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# Conceptual Design Code Validation and Optimization of Aircraft for Minimum Drag and Maximum Range

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**Abstract**

This paper develops conceptual design code and validate with existing results of Single Seat Aerobatic aircraft (SSA) by the user requirements. Special consideration is given to minimize total Drag, maximum Range for optimum conceptual design based on developed design code.



Keywords:Conceptual Design; Validation; Range; Total Drag

## 1. Introduction

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 [1]. The Range is the furthest distance the aircraft can fly without refueling and is larger effect on aircraft takeoff weight [2]. The minimization of total Drag indirectly improves the performance parameters such as Range [3]. So, we need to minimize total Drag.

The Range and the total Drag are largely effect on aircraft design, Therefore, the researcher are optimize the design of aircraft for maximum Range and minimum total Drag.

A researcher who minimize total Drag of VLA by using aircraft layout data as variable [3]. And also optimize aircraft configuration for minimum Drag and maximum Range by the use of optimization MATLAB program, FMINCON 4]. Optimization of Supersonic Business Jet (SSBJ) for maximum Range by using Genetic algorithm [5]. In this research, conceptual design of SSA [1] is developed MATLAB codes to validate. And the codes results are used as baseline to optimum design for minimum total Drag, maximum Range.

## 2. Conceptual Design

Conceptual design usually begin with a specific design requirement established by the prospective customer [1]. And the conceptual design of SSA [1] is used to develop MATALB code and to validate.

## 3. Requirements

The SSA need to design cruise Range ⩾ 280nm at 115Kts, and maximum velocity of 130Kts, and a stall velocity of 50Kts.

Take off distance ⩾ 1000ft
Rate of climb ⩾ 1500 ft/min
Crew weight = 220 lb

The Engine ( LYCOMING O-320-A2B) having Cbhp, specific fuel consumption is assumed 0.5 at cruise speed, revolution of 2700RPM and horse power of 150hp.

The SSA has to fly with the requirements, and the related mission profile is given in Fig .1.

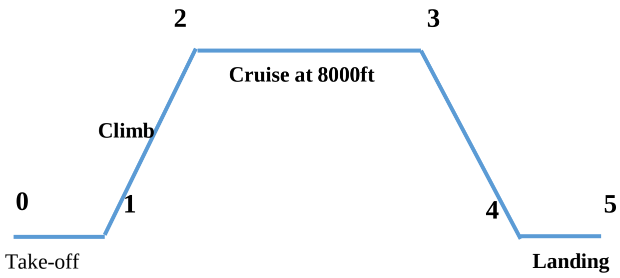


Fig. 1. Mission profile segments

## 4. Conceptual Design Steps

Hp/W is chosen by the engine. Wing aspect ratio of 6, taper ratio of 0.4, NACA $63_2015$ as root and $63_2012$ as tip are used from the historical data. Horizontal and Vertical tail are used Aspect ratio NACA 0012 and taper ratio of 0.4.

W/S is calculated each mission segments and then selected lowest wing loading. Take-off weight and empty weight are calculated using (1) by iterative process on rubber engine sizing.

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

After this, the layout design of wing, fuselage, tails, fuel tank, tire size, and propeller diameter are calculated and total Drag is calculated by using

$$C_D = C_{D0} + K\,C_L^2 \quad (2)$$

Total drag is the sum of parasite drag ($C_{D0}$) and lift induced drag ($K\,C_L^2$).

$$C_{DO} = \Sigma C_f\,(Re, M)\,(S_{wet}/S_{Ref}) + C_{Dmisc} + C_{DL\&P} + CD_{cooling} \quad (3)$$

Parasite drag ($C_{D0}$) is the total sum of wing, tail, fuselage ($\Sigma C_f$ (Re, M) ($S_{wet}/S_{Ref}$)), leakage and protuberance drag ($C_{DL\&P}$), nacelle drag, landing gear drag and miscellaneous drag ($C_{Dmisc}$).

$$K = 1 / (\pi\, e\, Aw) \quad (4)$$

$$e = 1.78\,[\,1-0.045(Aw)^{0.68}] - 0.64 \quad (5)$$

$$C_L = (W/S) / (1/2\, \rho_{cr}\, V_{cr}^2) \quad (6)$$

Range is calculated at L/D for the cruise condition.

$$Range = 550\,(\eta_p / C_{bhp})\,(L/D)\,\ln(W_3/W_2) \quad (7)$$

Calculation is done by the conceptual design step. And MATLAB codes are developed.

