TANDEM WING CONFIGURATION
- A PERSONAL AIR TRANSPORT VEHICLE PROPOSAL

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Abstract. The paper presents a concept of tandem-wing configuration aircraft, that was a WUT (Warsaw University of Technology) proposal for the Personal Air Transport System-PATS. The project was designed in Warsaw University of Technology, within the frame of PPlane (Personal Plane) project sponsored by European Union under VII Framework. The paper contains the analysis of the general concept, advantages and disadvantages of tandem-wing aircraft configuration and possible application as a PATS vehicle

Keywords. personal aircraft, tandem wing, aerodynamics

1 Introduction

The main idea of the innovative PPlane project [1] is to build the high level, fully autonomous system which uses the quick air transport for passengers, goods and other. The system will consist of a dedicated network of PPort and will include its own Air Traffic Control (ATC) system. All vehicles are fully automated. The Ground pilots (placed in Remote Pilot Station - RPS) - the high level managers are able to intervene in case of not standard situations. They are not manually controlling the aircraft. PPlane Operation Centre – POC generates contracts request to the PPlane System Operation Management Centre (PSOMC). This centre manages and links the entire PPlane system and generating and managing the 4D contracts at the strategic level (before the flight). Conflict free 4D contracts are generated at a planetary scale, taking into account PPlane operators wishes and PPort capacity [2]. The described PPlane strategic planning is presented on the Figure 1.

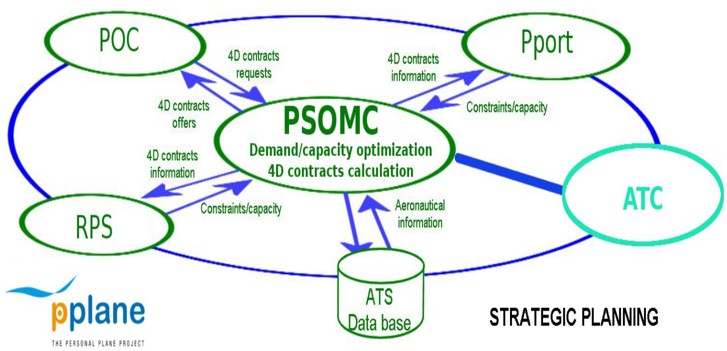

Figure 1: PPlane strategic planning [2] (Property of PPlane consortium)

The Figure 2 presents the scheme a of proposed network PPlane system. It would be optimized in accordance to the various requirements that will shape the 21st century, i.e. safety, capacity, cost effectiveness, global efficiency and environmental sustainability. Moreover, this system is assumed to be strongly connected with ground transport system and other air transport system. It is presented on the Figure 2.

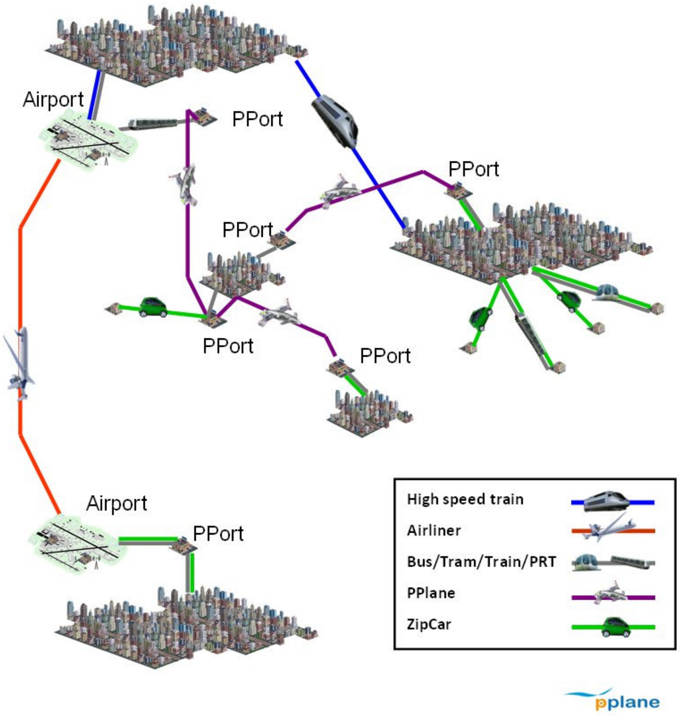

Figure 2: Scheme of PPlane network system [2] (Property of PPlane consortium)

One of the most important components of presented PPlane system is vehicle. It should meet the very high level of requirements. The choice of aircraft configuration has a huge influence on the whole system especially on the infrastructure of PPorts etc. The requirements describes aircraft capacity, the number of engines, aircraft performances, environmental impact (e.g. CO_2 emission), manufacturing and others.

It is likely that one single PPlane configuration will not satisfy all the needs for an individual public air vehicle mainly owing to cost effectiveness. It is anticipated that the PPlane fleet will be composed of 4 to 6 seat vehicles in rotary and fixed wing configuration. The main part of PPlane fleet will be consist of fixed wing aircraft configuration. The Rotary wing, vertical take off and landing vehicles (VTOL) will likely be reserved for special missions that require a high flexibility in the location where to land and take off such as for emergency medical evacuation.

A multi-engine configuration has been preferred for two main reasons. The main one is reliability and safety as it would be difficult to guarantee a satisfactory safety level with a single engine configuration. The second reason is performance. The multi engine configuration can give higher thrust and in consequence better performance.

