the development of the design past its conceptual stage, but that is outside the scope of this assignment.
Please do note that Airbus is not guaranteed to buy the winning concept based on solid engineering alone: to convince Airbus, you will have to very clearly point out why it is reasonable to assume that clients (operators) will be interested in acquiring the airplane after its design is completed. This means that you will have to prove that the economic and technical performance of the to-be-designed aircraft is superior to the performance of existing planes. Also, you will have to convince Airbus of the fact that enough situations suitable for use of the aircraft exist to merit the construction of a few hundred of these new airplanes.

1.2: Global airplane description

The aircraft that you are to design is a regional airliner intended for transporting around 80 passengers over a distance of maximum 1000 kilometers.

To meet the increasingly strict environmental requirements in the operational regions of this plane, it is required that this plane is climate neutral, i.e. it does not produce any greenhouse gases. This can be accomplished in several ways, e.g. fully electric, hybrid electric with fuel cells and even combustion of hydrogen. All these examples have their own challenges, although the use of fully electric and hybrid electric systems also lead to new opportunities

Figure 1 ONERA's Ampere aircraft, which uses distributed electric propulsion.

in terms of propulsion systems that are not possible in combination with conventional combustion engines. An example of such a new opportunity is distributed propulsion, see figure 1 for one of the possibilities to achieve this.

The concept of operations, which Airbus has acquired from a representative market survey, is as follows: the aircraft uses ordinary runways for take-off and landing, albeit from airports relatively close to the city centers, flies with a cruising speed of at least 550 km/h at an altitude of maximum 9000 meters and uses relatively steep ascent and descent trajectories of 7.5 degrees. The plane should be able to operate in most weather conditions and the turnaround time on the ground should be half an hour or less in order to maximize the efficiency. As the plane operates from ordinary airports full ground service can be expected to be present.

1.3: Assignment overview

You are required to make a conceptual design and write a report that is to be presented to the board of TITAN. The design will be presented orally and you will be competing with the other groups of students. The topics you will have to address are presented below.

1. The requirements set out by the customer will have to be translated into technical specifications. Make sure to include requirements concerning features not strictly part of the plane as well. For example: What ground equipment is necessary to prepare the plane for departure again after it has landed? Important in this context is

that the client is not always aware of the optimum features of a product. Because of this, you are allowed to come up with additional requirements on top of or replacing the ones stated in section 1.4, as long as you can properly justify these modifications. In section 1.6 you will find some tips on defining the list of design goals.

2. Based on the requirements, you are to define a global plane configuration. In the courses 'Introduction to Aircraft Technology' and 'Aerodynamics' you will be taught the way airfoil and planform design influence flight performance. Design features which must be included in the report are: fuselage configuration (for example, dimensions and shape of the cross-section), wing lay-out and placement of the wing on the body, tail plane configuration and flaps set-up, engine positioning, number of engines used, fuel type used, and finally the lay-out of the landing gear. This is the minimum number of features required to be present in the report; should you find additional features relevant for your final design you are encouraged to add these to your report and presentation.
3. General structural properties must be discussed. In the course 'Aircraft Structures' you are taught the required knowledge to do so. Hence, some of your work is expected to tackle material choice, stiffness properties of the wing and fuselage but also location and general dimensions of the battery packs (if used), (cryogenic) storage of hydrogen (if used), wing placement on the fuselage, engine and landing gear configuration, cargo door placement and similar features. Further a Free Body Diagram with all external loads on the airplane and their magnitudes should be provided. Also, the maximal internal loads (moment, shear and normal force) in a cross section of the fuselage should be estimated and conclusions concerning the geometry should be drawn. As was already noted under 2, should you come up with an airplane feature you believe to be relevant, but which is not in the above-mentioned list, you are free to add it to your report and presentation.
4. Key strategic choices must be documented. In aircraft design, one must always sacrifice certain desirable properties in favor of others. A few examples: a short runway usually requires a large wing, which results in a lower cruising velocity. A longer range requires more fuel and thus a decrease in payload or an increase in size. A carbon composite plane is lightweight and maintenance friendly, but expensive and often difficult to repair if damaged. Be sure to clearly indicate what compromises are made in your design and include a motivation. You are free to assign a higher priority to some requirements at the cost of others, provided that you motivate the choices you make. It is not impossible that the principals desire plane properties which are not feasible given certain mechanical, aerodynamic or financial constraints. Do keep in mind that, should you forego some requirements, a proper motivation is required.
5. Market placement must be discussed. How does your aircraft compare with existing and future competitors? Elaborate about potential advantages and disadvantages of your design and, more importantly, how the technologies included in your design will contribute to increase the revenue of Airbus and TITAN.
6. The final report must contain a short documentation on the group process. Who was responsible for what aspect of the design? How did you combine the individual work of group members into the final product? A table is a very good way to present this information.
7. A visualization of the conceptual design is required. This visualization may be presented in the form of (scaled) construction schematics. These schematics have to

be sufficiently representative of the design such that the TITAN could figure out dimensions even if not explicitly calculated in the conceptual design process;

