A CONCEPT OF TWO-STAGED SPACEPLANE FOR SUBORBITAL TOURISM

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Abstract

The concept of simple two-staged spaceplane for suborbital tourism is presented in this paper. Flying wing configuration is proposed for the first stage mothership and cranked delta wing for spaceplane. It is assumed that the spaceplane will be rigidly connected behind the mothership, so that the spaceplane's wing will act as a horizontal stabilizer for the assembly. Predicted advantages of such assembly are discussed, as well as potential problems that may arise during the development. Undertaken and planned research tasks are briefly mentioned at the end.

1. INTRODUCTION

It is believed that extremely high cost of space travel is the result of inertia of large, bureaucratic organizations such as NASA. Unfortunately, effort of privatization of some parts of NASA activity failed. As a result a group of space travel enthusiasts (Peter H. Diamandis Byron K. Lichtenberg, Colette M. Bevis and Gregg E. Maryniak) funded X Prize foundation in 1995 [1]. Organization of the private suborbital travel contest was an objective of this organization. The idea of the contest was applied since similar contests, organized in twenties and thirties, triggered rapid development of aviation. X Prize contest was announced on 18 May 1996. Two suborbital flights at the altitude of 100km, performed by the same spaceship within two weeks were required, according to the contest rules. Spaceship should be able to carry three people including pilot. It was allowed however, not to carry passengers during competition flights. Instead, ballast with the mass equal to the mass of two people with necessary equipment was required. Government support was forbidden. These rules were expected to support the development of a new branch of aerospace business – space tourism.

According to the Futron Corporation, demand for suborbital space travel is high [2]. Market research carried out in 2002 revealed that more than 15000 people would like to participate in such a tour before 2021 with assumption that the ticket price will be of order of $100 000.-. Annual revenue greater than $M700 was expected (Fig.1.). Unfortunately, the absence of suitable spaceships blocked so rapid development. Research repeated in 2006 revealed the same demand curve only shifted in time [3] (Fig.2.).

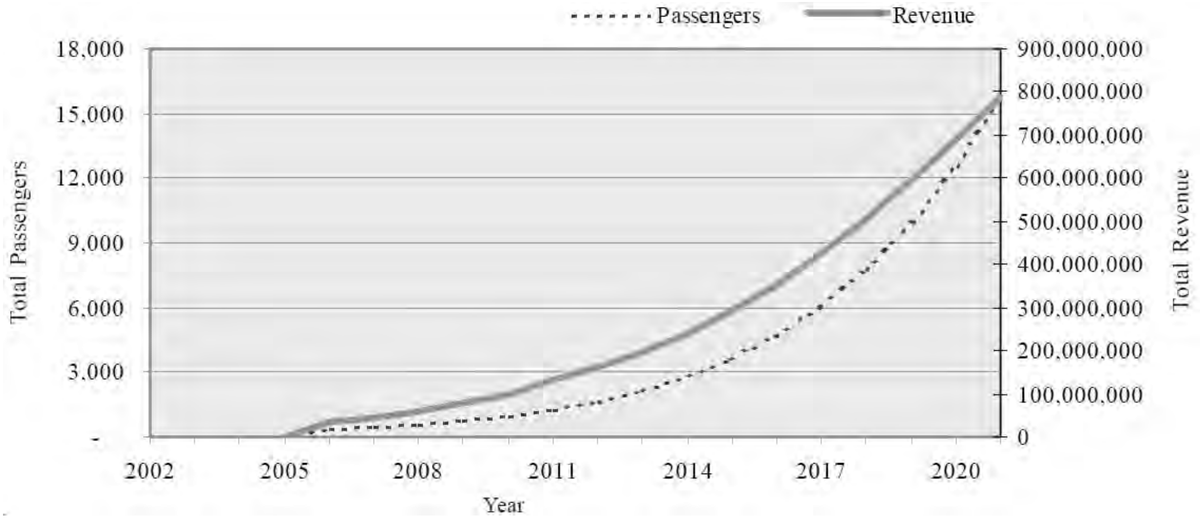

Fig.1. Expected number of suborbital passengers and annual revenue in US dollars, according to the Futron's market research from 2002 [2].

