IN-FLIGHT TAILLOAD MEASUREMENTS

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Abstract

Fatigue load spectra that are used for the design of aircraft tail structures are based on simplifying assumptions with respect to external disturbances, such as gusts, turbulence and control inputs, as well as aircraft response behaviour. Past service-load measurement programs have been restricted to measuring the vertical acceleration of aircraft at the centre of gravity, which gives ample information about main wing loads but lacks a proper correlation with tailloads.
In general the relation between aircraft tailloads and aircraft motion parameters (lateral or vertical acceleration, pitch or yaw rate) is insufficient. Therefore the best way to obtain this information is by direct measurement of these tailloads by means of calibrated strain gauges.

This paper describes tailload measurements carried out using a commercially operated civil aircraft that has been equipped with a compact micro-processor based data recorder. The measured tailload data is combined with flight parameters from the Aircraft Condition Monitoring System (ACMS), in order to create a database for further analysis. Some results are presented to illustrate that valuable information can be obtained with a relatively simple and straightforward procedure, which is easy to install in an aircraft and does not interfere with other aircraft systems.

I. Introduction

An investigation "Study of Operational Tailloads" is carried out under contract for the Netherlands Agency for Aerospace Programs (NIVR). This investigation consists of a theoretical study in combination with a measurement program of in-service loads of a Fokker 100 aircraft.
The theoretical study is carried out by the National Aerospace Laboratory (NLR), while the measurement program is carried out in a co-operative program by the aircraft manufacturer Fokker Aircraft BV, the airline company KLM (Royal Dutch Airlines) and the National Aerospace Laboratory (NLR).
Installation of (NLR) equipment, instrumentation and calibration of nine strain gauge bridges in the tailsection of the aircraft has been carried out by Fokker Aircraft BV. The equipment and instrumentation has been installed in a KLM aircraft.

Fatigue load spectra that are used for the design of aircraft tail structures are based on simplifying assumptions with respect to external disturbances, such as gusts, turbulence and control inputs, as well as aircraft response behaviour. Past service-load measurement programs have been mainly restricted to measuring the vertical acceleration at the centre of gravity of aircraft which gives ample information about main wing loads but lacks a proper correlation with tailloads.

In general the relation between aircraft tailloads and aircraft motion parameters (lateral or vertical acceleration, pitch or yaw rate) is insufficient. Therefore the best way to obtain this information is by direct measurement of these tailloads by means of calibrated strain gauges.

In order to :
a) validate the procedures currently used for the determination of tail fatigue load spectra, and to
b) improve the statistical knowledge of gusts and manoeuvres with respect to tailloads,

a Fokker 100 aircraft has been equipped with a "Spectrapot-4C" data recorder, which is a compact micro-processor based recording device. Four independent load signals are searched for peaks and valleys. These successive peaks and valleys are stored in the (chip) memory. The memory capacity is such that it needed to be changed only once per four weeks. The replacement of this memory was a simple procedure, that had no impact on the operational availability of the aircraft.
Furthermore the acquired (load) data is complemented by (aircraft and flight) data obtained from ACMS (Aircraft Condition Monitoring System) as used by KLM.

This paper describes the way in which the measured information has been acquired. Since the amount of available flights is considered to be too small to provide statistically relevant information only preliminary overall results will be presented. In addition the results obtained from specific flights will be analysed in some detail.

II. Measurement of tailloads

Instrumentation and calibration.

In order to quantify tailloads, bending moments in the horizontal tail were considered to be of prime interest. In order to measure these bending moments nine strain gauge bridges (3 shear- and 6 tension bridges) have been installed, in the root section of the horizontal stabilizer of a Fokker 100 aircraft, see also figure 1 for a general idea of the location of the strain gauges. The positions of strain gauges were determined by NLR, based upon experience and results obtained from the Fokker 100 fin and horizontal stabilizer full-scale fatigue tests, as performed by NLR. More than the minimum required number of strain gauges were installed in order to have some spare gauges in case of malfunctioning or breakdown during testing or operation. Installation of the bridges, accelerometer and cables, as well as the calibration of the instrumentation in order to establish the strain-bending moment relationship, was carried out by Fokker Aircraft BV.
From the results of the calibration measurements the following bridges were chosen to be used during the in-flight measurements.

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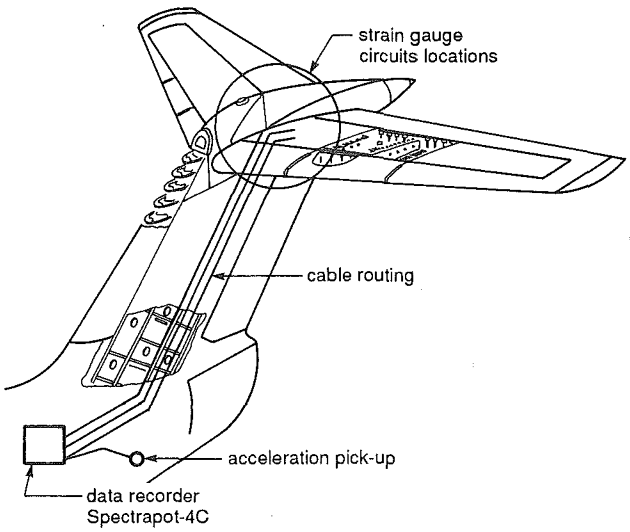
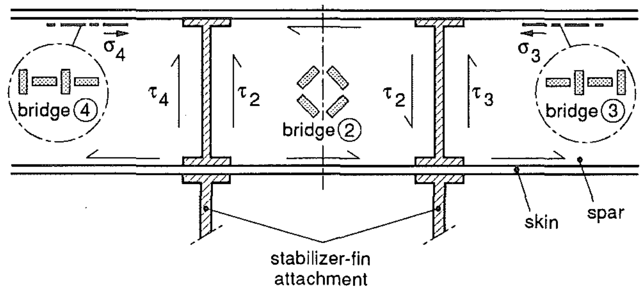