In the frame of PPlane project some vehicles were proposed and rated using House of Quality process [3]. One of the candidate to PPlane vehicle is multipurpose tilt rotor in Tandem wing Configuration proposed by WUT [4]. The further consideration in the paper will concern on the advantages and drawbacks of tandem wing configuration aircraft as a PPlane vehicle. The description of the conceptual design of aircraft structure will be introduced. Moreover, the results of aerodynamic and performance calculation are presented.

2 Tandem wing configuration

The Tandem wing configuration is not new idea. The very big enthusiast of tandem wing was British designer George Herbert Miles [5]. A few tandem wing aircrafts designed by Miles was built, however they didn't meet similar pilots' enthusiasm. Till today also other aircraft designers have designed and built similar aircrafts, but only a few of them finished with success. A number of problems with stability caused, that the support of smart Automatic Flight Control System was necessary. Just nowadays such systems are available. The good examples of the tandem wing configuration aircrafts are Proteus and Quickie presented on the Figure 3 and Figure 4.

Figure 3: Proteus (Courtesy of Scaled Composites, LLC.)

Figure 4: Rutan's Quickie (Courtesy of Scaled Composites, LLC.)

However the most successful tandem wing configuration aircraft ever built is Rutan's Model 133 ATTT [6]. The idea was born in 1987. It was initiated and supported by DARPA project. It was assumed, The that maximum take-off weight (MTOW) will be equal to 25 tons (including 5 tons of payload). The computed maximum L/D ratio was about 20 and maximum lift coefficient was equal to 3.55. Only scaled technology demonstrator (0.62) was built. The project was very promised but it was cancelled due to not clear reasons.

Figure 5: Model 133 ATTT, (Courtesy of Scaled Composites, LLC.)

2.1 Tandem Wing Configuration – Pros and cons

The tandem wing configuration is highly unconventional. The mutual influence of the two pair of wings (forward and rear) causes that the configuration is strongly aerodynamically coupled. Nevertheless, it has a few advantages which can by utilized with success. The most important advantages are as follows:

- very low airspeed for take-off and landing, due to high lift devices on both wings;
- very mild stall characteristics;
- easier trimming due to CG travel;
- higher safety level during take-off and landing when 4 engines are in operation;• lower landing speed, lower community noise;

Unfortunately, this configuration has the drawbacks too. The main are listed below:

- higher risk for potential producer, no too much experience;
- higher induced drag;
- sophisticated Automatic Flight Control system AFCS is needed;
- a small weight increase is possible;

2.2 PPlane VTOL configuration – WUT proposal

The PPlane system needs the reliable vehicle. The WUT proposal assumes to utilize unconventional configuration, which has to connect advantages of tilt rotor and tandem wing configuration. Although this proposal was not selected as most promising vehicle for PPlane, the presented tandem wing is a very interesting configuration and analysis was continued. The conceptual view is presented on the Figure 6. The proposed configuration (tandem wing) allows to achieve high maximum lift coefficient. Moreover, tilt rotor concept allows to have vertical take-off and landing (VTOL) characteristics and realize the mission as classic aircraft as well.

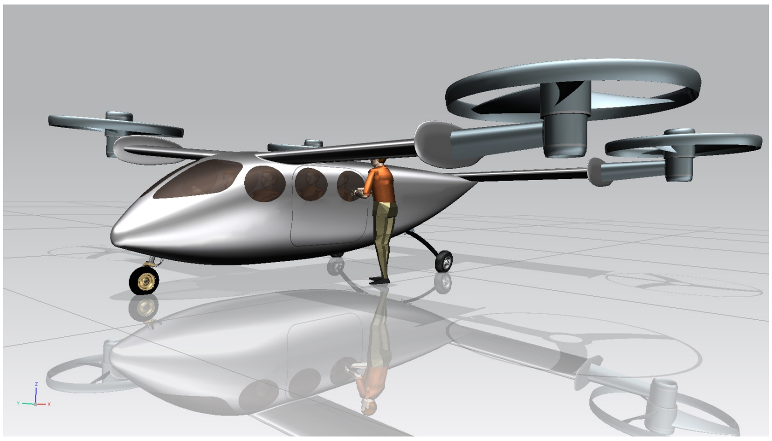

Figure 6 Tandem wing configuration

The maximum Take-off weight of presented aircraft is about 1600 kg, while empty weight is equal l200 kg. It is designed as four sits configuration with small payload. The total payload is assumed to 400 kg (4 persons + baggage). The basic geometry data of described aircraft is presented in the Table 1.

Table 1: The basic geometrical dimensions

Aircraft span	9,7 m
Wing span	5,4 m
Wing chord	1,0 m
Gross wing area	10,8 m^2
Aircraft length	7,0 m
Wings stagger	4,5 m
Rotor diameter	2,0 m

The aircraft is equipped with four electric engines located on the tip of each wing. The maximum power of one engine is equal to 150 kW, so total maximum available power of designed aircraft is about 600 kW. All engines are powered by electric energy stored in battery packs. The battery packs are mounted in the wings. To realize the assumed performance the total battery capacity should be equal 2000 Ah. This value of battery capacity is very huge, however technology in this area is now under very rapid development and taking into account, that aircraft is designed for the not close future (about 20 years), the expectation of such capacity of batteries could be rational and reasonable.

