ANALYSIS OF WING-FUSELAGE STRUCTURE INTERACTION UNDER ASYMMETRIC TORQUE

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ABSTRACT

The present paper solves the arrangement of the wing and fuselage structures with respect to the relative position of the large cutouts in both airframe parts. The finite element method based on displacement field is used for the analysis of wing structure, while the matrix force method as given by Prof. Argyris is used for the analysis of fuselage structure. A computer program for the combined displacement-force method is constructed. Numerical examples, representing different arrangements are included which illustrate the application of the method to practical problems. The calculated results are compared with those obtained by measurements.

INTRODUCTION

During the flight of the aircraft, the external forces acting on the wing form a space system producing distributed internal forces along the wing span. These loads can be either symmetrical or asymmetrical with respect to the plane of symmetry of the aircraft. For wing structures with large cut-outs, the most decisive load, from point of view of load transfer, is the torque moment.

The present work solves the arrangement of wing structure under asymmetric torque connected to multistringer fuselage structure. The problem is to find out the optimum arrangement of the central part of the airframe structure connecting the wing with the fuselage from the point of view of the position of the large cut-outs in both parts. This optimum arrangement is a step to reach the main goal of obtaining the minimum weight of the optimum arrangement of the structure(5).

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GENERAL FORMULATION OF THE PROBLEM AND METHODS OF ANALYSIS

The wing structure can be made either from one piece passing through the fuselage or can be splitted into two parts, each part separately connected to the fuselage. Here, it is discussed the case of a wing made from one piece passing through the fuselage. There are several ways for the connection of such type of wing structure with the fuselage. In the following analysis, it is assumed the case of four point connection of the wing to the fuselage. Such connection, under torque moment on the wing, is once statically indeterminate. For the solution, all four connections are released and the basic structure is then composed of separate wing and fuselage. The redundant unknown in the connection is a bimoment load in the form of four forces in the connection points.

To perform this redundant analysis, it is necessary to determine the stress distribution in the wing and the fuselage structures, each individually, under the external torque moment and the unit redundant bimoment load. The wing carrying structure is formed as a four-flange torsion box structure with finite number of ribs along the span. In the wing structure two large cut-outs exist for the retraction of the undercarriage. Such type of structure, under torque moment or bimoment load, is generally many times statically indetermined depending upon the number of ribs and cut-outs. The finite element method is used for the determination of the stress distribution in the wing structure(2). Under the basic assumptions of spar structures, it is divided into two basic types of elements(3):

- flange elements with linear variation of displacement in space,
- rectangular membrane elements with bilinear variation of displacements.

The fuselage structure is composed of a great number of longitudinal stringers and a number of transversal bulkheads covered by a stressed skin. In the fuselage structure, there is considered large cut-out. Thus, the fuselage structure is many times statically indeterminate depending upon the number of stringers,bulkheads and cut-outs. For the determination of the stress distribution in the fuselage structure, the matrix force method of fuselage analysis as given by Prof. Argyris (1), is used.

Then, the problem of wing-fuselage arrangement arises. This arrangement can differ according to the place of the connection with respect to the position of the large cut-out in the fuselage and whether it is necessary the wing part passing through the fuselage to be a complete torsion box or only two spars without covering skin. Therefore, the following four alternative arrangements are investigated:

a) Open fuselage and open central part of the wing.
b) Open fuselage and closed central part of the wing.
c) Closed fuselage and closed central part of the wing.
d) Closed fuselage and open central part of the wing.

The unknown redundant force, X_1, in the connection is determined from the

condition of compatibility in the connection expressed in the form:

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$$\Delta_{10} + X_1 \delta_{11} = 0 \qquad (1)$$

Where:

X_1 unknown redundant force in the connection.

Δ_{10} deflection of the connection point in the basic structure under external torque moment.

δ_{11} deflection of the connection point in the basic structure under unit bimoment forces acting in the connection points.

The values of Δ_{10} and δ_{11} are calculated for the wing and the fuselage structure using the principle of minimum strain energy (4). Since in the basic system the fuselage structure is not loaded by external torque moment, it is possible to write:

$$\Delta_{10} = \Delta_{10W} \qquad (2)$$

$$\delta_{11} = \delta_{11W} + \delta_{11F} \qquad (3)$$

where:

Δ_{10W} deflection of the connection point in the wing structure of the basic system under torque moment.

δ_{11W} deflection of the connection point in the wing structure of the basic system under unit bimoment forces acting in the connection points.

δ_{11F} deflection of the connection point in the fuselage structure of the basic system under unit bimoment forces acting in the connection points.

For the application of the method, a computer program, demonstrating the mixed matrix displacement-force methods, is done. A general block scheme demonstrating the program is given in Fig. 1.

MODEL ANALYSIS AND MEASUREMENTS

In order to verify the validity of the used theoretical methods, models are designed to suit as much as possible the mathematical model prescribed previously.

Wing model: it is designed as a two spar wing. Its cross-section is rectangular and constant along the whole span. Along the span, there are distributed 18 ribs. In the lower skin, there are two large cut-outs between ribs 4 to 6 and 13 to 15. The middle part of the wing, passing through the fuselage, is without upper and lower skins. The end of the wing is loaded only by means of torque moment. The stress distribution is measured by means of 52 strain gauges and 32 strain rosettes distributed along the wing model. All dimensions of the wing model and the positions of the strain gauges and strain rosettes are shown in Fig. 2.

