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VALIDATION OF DESIGN METHODS AND DATA BY FLIGHT TEST

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1. Introduction

In the period of design of a new aircraft theoretical maneuvers are carried out using detailed wind tunnel aerodynamic data combined with all other theoretical data as are e.g. stiffnesses, geometry, massdistributions and system informations.

These theoretical design maneuvers are presented in known requirements as are FAR, BOCA and JAR.

Due to these requirements design loads are determined rather by defining the control surface deflections to permit calculation of the aircraft response and thus of the component loads.

Normally this work will be started a long time before any component of the new aircraft is produced.

It is evident that design loads determination under such conditions are usually done by an iterative process ('loads loop') which converges on the final state of data and results at least in the design loads.

These final design loads are used for structural justification and certification of the present Airbus A 310 aircraft.

Now it stands to reason that one would like to know the relationship between the theoretically calculated loads and the real loads in flight by flight test measurement.

Military specifications have required flight load measurements for a long time. Of late special requirements of FAR 25 demand flight load measurement for commercial aircrafts, too.

But additional to these requests, manufacturers of aircrafts are highly interested in flight measurement of loads to find out reliability and validation of the used data and methods.

Furthermore flight tests are done with the special aim of finding out structural margins allowing to build a more economical aircraft without any decrease in the level of safety.

In picture 1 a procedure is shown giving a view about the validation procedure of design methods and data.

It can be seen that the validation is an iterative process which consists of several circuits. Each circuit represents a check of a special data set used for loads calculation.

Mainly three parts are defined

- o rigid aerodynamic/stiffnesses
- o flexibilization
- o methods

Today mathem. modelling of aircraft motion in rigid body modes are of great acuracy, the overall rigid aerodynamics obtained from windtunnel evaluation are the same as well.

Basic assumption for a reliable comparison is the demand that the same methods and data have to be used than for design ones.

The only input data, not used for design are as follows:

- o time history of control deflections
- o mass distributions
- o flight conditions

These data are taken directly from the flight test transfer tapes.

Loads calculated with these data are compared with loads measured during the flight and showed in the following chapters.

This report concerns as an example for the total flight load investigation the loads at tailplane due to an elevator induced maneuver.

2. Design Maneuver Loads

For design purposes of large aircrafts like the Airbus A310 the official requirements of FAR 25 and in future the new european requirement JAR 25 have to be applied.

In these requirements the pilot's action is given in general as a control movement of the controls (elevator, aileron, rudder ect.) - each on its own - and the calculation of the response of the aircraft requires to take into account sufficient degree of freedom [1].

The control angles may be limited by any of the following:

- o control steps
- o hydraulic characteristics
- o max. hinge moments
- o max. pilot efforts
- o any other limitation if installed.

All in the requirements requested design maneuvers have to be investigated within the whole flight envelope taken into account all available design data. The philosophy is described in [2]. Result of these load investigations build the maneuver loads envelope expressed by spanwise distribution of shear, bending and torsion or combination of them [1].

3. Flight Test Loads

The flight test is carried out with a normal aircraft, which will be used in airline service after finish of flight test program.

The aircraft equipped with strain gauges for load measurement passes a flight test program of more than 100 flights within a year for performance, handling quality, structural loads and other purposes.

That means about 500 flight hours are available for different evaluation work. From these great number of flight hours time slices interesting for load evaluation are selected.

The **test** measurement data run a validation procedure to find drop outs, fading of strain gauges and to check the plausibility.

The results of the validation procedure are e. g. the correction of the angle of incidence, angle of sideslip ect.

With the checked data the real structural load evaluation is done.

3.1 Flight Test Equipment

The aircraft is equipped with a weight and balance system consisting of fixed ballast in the fuselage and water ballast in both cargo compartments.

The C.G. position can be changed during flight by pumping waterballast from one compartment to the other.

This allows to fly extreme C.G. positions for a short time period or to guarantee a constant C.G. position during the whole flight.

To check the aircraft response during flight an "On board computer" is installed which is equipped with two screens positioned on the flight engineer panel.

The first screen shows the flight test engineer the important flight data which are necessary to check during each flight. The second screen serves to observe different tasks which can be changed before and during flights.

During structural flight test all load parameters run a limit check program and are shown on the second screen.

These limits are defined by 80 % of the design loads of each measurement section.

A special interface allows the flight test engineer to take hard copies of the information shown at the second screen.

During other flights (performance, handling quality) only selected load parameters run the limit check program and is shown on the first screen together with an acustic warning, if the limit is reached or exceeded.

Besides this "On board computer" magnetic tape recorder and brush recorder complete the recording system.

On the tape recorder the total amount of measurement parameters are recorded during the whole flight.

The line prints of the brush recorder are used besides other criteria to select interesting time intervals for load evaluation.

