Experimental and computational investigations aimed at improving stability and controllability of a “flying wing” aircraft configuration

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Abstract
Investigated is a possibility of improving the characteristics of directional stability and longitudinal and directional controllability of a “flying wing” aircraft configuration by virtue of installation of a twin tail unit with fins inclined to the plane of symmetry at angle of about 50 degrees and with rudders mounted on the trailing edge. Experiment conducted on a research test model at low subsonic speed in the TsAGI T-102 wind tunnel showed that the tail unit of such type makes it possible to provide for directional static stability of the configuration, and tail rudders are effective controls both in pitch and yaw in a wide range of angles of attack. Numerical investigation based on the RANS solution showed the potentials of improving the aerodynamic characteristics of the configuration at the full scale Reynolds numbers.

1. Introduction

In comparison with an aircraft of conventional aerodynamic scheme an aircraft of a “flying wing” configuration may have considerably lower takeoff weight and fuel consumption for the same design mission (the number of passengers and range) [1]. This potential advantages from an aerodynamics point of view stem from the fact that such an aircraft has higher lift-to-drag ratio due to lower friction drag (the wetted area is lower) and lower induced drag (spanwise distribution of the velocity circulation doesn’t have a gap at the central part and is more close to the optimum one). However putting this advantages into practice will entail a lot of difficulties [2, 3, 4]: a configuration doesn’t have inherent longitudinal and directional stability, pitch and yaw controls (elevons and split ailerons) have short moment arms, stability and controllability characteristics essentially depend on the angle-of-attack, use of landing high lift wing devices is impossible because of inability to trim pitch moment, to provide for artificial longitudinal and directional stability by virtue of control system control surfaces with high control rate (and hence high energy consumption) are needed. All these arguments point in favor of inclusion into the flying wing configuration an element which could perform functions of both vertical tail with rudder and horizontal tail with elevator. Presented in the paper as such an element is twin tail unit with fins inclined to the plane of symmetry of the configuration at an angle of about 50 deg. The idea has been verified experimentally on the simplified research aircraft model at low subsonic speed. It has been shown that in the wide range of angles of attack that tail unit provide for yaw static stability, and rudders mounted on the fins are more effective than elevons in pitch control end substantially more effective than drag ailerons in yaw control. Numerical investigation of the configuration (RANS, ANSYS CFX with SST turbulence model) showed that local static longitudinal instability of the model, obtained in the wind tunnel experiment at angles of attack above 10 degrees and caused by flow stall development on the outer wing panel, may not appear in full scale conditions up to angles of attack of 16 degrees.

2. The model and test conditions

The CAD representation of a general view of the aircraft test model is shown in figure 1. The model has a span of 2.5 m, a plan view area of 0.948 m, a leading edge sweep angle of 30 degrees. The planview aspect ratio is equal to 6.6.
Manufactured on the left and right wing panels have been elevons with relative area (both left and right sections) of 0.036 and deflection angle range from –30 (trailing edge up) to +40 (trailing edge down) degrees. Split aileron has

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been manufactured on the left wing panel with relative area (left section only) of 0.0092 and slit angle up to 120 degrees.
A twin tail has been installed at the central aft part of the model with fins inclined to the symmetry plane of the model at angle of 50 degrees. The relative area of two fins is equal to 0.115. Manufactured on the fins have been rudders with relative area of 0.383 and deflection angle range from –30 (trailing edge up) to +30 (trailing edge down).
The model has been made without inlets, internal ducts and nozzles.