Fuselage model: it is of two meters in length, with a large cut-out and there is no symmetry with respect to the cut-out. The fuselage model is ended by means of two closed diaphragms. They are used for the connection of the fuselage model to the stand. At one end the diaphragm has the connection in two points while the other end in one point only to enable the free twisting of the model. These connections also enable the free warping of the ends of the fuselage model. Its cross-section is of polygonal shape with ten sides not equal in width. The fuselage cross-section is symmetric with respect to the vertical plane and has no taper. The structure of the fuselage model is composed of longitudinal and transversal members. The distribution of the stresses is measured by means of 20 strain gauges and 64 strain rosettes. All dimensions of the fuselage model and the distribution of strain gauges and strain rosettes are shown in Fig. 3.

The wing model is connected to the fuselage model in 4 points on the upper flanges of the wing, two on each flange at the end of the middle open bay. The fuselage connections are performed at 4 points in places of the bulkheads at the end of the large cut-out of the fuselage and to the main longitudinal stringers No 5 and No 8. Between each lug of the wing model and the corresponding lug of the fuselage model, there are 4 intermediate sheets forming a triangle. On these sheets are glued strain gauges for the measurement of forces in the connections. The constructional schemes of the wing and the fuselage connections as well as the arrangement of the wing fuselage connection are shown in Figs. 4,5 and 6 respectively.

The wing is loaded at its ends by means of asymmetric torque moments. The stress distribution on the wing and the fuselage models and the forces in the connections are measured for different levels of external load.

ANALYSIS OF RESULTS

1) Comparison of calculations and measurements on wing and fuselage models assembly, both with large cut-outs.

The measured and calculated normal stresses along the flange of the wing are shown in Fig. 7. It is clear that the variation of stresses corresponds for both measured and calculated values. The greatest difference is in the closed part near to the wing tip and this is due to the effect of the loading. The other difference is in the closed bay near to the connection of the wing to the fuselage. This is due to the fact that the calculation assumes that the connecting point is totally restrained in all directions, but in the real structure the connection has a finite rigidity and thus the measured stress is smaller than the calculated one.

The forces in the connections due to external torque moment given from applied forces of 1000 (N) are obtained as follows:-

- calculated force is 871.11 (N)
- measured force is 765.42 (N).

The measured force is the average one of the four connecting points. The difference between the calculated and measured forces is relatively small and is due to the elasticity of the connection itself which is not taken into consideration during calculation.

The measured and calculated longitudinal forces in the stringers No 8 and No 11 of the fuselage model are shown in Figs. 8 and 9 respectively. It is clear from these results that the matrix force method gives relatively accurate results with respect to the measured one.

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From the previous results, it is clear that the method of analysis of the wing and the fuselage structures give relatively accurate results for the stress distribution in case of wing-to-fuselage assembly. Therefore, it is possible to choose the optimum wing-to-fuselage arrangement from the calculated results of all possible arrangements given previously.

2) Comparison of different wing-to-fuselage arrangements.

The forces in the connections due to an external torque moment given form applied forces of 1000 (N) for different wing-to-fuselage arrangements are obtained as follows:

a) Open wing and open fuselage : R = 871.11 (N)
b) Closed wing and open fuselage : R = 929.33 (N)
c) Closed wing and closed fuselage: R = 963.44 (N)
d) Open wing and closed fuselage : R = 897.12 (N)

It is seen that the variation of the reaction forces in the connections is relatively very small for different arrangements. The two extreme cases are when both wing and fuselage structures are with cut-outs or without cut-outs. Thus, these two cases are compared and the results of calculations are in Figs. 10 and 11. From Fig. 10, it is clear that the stresses in the closed wing with closed fuselage are smaller than in open wing with open fuselage. Generally, it does not exist a major difference in the normal stress distribution between both cases.

From Fig. 11, it is clear that the longitudinal forces in the stringer No 8 are nearly the same for both cases.

Thus, the stress distribution in the wing-to-fuselage structure assembly varies only slightly for different arrangements. The main difference is in the element near to the cut-outs. Therefore, it can be concluded from the above results that to reach an optimum arrangement, it is suitable to take the wing-to-fuselage arrangement with large cut-outs in both structural parts.

CONCLUSION

This work investigated the solution of asymmetric case of torque loads on the opposite sides of the wing structure connected by differently arranged central parts of the fuselage structure. The matrix methods of structural analysis proved to be very efficient in solving such type of problems. This investigation showed also that the different wing-to-fuselage arrangements have relatively small influence on the stress distribution on both aircraft parts. Thus, to obtain the minimum weight of both parts, it is preferable to use them both with large cut-outs in the place of the connections.

The methods introduced in this work can be used in further investigations by elaborating more complex and accurate solutions for different loading cases on real wing-to-fuselage structures since they can be directly used for the calculations of longitudinally stiffend skin wing structure and fuselage structure with taper. A following step in this work is to apply an optimization technique to reach the minimum weight of the structure of the chosen arrangement.

