MODULAR AEROPLANE SYSTEM. A CONCEPT AND INITIAL INVESTIGATION

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Abstract

This paper presents results of an initial investigation on the Modular Aeroplane System, consisting of the flying wing carrier and cranked delta wing carried aeroplane. The system takes off in "conventional" configuration with the wing of the carried aeroplane working as a horizontal stabilizer of the system. At the certain altitude carried aeroplane is detached and both vehicles continue their missions separately. Each of them maintain flying wing configuration after split. The paper includes results of aerodynamic investigation related to the whole system, the carrier and the highly maneuverable airplane as an isolate components. Moreover analysis of stability for all vehicles configurations are presented. Furthermore paper contains initial performance calculations and discussion on possible applications of Modular Aeroplane System.

1 Introduction

Many aeronautical applications require contradictory qualities of an aeroplane. Quite frequently long range and endurance have to be combined with ability to fly very fast and maneuver very vigorously from time to time. First set of requirements suggests application of long aspect ratio wing with relatively thick airfoil, whereas second one requires thin wing with short aspect ratio. Application of variable sweep wing is a conventional approach to solve this problem. Unfortunately this solution is heavy and very expensive, thus not optimal for any flight mode. Our approach was inspired by WhiteKnight-SpaceShipOne [1] suborbital system built by Scaled Composites. It is assumed that combination of long range with high speed can be achieved by a system of two aeroplanes attached one to another that can be disconnected in flight when necessary. This concept is not new, since it was applied several times in Russia, Germany and United States [2]. What makes WhiteKnight-SpaceShipOne system unique is a proportion of weights of the carrier and carried aeroplanes. In previous cases carrier was much larger and heavier than carried aeroplane. WhiteKnight and SpaceShipOne seem to have almost the same weight and in some flight phases WhiteKnight might be even lighter. This has significant impact on stability and control issues. However successful flight test program carried out by Scaled Composites demonstrated that problems associated with this can be solved. Our approach is going a step forward [3]. SpaceShipOne is attached approximately below WhiteKnight gravity center, so it remains in the same place after SpaceShipOne is released. We propose the system where carried aeroplane is attached to the carrier significantly behind the common gravity center.

2 Concept of Modular Aeroplane System

Proposed concept of Modular Aeroplane System (MAS) consists of two coupled vehicles (Fig. 1). The bigger one is the Carrier, the smaller one is the Highly Maneuverable Aeroplane - HMA. Both vehicles have been designed in tailless configuration. The whole system has more conventional configuration where the wing of HMA is used as a horizontal stabilizer of MAS. This combination should provide smaller drag coefficient in comparison to the WhiteKnight-SpaceShipOne system. Drag reduction should result from smaller wetted area and smaller interference drag.

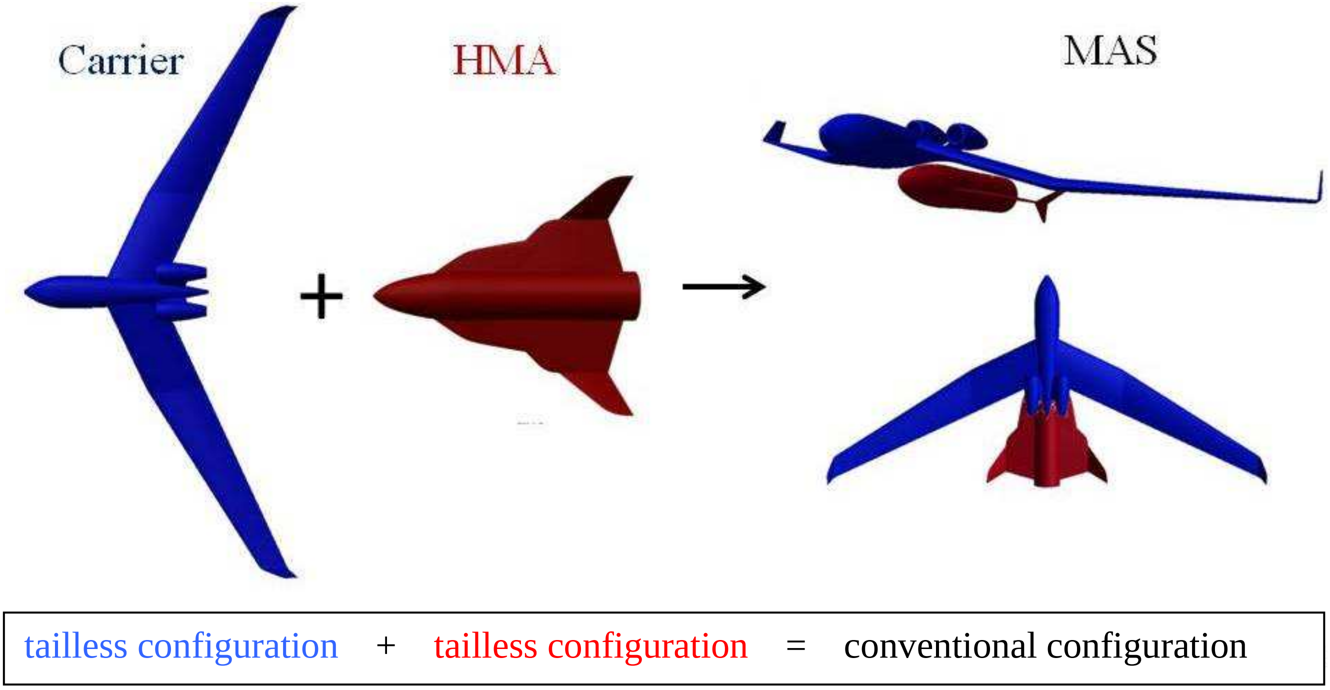

Fig. 1 Concept of Modular Aeroplane System (MAS)

As mentioned before, our concept of MAS assumes that the carrier is designed as a flying wing. High sweep angle of the carrier's wing allows obtaining static stability and equilibrium state, especially during individual flight. It is also more advantageous at large Mach numbers than straight wing. HMA is equipped with a thin, short aspect ratio, tapered wing with a strake. This configuration provides a potential for combining high speed at low angles of attack and high maneuverability at large angles of attack (Fig. 2). The last feature is possible thanks to the vortex lift generated by the strake.