3.2 Flight Test Measurement

The first step to measure flight loads with strain gauges is to select the measurement stations.

Stations with local stress concentration can not be used, otherwise the strain of the structure have to be high enough, to obtain sufficient measurement accuracy.

The best places for the strain gauges are those which are assumed to show linear relationship towards loads.

In picture 1 the loads measurement stations of the test aircraft are shown.

The optimal bridge selection can be carried out in regard to load error and number of strain gauge bridges. The realization can be done either in generating electrical bridge summation or by recording single bridge responses and add those signals by computer in the laboratory.

The advantage of the computer method consists in the great flexibility of bridge combination calculations. If a strain gauge is no longer usable for measurement, another bridge combination with the lowest error can be calculated.

By an electrical summation a new bridge combination can be realized only with expenditure of work and time delay in flight test program.

3.3 Flight Test Load Determination

The flight loads are measured indirectly with the well known method of Skopinsky [3]. That means the output of the strain gauges as a nondimensional gauge response due to load will be recorded and after flight test transformed into shear, bending and torsion with the β-coefficient matrix obtained by the strain gauge calibration.

A load equation can be developed in the following form:

$$L = [\mu_1 \; \mu_2 \; \mu_3 \; .. \; \mu_j] \begin{Bmatrix} \beta_{11} \\ \beta_{12} \\ \beta_{13} \\ \vdots \\ \beta_{1j} \end{Bmatrix}$$

L - load
β - influence coefficient
μ - strain gauge response

The load calibration will be performed by applying discrete loads in a grid pattern over the component.

During the calibration more discrete loads than the number of strain gauges have to be introduced at the structure, to obtain a over-determined equation system.

With this equation system the probable error of the load vector and the scatter of the coefficient can be calculated. Thus redundant and irrelevant bridges can be detected and deleted.

4. Results and Comparisons

4.1 Moving Parameters

Taking into account the same kind of control deflections and the same flight conditions as measured in flight the response of the aircraft is calculated by use of design programs and data (aerodyn., efficiencies ect.). This is done for all those time slices which have shown sufficient magnitude of control deflections and consequently sufficient change in moving parameters which on the other hand produce a sufficient level of loads.

The calculated moving parameters are compared as function of time with the measured ones. From all evaluated flights an example is given in fig. 1 to 4 which is an elevator induced maneuver.

Fig. 1 shows the elevator movement as measured during the flight. This measured elevator deflection is used unchanged as input data for the simulation program.

In fig. 2 the corresponding measured loadfactor is given in comparison to the calculated loadfactor, fig. 3 shows the incidence, fig. 4 the corresponding pitch.

The close curves of measured and calculated moving parameters demonstrate the good level of data evaluated from windtunnel tests and shows the accuracy of all other necessary data.

Furthermore proves the good agreement that the mathematical model used takes into account all main effects including nonlinearities so that the dynamic response of the aircraft is sufficient reproduced theoretically.

These sufficient agreements are exspected because such investigations have been carried out in our department since years and meanwhile done as a standard procedure.

Evaluation of flight test measurement are done for a lot of time slices selected from all usable flights.

They all show the same result as given in the example presented here. Worth to mention is that the rigid derivatives used are flexibilized by a common procedure which is explained in ref. [4].

This flexibilization procedure takes into account the stiffnesses of the particular components and determines in combination with the rigid aerodynamic distributions the flexible aerodynamic.

The flexible coefficients which are function of Machnumber and of dynamic pressure are introduced in simulation programs for the design maneuvers. The flexible aerodynamic distributions are used to calculate the loads contribution along span.

4.2 Loads

The corresponding loads due to the a. m. elevator induced maneuver are shown in fig. 5 and 6; fig. 5 gives the shear on tailplane at measurement station, fig. 6 the pertinent bending.

Both loads represent in a good manner the total envelope of flight load measurement because the relationship between measured and calculated values is similar in all evaluated flights.

At the starting-point of the evaluation which normally is the steady level flight a constant difference between measured and calculated load can be seen. This difference is also found in angle of trim.

The difference in loads remain nearly constant during the whole time slice, that means the correlation and phase of measurement and calculation is acceptable. In all evaluated flight-loads on tailplane the calculated loads are found to be conservative.

4.3 Modification of Data

Due to the fact that the measured loads at tailplane are a certain margin lower than the calculated loads the interest question of reason arises and the question with which modification in data it will be possible to achieve agreement in loads.

In an extended investigation a lot of data variation are carried out using different kind of methods.

One modification which leads to a sufficient coincidence of measured and calculated load is a change in zero pitching moment C_{mo} and in elevator efficiency $C_{A\eta}$.

