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AGARD Flight Test Instrumentation Series Volume 12 on Aircraft Flight Test Data Processing A Review of the State of the Art

by

L. J. Smith and N. O. Matthews

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AIRCRAFT FLIGHT TEST DATA PROCESSING.

A REVIEW OF THE STATE OF THE ART,

(10)

by

Lawrence J. [redacted] Smith [redacted] N.O. Matthews A. Pool K.C. Sanderson

Volume 12

of the

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Edited by

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PREFACE

Soon after its founding in 1952, the Advisory Group for Aerospace Research and Development recognized the need for a comprehensive publication on flight test techniques and the associated instrumentation. Under the direction of the AGARD Flight Test Panel (now the Flight Mechanics Panel), a Flight Test Manual was published in the years 1954 to 1956. The Manual was divided into four volumes: I. Performance, II. Stability and Control, III. Instrumentation Catalog, and IV. Instrumentation Systems.

Since then flight test instrumentation has developed rapidly in a broad field of sophisticated techniques. In view of this development the Flight Test Instrumentation Group of the Flight Mechanics Panel was asked in 1968 to update Volumes III and IV of the Flight Test Manual. Upon the advice of the Group, the Panel decided that Volume III would not be continued and that Volume IV would be replaced by a series of separately published monographs on selected subjects of flight test instrumentation: The AGARD Flight Test Instrumentation Series. The first volume of the Series gives a general introduction to the basic principles of flight test instrumentation engineering and is composed from contributions by several specialized authors. Each of the other volumes provides a more detailed treatise by a specialist on a selected instrumentation subject. Mr W.D.Mace and Mr A.Pool were willing to accept the responsibility of editing the Series, and Prof. D.Bosman assisted them in editing the introductory volume. In 1975 Mr K.C.Sanderson succeeded Mr Mace as an editor. AGARD was fortunate in finding competent editors and authors willing to contribute their knowledge and to spend considerable time in the preparation of this Series.

It is hoped that this Series will satisfy the existing need for specialized documentation in the field of flight test instrumentation and as such may promote a better understanding between the flight test engineer and the instrumentation and data processing specialists. Such understanding is essential for the efficient design and execution of flight test programs.

The efforts of the Flight Test Instrumentation Group members (J.Moreau CEV/FR, H.Bothe DFVLR/GE, J.T.M. van Doorn and A.Pool NLR/NE, E.J.Norris A&AEE/UK, K.C.Sanderson NASA/US) and the assistance of the Flight Mechanics Panel in the preparation of this Series are greatly appreciated. In particular, credit is due to the late Mr N.O.Matthews. Mr Matthews was Chairman of the Flight Test Instrumentation Group from 1976 until 1978 during which period he prepared portions of this volume.

F.N.STOLIKER
Member, Flight Mechanics Panel
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AIRCRAFT FLIGHT TEST DATA PROCESSING

A REVIEW OF THE STATE OF THE ART

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SUMMARY

This volume describes the application of data processing systems to produce data in support of flight testing. The generalized techniques are appropriate to large test centers which support multiple testing programs simultaneously. The concepts, however, are as equally valid for a single test program using a dedicated data processing system.

Starting from a discussion of data sources, the text proceeds to a review of the considerations required prior to data processing. A simplified discussion of two major components of data processing - hardware and software - follows. The volume then looks at the third major component of data processing - the people to make it work. The data processing in support of flight testing is described according to processing functions. An attempt is then made to identify potential problem areas.

Since every organization which conducts test flights develops its own methods and techniques for this purpose, it is not always possible to give specific details that can be universally applied. The intention is to present a general outline of the methods, techniques, and problems associated with data processing for the benefit of individuals not experienced in this field. It is hoped that experienced Flight Test Engineers will be able to make use of this review to assist with instructing new entrants to the field of flight test data processing and to stimulate future developments.

1.0 INTRODUCTION

The demand for a test flight arises from the need for information concerning one or more characteristics of the aircraft under investigation. But planning cannot be commenced until it is stated what specific information is required and if it can actually be obtained to the required accuracy using the techniques and instrumentation available. Planning, however, is an iterative process and begins with general requirements. The requirements need to be discussed and reviewed in developing detailed specifications for the test planning, instrumentation and data processing. Requestors and producers must work together from the start, with all participants having a common objective as well as having an appreciation of each other's processes. Requirements are just that - "Requirements" - the mechanics of satisfying those requirements are what generally undergo change unless the basic objective is changed or modified. If the specific information required cannot be obtained, then the requirements must be changed or the flight test delayed.

Quantitative data obtained during flight testing is often not in a form that will communicate to the aircraft development agency the information that they seek. It is, therefore, necessary to convert the data into a more meaningful form. The term "Data Processing" is applied to this activity, whether it entails making simple manual calculations or the full use of powerful computers.

For a test flight to be successful, the planning must follow a methodical course. Normally, a many-sided problem exists, demanding that the planning process converge on the best compromise. All the personnel requiring information from a test flight must be aware of the capabilities, limitations, and accuracy of the proposed methods, instrumentation, and data processing systems. Initially, it is necessary to establish the following:

- The stimuli to be measured, the accuracy required, and the types of transducers and signal conditioning to be used.
- The effect on the results of the capabilities and limitations of available transducers best able to obtain data that can be processed.
- The method and position of installation of the transducers to ensure that the intended stimuli act on them and not some stimuli spurious to requirements, and that the measurement system does not change the characteristics of the system

being monitored. Alternatively, if spurious stimuli cannot be avoided, the nature of these stimuli should be established by measuring them in isolation or a means of isolating and discarding the spurious stimuli (noise) should be devised.

- The effects on the results of the capabilities and limitations of available signal conditioning equipment best able to withstand the working environment.
- The effects on the results of the capabilities and limitations of data storage or transmission equipment (if required) best able to withstand the working environment.
- The ability of the aircraft to perform maneuvers required for the acquisition of the required data.
- The effect on the results of the capabilities and limitations of the data processing system, to include both hardware and software.
- The effects of the capabilities and limitations of available mathematical techniques that can be employed for the processing of the data in a timely fashion.
- The ability of the personnel to analyze and interpret the processed data to obtain valid information.
- The effects on the validity of the results arising from the accumulation of limitations from stimuli to interpretation of processed data.
- The cost of each part relative to the whole cost, and the whole cost itself.

It can be seen from these stages that, in most cases, each element in the system reflects itself in all of the others and that the whole system can be no better than its weakest link. The result is that the first consideration in planning a test flight is that of the effects of the limitations of each element and, most important the limitations of the system. Although the progressive nature of the "State-of-the-Art" introduces new capabilities, the inevitable result is a complementary increase in the number of limitations.

2.0 SOURCES OF FLIGHT TEST DATA

Flight test data is derived from two major sources: (1) on-board sensors; and (2) ground-based instrumentation. Information concerning specific subsystem performance, propulsion, structural deflections, stability or control, and performance comes from the signals generated by the on-board transducers and recorded on-board or telemetered to the ground. Ground-based instrumentation systems usually consist of radar and optical equipment and are used to obtain aircraft trajectory and attitude data. In either case, the method of recording the data will be selected to optimize the amount which can be sampled and stored in the smallest time interval and recording medium. Such a recording scheme is generally unsuitable for direct entry into a computer and requires one or more intermediate steps to transpose the data into a format which the computer can accept (this is generally defined as "preprocessing"). When multiple recordings of raw data are made of some physical phenomena, a requirement for correlation of timing adds another stage of processing.

2.1 AIRCRAFT CATEGORY

The characteristics and amount of data is dependent upon the type of information that is sought, which in turn can be dependent upon the category of the aircraft. These categories are:

2.1.1 Uncertificated Aircraft

- Experimental aircraft used for research.
- Prototype aircraft in development.
- Aircraft test flown for certification.

2.1.2 Certificated Aircraft

- Aircraft used as a "flying platform or test bed" for testing on-board equipment.
- Aircraft used for testing weapons.
- Research and training (including "flying laboratories").
- Investigation of post-certification deficiencies.
- Flight data recording for fleet life fatigue data or crash investigation.

These categories are treated in detail in Reference 1.

Generally, test flights on uncertificated aircraft are conducted to yield as much information as possible, while test flights using certificated aircraft can be conducted for the purpose of obtaining a small amount of detailed information.

2.2 DATA TYPES

The types of data that can be derived from test flights and their frequency ranges vary widely as can be seen from the following important examples.

2.2.1 Aircraft Performance

One of the main reasons for instrumenting an aircraft for either prototype or research flying is to examine its performance characteristics. This generally involves low frequency measurements in the range from 0 to 25 Hz. and the vast majority of the measurements are quasi-static. There is, however, an increasing tendency to obtain performance data from dynamic maneuvers.

2.2.2 Flying Qualities

Similar characteristics can be applied to the examination of aircraft flying qualities. This involves a different form of instrumentation but, again, normal Flight Mechanic measurements in aircraft tend to be quasi-static although the phase relationship characteristics between the various quantities can be of interest. Care is needed in the handling, recording, and analysis of this type of data.

2.2.3 Power Plant

The majority of power plant performance information such as temperatures and pressures are quasi-static, but during evaluation of engine handling qualities dynamic conditions can be experienced which require measurements in the range of 0 to 50 Hz. In some cases, vibration measurements have been used as a monitor of the "health" of power plants in service. Where these techniques have been employed, the measurement responses range to several thousand Hertz.

2.2.4 Flutter

Airframes flutter characteristically in range 0 to 50 Hz and special techniques are necessary for handling this type of data. (Reference 2)

2.2.5 Structural Measurements

Most prototype aircraft are equipped with strain gauges and similar devices so that measurements of the forces present in the structure can be made during test flight. This is particularly important when new concepts are involved such as high temperature flight loads and maneuver loads on highly maneuverable aircraft. (e.g. the NASA YF-12 High Temperature Flight Loads Research and joint NASA-USAF Highly Maneuverable Aircraft Technology (HiMAT) Programs.) The normal range of structural measurements is from 0 to 1 kHz.

2.2.6 Vibration Measurements

Components in equipment and weapons carried in or on an aircraft can be seriously affected by vibration levels present. Vibration measurement is becoming increasingly important, particularly as the range of frequency analysis available in the data processing facilities become greater. Current vibration analysis techniques covering ranges from zero frequency to several thousand Hertz reveal that considerable power is being delivered to components and equipment carried in aircraft at frequencies far outside the ranges previously suspected. Helicopters are particularly subject to vibration. (Reference 3)

2.2.7 Avionics

Avionics equipment such as automatic flight control systems have to be flight tested and some of the electronics signals in this equipment can be at very high frequencies. Test systems need to cover ranges up to tens of thousands of Hz and, in the case of radar and similar equipment, up to several hundred megahertz (MHz).

2.2.8 Acoustic Measurements

Since increasing concern in recent years has been expressed on the noise levels of aircraft, there is more emphasis on measuring cabin noise and "ground" noise levels during prototype testing.

2.2.9 Bio-Engineering

Measurements of heart-rate, blood pressure, and other characteristics of the pilot and aircrew during flight have been important, particularly in space flight. The frequency range of these measurements is relatively low and does not present any basic data recording problems.

2.3 INSTRUMENTATION SYSTEMS

There are often several versions of any particular type of equipment that can be used for the acquisition, recording, or transmission of data. Even though the differences between versions can appear subtle, they can have a large effect on the ability of the data processing equipment to handle the data.

2.3.1 On-Board Equipment

Equipment in use today has developed from that used in the early days of test flying. In many instances, the equipment of today bears little relation to the early types as a result of present sophisticated techniques. But there are a few cases where the use of early techniques with modern equipment is the most convenient and sometimes only means of gathering data.

2.3.1.1 Manual Recording

The first attempts at gathering data on the behavior of aircraft were made by installing the simple and sometimes crude sensors of the day on the aircraft and arranging for the indicating part, whether it was a dial or manometer tube, to be within sight of an observer. The readings were then noted at intervals, the minimum length of the interval being dependent upon the number of indicators to be read and the number of observers. Accuracy was generally limited, the process was tedious, and it was difficult to obtain accurate time correlation among readings from separate sources. Even so, there are instances today where manual recording of instrument readings is the most convenient and economical, e.g., ground calibration data, test flight event times. Use of manual recording in flight should be limited to low performance light aircraft only or where time and/or circumstances do not warrant a more complete instrumentation system.

2.3.1.2 Photo Recorders

An improvement to manual recording of data by an observer was made by photographing the indicators with a cine camera and, subsequently, extracting the information from the developed film. All this did was to transfer the observer's work to the analysis staff with the advantage that improved time correlation among readings was possible. But still the data often had to be analyzed manually in order to obtain a meaningful presentation of the data.

2.3.1.3 Trace Recorders (Strip Charts)

Concurrent in the development of the trace recorder (or strip chart), which translates an electrical signal into a trace on paper, came transducers which produced an electrical signal proportional to the strength of the stimulus. The combination of the two made a substantial improvement in the recording of data, since it then became possible to plot simultaneously and automatically many channels of data while the flight was in progress. Trace recorders could also be used to display data recorded on magnetic tape, prior to conversion to engineering units. This lead to a technique known as "quick-look" which remains a valuable facility to this day. The use of "quick-look" is a convenient means of scoping and/or reducing the data processing task.

Strip charts for trend information and listings for absolute values is a key point in display technology. In fact, strip charts are a special case of x-y plots. All show interrelationship information whereas listings are valuable when actual quantitative values are desired.

Occasions still arise, as with manual recording, where the use of a trace recorder or a photo recorder on-board the aircraft gives sufficient information conveniently and economically, whether or not other recording techniques are employed at the same time. This is particularly true for the instrumentation of light aircraft for simple tests or where the prime data requirement is for trend information.

2.3.1.4 Magnetic Tape Recorders

Tape recorders soon surpassed the trace recorders in number of parameters which could be recorded per time interval and had the added advantage of being able to reproduce the original data signals electrically.

This form of data recording is still at the "state-of-the-art" and, until solid-state memories become available, it is likely that the magnetic tape recorder has many years of duty still to fulfill. Detailed descriptions of magnetic tape recording techniques can be found in Chapter 9 of Reference 1 and Reference 4.

There are three main types of tape format: open reel, cassette, and cartridge. Other formats not in general use have been developed for special purposes. In addition, there are four recording modes: direct, frequency modulation, digital, and computer compatible.

2.3.1.4.1 Tape Formats

Extensive use has been made of the open reel tape recorder since it has the greatest flexibility in meeting a variety of applications. Although this was the earliest type of magnetic tape recorder, with refinements and the use of modern techniques, the fidelity of data reproduction remains superior to other formats.

Open reel machines are available to accommodate one-quarter inch to one inch wide tape which, in turn, can contain from one to fourteen or more data tracks (special tapes can be wider, up to 2.5 inches). The tape speed can usually be varied to suit the bandwidth of the data. Different tape lengths and spool sizes are available to enable various recording times to be accommodated or, conversely, to allow the use of compact machines for installation in small spaces.

The requirement for small data recorders led to the adaptation of the compact cassette for any tape length up to an amount sufficient for one hour's recording. The tape width is one-eighth inch and the recording speed is one and seven-eighths inches per second. The combination of these two figures result in a very small rate of consumption of tape. It is, therefore, very economical and, in addition, very convenient to handle.

Like the compact cassette, the tape cartridge is of fixed size but larger. It contains one quarter inch wide four-track tape which is recorded at three and three-fourths inches per second. The tape is a continuous loop feeding from the hub of a flangeless spool and returning to the perimeter. The bandwidth is better than that of the cassette and approaches that of open reel machines running at the same speed. In this instance, it has the advantage of compactness and convenience of handling without so much limitation on bandwidth as the cassette.

2.3.1.4.2 Recording Modes

Initially, the only means of transferring data signals onto tape were by modulating the magnetic flux of the record head with the (compensated) data signal. The process is known as "direct recording" since the signals contained in the tape coating are directly related to the original signals. The bandwidth obtainable with this mode normally extends to not less than 50 Hz, and up to 100 kHz at high tape speeds. Although this bandwidth has many applications, such as audio reproduction, it cannot accommodate low frequency flight maneuver or static load signals. Because of this, the techniques of radio communications were applied to produce the frequency modulation mode of recording. There are two variants, single carrier mode and frequency division multiplex mode.

With the frequency modulation technique, recording is possible down to zero Hertz, thereby, allowing static loads and low frequency signals to be recorded. There are several common standards for single carrier Frequency Modulation (FM) recording, the most frequently used being that of the Inter-Range Instrumentation Group (IRIG) which dictates a constant relationship between tape speed, carrier frequency, and bandwidth as well as defining the track layout. (Reference 5) This enables recorded data to be replayed at different speeds without altering the characteristics, an important feature in later processing.

The present trend is towards the use of digital form before committing data signals to tape. The resolution capability is dependent upon the length of the binary word. Each word gives one instantaneous value of one parameter. In the recording process, only two magnetic states are used for the binary values: saturation in one magnetic direction or the other. The digital sampling rate can exceed that of analog machines with the advantage that speed variations do not affect the data.

The data can be recorded in parallel, that is, a track allocated to each channel, or in serial, where one track can accommodate many channels of data by time division multiplex. This latter technique lends itself to computer compatible tape recorders and has the advantage that head alignment and tape skew are not as critical as they are with any form of parallel recording where phase relationships between tracks would be altered.

Most modern recorders use time-division multiplexing to increase the capacity for data. It can be used in digital, FM, and direct recording. This is done by varying the rate at which parameters are recorded (also known as commutation rate). This basic rate is dependent upon the frequency spectrum of the desired signal. In its most elementary form, the values of various parameters are recorded in a time-dependent sequential action. Items of higher frequency content are recorded more often than the normal cycle, while elements of lower frequency content are recorded every other cycle. This latter scheme increases the number of parameters which can be recorded in a commutation cycle.

At the present time, on-board production of computer-compatible tapes is not conducted on a wide scale. Such tapes have the advantage of being capable of being read directly by the standard digital computer, eliminating the need for the intermediate stage of processing required to convert digital tapes to a computer-compatible tape. However, standard computer tapes are half-inch in width with data recorded in parallel on either seven or nine tracks at closely specified bit densities. The tolerances for bit density and skew are so close that it is difficult to remain within these tolerances with today's flight recorders. The bit densities for computer-compatible tapes are relatively low when compared to standard airborne digital tapes. Finally, digital computers require "inter-record gaps" on the tape after a certain number of data words and no data can be recorded during the gaps.

The capabilities of these recording systems and their applications are covered in References 1 and 4.

2.3.1.5 Optical Systems

Many areas of flight test data acquisition are still best achieved using optical systems of various sorts. The advantages of these systems are their ability to record the actual overall picture in addition to using certain specialized techniques. Optical systems form a large part of the ground based data gathering facility, but here we are concerned mainly with systems installed in the aircraft and using only aircraft data. (Reference 6)

2.3.1.5.1 Airborne Cameras

There is a wide range of applications for airborne cameras in flight work. One of these is a system which uses a motion picture camera mounted in the forward part of the test aircraft to obtain a forward and downward view of the runway. Surveyed pairs of markers arranged in parallel lines, such as runway lights, may be used to obtain aircraft altitude and position along all three axes by means of perspective geometry and photogrammetric techniques. These systems are useful for takeoff and landing measurements, and also for noise measurement in conjunction with ground recording of the noise level generated by the aircraft.

Other uses of airborne cameras are for monitoring the condition and situation of inaccessible parts of the airplane such as under-carriage, flaps, or for observing stores separation and recording of head-up display (HUD) data from suitably mounted cameras.

2.3.1.5.2 Television Systems

The use of these for flight test purposes in conjunction with video recorders or video transmission equipment is increasing. One of the advantages of these systems is that, using the video recorder, instant replay of the data is available in visual form. Systems of this sort can be used for monitoring cockpit performance, and for other external items such as undercarriages, in place of cine cameras.

2.3.1.6 Solid State Memory Devices

At present there is not a suitable high speed solid state memory device available that can store large amounts of data in a sufficiently compact unit. But development of high density memories including magnetic bubble memories is in progress. So far, experimental devices have been made with a one mega-bit per square inch packing density. Initial production prices of bubble memories are very high, but as is the case with semiconductor devices, these prices should reduce in time and it appears that the market is going to be very competitive as the result of the highly intensive development currently in progress.

The advantages that these devices will have over present data storage equipment are numerous. The devices themselves and their interfacing equipment will not be affected by incidental influences such as vibration. The size of the equipment will be reduced for the same amount of stored data. Reliability is expected to be better since there will be no moving parts and the data can be stored in a computer compatible form.

2.3.2 Telemetry

In many instances, it is preferable to analyze the data while it is being obtained. This can be done using a computer on-board the aircraft, but weight and size restrictions can limit the processing power of such a computer to inadequate levels. The alternative to on-board processing or recording is to transmit the data to a ground based data processing facility using a telemetry link. In fact, the modulation schemes for magnetic tape recorders are basic to telemetry. Most modern aircraft testing uses a combination of on-board recording and telemetry, with critical parameters being selected for telemetering and displaying in real time. The displayed data can then be used by the flight test engineer to study the results in order to ascertain the validity of the performed test, improve safety and expedite the conduct of the tests.

2.3.3 Ground Systems

Not all flight test data is obtained from instrumentation installed in the aircraft. In tests requiring the trajectory of the aircraft (or of a weapon) to be known, the primary means of obtaining this information is by tracking the aircraft from the ground.

2.3.3.1 Aircraft Tracking Equipment

A common means of tracking aircraft is with a cinetheodolite. Equipment of this type has been in use for this purpose ever since the requirement first arose in flight testing. Nowadays the cinetheodolite can be a sophisticated instrument linked directly to a computer or it can be quite basic, having features similar to the early models.

The method of tracking the aircraft is optical, the instrument having one or more mutually aligned telescopes mounted on a common rotating head. This head is calibrated in lateral angle (azimuth) and vertical angle (elevation).

The principle of operation is that as the aircraft travels across the field of view of the cinetheodolite, the telescopes are rotated in azimuth and elevation to maintain a target point on the aircraft on a pair of cross-wires. While the tracking is in progress, a camera records the telescope view at regular intervals of one, five, ten, or twenty frames per second. Each frame contains azimuth, elevation, and timing information in addition to the photographed image.

During processing, the azimuth and elevation values are extracted from the film. The cross-wires are reproduced on each frame so that tracking errors can be scaled off to correct the scale readings. Multi-station solutions are used to calculate the position of the aircraft at the time each frame is recorded. The acquisition of the data from the film is by necessity manual and unavoidably tedious. If aiming errors are not significant, a cinetheodolite having transducers giving either analog or digital output of the scale readings can be coupled directly to a computer for immediate processing and plotting or to a card or paper tape puncher. If aiming errors need to be compensated for, a useful expedient is to apply smoothing during processing, but this cannot be as accurate as measuring the error in each frame.

An alternative method of tracking aircraft is with the use of a servo-controlled radar system which automatically follows a reflecting target or beacon on the aircraft. This principle has been applied also to a laser tracking system, but whatever the medium, accuracies can be very much improved and tedium reduced since aiming errors are automatically made very small allowing the data to be processed without, or with minimal, manual assistance.

Distributed electronic sensor systems using multilateration techniques consist of multiple measurement sensors (three or more) located some distance from each other. Each sensor makes a measurement of target range and then a mathematical process is used to extract target position. Such systems can track and present target information simultaneously for multiple targets. Accuracy becomes highly dependent upon the geometric relationship between the stations and the target.

Detailed descriptions of aircraft tracking equipment can be found in Reference 7.

2.3.3.2 High Speed Cameras

One of the essential requirements of ground based camera systems is their ability, through the use of high shutter speeds, to slow down the processes which are being photographed in any particular flight test. These cameras have particular uses in trials involving the release of weapons and stores from aircraft and also in guided weapon tests where the accurate knowledge of the mechanical processes taking place is frequently required.

3.0 PREPARATION FOR DATA PROCESSING

Whatever the test flight requirements, the data processing personnel should be given details of the significant limitations and characteristics of the airborne instrumentation and of any spurious influence acting upon that equipment. Likewise, the instrumentation personnel must be aware of the limitations and idiosyncransies of the data processing system rather than assuming the modern, large computer can handle an infinite variety of data formats, manipulations, and output presentations. No amount of processing manipulation can retrieve an unrecorded signal. If the recorded signal is noisy, then expect noisy data or unacceptable smoothing. Recording all possible parameters at the highest possible sample rate should not automatically dictate the requirement to then attempt to process all of it at those rates. Documentation of data processing requirements and their solutions must be as thorough as that required for the instrumentation.

3.1 CRITERIA FOR COMPUTER USE

Today, data processing in support of flight testing connotes the use of some type of computer system to apply calibration corrections, arrange data in usable format or perform computations among derived data points. Intelligent use of a computer requires:

- The Problem Must Be Useful

  In the real world, the computer is always an expensive device and "usefulness" is defined by someone other than the data processor.

- The Problem Must Be Precisely Defined

  A problem is defined when you know its inputs, what to expect for outputs, and how to tell if the outputs are correct.

- We Must Know How To Solve The Problem

  We must have a method of solution, with or without the computer. The computer adds nothing to the solution method. Such methods are called "algorithms" and can, at the start of the problem solution, be relatively crude and unsophisticated. A small amount of work with the crude method frequently reveals improvements, short cuts, or a better method.

- The Problem Must Fit The Machine

  The problem must fit the machine in two ways. First, the instructions and data must fit within the storage of the machine, at least for any part of the problem solution that is to be expected at a given time. An elegant program that consumes all or most of the storage space is of little practical use. Second, the solution must be executed within the time constraint of the computer system.

- The Problem Must Involve Much Repetition

  Computers are best at repetitive manipulations where the speed of operation can be used most efficiently.

3.2 CONSIDERATIONS AND CONSTRAINTS

3.2.1 Human Considerations

Care must be taken to provide for the "people" portion of data processing. Regardless of the level of the automated processes, there still must be request and tracking forms, manual procedures, documentation, personnel training, and effective matching of individual talents to the task at hand. The program manager, instrumentation engineer, flight test engineer, and data processing personnel all speak in individual argot which easily leads to false assumptions and production problems. The trivial manual steps (e.g., properly labeling a tape, keypunching a card) if not properly performed can result in expensive reruns. It must constantly be remembered that people think, but computers must perform only according to precise and literal instructions. Output is never better than input and is seldom equal.

