LESSONS LEARNT FROM SAMONIT PROGRAM - A LONG ENDURANCE, SURVEILLANCE, LIGHT UAV

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Abstract. This paper is focused on design, optimisation, dynamic research and testing of UAV system for long endurance border surveillance having high-level requirements in term of reliability, safety and low cost. Comparisons between 3 configurations are analysed to show expected advantages and possible drawbacks. A special attention was devoted to trimming, stability, control and take-off of tailless configuration. After a theoretical analysis and optimisation a number of free flight tests were performed and most of numerical predictions and theoretically prepared procedures were fully confirmed. These free flight tests were focused on comparisons between configurations characteristics, manual and automated flight control modes, post-flight inspection of selected structure parts due to load spectrum, comparison between measured parameters and their simulated equivalents, techniques of take-off and landing and many others.

Keywords. Aircraft design, Manufacturing, Flight testing, Unmanned Aerial Systems.

1 Introduction

SAMONIT is an acronym of a national Polish project, financially supported by Ministry of Science and Higher Education. The main goal of the activity within this project was to design an UAV system for long endurance border surveillance and monitoring having high level requirements in term of reliability and safety and being affordable for potential users in terms of cost [1-5]. The design process was treated as an interdisciplinary approach, and included a selection of thick laminar wing section, aerodynamic optimisation of swept wing, stability analysis, weight balance, structural and flutter analysis, many on-board redundant systems, reliability and maintainability analysis, safety improvement, cost and performance optimisation [6-8]. It was developed by a group researchers and designers having a very wide experience gained in various former projects, both industrial and academic and also involved in many international, mainly European V, VI and VII FP projects [9-10].

2 Design and configurations

This paper is focused on design, optimisation, dynamic research and testing of a mini UAS called SAMONIT [11-17]. A baseline configuration (straight wing with V-tailplane placed behind the main wing) is used as a reference for more advanced layouts, especially swept tailless configuration, considered as the goal configuration in two versions – with pulling and pushing propellers. Comparisons between these 3 configurations based on free flight experience, are analysed to show expected advantages and possible drawbacks. Flight-testing has been started in the fall of 2009 and it is still in progress, both in manual and automated modes. All 3 prototype airplanes flew more than 10 hours [18-19] and delivered a lot of interested data of high importance for performance, safety, flight control, maintenance, flight preparation time, repair after small damages, sensitivity to weather conditions etc. Figures and photos attached bellow (Fig. 1-8) show some important details and phases of the project.

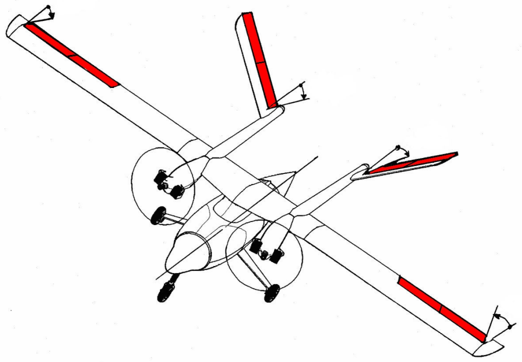

Fig. 1 SAMONIT in classical, tailed, tractor configuration. Flight control surfaces are marked in red colour

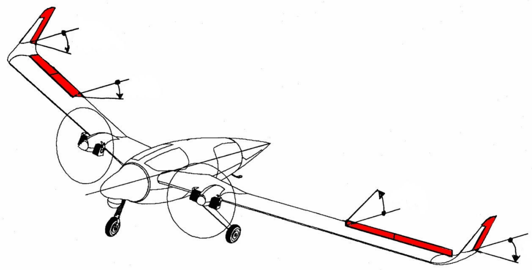

Fig. 2 SAMONIT in tailless, tractor configuration. Flight control surfaces are marked in red colour

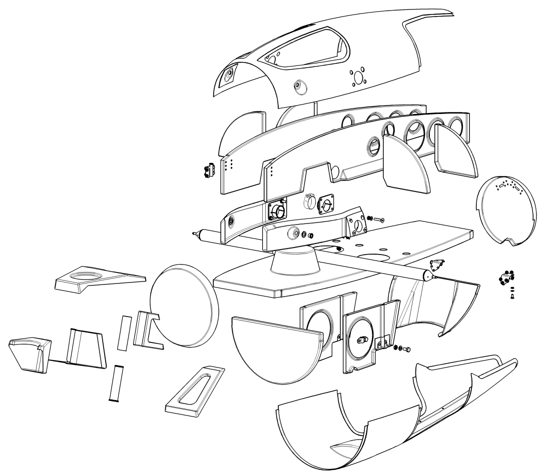

Fig. 3. Structure of the container for main on-board systems and sensors

Fig. 4 SAMONIT in tailless configuration with pushing propellers

Fig. 5 Airplane in tailed, tractor configuration. Flight test with autopilot in the loop. Daylight camera (FLIR) visible at the nose of the container. Sochaczew, April 2011.

