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AE 442 Section A1

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AE 442 Sizing Practice Project

I. Requirements

When companies design aircraft, the designs they create are driven by sets of requirements that the aircraft must meet. These requirements are driven by an overarching mission(s) that the aircraft must by able to accomplish. For the case of this project, two missions were given that drove the sizing of a fast attack aircraft. However, for simplicity and to stay within the scope of what has been taught in AE 442 so far, only a more straight-forward long-range ferry mission was focused on. This ferry mission consisted of the following with a two-person crew and 60% payload requirement of 3000 lbs.:

1	Warm Up / Taxi	5 minutes
2	Take Off	Austere field, 50 ft obstacle, ≤ 4000 ft
3	Climb	To cruise altitude; with range credit
4	Cruise	At best range speed/ altitude (≥ 18,000 ft), 900 nmi
5	Descent / Landing	To austere field over 50 ft obstacle in ≤ 4000 ft
6	Taxi / Shutdown	5 minutes
7	Reserves	Sufficient for climb to 3,000 ft and loiter for 45 minutes

Table 1. Design Mission

From this mission, many requirements can be pulled. However, for this project, only the requirements that drive the aircraft sizing specifically were focused on. These requirements include the 3000 lb. payload requirement, the requirement that the cruise altitude must be ≥ 18,000 ft., the 900 nmi range requirement, and the requirement that the balanced field length must be ≤ 4000 ft. From these requirements, the sizing process can begin.

II. Similarity Analysis

For this project, a fast attack aircraft that performs similarly to the requirements given was needed to perform similarity analysis. After some research, the Cessna A-37 Dragonfly was chosen to be the seed aircraft to drive the design. This aircraft was chosen because it uses two turbojet engines, and it would be interesting to see how a turbojet engine performs as opposed to the commonly used turbofan or turboprop engine. It also performs similarly to the requirements given. A detailed summary of the specifications of the A-37 can be found below in Table 2.

Cessna A-37 Dragonfly Specifications					
Weights			**Geometry**		
Ramp Weight	lb	12647	Wing Area	sq ft	184
Empty Weight	lb	6210	Span	ft	33.78
Max Zero Fuel Weight	lb	9210	Taper		0.69
Payload Weight	lb	3000	Sweep (C/4 MAC)	degrees	0
Fuel Weight	lb	3447	T/C Average		0.09
Max Landing Weight	lb	11075	Fuselage Length	in	339
Aerodynamics/Range			Fuselage Diameter	in	59
Induced Drag Coefficient		0.0209	Nose Taper Length	in	61
Initial Altitude	ft	25000	Tail Taper Length	in	146
DISA	C	0	**Engine Parameters**		
Cruise Mach		0.71	T/Engine	lb	2850
Range	nm	1180	T/W IPPS	lb/lb	5.18
Takeoff/Landing			Fan Diameter	in	54.72
TO CLMax		1.8	Reference Nacelle Diameter	in	28
Landing CLMax		2.2	Nacelle Length	in	83
Landing Breaking Coefficient		80	Approximate SFC at Cruise	lb/lb-hr	0.9
Balanced Field Length	ft	3363	Number of Engines		2

Table 2. Cessna A-37 Specifications

III. Initial Sizing and Constraints

From this seed aircraft, the sizing process could begin to design an aircraft that optimally performs the prescribed mission with the specified requirements. Within the attached Excel document, an iterative sizing process was created that looked at the requirements and seed parameters and created guesses of the design parameters. Applying equations from Chapter 5 of Raymer [2], the design parameters were updated until the calculated and guessed design parameters converged. The parameters that were chosen to be iterated were the thrust per engine, the required fuel weight, and the delta weight between the seed aircraft and the weight required for the design aircraft. These parameters were chosen because they would help determine the engines that could be used, the amount of fuel that would be needed for the mission, and the weight of the designed aircraft in comparison to the seed aircraft.

