ULTRA LIGHT WING STRUCTURE FOR HIGH ALTITUDE LONG ENDURANCE UAV

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Abstract

This paper presents a conceptual design of main wing, body and empennage for high altitude long endurance unmanned aerial vehicle. An arrangement of main spar, ribs, shell and strut for high aspect ratio main wing and tailplane has been proposed. A number of characteristics (stiffnesses, mass distributions, moments of inertia etc), necessary for flutter calculations, is included in this paper. The structural characteristics are computed using NASTRAN programme. The critical flutter speed for empennage has been found by means of the conventional U-G method. The Doublet-Point-Method (DPM) for non-coplanar configuration was used to compute the unsteady aerodynamic forces. Aerodynamic model of empennage includes 168 aerodynamic panels. This analysis can be treated as a starting point for further wing optimisation. The main goal is to obtain the structure lighter and aerodynamically more efficient - the feature - being very important in long endurance missions.

1 Introduction

Stratospheric flights can provide wide, new opportunities for commercial, scientific and military activity. Among typical tasks there are: reconnaissance, border patrol, illegal air traffic control, source of pollution emissions and transport of pollutants observation, crop and forest assessment, flood and fire control, monitoring and wildlife migration, volcanic eruptions and ocean currents, observation of highway traffic-patterns and congestion, clouds and their influence on climate processes, exchange processes between biosphere and atmosphere, observation of land/ocean/polar icecaps and many others. Successful building of the High Altitude Long Endurance (HALE)

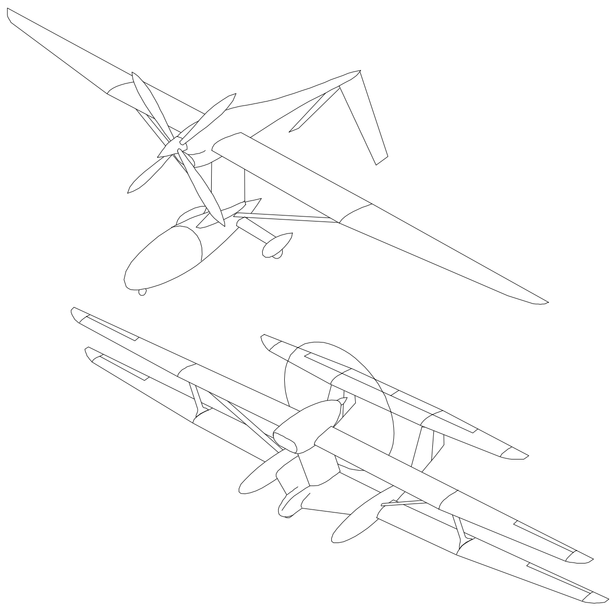

Fig.1 Configurations initially considered

UAV aircraft is conditioned by overcoming a few serious obstacles. Among these obstacles there are very special aerodynamics (low Reynolds Number coupled with locally transonic speeds), propulsion technology (in civil application the turbocharged piston engine of low operating cost is preferable), control system (possessing the best features of preprogrammed and hand-flown modes) and very light structures of wing and fuselage. This paper focuses mainly just on aircraft structure, being very light and intended to be flutter resistant.

Aircraft should be inexpensive in initial and operating costs. The basic option is payload weight of 300 kg. Depending on expected mission the payload weight is flexible in the range from 100 to 1000 kg. The maximum altitude is 26 km and corresponding endurance is 48 hours. However this endurance can be elongated for lower altitude [1]. The basic idea for such aircraft has been created in 1995 [2], when a conceptual project has been developed and submitted for DARPA, Fig1. This paper presents some major milestones in the project development, made jointly by Warsaw University of Technology and National Aerospace Laboratory and is devoted mainly to the main wing design and preliminary flutter analysis.

Sufficient power at departure altitude could be obtained only by the use of multistage turbocharger with a liquid intercooler. The compound propulsion system concept, developed by GROB Luft und Raumfahrt for STRATO 2C, has been adopted, as a basic solution with a modification presented in [1]. The power requirement of the aircraft - a product of drag and airspeed - increases rapidly with altitude. A suitable regulated turbocharger of the modified, compound propulsion system can maintain its available power of 400 kW at a constant value right up to the design altitude. Details of the compound propulsion system are given in [1,3,4]. The construction of the aircraft is based on glass fibre / carbon fibre design, including the fuselage, the container with measuring apparatus and a spring undercarriage.

2 Main wing structure

The wing consists of an upper and lower shell of sandwith construction, a number of ribs, the main spar, a nonbearing front wall, a torque box and a number of chordwise stiffening strips, Fig.2. These prefabricated fibre composite components are joined using the same synthetic resin as a bonding agent. The chordwise stiffening strip section is shown in Fig.3. Its external envelope consists of the two interglass fabric, of 92110 symbol. The unit weight of this fabric is 140 g/m^2. The internal filling weights 60 kg/m^3. The wing is supported on a double-rod angle struts, increasing both bending and torsional wing stiffness, Fig.4,5. Wing area is 60 m^2 , its span is 34 m and aspect ratio is 19.3 [5]. The general arrangement of the main spar, the rear wall torque box, main ribs and the angle strut support point are shown in Fig.6. More details, including aileron, angle strut and various dimensions, are shown in Fig.7. The shell of sandwith construction is also shown here. It consists of one outer layer fabric (91110), two inner layer fabric (92125) and filling of 8 mm thick. Attachment of the main wing to the fuselage is shown in Fig.8. The main spar of the wing (shown in Fig.2,4,5,6,7,8) has two strips of constant strength. Its dimensional mass (the mass of the current unit length per the mass of unit length in the area of angle strut attachment) is given in Fig.9. For general flutter prevention of the airplane the following design characteristics and solution are usually used [6]:

- torsional stiff wing
- light control surfaces
- stiff control system
- a partial mass balance of the primary control surfaces
- a stiff servo tab linkage (or rods) with minimum backlash
- very light aileron, made of carbon fibre (Fig.10).

