Aircraft Tutorial

"Meeting the goal of sustainability in the regional transport: the ATR 72-HE"

1. Introduction

1.1.Instructions

This document provides all necessary information you will need to prepare and to execute the Aircraft Tutorial. Read this entire document carefully before beginning to work on it.
It is assumed that you have studied the lecture notes of the course with a special attention to the aircraft design specific module dedicated to **weight&balance** and **stability&control**. Some of the additional material present on the book suggested in as a study material and related to the aforementioned topics, can be useful to perform this tutorial, hence you are advised to familiarize with it. It is assumed that you are able to use knowledge from the previous course AE2111 (wing design modules).

1.2.Project background and objective

The ATR 72, designed and produced by the French-Italian ATR consortium, represents today the state of the art for regional air transportation. One of its strengths is of course based on the use of propelled propulsion that guarantees a very high propulsive efficiency in subsonic flight when compared to correspondent turbofan engines. The aircraft is characterized by a high wing configuration and landing gear mounted in the fuselage belly. The passenger cabin and the cargo compartments are located in the same deck, as reported in Figure 2 (cargo areas are indicated in red).

Figure 1: ATR 72-600 (credits @ATR)

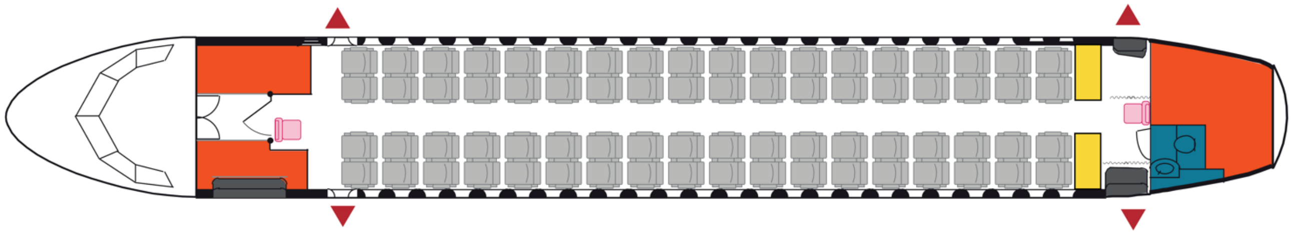

Figure 2: ATR72-600 cabin layout

Mission

You are working for an engineering consultancy company, spin-off of TU Delft, that is specialized in the integration of innovative Hybrid-Electric (HE) powertrains into existing aircraft and you have just been contacted by ATR to perform a feasibility study on the re-design of a HE ATR 72-600. Your task is to investigate the effect of certain design changes, which are communicated to you in the second part of the present document. You have been already informed that these changes are likely to have an impact on the balance of the aircraft, its stability and control. The fuselage cross section will not change (in order to limit as much as possible the costs for new certification processes and the design of new tooling). Possibly a new payload configuration will be asked and therefore a tail resizing might be necessary.

2. First Part: assessment of the reference aircraft

2.1.Deliverables of the first part

The characteristics of the reference aircraft need to be determined prior to evaluate possible further modifications. Therefore, your group is asked to determine weights, balance, stability and controllability parameters of the reference ATR72-600 configuration **all-economy seats version, with 72 passengers @ seat pitch of 29 inch**.

In particular you are asked to:

a) **Familiarize** with the entire task list and collect data and information on the Fokker 100 aircraft (general dimensions; weights and performance data; layout of cabin, wing, tail, engine, high lift devices, landing gear, etc.). Hint: *For the retrieval of the aircraft data, you can consult the website of the manufacturer (https://www.atr-aircraft.com) and/or the Jane's All the World's Aircraft catalogue (available on paper at the TUD library or digitally at www.Janes.com, when accessed within the TU network). Other popular websites such as www.airliners.net and Wikipedia provide plenty of data and also some MsC theses you can find in the TU Delft repository. To extrapolate geometry you can also refer to 3view drawing being sure that they are in scale. In any case, indicate in the reference list all the sources of information used to complete your tutorial report.*

b) **Generate a table and a pie chart** showing the values of the operational empty weight (OEW), fuel weight and payload weight of the ATR72-600. The chart shall indicate these three weight contributions, both in absolute value and as percentage of MTOW.

c) The weight department of Fokker sent you the following table containing the weight breakdown (expressed in percentage **of the MTOW**) of the main components affecting the CG @ EOW:

Table 1: weight breakdown

Component	Weight [% MTOW]
Wing	14.9
Horizontal Tail	1.8
Vertical Tail	2.0
Fuselage (including cabin and cockpit systems)	24.8
Main Landing Gear	3.5
Nose Landing Gear	0.5
Propulsion (including nacelle)	10.3

Note some of the items composing the Empty Operative configuration might be excluded from the table. In that case, you can assume that the components that are not reported in the table simply don't affect notably the position of the CG. **Generate a table** where information of the different centers of gravity are reported according the following guidelines:

I. The components shall be re-arranged into a "fuselage group" and a "wing group" (make sure to include the right components in each group!). The total weigh of both groups shall be provided as well.

II. Calculate the CG of groups and components; you shall make use of **two reference systems**:
- One global system positioned ahead of the aircraft;\
- One system fixed at LEMAC (i.e., the leading edge of the wing mean aerodynamic chord).

III. In the table you will report the CG positions of the components, of both the wing and fuselage groups and of the empty operative configuration of the aircraft with respect to reference system fixed at LEMAC. Express these CG positions as percentage of the wing mean aerodynamic chord (MAC)

d) Consequently **generate the aircraft loading diagram**. Organize the passengers into groups, according to their seating position following the window-aisle rule. Place the remaining payload weight in the front and aft cargo holds, according to their capacity. Make use of drawings and payload information as available on the websites of manufacturer and/or operators.

e) **Identify the most aft and forward c.g. positions** during operation and report them in a table, indicated as percentage of the aircraft mean aerodynamic chord MAC. Indicate in the same table the specific loading conditions that are responsible for the achievement of the most aft and forward c.g. positions. In the same table, you will report also the position of the aircraft c.g.@OEW (indicated as percentage of MAC), the c.g. position of both the front and the rear cargo, and the c.g. position of the fuel tank(s).

f) Determine and **report** in a table **all the geometry parameters** that are necessary to assess both stability and controllability characteristics.

g) Ultimately **generate the complete scissor plot** of the reference aircraft with the neutral stability line, the stability line and the controllability line.

3. Second Part: evaluation of design modifications

In the second part of your study, you are asked to evaluate possible effects of some design input coming directly from the customer.

3.1.Customer design modifications

The R&D department of ATR has already performed initial studies that have identified the type of propulsion system (serial hybrid electric) as well as other design changes. More specifically:

- The effective aspect ratio is 20% higher than the geometric AR thanks to innovative winglets;
- The nacelles have increased dimensions in both diameter (+25%) and length (+30%) in order to accommodate other subsystem and allow a proper cooling condition of the components;
- The overall weight of the propulsion system hasn't varied with respect the conventional version; on the other side, the weight of the wing group is 10% lighter than the initial one and the fuselage weight results increased by 5% (always when compared to the initial value);
- The last four rows of passenger are removed;
- The electric part of the powertrain is powered by two battery packs. The first pack is located just underneath the CG of the front cargo area and it weighs 300 kg. The second battery pack is located underneath the rear cargo area and it weighs 1000 kg. The battery are not removable and it is explicitly noted that a new CG@EOW+Batt shall be calculated;
- The MTOW of the aircraft will be kept constant by assuming that a modification of the amount of embarked fuel will compensate any weights difference;

3.2. Customer questions

ATR is asking your team to address the following question:

a) How do the aforementioned design modifications affect both longitudinal stability and controllability? Provide evidence of your answer providing calculation steps where necessary.

b) Would it be still possible to fulfill the longitudinal S&C requirements without changing the current horizontal tail size, longitudinal wing position and stability margin?

If **NOT:**

c) *What would be the critical longitudinal requirement? Stability or controllability?*
d) *How larger should be the horizontal tail to fulfil again both the longitudinal S&C constraints, while maintaining the same longitudinal position of the wing?*
e) *What design iterations (if any) would be necessary to confirm your answer? (provide just a qualitative answer)*

If **YES:**

c) *How smaller could be the horizontal tail size, while still fulfilling both the longitudinal S&C constraints and without modifying the longitudinal position of the wing neither the stability margin?*
d) *In this case what would become the critical longitudinal requirement? Stability or control?*
e) *What design iterations (if any) would be necessary to confirm your answer? (provide just a qualitative answer)*

f) *Is there any modification on the longitudinal position of the main landing gear that is needed to guarantee stability during the take-off maneuver?*
g) *Would you suggest a different combination of rear and front battery pack in order to improve stability and controllability characteristics?*

Recommendations:

- Make use of loading diagram and scissor plot to provide clear evidence to your answers.
- If you are suggesting the need of iterations, be specific on the parameters to be iterated.