Fig. 1 Lay-out of the instrumentation in the tail of the Fokker 100



	symmetric loading condition	anti-symmetric loading condition
shear bridge ②	$\tau_2 = 0$	$\tau_2 \neq 0$
tension bridges ③, ④	$\sigma_3 = \sigma_4$	$\sigma_3 = -\sigma_4$
③+④ in parallel	$\sigma_3 + \sigma_4 \neq 0$	$\sigma_3 + \sigma_4 = 0$

Fig. 2 Strain-gauge type and -location in relation to measured output

a) Two tension bridges, one on the left-hand side and one on the right-hand side of the stabilizer, connected in parallel were used to measure the symmetrical part of the horizontal stabilizer bending moment (SYMM).

b) A shear bridge was used to measure the anti-symmetrical part of the horizontal stabilizer bending moment (ASYM).
Note that for symmetrical bending moments the shear stress at this location is zero, which makes this bridge an ideal sensor for the anti-symmetric part of the tailplane bending moment.

c) A tension bridge was used to measure the bending moment of one half of the horizontal stabilizer (BMOM).

From the sketch in figure 2 it can be seen why a shear bridge is an ideal sensor for the anti-symmetric loading conditions and why two tension-bridges in parallel are ideal sensors to determine the symmetrical part of an arbitrary loading condition.

Also lateral acceleration at the tail of the aircraft was considered to be of interest in the investigation of tailloads especially in order to determine if a correlation exists between lateral acceleration and (anti-symmetric) tailloads. Hence an accelerometer has been installed in the tailcone of the Fokker 100 (Fig. 1).

As mentioned in the introduction the tailload measurements were carried during normal operation of an aircraft in service by KLM. The measurements had to be carried out without any restrictions to or impact on the normal operation and availability of the aircraft, and without any changes to the aircraft's systems. This excluded the possibility to record the strain gauge signals and accelerometer signal with the on-board ACMS (*Aircraft Condition Monitoring System*).

Therefore these signals were recorded by a compact micro-processor based recording device (Spectrapot-4C, Fig. 3). With this data-recorder four independent input signals can be digitized, processed and recorded for further analysis. One of the advantages of this stand-alone device is the possibility to mount it in the vicinity of the sensors and thus avoiding the need to install long cables throughout the aircraft for signal transfer and power supply.
The three (analog) strain signals were filtered by the low-pass filters (12 Hz) from the bridge amplifier units and also by the pre-sample filter of the Spectrapot data collector (20 Hz low-pass).
The (analog) lateral accelerometer signal was filtered by the data collector pre-sample filter only (5 Hz low-pass).
These four channels were sampled sequentially at 128 Hz, with a 12 bit ADC (Analog to Digital Converter). Processing consisted of searching for "peaks" and "valleys" in the signal and storing these successive values into the solid state memory, including time marks. Due to the fact that only a limited amount of data needs to be stored, the (chip) memory had to be changed approximately once per four weeks (however it was done for practical reasons almost every week). Changing memory was carried out without any impact on the operational availability of the aircraft.

The Spectrapot data recorder (Fig. 3) has been mounted in the tail cone of the Fokker 100, as can

Fig. 3 The Spectrapot-4C data recorder be seen from figure 1, which gives a global indication of the position of the recorder and sensor locations.

In order to verify that no electro magnetic interference (EMI) effects exist or occur during operation between aircraft systems and the data recording equipment, EMI-tests were carried out during some special test flights by Fokker.

<u>Acquiring loads data.</u>
The Spectrapot data recorder stores its information into solid-state (chip) memory. The device used for the measurements described in this report had a memory capacity of 512 kByte.
280 kByte is available for data storage, the rest is needed for storing the software that controls the (micro)-processor.
The Spectrapot memory was changed on a regular basis, usually once per week, sometimes once per two or three weeks. The advantage of (frequent) changes is that irregularities in the data can be detected in an early stage without the risk that large amounts of data will be lost or turn out to be useless.
The Spectrapot datarecorder starts measuring/-recording when the beacon-light of the aircraft is switched on, during pre-flight checks. A peak/valley 4 point search algorithm with range filter "R" is applied before data is stored into memory. Successive peaks and valleys are only recognized as such when they differ at least a value R. The used "Range filter" values can be found in table 1. This "peak/valley" search procedure has been extensively described in [2]. An illustrative sketch of the procedure is given in figure 4. This figure shows for an arbitrary signal the recognized "peaks" and "valleys" (maxima and minima) in relation to a given "Range-filter size".
Data (channel number, dataword (parametervalue), and timemark) are stored as integer numbers (classes) from 0 - 239. A proper measuring range can be selected by changing the offset and gain (attenuation) of the Analog-to-Digital converters.