3 Stiffness, mass, moments of inertia and other distributions for wing, tailplane and fuselage

The main wing, tailplane and fuselage and their dimensions are shown in Fig.11. All distributions needed for aeroelastic analysis were calculated coming from wing structure (Fig.2,7) and characteristics of applied materials. Basing on the glider design experience, gained in the Warsaw University of Technology, some of the obtained results were compared to the corresponding characteristics of composite wings of similar dimensions.

However, because these numerical results were not validated by testing a representative structure, so they have to be treated as approximated values with a prescribed degree of uncertainties. Fig.12,13 give bending and torsional stiffness for main wing, versus spanwise station. Fig.14,15,16 present: (1) centre gravity location; (2) polar moment of inertia per unit length and (3) mass distribution per unit length, respectively. Fig.17-21 relate to tailplane wing and give: (1) bending stiffeness; (2) torsional stiffness; (3) relative centre gravity location; (4) polar moment of inertia per unit length and (5) mass distribution per unit length , respectively. Fuselage has circular cross section and its stiffness and mass characteristics are shown in Fig.22-24. All characteristics given in Fig.12-24 correspond to empty structure (excluding fuel, power unit, control systems etc).

4 Aeroelastic analysis

As a starting point an empirical method (developed by W.Stender and I.Kiessling, [7]) was used to evaluate flutter vulnerability without extensive computational analysis and to take appropriate preventive measure. Statistically derived design frequencies restricted the number of vibration modes which had to be considered. Simple formulae were used for the calculation of the torsion frequency and the critical torsional flutter speed. The first approximation structure designed on this basis was further analysed in details by means of more refined approaches using FEM ANSYS and NASTRAN coupled with external loads given by unsteady aerodynamics. The point-doublet lattice method (developed by T.Ueda and E.Dowell, [8]) was used to estimate the aerodynamic pressure distribution along wing chord and wing span and then to calculate the bending and torsion modes of vibrations and the corresponding frequencies. A number of design variants has been checked out and optimised. In some area of the flight envelope the basic non-augmented configuration was expected to be vulnerable to flutter.

Tailplane was selected as a starting point for preliminary consideration of flutter. Since the main wing is braced with struts which add the stiffness for bending and torsion, it seems to have rather high flutter speed. However, this should be checked later. Meanwhile, the empennage has uncommonly high aspect ratio and negative dihedral angle. It would be interesting to know its flutter characteristics although the results are rather conventional. However, the flutter model hasn't included the elevator, which is usually checked for the design in details.

NASTRAN programme was used to compute the structural characteristics. Model under consideration has 289 elements. It consists of beam elements and concentrated masses, Fig.25. Computed modes are shown in Fig.26-29. Most of them are bending modes exept of the third one. Because usually the symmetric flutter is though to have a higher critical speed, so calculations were performed for anti-symmetric modes.

The Doublet-Point-Method (DPM) for non-coplanar configuration was used for unsteady aerodynamic forces. It has 168 aerodynamic panels. For flutter calculation, a conventional U-G method was used to find the critical speed. The third mode branch goes into flutter for this case. The flutter speed appeared to be equal 236 m/s - well above the maximum design speed V_D.

5 Conclusion

Tail wing appeared to be stiff enough and resistant to flutter. However, one should check the flutter of main wing and tail wings with control surfaces. The calculation should include the effects of mass balances for the control surfaces. It is possible that if the wing appear to be stiff enough, than the double rod - angle strut can be removed to have cantilever, aerodynamically more efficient wing. Also the high diameter wood-composite propeller has to be checked for possible whirl flutter. This kind of flutter was observed on STRATO 2C and it requires a special attention [1].

6 Acknowledgements

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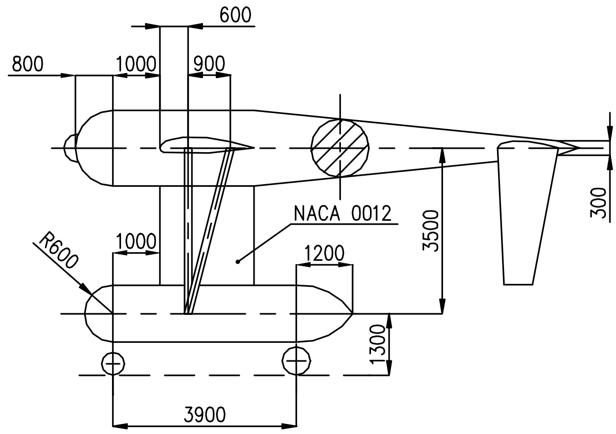