To validate the data found through the iterative process, a valid design region needed to be defined. This design region is driven by the constraints put forth by the requirements given. A diagram summarizing these constraints is presented in Figure 1. The wing loading and thrust-to-weight ratio are derived from the maximum ramp weight; this maximum ramp weight correlates directly with the balanced field length given in the requirements. Within the constraint diagram, the thrust-to-weight ratio at cruise, the wing loading at landing, and the relationship between the thrust-to-weight ratio and wing loading during takeoff are what constrain the data to a specific design region.

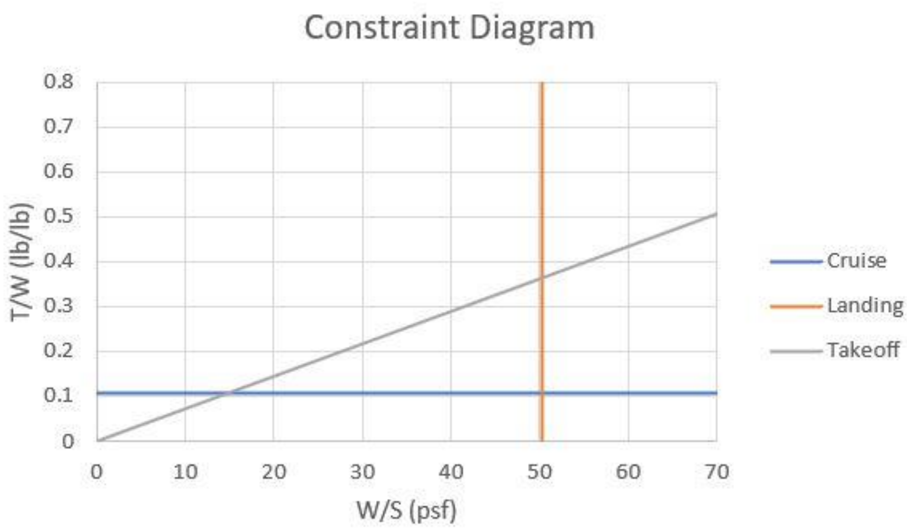

Figure 1. Constraint Diagram

In this constrain diagram, the design region is the upper left-hand side of the plot above the cruise and takeoff lines and to the left of the landing line. This design region will the basis in how the aircraft sizing is optimized so it can be realistically created. It will also drive the further trade studies that will be performed to further optimize other parameters within the design of the aircraft.

IV. Trade Studies

To properly size the aircraft, a trade study was conducted with a range of wing areas and aspect ratios being looked at. Data was taken on how wing area and aspect ratio affects the thrust output required for each engine, the fuel weight required, and the maximum ramp weight. The purpose of these trade studies was to minimize all three of these parameters as well as prioritize which parameters seem for important to the overall design, keeping in the mind the constraints discussed previously. The results of these trade studies are pictured in Figures 2,3, and 4.

