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CONCEPT SPACE EXPLORATION OF GUIDED AIR TO GROUND MUNITIONS

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ABSTRACT

Concept space exploration provides initial information and knowledge for preliminary concept designs. The optimal preliminary concept design can be rapidly developed according to the specifications with the help of obtained information from concept space exploration. Obtaining the optimal preliminary concept design in a rapid way, results in a more robust and practical detailed design process. This paper presents concept space exploration and obtained results in a design space of possible guided munitions with the use of the design tool which is formed from genetic algorithm and 3 DoF flight simulation.

INTRODUCTION

The initial phase of designing a new munition is the preliminary concept design procedure. This procedure starts with generating the design space which is formed from the aerodynamic sizing parameters according to the requirements. Aerodynamic sizing parameters should define the munition geometry and dimensions which includes munition length, diameter, wing and control surface dimensions [Fleeman, 2001]. After this step, a rapid analysis is a necessity as design problem has a multi-dimensional nature and this results in examining thousands of potential system configurations [Frits, Fleeman and Mavris, 2002]. In order to rapidly and consistently examine the geometry, aerodynamic and performance parameters of potential preliminary concept designs, a design tool is a must. In this study, design space is obtained by investigating similar munition types and concept space exploration is done by the design optimization tool developed by Varol et.al. [Varol, Akgül and Aydın, 2019]. With the help of the design tool, various missile configurations such as missiles with cruciform fins with plus and cross configurations and missiles with and without wings are examined.

This paper is structured as follows: in 'Method' section, the construction of design space is defined. Later, the optimization tool, which explores the design space and finds the optimal design, is explained. In 'Results' section, the chosen optimal tool components, the obtained

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optimal design solutions and their flight performances are defined. Finally, conclusions of the study and future works are explained in ‘Conclusion’ section.

METHOD

The first stage of the concept space exploration is generating the design space. As mentioned, to form the design space, aerodynamic configuration sizing parameters should be selected and boundaries for each parameter should be determined. 12 sizing parameters are chosen in order to form the design space [Varol, Akgül and Aydın, 2019]:

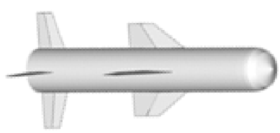
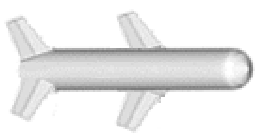
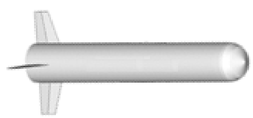
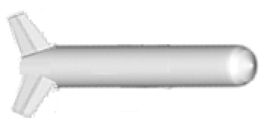
Table 1: The Parameters Chosen for Generating Design Space

Parameter Names
Munition Length(m)
Munition Diameter(m)
Wing Span/Munition Length Ratio
Distance from nose tip to WLE at tip/Munition Length Ratio
Distance from nose tip to WLE at root/Munition Length Ratio
Wing Root Chord/Munition Length Ratio
Wing Tip Chord/Munition Length Ratio
Tail Span/Munition Length Ratio
Distance from nose tip to TLE at tip/Munition Length Ratio
Distance from nose tip to TLE at root/Munition Length Ratio
Tail Root Chord/Munition Length Ratio
Tail Tip Chord/Munition Length Ratio

Boundaries for each parameter are selected by investigating similar munitions that are in use and specific parameters are normalized with respect to the munition length to have well-proportioned possible designs.

Second stage is determining the morphological matrix where propulsion system and fuselage type is fixed and planform/fin types are selected [Jimenez and Mavris, 2005]. 4 different morphologies are chosen in order to be explored with the design tool. For the propulsion system, it is accepted as there is no thrust in the system and munition has a fixed initial speed of 0.5 Mach.

Table 2: The Morphological Matrix of the Munition Configurations

		Cruciform Fin Types	
		Plus Configuration	Cross Configuration
Wing Configuration	With Wings		
	Without Wings		

The third stage is using the design tool for each of the four morphologies in the selected design space. The flowchart for this tool [Varol, Akgül and Aydın, 2019] is given in Figure 1.

