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FLIGHT TEST VALIDATION OF THE OPERATIONAL LOADS MONITORING SYSTEM (OLMS)

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Abstract

The prospected Airframe Condition Monitoring Procedure (ACMP) needs an appropriate on-board equipment. The Operational Loads Monitoring System (OLMS) can be regarded as an advanced device for this purpose. OLMS is an electronic device to be fitted on aircraft in airline service. The principle feature of OLMS is to calculate loads which will be reduced instantly to frequency distributions. The OLMS input data will be received from avionic systems providing full information about the actual operational condition. OLMS is therefore the tool for the Airline Service Data Collection as the first step in the ACMP which takes care of damage tolerance qualities and will increase the efficiency of structural inspections.
The OLMS as an device needing no extra sensors and cable looming necessitates a verification and validation of its appropriate operation prior to introducing it into the aircraft in airline operation.

The methods used, the experiences gathered the limitations and future aspects are subject of this presented paper. The basic philosophy behind the OLMS, the advantages for A/C-operators and A/C-manufacturers will only be touched here since several presentations have already taken place [1,2].

Nomenclature

F, G, G_Q	Matrices in time continuous system
Φ, Γ, Γ_Q	Matrices in time discrete system
H	Matrices of the measurement system
R	Covariance of the measurement error
Q	Covariance of system noise
N, K	Number of samples, Index
α_0	Incidence of zero lift
c_{m0}	Pitch moment of zero lift
$\delta p, \delta q, \delta r$	Control surface deflection
$\delta_{cz\alpha} / \delta_\alpha \triangleq c_{z\alpha}$	Derivative of lift force
$\delta_{cm\alpha} / \delta_\alpha \triangleq c_{m\alpha}$	Derivative of pitching moment
Cx	Derivatives on grid points
α, β	Incidence angle of sideslip
p, q, r	Roll, pitch and yaw rate
nx, ny, nz	Longitudinal, lateral, vertical loadfactor
c/g	center of gravity

Introduction

New civil transport aircraft equipped with Electronic Flight Control Systems (EFCS) allow for the complete digital information about all its operating conditions. Since load relevant parameters like accelerations, control surface deflections etc. can be received from sophisticated avionic and control systems, the use of this information as input data for an OLMS is logical.

OLMS is such an advanced monitoring system which is under development for the A320 now (see Fig. 1). It can become the basis for an ACMP, with the aim to perform structural inspections on condition (Fig. 2).

Fig. 1 TEST AIRCRAFT

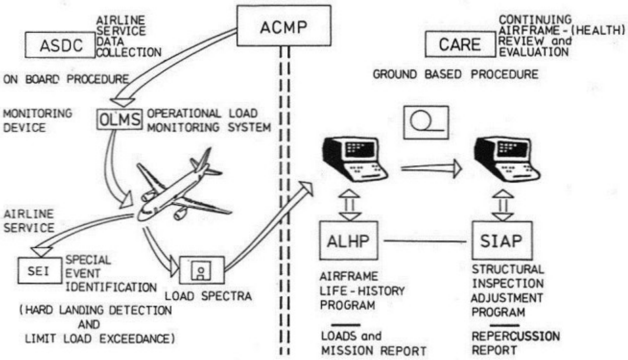


Fig. 2 AIRFRAME CONDITION MONITORING PROCEDURE

It was decided in an early stage, that the qualification of such a system will be conducted with a prototype and the decision to launch the development for the serial device will be made on the findings during the qualification phase. The flight test verification was planned to commence in early 1989 and to finish by mid of 1990. Unfortunately the flight qualification phase was delayed by 8 months. So the start of this period was in October 89. The due date for flight test finalization is now planned for end 1990. Nevertheless the elapsed 6 months of flight test verification revealed a great deal of interesting findings worth to be reported.

Architecture and working principle

Since a serial device is planned for in-service operation one of the design aims is a small size. As a reasonable size it is intended to use 3 boards (2 for processing and memory, 1 for power supply) housed in a 3 MCU-box (ARINC norm) to be placed in one of the electronic compartments, see Fig. 3.

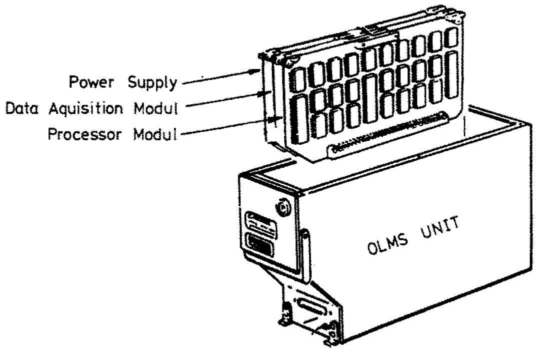


Fig. 3 EXAMPLE FOR THE OLMS HARDWARE INTEGRATION (SERIAL DEVICE)

As mentioned above, for development purposes a special device has been designed incorporating all OLMS features.

Due to the fact that for this special test system no extreme weight restrictions have to be observed and in order to ease the verification and validation process a real time M-VAX-Computer including an ARINC 429 Data-Bus-Interface Unit has been incorporated in an A320 test A/C.

Data Processing and Reduction

In principle three major functions are integrated in the OLMS

a) Data Acquisition
This will be managed by the already mentioned interface unit.

b) Data Processing
In this function the loads will be calculated but also typical data to determine the mission profile will be accumulated.

c) Data Reduction
In this function the statistical counting methods (RTRF etc.) will be used to analyse the load time histories and allow for a data storage in small sized memories.

As an additional option, in-flight events can be made available directly after or during flight, such as heavy/overweight landing, exceeding of limit loads etc. Points a, b, c and options will run online in real time.

The data acquisition unit receives, identifies and accommodates the data from the different A/C systems for further processing in the real-time (RT) computer. Both, the interface unit and the RT computer are housed in a rack located in the vicinity of the A/C-Data Aquisition System for flight test purposes. Prior to giving more details about data-processing the loads to be processed will be summarised.

Fig. 4 demonstrates the main components selected for loads calculation (bending, shear force, torsion). Additionally the hinge moments on primary flight control (ailerons, elevators and rudder), normal forces on secondary flight controls (slats/flaps, spoilers) are included. In total 43 quantities are determined but the number can be increased.

