Design Lab Aircraft Assignment: Boeing 787 Performance Modifications

ASEN 2004: Vehicle Design and Performance
Assigned: Wed 18 Jan 2017

Presentations due: In dropbox by 11:59 pm, Sun 26 Feb 2017

1.0 Background and Introduction

1.1. Foundations

The following definitions are from **Webster's New Universal Unabridged Dictionary** (1996, Random House Value Publishing, Inc.) and all are important in engineering:

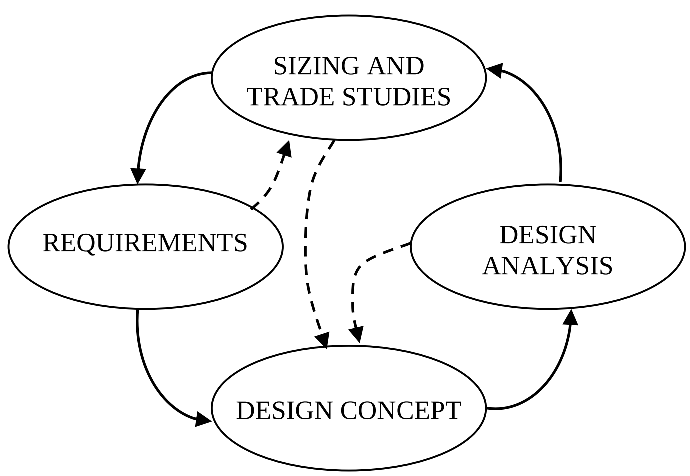
engineering (en′jə nēr′ing), *n*. **1.** the art or science of making practical application of the knowledge of pure sciences, as physics or chemistry, as in the construction of engines, bridges, buildings, mines, ships, and chemical plants…

aerospace engineering. the branch of engineering that deals with the design, development, testing, and production of aircraft and related systems **(aeronautical engineering)** and of spacecraft, missiles, rocket-propulsion systems, and other equipment operating beyond the earth's atmosphere **(astronautical engineering)**.

technology (tek nol′ə jē), *n.* **1.** the branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment, drawing upon such subjects as industrial arts, engineering, applied science, and pure science.

ethics (eth′iks), *n.pl.* …**2.** the rules of conduct recognized in respect to a particular class of human actions or a particular group, culture, etc.: *medical ethics; religious ethics.* …**4.** that branch of philosophy dealing with values relating human conduct, with respect to the rightness and wrongness of certain actions and to the goodness or badness of the motives and the ends of such actions.

1.2. The Design Process[1, 2]



1.3. Performance Characteristics

The Boeing 787-8 (same as the wind tunnel model) has the following performance characteristics:

1.3.1. Cruise speed of M = 0.85 (487 kts).

<u>Note:</u> 1 kt = 1.151 mph = 1.688 ft/sec

1.3.2. Cruise altitude of 43,000 ft.

1.3.3. Range is 7,355 nm with a full payload.

1.3.4. Takeoff and land at Denver. Field length is 12,000 ft at Denver International Airport (DIA).

1.3.5. Loiter time of 45 min based on Federal Aviation Regulations (FAR part 91).

1.3.6. Payload consists of 242 (2-class seating) passengers, baggage and crew. Assume each passenger weighs 175 lb and each carries 40 lb of baggage. There are 2 flight crew – assume same weight and baggage – and 1 flight attendant for every 50 passengers or additional portion thereof. The plane is also carrying an additional 3,000 lb cargo.

1.3.7. The engines used are either 2 General Electric GEnx-1B engines or 2 Rolls-Royce Trent 1000 engines. Since the fuel consumption of these engines is proprietary, assume for both engine models a specific fuel consumption (c_j) of 0.37 lb/lb/hr. Each engine produces 64,000 lb.

1.3.8. The wing area is 3,501 ft^2 and the wing span is 197 ft 3 in. The (L/D) in cruise can be estimated as 16 and the (L/D) in loiter as 19.

1.4. Estimating Takeoff Weight

The total weight of an airplane at the beginning of a mission, W_{TO}, is the sum of the empty aircraft weight, W_{empty} (structure, engine and interior equipment weight), payload weight, $W_{payload}$, fuel weight, W_{fuel}, crew weight, W_{crew} and weight of the trapped fuel and oil, W_{tfo}:

$$W_{TO} = W_{\text{empty}} + W_{\text{payload}} + W_{\text{fuel}} + W_{\text{crew}} + W_{\text{tfo}} \tag{1}$$

where:

$$W_{fuel} = W_{fuelreqd} + W_{fuelres} \tag{2}$$

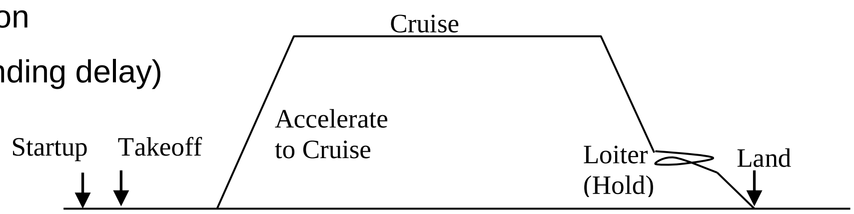
$W_{fuelreqd}$ is the takeoff weight less the landing weight:

$$W_{fuelreqd} = (W_{TO} - W_L) = [1 - (\frac{W_L}{W_{TO}})]W_{TO} = (1 - M_{ff})\, W_{TO} \qquad (3)$$

and M_{ff} is defined as the mission fuel fraction. $W_{fuelres}$ is a function of regulations and is the 45 min loiter mentioned previously. W_{tfo} is assumed to be $0.005W_{TO}$.

