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MRVS
A SYSTEM FOR MEASURING, RECORDING AND PROCESSING FLIGHT TEST DATA

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Abstract

This paper describes a new system for measuring, recording and processing flight test data, with the (dutch) acronym MRVS. The system is designed for a wide range of tests with various aircraft, such as the Fokker 50, Fokker 100, General Dynamics F16, etc., aircraft either developed or in operational use in the Netherlands.

Especially the Fokker 100, at this moment one of the most advanced airliners in operation, placed high demands with respect to data quality and quantity, the versatility and the integrity of the system and the availability at any time under all circumstances.

The paper presents the requirements which led to a unique, highly modular design which facilitates the construction of flight-test instrumentation systems that are optimally adapted to the test program and test aircraft under consideration.

Especially the subsystems which to a certain extent have unique features, are described in more detail.

The operational experience with up to 20 different test aircraft and instrumentation systems will be discussed. It can be concluded that untill now MRVS has outperformed its specifications. Less than 1 percent of test time has been lost due to instrumentation malfunction.

1. Introduction

In the past the National Aerospace Laboratory NLR and the Fokker Aircraft Company decided that a new wave in aircraft development and deployment in the Netherlands necessitated an extensive new development of flight test instrumentation for the upcoming projects. As the continuity in the Netherlands in this type of development is less obvious than in some other countries, a jump-effort had to be undertaken to reach the desired level of technology in this field.

In a flight test program, a large amount of information must be gathered and interpreted. For that purpose an aircraft is fitted with a system that measures and records the required data during the test flights. Very severe demands are made upon the quality of the measured data and upon the reliability of the instrumentation system. Moreover, the instrumentation system can be and must be designed to help shorten the flight test programs. By the time a new aircraft type has reached the stage of flight testing, a large amount of money has been invested, and the first delivery date is so close, that the testing program comes under great pressure. Any setback may then cause a delay and therefore additional costs.

In the definition phase of the new instrumentation system it became clear that the design could not be tailored to a specific new aircraft. The design should be such that instrumentation systems for large and small flight test programs, for military fighter aircraft, civil transport aircraft and helicopters could be configured easily. This led to developing a large set of independent modules. The modules can be interconnected in a variety of ways to form complete dedicated systems for measuring, recording and processing flight test data, tuned to different aircraft and different test programs.

In the most extensive configuration, MRVS was intended for flight testing the joint McDonnell-Douglas/Fokker MDF100 aircraft and, after termination of that project, the Fokker 100 aircraft now in operational use.

This paper will describe how the MRVS concept grew to maturity. The well known and commonly used modules or subsystems will be touched upon briefly. An enumeration will be given of performance parameters such as the capacity in terms of type and number of input channels, throughput rates and measurement accuracies. More detailed attention will be given to those modules and subsystems of MRVS that are believed to have unique features.

These subsystems are:
- ARINC Databus Multiplexer
- On Board Computer
- Take-off and Landing Trajectory Measurement System
- Automatic Landing Flight Path Measurement System
- Multi-Sensor Positioning System
- Noise Measuring System
- Ground Vibration Test System
- System Management Information Database
- Data Storage and Analysis System.

The paper closes with a summary of the operational experience gathered during flight testing with more than twenty different instrumentation systems built into as many test aircraft, the Fokker 100 test program being by far the largest.

2. Requirements

The MRVS program entered into its first phase with a set of very generally formulated requirements:
- the system should be capable of serving in flight test programs of an undefined magnitude during the next 10 to 15 years
- the quality of the system should at least equal the quality of systems in use at the large aircraft companies
- the capability of the new system should be an order of magnitude greater than the available systems in the Netherlands.

Armed with the above mentioned general requirements a thorough analysis was made of all expected flight test programs in the future and the demands that these programs could place on flight test instrumentation. All potential users of the future MRVS-data were interviewed. This effort resulted in a set of user's requirements. The main requirements were:

- The structure of the system should allow easy adjustment to a variety of projects. Both very large projects such as flight testing new Fokker aircraft, and limited projects such as tests with an F16 of the Royal Netherlands Air Force or with NLR's own laboratory aircraft should be possible within the same concept.
- A stock of transducers should be available to convert a variety of physical quantities into electrical signals ready to be recorded.
- It should be possible to relate all measured data, coming from thousands of sources, to one single time base, so that they can be correlated with one another.
- The data processing should be organized such that the required information can be supplied to the customer within 24 hours.
- Parameters not directly measured should be calculated from the flight data during ground processing, and supplied within 24 hours as well, if requested.
- Processing of flight test data should remain possible during many years after the flight.
- A measurement system should be expandable to present readily interpretable information in-flight to an on-board observer or, using a telemetry link, to a ground-based observer.
- The duration of the check-out of the measurement system should not limit the number of a day's flights.
- To ensure reliability, the on-board equipment should at least withstand the conditions laid down by the Radio Technical Commission of Aeronautics [Ref. 1], but preferably the conditions laid down in Military Standards [refs. 2, 3, 4].
- Re-use of all modules should be possible in order to minimize building time and cost of future instrumentation systems.

Based on these requirements a system specification was written, followed by a preliminary design phase. In this phase the modular concept of MRVS, described in the next chapter, was developed.

3. System description

3.1 System concept

Although an attempt was made to write a detailed and complete specification, it was realized that the uncertainty about the future projects would lead to significant changes and additions to the specifications in the future. To master this situation it was decided to design MRVS as a collection of hardware and software modules and procedures. Prerequisites were:

- it should be possible to develop each module independently of other modules
- a module should never be changed after reaching the final design stage
- if existing modules cannot accommodate new requirements a new module should be developed
- development of a new module should never necessitate a change in existing modules or in interfaces between modules
- modules should be designed in such a way that they can easily be connected and configured to suit the requirements of a specific flight test program (Fig. 1).

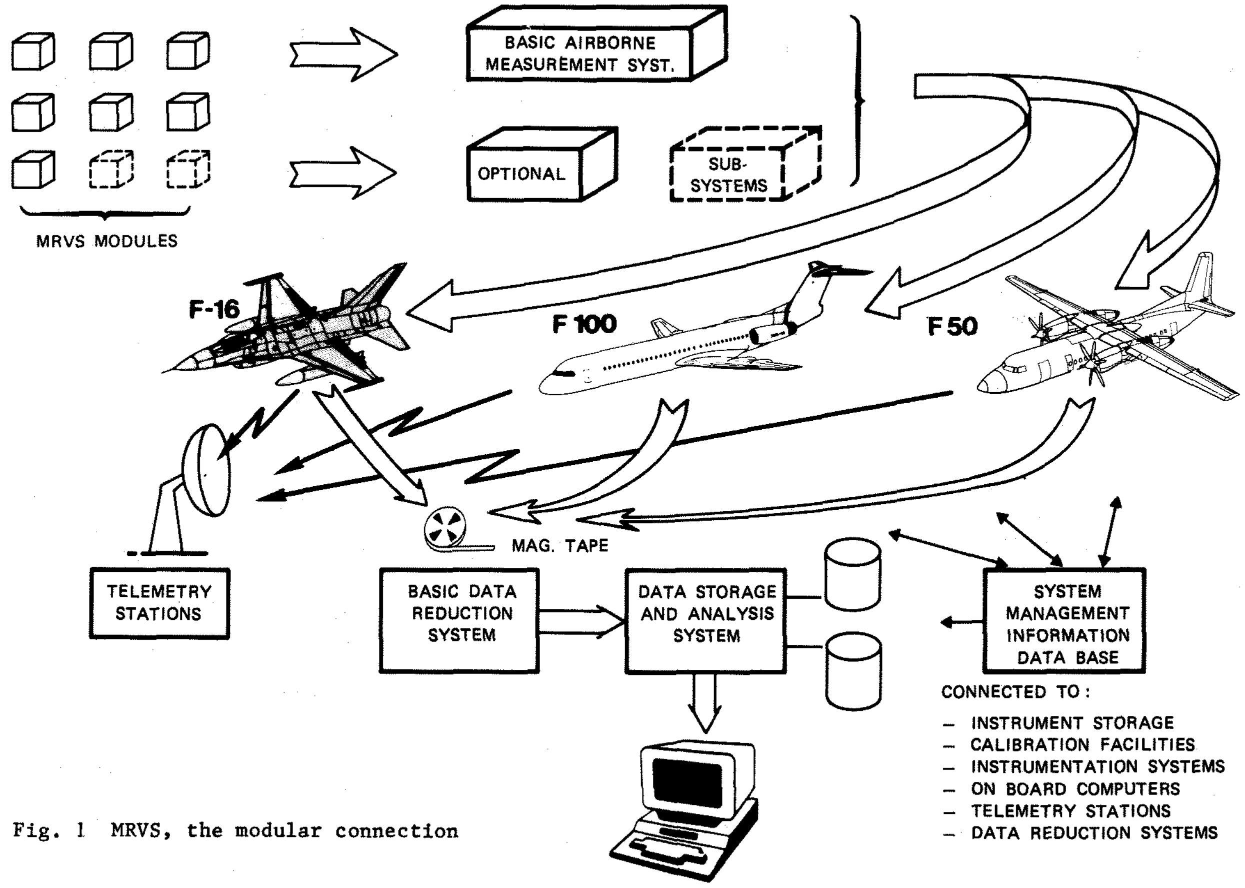


Fig. 1 MRVS, the modular connection

In an analysis of the different types of flight test projects to be expected, a number of functions appearing in all projects were identified. These functions can be realized with a basic airborne measurement system and a basic data reduction system on the ground. These functions are:
- measuring,
- recording,
- data processing,
- data delivery.

Depending on the number of parameters to be measured, single or multiple basic measurement systems can be built. To a lesser extent this also holds for basic data reduction systems. They are described in further detail in section 3.2.

Optional subsystems were defined to satisfy additional requirements and wishes, to be connected to basic systems. Their functions include:
- measuring a special set of parameters,
- data presentation,
- checking the measurement system
- structural storage of processed data,
- special data processing.

The optional subsystems which have unique features, are described in detail in section 3.3.

Both the basic systems and the optional subsystems consist of assemblies of MRVS-modules. They also are to be considered as "modules" (of a higher order) meeting the above mentioned prerequisites.

3.2 Standard Subsystems

Standard subsystems in the context of this paper are the systems in use in identical or congruent form in other flight test centres. They will be touched on briefly and referenced for more detail.

3.2.1 Basic Airborne Measurement System

The Basic Airborne Measurement System encloses a digital recording part and an FM-recording part (Fig. 2). Both parts can be installed independent of each other or simultaneously. They consist of equipment (transducers) to convert a multitude of physical quantities into electrical signals to be recorded on a magnetic tape, after signal processing. In most cases these transducers must be specially installed in the aircraft. Frequently, however, it is important to record data from the operational on-board systems as well. These on-board systems, like the specially installed transducers, produce a variety of electrical signal types that must either be digitized or conditioned for FM-multiplexed recording.