8. An argumentation on why the market for the new airplane is large enough to justify its production must also be included in the report. (See section 1.5)

1.4: Airbus requirements (user requirements)

The list of requirements given by Airbus is

1. The plane should be compatible with the Flight Path 2050 targets regarding improved mobility, emissions and economic efficiency, see https://ec.europa.eu/transport/sites/transport/files/modes/air/doc/flightpath2050.pdf.
2. The plane must be capable of delivering 80 people of 90 kg, each with 20 kg of luggage to locations which is at most 1000 km away from the departure point. For this type of aircraft diversion capabilities of 10% of the range and 10% of the flying time are required. Take head wind into account.
3. The minimum cruise velocity is 550 km/h.
4. The cruise altitude is 9000 meters.
5. The plane should fly climate neutrally, i.e. it should not produce any greenhouse gases. Other than that, the fuel (or batteries) can be chosen freely.
6. The maximum required runway length for a fully loaded aircraft should be within acceptable limits. It is up to you to determine these limits, depending on your business case.
7. The plane should be able to use ascent and descent angles of up to 7.5 degrees. A descent angle of 7.5 degrees during landing should not lead to more than 5 percent extra runway length compared to 4.0 degrees.
8. For comfort reasons the cabin altitude should not be higher than 1800 meters.
9. When combustion engines are used in combination with hydrogen, the engine performance can be assumed to be the same as for fossil fuels. However, the actual storage of hydrogen will require attention. This is also the case when fuel cells are used.
10. When batteries are used the energy density of batteries can be taken 1.5 times the current state of the art, as it will take some time before this aircraft will actually fly.
11. Direct operating cost should be as low as possible. Unless otherwise indicated, extra performance does not increase your chances of winning, low cost does.
12. There are no restrictions on engine type selection (ducted fan, propellers), nor on the number of engines you are allowed to use, as long as the propulsion is climate neutral.
13. Parts of the aircraft that need more than minor repairs should be easily removable.
14. The aircraft should be able to operate continuously for a period of at least 36 hours without other servicing than replacing the battery pack or loading fuel and performing a pre-flight check. Maintenance after this period should not take longer than two hours. Better serviceability is appreciated.
15. The turnaround-time of the plane is to be no more than 30 minutes when loads are issued in standard packages.

16. The aircraft should be able to withstand hard landings and rough treatment on the ground without sustaining damage that makes it unserviceable.
17. The design life of the plane, TBO (time between overhauls), must be 20,000 flight hours or more. For this requirement, a global computation will suffice; do not lose yourself in detailed formulae.
18. The aircraft should not contain materials that pose hazards were it to crash in a densely populated area.

Please note that the above-mentioned requirements may roughly be divided into two categories. Some requirements must simply be met, but few additional points will be awarded for exceeding the minimum value. For other requirements, the board of TITAN will award a substantial amount of points if the requirement is fulfilled beyond the minimum demands set out in the list above. An example of the first category is requirement 6. The attractiveness of your design will only marginally change if the plane is capable of taking off from a shorter runway. The most important requirement from the second category is direct operating cost. Lower costs mean a higher chance of winning the competition.
For all other requirements, we allow you to decide what demands fit which category. Do make sure that your argumentation as to what demands are more important than others, is sound. Also, should you find a valid reason for disregarding one or more requirements you are free to do so but keep in mind that such a decision might come back to haunt you later during your project. Should you, for example, opt for a flying wing design, take note that the performance must be excellent to justify the extra airframe costs and hassle of loading passengers.

1.5: The 'business case'

Regardless of the quality of your design it will differ significantly from currently available aircraft. You will therefore have to convince Airbus that there will be enough of a market for it (see section 1.1). Argue your business case based on - for instance - market predictions or specialized articles. Convince Airbus that your aircraft is a necessary development, and indicate how potential issues could be solved. For this you may consider the following questions:

- What situations could the aircraft be used for? What customer market are you aiming for?
- What operational or economic advantage does the new plane have over existing transportation means? What would be the disadvantages of, for example, using a train?
- Distinguish between doing things better than with the resources available today and doing things that cannot be done with today's resources, like flights in night and evening hours in densely populated areas (due to noise regulations).
- Estimate the costs of the new airplane. Think about series size, availability of production resources, parts and materials.
- Based on the depreciation of the airplane, the estimated costs of energy, maintenance and other operating fees, you can determine the economic feasibility of your proposed solution. How many flights and which prices are required to provide a proper return on investment for the airliner?

