RELAZIONE VEICOLI AEROSPAZIALI

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1 Assignment 1

1.1 Assignment 1.1

Assignment: Write down an initial list of requirements for an aircraft that shall replace A350, with an entry into service in 2030. Please, while listing the requirements, refer to the categories reported in Sect.1.4

List of Requirements

(Mainly based on Airbus A350-900 [1])

Design and Performance

- Number of pilots: 2
- Cruise Mach: 0.85
- Max Operating Speed Mach: 0.9
- Cabin Crew: 8 (2 for each emergency exit)
- Number of passengers: 440
- Wing Span: under 70 m
- Fuselage Length: under 75 m
- Range: over 15000 km
- Height: under 18 m
- Wing Surface: 450 m^2
- Max Payload: over 50 metric tonnes
- Number of engines: 2

Operational requirements

- Cruise altitude: 10 - 13 km
- Turn around time: under 60 mins
- Takeoff distance: under 1 km
- Landing distance: under 2.5 km
- Rate of climb: 3000 ft/min (Initial climb)
- Ceiling: 13.15 km (FL431)

Analysis of applicable regulations

- Number of exits: 8
- External noise (a terra a 5km di distanza) decollo: under 90 dB
- External noise (a terra a 5km di distanza) atterraggio: under 95 dB
- N max in condizioni operative: 2.5
- N min in condizioni operative: -1

1.2 Assignment 1.2

Assignment: On the basis of the list of Requirements elicited in the previous step, identify a good list of reference aircraft and collect data to be used as meaningful statistical population.

Several commercial aicrafts from *Airbus* and *Boeing* have been chosen, with the goal of having a statistical population to compare to in mind, as well as a reference list for inspiration with consolidated concept designs and technologies. Acquiring all the data for the entire population was not easy, as their availability is scattered and varies from source to source.
Despite the overall scarcity of clear, organized and transparent information, a significant amount of statistically meaningful data has been acquired and ordered in the following landscape tables.

A *GNU/Octave* [2] (or Matlab) script that elaborates all the data has been written, with the goal of easy readability in mind, as everything has been split into functions.
The script and its functions are publicly available in this works' *GitHub* repository [4] (*Code* directory) and licensed under the *GNU GPL v3* license.
Bear in mind that Octave outputs all the plots at once when you run the whole script, while on Matlab you may need to run each separate Section, as some versions overwrite *figure()* when it's implemented within a custom function.
This will of course depend on the Matlab version you're currently running.
The code itself is short and easy to read, while also being full of step-by-step comments.

Design & Performance parameters	B787-10 Dre	A350 XWB-900	A330 Neo -900	B777-300ER	B777 X-900	B787-8	A340-500	A330-300	A340-600	A330-200	B767-300
Number of pilots	2	2	2	2	2	2	2	2	N.A.	2	2
Cruise Mach number	0.85	0.85	0.81	0.84	0.84	0.85	0.83	0.86	N.A.	0.86	0.86
Max Operating Speed Mach	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Cabin Crew	8-9	8-9	8-9	14	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Number of passengers	330	440	440	550	426	359	375	275	N.A.	N.A.	N.A.
Wing Span [m^2]	60.81	64.75	64	64.8	72.8	60.12	60.3	N.A.	N.A.	N.A.	N.A.
Fuselage Length [m]	68	66.8	63.66	73.86	76.72	56.72	67.93	N.A.	N.A.	N.A.	N.A.
Range [km]	11750	15000	13334	13650	13500	13620	12400	11750	14450	N.A.	N.A.
Wing Surface [m^2]	377	443	465	436.8	516.7	377	437.3	N.A.	N.A.	N.A.	N.A.
Height [m]	17.02	17.47	16.79	18.76	19.53	16.92	17.53	N.A.	N.A.	N.A.	N.A.
Max Payload [metric tonnes]	57	53	44	69.8	73.5	43.318	54	N.A.	N.A.	N.A.	N.A.
Number of engines	2	2	2	2	2	2	4	N.A.	N.A.	N.A.	N.A.

