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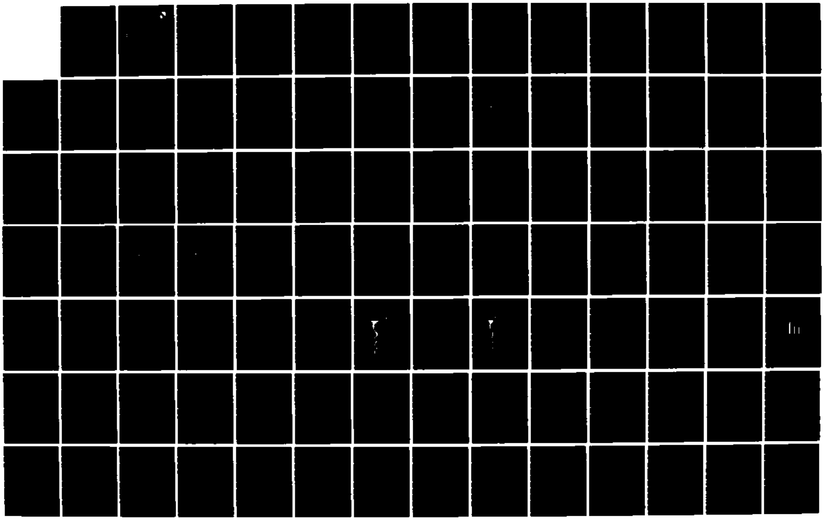

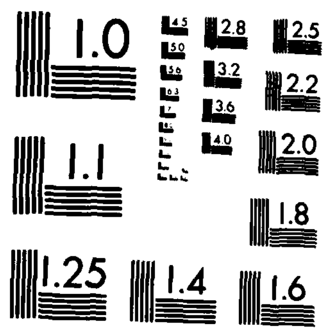
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AFFTC-TIM-84-4

INTERACTIVE SIGNAL ANALYSIS SOFTWARE (ISAS)

USER'S MANUAL

BY
Ronald M. Davino

Final Report
July 1984

Approved for public release;
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AFFTC

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

This handbook, TIM-84-4, Interactive Signal Analysis Software User's Manual, was submitted under Job Order Number SC6313 by the Commander, 6520 Test Group, Edwards Air Force Base, California 93523.

This handbook has been reviewed and cleared for open publication and/or public release by the AFFTC Office of Public Affairs in accordance with AFR 190-1, Chapter 6. There is no objection to unlimited distribution of this handbook to the public at large, or by DDC to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public including foreign nationals.

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The interactive dynamic signal analysis software consists of a set of generalized interactive programs which are user friendly and capable of the enhancement, analysis, and display of digital time history data. This software is hosted on the Control Data Cyber 740 Computer System. The analysis software is generalized to allow application to many unique and specific project analysis requirements. Time history data can be edited, modified according to appropriate calibration requirements, and consolilated for convenient handling of parameters. Time history data can also be enhanced through several digital filtering techniques. Data analysis is performed in the time domain and in the frequency domain through Fourier transform based spectral analysis techniques. This provides analysis capabilities such as the determination of the fast Fourier transform and the power spectral density of a parameter as well as the transfer function between several parameters. Analysis results are presented in tabular and graphic form through a line printer or
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terminal display. These generalized analysis techniques are exemplified through an application to gas turbine engine dynamics.

CONTENTS

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1. INTRODUCTION

The Interactive digital Signal Analysis Software package (ISAS) provides a set of analysis programs which are capable of assisting a user in the investigation of the dynamic characteristics of a system. The increasing use of digital instrumentation techniques and a corresponding increase in the volume of digital data have driven the utilization of digital signal analysis software. The requirement to scan and analyze a large volume of data is commensurate with interactive analysis programs which provide immediate graphic representations of the analysis results. A flexible methodology for the investigation of a dynamic system is also highly desired. The analysis software package documented by this user's guide attempts to provide these capabilities by supplying interactive analysis tools that have a graphic representation of analysis results where appropriate. Additionally, this user's guide exemplifies a methodology for a typical application of the analysis software.