Digitizing is done in a Remote Multiplexer Digitizer Unit (RMDU) that subsequently writes the digital data in IRIG-PCM standard code on one of the 14 tracks of the instrumentation recorder, in a programmed sequence and with a predetermined frequency.

Especially in case of signals with a high frequency content or an unknown bandwidth it was chosen to condition these signals for FM-recording. Also FM-recording is applied in case of signals that have to be recorded on very short notice or for just one flight, provided that the accuracy requirements will be met. Depending on the transducer output signal, an appropriate signal conditioner is placed in the measurement chain. Its setting and the connection via the matrix-selector and FM-Multiplexer is computer controlled. So quick changes in parameters to be recorded on the FM-tape-recorder can be made, while the information about the current lay-out of the system itself is also recorded.

With the appearance of digital data buses a large amount of data from the operational aircraft systems is already in a digital format. Using appropriate interface cards a selectable part of these data can be fed into an RMDU. When a larger quantity of the databus information is needed (which is the case in a civil airliner like the Fokker 100) a specially developed ARINC Databus Multiplexer is applied (see paragraph 3.3.1).

On one track of the tape-recorders a time

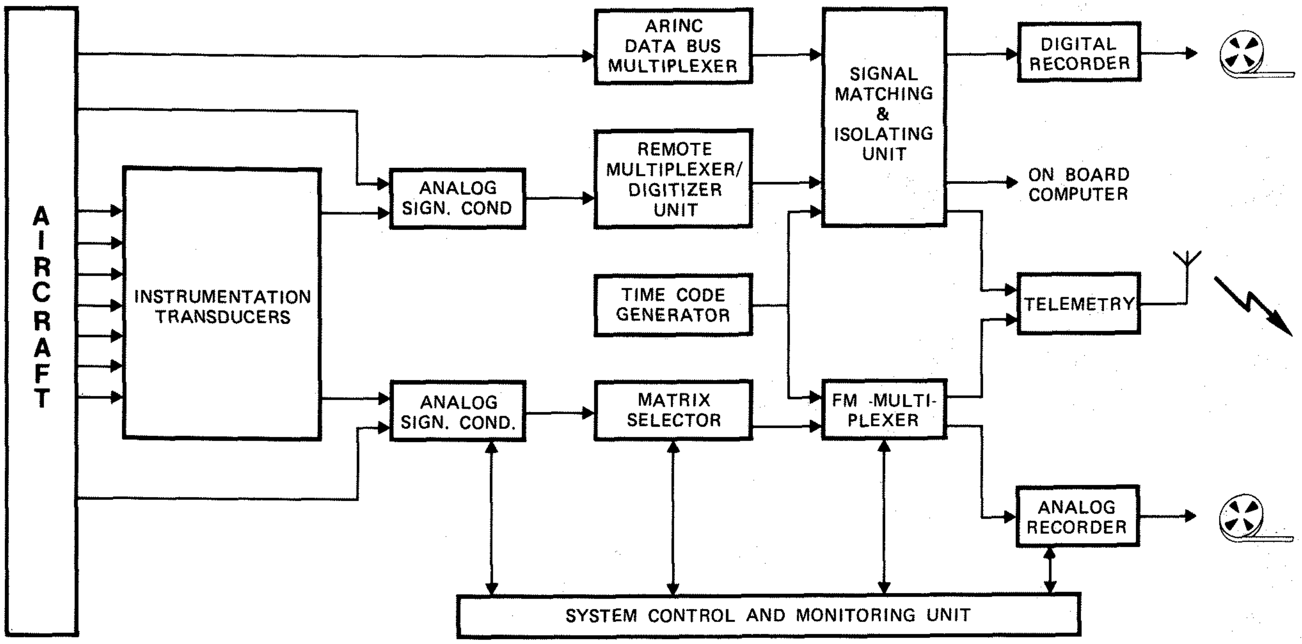


Fig. 2 Basic Airborne Measurement System

signal is recorded. After the flight, data tracks are always read simultaneously with the time signal track, so that all data can be correlated indirectly via the time signal. This is done with an accuracy better than 1 ms. A tape monitor checks the recording quality during the measurements. Modular expandability has been obtained by creating the possibility of adding one or more RMDUs in the digital part to increase the capacity almost without limit, and to add signal conditioners and multiplexers in the FM chain.

In case of the Fokker 100 about 900 MRVS-transducers were installed in one prototype and about 500 analog signals from the on-board systems were recorded simultaneously. Their frequency content ranged from 1 Hz to 500 Hz, their accuracy from .03% to 5% full scale (excluding the inertial systems).

Detailed descriptions of Basic Airborne Measurement Systems can be found in the references 5, 6 and 7.

3.2.2 Inertial Systems

Inertial Systems, containing primary sensors for linear and angular accelerations and for attitude, supply the most important parameters to be measured, especially with the emphasis now placed on parameter identification techniques for the determination of aircraft performance and flying qualities. They are, within the MRVS-scope, available in different configurations:

- the Honeywell IRS, a strap-down system with ring laser gyro's, modified for flight test purposes with respect to the standard unit
- the Litton LTN76 INS, with a (gimballed) stabilized platform, also modified for flight test purposes
- a transducer platform (strap-down) with a three-axis accelerometer and three-axis rate-gyro package and a conventional vertical gyroscope.

The output of these systems can be treated either in the same way as the output of all other transducers, or as digital datastreams that can be recorded via the RMDU, via the ARINC Data Bus Multiplexer or directly on the tape-recorder, thus ensuring the possibility of using these systems in any given configuration of the measurement system.

3.2.3 Video/Camera System

The MRVS video and camera system is used to observe water ingestion and icing, for example on the wings and on the empennage, or on other parts of an aircraft that cannot be observed directly from the cockpit or the cabin. Another application is the observation (and registration) of the flow behaviour on the aircraft skin. The correlation with the other measurement results can be made using the time code information that is continuously shown in the video image. An On-Board Computer can add selected parameters expressed in engineering units to the image. As an example, in case of stall tests the air speed or the angle of attack can be selected and displayed in the video image showing flow separation on the wing.

In stores separation tests or missile launch tests high speed camera's are used. Correlation with other measurement results is obtained via event recording.

3.2.4 Telemetry System

Due to the large variation in test programs several telemetry systems are in use, both mobile and fixed. The larger system is capable of transmitting four 37.5 kHz wide channels to a ground based tracking antenna. It is used for transmission of analog signals and/or digital signals. The smaller portable systems are mostly used with short-range helical antenna's.

All telemetry systems can be connected to the System Management Information Data Base (SMID, see paragraph 3.3.8) in order to get the configuration and calibration data of the measurement systems. The result of this set-up is that each telemetry system can -on short notice- be used in combination with each measurement system.
In the telemetry station, either mobile or permanent, the test data are presented, real time, in engineering units both tabular and graphical.
In between the testruns, analysis programs present calculated results and correlation between test results of consecutive testruns.

A rather unique solution to off-load the telemetry system with the help of the on-board computer, is described in paragraph 3.3.2.

3.2.5 Basic Data Reduction System

The Basic Data Reduction System (Fig. 3) comprises a digital and an FM-replay facility. The general purpose computers in the system are connected to the play-back facilities using standard front-end equipment.

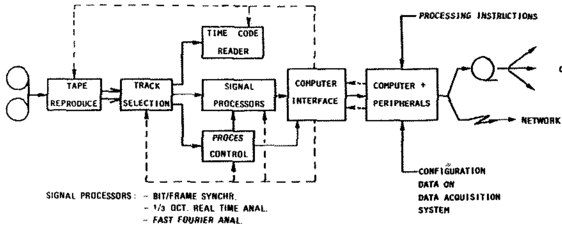


Fig. 3 Basic Data Reduction System

In case of digitally recorded data a selected data track is always read simultaneously with the time track. The bit and frame synchronizer unravels the data bits, identifies the beginnings of the recurring data frames and groups the bits into words. The time code reader interprets the time code track, so that the time can be added to the measured data by the frame synchronizer. Data and time are read by the computer simultaneously. The front-end equipment is instructed about the part of the flight and the data to be selected under control of the computer. The actual processing consists of converting the recorded data in engineering units and correcting them according to the calibration information of the measurement channel. After being properly ordered and grouped, the data is sent to the Data Storage and Analysis System for data analysis (par. 3.3.9). All information that the system needs for its reduction tasks is stored in the System Management Information Database and is retrieved from that Database at the beginning of each reduction session.

In case of FM recorded data the information is demultiplexed first. The parameters can than be displayed directly as time histories or be digitized and considered as digital signals as described above. Special data analysis equipment, such as Fourier analysers can be coupled directly.

The modular concept of MRVS can be found here especially in the software. The system, however, is rather straight-forward apart from the way it gets the necessary information about the instrumentation systems in use, as described in more detail in paragraph 3.3.8.

3.3 Advanced Subsystems

Advanced subsystems in the context of this paper are the systems that are believed to have unique features compared with other solutions in the field of flight test instrumentation.

3.3.1 ARINC Data Bus Multiplexer

Modern civil aircraft are equipped with avionics systems which communicate via so-called ARINC-databuses. Data is transmitted via serial links according to the transmitter-receiver principle. The characteristics of signals and contents of datawords are described in ARINC Specification 429.

In case of the Fokker 100 aircraft data from about 48 ARINC databusses, both high- as well as low-speed types (100 and 12.5 kHz) have to be acquired. The ARINC 429 datastreams are not suitable for direct digital recording on the instrumentation recorder because these signals are bipolar and asynchronous. Moreover the number of ARINC channels exceeds the number of available recorder tracks (normally 14).

Recording requires:
- multiplexing the ARINC databusses, without loss of information and without loss of time information,
- converting the signals into IRIG-PCM code, equal to the RMDU output data streams.

An ARINC Multiplexer Module (Fig. 4) was developed, having the following characteristics:

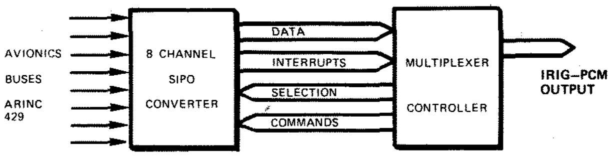


Fig. 4 ARINC Multiplexer Module

- 8 ARINC 429 inputs, high or low speed. Each input circuit automatically adapts to the speed of the signal input.
- 1 IRIG-PCM output, in which all input data are included. Each data sample is supplied with an identification and a time tag. By itself this time tag is insufficient for reconstruction of the time, but used in combination with the time track on the tape, time reconstruction for each ARINC dataword is possible with an accuracy of 0.1 milliseconds.
- maximum input rate, without loss of data, is 1860 samples per second, for 8 inputs operational.