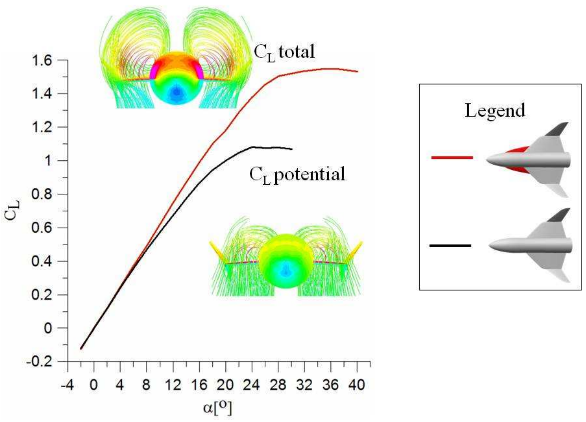

Fig. 2 Comparison of configurations with and without strake.

Most aeroplanes utilizing the vortex lift are designed in conventional configuration with control surfaces installed behind a wing, which provides a long arm of controlling force, but also increase in a moment of an aircraft inertia. The proposed concept has more compact design which produces smaller moment of inertia. Additionaly, negative effect of vortex flow on lateral stability is reduced because of the tailless aeroplane configuration with stabilizers installed on wing tips. In particular the lower part of the stabilizer allows obtaining lateral stability at high angle of attack. Providing an effective control for both ranges of airspeed (supersonic and subsonic) is one of main design problems. HMA is designed for high angles of attack when the vortex lift is generated [4, 5]. Concept of control assumes two pairs of elevons on main wing and inclined, all moving plates on the wing tips (Fig 3). These surfaces allow achieving longitudinal control and equilibrium state in both subsonic and supersonic flight regimes.

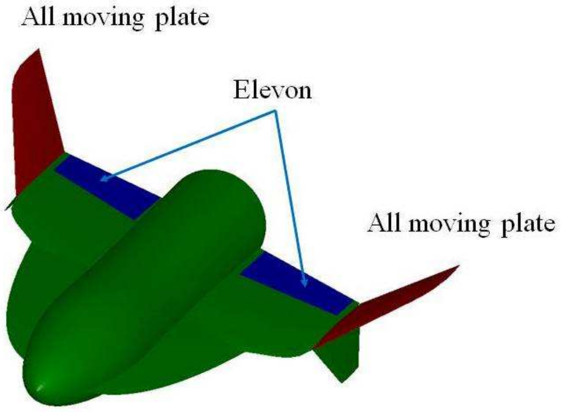

Fig. 3 Concept of control surfaces

3 Concept development

MAS geometry development is presented on Fig 5. Geometry of the wing was the main carrier modification. It was caused by the problem of HMA mass variation between the whole system takeoff and release moment.

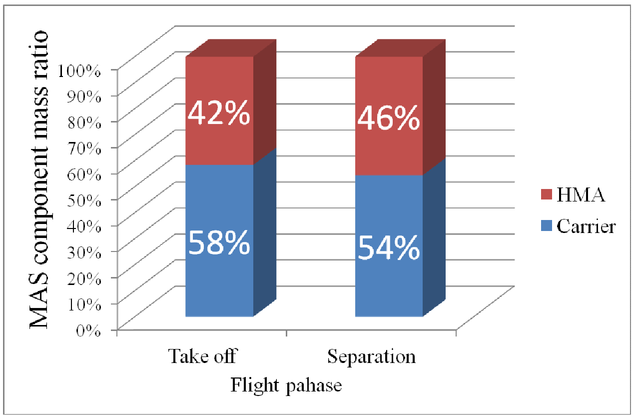

Fig. 4 Mass ratio for takeoff and the moment of HMA release.

Masses of both vehicles are similar, Fig 4 presents mass ratio for two configurations: take off and just before HMA separation. In that last case maintaining static stability is a challenge because center of gravity is shifted backwards. Moreover, both vehicles have centers of gravity in different places than the whole system, so HMA release causes rapid configuration change. However initial analysis of separation process was conducted [6] with positive result.