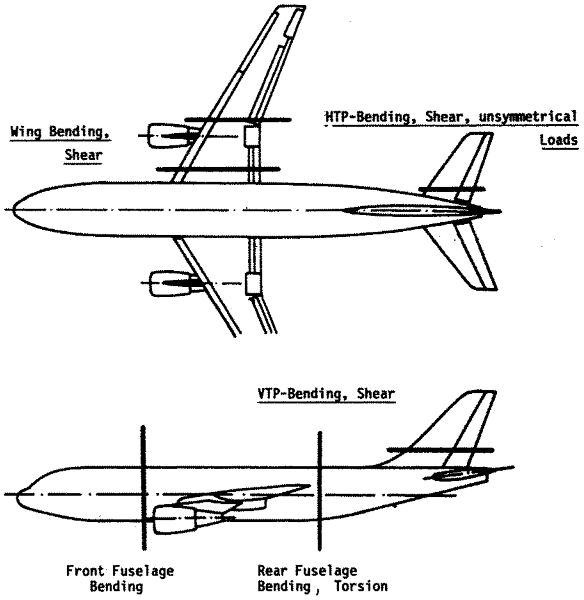


Fig. 4 MAIN COMPONENTS FOR LOAD CALCULATION

To ensure a proper calculation all necessary input parameters have to be tapped from the systems. A summary of these parameters and the concerned systems are depicted on Fig. 5.

PARAMETER	SYMBOL	ALPHA COD.	SYSTEM	REMARKS
Machnumber	Ma	MN	ADIRU	
Altitude	H	ALT	ADIRU	(ft)
True airspeed	V_{TAS}	TASP	ADIRU	
Position of cg	cg	CG	FMGC	calculated
Gross weight	W_g	GW	FMGC	lbs,calculated
Load factor	n_z	VRTG	ADIRU	
Load factor	n_y	LATG	ADIRU	
Cabin diff. pressure	Δp	PDC		
Total air pressure	p_∞			
Time (flight duration)	t	T	FDIU	Duration between Flight ph. ② and ⑨
Flight phase		PH 1-10	FWC	
Fuel		FUEL		RH Wing fuel Total fuel
Roll rate	$p, \dot{p}$	ROLR,ROLA	ADIRU	
Elevator position	δ_η	ELEV	FCDC	
Pitch rate	$q, \dot{q}$	PTCR,PTCA	ADIRU	
Angle of attack (correc.)	$\alpha, \dot{\alpha}$	ADIRU	ADIRU	A1-11/1
Rudder position	δ_r	RP	SDAC	
Yaw rate	$r, \dot{r}$	YAW,YAWA	ADIRU	
Aileron position	δ_p	AILR	FCDC	
Spoiler position	δ_{SP}	RHSPL	FCDC	RH Spl 1,3,5
Slat position	δ_{SL}	SLAT	SFCC	
Flap position	δ_{FL}	Flap	SFCC	
Stabilizer position (Trimm)	$\delta_{\eta Tr}$	STAB	FCDC	
Engine thrust from EPR	T_N	EPR	DMC	EPR ENG 1 EPR ENG 2
Radio height	RALT	RALT	DMC	Hard landing detection
Flight No			CFDIU	A1-24-1
Engine Revolution N_1 CFMI	N_1			
AC/Tail No.				

Fig. 5 OLMS INPUT PARAMETERS

The mentioned 10 computer buses, from system 1 and system 2 of the A/C are connected to the OLMS interface. Errors of one system will automatically cause a change-over to the other system.

For the processing of the data to achieve loadings at the mentioned sections or flight controls the equivalent equations will be used as taken for loads calculations during the development phase of the A/C-type itself. A typical example out of the 43 in total the recalculation of the shear force of a wing section outside the landing gear will be demonstrated.

MASSES INFLUENCES

$$\mathrm{WSM_1} = -(\mathrm{WM_1} + \mathrm{FUEL_1})(\mathrm{VTRG} \cdot \mathrm{G} + \mathrm{YWPP} \cdot \mathrm{ROLA} + \mathrm{XWQP1} \cdot \mathrm{PTCA})$$

AERODYN. INFLUENCES

$$\mathrm{WSA_1} = \mathrm{S} \cdot \mathrm{Pd} \cdot [\mathrm{B}(\mathrm{C8} + \mathrm{C9} \cdot \mathrm{AOA}) + (\mathrm{C2} + \mathrm{C3} \cdot \mathrm{AOA} + \mathrm{ROLR}\,\frac{\mathrm{LA}}{\mathrm{V}}\,(\mathrm{C30})) + \\ + \mathrm{AILR}(\mathrm{C32}) + \mathrm{RHSPL3}(\mathrm{C34}) + \mathrm{RHSPL5}(\mathrm{C36})]$$

$$\mathrm{WS_1} = \mathrm{WSM_1} + \mathrm{WSA_1} + \mathrm{TRANSFERFUNCTION}$$

Fig. 6 LOAD EQUATION FOR WING SHEAR RIB 10/11

The abbrevitions used for the quantities are tabulated on Fig. 7
CX are the aerodynamic derivitives. Any CX is stored in its own matrix for Mach-Nos (MN) and dynamic pressure (Pd) influences. As initial values for the aerodynamic derivatives the valid aero-data bank have been used (adaptions and adjustments see in the next chapter).