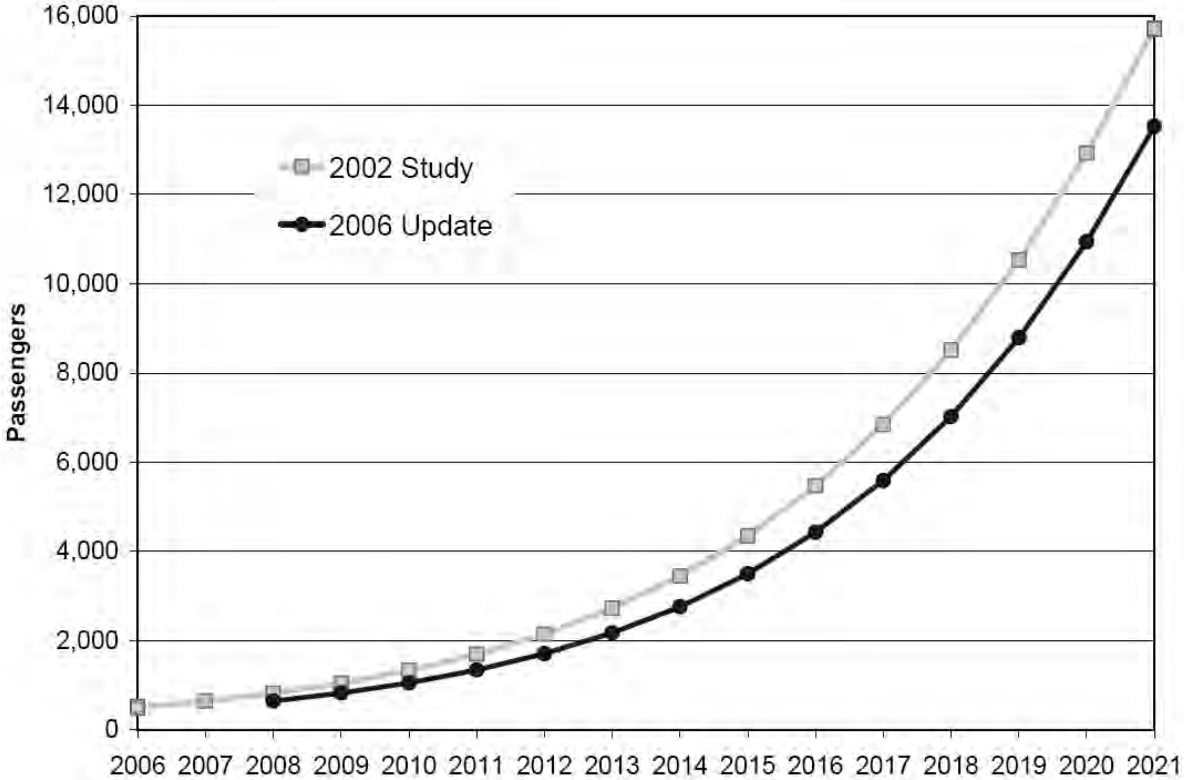

Fig.2. Futron's prognosis concerning expected number of suborbital passengers revised in 2006 [3].

Ansari family supported X-Prize foundation providing sum of $M10 for the prize for the contest winner in may 2004. Scaled Composite was named a winner on 4 October 2004. Scaled Composite team was led by Burt Rutan and supported by Paul Allen, who is co-owner of Microsoft[4]. Their spaceship applied two-staged configuration consisting of high altitude mothership, powered by two turbojets and spaceplane with rocket propulsion. Spaceplane was released at the altitude of 15000m and ignited its rocket after a brief period of glide, finally accelerating to velocity of 1000 m/s in steep climb. Altitude of 100km was then achieved in ballistic flight. Finally it returned gliding to the airport. The project was successful and should be perceived as a great achievement, however, it is estimated that the total cost of the project reached $M25. Therefore possible cost cuts should be considered, since the suborbital travel cost reduction is a key target here. One possible way to reduce costs is simplification and aerodynamic improvement of applied mothership/spaceplane assembly. It should reduce power consumption during the mission, thus decreasing spendings. Fuel costs are quite high here since a fuel weight is almost equal to the half of the assembly takeoff weight. Our paper presents one of possible methods of such simplification and improvement.