## 5. Conceptual Design Code Validation

The design codes are developed by the conceptual design steps. And validate with SSA [1] as shown in TABLE I.

MATLAB code results are closed enough to the existing SSA. Distinctly, the Range is less than the requirement (need of 24 nm). The code results are agreed well with existing data.

Table 1. Design Code Validation with Existing Data

| | SSA | Code | Units |
|---|---|---|---|
| **$C_D$** | 0.0323 | 0.0323 | |
| **Range** | 256.84 | 256.84 | nm |
| **$W_0$** | 1290 | 1287.3 | lb |
| **$W_e$** | 941 | 940.45 | lb |
| **W/S** | 10.2 | 10.3115 | lb/ft$^2$ |
| **Sw** | 125 | 124.8362 | ft$^2$ |
| **bw** | 27 | 27.3682 | ft |
| **Aw** | 6 | 6 | ft$^2$ |
| **lambaw** | 0.4 | 0.4 | |
| **Sht** | 27.8 | 27.7 | ft$^2$ |
| **bht** | 10.55 | 10.529 | ft |
| **Svt** | 12.5 | 12.5 | ft$^2$ |
| **bvt** | 4.34 | 4.336 | ft |

## 6. Optimization

The SSA has low Range comparing with requirements from Table I. The minimization of total Drag indirectly improves the performance parameters such as Range [2]. So, we need to minimize total Drag.

So code results are used as baseline and the existing aircraft data are used for upper and lower bounds to optimum design.

### 6.1. Geometry Selection

For getting optimum design, wing aspect ratio and taper ratio are used as variables.

Wing aspect ratio range is between 5 and 10 and taper ratio is from 0.2 to 1. These two variables are chosen for minimum total drag and maximum Range from fig.2 by using (2) and fig.3 by (7). In fig.3 the range is calculated at the cruise condition, means L/D at cruise. For the maximum Range, L/D must use optimum point from drag polar but Fig.3 is plotted for getting the variation of Range and aspect ratio.

From Fig.2, the higher the aspect ratio (Aw), the lower the total Drag (CD) and also the lowest taper ratio (lambaw) give minimum total Drag (CD).

The higher aspect ratio (Aw) give lower Range and the higher taper ratio (lambaw) give higher Range from Fig.3.

Therefore, aspect ratio maximum give lowest total Drag and taper ratio minimum give lowest total Drag and highest Range.

Aw=10, lambaw=0.2 are the optimum for minimum total Drag, and Maximum Range.