3.2.2 Budget Constraints

Data processing is expensive, but properly planned and executed can reduce the overall cost of the flight test program. Today the budget for data processing can approach forty percent of the total test program budget. Giant strides have been made in the quantity of data which can be recorded and processed. As a general rule, the earlier in the data processing stream that the data requirements can be reduced, the more effective will be the reduction in cost. Real time processing and display, while glamorous and technically exhilarating, should be used to reduce the overall testing time and increase test safety. Reruns of data processing can negate the savings in overall program costs. Data reruns are most often caused by improper data or program instruction entries. Time spent in a detailed logical review of the data processing requests prior to submission can prevent costly reruns.

3.2.3 Sophistication

The flow of data processing should be as straightforward and simple as is consistent with the accuracy of the recorded data. A one percent value expressed to twenty significant figures, while impressive, is not of any more use than one of four or five significant figures. Often the speed and versatility of the large computers bedazzles the engineer as we try for more exotic ways to produce answers. A computer program is extremely literal and a seemingly minor change can reverberate through the program structure. Development of analysis equations should precede the mathematical operations used to produce the results. If the test manager is fortunate enough to be testing at a facility which has a library of routines used successfully on other test programs, he should certainly use these rather than embarking on a new independent path.

3.3 TYPES OF DATA

Section 2 demonstrated the wide range of data characteristics obtainable during flight tests. When planning or selecting a data processing system to analyze test flight data, careful consideration must be given to the system's ability to fully accommodate the characteristics of the data to be analyzed.

Approximately ninety-five percent of flight test data has a frequency content of interest of less than 6Hz covering areas such as stability and control, performance, flight control, and navigation systems. Some three percent, which extends to about 150Hz is concerned principally with vibration and flutter. Approximately one percent may extend to 6kHz, accounting for noise, speech, and possibly, electrical power supply quality.

A required accuracy of 0.1 percent is expected for only about ten percent of the total data, for performance, stability and control, and navigation systems. The remaining ninety percent usually requires an accuracy of approximately one percent; this figure increasing for high frequencies. Accuracy in this context relates to the residual random error remaining after all bias compensation has been applied. (Reference 1)

3.4 CALIBRATION METHODS

The process of converting data to engineering units requires a knowledge of the entire system design from the initial conversion of the physical force to an electrical function by a transducer; then in turn through the signal conditioning, the tape recorder, preprocessing station, and the computer. What is performed in the instrumentation calibration may limit what can be done in data processing to convert the recorded data to engineering units. Care must be exercised in the choice of calibration methods. What appears simple and desirable from an instrumentation point of view can have a large impact on the ease or difficulty of data processing. For example, a piecewise linear calibration curve can more easily be constructed by connecting calibration points than in trying to develop a second, third, or higher order curve. In storing the calibrations for data processing use, however, it is more efficient to store the curve coefficients than an array of many linear slopes and intercepts.

Calibrations must be verified prior to use in processing, generally by producing a plot which can be quickly scanned and used for later reference. The calibrations must be entered into a data base or file for use in conversion of the recorded data to an engineering units output.

This data base may be structured to contain all calibrations performed during the life of the program or limited to only current calibrations. The prime factor in deciding on the type of measurand data base (called a "Project History File" at the AFFTC) is the amount of storage file space available. In either case, the calibrations must be keyed against a specific test number for proper sequencing during data production. Where the file space is limited and only "current" calibrations are maintained ready for access, care must be taken to insure a match between calibration and test number prior to processing.

The use of calibration plots, created from the values in the measurand data base, are strongly recommended to avoid the problems of transposed digits, values, or decimal places. Scanning a tabular listing does not lend itself to discovering such mistakes. A plot is considerably more reliable.

The conversion of raw flight test data to engineering unit data depends upon many items to determine what techniques will be used; such as transducer characteristics, instrument calibration method used, and type of data recording system. (Paragraph 7.2.1)

3.5 PARAMETERS

3.5.1 Identification

The parameters for which data is to be recorded and processed must be identified and the accuracy and frequency response for these parameters are used to select the transducers and data acquisition scheme. A meticulous form of bookkeeping must be used for parameter identity, location in the recording scheme, and the calibration information associated with the parameter. A measurand data base or data file is usually developed which contains this basic information as well as a history of changes in location or calibration. This permits processing of data from past as well as current tests. A single data base permits the extraction of information required to configure real time processing and display systems.

3.5.2 Combinations

To reduce the amount of data processing, it is prudent to identify selected groupings of those parameters required for particular configuration or a desired specific test of the aircraft. For example, during a speed power maneuver the parameters associated with the aircraft stability would not be required. Likewise for a stability maneuver, engine pressures and temperatures would not be required. This will avoid processing data not related to a specific test.

3.5.3 Rates

It is conventional practice to record data at much higher sample rates than required for normal analysis. This provides for the ability to expand the area of interest in case of problems. Since most test data today is recorded in a format which is different from that used in the computer, the "decommutation" of the data from the recorded stream offers a convenient place to start in the reduction of data processing volume. Only those parameters of interest should be transcribed and then only at the minimum sample rate consistent with the next stage in processing or the final output. In addition to parameter selection, there are several "data compression" techniques which may be employed. At the AFFTC, "PSAMP," for example, is a function which periodically samples the data at a lower periodicity than recorded. A "ZFN" algorithm is one which will only select data values whose least significant bit or "N" least significant bits change. Combinations of compression algorithms are also possible.

3.6 SOFTWARE SELECTION

For a flight test program which is to be conducted at a large test facility, there should be available a library of "standard programs" which can be used. Care must be exercised in such a selection to avoid an overly complex solution to a minor problem. Since most of today's engineers receive a grounding in FORTRAN and digital computer usage, there is also the tendency to "write a little program to do what I want." This approach can very rapidly turn a flight test engineer into a data engineer who spends the bulk of his time trying to process, rather than analyze, data. Judgement must be exercised for trivial tasks which can take longer to describe what is required than to do the job.

Most large test facilities have a software development organization which is responsible for the coding and checkout of new software or modification of existing software. Such service does not come gratis, since the aircraft test engineer must develop the program specification document which outlines the equations and mathematical techniques to be used, along with assumptions and constraints. This tailoring of the software can be done manually or through the use of adaptive, higher-order programming languages and techniques.

Besides selecting software to perform the test data processing tasks, the program manager should also become familiar with the status reporting and tracking systems which are in use at most large test centers. This software usually will provide current costs and charges and should also be used to track the status of processing requests and data output.

3.7 DATA PROCESSING CONTRACT

The support required to produce the necessary flight test must be clearly defined and understood by both parties, the test engineer and the data processor, in a formal data processing contract. The urge to procrastinate in defining requirements, characterized by "do it just like the last test" or "I know of a new system that can ..," can lead to frustration on the part of both parties. The project requirements must be clearly defined, within the capabilities of the hardware and software, and acknowledged by both the requestor and the data processor. This iterative process involves considerable education, bargaining and revisions. Changes to requirements and support methods are inevitable, but they must be controlled to permit sufficient time for the development of the complete data production flow and preoperational validation of that flow.

3.7.1 Program Introduction Document

This document (variously titled as Support Request, Project Proposal, etc.) outlines the scope of the test program and support requirement in general details. It is, in effect, a solicitation of support from a test center or organization. In most cases, it is not couched in the jargon of phrases familiar to the data personnel processing and must undergo further expansion.

3.7.2 Test Concept

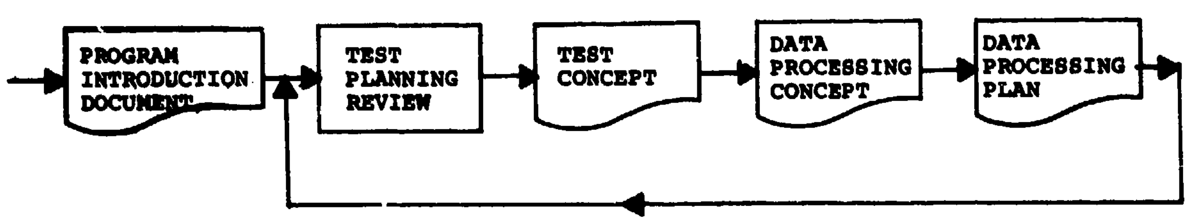
A Test Concept should be formulated by the organization which is to be responsible for the conduct of the test. It translates the Program Introduction Document into the language which is more familiar to the test engineer and instrumentation engineer and reflects the ideas or concepts of the test conductor (or project manager, project engineer, project pilot .....) such as flying hours, type of test (performance, flying qualities), number and type of parameters, support requirements, etc. Prior to the actual start of testing, this document is expanded into a detailed Test Plan.

3.7.3 Data Processing Concept

The astute program manager will marshall his engineering and instrumentation forces and then attempt to translate his needs, wants, and desires (the Test Concept) into the even more esoteric language of the data processing community. This enables the manager to modify the overall concept in the early stages based upon the limitations or capabilities of the available instrumentation systems and the data processing center. For example, real time presentation of data, rates, simplified calibrations, hardware capabilities, and cost (in either operating or development time and money) become totalled. A careful differentation must be made between what parameters are to be recorded at what specific rate for the case of catastrophic incident investigation versus what parameters will be required for the model case. Data acquisition and processing can account for forty percent of a flight test program's budget in today's environment of high quantity, high rate instrumentation systems. Attention to details in the conceptual stage can yield great benefits once into the test.

3.7.4 Data Processing Plan

As the test period approaches, the Data Processing Concept should be amplified into a firm plan. The primary difference between the two documents is that the plan contains specific responsibilities for specific events (e.g., who delivers the magnetic tape from the air vehicle to the data processing center?). This detailed plan is especially important in a large government test facility where multiple flight test programs are being conducted simultaneously. Just as detailed flight profiles minimize unproductive flight, so a detailed Data Processing Plan minimizes excessive data processing runs, reruns, and turnaround time. It must be a clearly defined contract between the test agency and the data processing facility.



4.0 THE COMPUTER (Reference 8)

This section covers the basic operation of a general purpose digital computer. Its primary purpose is to refresh the memory of the newly graduated engineer and to fill in some spaces for the senior engineer who has become less familiar with basics over the years. The engineer well versed in computer operation may elect to skim through the section.

Computers are controlled by reference to a list of instructions which sets out in complete detail and in order, step-by-step, exactly which operations are to be performed. This list of instructions is called the program. A typical computer instruction contains two parts: function and address. The function statement indicates what is to be done (e.g., ADD, SUBTRACT). Large computers contain a library of the most commonly used functions in the instruction set or order code. The address part of the instructions indicates where the quantity to be operated upon (the operand) is stored.

4.1 BITS, BYTES, AND WORDS

The list of instructions (program) and the data are held in storage in the form of binary digits, which is abbreviated to "bits". Binary representation is natural to computers since electronic equipment can discriminate reliably between two states - on or off.

Data can be composed of letters, numerals, punctuation marks, or other symbols which are called "characters". In practice, this data is processed in chunks which are known as "words". Depending upon the design of a computer, word length can very from eight to sixty-four bits. One computer word can be used to represent a binary number, or it may be divided in sections of eight bits call "bytes". Since the eight bits in a byte can be arranged in 2^8 or two hundred fifty-six different ways, a byte can be used to represent characters in common use.

For numerical data, four bits can be used to represent a decimal digit (e.g., binary 0010 = decimal 2; binary 1001 = decimal 9). Use of a separate group of four bits for each digit of a decimal number is called "binary coded decimal" or BCD (e.g., decimal number 1234 can be represented in packed decimal form by two bytes: 0001, 0010, 0011, 0100). Using all of the combinations of four binary bits will permit numbers to be expressed in hexadecimal form (digits in the base of 16). Current instrumentation formats make use of the octal representation since 8 is an integral power of 2, conversions to binary are simple and each octal digit converts to three binary bits. Decimal to octal conversions involve less work than decimal to binary (and hence less error) and the subsequent conversion from octal to binary is trivial.

The number of bits in a computer's word and the way in which the bits are allocated determine the precision with which the numerical data can be handled. A typical word of thirty-two bits can handle an eight digit number in packed decimal form or a binary number of thirty-two digits. When the precision offered by one word is insufficient, adjacent words can be linked together for double length or "double precision" arithmetic. Many calculations involve negative numbers and fractions. Sign can be indicated by using one bit of the word (e.g., 0 = +, 1 = -). Fractional numbers can be handled provided a standard position for the location of the decimal (or binary) point is selected. A common convention (fixed point) places the point at the extreme left-hand side, which makes all numbers in the computer less than one.

To avoid the problems of scaling and overflow associated with Fixed Point, use is made of "Floating Point" notation where the word is divided into two parts. The first part is a fraction called the mantissa or fixed point segment. The second part is an integer called the characteristic or exponent. There is some loss in precision when using floating point because the precision depends upon the mantissa and number of bits it contains. Providing the exponent is not too small, it is possible to cover a range of magnitudes wide enough to make scaling unnecessary. When two very small numbers are multiplied, the product may be too small to be represented by the available exponent.

4.2 BASIC COMPONENTS

Most computers are segmented functionally into: (a) input and output services; (b) Central Processor Unit (CPU); and (c) auxiliary storage. Items other than the CPU are also lumped under the generic term "peripherals".

4.2.1 Central Processor Unit (CPU)

The CPU can be subdivided in three main segments: the Control Unit; Arithmetic Unit; and Main Storage.

4.2.1.1 Control Unit

The control unit regulates all other parts of the computer. It extracts the instructions one-by-one from the stored program in proper sequence, decodes the instructions, and initiates the indicated action.

4.2.1.2 Arithmetic Unit

The arithmetic unit performs the series of instructions (from the program via the control unit) on the data. As well as performing the arithmetic operations of adding, subtracting, multiplying and dividing, the unit can also perform logical functions such as comparing two items of data for identity or determine which is the larger. The data operated upon need not be restricted to numbers, since the data is composed of strings of bits which may represent a binary number, a packed decimal number, letter of the alphabet or any other designated symbol. The unit will switch and combine these trains of electrical pulse according to the rules of arithmetic or logic in order to generate an output train which corresponds to the desired results.

4.2.1.3 Main Storage

Main storage contains the program, current data, and partly finished results. It is divided into sections called "locations," each of which is able to hold one word and identified by a unique number known as its "address." Most core storage today is a lattice of small magnetic "donuts" capable of being polarized in one of two directions. Replacing this ferrite storage now are large scale integrated circuits, with "magnetic bubbles" as a future possibility. The search is for faster access time, achievable through smaller segments, shorter signal distances, and higher packing density. This is important since in most designs the speed of the computer is set by the speed of storage access. Today, a storage with a range of four thousand to one hundred million bytes can access any specified location within 0.2 to 2.0 microseconds. New storages have nanosecond (10^{-9}) access times.

4.3 PERIPHERALS

Peripherals are auxiliary hardware used to enter programs and data into the CPU, extend the amount of storage, and present the output in a usable form. A "buffer" is a storage device used to compensate for widely disparate speeds of different devices. This permits a relatively slow card reader, for example, to input instructions into a computer at the rate of one card every sixty milliseconds when the computer can transfer a card of instructions to storage in one millisecond. The instructions are loaded into the buffer at a card reader speed and then accessed from the buffer at CPU speed.

4.3.1 Input

The set of instructions unique to the planned computations, known as the job program, can be input into the CPU by a deck of punched cards via a card reader. Data to be processed can also be loaded via cards, but more suitable media for large amounts of data (as would be appropriate to flight testing) are paper tapes, magnetic tapes, cassettes, disks or disk packs. A remote job entry terminal usually consisting of a specialized keyboard and cathode ray tube display may also be used for program and data entry. A control console, either at the CPU or a remote terminal is used to transfer control of the computer to the first instruction of a loading program (already permanently stored) which causes the job program to be placed in known locations in storage. The operator then transfers control to the first instruction of the job program. Where there are many peripheral units, a small special purpose controller (front-end computer) is used to regulate the traffic between the peripherals and the CPU and is typically responsible for control of the communications network, queuing of messages, handling of priorities, input data transfers, and interrogation of files.

4.3.2 Storage

In time-sharing computer systems, the main storage is extended by means of fixed disks and exchangeable disk packs. This extended storage is organized and controlled such that each user sees only a single level storage. The controller anticipates the demand for data and program segments by transferring them from the disks to the main storage ahead of the requirement. The unit of data which is transferred is called a "page" and typically contains a few kilobytes. This hierarchial storage is also known as "virtual memory" and acts in such a way that the user feels he is the sole occupier of computer storage.

4.3.3 Output

Output peripherals can take several forms:

- Printer output such as line printers, electric typewriter (10 characters/second), and typesetter.
- Graphical such as cathode ray tube display and automatic plotters.
- Storage such as magnetic tapes, magnetic disks, microfilm, microfiche, punched cards, and punched tape.

4.4 FILES

Files are records arranged systematically in an orderly fashion. Content is dependent upon the nature of the job which the file is to support. The arrangement of a file depends upon the operations which must be performed on the contents and the technical characteristics of the equipment to be used.

4.4.1 File Organization

BIT — Binary digit.

↓

BYTES — Eight bits which can represent one letter or two packed decimal digits.

↓

FIELD — String of bytes that represents one complete item of data.

↓

RECORD — Set of logically related fields.

↓

BLOCK OR SECTOR — Set of records determined by computer hardware requirements rather than a logical relation between the records.

4.4.2 Types of Files

- Single-User File (job oriented).
- Data Base Files (same data, different users).
- Public Files (shared with other users).

4.4.3 File Changes

Data changes are accumulated on a "change file" which is used to update the master file. Magnetic tapes must be updated serially and are amended by creating a new data tape. Disks can be updated sequentially by identified fields and are amended by overwriting.

4.5 DEDICATED, CENTRALIZED, AND DISTRIBUTED PROCESSORS

4.5.1 Dedicated (Specialized) Processors

All good engineers and program managers recognize the validity of consolidation of resources and control - as long as it occurs on a level just beneath them! There is no argument that from the viewpoint of a person responsible for test that the most desirable course is one where a dedicated computer system (processor) is available for sole use. And for a specialized task (flutter analysis, real time display), such a use today is both practical and economical. Today's rapidly developing field of so-called "mini-computers" makes possible the use of many specialized computer systems. However, what one gains in exclusiveness, one gives up in flexibility and throughput time since a mini-computer cannot compete with a large-scale computer on a one-to-one computation time or storage capacity.

4.5.2 Centralized Processors

Where the volume and diversity of computer processing is large, a central processor is used. "Time-sharing" is employed where the CPU appears to be working simultaneously on many jobs. In actuality, the CPU uses the difference in access speeds between itself and the peripherals to load a segment of data from one peripheral, while operating on data loaded from another peripheral while dumping output from still another job to an output peripheral. This is the arena of the modern large computer usually complete with attendant systems analysts and software specialists. Until the introduction of the mini-computers, the trend in computers was to larger and larger centralized systems with faster access time and time-sharing operation to increase utility and minimise individual job costs.

4.5.3 Distributed Processors (Reference 9, 10 and 11)

Data processing tasks in support of flight testing are not uniform in volume, complexity, and throughput time requirements. Today's natural growth is toward a distributed systems combining the modern large computers, specialized processors, and communications controller. This gives the flexibility of stand alone operation for specific tasks (e.g., real time) and the synergistic operation of the computer segments together in a network. A typical distributed system employed in The Netherlands is shown in Figure 4-2 in which the levels are described in Figure 4-1:

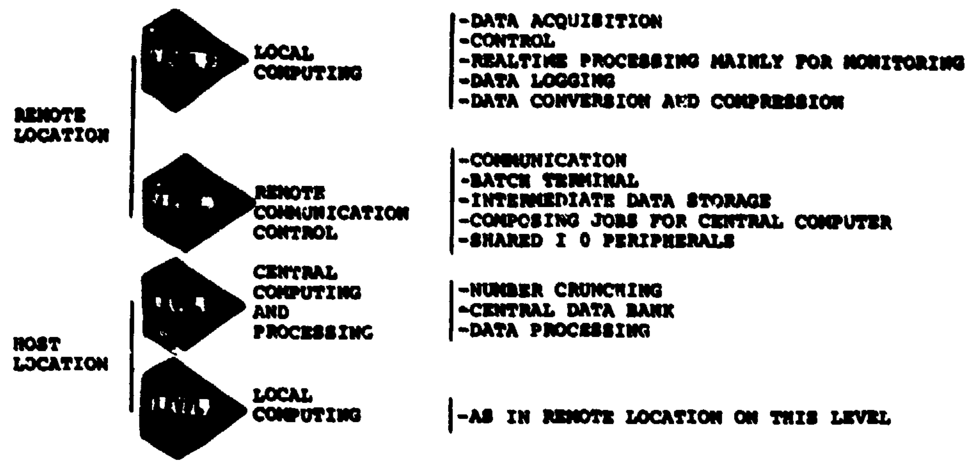


FIGURE 4-1

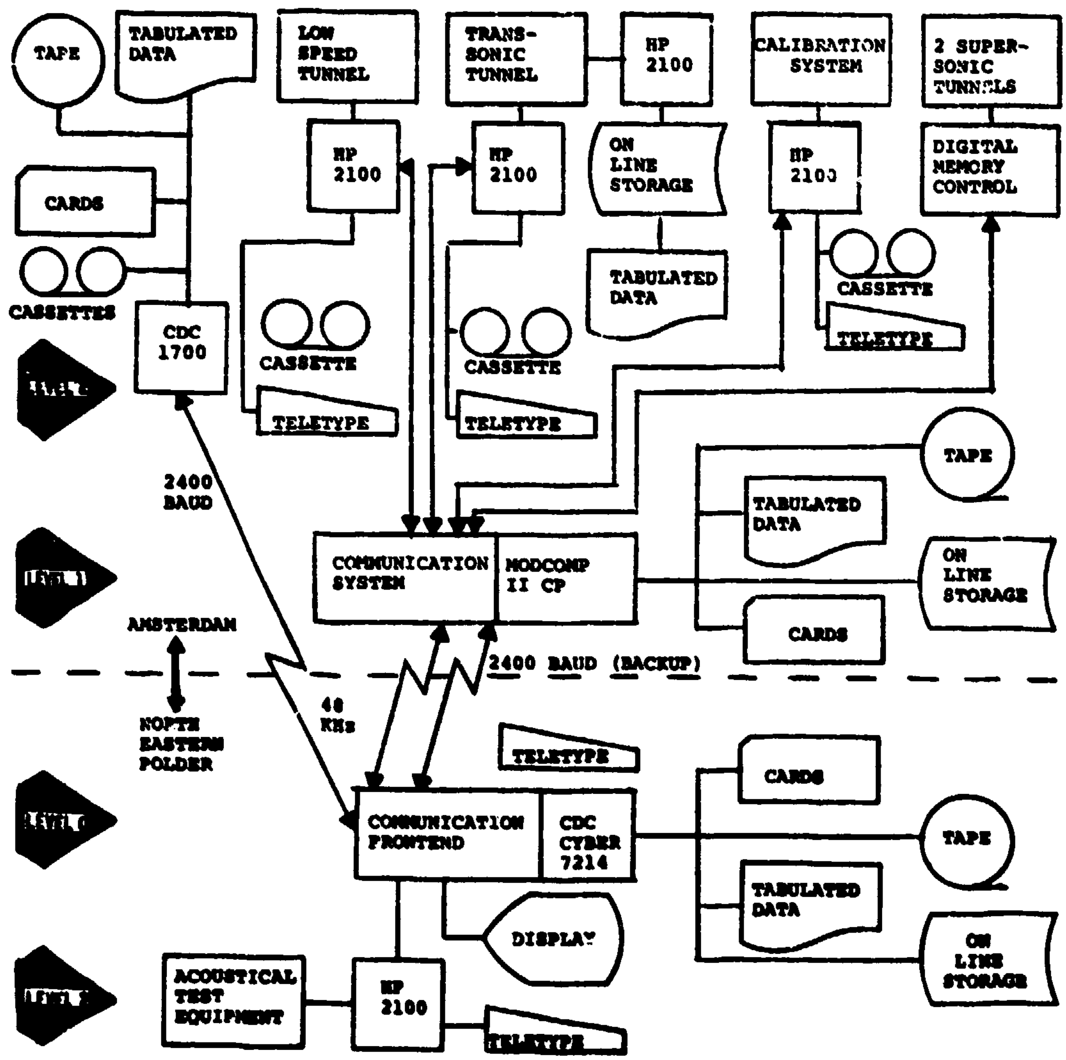


FIGURE 4-2

5.0 THE SOFTWARE

The planning of the sequence of operations in advance is known as programming. The sequence of instructions created is called software. Software is the key to the power of the digital computer, enabling one computer to perform a variety of tasks. It permits modification of a data processing sequence to meet an unusual requirement or solves a problem area. This flexibility is both a blessing and curse. It allows for rapid change, but also encourages constant "just one more refinement" changes.

Stored programming operates on the principle that the data to be manipulated and the instructions for their manipulation are stored in the same medium and are indistinguishable. The instructions for the machine are expressed by numbers which are stored the same as the numbers for the data. It is not possible to tell, just by looking at the numbers in storage, which are data numbers and which are instruction numbers. A computer instruction is a word of information that provides momentary control of a computer. The instruction has two parts: the Operations Code (op-code) specifies the action to be taken (e.g., add the contents of some other word to the accumulator); the Address indicates where that other word of information is to be found in storage. A "routine" is a set of instructions used in a cycle of operation.

The routine also gives the ability to break out of normal sequencing in a straight line to any arbitrary point under control of the conditions of the problem as it develops. (See Figure 5.1)

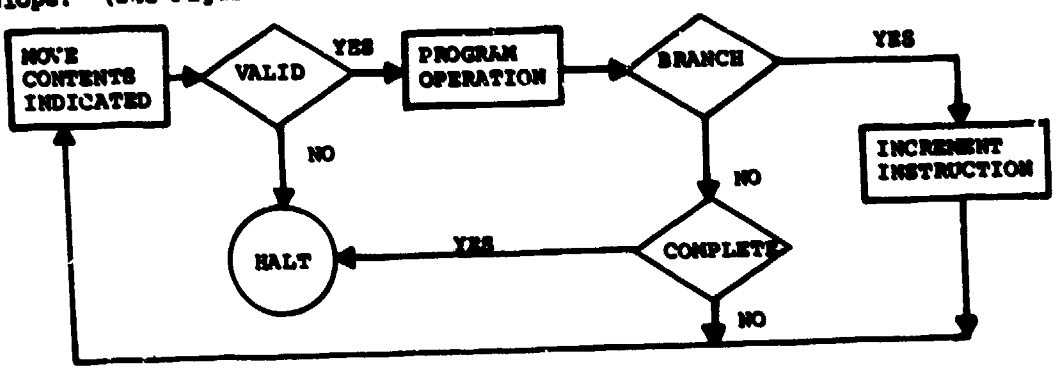


FIGURE 5.1

5.1 PROGRAMMING FLOW

Prior to the use of software in production, there are several sequential processes in the programming phase:

5.1.1 Analysis

At this stage, the programmer must ask several questions:

- Is the problem worth doing? (Has it been solved before and is a software package available?)
- Do we know a way to do it? (This would be contained in a set of program specifications furnished by the test engineer.)
- What precisely, are the inputs and outputs? (Again, this information should be contained in a specification document.)
- Are parts of the problem already programmed?
- What language should be used?