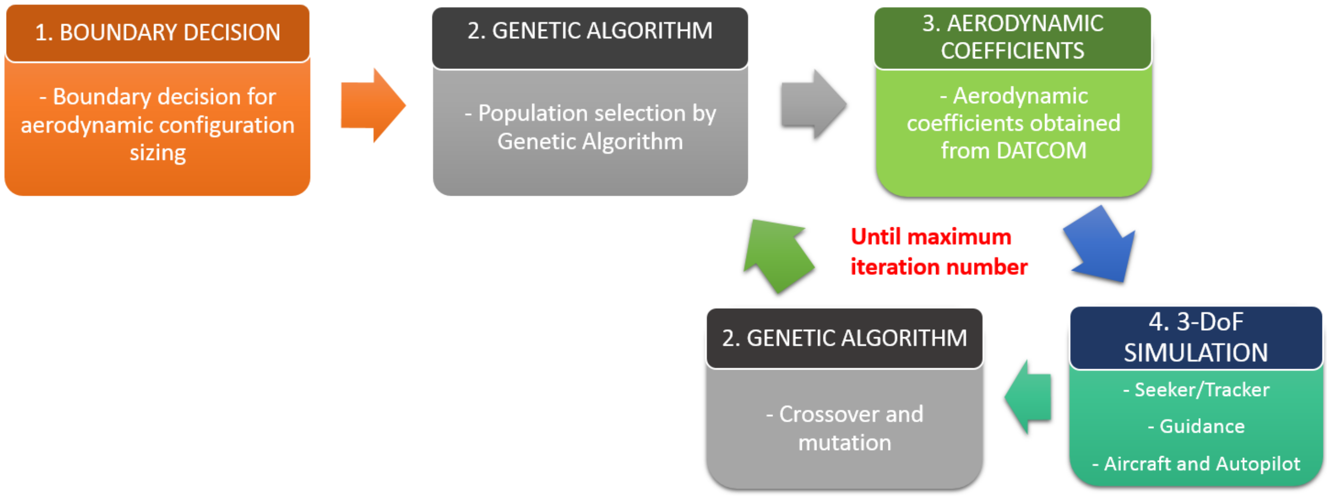


Figure 1: Flowchart of the Design Tool

The design tool starts with the user inputs which are the aerodynamic boundaries, physical properties, thrust profile, simulation and optimization parameters. According to the inputs, the genetic algorithm generates the initial random design population. After this step, Missile DATCOM calculates the aerodynamic parameters of each design in the population one by one. By using the aerodynamic parameters, 3 DoF flight simulation is performed for each design. Flight simulation provides the performance outputs which are used in the cost function. Design tool provides the output parameters which are:

- Time of Flight,
- Miss Distance,
- Maximum g Capacity,
- Mass of the munition and
- Hit Angle.

User selects the performance parameters to be used in the cost function and determines the weights of each parameter. Each performance parameter is normalized as parameters significantly differ with each other in order of magnitude. The normalized values used while calculating the cost function are:

$$norm_{time\ of\ flight} = \frac{(tof - min(tof))}{(max(tof) - min(tof))} \tag{1}$$

$$norm_{miss\ distance} = \frac{(miss\_dist - min(miss\_dist))}{(max(miss\_dist) - min(miss\_dist))} \tag{2}$$

$$norm_{maximum\ g\ capacity} = \frac{(max(max\_g) - max\_g)}{(max(max\_g) - min(max\_g))} \tag{3}$$

$$norm_{mass\ of\ munition} = \frac{(mass - min(mass))}{(max(mass) - min(mass))} \tag{4}$$

$$norm_{hit\ angle} = \frac{(max(hit\_theta) - hit\_theta)}{(max(hit\_theta) - min(hit\_theta))} \tag{5}$$

The genetic algorithm tries to find the possible designs with high maximum g capacity and hit angle and low time of flight, miss distance and mass. The effect of the parameter to the cost function is proportional with the weight so weights should be chosen according to the requirements. After all the values of cost function are calculated for a population, crossover and mutation are applied to the members and a new population is generated. Aerodynamic parameter calculations and 3 DoF flight simulations are applied to the new population until the maximum iteration number is reached. At the end, the design solution with the minimum cost, which is the optimal solution, is determined.

The last stage is comparing the performance results of the four optimum design solutions of the four different morphologies. The morphology with the best performance among the four morphologies is determined. The design tool is again used for the optimal morphology with a different cost function and the optimal design solution is obtained.

RESULTS

Similar guided air to ground munitions are investigated and aerodynamic properties of the munitions are recorded. By using the limit values of the aerodynamic parameters of the similar munitions, Table 3 is obtained [Varol, Akgül and Aydın, 2019].