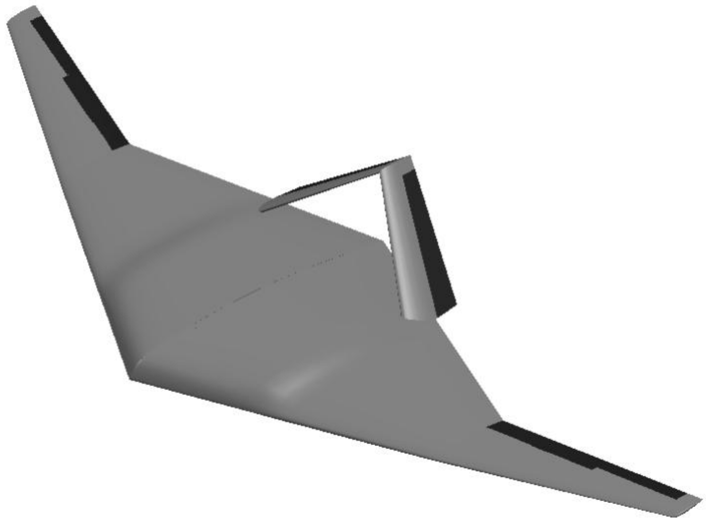

Figure 1: CAD representation of the aircraft test model

The experiment was carried out in the TsAGI T-102 wind tunnel. The TsAGI T-102 is a low speed (up to 60 m/s) wind tunnel with closed contour and open test section of elliptical cross section with dimensions 4×2.33 m^2.
The model was tested on a shaped band support of the six-component electromechanical balance AB-102 and was fastened in the tunnel (overturned) position at three points. The two forward points, which are the rotation centres with respect to angle-of-attack, are separated from each other at a distance of 1 m. The rear one is separated from the rotation axis at a distance of 0.6 m.
The angle-of-attack was counted from the fuselage horizontal reference plane. The angles of deflection of the controls was measured in the planes normal to the corresponding rotation axes.
The tests were carried out at the free stream velocity of 50 m/s in the of angle-of-attack range from -4 to 24 deg. and angle of sidesleep range from -16 to 16 deg. The corresponding Reynolds (based on the planform mean aerodynamic chord) and Mach numbers values equal to $1.83 \cdot 10^6$ and 0.15, respectively.
The aerodynamic moments were counted with respect to the conventional centre of mass located on the fuselage horizontal reference plane at a distance of 0.3668 m from the model nose, which corresponds to the one quarter of the mean aerodynamic chord.
The readings of the experiment were corrected for drag and moment of the support system, stream boundaries, flow washes, and wind tunnel blocking.
In calculating the coefficients of the model aerodynamic forces dimensional values were referenced to the dynamic pressure and the model planform area (0.948 m^2), in calculating the pitching moment coefficient – additionally to the planform mean aerodynamic chord (0.526 m), and in calculating the roll and yaw moment coefficients – additionally to the wing span (2.5 m).

3. The effect of the tail unit installation on the aerodynamic characteristics of the model

Experiment showed that installation on the model of the tail unit resulted in some increase in the drag coefficient at zero lift (from 0.0078 to 0.0094). The aerodynamic centre of the model shifted approximately 2% of the mean aerodynamic chord rearward, resulting in the enhanced longitudinal static stability margin of the model, and directional static stability of the model was provided for: the derivative of the yaw moment coefficient with respect to the sidesleep angle for the model with the tail unit equals –0.00044, whereas the model without the tail is practically neutral (figure 2).