5.1.2 Flowcharting

A flowchart is a blueprint of the logic of a problem. It is a drawing made up of symbols connected by straight lines which lays out the logic of a problem solution. It is used to break up the solution so that during "coding" the programmer can focus on one detail at a time. Flowcharts are also used to simplify communications between engineers and programmers.

5.1.3 Debugging

Debugging is the entry of the programmed instruction into the computer and by actual machine passes the programmer determines if the instructions will execute properly. If not, the necessary corrections (debugging) must be made.

5.1.4 Testing

Using known inputs and having available the expected outputs, the programmer must determine that the problem being solved is the one we wish to solve and the program is satisfying the program specifications.

5.1.5 Documentation

As with other endeavors, the job is not complete until the paperwork is done. The solution should be documented for others to use and should include as a minimum:

- A statement of the problem in coloquial language.
- Flowcharts.
- Symbolic listings and core dumps.
- User Instructions.
- Test cases and sample results.
- Error conditions.
- Any history of use or trouble.

5.1.6 There are several axioms which must also be kept in mind during the development of a program.

- Every program contains at least one bug.
- If there is a bug, the computer will find it.
- Every program can be made shorter and be made to run faster, which will foster the atmosphere for constant change.
- If anything can go wrong, it will.

5.2 LANGUAGES

All computers manipulate numbers using a repertoire of operation codes wired in at time of construction. This machine language is awkward and difficult to use for the general user of the computer. As a result, a hierarchy of languages has been developed with the goal of permitting the user to list his sequence of instructions in a language close to that used in his discipline. These languages in turn produce (compile) the machine code. The conventional hierarchy is, in ascending order:

5.2.1 Machine Language

This is the code of the computer itself and gives direct access to the machine. Each and every instruction must be carefully stated in proper sequence. The alphabet of this language is 0 and 1.

5.2.2 Interpreters

An Interpreter is a subroutine whose function is to control the execution of a battery of other subroutines. An interpreter translates instructions from non-machine language to machine language and executes the machine language immediately before proceeding to the next piece of translation. An interpreter can be used to simulate the operation of a different computer.

5.2.3 Assemblers

Assembly language is characterized by paralleling the format of the machine's language and is machine dependent. Generally, the conversion from assembly language to machine language is one for one; that is, one instruction in assembly language yields one executable machine instruction. Mnemonics are now used for instruction in place of numbers (e.g., CLA - clear and add, SUB - subtract).

5.2.4 Compilers

Compiler language provides freedom of format and creates many machine instructions for each source statement. The format of these statements will not parallel the format of any machine. The compiler is essentially a machine-independent language. The overall bulk of today's applications programming is done in compiler languages. FORTRAN (FORmular TRANslation) is the most commonly used compiler language for engineering purposes; however, the U.S. Department of Defense is attempting to standardize on two versions of Higher Order Languages (HOLs).

5.2.5 Generators

Generators are programs for specific tasks (e.g., file maintenance, sorting, report writing) whose input language is the parameters of the problem. The generating program creates a new program to perform the task.

5.2.6 Specialized (Problem-Oriented)

Specialized languages are nearly always compilers and are created for specific problem situations (e.g., simulation - SIMSCRIP, list processing - LIST).

5.3 PROGRAM LIBRARY

Most test facilities maintain a library of developed software programs. A typical grouping would be:

5.3.1 Generalised Application

This would include software which makes the computer perform an application function and are for wide-spread or general use (e.g., routines which transform data).

5.3.2 Project-Unique Application

This software would include special merges, unique transformations, or classified routines which will not be available to general usage.

5.3.3 System Software

System software is any software which makes the computer system operate independent of manual operation and includes executive operating routines, Job Control Language (JCL), device operating routines, standard language compilers (FORTRAN, BASIC, COBOL ....), assemblers, loaders, and input/output (I/O) routines.

5.3.4 Applications

For flight test programs, two generic systems are usually used:

5.3.4.1 Engineering Units Conversion (First Generation)

This grouping covers the conversion of "raw data" through the application of calibrations to produce an output scaled in engineering units, generally as a time history.

5.3.4.2 Analysis (Second Generation)

This software performs the actual engineering analysis, generally using first generation output as input. Categories are frequently Flying Qualities, Performance, and Aircraft-Specific.

5.4 FLIGHT TEST UNIQUE DATA PROCESSING PROGRAMS

The overall format of any given data processing system is largely dependent on the type of data to be analysed and the overall system considerations for the use of that data. We shall now consider a series of typical data processing programs which are widely used for flight test work. There is no intention that the programs quoted are fully comprehensive, although it is worth remembering that they are typical of many systems in current use.

We may consider three basic series of programs which can be used together to provide an overall integrated data processing system or can be, and are, used individually in particular applications. The first of these is generally concerned with the task of producing a data base, either as a computer compatible tape or in the form of a disk file.

5.4.1 Engineering Units Processing

Flight test data, whether from telemetry or on-board tape recorder sources, is programmed through a series of stages to provide final data in engineering units, either for record purposes or for further processing in-house or at other organisations. This system consists of a series of programs, each with one or more files of information relating to flight test activities or files directly supporting the final analysis programs. Some of these programs are independent of other sources of information and these can be added to the system as required. Other programs, however, are related to each other and to final analysis programs which will be discussed later. Typical programs are used to provide preflight control information, system and instrument calibrations, to maintain instrumentation project history, to control data editing and data compression, and to correlate airborne data with other sources such as ground data and internal files. The end product in all cases is a data base in engineering units for use in subsequent processing though in some cases this might be the ultimate purpose of the analysis system. Typical programs used in this phase are discussed in Appendix I.

5.4.2 Analysis Processing

This phase is normally found in batch processing systems and is used to process test data recorded on magnetic tape or disk. Some of these programs can be operated separately using the calibrated data from Engineering Units phase while others operate as a system of integrated programs. The primary function is to conduct standard repetitive calculations of data or special calculations defined for the particular flight trial from selected test data. The output of most of these systems is in the form of tabulated listings or plots and special programs are available to handle this particular aspect of the analysis. Typical programs are discussed in Appendix I.

5.4.3 Real Time Processing

A number of systems have been developed where either the airborne information is transmitted to the ground by telemetry or the flight data is processed in flight on the aircraft to provide real time information as discussed earlier. The basic programs used in these types of systems are very similar to those described above for Engineering Units and Analysis but because of the problems involved in these systems, special considerations have to be covered. Computer oriented data systems of various sizes and complexity have become a necessary tool for the collection and verification of test results. The data system using real time processing can handle this sort of information very flexibly and the essential requirement of this data is to be able to provide, either onboard, or on the ground, a real time monitoring system. Essential tasks for such a system can include the ability to display in Engineering Units any parameters being recorded, and to provide the ability to perform mathematical computations for advanced analysis and to display the results. On-line or real time processing can, however, be constrained by storage availability, throughput time, or machine limitations such that calculations may be truncated, smaller word lengths required or calibrations simplified. The result of such compromises can be a "difference" in data values produced in real time and those derived in a post flight mode. Typical programs are discussed in Appendix I.

5.5 PROGRAM SPECIFICATIONS

At large flight test facilities, a software program library is developed and maintained by a specialized cadre of mathematicians and engineers. The role of these specialists is to translate the discipline engineer's requirements into an operational software program by writing a new set of software, modifying an established set, or using an established program as written. The success of this software depends to a large extent on the success of communicating the requirement. It is somewhat like a world traveler in a restaurant in a foreign land requesting a dish in his own language. The probability of successfully obtaining the meal depends on the complexity of the desired dish, availability of ingredients, equipment, and difficulties in language communications. The more definitive the description, the better the software. This definitive description should be contained in a Program Specification Document which acts as the contract between the flight test engineer, the instrumentation engineer, and the programming expert. Even if the discipline engineer is the one to write the program, a rigorous approach will produce a better set of instructions than blindly starting to code.

5.5.1 Format

The format for a Program Specification Document should contain:

- Identification of the task.
- Listing of responsible personnel.
- Description of the required computations.
- Input description.
- Computational procedures.
- Output requirements.

To best illustrate the specification, a copy of a recent specification for a test at the U.S. Air Force Flight Test Center is shown in Appendix II.

5.6 MANAGEMENT CONTROL OF SOFTWARE DEVELOPMENT

A significant problem in software development is the control of the human resources, computer resources and development time. This difficulty is often due to the lack of uniformity in the development approach and inadequate software configuration management.

5.6.1 Development Approach

The general feeling today is that software production is still more of an art than an engineering science. It is strongly dependent upon the approach, experience and capability of the individual programmer. Development techniques such as "structured programming," "modular construction," and program verification techniques are bringing a measure of order to the task.

5.6.2 Configuration Management

The major objectives of software configuration management should be:

- To describe at each time the current configuration of the software system (configuration identification).
- To assure that changes made to this configuration are necessary, reflect a thorough consideration of all interfaces affected and represent an optimal trade-off among performance, cost and schedule (configuration control).

- To record and report effectively the technical status of the software development products (configuration status accounting).

An excellent review of software management control techniques can be found in References 12 and 13.

6.0 THE PEOPLE

The size and complexity of any flight test organization will depend on the number and types of projects which it is currently called on to handle and the size and importance of those projects. Flight test engineering covers a wide field from the ultimate complexity of space flight planning down to the flight test on a single light aircraft. Consequently, it is only possible here to give a general idea of the type of organization which will be necessary and an indication of the typical staff who may be employed in such an organization. As discussed earlier in the system planning phase of the program, it was indicated that in some cases pre-processing and computation phases are handled in different organizations. This, again, will lead to a difference in the approach to the organizational planning of the system. Finally, we shall consider the handling of data within these organizations from the point of view of the overall capacity of any given system to process and evaluate the mass of data which is normally recorded in flight test work.

6.1 ORGANIZATION

In a flight test facility, there are a number of well-defined functions associated with the test flight of a new aircraft or installation on an aircraft. These in general encompass the following:

- Flight Test Engineering or Project Engineering
- Engineering Services
- Data Processing
- Technical and Development Engineering
- Flight Test Aircrew

6.1.1 Flight Test Engineering or Project Organization

This unit is normally responsible for the planning of any flight test on an aircraft. They are responsible to the aircraft project manager for the conduct of the flight test and for the specification of the various requirements in the flight test plan. This can be a very extensive program of work when a large modern aircraft system is involved, or it can, in fact, be one man who is the designer of a new light aircraft. This organization is responsible for program management of any selected program for:

- Performance and Flying Qualities
- Systems Engineering Testing
- Human Factors Testing

In the case of aircraft or systems where specialized testing is required, this organization would perform necessary liason with the Design Department concerned with such specialized testing.

6.1.2 Engineering Services

This organization plans, coordinates, operates, and maintains the data acquisition systems in support of the test program. It also plans the use of ground facilities, special instrumentation, and range data acquisition (i.e., telemetry, radar, photo-optics, etc.). In fact, its responsibility covers the whole range of the technical instrumentation requirements for a flight trial. Typical sub-sections of this unit are:

- Range Management
- Airborne Instrumentation
- Photography
- Aircraft Modification Engineering

6.1.3 Data Processing

This unit provides overall support for the processing of data which has been acquired during flight trials from both airborne and ground based facilities. It operates the data processing facility and is responsible for the continual development of that facility to meet test requirements. This organization will normally contain a software development organization in support of the data processing facility. Typical branches in such an organisation are:

- Computer Operations (Processing)
- Software Development
- Data Production Analysis

6.1.4 Technical and Development Engineering

Any organization set up to handle modern flight test data analysis and flight instrumentation projects needs a development organisation which can look into the future without the day-to-day problems of a vast throughput of flight test analysis work. Typical problems this unit could be asked to solve are new flight test techniques, new methods and procedures for carrying out the flight tests, and the technical development of new equipment and instrumentation in support of flight test work.

6.1.5 Flight Test Aircrew

The test pilot and flight test engineers will normally be part of the organisations above. However, it is convenient to consider them separately as they each have a vital function to perform in any flight test organization. Ultimately the planning and coordination of all the teams on the ground depends on the selection of suitable flight test personnel. For this reason, test pilots receive a very extensive and specialized training, and ideally, the flight test engineers should be similarly trained for the role they have to perform. This is normally the case in large flight test organizations but, all too often, the training of these personnel is neglected in smaller flight test teams. It cannot be over-emphasized that the ultimate success of the operations depends on proper training for these personnel.

6.2 COORDINATION OF THE OPERATION

All too often, the teams mentioned above are not properly coordinated in the performance of their duties. The coordination function rightly belongs with the project engineer involved on any particular flight test, and arguably the best approach to this problem is to use the main organizations in a joint inter-related fashion. Choosing key personnel from each organization, form a small liaison group to ensure that the proper feedback and interchange of information occurs.

In many flight test organizations, this policy is not followed and a functional alignment is used as an alternative. This can be regarded as the serial approach where the Flight Test engineering organization states its requirements to the Engineering Services organization who, after the Flight Test, hands its information to the Data Processing unit. This approach can very often be counter-productive in that the Data Processing personnel are frequently not properly aware of the nature of the requirements of the project engineers and flight test engineers, leading to a situation where the type of processing adopted is not compatible with the data that is being executed.

6.3 TYPES OF PERSONNEL

Flight test work involves a very wide range of skills in the personnel employed. We shall now consider in some detail the categories of personnel who should be used in the various organizations.

6.3.1 Flight Test Engineering and Project Personnel

Personnel in this organization are basically tasked with the overall planning execution, and reporting of the flight test. It is, therefore, essential that they should have good engineering background in the area of the test. If this encompasses the maneuvering of the aircraft in flight, a knowledge of aircraft design and/or flight dynamics is essential. If the system under test is an avionics system, then these personnel should have a sound knowledge of the basic system which they are being asked to test and of its basic operational characteristics. For example, if a radar set is under test, they should have an extensive knowledge of the limitations and performance characteristics of radar equipment in order that the test can be properly designed and conducted. Personnel are usually aeronautical and electronic engineers.

6.3.2 Instrumentation Personnel

This is one of the most difficult areas of recruiting staff for flight test work. All too often the assumption is made that instrumentation installations can be carried out by any competent electronics engineer. This frequently leads to trouble in that the installation of instrumentation systems is an important as any other phase of flight test work.

Reference 14 notes that great care has to be exercised in the use of instruments and transducers in the aircraft environment. The training of engineers in this field, therefore, is of supreme importance, otherwise it is very easy to produce a load of meaningless data which, to the inexperienced data analyst in particular, looks genuine. The training of flight test instrumentation engineers has tended to be conducted "on the job" and in only a limited number of cases have specific training courses been used for these personnel. The French in particular have used courses for training flight test instrumentation engineers but, in general the process has been to take qualified electronics engineers and to let them learn by their mistakes and from other team members while working on specific projects. This can produce, and has produced, very successful flight test instrument engineers but it can lead to a situation where the engineer's view of the problem can and is limited by his experience. Thus, one finds that there are significant differences in approach to the same problem by different flight test organizations because each has developed its philosophy independently from the others. There is a very definite need, therefore, in planning a flight test organization to make sure that the instrumentation engineers used have the widest possible experience and for them to gain that experience from as many different organizations as possible. Even in some of the major organizations at present engaged in flight test work, an evaluation of replies to questionnaires indicate very significant differences in understanding of common instrumentation problems among these personnel. There is no easy answer to this problem because of the limited number of specific courses in many countries. Such courses do exist, in France, the United Kingdom, and in the United States. For this reason, it is essential that the flight test engineer establishes a very close relationship with the instrumentation engineer to ensure that they have a clear understanding of the physical nature of the measurements they are planning to make and of the limitations imposed on those measurements by the structure and the environment in which the transducers have to be mounted. A flight test engineer who, by his experience, knows how to tackle them can ensure that the data gathered on a flight test is meaningful and valid.

6.3.3 Data Processing Personnel

In the majority of cases today, even on small installations, data processing will at some stage involve the use of a digital computer. In the small number of cases where this is not so, it is usual for the analysis (normally through the reading of trace records) to be carried out by the flight test engineer himself. In these circumstances he has a reasonable understanding of the limitations of the data he is considering and can, therefore, be expected to draw reasonable conclusions from the results of his analysis. In the majority of cases, however, the analysis phase of processing is conducted in a digital computer and the personnel manning these machines are usually computer specialists, with degrees in mathematics or computer sciences.

6.3.3.1 Data Analyst

Much grief can be avoided through the use of a clear Data Processing Concept and Plan, as discussed in Section 3. Data analysts, who are capable of analysing the flight test engineer's requirements and the instrumentation engineer's mechanization in line with the capabilities of the data processing center, are trained principally in the school of hard knocks. The data analyst can be drawn from any of today's engineering disciplines since all students receive early and constant exposure to computers. Flight test and instrumentation engineers are a good source as they bring the expertise and technical jargon from the other organizations. The other basic requirement is patience for data processing is the last step to the final test report and inherits all of the test program delays and frustrations. Without proper planning and verification of the data production system, initial data processing runs will be beset by program aborts, invalid answers, and delivery delays. A modern large computer facility is still at the mercy of the input, and output can never be better than input.

6.3.3.2 Data Operations

Large computer centers will have a staff of systems analysts, who at first glance appear to be charged with the responsibility of keeping data processing a deep mystery and separating the user from the machine. They are, however, charged with the important function of insuring that the computer system software and hardware function properly. New routines which are part of the basic software must be debugged and made operational. It is suprisingly easy for an inexperienced data requestor to bring a large computer system "crashing down" as a program hangs in an endless loop or consumes all of the available storage space. The Data Operations unit must first of all make available to the user a functioning computer system, for batch or interactive processing. The system software must be operational and user software must be reviewed to insure compatibility with the processing machine and the organization's concept of operations for processing. (For example, some processing centers place limits on file lengths to insure equality to all time-sharing users).

6.3.3.3 Software Development

Large flight test centers have a software development organization which will either prepare a new software program, modify an existing program, or select an existing program to meet the test engineer's needs. It has often been stated that all flight test programs are alike, but all are also different. Care must be taken to prevent re-inventing the wheel in data processing. The experienced software development personnel have a basic understanding of the test engineer's requirements and will create a program to meet those requirements in an efficient and complete manner. The key to good software lies in the preparation of a comprehensive Program Specification Document, adequate lead time to code and debug the program, and sufficient pre-test data to exercise the software in the complete data production loop. In smaller installations it is frequently possible for an engineer trained in flight test and instrumentation field to be able to handle the necessary software himself with a full understanding of the problems he is tackling. In major installations, this is not always possible and it emphasizes the need for the liaison committee discussed above and for the various elements in that committee to be able to have a working understanding of the techniques and procedures adopted by his opposite number in different parts of the organization.

6.3.4 Aircrew

In any flight test situation, the people required to conduct the flight and to operate the instrumentation and other systems (such as Avionics) during the flight must be properly trained for the work, otherwise the work of all the ground based personnel can be set at nought. The pilot in particular needs special training, especially if the flight test involves the handling and maneuvering of the aircraft. These test pilots normally receive a very specialized training for the work in which particular emphasis is placed on their ability to assess the response of the aircraft to different inputs from the pilot. In particular, their report of the test is very often an essential contribution to the flight tape or the telemetered information. In aircraft where an observer is carried or, in some cases many observers, their training must not only cover the operations of the systems for which they are responsible but also their ability to observe and report on the general aircraft situation at any particular time. Effort spent, therefore, in specialized training for these personnel can always show a very substantial dividend. If they are instrumentation observers, then their ability to understand the design problems of the instrumentation is a necessary asset in enabling them to handle the system during its use in flight tests. On larger aircraft where quick-look information may be produced by an on-board computer, the observer's ability to interpret this data accurately and rapidly and either report it to the ground for decision on the next phase of the flight test or, in some cases, to make that decision himself is an essential requirement to the successful completion of the flight test. Proper training and briefing for these personnel before the flight test is, therefore, essential.

7.0 DATA PROCESSING FUNCTIONS AND TECHNIQUES

In the preceding chapters we have considered the methods for obtaining data, and the hardware, software, and personnel to process it. The data is now available in some form or other and it is the responsibility of the data processing personnel to present this recorded data in a form which is acceptable to the flight test engineer or data analysis engineer.

7.1 QUICK-LOOK PROCESSING

Quick-look data is an essential requirement in all flight tests in that it is usually necessary for the flight test engineer to be able to assess whether a particular flight test has been satisfactory before the full analysis of the data is made. On such ad hoc decisions, the continuation of the flight test program is frequently based. It is, therefore, desirable that all the essential information should be presented as quickly as possible in a form which enables this sort of decision to be made. Quick-look data can take many forms.

7.1.1 On-Line/Real-Time Information

On-line quick-look information can be obtained by on-board observers who follow the time history of essential parameters using, in some cases, on-board computers to provide the necessary data; or from telemetry systems which pass the essential data to the ground where they can be displayed in real time. In both cases, calculations may need to be done from this measured data to provide information which can be displayed to the engineer who has to make the decisions on the progress of the test flight. This type of system is also frequently called a real time system in that the data being gathered, whether in the aircraft or on the ground, is being computed on-line in real time so that effective decisions can be made on the information governing the future progress of the test flight. These systems are widely used for two specific purposes:

7.1.1.1 Safety

Many flight tests involve a considerable element of hazard to any aircrew involved in the trial, and it is, therefore, necessary on many occasions to provide a data analysis system which is capable of presenting a ground observer with the immediate up-to-date information on the progress of the flight to supplement the pilot's observation (in some cases, the ground observer is the sole source of such information) to ensure that the flight test being conducted does not exceed expected safety limits. Real time, in context, therefore, means the ability to take effective safety action within the minimum time scale set by the normal limitations of a data system.

7.1.1.2 Program Sequence Control

A complementary function to the safety function is the ability to analyze the progress of the flight test from the ground and decide what next phase should be attempted without bringing the aircraft back to land. This function of the real time system is complementary to the airborne system in that they are both capable of enabling the control of the test flight to be monitored and, if necessary, varied on a real time basis. A real time system used at the US Air Force Flight Test Center is described in Appendix III.

7.1.2 Off-Line Information

In these systems, data recorded during flight, either on the aircraft or by telemetry link, is given to the data processing facility for processing. The data is then run through replay (playback) equipment which is capable of producing output in a graphical trace form or computer listing. This enables the experienced engineer to assess the validity of the data that has been gathered. This is an area where the small digital computer and line printer or analog trace output is extremely valuable. In the case of analog data, the ultraviolet (UV) trace recorder is almost exclusively used for this purpose in modern flight test systems. The off-line system is the same as real time, except data input is from magnetic tape.

This same data can often be used to verify the operation of the instrumentation system, evaluate calibration values and to identify problem areas. The medium used can be a trace on strip chart recordings or tabulated listings of raw data values ("digital dumps"). These can be used as valuable quality control checks before continuing with data processing or as check points in the processing stream for troubleshooting.

7.1.3 Comparison of On-Line/Real-Time and Off-Line Systems

These terms are widely used in the data processing world and this is an opportune place to define application of these terms. The use of these techniques has a direct application to quick-look data but, as will be seen from paragraphs above, the phrases can have a wider connotation. On-line systems cover any system where the flow of data from the point of measurement to the presentation of that data is continuous. This data may or may not be processed en route, and the final output may present data to the test engineer in real time, in a form in which he can take quick-look decisions. On the other hand, some on-line data will be fully processed as the test is proceeding and, in this case, there is less justification for the application of the real time description to this data because the processing time may be such that, although the data is being handled continuously, it is not being done, perhaps due to computer time, in a time scale which permits immediate decisions to be made on the results of the analysis.

Off-line systems similarly do not have a direct link between the measuring system and the data processing and in these cases the transfer of data is usually by one of the recording methods described earlier. This data can still, of course, be analyzed quickly on receipt at the data processing center to give quick-look information which, in this case, more normally has the function of enabling the analysts to decide on the data which must be processed for further analyses.

The difference between these systems is, therefore, fundamental to the design of the overall processing system and considerable thought must be given to these elements when deciding on the system that will be used in order to cover the safety of the crew and the aircraft, monitoring the performance of the instrumentation system, "goodness" of the maneuver performed, aircraft systems operation, etc.

Off-line systems in general are more flexible in that they do not require large ground based communication facilities which can, in the case of aircraft, limit the area in which the flight can take place. These systems, therefore, depend very heavily on digital and analog magnetic tape recorders in order to provide a means of transmitting the data to the data processing facility. In some cases, where the aircraft size permits, some of the computation may be done on-line in the aircraft and then transmitted off-line by magnetic tape or disk to the data processing facility on the ground. This is a typical example of the flexibility that is possible with these types of systems.

7.2 ENGINEERING UNITS (FIRST GENERATION)

Data processing, particularly in modern automatic data processing systems tend to be divided into three parts; engineering units, intermediate processing (merges), and analysis computation. Some confusion occurs at times between different systems on the division between these areas. For the purposes of this document, we shall take the situation where the engineering units phase is understood to cover all the work carried out on the flight data up to and including the preparation of the data base of computer compatible tape of the engineering data. (Engineering data can also be described as the recorded parameters which have been modified by the application of calibration data and produced in a time-history format.) (Raw counts + calibrations = engineering units.) Generally speaking, data recorded in flight or received on the ground by telemetry link is recorded in a format which is not consistent with a modern ground based digital computer. The reason for this is that the limitation imposed on a digital computer in terms of the cleanliness of tape and operating environment necessary for high packing density used on its digital tapes means that data from flight sources has to be processed before being fed into the computer. This can be done whether the information is in analog or digital form, and leads ultimately to the generation of either a data base on a disk file, or a computer compatible tape. It is convenient during this process to add the calibration data to the information so that the data base is generated in true engineering units. This has the great advantage that, where various organisations have an interest in the flight test, the data base can be distributed to these organizations in a standard engineering format, enabling further computation to be conducted in the individual facilities of the contributing organization. In modern large installations, disk files are normally used for this purpose as the availability of the data for random access is very much more rapid on disks rather than on magnetic tape. A typical flow is shown in Figure 7-1.