In fig. 7 (shear) and fig. 8 (bending) the loads comparison after data modification is given and it can be seen that the curves of measured and calculated loads are closely in agreement.

The dynamic behaviour of the aircraft remains unchanged.

5. Conclusion

From the total envelope of flight tests a lot of evaluations for loads are carried out, a great part of them concerns elevator induced maneuvers.

As said before it has been shown that for a given time history of elevator deflection and with knowledge of the aircraft moving parameters the horizontal tail loads are readily calculable.

The close coinincidence in moving parameters is excellent; in loads there are certain differences (measured loads smaller than calculated) which could be reduced by modification of data.
Taking into account these modification of data in design maneuvers no higher loads level is found than used for design.

This means that from the point of flight test evaluation there is no structural margin in static design deducible.
For fatigue purpose the level flight loads can be reduced because the tailplane loads in this case are a certain margin lower than in theoretical calculation depending on Machnumber.

References

[1] FAR 25, Part C
§§ 321, 331, 349, 351, 333, 335

[2] MBB-UT/TN-TE271/4-81
Philosophies of Methods
Vertical Maneuvers/Lateral Maneuvers
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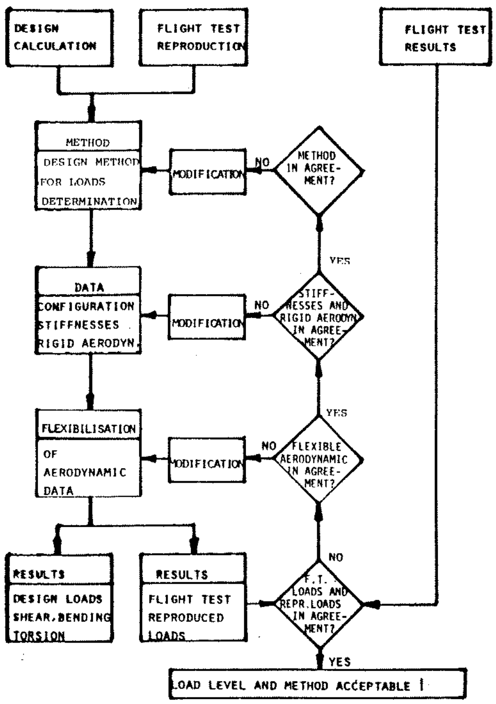
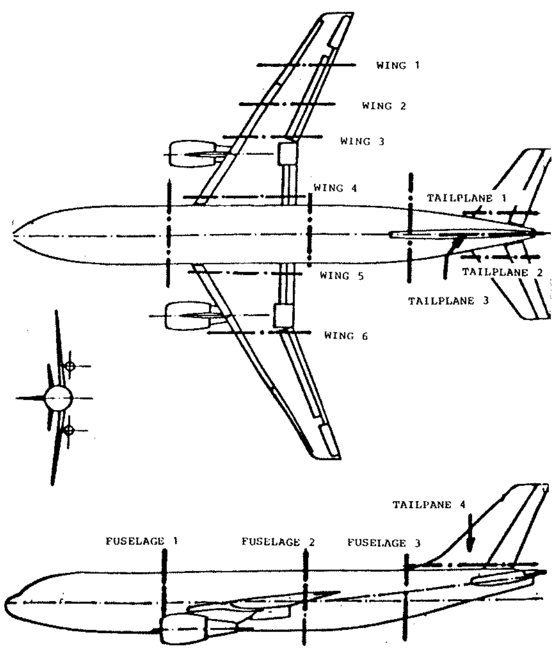
[3] NACA-Report 1178
Calibration of Strain Gauge Installations in Aircraft Structures for the Measurement of Flight Loads
Skopinski, Aiken Jr., Huston