No	Component/ Parameter		Loading	Flightphase (A320 FWC)	Correlation (additional)	Remarks
1	Wing	Rib 1/ 2	S_z, Mb_x, Mty	2 - 9	Compound Probability Pod Pylon P_y/Mb_x Rib 1/2 for flightphase on ground/ in air	
		Rib 10/11	S_z, Mb_x			
2	Fuselage	Fr. 29/30	Mby	2 - 9	counting of Mb_y Fr 29/30 in 4 ranges of Δp_{diff} Flightphase 5 - 7	
		Fr. 48/49	Mt_x, Mb_y, Mb_x			
3	H T P	Rib 4/ 5 Horizontal Tailplane	S_z, Mb_x	2 - 9		
			M_R	on ground 2,3,4,8,9 in air 5 - 7		
4	V T P Rib 2/3	Vertical Tailplane	S_y, Mb_x	on ground 2,3,4,8,9 in air 5 - 7	Compound Prob Mb_{xVTP}/M_{RHTP} 5 - 7	
5	Pod Pylon		P_y			
6	FLaps	inner	Normal force P_N	2 - 9		
		outer	Normal force P_N	2 - 9		
7	Slats		Normal force P_N	2 - 9		
8	Spoiler		Hingemoment	2 - 9		
9	Elevator		Hingemoment	2 - 9		
10	Rudder		Hingemoment	2 - 9		
11	Aileron		Hingemoment	2 - 9		
12	Radio Altitude		Sink. Speed	7 - 8		1 value per flight
13	Loadfactor n_z		n_z	on ground 2,3,4,8,9 in air 5 - 7		
14	Loadfactor n_y		n_y	on ground 2,3,4,8,9 in air 5 - 7		
15	Derived gust UB		UB	5 - 7		
16	Ailerondeflection		δ_p	4 - 8		
17	Elevatordeflection		δ_q	4 - 8		
18	Rudderdeflection		δ_r	4 - 8		
19	cab. diff. pressure		Δp_{diff}	5,6,7		3 values per flight
20	Stabilizer position		δ_{qTH}	5,6,7		3 values per flight
21	c/g position		% MAC	1,10		2 values per flight
22	Fuel state			1,10		2 values per flight
23	a/c weight		W	1,10		2 values per flight
24	Altitude		H	6		1 value per flight
25	Flight duration		T			1 value per flight
26	No of flights		Flight No			1 value per flight*

* cumulative

Fig. 7 OLMS CALCULATED LOADS

As an appropriate update rate for the loads calculation 50 sps has been chosen. To ensure the real time operation with the recently available CPUs a special assessment have been made for interpolation.

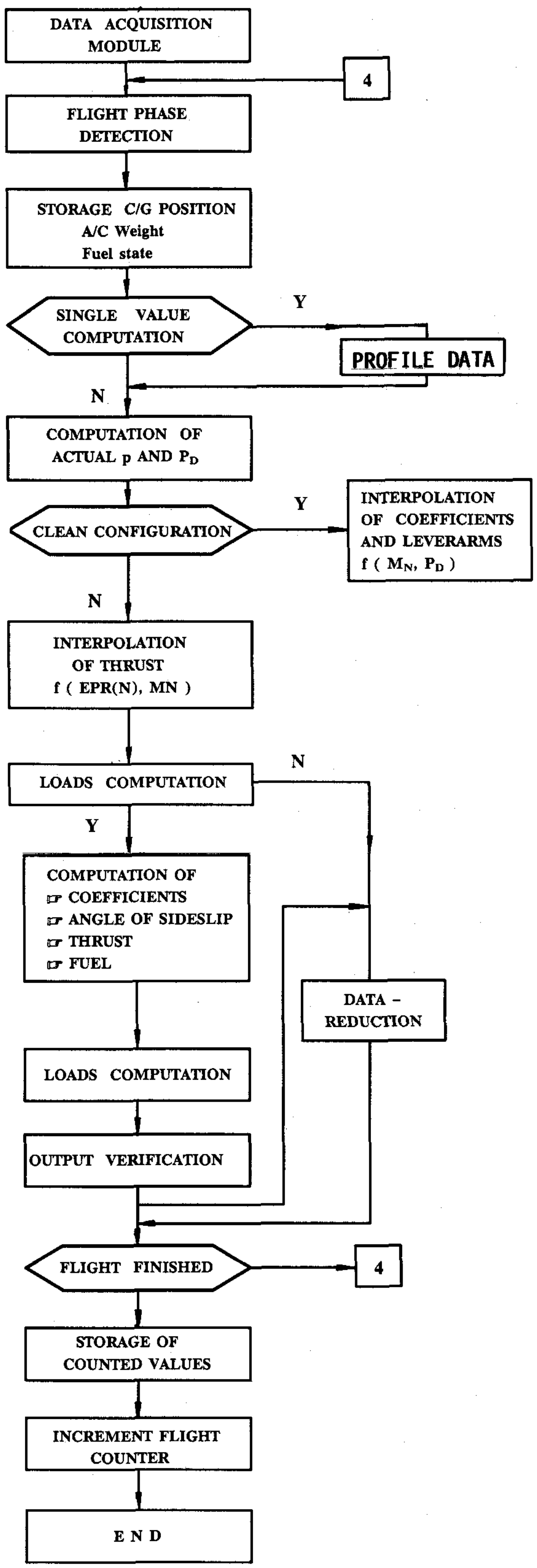
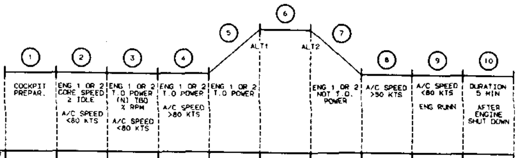


Fig. 8 FLOW CHART OF OLMS PROCESSING

As mentioned the aerodynamic derivatives are given in a MN and Pd-grid. Between the grid points a linear interpolation is required.

Since MN and Pd changes are slow compared to the quantities such as α, β or load factors an interpolation will be managed every 50 time steps only, this means once per second. The same is valid for the MN and altitude correction of the thrust model. The impact on the calculated loadings is below the threshold of accuracy which can be achieved (see next chapters). Incorporated is also a calculation of gusts (PRAT-Formular). A flow chart of the data handling in the data processing module is depicted on Fig. 8. This module contains also the calculation of the relevant mission profile data.

As can be seen from Fig. 8 a logic decision to incorparate different flight stages is included. The necessary information is tapped from the Data-Bus (FWC-System, Fig.9) and will allow for a flight phase related data reduction to distinguish between ground cases and flight cases or between initial climb and cruise etc, see Fig. 7.



PARAMETER NO	FLIGHT PHASE / PARAMETER	ELECTRICAL POWER ON	TAXI OUT	TAKE OFF ROLL 1	TAKE OFF ROLL 2	TAKE OFF CLIMB	CRUISE	FINAL APROACH	LANDING ROLL	TAXI IN	ENGINE SHUT DOWN
60.1.021.01.12 60.1.021.01.13 60.1.021.01.14	NOSE GEAR LH GEAR RH GEAR	GROUND		GROUND	GROUND	AIR	AIR	AIR	GROUND	GROUND	GROUND
26.1.126.01 BIT 11-14	FWC FLIGHT PHASE	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010
7C.1.270.01.13 7C.2.270.10.14	STARTER AIR VALVE										
04.1.365.01	IVV INERT.VERT VELOCITY										
06.1.203.01	ALT						≥ ALT1				
18.1.127.01	SLAT										
7C.1.133.01 7C.2.133.10	THROTTLE RESOLVER ANGLE										
POSSIBLE PREVIOUS FLIGHT PHASE		10 OR 2		9	8	7	7	6	4	3	

Fig. 9 FWC - FLIGHT PHASES

For the data reduction a derivative version of the rainflow-counting method (RTRF), the range-pair-range counting method RPR has been selected, see Fig. 10.