REFERENCES

1. Argyris J.H. and Kelsey.S., "Modern fuselage analysis and the elastic aircraft", Butterworths, London, 1963.

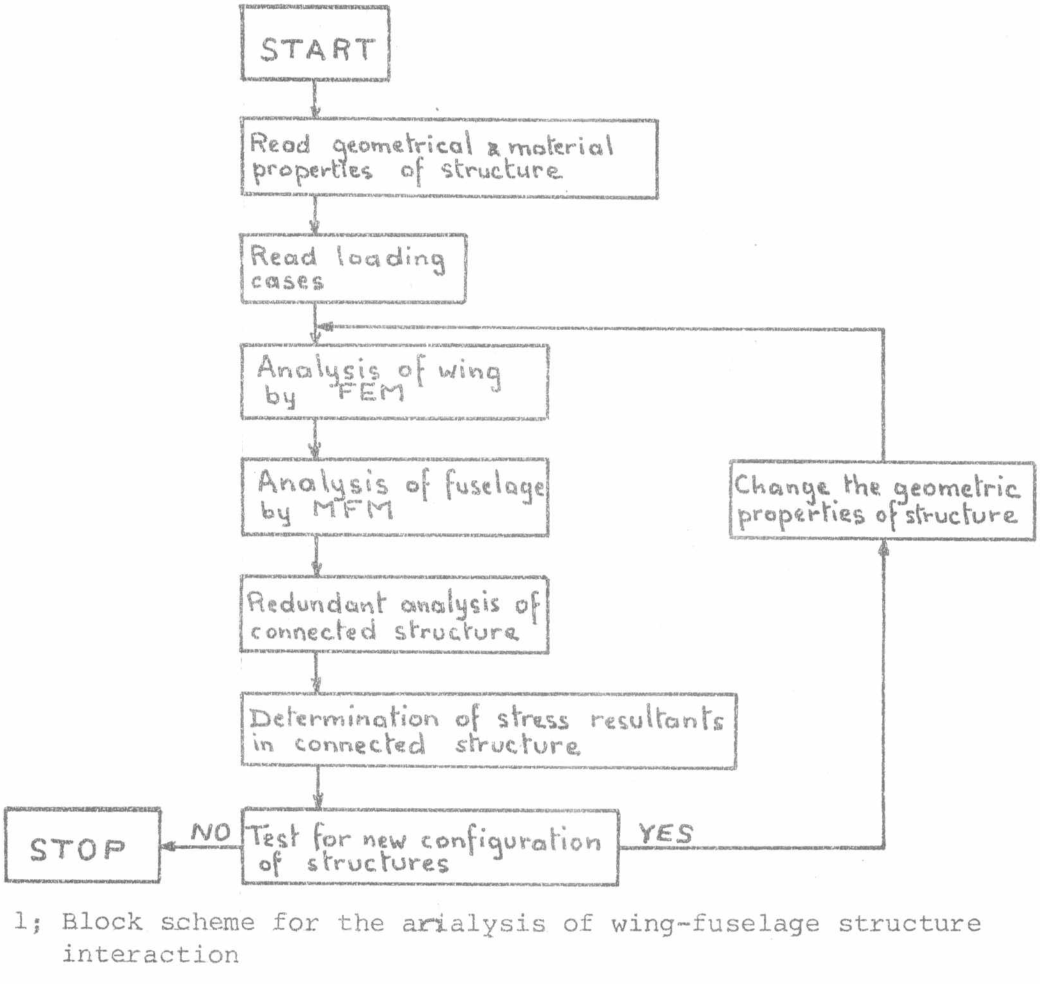
2. Zienkiewicz O.C. and Cheung Y.K., "The finite element method in structural and continuum mechanics", McGraw Hill, New-York, London, 1967.

3. Robinson J., "Integrated theory of finite element method -Fundamentals and applications", Academic Press, New York, 1973.

4. Valenta J., Němec J. and Ulrych E., "Novedobé metody vypočtů tuhosti ve strojirenstvi ", SNTL, Praha, 1975.

5. Gallagher R.H. and Zienkiewicz O.C., "Optimum structural design -Theory and applications", John Wiley & Sons, London, 1973.

6. ElNomrossy M. and Kholoussy M.I., " A variational approach to the analysis of thin walled structures", Proceedings of first conference for theoretical and applied mechanics, Cairo, 1980.



Fig, 1; Block scheme for the analysis of wing-fuselage structure interaction

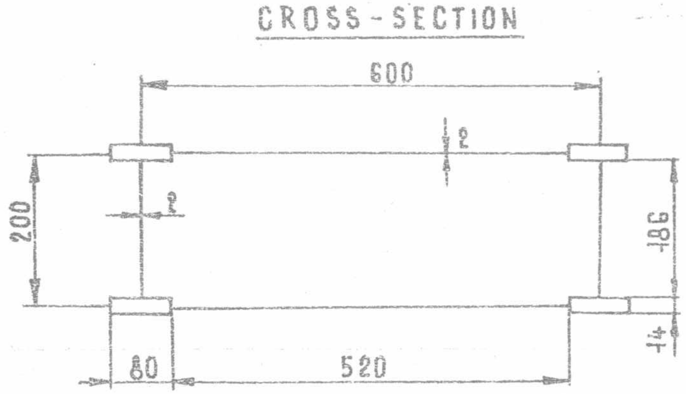
<u>Material</u> : NOVODUR

<u>Thickness of inner ribs</u> : 2 [mm]

<u>Thickness of end ribs</u> : 8 [mm]