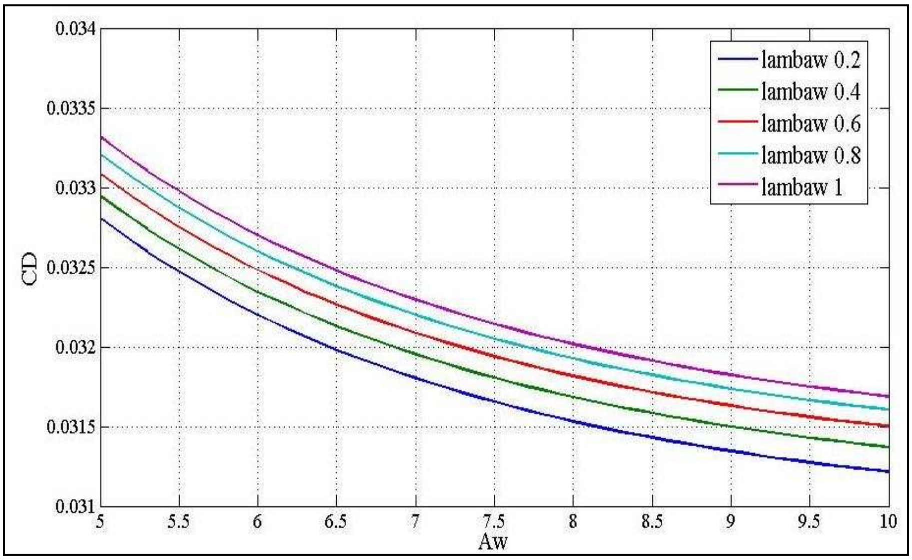


Fig. 2. Aspect ratio and total Drag with taper ratio

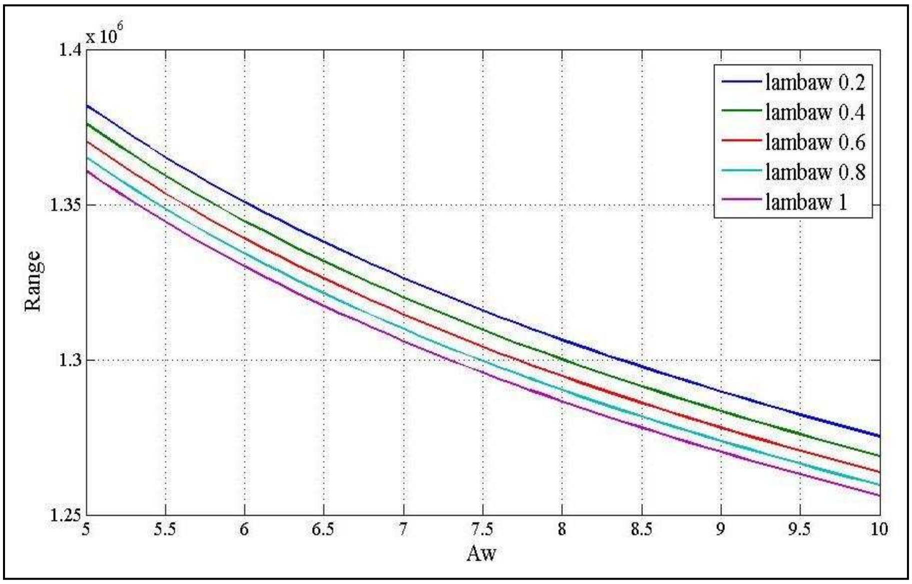


Fig. 3. Aspect ratio and Range with taper ratio

## 6.2. Optimum L/D

Drag polar is plotted by using (2), the velocity range is stalling speed to maximum speed. The optimum L/D is a point from drag polar that is tangent to a line from the original and closest to the vertical axis [1]. L/D is compared in with SSA code results and optimum results in Fig. 4.

L/D for optimum design is 12.7. L/D for SSA design is 10.5 from Fig.4.
For the maximum Range, calculation is done by (7)

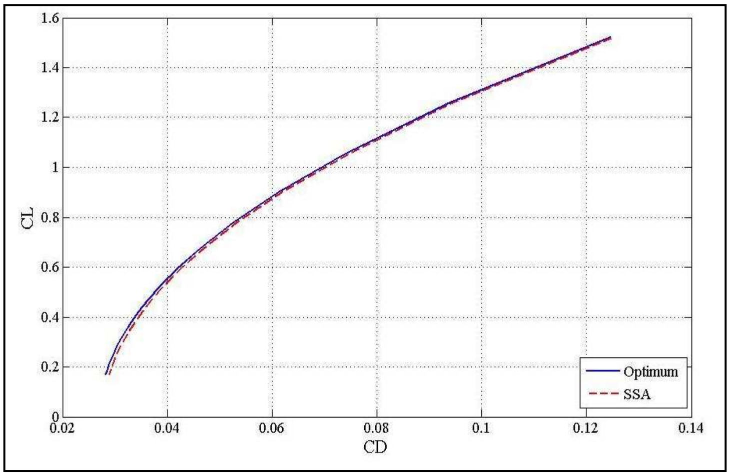


Fig. 4 Drag polar for L/D optimum

## 7. Baseline Design and Optimum Design Comparison

Optimum results are shown in TABLE II, comparing with SSA design code results. Also, the optimized SSA's wing mapping configuration data are created in Fig.5 to prove that the optimum configuration data are in the bounds of current SSAs.

Table 2. Design Code Validation with Existing Data

| | SSA | Optimum | Units |
|---|---|---|---|
| $C_D$ | 0.0323 | 0.0309 | |
| Range | 256.84 | 285 | nm |
| $W_0$ | 1287.3 | 1267.3 | lb |
| $W_e$ | 940.45 | 927 | lb |
| W/S | 10.3115 | 10.3115 | lb/ft$^2$ |
| Sw | 124.8362 | 125 | ft$^2$ |
| bw | 27.3682 | 35.375 | ft |
| Aw | 6 | 10 | ft$^2$ |
| lambaw | 0.4 | 0.2 | |
| Sht | 27.7 | 23.39 | ft$^2$ |
| bht | 10.529 | 9.6 | ft |
| Svt | 12.5 | 16.3 | ft$^2$ |
| bvt | 4.336 | 4.9 | ft |

By the optimum configuration, the total Drag is reduced by 4% and the Range is increased by 11%. The Range is also higher than the required Range of 280 nm, increase about 2%. The total take-off weight and empty weight are also reduced.

