4th EASN Association International Workshop

THREE SURFACE AIRCRAFT (TSA) CONFIGURATION – PROFITS AND PROBLEMS

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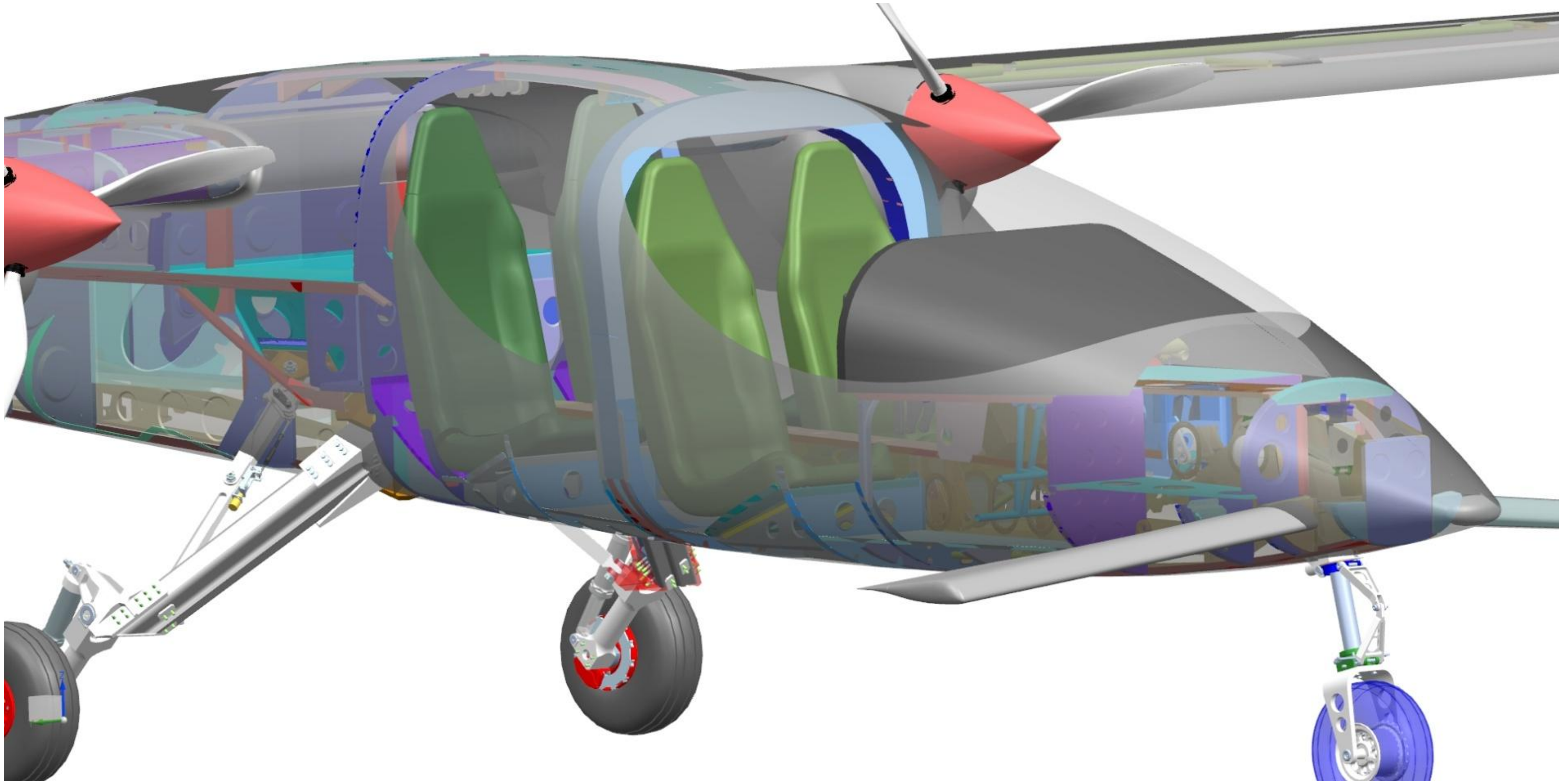
Introduction

- The fundamental feature of today aircraft has to be its ability to sell.
- Design of a new aircraft is always a challenge: how to design a new aircraft, which is better than competitive:
  - by improving the opposite features – it is difficult for classical configuration with current engines
  - PSE - Performance Safety & Economy

Introduction

- PSE - Performance Safety & Economy:
  - **Safety** was satisfied by use of two engines and parachute recovery system.
  - The **economy** was due to two Rotax engines, which are able to use the fuel used also by cars.
  - Advanced aerodynamic project had to give good characteristics to improve **economy** and **performance** as well. Additionally innovative flaps, which are deflected up in cruise condition and partially retracted to decrease wetted area, increase the aerodynamic effectiveness

Main ideas



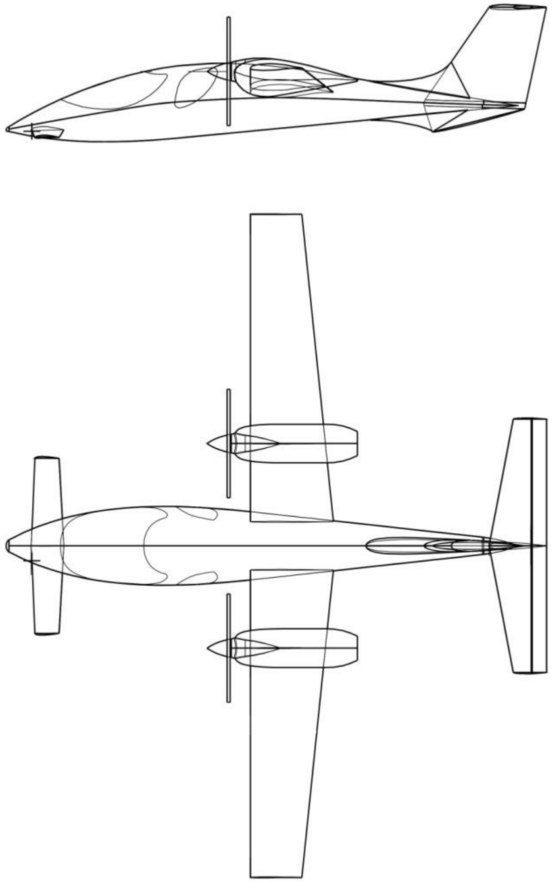
Initially the ergonomics of cabin was the starting point

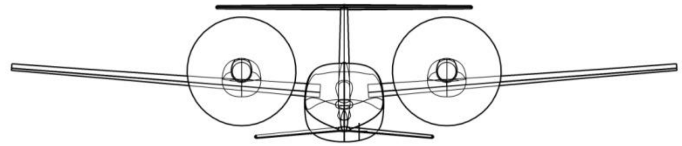
Main ideas

- The visibility from cabin had to be similar to visibility from helicopter cabin, not as in small Cessna case, so it should be highly glazed cabin
- Easy entering for each pilot and passenger, thus one large glazed door for pilots and two “gull wing” doors for each passenger
- It results, that wheel base of landing gear was increased and, what is most important, main wing was shifted back, which caused, that gravity center is located in front of the leading edge of main wing.
- Such extreme CG position forces the additional lifting surface on the front of fuselage (canard) to satisfy trim and to decrease very big, negative force on the horizontal tail.
- Thus the concept of three surface aircraft (TSA) was born and it was named AT-6.

Unconventional configuration requires to check flying qualities as early as possible