With this multiplexer module two ARINC Databus Multiplexers, which differ in the number of in- and outputs, were developed:
- AMUX, a 1/1 ATR chassis, with up to 48 ARINC input channels, which are multiplexed into 6 IRIG-PCM datastreams,
- MINI AMUX, a 1/2 ATR chassis, with up to 16 ARINC 429 input channels, which are multiplexed into 2 IRIG-PCM datastreams.

A more detailed description is given in reference 8.

3.3.2 On-Board Computer

The On-Board Computer system (OBC) was introduced as part of MRVS to meet the requirements for:
- pre-flight system check-out, to reduce the time required for the flight preparation,
- in-flight system checkout, to monitor the integrity of the flight-test equipment during the flight,
- in-flight quick-look and analysis, on-board (display) as well as on the ground (via telemetry),
- post-flight quick-look.

Together with the more general requirements set for MRVS, the above mentioned requirements led to the following functions to be performed by OBC [Ref. 9]:
- calibration of data into engineering units (EU), and presentation in numerical as well as in graphical form (time histories) on a Visual Display Unit (VDU) and/or on a printer/plotter (LPT/PLT). This facility is used by the flight-test instrumentation engineer (FTIE) during system integration, flight preparation and during the flight.
- quick-look presentation for the flight-test engineer (FTE) using the above mentioned facilities. For each particular test run one or more predetermined selections of parameters to be presented are available and instantaneously recallable by function keys.
- the capability to transfer parameter data, via a telemetry link, to the ground. In order to off-load the telemetry ground-station computer, doing its job in real-time, parameter data are labeled, expressed in EU's and are timetagged. If telemetry is required, one or more predetermined telemetry parameter selections are available, also recallable by function keys.
- recording of selections of parameter data on a Computer Compatible Tape (CCT). Parameters are labeled, expressed in EU's and are timetagged. If tests are performed at remote locations, post-flight analysis is possible by replaying the CCT on either the OBC or a general purpose mini-computer.
- during the flight a subset of parameters have to be checked against predefined limits. Two types of checks are required:
  - check on status words of the various instrumentation modules, which may result in an Instrument Warning,
  - check of flight critical parameters, which may result in an Annunciator Warning.
- limited real-time dataprocessing. Depending on the project real-time calculations are performed, for instance the calculation of Fuel Consumed as a function of Fuel Flow and Time.
- postprocessing, in fact play-back of the data recorded on CCT.
- furnishing parameter values in EU's to other on-board systems, for instance to the Video System for insertion in the video image.

To perform these functions the OBC requires the following inputs:
- serial datastreams in IRIG-PCM format from the Basic Airborne Measurement System (par. 3.2.1),
- the time code signal from the Time Code Generator System (par. 3.2.1),
- warning messages from the FM-recording system (par. 3.2.1),
- parameter calibration- and selection- data from the System Management Information Database:
  - . Parameter selections for presentation on VDU and LPT/PLT, for CCT recording and for telemetry.

- Calibration coefficients, needed for conversion of raw parameterdata from the acquisition systems into EU's.

These data are retrieved from the System Management Information Database and transferred to OBC as a local database (OBCDB) on floppy disk.
- commands and messages from the FTE and the FTIE, to activate the various OBC functions.

The OBC hardware configuration (Fig. 5) is built around the 16-bit powerful MIL-SPEC minicomputer from the ROLM 1600 series. Details are described in reference 9. Two types are available, the ROLM 1664 with 64 kw. memory and the ROLM 1666B with 256 kw. memory. A fully compatible ground-based system, also encompassing a ROLM 1666B (with 512 kw. memory), is available for software development, failure-analysis and production of the OBCDB on floppy disk.

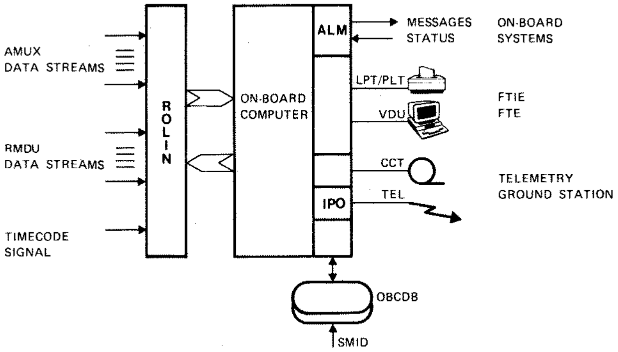


Fig. 5 The On Board Computer System

Because interfaces for IRIG-PCM data and IRIG-B time code were not available, a hardware preprocessor, the ROLM Interface (ROLIN), was developed. ROLIN is laid out for 16 serial datastream inputs. Data transfer to the computer is realized in high speed Direct Memory Access Mode (DMA). The incoming parameter samples are handled in two different ways:
- All parameters, not all samples, no timetagging.
  Several times per second the most recent sample of each parameter is transferred to the computer, for presentation purposes.
- All samples, not all parameters, timetagging.
  All incoming samples of a subset of parameters is labeled, timetagged and transferred to the computer. This mechanism is used for data transfer via telemetry and for recording on CCT. It gives the possibility of data analysis as the data samples are timetagged.

The OBC-configuration encompasses an Interstate Plasma Display Unit (VDU), a Miltope computer magtape unit for recording (CCT), and the Miltope high speed printer/plotter (LPT/PLT). For storage of programs and the local database (OBCDB) with parameter calibration- and selection- data, the Miltope Floppy Disk System (FDS), is used.

For interfacing with other on-board systems the ROLM asynchronous line multiplexer (ALM) is incorporated in the ROLM computer.

For transmission of telemetry data, a special ROLM computer interface, an IRIG-PCM Output Interface (IPO) was developed.

The OBC software actually executes the various tasks. For each flight test program all parameter calibration data and parameter selections for data presentation, telemetry and CCT-recording are defined and stored in the System Management Information Database. The OBC data base conversion program (KON), retrieves the SMID data, creates the OBCDB and presents its content. KON is installed on the ground-based system which is connected to the central computing system containing the SMID. The OBCDB is written on a floppy disk and transferred to the aircraft. The software module MUTE permits last minute changes to the contents of OBCDB on-board the aircraft. Figure 6 gives an overview of the software configuration.

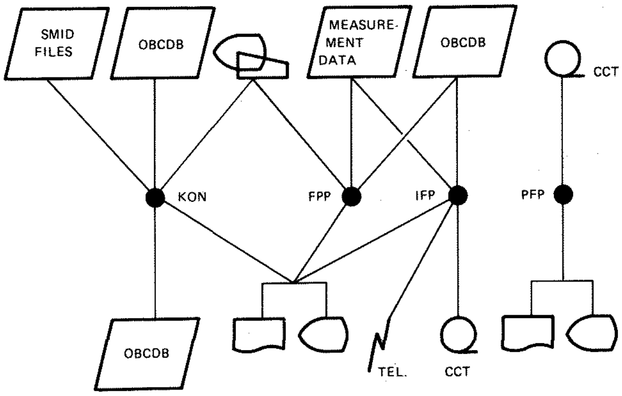


Fig. 6 The On Board Computer Software Configuration

The Flight Preparation Program, FPP, automatically checks the parameters against requirements with respect to mean value and/or min. and max. values, before (and after) each flight. Results are printed or plotted for evaluation by the FTIE.

The In-Flight Program, IFP, performs system monitoring, checking and displaying of data and statuswords of acquisition units, quick-look, checking of test parameters, presentation of parameters in tables or plots, recording a subset of parameters on CCT, selection of a subset of parameters in EU's for telemetry and for realtime data processing.

The Post-Flight Program, PFP, consists of functions which enables a quick provisional analysis of test runs. Test runs can be "repeated" by running various software routines, similar to the IFP routines, using the data recorded on CCT.

3.3.3 Take-off and Landing Trajectory Measurement System

This system STALINS (a dutch acronym) was developed to overcome the cumbersome and time consuming film reading associated with the nose-mounted camera method used previously.

Performance characteristics of the system are:
- the accuracy for the along-track distance from standstill to threshold height (reversed for landing) is 0,1% (1-σ) of the traversed distance
- the accuracy of the measured height above the runway over that same distance is within 0.15 m (1-σ)
- flight tests on non-instrumented airfields all over the world are possible, only the runway height profile must be available with high precision (± 0.05 m)
- the only ground equipment, a small radio marker (2 for redundancy), can be easily transported on board the test aircraft and placed into

position within an hour after arrival
- the system can be used in an all weather environment.
- processed results are available in real time with sufficient accuracy to judge the progress of the test program using telemetry. The trajectory data of a day's program of 25 runs is available in full detail within 12 hours after delivery of the test data to the Data Reduction System.

The primary data source for STALINS is a flight test version of the Litton LTN-76 Inertial Navigation System. The North-South Velocity (VNS) and East-West Velocity (VEW), as calculated by the LTN-76 itself, are integrated to provide distance with respect to the position of the aircraft at the beginning of the test run. A number of error sources, contributing to the total error in the velocity components, has to be taken into account:

a. The Schuler motion of the stabilized platform in the LTN-76. The Schuler tuning tries to keep the platform aligned parallel to the local horizontal. In practice, the platform will oscillate around the horizontal position. This results in errors in the velocity outputs of the order of 0.5 m/sec (Fig. 7). These errors are reduced by measuring the values of VNS and VEW during standstill immediately before take-off or immediately after landing and correcting for these values.

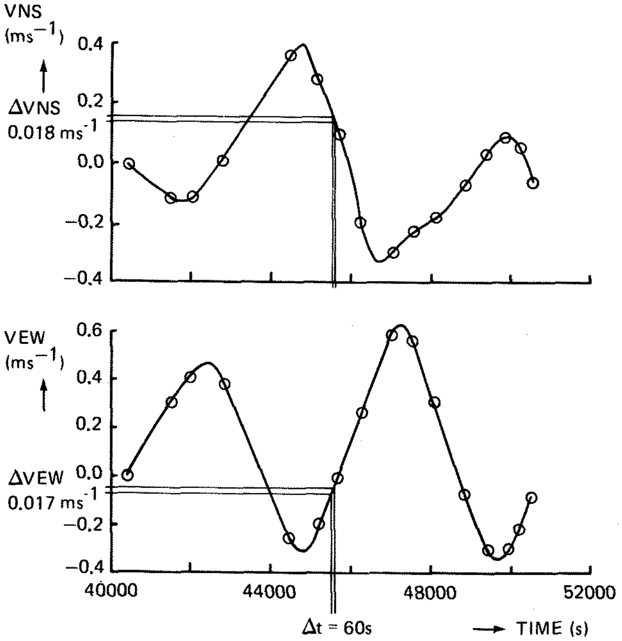


Fig. 7 The effects of the Schuler motion on the horizontal velocities during one flight

b. Incorrect orientation of the platform with respect to the North direction. The resulting error is eliminated by using a calculated runway direction instead of the nominal value. The runway direction is calculated from the VNS and VEW after they have been corrected for their values during standstill.

c. Calibration errors of the horizontal accelerometers are detectable. The resulting error, however, can be neglected with respect to the required accuracy.

