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Range and Payload Trades Study on Aircraft Conceptual Design

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Abstract

This paper proposes an introduction to aircraft payload-range performance analysis by examining the details that make up its capabilities; aircraft operational weights are studied, and their cause and effect relationship on payload-range performance are investigated in great length. In particular, payload-range analysis involves examining Maximum Take-off Weights (MTOW) and its various components to assess the aircraft's payload capability at different ranges, as well as range capability with different payloads.

Keywords:Conceptual Design; Sizing; Range Trade; Payload Trade

1. Introduction

A complex aircraft design process consisting of numerous disciplines has been developed over many years. These disciplines are integrated and blended together to generate an optimum configuration that satisfies the given requirements [1]. There are three phases of aircraft design; conceptual, preliminary and detail phases. Among them, the conceptual design phase is characterized by the initial definitions that come from requirements established by market needs. Thus, this phase is the most interactive in the whole aircraft design process. The aircraft geometry will change several times driven by optimizations done in order to achieve mission requirements [2].

Daniel P. Raymer et al. who established an aircraft conceptual design process characterized by a large number of design alternatives and trade-off studies, as well as a continuous change in the aircraft concepts under consideration [3]. D. Howe proposed a systematic and logical approach for several types of aircraft such as two-seat, aerobatic, short- and medium-haul airliners or short take-off landing (STOL) aircraft [4]. Thomas C. Corke proposed an optimization approach to conceptual design of a supersonic business jet (SSBJ) [5].

The role of aircraft performance analysis is to examine the capabilities and limitations of an aircraft in context to an operator's requirements. A carrier, for example, might be looking at aircraft optimized for particular routes in their network, or it might be more interested in the flexibility to operate an aircraft profitably across multiple routes. One of the most widely means used by airlines to compare the operating economics of an aircraft is by evaluating its payload-range performance, which can be illustrated graphically through the payload-range diagram [6].

This report provides an introduction to aircraft payload-range performance analysis by examining the details that make up its capabilities; aircraft operational weights are studied, and their cause and effect relationship on payload-range performance are investigated in great length. In particular, payload-range analysis involves examining Maximum Take-off Weights (MTOW) and its various components to assess the aircraft's payload capability at different ranges, as well as range capability with different payloads].

2. Conceptual Design

The role of the conceptual aircraft design is to propose aircraft configurations that can best meet a set of needs, then to identify several design alternatives. The choice of an aircraft is predicated upon the requirements of its mission and specific operating economics. Each aircraft type has unique capabilities and limitations that dictate its optimum deployment within a carrier's network. One method employed by airlines to assess aircraft selection involves the evaluation of its payload and range performance. Ideally, there should be a match between the stage lengths in an airline's network and the optimum payload-range of the aircraft employed. [6]

3. Aircraft Design Requirements

The key requirements for the designated aircraft is the ability to loiter for 3 hrs. at a distance of 1500 n mi from the takeoff point. While loitering on station, this type of aircraft uses sophisticated electronic equipment to detect and track submarines. For the sizing, this equipment is assumed to weight 10000 lb. Also four man crew is required totaling 800 lb. The aircraft must cruise at 0.6 Mach number.

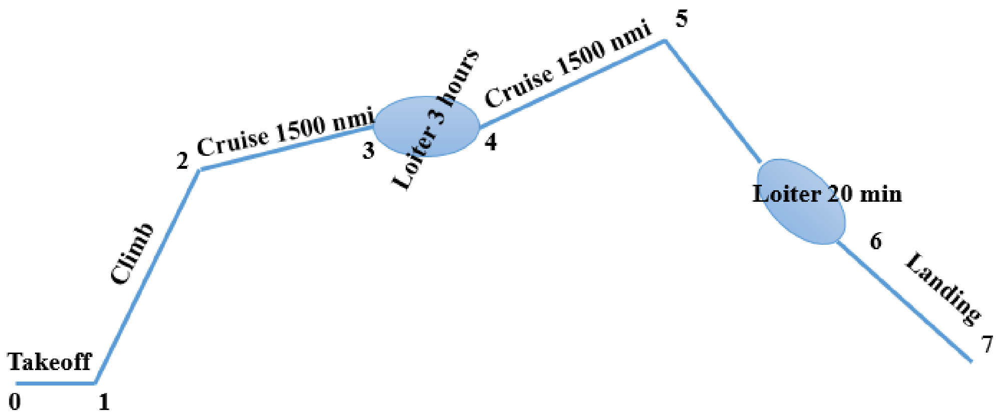

Fig. 1. Mission Profile

4. Trades Study on Aircraft Sizing

The important part of conceptual designs the evaluation and refinement, with the customer, of the design requirements. [3]. In this study SSA optimized design required weight is 1500 nm. That is probably less than the customer would really like. A '**Range Trade'** can be calculated to determine the increase in design takeoff gross weight if the required weight is increased.