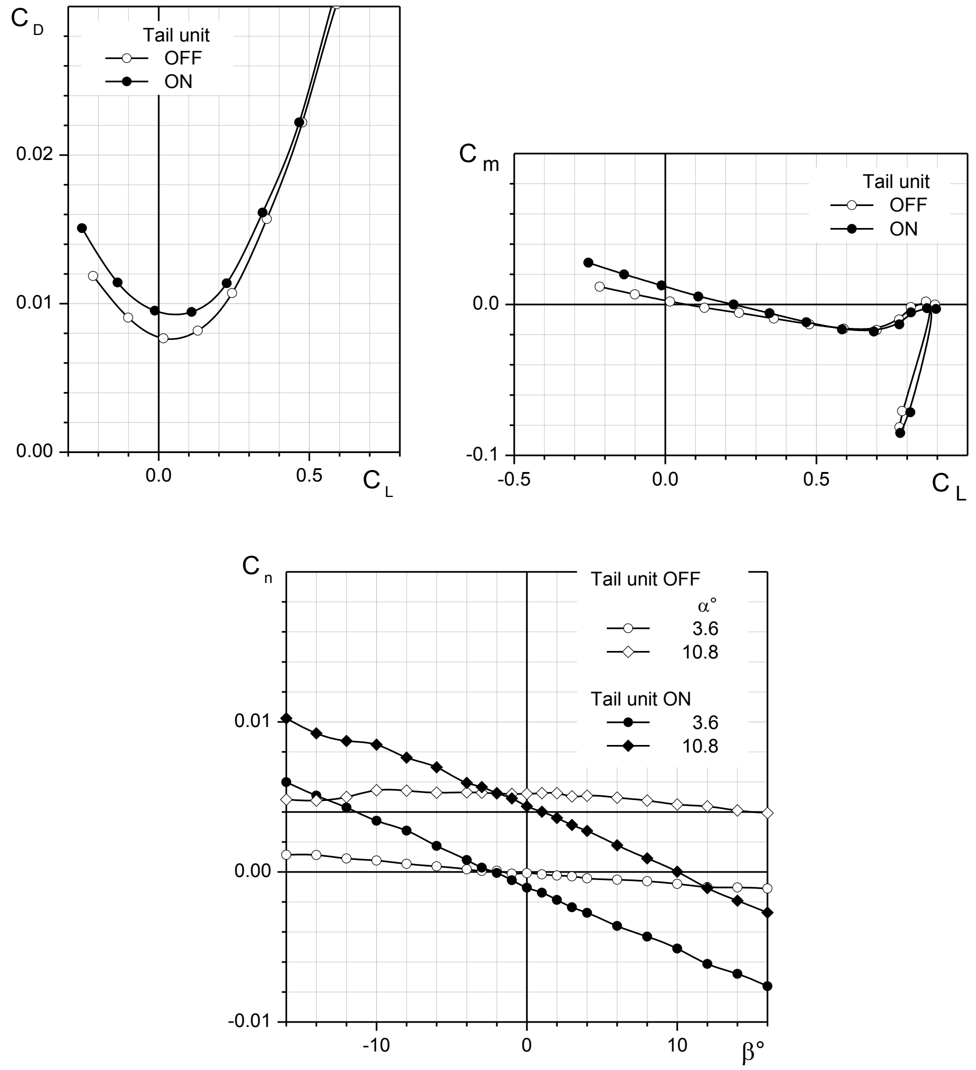

Figure 2: The effect of tail unit installation on the drag polar and the longitudinal and lateral static stability of the model

4. The effectiveness of the tail unit rudders

4.1 The effectiveness of the tail unit rudders in yaw control

In comparison with the split ailerons the tail unit rudders are more effective in yaw control. The increments of the yaw moment coefficient due to rudders deflection increase with angle of deflection in nearly linear law and remain practically constant in varying the angle-of-attack from –4 to 18 deg. On the contrary, the increments of the yaw moment coefficient due to aileron splitting increase with angle of splitting in nearly quadratic law and abruptly diminish at angles of attack above 10 deg. (figure 3) owing to flow separation from the outer wing panels.
Moreover, creating the control yaw moment by virtue of tail unit rudders deflection is accompanied by several times smaller increments in the drag coefficient than when the moment is created by splitting the aileron (figure 4).