Two concepts of control were assumed. The first one assumes to change of the thrust value or direction of thrust by rotating the engines. It is necessary, particularly during the hover phase. This possibility is not presented in the paper. The second possibility assumes to use the classical control surfaces. To control the aircraft, two pairs of elevons (Figure 7) on the front and rear wing are applied. Both of them can be used to increase the lift coefficient and to trim or control in pitch channel (symmetrical case of deflection). Lateral control (roll) is realized by asymmetrical deflection of all control surfaces.

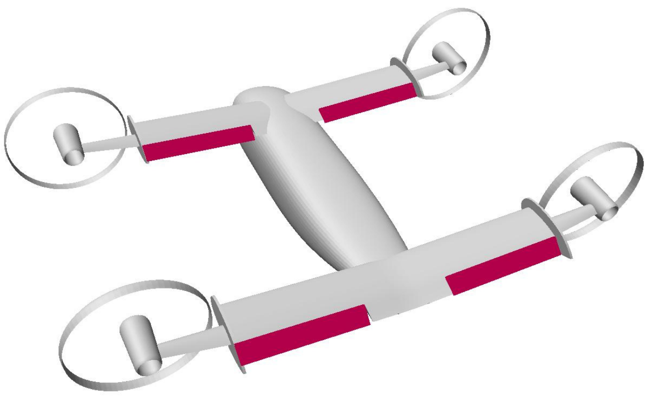

Figure 7: Aircraft control surfaces

All main elements of the structure will be manufactured from composite materials. The Figure 8 presents the concept of wing structure of the presented aircraft. The structures of the forward and the rear wing are the same. It should reduce manufacturing cost. The Figure 8 presents also the additional division on the ailerons and flaps. This modification was proposed during the development of project.

Figure 9 presents the proposal of landing gear. To reduce the weight and cost the fixed undercarriage were applied.

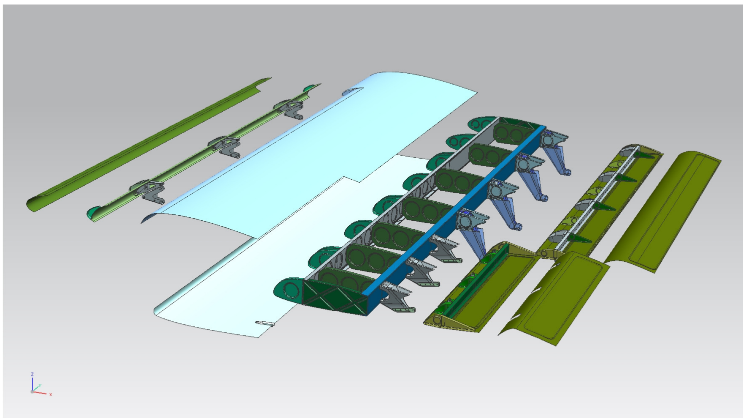

Figure 8: The concept of wing structure

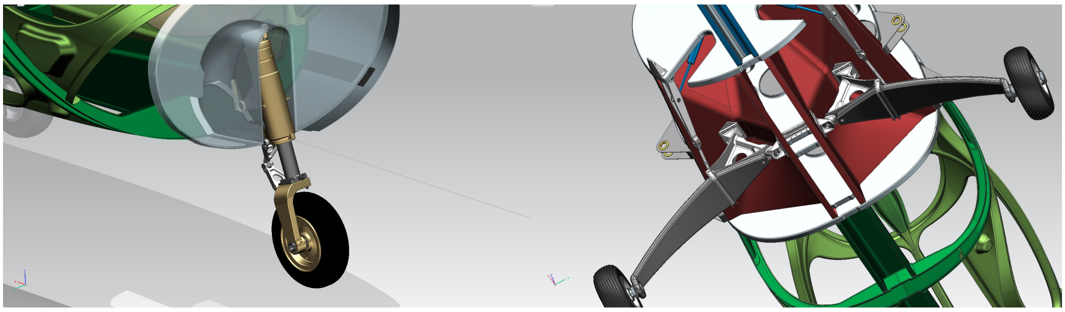

Figure 9: Landing gear – nose wheel (left), main undercarriage (right)

The view of cockpit arrangement concept is presented on the Figure 10. This is classic layout of seats for passengers configuration. For the special configuration a part of place will be replaced by special equipment e.g. stretcher, equipment to save life, etc..

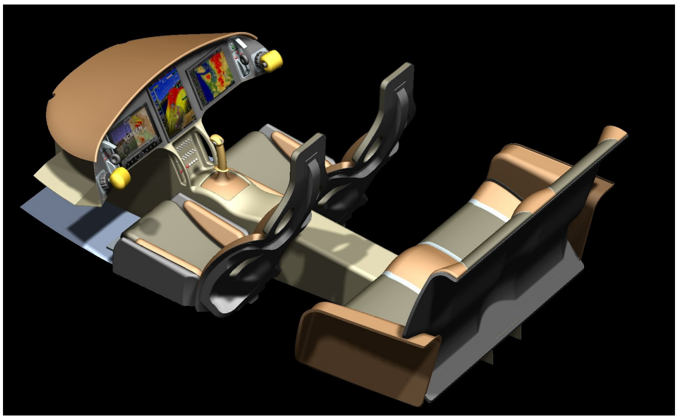

Figure 10 The view of inside arrangement – passengers configuration.