<u>Acquiring flightparameter data.</u>
KLM operated Fokker 100 aircraft have been equipped with a Digital Expandable Flight Data Acquisition and Recording System (DEFDARS). The purpose of this system is to acquire, condition and process all required aircraft parameters and output them to the Digital Flight Data Recorder (DFDR) to satisfy regulatory requirements. In addition, the system outputs under processor control or manual input from the Control and Display Unit (CDU) data

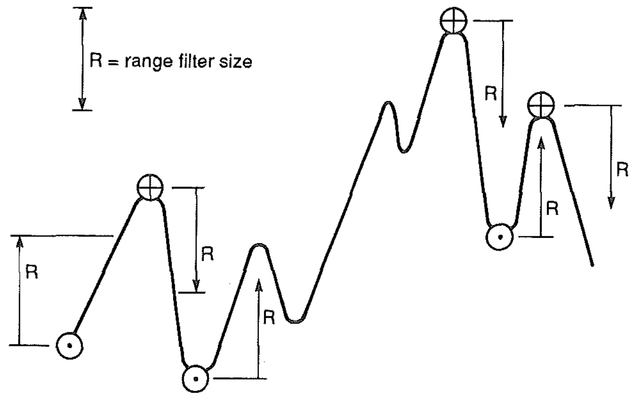
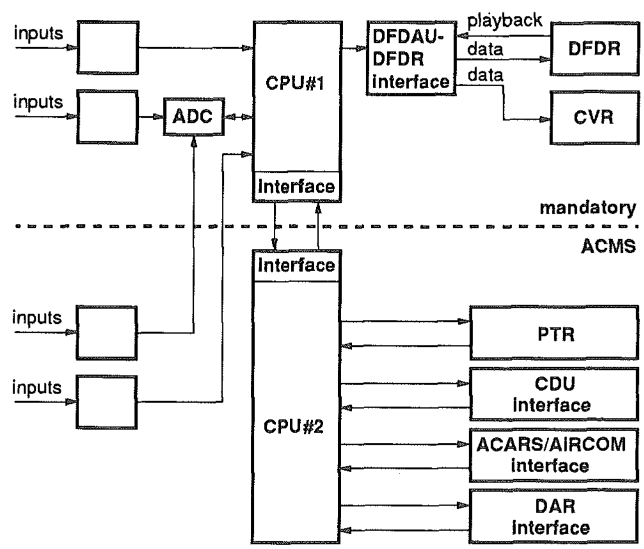


Fig. 4 Classification of peaks and valleys using a range-filter with size R



CVR - Cockpit Voice Recorder
CDU - Command and Display Unit
DAR - Digital Airborne Recorder
DEFDARS - Digital Expandable Flight Data Acquisition and Recording System
DFDAU - Digital Flight Data Acquisition Unit
DFDR - Digital Flight Data Recorder
PTR - Cockpit Printer

Fig. 5 Block diagram for DEFDARS

Parameter name	YACC [g]	SYMM [Nm]	ASYM [Nm]	BMOM [Nm]
Spectrapot channelnr.	0	1	2	3
Resolution	.01255	361	157	387
Measuring range class = 0 class = 239	-1.50 +1.50	-34,500 +51,779	-18,800 +18,723	-55,400 +37,093
Range filter class units	8 .01004	15 5415	18 2826	5 5808

Table 1 Spectrapot-4C channel assignment

to a cockpit printer (PTR) and/or to the Digital Airborne Recorder (DAR) when so directed by the operational program resident in the Digital Flight Data Acquisition Unit (DFDAU).
All data output to the Digital Airborne Recorder (DAR) is under control of the CPU#2 software. Recordings are initiated either automatically (flight mode or exceedance related) or manually via Control and Display Unit (CDU) requests.
All recordings consist of data frames with a duration of four seconds, equally divided into four mini-frames of one second each. Each mini-frame in its turn is further divided into 64 words of 12 bits. A schematic diagram of this system is depicted in figure 5.

Flight mode related recordings. The Digital Airborne Recorder (DAR) records data continuously during Engine Start (ES), Take-Off (TO), Climb (CL), Approach/Land (AL) and Go Around (GA) flight modes. During Taxi (TA) and En Route (ER) modes one frame of data is recorded every 100 seconds. During transition from Pre-Flight (PC) to Engine Start (ES) mode a 20 second history is recorded. This transition is regarded to be the beginning of a new flight.

Exceedance related recordings. A number of parameters is tested for limit exceedance. Depending on the nature and duration of the exceedance, the Digital Airborne Recorder (DAR) records varying number of periods (frames). For instance during Taxi (TA) and En Route (ER) modes, the limit exceedance value for vertical acceleration is 0.18 g, with a recording time of 20 seconds after exceeding the limit value.

From all recorded parameters 27 have been selected by NLR for further processing (Table 2). The data pertaining to these selected parameters were extracted from the complete ACMS records at the KLM computing center.

Database creation.
A database has been created containing the recorded information for each flight. To that purpose the Spectrapot and ACMS data had to be combined. The ACMS recorded data were subjected to a further data reduction before they were entered into the database. Similar to the way of storing the Spectrapot parameters, a "peak/valley" search has been applied to the vertical acceleration ("range filter" = 0.1 g). In case of occurrence of a peak/valley the record with 27 ACMS parameters is stored into the database. Some other parameters were checked upon exceedance of a threshold value in relation to the previous value. If one of the parameters exceeds the corresponding threshold, the record with ACMS parameters is stored into the database as well. The used threshold values can be found in table 2. ACMS records have been checked for out-of-range values also and Spectrapot data have been checked for invalid 'SYMM' records, probably caused by malfunctioning of a straingauge.
The basis for combining Spectrapot and ACMS data is the time-parameter. Due to the fact that the initial ACMS time has to be manually entered by the crew, quite often discrepancies were found between the two data sources.

In figure 6 a diagram is presented of the process to create the Fokker 100 database and the number of computer systems involved.