Fig.4 Side view of Harve 2 airplane

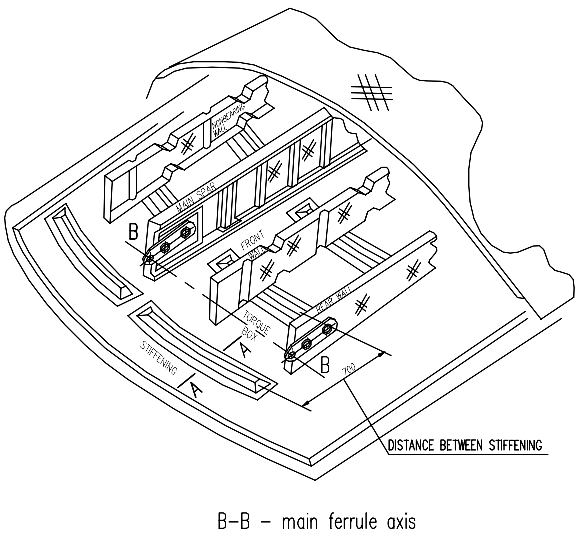

Fig.2 Main wing structure

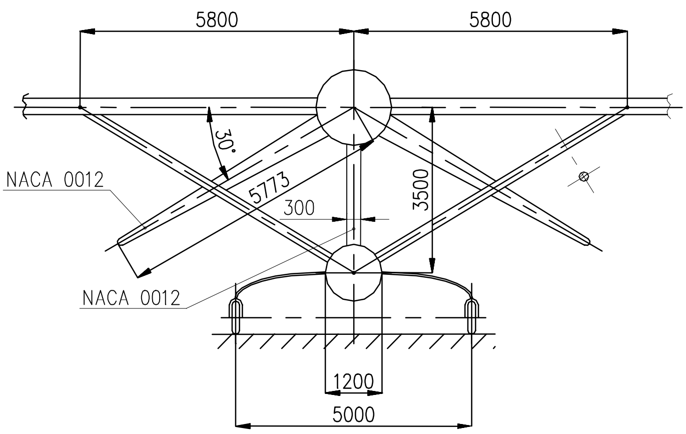

Fig.5 Front view of Harve 2 airplane

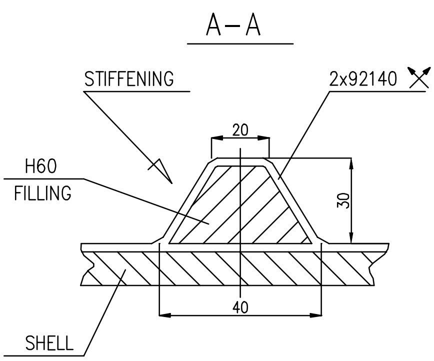

Fig.3 Chordwise stiffening strip section

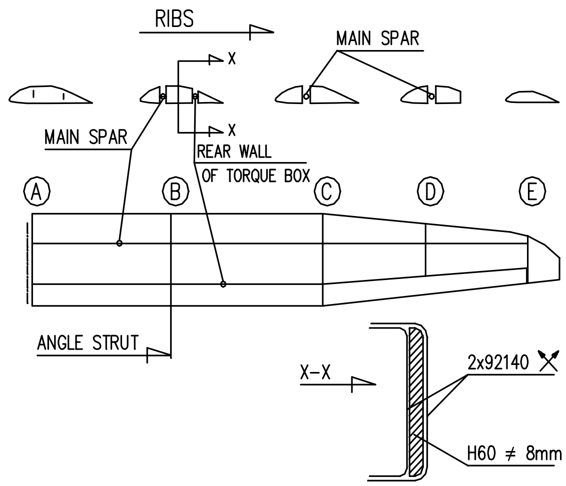

Fig.6 Plain view of the main wing

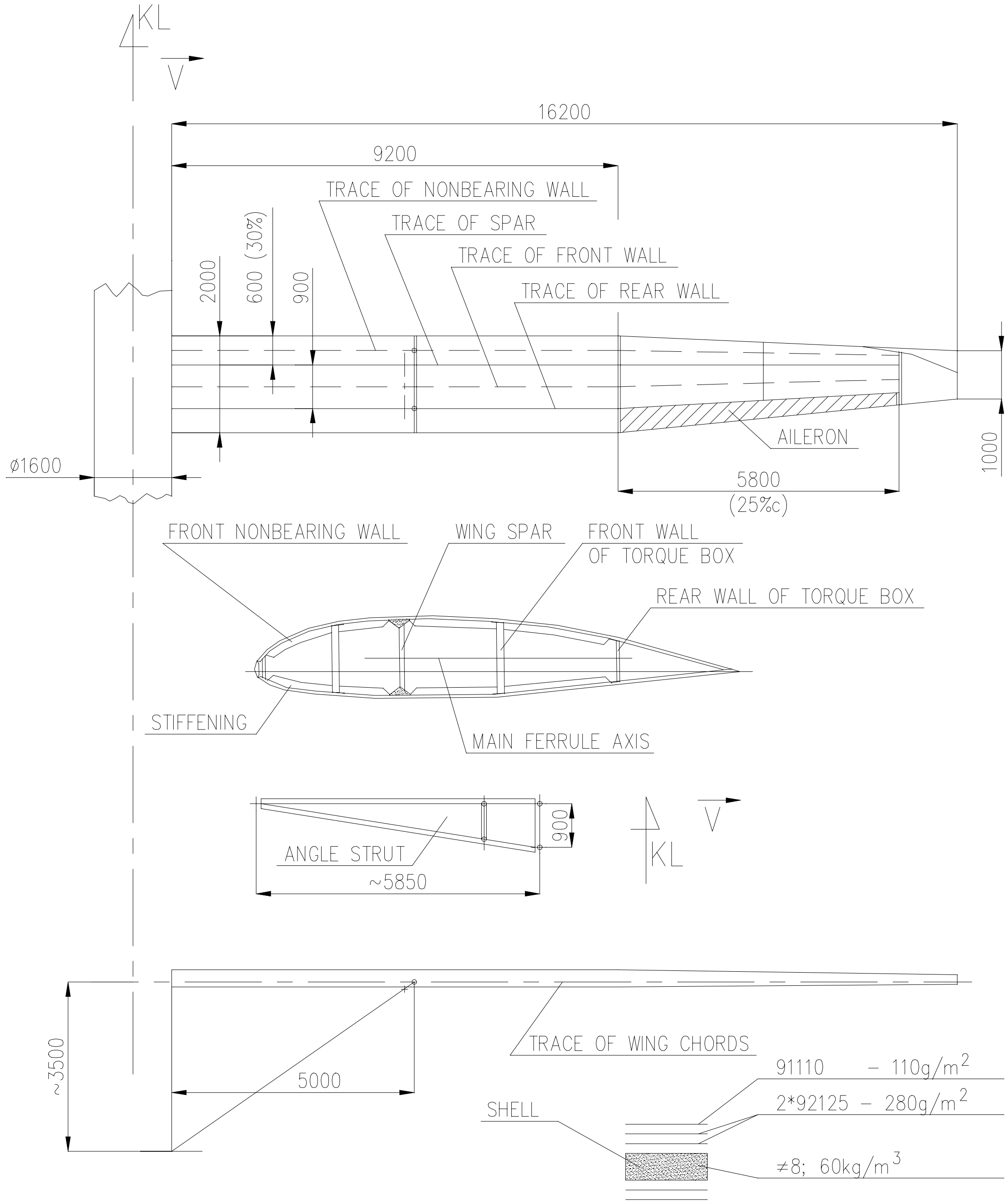