It was assumed, that the presented aircraft is able to realize the hover including vertical take-off and horizontal flight and take-off in the classic way from tarmac as well. The hover configuration means that all power of engines and thrust of rotors are used to give lift (and to satisfy longitudinal and lateral stability and trim). This configuration will be used only for special cases because a lot of energy is needed to realize this flight condition. This flight configuration could be necessary during transport injured people from dangerous place to the landing field near Hospital.

The Figure 11 presents the phase transition from hover to horizontal flight.

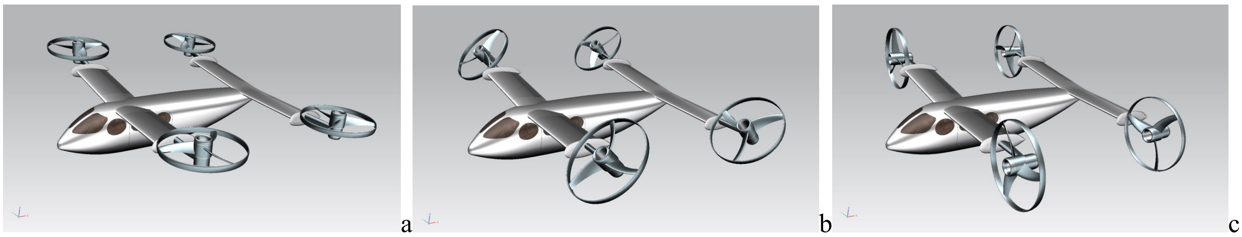

Figure 11: Transition from hover to horizontal flight

Two possible configuration of horizontal flight are considered for WUT tilt rotor. First one is called the Low Speed Configuration - LSC. It will be used for flight with low speed e.g. to patrol the roads. During low speed flight only engines on the front wing are in use and rotors give thrust parallel to longitudinal axis. The engines mounted on the rear wing may be used to support lift force and the longitudinal stability or may by turned off. The Figure 12 presents LSC.

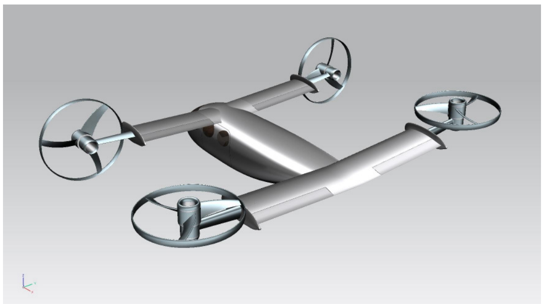

Figure 12: Low Speed Cruise configuration

The second flight configuration is High Speed Configuration HSC, which corresponds to horizontal flight presented on Figure 11c. All engines are working and all propeller axes are parallel to the longitudinal direction. The total power may be used to flight. The best performances will be achieved for this configuration.

The best configuration of aircraft (engines) can be chosen according to the mission profile and may be changed every time during the flight.

3 Aerodynamic calculation and performance

3.1 Introduction

The aerodynamic analysis was performed to obtain the basic aerodynamic characteristics, stability and control derivatives. The aerodynamic analysis was made for two configurations – low (LSC) and high (HSC) speed. Moreover, the aircraft performance (for both speed configuration) were computed. The aerodynamic analysis was made for low Mach number equal 0.2. Symmetrical and asymmetrical cases of flow were considered.

3.2 Numerical method

The Aerodynamic numerical calculation of presented models was performed by MGAERO Software [7]. This software package includes a set of programs to calculate flow around an aircraft. It contains three elements: pre-processor – program to generate a mesh, the main program – to calculate flow around an aircraft and postprocessor – to show and analyze a solutions

The numerical code of software bases on Euler model of flow [8]. A multigrid algorithm is usually used to reduce the computation time. In this case the multigrid scheme improves convergence of algorithm. MGAERO uses Euler system of equations to simulate the flow. The best way to solve this hyperbolic system of equations is V-cycle scheme of the multigrid method. MGAERO implements this algorithm by Λ-cycle scheme (inversed V-cycle).

3.3 Model

As it was mentioned before, aerodynamic analysis was performed for two models: low speed - LSC and high speed – HSC. Figure 13 presents models used in aerodynamic calculations. Moreover, both models were analyzed with deflected rear flaps.

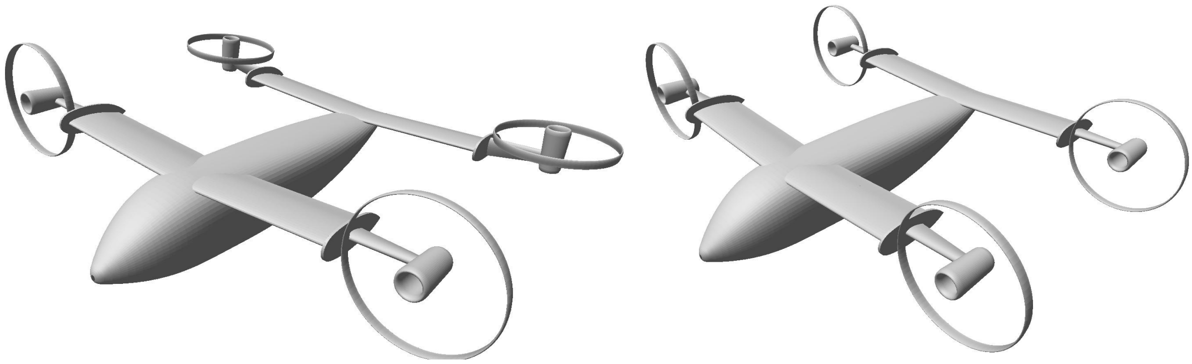

Figure 13: Models applied in aerodynamic analysis (LSC - left, HSC - right)