This method is regarded to be the most appropriate for all follow-up work as fatigue or crack propagation exploitations. For the investigation of coupled loadings such as the carry-over of shear force and torsion a two-dimensional counting method (compound probability) is added. Due to this on-line data reduction the necessary capacity for data to be stored is dependent on the number of quantities, product of counted classes and ranges (semi-matrix) and the number of flight stages only. An addition for compound probability and mission profile analysis had been considered.
With 50 classes and ranges and the above mentioned addition a memory capacity of 512 K-words is sufficient. In the development phase this memory is realized by a tape since more capacity is necessary for the verification process (next chapter). In the serial solution this memory will be realized by EEPROM's.

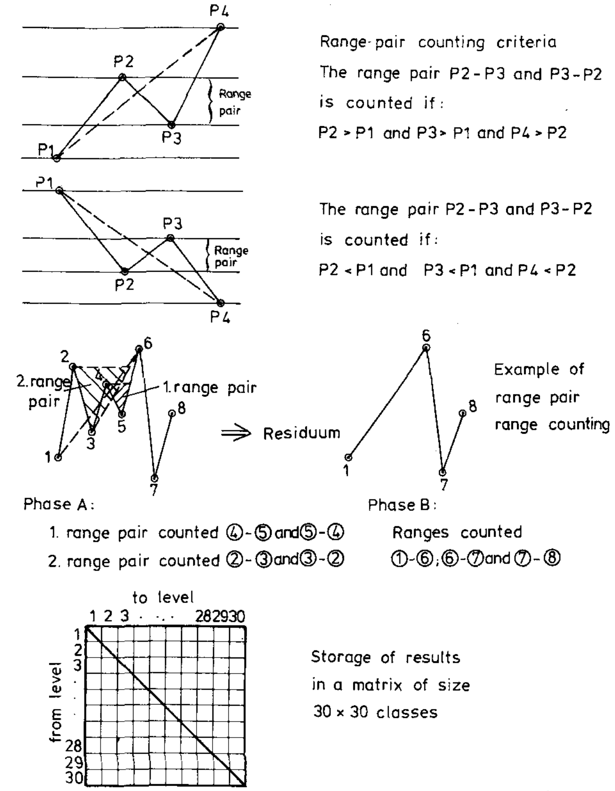


Fig. 10 DESCRIPTION OF THE COUNTING METHOD

The OLMS is designed for data retrieval any 1000-2000 flights. The limitation is given by the word length only (loadings) and the number of the flights (mission profile data). For event monitoring a report will be triggered during or after flight and will not use additional memory.

Flight Test Verification and Validation

The following questions concerning the verification of the OLMS were regarded

a) System interferences
b) Real time behaviour
c) Quality of recalculated loads
d) Quality of reduced data
e) Appropriate capacity of the memory

For the answer on the question b) through e) there is no difference between the prototype and the later envisaged serial solution. So the findings gathered during flight test verification of the development unit are representative and need merely a check of the correct implementation to make it valid for in-service usage.

System interference

This question can not totally be answered with the selected development unit. So the investigation of system interference was reduced to the check that no impact is possible from the OLMS-unit to the A/C systems and that the OLMS-unit meet the requirements for secondary systems under development conditions.

A comprehensive investigation concering interference when the OLMS will become a serial unit is essential.
In the following questions b) through e) will be treated.

Real time behaviour

The implementation of the OLMS in the aircraft including hardware and software revealed, that it was no problem to realize an update rate of 50sps for all three steps with the required number of quantities to be calculated. That means in particular, that in the 20ms time period all three steps: acquisition, data processing (loads) and data reduction (statistics) are possible with sufficient reserve.

It is necessary to point out that the first step:data acquisition has a constant computing time. The second step has a constant block-time for any 50 time steps (see further above). For the third step the elapsed time varies with the flight stage and as a natural corollary of this with the dynamic behaviour and complexity of the signal.
Special emphasis has been laid on the variation of the residuals to be counted (see description of RF or similar counting methods) which directly will impact the time consumption. Besides some theoretical investigations including worst cases in a realistic scenario the OLMS has been checked under real conditions in the test aircraft since autumn 89 up to now.

From the achieved results the conclusion can be drawn that the computer power of a M-VAX under a real-time operating system (VAX-ELN) is sufficient for this task. There is a large number of CPU's with a comparable power or even more which are small enough to be placed on one or two cards together with the necessary memories (0,5 Mbyte) to be housed in a 3 MCU-box.

Recalculated loads

The total required accuarcy of the recalculated loads is dependent on the task. It is obvious, that a perfect agreement is not possible since there is no absolute quality to compare.
The desired quality to be achieved is given by the number of classes to be counted in the data reduction step. This number is dictated by the required accuracy for fatique assesments.

A total accuracy between 3% and 5% seems to be sufficient for all subsequent work to be done in ACMP. The chosen 50 classes allow for a ± 1% discrimination (2% total) of the mean value related to the total range. The same is valid also for the width of a range pair. In principle the design limits (loads) or the area of operation (other quantities than loads) respectively have been chosen as total range. Consequently all further work concerning accuracy of the OLMS-recalculation function are measured on this fact.

It should be pointed out, that during normal operation only a fraction of the design limit loads will be encountered. This fact rectifies the high number of classes.

The verification of the loads recalculation includes the steps:

- comparison of recalculated (OLMS soft- and hardware) and measured quantities
- check of measurement quality
- adaption and improvement of the recalculation software (data and methods).

During the whole procedure the main flight quantities such as altitude, speed, MN rates, acceleration (including a position correction) were regarded as accurate and only a comparison between received OLMS-data and quantities of the data acquisition system has taken place. Anemometrydata such as incidance (α) and angle of sideslip (β) have been checked during the normal flight test phase and the addition to the corrections which are allready implemented in the air data computer (ADIRU) have been added to the OLMS-software (dynamic and damping corrections). For this the relevant kinematic relation is used.