- Make sure that you aware of any legislation or regulations that might inhibit the operation of the aircraft.
- Make sure that you do not base your analysis on the current situation, but also take into account any relevant future developments. Incidentally, be honest about disadvantages, too.

This list is far from exhaustive, but it should provide you with sufficient inspiration.

1.6: Tips on defining your design goals

The set of requirements as formulated by a customer such as Airbus often only partially reflects the necessary elements for a successful airplane. Airbus is not the end-user of the aircraft; their goal is to produce and sell it. Their customers in turn have to meet the expectations of their clients. Thus, prior to starting with the design, you should formulate a governing set of design targets and requirements for the aircraft. You should:

1. Formulate the user requirements. Take note: the requirements mentioned in Section 1.4 are a basis for this, as they may not be complete. Besides, some of them, like requirement 7, are more technical requirements than user requirements.
2. Assign relative importance to your requirements.

Take an hour or two with your group to do this, keeping the following tips in mind:

1.6.1: Setting requirements and targets

1. Start by laying down a framework of criteria (such as 'Cruise speed', 'payload'), before filling in the requirements ('550 km/h', '80 passengers').
2. Imagine buying a regional airplane: What would you look for as an organisation? How do your wishes (for instance: no emission of greenhouse gases) translate into design requirements (Choice of energy storage and propulsion system)?
   - Start by grouping everyone's individual ideas, and then brainstorming with the group.
   - Write down your own thoughts before diving into literature.'
3. Check your criteria for completeness, overlap and relevance. 'Engine power' for instance would overlap with 'Cruise speed' and 'Rate of climb'.
4. Downsize to practical criteria only. Merge overlapping ones and disregard the unimportant, unclear, and unquantifiable ones.
5. Quantify the remaining criteria. 'Ruggedness' for instance can be judged by maximum vertical speed during landing, by propensity to rust, etc.
6. Set brackets for the quantified criteria. These will be your design requirements.
7. For each criterion determine whether it is a pass/fail or a 'the more the better' criterion.
8. Construct a scoring system for your criteria, for instance on a 1-5 scale. A minimal pass would imply a '1', the best useful score a '5'. Keep in mind that more does not always mean better. E.g. a single engine may result in an unreliable aircraft, a twin is safe, but four complicates maintenance.

1.6.2: Assigning relative importance

1. You can choose to assign weights to your criteria, indicating their importance, or simply rank them from most to least important. The latter option is often the easiest to work with, and presents less risk of false accuracy. On the other hand, if you can come up with good weights you will have a good way of scoring your concept.
2. Many criteria, such as cruise speed and runway length, depend on the same design parameters. Try and find out for which criteria this is the case, and how they influence one another. If a 100 meters reduction in take-off runway reduces the cruise speed by 5 km/h, your optimal balance might be different than if this reduction eats up 100 km/h cruise speed.
3. Having certain minimum/maximum requirements, either as given by Airbus or by yourself, will make it easier to determine importance. You can choose to simply require them to be met, discarding any design that cannot. Alternatively, you might give them a weight, if exceeding the minimum requirement would be relevant (for instance, cruise speed). Make sure however not to set so many minimum requirements that your aircraft cannot possibly meet all of them.
4. There may be several roads leading to Rome. For example: high rates of climb can be achieved either by increasing engine power, or by decreasing wing loading. Powerful engines use a lot of (electrical) power, while low wing loading will decrease cruise speed. If cruise speed and rate of climb are coupled strongly you could try to find a higher-level criterion they relate to, such as time of travel. Now you can replace the base criteria weights with causal relations to the higher level one.
5. There are several ways to compare criteria and set relative weights. The most practical is the following stepwise approach.
    1. Compare every pair of criteria with one another, determining each time which is the most important. This criterion is given a point. Having compared all possible pairs you will have a ranking of relative importance. This method is called 'Pairwise comparison'. There are more complex methods such as AHP (Analytic Hierarchy Process), but you do not need to bother yourself with those. The pairwise comparison process can be put in a matrix form, as shown below. In this example A is more important than B and D, B more important than D, and C more important than the other tree. The final ranking is thus C A B D.

Criterion	**A**	**B**	**C**	**D**
A	--	A	C	a
B		--	C	b
C			--	c
D				--

    2. If you are unhappy with the final ranking you could decide to assign numeric weights. Take a number of points (five per criterion is typically a good number), and distribute them, in such a way that any higher ranked criterion has an equal or higher number of points than a lower-ranked one.

This method has two important weaknesses however:

1. There can be cyclic inconsistencies: A > B > C > A. If these occur among the most important criteria you might want to re-discuss, at the lower end you can safely leave them in.
2. The points distribution will be somewhat arbitrary. The same can be said of more complex mathematical methods however.