Fig.7 Ribs, spar and torque box

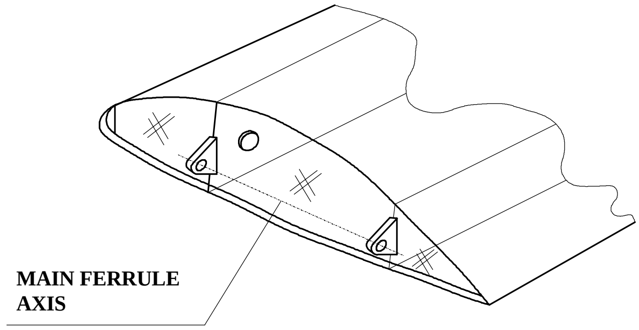

Fig.8. Details of the joining of the main wing to fuselage

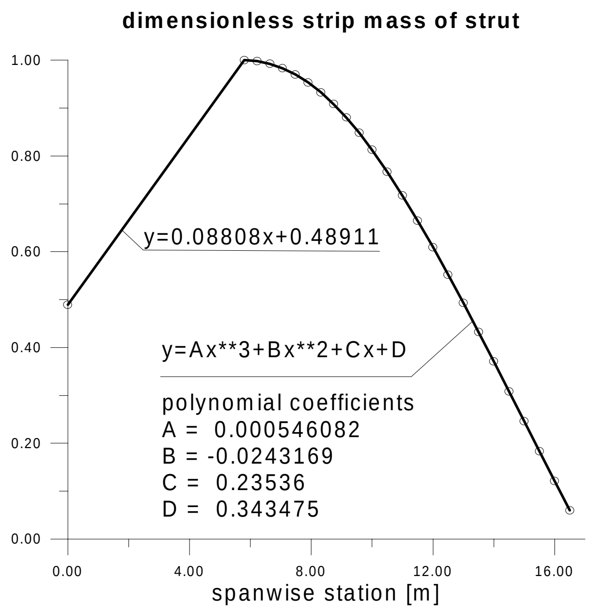

Fig.9 Spanwise mass distribution of the strut

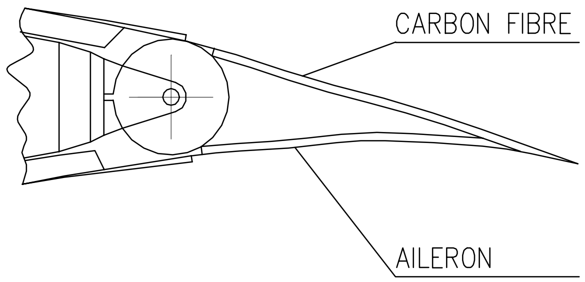

Fig.10 Trailing edge in aileron area

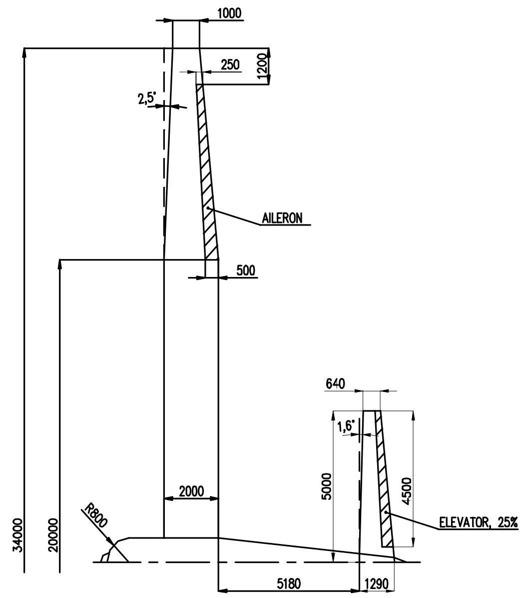

Fig.11 Plain view of whole airplane

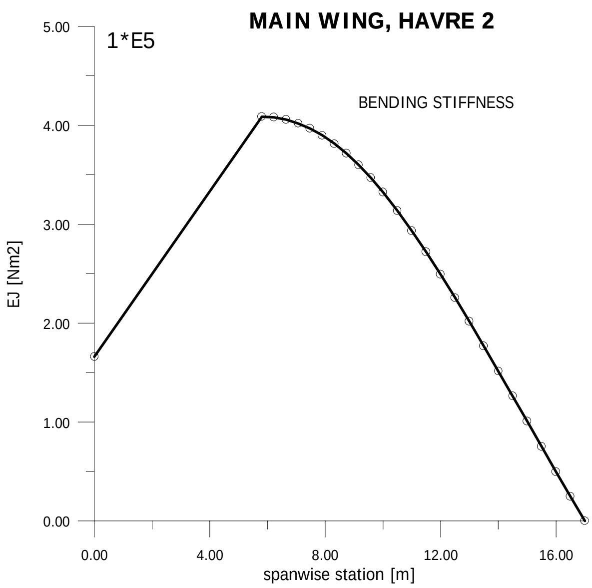