The quality and repeatability can be regarded as to be sufficient.

A big item is the verification of the loads calculation algorithmen itself. Prior to conducting any comparision with measured loads those were checked very thoroughly.

Loads measurements in the test aircraft were realized by calibrated strain gauge arrangements as it is the state of the art [3].

During the flight test phase of the aircraft the principle errors of the measurements have been recognised and cured such as

- long term drifts
- residual thermal drifts
- problems of repeatability.

All those findings have been used for the OLMS verification work.

As expected, the biggest measurement problems were represented by the drifts. Since the OLMS recalculations incorporate no drifts, very thorough investigation of the reference conditions have been performed to overcome this particular property during the comparison.

The other major item to solve was the treatment and/or correction of the data incorporated in the OLMS software.

These data were:

- geometrical/configuration data
- mass data
- thrust models
- atmospheric data
- aerodynamic data

During the verification phase the geometrical and configuration data from the test A/C have been used. Prior to in-service operation possible changes and modifications have to be considered. As an example a modification of the slat/flap angle can be cited.

Concerning the mass data the components leading to the OWE are incorporated in the OLMS-software. In order to cope with the different mass distributions the possible loadings of the A/C including the fuel state is incorporated. An automatic recalculation of the weight and balance of the A/C is managed by the FMGC.

For in-service operation it is planned to use as start condition the data from the weight and balance system (if present) or the initial value will be entered by the crew via ARINC data bus.

To cope with the discrete loads (fuselage loads) the loading plan No. are received from OLMS and processed. Incorporated are also the discrete loads from the landing gear (derived from weight and c/g-position of the A/C).

For the thrust model the data for the actual engines are included during the verification period. To cope with the different engine types the thrust models of all selected engine manufacturers are included and will be activated by the A/C identification No.(A/C-Tail No.). Due to the complexity of this item no validation of the thrust model has been undergone. The impact on the loads calculation due to possible errors are believed to be small. Athmospheric data are calculated by the norm athmosphere by using the normal temperature distribution under ISO-conditions.

The biggest job is to adapt the aerodynamic data (derivatives and coefficients). As already mentioned, the aerodynamic data are stored as grid points representing different MN and dynamic pressures (due to A/C-flexibility). These values have been taken from the aerodynamics data bank and are the results of windtunnel tests and calculations. As it is well known those numbers do not represent the real data on the full scale A/C in all cases due to different reasons

- windtunnel errors
- model accuracy and model laws
- calculation problems etc.

As the state of the art identification procedures will be employed during flight test in order to check and to improve the aerodynamic data base.

For loads purposes a comprehensive investigation has been carried out during the development test phase of the aircraft. This findings have been used to improve the OLMS-data tables.

The used method for this task was a so called output error procedure by using maximum likelihood algorithmen with and without Kalman-Filter techniques [5,6]. For these investigations maneuvers to check the handling qualities, dynamic load manoeuvres but also special stochastic inputs of the controls (multistep) have been used [4].

Below the principle of this identification procedure is given

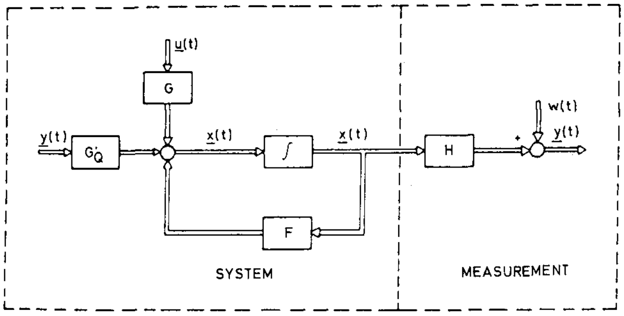


Fig. 11 SCHEME OF IDENTIFICATION

In the state space form the model and output equations can be given in the following form.

$$\dot{\underline{x}}(t) = F\,\underline{x}(t) + G\,\underline{u}(t) + G_Q\,\underline{v}(t)$$

$$\underline{y}(t) = H\,\underline{x}(t) + \underline{w}(t)$$

time continuous system

$$\underline{x}(k+1) = \Phi\,\underline{x}(k) + \Gamma\,\underline{u}(k) + \Gamma_Q\,\underline{v}(k)$$

$$\underline{y}(k) = H\,\underline{x}(k) + \underline{w}(k)$$

discrete system

As an example the equations are demonstrated for the longitudinal motion including the shear force on the root section of the horizontal tailplane but without system noise. The equations for the lateral manoeuvres can be denoted in the same manner, including the shear force on vertical tailplane and horizontal tailplane.

In principle the equations for all degrees of freedom could be set up including the attitudes of the aircraft.

Preferable however is in any case to perform longitudinal and lateral maneuvers separately and to carry out the identification separately as well. The benefit is: lower calculation effort with better results (reliability, repeatability). A six degree of freedom model is used for final checks only.

$$\frac{d}{dt}\begin{bmatrix} u \\ \alpha \\ q \\ \vartheta \end{bmatrix} = \begin{bmatrix} \dot{X}_u & X_\alpha & 0 & -g \\ Z_u & Z_\alpha & 1 & 0 \\ 0 & M_\alpha & M_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} u \\ \alpha \\ q \\ \vartheta \end{bmatrix} + \begin{bmatrix} 0 & X_{\alpha^2} & 0 & 0 & 0 & X_\Delta \\ Z_{\delta q} & 0 & Z_{\dot\alpha} & Z_{\dot q} & Z_{nz} & 0 \\ M_{\delta q} & 0 & M_{\dot\alpha} & M_{\dot q} & M_{nz} & M_{\Delta z} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \delta q \\ \alpha^2 \\ \dot\alpha \\ \dot q \\ n_z \\ \Delta s \end{bmatrix}$$