- points of strain gauges on flanges

ᴪ points of strain rosettes on sheets



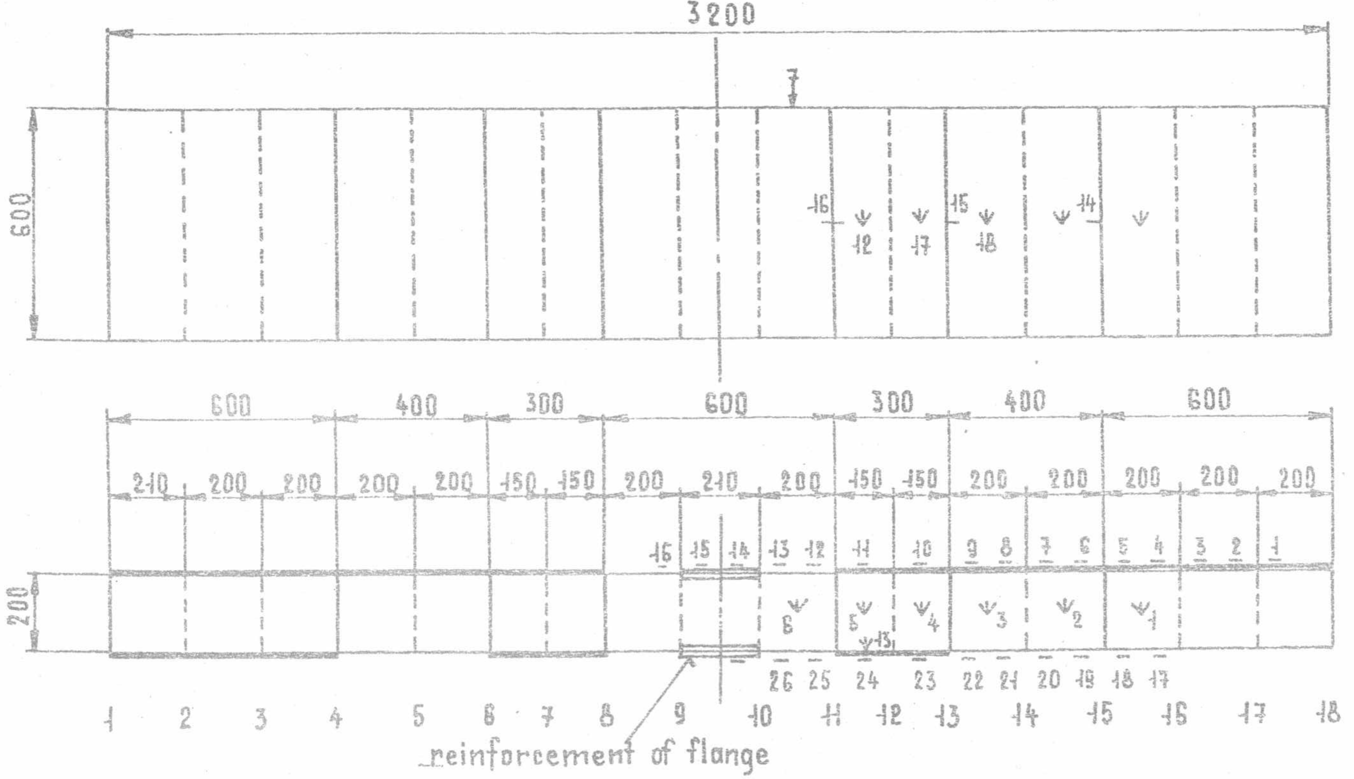
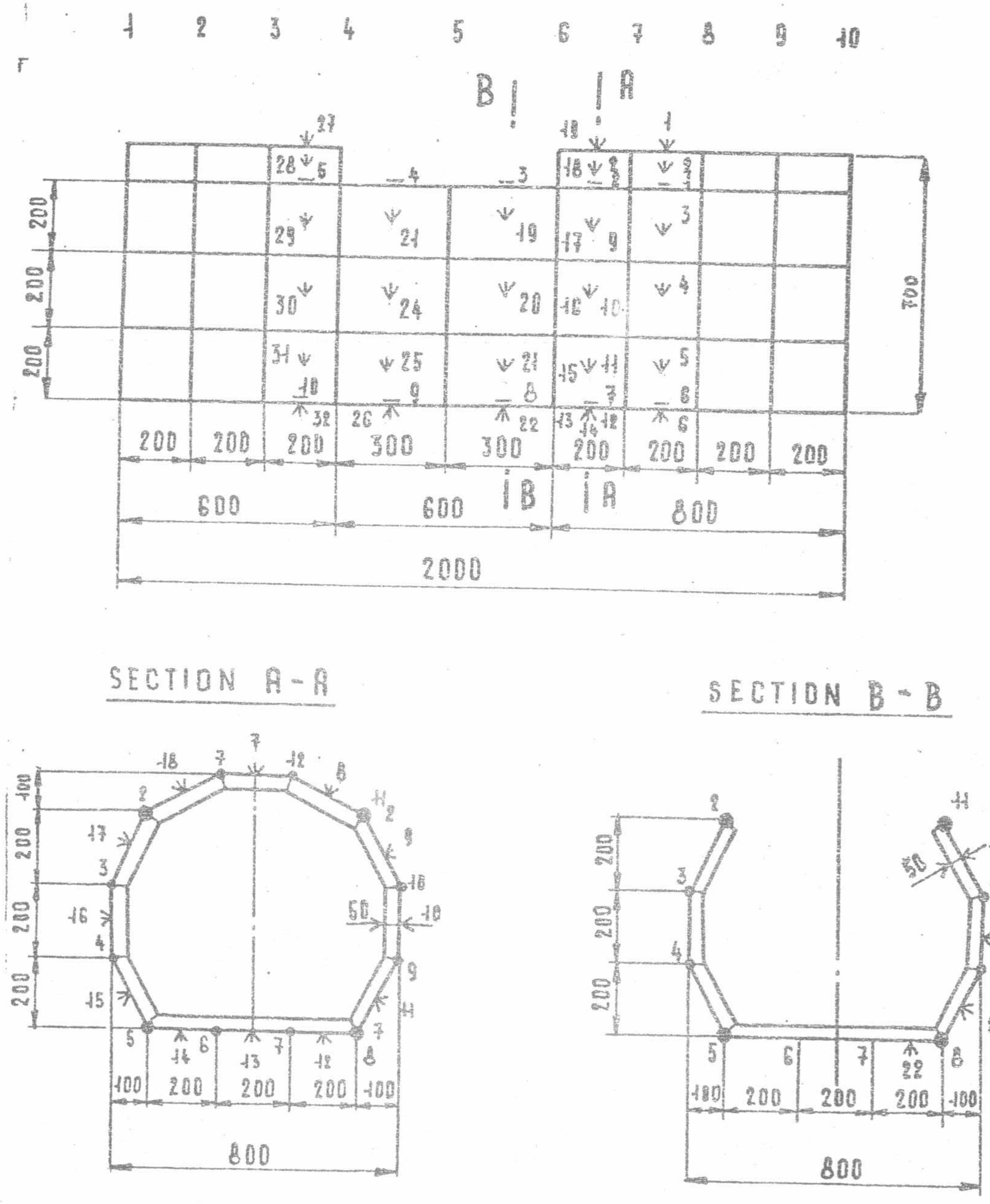


