AERODYNAMIC INVESTIGATION OF THE ROCKET PLANE FOR SUBORBITAL SPACE FLIGHT

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Abstract. This paper includes research on designing tourist rocket plane, as a part of two stage space plane. The rocket plane has delta wing with leading edge extension (LEX). It is uplifted by flight wing carrier and then, after separation, it performs suborbital space flight. This paper focuses on aerodynamic analysis of the rocket plane. The numerical calculations were made using Euler's system of equations and multi-grid scheme. During the mission rocket plane flies with velocity up to 3-4Ma, hence subsonic and supersonic cases were examined. All calculations were conducted for inviscid flow.

Keywords. numerical calculations of aerodynamic, rocket plane, suborbital space flight.

1 Introduction

1.1 The border between outer space and Earth's atmosphere

Theodore von Kármán, an American scientist with Hungarian ancestry, establish the altitude where every vehicle must obtain larger velocity than orbital, in order to gain enough aerodynamic lift to maintain this altitude. This altitude constitute the border between outer space and Earth's atmosphere, placed 100 kilometers above the sea level – called the Kármán line, accepted by the Fédération Aéronautique Internationale (FAI). Everyone who cross this boundary becomes an astronaut.

1.2 Suborbital space flight

Space tourism is becoming very popular recently but the cost of the travel is very high, about 20 million $ [1] and require many weeks of trainings and flight preparations. The cheapest way to become an astronaut is suborbital spaceflight. The cost of such a travel is about 100 000$ [2]. Idea of this flight assumes exceeding of the Karman Line. During the travel passengers are in zero-gravity conditions and can observe the ball shape of the Earth.

The first private space plane for human suborbital flight was developed by Scaled Composites. This company designed White Knight and Space Ship One. On September 29th and on October 4th 2004 they made two first flights simultaneously winning the Ansari X-Prize. Maximum altitude achieved equal to 102.9 kilometers.

In spite of high costs of space flights, many people would like to be astronauts. Therefore in 2005, in Warsaw University of Technology, a concept of two stage space plane TOLA [3] for suborbital tourism flight were created. This concept assume configuration, consist of the carrier (BOLEK) and the rocket plane (LOLEK). This paper includes calculations only for rocket plane (omitting influence of carrier).

2 Mission of the profile

The concept of space plane TOLA assume following phase of mission Figure 1

1) The rocket plane (LOLEK) is uplifted by the carrier (BOLEK) to the attitude equal 15 kilometers above the sea level where the objects are be separated.
2) BOLEK resumes to the airport, LOLEK rocket engine is turned on and flight to 60 kilometers above sea level where the engine is turned off.
3) The rocket plane starts ballistic flight and achieves attitude over 100 kilometers above the sea level – cross a boundary of Earth's atmosphere and outer space.
4) LOLEK glides using leading edge extension vortex.

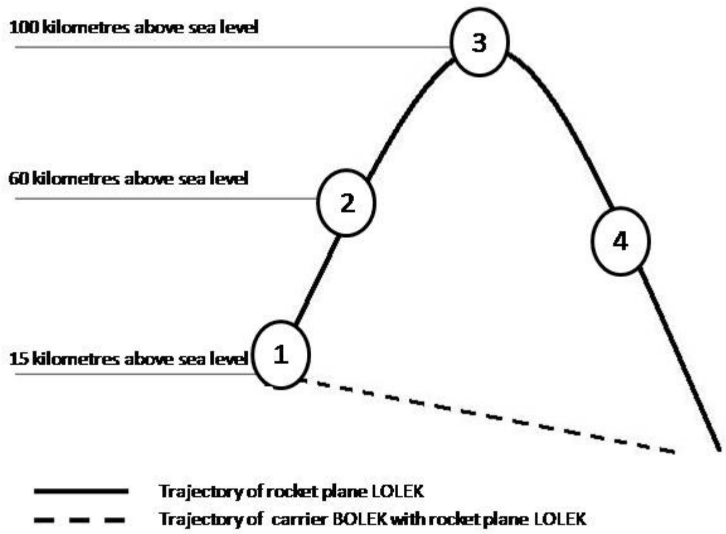

Figure 1: the mission profile

It is similar to the mission performed by White Knight + Space Ship One system [4].