AT-6 - Initial version

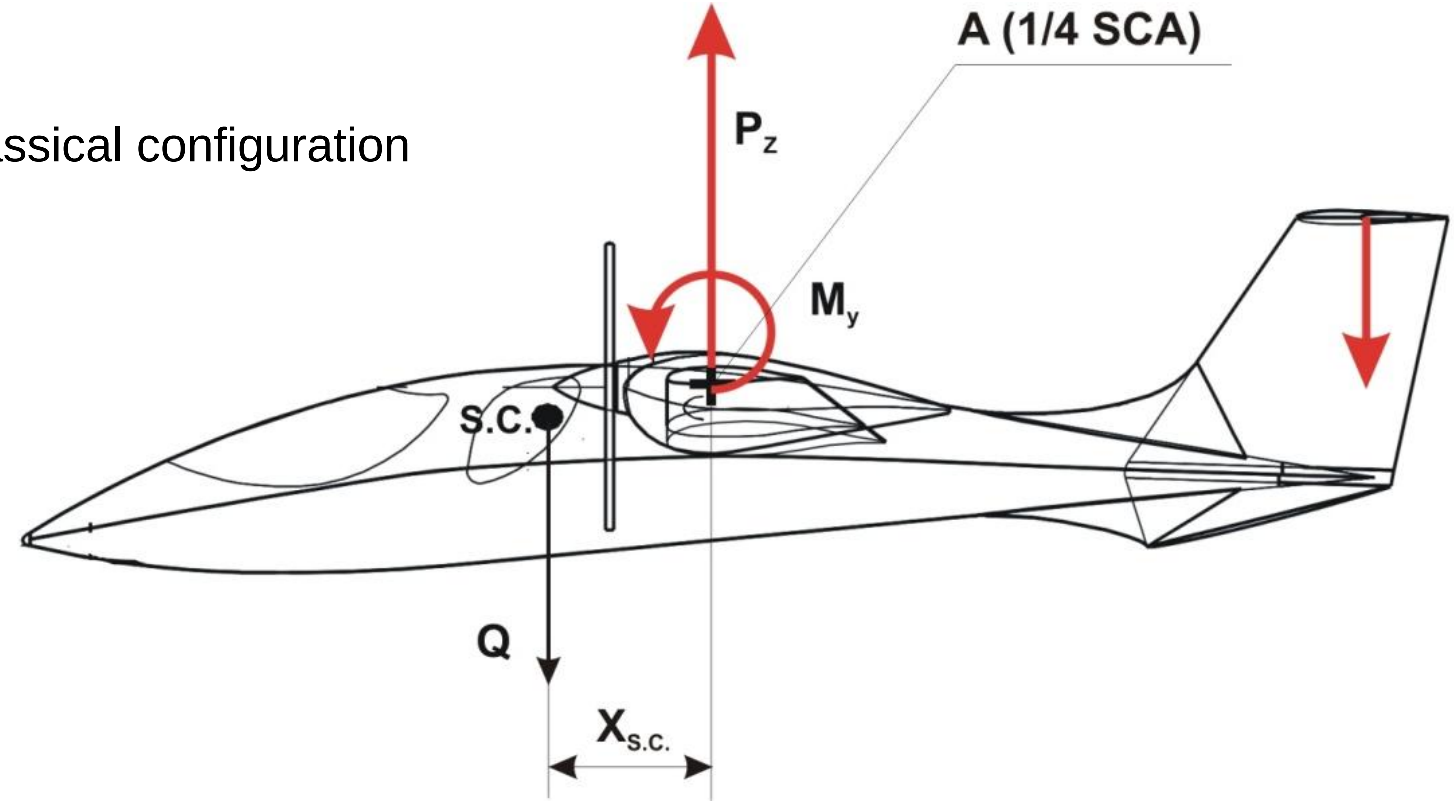




Wingspan 11.0 m
Length 9.0 m
Height 3.0 m
Wing area 12.5 m2
Max. TO weight 1280 kg
W/S 103 kg/m2
Engines power 230 HP
Minimum airspeed 90 km/h
Cruise airspeed (at sea level) 280 km/h
Cruise airspeed (at 14000ft) 320 km/h
Ceiling 18000 ft

Main advantage of TSA

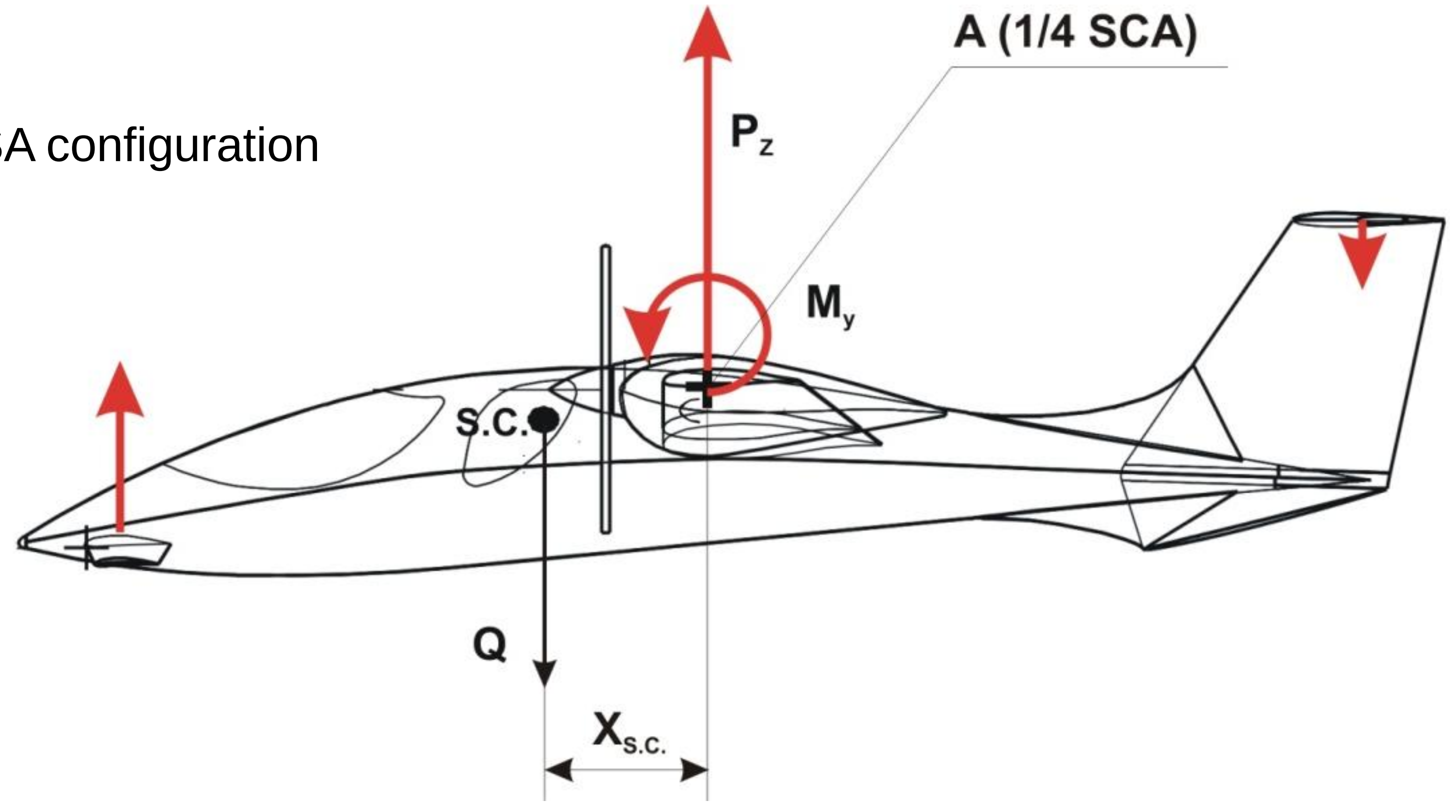
classical configuration



Extreme front CG position requires significant negative force on the horizontal tail

Main advantage of TSA

TSA configuration



Additional 3rd surface decreases negative lift on the horizontal tail and improves the lift balance and classical horizontal tail satisfies longitudinal stability

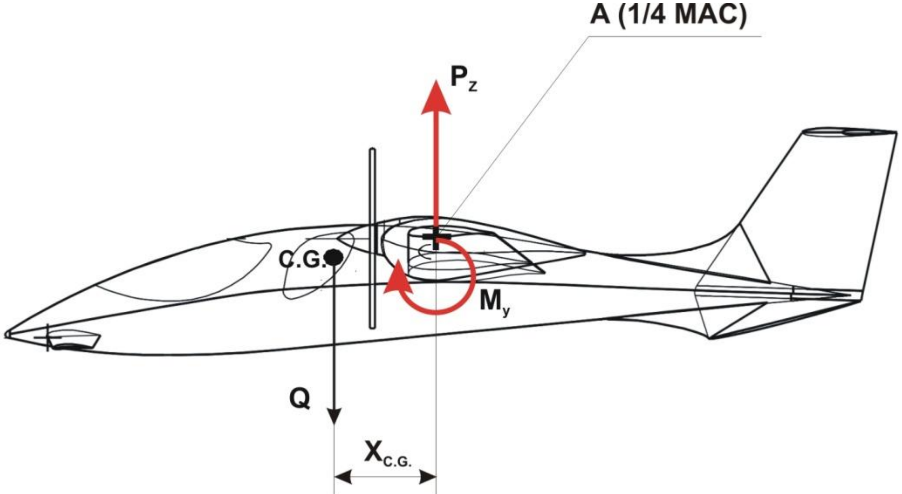
Main problems

- stability
  - longitudinal
  - lateral
- equilibrium
- forces on the tail should be decreased

Methodology of analysis

The stability and trim analysis needs aerodynamic characteristics, including the stability and control derivatives. They were computed by use of the **PANUKL** package, which is a low order potential solver. The trim and stability analysis was performed using **SDSA** (part of CEASIOM system).

Neutral point of stability



The neutral point of stability can be defined as the point which satisfies condition, that pitching moment coefficient is constant versus angle of attack or lift coefficient:

$$\frac{\partial C_{m,N}}{\partial C_Z} = 0$$

The equation of moment balance according to figure above can be written as follows:

$$\sum M_{CG} = M_Y - P_Z x_{CG}$$

Neutral point of stability

The equilibrium equation presented on the previous slide can be extended by aerodynamic forces to the following form:

$$\sum M_{CG} = \frac{1}{2}\rho S V^2 C_a C_{mCG} = \frac{1}{2}\rho S V^2 C_a \left(C_m - C_Z \frac{x_{CG}}{C_a} \right)$$

Differentiating this equation side by side and assuming that CG (center of gravity) is located in the neutral point, we obtain:

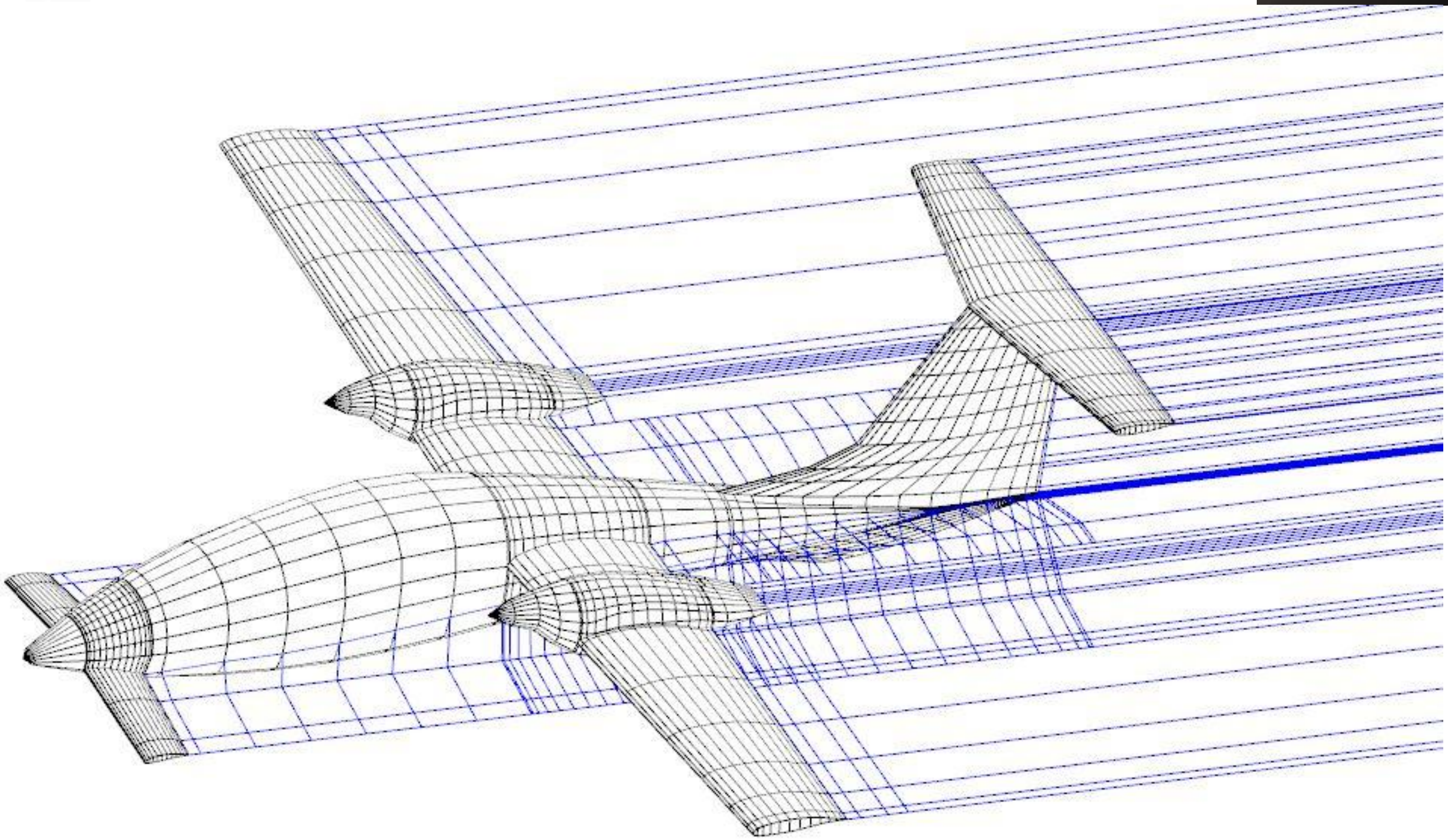
$$\frac{\partial C_{mN}}{\partial C_Z} = \frac{\partial C_m}{\partial C_Z} - \frac{x_N}{C_a} = 0 \qquad \text{thus} \qquad \bar{x}_N = \frac{\partial C_m}{\partial C_Z}$$

Neutral point of stability

The positive sign of X_N denotes, that neutral point is located forward with respect to point of aerodynamic forces reduction. The computation of the pitching moment coefficient versus angle of attack was done using the panel method (PANUKL).

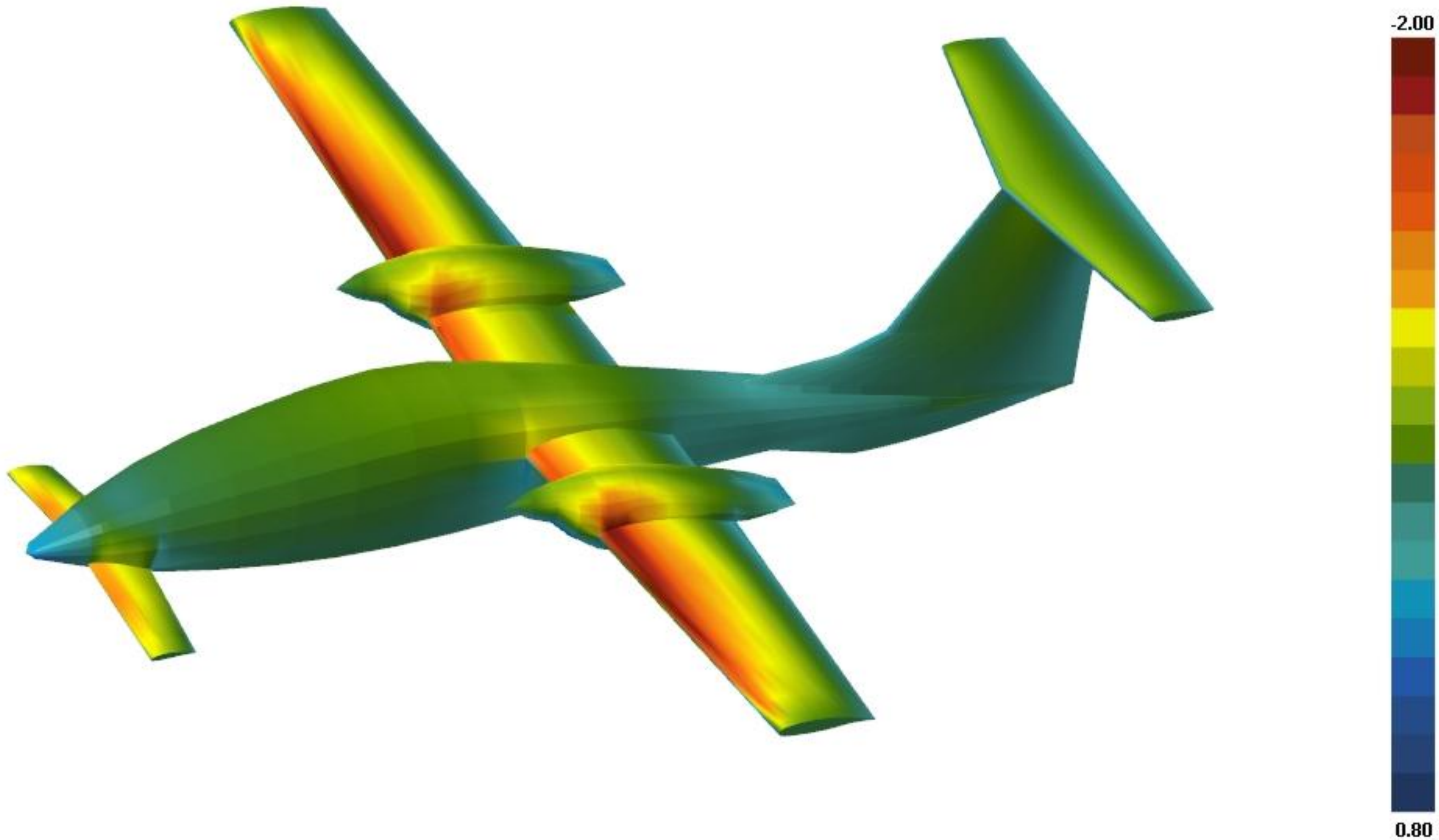
Position of the neutral point of stability allows to compute the static margin, which is the distance from center of gravity to neutral point, measured in percentage of MAC. This value is the basis for estimating the handling qualities of an aircraft.