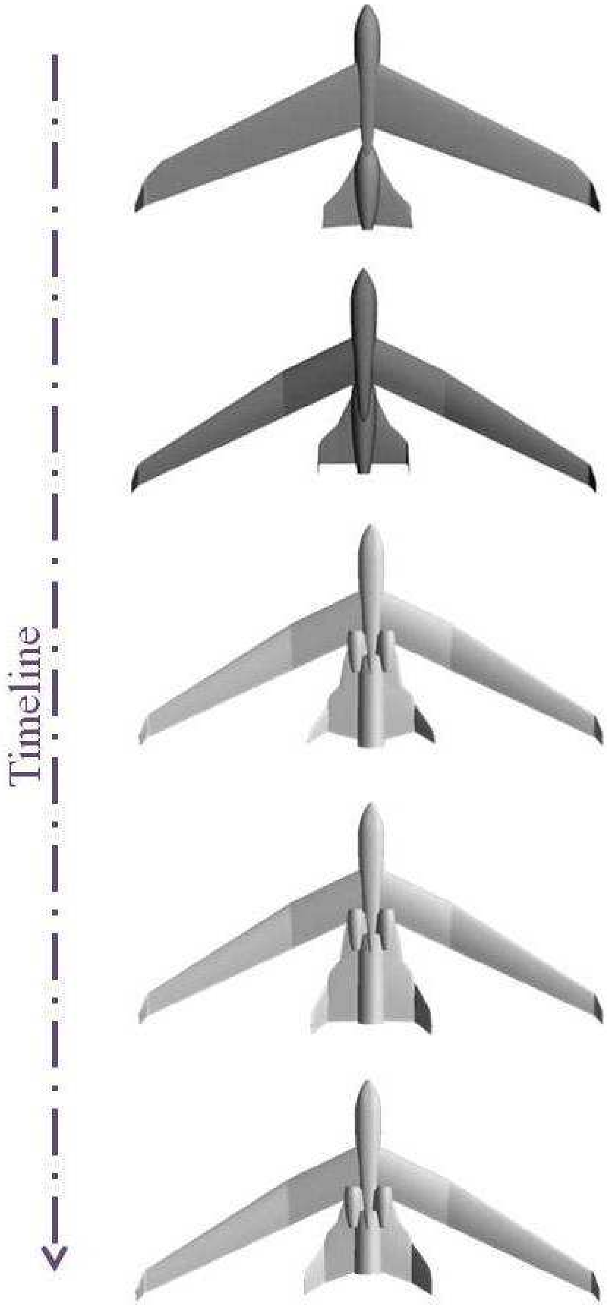

Fig. 5 Modular Aeroplane System geometry development

Fig.6 presents HMA geometry development. The first model consists of double delta wing with vertical side plates on the wing tips. The first version of the fuselage was tapered at the end, but it was changed due to problem with disadvantage distribution of pressure coefficient (Fig 6b). Moreover configuration of side plates was modified, the lower part was added due to problem with stability at high angles of attack (Fig. 6b). Upper part was inclined and designed as all moving to provide greater longitudinal maneuverability at high Mach numbers.

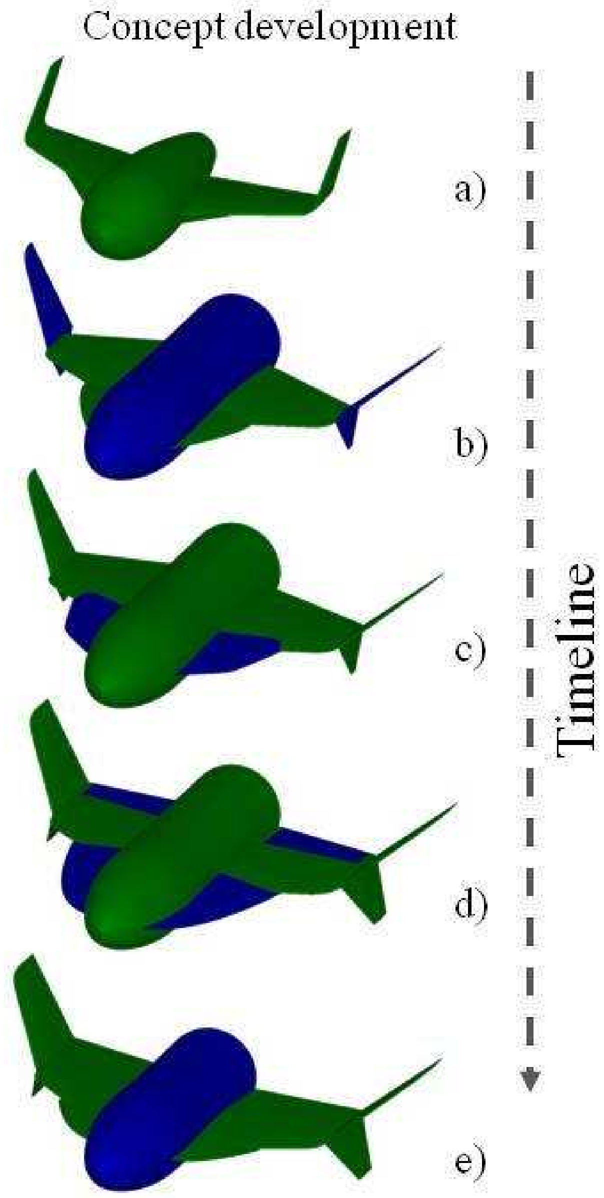

Fig. 6 HMA main modifications (highlighted in blue color)

To improve vortex generation, shape of the strake was optimized [7]. The process was conducted with gradient method for two concepts of geometry description. The best final shape was smoothed (Fig 6c,d). Next design step concerned stability and control problems. The previous model had problem with stability, therefore the current model received shorter fuselage, greater wing sweep and scaled strake (Fig 6e).

4 Initial investigation

A lot of effort was focused on the aerodynamic calculations of the carrier, HMA and the whole MAS as well. Analysis of initial concept of control of the HMA is a part of this effort [8].

4.1 Methods and conditions

Numerical aerodynamic calculations were conducted with application of the software which is based on Euler equation and multi-grid scheme [9, 10], which in that case reduces computation time. The flow is simulated as an inviscid which means that the vortex breakdown is not modeled [11]. The strake numerical model was a flat plate with sharp landing edge. The calculations were conducted for sub and supersonic flow and for wide range of angles of attack, especially for high angles of attack.

4.2 Carrier

The carrier will be flying in subsonic airspeed range. Calculations were conducted for Mach number equal Ma=0.51, which corresponds to the HMA release velocity. Distribution of pressure coefficient and Mach number are presented in Fig 7 and Fig 8.