2: Organisation

2.1: Available information

For this assignment you should use the literature from this module. Additionally a pdf-file containing several chapters from J D Anderson's 'Aircraft Performance and Design' (pg. 381-519) is available. You are free to collect any additional information. ***You may not personally contact any aerospace manufacturers or airline companies, even by e-mail.*** Any information posted on such companies websites is fine.

2.2: Assistance

On Monday November 9 the assignment will be introduced (8:45-10:30 in an online session) and on Tuesday November 10 a lecture will be given on aircraft conceptual design (9:00 to 10:45 in OH 211, this is an on-campus event). A lecture on the business case is scheduled on Tuesday, November 17, while (part of) the board of TITAN will meet the project leaders on Tuesdays November 17, December 1 and January 5. On Tuesdays November 24, December 8 and December 15 the board of TITAN will meet ALL project group members at 11:00. All these meetings will be online meetings. On Wednesday November 18 and Thursday December 17 at 9:00 workshops will be held on multi-disciplinary collaboration in project groups, again online.

2.3: Your report

Your report has to be legible. Use clear structure and correct formulation. The layout should be clean and neat, but it does not have to be a work of art. Use **no** more than 15 pages (excluding appendices), with a 12 point font for the core content and a total maximum of 25 pages for the entire report. Include a short introduction on the group process, explaining who was responsible for what parts, as an appendix. Also give an attractive fact sheet with an image and the main characteristics of your design, e.g. propulsion, energy carrier (fuel), dimensions, max. weight, etc.

The deadline for your report is Friday, January 15, 2021 at 9:00 am. Hand in electronic and, if circumstances allow, hard copies of your report to:

- Dr. W.J.B. Grouve
- Dr. D.R.J. Prak
- Dr. L.D. De Santana
- Dr. E.T.A. van der Weide

2.4: The presentation

On Wednesday January 20, 2021 and Thursday January 21, 2021, the results will be presented from 9:00-12.35. Each group will present for 15 minutes, which is followed by up to 30 minutes of discussion. Questions will be asked by board members of TITAN as well as other students. Feedback will be given at the end of the session. You do not have to present your business case, but you are expected to answer questions about the case should they arise during the discussion. These presentations will be online events. In order to stimulate the interactive part, groups will receive reports from other groups and have to prepare questions for the discussion. The activity in this part will also determine the mark for the presentation.

A presentation does of course imply a winner. The TITAN board members will choose the concept to be bid to Airbus.

2.6: Assessment

Both the presentation and report will be assessed.

2.6.1: Report

The report is assessed based on:

1. Design quality:
    - Is the design sufficiently convincing? Does it satisfy the explicit requirements, and if not, is this motivated sufficiently? Additionally, motivate the relative importance of the various requirements.
    - Is the design inspiring? Does it have any qualities not explicitly required but nevertheless useful for its intended users?
    - Is the design complete? Are all components (Aerodynamics, Structure, Propulsion, ...) handled adequately? Note that Avionics do not need any specific attention unless your design includes or requires a non-standard suite.
    - Is the design creative? Have you found any unconventional solutions to technical challenges, or does the design differentiate itself from contemporary aircraft in any other way? Have you found innovative ways of utilizing the new plane which might give users an advantage over their competition?
2. Design motivation
    - Did you formulate clear technical specifications based on user requirements?
    - Is the list of technical specifications complete - does the list fully define the basic configuration of the airplane?
    - If compromises were made in the process of converting the user requirements into technical specifications, how adequately were these compromises made and are they explicitly mentioned?
    - Are design choices made consciously and in an adequate fashion?

- Does the list of advantages and disadvantages of design choices adequately represent the effects the choices will have on the final design?
- Are subsystems properly defined and how efficient is their integration into the final design?

3. Business case quality
   - How convincing is the argumentation used to persuade the reader that enough situations exist where the aircraft is useful to merit the production of the designed plane?
   - Are the advantages the designed plane has over existing alternatives (existing airplanes, other modes of transport) presented convincingly?
   - How complete is the discussion on relevant technological, economic, social and cultural developments which could have an influence on the demand for the airplane?
   - How in-depth is the analysis of Airbus' advantages and risks if it is to develop the designed airplane?
4. Report structure: are the different sections of the report clearly linked to each other?
5. Legibility of the report: language use, spelling, brevity, professional choice of words; not too colloquial nor too formal.

2.6.2: Oral presentation

The presentation has less impact on your final grade than the report: it is mostly used to determine whether your final grade will be rounded off up or down. Make sure the presentation is convincing, clear and factual. Good looking pictures and movies are fun but should not be used excessively or to cover up inaccurate/inadequate information. Finally, it is the content on which the assessment will primarily be focused, not the form in which the content is presented.

Because this is a group assignment you will be graded as a group. Of course you will receive relevant feedback from the lecturers and a winner will be declared.