2. MISSION PROFILE

The assembly consists of the high altitude mothership and the spaceplane. Mothership is supposed to lift the spaceplane to as high altitude as possible with turbojet propulsion. Therefore, the spaceplane can be equipped with the rocket engine nozzle optimized for low ambient pressure. Moreover it needs less fuel thus reducing wetted area and airframe weight comparing to the one staged concept. After release at high altitude mothership returns to the airfield, while spaceplane glides for the moment and ignites the rocket engine to accelerate and climb. Acceleration is powered by rocket engine, then, after all fuel is consumed, spaceplane continues climbing according to the suborbital trajectory. Apogee of 100km can be achieved if spaceplane is accelerated to M~4. Spaceplane falls freely after apogee is achieved. Atmosphere density increases with altitude decrease thus allowing for aerobraking. It is necessary to avoid excessive acceleration and overheating of exposed zones like aerofoil leading edges. In comparison to orbital flight, overheating problem is reduced here since temperatures are proportional to the airspeed and airspeed during reentry is much smaller in the case of suborbital flight reentry (in order of M~4) than in the case of orbital flight reentry (in order of M~26). Anyway, despite of aerodynamic braking, the descent is initially supersonic. Spaceplane can glide normally to the airfield after the airspeed becomes subsonic in the dense layer of atmosphere.

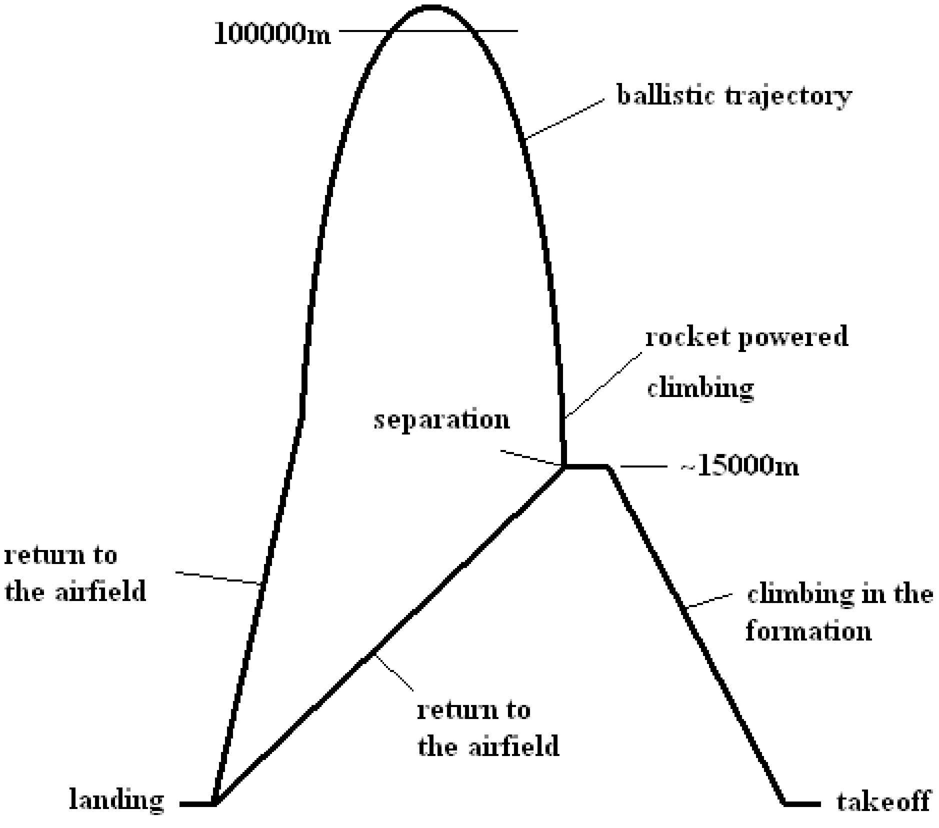

Fig.3 Mission profile [4]

3. ASSEMBLY CONFIGURATION

Assembly applied by Scaled Composites consists of high altitude mothership White Knight and spaceplane SpaceShipOne. White Knight was also used to carry X-37 experimental vehicle. All of them were designed in the classical configuration i.e. with separate wing and horizontal stabilizer behind the wing. Spaceplane was attached under the mothership so that their CG positions are as close to each other as possible. As a result very high landing gear had to be used in the mothership. Moreover mothership has two, wide spaced tail beams to provide a space for the spaceplane. The crew and turbojets are located in the central nacelle. Each tail boom is equipped with its own T tail stabilizers. Spaceplane is designed in similar configuration except beams, which are located at wing tips and horizontal stabilizers, which are located outside wingtips only. This was done to avoid collision between stabilizers and the rocket plume. Aerobraking system in their design is very interesting, however quite complex. The whole rear part of the wing (~50% of the chord) is rotated upwards together with tail beams and stabilizers. This allows for stable aerobraking during the return to the dense atmosphere. Similar solution has been applied for many years in FAI free flying models to enforce landing from thermal columns without models' acceleration. It was also applied in the Pointer UAV in early nineties.