Fig. 2.1 Scheme of wing model with internal ribs



Material : NOVODUR

Thickness of bulkheads 4 and 6 : 5 [mm]

Thickness of bulkheads 2, 3, 5, 7, 8, 9 : 2 [mm]

Thickness of ending diaphrams 1 and 10 : 20 [mm]

– points of strain gauges on main longitudinal stringers № 8 and № 11.

ᴪ points of strain rosettes on sheels

Diameter of main longitudinal stringers № 2, 5, 8 and 11 : 13 [mm]

Diameter of longitudinal stringers № 1, 3, 4, 6, 7, 9, 10 and 12 : 8 [mm]

Fig. 3.: Scheme of fuselage model

Material: DURALUMIN

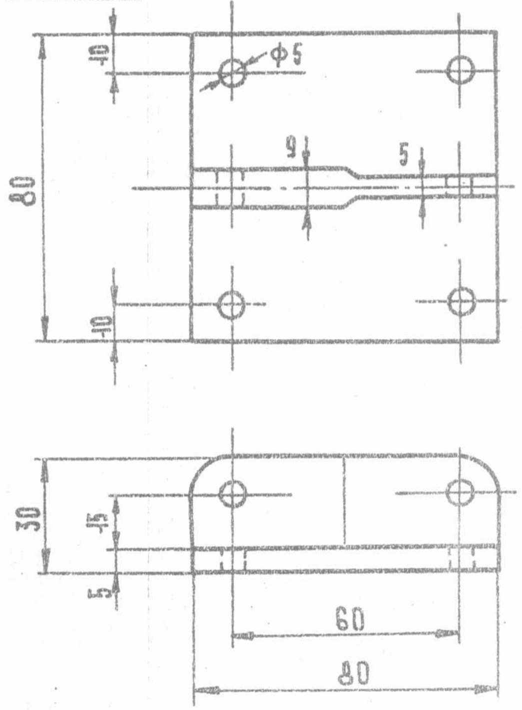
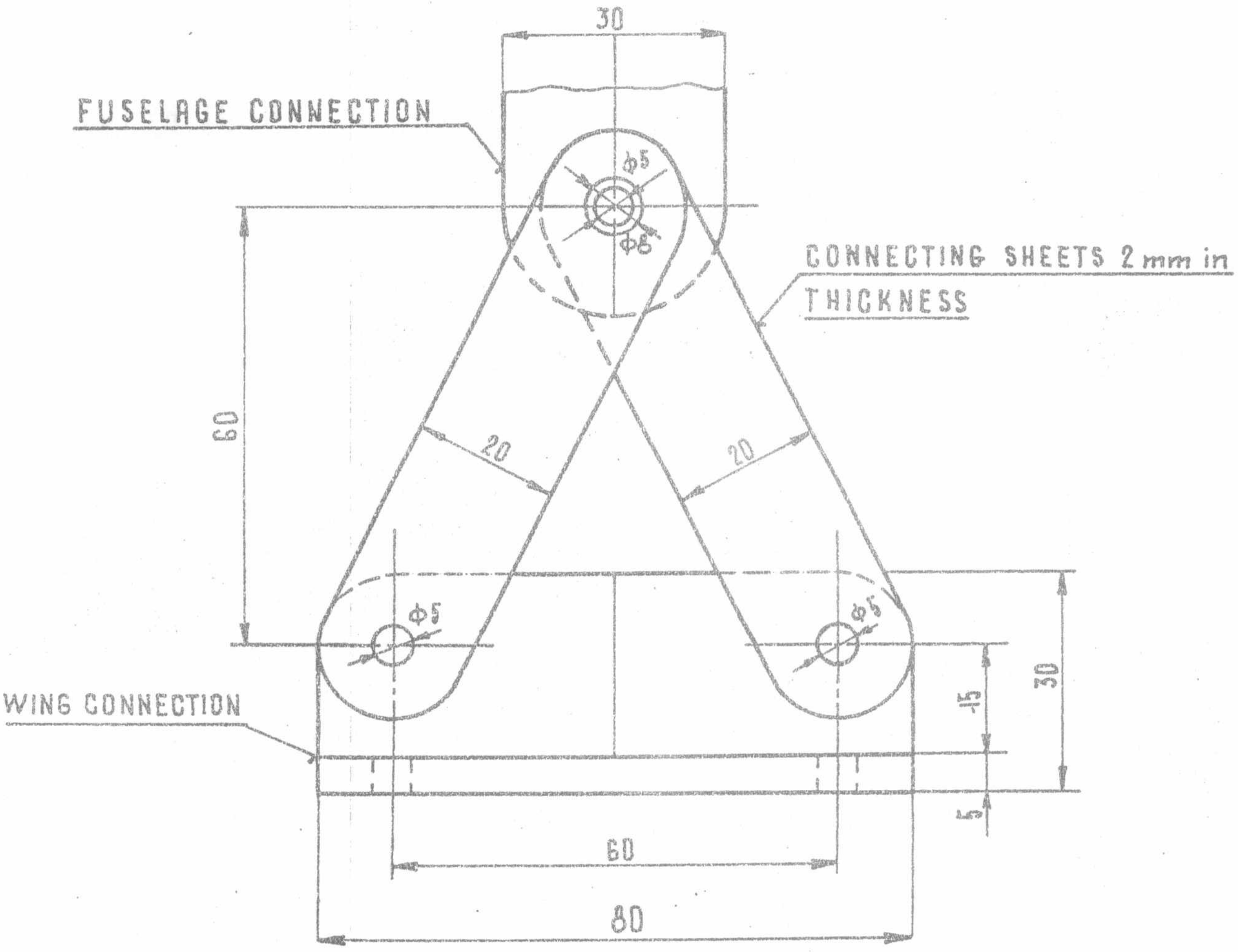