3.4 Results

The results of aerodynamic calculation are the pressure distributions. Both considered configurations were analyzed and C_P distribution was obtained. Figure 14 and Figure 15 presents the C_P distribution for symmetrical and asymmetrical case of flow. It is visible, that rear wing gives lesser lift force than front wing, for both configurations. This effect is caused by influence of front wing. Downwash behind front wing reduces local angle of attack. Figure 16 presents the C_P distribution of model with deflected flaps on the rear wing. Also in this case the effectiveness of the control surfaces is reduced by influence of the front wing. The visualization of flow around forward and rear wing were presented on the Figure 17. The flow is visualized by off-body streamlines.

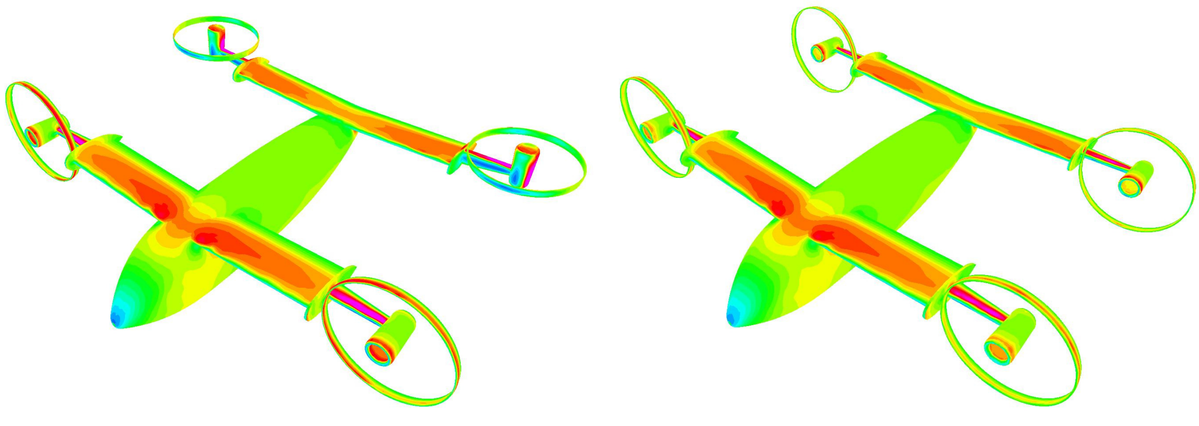

Figure 14: C_P distribution - the Low Speed Cruise configuration (left)
and the High Speed Aircraft Configuration (right) for angle of attack $\alpha = 0$ [deg].

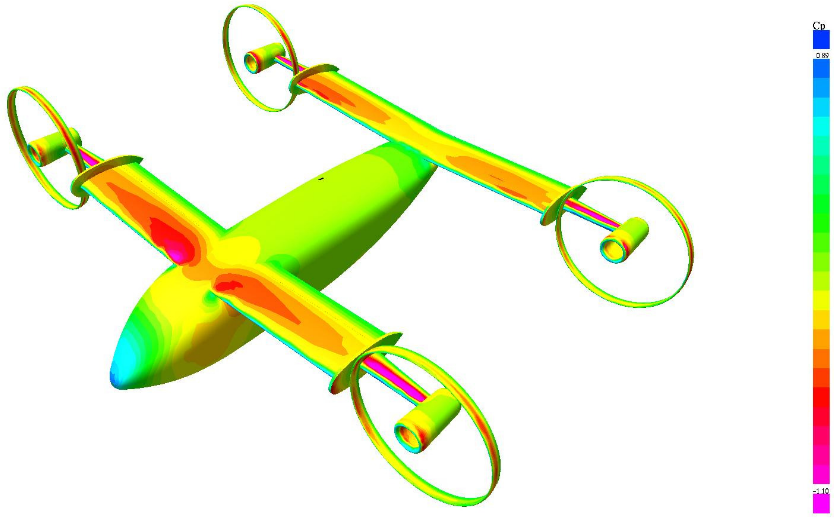

Figure 15: Asymmetric flow around High Speed Configuration for sideslip angle β=4[deg]