Table 3: Minimum and Maximum Values of the Parameters for Aerodynamic Configuration Sizing

	Min	Max
Munition Length(m)	0.30	1.00
Munition Diameter(m)	0.06	0.16
Wing Span/Munition Length Ratio	0.04	0.25
Distance from nose tip to WLE at tip/Munition Length Ratio	0.51	0.63
Distance from nose tip to WLE at root/Munition Length Ratio	0.33	0.56
Wing Root Chord/Munition Length Ratio	0.12	0.50
Wing Tip Chord/Munition Length Ratio	0.08	0.12
Tail Span/Munition Length Ratio	0.09	0.21
Distance from nose tip to TLE at tip/Munition Length Ratio	0.82	1.00
Distance from nose tip to TLE at root/Munition Length Ratio	0.79	0.93
Tail Root Chord/Munition Length Ratio	0.04	0.13
Tail Tip Chord/Munition Length Ratio	0.04	0.11

The boundaries of aerodynamic parameters, genetic algorithm components and simulation parameters are inputs for the design tool. Genetic algorithm and simulation input values are chosen as in Table 4.

Table 4: Inputs of Design Tool

Number of Genes(Parameters) in each Chromosome(Design)	12
Chromosome Number in each Population	100
Maximum Iteration Number	10
Selection Rate	%50
Mutation Rate	%20
Total Chromosome Number	1100
Initial Altitude of Munition(m)	6000
Initial Velocity of Munition(Mach)	0.5
Horizontal Distance between Target and Munition(m)	10000
Lock on Range of the Seeker(m)	5000
Mach Range for Aerodynamic Parameters	[0.3 0.4 0.5 0.6 0.7]

The next step is selecting the cost parameters and their weights. The selected cost parameters while exploring the morphologies are time of flight, miss distance and hit angle. Mass of the munition and maximum g capacity are not used in this stage. The weights of each parameter are selected as nearly equal because it is planned that each parameter affects the optimal solution in a same amount. Therefore, the cost function is selected as:

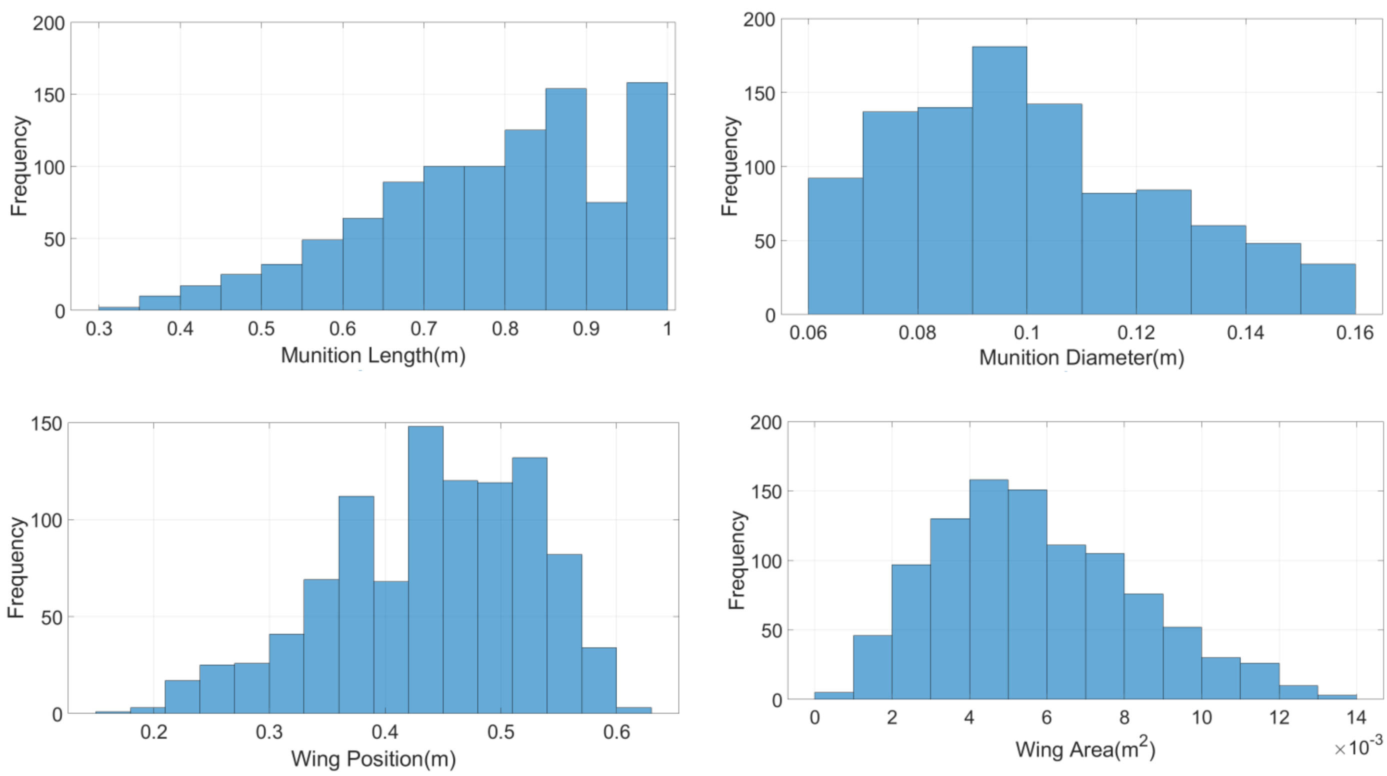
$$Cost = 0.\overline{3} * norm_{time\ of\ flight} + 0.\overline{3} * norm_{miss\ distance} + 0.\overline{3} * norm_{hit\ angle} \quad (6)$$