	Variable	Units	Sample rate	Treshold value
1	aircraft id.			
2	date			
3	time	[hr,min]		
4	time	[sec]		
5	flight nr.			
6	flight count			
7	subframe counter			
8	gross weight	[1000 kg]	1	.2
9	fuel quantity	[1000 kg]	1	.2
10	flight mode	[-]		≠
11	true air speed	[knots]	1	10
12	true heading	[deg]	1	
13	angle of attack	[deg]	2	
14	press. alt.	[ft]	2	1000
15	pitch angle	[deg]	4	
16	elevator pos.	[deg]	1	2
17	aileron pos.	[deg]	1	4
18	Mach number	[-]	2	.15
19	roll angle	[deg]	4	5
20	rudder pos.	[deg]	2	2
21	h-stab. pos.	[deg]	1	1
22	flap pos.	[deg]	1	≠
23	epr eng #1	[-]	4	.05
24	epr eng #2	[-]	4	.05
25	rev eng #1	[-]	4	≠
26	rev eng #2	[-]	4	≠
27	vert. acc.	[g]	16	.18
↓	↓	↓		
34	vert. acc.	[g]		

Table 2 Parameters obtained from ACMS database

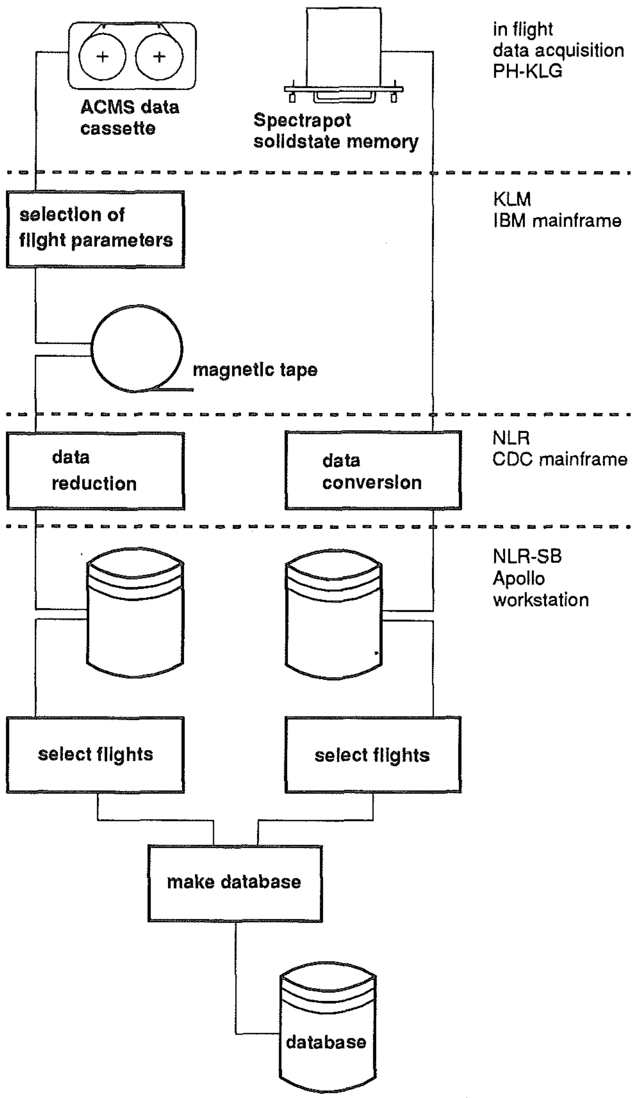


Fig. 6 Flowdiagram of the creation of the database

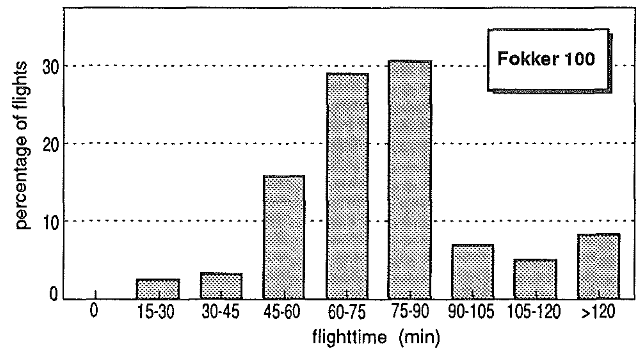


Fig. 7 Flighttime distribution

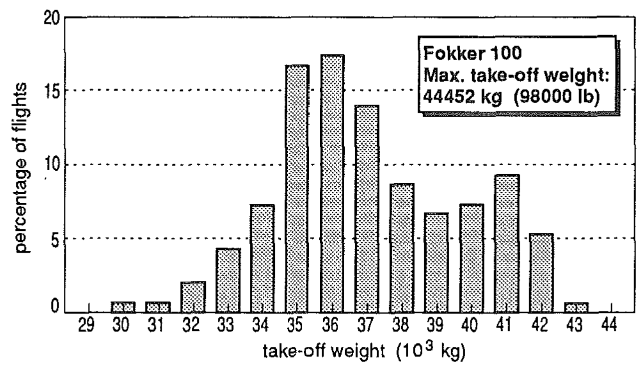


Fig. 8 Take-off weight distribution

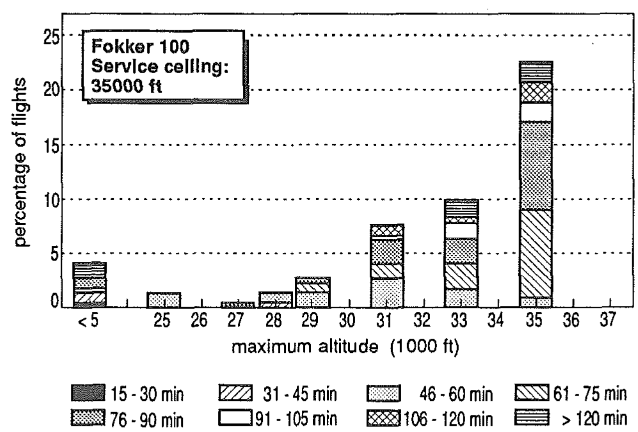


Fig. 9 Maximum altitude distribution

III. Results

Some results obtained from the Fokker 100 tail-load measurements are presented in this paper by means of:

- presentation of general data (average flight time, distribution of flight altitudes, Mach-number etc.);
- description of typical flight recordings (commercial flight, training flight, flight with turbulence, etc.);
- presentation of load spectra.