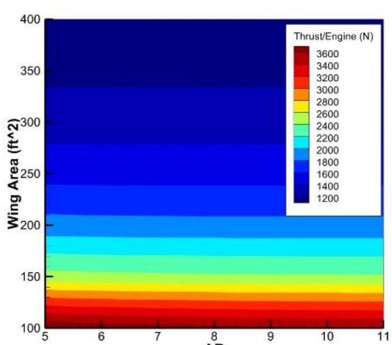

Fig. 2. Thrust/Engine

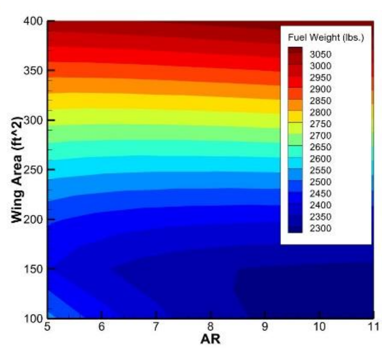

Fig. 3. Fuel Weight

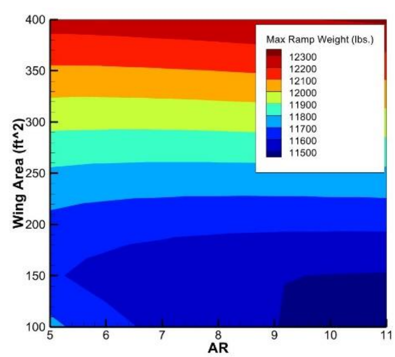

Fig. 4. Max Ramp Weight

From these contour plots, having a high aspect ratio and a low wing area minimizes the fuel weight and the maximum ramp weight. This makes sense because have smaller wings reduces the weight of the wings and, therefore, reduces the overall weight of the aircraft. Also, high aspect ratio wings produce less drag and, therefore, less fuel is required for flight. On the contrary, with regards to the thrust required per engine, a larger wing area is needed to lower the thrust required. This is because larger wings produce more lift and, therefore, less thrust is needed to lift the aircraft.

It is possible to find an optimal aspect ratio and wing area from this data alone but seeing how different parameters effect these contour plots can optimize it further. First, the specific fuel consumption was altered, lowering from the initial value of 0.9 down to 0.75 and finally down to 0.5. The results of this study are presented below in Figures 5, 6, 7, 8, 9, and 10.