As the integration of the horizontal velocities starts from a point of standstill that is not known in runway co-ordinates, a correlation between the calculated trajectory and the runway co-ordinates must be established before the runway profile can be correctly applied to the height calculation. This is done by recording on board the passage of a small radio marker [Ref. 10], placed along the runway at a known point. This radio marker has a radiation pattern that produces zero field strength in a vertical flat plane perpendicular to the runway centerline. The transmitter is small enough to be carried to its destination on board a small commercial aircraft.

Direct calculation of vertical velocity and height from the so-called "Integral of Vertical Acceleration" (IVA) output of the INS and the local g-value obtained from outside sources does not provide the required accuracy due to the following reasons:

a. The IVA output of the LTN-76 is not corrected for Coriolis effects. The Coriolis correction is applied in the postprocessing software.

b. In most cases the local acceleration of gravity is not known with sufficient accuracy.

c. Since the required accuracy in height is a factor of 10 higher than in the horizontal distances and since the effect of accelerometer sensitivity error is greater because the mean acceleration level is 1 g, the calibration errors of the vertical accelerometer will have significant influence on the calculations in the vertical direction.

The problems mentioned under b. and c. are solved by calibrating the vertical accelerometer during each measurement. The calibration can be established by the comparison of the LTN-76 measured height with the actual (geographic) height trajectory during the ground roll. The latter can be calculated if the following parameters are known (Fig. 8):

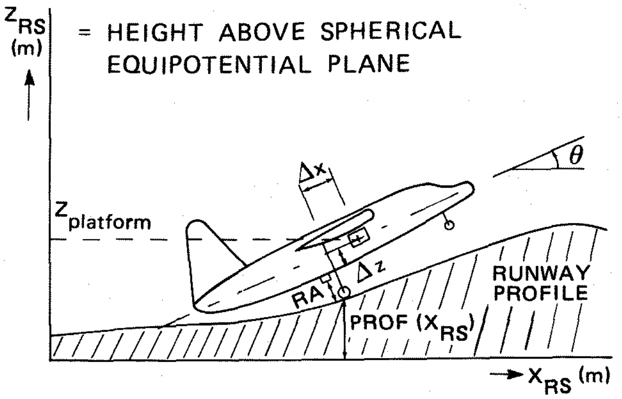


Fig. 8 Platform height Z with respect to the XY reference plane during the ground run

- the height profile of the runway, measured by geodetic survey methods,
- a time history of the position of the aircraft on the runway,
- a time history of the pitch angle, measured by the LTN-76,
- a time history of the small variations in the height of the aircraft caused by deflections of the landing gear and the tyres; these can be measured with sufficient accuracy by a flight test radio altimeter.

The calibration method described above establishes an apparent g value as a by-product of the postprocessing process. This value is used as a check on the quality of the processing.

The runway survey and the use of the radio marker add some complexity to the operational use, but they contribute significantly to the accurate height measurement which was a great problem in previous attempts to use an INS for take-off and landing measurements. Once the runway profile has been measured it can be used for many years.

The STALINS-system has been described in detail in reference 11 and has recently proven its capabilities many times during the certification program of the Fokker 50 and Fokker 100.

3.3.4 Automatic Landing Flight Path Measurement System

The Fokker 100 aircraft is equipped with a digital Automatic Flight Control and Augmentation System (AFCAS) enabling Cat. III automatic landings. In the Fokker 100 flight test program approximately 600 automatic landings have been carried out for evaluation and certification. An accurate, fast and flexible flight path measurement system has been developed for these trials.

Purpose of the system was: 3-dimensional aircraft trajectory measurement during approach, landing and roll-out, suitable not only for full stop landings, but also for touch-and-goes and go-arounds (aborted approaches). The most important requirements concerned accuracy, data turn-around time and mobility.

The most stringent position accuracy requirements apply to the final part of the trajectory, from runway threshold up to and including roll-out and standstill: 0.3 m standard deviation along track, 0.15 m cross-track and 0.15 m in height. The velocity accuracy requirement was: 0.025 m/s standard deviation (crosstrack and height).

In the approach to the runway threshold the requirements are less stringent with increasing distance to the threshold.

Trajectory data of a day's flight should be available within 12 hours.

Automatic landing trials were to take place on approximately 6 different runways in Western Europe, and change of location had to be possible at 24 hours notice. So the system had to be mobile.

The forward-looking camera method was the obvious choice because of its mobility, but it was not able to meet the data turn-around time requirements because this method requires hundreds of pictures per run to be digitized and processed. Film reading is time-consuming and its quality is strongly dependent on the operator's degree of accuracy, motivation and physical fitness. Thus, reducing the film reading effort offers great advantages, and this was done by combining it with inertial data from modules used in STALINS, described in the previous paragraph 3.3.3.

The general set up of ALAND is shown in figure 9.

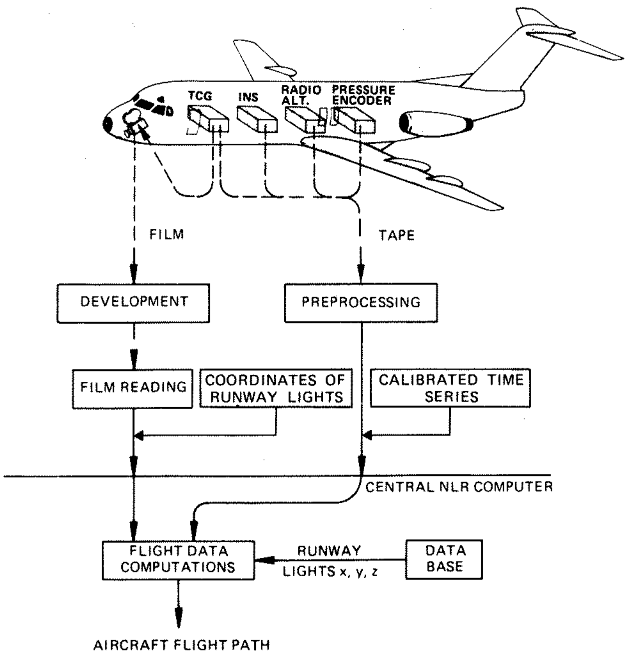


Fig. 9 General set-up of the Automatic Landing Flight Path Measurement System

A filmcamera is mounted in a bay in front of the nosewheel, looking forward and slightly downward via a mirror. It takes pictures of the runway lights during approach and landing.

In front of the camera lens a calibration facility consisting of light sources, collimating lenses and prisms is mounted. It projects, under fixed and accurately known angles, six collimated light beams on the lens, which become visible as fiducial marks on the film. This way one can correct for:

- film translation and/or rotation in camera and/or film reading projector;
- variations in focal distance in camera and/or projector;
- anisotropic film shrinkage caused by the development process.

The inertial data comes from the Litton LTN-76 Inertial Navigation System, operating in a stand-alone mode or VOR/DME-update mode.

Pressure encoder data is used for updating the INS-vertical channel. Radar altimeter data are only used to verify the results. Time-correlation is accomplished by recording the time code signal (from a time code generator) both on tape and on film.

The three-dimensional positions of the runway lights (edge lights, centre lights and approach lights) have been surveyed beforehand with the required accuracy and stored in the data analysis computer.

The exposed film is developed and the runway pictures projected on a digitizer in the film reading station, which is connected to the data analysis computer.

Both film projector and digitizer are mounted rigidly and vibration-free. During film reading the film is sucked against a glass window.

To help the operator in positioning the cursor on the digitizer accurately, quickly and without excessive effort a small part of the projected image, surrounding a point to be digitized, is projected on a TV-camera (without lens) and shown enlarged on a TV-monitor.

Film reading accuracy is better than 10 µm (on film) and film reading time is less than 1 minute per photograph (6 fiducials, 26 runway lights, no manual light-identification).

Before the film reading commences, a rough trajectory is computed from the INS-data. This trajectory suffers from both position and velocity errors but is sufficiently accurate for position-prediction during film reading.

Interactive film reading starts now. First a photograph is chosen on which runway lights are easy to recognize and identify, generally one on which the runway threshold is visible. Fiducials and runway lights are digitized, three lights are identified manually. From this data the aircraft position and attitude are computed. This computation includes:

- fiducial processing
  lens distortion-correction; computation of optical centre, rotation angle and enlargement factors;
- lamp processing
  - . initial position estimate computation from the 3 manually identified lamps (for threshold picture)
  - . automatic lamp-identification if initial estimate is sufficiently accurate;
  - . minimum variance estimate of camera position and -attitude from at most 26 lamp readings.

The second and following pictures to be digitized are chosen at 3 to 4 seconds intervals. For each picture the position is predicted using the previous picture and the raw INS-displacements. Manual lamp-identification is not required further but is performed by the computer. Generally 7 to 8 photographs are sufficient for a run (landing, touch-and-go or go-around)

By comparing the rough INS-trajectory with the set of photo-positions the coefficients of an INS-error model are estimated (position-, velocity- and acceleration-offsets, heading misalignment. The rough trajectory is then corrected for these errors. The result, the final trajectory, gives continuous information on the aircraft position and speed from 4 km before the runway threshold onward.

The dynamic accuracy of the system has been checked by means of geodetic survey cameras alongside the runway. The result was three times better than required. The application in the Fokker 100 flight test program has proven that the mobility and data turn-around time requirements have also been met.

A detailed description of the system can be found in reference 12.

3.3.5 Multi-Sensor Positioning System

Either for very accurate in-flight position determination or for establishing the performance of the installed aircraft navigation system a Multi-Sensor Positioning System has been developed, based on existing or new MRVS-modules.

The system has been designed around a ROLM 1602B airborne computer that integrates the information from the different sensors, controls the sensors if necessary and calculates the aircraft position in real time. It also stores the raw data on tape, thus facilitating a post-flight analysis, leading to a more accurate position determination.

In the choice for the basic sensor use was made of the high density of DME (Distance Measuring Equipment) and TACAN (Tactical Air Navigation) stations in the Netherlands and the surrounding countries. A DME interrogator is tuned sequentially by the computer to 3 to 5 stations. Normally a valid distance is acquired within 0.5 seconds. The calculation of the position from the multi-DME data is based on the minimization of the sum of the squared distances ΔR_i of the position estimate to the spheares with radius R_i, representing the measured DME distances (Fig 10). A better accuracy can be reached by adding height information (radio-altimeter or barometric altitude) and the speed vector (airspeed and compass heading). Especially the speed vector contributes significantly to the accuracy, because the displacement of the aircraft between the consecutive DME measurements can then be easily corrected for (Fig. 11).