Table 1: Statistical Population - Design and Performance parameters

Operational requirements	B787-10 Dre	A350 XWB-900	A330 Neo -900	B777-300ER	B777 X-900	B787-8	A340-500	A330-300	A340-600	A330-200	B767-300
Cruise altitude [m]	N.A.	N.A.	N.A.	N.A.	13136.88	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Turn around time [min]	44	34 -62	N.A.	30	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Takeoff distance [m]	2600	N.A.	N.A.	N.A.	N.A.	2600	13350	N.A.	N.A.	N.A.	N.A.
Landing distance [m]	2000	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Rate of climb	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Ceiling [m]	13136	13100	12634	13136	13140	13100	12634	N.A.	N.A.	N.A.	N.A.

Table 2: Statistical Population - Operational Requirements

Weights, Fuel and Aerodynamics	B787-10 Dre	A350 XWB-900	A330 Neo -900	B777-300ER	B777 X-900	B787-8	A340-500	A330-300	A340-600	A330-200	B767-300
MTOW [kg]	250000	275000	251000	351535	352000	227940	365000	242000	380000	230000	158758
Fuel Mass [kg]	101456	110523	111272	146839	160000	101323	110400	N.A.	N.A.	N.A.	N.A.
Empty Weight [kg]	135500	142400	137000	167829	181400	119950	177755	109400	174000	120600	86069
Allungamento Alare	10.03	9.49	11	9.82	9.96	9.59	9.3	N.A.	N.A.	N.A.	N.A.
Cruise Speed [km/h]	1050	903	918	905	900	903	871	N.A.	N.A.	N.A.	N.A.
L/D	20	21	N.A.	N.A.	N.A.	21.23	16.2	N.A.	N.A.	N.A.	N.A.
SFC [lb/lbh]	0.506	0.478	0.506	0.56	0.545	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Table 3: Statistical Population - Weights, Fuel and Aerodynamics

1.3 Assignment 1.3

Assignment: *Critical Analysis of statistical trends.* Verify whether your statistical population fits the trend reported in literature (e.g. Raymer) or suggest improvements to the simple mathematical models (e.g. updates of coefficients).

Among all of the acquired data, the *Empty Mass Fraction* is a particularly significant statistical trend.
The raw data trend has been comparatively plot in the script, along with an improved algorithm, proposed by *Daniel P. Raymer* [3].

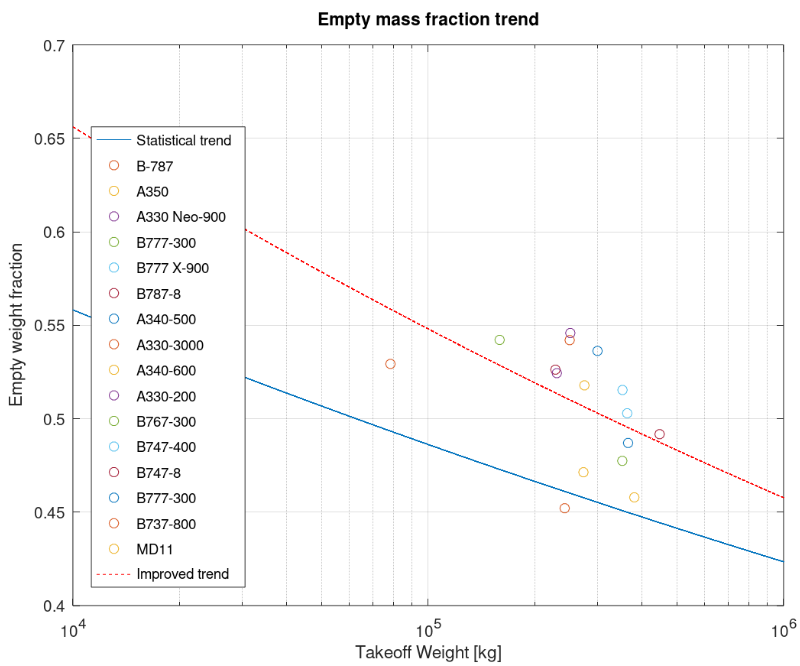

Figure 1: *Empty Mass Trend*

As clearly visible, the improved trend is substantially more in line with the acquired data.