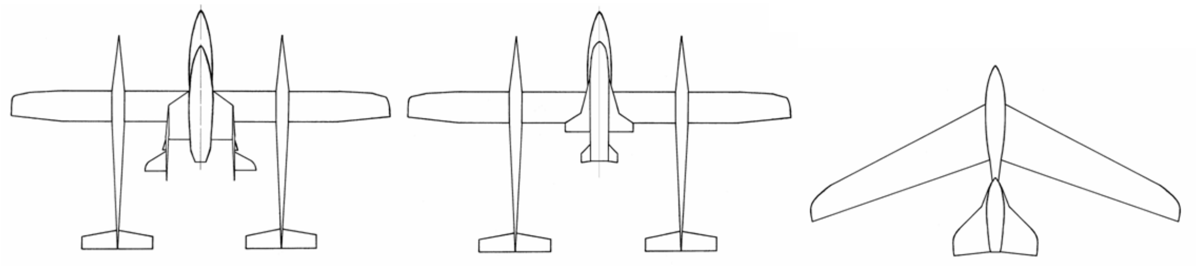

Fig.4 Comparison of three assemblies: White Knight + SpaceShipOne, White Knight + X-37 and the assembly proposed in this paper [5,6].

Complexity of the configuration seems to be the most important drawback of this design resulting in high interference drag. It seems possible to increase the L/D ratio of the assembly thanks to its simplification. To achieve this goal flying wing configuration can be applied to the mothership and cranked delta wing for the spaceplane. Spaceplane can be rigidly attached to the mothership so that the spaceplane's wing acts as an assembly's horizontal stabilizer. This allows not using tail beams and additional stabilizers. As a result the wetted area is lower and so the friction drag, with the lifting area remaining the same. Number of inclined surfaces is also reduced thus reducing interference drag. Further on, shorter landing gear can be applied if spaceplane is attached behind the mothership instead of below the mothership.