Fig. 4.: Scheme of wing connections

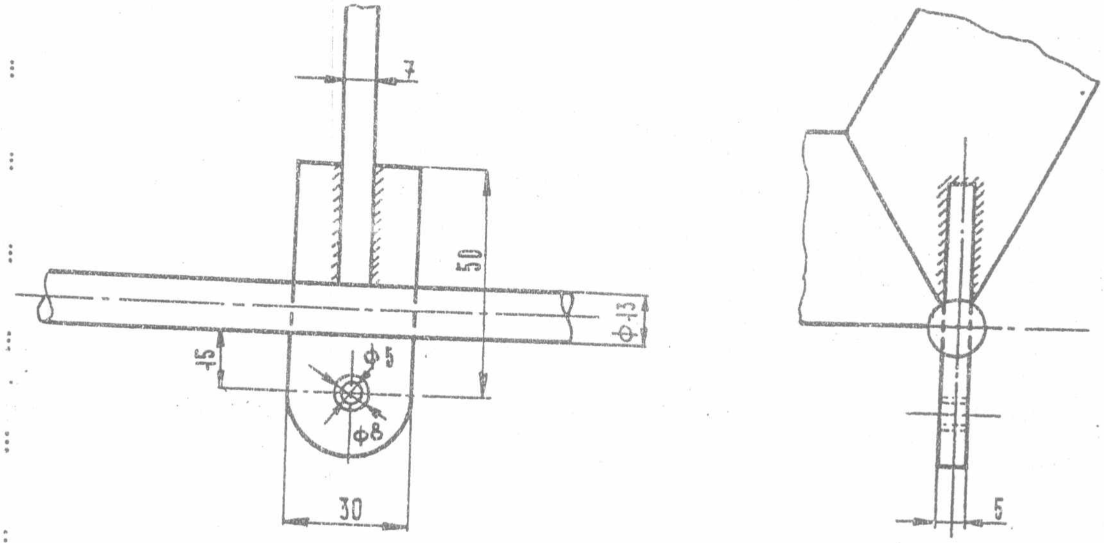


Material of connecting sheets: NOVODUR

Fig. 6.: Arrangement of wing-to-fuselage connection

a) FUSELAGE CONNECTION TO BULKHEAD № (4)

Material: NOVODUR



b) FUSELAGE CONNECTION TO BULKHEAD № (6)