1.1 Background of the Analysis Software

The development of the Interactive Digital Signal Analysis Software Package resulted from a requirement to determine the dynamic operating characteristics of gas turbine engines during propulsion system flight tests. Digital data were typically obtained at appropriate sample rates to capture the transient event or operational anomaly of interest. At the time, several schemes for digital data analysis were available. However, the associated analysis programs often imposed compromising data processing restrictions or required time consuming execution through a batch job processing structure. Therefore, it was deemed appropriate to develop a unified set of analysis routines with interactive execution and graphic display of results.

The interactive digital signal analysis software package has its origin in the utilization of digital filter and arithmetic overlays for batch job digital data processing available through the Uniform Flight Test Analysis System (UFTAS). From lessons learned by the application of these overlays to propulsion system flight test data, a foundation was established for the development of a generalized analysis methodology of dynamic data. This methodology consists of a systematic application of the interactive signal analysis software which is capable of conditioning, displaying, analyzing, and filtering digital data. The development of this software consisted of the generation of new analysis programs and the enhancement of existing software. It was necessary to develop methods of signal conditioning which would correct data dropout and improper signal levels set during the digitization of analog signals. Also, a method to interactively edit and plot time history data for viewing on a Tektronix graphic terminal was developed. The standard UFTAS file structures and some UFTAS utility programs were employed for the handling of time history data. Many of the frequency analysis programs were built upon basic concepts of frequency response analysis software algorithms. Digital filtering programs were modified from programs contained in a digital signal processing software package and enhanced for interactive usage. The resultant programs were consolidated and grouped according to general function and utility. ISAS is maintained on a permanent file fileset which is available for execution on the AFFTC CYBER computer system.

A methodology for the utilization and interactive execution of the analysis software is exemplified in this user's guide through the analysis of gas turbine engine dynamic data obtained through flight test. However, the analysis software is generalized and can be applied for the investigation of other dynamic systems (e.g. mechanical, hydraulic, and avionics systems).

1.2 Example Application to the Analysis of Aircraft Gas Turbine Engine Dynamic Instabilities

The complex design of the modern gas turbine engine often harbors operational anomalies. Operation of an aircraft's propulsion system at extreme regions of the flight envelope can cause components of the gas turbine engine to operate off their design point. Compression components can experience rotating stall or surge which adversely affects other engine components. The transient processes which occur during a rapid advance of the throttle may induce combustion instabilities in the engine afterburner and its control system. Combustion instabilities often inherent in high performance thrust augmentation systems can result in large amplitude pressure oscillations. These pressure oscillations can stall the compression components of the engine or induce augmentor blowout. Phenomena of these types may restrict the operation of an aircraft in a region of its flight envelope and reduce the effectiveness of its mission.

Operational difficulties accompanying engine component off-design performance and throttle excursions can be minimized through an understanding of the underlying physical principles and characteristics of the encountered anomaly. For example, an understanding of the driving mechanisms behind the unstable operation of an afterburner can direct hardware modifications to reduce or eliminate the the source of the instability. This understanding of an engine anomaly is facilitated through the performance of appropriate propulsion system flight tests and the application of methodical post-flight data analysis.

A methodology for the utilization of the interactive digital signal analysis software to investigate unstable afterburner operation is exemplified in this user's guide through the analysis of gas turbine engine dynamic data obtained from flight test. The data analyzed were from a propulsion system which is typical of a modern high performance augmented turbofan engine. Figure 1 shows a cross sectional schematic of this type of propulsion system. Primary engine components and stations are indicated. The engine is typical of a low bypass ratio and high