Fig.12 Spanwise distribution of bending stiffness

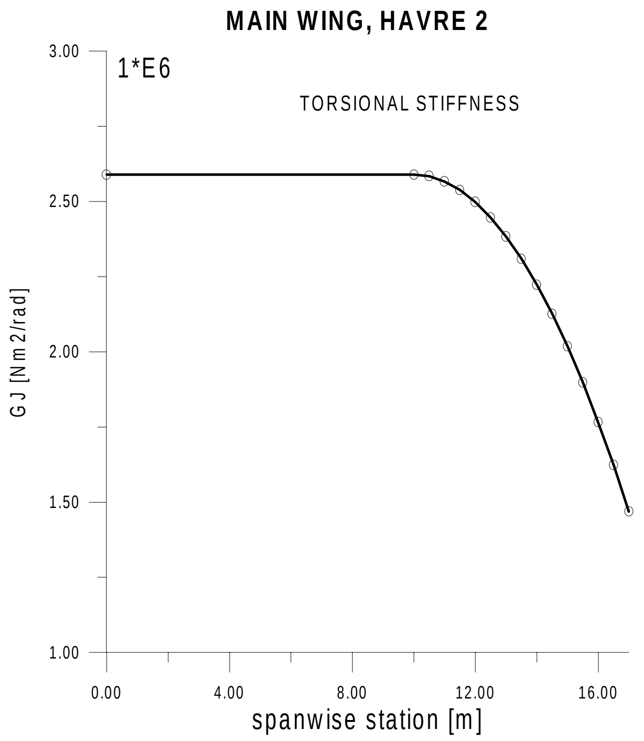

Fig.13 Spanwise distribution of torsional stiffness

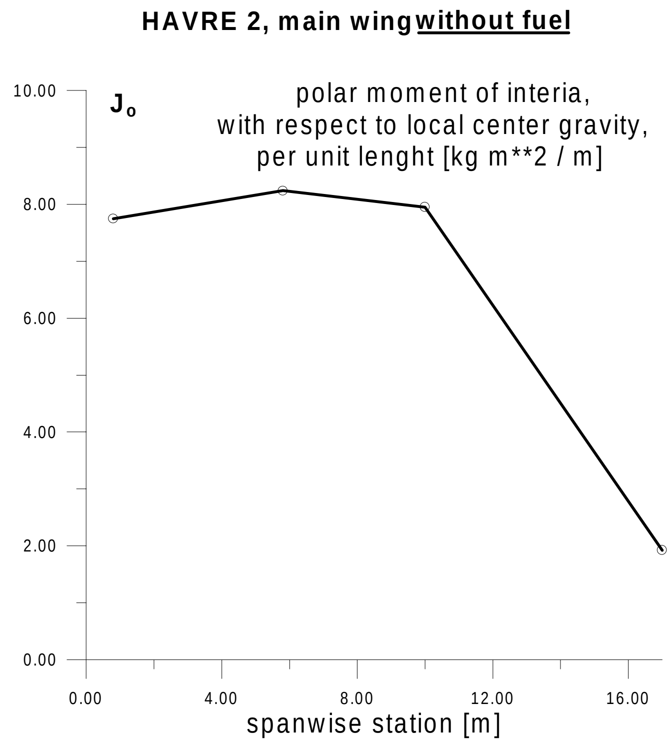

Fig.15 Spanwise distribution of the polar moment of inertia

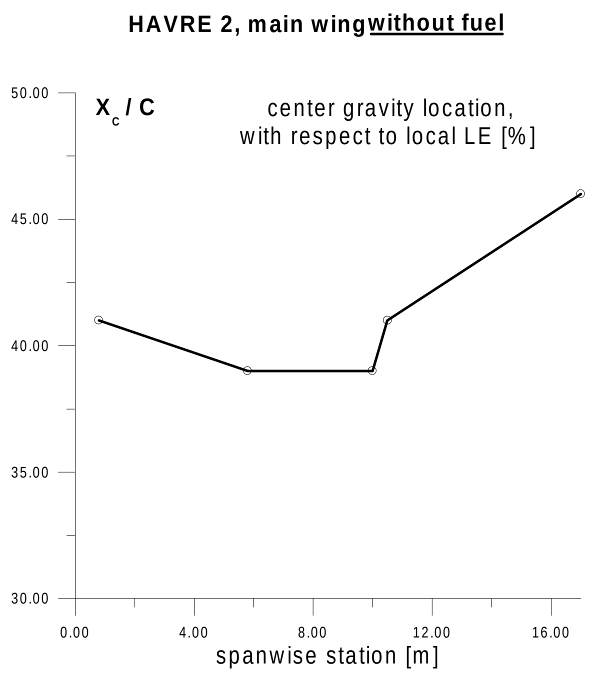

Fig.14 Spanwise distribution of the mass centre location

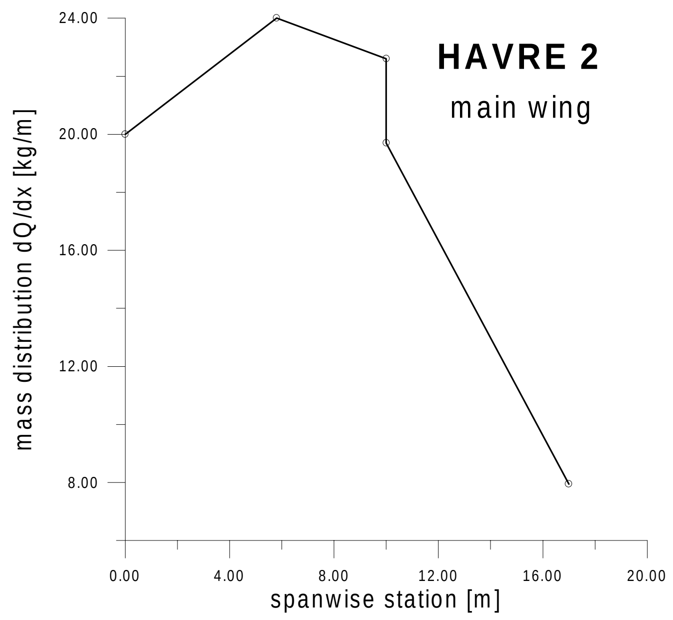