4.3 Highly Maneuverable Airplane

Calculations for HMA are particularly focused on high angles of attack due to vortex lift phenomenon. Moreover supersonic cases were also examined. Examples of distribution of pressure coefficient and Mach number are presented in Fig 9-Fig 12.

Visualization of the shock wave for Mach number equal 1.5 and angle of attack equal 0° is presented in Fig 13 and Fig 14.

Vortex flow visualization for different shapes of the strake is presented on Fig. 15.

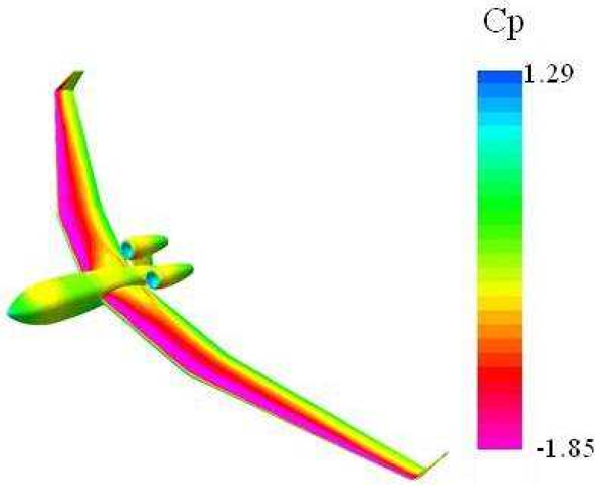

Fig. 7 Pressure distribution for the carrier, Mach Number Ma=0.51 and angle of attack α = 8 deg.

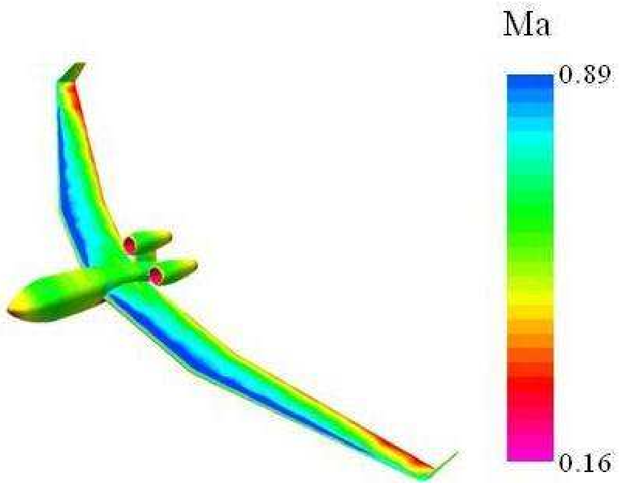

Fig. 8 Mach number distribution for the carrier, Mach number Ma=0.51 and angle of attack α =8 deg.

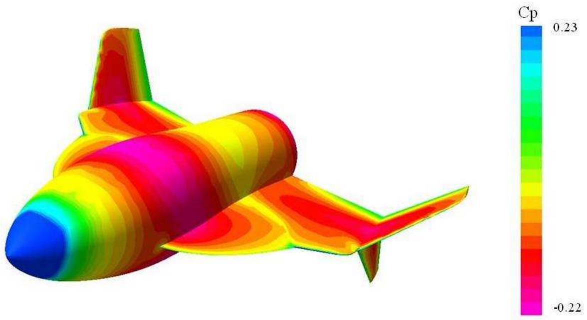

Fig. 9 Pressure coefficient distribution for Mach number Ma=0.5 and angle of attack α=0 deg.

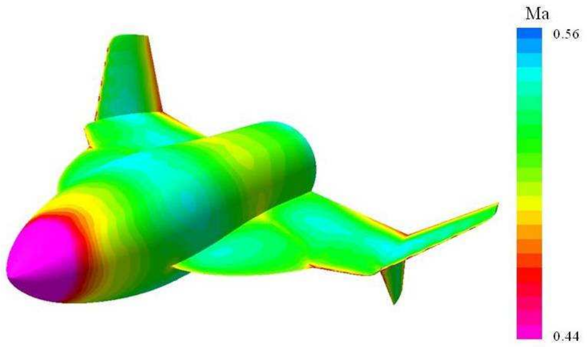

Fig. 10 Mach number distribution for Mach number Ma=0.5 and angle of attack α=0 deg.

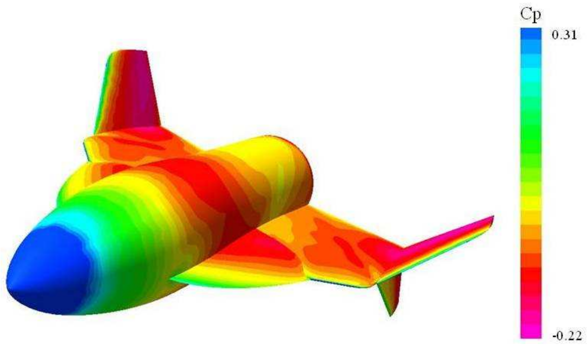

Fig. 11 Pressure coefficient distribution for Mach number Ma=1.5 and angle of attack α=0 deg.

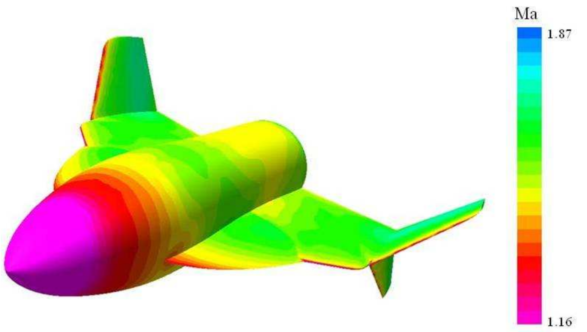

Fig. 12 Mach number distribution for Mach number Ma=1.5 and angle of attack α=0 deg.