From wing mapping Fig.5, the red point is the optimum configuration of SSA,

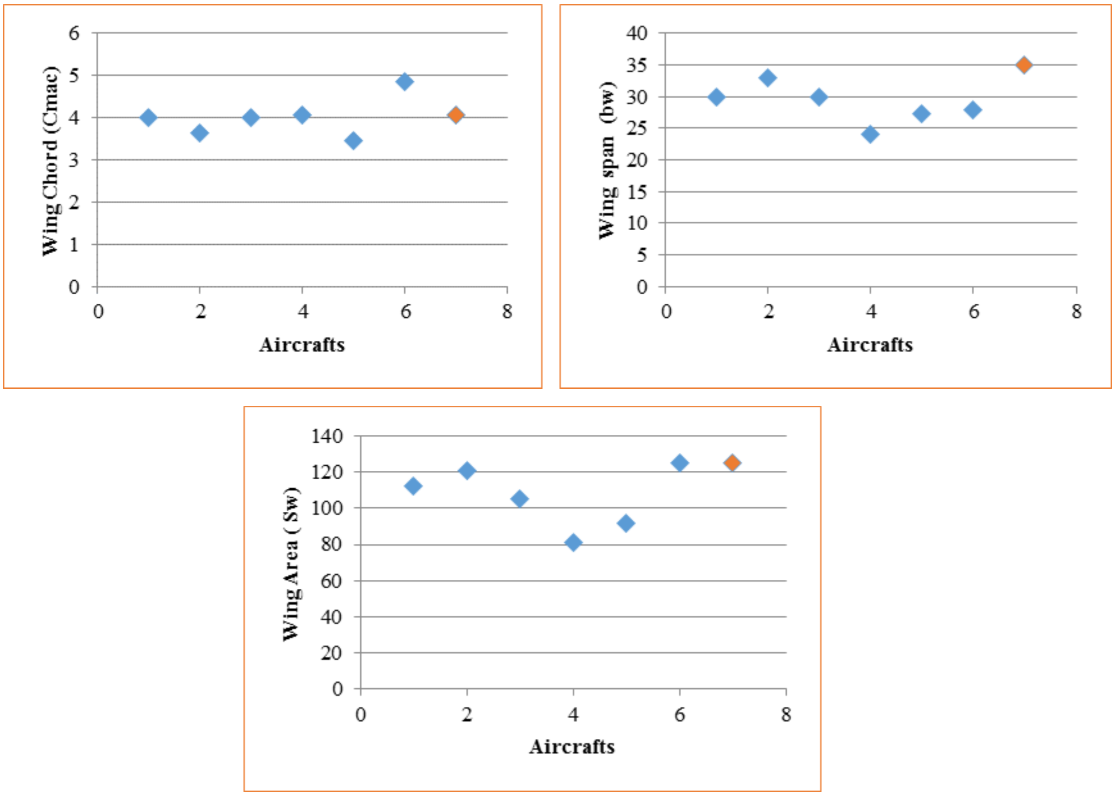


Fig. 5. Wing Mapping for Optimized SSA configuration

## References

[1] Daniel P. Raymer, “Aircraft Design: A Conceptual Approach.”

[2] Thomas C. Corke. Design of Aircraft. Prentice Hall, Pearson Education., Inc; Upper Saddle River. New Jersey 07458. p 109.

[3] Nguyen, N. V. (2011). Multidisciplinary configuration design optimization for advanced very light aircraft. The Korean Society for Aeronautical and Space Sciences, 18-23. http://www.dbpia.co.kr/Article/NODE01839444.

[4] Boone IV, T. R., & Striz, A. G. (2010). Optimization of aircraft configuration for minimum drag. In the proceedings of the 51st AIAA/ASME/ASCE/AHS/ ASC Structures, Structural Dynamics, and Materials Conference, Orlando,FL. doi:10.2514/6.2010-3000.

[5] Hamza Ashraf, Afreen Abbas, “Conceptual Design and Optimization of Supersonic Business Jet,” Student Research Paper Conference Vol-1, No-3, Aug 2014.