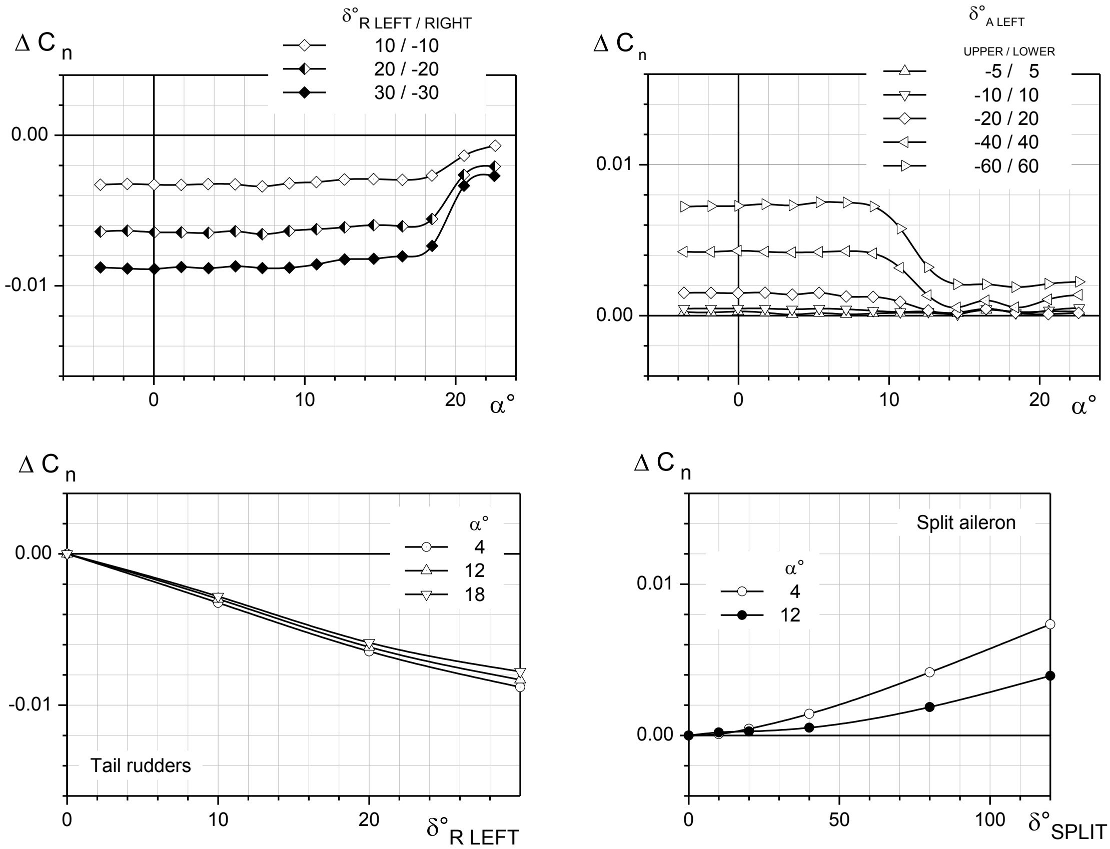

Figure 3: The increments of the yaw moment coefficient due to deflection of the tail unit control and splitting the aileron on the left wing panel

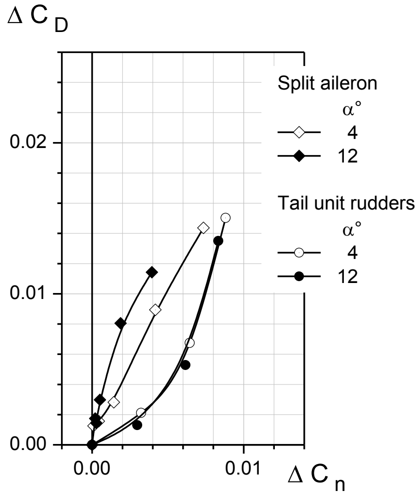

Figure 4: The increments of the model drag coefficient due to creating yaw moment by deflecting the tail unit rudders and by splitting the aileron on the wing left panel

4.2 The effectiveness of the tail unit rudders in pitch control

The tail unit rudders are also shown to be an effective longitudinal controls: their effectiveness is practically invariable in the angle of attack range from –4 to 18°, whereas the effectiveness of the elevons diminishes starting from angle of attack of about 10 deg. (figure 5) owing to flow separation from the outer wing panels.
The tail unit rudders have nearly twice longer longitudinal moment arm in comparison with the elevons (figure 6).

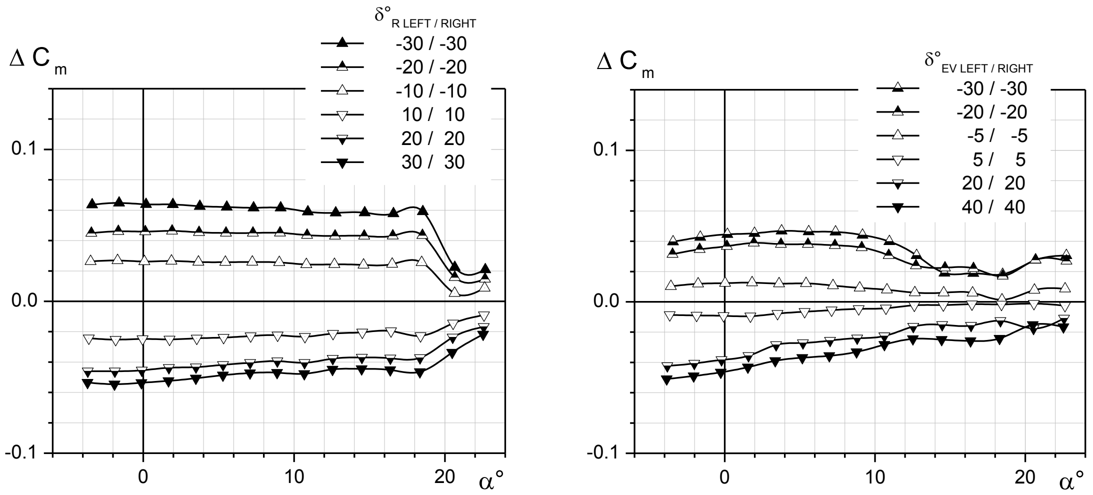

Figure 5: The increments of the pitch moment coefficient due to symmetrical deflection of the tail unit rudders and the elevons on the left and right outer wing panels