3 Numerical calculation

3.1 Software

The calculation were made by commercial software, using the Euler system of equations and multi-grid scheme. This program offer calculation for inviscid compressible flow and also shocked flow [5]. The code consist of two modules pre-processor and solver. The first step is verification of geometry and grid as well as preparing data to calculations, and then conducting proper calculations. To improve a convergence code uses multi-grid scheme. This method required create a block around the object. First of the blocks has coarse grid, and succeeding consists of finer grid. Typical model include 4-10 levels of block. The additional level is required in parts where problems are supposed to appear or where advance flow or interesting effects take place. Because the Euler equation is hyperbolic, the best way to solve this problem is V-cycle scheme of multi-grid method [5]. The software implements this algorithm by Λ-cycle scheme (shift fine to coarse to fine grid).

3.2 Assumption

The rocket plane is equipped with leading edge extension (LEX), that will be used to generate vortex lift during return flight. Because Euler's code encounter some difficulties when calculating airfoil with bunt noses[6], LEX was designed as a sharp plate. What's more the software required the hole on the fuselage[5]. The model of rocket plane for numerical calculation shows the Figure 2. The mesh create on the model show the Figure 3. In this case six level of block was created.

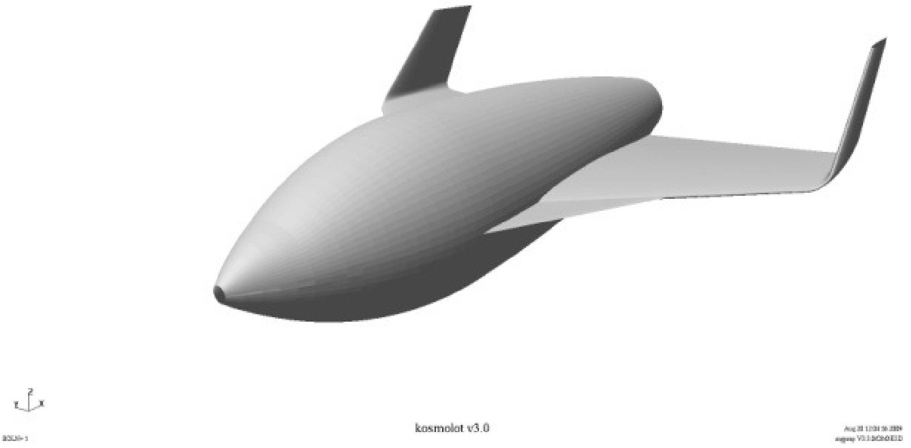

Figure 2: geometric model to numerical calculations

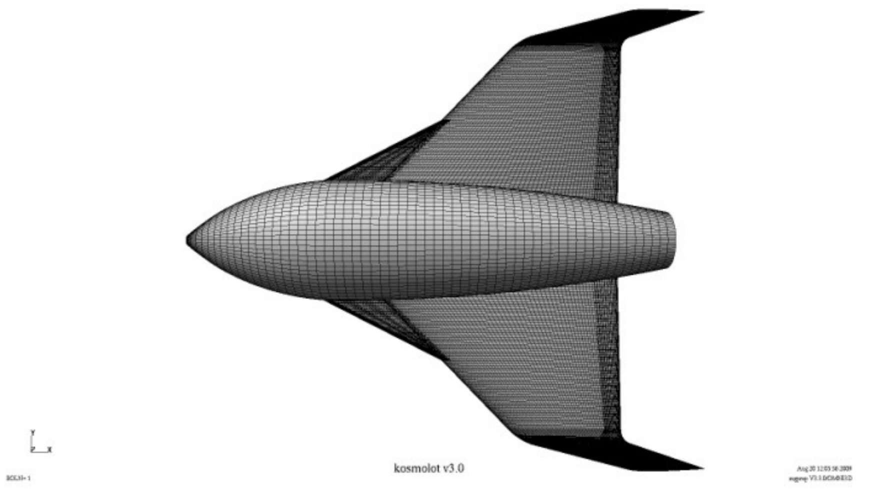

Figure 3: mesh on the model to numerical calculation

During the mission rocket plane flies with velocity up to 3-4Ma, hence subsonic and supersonic cases were examined. The Table 1 consist of particular information about range of calculations. In some cases problem with convergence appears. All calculations were conducted for inviscid flow. This paper includes calculations only for rocket plane (omitting influence of carrier).