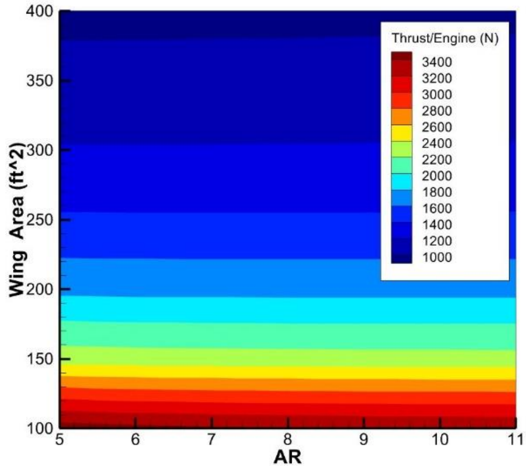

Figure 5. Thrust/Engine, SFC=0.75

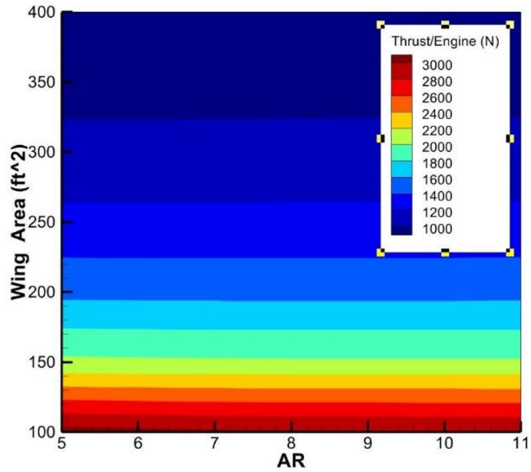

Figure 6. Thrust/Engine, SFC=0.5

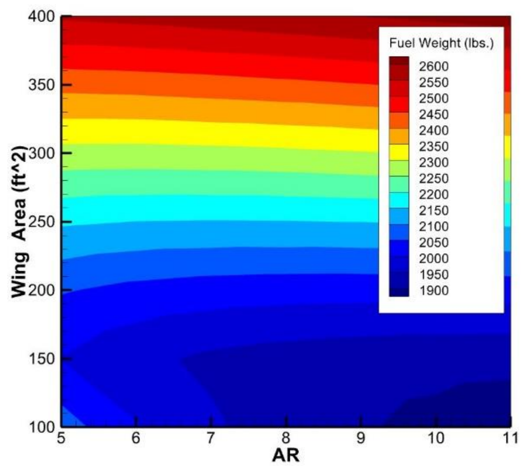

Figure 7. Fuel Weight, SFC=0.75

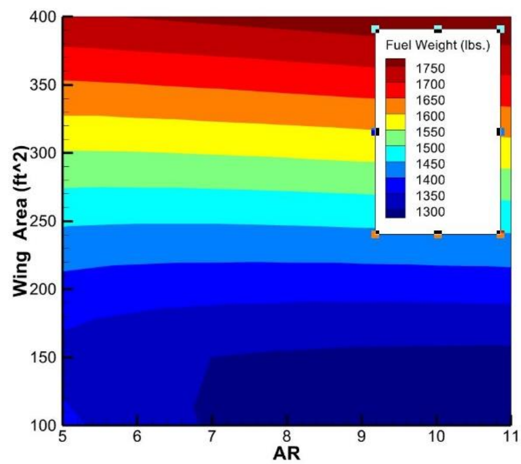

Figure 8. Fuel Wight, SFC=0.5

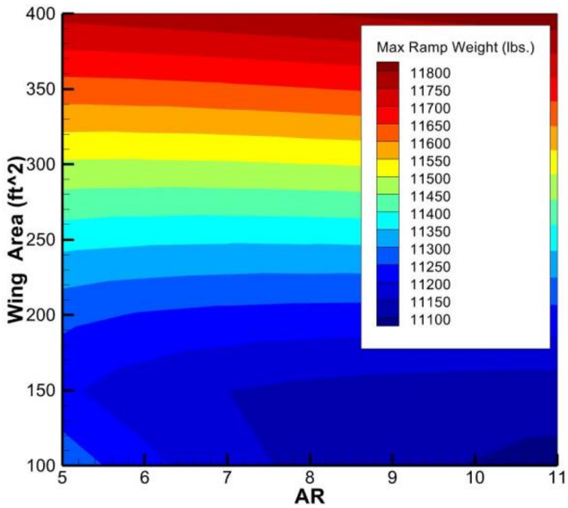

Figure 9. Max Ramp Weight, SFC=0.75

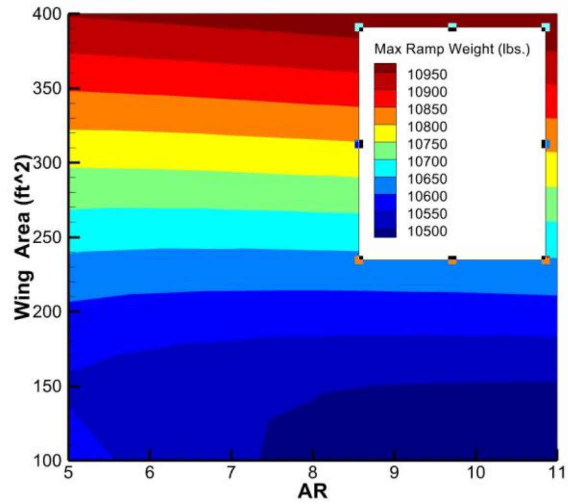

Figure 10. Max Ramp Weight, SFC=0.5

From these figures, it is clear that the specific fuel consumption did not affect the distribution of the three parameters with regards to aspect ratio and wing area. However, lowering the SFC did lower the magnitudes of the requirements of the three parameters. The required fuel weight is less because less fuel is being consumed during flight with a lower specific fuel consumption. With less fuel weight, the maximum ramp weight is lowered as well since these values correlate directly. With a lower maximum ramp weight, the thrust required per engine also becomes lower because less thrust is needed to carry lower weights.

Another parameter that was altered was the fuselage length. Values of 500 in. and 200 in. were used in comparison to the base fuselage length of 339 ft. The results of this study are in Figures 11, 12, 13, 14, 15, and 16.

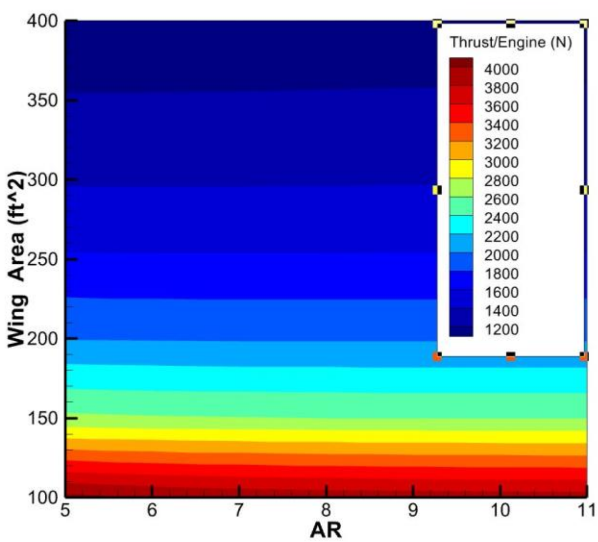

Figure 11. Thrust/Engine, L=500in.