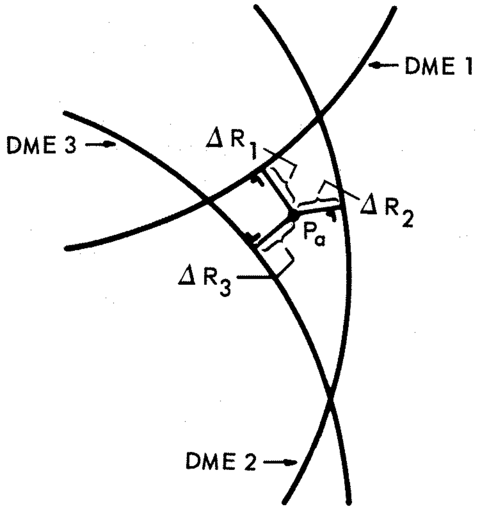


Fig. 10 Multi-DME positioning

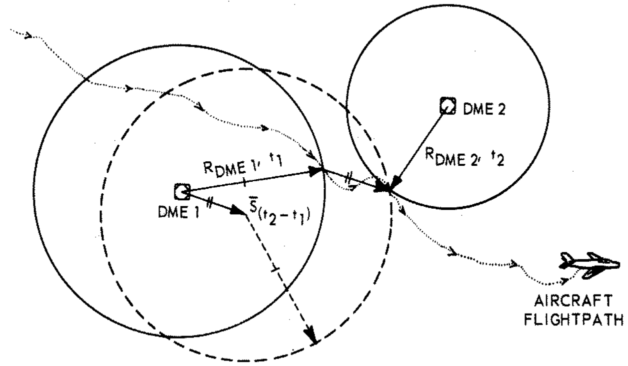


Fig. 11 Displacement vector

DME distances themselfs are corrupted with random errors, bias errors and position errors. The latter is normally the result of an incorrect survey of the ground station coordinates. If a certain ground station is interrogated from different angles, both the bias and the position error can be determined in post-flight analysis and used in a following flight.

Other sensors can be added either to give a precise ground speed vector or independent position information. The latter information can than be used to enhance the position accuracy, using Kalman filter techniques. Available sensors at this moment are inertial navigation systems (see paragraph 3.2.2) and the NAVSTAR-Global Positioning System. Less accurate systems like LORAN-C and OMEGA can be added also, replacing multi-DME in areas without DME coverage.

In and around the Netherlands a position accuracy of 30 to 50 meters has been demonstrated in flight [Ref. 13].

3.3.6 Noise Measurement System

In the past decade aircraft noise has become an important issue in certification testing.

When performing noise measurements one is restricted to a rather narrow weather envelope.

Since in Western Europe this weather is only available for short periods of time it is clear that noise testing should be a fast and smooth operation. Thus in an early stage it was concluded that these goals could be achieved only by a concentrated effort in measurement accuracy and sophisticated monitoring facilities.

The noise measurement system comprises a flight path measurement system, telemetry equipment, automatic noise measurement stations, meteo units, communication links and a central control station. A diagram of the subsystems involved is given in figure 12.

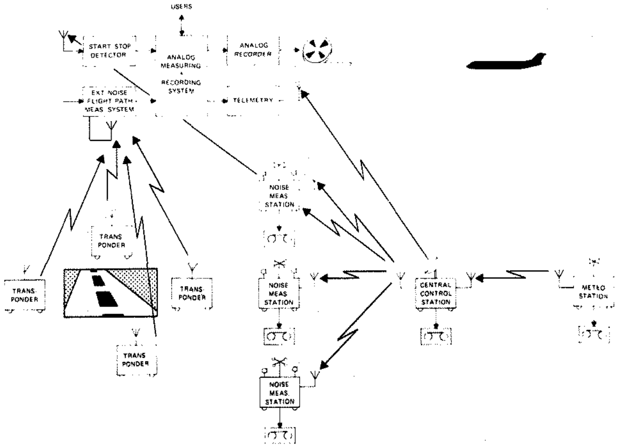


Fig. 12 The Automatic Noise Measurement System

At the Central Control Station the operator can control the noise measurements. The operator can communicate with the aircraft, with the tower and with the noise measurement stations by means of VHF links. The VHF links are also used to send start/stop signals to the aircraft and to the noise measurement station recorders. The central control station sends a time code signal to the noise measurement stations and triggers data transmission from the noise measurement stations to the central control station. The station is housed in the telemetry mobile ground station.

The main functions of the Start-Stop Detector are to start and to stop recorders in the aircraft simultaneously with ground based recorders.

The SSD also provides a start and stop criterion for the flightpath measurement system described in the next subchapter.

The Flight Path Measurement System is an aircraft position measurement system based on a Motorola MiniRanger Mk III system (MR Mk III) and an On Board Processor (OBP) for real time guidance of the aircraft using standard cockpit instruments.

The MR Mk III is a pulsed radar distance measurement system, operating at a frequency of 5.5 GHz. The MR Mk III console (situated in the aircraft) interrogates four ground based transponders. They are placed at locations with known coordinates. To counter the movements of the aircraft (pitch and roll) two transponders are located longitudinally and the other two laterally on opposite sides of the runway. The flight path lies within a quadrangle defined by the transponders. For calculating the position of the aircraft one laterally and one longitudinally located transponder is used. In this way the position error is as small as possible.

The aircraft speed and height are determined by measuring aircraft static pressure, impact pressure and total air temperature.

The On Board Processor controls system timing, performs data acquisition and calibration, calculation, data conversion and data output. Calibration data is put into the processor's non-volatile memory before a measurement session.

A special ARINC transmitter drives the localizer- and glideslope bars through a dummy NAV receiver, using signals generated by the OBP. Thus the pilot is provided with guidance information which enables him to fly a predefined flight path.

The Telemetry System is used for transmitting digital data, e.g. from the flight path measurement system to the mobile Central Control Station.

A fixed back-to-back helical antenna is used, giving sufficient telemetry coverage over the runway and its vicinity.

The time code signal is always embedded in the telemetry data, enabling time correlation between the aircraft and ground based equipment.

In the Noise Measurement Station the aircraft noise is measured by condenser microphones with preamplifiers. In each station the signals from one or two microphones are recorded on a videocassette recorder using a Pulse Code Modulation (PCM) technique. The PCM technique with its high dynamic range has been chosen to eliminate the need for ranging and to increase measurement accuracy.

A direct channel on the recorder is used to record a datablock, containing administrative data, warning signals, weighted noise levels from the last measurement and wind speed and air temperature measured by the local meteo unit.

To enable synchronisation a time code signal is sent to each noise measurement station by the Central Control Station via a VHF-FM link and recorded on a second direct channel of the recorder. The VHF-FM link also contains start/stop signals. Thus the station can be controlled remotely.

A unit named "Automatic Controller and Calibrator" generates all necessary control signals and electrical calibration signals. The calibration signals are fed into the microphone preamplifiers using the insert voltage method. These signals consist of a pink noise signal to determine the system frequency response and a tone signal to establish an absolute reference level.

Besides the electrical calibration signals external acoustic calibrators such as a pistonphone and a sound level calibrator are used.

The units of the noise measurement station are housed in a case, giving environmental protection. Another case, the accessory case, contains the batteries for stand-alone operation, a tripod, an antenna and the necessary acoustical items. The cases are transportable by car. The car can also deliver back-up power.

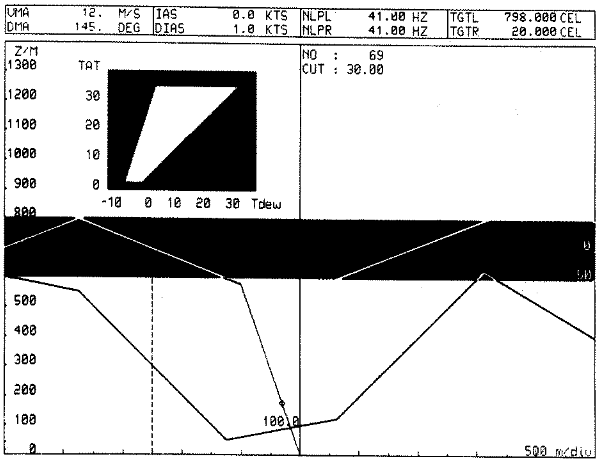
In accordance with the noise measurement procedure ICAO Annex 16 a central meteo station is used to obtain measurements of meteorological conditions at the test site. Also the surface wind speed and air temperature near the microphone positions have to be measured. For this purpose each noise measurement station incorporates a meteo unit. Such a unit measures the wind speed by means of a cup anemometer on a mast. The mast is attached to a box containing a temperature transducer and conditioning electronics.

The box is connected to the noise measurement station which also supplies power. The wind speed and temperature signals are further processed in the noise measurement station. From both parameters an average value can be obtained.

A DEC PDP 11/44 minicomputer in the telemetry ground station is used for real time data reduction of the noise data. Peripherals such as color graphics displays, hard copy units, terminals and printers provide the interfaces to the test engineers.

The noise is 1/3 octave analyzed according to FAR 36 and ICAO Annex 16 and results are fed to the computer twice per second. The following information (Fig. 13) is presented in real time to the flight test engineer in charge of the program and to the noise specialist:

- the reduced noise parameters.
- aircraft parameters such as engine rating, attitude, position, ambient temperature and dewpoint temperature.
- meteo parameters from the central meteo station.
- parameters from the noise measurement stations.



VMA	12.	M/S	IAS	0.0	KTS	NLPL	41.00	HZ	TGTL	798.000	CEL
DMA	145.	DEG	DIAS	1.0	KTS	NLPR	41.00	HZ	TGTR	20.000	CEL

NO : 69
CUT : 30.00

Fig. 13 Example of a FTE screen showing engine parameters, weather envelope and flight path graphics

The telemetry ground station operator also has the possibility of real time presentation of incoming data in order to check all instrumentation.

Initial analyses and conversions to reference conditions are carried out in the telemetry station minicomputer. A flow diagram for noise data is given in Fig. 14.

The use of telemetry gives great freedom in the disposition of microphones and real time observation indicates immediately whether or not a particular run has been succesful in providing the data required. If not, then another pass can be requested until the observers have the information they need. In practice though, repetition is rare.

The tests conform to the requirements of FAR Part 36 (up to and including Amendment 12) and ICAO Annex 16, chapter 3. They are performed by the "fly-around" procedure, that is without repeated landings and take-offs but in a series of sorties each lasting up to several hours. In each sortie the aircraft will make a series of passes in which it will intercept the normal flight path and from that point follow the required flight profile.

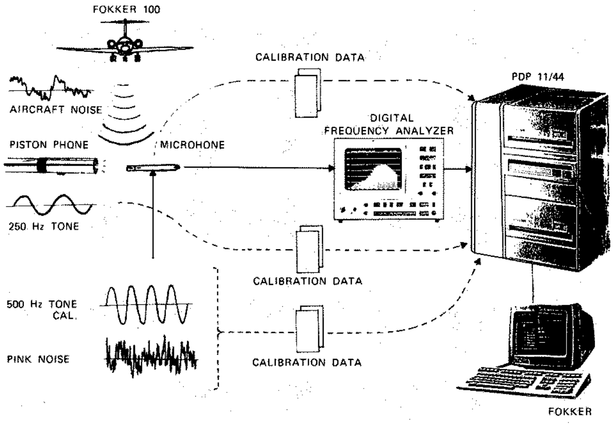


Fig. 14 The noise data flow

Within two minutes of each run the specialists are able to present diagrams giving a visual realisation of all major parameters. Especially valuable as an addition to presentation of average and corrected data is a block of "predictions" providing a form of crew briefing on flight test conditions to be observed on the next run, information which is conveyed verbally to the aircraft.