4.1. Aircraft Sizing

Gross take-off had been calculated (1) using an iterative process and by using the fuel fraction for each mission segment along with an estimated weight of the same type of aerobatic aircraft from historical data. Gross take-off weight is the sum of Payload weight, Crew weight, Fuel weight, Empty weight of the aircraft. The SSA was designed one crew member.

$$W_0 = (W_{crew}+W_{pay}) / [1- (W_f/W_0)-(W_e/W_0)] \quad (1)$$

$$(W_f/W_0) = 1.06 (1 – W_7/W_0) \quad (2)$$

$$(W_7/W_0)= W_1/W_0 * W_2/W_1 * W_3/W_2 * W_4/W_3 * W_5/W_4 * W_6/W_5 * W_7/W_6 \quad (3)$$

$$(W_e/W_0) = 1.495\ W_0^{-0.1} \quad (4)$$

4.2. Weights Frictions for Each Mission Segments

According to the historical data that shown in Raymer. In Table 1.

Table 1. Historical mission segment weights friction

Missing Segment	W_i/W_{i-1}
Warmup and takeoff	0.97
Climb	0.985
Landing	0.995

4.3. Cruise Mission Segment

Cruise mission segment fractions can be found using the Breguet range equation.

$$\text{Range} = (V / C)\ (L/D)\ \ln (W_3/W_2) \tag{5}$$

$$W_3/W_2 = \exp \{ - \text{Range} / (V/ C)\ (L/D)\} \tag{6}$$

4.4. L/D Estimation

Lift to drag ratio estimation is unknown for Range. That is a measure of design's overall aerodynamics efficiency. Unlike the parameters estimated above, the L/D is most directly affected by the configuration arrangement. At subsonic speeds L/D is most directly affected by two aspects of design: wing span and wetted area. The design aircraft is a Jet aircraft so the L/D is 0.866 L/Dmax for cruise and L/D max for loiter condition.

For initial sizing, wing aspect ratio of 10 was selected. And The L/D max is about 16 from the figure below.

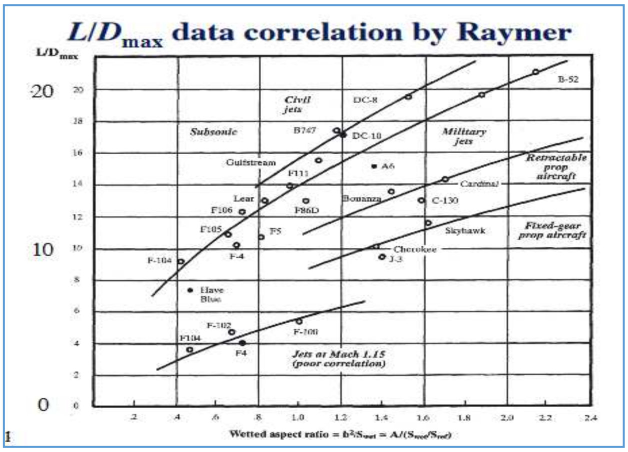

Fig. 2. Maximum Lift to Drag Ratio

5. Trades Study

5.1. Maximum Takeoff Weight Estimation

Maximum takeoff weight was estimated by the First order design method by iterating. The method is shown below.