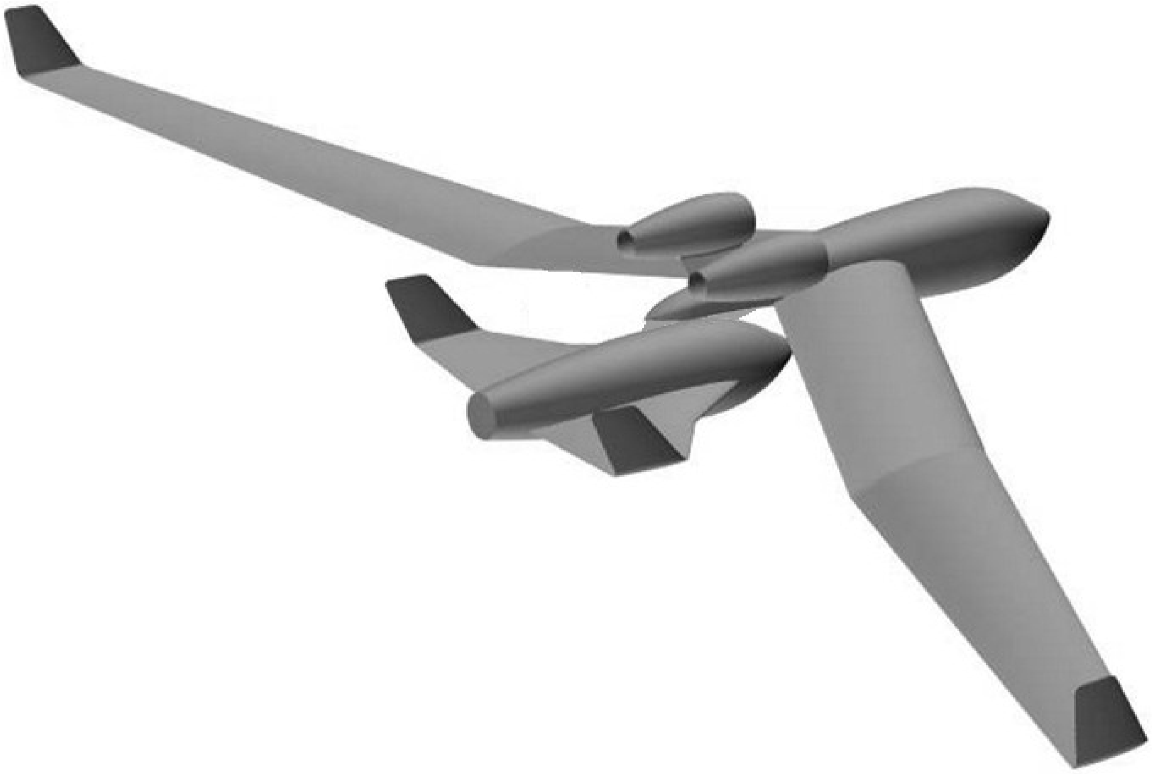

Fig.5 The concept of the mothership/spaceplane assembly proposed for suborbital spaceflights.

It is also possible to design simpler aerobraking system for the spaceplane utilizing the leading edge vortices generated by cranked delta wing at high angles of attack [7,8], which can be achieved with simple elevator deflection only. The existence of leading edge vortices significantly increases lift and drag coefficients as well as stall angle of attack. This effect is frequently applied during airshows to demonstrate extremely low airspeeds achievable by airplanes like Mirage 2000, or F-16. During such presentations high thrust has to be set to maintain horizontal flight. However, if low thrust was set, such airplane would descent relatively slow, maintaining stability and controllability. Similar procedure was tested recently for the cranked delta wing micro UAV [9]. It is believed that spaceplane in this configuration will need nothing more to descend without acceleration than large elevator deflection.

4. EXPECTED PROBLEMS

Significant spaceplane mass attached behind the mothership will certainly shift the assembly's CG backwards. However it should be noted that spaceplane's wing would act as an assembly's horizontal stabilizer. Therefore neutral point of assembly's stability will move backwards as well. It is believed that stability margins can be large enough both for the assembly and for separated objects. The major concern is the effect of the fuel used. In the case of White Knight, fuel mass is almost as high as a mothership's empty mass. It is used mainly during climb with a spaceplane. Flying wing mothership will use comparable amount of fuel, therefore assembly's CG position will move backwards during flight, since spaceplane is expected to burn its fuel later. Assembly's CG will be in aft position at high altitude, just before the spaceplane release. This may be important since aerodynamic damping is low at high altitudes. The effect of fuel consumption may be reduced if fuel from outboard (aft in swept wing) fuel tanks is used first. However, this will increase wing loads, thus requiring stronger and heavier wing structure. It should be noted here that both the assembly and the spaceplane have to be optimized, whereas the mothership alone may not be optimal. After spaceplane release it needs return to the airfield only, which should be easy bearing in mind high aspect ratio expected for the wing, even if details are not optimal. Therefore mothership's aerodynamics may be optimized for assembly flight conditions, not for separated flight conditions. Assembly flight conditions optimization may include the fuel consumption sequence optimization, thus solving the CG in-flight shift problem; however solution may be valid for constrained range of mothership/spaceplane distances only.

Another serious problem to analyze is the process of spaceplane release. In the more conventional cases (weapon releases) the object with small mass and small dimensions is released from large and heavy mothership. In the case of White Knight + SpaceShipOne assembly, the size and mass of the released object are greater than usually, however there is no major configuration and CG position change at the moment of release. In the case of currently proposed assembly, changes during release are significant; therefore they have to be analyzed carefully.

Finlay, spaceplane aerobraking may create a problem. Generation of the leading edge vortices is pretty well understood for subsonic conditions, whereas for supersonic conditions it is much more complex [11-13]. Unfortunately, spaceplane aerobraking will occur in supersonic conditions at least initially, at high altitudes.