Neutral point of stability



Computational model of AT-6 (first version) - mesh of 3609 panels

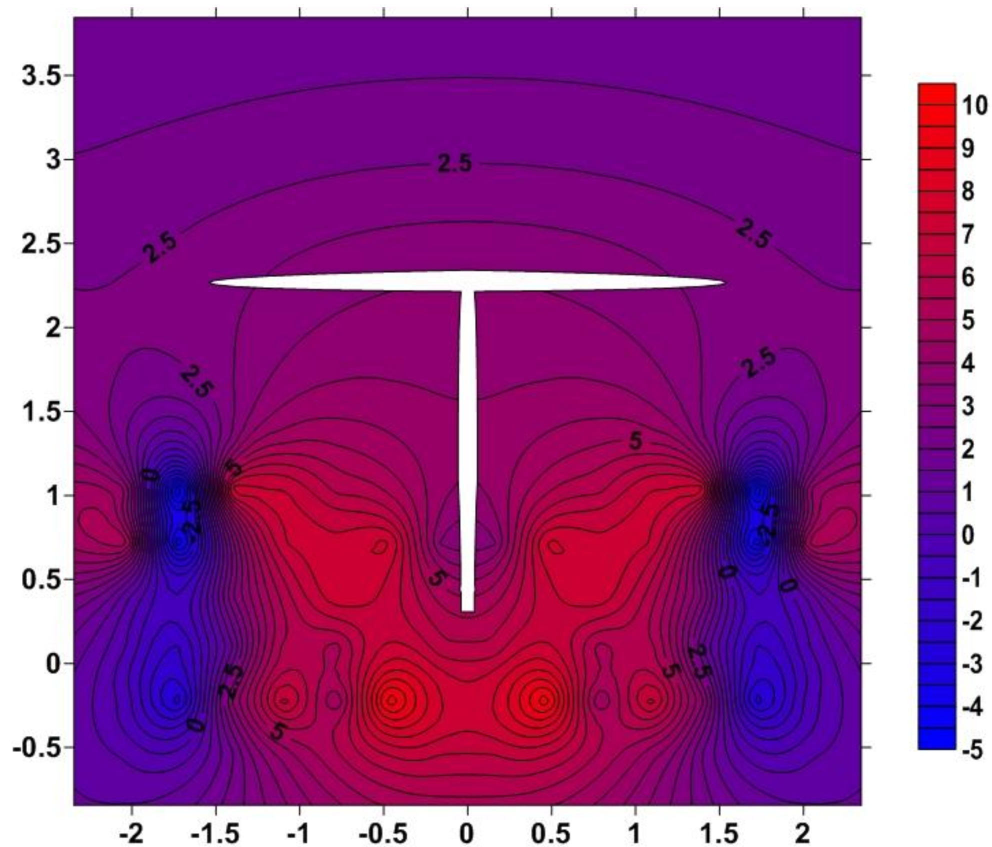
Neutral point of stability



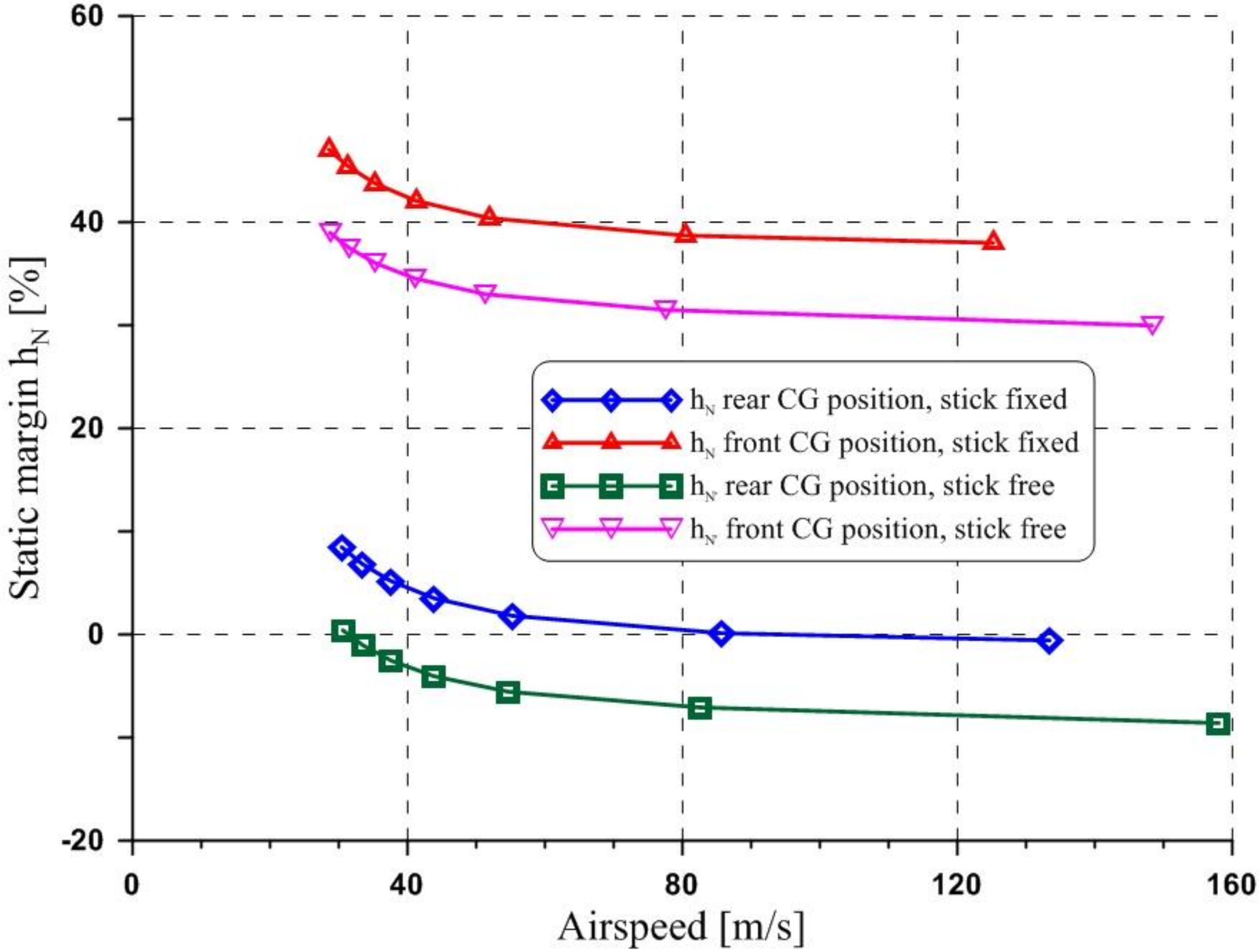
Pressure distribution, angle of attack $\alpha = 7.5°$

Neutral point of stability

The static margin in case of free stick, is computed using the similar method. However it requires to compute moment coefficient in case when elevator is free. This in turn requires the calculation of free elevator deflection versus angle of attack. To compute such characteristics hinge moment coefficient of elevator is needed. It was estimated using sufficient (ESDU) reports. The necessary downwash characteristics were obtained from panel code (PANUKL).



Longitudinal static stability



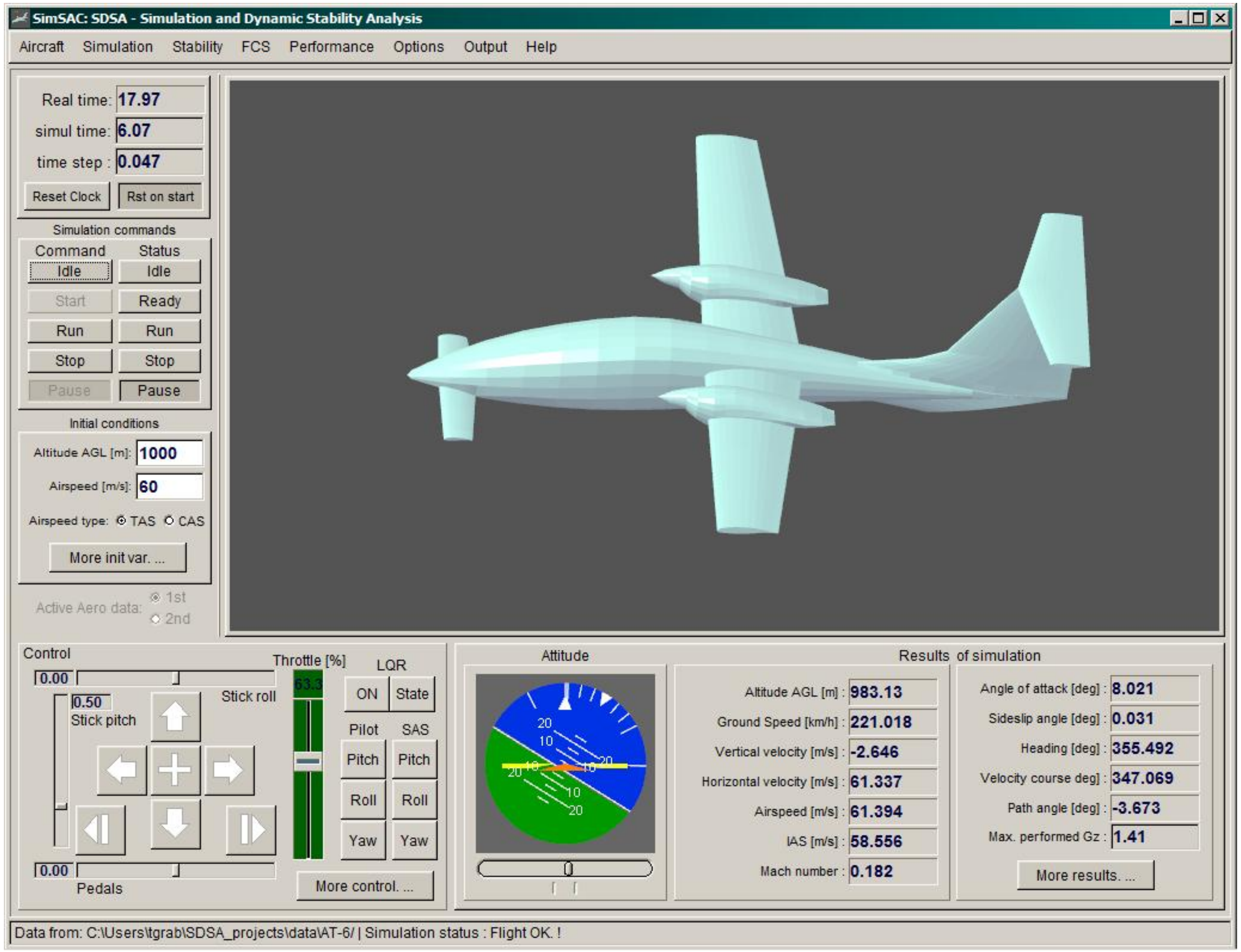
Lateral dynamic stability initial version

The aircraft configuration, especially major part of fuselage in front of main wing and big dihedral angle of main wing, is the reason why particular attention must be paid to the lateral stability.

The basic factor of directional static stability, i.e. derivative of yawing moment with respect to sideslip angle is positive, which means, that aircraft is statically stable.

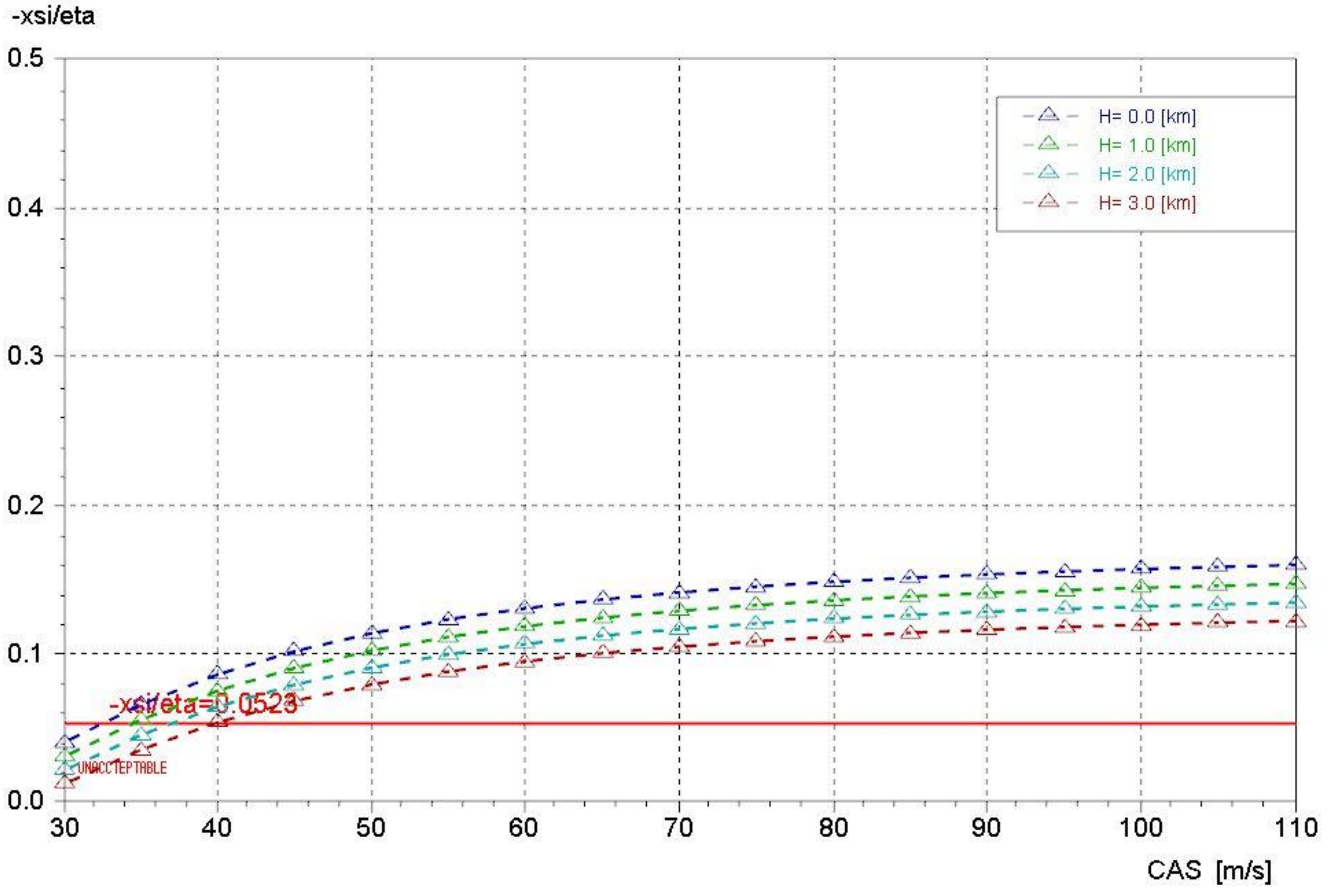
The dynamic analysis showed, that characteristics of the most important, from flying qualities point of view, lateral mode of motion, i.e. Dutch roll may not be satisfying and it can even be unstable for higher angle of attack.