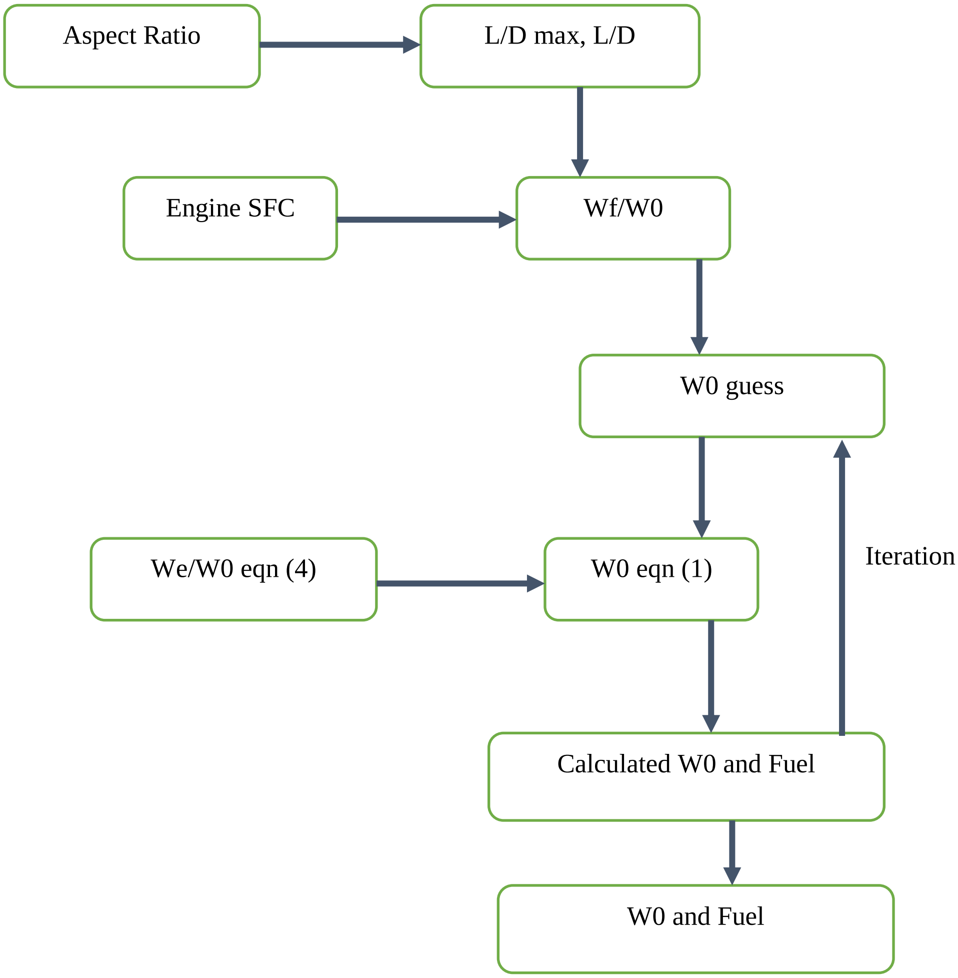

Fig. 3. Take-off weight estimation

Table 2. Take-off weight estimation

W0 Guess	We/W0	W0 calculated
50000	0.4361	61057
60000	0.4305	59191
59200	0.4309	59328
59300	0.4309	59311
59310	0.4309	59309.6

5.2. Range Trade Study

As describe above, the range trade should be done for the customer need. The Range trade is done by the following graph. This is done by recalculating the weight frictions for the cruise mission segment, using arbitrarily selected ranges. Calculated by changing the cruise range from 1500nm to 2000nm. From Figure 4, the aircraft range is directly increase with the gross takeoff weight. From this figure we can visually design the aircraft, if the customer is need to design the aircraft with the weight of 6000 lb, this aircraft cruise range will be 9500000 ft. and also 9000 lb at 1300000 ft.