Fig. 6 Airplane in tailless, tractor configuration. Flight test in manual mode. Daylight camera visible at the nose of the container. Sochaczew, September 2010.

Fig. 7 Ground preparation for flight-testing. Tailless, pushing propeller airplane on the left, the classical V-tail configuration on the right and Ground Control Station (also used for transport of airplane parts) behind. Minsk Mazowiecki, July 2011.

Fig. 8 Tailless, pushing propeller airplane after flight show, just before touchdown. Minsk Mazowiecki, July 2011.

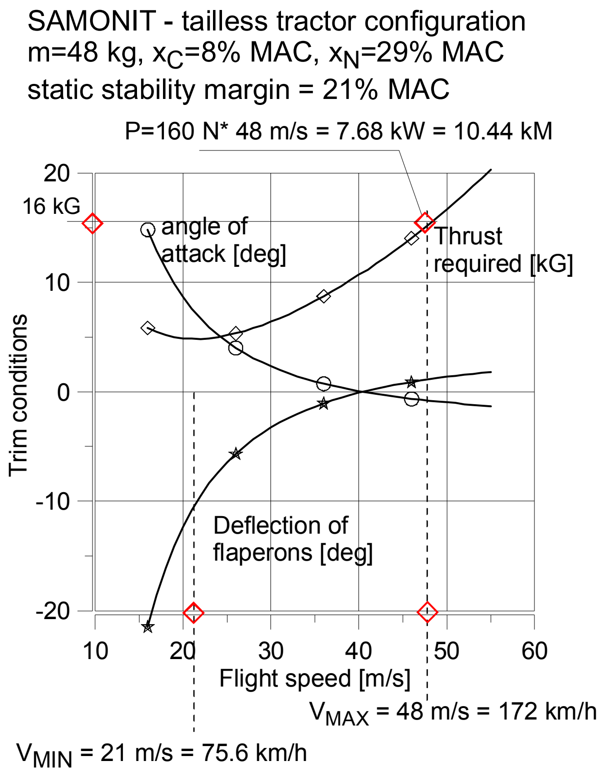

Fig. 9 Parameters in trim – thrust required, angle of attack and flaperons deflections

3 Trimming, control and stability

Trimming, control and stability were analysed through the whole time of the project since its kick-off. A special attention was devoted to flying wing configurations. Team of designers were conscious that successful solution of challenges of stability and controllability can decide about the dynamic properties of the vehicle and either a success or failure of the project. Advantages, drawbacks and risk associated with tailless configuration are well known for decades. Selected problems must be treated with special care. These include optimal centre gravity location for proper static stability margin, limitation of flaperons' hinge moments, ensuring that the flaperons and rudders are efficient and robust in regular flights and in hazardous states (for example if one engine failed), achieving the dynamically stable platform and many others. In aviation history there were not too many very successful tailless aircraft. VeryEasy designed by Burt Rutan and B2 by Northrop Grumman are rather exceptions among manned airplanes, also the KillerBee by Swift Engineering among unmanned versions are good examples of successful designs. However, it is very difficult to find in open sources any aerodynamic characteristics of tailless aircraft, their stability derivatives, times to double and similar dynamic properties. So, when working on SAMONIT, one had to analyze the stability and manoeuvrability in the so-called full cycle, i.e. since conceptual project, through Wind Tunnel tests till free flight tests. During the critical design review, organized after the number of flight tests, the final configuration was approved and accepted as the test-bad for more advanced free flight testing.

All numerical analyses were based on aerodynamic characteristics and static stability derivatives measured for full scale platform in a large wind tunnel Φ5 at the Institute of Aviation. The so-called dynamic stability derivatives (lp, l_r, n_p, n_r,) were computed using CFD software and also assessed using ESDU sheets. Trim parameters and stability characteristics are shown at figures 9-30 and discussed below. At Fig.9 trim parameters – i.e. thrust required for steady horizontal flight, angle of attack and flaperons deflection – all versus flight speed - are presented. These results were computed for aircraft weight equal to 48 kg, centre of gravity located at 8% of MAC, what means that for neutral point of static stability located at 29% of MAC and measured from MAC LE it gives the stability margin equal to 21% of MAC. At Fig. 9 two characteristic speeds are distinguished – stall speed corresponding to $C_{L,max}$=1.4 for clean configuration and max speed corresponding to the maximum available power equal to 10,5 horsepowers. Stall speed and maximum speed are equal to 21 m/s (75 km/h) and 48 m/s (172 km/h), respectively. Curves of required thrust, angle of attach and flaperons deflection are typical. A possible correction might include a vertical shift of the flaperons deflection curve in order to ensure the flaperon deflection corresponding to loiter speed is equal to zero (what means that loiter speed gives the best aerodynamic efficiency and the minimum fuel consumption). This effect could be achieved by redesign of the wing, however it is not planed at this stage of the project.