Dynamic stability



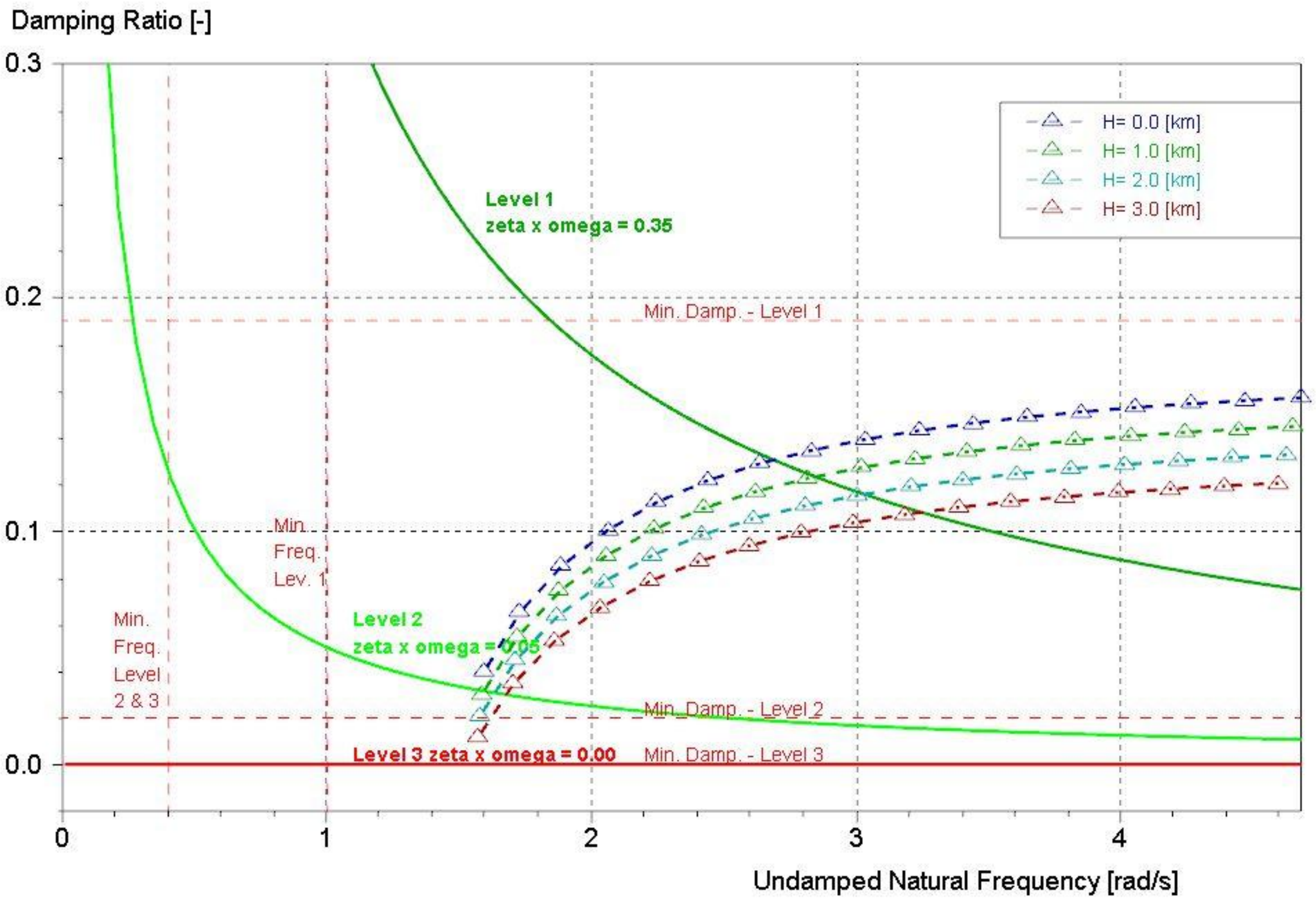
SDSA window - AT-6 flight simulation

Lateral dynamic stability initial version



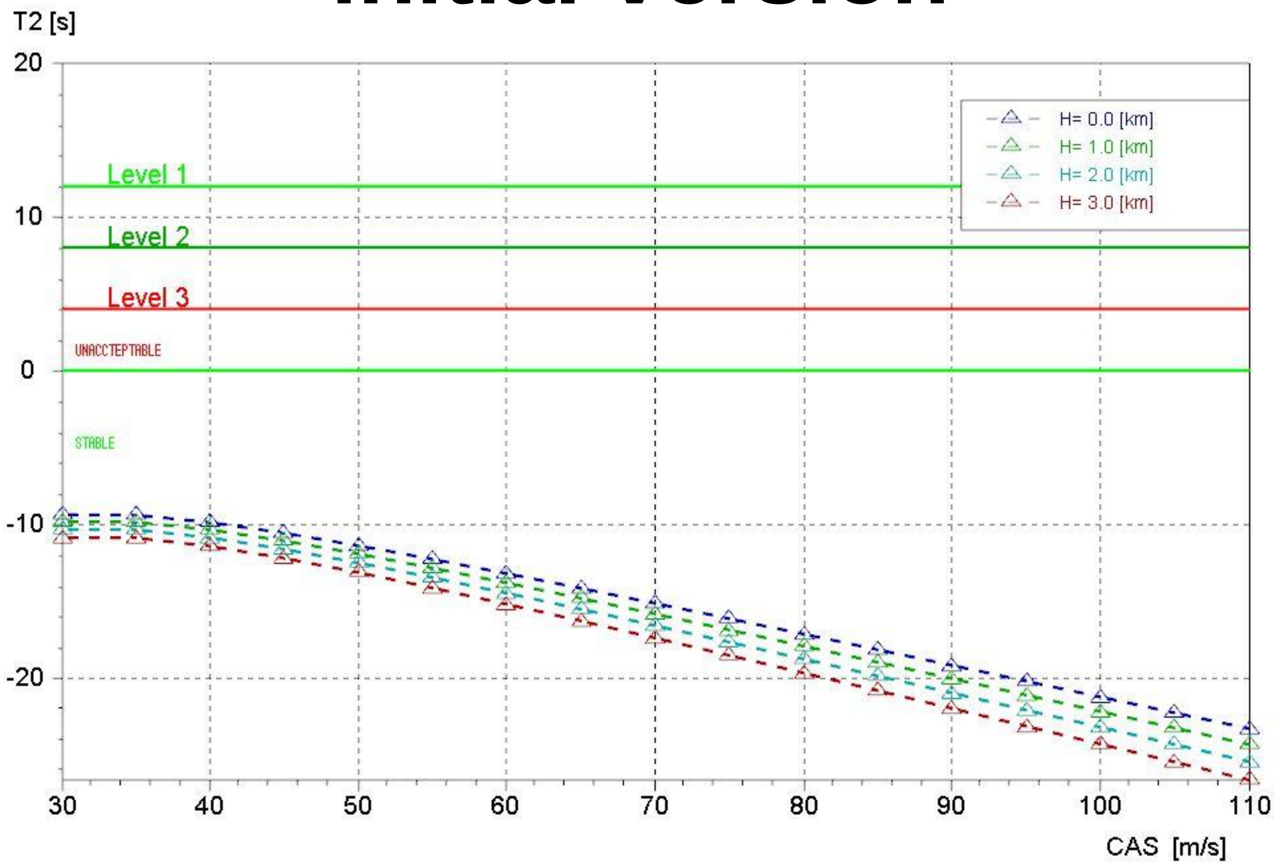
Dutch roll characteristics versus calibrated airspeed (CS-23.181 criterion)