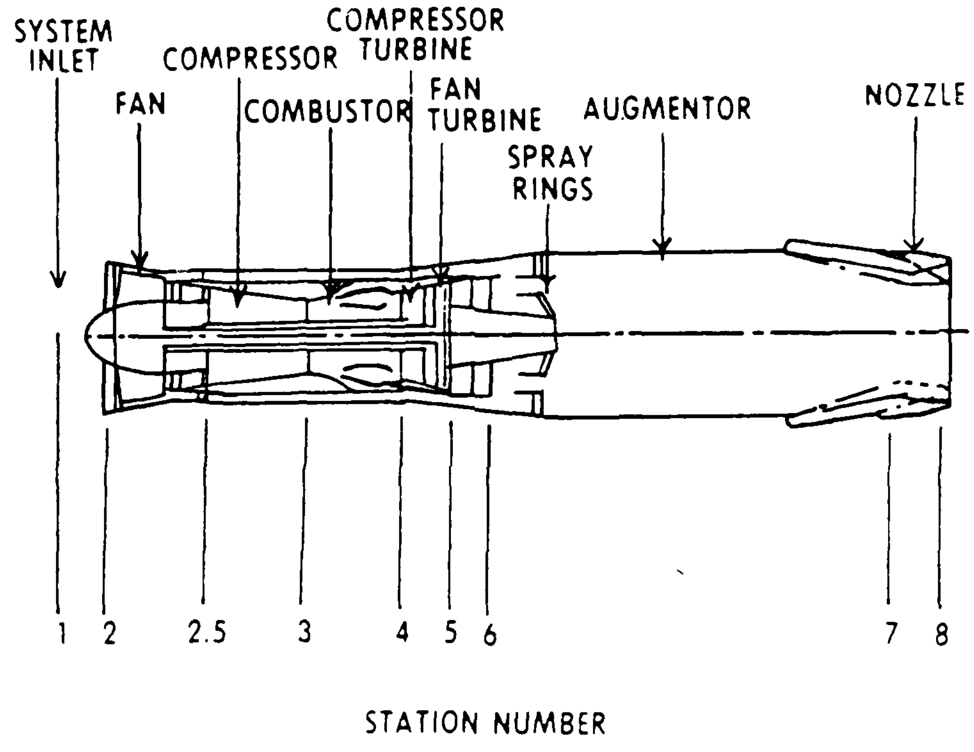


Figure 1 - Cross Sectional View of a Typical Propulsion System

pressure ratio design.

Dynamic engine instabilities have been observed to result from throttle excursions which involve transient augmentor operation during propulsion system flight tests. These instabilities were recorded by pressure transducers located in the engine core and bypass flowpaths and in the the augmentor fuel delivery system. Data obtained during typical unstable augmentor transients were chosen to exemplify the application of the signal analysis software. These augmentor instabilities were characterized by engine stall or stagnation as well as pressure oscillations in the fuel metering and distribution manifolds. Analysis techniques typical of the example application presented in this user's guide have revealed basic mechanisms underlying tnese unstable augmentor transients. The analysis of these gas turbine engine dynamic instabilities was the subject of an investigation reported in Appendix A .

1.3 Structure of this User's Guide

This user's guide is organized into several chapters which explain the operational philosophy of the signal analysis software. Chapter 2 provides an introduction to the analysis software and explains the basic concepts underlying the structure and control of the individual programs and data files. Functionally related software are organized into program groups which are described in Chapters 3 through 6. Each of these chapters provides a brief discussion of pertinent technical concepts, a functional description of the analysis routine, a list of required input and resultant output, a discussion and example of program execution, and a list of limitations or nuances for each analysis program. Test source data files are detailed in Chapter 7. These data files primarily provide a check for digital filter designs.

2. SOFTWARE STRUCTURE AND CONTROL

The interactive digital signal analysis software is organized into four groups of programs. Each program group contains several analysis programs which perform similar or related tasks (e.g. frequency response analysis). A detailed discussion of the analysis software organization, documentation, file standards, and execution is given in the following sections.

2.1 Fileset Software and Documentation

The interactive signal analysis software package resides on the AFFTC Cyber 170 Model 740 mainframe computer system as a direct access NOS permanent file fileset. This fileset is catalogued under the username of PANDFQ. The fileset ISAS contains the source, object, data, and documentation files for the various analysis programs. The program source files are identified by a filename of the form SOURCE/"name", where SOURCE is the group name for the source code of the analysis program and "name" is the element name for the particular analysis program. Similarly, the executable object files are identified by a file name of the form ABS/"name" and the data files are identified by a file name of the form DATA/"name". Associated with the executable code of each program on the fileset is a file of documentation. This documentation annotates the fileset directory listing and provides a summary of relevant information necessary for the interactive execution of a program. This documentation is a quick reference that is available at the terminal screen.