1.4 Assignment 1.4

Assignment: *Guess data estimation for the reference case study.* Apply the original or improved statistical trends to perform the first guess data estimation for the reference case study. Please, report all iterations needed to converge to the design maximum take-off mass.

The first hypothesis for the $MTOW$ estimation was using the *True Air Speed* at an altitude of 10 km, as that would be a worse case scenario compared to the goal design of a cruise Mach of 0.85.
The entire calculation is made assuming a range of 11 km and a maximum range of 15 km, as well as a 50 metric tonnes design payload, with the awareness that a lighter payload might be necessary in order to improve range.

The function

```
mtow_range_plotter.m
```

takes a guess $MTOW$ value as one of its inputs, generates some mass coefficients, elaborates and uses them to finally return the desired $MTOW$ as one of its outputs (see repository [4] for the implementation).
The function also plots the MTOW as a function of the range.
One issue that has been immediately noticed is an instability with the plot around 15000 km, therefore a compromise payload of 40 metric tonnes has been used for this specific plot, in order to get a more accurate visualization.

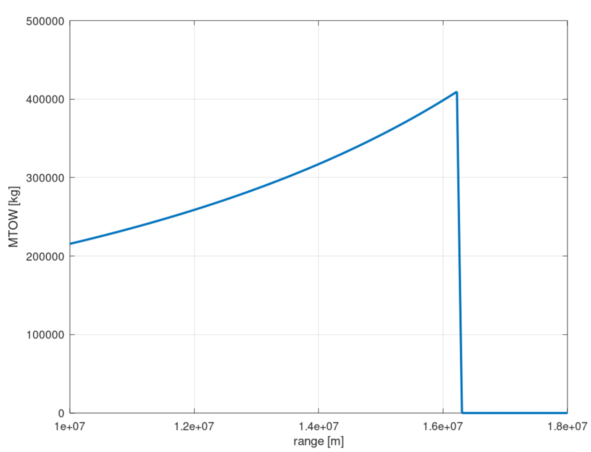

Figure 2: MTOW-Range

Similarly, with the function [4]

```
mtow_payload_plotter.m
```

the $MTOW$ has been plotted as a function of the payload with the design range of 11000 km first, then with the maximum range of 15000 km, as pictured below.