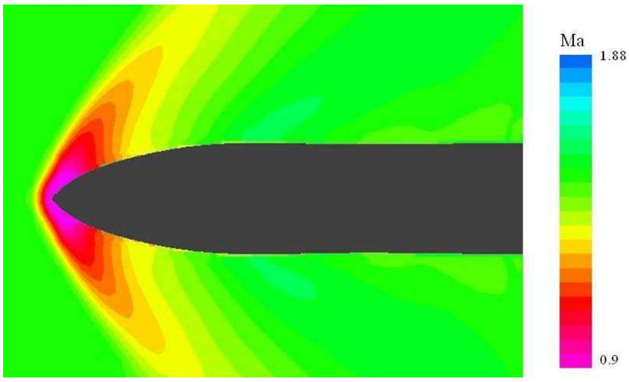

Fig. 13 Shock wave visualization for Mach number Ma=1.5 and angle of attack α =0 deg.

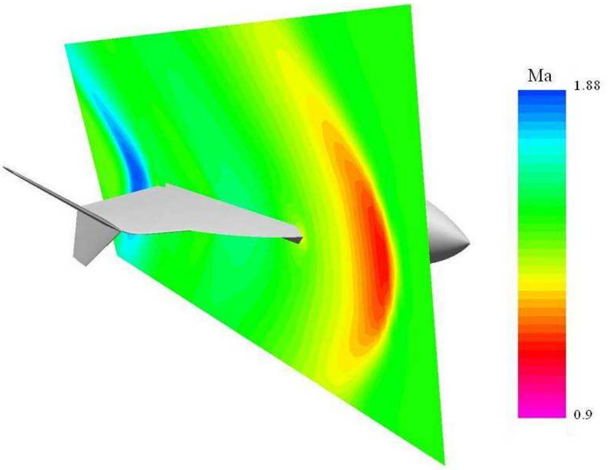

Fig. 14 Shock wave visualization for Mach number Ma=1.5 and angle of attack α =0 deg.

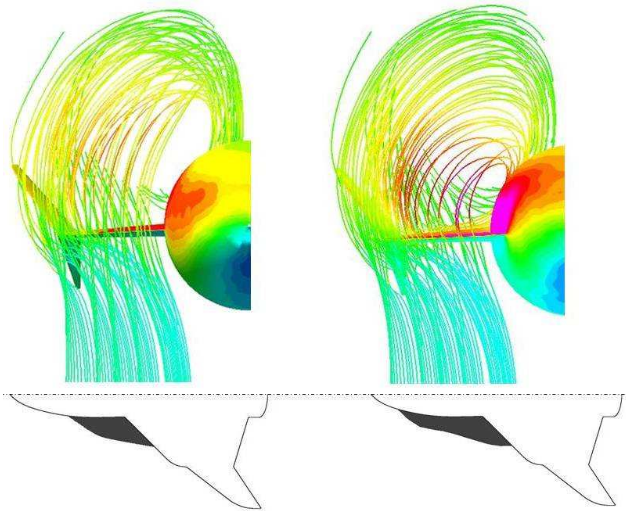

Fig. 15 Vortex visualization for Mach number Ma=0.5 and angle of attack α=26 deg.

Several cases with control surface deflected were examined. This paper includes examples of distributions of pressure coefficient and Mach number for models presented in Fig 6d and e with deflected elevons and wing tip plates. Principle of operations of the proposed concept of control is presented in Fig. 16 and Fig. 17. Control surfaces can be deflected symmetric and asymmetric. Subsonic case for model 6d is presented in Fig. 18 and Fig. 19 while Fig 20 and Fig 21 present results for supersonic calculations. Fig 22 and Fig 23 show distribution of pressure coefficient and Mach number for model 6e with deflected all moving plates. Effectiveness of elevons and tip plates in sub and supersonic case are presented in Fig 24 and 25. Line presenting combined deflection represents the case when elevon has constant deflection of 8 deg and tip plate rotates.

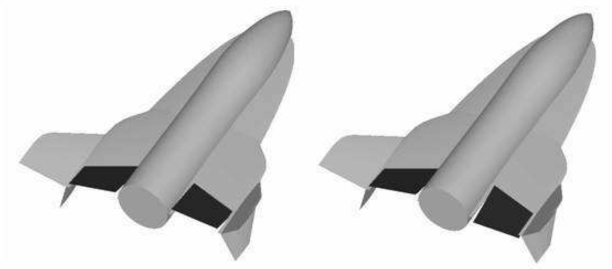

Fig. 16 Deflection of elevon in considered concept of control (symmetric deflected on the left; asymmetric deflected on the right)

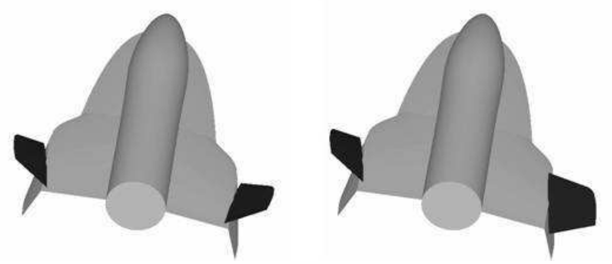

Fig. 17 Deflection of all moving plates in considered concept of control (symmetric deflected on the left; asymmetric deflected on the right)

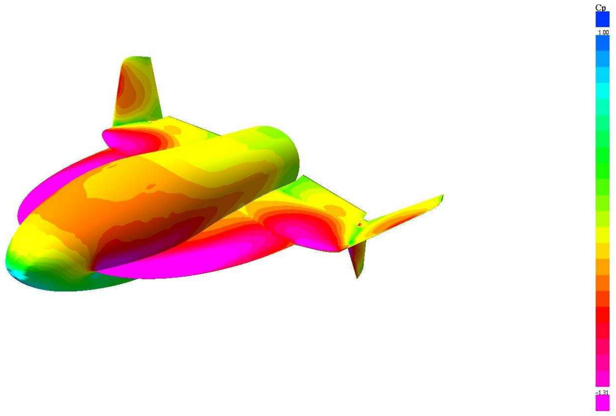

Fig. 18 Pressure distribution for Mach number Ma=0.5 and angle of attack α=20 deg, elevon deflection -10 deg.