The functional relationship of the various analysis programs, associated data files, and output files is shown schematically in Figure 2. The analysis programs are conceptually organized into four program groups which are noted in Figure 2. These groups are the data conditioning program group, the data list and display program group, the frequency analysis program group, and the digital filter program group.

The data conditioning program group provides the following capabilities:

1. Consolidation of parameters onto one data file (CONSO)
2. Correction ofinstrumentation and digitization errors (CONSO and SEQCOND)
3. Generation of derived parameters (SEQCOND)
4. Conversion of data files of one format to another (BTOC)
5. Temporal alignment of parameter time histories (TIMALIN)

where the name of the associated analysis program is given in parentheses.

These data conditioning programs utilize the standard UFTAS C-file and B-file data formats for the handling of parameter time histories. This is illustrated in Figure 2. These programs will output a resultant time history in either a C-file or B-file

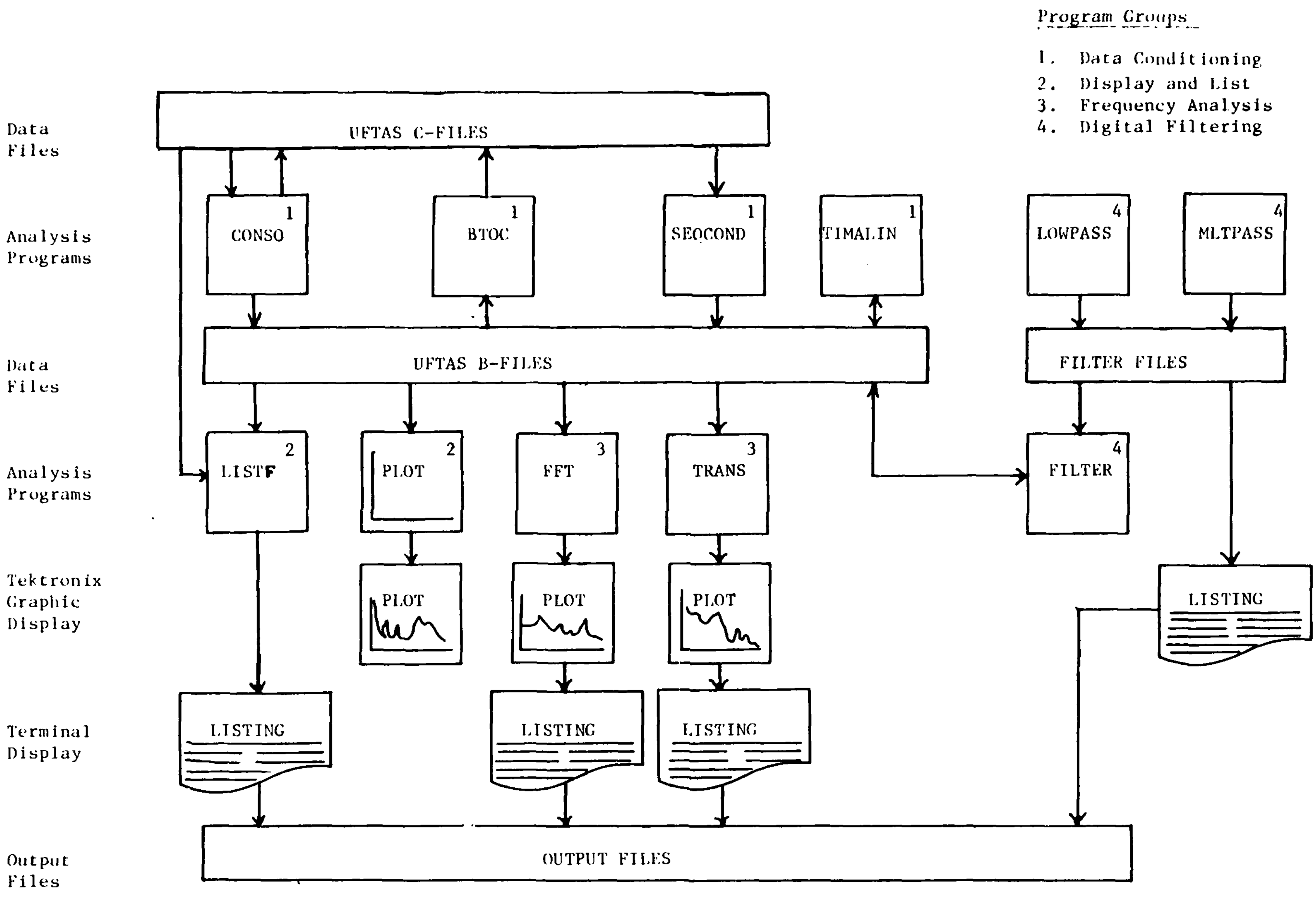


Figure 2 - Diagram of Interactive Signal Analysis Software

format. Utilization of these file formats is discussed in Section 2.2. The data conditioning program group is discussed and exemplified in Chapter 3.

Another group of related software is the data display and list program group. The following operations are performed by this program group:

1. List of a parameter time history (LISTF)
2. Plot of a parameter time history (PLOT)

Figure 2 shows the functional relationship of this software group within the software package. These programs require that the parameter time histories be input in a C-file or B-file format. Output from these programs can be listed or displayed on a terminal screen or directed to a printer. This program group is discussed and exemplified in Chapter 4.

The frequency analysis program group provides the following capabilities:

1. Fast Fourier transform of a parameter time history (FFT)
2. Derivation of a transfer function between parameters (TRANS)

As Figure 2 indicates, these programs also require that data be input in a B-file format. These programs produce results which can be graphically displayed on a Tektronix graphic terminal screen or directed through a local file to be listed on a line printer. These programs are discussed and exemplified in Chapter 5.

The last program group is the digital filter program group. These programs are shown in Figure 2 and they provide the following capabilities:

1. Design of a lowpass filter file (LOWPASS)