5. RESEARCH UNDERTAKEN AND PLANNED

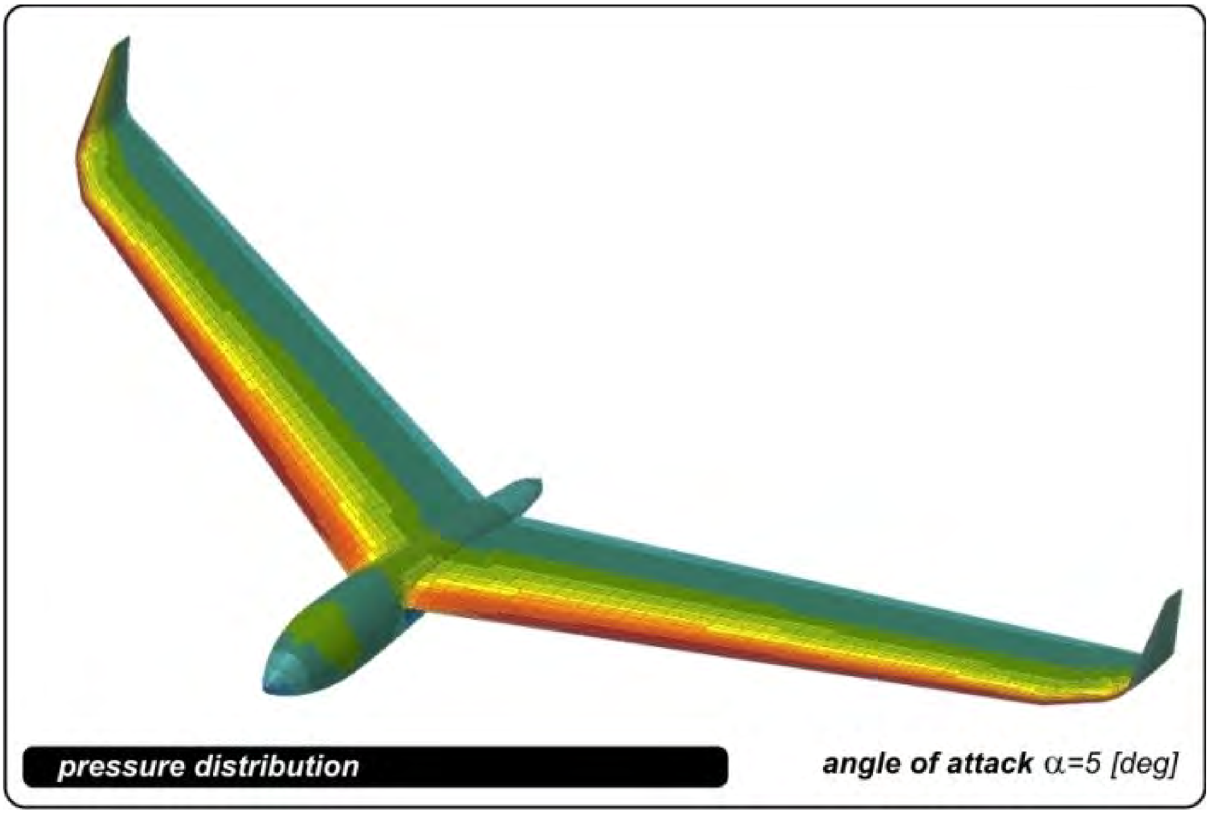

Fig.6 Pressure distribution over the flying wing mothership at AoA=5º [deg] calculated with PANUKL package [14]