3.3. Deliverables of the second part

a) Generate a second **weight table** for the ATR 72-HE aircraft similar to the one indicated in **deliverable b)** of the part1.
b) Generate a second **loading diagrams** for the ATR 72-HE aircraft similar to Task d) of part 1. Preferably you will display the two loading diagrams together on the same plot. In case they will be displayed in two separate plots, their scale and size must be adequate to compare easily the difference of the two diagrams.
c) Provide a second **c.g. data table** for the ATR 72-HE**,** similar to the one indicated in **deliverable e)** of the part1.
d) Generate **the complete scissor plot** (stability + neutral stability + controllability curves) for the ATR 72-HE reporting also the CG range. The scissor plot must be scaled and sized in such a way it can be easily compared to the one of the reference aircraft. To make this comparison easy, you can report the two scissor plots together in a separate figure.
e) **Provide a table** displaying the data necessary to build the scissor plot(s). You shall indicate at least the following data for both the ATR 72-600 and the ATR 72-HE:
    - Cruise speed
    - Approach speed

- Tail-wing speed ratio (Vh/V)
- Lift rate coefficient of the tail at cruise speed

- Lift rate coefficient of the aircraft-less-tail at cruise speed, including the separate contributions of:
  - Wing
  - Fuselage
- Wing downwash gradient
- Position of the aerodynamic center of the aircraft-less-tail, evaluated both at cruise and approach speed, and including the following separate contributions:
  - Wing
  - Fuselage
  - Nacelles
- Maximum horizontal tail lift coefficient (indicate also the type of tail, e.g. full moving, fixed, etc)
- Zero Lift pitching moment coefficient of the aircraft-less-tail, including the separate contributions of all the aircraft parts.

f) Based on calculations and on the qualitative reasoning, provide an answer to each of the customer questions reported in paragraph 3.2 from *a)* to *g)*

4. Part3: organization of the group

The tutorial is a group work where all the group members must contribute equally. Each student must actively perform both the calculation/design tasks and reporting ones. It is up to the group members to organize the group and to constantly self-monitor progresses and to do possible actions to improve the outcome of the tutorial.
Group organization as well as tasks division shall be briefly reported in an appendix (max 3 pages long) of the report.

5. Requirements on the report and grading criteria

The report must meet the following characteristics:

- Your group must deliver an electronic version of the report in PDF format not later than the deadline indicated on BrightSpace for the delivery of the tutorial in the regular session.
- The report will be uploaded in the "Aircraft Tutorial - Regular Session" assignment folder that will be created on BrightSpace by the teaching staff.
- The report shall be named: *"AE3211_Aircraft_Tutorial_Group_#"* (where # indicates your group number).
- The report shall clearly indicate on the front page, the name and the student number of all the team members, as well as the group number assigned during the tutorial session.
- The report has a page limit of **25 pages (including everything)**: it must include all the deliverables described in both Part1, Part 2 as well as the organizational appendix (Part 3).

- In addition to the asked deliverables, a **limited** amount of text will be necessary to answer to the customer questions, describe the main characteristics, justify and state all the design assumptions and decisions. Text to explain theoretical background is not needed.
- Shows all the numerical results with proper unit of measures and shows calculation steps when they are needed to answer the deliverables.
- Include clear and readable plots: do not forget labels and consider to scale its dimension to favor comparison when requested (e.g. comparison of loading diagrams).
- Include a list of references when data and/or equation are used from literature.
- **Ignoring the aforementioned indications, might affect the final grade for this assignment.**

The report will be graded as a whole (no intermediate points for each part will be given) according to the following criteria:

- **Completeness and correctness:** Did you answer all the posed questions? Did you include all the requested deliverables and information? Did you properly compute all the coefficients, at the required conditions? Did you indicate the correct units?
- **Consistency:** Did you use data and assumptions consistently through your report? Do your plots match your assumptions and calculations? Do you explain/justify the source of all your data, plots, charts etc.?
- **Reporting quality**: Is your story clear and concise? Is the report properly structured? Are your paged numbered, as well as your figures, tables and equations? Are all your tables and plots readable and provided with caption, units, labels and legend?