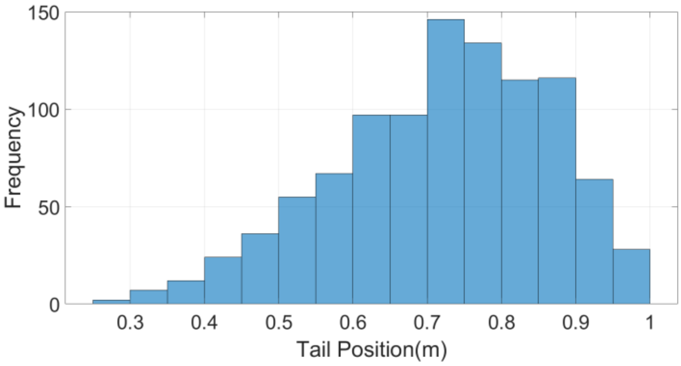
Table 5: Performance Parameters of the Different Morphologies

	Cross Cruciform Configuration with Wings	Cross Cruciform Configuration without Wings	Plus Cruciform Configuration with Wings	Plus Cruciform Configuration without Wings
Time of Flight(s)	58.14	58.56	55.91	56.32
Miss Distance(m)	0.12	27.19	3.43	3.51
Hit Angle(°)	23.86	82.74	98.00	31.93

According to the obtained performance parameters, it is obtained that cross cruciform configuration with wings has the optimal performance as expected. Therefore, as mentioned before, a new concept space exploration for only this morphology type is made. It can be seen that the morphologies without wings have high miss distances. The reason for this is the morphologies without wings have low maneuverability which results in a high miss distance.

For the new concept design exploration, the boundaries of the chosen design space are minimized across the obtained optimal solution in order to reduce the simulation time. Histogram graphs are generated for obtaining the convergence region of the parameters. The convergence regions form the new boundaries of the new design space.





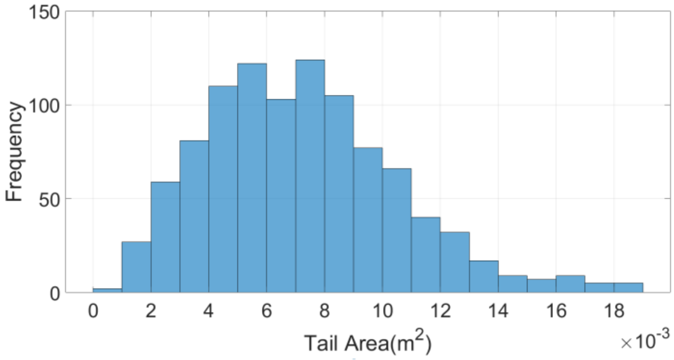


Figure 2: Histograms of Aerodynamic Sizing Parameters for Cross Cruciform Configuration with Wings

According to the histogram graphs in Figure 2, as the histograms have a triangular behavior, it can be said that all aerodynamic parameters converges to an optimal region. Therefore, it is logical to minimize the boundaries. The new boundaries while exploring the cross cruciform configuration with wings are:

Table 6: Modified Minimum and Maximum Values of the Parameters for Aerodynamic Configuration Sizing