Lateral dynamic stability initial version



Dutch roll characteristics against background of MIL-F-8785C criteria

Lateral dynamic stability initial version

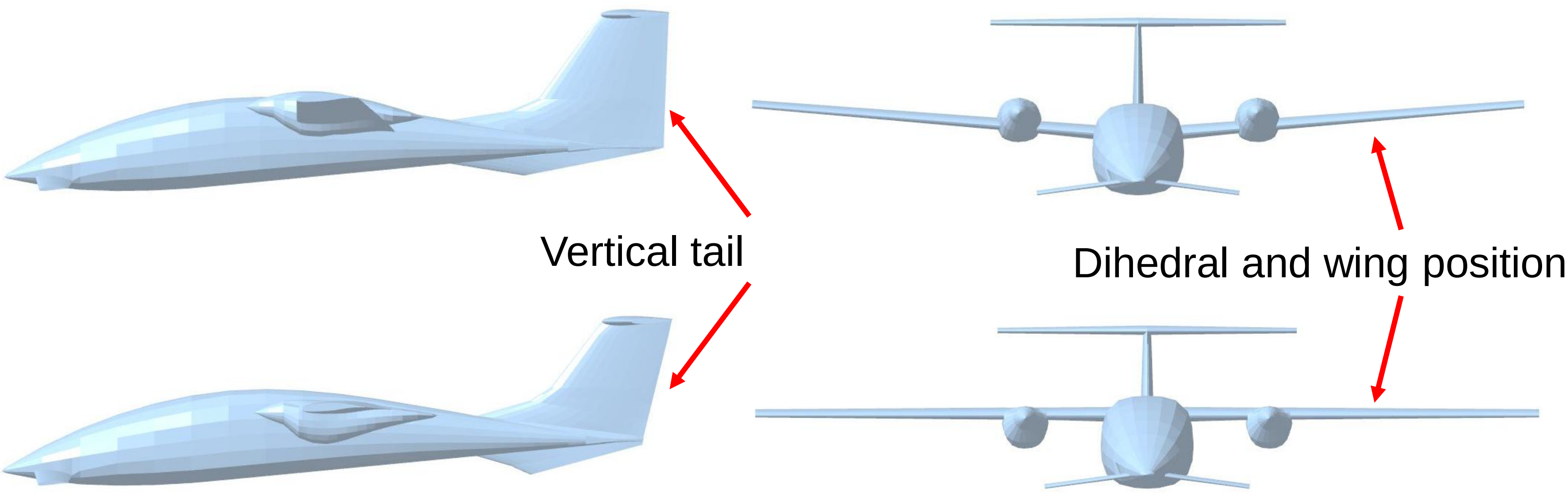


Second essential lateral mode of motion is spiral mode. This mode is stable in whole airspeed range – figure above (MIL-F-8785C criteria).

Handling qualities - results changes in configuration

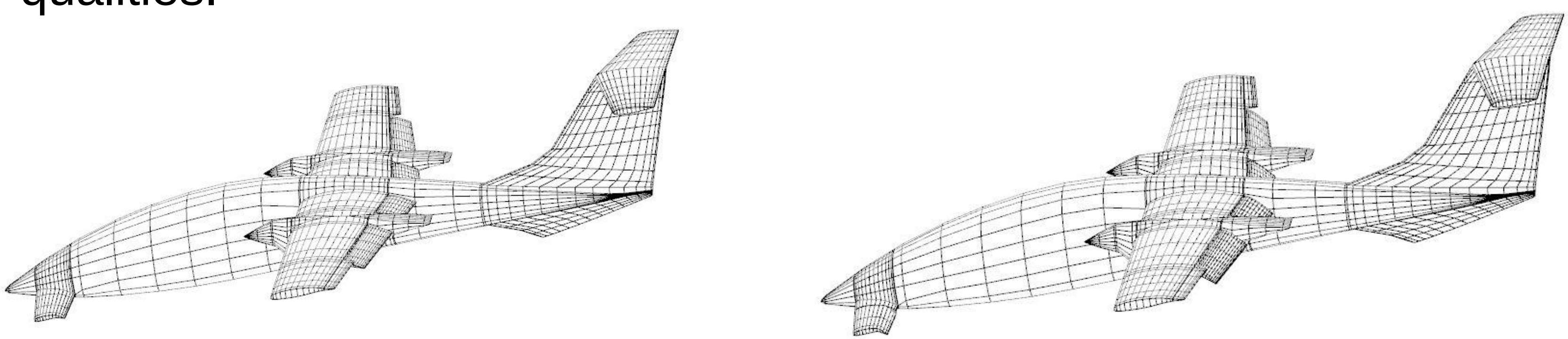
- The results of stability analysis of the first version of presented aircraft were not satisfying. Both longitudinal and lateral characteristics had to be improved.
- Longitudinal stability was improved by changing the internal layout of the aircraft and by rearranging of the weights breakdown.
- The lateral stability was improved by decreasing dihedral angle to zero and moving the main wing up, to perform the same position of engines. It improved Dutch roll and allowed to decrease the vertical tail area.

AT-6 – change of geometry



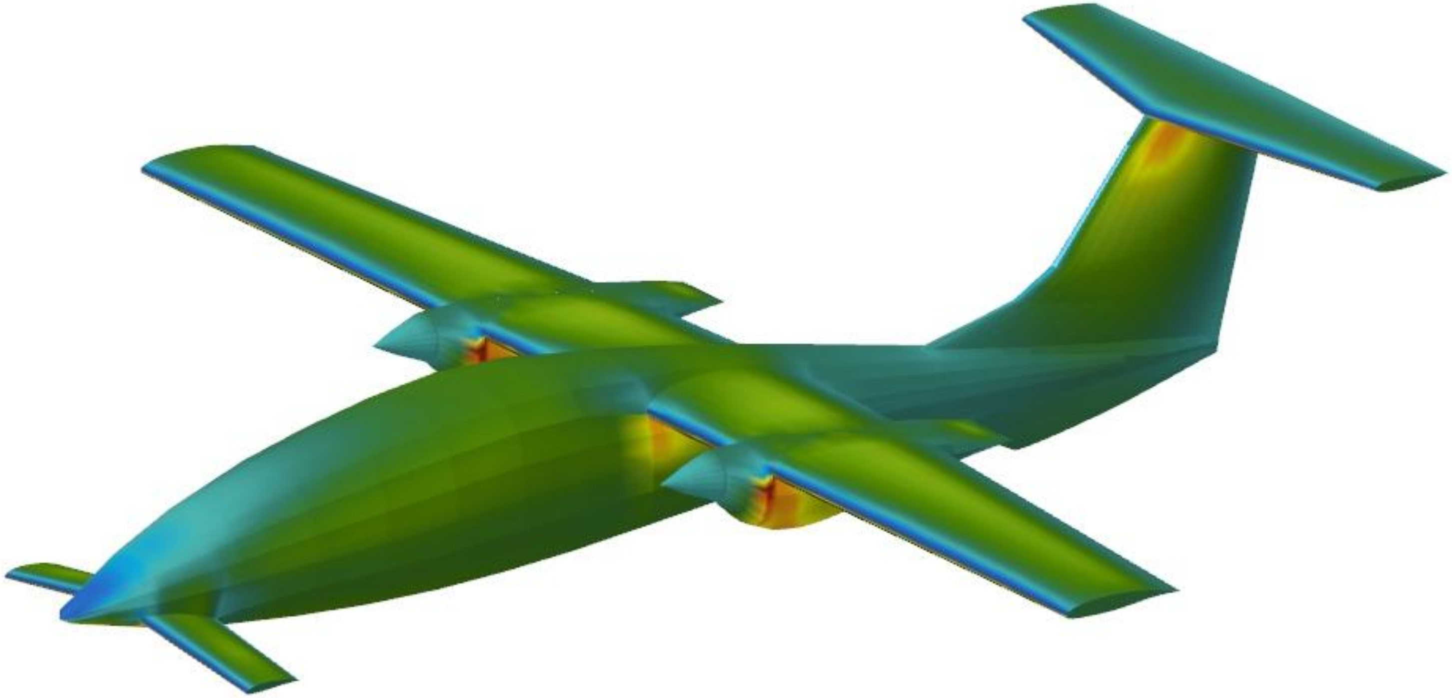
Handling qualities final version

New configuration was tested. Three aerodynamic configurations were considered: clean, take-off (flaps 15°), landing (flaps 30°) – next figures. The aerodynamic characteristics were obtained using panel methods (PANUKL). All modes of motion were checked, taking into account requirements from airworthiness regulation for handling qualities.



New configuration AT-6 meshes
main wing flaps deflected with: 15°(left), 30°(right).