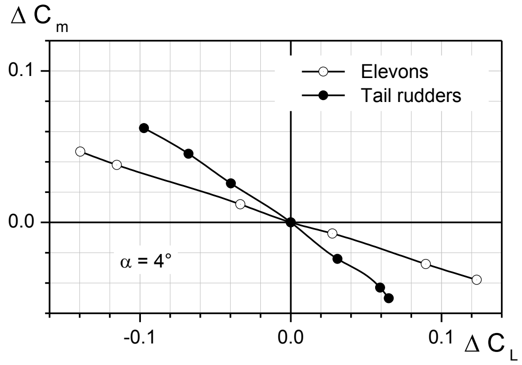

Figure 6: Comparison of the longitudinal effectiveness of the tail rudders and the elevons

5. The effect of the Reynolds number

Numerical investigation of the configuration (RANS, ANSYS CFX with SST turbulence model) showed that local static longitudinal instability of the model, obtained in the wind tunnel experiment at angles of attack above 10 degrees and caused by flow stall development on the outer wing panel, may not appear in full scale conditions up to angles of attack of 16 degrees (figure 7).

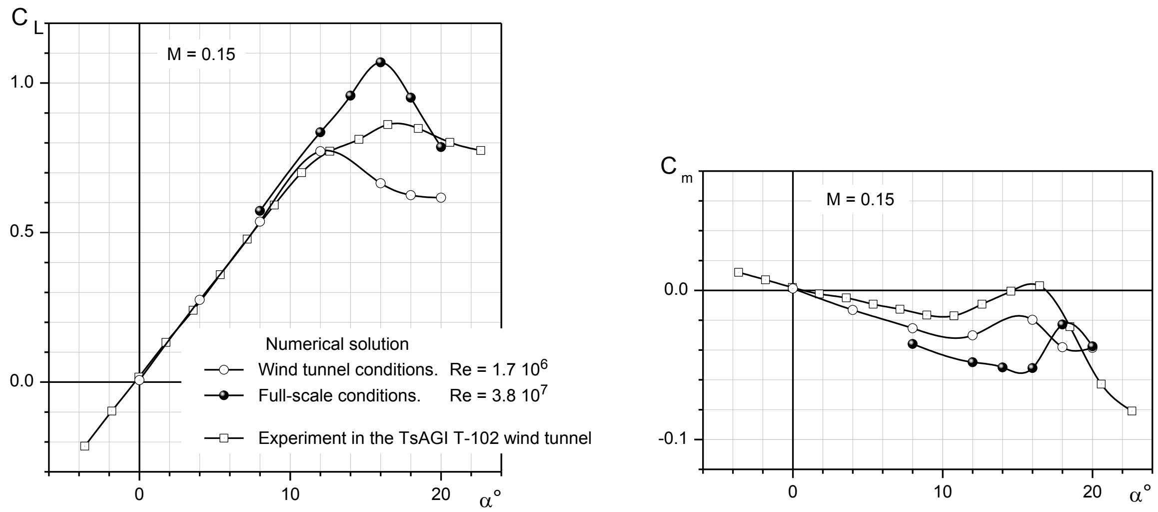

Figure 7: The results of numerical investigation of the Reynolds number effect on the lift and the pitching moment coefficients of the "flying wing" configuration aircraft

6. Conclusions

Experiment on a research model of an aircraft performed at low subsonic speed in the TsAGI T-102 wind tunnel demonstrated that inclusion into the flying wing configuration twin tail unit with relative area of 0.115 with fins inclined to the symmetry plane of the model at angle of 50 deg. provides for yaw static stability of the configuration, and rudders mounted at the fins trailing edges are effective controls both in yaw and pitch in a wide range of angles of attack.

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