AE 442 Homework 7

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Sizing Spreadsheet

The mentioned sizing spreadsheet, performed in excel is attached to the submission. It performs a sizing analysis to converge the seed parameters to the required and inputted constraints. After performing a similarity analysis, the A-10 Thunderbolt II was chosen as the seed aircraft. Following a constraint analysis based on the requirements and objectives of the project, the seed was manipulated to simulate the parameters of a smaller hybrid of the A-10 and the compared air crafts in the similarity analysis. This was done as the A-10 is seen as a more massive light attack air craft for this mission. The requirements were inputted in order to verify that the air craft can handle the objectives of the Ferry Mission. The Design Mission can also be met by the purposes of the seed aircraft. Once the dimensions of the chosen aircraft met the standards of the assignment, a dimensional analysis of the SFC and thrust over weight effects can be investigated as the aspect ratio and wing area varied [1][2][3][4][5] [6].

Similarity Analysis

A Similarity Analysis is performed to explore the different solutions to light attack air crafts for close air support purposes. When doing this, it is necessary to investigate air crafts of different sizes and engines to compare and build confidence in the ultimate chosen parameters. Thus, the air crafts chosen to study were the A-10 Thunderbolt II, the Douglas A-1 Skyraider, and the Super Tucano (A-29). Although functioning in a similar purpose, the obvious findings from the selected air crafts are the great differences in size. The A-10 stands at the biggest overall air craft at at a ramp weight of 51960 lbs while holding 11000 lbs of fuel [1]. The wings also have an area of 506 sq ft contrasting from the smaller 400 sq ft for the A1 [2] and 209 sq ft for the Super Tucano [4]. Along with the gradual decrease in area of the air crafts, the planes drop significantly in weight as the A1 Skyraider stands at a ramp up weight of 28748 lbs and the Super Tucano at 10420 lbs. While the size and weight of the physical air crafts change, the corresponding performance is shifted drastically. Therefore it is necessary to balance the selected sizing parameters in order to satisfy the required range and take off distances. While the larger size and weight may impact the range and balanced field length, the large amount of fuel in the bigger air crafts will be beneficial for the lengthy ferry range as proven by the found data. In order to take off and land within a 4000 ft austere field as well as reaching a ferry range of approximately 1200 nmi (including climb, cruise, and descent), the A-10 and A-1 Skyraider will be referenced heavily when selecting sizing parameters. These air crafts will represent the larger air crafts of the group and have proven evidence of satisfying the objectives. It is important to note that the large size of the A-10 will be balanced in order to conserve the parameters when satisfying the Design Mission laid out by the report. This mission requires a shorter travel but a larger payload, causing the landing field length to vary greatly.

The other main consideration when analyzing the selected air crafts are the different types of engines used. The engines of these air crafts are of three different types, Turbofan, Reciprocating, and Turboprop. All three of these engines prove to be successful in operating their corresponding light attack air craft although the familiarity and lack of time contributed to choosing a turbofan engine similar to the A-10 (General Electric TF34-GE-100 [3]) for the ultimate air craft. When selecting this, the engine parameters were analyzed as well in the form of SFC and T/W amd their affects on the ultimate weights and range. This is further analyzed in the spreadsheet data. By the found data, it can be seen that the turbo fan produces a more efficient SFC (.371) at high weights and ranges like the ones needed in this project. The T/W will also prove to successfully fit within the constraints of the project and return a range and balanced/takeoff/landing field length that fits well within the requirements. Therefore, the turbofan engine will be utilized as it proves to be the best suited for these missions.

Constraint And Design

As stated in Raymer [7], the required takeoff distance is connected with the ultimate performance computations in the form of thrust to weight ratio (T/W) and wing loading (W/S). These parameters allow the optimization of the aircraft in terms of fuel, payload, and other necessary components on the air craft. This performance is initially hard to calcuate as the designer must guess and check parameters of the aircraft with little insight to historical data. There also must be corrections according to the type of engine and purpose of the air craft. In this case, the equations from lecture and from Raymer were used to formulate an appropriate constraint region with a requested landing distance of 4000 ft. This is needed when initially finding the wing loading. Equation (5.11) from Raymer was used as shown:

$$S_{landing} = 80\frac{W}{S}\left(\frac{1}{\sigma C_{Lmax}}\right) + S_a \tag{1}$$

Where $S_{landing}$ is the landing distance, σ is the density ratio approximation, C_{Lmax} is the max lift coefficient at landing for the specified air craft type, and S_a is the obstacle-clearance distance as approximated in lecture. This incorporates the required 50 ft obstacle avoidance with the approximation of the jet fighter conditions. This landing constraint will represent the right most line of the selected region.