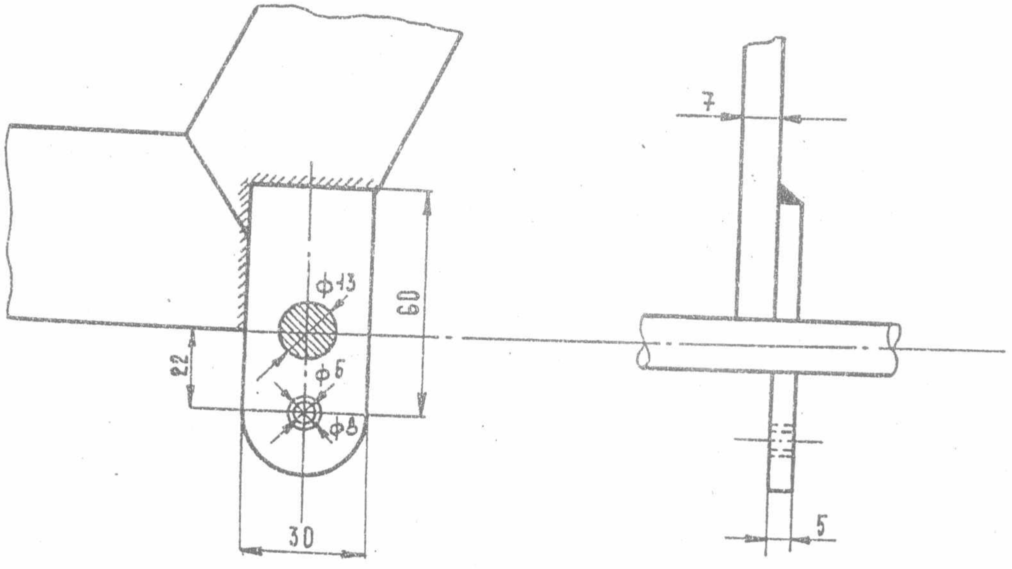


Fig. 5.: Scheme of fuselage connections

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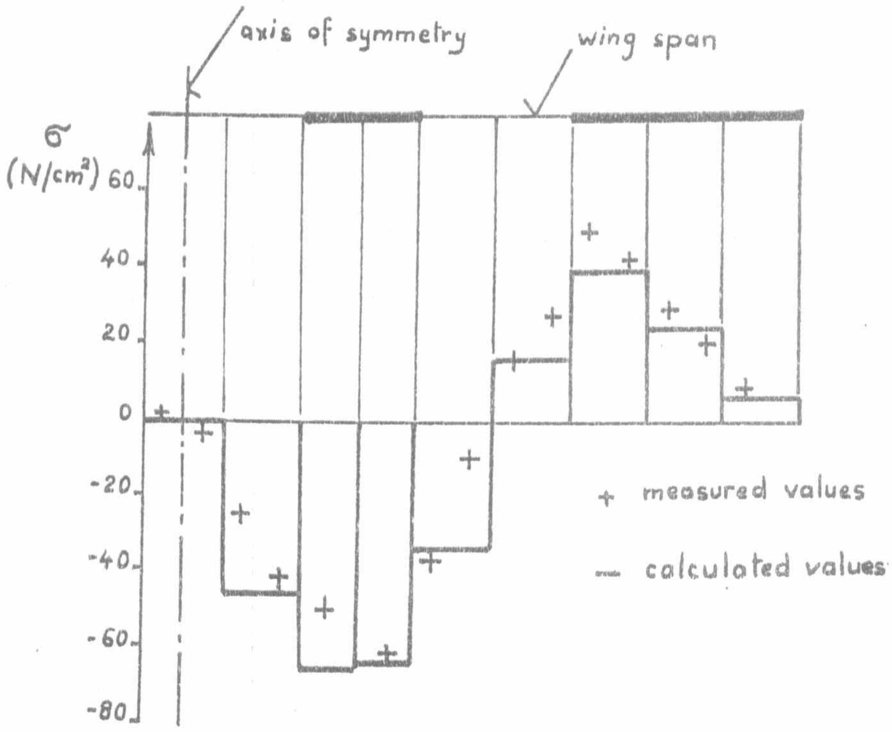

Fig. 7: Stresses in wing model under asymmetric torque of Forces 1000 (N)

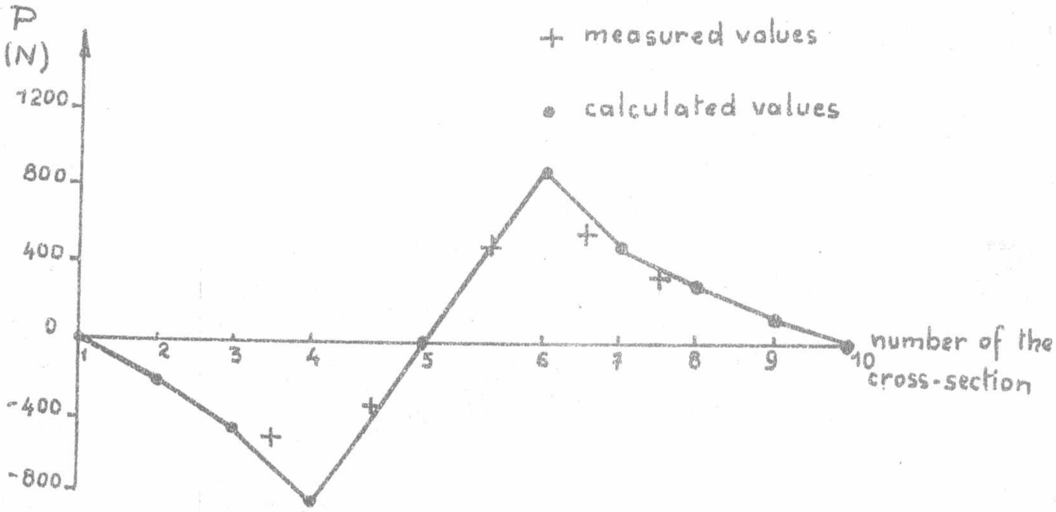

Fig 8: Distribution of longitudinal forces in stringer No 8 of the fuselage under asymmetric torque of forces 1000 (N)

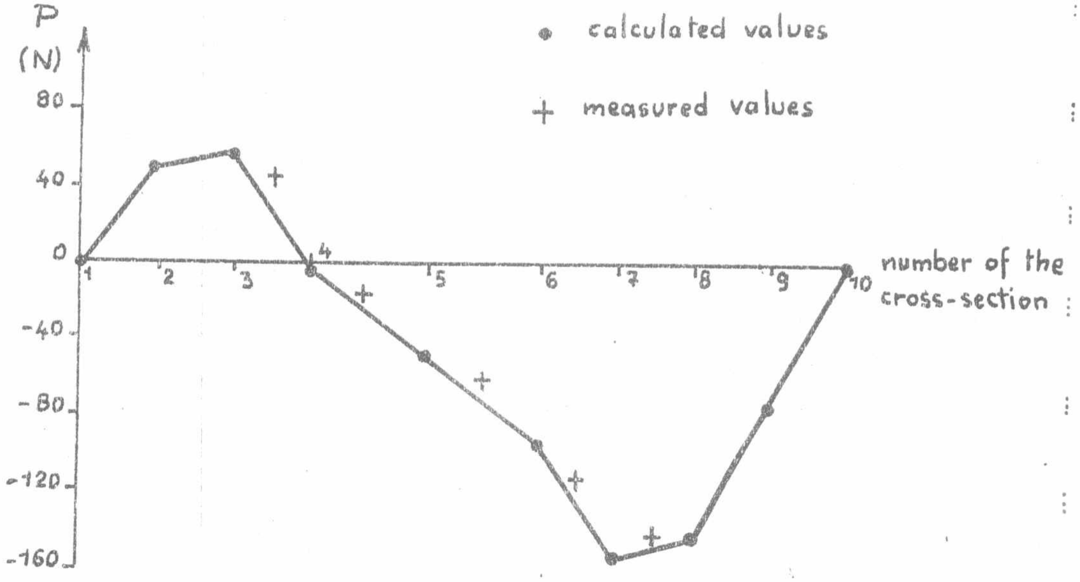

Fig. 9: Distribution of longitudinal forces in flange No 11 of the fuselage under asymmetric torque of force 1000 (N)