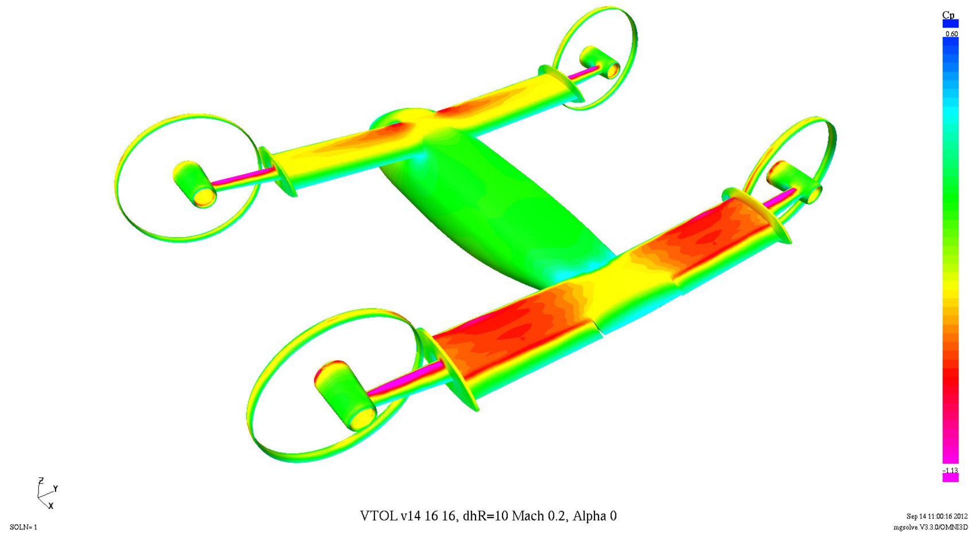

Figure 16: Cp distribution on aircraft with deflected rear flaps δ_H=25[deg] (symmetrical case).

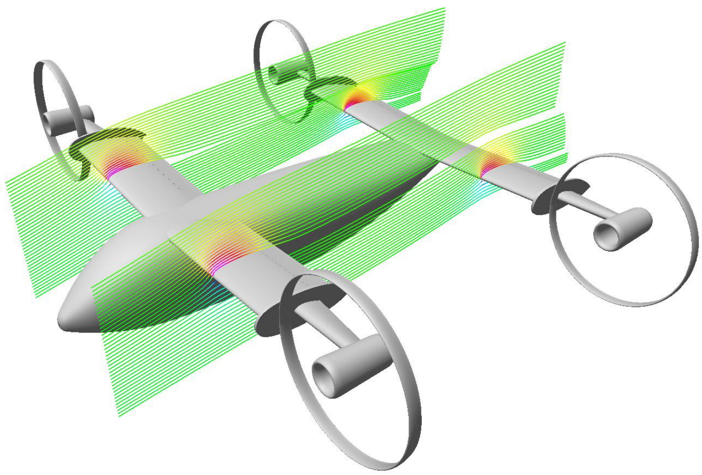

Figure 17: Visualization of flow around Tandem wing configuration for angle of attack α=12 [deg]

3.4.1 Aerodynamic Characteristics:

A number of flow cases were computed. It allows to obtain basic aerodynamic characteristics. The results for both considered configuration were compared.

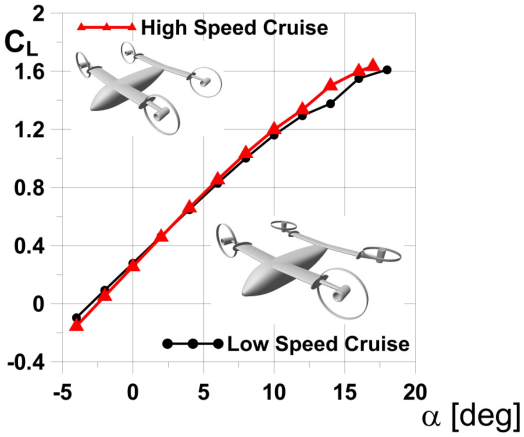

Figure 18: Lift coefficient versus angle of attack for two cases: Low and High Speed configuration

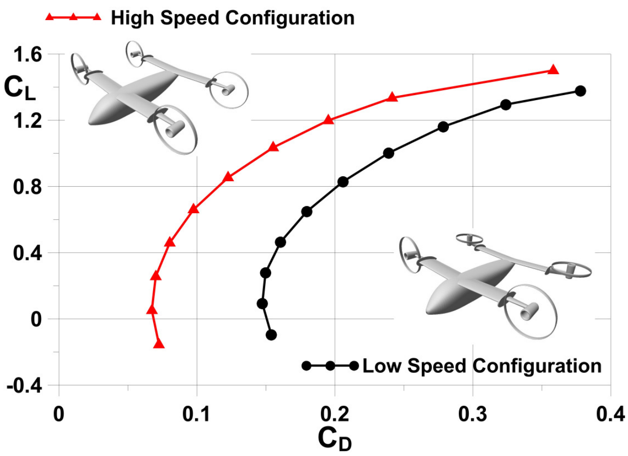

Figure 19: Drag polar for two cases: Low and High Speed configuration

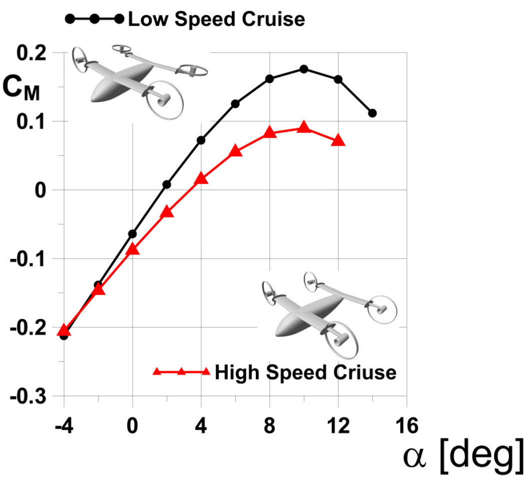

Figure 20: Pitching moment coefficient versus angle of attack for two cases: Low and High Speed configuration

The main differences in aerodynamic characteristics between two presented models comes from the configuration of engines. For the both cases the lift force is not changed (Figure 18). The rear pair of engines for the LSC increases significantly the drag coefficient and pitching moment (Figure 19 & Figure 20). The drag of LSC is higher than in HSC case. It is connected with direction of rear engines axes perpendicular to the flow.