General Data.
Some general information with respect to the recorded flights can easily be obtained from the database. In figures 7 through 9 distributions of flight ltime, take-off weight and maximum altitude are presented for the present batch of 163 flights.

- Flight time
  The flight time is defined as the time between the start of engines (i.e. the first ACMS recording in the NLR-database, which is the last record of flightmode 1 (PC) in the KLM-database) and the last ACMS data-record for the given flight, which occurs at the end of taxiing after touch down.
  The distribution of flight time is presented in figure 7. Most flights (60 %) have a duration between 60 and 90 minutes. The average flight time is approximately 80 minutes.

- Take-off weight
  The distribution of take-off weight is presented in figure 8. The average take-off weight is 37000 kg.

- Maximum altitude
  The distribution of the maximum altitude attained during each flight is presented in figure 9. In the presented altitude distribu-

tion standard flight levels with a flight-separation zone of 2000 ft are clearly visible. During most flights an altitude over 30,000 ft. was reached.

Presentation of load data and flightparameters. Time histories of different parameters during each flight can be visualized by plotting the given parameter as a function of time. In order to have means to check the loads data, obtained from the Spectrapot system, a plotting procedure has been created to enable visual inspection of the recorded parameters.
The data collected by the Spectrapot system, consist of information that has been recorded, only when a specified range between extreme signal values ("peaks" and "valleys") has been exceeded. These "peak" and "valley" values are plotted with a minimum time interval needed for detection in the resulting graph. When no "peaks" or "valleys" are present, the time-base has been contracted.

In figure 10 an example is given of the following signals that have been plotted as a function of this artificial time base:

1. The lateral acceleration measured in the tail structure (YACC).
2. The symmetrical component of the horizontal stabilizer bending moment (SYMM).
3. The anti-symmetrical part of the horizontal stabilizer bending moment (ASYM).
4. The bending moment of one half of the horizontal stabilizer (BMOM).
5. Flight mode number (mode) - NB. Flight mode numbers are indicated by a vertical shift. Activation of the thrust reversal system is indicated by half a shift. The definition and coding of the Fokker 100 flight modes is given in table 3.
6. Time base (time) - NB. The slope of this curve is an indication of the time base being contracted or expanded.

These plots have been made for all flights as a "quick look" facility. Plotting procedures to compare time-traces of other parameters have also been made and have been used on an ad-hoc basis for the purpose of more detailed investigations of particular flights.

Typical flight profiles. From the collected time histories different flight profiles can be distinguished:

- commercial (normal) flights;
- training flights;

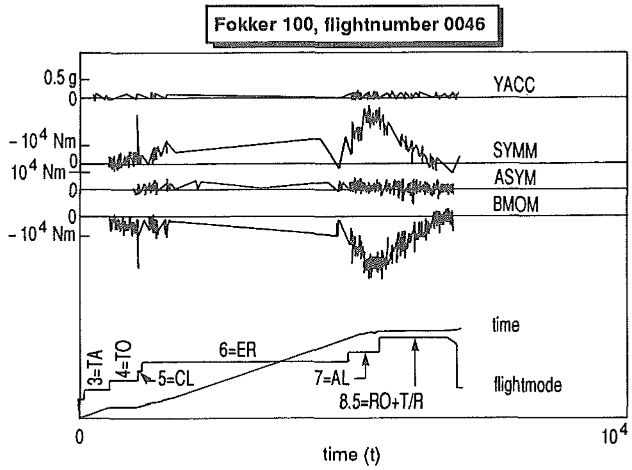


Fig. 10 Quick-look plot of Spectrapot parameters for one recorded flight

A description of a typical flight for each of these flight profiles is given in the following chapters. In addition, the time history of a flight in which noticeable turbulence was encountered will be reviewed in some more detail.

Commercial flights. Most flights in the database are considered to be commercial flights with the following typical flight profile: taxiing, take-off, climb, en-route, approach & landing, roll-out and taxiing. A definition of the flightmodes is given in table 3.
An example flight has been selected and the following parameters are presented:

- Landing flap position;
- Elevator position;
- (EPR - 1), EPR is the average Engine Pressure Ratio of both jet-engines, subtracted by 1, since only values of EPR > 1 are of interest;
- Anti-Symmetrical part of the horizontal tail bending moment at station 215 (M_x-.215);
- Symmetrical part of the horizontal tail bending moment at station 215 (M_x-.215);
- Time (see item 6 in previous section);
- Indication of changes in flightmode.