There must then be an estimation of thrust to weight ratio at cruise that will remain constant along the bottom of the constraint diagram. This will be estimated using "thrust matching." The thrust will be assumed to be equal to the drag during this condition and the needed ratio can be determined finding the inverse of the lift over drag. The thrust to weight ratio can then be calculated using equation (5.2) of Raymer as shown.

$$\left(\frac{T}{W}\right)_{cruise} = \frac{1}{(L/D)_{cruise}} \tag{2}$$

Where L/D is the estimated max L/D of the jet fighter type. In this case, 15 will be used as the estimation as used in lecture. After this is computed, the T/W can be corrected using the weight fractions from the climb. This weight fraction is listed in Raymer as about .97 for the remaining legs of the mission. It can also be assumed that there will be significantly less thrust at cruise than takeoff, so 20 percent of the thrust will be estimated. The final cruise T/W can then be utilized as the bottom line of the constraint diagram.

The last part of the constraint diagram that is needed is the relation of T/W vs wing loading at takeoff conditions. This will investigate the takeoff T/W as the wing loading is varied. This relation is provided in Chapter 5 of Raymer and represented as a linear constraint to the diagram. The ultimate constraint diagram can be shown below:

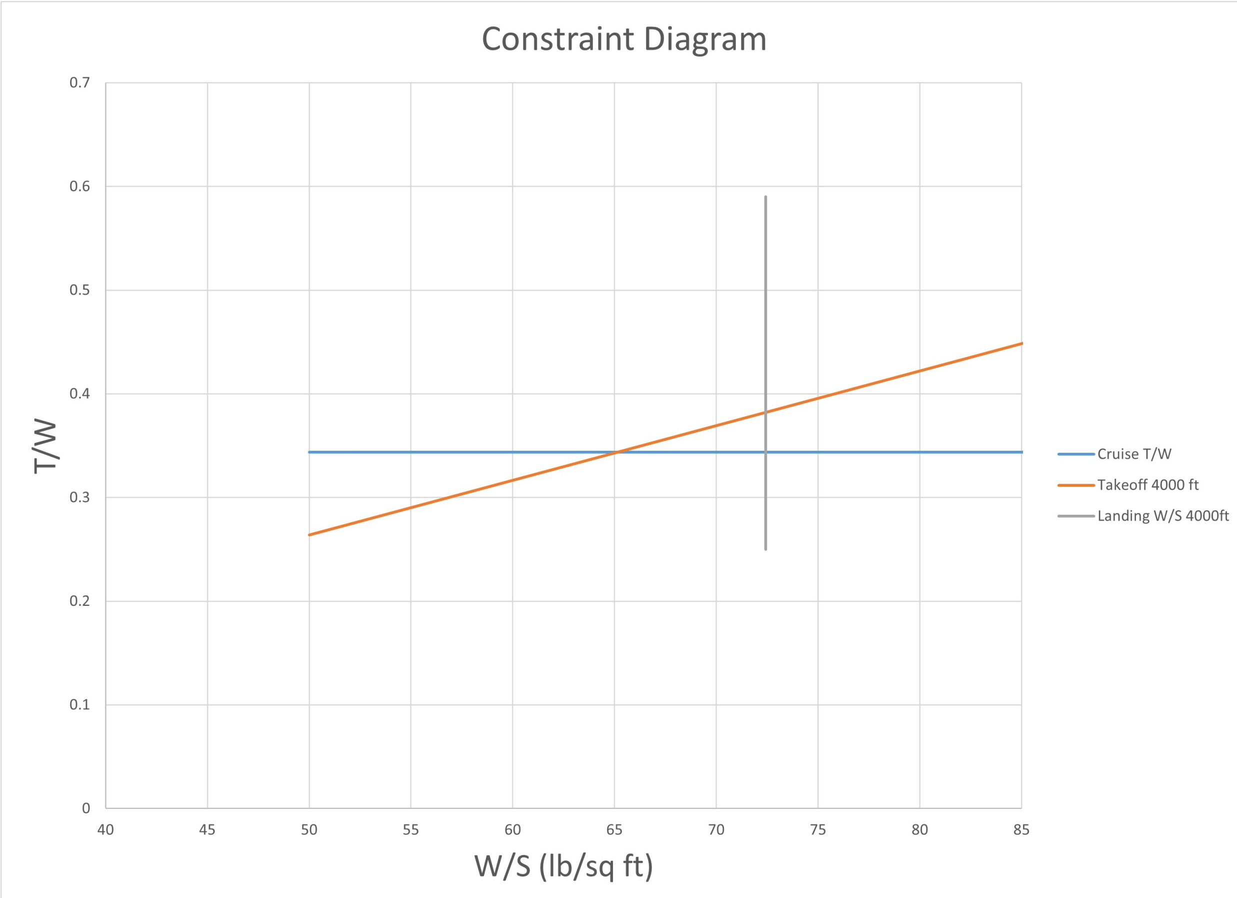

Fig. 1 Represents the design region for the computed T/W and Wing loading

As shown, this will portray the estimated performance of the aircraft that is necessary to fulfill the required parameters. In order to satisfy the design, the wing loading should result to around 65 - 73 lb/sq ft. The T/W ratio of the air craft must then lie in the range of .33 to .39. The spreadsheet can then be used along with the similarity analysis to match the performance of the aircraft to the design parameters.

Dimensional Analysis

The dimensional analysis of the simulated air craft can be demonstrated by evaluating the effects of SFC and T/W in addition to the aspect ratio and wing area variance. The rest of the inputs of the selected air craft will remain constant as the ramp weight, empty weight, and fuel weight amounts can be represented visually on a contour plot against the varying aspect ratio and wing area. The trends of the resulting data can then be analyzed to first verify the function of the air craft simulation, and then to determine the effects of each parameter on the performance.

The first variance is as shown. The SFC will be varied from .3 to .5 by steps of approximately .1. The analysis with the featured SFC = .629 is investigating the seed SFC input while the aspect ratio and wing area is changed.