Angel of attack [deg]	Mach number												
	0.2	0.5	0.8	1.1	1.2	1.3	1.4	1.5	2.0	2.5	3.0	3.5	4.0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	2	2	2	2	2	2	2	2	2	2	2	2
	4	4	4	4	4	4	4	4	4	4	4	4	4
	6	6	6	6	6	6	6	6	6	6	6	6	6
	8	8	8	8	8	8	8	8	8	8	8	8	8

Table 1: range of Mach number and angle of attack

4 Result

This paper focuses on numerical calculation of aerodynamic force coefficient. The numerical calculations obtain lift, drag, pitching moment coefficient and the pressure distribution. The Figure 4 and 5 show the result.

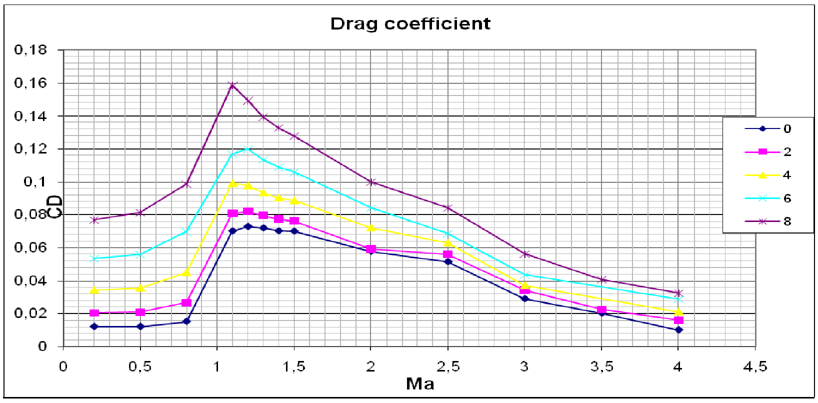

Figure 4: diagram of drag coefficient for angle of attack of 0 deg to 8deg as a function of Mach number

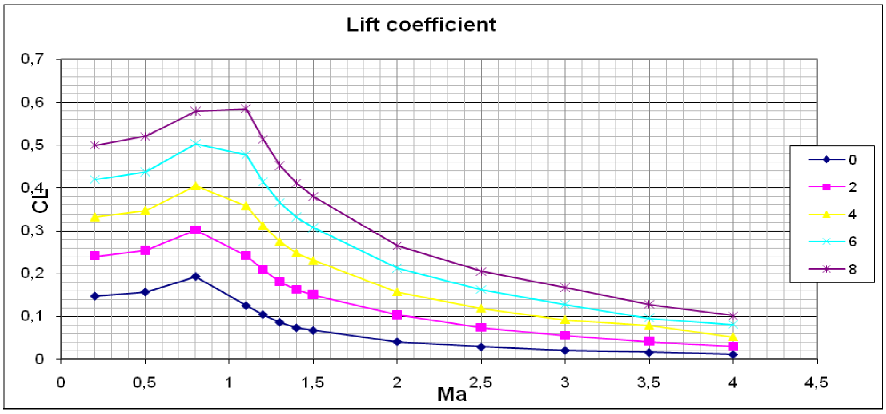

Figure 5: diagram of lift coefficient for angle of attack of 0 deg to 8deg as a function of Mach number

On the basis of diagram of lift and drag coefficient we suspect the shock wave, which was observed The figure below presents some important result of distribution of the local Mach number.