Fig.16 Spanwise mass distribution

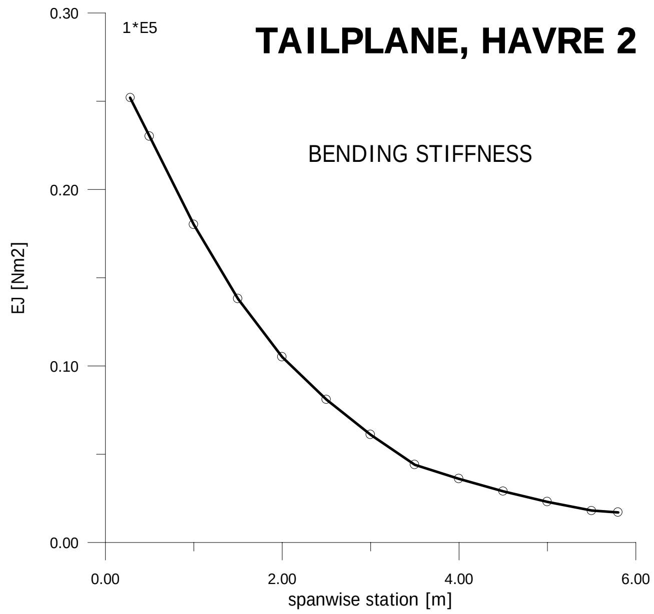

Fig.17 Spanwise distribution of bending stiffness

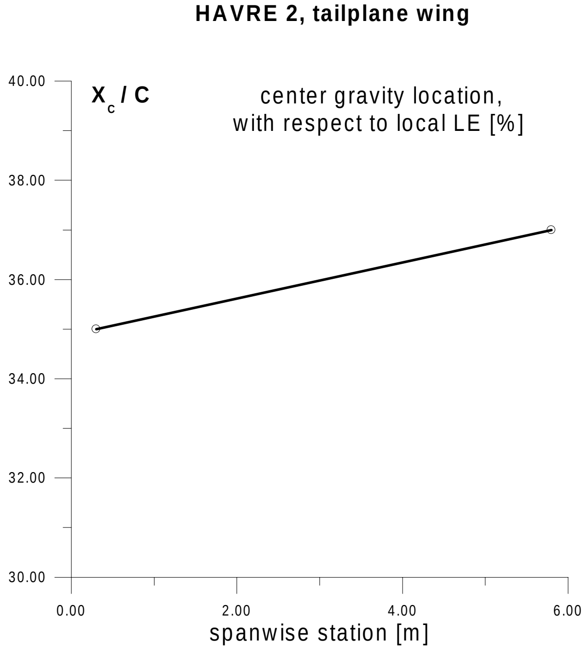

Fig.19 Spanwise distribution of the mass centre location

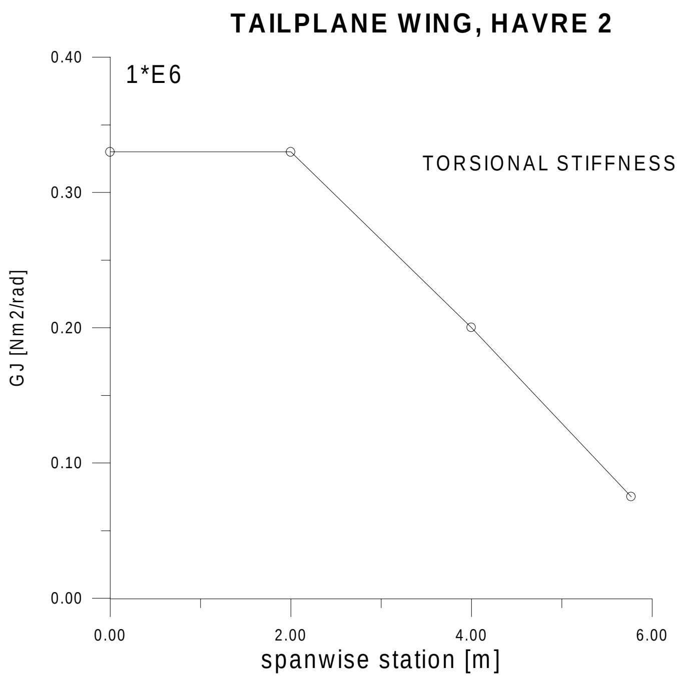

Fig.18 Spanwise distribution of torsional stiffness

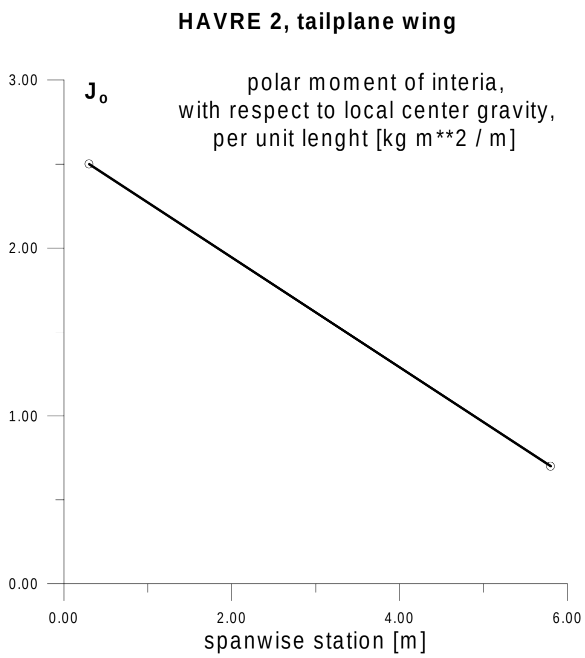

Fig.20 Spanwise distribution of the polar moment of inertia