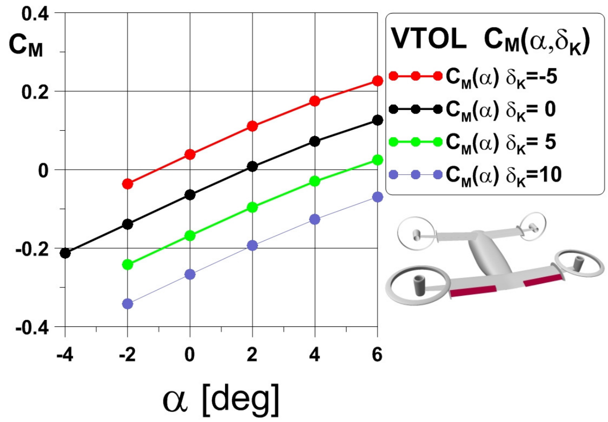

Figure 21: Equilibrium state for Low speed aircraft configuration

The analysis of equilibrium state shows, that the deflection angle of elevator, necessary to perform trim is not big for wide range of angle of attack. Therefore, the efficiency of control surfaces satisfies the control requirements.

3.4.2 Performance

The basic performance including flight envelope, range and endurance, were calculated for both configurations to test if they meet project assumptions and if they are satisfying. The figures below presents results of performance analysis obtained for maximum take-off weight and with assumption, that engine's power doesn't change versus altitude.

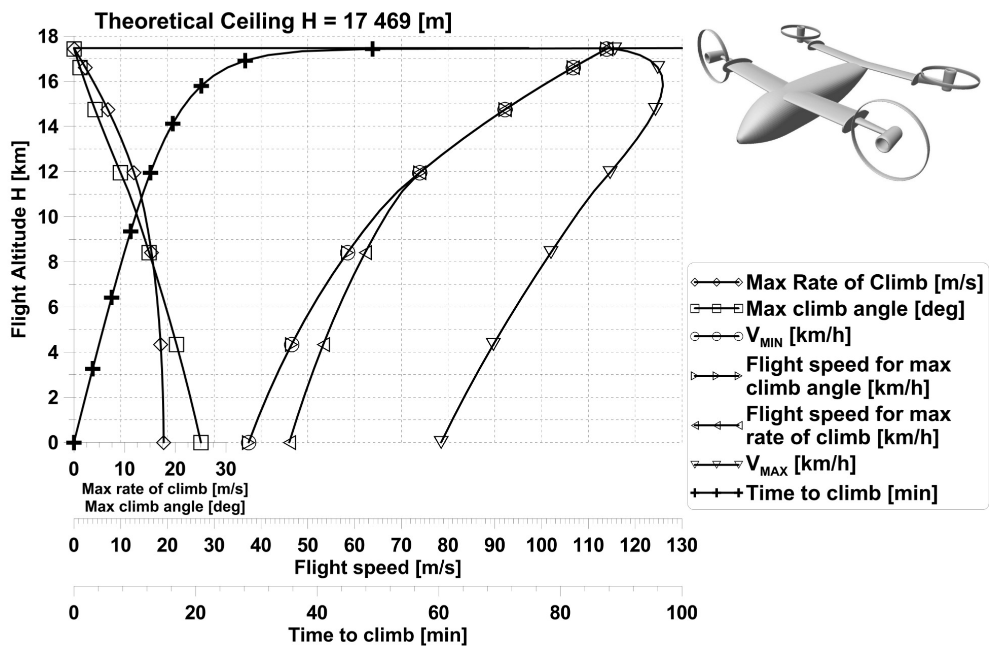

Figure 22: Flight envelope for LSC (m=1600 kg)

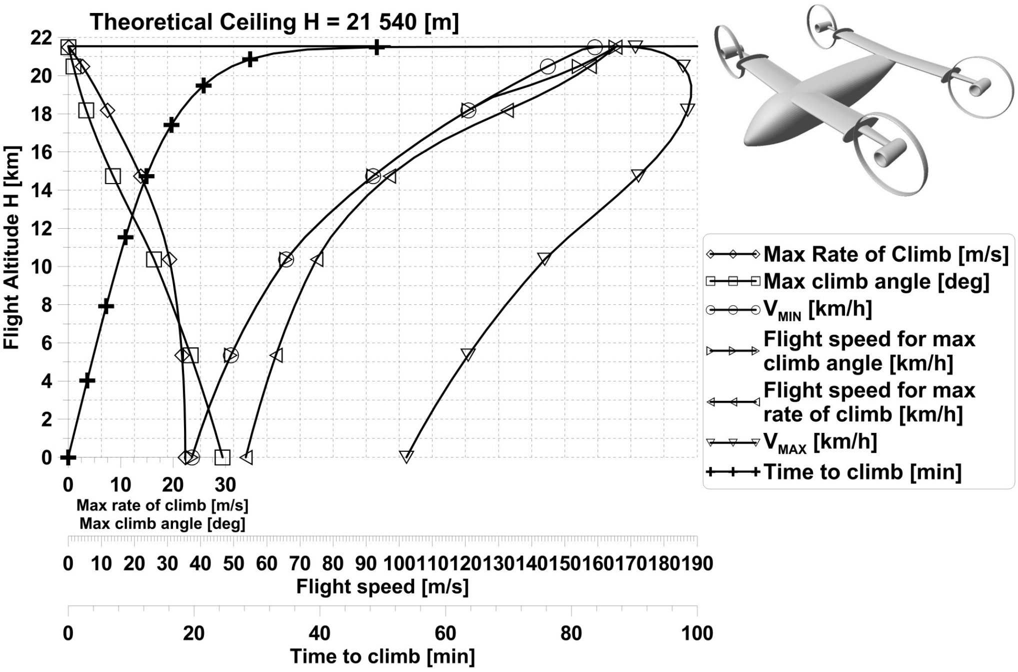

Figure 23 Flight envelope for HSC (m=1600 kg)