3.3.7 Ground Vibration Test System

Each new aircraft structure is subject to ground vibration tests prior to the first flight. Major goals of these tests are verification of the aeroelastic model of the aircraft and search for potential flutter behaviour.
Ground vibration tests usually are performed on the first prototype giving little time for preparation and actual testing. Therefore the results must be available immediately after the completion of the tests.

A diagram of the system which consists of excitation units, vibration measurement units, a control unit and sophisticated quick look facilities, is given in figure 15.

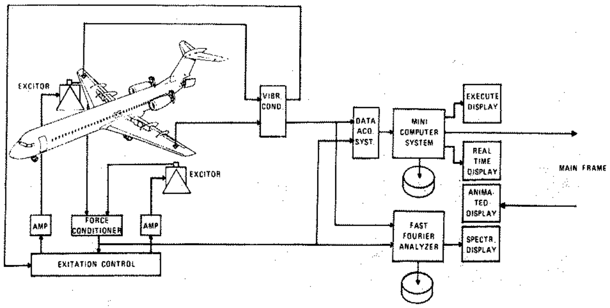


Fig. 15 Blockdiagram of the Ground Vibration Test System

Up to six Excitation Units (Fig. 16) which can deliver a force of either 380 N or 112 N are available to bring the aircraft in the desired vibration mode. Control units are deployed to control the phase between applied force and resulting displacement. This may be executed using either frequency or force as variable whichever is applicable.

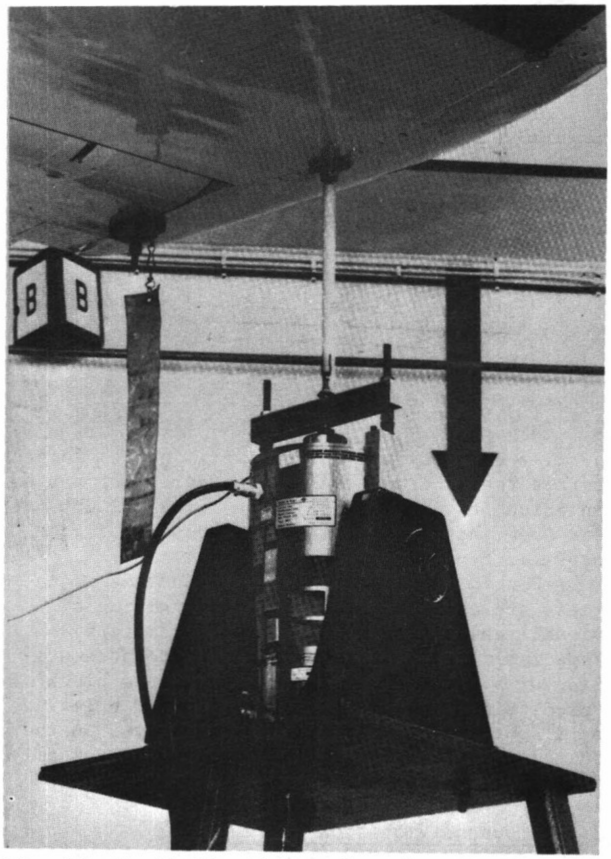


Fig. 16 Excitation Unit under wing

Excitation signals may be either periodic or random.

The vibration measurement units comprise vibration and force transducers (Fig. 17), signal conditioners and a data acquisition system coupled to a minicomputer. Software packages for data acquisition transcription and disk registration are installed on the minicomputer.
A maximum of 128 channels is available with a total throughput rate of 46 kw/s.

For Quick Look analysis a Fast Fourier Analyzer with up to 16 signal outputs is available in order to establish the precise frequencies of the several vibration modes of the structure. This is accomplished using random excitation signals. After that pure sine excitation is used for further measurements.

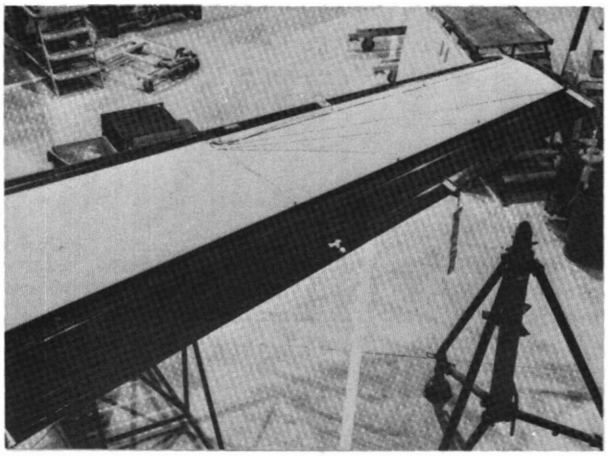


Fig. 17 Vibration transducers on outer wing

For the analysis of the ground vibration tests the minicomputer is linked to a mainframe. Software packages for the mini as well as the mainframe deal with real time system control, presentation of excitation parameters and animated display of vibration modes of the structure (Fig. 18).

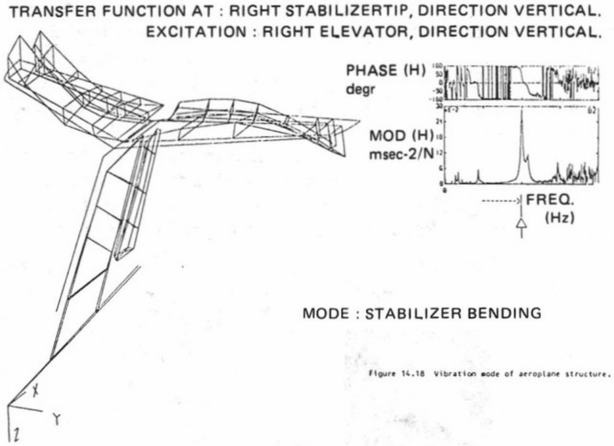


Fig. 18 Animated display of moving structure

The aeroelastic specialist has the test results at his disposal for comparison with the figures of the analytical model only a few seconds after each test run.

With all the (mechanical) preparations carried out, the system build-up time is about 3 days. This includes: locating and placing the exciters, loadcells, accelerometers and associated equipment. The measurement period will take about 150 hours, which means that the job can be done within one week.

3.3.8 System Management Information Database

The System Management Information Database (SMID) is the central repository for all information on measurement systems and on their application. The main objective of SMID is to serve the various management functions involved in preparation, execution and data preprocessing of flight test measurements during the flight test programs as well as many years thereafter.

Within the flight test instrumentation field a number of management functions can be recognized, leading to the following tasks for SMID:

- project management. A series of flight tests with one aircraft is treated as a project. A description of the flight parameters to be measured, their abbreviations, and the standard units to be used, have to be defined. This information is used as the basis for all instrumentation activities during set-up of each flight test project. Decisions made on this level are clearly made available to the instrumentation engineers involved in preparation and execution of flight tests.
- flight test management. Information has to be made available on the kind of tests to be performed, the parameters to be recorded, the selection of the measured data for monitoring functions on-board and at the ground station, and the selection of the measured data to be processed. This information is used by various processes during preparation and execution of flight tests, and for the data processing functions.

- management of instrumentation. All relevant data on equipment, such as technical specifications, operational limits, calibration data with date and time, value and insurance cost, have to be available upon request. Users of the information are the equipment manager, calibration laboratory, and the designer of a measurement system to be used during flight tests.
- measurement system management. The measurement system is the assemblage of all equipment used during flight tests in order to be able to acquire the data required. The information about a measurement system is used by the flight test engineers and by the data processing functions.
- dataprocessing management. The data preprocessing function needs directives about the measured data to be processed, the output selected, the equipment used and the calibrations (transfer functions) to be applied.

Operational requirements which have been realized for SMID are:
- a historical record is kept of all measurement system related data. This data is available for several years after the measurement system has been used in order to process the measured data many years after the actual flight;
- input of data is carried out in a conversational way in order to communicate the results of input validation directly to the instrumentation engineers;
- input of and requests for information is possible from different locations at the same time, in order to avoid activities having to wait for completion of other, non-related activities;
- data of all measurement systems in use at the same time are validated in order to prevent for example one piece of equipment being allocated to more than one measurement system;
- data necessary to support the data processing (e.g. transfer functions of equipment) are only valid at the time of the measurement of the flight data;
- data necessary to support a data processing run are available upon request within 5 minutes, thus meeting the timing constraints of the data processing.
- data are safeguarded against unauthorized access and usage. For example data related to one project are not accessible to persons performing other projects. Even within the data sets related to one project, access may only be granted to authorized project members.

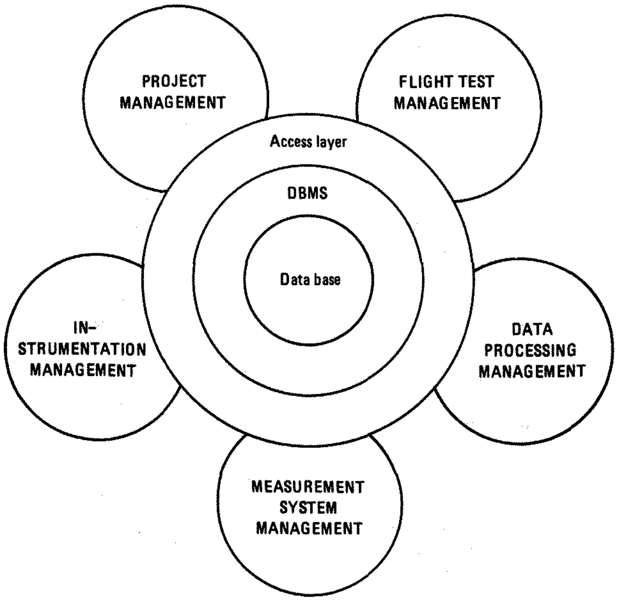


Fig. 19 SMID, application areas

As a consequence of requiring the support of independent management functions that have to communicate, a software concept has been chosen as depicted in figure 19. The application areas that support the management functions are independently interfaced to the database by means of an access layer. In this concept the database serves as the means of communication between the application areas. The access layer comprises various layers (Fig. 20). These layers facilitate access from the end-user, various checks, and access to the database itself. The communication layer is the interaction between the user and the database. The COmmand LAnguage System (COLAS) is used in order to obtain a uniform style of interaction [Ref. 14]. COLAS is developed especially for the generation of user interfaces for interactively driven application software.