2. Design of a multiple band filter file (MLTPASS)
3. Implementation of a filter design (FILTER)

The filter design programs produce a filter file which is based on design specifications. If desired, a listing of these specifications can be displayed at the terminal screen or directed to a local file for cataloging or listing on a printer. The filter files are employed by the filter implementation program and applied to data time histories input in a B-file format. This program group is discussed and exemplified in Chapter 6.

The four program groups provide analysis software capable of processing time history data. These programs and their associated data, filter specification, and output files are summarized in Figure 2 which also presents a type of flowchart for data processing. Paths of program implementation are indicated in this figure. Many of the processing paths are parallel and several of the analysis programs need not be executed serially. The only restriction is that data input to an analysis program must be in either a C-file or B-file format. Beyond this requirement, implementation of the analysis software to data time histories of system dynamics is up to the user's discretion. An example application of the analysis software to observed gas turbine engine dynamics is presented in Chapters 3 thr ugh 6. This example will illustrate many of the analysis paths through the interactive signal analysis software.

2.2 Data, Filter, and Output Files

Various types of files are employed by the analysis software to communicate information to and from the various analysis programs within the software package. The four types of files used are:

1. Standard UFTAS C-files
2. Standard UFTAS B-files
3. Digital filter description files
4. Output files

The relationship of these files with respect to the analysis programs is illustrated in Figure 2. During processing of data, these files are attached to the terminal local file space and are associated with the particular program being executed. These files can be retained as permanent files and catalogued by the NOS operating system of the Cyber.

The standard UFTAS C-files and B-files are employed by the analysis software to transfer time history data from one analysis program to another. A B-file consists of a group of parameters recorded over the same time period and written at the same rate. A C-file is a collection of catenated B-files. Each B-file is a section of the C-file. C-files and B-files have unique header records which document a particular test event. A detailed discussion of UFTAS C-files and B-files is given in Reference 1.