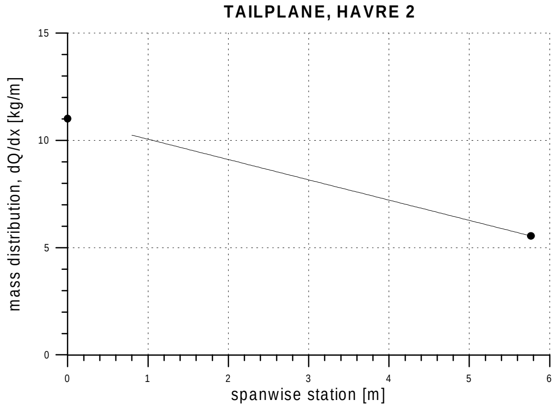

Fig.21 Spanwise mass distribution

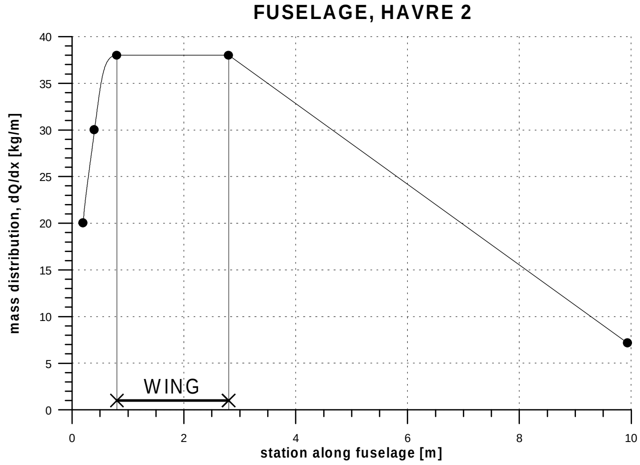

Fig.24 Mass distribution along fuselage

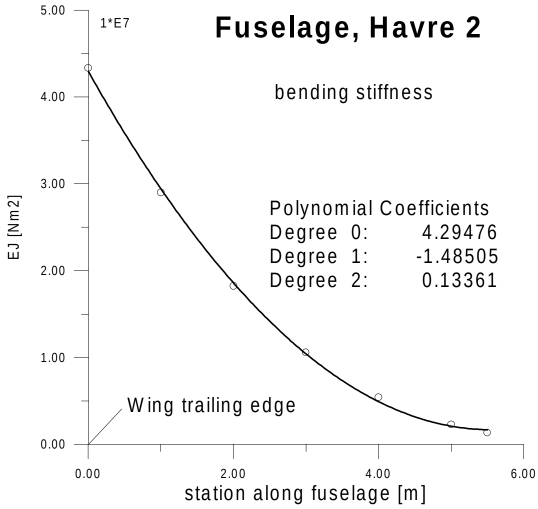

Fig.22 Bending stiffness along fuselage

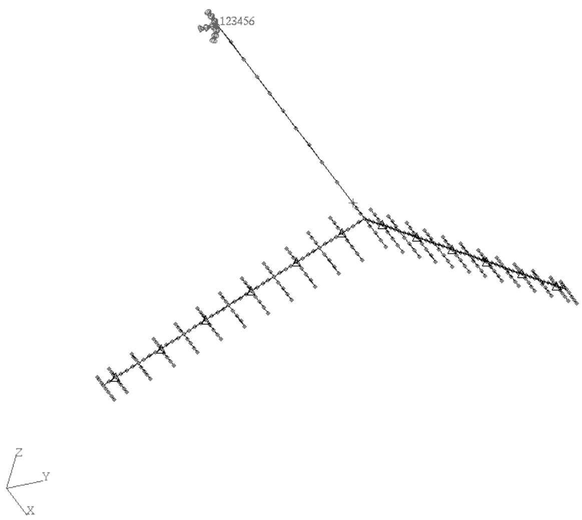

Fig.25 FEM model for tailplane

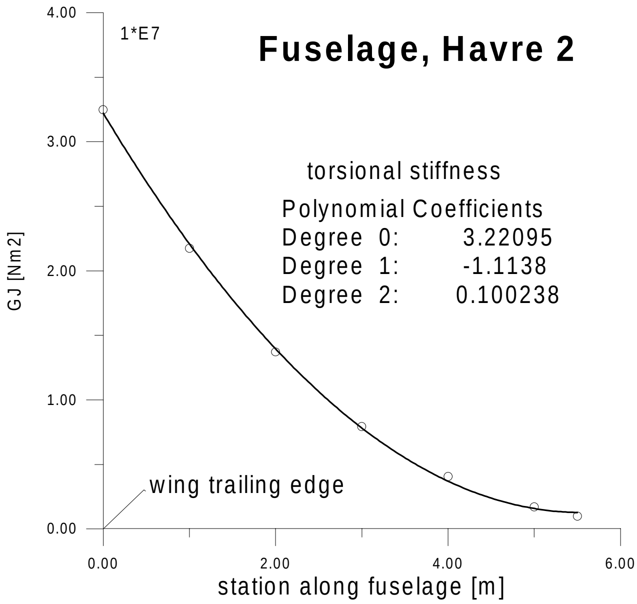