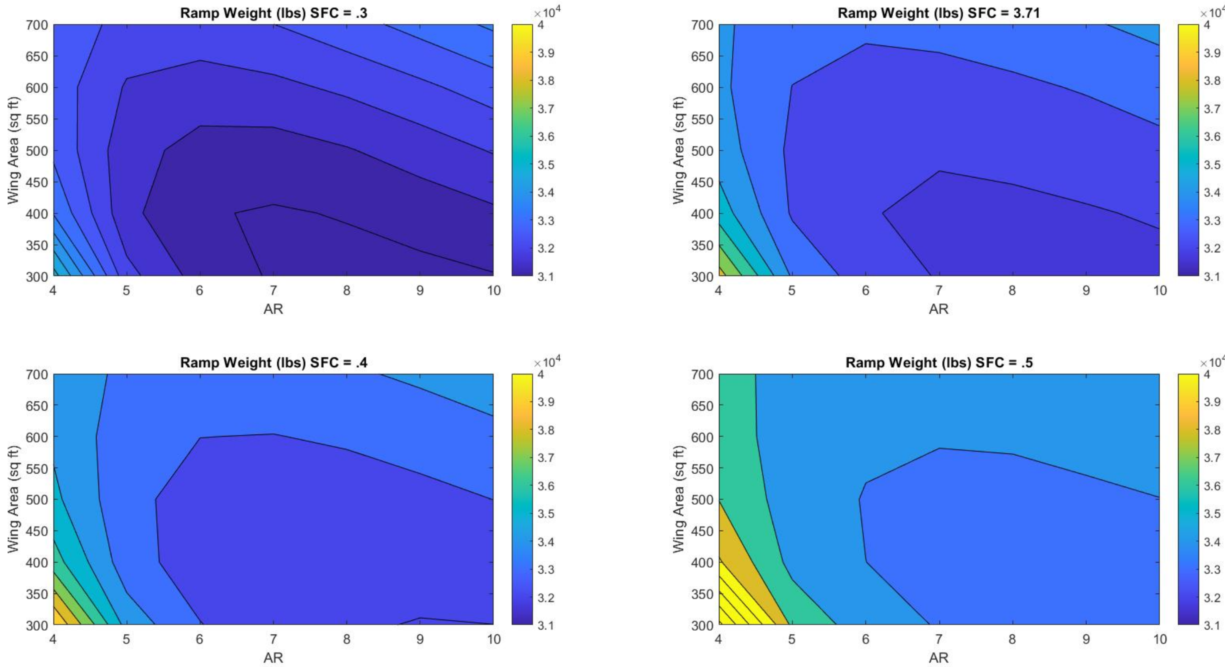

Fig. 2 Ramp Weight contour representation as AR and Wing Area varies with SFC

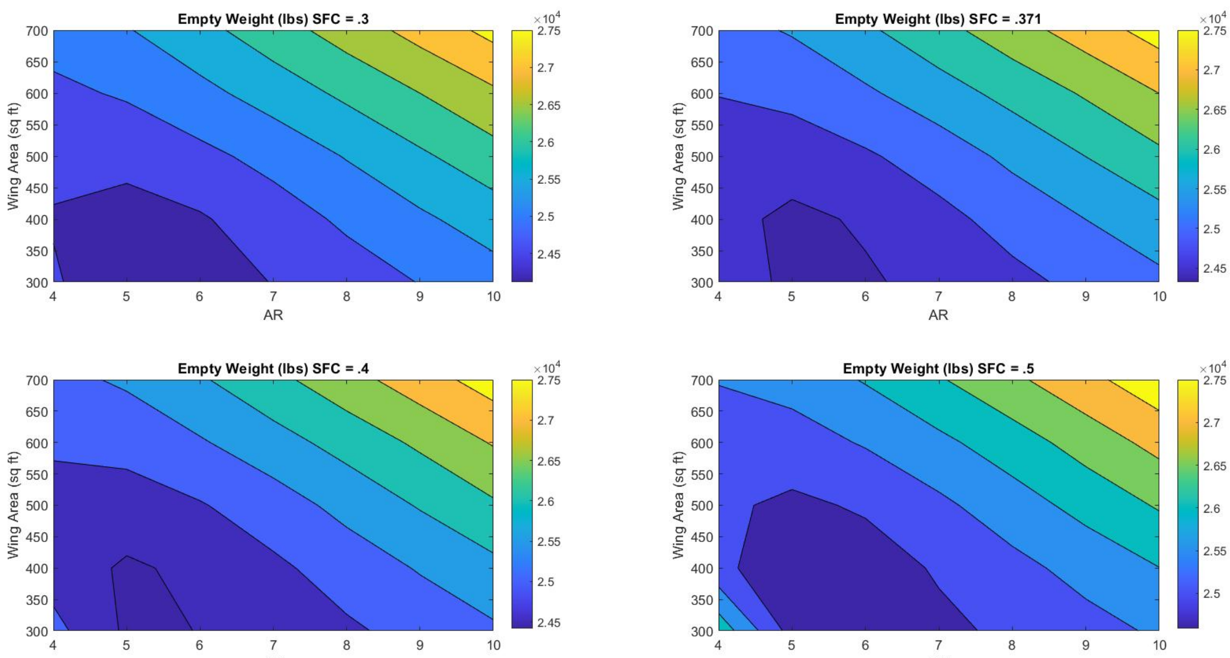

Fig. 3 Empty Weight contour representation as AR and Wing Area varies with SFC

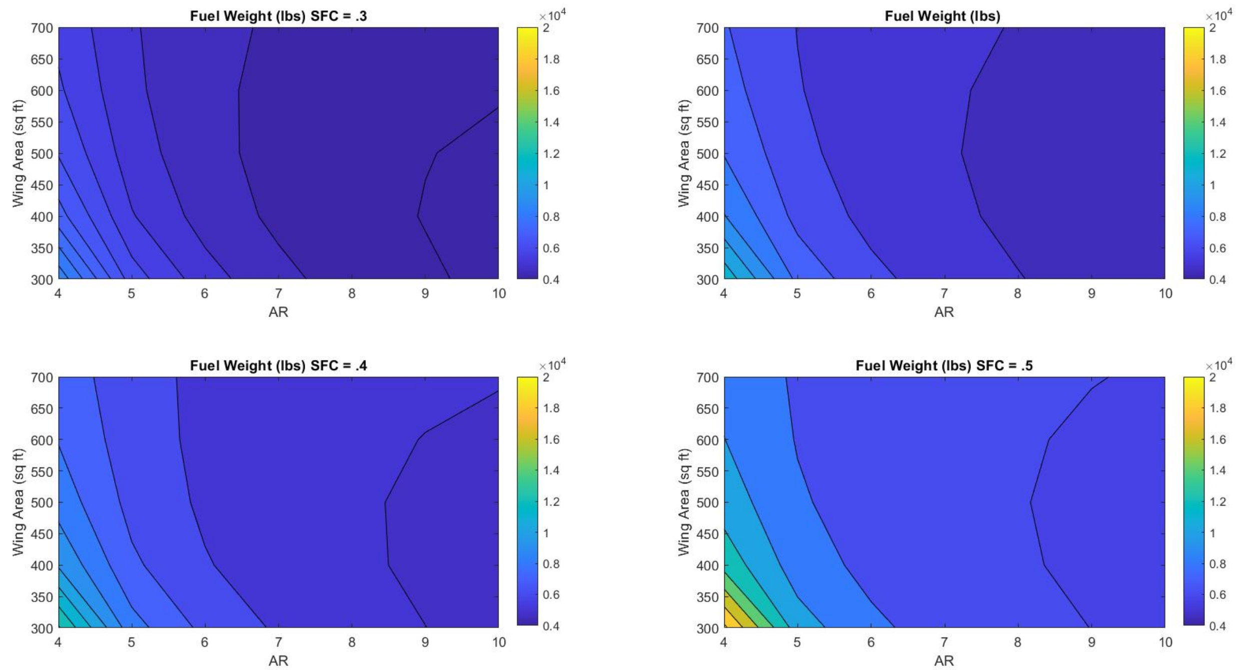

Fig. 4 Fuel Weight contour representation as AR and Wing Area varies with SFC

As visually represented, as the SFC increases, the ramp and fuel weights will significantly increase along with it. This occurs because the SFC will directly impact the amount of fuel needed for flying to the necessary 1200 nmi. When the SFC rises, the necessary fuel amount will rise due to the fast consumption of it. The fuel amount in this study is approximately 1/3 of the ramp weight. Therefore, when the fuel weight increases, the ramp weight will increase as well. In contrast, the Empty weight does not seem to change much despite the slight variance in contour shapes. This makes sense as the empty weight does not incorporate the fuel in the computation.

The dimensional analysis can continue by analyzing the affect of varying the T/W IPPS of the specified engine. This will in turn decrease the weight of the engine and allow the aircraft to supply a more efficient thrust in getting to the necessary range. The choice of T/W = 6.29 is chosen as this represents the T/W IPPS of the seed air craft. The T/W will then be varied from 5 to 7 by 1.