Model : State Equation

$$\begin{bmatrix} \alpha_x \\ \alpha_z \\ \alpha \\ q \\ \vartheta \\ P_{HT} \end{bmatrix} \quad \begin{bmatrix} X_u & X_\alpha & 0 & 0 \\ 0 & V_\infty Z_\alpha & V_\infty Z_q & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & Z_{\alpha h} & Z_{qh} & 0 \end{bmatrix} \cdot \begin{bmatrix} u \\ \alpha \\ q \\ \vartheta \end{bmatrix} +$$

$$+ \begin{bmatrix} 0 & X_{\alpha^2} & 0 & 0 & 0 & X_{\Delta s} \\ V_\infty Z_{\delta q} & 0 & V_\infty Z_{\dot\alpha} & V_\infty Z_{\dot q} & V_\infty Z_{nz} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ Z_{\delta qh} & 0 & Z_{\dot\alpha h} & Z_{\dot q h} & Z_{nzh} & 0 \end{bmatrix} \cdot \begin{bmatrix} \delta q \\ \alpha^2 \\ \dot\alpha \\ \dot q \\ nz \\ \Delta s \end{bmatrix} + \begin{bmatrix} W_{ax} \\ W_{az} \\ W_\alpha \\ W_q \\ W_\theta \\ W_p \end{bmatrix}$$

Model : Measurement (output) Equation

This investigation has been done in the relevant MN and dynamic pressure range. As demonstrated in Fig.12 measurement and recalculation are pretty good matched. However the problem was to find repeatable results. This is essential for OLMS since an unequivocal loads recalculation algorithm is required to cover a whole flight with all the different inputs.

Besides the general loadings also specific loads have to be covered by OLMS such as flap loads.

Important is also the check of the stability of the A/C to cope with initial load cases. An example is given below:

From the equations

$$Lift = m\ n\ g - T \sin(\alpha + \delta_{eng})$$

$$M_{25} = J_{yy}\ \dot\omega_y - T\ Z_{eng} - m\ n\ g\ (X_s - 0.25)\ l_A$$

the aerodynamic coefficients have been determind by using measured tail loads

$$\frac{\partial_{cz}{}^{tot}}{\partial_\alpha}\, flex = \frac{\partial_{cz}{}^{wfp}}{\partial_\alpha}\, flex + {} + \frac{s^H}{s}\,\frac{\partial_{cz}{}^{H}}{\partial_\alpha}\, flex\ (1 - (\partial_\epsilon/\partial_\alpha)\, flex)$$

$$\frac{\partial_{cm}{}^{tot}}{\partial_\alpha}\, flex = \frac{\partial_{cz}'{}^{wfp}}{\partial_\alpha}\, flex\ (0.25 - (X_n)\, flex) + {} + \frac{s^H\ r^H}{s\ l_A}\ \frac{\partial_{cz\,H}}{\partial_\alpha}\, flex\ (1 - (\partial_\epsilon/\partial_\alpha)\, flex)$$

The following tail of coefficients have been derived

$\alpha_0{}^{wt}$: incidence of zero lift
$c_{m0}{}^{wt}$: moment coefficient at zero lift
$\dfrac{\partial_{cz}{}^{wt}}{\partial_\alpha}$: normal force derivative
$\dfrac{\partial_{cz}{}^{wt}}{\partial_{c_\alpha}}$: pitch moment derivative
$x_N{}^{wt}$: airload pressure point

This job runs rather successfully and the final solution is expected very soon. The quality achieved depends on the regarded component and the flight manoeuvres. The hinge moments and flap loads are very well verified. All other components show a good agreement in dynamic manoeuvres. For the stationary part of the flight and for the take off and landing load cycle, some remaining uncertainties have to be overcome. These could be however purely a measurement problem.

Some bigger problems to solve are created by the fuselage loads (measurements affected by cabin differential pressure) and shear force on the wing station. The major item which has been tackled recently is to ensure the full repeatability during all flights. For this some modifications have been implemented into the software. Additional updates are planned.
The necessary updates are very simple to incorporate into the OLMS by means of a RS 232 interface or by loading via a floppy disk. The accuracy now achieved is in the range of ±5% (static load share) and about ±3% (dynamic increment) related to the full scale.

Another very important item is the treatment of special load shares which cannot be directly calculated using the data from the different mentioned data buses. One of these is represented by the incremental load due to the different structual modes. In many cases the load shares are below the threshold given by the counted classes but a very thorough investigation have been applied in order to qualify these influences.

As an example, the load increments due to the first wing bending mode during ground rolling operation (landing bounce, taxiing over thresholds) and during flight (heavy turbulence, sudden avoidance manoeuvres) are not negligible.

Due to the lack of input data no discrete algorithm is available. In OLMS a transfer function has been used and the coefficients are adapted until the residual error is supressed below the given threshold.

Fig. 13-17 show the comparison between OLMS calculation and upgraded flight measurements for the important steps of a flight with some relevant parameters.

From this comparison it can be concluded that for a particular flight the quality is sufficient for further data reduction.

A great deal of investigated flights, special manoeuvrers to check the system under adverse conditions revealed that the system is nearly ready to meet the targets. For the time being the work is still going on to optimize it.

Quality of reduced data

The data reduction - counting of the loads with rainflow counting methods - is the last step of the Verification.

The quality has been checked by comparison of counted results from OLMS calculated loads and flight load measurements. It is self evident, that a good agreement in loads must also lead to a good agreement in the counted results. Incorporated in the check is also the correct functioning of the OLMS-logic, the automatic switch over to specified memories when flight phases are changing and the recovery after system failures (interuption in data stream etc.)
Typical results are given on Fig. 18.

The investigations concerning this item are still going on to ensure the reliability of this step under all operating conditions.

Appropriate data memory

The decision which data should be stored in the OLMS memory has been made on the basis of the later usage for fatigue assessments. For this task a not so frequent retrieval of data seems to be sensible in order to reduce the workload. On the other hand a more frequent readout will help to find and adjust trends of the A/C usage and could also indicate possible malfunction of the system. As a good compromise a regular data retrieval after every 2000 flights was chosen. This means for a short range transport a time internal between 6 and 12 months.

On this basis the memory is designed. As mentioned before the test OLMS is equipped with a disk and tape system for data storage. The serial system will have a fixed memory (EEPROM) for final data storage. Nevertheless all respective investigations have been made to optimize a memory for the planned serial sytem.

From Fig. 7 the necessary capacity can be derived. Position No. 1 to 11 and 13 to 18 are undependently on the number of flights (only word length restriction).

The other positions are directly dependent on flight cycle numbers.