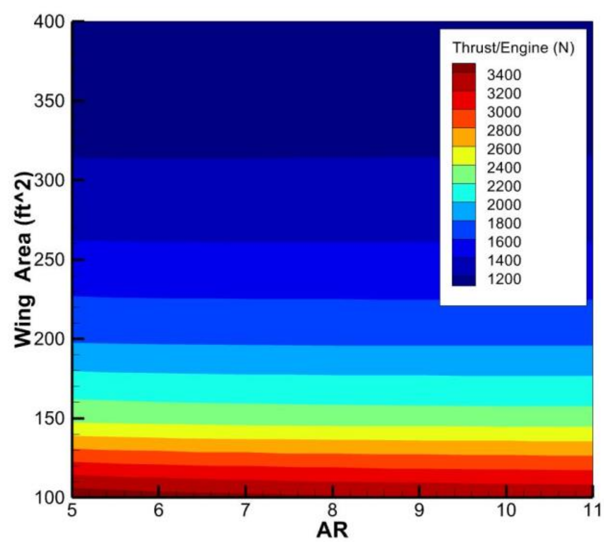

Figure 12. Thrust/Engine, L=200in.

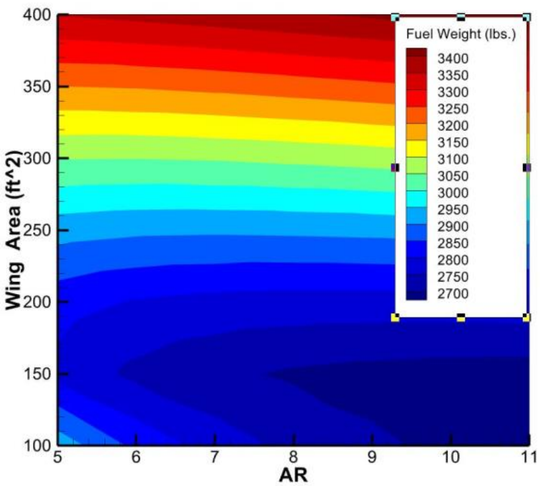

Figure 13. Fuel Weight, L=500in.

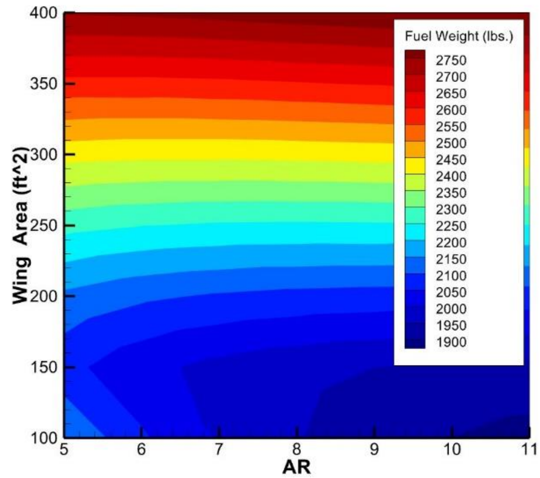

Figure 14. Fuel Weight, L=200in.