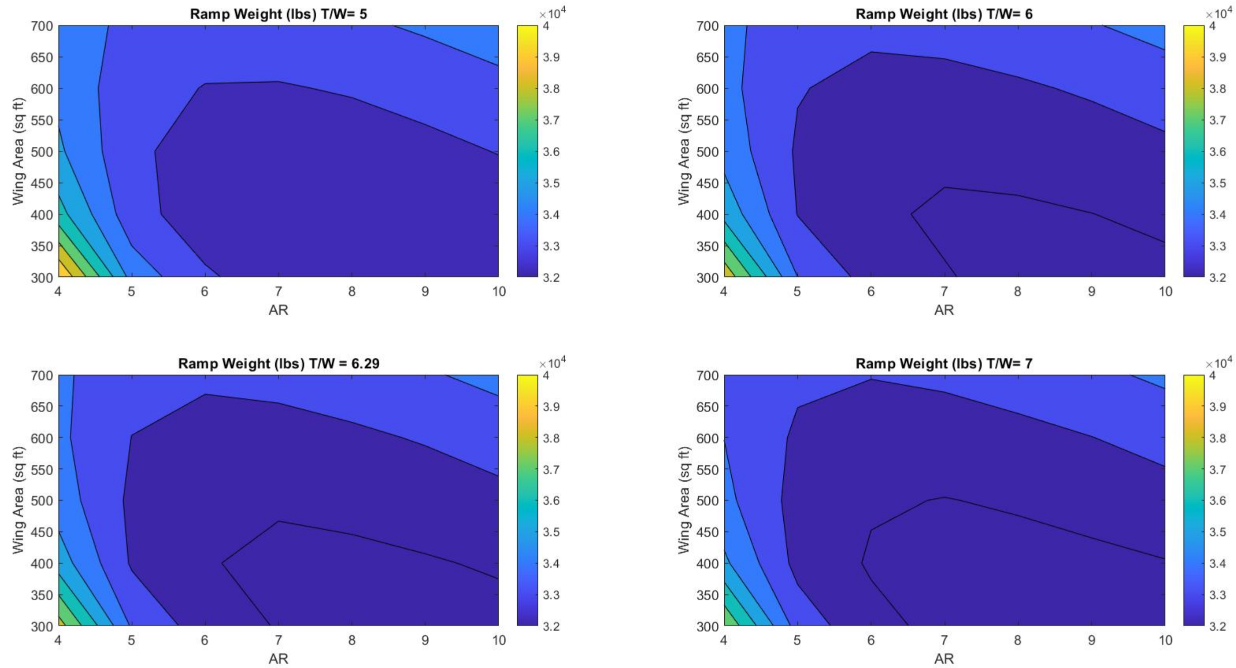

Fig. 5 Ramp Weight contour representation as AR and Wing Area varies with T/W

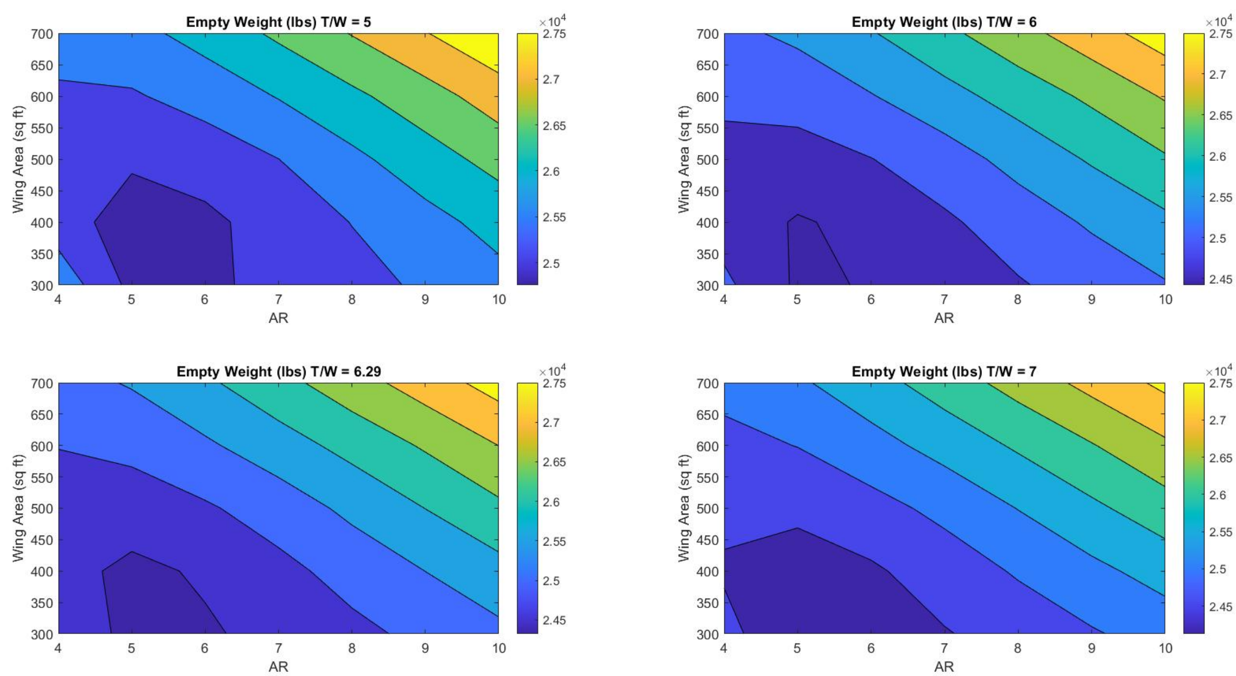

Fig. 6 Empty Weight contour representation as AR and Wing Area varies with T/W

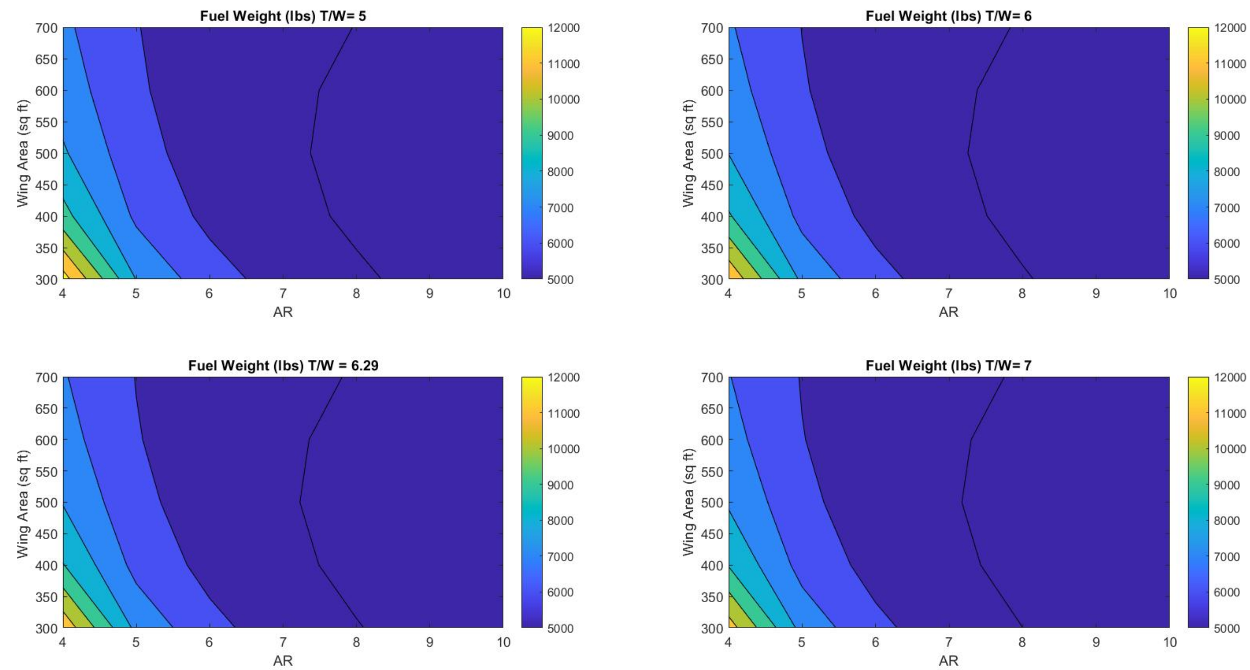

Fig. 7 Fuel Weight contour representation as AR and Wing Area varies with T/W

In contrast to the studied SFC variance, the change in thrust to weight ratio is not nearly as sensitive when inspecting the resulting change in weights. Although this is the case, there are common trends that can be analyzed. As the thrust to weight IPPS is increased, the ramp weight and fuel weight decrease gradually as shown. This is as expected as the plane will intuitively have to use less fuel to thrust the air craft to the proper range. The engine weight also decreases as a function of the T/W IPPS and will contribute to the loss in ramp weight. As these parameters drop significantly in weight, the drawback will be the increase in other components of the air craft structure such as wing weight that will cause the resulting empty weight to remain fairly similar throughout the change in T/W.