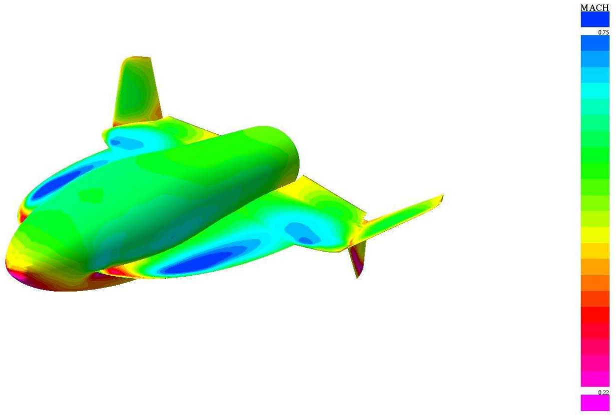

Fig. 19 Mach number distribution for Mach number Ma=0.5 and angle of attack α=20 deg, elevon deflection -10 deg.

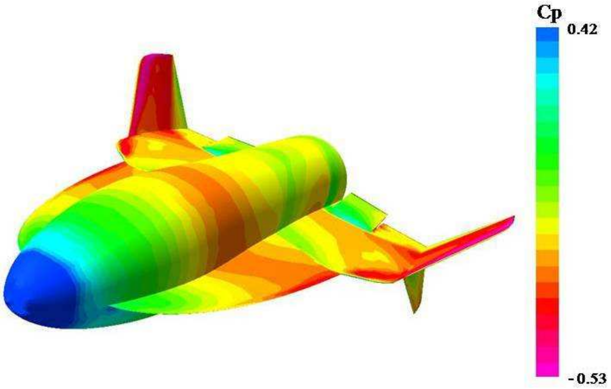

Fig. 20 Pressure coefficient distribution for Mach number Ma=1.2 and angle of attack α=4 deg, inner part of elevon deflection -10 deg.

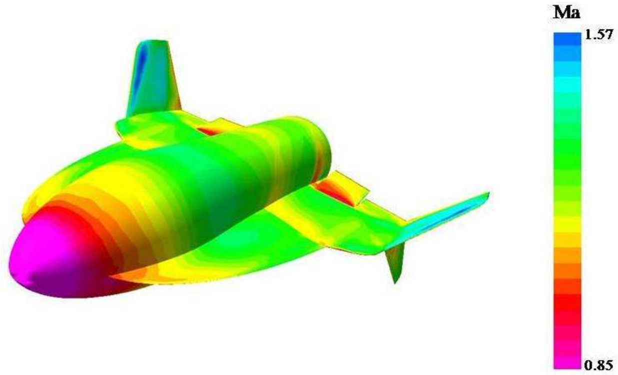

Fig. 21 Mach number distribution for Mach number Ma=1.2 and angle of attack α=4 deg, inner part of elevon deflection -10 deg.

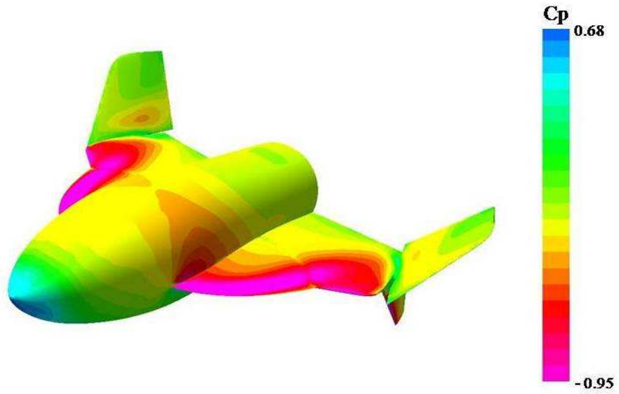

Fig. 22 Pressure distribution for Mach number Ma=0.5 and angle of attack α=20 deg, all moving plates deflection -10 deg.

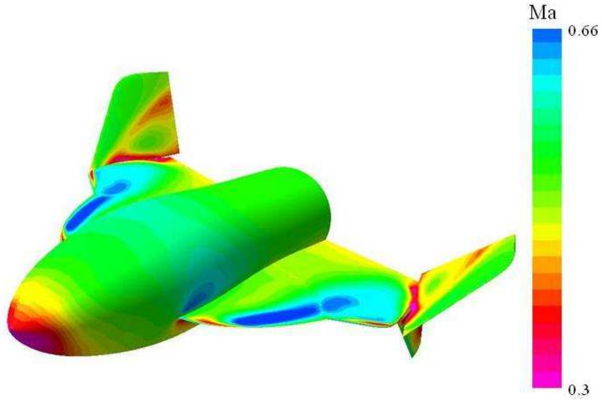

Fig. 23 Mach number distribution for Mach number Ma=0.5 and angle of attack α=10 deg, all moving plates deflection -10 deg.