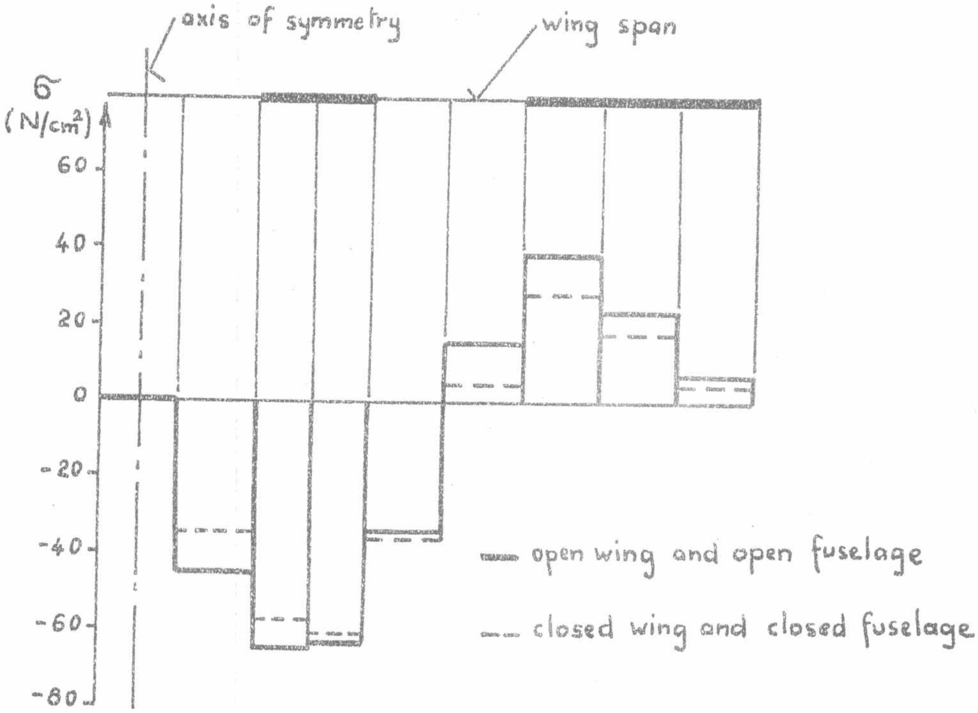

Fig. 10: Stress distribution in the flange of wing model under asymmetric torque of forces 1000 (N) for different arrargements of wing and fuselage

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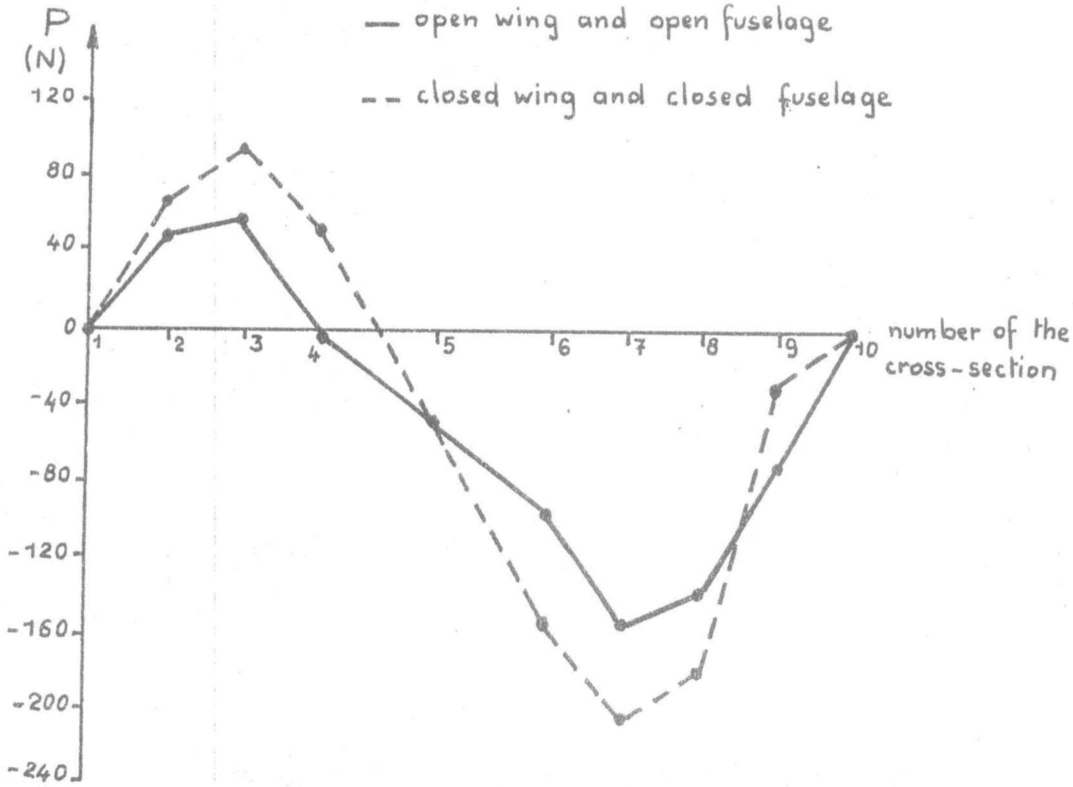

Fig. 11: Distribution of longitndinal forces in stringer No 11 of the fuselage for different arrangements of fuselage and wing under asymmetric torque of forces 1000 (N)