From the recorded signals some typical points relating to specific flight conditions can be observed (Fig. 11):

- After engine start (FM: ES, 2), (point (a)) and taxiing (FM: TA, 3) to the runway, power is

Nr.	Code	Description	Criteria
1	PC	Pre-flight check	
2	ES	Engine start	
3	TA	Taxi before take-off after touch-down	LFM=ES, CAS < 60 knots LFM=RO, CAS < 60 knots
4	TO	Take-off	N2 > 90 %
5	CL	(initial) climb	LFM=TO, RALT < 2500 ft
6	ER	En Route	SQAT=Air, RALT > 2500 ft
7	AL	Approach & Landing	SQAT=Air, RALT < 2500 ft
8	RO	Rollout	SQAT=Ground, CAS > 60 knots
9	GA	Go-Around	
			LFM = Last Flight Mode SQAT = Air-Ground switch RALT = Radio Altitude

Table 3 Definition of Fokker 100 flight modes

applied (point (b)), which can be seen from the increase in the EPR signal. Elevator position is maintained at a constant position, during the take-off run, of approximately 9 degrees (elevator trailing edge down), until the airplane is rotated by an elevator angle of approximately -8 degrees. Rotation of the aircraft during take-off (FM = 4,5) is associated with a severe peak in the symmetrical bending moment (SYMM). After take-off engine power is decreased and the aircraft climbs to cruising altitude (FM: ER, 6). During cruise the bending moment reduces to small values, which implies that the required (negative) tail load for aircraft equilibrium is rather small.

- At point (e) engine power is cut back to start the descent. At point (f) the landing flaps are extended and a lot of activity is noticed in both the engine signal as well as in the elevator signal in order to maintain course at the glide path. The symmetrical bending moment (SYMM) gradually increases when landing flaps have been extended because aircraft equilibrium needs to be maintained by a larger tailforce (FM: AL, 7). A distinct peak in bending moment is visible during the flare manoeuvre, which coincides with maximum elevator deflection (point (g)).
- Symmetrical (and total) bending moments (SYMM and BMOM) gradually decrease to approximately zero during landing and roll-out (FM: RO, 8). During this particular flight the elevator was "pushed" to a trailing-edge-down position right after touch-down until the end of the "roll-out".

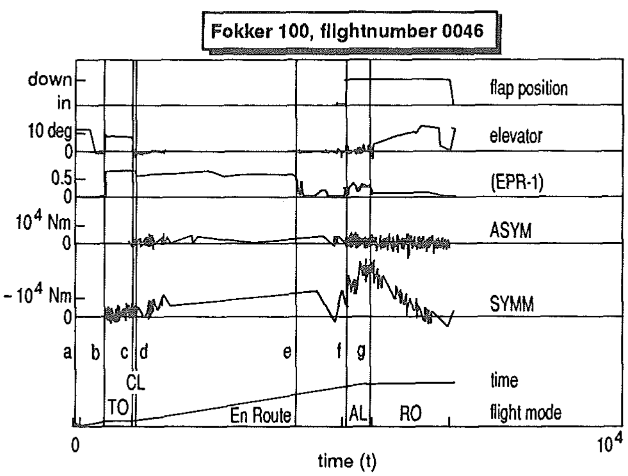


Fig. 11 Typical example of a commercial flight

Generally speaking the main load cycle for the symmetrical tail bending moment is governed by the peaks in the bending moment caused by rotation during take-off and the flare manoeuvre during landing.

Because the measured load data has not been recorded as time histories it is not possible to extract accurate frequency information from the database. However an indication of frequency (pseudo-frequency) can be obtained especially for higher frequency values (freq. > 1 Hz) by simply counting the number of load cycles (half the total number of recognized peaks and valleys) per second. This indication is of special interest during roll-out (FM: RO,8) in combination with thrust-reverser deployment.

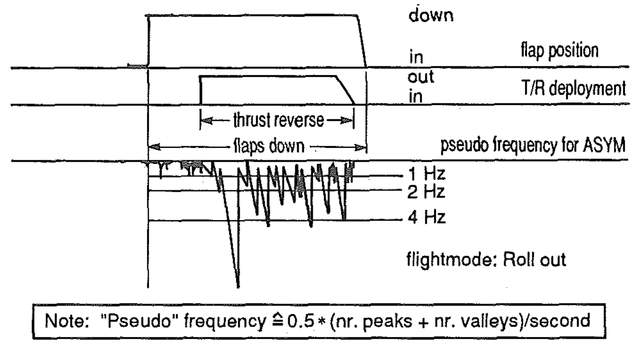


Fig 11a "Pseudo" frequency for ASYM signal during landing

From the "pseudo"-frequency of the anti-symmetrical bending moment during thrust-reverser deployment, oscillations with frequencies in the range of 2-4 Hz are observed. The frequencies of fin torsion and lowest anti-symmetric tailplane bending mode are within this range.
Figure 11a shows an example of the "pseudo" frequency content in the anti-symmetric bending moment signal (ASYM) during the landing phase, in combination with the flap position (in or down) and thrust reverser usage (in or out). Besides the high-frequency content (2-4 Hz) due to thrust-reverser usage a low-frequency content (< 1 Hz) is noticed. Similar low-frequency load changes are observed both in symmetric and in anti-symmetric bending moments during approximately 50 % of all landings.
By inspecting the corresponding control surface signals it is concluded that these load changes are caused by control surface deflections due to manoeuvres in turbulence.

<u>Training flights.</u> Not all flights of the aircraft are commercial flights. Nine flights (out of 163) are considered to be training flights because of the following circumstances:

- maximum altitude < 5000 ft;
- maximum Mach-number < 0.35;
- absence of an 'En-Route' flight mode (FM: ER,6);
- more than one take-off and landing.