Handling qualities - final version

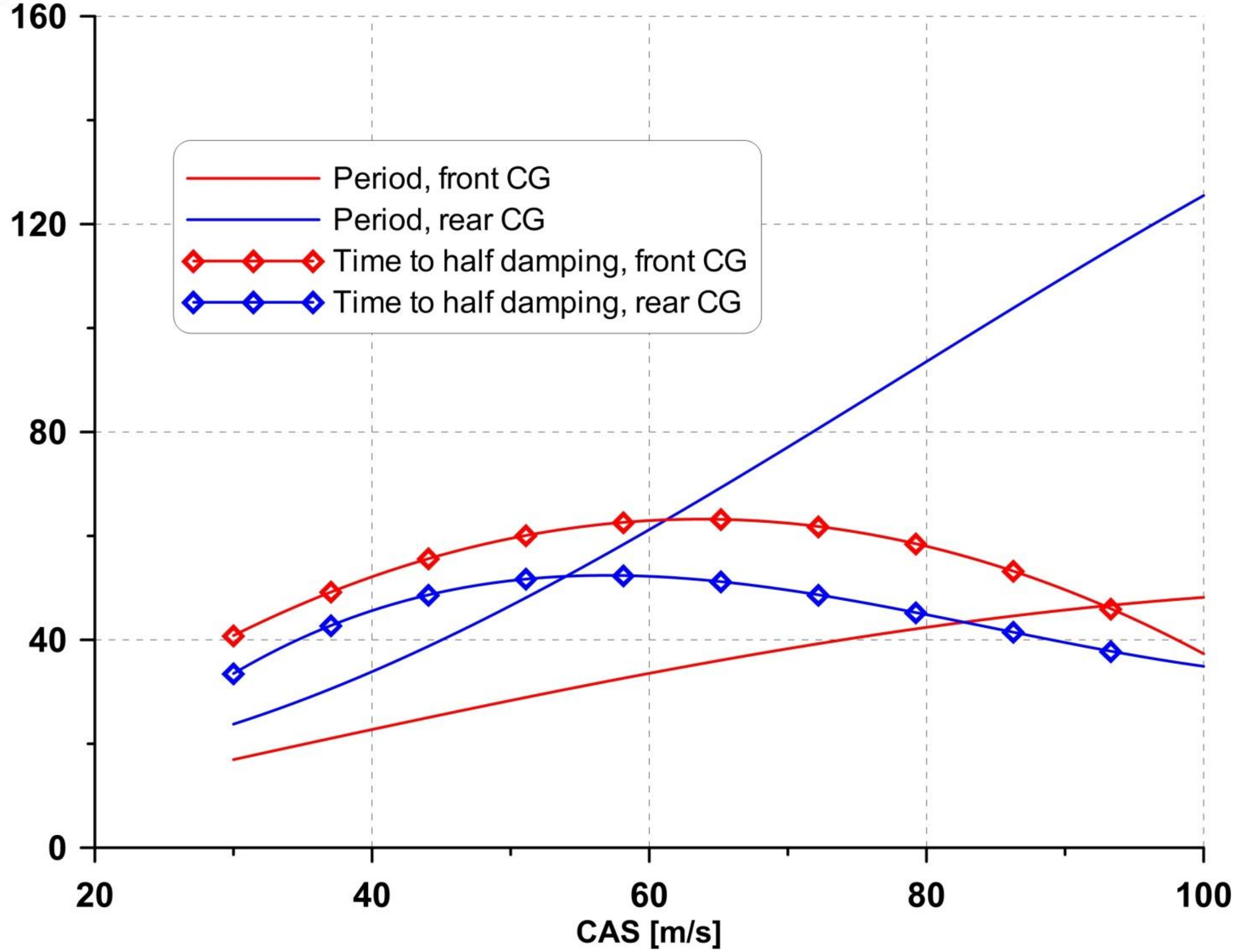


New configuration of AT-6 - example of pressure distribution (PANUKL), angle of attack α = -5°

Dynamic analysis - phugoid

The dominating state variable in phugoid mode is the airspeed, and angle of attack is almost constant. The period is usually long and oscillations are well damped. The airworthiness requirements are not strong: "**Any long-period oscillation of the flight path (phugoid) must not be so unstable as to cause an unacceptable increase in pilot workload or otherwise endanger the aeroplane**." (CS-23.181). The results obtained for AT-6 show (next slide figure), that phugoid is stable in the whole range of CG position. Time needed to damp the amplitude to half is comparable with the period and varies between 40-60 s.

Dynamic analysis - phugoid

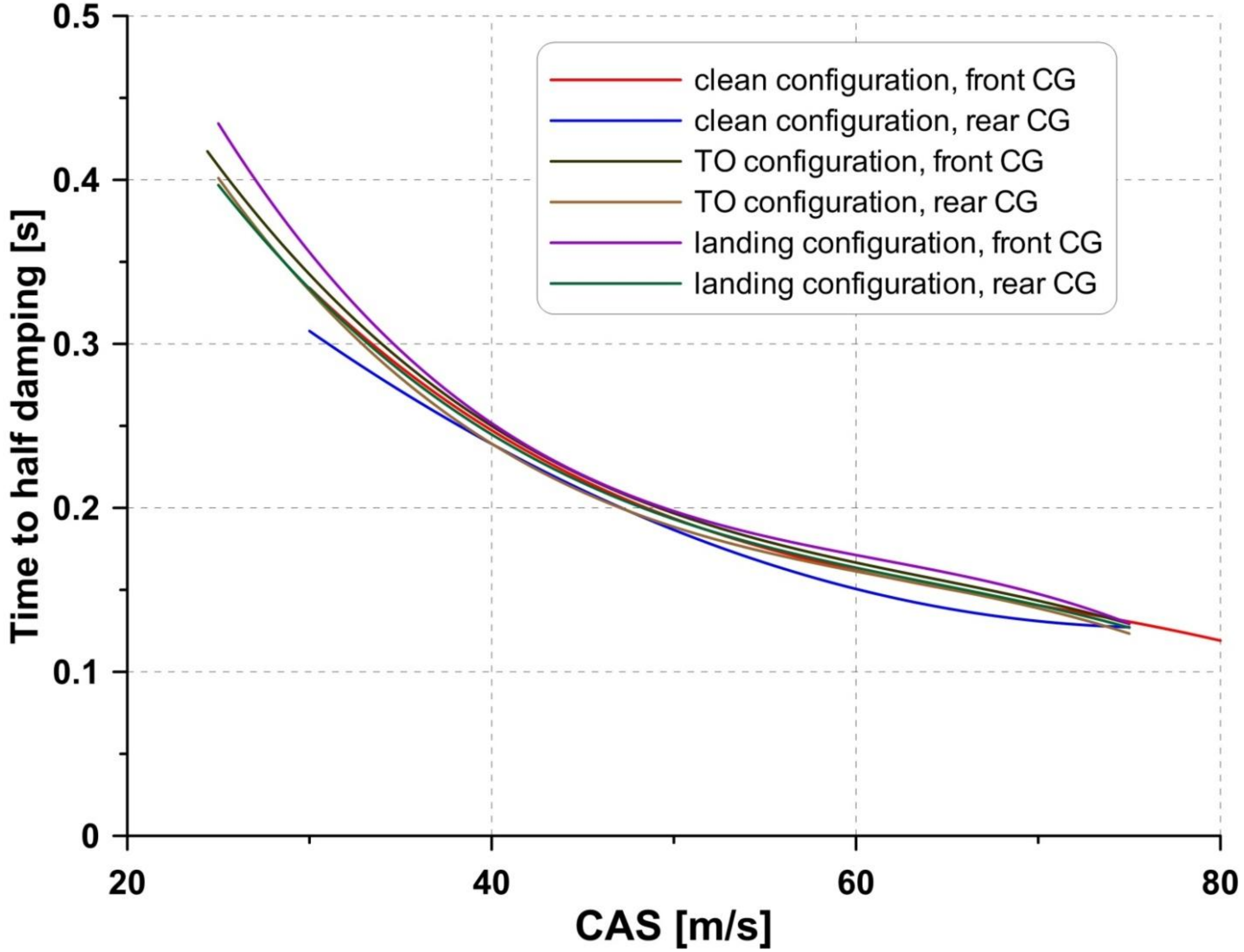


Phugoid - period and time to half damping versus calibrated airspeed

Dynamic analysis – Short Period

The short period oscillations connect rapid changes of angle of attack with pitch rate. The period is usually very short. The requirements according to CS-23.181 say: "**Any short period oscillation not including combined lateral-directional oscillations occurring between the stalling speed and the maximum allowable speed, appropriate to the configuration of the aeroplane must be heavily damped ...**". The results of computation show, that short period oscillations are well damped (next slide figure), however for clean configuration in case of rear CG position, periodical character vanishes. Two non-periodical modes are stable.

Dynamic analysis
Short Period



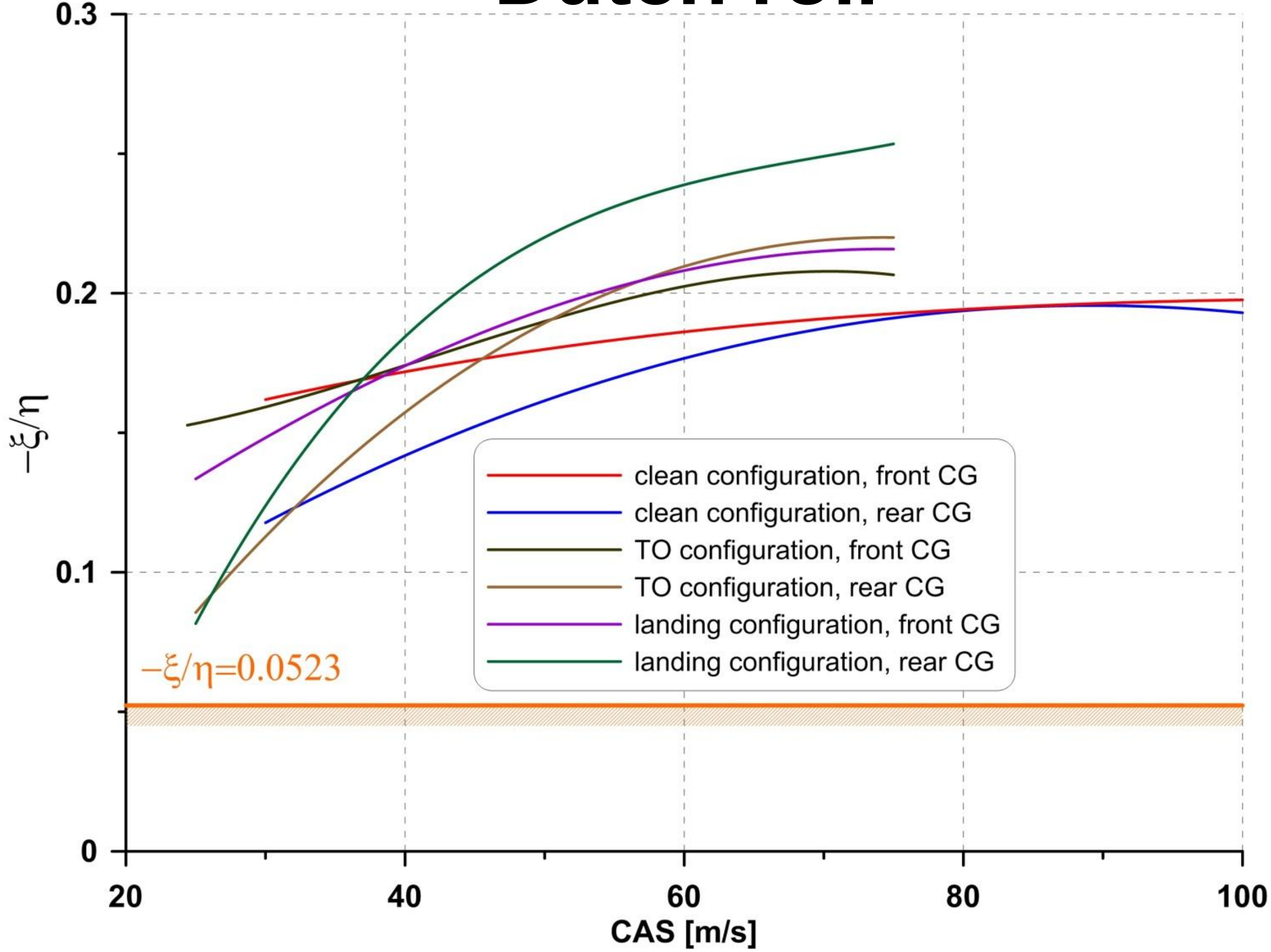
Short Period oscillation - time to half damping versus calibrated airspeed

Dynamic analysis – Dutch roll

Dutch roll requirements according to CS-23.181 are well defined: "Any combined lateral-directional oscillations ("Dutch roll") occurring between the stalling speed and the maximum allowable speed appropriate to the configuration of the aeroplane must be damped to 1/10 amplitude in 7 cycles ...".