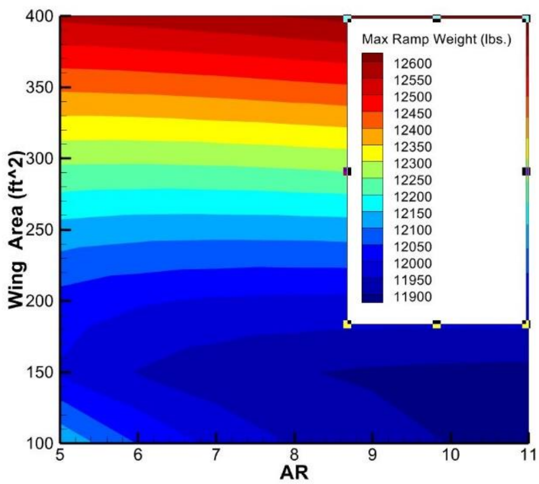

Figure 15. Max Ramp Weight, L=500in.

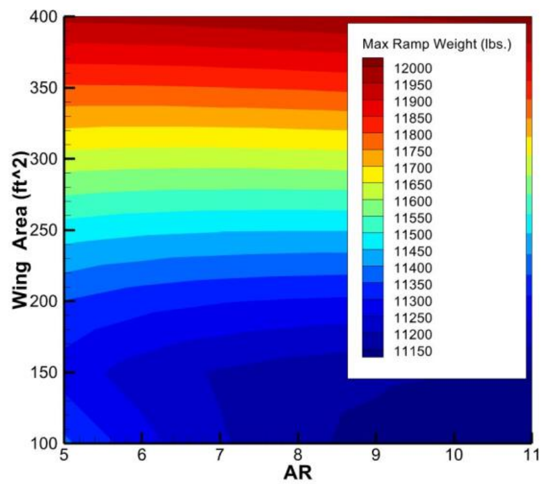

Figure 16. Max Ramp Weight, L=200in.

Like altering the specific fuel consumption, the distribution of the three parameters did not change very much while the magnitudes did. It appears that raising and lowering the fuselage length raised and lowered the magnitude of the maximum ramp weight. This is expected because a shorter fuselage will have a smaller structural mass than a longer one if it is made up of the same material (the fuselage material is held constant in this case). Structural mass directly correlates to the maximum ramp weight. With a smaller maximum ramp weight, the thrust required will also decrease since less thrust is required to carry smaller weights. The decrease in fuselage length also decreases the fuel weight required because less mass is being propelled through the air with a smaller fuselage, so less thrust is being used and, therefore, less fuel is being consumed throughout the flight.

V. Optimization

With this data in mind, the optimal data could be found. From looking at the contour plots, the wing area has more of an effect on the thrust per engine in comparison to the aspect ratio. Also, an increased aspect ratio is beneficial to decreasing both fuel weight and maximum ramp weight, so the aspect ratio was maximized when iterating the data to fit the constraint plot while reflecting the contour plot data. While maximizing the aspect ratio, the wing area was left more in the middle of the range of values that were evaluated. With the specific fuel consumption and the fuselage length, these values were slightly decreased since the data that was gathered from the trade studies found that decreasing these values minimized the thrust per engine, the required fuel weight, and the maximum ramp weight. The values that were used and measured are summarized in Table 3.

Aspect Ratio		10
Wing Area	ft^2	250
SFC	lb/lb-hr	0.7
Fuselage Length	in.	300
Thrust/Engine	lb.	1370.71
Fuel Weight	lb.	1947.98
Max Fuel Weight	lb.	11157.98

Unfortunately, while these design parameters do reflect the results found in the trade study, they do not meet the constraints put forth within the constraint diagram. After numerous attempts in changing the aspect ratio, wing area, SFC, and fuselage length with many different combinations of numbers, at no point did the thrust-to-weight ratio and wing loading point fall within the design region. Whether it was an equation(s) within the Excel document that were wrong or something wrong with the constraint diagram itself could not be figured out. There were several troubleshoots performed to see what was wrong with no luck.

VI. References

[1]“Cessna A-37 Dragonfly,” *Wikipedia* Available: https://en.wikipedia.org/wiki/Cessna_A-37_Dragonfly.

[2] Raymer, D. P., *Aircraft Design: a conceptual approach*, Washington, D.C.: 1992.