The flight profile for such a training flight usually comprises several take-offs, approaches, and/or touch-and-go's and/or go-arounds.
The occurrence of these events during training flights may be used for the determination of the number of Ground-Air-Ground cycles (GAG's) for other purposes (e.g. life-time-analysis).
For the definition of a GAG cycle a full-stop of the aircraft is usually considered to be the end of one cycle, which occurs in the present situation when take-off (flight mode 4) is preceded by taxiing (flight mode 3 and CAS < 60 knots).
Figure 12 shows an example of such a training flight. After taxiing (FM: TA,2) and take-off (FM: TO,3) power is cut back. The maximum altitude reached is approximately 1500 ft. After each take-off two (long) turns (bank angle ϕ = + 25-30 degrees, with a change in heading of 180 degrees, duration approximately 80 seconds) in the same direction are made followed directly by approach and landing (FM: AL,7). During this phase a large number of (asym) bending moment oscillations occur. After four touch-and-go's the final landing was made.

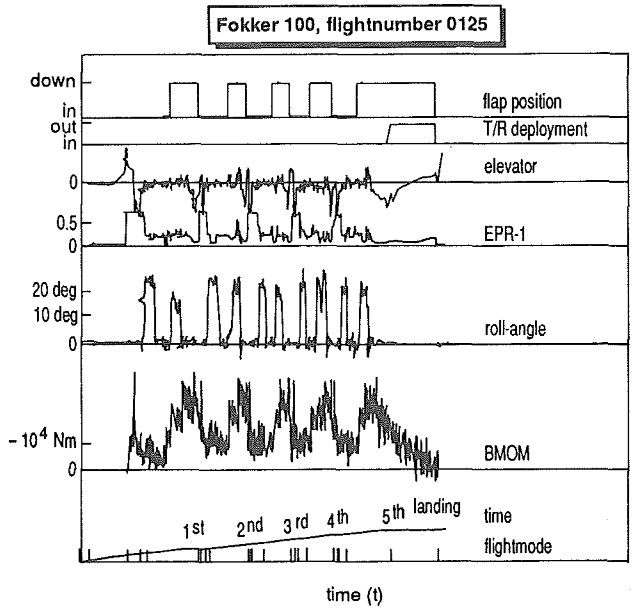


Fig. 12 Typical example of a training flight

Flights with turbulence. During the 163 recorded flights, sometimes turbulence has been encountered at altitudes above 2500 ft to a noticeable extent, considering the number of load changes, for longer periods of time. A typical profile of a flight in which turbulence is clearly noticed is presented in figure 13. Two "patches" of turbulence are encountered when flying at cruising altitude (FM: ER,6). The duration of those patches is approximately 287 and 86 seconds. The range between minimum and maximum total bending moment (BMOM) is for both "patches" approximately 23,000 Nm. It may be noted that this load variation is much smaller than the load change associated with the rotation manoeuvre at take-off and change in balancing load due to flap extension at the end of each flight.

Load spectra.

The recorded load time histories have been analysed using the so-called "Range-Pair Range" counting method [2]. The results of those countings are stored in a "from-to" matrix. From such a matrix the number of crossings of various load levels can easily be derived [2].

In figures 14 through 16 spectra for positive level crossings are presented for the (vertical) load factor at the centre of gravity of the aircraft and the bending moment of one stabilizer-half.

It is possible to make selections for instance by taking into account only those data-records that relate to a specific condition, such as flight mode, flap position etc.

Loadfactor-spectrum. From the spectrum of vertical accelerations at the centre of gravity of the aircraft, expressed in the form of a loadfactor (measured acceleration, normalized by the acceleration of gravity), a general impression can be obtained whether or not the batch of flights is more or less "normal" and representative for the usage of a Fokker 100. In figure 14 the spectrum for "airborne" modes (FM = 5,6,7,9) is presented in combination with the Fokker 100 and Fokker F28 design spectra and results from fatigue meter readings of Fokker F28 aircraft.

As might be expected the spectrum for the Fokker 100 is less severe than for the Fokker F28, mainly due to its larger W/S ratio. For an average aircraft mass and cruise conditions the gust sensitivity of the Fokker 100 is about 66 % in comparison with the Fokker F28 Mk1000.