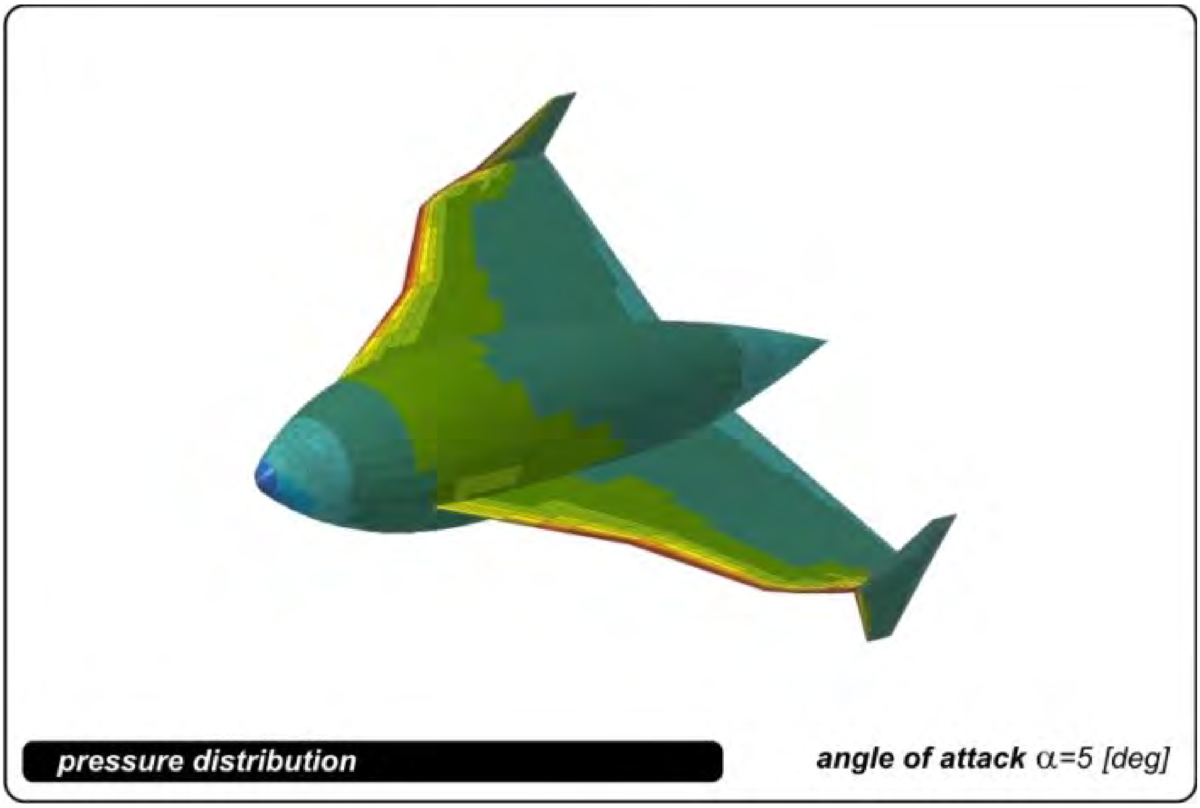

Fig.7 Pressure distribution over the cranked delta wing mothership at AoA=5º [deg] calculated with PANUKL package [14]

Mass and aerodynamic analyses are under way at the moment to asses the influence between the mothership and the spaceplane in the rigid formation. They should allow to asses the optimal spaceplane position in relation to the mothership in terms of performance and stability of both the assembly and separate vehicles.

Simulation of the release process is also being prepared. It should allow analyzing the ability to perform safe release.

Results of all these activities will be verified in the course of wind tunnel test programme. Finally, it is planned to build dynamically similar flying models of both vehicles and perform flight testing campaign including spaceplane model release experiments.

6. CONCLUSION

Space tourism will be developing rapidly in years to come according to available market research results. However, new generation of spacecraft has to be developed first. Low acquisition and operational costs should characterize future commercial spaceplanes. They should be reusable and simple enough to enable serial production. One of possible solutions is a flying wing mothership and cranked delta wing suborbital spaceplane. In comparison to existing systems (White Knight + SpaceShipOne) application of flying wing configuration for mothership offers cleaner aerodynamics with lower friction and interference drag. Also cranked delta wing spaceplane should simplify the control system of space component, since leading edge vortex is capable to generate aerodynamic forces large enough for aerobraking. This vortex is a flow feature, typical for cranked delta wing at high angles of attack and can be controlled by a simple elevator. Both aerodynamic streamlining and mechanical simplification should allow creating less expensive system for suborbital tourism.