The computed performance characteristics - the high maximum airspeed, ceiling and rate of climb are accordant to assumed values

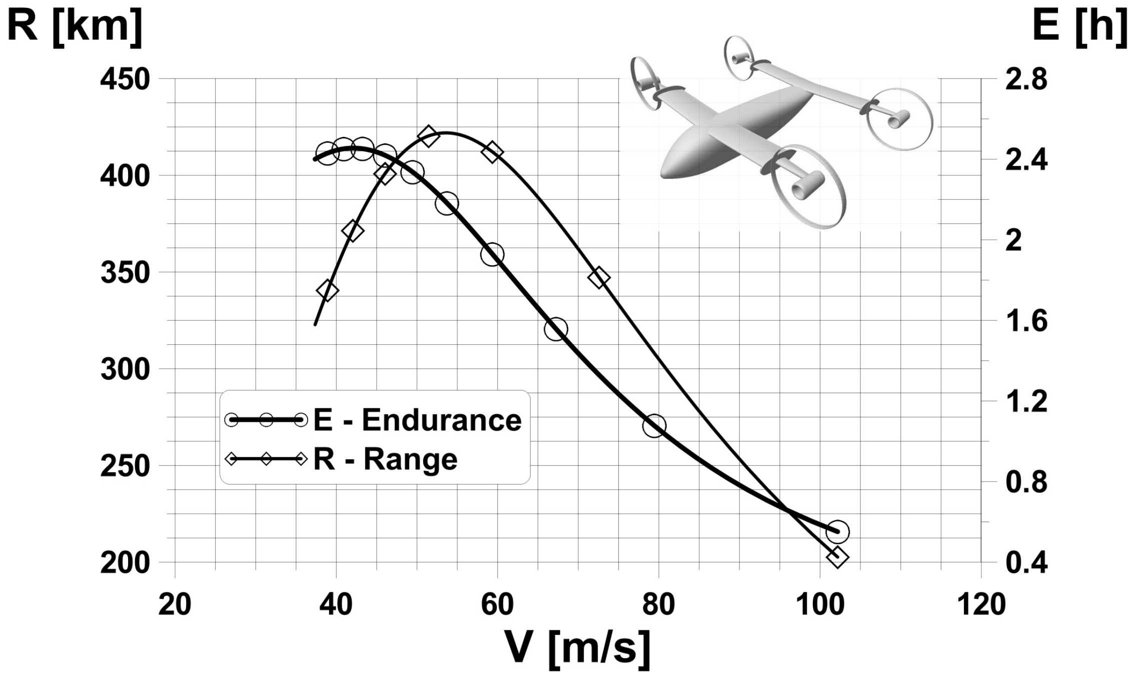

Figure 24: Range and Endurance for HSC (H=0[m], V=const., η_{prop}=0.8, m=1600 kg)

It was assumed that aircraft will be powered by electric engines only. Therefore to calculate the Range and endurance it was assumed that power doesn’t change versus altitude. All battery packs has a capacity equal to 2000 Ah. The Endurance and Range were calculated only for HSC.

4 Additional applications of PPlane VTOL vehicle

The PPlane system is designed (as a Personal Transport system) to fly passengers from one point to another – e.g. from one city to another. This is the main goal of the PPlane system. Within the frame of the PPlane system a network of PPorts is assumed for whole continent. All these assumptions should allow easy transportation of passengers.

In order to increase the overall attractiveness and usefulness of system and also possibly to gain more easily social acceptance, the overall PPlane system capabilities can be extended and can offer some additional applications. The following list presents the possible solutions of additional utilization of the PPlane system, which will be taken into account:

- Light freight shipment – to transport deliverers, goods, post etc.
- Medical services – to transport patients, organic implants, medicines
- Special purpose - Police forces, Fire brigades, Air ambulance

Figure 25 and Figure 26 present the conceptual view of possible use of Air ambulance and Police force.

Figure 25: Conceptual view of Air ambulance use

Figure 26 Police force to monitor the traffic.

The VTOL feature allows to land and take-off almost everywhere. It is very useful especially for air-ambulance. The possibility to obtain the high lift force by vehicle allows to reduce the minimal speed. This feature will be useful for police force for example in traffic control case.

5 Conclusions

The PPlane system needs reliable vehicles to proper operation. The presented vehicle should satisfy all established requirements. The proposal of WUT includes a multipurpose air vehicle with not classic configuration. The unconventional configuration gives VTOL and STOL functionality, which will be a good solution for PPlane vehicle. These features allow to reduce the take-off and landing distance, which could be very useful, especially in case of Air ambulance.

Acknowledgment

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