While the increase in SFC and thrust to weight ratio vary the shape of the contour plots, each plot can be analyzed to determine the effects of the aspect ratio and wing area on each resulting weight as well. It can be determined that the increase in aspect ratio while wing area stays constant will result in a lower ramp weight. This will result in the trends shown where the ramp weight will decrease towards the bottom right corner of each ramp weight plot as the geometry change will force the air craft design to compensate for the loss in performance. The design parameters can then be chosen based on the optimal positions on the plot for the necessary purpose. For example, to conserve cost, it may be necessary to pick the point on the plot where AR and wing area is optimal for the SFC of the chosen engine. Then further research can take place to confirm the performance based off of that choice.

Further, the Empty weight plots can be analyzed as well. Typically the lowest empty weight results from an optimal small aspect ratio and small wing area according to each specified input. This trend continues for both tests as the smallest empty weight occurs at low values. The fuel weight in contrast to the other two have clear trends that show the decreasing weight as the aspect ratio is increased. This leaves the designer with a difficult task as he/she must balance the aspect ratio and wing area in order to optimize the weights of all three trends.

References

[1] Corporation, N. G., "A-10 Thunderbolt II," , 2020. URL `https://www.northropgrumman.com/what-we-do/air/a10-thunderbolt`.

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[5] Rasnick, M., "Aerodynamic Analysis of the A10," , 2020. URL `http://www.dept.aoe.vt.edu/~mason/Mason_f/A-10Spr09.pdf`.

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[7] Raymer, D. P., *Aircraft design: a conceptual approach*, AIAA education series, American Institute of Aeronautics and Astronautics, 1989.