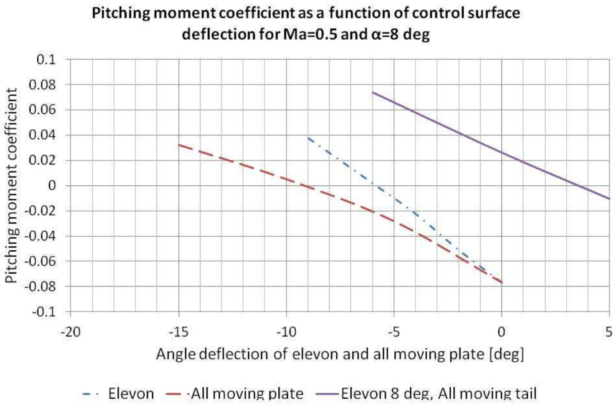

Fig. 24 Effectiveness of various combinations of control surfaces for subsonic airspeed

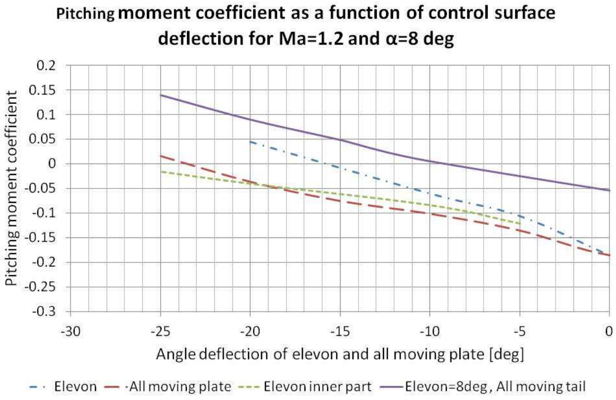

Fig. 25 Effectiveness of various combinations of control surfaces for supersonic airspeed

4.5 Coupled configuration

Aerodynamic calculations of coupled MAS were conducted for Mach number Ma=0.51, this value corresponds to the HMA release velocity. Several different configurations of Modular Aeroplane System with various position of HMA were examined. Position providing static stability for all flight conditions was found. Calculation of flight envelope also were conducted, the results presents Fig.28. It proves that coupled MAS can climb up to the altitude of 15 km.

5 Possible applications

Proposed system can be used for suborbital space tourism [12]. In this case HMA would be used as a rocket plane equipped with hybrid rocket engine. It would be designed for pilot and two passengers.

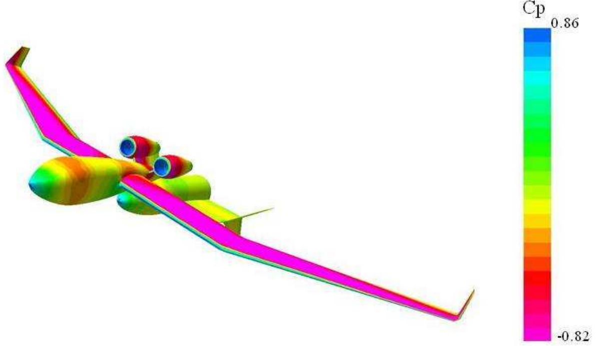

Fig. 26 Pressure coefficient distribution for Mach number Ma=0.51 and angle of attack α = 2 deg.

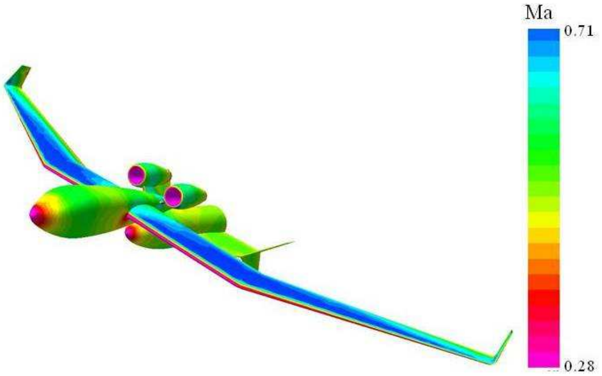

Fig. 27 Mach number distribution for Mach number Ma=0.51 and angle of attack α = 2 deg.

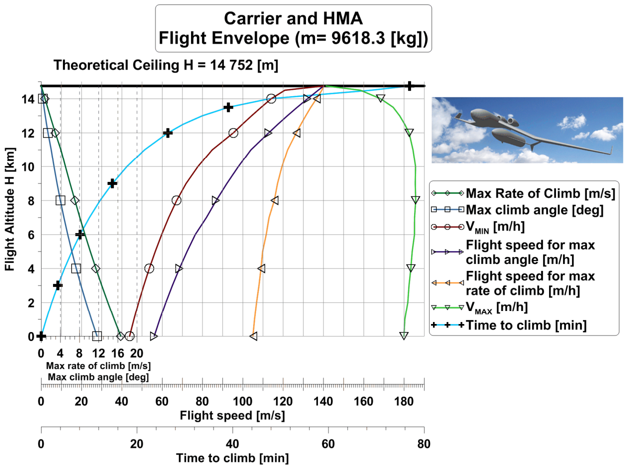

Fig. 28 MAS flight envelope

Different configurations of cabin arrangement were considered (Fig. 29). Mission profile of such a system is presented in Fig. 30. The whole system takes off as a conventional passenger aeroplane and can use commercial airport. About 15 kilometers above sea level

HMA is released. The carrier returns to the airfield while the hybrid rocket engine is turned on in HMA and the rocket plane begins steep climbing. At certain altitude the engine is turned off and the rocket plane begins ballistic suborbital flight. The main goal of the rocket plane is crossing a Karman Line [1] which is a border of outer space. This allows passengers to become astronauts. During the flight the passengers are in zero gravity condition and see spherical shape of the Earth. Return flight is performed as a glide while the phenomenon of vortex lift is used to aero-braking and protects structure against aerodynamic heating.