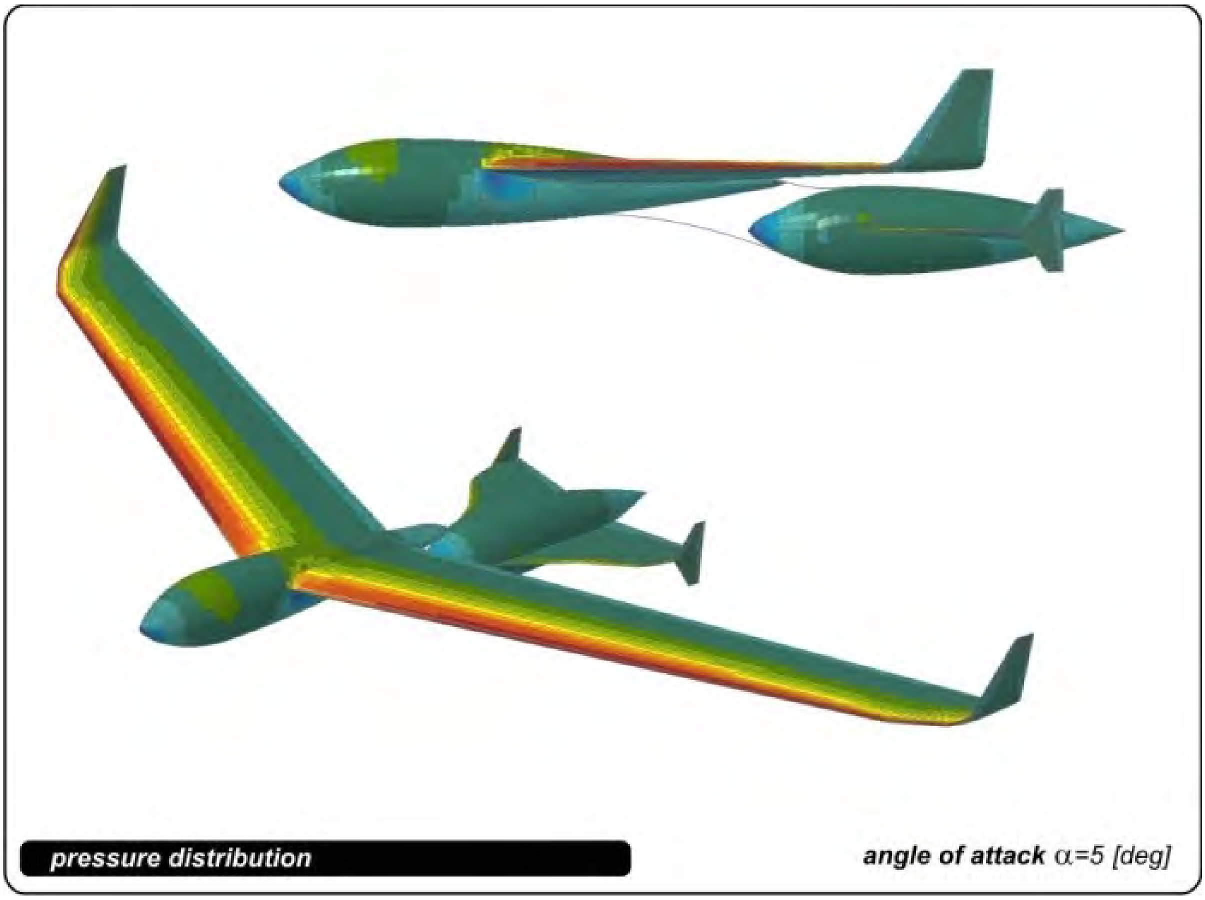

Fig.8 Pressure distribution on the mothership/spaceplane assembly at AoA=5º [deg] calculated with PANUKL package [14].

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Streszczenie

Artykuł prezentuje koncepcję prostego dwustopniowego samolotu kosmicznego przeznaczonego do turystyki suborbitalnej. Proponuje się zastosowanie układu latającego skrzydła dla nosiciela i pasmowego skrzydła delta dla rakietoplanu. Zakłada się przy tym, że rakietoplan będzie zawieszony sztywno za nosicielem, w taki sposób, że skrzydło rakietoplanu będzie mogło odgrywać rolę statecznika poziomego całego układu. Omówiono przewidywane zalety takiego zespołu, problemy jakie mogą wyniknąć w trakcie projektowania oraz podjęte i planowane prace badawcze.

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КОНЦЕПЦИЯ ДВУХСТУПЕНЧАТОГО, ТУРИСТСКОГО, СУБОРБИТАЛЬНОГО КОСМИЧЕСКОГО САМОЛЕТА.

Резюме

В статье представлена концепция простого двухступенчатого космческого самолета предназначенного для суборбитальной туристики. Предлагается применение компоновки летающего крыла для носителя и крыльев дельта с наплывом для ракетоплана. При этом предполагается, что ракетоплан будет жестко подвешиваться за носителем таким образом, что крыло ракетоплана сможет выполнять роль горизонтального стабилизатора целой системы. Обсуждаются предполагаемые преимущества такого комплекса, проблемы которые могут появиться в ходе проектирования, а также исследовательские работы, которые уже выполняются и предусмотрены в планах на будущее.