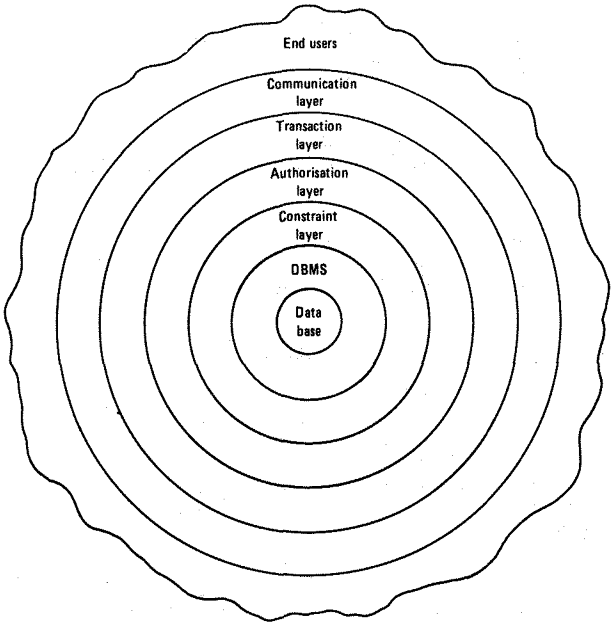


Fig. 20 SMID, layer model

Filing programs are going from outside through every layer. If the given data are correct, they are finally stored in the database. Each program is composed of a number of transactions depending on the activities of the involved management. For back-up purposes the data are also written to a logfile. A filing report is generated as a result of the executed transactions.

The application areas of SMID supporting the management functions, mentioned above, are subdivided into various transaction processing application programs. The database, being the kernel of the system, contains the data, entered by the specialists of the management functions supported (Fig. 21). The database of SMID serves as a means to interchange data between the management functions involved in flight testing. The actual activities of the specialists are supported by various reports that can be obtained from SMID

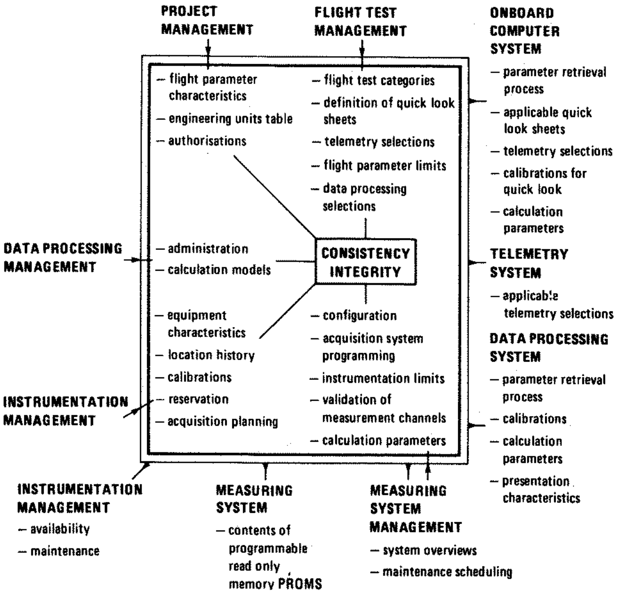


Fig. 21 SMID, datasets and their relation to management and processing functions

upon request. The reports for instance contain instructions for maintenance, data to instruct the On-Board Computer (OBC) employed in the measurement system, and overviews of available equipment.

A more detailed description of this database system can be found in reference 15.

3.3.9 Data Storage and Analysis System

The Data Storage and Analysis System (with the dutch acronym FDVS) is designed to be a complete but open-ended flight test management and engineering tool. The system enables each member of the flight test team (including engineering development) to perform his particular task more efficiently, with the result that flight test programs can be carried out in minimum time. FDVS supports the flight test team in test planning, preflight preparation, monitoring of test execution, and post-flight analysis. It supports multiple interactive users performing any available task.

FDVS became operational in 1985, being used for the flight testing of the Fokker 50 in 1986, and the flight testing of the Fokker 100 in 1987.

A summary of FDVS's major capabilities is listed below:

- It is an interactive system that allows many data users to search simultaneously a large database for specific flight test data, perform any of the available analysis functions on that data, and display the results. Output may be displayed in tabular form or in graphic form on the high resolution graphic terminal or (electrostatic or pen) plotter.
- The transcription from the airborne measurement tapes is carried out by so-called Data Reduction Stations that (using specifications maintained in the FDVS database) pre-process the telemetry, analog and digital measurement recording into standard formats, for further processing within FDVS. The advantage of this approach is that:
  a) the number of stations supported by FDVS is essentially unlimited, and
  b) each Data Reduction Station can be individually tuned to the response and processing requirements of the particular data stream for which it is responsible, such as telemetry, post-flight tape playback or mechanical lab (shake test) activities.
  c) In addition this feature enables the insertion of specialized off-line computing systems into the data acquisition process that are able to carry out major processing of the data; such as is required for performance analysis of automatic landing systems or advanced aerodynamic analysis, etc.

- The system provides rapid turn-around of flight test data. During telemetry operations, the telemetered data is directly available for quick look purposes. Hard copies of this data can be used during the flight and presented at the debriefing. The definitive data is delivered by FDVS. The data is provided at the specified accuracy and resolution for all the parameters requested, and is supplemented with the so-called Kneepad information and the Standard Computation results. To achieve the required turnaround times while allowing maximum flexibility the following features are provided:
  a) the user can specify in advance a standard set of parameters that must be made available from the airborne measurement tapes. Per flight or recording within a flight specific additions or deletions may be requested.
  b) the data is processed depending on the amount of post-processing required within 8 to 36 hours of the flight and made available to the data specialists via an online database and primary analysis software that uses full-screen menus and dialogs for "user-friendly" access.
  c) FDVS is capable of processing and making available to the data analyst more than 50 million measurement samples daily; where the data may originate from several different aircraft, and each sample may have up to 24 bit resolution. An individual parameter time series may consist of in excess of 10 000 samples and up to 1400 parameters have been processed per flight recording.
  d) all data received from the Data Reduction Stations is made available in the online database, and permanently archived on magnetic tape (double copies, one copy being kept off-site). The online database is currently 9 Gigabytes in size.

- The system is capable of simultaneously processing data from several different aircraft or other test-articles.

  a) the system is capable of storing and processing data in a wide range of formats - not only equidistant or non-equidistant time series, but also frequency spectra and other data consisting of a vector of values per sample.
  b) in particular the system also provides the flexibility required for dealing with ARINC digital databuses, such as ARINC-429. Not only the standard parameters delivered by an instrument, but also test-data buses (256 labels per bus) can be specified and rapidly changed when necessary for the flight test procedures.

- The system receives data via the network automatically, and is capable of processing hundreds of files per day. The incoming data is checked to ensure that the data file was completely and correctly received, and that the associated administrative data is in order: known aircraft, flight, recording; data is in valid units, etc.. Each set of data for each parameter received is given a status accordingly, and the data is registered against the open data processing order. If the data receives a status indicating possible errors then the general user cannot retrieve it from the database. Only those responsible for determining and correcting the fault can do so. Therefore the data analysts can in general only use data that has been approved by the data suppliers. All data received, including data with an error status is retained, and can be made available when required.

- FDVS itself is implemented on a network of different computers and is capable of exchanging data with external systems at all phases in the process - in particular:
  a) supplying parameter definition data to systems external to FDVS for the purposes of carrying out measurements (parameter lists);
  b) receiving measurement data pre-processed by external systems;
  c) providing information about the data contained in the measurement data archives, or extracts of the data itself to external systems.

- FDVS is designed to support an environment of several cooperating institutions, each of whom may choose to use its own (sub)systems for some of the functions.

The complete FDVS is made up of several subsystems, each supporting a group of functions usually carried out by one organisational unit (Fig. 22). The subsystems (Fig. 23) are as follows:

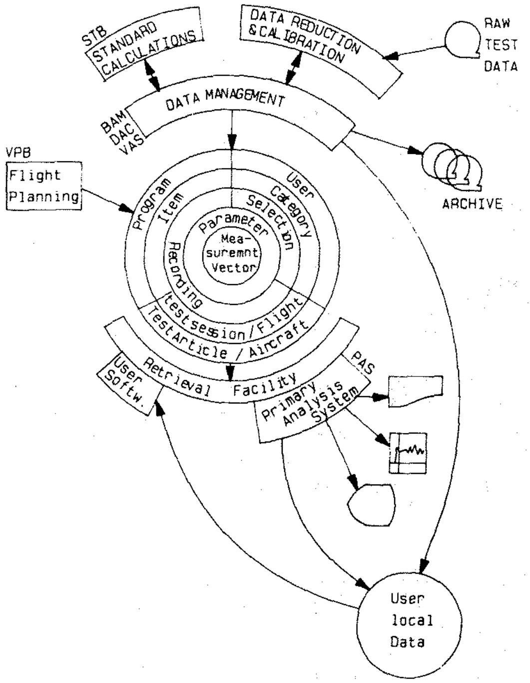


Fig. 22 The structure of FDVS

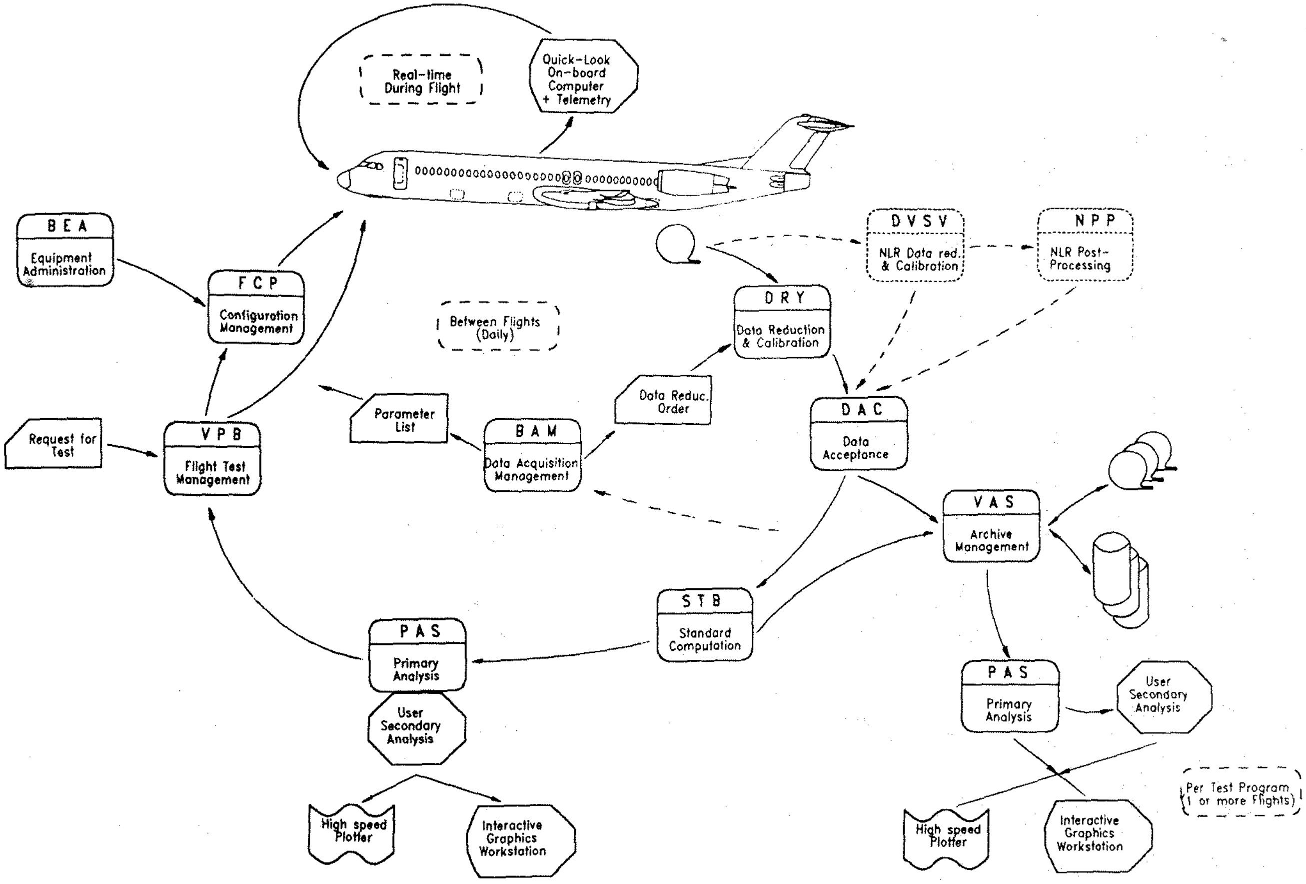


Fig. 23 FDVS subsystems in time sequence

- VPB - Flight test planning and management
  This administrative subsystem is used by the flight operations department to:
  - track the planning of the test-flights;
  - specify the particular tests that are to be carried out during the flight;
  - prepare the instructions for the execution of the tests (Test Flight Cards); and
  - record the results of the flights and the progress of the test program.

  In addition the subsystem provides functions to handle last minute changes in the test runs, made just before, or during the flight.

- BAM - Data acquisition management
  A modern measurement system produces large amounts of data, that must be validated, stored and distributed. BAM assists the Data Acquisition Systems department in coordinating and managing the flow of data within the whole system.

- DAC - Data acceptance and validation
  The data pre-processed by each Data Reduction Station is presented via the network to subsystem DAC. After validating the data and registering its arrival, DAC sets the data in the online measurement data database used by the design specialists, and also ensures that the data is added to the offline tape archive.

- VAS - Data archive management
  All data received into the system is archived, so that whenever it is required again it may be made available. The data must in principle be kept for as long as it may be necessary to show how certain test results and conclusions were obtained. The task of administering and maintaining the ever-growing archives of data is supported by VAS.

- STB - Standard Computations
  In general not all parameters required by the data specialists can be directly measured; some must be derived from other, measurable parameters. When the arithmatic involved is comparable in nature to a calibration process then the parameter can be derived directly by the Data Reduction Station. When the process is more complicated or requires greater accuracy then the calculation is performed centrally by STB.

- PAS - Primary data analysis
  The measurement data obtained during the flight tests is required by a wide range of data specialists, each of whom wishes to apply his own form of analysis for his own purposes. However, many of the data analysis tasks are common to all users, and these are provided by the central, highly flexible subsystem PAS. In addition, a standard interface to the measurement data is provided by PAS, enabling the specialists to access the data via their own specialised analysis software when necessary.

A summary of the post-flight data analysis process is as follows. After determining a description of the desired data the user selects the data. Once the engineer is satisfied that the desired data has been located, the retrieved data is used as input to the various analysis modules. There are many analysis modules which may be executed in series on all or part of the results of the previous analysis. Finally the results of the series of analyses are ready for display, so the display forms are selected and filled in with the appropriate information. The results of this process are then shown on the terminal CRT or a hardcopy is produced.

While allowing maximum flexibility in data manipulation, this procedure is tedious and to require an engineer who is only interested in viewing flight test data to go through it each time would ensure total dissatisfaction with the system. The solution is to group the appropriate software building blocks (modules) together in pre-defined functions, and FDVS offers three methods of doing so. Each method is best suited to a particular type of usage. These methods are as follows:

a) Batch Plot Definitions
   The user may define the measurement parameters from one or more flight tests that he wishes to see, as well as the form of the plot in which he wishes to see them, in a special file. Upon receipt of the requested measurement data, the required plots are produced for the user by the central data acquisition services department.

b) Standard Computations
   The Standard Computations subsystem provides a centralised facility for performing calculations. It runs in batch mode on a powerful mainframe computer and can thus be used for highly complex analyses. The process is started automatically as soon as all the required input has been received by FDVS. The output is added to the measured data and made available in the same way to all authorised users.

c) PAS procedures
   These procedures are roughly equivalent to a stand-alone function within PAS that performs all or part (as defined by the user) of the data compression, analysis and display for a specific type of test. Procedures may be built by an individual user by simply entering all the steps executed during a one-form-at-a-time process, or by editing a previously built procedure. However, many routine FDVS analysis and display functions can be executed using system wide procedures maintained in a generally accessible library.
   When executing a procedure the user is only prompted for the variable information. The forms are executed in the required order, with the results being the desired output plot(s) or table(s) displayed on the CRT or hardcopy.

The FDVS is described in more detail in reference 16.

4. Operational Experiences

The concept of MRVS proved to be very advantageous in the daily practice of flight testing. From 1983 on around 20 instrumentation systems have been built using the same modules over and over. They have been built by a team from Fokker and NLR for the evaluation and certification trials with the Fokker 50 and Fokker 100 aircraft or by NLR alone for projects with the Air Force and Navy. Also the NLR-research aircraft are equipped with "MRVS"-instrumentation systems.

The MRVS concept made it possible to optimize each system for its measuring task and to assemble it in a very short time, using the standard MRVS "box of bricks" and the accumulating experience. It also proved to be possible to achieve an almost 100% availability of the systems in use by overnight maintenance or quick exchanges of modules between flights. Larger maintenance and calibration activities could be planned in parallel with ground periods of the aircraft.

There even was a period that unforeseen 7 aircraft had to fly in the same period. The shortage in modules was such that modules had to be carried from one aircraft to the other. Although rather tedious for the instrumentation engineers no delays in the test programs, due to instrumentation shortages, were encountered.

The optional subsystems of MRVS for take-off and landing trajectory measurements, noise tests, ground vibration tests and navigation accuracy tests that were developed with the aim of performing the tests independent of a fixed test site and of providing the information to the analyst at very short notice, all fulfilled the expectations. The entire exterior noise certification program of the Fokker 100 with Rolls Royce Tay 620 engines for example was completed in just nine days of flying at Granada, Spain. Take-off and landing performance measurements were carried out with the Fokker 50 and Fokker 100 on two airfields in the Netherlands and on airfields near Münich in Germany and near Granada and Madrid in Spain. The only delays encountered were due to the weather circumstances.

In test programs involving prototypes, it was decided to have the majority of all test parameters necessary for a part of the program, connected and recorded during the entire program. It also was decided to record continuously during the whole flight. Unexpected situations with aircraft or systems could thus be analyzed provided the crew had written down the time of the occurrence. Especially in the field of avionics testing, where it sometimes appeared to be very difficult to reproduce the exact condition under which an event took place, this rather expensive decision proved to be very cost-effective because it saved a lot of test time and prevented slippages in the test schedule.

The efficiency of the flight test program was improved in many tests using telemetry. Although obvious in the case that no flight test engineers could be on-board the aircraft due to safety reasons or lack of space, it was also efficient during other tests because:

- it avoided having a number of (expensive) specialists on-board who were effective during only part of the flight,
- during the test flight discussions could take place between specialists on the ground without interruption of the flight, while the outcome still could change the course of action of that particular flight,
- upon return of the aircraft data and specialists' conclusions were available at the debriefing of the test flight. Decisions about the continuation of the program could then quickly be made.

In connection with the larger instrumentation systems the on-board computer system proved to be an indispensable and valuable tool for system monitoring and check out. The attained high availability of the instrumentation is certainly also due to the use of this type of equipment.

The on-board computer also was of tremendeous value for the flight test engineer who could analyse the tests in a very convenient manner while flying. It was observed that in a number of cases the efficiency of the flight tests could be enhanced with a factor 1,5 to 2. In this respect the on-board computer has to be regarded as complementary to telemetry, each having its own merits. Both are now considered as no-go items within the instrumentation system.

Keeping track of all the instrumentation modules, the calibrations, configurations, processing selections, in short all the information circling around the measurement systems, creates a major challenge in a multi-test environment. The approach taken to store all the information in a data base, to make the database on-line accessible from all fixed and remote test sites and to make it accessible for every instrumentation and flight test engineer, not only enhanced the efficiency and flexibility but also dramatically reduced the number of human errors in comparison with earlier "manual" systems. Especially errors in the data processing, sometimes discovered after a long time and far underway in the analysis process, can account for an unmeasured but certain large amount of wasted time and money. The proven drastic reduction of this type of errors alone justified the development of the System Management Information Database.

The enormous amount of test data to be analysed in present-day test programs requires large-scale use of computers. Organization of the data storage, facilitating quick and transparent retrieval, combination of data from different sources and the possibility of using a number of highly specialized analysis programs is of paramount importance to ensure that the analysis process keeps pace with the flight test program. After a hesitating start experience was gained in the use of such a complex system. This experience could be translated in actions to improve the system, as was anticipated during the initial design. Today it is a flawlessly working system, which provides the engineers with the information at the time and place they need it. It is a true statement that without such a system certification of a civil aircraft like the Fokker 100 and other large scale flight test programs are no longer possible [Ref. 17].

5. Conclusions

MRVS, developed as a collection of hardware and software modules that can be integrated in an easy way into a flight test instrumentation system, has fulfilled its role up to now in 20 different aircraft and test programs in the Netherlands.

The modular concept has led to a shortening of the time necessary for the composition of a new instrumentation system, optimally adapted to its task. At the same time the costs have come down, thus more than compensating the initially higher development cost.

The modular concept, and the strict development rules applied to the modules, facilitate the uncomplicated addition of new modules to cope with new functions.

The experience gained has proven that the installed systems are flexible in accepting numerous changes in the parameter list during the execution of the flight test program. It has also been proven that the quality of the results is according to the specifications while the reliability is better than expected. Less than 1 percent of test time has been lost due to instrumentation malfunctioning.

The data base approach for both the instrumentation system management information and the measurement data storage and analysis has created an excellent and very quick on line information storage and retrieval mechanism for the instrumentation specialists and the data analysis specialists.

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