Fig23 Torsional stiffness along fuselage

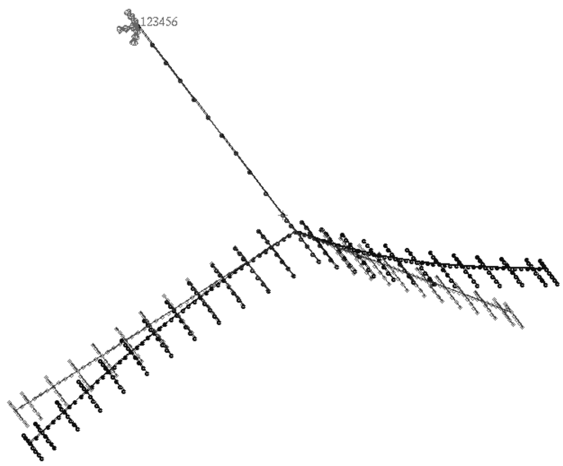

Fig.26 1st mode - frequency = 0.8 Hz

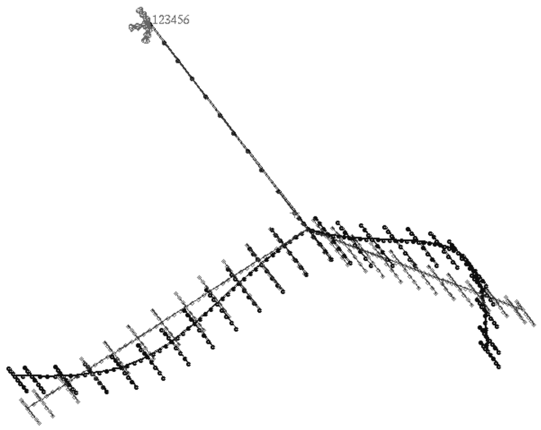

Fig.27 2nd mode - frequency = 3.1 Hz

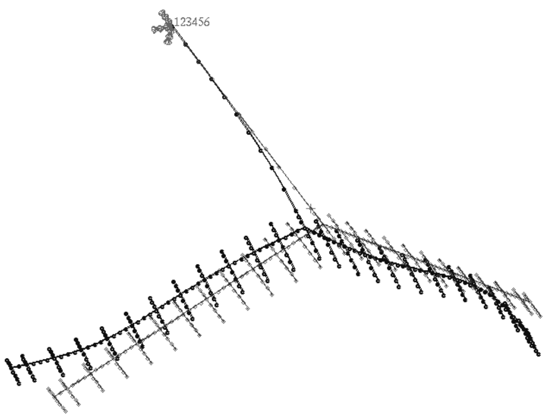

Fig.28 3th mode - frequency = 5.6 Hz

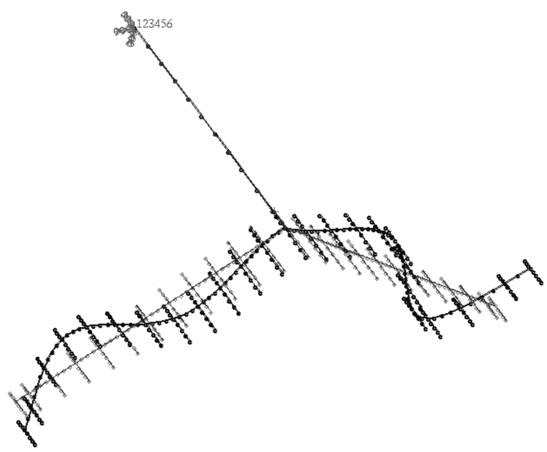

Fig.29 4rd mode - frequency = 8.2 Hz

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