4 In-flight testing

Signals registered in datalogs were used to compute damping coefficients and frequency of various modes of vibrations (Short Period, Phugoid, Dutch Roll and Spiral). Fig.10 shows comparison between the measured and simulated (computed) damping and frequency coefficients of Short Period mode. Measured data correspond to flight speed equal to 30 m/s and demonstrates an excellent convergence of both methods.

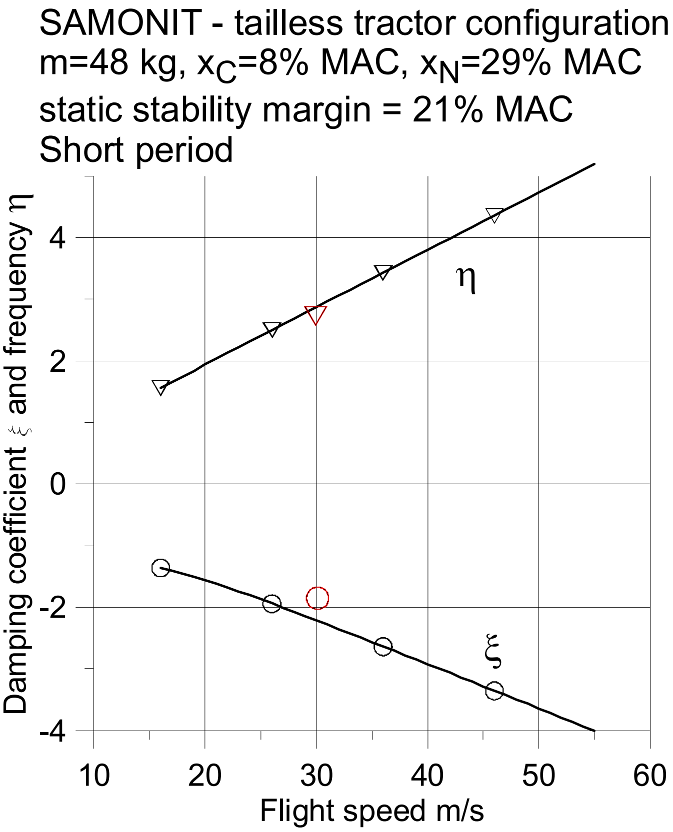

Fig. 10 Damping coefficients and frequency – measured in flight (red triangle and circle) and numerically computed (black solid lines)

Fig.11 shows aircraft flight path for manual and automated flight control mode. In both cases the assumed flight trajectory was just classical „eight manoeuvre“, without any excessive normal acceleration. It shows that signal analysis is especially important when UAV is manually controlled because it create much extensive fatigue loadings than in case of automatic control.

Fig. 11 SAMONIT pathflight, automated (lower right) and manual (upper left) control mode

5 Conclusion

The most important conclusions could be summarised as follows:

(1) V-tail enables a relatively easy parachute deployment in emergency with a minimal risk of getting into propeller. However, longitudinal and lateral control is coupled what can involve difficulties, especially at higher angles of attacks; (2) V-tail configuration with 2 isolated, laterally shifted segments decreases its anti-spin characteristics; (3) Take-off minimum speed for tailless configuration is higher than for the classical one. Moreover, control during take-off must be more precise for tailless configuration than for the tailed one because flaperons deflection influence both on pitching moment and lift. If trailing edges of flaperons go up, then pitching moments increase and lift decrease what can result in airplane stall if the airplane speed is too small. In the case of tailed configuration the lift and pitching moment are controlled independently – lift by flaps and pitching moment by elevator deflections; (4) Tailless configuration offers much higher maximum flight speed and the so-called "wetted aspect ratio". So, for the long endurance missions this configuration offers better performance; (5) Tailless pushing configuration has even higher maximum speed than the corresponding tractor configuration. It is because of wider area of natural laminar flow over the wing in the neighbourhood propellers and nacelles. The corresponding maximum speeds achieved during flight tests were 39 m/s, 45 m/s and 53 m/s for tailed, tailless tractor and tailless pushing configuration, respectively; (6) Rudders located on winglets in tailless tractor configuration are effective in most of manoeuvres. However, if one engine is inoperative the rudders are too small for trimming. Pushing configuration with rudder located on vertical tail attached to the central container is fully effective irrespectively on flight regime; (7) Both tailless configurations offer better access to all on-board systems and sensors. Also, time of assembling and de-assembling is shorter in the case of flying wing configuration;

(2) SAMONIT program can be treated as technology demonstrator and used as a starting point for MALE class military UAS;

(3) There was found that maximum load factor at manual flight reached the value of 5.5 (without any aerobatics figures) and 2.5 in automatic controlled flight, respectively;

(4) Selected steady state and dynamic characteristics measured in free flight are fully consistent with results of numerical simulations.

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