ENGINEERING UNITS

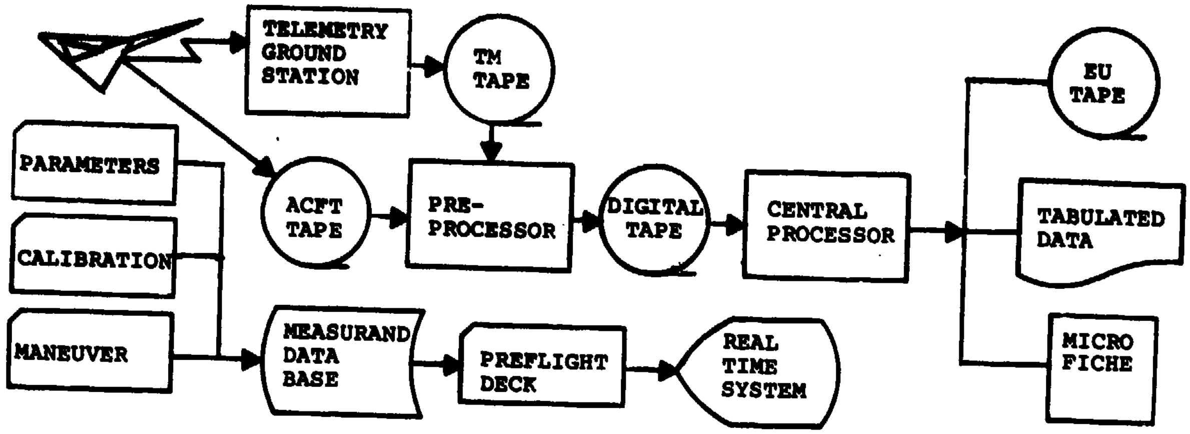


FIGURE 7-1

7.2.1 Measurand Data Base (Project History)

An important part of the engineering units processing system is the measurand data base (called a Project History File at the US Air Force Flight Test Center). It contains the parameter identification and calibration information which must be applied to the raw data. The calibrations are usually stored in two forms: polynomial and table look-up. (The frequently used linear slope-intercept function, Y=MX+B, is considered as a polynomial.) With the polynomial method, the calibration curve which is derived from the instrument or transducer is approximated by a polynomial function whose degree is usually no larger than fifth order. Once the polynomial is determined, only the coefficients need to be stored in computer memory. With the use of a polynomial function, care must be exercised that values are not obtained by extrapolation beyond the upper and lower limits of the actual calibration points which have been measured. Where a polynomial fit is not possible, the complete table of calibration points must be entered into storage. Values between points are calculated by linear interpolation. Table look-up does require more storage space and can increase the time required by the central processor. This data base requires meticulous bookkeeping to insure the proper calibrations are selected for a particular test. The project history also offers an opportunity to decrease the amount of data processing by grouping parameters of interest to a particular test or engineering discipline and processing only those parameters. Such a grouping is identified above as a "maneuver." The project history also contains the data required to set up the real time data systems. This importance of using a common data base for real time and post flight processing is obvious. (Figure 7-1)

7.2.2 Pre-Processing

The format conversion of test data into a digital tape or computer file compatible with the central processor is performed by a preprocessor, which is generally a specialized computer. The preprocessor "front end" is usually structured to accept a variety of input formats. Data recorded in analog form (direct recording of FM, for example) must be separated into the individual signals from the multiplexed stream through the use of discriminators and converted into digital form with analog to digital converters. Digital data, on the other hand, can be encoded in several formats (e.g., PCM - Pulse Code Modulation; PDM - Pulse Duration Modulation) and time-multiplexed into a continuous stream. A special set of instructions (decommutation deck) is used to select the desired parameters from the data stream at the desired sample rate - which can be less than the recorded rate. The individual parameters must then be changed from the particular encoded format (PCM, PDM, etc.) into the format compatible with the computer to be used for processing. (As a note of caution, a "computer compatible" tape cannot be assumed to be compatible with all computer makes and models.) The final action is to insure proper assignment of timing information to the individual parameter values.

7.2.2.1 Data Compression Techniques

There is a constant trade-off analysis required between the desire for maximum data and the cost of producing that data. The initial preference is to have all the data recorded on a flight tape available on the engineering units tape. When this has been proven costly, the next step is to have all of the recorded data available on the preprocessor digital tape and use the engineering units program to compress output volume. Volume compression can be performed in the engineering units program but the computer must still examine each data point and make a retain/discard decision. This uses the most expensive part of the data processing stream, the scientific computer, as a data filter. With compression performed at the preprocessor point, maximum reduction in processing costs are achieved. It is far less costly to digitize and produce an event time or parameter which may have been missed on a data processing request than it is to process all recorded data to engineering units.

- Time Editing

Raw test data is generally recorded for the major part of a flight to provide data for the test anomalies. The data of normal interest is somewhat less and the recommendation is to reformat only the test segments of interest. This can be done inflight by turning the recorder off, or at the preprocessor station by selecting only time segments of interest from the airborne or telemetry recorded magnetic tape.

- Parameter Editing

In most computer systems for engineering units conversion, the software program must consider each word of data, on the input tape or file, even if that parameter is not to be converted to engineering units. This manipulation adds to the overhead cost of processing. If the parameter is not on the reformatted tape, the workload on the conversion computer is less. The process of reformatting only parameters of interest is called "decommutation" and the parameters are identified in a decommutation punched card deck or file which is used by the preprocessor as a control. The use of time and parameter editing (in conjunction with maneuver identification in the main software) to reduce computer running time was investigated at the US Air Force Flight Test Center with the results shown in Appendix IV.

- Hardware Compressors

Compression algorithms generated by specialized compressors which can be used in addition to parameter editing and event time editing are PSAMP; ZFN (O); and ZFN (1). PSAMP (N) compression selects every Nth sample of the data, where N is specified by the test engineer. For example even if a parameter is recorded at 800 samples per second, the engineer may only need a rate of 100 samples per second for normal data processing. A PSAMP of eight would then be used in the preprocessor to digitize the raw data. The basic recorded data is still retained on the initial data tape and can be redigitized at a higher sample rate for events of particular concern where more data points are required. It must be realized that PSAMP is in the nature of a brute force compression, and does not account for variation in the activity of the data parameter. Recognizing this limitation, it is an effective technique.

The ZFN compression algorithms are by nature adaptive sampling techniques. ZFN (O) will pick out and digitize only those parameters which change from one sample to the next. For example, ZFN (O) applied to the discrete event parameter would digitize only that raw data associated with movement. With ZFN (O) applied, any change in that parameter would register and be digitized, alerting the engineer to parameter change during the flight. Redundant data would be eliminated. This results in saving of engineer effort in scanning a supposedly quiescent parameter for the entire flight, looking for a change.

ZFN (1) compression would permit digitizing of a parameter if the change in data word was greater that one bit. This technique is useful for parameters where only changes of a specific magnitude are of interest or if low bit noise is known to be present in the parameter measurement, invalidating the accuracy of less significant bit.

7.2.3 Engineering Unit Conversion (Reference 15)

Engineering unit conversion was defined earlier as the application of calibration data to the raw counts. At the US Air Force Flight Test Center, the programs which perform the application of calibration form a block of records that consists of information on the parameters required for the particular maneuver to be calculated. Only the parameters in that maneuver appear. Each parameter will have information on parameter number, digital tape location for the inputs, conversion algorithm (method) and calibration values to be used. The parameters are then sorted by parameter number and source and each parameter is then assigned a location in the block called "source order number."

The calibration programs also do some pre-calibration method processing, time-search, auto-cal search, etc., before entering the DLC (definition, location, calibration) record to convert the data. The conversion program then starts with source order number one and finds the digital channel or channels required, enters the conversion method, processes the channel information for the maneuver start time, goes back to the DLC record block if calibration tables are required and then outputs the answer as instructed by the method into an output block. The program then goes on to source order number two, three and so on until source number N is reached. It then restarts with source number one for the next time sample and continues these cycles until the end time of the maneuver is reached. The program then searches for the next time sample and continues these cycles until the end time of the maneuver is reached. The program then searches for the next event time and starts all over with source order number one for the maneuver involved in that event from start event to end event time.

The conversion functions used depend to a great extent upon the complexity of the data, type of calibration and recording method. The generalized engineering unit conversion program at the US Air Force Flight Test Center contains forty different conversion methods which have been added over the years in response to changing instrumentation systems. During processing, only the applicable methods are selected for use. Some typical methods are:

- Mask Function By Parameter

  This allows for multi-word operation by "masking" (blocking out) selected numbers of bits of input and apply the logical "OR" function into selected numbers of bits of inputs.

- Wait Function

  This is performed for multi-parameter operation where parameter A is masked and stored and waits for the appearance of parameter B before proceeding.

- Bit Match Function

  Bits from selected words are compared for match or non-match (as defined previously) to identify halt in processing.

- Data Type Conversion

  Conversion to binary can be performed using several computational methods:

  Two's Compliment
  Signed Binary
  Two's Compliment MSB (Most Significant Bit) inverted
  BCD (Binary Coded Decimal) decode
  Hexadecimal Decode

- Table Look-up

  Calibration values are selected point by point from a two or three dimensional array with interpolation and/or extrapolation.

- Polynomial Fit

  Coefficients for polynomials up to fifth order are stored and used to define the polynomial.

7.3 INTERMEDIATE MERGES

The engineering units data base can be composed of data derived from numerous sources: airborne magnetic tape, telemetry recordings, trajectory information, weather data, systems constants, and correction factors. A typical data merge used to support testing of a gunnery computer system is shown in Figure 7-2.

INTERMEDIATE MERGES

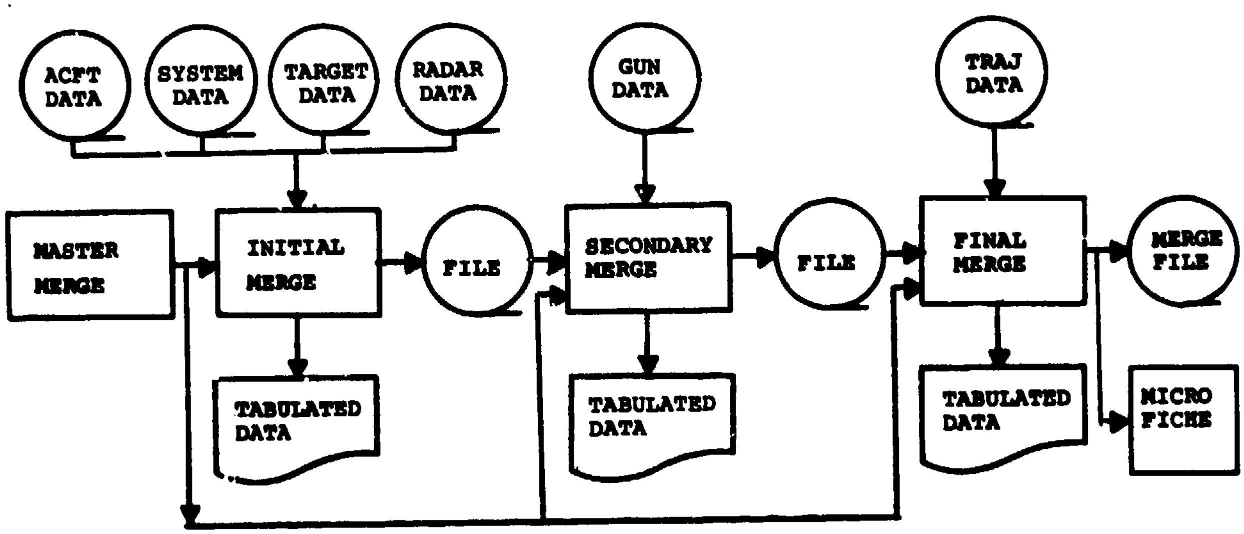


FIGURE 7-2

The primary purpose of the merge process is to create a new intermediate data base composed of data from multiple sources expressed in engineering units which can be used as input into the Analysis Programs. In merging, care must be exercised in both parameter and timing constraints. Most computer programs will halt if a timing overlap forces it to go "backwards in time." Likewise the disappearance of a parameter from one location and its re-emergence in another location will cause a program halt.

7.4 ANALYSIS COMPUTATION

This phase of data analysis is arguably the most important general area of handling flight test data. So far the information gathered during the flight test has been processed into calibrated engineering units data which represent the real information gathered during any particular test flight. This data, which may be on disk or on computer compatible tape, has been referred to above as the data base. As such, it can be fed into existing file information for use during future engineering work on a similarly fitted aircraft, or it can provide the basis for developing the derived information on the flight for use by the aircraft or system designers. Typical analysis flow is shown in Figure 7-3.

ANALYSIS COMPUTATION

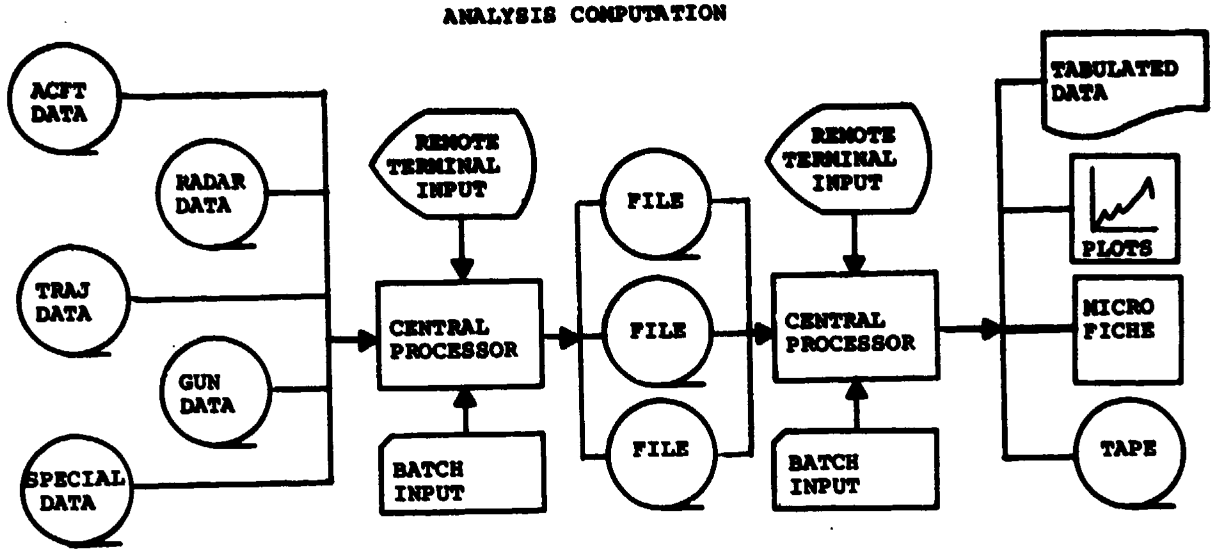


FIGURE 7-3

This analysis may be carried out either within the flight test organization which has been responsible for the aircraft test program, or the data base may be supplied to other organizations which have an interest in analysing specific data gathered from a flight performed by somebody else. For example, in the first case, the whole process of handling data from a flight test within the Boeing Commercial Aircraft Division is carried on within the flight test data analysis facility. An example of the second case is where normal output of flight test organisations such as the Flight Test Center at Edwards, California and the NLR in Amsterdam, Netherlands, is a data base which in addition to being used by the test center, is transmitted to other organizations such as aircraft manufacturers and design groups who are outside the control of the flight test organization.

Typical areas of final processing include stability and control parameters derived either by steady state techniques or parameter identification, aircraft and engine performance measurements, trajectory measurements including take-off and landing performance, frequency analysis of both flutter and vibration data from aircraft and handling qualities analysis. Typical software packages were described in Section 5 and Appendix I.

7.5 PRESENTATION

Presentation is an essential segment in the data processing sequence. It is in this part that the information derived is output in a format which is acceptable to the user. In general, this presentation takes two major forms - tabular listings and graphical printouts. Samples are shown in Appendix V.

Tabular listings retain all the precision of the original computation and may either be provided by teletype outputs, which is rather slow, or by high speed line printers. These tabular listings are generally favored by computer engineers as this is the normal output from computers used throughout industry.

Flight test engineers and designers frequently prefer graphic information. This is normally provided by a variety of plotters including electro-static plotters, X-Y plotters, strip chart recorders, etc. A recent application of this technique, which provides very high speed output and also interactive response with the analysis engineer, it is to use a cathode ray tube display of the data, associated with a hardcopy unit which can be activated once the displayed data is to the satisfaction of the analyst.

7.6 VALIDATION AND INTERPRETATION

This is the essential phase between the final processing of the data in the computer and the writing of the test report. The first step, usually accomplished during software development and checkout, is for someone to validate the output of the computer. This can either be done by checks within the computer program by the computer processing personnel, or it may be left to the flight test engineer when he is presented with the output data either in tabular or graphical form. Whichever way, the validation must be done with a broad understanding of the purposes of the test and of the computer techniques employed to analyze the data. Incomplete understanding of either of these matters can lead to incorrect information being accepted at this final stage. Once the flight test engineer has accepted data which has been validated, the next phase is the interpretation of this data. This consists of taking the test results and comparing them with the theoretical models of the flight test exercise which has been performed. If these test results conform to the theoretical model, then the values of the parameters that have been measured and calculated can be determined from these test results. If, however, the results do not conform to theoretical background, it may be necessary to go back to the computational phase to check every step of the process to try and identify what the cause is of the lack of compatibility in the data. This may well be due to a true difference in the flight test data, in which case, the necessary remedial action can be taken. It can, however, sometimes arise due to a peculiarity in the measurement and data processing chain which needs to be eliminated before the final information is accepted. In other cases, the theoretical or wind tunnel data may be wrong. In either event, the total data acquisition and processing chain must be reviewed step by step to insure data from one phase in the processing is passed to the next phase without change.

The final step in this phase is to publish the results in the test report. This is the stage at which the flight test engineer must consider whether the test results really are a relevant answer to the problem for which the test is being conducted. The test report should, for this reason, always point out in its conclusions whether any remaining uncertainties exist rather than to have them discovered later.

8.0 DATA PROCESSING CAUTION AREAS

8.1 DATA VOLUME

Airborne instrumentation technology has enabled the measurement and recording of huge amounts of data. Though this allows a greater assurance of measuring the information required to test the vehicle, it results in considerably more data being recorded than is actually required for engineering reporting of the vehicle test results. These volumes of data are of such magnitude that it is not economically practical nor should it be desirable to process all of the data through computer equipment. To do so results in (1) unnecessary program dollars being spent on data processing, (2) proliferation of excessive computer facilities and equipment, (3) increasing the turnaround time to get final data into the hands of the test engineers, and (4) burdening the test engineers with great volumes of data output that require his time and effort to separate the needed information from the data. It is not the function of the data processing organization to determine what volume of data must be processed to meet the needs of the test engineer. This determination is made by the recipient of the data. What the data processing organization can do is point out the impact of excessive volumes of data in terms of cost, turnaround time, and saturation of the data processing facility. In today's technology the test engineer reviews countless reams of tabulated data or graphical representations to segregate those segments required for the test report. Future systems, using interactive "smart terminals" capable of presenting both tabulated and graphical data on a CRT will permit such scanning for events of interest to be performed more efficiently. A word of caution, however, the data base or file which feeds this smart terminal must still be created by the application of calibrations to raw counts to produce data expressed in engineering units. If restraint is not exercised in the initial selection of data to be processed, then all that has taken place is to substitute a very expensive remote terminal for a line printer. Volume reduction must be used from the very first step in data processing to avoid spending the major portion of the allocated funds on data which ends up in the trash bin.

8.2 DATA RATES

The rate at which parameters are sampled are usually those which represent the upper limit of the transducer, signal conditioning and telemetry or recording system. This is desirable since it will give a raw data base the maximum intelligence it is possible to gather. The information required for the test report is significantly less than that recorded and a logical point at which to start reduction is with the sample rate selected for conversion from raw data to engineering units. The output of a line printer for thirty minutes of data at a thousand samples per second is indeed awesome. The use of time and parameter editing techniques coupled with cascading compression algorithms can reduce the data processing task significantly.

8.3 PERFECT DATA

There is no such thing as perfect data for flight testing, regardless of the sophistication of the data processing system. The potential for dropped or transposed bits, breaks in transmission or recording and anomalies within the hardware or software all work to produce imperfect data. A software program which expects perfect data can churn for hours, then a parity error or data gap will lose everything. The test engineer must be prepared to accept data losses and still finish the test report. Data can be salvaged out of noisy recordings by skilled preprocessor station operators, but it can never be manufactured. The complete system, from transducer to line printer or tape drive must be considered as an entire process with capabilities and limitations full defined. A small compromise in request requirements can often yield major benefits.

8.4 SOFTWARE ANOMALIES

The use of "canned" software routines offers the test engineer both flexibility and the reduction of labor in developing a set of instructions to produce the required output. It must be recognised that the more general the application of the software, the more likely will be the existence of unwanted branches lurking in storage recesses to trap the unwary bit and produce a nonsense answer. Small program changes, which seem insignificant at first glance, and made as "quick fixes," to "get the data out," invariably richochet throughout the program causing it to fail to run to completion. The more careful the definitions and instructions in the initial Program Specification, the more likely will the software run to completion. Preproduction testing of the software through the use of known inputs to produce expected outputs for all cases of interest will significantly reduce the number of failures and reruns once real test data is run.

8.5 HARDWARE LIMITATIONS

Today's large scale computer systems appear so overwhelming that little notice is taken of the equipment limitations. Advances in speed and internal self-checking capability have been impressive, but it is still possible to saturate a system with excessive input volume coupled with inefficient or faulty software. Word size, storage capacity, and ancillary equipment (card readers, tape drive, printers, terminals) will always have finite limitations. These must be identified and accommodated. The computer may be capable of marvelous performances, but it is still a literal machine which will follow input instructions within the limitations innate to its construction.

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APPENDIX I

TYPICAL FLIGHT TEST SOFTWARE PROGRAMS

I.1 INTRODUCTION

Section 5 contained a general definition and description of the software programs required to produce flight test results as a usable form of data. This appendix describes the types of software peculiar to each of the major areas of engineering units, analysis, and real time processing. The programs listed are not purported to be all inclusive, but rather as a typical array used in flight test work.

I.2 ENGINEERING UNITS PROCESSING

Typical programs in this phase are used to provide preflight control information, define system and instrumentation calibrations, maintain measurand data base, control data editing and data compression, and correlate airborne data with ground data.

I.2.1 Curve File

The Curve File program maintains a file of curves, constants, and identifiers in an on-line mass storage unit for selective retrieval. The Curve File is an active file that undergoes frequent changes in contents which are input via cards or remote terminals. The Curve File consists of an index section which identifies particular tables in the file and a data section which contains the tables of constants, tables of identifiers and tables of curves. Thus, the Curve File structure should provide for the filing of many tables which can be referenced by several airplanes for which many table names apply and several test numbers can be associated with each table name.

I.2.2 Flight Test Instrumentation Requirements (FTIR)

The FTIR program maintains a file of the measurement specifications for the instrumentation that is required and authorized for the testing of an airplane. The FTIR consists of a Model (or master) file and at least one Airplane file. The Model file contains the specifications of each measurement required to test a particular airplane model. The Airplane file associated with each test airplane of the same model contains only those measurement numbers authorized for the test airplane. Most of the data are input via punched cards and selected parts of this data are also used by the following programs:

I.2.2.1 Test Item Measurement Requirements (TIMR)

The TIMR program maintains a file of active test items and their associated measurements numbers. Information related to the test items is input by cards, and the descriptions of the measurements are retrieved from the FTIR file.

I.2.2.2 Request for Instrumentation Preflight (RIP)

The RIP program produces an on-line storage file of the instrumentation measurements required for a specific test on an individual airplane. The RIP program merges information from the FTIR and TIMR files to generate the file of required test measurements. The RIP program then calls the FTIC program to produce a preliminary listing of the measurements for instrumentation engineers to use during preflight work on the test airplane. The RIP file is "cleaned off" periodically in the interest of economy.

I.2.2.3 Flight Test Instrumentation Configuration (FTIC)

The FTIC program maintains a complete and current file of the instrumentation installed on each airplane in test status. The file can contain all calibrations, or have only the most recent configuration accessible. Within each airplane file, the configuration is stored and accessed by recorder number, recording medium, track number, channel number, and when applicable by subchannel and bit number. A preliminary listing of an airplane file is generated by the program for the engineer to use during a preflight check of the airplane instrumentation system. Any instrumentation changes made prior to or during the test are input to the program which then produces a final instrumentation configuration listing for the test and automatically updates the Arrangement and Calibration File (A/CF).

I.2.2.4 Transducer Calibration File (TCF)

The TCF program computes the calibration coefficients for transducers by applying a polynomial fit to test results from the Calibration Laboratory. The data are input to the computer either by cards or by using a remote terminal located in the Laboratory. Access to the file is by transducer number. The coefficients are stored on an on-line mass storage unit to be retrieved by the A/CF program for use in calibrating flight test data. The data may be output either on cards, as plots, or in printer formats.

I.2.2.5 Arrangement and Calibration File (A/CF)

The A/CF program prepares and maintains a file of the calibration values and the track/channel arrangement for each measurement number to be used by subsequent programs. A separate file is established for each flight test airplane using the data available in the FT/R, FTIC, and TC files, as well as punched card and remote terminal input when required. Normally, the data are retrieved from an airplane file by an ordered indexing with measurement, recorder, track, and test numbers; or the file may be accessed by test number only in which case all the measurements associated with the test are retrieved. Optionally, a file may be accessed by test, recorder, and track numbers to retrieve all the measurements recorded on that track. Following active usage the separate and complete A/CF for an individual test may be sorted on a historical tape. The A/CF output may be listed on paper or punched on cards.

I.2.2.6 Arrangement/Calibration File Plot (A/CFP)

The A/CFP program produces a graphical representation of the calibration function of a measurement. Plots for specific measurements on file or for the entire file may be obtained depending on the accessing request. The file is accessed by airplane number, test number, and sort code to obtain plots of the entire file. Inputting specific measurement numbers in place of the sort code generates plots for only the measurements. The plots are used to facilitate converting signal reference values to engineering units when required.