Commercial missions can be typically broken into the following mission phases:

- Engine startup and takeoff
- Climb/Acceleration to cruise velocity and altitude
- Cruise to destination
- Descent/Loiter (landing delay)
- Landing



The weight fraction for each phase of the flight is defined as the ratio of the airplane weight W_i, leaving phase *i*, to W_{i-1}, the airplane weight entering phase *i*:

$$\text{Mission segment weight fraction} = \frac{W_i}{W_{i-1}} \qquad (4)$$

The ratio of the airplane weight at the end of a mission with *N* segments, W_N, to the initial gross weight, W_{TO}, is:

$$\frac{W_N}{W_{TO}} = \frac{W_1}{W_0}\frac{W_2}{W_1}\cdots\frac{W_N}{W_{N-1}} = \frac{W_L}{W_{TO}} = M_{ff} \qquad (5)$$

So the required fuel weight can be calculated as a function of takeoff weight if the fuel burn during each segment can be calculated. Estimates of the fuel fraction for each of the phases are given in the following table where:

L = lift (lb)

D = drag (lb)

V = velocity (speed) (mph)

c_j = specific fuel consumption [(lb thrust)/(lb weight)/(hr)] = (1/hr)

E = endurance (hr)

R = range (mi)

Startup/Taxi/Takeoff/Climb	0.990 / 0.990 / 0.995/ 0.980
Cruise to Destination (turbojet)	$R = \frac{V}{C_j}\frac{L}{D}\ln\left(\frac{W_{i-1}}{W_i}\right)$ (6)
Loiter	$E = \frac{1}{C_j}\frac{L}{D}\ln\left(\frac{W_{i-1}}{W_i}\right)$ (7)
Descent	0.990
Land/Taxi	0.992

It is generally assumed that unusable, trapped fuel and oil is 0.5% of the takeoff weight.

1.5. Your Assignment

1.5.1 You are going to modify the 787 for different performance characteristics. First develop a performance sizing plot for the existing 787-8 aircraft using the Advanced Aircraft Analysis (AAA) program. Record the takeoff weight, design thrust and wing area.

You will separately, without any additional changes:

1.5.2 **Just** increase the number of passengers by 85 (they will also each have 40 lb of baggage). Developing a performance sizing plot for the modified 787-8 aircraft and, keeping the thrust and wing area the same as previously, record the new takeoff weight. Is this performance change possible with the current engines?

1.5.3 **Just** increase the range by 1,000 nm. Developing a performance sizing plot for the modified 787-8 aircraft and, keeping the thrust and wing area the same as previously, record the new takeoff weight. Is this performance change possible with the current engines?

1.5.4 **Just** increase the loiter by 15 min. Developing a performance sizing plot for the modified 787-8 aircraft and, keeping the thrust and wing area the same as previously, record the new takeoff weight. Is this performance change possible with the current engines?

1.5.5 **Just** change one parameter of your choice (c_j, (L/D), AR, flaps, airport, cruising altitude…). The change can be an increase or decrease from the given performance characteristics. Don't choose takeoff weight or wing area, since they are plot variables, and do not choose velocity, as it gives a physically impossible answer!

Justify your change, i.e., if you change airports, look up the runway length and elevation, if you change c_j, find a comparable engine which has that value. Developing a performance sizing plot for the modified 787-8 aircraft and, keeping the thrust and wing area the same as previously (or as close as possible without violating the design area), record the new takeoff weight. Is this performance change possible with the new change?

1.5.6 Repeat **1.5.5** with another parameter of your choice.

1.5.7 For all the previous cases, how much did the takeoff weight change from the existing 787's takeoff weight? What is the value of takeoff weight per unit change in the variable analyzed, i.e. how much does the takeoff weight change per 1 nm change in range? Per unit decrease in (L/D)?

1.5.8 You have just performed a trade study, or sensitivity analysis. Now do this in AAA and compare your results, when possible (AAA may not have a sensitivity analysis for the variable you selected), again, in a table. Do the AAA results differ from your own calculations? Why or why not? What change, in your opinion, makes the biggest impact? How could a sensitivity analysis be useful in preliminary design?

2.0 Required Deliverables

2.1. Group Presentations

Your group will prepare a 15-minute presentation (with an additional 5 minutes for questions and answers) reporting the results of your design investigation. Include at least a title slide with all team members listed, outline, introduction, performance sizing plots for each case, the required data tables, a summary, and any references used. Fifteen minutes isn't much time, so present what you think are the important points.

2.2. Individual Peer Reviews

Each person **must** submit <u>confidential</u> peer reviews of their team members regarding their participation in and contribution to both the experimental F-16/787 and 787 design labs. This will count as a quiz grade and is due on midnight, Tuesday, 3/7/2017. Each day submitted after this will result in loss of points. Forms and a separate dropbox can be found on D2L.

3.0 References

1. Corke, T., **Design of Aircraft**, Prentice Hall (2003).
2. Raymer, D. **Aircraft Design: A Conceptual Approach**, AIAA (2012).