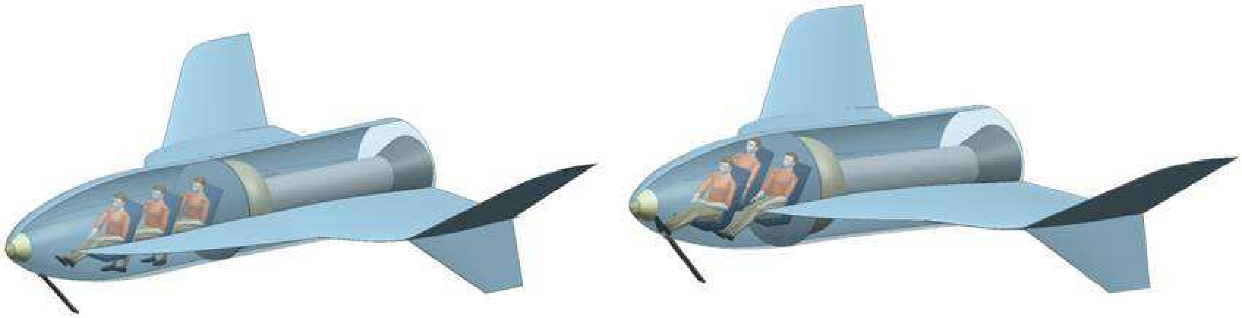

Fig. 29 Cabin arrangement

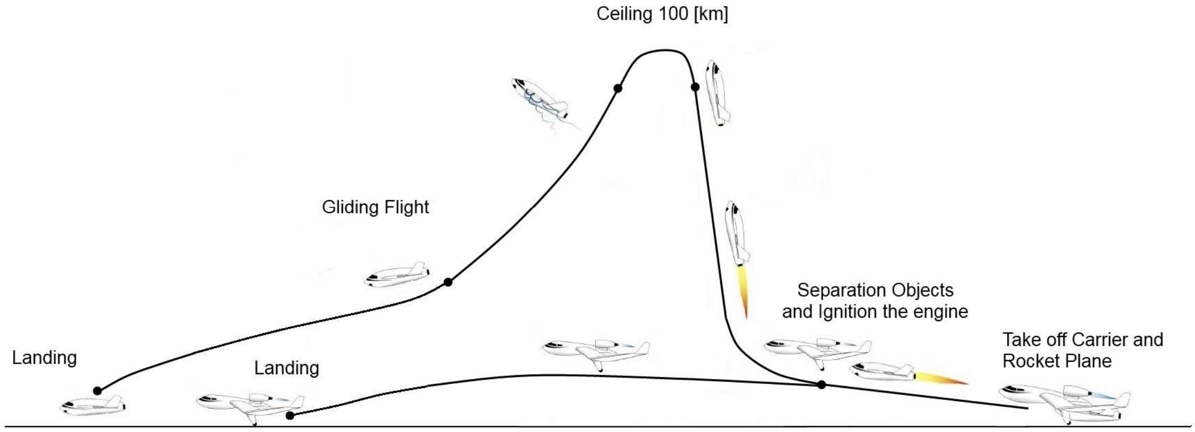

Fig. 30 Mission profile

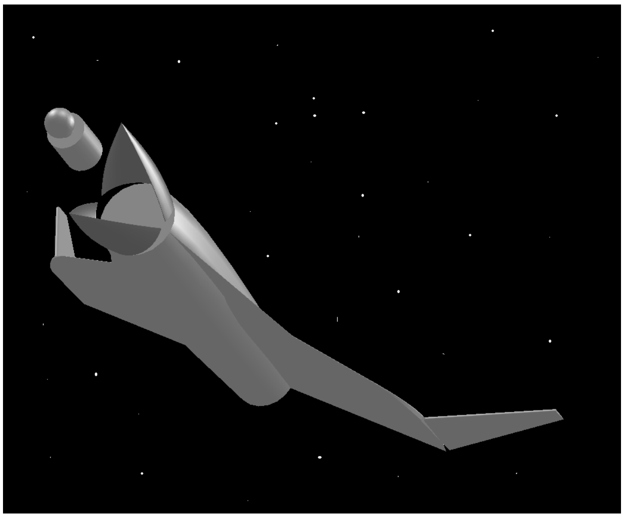

Fig. 25 Third stage release.

Space launch vehicle for small satellites [13] could be another application. In this case an additional stage of the system is required (Fig.31). The third stage is equipped with rocket engine and p-pod for a micro satellite. The first part of mission profile is similar to the suborbital case. The third stage is ejected when the rocket plane achieves apogee of its trajectory. The satellite is released when third stage achieves orbit with assumed parameters.

Modular Aeroplane System has been designed to take off from commercial airport and does not need additional ground facility. Therefore it will create great opportunity for countries which does not have a launch complex.

Moreover the proposed system could be used for military applications as an unnamed aerial vehicle. In that case a jet engine could be used in HMA instead of a rocket engine.

6 Conclusions

Results of the initial investigation seem to be promising. All challenges which occurred so far in the course of the design process of the carrier and HMA were successfully solved. Obtaining an equilibrium state is possible using elevon and all moving plate. Moreover the all moving tail allows increasing the efficiency of the whole control system, especially for higher Mach numbers. The aerobraeking effect with application of vortex flow seems to be efficient and very promising. Use of the vortex lift to decrease sink rate during reentry from suborbital flight to outer space could be an alternative for heat shield.

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