I.2.3 Test Accountability (TA)

The TA program is primarily responsible for maintaining status of Flight Test Engineering Work Authorizations and Test Items associated with airplanes in the flight test inventory. The status maintenance is accomplished using major files and subsidiary files. The major files provide data storage and retrieval capability with some automatic crossfeed or data between the files. The subsidiary files contain data of a comparatively permanent nature. Program input is accomplished using primarily magnetic tapes although punched cards may also be used. The output may be listings.

I.2.4 Flight Test Equipment Management (FTEM)

The FTEM program maintains a file of all accountable equipment in the Flight Test inventory. The information and data are stored on an on-line mass storage unit such that the file may be added to, revised, or deleted as required. The FTEM output is tabulated as various equipment lists and summary reports of Calibration Laboratory activities. A historical file is also maintained to facilitate evaluating individual items of equipment and to provide statistical data regarding laboratory workloads and group performance.

I.2.5 Pilots and Flight Engineers Records (PFER)

The PFER program maintains and lists, when requested, simulator and flight information acquired by test pilots and flight engineers. In addition, the program will develop currency projections for crew members of the Flight Crew Training.

I.2.6 Airplane Configuration and Status (AC&S)

The AC&S program maintains an up-to-date record of the present and past configuration of an airplane as long as the airplane remains in the Flight Test inventory. The information is processed and arranged so that a record is always available of the airplane configuration existing at the time of each numbered test. The information can also be sorted in a variety of ways to meet the objectives of participating organizations.

A number of other data files, cost files, and library location files can be kept on this system and called up as required for the analysis of a particular flight test. The output data from this part of the system is fed into a calibration stage which reads, edits, and calibrates the flight data which has been produced in a format suitable for the computer. This may be done for FM data in a ground station, from airborne tapes, or from telemetry data. Card data can also be used as an input to this stage and the calibration data is used by a number of mathematical techniques to ensure that the output of the initial analysis system is in the form of engineering units which can be printed, plotted, or handled in a data base for further analysis.

I.3 ANALYSIS PROCESSING

This phase is normally found in batch processing systems and is used to process test data recorded on magnetic tape or disk. Some of these programs can be operated separately using the calibrated data from the engineering units phase while others operate as a system of integrated programs. The primary function is to conduct standard repetitive calculations of data or special calculations defined for the particular flight trial from selected test data. The output of most of these systems is in the form of tabulated listings or plots and special programs are available to handle this particular aspect of the analysis.

I.3.1 Gross Weight-Center of Gravity Program (GWCG)

The GWCG program calculates the gross weight and center of gravity profile of an airplane for any given flight. Normal data input to the program is provided by the Curve File program and the engineering units tape.

I.3.2 General Calculation and Average (GCAA) Program

The GCAA program gives the requesting engineer the capability to specify, at request time, a variety of calculations to be performed on time history variables. The time history variables may be the output of any other Final Data System program except LIST and PLOT or they may be card input data. The calculation may be a standard calculation or an equation that is specified on the data request.

I.3.3 Basic Airplane (BA) Program

This program calculates the basic airplane parameters of airspeed, altitude, ambient air temperature, and lift coefficient. The input data required for these parameters are impact pressure, static pressure, indicated outside air temperature, and gross weight.

I.3.4 Engine Performance (EP) Program

This program computes the performance of one, two, or more turbo-jet engines at one time. The input data consists of the BA program output and of normal engine parameters such as compressor speeds, exit temperatures and pressures, and fuel used quantities.

I.3.5 Engine Fuel Flow (EFF) Program

This program calculates fuel flow rates and specific fuel consumption for individual engines, total flow rates per airplane, and average values of the parameters for each condition.

I.3.6 Airplane Performance (AP) Program

This program computes the values of parameters that describe the performance of the airplane during steady level flight conditions. Normal calculations assume that engine thrust is parallel to the flight path and the rates of change of airspeed and altitude with respect to time are constant. At high angle of attack engine thrust is not parallel to flight path and a correction is normally included. Normal input are provided by the Curve File, Basic Airplane, Engine Fuel Flow, and Engine Performance programs.

I.3.7 Time-Space-Position-Information (TSPI) Program

This program computes airplane position, attitude, velocity, and acceleration using data from Cinetheodolite systems. The film associated with each system is semi-automatically read and the azimuth and elevation data punched on computer cards or entered on magnetic tape. The data are input to the program to compute the TSPI.

I.3.8 Automatic Approach (AA) Program

This program computes the automatic approach data that is pertinent to evaluating the ground facilities and airplane systems used during instrument landings. The position of the Instrument Landing System (ILS) beams and the relative position of the airplane to these beams are determined by the program. Normal input data is provided by the TSPI program output and by the glide slope and localizer deviation signals recorded on-board the airplane.

I.3.9 Static Port Survey (SPS) Program

This program computes a position error correction factor for each of several static pressure sources based on data taken from the static sources and from one of several reference systems. (Reference 16). The input data are obtained from the Curve File and Basic Airplane Programs.

I.3.10 Pressure Coefficients (PC) Program

This program computes the pressure and pressure coefficients for the static points on the periphery of a specified cross-section or sections, and also computes the normal chord and moment force coefficients for each section. The input data are supplied by the C&BA programs.

I.3.11 Sideslip Angle Calibration (BETA) Program

This program applies aerodynamic calibration to sideslip differential pressure or sideslip vane angle data to provide sideslip angle data. Program options are provided to transform kinematic data and airplane moments of inertia from body axes to stability axes and principal axes. The input data are provided by the Curve File and Basic Airplane Programs.

I.3.12 Inlet Pressure Survey (IPS) Program

This program calculates the distribution of total pressure and pressure recovery across the inlet of a turbojet engine. The output of each angular ring of pressure probes is calibrated by the Curve program and, together with BA data, are input to the IPS program.

I.3.13 Nacelle Cooling (NACL) Program

This program corrects the test-day temperature values of engine components to the equivalent hot-day values. The CAMA programs provide the input data.

I.3.14 Brake Energy Program

This program computes the brake energy and associated parameters required to evaluate the braking performance of an airplane. The method is termed indirect because the energies and forces are not measured directly from the brakes or wheels but are calculated using summation of airplane forces and integration methods. The input data is normally provided by the GWCG, TEPI, BA, and EP programs.

I.3.15 Braking Force and Efficiency (MUSP) Program

This program computes the braking force and efficiency data to indicate the performance of a wheel while braking. The input data are provided by the Curve and THEO programs.

I.3.16 Strain Gauge Bridge Response Least Squares Fit Program (Reference 17)

This program computes the strain gauge bridge responses to specified target loads; then develops a least squared line from the data and computes influence coefficients standard response coefficients, and deviations of the responses. The input data are provided by the Curve program or punched cards.

I.3.17 Frequency Analysis (FREQ) Program (Reference 2)

This program can analyze any measurements in the frequency domain, but normal operation is to provide power spectral densities and autocorrelation values for input measurements.

I.3.18 Structural Zone Load Level Program

This program determines the zero load intercept for the complex calibration equation associated with a combined arrangement of strain gauge bridges. Several arrangements are used to measure the shear, moment, and torsion loads on the airplane during flight load survey testing. Normally, the program evaluates the linear least squares solution of the load versus factor data for each test condition. The required input data are provided by the Curve and BA programs.

I.3.19 Structural Fatigue (SF) Program

This program performs a statistical analysis of the structural load cycles as concurrently related to a relatively stable average load. Loads recorded during flight through turbulent air are particularly suitable for this analysis. Required input data are provided by the Curve program and optional input is provided by the GWCG, GA, and Structural Zero Load Level programs.

I.3.20 Flying Qualities Program

This program covers a wide area of aircraft handling characteristics. Stability and control data is calculated from level accelerations and specialized in-flight maneuvers such as side-slips, rolls, stalls/spins, roller coaster, and wind-up turns. Similar information is also used for the standardization of stability and control data and this information can also be used as a direct input to a number of the other programs described above.

I.4 REAL TIME PROCESSING

The basic programs used in these types of systems are very similar to those described above for engineering units and analysis but, because of the problems involved in these systems, special considerations have to be covered. Essential tasks for real time systems can include the ability to display in engineering units any parameters being recorded, to provide limit tests on any of these parameters being recorded, and to provide the ability to perform mathematical computations for advanced analysis and to display the results.

Typical programs are:

I.4.1 Cruise Performance Program

This program is a system application program which provides near-time and summary data for analysis of airplane cruise and drag performance during test flights.

The program provides data in engineering units. Operator instructions then control the display of this information on a monitor screen, remote display panels, a printer, or analog devices such as oscillographs, for analysis and decisions during the test flight.

The Cruise Performance program will use measurements from the data acquisition system, Basic Airplane Parameters program, data files such as thrust curves, and operator supplied constants and options. The program will calculate pressures, temperatures, airspeeds, drag, fuel flow, thrust, slopes, and standardized parameters.

I.4.2 Stall Performance Program

This program is a system application program which computes parameters useful in analyzing stall performance of the airplane during test flights. The program will display some parameters in real time during a test condition and then compute summary parameters in an inter-maneuver mode. This necessitates temporary storage of some time history data during real time processing. An operator will control the start and stop of the real time processing. The inter-maneuver mode calculations will automatically be done upon the receipt of the command to stop real time processing. All of the normal monitoring capability within the system will be available during both real time and inter-maneuver mode except for display on the printer. A printer/CRT display, or stripchart can be used for displaying a special time history printout as well as a condition summary by the Stall Performance program.

I.4.3 Take-Off Performance Program

This program calculates parameters which are used to monitor aircraft take-off performance. Aircraft position, velocity and acceleration can then be displayed in tabular or plotted format on a CRT.

I.4.4 Basic Airplane (BA) Parameters Program

The BA program computes and displays on request, the basic flight test data parameters of airspeed, altitude, gross weight, and lift coefficient. It can be operated concurrently with other programs to provide input data to those programs.

I.4.5 Power Plant Parameters Program

The Power Plant Parameters program is a system application program which calculates parameters that are useful for analysing power plant conditions during test flights. All output from this program is available for display using the peripheral display devices. Condition average values are displayed on the printer automatically when the stop command is entered.

I.4.6 Loads Program

This program computes structural load parameters in real time for in-flight monitoring and analysis of test flights. The program produces a variable number of shear, moment, and torsional load calculations and concurrently checks a variable length list of measurements for out-of-limits condition. Extensive options are provided to allow operator control of equation selection, modification, allocation, and activation.

APPENDIX II

SAMPLE COMPUTER PROGRAM SPECIFICATIONS

II.1 The primary purpose of a Program Specification is to identify to the software developer the complete computational requirement. It serves a secondary purpose in that it requires the project engineer to define the required parameters, input and output constraints, computational processes, and expected products in a rigorous fashion.

II.2 This appendix contains an example of a program specification which was extracted from an overall flight test specification. It is meant to be illustrative and no attempt is made to define terms or explain content in detail.

II.3 Samples of Programs Specifications

AIRSPEED/ALTITUDE TRAJECTORY INFORMATION

General Description:

Herein, "trajectory calculations" refers to the calculation of the following parameters:

(1) tapeline altitude (h_t)
(2) rate-of-change of tapeline altitude ($\dot{h}_t$)
(3) geopotential altitude (H_t)
(4) energy height (H_{Et})
(5) rate-of-change of energy height ($\dot{H}_{Et}$)
(6) flightpath climb angle (γ_t)
(7) rate-of-change of flightpath climb angle ($\dot{\gamma}_t$)
(8) normal load factors ($n_{x_{wt}}$ and $n_{z_{wt}}$)

On-board measurements of airspeed and altitude are the basis for these calculations. Simplifying assumptions made in this program include:

(1) spherical, non-rotating earth (no centrifugal relief from the force of gravity).
(2) constant gravity (32.174 ft/sec^2), making geopotential altitude equal to tapeline altitude.
(3) no accelerations caused by wind gradients.

These assumptions are acceptable for a subsonic relatively low performance aircraft.

Subroutine HETEST assumes that in the equation for geopotential altitude,

$$H_t = \frac{R_e h_t}{R_e + h} \cdot \frac{g_{SL}}{g_r},$$

that

$$\frac{R_e}{R_e + h} = 1$$

and

$$\frac{g_{SL}}{g_r} = 1, \text{ hence } H_t = h_t.$$

HETEST computes

$$h_{t_i} = h_{t_{i-1}} + 96.0339 \left[\frac{T_{at_i} + T_{at_{i-1}}}{2}\right] \ln \left[\frac{P_{at_{i-1}}}{P_{at_i}}\right]$$

$$H_{Et} = H_t + \frac{V_{tt}^2}{64.34810}.$$

Subroutine DIFFR is called to numerically differentiate

$$\dot{H}_{Et} = dH_{Et}/dt$$

and

$$\dot{h}_t = dh_t/dt.$$

The flightpath angle is computed,

$$\gamma_t = \sin^{-1}\left[\frac{\dot{h}_t}{V_{tt}}\right]$$

and DIFFER IS AGAIN CALLED TO COMPUTE

$$\dot{\gamma}_t = d\gamma_t/dt.$$

Finally, the normal load factors are computed,

$$n_{x_{wt}} = \frac{\dot{H}_{Et}}{V_{tt}}$$

$$n_{z_{wt}} = \cos\gamma_t + \frac{V_{tt}\,\dot{\gamma}_t}{32.17405}$$

HETEST then returns to the calling program.

Input

Parameters

The following are the input parameters necessary to process data through link 3A of the UFTAS program.

LINK 3A INPUTS (B - file)

ENGR. Symbol	FORTRAN Symbol	DESCRIPTION	SOURCE	UNITS (Meas. List)	Sample Rate	Measurement Number
h_{ct}	HCT	Test Pressure Altitude	Link 2	ft.	-	-
P_{at}	PAT	Test Ambient Pressure	Link 2	lbf/ft²	-	-
T_{at}	TATK	Atmospheric Temperature	Link 2	°K	-	-
V_{tt}	VTT	Test True Airspeed	Link 2	ft/sec	-	-

The constants necessary to direct the program flow are input through common blocks. These blocks are shown below.

ENGR. Symbol	FORTRAN Symbol	VALUE	UNITS
COMMON/ALL/			
	LUI	*	
	LUO	*	

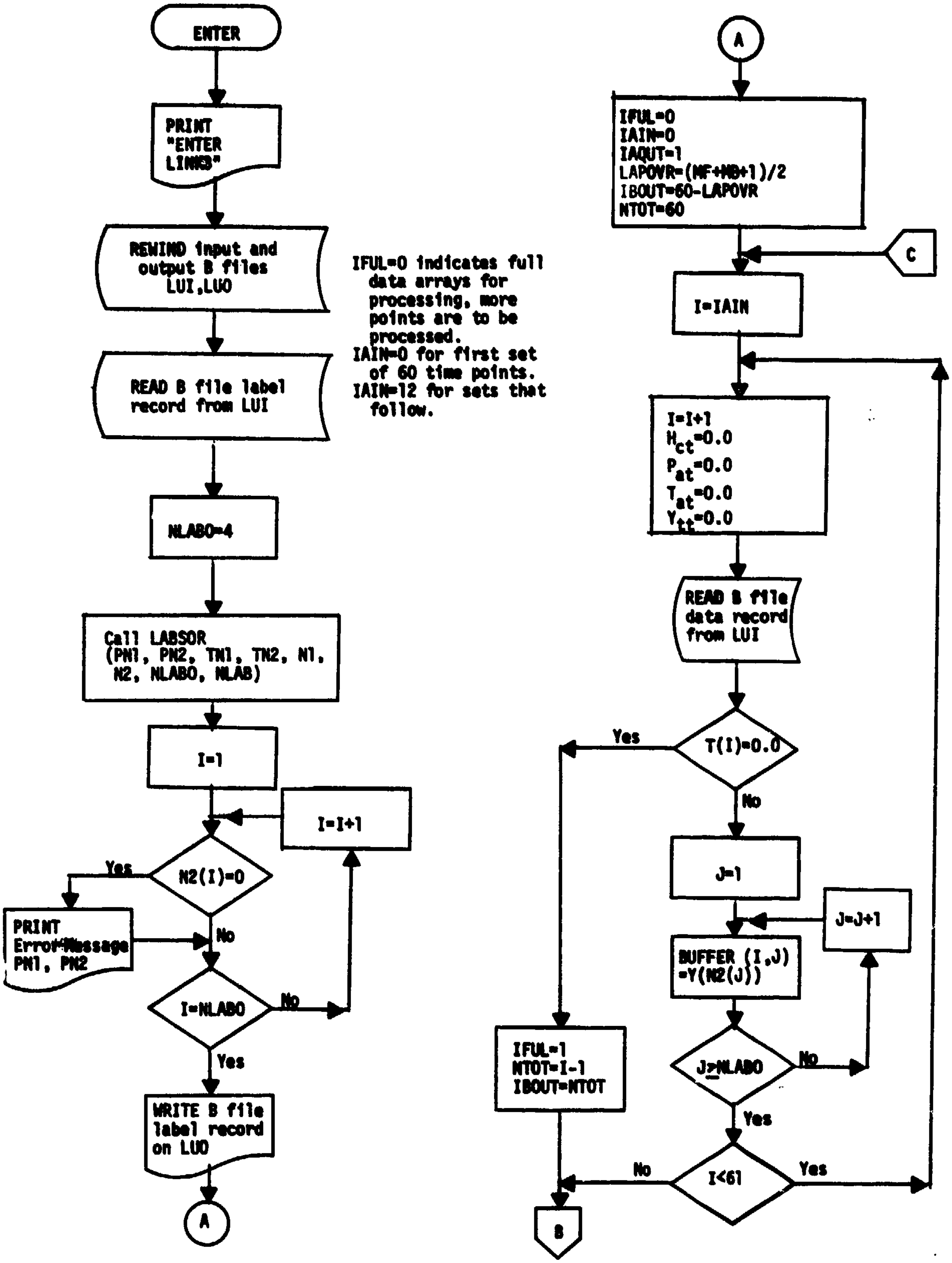
*To be determined by the programmer.

ENGR. Symbol	FORTRAN Symbol	VALUE	UNITS
COMMON/LSDATA/			
	IQ	1	
	ISM	1	
	MB	10	
	MF	10	
	NANC	0	
	SDIF	1	

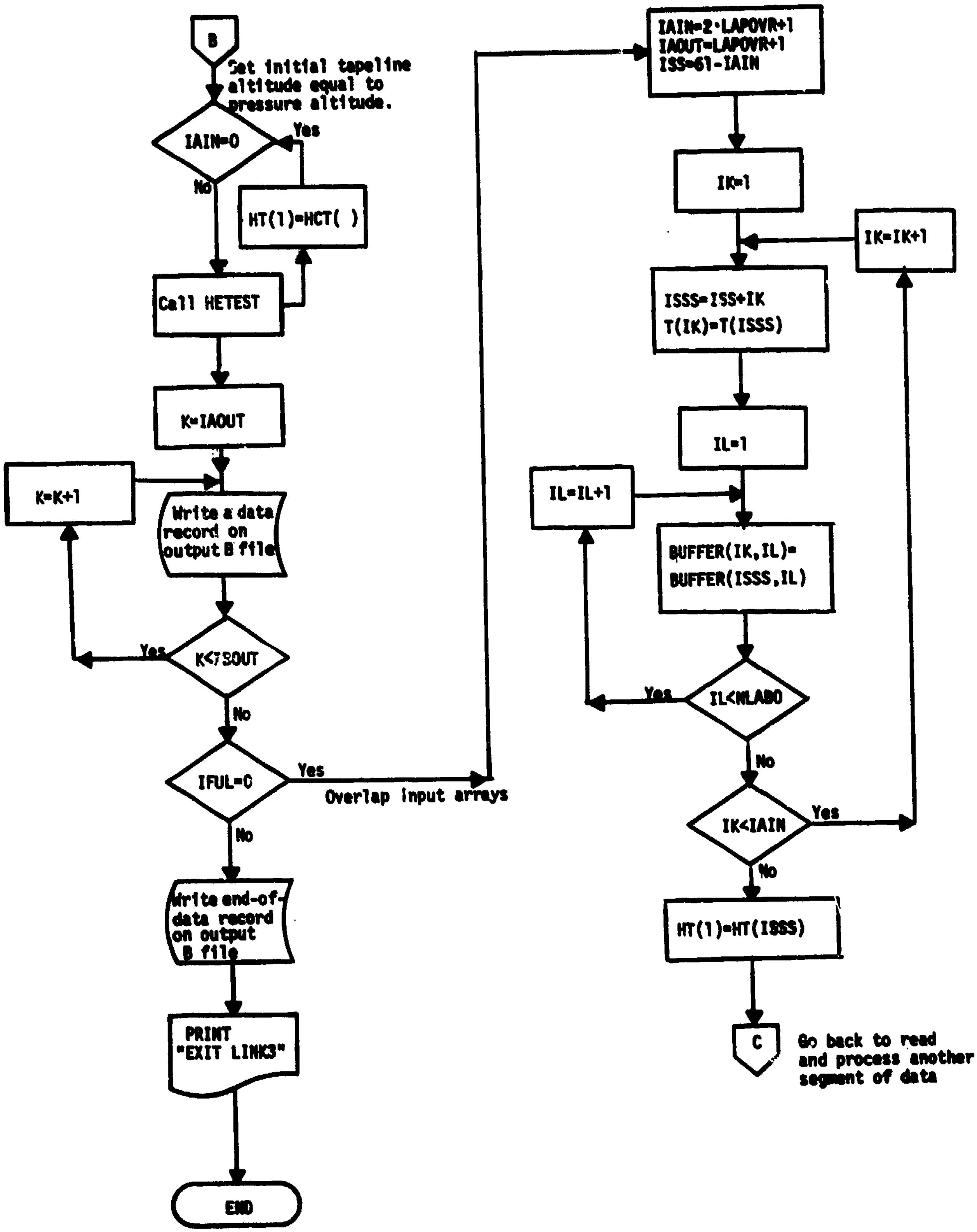
Tables. No tables are required to process the trajectory information.

Computational Procedures. The computational procedures are detailed in Reference 1. The flow diagrams associated with the "usual" computational paths are presented below.

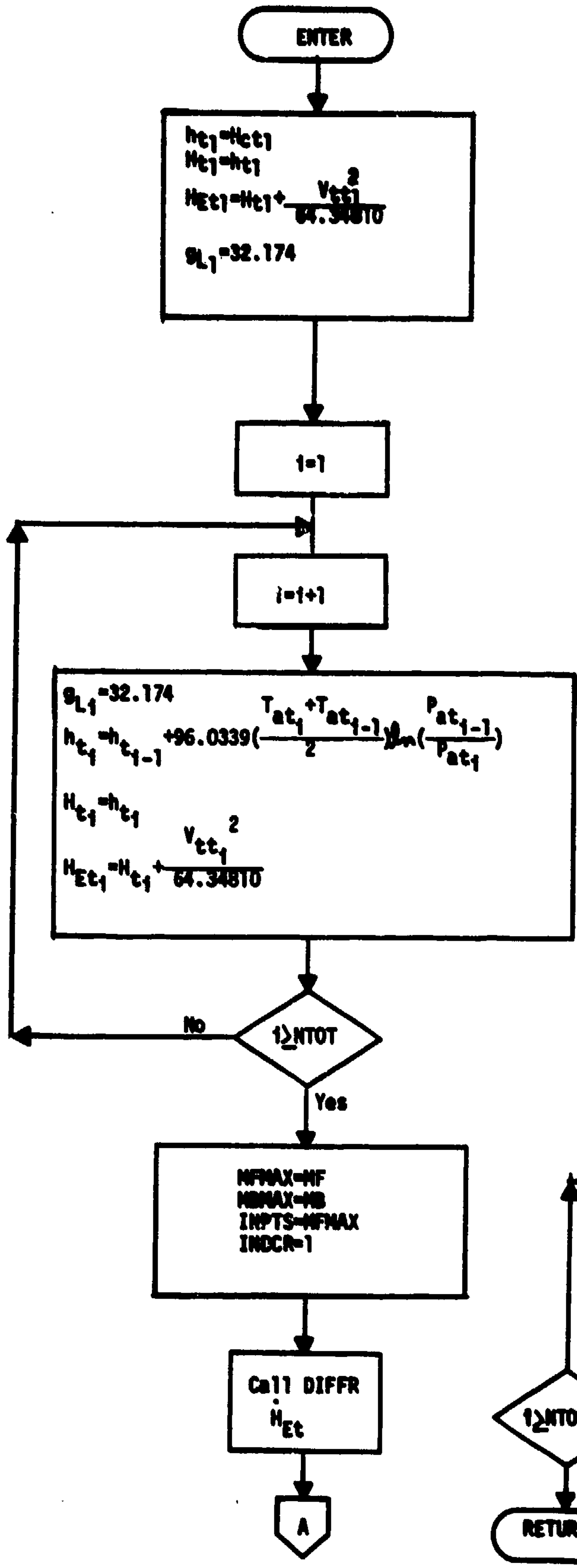
Program LINK3A



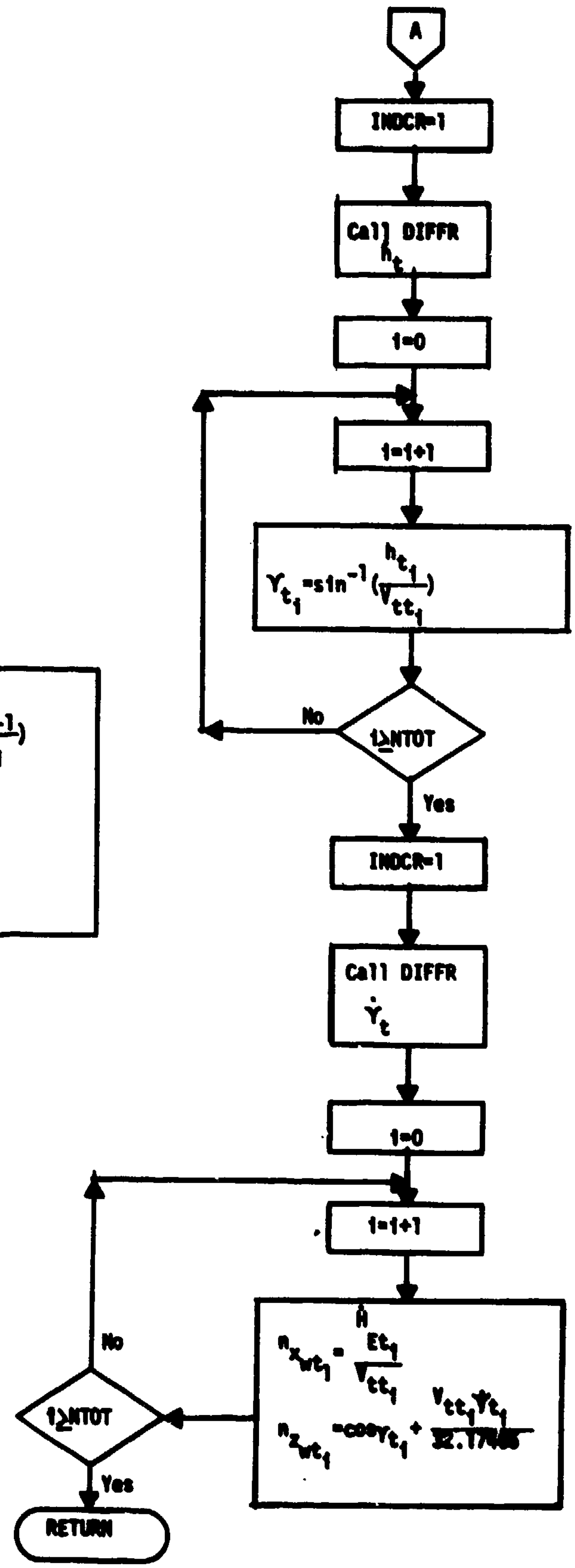
Program LINK3A Continued



Subroutine HETEST



Subroutine HETEST Continued



APPENDIX III

TYPICAL QUICK-LOOK OR REAL-TIME PROCESSING TECHNIQUES

III.1 AUTOMATED FLIGHT TEST DATA SYSTEM (AFTDS)

The US Air Force Flight Test Center system for real-time processing and display is called the AFTDS. AFTDS consists of both hardware and software to perform real time on-line flight test analysis. The characteristics of this system are designed to increase the probability of safe and timely completion of a flight test program by:

- Providing quality control of each maneuver and allowing the test conductor to direct repeats of invalid maneuvers.
- Monitoring selected instrumentation throughout the flight both for safety purposes and for instrumentation system health.
- Displaying engineering data in a readily understandable form.
- Faster envelope expansion due to on-line evaluation.
- Reducing data time for selected engineering units data.
- Providing preliminary data plots or tabulations which in some cases may replace output by batch processing

Shown below are the four basic hardware subsystems of the AFTDS and the functional responsibilities of each. The AFTDS system integrates a telemetry formatting subsystem, a preprocessor subsystem, a central computer subsystem, and a display subsystem into a real time flight test analysis capability. From the Flight Analysis Station (FAS) console, a flight test engineer can direct the system to acquire, condition, format, and display the particular data parameters for real time analysis. These functions are applicable to most real time displays and analysis system.