The analysis programs in the ISAS take advantage of two key features of the UFTAS B-file structure. These features are the adjustable number of parameters available on the file and the variable length of file. Figure 2 shows the utility of using these files to communicate and store data.

Normally, C-files and B-files are supplied to the analysis programs by the user or are automatically generated by an analysis program as the result of data conditioning. An exception to this convention are data files supplied with the analysis programs in the ISAS. Currently, one such data file exists. This data file is a B-file named DATA/WHITE and contains one parameter named NOISE1 which is useful for testing a digital filter design. The utility of this program is further explained in Section 7.1.

The filter description files shown in the right hand side of Figure 2 are used to store design specifications of a filter. These specifications are output from the filter design programs and are employed by the filter implementation program to filter a parameter time history. These files are similar to the UFTAS data files and contain the required number of values for the finite impulse response of a digital filter. These files are documented in Reference 2.

Output files contain results of an analysis program. These sequential files are produced during or at the end of a program's execution. They contain analysis results which can be directed to a printer for listing or saved on a permanent storage device.

2.3 Interactive Execution and Documentation

The interactive signal analysis software package resides on the AFFTC Cyber mainframe computer system as a direct access fileset. This fileset is named ISAS and catalogued under the username of PANDFQ. The signal analysis software is designed to operate under the interactive facility of the Cyber NOS operating system. Some of the analysis programs will provide graphic representations of the analysis results as a plot of the data time histories at a Tektronix graphic terminal. Otherwise, program execution and output can be directed from a nongraphic type of terminal.

To execute any analysis program at a Cyber remote terminal, the direct access fileset ISAS must first be attached to the terminal local file space by entering the command:

```
ATTACH,FILESET=ISAS/UN=PANDFQ.
```

A complete listing of the fileset elements (i.e. source, absolute, and data files) as well as a one line description of the fileset element can be obtained by entering the command:

```
LD
```

This command produces a listing of the fileset elements at the terminal screen. This listing is given by Display 1. A complete description of fileset commands is given in Reference 3.

The executable code of an analysis program can be obtained by entering a command of the form:

```
GF(ABS/"name")
```

where "name" is the particular name of the desired analysis program. For example, to access the executable code for the fast Fourier transform analysis program which is named FFT enter:

```
GF(ABS/FFT)
```

FFT can now be executed by a name call load of the program.

Associated with the executable code of each analysis program is a

```
/LD

   FILESET CONTAINS
 GROUP/ELEMENT       COMMENTS
ABS/BTOC          CONVERSION OF A B-FILE TO A C-FILE
ABS/CONSO         CONSOLIDATION OF C-FILE PARAMETERS
ABS/FFT           FAST FOURIER TRANSFORM OF A B-FILE PARAMETER
ABS/FILTER        DIGITAL FILTER IMPLEMENTATION
ABS/LISTF         B-FILE OR C-FILE LISTING OF PARAMETERS
ABS/LOWPASS       DESIGN OF LOWPASS DIGITAL FILTERS
ABS/MLTPASS       DESIGN OF MULTIPLE PASSBAND & STOPBAND DIGITAL FILTERS
ABS/PLOT          PLOT OF A B-FILE PARAMETER TIME HISTORY
ABS/SEQCOND       MANIPULATION AND CONDITIONING OF PARAMETER SEQUENCES
ABS/TIMALIN       TIME SHIFT OF A B-FILE PARAMETER SEQUENCE
ABS/TRANS         TRANSFER FUNCTION BETWEEN TWO B-FILE PARAMETERS
DATA/WHITE        WHITE NOISE DATA FILE
SOURCE/BTOC       CONVERSION OF A B-FILE TO A C-FILE
SOURCE/CONSO      CONSOLIDATION OF C-FILE PARAMETERS
SOURCE/FFT        FAST FOURIER TRANSFORM OF A B-FILE PARAMETER
SOURCE/FILTER     DIGITAL FILTER IMPLEMENTATION
SOURCE/LISTF      B-FILE OR C-FILE LISTING OF PARAMETERS
SOURCE/LOWPASS    DESIGN OF LOWPASS DIGITAL FILTERS
SOURCE/MLTPASS    DESIGN OF MULTIPLE PASSBAND & STOPBAND DIGITAL FILTERS
SOURCE/PLOT       PLOT OF A B-FILE PARAMETER TIME HISTORY
SOURCE/SEQCOND    MANIPULATION AND CONDITIONING OF PARAMETER SEQUENCES
SOURCE/TIMALIN    TIME SHIFT OF A B-FILE PARAMETER SEQUENCE
SOURCE/TRANS      TRANSFER FUNCTION BETWEEN TWO B-FILE PARAMETERS
/
```