From the different loadings including the countings in different flight phases (Fig.7) and the additional correlation a memory of about 60 K-words is necessary.

For the other items which are to be stored for every flight a memory of 32 K-words is necessary. With a 4 byte word and a back up for modifications, additions and possible delayed data retrieval a 0,5 Mbyte memory is fully sufficient. For the task of fatigue investigation there is no need to store additional data. Possible extra functions (see next item) will be printed on event or after the respective flight and can be handled by the processor memory.

Extra Functions

After a great deal of discussions with different specialists from airlines, manufactures the request to incorporate in-flight findings into the OLMS as they exist in the Aircraft Condition Monitoring System (ACMS) for engine health monitoring emerged. As there are no specific parameters which indicate directly the "health" of the structure the following items were chosen as an indicator for inspections on event.

- Overweight landing
- Hard landing
- Limit load exceeded in any flight phase

It is planned for the serial device to incorporate on request the possibility to trigger special reports after event or after landing.

The necessary algorithms are already incorporated in the OLMS since these belong to the basic software. For realisation the triggering function in OLMS has to be activated and according to the signal paths the information will than be sent to the corresponding printer or recorder. For the time being no flight test verification of the correct signal path after triggering of a report was feasible because no interface between OLMS and A/C recorders / printers is present. It is planned to use the same output devices as the ACMS.

Nevertheless these investigations will be conducted in the near future. In order to have any chance that a report will be triggered during normal flights the thresholds will be set to artificial limits.

Concluding Remarks

In the preceding chapters the method of the verification and validation of the OLMS have been described. For one part of the load quantities the requirements for accuracy and repeatability have already been met. For the other part of the quantities it is expected that the verification work can be finalised by end of 1990 as planned after the already mentioned delay of the program.

After successful demonstration of the correct function of OLMS a serial device will be developed to be integrated as an option in the aircraft of this type. A modification of the system to suit derivatives of the aircraft is also envisaged.

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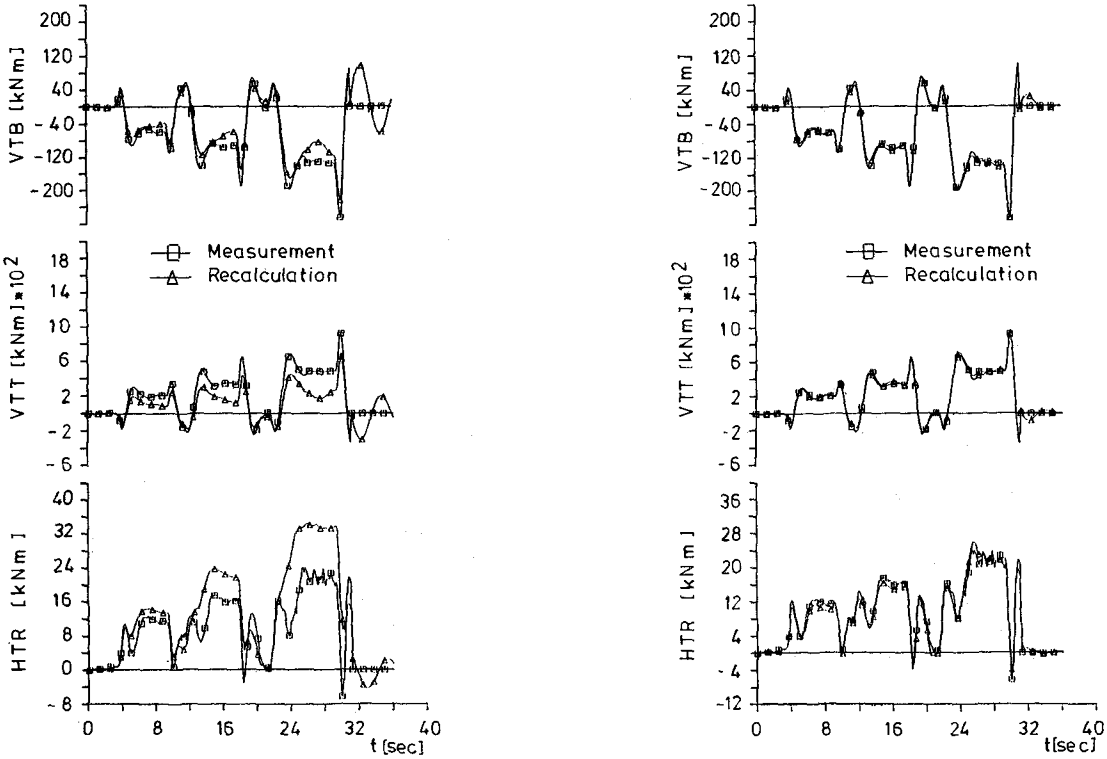
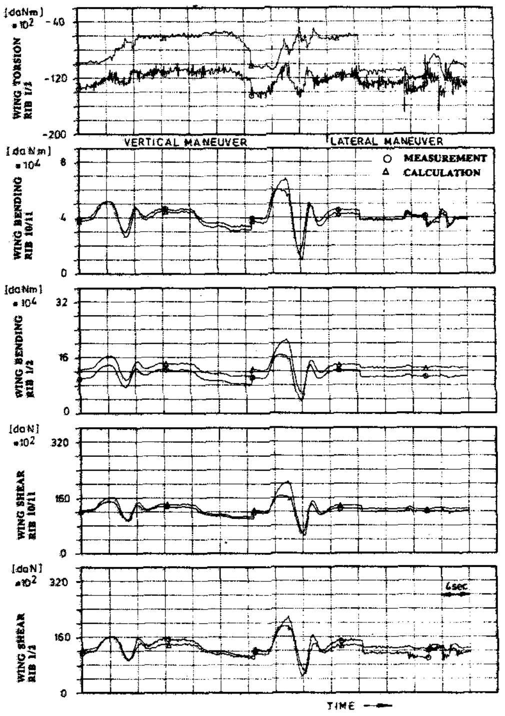