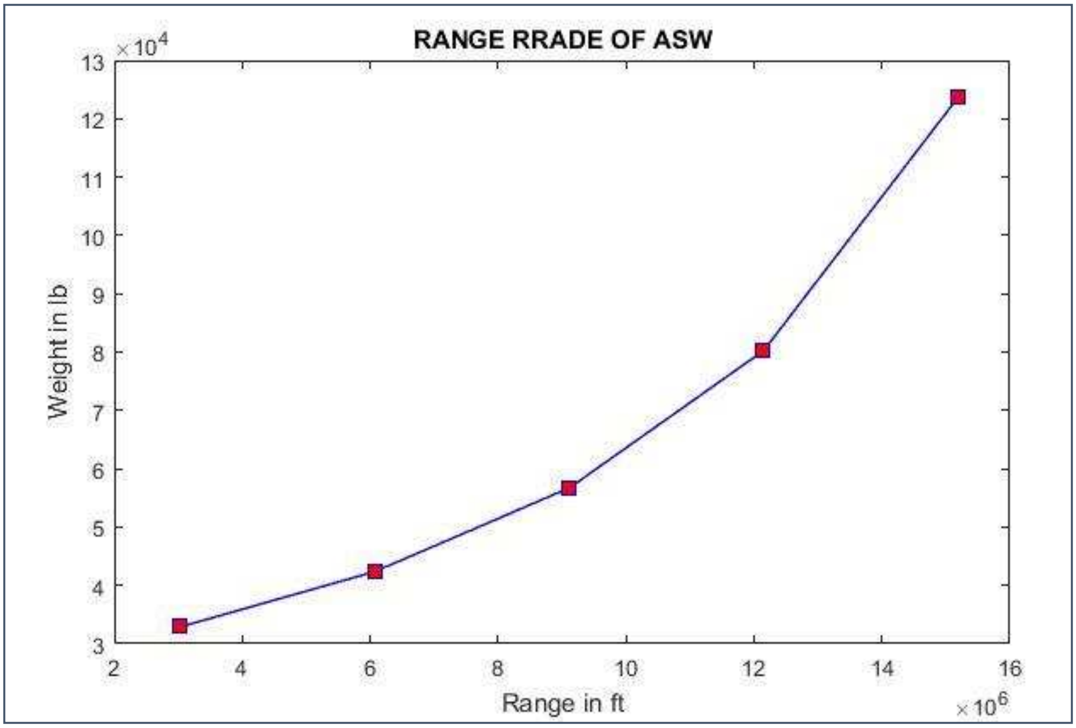

Fig. 4. Range Trade

5.3. Payload Trade Study

The payload trade also can be made. The mission segment weight frictions, and fuel friction are unchanged but the numerator of the sizing equation is parametrically varied by assuming different payload weights. The given payload requirements is 10000 lb of avionics requirements. Payload weights are ranging from 5000 lb to 20000lb. The result is plotted below.

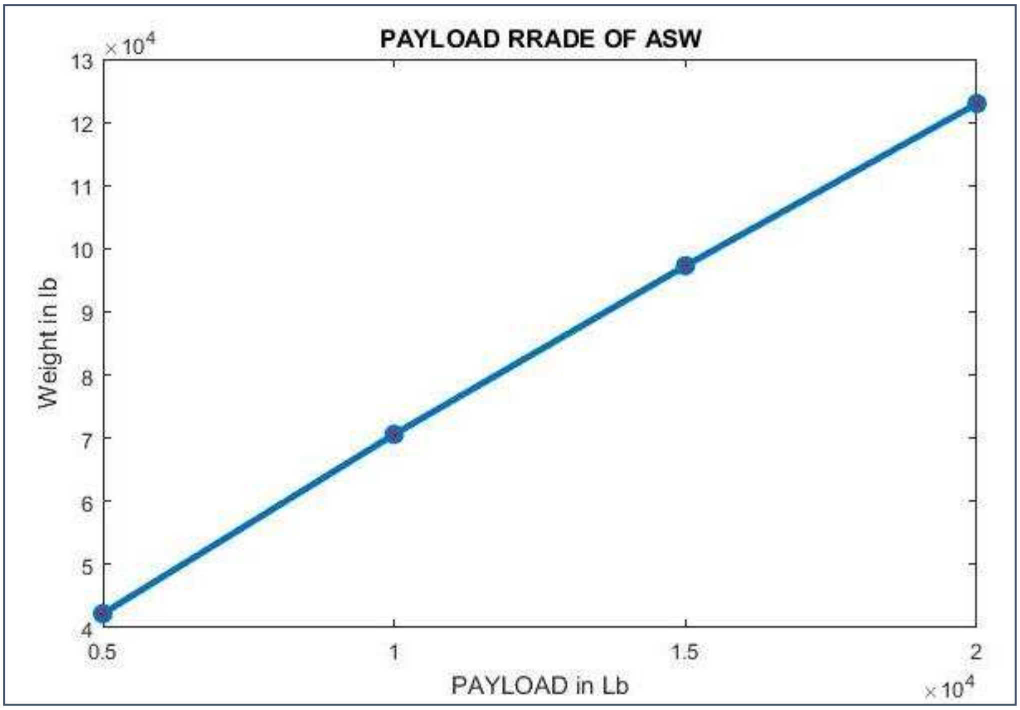

Fig. 5. Payload Trade

6. Conclusion

As conclude the conceptual fighter aircraft design is select to determine the weight friction and the effect of range and payload are also determined. The aircraft was estimated to weight 59309.6 lb. This weight could be changes scientifically if the customer decided to change the requirements or if the aircraft is manufactured from composites. So, to satisfy the customer need of aircraft design the tradeoff study are followed. The Range trade off show that the changes between the Range and takeoff weight. And Payload trade show that the changes between the payload and takeoff weight.

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