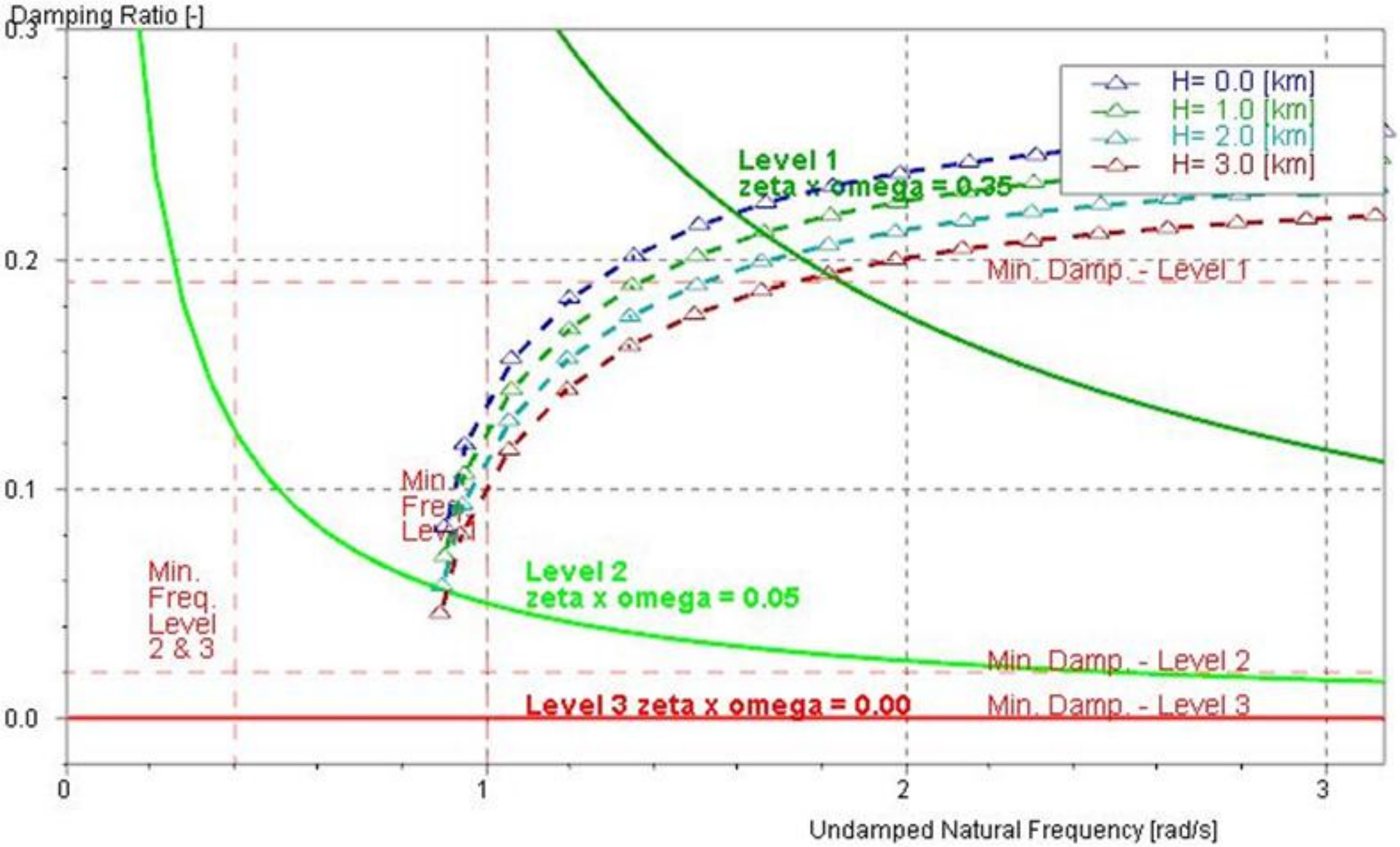
The obtained results show, that all configurations satisfy this criterion.

Dynamic analysis
Dutch roll



Dutch roll characteristics versus calibrated airspeed (CS-23.181 criterion)

Dynamic analysis
Dutch roll

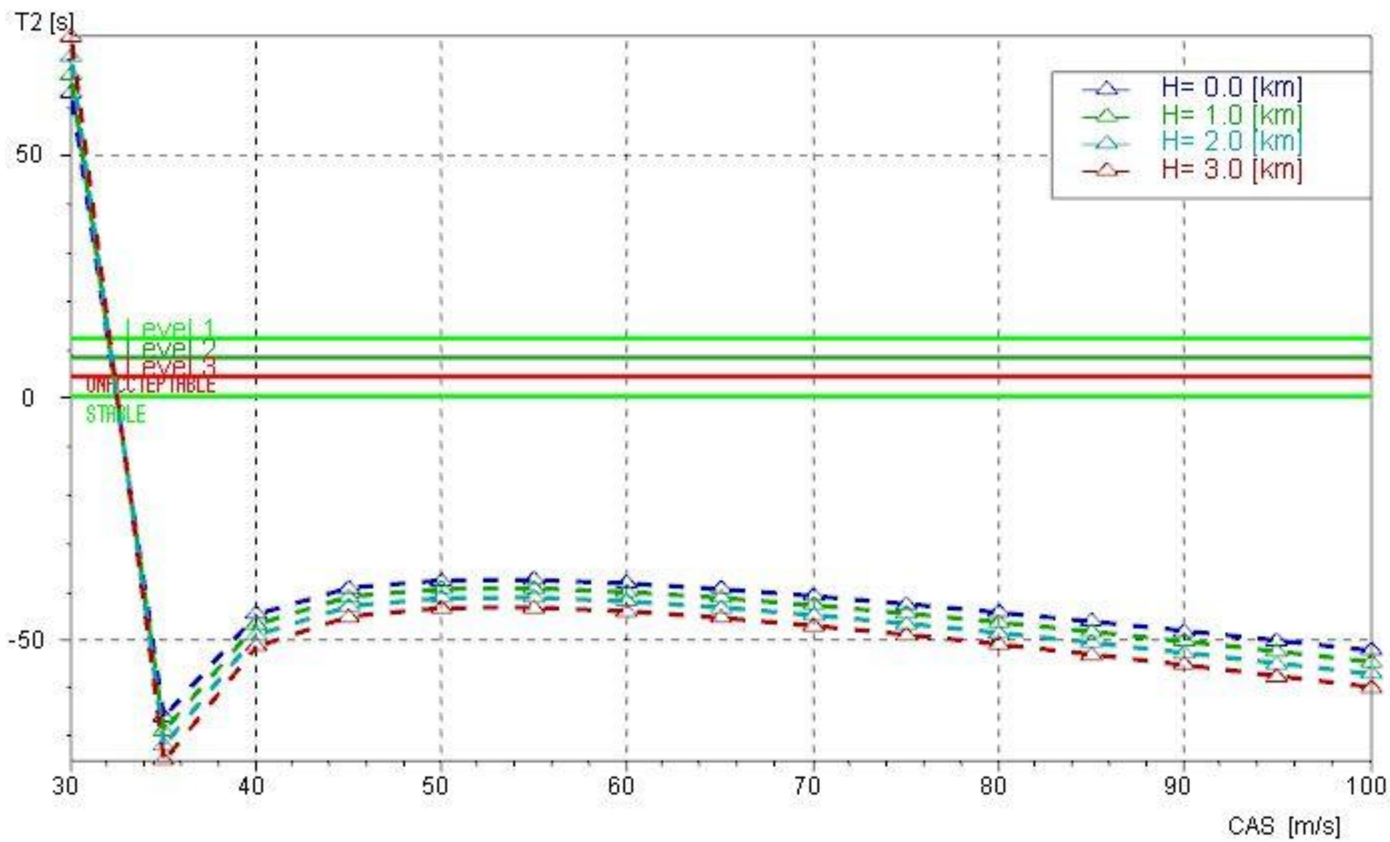


Dutch roll characteristics against background of MIL-F-8785C for landing configuration and rear CG position criteria. It also shows good Dutch roll characteristics, which are in Level 1 & 2 for whole flight envelope.

Dynamic analysis – Spiral mode

After improvement of the previous version, spiral is the only mode, that is worse. However, airworthiness requirements are not strong - CS-23-BOOK2: "... a slowacting mode called the spiral which may be stable, but is often neutrally stable or even mildly divergent in roll and yaw?". Similar requirements are in MIL-F-8785-C. Figure on the next page presents time to double of spiral mode, which shows, that spiral is unstable only for small values of airspeed and time to double is sufficiently big.

Dynamic analysis – Spiral mode



Time to double for spiral mode against background of MIL F-8785C for clean configuration, front CG position criteria

Concluding remarks

According to the results of flight tests of the scaled model, which is dynamically similar, we can be optimistic for the achievement of the objectives set for the full-size aircraft, namely:

- cruising speed should be greater, that 150 knots,
- minimum airspeed, for configuration with flaps, corresponds to aircraft with bigger area (with the same weight),
- “aerodynamic safety” is satisfied – stall, spin characteristics, static and dynamic stability
- good visibility and comfort of cab
- other performance and low operating costs resulting from the aerodynamic characteristics (L/D over 15)

The End

Thank you for attention