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Conceptual Design & Validation of a Multi-Planetary Transit Vehicle

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***Abstract*—This is a space era for unmanned aerial vehicles (UAVs) with complex autonomous systems to have an objective research on interplanetary studies. The UAV design for the space application is a complicated approach due to its involvement with initial conditions such as the atmospheric data of that particular planet and in later stages, where the experimental testing setup requires a separate infrastructure to match that atmospheric conditions. So, where the planetary data required for design are density, temperature, viscosity, pressure and gravity. These are initial conditions which affects the design and performance parameters in the conceptual stage of the planetary UAV. This paper describes the UAV conceptual design methodology for the Mars application which includes the configuration selection, sizing, aerodynamic analysis and performance evaluation using low fidelity tools such as XFLR5 and OCTAVE (Low order code). The design performance is compared with Earth atmosphere and Martian atmosphere to estimate the impact created by the initial conditions. However, the performance validation for the design on Earth atmosphere is justified in correlation with XFLR5 and wind tunnel data of Sky walker X8. But the design on Mars atmosphere is correlated with the literature available from recent research studies and observed to be fair, which would an acceptable correlation during the conceptual stage.**

***Keywords*—Conceptual design, Aerodynamics, Peformance, Space application, UAVs, XFLR5, OCTAVE, Martian atmosphere,VLM, Low fidelity tools, space drones, Sky Walker X8, Wind tunnel Data.**

I. Introduction

In the past decade, there has been a trend movement towards fabricating the drones which are ready to perform planetary exploration. Actually, there are various ways to perform the research on the space objects, like through telescopes and satellites, launching probes , landers, orbiters, rovers or sending astronauts to the selected solar bodies. However, due to the advantages of the space drones compared to other approaches in the planetary exploration as shown in the table below. So, many researches has been administered by the different space agencies within the world which includes NASA made to use these space drones approach.

Ongoing development of NASA's Mars Helicopter, Mars Sample Return Mission and NASA's Dragonfly to Titan there is a tremendous scope for the deployment of UAV's on the surface of MARS. The proposed design in this research has the ability to extract and deliver the samples collected by the rover on Mars, to the Mars Sample Return Vehicle. The design discussed above is capable of mapping areas of Martian surface very closely to examine the presence of dried up ancient mars lakes and in assisting the rover path planning. With mission specific design there is tremendous scope to deploy UAV's for various experiments on Mars and Interplanetary atmospheric bodies. The present paper describes about the proposed design performance on earth and mars atmosphere along with evaluation in terms of aerodynamics.

TABLE 1: PLANETARY EXPLORATION APPROACHES COMPARISON

	Orbiter	Rover	Humans	Drones
Payload	Low	High	High	Moderate
Cost	Low	High	High	Moderate
Accuracy	Low	High	High	High
Power	Low	High	High	Moderate
Resources	Low	High	High	High
Technology	High	High	Moderate	High

II. Requirements

This consists of the system engineering approach requirements for UAV design in the space application as shown in the matrix below. In which it includes the requirements like initial conditions (planetary conditions/ atmospheric data - that can describe the earth atmosphere and Martian atmosphere such as air density, air viscosity, air pressure, temperature, wind speeds and gravity), Reynolds number limitation for testing on earth atmosphere, even electronics such as equipments & sensors (payload requirement) required for the space application or launch & landing requirements (affects the sizing and desired weight), mission duration (endurance which affects power and speed requirement), aerodynamic requirements such as lift and drag and however, production cost requirement is very critical in the space exploration missions.

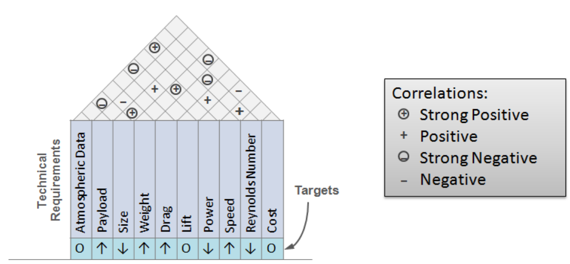

FIGURE 1 : TECHNICAL REQUIREMENT MATRIX

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III. Configuration Selection

The configuration selection is to meet the mission requirements mentioned in the previous section matrix. The following fixed wing configuration is proposed design for the mission specified as follows;

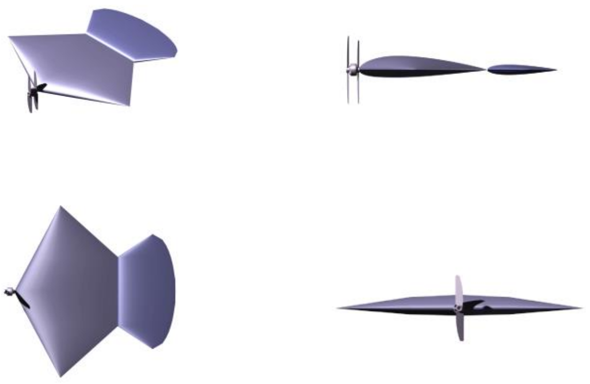

FIGURE 2 : CONCEPTUAL 3D VIEWS OF PROPOSED DESIGN

IV. Sizing

The sizing of the vehicle with trends and the limitations of the space application is based on collected literature of the atmospheric data of mars & earth.