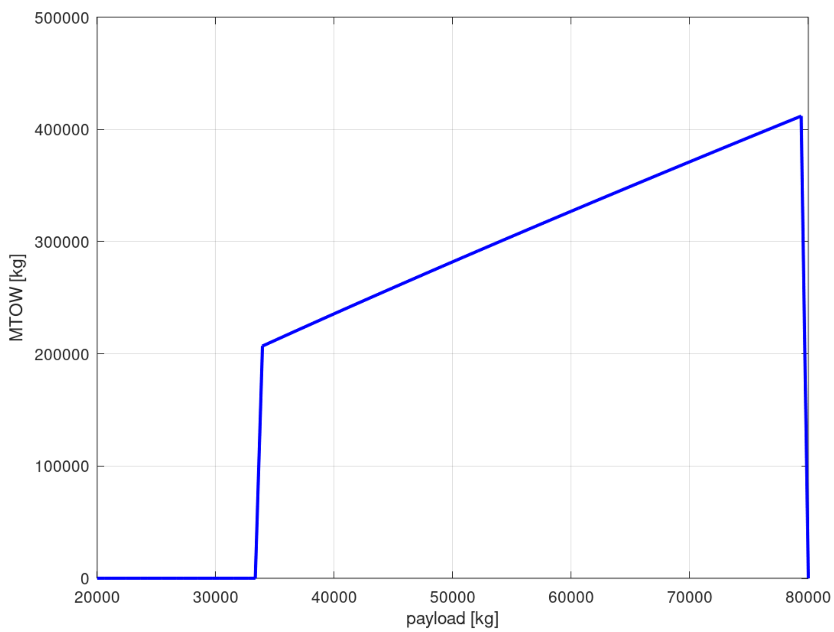

Figure 3: MTOW-Payload (11000 km)

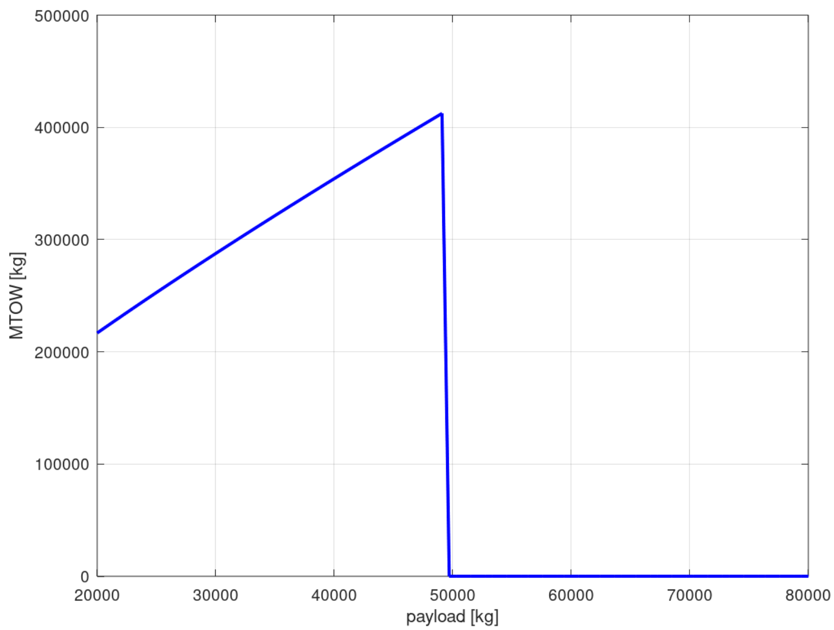

Figure 4: MTOW-Payload (15000 km)

As you can see, there are areas where the function drops to a null value, but that's because the MTOW ceases to have a physical meaning above or below certain thresholds, depending on the input parameters.
However there seems to be a convergence slightly above 40 metric tonnes.

2 Assignment 2

2.1 Assignment 2.1 and 2.2

Assignment: Perform a Tradeoff and identify a suitable design point that guarantees the aircraft concept to be competitive with A350 and competitors.

Assignment: Create a Payload-Range Diagram representative of your aircraft concept. On the basis of the results achieved, draw different Payload-Range diagrams to explore the possibility to create a family concept.

Another key aspect to take into consideration is how the *Payload* changes with range, considering that fuel contribution to the total mass is obviously going to change over time, thus influencing other factors as well.
The fuel volume of the Airbus A350 (141 m^3) as well as the fuel itself ($AVGAS$) have been taken as a reference point.
In order to better represent this function within a family of aircrafts that is compatible with our statistical sample, a variation around the design point values has been taken into account.

- Payload variation: $\pm$ 5000 kg
- MTOW variation: $\{0.88\ MTOW, 1.077\ MTOW\}\ \ kg$
- Range variation: $\pm$ 500 km

The result is calculated and plotted with the function [4]

```
payload_range_plotter.m
```

which takes into consideration all the parameters involving the fuel, as well as other design values for the airplane.
The plotter can be called with input variations as many times as the user needs, while the '*On*' parameter is passed.
Finally, when the '*Off*' parameter is passed, all the cases are plot on a single figure, with a randomized color palette.