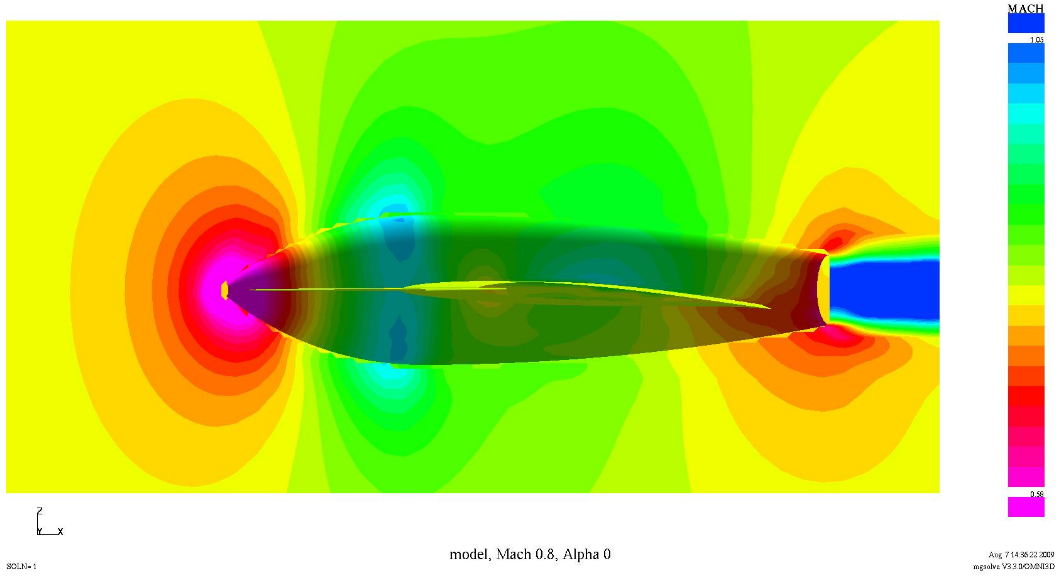

Figure 6: Mach number distribution for Ma=0.8 and angle of attack 0 degree

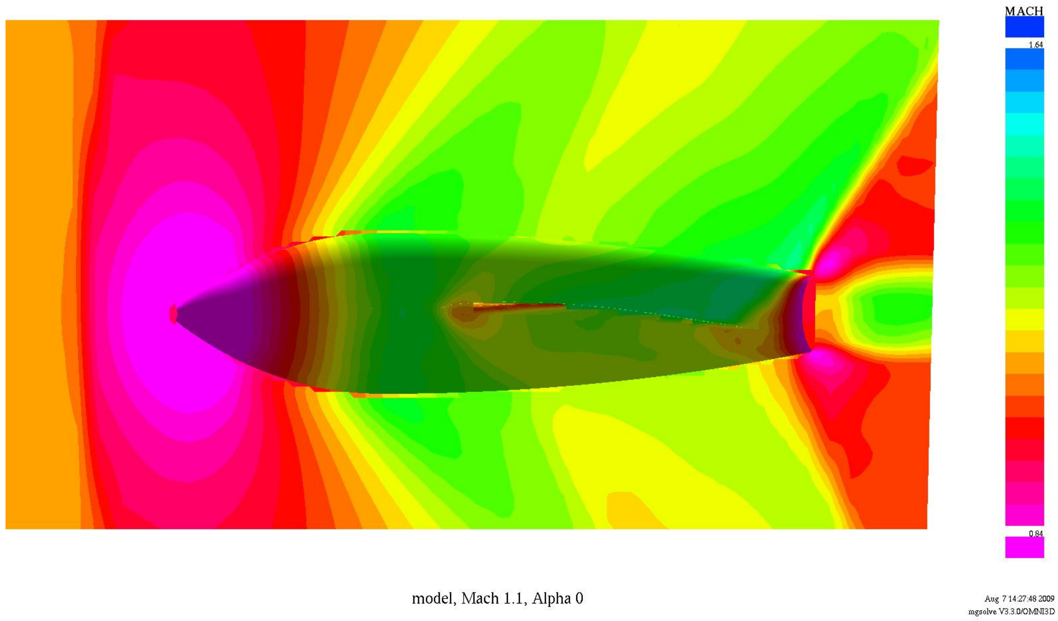

Figure 7: Mach number distribution for Ma=1.1 and angle of attack 0 degree

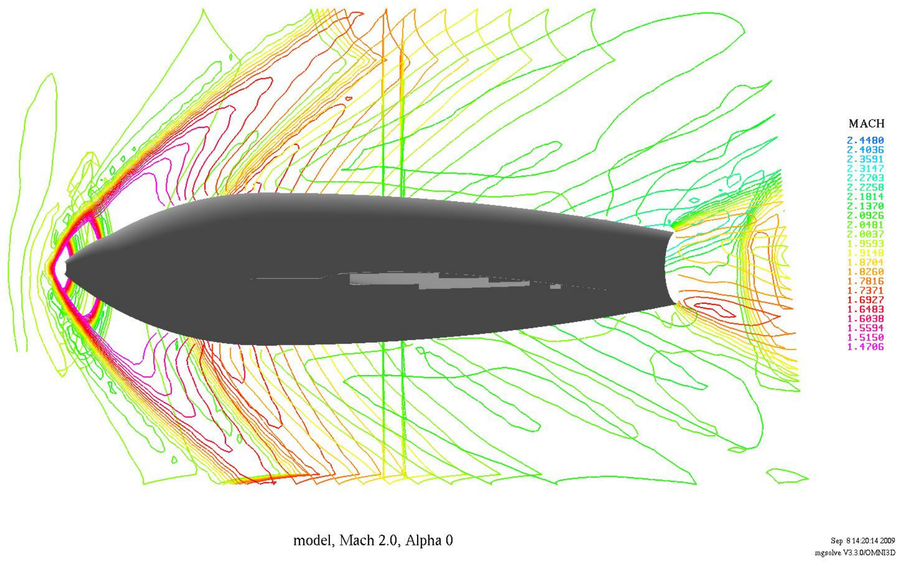

Figure 8: Mach number distribution for Ma=2.0 and angle of attack 0 degree.

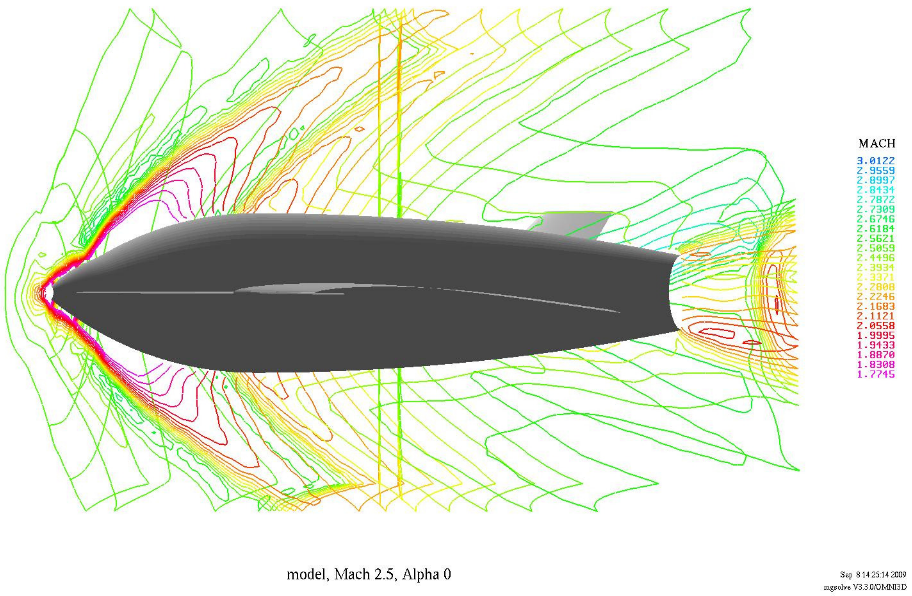

Figure 9: Mach number distribution for Ma=2.5 and angle of attack 0 degree.

On the basis of [7] the mass estimation was made, position of the centre of gravity is 32% mean aerodynamic chord. Take advantage of numerical result and information about the centre of gravity the stability of margin was evaluated. For supersonic flow the rocket plane is longitudinal stability but for subsonic flow is longitudinal instability. Therefore the fly-by-wire system is necessary to obtain a equilibrium.

5 Conclusion

The shock wave appears first on the wing and then shifts to nose. Next, the shock wave stands off. Finally, the shock wave is suctioned to the body. The numerical calculations shows that the rocket plane for some flight conditions is longitudinal instability. Therefore next version need modification of geometry and new mass estimation.

Acknowledgment

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