TABLE 2: SKYWALKER X8 XFLR5 AND WT ATMOSPHERIC DATA

Earth Atmosphere	XLFR 5	WT	units
Density	1.225	1.225	kg/m3
Viscosity	1.73E-05	1.73E-05	Kg/m/sec
MAC	0.357	0.357	m
Speed	20	20	m/sec
Dynamic Viscosity	1.41E-05	1.41E-05	m2/sec

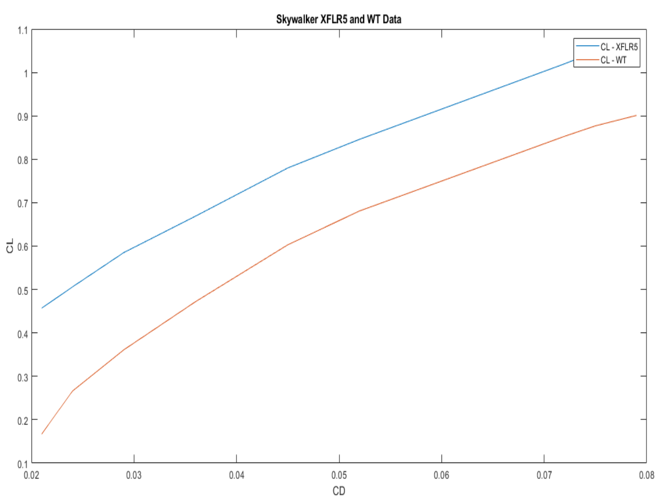

FIGURE 3 : SKYWALKER X8 XFLR5 AND WT PLOT AT RE=5.00E+05

Here, Table 2 describes the earth atmosphere to review the aerodynamics properties of Skywalker X8. And the following table below lists out the XFLR5 and wind tunnel data of Skywalker X8 at Reynolds number =5,00,000. The RSME is estimated to correlate the wind tunnel of the proposed design on the earth atmosphere and equivalent Martian atmosphere.

TABLE 3: RSME ESTIMATION BETWEEN XFLR5 AND WT DATA

	Re	**5.00e+05**	
CD	**XFLR 5 CL**	**WT CL**	**Error**
0.021	0.457	0.167	0.08
0.024	0.506	0.266	0.06
0.029	0.585	0.361	0.05
0.036	0.669	0.472	0.04
0.045	0.78	0.603	0.03
0.052	0.846	0.681	0.03
0.072	1.02	0.853	0.03
0.075	1.048	0.877	0.03
0.079	1.075	0.901	0.03
	RMSE	0.2046	

So, the sizing is done under two cases in order to evaluate the XLFR5 data of the proposed design i.e;

(i) Proposed design at Re=5,00,000 on the earth atmosphere and correlate

(ii) Proposed design at equivalent Martian atmosphere i.e Re=80,000 and correlate

The tables below describes the sizing parametric study using the same Reynolds number on the earth and Martian atmospheres as follows;

TABLE 4: PROPOSED DESIGN SIZING ON EARTH ATMOSPHERE

Earth Atmosphere	Proposed Design XFLR 5	scale up	units
Density	1.225	1.225	kg/m3
Viscosity	1.73e-05	1.73e-05	Kg/m/sec
MAC	0.7	6.9	m
Speed	10	1.023366	m/sec
Re	5.00e+05	5.00e+05	No units

TABLE 5: PROPOSED DESIGN SIZING ON MARTIAN ATMOSPHERE

Mars Atmosphere	Mars Proposed Design	Earth Scale down	units
Density	1.50e-02	1.225	kg/m3
Viscosity	1.30e-05	1.73e-05	Kg/m/sec
MAC	0.70	5.70	m
Speed	10	0.020	m/sec
gravity	3.71	9.81	m/sec2
Re	8.08e+03	8.08e+03	no units

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V. Aerodynamic analysis

The analysis was performed using XFLR5 which is an analysis tool that uses Lifting Line Theory, Vortex Lattice Method, and 3D Panel Method for calculation of the aerodynamic properties of the proposed design on the both earth atmosphere and Martian atmosphere . The following plots illustrate between coefficient of lift and coefficient of drag along with WT correlation using Skywalker X8 RMSE as follows;