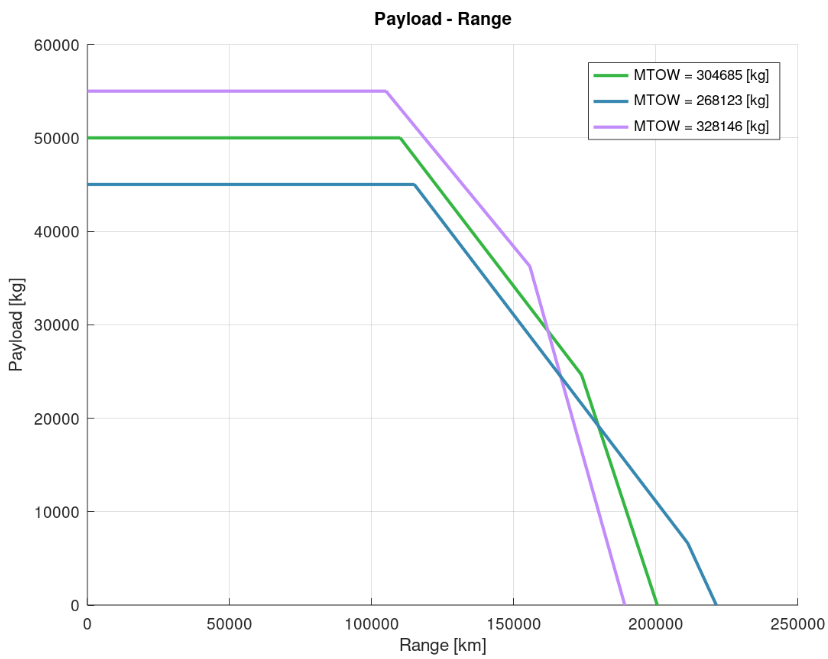

Figure 5: Payload Range

As expected, the same fuel conditions for each sample case will produce the same slopes for each segment; moreover a higher payload implies a higher MTOW (provided that all other factors are equalized), which in turn will reduce total range.
More precisely, the surface subtended by each segment defines three different areas (from left to right respectively) [2.1]:

- Maximum payload
- Tradeoff between fuel and payload
- Tradeoff between payload and range

With a maximum design range of 15000 km and a starting payload of 50 metric tonnes, the designed aircraft is in an area where there needs to be a tradeoff between fuel and payload.
In order to achieve that range, some payload capacity needs to be sacrificed for more fuel.
However, with a minimum goal range of 11000 km, there is still is a chance to use the highest payload possible, while increasing fuel, as that range falls within the first segment area.
It turns out that even the Airbus A350-900 XWB (which is the target retiring aircraft) declares a maximum range of 15000 km; however, this range is not reached at maximum payload [1].

2.2 Assignment 2.3

Assignment: Once the maximum range requirement is refined, identify a set of city-pairs that can be connected with no-stop flight.

2.3 Assignment 2.4

Assignment: Build the Matching Chart for your case study and define Wing Surface and Engine Thrust

References

[1] Airbus. *A350-900*. https://www.airbus.com/aircraft/passenger-aircraft/a350xwb-family/a350-900.html. Accessed on 2020-11-11.

[2] John W. Eaton and many others. *GNU Octave*. https://www.gnu.org/software/octave/index. 2020.

[3] Daniel P. Raymer. *Aircraft Design: A Conceptual Approach*. 6th ed. American Institute of Aeronautics and Astronautics Inc., 2018. ISBN: 1624104908,9781624104909.

[4] Giorgio De Trane. *Airbus A-350 Replacement Project, Personal Repository*. https://github.com/BaldPolnareff/Relazione_individuale_Veicoli_Aerospaziali/tree/main. Accessed on 2020-15-12. 2020.