[4] MBB-UT/TN-TE271/5-81
Philosophy of Methods
Flexible factors
Möbest



Pict. 1: Validation Procedure



Pict. 2: Measurement Stations

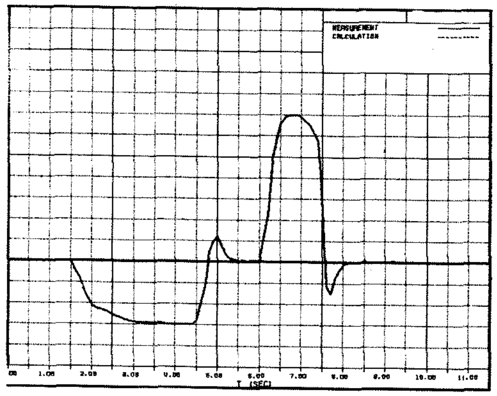


Fig. 1: Elevator Deflection

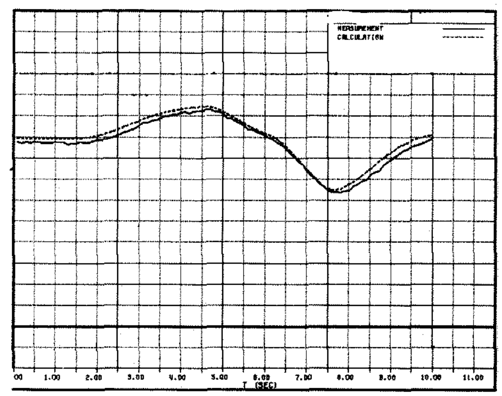


Fig. 3: Incidence

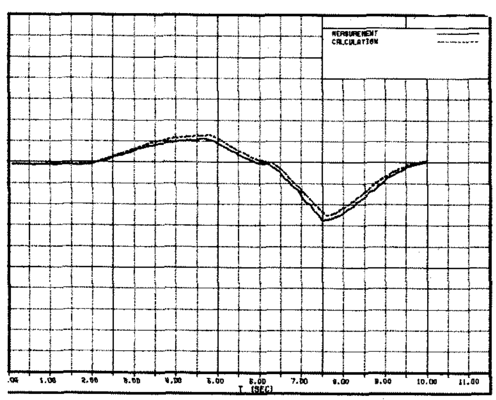


Fig. 2: Load Factor

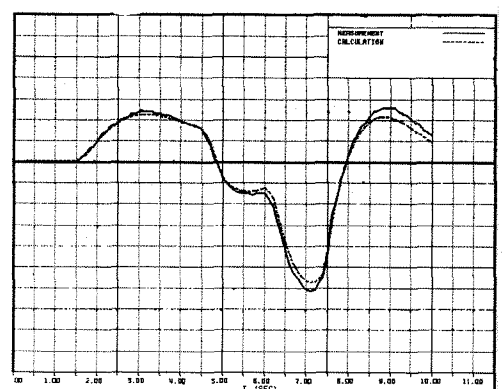


Fig. 4: Pitch Rate

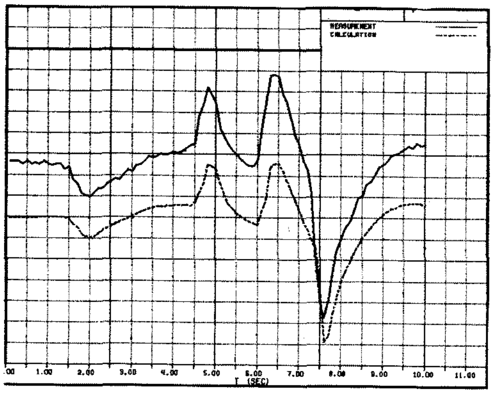


Fig. 5: Shear Force

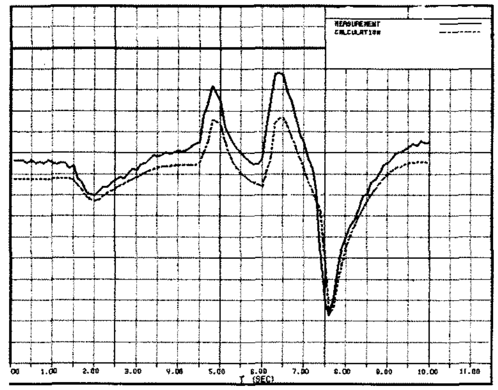


Fig. 7: Shear Force
After Modification

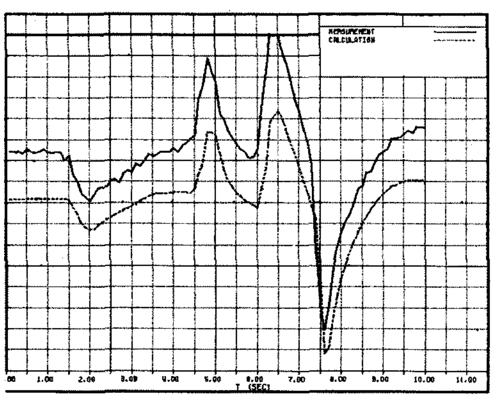


Fig. 6: Bending Moment

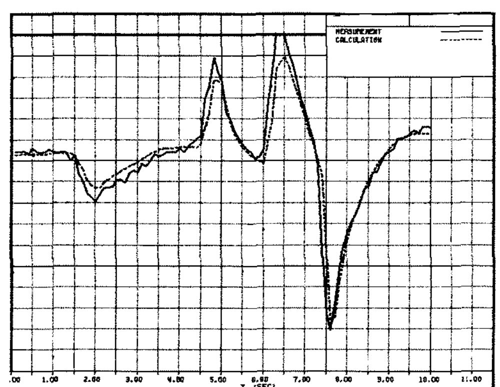


Fig. 8: Bending Moment
After Modification