Fig. 12 COMPARISON OF CALCULATED AND MEASURED LOADS BEFORE (LEFT) AND AFTER (RIGHT) IDENTIFICATION



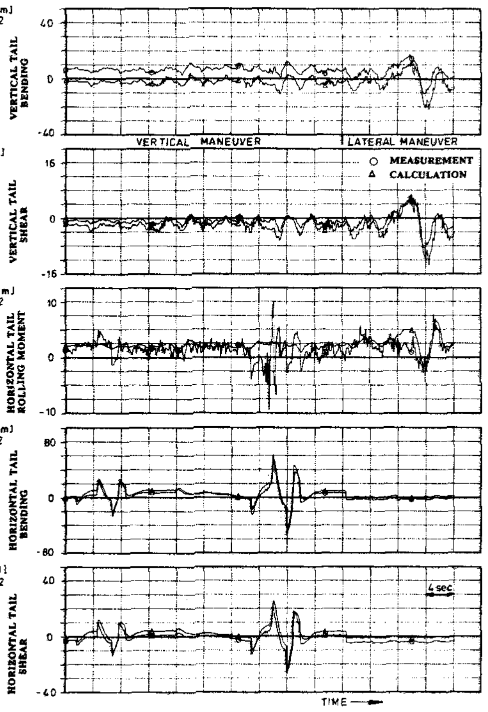
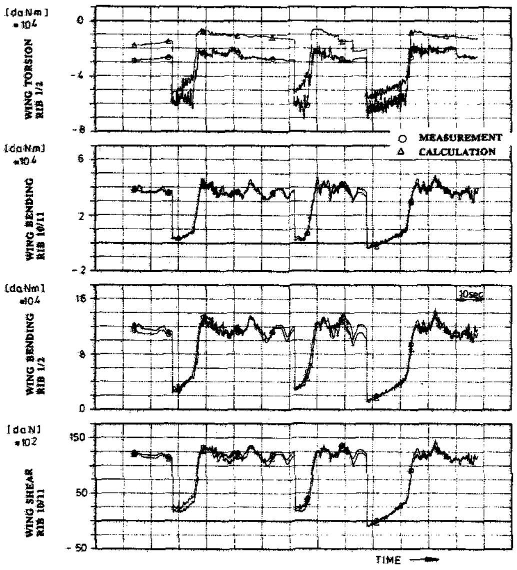


Fig. 13 COMPARISON OF OLMS-CALCULATED AND FTI-MEASURED LOADS DURING VERTICAL AND LATERAL MANOEUVRES

Fig. 14 COMPARISON OF OLMS-CALCULATED AND FTI-MEASURED LOADS DURING VERTICAL AND LATERAL MANOEUVRES



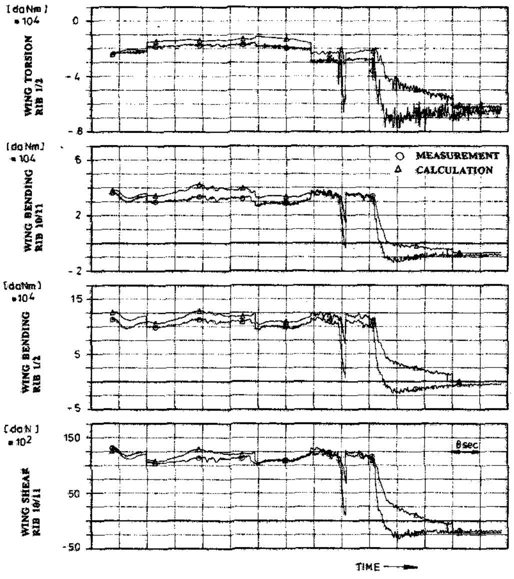


Fig. 15 COMPARISON OF OLMS-CALCULATED AND FTI-MEASURED LOADS DURING DIFFERENT TAKE OFF CONFIGURATIONS

Fig. 16 COMPARISON OF OLMS-CALCULATED AND FTI-MEASURED LOADS DURING DIFFERENT HIGH LIFT CONFIGURATION

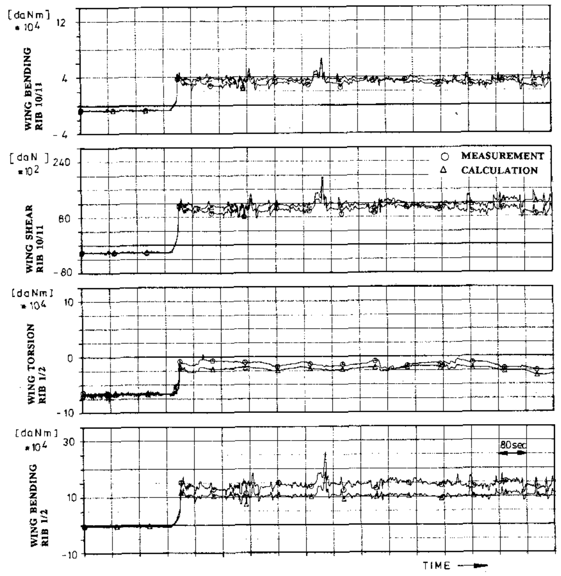


Fig. 17 COMPARISON OF OLMS-CALCULATED AND FTI-MEASURED LOADS DURING TAKE OFF, CLIMB AND CRUISE.

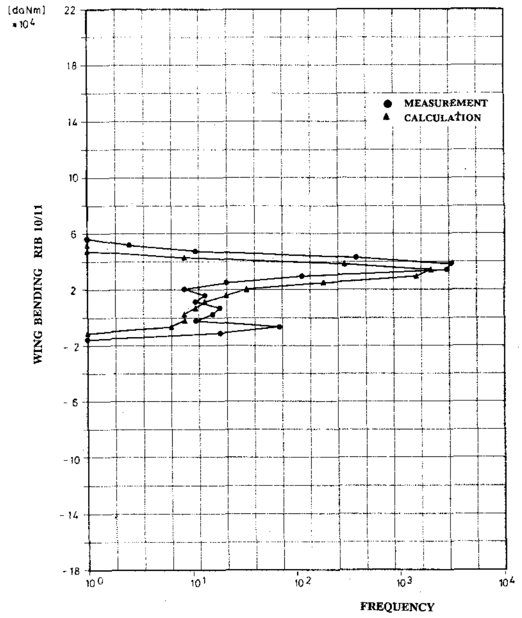


Fig. 18 CUMULATIVE FREQUENCY DISTRIBUTION OF OLMS-CALCULTED AND FTI-MEASURED WING BENDING MOMENTS FOR A TOTAL FLIGHT (DERIVED FROM RPR-COUNTING)