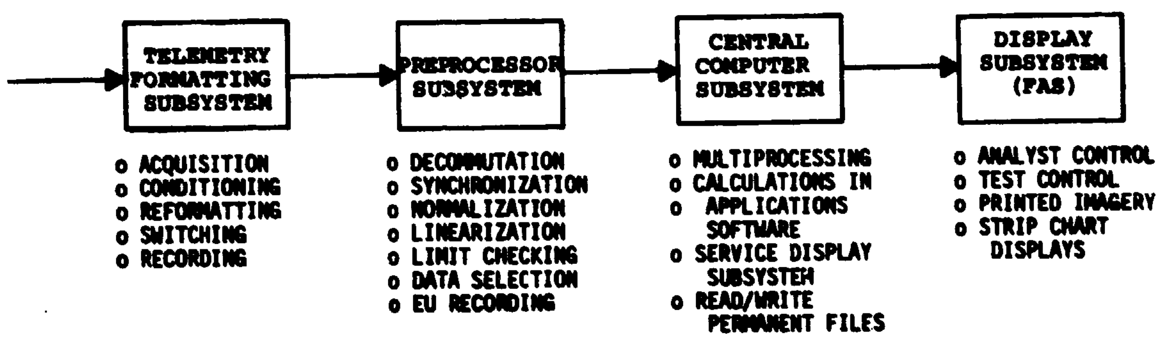


FIGURE III-1

AFTDS single stream operations provides one telemetry stream input, and two data stream outputs utilizing the TeleSCOPE 340 operating system. The displays include two master cathode ray tubes (CRT), three repeater CRTs, and three analog stripchart recorders. The hardware required for the system is shown below:

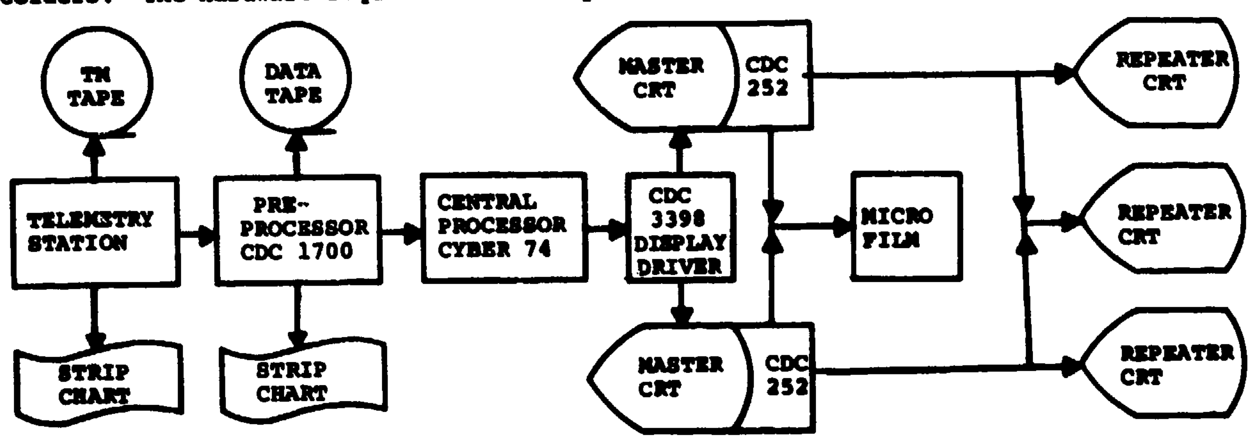


FIGURE III-2

- System Software - This is the operating system software resident in the CYBER 74 during real time processing operations. It provides the basic capability for the concurrent (time-shared) processing of AFTDS, and aircraft or project-unique programs.

- Interface Software - This category includes a number of support and utility programs used to assist in configuring the system for real time operations. Like the operating system software, these programs are transparent to aircraft/project differences.

- Applications Software - Of prime interest to the user, this category includes all software written for the particular aircraft test program. There are several standardized routines which perform common functions, and a number of aircraft unique programs, termed "Data Analysis Packages" (DAPs).

- DAPs are written in FORTRAN, the most widely used programming language for engineering, and the software is broken up into convenient packages to suit the user's test objectives. For example, these packages might be broken up into the engineering disciplines of propulsion, flying qualities, or fire control system for some projects. Very comprehensive projects with large input parameter lists might further subdivide DAPs, for example, flying qualities might be broken into a longitudinal stability package, a dynamic response package, an maneuvering stability package, and a control sweep package. For a given set of instrumentation parameters, up to thirty such DAPs may be initialized at one time.

- DAPs can be loaded and changed between maneuvers. Packages which are inactive during a particular maneuver, and which are to be recalled during a subsequent maneuver, have the capability of saving and restoring values calculated during previous maneuvers through the use of permanent files.

III.1.1 Stripcharts

The analog trace of the signal may also be displayed in real time. The telemetry signal is passed through ground station discriminators which extract the data stream of interest. Frequency Modulation (FM) signals are then routed to strip chart recorders. For Pulse Code Modulation (PCM) signals, a frame bit synchronizer is required prior to conversion to an analog signal. The raw data can also be converted to a pseudo engineering units analog trace by the application of calibration data through the use of a moderate speed processor. The same system may also be used for post flight quick-look through use of magnetic tape as shown below:

DATA FLOW - STRIP CHART

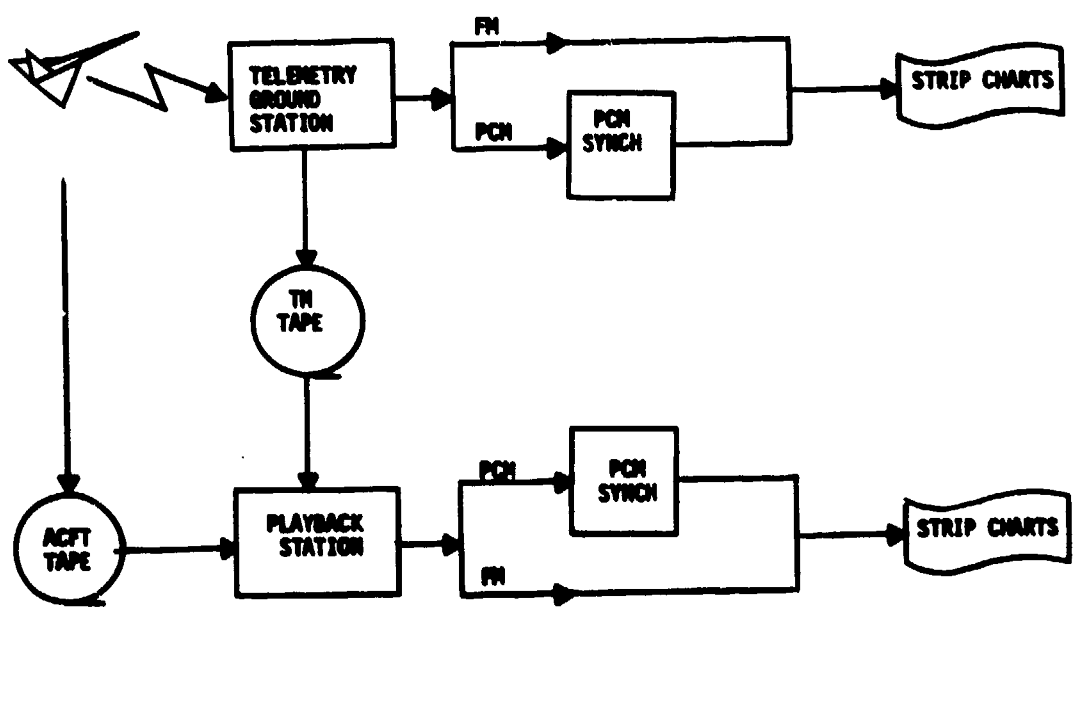


FIGURE III-3

III.1.2 Trajectory Information

Test vehicle trajectory may be displayed in real time on vertical plot boards or on a real time analysis system CRT (such as the AFTDS PAS). Input data is usually furnished by ground based radars or optical trackers equipped with shaft angle encoders. Test vehicles with inertial systems can also display telemetered inertial position data.

DATA FLOW - TRAJECTORY

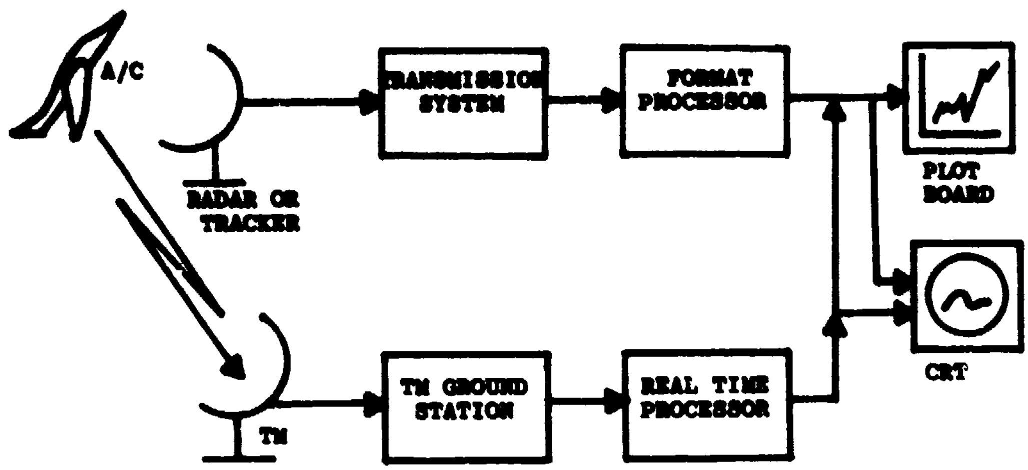


FIGURE III-4

APPENDIX IV

CENTRAL PROCESSOR UNIT (CPU) TIME REDUCTION

IV.1 TEST CASE FOR REDUCING CPU TIME

To improve data turnaround time and lower the cost of data processing, several test cases were run to evaluate parameter and time compression techniques at the preprocessor and in the engineering units processing program. These are shown in Tables IV-1 and IV-2. Two parameter compression cases were run; one for stability and control, which processed fifty-one parameters; and one for performance and propulsion, which processed sixty-six parameters. Time compression was achieved by reducing data time thirty seconds. The columns labeled "EMR" and "SANDS" represent the preprocessor and engineering units data processing segments.

IV.1.1 Results

Test Case 1 represents a baseline condition where all one hundred and ninety-five recorded parameters are processed for total data time of sixty seconds. Test Case 2 shows the savings in computer costs (CPU seconds) achieved by time editing (note a fifty percent decrease in event time yields only a thirty-five percent decrease in CPU time because of the system overhead, time required for search, and access). Test Case 1 is again shown as baseline. Test Case 2A shows the effect of parameter editing in the engineering units processing for stability and control parameters. Test Case 2B shows the effec: of both time and parameter compression in the engineering units processing, again for stability and control. Test Case 3A and 3B shows the same respective cases of performance and propulsion. This set of compression assumes that nothing is done at the preprocessor level.

The next set of test cases show the cascade effect of applying compression at the preprocessor point. The first section (Test Cases 2A, 2B, 2C, and 2D) shows the effects for stability and control while the second section (3A, 3B, 3C, and 3D) shows the effects for performance and propulsion.

ENGINEERING UNITS TEST CASES

DEFINITIONS

Total Parameters:	195 Parameters
Stability and Control Parameters:	51 Parameters
Performance and Propulsion Parameters:	66 Parameters
No Time Edit:	10 Seconds Cal and 60 Seconds Event
Time Edit:	10 Seconds Cal and 30 Seconds Event

TEST CASE	EMR TIME	EMR PARAMETER	SANDS TIME	SANDS PARAMETER	CPU TIME SECONDS	% REDUCTION IN CPU TIME
1	No Time Edit	All	No Time Edit	All	280.313	Base Line
2	No Time Edit	All	Time Edit	All	182.043	35.0
1	No Time Edit	All	No Time Edit	All	280.313	Base Line
2A	No Time Edit	All	No Time Edit	S&C	125.776	55.1
2B	No Time Edit	All	Time Edit	S&C	94.201	66.4
3A	No Time Edit	All	No Time Edit	P&P	154.190	44.9
3B			Time Edit	P&P	112.837	59.5

TABLE IV-1

TEST CASE	EMR TIME	EMR PARAMETER	SANDS TIME	SANDS PARAMETER	CPU TIME SECONDS	% REDUCTION IN CPU TIME
2A	No Time Edit	All	No Time Edit	S&C	125.776	
2B	No Time Edit	All	Time Edit	S&C	94.201	
2C	No Time Edit	S&C	No Time Edit	S&C	56.768	79.7
2D	Time Edit	S&C	Time Edit	S&C	36.749	86.7
3A	No Time Edit	All	No Time Edit	P&P	154.190	
3B	No Time Edit	All	Time Edit	P&P	112.837	
3C	No Time Edit	P&P	No Time Edit	P&P	73.924	73.6
3D	Time Edit	P&P	Time Edit	P&P	47.322	83.2

TABLE IV-2

IV.1.2 Conclusions

The major conclusion to be drawn from these tests is that parameter and time compression are very valuable techniques to be used to reduce the volume of data processing, shorten data turnaround time, and lower the cost of data processing. For the cases where compression is also used in the preprocessor, it can be seen that savings in computer run are achievable. An equally important conclusion is that the earlier in the data processing stream this compression can be introduced, the more significant the savings. A further additional benefit, proven only over the long time span, is that fewer reruns are required when all extraneous data and processing steps are eliminated as early as possible in the data processing stream. The end result is shorter turnaround times for data at lower cost.

APPENDIX V

SAMPLE OUTPUTS

V. This appendix contains sample data products produced at the AFFTC. This set of sample cases are taken from several tests and aircraft, primarily to show diversity.

The following samples are shown:

- V-1 Tabulated radar track data.
- V-2 Tabulated takeoff data derived from Cinetheodolite track.
- V-3 Tabulated landing data derived from Cinetheodolite track.
- V-4 Graphical presentation of takeoff data derived from Cinetheodolite track.
- V-5 Tabulated calibration data for a single parameter.
- V-6 Graphical presentation of calibration data for a single parameter.
- V-7 Project history entry of parameter data.
- V-8 Tabulated engineering units data.
- V-9 Tabulated analysis data.
- V-10 Analysis plots.

EDWARDS RADAR TRACKING

22 MAY 78

EVENT 7 PAGE 16

PROCESSED 12 JUN 78 11.11.41.

AIRCRAFT T38/TGT
REFERENCE MAIN ASKANIA STATION(A-9)
GEODETIC COORDINATES 34.94535 117.91269 2574.

OPERATION 142-14
TRACKING STATION FPS-16,NO. 41 **
METRO DATE/TIME 0/ 0/ 0 0

TIME HRMN	SEC		ET SEC	ALT FEET	X(E-W) FEET	Y(N-S) FEET	Z(LP) FEET	DX/DT FT/SC	DY/DT FT/SC	DZ/DT FT/SC	DX/DT-W FT/SC	DY/DT-W FT/SC	LATITUDE DEG	LONGITUDE DEG	SOUND FT/SC
1933	06.00	0	45.00	5890.	180838.	75821.	2454.	970.6	18.9	-236.1	970.6	18.9	35.15218276	117.30812168	1043.6
1933	06.10	0	45.10	5812.	180939.	75818.	2314.	968.6	24.4	-301.6	968.6	24.4	35.15218625	117.30780280	1043.5
1933	06.20	0	45.20	5813.	181040.	75814.	2320.	970.2	24.7	-324.9	970.2	24.7	35.15208722	117.30744430	1043.9
1933	06.30	0	45.30	5787.	181135.	75827.	2292.	972.7	27.9	-273.7	972.7	27.9	35.15212381	117.30714370	1044.0
1933	06.40	0	45.40	5722.	181234.	75843.	2227.	974.9	23.9	-82.3	974.9	23.9	35.15214430	[illegible]	1044.3
1933	06.50	0	45.50	5695.	181333.	75828.	2199.	972.2	18.3	173.1	972.2	18.3	35.15212564	[illegible]	1044.4
1933	06.60	0	45.60	5725.	181427.	75831.	2228.	963.3	23.1	341.0	963.3	23.1	35.15211993	[illegible]	1044.3
1933	06.70	0	45.70	5794.	181527.	75826.	2296.	957.6	20.8	370.5	957.6	20.8	35.15211433	[illegible]	1044.0
1933	06.80	0	45.80	5891.	181621.	75830.	2352.	954.0	26.2	354.8	954.0	26.2	[illegible]	[illegible]	1043.8
1933	06.90	0	45.90	6093.	181720.	75835.	2594.	949.9	29.4	284.4	949.9	29.4	35.15213081	[illegible]	1042.8
1933	07.00	0	46.00	6114.	181809.	75835.	2614.	948.8	33.3	159.5	948.8	33.3	35.15218972	[illegible]	1042.7
1933	07.10	0	46.10	6068.	181902.	75849.	2527.	949.9	31.7	-7.1	949.9	31.7	35.15218724	[illegible]	1042.6
1933	07.20	0	46.20	5994.	181998.	75863.	2492.	951.6	52.8	-192.1	951.6	52.8	35.15214920	[illegible]	1042.2
1933	07.30	0	46.30	5929.	182093.	75856.	2426.	955.8	44.7	-353.7	955.8	44.7	35.15210622	[illegible]	1042.2
1933	07.40	0	46.40	5865.	182189.	75870.	2360.	957.7	41.4	-458.9	957.7	41.4	35.15222207	[illegible]	1043.7
1933	07.50	0	46.50	5837.	182287.	75879.	2332.	962.6	34.6	-436.6	962.6	34.6	35.15223394	[illegible]	1043.0
1933	07.60	0	46.60	5800.	182380.	75877.	2292.	962.4	30.6	-343.9	962.4	30.6	35.15222023	[illegible]	1044.2
1933	07.70	0	46.70	5745.	182482.	75873.	2236.	962.4	31.3	-247.4	962.4	31.3	35.15222663	[illegible]	1044.3
1933	07.80	0	46.80	5718.	182578.	75866.	2211.	962.0	21.7	-116.9	962.0	21.7	35.15220736	[illegible]	1044.3
1933	07.90	0	46.90	5710.	182670.	75869.	2202.	955.6	16.9	-7.2	955.6	16.9	35.15221237	[illegible]	1044.3
1933	08.00	0	47.00	5711.	182768.	75873.	2203.	956.5	23.0	73.0	956.5	23.0	35.15222277	117.30160103	1044.3
1933	08.10	0	47.10	5723.	182863.	75880.	2213.	954.7	25.8	129.3	954.7	25.8	[illegible]	[illegible]	1044.0
1933	08.20	0	47.20	5792.	182960.	75890.	2281.	952.7	30.3	170.9	952.7	30.3	35.15226641	[illegible]	1043.9
1933	08.30	0	47.30	5861.	183055.	75883.	2349.	956.0	37.7	142.7	956.0	37.7	35.15224403	[illegible]	1043.7
1933	08.40	0	47.40	5862.	183147.	75886.	2350.	961.2	33.8	151.7	961.2	33.8	35.15224399	[illegible]	1043.7
1933	08.50	0	47.50	5864.	183242.	75899.	2351.	968.0	32.1	94.1	968.0	32.1	35.15224437	[illegible]	1043.7
1933	08.60	0	47.60	5866.	183338.	75892.	2352.	973.4	11.4	62.7	973.4	11.4	35.15224377	[illegible]	1043.7
1933	08.70	0	47.70	5839.	183436.	75896.	2324.	975.7	-1.9	-11.6	975.7	-1.9	35.15227519	117.29645839	1043.8
1933	08.80	0	47.80	5783.	183537.	75912.	2268.	980.3	-12.7	-50.0	980.3	-12.7	35.15231364	117.29711102	1044.0
1933	08.90	0	47.90	5795.	183637.	75927.	2278.	982.3	-20.6	-38.7	982.3	-20.6	35.15235461	117.29677592	1044.0

TIME HRMN	SEC	VW FT/SC	VD DEG	VT FT/SC	VTW FT/SC	HDG DEG	FPA DEG	Q LB/FT2	MACH	PA LB/FT2	TA DEG-R	R/C FT/SC	AC RNG NM	RANGE FEET	AZIMUTH DEG	ELEVATION DEG
1933	06.00	0.0	0.0	998.4	998.4	88.9	-14.1	990.6	.9133	1696.6	497.3	-225.7	7.24	197730.	70.2795410	.8764111
1933	06.10	0.0	0.0	1014.8	1014.8	88.6	-17.8	1025.6	.9277	1700.1	498.0	-293.1	7.25	197826.	[illegible]	[illegible]
1933	06.20	0.0	0.0	1023.4	1023.4	88.5	-19.6	1046.5	.9356	1700.0	497.9	-315.6	7.27	197918.	70.2815157	[illegible]
1933	06.30	0.0	0.0	1010.8	1010.8	88.4	-16.2	1021.7	.9260	1709.7	498.0	-265.2	7.29	198012.	[illegible]	[illegible]
1933	06.40	0.0	0.0	978.6	978.6	88.6	-5.3	955.5	.8959	1713.6	498.3	-73.9	7.30	198111.	[illegible]	[illegible]
1933	06.50	0.0	0.0	987.7	987.7	88.9	9.6	978.2	.9025	1713.6	498.4	181.5	7.32	198199.	[illegible]	[illegible]
1933	06.60	0.0	0.0	1022.2	1022.2	88.6	19.0	1046.7	.9341	1713.6	498.3	340.4	7.34	198297.	[illegible]	[illegible]
1933	06.70	0.0	0.0	1027.0	1027.0	88.8	20.8	1054.3	.9387	1709.2	498.9	378.8	7.35	198391.	[illegible]	[illegible]
1933	06.80	0.0	0.0	1018.1	1018.1	88.8	19.5	1033.1	.9309	1703.0	497.9	363.1	7.37	198475.	[illegible]	[illegible]
1933	06.90	0.0	0.0	992.0	992.0	88.2	16.1	974.6	.9078	1698.9	498.3	282.8	7.38	198568.	[illegible]	[illegible]
1933	07.00	0.0	0.0	964.0	964.0	87.3	9.0	915.5	.8822	1691.9	498.9	151.8	7.40	198656.	[illegible]	[illegible]
1933	07.10	0.0	0.0	951.3	951.3	86.9	-.9	897.2	.8703	1691.6	497.6	1.3	7.41	198744.	[illegible]	[illegible]
1933	07.20	0.0	0.0	972.3	972.3	86.8	-11.6	939.3	.8894	1696.4	497.3	-183.6	7.43	198832.	[illegible]	[illegible]
1933	07.30	0.0	0.0	1020.2	1020.2	87.3	-20.6	1036.1	.9330	1700.6	497.3	-358.2	7.45	198920.	[illegible]	[illegible]
1933	07.40	0.0	0.0	1062.8	1062.8	87.5	-26.1	1126.7	.9717	1704.9	497.8	-466.4	7.46	199020.	[illegible]	[illegible]
1933	07.50	0.0	0.0	1027.3	1027.3	87.2	-24.5	1114.2	.9448	1706.3	497.8	-428.3	7.48	199111.	[illegible]	[illegible]
1933	07.60	0.0	0.0	1024.1	1024.1	88.2	-21.2	1052.4	.9387	1708.0	498.0	-384.5	7.49	199201.	[illegible]	[illegible]
1933	07.70	0.0	0.0	994.2	994.2	88.1	-14.6	985.7	.9084	1712.4	498.2	-238.9	7.51	199293.	[illegible]	[illegible]
1933	07.80	0.0	0.0	969.2	969.2	88.4	-7.4	941.3	.8857	1714.1	498.5	-107.5	7.53	199385.	[illegible]	[illegible]
1933	07.90	0.0	0.0	959.7	959.7	89.0	-.6	922.9	.8778	1712.9	498.3	1.2	7.54	199471.	[illegible]	[illegible]
1933	08.00	0.0	0.0	954.5	954.5	88.8	3.6	922.7	.8768	1712.9	498.3	61.4	7.56	199564.	[illegible]	[illegible]
1933	08.10	0.0	0.0	965.1	965.1	88.2	7.8	931.2	.8820	1713.9	498.3	137.7	7.57	199658.	[illegible]	[illegible]
1933	08.20	0.0	0.0	965.3	965.3	88.2	6.6	937.4	.8851	1704.3	498.0	174.0	7.59	199742.	[illegible]	[illegible]
1933	08.30	0.0	0.0	967.3	967.3	87.7	6.9	932.5	.8864	1704.8	497.8	121.2	7.60	199838.	[illegible]	[illegible]
1933	08.40	0.0	0.0	967.6	967.6	87.5	5.5	934.1	.8847	1704.8	497.8	118.3	7.62	199928.	[illegible]	[illegible]
1933	08.50	0.0	0.0	973.1	973.1	88.1	5.0	944.6	.8897	1704.7	497.8	102.6	7.64	200021.	[illegible]	[illegible]
1933	08.60	0.0	0.0	975.3	975.3	89.3	3.5	946.1	.8919	1704.9	497.8	71.3	7.65	200114.	[illegible]	[illegible]
1933	08.70	0.0	0.0	975.8	975.8	90.1	-1.2	950.6	.8921	1704.3	497.9	-3.0	7.67	200203.	[illegible]	[illegible]
1933	08.80	0.0	0.0	981.6	981.6	90.7	-3.4	963.6	.8973	1709.5	498.1	-41.9	7.68	200303.	70.5157471	[illegible]
1933	08.90	0.0	0.0	983.3	983.3	91.2	-2.8	966.5	.8988	1709.2	498.0	-38.7	7.70	200402.	70.5212403	.8044129