	Min	Max
Munition Length(m)	0.7	1
Munition Diameter(m)	0.08	0.13
Wing Span/Munition Length Ratio	0.03	0.13
Distance from nose tip to WLE at tip/Munition Length Ratio	0.51	0.57
Distance from nose tip to WLE at root/Munition Length Ratio	0.41	0.50
Wing Root Chord/Munition Length Ratio	0.12	0.14
Wing Tip Chord/Munition Length Ratio	0.08	0.12
Tail Span/Munition Length Ratio	0.11	0.17
Distance from nose tip to TLE at tip/Munition Length Ratio	0.85	0.95
Distance from nose tip to TLE at root/Munition Length Ratio	0.82	0.90
Tail Root Chord/Munition Length Ratio	0.04	0.08
Tail Tip Chord/Munition Length Ratio	0.04	0.08

After choosing the new boundaries, the cost function is improved. The maximum g capacity and the mass of munition is added to the cost function in order to increase the capability and consistency of design tool to find the optimal solution. The weights of each parameter are given as equal again to see the effect of each parameter equally.

$$Cost = 0.2 * norm_{time\ of\ flight} + 0.2 * norm_{miss\ distance} + 0.2 * norm_{maximum\ g\ capacity} + 0.2 * norm_{mass\ of\ munition} + 0.2 * norm_{hit\ angle} \quad (7)$$

The aerodynamic properties of the final optimal design solution which is obtained from the second concept space exploration are in Table 7.

Table 7: Final Optimal Design Solution

Munition Length(m)	0.913
Munition Diameter(m)	0.087
Wing Span(m)	0.049
Distance from nose tip to WLE at tip(m)	0.469

Distance from nose tip to WLE at root(m)	0.446
Wing Root Chord(m)	0.124
Wing Tip Chord(m)	0.086
Tail Span(m)	0.101
Distance from nose tip to TLE at tip(m)	0.842
Distance from nose tip to TLE at root(m)	0.793
Tail Root Chord(m)	0.044
Tail Tip Chord(m)	0.039

Table 8: Solid Models of the Previously Obtained Optimal Design Solution and the Final Optimal Design Solution

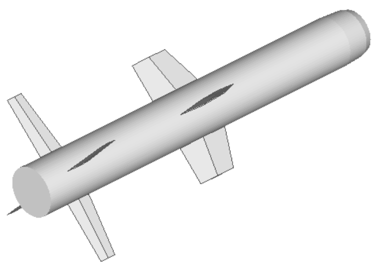
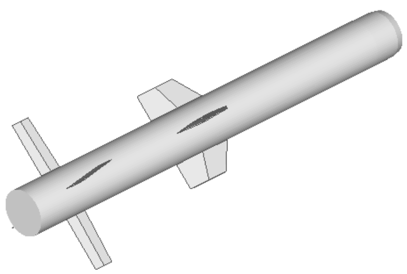
Previously Obtained Optimal Design Solution	Final Optimal Design Solution
	

Table 9: Performance Parameters of the Previously Obtained Optimal Design Solution and the Final Optimal Design Solution

	Previously Obtained Optimal Design Solution	Final Optimal Design Solution
Time of Flight(s)	58.14	58.83
Miss Distance(m)	0.12	0.11
Hit Angle(°)	23.86	21.73
Maximum g Capacity(g)	5	5
Mass of the Munition(kg)	14.24	9.88

As can be seen from Table 9, it can be said that the mass of the munition becomes significantly smaller after the second concept exploration which is an important advantage for guided air to ground munitions. In addition, other parameters do not change significantly so it can be said that both of the cost functions are consistent and gives reasonable results.

CONCLUSION

During the development of a new munition, concept space exploration is a necessity for obtaining a realistic and practical preliminary concept design. Concept space exploration provides information about aerodynamic and performance parameters of potential preliminary concept designs and leads one to find the optimal design solution. In this study, a design tool is used for exploring the concept space. It can be said that the design tool which is formed of genetic algorithm and 3 DoF flight simulation is capable to explore the design space and reach the optimal design solution in a rapid and conceptive way. With the help of the design tool, different morphologies can be investigated in a short time and the optimal preliminary concept design according to the requirements can be obtained practically.

The design boundaries are selected by investigating similar munitions which gives a reasonable design space. Since similar munitions have different morphologies, four different morphologies are selected for this study. As expected, the cross cruciform configuration with wings has the best performance and cross cruciform configuration without wings has the worst performance among various morphologies.

The obtained final optimal design solution shows that a second concept space exploration is a necessity to improve the optimal design and improving the cost function and boundaries results in a more optimal design.

For the future work, more morphologies can be added for space exploration such as different wing types and different fin configurations. In addition, cost functions can be improved by adding more performance outputs.

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