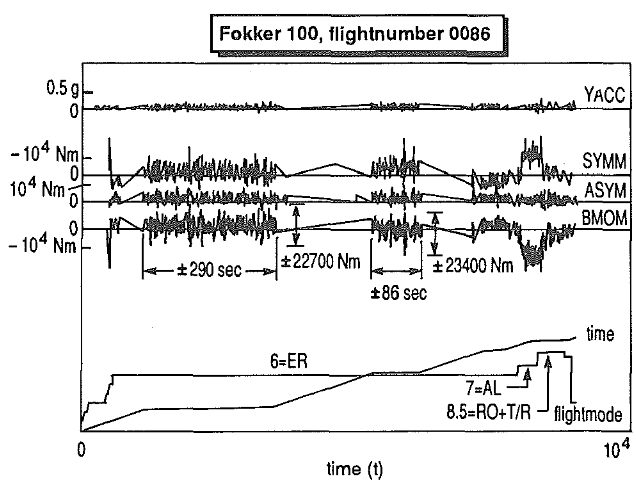


Fig. 13 Typical example of flight with turbulence

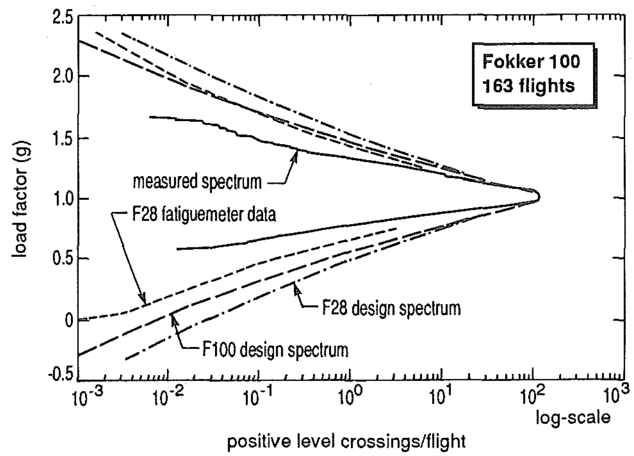


Fig. 14 Operational vs design load factor spectra

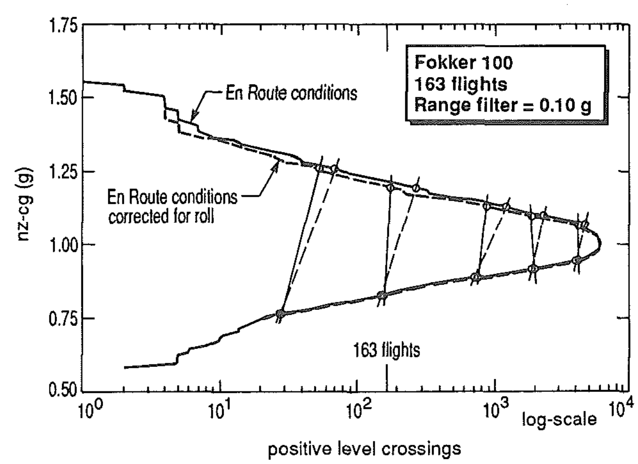


Fig. 15 Measured load factor spectrum

Since the measured loadfactor spectrum is well within the design spectrum and has a regular shape it is concluded that the batch of flights does not contain extraordinary flight conditions or flight conditions with heavy (wing) loads, however it should be noted that a total of 163 flights has hardly any statistical significance.
From cg-accelerations of all flights loadfactor (n_z) spectra have been derived. Assuming a symmetric distribution of (vertical) gust velocities, the sum of positive and negative accelerations of the aircraft due to turbulence, should be approximately zero and the resulting spectrum is expected to be approximately symmetric. However due to manoeuvres (eg. level turns, pull-up manoeuvres) more positive accelerations will be present in the measured data. In order to eliminate the effect of level turn manoeuvres, a correction for bank angle has been carried out according to:

$$n_{corr} = n_{meas} - \Delta n_{bank}$$
$$\Delta n_{bank} = [1/\cos\varphi - 1]$$

where

n_{corr} = corrected loadfactor
n_{meas} = measured loadfactor
Δn_{bank} = correction due to roll manoeuvre
φ = bank angle

In figure 15 the number of positive level crossings per flight is presented for 'en route' (FM=6) conditions with and without correction for roll-manoeuvres.
The roll-manoeuvres are usually smooth turns with maximum bank-angles of +/- 25 degrees, resulting in an increased cg-acceleration of approximately + 0.1 g.
The effect of the correction (Fig. 15) is indeed particularly noticeable for positive load increments and the resulting spectrum becomes quite symmetric for (smaller) load increments that occur more than once per flight. This result is in agreement with similar corrections applied to ACMS data of Boeing 747 aircraft as described in [3].

BMOM-spectrum. The spectrum of bending moments of one stabilizer half (Mx-.215) is presented in figure 16 for various conditions.

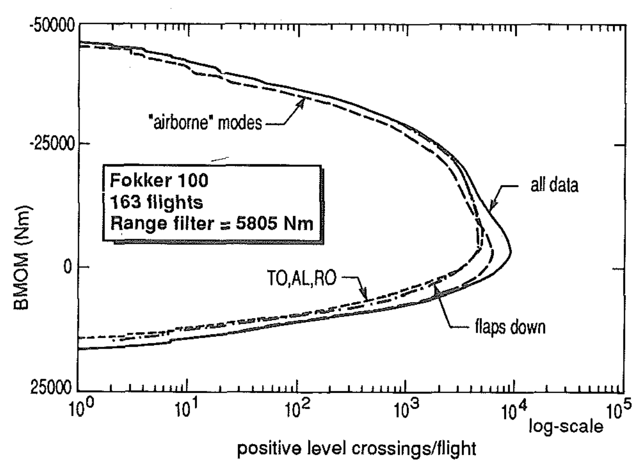


Fig 16 Spectrum of total tailplane bending moments (BMOM)

- For all data
This gives the outer curve showing clearly that the average stabilizer bending moment has a negative value due to negative (downward) tail forces as required for static aircraft equilibrium.
- For "airborne" modes (FM=5,6,7,9).
This curve shows clearly that the major contribution to the positive moments in the spectrum arises from conditions when the aircraft is airborne.
- For flightmodes concerning take-off, approach and landing (FM=4,7,8).
- For conditions when flaps are extended.
From these last two conditions it may be concluded that the largest bending moments, (all bending moments less then -25000 Nm) occur during that part of the approach and landing phase when the (landing) flaps are "out".

IV. Conclusions

* A system has been described for the recording of tailloads during operational flights, which makes use of the aircraft ACMS in combination with a dedicated smart data recorder.

* This smart datarecorder can be operated without any interference to other systems.

* The possibility to combine these load parameters with flightparameters has proven to be essential for a proper analysis of the results.

* Analysis of individual flights gave relevant information about the tailload experience during those flights.

* A limited batch of 163 flights has been recorded.

* To obtain reliable statistical data on tailloads, more flights will have to be recorded. It is hoped that the measurements can be continued in the near future.

V. Acknowledgement

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VI. References

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