TAKEOFF AND LANDING DATA

TAKEOFF	TWO-STATION SOLUTION	GROUND ROLL	FT
WEST TOWER	EAST TOWER	AIR DISTANCE	FT
EAST PEDESTAL	EAST PEDESTAL	GROSS WEIGHT	LBS
		AMBIENT PRES	IN HG
FLIGHT		AMBIENT TEMP	DEG C
RUN 1		FLAP SETTING	DEG
DATE 15/06/73		POWER USED	
GROUND SPEED AT NWO	FT/SEC	IAS AT NWO	KNOTS
GROUND SPEED AT TO	FT/SEC	IAS AT TO	KNOTS
GROUND SPEED AT 50 FT	FT/SEC	IAS AT 50 FT	KNOTS
AVG PT7 IN HG		AVG EGT	DEG C
WIND KNOTS AT	DEGREES		

173-26 330300 FSE-42C 13 JUN 73 21/39/49.36 REAR MAIN WHEEL TAKEOFF

TIME HR MN SEC	GROUND DISTANCE FT, ZEROED	HEIGHT FEET	RATE OF CLIMB FT/SEC	GROUND SPEED FT/SEC	TANGENTIAL ACCEL FT/SEC2	TOTAL ACCEL FT/SEC2	GROUND DISTANCE FT, FROM W	GROUND DELTA DIST FEET	DELTA SPEED FT/SEC	ENERGY/WT (S2/2G)+H FEET	GROUND SPEED KNOTS
0* 0* .00	0.00	0.00	0.00	5.29	5.48	13.26	553.43	0.00	0.00	.44	3.13
0* 0* .25	1.79	0.00	0.00	5.51	7.57	16.70	555.22	1.79	.21	.47	3.26
0* 0* .50	3.35	0.00	0.00	8.04	9.66	15.43	556.78	1.56	2.53	1.03	4.76
0* 0* .75	5.67	0.00	0.00	11.44	11.75	14.53	559.10	2.32	3.40	2.04	6.78
0* 0* 1.00	8.57	0.00	0.00	14.87	13.48	14.02	562.00	2.91	3.43	3.44	8.81
0* 0* 1.25	12.93	0.00	0.00	18.36	13.89	13.96	566.36	4.35	3.49	5.24	10.87
0* 0* 1.50	18.62	0.00	0.00	21.94	14.14	14.39	572.05	5.69	3.57	7.48	12.99
0* 0* 1.75	24.42	0.00	0.00	25.42	14.43	14.91	577.85	5.80	3.48	10.04	15.05
0* 0* 2.00	30.97	0.00	0.00	28.79	14.69	15.19	584.43	6.55	3.36	12.87	17.04
0* 0* 3.00	67.24	0.00	0.00	44.41	15.44	15.48	620.67	36.27	15.63	30.65	26.29
0* 0* 4.00	119.83	0.00	0.00	60.25	15.67	15.62	673.27	52.59	15.85	56.43	35.68
0* 0* 5.00	188.21	0.00	0.00	75.97	15.62	15.63	741.64	68.37	15.71	89.69	44.98
0* 0* 6.00	272.21	0.00	0.00	91.57	15.54	15.55	825.65	84.61	15.60	130.30	54.21
0* 0* 7.00	371.71	0.00	0.00	107.03	15.44	15.44	925.14	99.50	15.46	178.01	63.37
0* 0* 8.00	486.33	0.00	0.00	122.41	15.34	15.34	1039.77	114.62	15.39	232.87	72.48
0* 0* 9.00	616.39	0.00	0.00	137.69	15.24	15.24	1169.82	130.05	15.28	294.64	81.52
0* 0*10.00	761.92	0.00	0.00	152.90	15.13	15.13	1315.35	145.53	15.20	363.33	90.53
0* 0*11.00	927.69	0.00	0.00	168.00	15.07	15.02	1476.12	160.77	15.10	438.60	99.47
0* 0*12.00	1098.17	0.00	0.00	182.96	14.91	14.91	1651.61	175.48	14.97	520.23	108.33
0* 0*13.00	1288.77	0.00	0.00	197.79	14.80	14.80	1842.20	190.59	14.82	607.93	117.13
0* 0*14.00	1493.99	0.00	0.00	212.54	14.65	14.65	2047.42	205.22	14.75	701.99	125.84
0* 0*15.00	1714.00	0.00	0.00	227.19	14.41	14.42	2267.43	220.01	14.65	802.10	134.51
0* 0*16.00	1948.44	0.00	0.00	241.70	13.95	14.09	2501.89	234.45	14.42	907.08	143.10
0* 0*16.25	2009.38	0.00	0.00	245.03	13.54	13.94	2562.81	60.93	3.32	933.02	145.07
0* 0*16.50	2071.08	0.00	0.00	248.29	13.19	13.72	2624.51	61.70	3.25	957.95	147.06
0* 0*16.75	2133.70	0.00	0.00	251.62	12.98	13.37	2687.13	62.62	3.35	983.94	148.98
0* 0*17.00	2196.92	0.00	0.00	254.80	12.67	12.79	2750.36	63.22	3.18	1008.97	150.86
0* 0*17.25	2261.01	0.00	0.00	257.94	12.32	12.33	2814.44	64.09	3.14	1033.97	152.72
0* 0*17.50	2325.93	0.00	0.00	260.97	11.85	12.08	2879.36	64.92	3.03	1058.41	154.51
0* 0*17.75	2391.63	0.00	0.00	263.93	11.39	11.89	2945.06	65.70	2.96	1082.52	156.26
0* 0*18.00	2458.02	0.00	0.00	266.71	10.91	11.52	3011.45	66.39	2.79	1105.58	157.91
0* 0*18.25	2525.06	.42	1.61	269.33	10.40	10.96	3078.50	67.05	2.62	1127.71	159.46
0* 0*18.50	2592.72	.97	2.17	271.85	10.16	10.45	3146.15	67.65	2.52	1149.48	160.95
0* 0*18.75	2661.02	1.61	2.66	274.33	9.98	10.15	3214.45	68.31	2.48	1171.14	162.42
0* 0*19.00	2729.88	2.35	3.07	276.75	9.95	10.03	3283.31	68.86	2.45	1192.98	163.87
0* 0*19.25	2799.40	3.39	3.54	279.22	9.81	9.99	3352.83	69.52	2.43	1214.69	165.32

ASKANIA RUN　　410AR0　LANDING　REAR MAIN WHEEL　FIRST DATA　　193655900

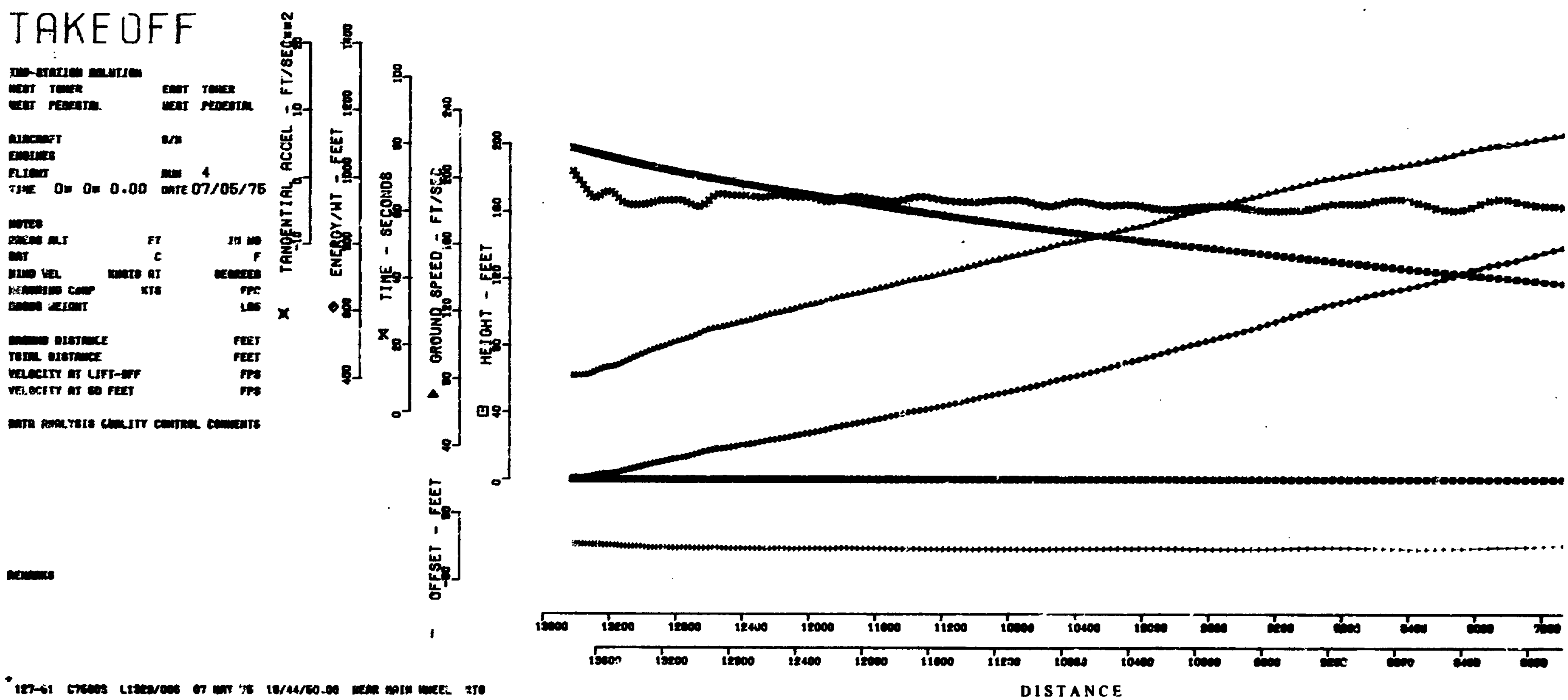
AIRCRAFT- C5A-454　　FLIGHT-　　RUN- 1　　OP.NO.- 172-84　21JUN3

GEODETIC COORDINATES OF ORIGIN ARE... LAT= 34/54/51.693　LONG=117/51/55.122　MSL ALT=　2287.0 FT.
Y-AXIS IS 328.242 DEGREES CLOCKWISE FROM TRUE NORTH.
POSITION DATA SMOOTHED 1 TIMES,　WILD POINTS DISCARDED 3 TIMES.　OBJECT WEIGHT =　0.0 LBS.　RUN=
WIND DATA NOT AVAILABLE.

NO BALLOON DATA. STANDARD DAY TEMPERATURE,PRESSURE,DENSITY USED.

TIME HHMMSS	X(EAST) FEET	Y(NORTH) FEET	Z(UP) FEET	X-AXIS VELOCITY FT/SEC	Y-AXIS VELOCITY FT/SEC	Z-AXIS VELOCITY FT/SEC	RATE OF CLIMB FT/SEC	TAN PLANE VELOCITY FT/SEC	TANG ACCEL. FLNT PATH FT/SEC.SQ	TOTAL VELOCITY FT/SEC
193715.00	94443.2	291.8	1920.7	-275.8	-7.1	-8.9	-10.1	275.9	-2.24	276.1
193716.00	94165.7	285.3	1910.0	-273.2	-7.8	-9.1	-9.3	273.3	-2.44	273.4
193717.00	93894.0	277.3	1902.4	-270.4	-8.5	-6.5	-7.7	270.5	-2.54	270.6
193718.00	93627.3	269.0	1896.2	-267.8	-9.1	-4.3	-5.5	267.9	-2.52	268.0
193719.00	93363.0	258.3	1893.3	-265.4	-9.6	-1.6	-2.0	265.5	-2.40	265.6
193720.00	93097.5	247.5	1893.2	-263.1	-9.8	1.4	.2	263.1	-2.16	263.3
193721.00	92833.0	238.2	1895.2	-260.8	-9.8	4.5	3.5	261.0	-1.75	261.0
193722.00	92573.4	229.6	1901.2	-258.8	-9.7	7.6	6.5	259.0	-1.14	259.1
193723.00	92316.6	218.8	1910.9	-257.5	-9.4	9.9	8.7	257.7	-.36	257.9
193724.00	92063.6	209.2	1924.2	-257.5	-9.0	10.9	9.9	257.7	.46	257.8
193725.00	91808.4	200.2	1938.5	-258.9	-8.5	10.4	9.2	259.0	1.13	259.1
193726.00	91548.9	191.8	1949.8	-261.1	-7.9	8.4	7.3	261.2	1.46	261.3
193727.00	91284.3	184.6	1957.1	-263.4	-7.2	5.5	4.4	263.5	1.41	263.5
193728.00	91019.6	177.7	1960.2	-265.1	-6.5	2.3	1.1	265.1	1.06	265.1
193729.00	90751.2	171.2	1959.7	-265.8	-5.9	-.7	-1.9	265.8	.59	265.8
193730.00	90483.9	166.3	1957.6	-265.6	-5.5	-3.2	-4.4	265.7	.19	265.7
193731.00	90219.7	161.7	1952.9	-265.2	-5.4	-5.1	-6.3	265.3	-.04	265.3
193732.00	89956.7	156.3	1946.1	-265.0	-5.4	-6.2	-7.4	265.0	-.12	265.1
193733.00	89691.3	151.4	1938.5	-264.9	-5.3	-6.5	-7.6	265.0	-.10	265.1
193734.00	89426.8	144.7	1930.6	-265.1	-4.9	-5.7	-6.8	265.1	-.05	265.2

TIME HHMMSS	MSL ALTITUDE FEET	X-Y PLANE TRACK DEG.TRUE	WIND VEL. FT/SEC	WIND DIR.FROM DEG.TRUE	AMBIENT TEMP. DEG.C	AMBIENT PRESS. MILLIBAR	AIR DENSITY SLUG/CU.FT	DYNAMIC PRESSURE LB./SQ.FT	IMPACT PRESSURE LB./SQ.FT	SLANT RANGE FEET	FLIGHT PATH DEGREES
193715.00	4416.5	236.8	0.0	0.0	6.3	861.65	.0020846	79.43138	80.69191	94463.1	-2.1
193716.00	4405.4	236.6	0.0	0.0	6.3	862.00	.0020853	77.55899	79.17758	94185.5	-1.9
193717.00	4395.7	236.4	0.0	0.0	6.3	862.31	.0020859	76.30690	77.55156	93913.7	-1.6
193718.00	4389.4	236.3	0.0	0.0	6.3	862.55	.0020863	74.90997	76.02952	93646.9	-1.2
193719.00	4384.3	236.2	0.0	0.0	6.3	862.60	.0020866	73.57461	74.65433	93387.6	-.6
193720.00	4382.9	236.1	0.0	0.0	6.3	862.77	.0020867	72.31974	73.36200	93117.1	.1
193721.00	4383.8	236.1	0.0	0.0	6.3	862.70	.0020866	71.09452	72.10240	92852.7	.8
193722.00	4389.7	236.1	0.0	0.0	6.3	862.54	.0020863	70.04240	71.02053	92593.2	1.4
193723.00	4397.2	236.2	0.0	0.0	6.3	862.27	.0020858	69.36194	70.32162	92336.7	1.9
193724.00	4409.4	236.2	0.0	0.0	6.3	861.97	.0020850	69.30017	70.26690	92083.9	2.2
193725.00	4422.5	236.4	0.0	0.0	6.2	861.45	.0020842	69.97296	70.95070	91829.1	2.0
193726.00	4432.8	236.5	0.0	0.0	6.2	861.12	.0020835	71.13774	72.14878	91569.9	1.6
193727.00	4439.0	236.7	0.0	0.0	6.2	860.93	.0020832	72.34249	73.38839	91305.4	.9
193728.00	4440.0	236.9	0.0	0.0	6.2	860.87	.0020830	73.21987	74.29144	91040.9	.2
193729.00	4439.1	237.0	0.0	0.0	6.2	860.92	.0020831	73.59610	74.67877	90772.6	-.4
193730.00	4435.9	237.1	0.0	0.0	6.2	861.03	.0020833	73.54312	74.62400	90505.3	-.9
193731.00	4429.9	237.1	0.0	0.0	6.2	861.21	.0020837	73.34696	74.42183	90240.9	-1.4
193732.00	4422.1	237.1	0.0	0.0	6.2	861.47	.0020842	73.23190	74.30300	89977.9	-1.6
193733.00	4413.3	237.1	0.0	0.0	6.3	861.75	.0020848	73.24506	74.31627	89712.4	-1.6
193734.00	4404.3	237.2	0.0	0.0	6.3	862.04	.0020853	73.31542	74.38834	89447.9	-1.5


TAKEOFF
TWO-STATION SOLUTION
WEST TOWER EAST TOWER
WEST PEDESTAL WEST PEDESTAL
AIRCRAFT
ENGINES
FLIGHT RUN 4
TIME 0= 0= 0.00 DATE 07/05/75
NOTES
PRESS ALT FT
OAT C F
WIND VEL KNOTS AT DEGREES
GROSS WEIGHT LBS
GROUND DISTANCE FEET
TOTAL DISTANCE FEET
VELOCITY AT LIFT-OFF FPS
VELOCITY AT 50 FEET FPS
DATA ANALYSIS QUALITY CONTROL COMMENTS
REMARKS
TANGENTIAL ACCEL - FT/SEC**2
ENERGY/HT - FEET
TIME - SECONDS
GROUND SPEED - FT/SEC
HEIGHT - FEET
OFFSET - FEET
DISTANCE

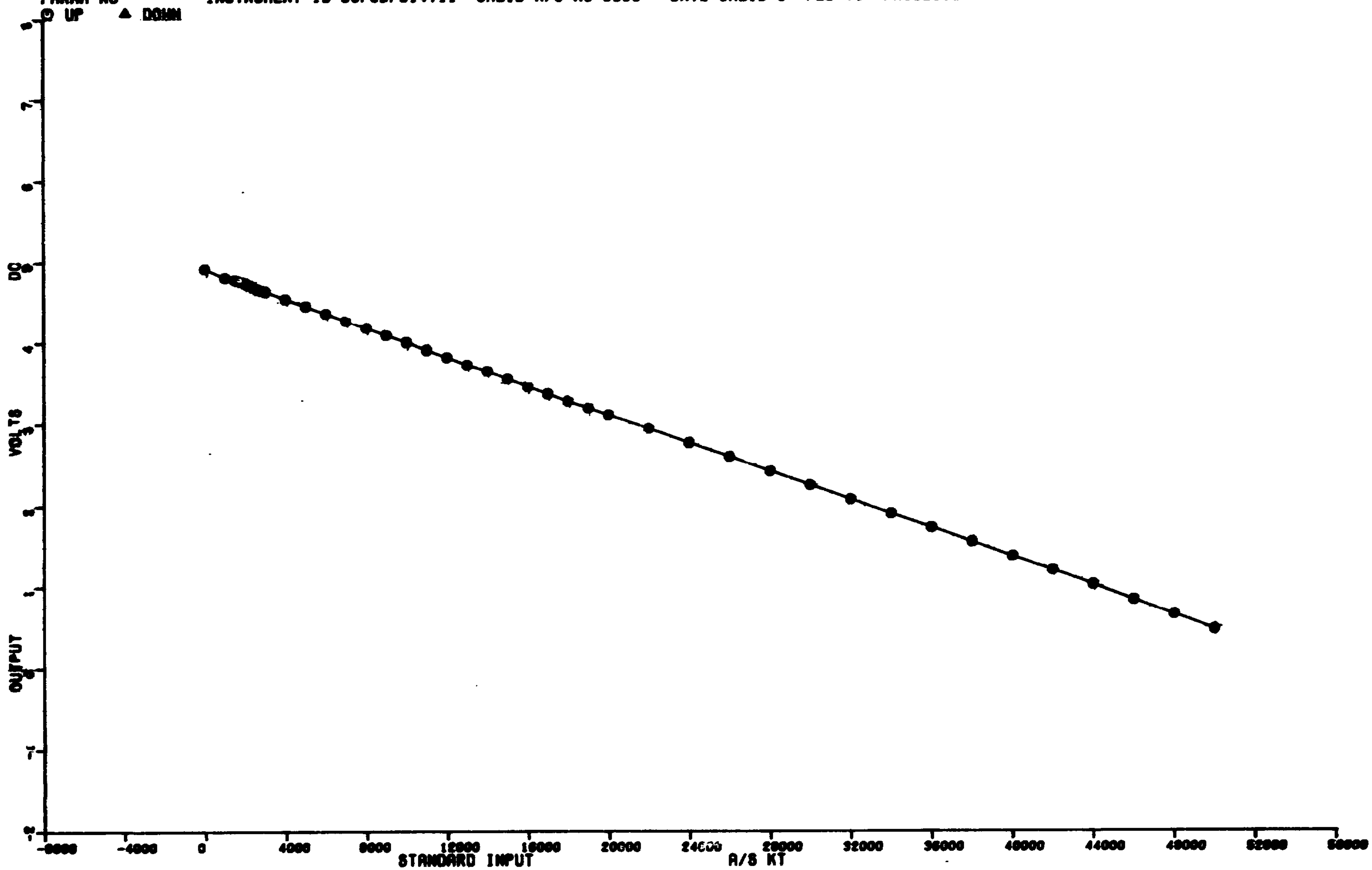
REDUCTION OF INSTRUMENT CALIBRATION DATA 12 FEB 70

INSTRUMENT I.D. 50EUR8C14711 DATE OF CALIBRATION 5 FEB 70 CALIBRATION WORK ORDER NUMBER 63988 RUN NUMBER 1

STANDARD INPUT	RECORDED OUTPUT UP	RECORDED OUTPUT DOWN	CALCULATED STD INPUT UP	CALCULATED STD INPUT DWN	CALCULATED HYSTERESIS	CALCULATED AVE OUTPUT	STANDARD INPUT
5.00000E+04	4.69000E-01	4.69000E-01	5.00982E+04	5.00887E+04	0.	4.69000E-01	5.00000E+04
4.80000E+04	6.55000E-01	6.54000E-01	4.79821E+04	4.79934E+04	1.13233E+01	6.54500E-01	4.80000E+04
4.60000E+04	8.37000E-01	8.35000E-01	4.59212E+04	4.58439E+04	2.26467E+01	8.36000E-01	4.60000E+04
4.40000E+04	1.01900E+00	1.01800E+00	4.38604E+04	4.38717E+04	1.13233E+01	1.01850E+00	4.40000E+04
4.20000E+04	1.19700E+00	1.19400E+00	4.18448E+04	4.18798E+04	3.39700E+01	1.19550E+00	4.20000E+04
4.00000E+04	1.37400E+00	1.37100E+00	3.98406E+04	3.98745E+04	3.39700E+01	1.37250E+00	4.00000E+04
3.80000E+04	1.55000E+00	1.54600E+00	3.76477E+04	3.78930E+04	4.52934E+01	1.54800E+00	3.80000E+04
3.60000E+04	1.72500E+00	1.72200E+00	3.58641E+04	3.58001E+04	3.39700E+01	1.72350E+00	3.60000E+04
3.40000E+04	1.90000E+00	1.89800E+00	3.38845E+04	3.39071E+04	2.26467E+01	1.89900E+00	3.40000E+04
3.20000E+04	2.07500E+00	2.07300E+00	3.19029E+04	3.19258E+04	2.26467E+01	2.07400E+00	3.20000E+04
3.00000E+04	2.24900E+00	2.24600E+00	2.99327E+04	2.99655E+04	3.39700E+01	2.24750E+00	3.00000E+04
2.80000E+04	2.42000E+00	2.41800E+00	2.79964E+04	2.80190E+04	2.26467E+01	2.41900E+00	2.80000E+04
2.60000E+04	2.59500E+00	2.59400E+00	2.60148E+04	2.60261E+04	1.13233E+01	2.59450E+00	2.60000E+04
2.40000E+04	2.76500E+00	2.76400E+00	2.40859E+04	2.41011E+04	1.13233E+01	2.76450E+00	2.40000E+04
2.20000E+04	2.93800E+00	2.93600E+00	2.21369E+04	2.21535E+04	2.26467E+01	2.93700E+00	2.20000E+04
2.00000E+04	3.11300E+00	3.11100E+00	2.01493E+04	2.01719E+04	2.26467E+01	3.11200E+00	2.00000E+04
1.90000E+04	3.19700E+00	3.19600E+00	1.91755E+04	1.91968E+04	1.13233E+01	3.19650E+00	1.90000E+04
1.80000E+04	3.28600E+00	3.28400E+00	1.81904E+04	1.82130E+04	2.26467E+01	3.28500E+00	1.80000E+04
1.70000E+04	3.37200E+00	3.37200E+00	1.72158E+04	1.72165E+04	0.	3.37200E+00	1.70000E+04
1.60000E+04	3.45700E+00	3.45500E+00	1.62941E+04	1.62767E+04	2.26467E+01	3.45600E+00	1.60000E+04
1.50000E+04	3.55300E+00	3.55200E+00	1.51670E+04	1.51783E+04	1.13233E+01	3.55250E+00	1.50000E+04
1.40000E+04	3.65000E+00	3.64900E+00	1.40687E+04	1.40800E+04	1.13233E+01	3.64950E+00	1.40000E+04
1.30000E+04	3.73000E+00	3.72900E+00	1.31628E+04	1.31741E+04	1.13233E+01	3.72950E+00	1.30000E+04
1.20000E+04	3.82300E+00	3.82100E+00	1.21097E+04	1.21324E+04	2.26467E+01	3.82200E+00	1.20000E+04
1.10000E+04	3.91200E+00	3.91000E+00	1.11019E+04	1.11246E+04	2.26467E+01	3.91100E+00	1.10000E+04
1.00000E+04	4.00600E+00	4.00500E+00	1.00375E+04	1.00489E+04	1.13233E+01	4.00550E+00	1.00000E+04
9.00000E+03	4.09100E+00	4.09000E+00	9.07506E+03	9.08635E+03	1.13233E+01	4.09050E+00	9.00000E+03
8.00000E+03	4.18300E+00	4.18200E+00	8.03372E+03	8.04464E+03	1.13233E+01	4.18250E+00	8.00000E+03
7.00000E+03	4.27100E+00	4.27000E+00	7.03686E+03	7.04518E+03	1.13233E+01	4.27050E+00	7.00000E+03
6.00000E+03	4.36200E+00	4.36000E+00	6.00644E+03	6.02908E+03	2.26467E+01	4.36100E+00	6.00000E+03
5.00000E+03	4.45200E+00	4.45100E+00	4.98734E+03	4.99866E+03	1.13233E+01	4.45150E+00	5.00000E+03
4.00000E+03	4.54000E+00	4.53900E+00	3.99066E+03	4.00271E+03	1.13233E+01	4.53950E+00	4.00000E+03
3.00000E+03	4.63000E+00	4.63000E+00	2.97178E+03	2.97176E+03	0.	4.63000E+00	3.00000E+03
2.80000E+03	4.64400E+00	4.64400E+00	2.81326E+03	2.81326E+03	0.	4.64400E+00	2.80000E+03
2.60000E+03	4.66100E+00	4.66000E+00	2.62076E+03	2.63208E+03	1.13233E+01	4.66050E+00	2.60000E+03
2.40000E+03	4.68400E+00	4.68300E+00	2.36032E+03	2.37165E+03	1.13233E+01	4.68350E+00	2.40000E+03
2.20000E+03	4.71200E+00	4.71200E+00	2.04327E+03	2.04327E+03	0.	4.71200E+00	2.20000E+03
2.00000E+03	4.73500E+00	4.73500E+00	1.76263E+03	1.78283E+03	0.	4.73500E+00	2.00000E+03
1.80000E+03	4.75400E+00	4.75200E+00	1.56769E+03	1.55024E+03	2.26467E+01	4.75300E+00	1.80000E+03
1.60000E+03	4.76500E+00	4.76600E+00	1.39784E+03	1.40914E+03	1.13233E+01	4.76550E+00	1.60000E+03
1.50000E+03	4.77600E+00	4.77600E+00	1.31857E+03	1.31857E+03	0.	4.77600E+00	1.50000E+03
1.00000E+03	4.80500E+00	4.80600E+00	9.90196E+02	9.78875E+02	1.13233E+01	4.80550E+00	1.00000E+03
0.	4.91600E+00	4.91300E+00	-2.66693E+02	-2.32723E+02	3.39700E+01	4.91450E+00	0.