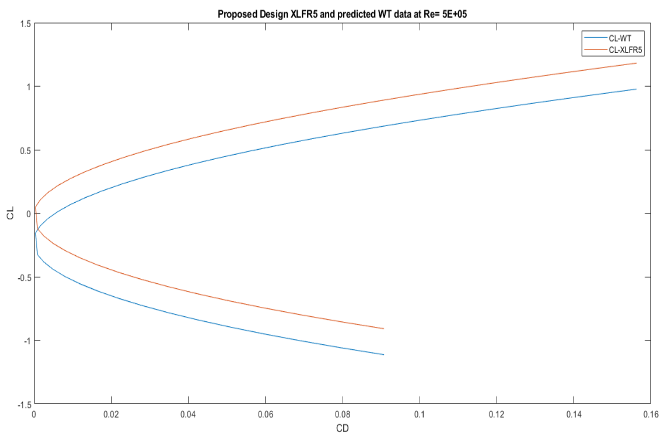

FIGURE 4 : PROPOSED DESIGN XLFR 5 AND CORRELATED WT PLOTS AT RE=5.00E+05 ON EARTH ATMOSPHERE

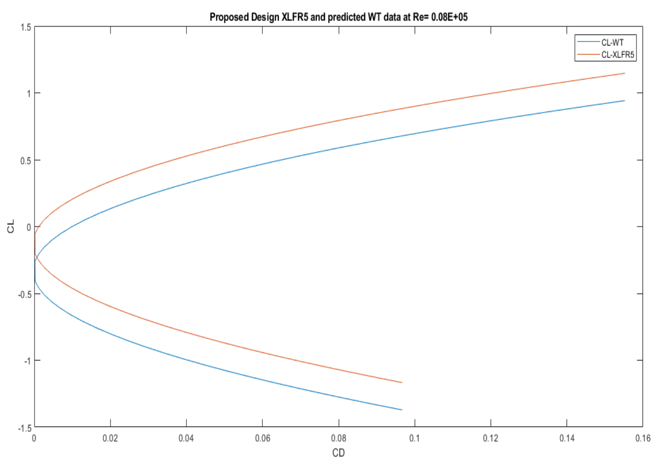

FIGURE 5 : PROPOSED DESIGN XLFR 5 AND CORRELATED WT PLOTS AT RE=0.08E+05 ON MARTIAN ATMOSPHERE

So, it was observed from the plots drawn that the aerodynamic properties at Re=5,00,000 on earth atmosphere are equivalent to Re=80,000 on the Martian atmosphere.

VI. Performance evaluation

The coefficient of drag data is generated using the method proposed by M. Hassanailan[1] to the available XFLR5 coefficient of lift data on the Martian atmosphere for the proposed design using octave as shown in the Figure 6. And the data generated using the method proposed by M.Hassanailan is found to be underestimate. However, the correlation is fair when compared with XLFR5 data, whereas the method by M. Haasanailan has the first-order code and XFLR5 has second-order code.

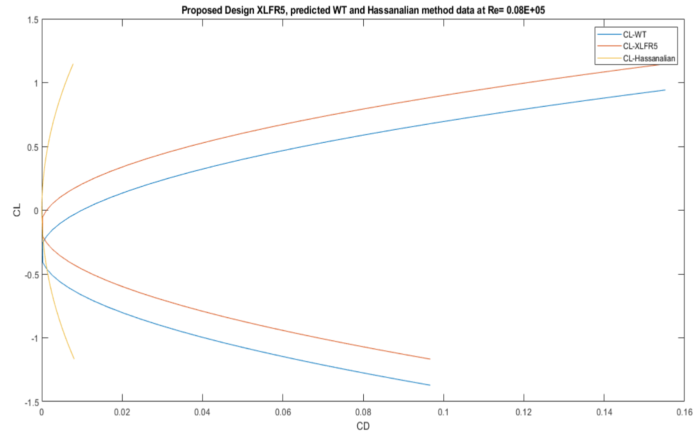

FIGURE 6 : PROPOSED DESIGN XFLR5, CORRELATED WT AND HASSANAILAN METHOD DATA PLOTS AT RE=80,000 ON MARS

VII. Conclusion

Finally, the described methodology would be useful during the conceptual stage in costly space drone missions. However, it can reduce the efforts and cost in the design process. The observation made in the present papers such as the same aerodynamic properties for the proposed design (MAC=0.7 m & Speed =10m/s) at Re=5.00e+05 on earth and Re=0.008e+5 on mars. Furthermore investigate is needed in the high fidelity tools and hence, correlate with available XLFR5 data.

Acknowledgment

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