A PUNCHED CARD INSTRUMENT CALIBRATION TABLE WAS PRODUCED AS REQUESTED

PARAM NO INSTRUMENT ID 50FUBPC14711 CALIB W/O NO 3968 DATE CALIB 5 FEB 70 PROCESSED 12 FEB 80 RUN NO 1 PARAM NO



DATE 19OCT9 PAGE NO. 140

PARAMETER DEFINITION PARAMETER NO. TH035

EFFECTIVE TEST	TITLE	SOURCE	MIN	MAX	ENG. UNITS	ACCURACY (PERCENT)	FREQ. RESPONSE (CYCLES/SEC)
1	THYDGUNIN	PCM	-70.00	350.00	DEG F	3.00	1.

ANALOG TAPE LOCATION

EFF TEST	FINE TRACK	OUTPUT CHAN
1	0	0

DIGITAL TAPE LOCATION

EFF TEST	FINE PASS NO.	OUTPUT CHAN
1	1	135

INSTRUMENT STATUS AND CALIBRATION

DATA SOURCE	EFF TEST	MTS NO.	W/O NO.	CALIB. DATE	APPRV DATE	CALIB. METHOD	RERUN NO.	SECONDARY EFF TEST
PCM	1		2		16FE88	18	0	0

(1) XXYYF = .511000E+04 XXYYM = 0. XXYYC = 0.

(2) A0 = -.81508E+02 A1 = .76122F+00 A2 = .10271E-03

NOTES:

1. The particular method allows the combination of up to three digital words or portions of those words. These are the control codes for the combining logic.

2. This method allows up to fifth degree polynominal conversion of the input data. For example:

$$EU=A_0+A_1(INPUT)+A_2(INPUT)^2$$

ALCM ATIS FORMAT 1 AND FM FORMAT X   JON 2182A   TAIL 498   EVENT 1, PAGE 2, SUM 1, TOTAL 2
DATE FLOWN 22JULO   DATE REQUESTED 15SEP0   DATE COMPUTED 09OCT0
0907   TEST 53   SEQUENCE 1   RUN 0   POINT 0   MANEUVER 807 B-52 ATIS ENVIRONMENTAL CONTROL - FL95

TIME OF DAY TOTAL HR MN SC SECONDS		TMCAFCUD M02T DEG F	TACCECUD M11T DEG F	AMCALI M06F LB/MIN	TACCFCUIN M07P PSIAF	THRANPCAN M16P PSIAF	AMCATFPB M01F LB/MIN	AACCPPUM M08F LB/MIN
16 49 39 60579.371	6	61.445 6	58.724 3	12.457 6	15.341 4	29.932 0	10.682 3	7.799 6
16 49 41 60581.477	10	61.44510	58.724 1	12.44110	15.321 7	29.932 0	10.682 7	7.743 8
16 49 43 60583.520	17	61.17417	58.724 2	13.13017	15.32111	29.932 0	10.68214	7.55414
16 49 45 60585.591	19	61.44519	58.724 2	12.86910	15.32110	29.932 0	10.71514	7.74317
16 49 47 60587.687	12	61.44512	58.724 0	12.60812	15.321 8	29.932 2	10.699 8	7.78012
16 49 49 60589.730	10	61.44510	58.724 1	12.54310	15.321 5	29.932 0	10.682 9	7.789 8
16 49 51 60591.952	6	61.445 6	58.997 5	12.885 6	15.321 6	29.932 0	10.682 6	7.789 5
16 49 54 60594.437	13	61.71713	59.270 5	12.86913	15.321 9	29.932 0	10.682 9	7.55610
16 49 57 60597.200	10	61.71710	58.99710	12.608 9	15.321 5	29.932 0	10.682 7	7.603 8
16 49 59 60599.351	14	61.71714	58.997 2	12.24014	15.30111	29.932 0	10.68213	7.57914
16 50 1 60601.457	17	61.44517	58.997 6	12.73917	15.30110	29.932 0	10.65015	7.78916
16 50 3 60603.941	8	61.445 8	58.724 7	13.065 8	15.301 6	29.932 0	10.682 8	7.696 7
16 50 5 60605.993	18	61.44518	58.997 5	12.70617	15.30111	29.932 2	10.71515	7.69616
16 50 8 60608.693	8	61.445 8	58.724 2	12.510 8	15.301 7	29.932 0	10.715 7	7.743 6
16 50 10 60610.799	6	61.445 6	58.724 0	12.804 6	15.341 3	29.932 0	10.682 3	7.813 6
16 50 13 60613.913	12	61.44512	58.724 2	12.77112	15.301 8	29.932 0	10.715 9	7.71911
16 50 15 60615.713	4	61.445 4	58.724 2	12.810 4	15.321 3	29.932 0	10.715 3	7.596 2
16 50 18 60618.305	4	61.445 4	58.997 2	12.902 4	15.321 3	29.932 0	10.617 4	7.836 3
16 50 20 60620.357	18	61.44518	58.99712	12.78816	15.321 9	29.932 1	10.71510	7.83613
16 50 22 60622.443	17	61.71717	58.99710	12.64117	15.32110	29.932 1	10.71512	7.60313
16 50 24 60624.623	2	61.717 2	58.724 2	12.820 2	15.301 1	29.932 1	10.650 2	7.789 1
16 50 30 60630.590	2	61.717 2	58.997 2	12.412 2	15.301 2	29.932 1	10.731 2	7.696 1
16 50 32 60632.841	17	61.44517	58.997 8	12.38017	15.30111	29.932 5	10.68210	7.78916
16 50 34 60634.667	19	61.71719	58.724 2	12.54319	15.30110	29.932 2	10.68213	7.64919
16 50 36 60636.773	19	61.44519	58.724 0	12.40819	15.32111	29.932 3	10.71513	7.74317
16 50 39 60639.941	14	61.44516	58.724 0	12.73914	15.341 7	29.932 2	10.715 9	7.83613
16 50 41 60641.093	21	61.71721	58.724 0	12.60820	15.34112	29.932 1	10.71516	7.57919
16 50 43 60643.523	10	61.71710	58.724 0	12.47710	15.341 4	29.932 0	10.715 8	7.78910
16 51 15 60675.275	4	61.717 4	59.270 2	12.673 3	15.341 3	29.932 1	10.699 3	7.603 3
16 51 17 60677.377	17	61.99817	59.270 3	12.85315	15.341 2	29.932 0	10.69911	7.60314
16 51 19 60679.370	23	61.71723	59.270 0	12.64123	15.341 4	29.932 0	10.71515	7.71922
16 51 36 60696.020	10	61.71710	59.270 2	12.80410	15.341 5	29.932 0	10.715 7	7.743 9
16 52 15 60735.018	2	61.717 2	59.270 2	12.641 2	15.341 2	29.932 2	10.633 2	7.836 2

F-16 FLIGHT LOADS PROGRAM - BASIC DATA

TAIL 746 FLIGHT 0394 RUN 0 SEQUENCE 7 DATE OF FLIGHT 21 JUL 78 PRINTOUT DATE 22 AUG 80 PAGE NO. 1

F16 A-2 FLIGHT 394 RUN 7E

POINT NUMBER	TIME HHMMSSSSSS	APCT	HCT FT	VCT KCAS	VET KEAS	QBART PSF	FNA LB	ANZCG G	ANYFCS G	ANXST G	ALFAT DEG	BETAT DEG
1	215638.001	1.038	29381.	412.	379.	487.5	34009.	1.17	.02	.05	2.69	.27
2	215638.026	1.036	29381.	412.	379.	487.5	34009.	1.17	.01	.09	2.78	.48
3	215638.051	1.036	29375.	411.	379.	485.3	33375.	1.15	.02	.04	2.73	.21
4	215638.076	1.036	29375.	411.	379.	485.3	33376.	1.15	.02	.05	2.73	.31
5	215638.101	1.036	29375.	411.	379.	485.3	33376.	1.15	.02	.06	2.77	.31
6	215638.126	1.036	29375.	411.	379.	485.3	33376.	1.15	.02	.07	2.73	.31
7	215638.151	1.036	29386.	411.	379.	485.3	33376.	1.15	.02	.08	2.68	.41
8	215638.176	1.036	29386.	411.	379.	485.3	34009.	1.17	.02	.04	2.64	.38
9	215638.201	1.035	29354.	411.	379.	485.4	32742.	1.12	.02	.02	2.68	.31
10	215638.226	1.035	29354.	411.	379.	485.4	33375.	1.15	.02	.00	2.68	.35

POINT NUMBER	TIME HHMMSSSSSS	GW LB	CG PCT	FQFWD LB	FQAFT LB	FQLW LB	FQRW LB	FQLE LB	FQRE LB	FQCTL LB	DELSB DEG	WVRQC E3LB
1	215638.001	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.3
2	215638.026	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.3
3	215638.051	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.2
4	215638.076	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.3
5	215638.101	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.3
6	215638.126	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.2
7	215638.151	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.2
8	215638.176	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.3
9	215638.201	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.2
10	215638.226	29138.	31.26	2594.	2271.	26.	26.	26.	26.	26.	1.	1.3

POINT NUMBER	TIME HHMMSSSSSS	FX LB	FY LB	FEP LB	DELFL DEG	DELHR DEG	FLEV DEG	DFLEL DEG	DELFR DEG	AILRN DEG	DELR DEG	DLEFR DEG
1	215638.001	.3	-1.5	.2	-3.4	1.6	-.9	-8.0	3.0	5.5	-.9	-2.6
2	215638.026	.1	-1.5	.2	-3.4	1.6	-.9	-8.1	3.1	5.6	-.8	-2.6
3	215638.051	.3	-1.5	.2	-3.4	1.6	-.9	-8.1	3.0	5.6	-.8	-2.6
4	215638.076	.0	-1.5	.2	-3.4	1.6	-.9	-8.1	3.1	5.6	-.9	-2.6
5	215638.101	.2	-1.5	.2	-3.4	1.6	-.9	-8.1	3.0	5.6	-.9	-2.5
6	215638.126	-.4	-1.5	.2	-3.4	1.6	-.9	-8.0	3.1	5.6	-.9	-2.5
7	215638.151	.2	-1.6	.2	-3.4	1.6	-.9	-8.0	3.0	5.5	-.9	-2.5
8	215638.176	-.1	-1.6	.2	-3.4	1.6	-.9	-8.0	3.1	5.5	-.9	-2.5
9	215638.201	.0	-1.6	.0	-3.4	1.6	-.9	-7.9	3.0	5.5	-.9	-2.5
10	215638.226	-.2	-1.7	.2	-3.4	1.6	-.9	-7.9	3.0	5.5	-.9	-2.5

POINT NUMBER	TIME HHMMSSSSSS	PHI DEG	PB DEG/SEC	PDOT RAD/SEC2	QB DEG/SEC	QDOT RAD/SEC2	RB DEG/SEC	RDOT RAD/SEC2	ANZLT G	ANYLT G	ANZRT G	ANYRT G
1	215638.001	2.	-1.	0.0	.4	0.00	-.2	0.00	1.3	-.0	1.5	.0
2	215638.026	2.	-1.	0.0	.7	0.00	.1	0.00	1.4	-.0	1.4	.0
3	215638.051	2.	-1.	.2	.3	-.20	.5	.12	1.4	-.0	1.6	.0
4	215638.076	2.	-0.	.4	.6	.14	.1	-.38	1.4	-.0	1.3	.0
5	215638.101	2.	-0.	-.1	.3	-.16	.1	.06	1.4	-.0	1.4	.0
6	215638.126	2.	-0.	0.0	.4	.08	.1	-.10	1.4	-.0	1.4	.0
7	215638.151	2.	-0.	.2	.3	-.09	-.4	-.05	1.4	-.0	1.5	.0
8	215638.176	2.	1.	.4	.3	-.02	.5	.45	1.4	-.0	1.3	.0
9	215638.201	2.	1.	.1	.2	-.02	.1	-.35	1.3	-.0	1.3	.0
10	215638.226	2.	1.	.2	.4	.11	.1	.05	1.3	-.0	1.1	.0

TAIL 746 FLIGHT 0394 RUN 0 F-16 FLIGHT LOADS PROGRAM - BASIC AIRFRAME LOADS SEQUENCE 7 DATE OF FLIGHT 21 JUN 71 PRINTOUT DATE 22 AUG 80 PAGE NO. 1

F16 A-2 FLIGHT 394 RUN 7E

POINT NUMBER	TIME HHMMSSSSSS	WVRO E3LB	WMRO E6INLB	WTRO E6INLB	WVR3 E3LB	WMR3 E6INLB	WTR3 E6INLB	WVR7 E3LB	WMR7 E6INLB	WTR7 E6INLB	WMR9 E6INLB	WTR9 E6INLB
1	215638.001	3.5	.28	-.10	-3.2	.17	-.014	1.6	.036	.018	.009	-.008
2	215638.026	3.5	.28	-.11	-2.9	.18	-.015	1.6	.035	.020	.009	-.007
3	215638.051	3.3	.28	-.11	-3.2	.16	-.014	1.6	.032	.018	.009	-.006
4	215638.076	3.3	.28	-.11	-3.2	.17	-.014	1.7	.035	.021	.010	-.008
5	215638.101	3.5	.28	-.11	-3.0	.17	-.014	1.6	.035	.018	.009	-.008
6	215638.126	3.3	.27	-.11	-2.9	.17	-.014	1.7	.037	.019	.008	-.008
7	215638.151	3.2	.28	-.11	-2.9	.18	-.015	1.7	.032	.018	.009	-.007
8	215638.176	3.5	.28	-.11	-3.2	.17	-.014	1.6	.034	.020	.012	-.007
9	215638.201	3.7	.28	-.10	-3.2	.17	-.014	1.6	.038	.019	.009	-.006
10	215638.226	3.4	.26	-.11	-3.1	.17	-.014	1.6	.035	.019	.008	-.008

POINT NUMBER	TIME HHMMSSSSSS	WVLO E3LB	WMLO E6INLB	WTLO E6INLB	HMFL E3FTLB	HMFR E3FTLB	FVF E3LB	FMF E6INLB	FVA E3LB	FMA E6INLB	FTA E6INLB	VENTR E3INLB
1	215638.001	2.6	.40	.09	1.2	-2.1	2.6	-.15	-3.1	.04	-.006	-.0
2	215638.026	2.5	.37	.09	1.2	-2.3	1.1	-.15	-3.1	.04	-.006	-.0
3	215638.051	2.3	.39	.09	1.2	-2.0	1.1	-.18	-3.1	.04	-.006	-.0
4	215638.076	2.5	.38	.08	1.2	-2.1	2.6	-.15	-3.1	.04	-.006	-.0
5	215638.101	2.4	.37	.09	1.1	-2.0	1.9	-.09	-3.1	.04	-.006	-.0
6	215638.126	2.1	.38	.08	1.1	-2.2	1.1	-.19	-2.6	.04	-.006	-.0
7	215638.151	2.1	.38	.09	1.1	-2.1	1.1	-.18	-3.1	.04	-.006	-.0
8	215638.176	2.6	.39	.08	1.1	-2.1	1.1	-.18	-3.1	.04	-.006	-.0
9	215638.201	2.5	.37	.08	1.1	-2.1	1.1	-.18	-3.1	.04	-.006	-.0
10	215638.226	2.4	.38	.08	1.1	-2.0	1.1	-.18	-2.6	.04	-.006	-.0

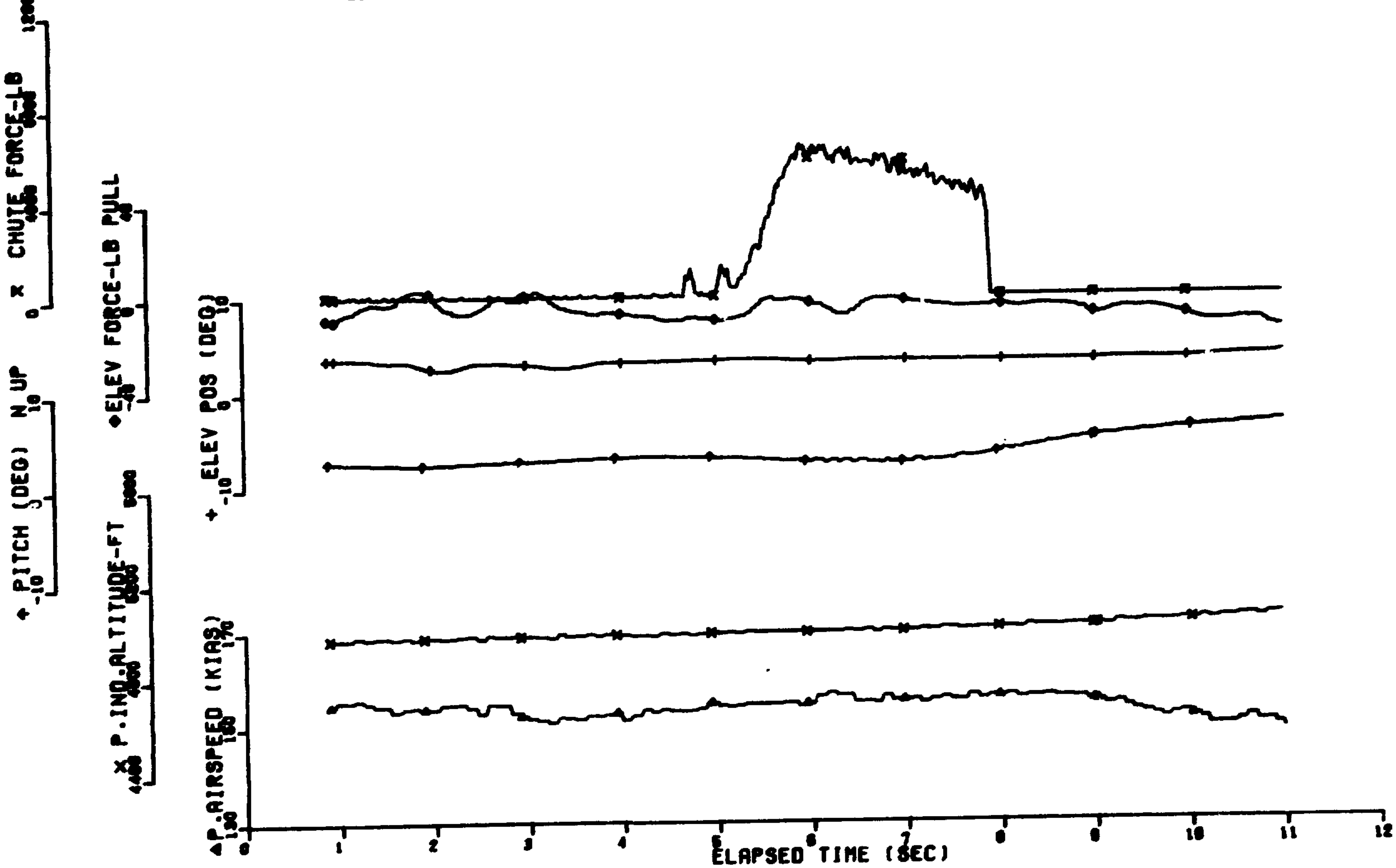
POINT NUMBER	TIME HHMMSSSSSS	HTVL E3LB	HTML E3INLB	HAHL E3INLB	HTVR E3LB	HTMR E3INLB	HHMR E3INLB	VTV E3LB	VTM E3INLB	VTT E3INLB	HMP E3FTLB	CP1 E3PS1
1	215638.001	-.0	9.8	.7	.6	-17.3	-.7	.2	-.3	23.3	.1	-.5
2	215638.026	-.0	8.8	-.2	.6	-21.2	-.7	.2	3.4	24.8	.1	1.6
3	215638.051	-.0	7.8	.0	.7	-17.3	.7	.2	-4.1	26.2	.1	2.5
4	215638.076	-.0	7.8	.0	.6	-17.3	-2.6	.3	1.5	26.2	.1	2.3
5	215638.101	-.0	10.9	-.5	.6	-19.2	-1.2	.2	5.3	24.8	.1	3.8
6	215638.126	-.0	6.8	.0	.5	-17.3	-1.2	.2	-.3	24.8	.1	3.4
7	215638.151	-.0	6.8	-.5	.6	-16.3	.3	.2	3.4	23.3	.1	1.1
8	215638.176	-.0	6.8	-.2	.6	-19.2	-1.2	.2	-.3	23.3	.1	2.7
9	215638.201	-.0	9.8	-1.0	.7	-17.3	.7	.1	7.2	24.8	.1	5.9
10	215638.226	-.0	7.8	-.2	.6	-15.4	-.7	.2	1.5	24.8	.1	5.2

POINT NUMBER	TIME HHMMSSSSSS	CP2A MICROSN	CP2B MICROSN	CP2C MICROSN	CP3 E3PS1	CP4 E3PS1	CP5 E3PS1	CP6 E3PS1	CP7 E3PS1	CP8A MICROSN	CP8B MICROSN	CP8C MICROSN
1	215638.001	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	58.	-20.
2	215638.026	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	73.	-20.
3	215638.051	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	58.	-20.
4	215638.076	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	73.	-20.
5	215638.101	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	58.	-20.
6	215638.126	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	120.	-20.
7	215638.151	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	58.	-20.
8	215638.176	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	89.	-20.
9	215638.201	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	58.	-20.
10	215638.226	-0.	-0.	-0.	-.0	-.0	-.0	-.0	-.0	159.	73.	-20.

YC-141B PHASE III CG = PCT GW = LB

TAIL 166 FLT 194 RUN 6 SEQUENCE 4 FLT DATE 16JAN80 PLOT DATE 02/06/80
START TIME SECONDS 60066.000 STOP TIME SECONDS 60087.000
NO. OF CHUTES = CHUTE SIZE = FT R.S. EXTRACTION LINE LENGTH = FT

TEST NO. = PLATFORM AIRDROP TIME HISTORY DROP WT. = LB



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14. Abstract

This Agardograph is the 12th of the AGARD Instrumentation Series and describes the application of data processing systems to produce data in support of flight testing. The generalized techniques are appropriate to large test centers which support multiple testing programs simultaneously. The concepts, however, are as equally valid for a single test program using a dedicated data processing system.

Starting from a discussion of data sources, the text proceeds to a review of the considerations required prior to data processing. A simplified discussion of two major components of data processing – hardware and software – follows. The volume then looks at the third major component of data processing – the people to make it work. The data processing in support of flight testing is described according to processing functions. An attempt is then made to identify potential problems areas.

Since every organization which conducts test flights develops its own methods and techniques for this purpose, it is not always possible to give specific details that can be universally applied. The intention is to present a general outline of the methods, techniques, and problems associated with data processing for the benefit of individuals not experienced in this field. It is hoped that experienced Flight Test Engineers will be able to make use of this review to assist with instructing new entrants to the field of flight test data processing and to stimulate future developments.

This AGARDograph has been sponsored by the Flight Mechanics Panel of AGARD.

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