Display 1 - Listing of the IDSASP Fileset Elements file of documentation. This documentation annotates the fileset directory listing and provides a summary of revelant information necessary for the execution of a particular program. This documentation is a quick reference that is available on the terminal screen. The documentation for an analysis program can be displayed after the fileset has been attached to the terminal local file space by entering a command of the form:

GD(ABS/"name")

For example, the documentation associated with the fast Fourier transform analysis program FFT can be displayed by entering the command:

GD(ABS/FFT)

The resultant display at the terminal screen is given by Display 2. A complete listing of the fileset documentation is given in Appendix B.

```
gdlabs/ff(1)

 FAST FOURIER TRANSFORM OF A B-FILE PARAMETER
 ********************************************

 PURPOSE:

     FFT PERFORMS A FAST FOURIER TRANSFORM ON AN INPUT B-FILE PARAMETER
     TIME HISTORY. THE FFT RESULTS CAN BE LISTED AT THE TERMINAL SCREEN,
     WRITTEN TO AN OUTPUT FILE, OR PLOTTED ON THE SCREEN OF A TEKTRONIX
     GRAPHIC TERMINAL.

 REQUIRED INPUT:

     1. MODEL NUMBER OF THE TEKTRONIX TERMINAL (IF APPROPRIATE).
     2. NAME OF THE B-FILE WHICH CONTAINS THE DATA SEQUENCE TO BE AN-
        ALYZED.
     3. NAME OF THE PARAMETER TO BE ANALYZED.
     4. UNITS OF THE PARAMETER.
     5. DATA SAMPLE RATE (SAMPLES/SECOND).
     6. ANALYSIS START TIME-OF-DAY (SECONDS).
     7. NUMBER OF POINTS TO BE ANALYZED.
     8. SELECTION OF THE FORMAT FOR THE FFT RESULTS.

 OPTIONAL INPUT:

     1. APPLICATION OF A HANN WINDOW TO THE DATA PRIOR TO ANALYSIS.
     2. SELECTION OF OUTPUT FORMAT REQUIRES:
        A. CHOICE OF TERMINAL SCREEN OR OUTPUT DUMP FILE.
     3. SELECTION OF GRAPHIC DISPLAY OF RESULTS REQUIRES:
        A. SELECTION OF THE TYPE OF PLOT (MAGNITUDE,PHASE,OR PSD VS.
           FREQUENCY)
        B. SELECTION OF AUTOMATIC OR MANUAL SCALING
     4. STATEMENT OF PLOT A REMARK.

 OUTPUT

     1. TABULATION OF FFT RESULTS ON THE TERMINAL SCREEN OR ON A SPECI-
        FIED OUTPUT FILE
     2. PLOT OF FFT RESULTS AT THE TERMINAL SCREEN.
```

Display 2 - Documentation of Fileset Element ABS/FFT

3. DATA CONDITIONING PROGRAM GROUP

The data conditioning program group contains software which consolidates and conditions parameter time histories as well as manipulates data files in the form of C-files and B-files. The discussion of this software follows a specific format. When appropriate, a brief technical discussion of the background of the analysis software is first presented. Program input requirements are then discussed followed by a discussion of the interactive execution of the program. Next, typical program output is discussed followed by an example of program execution as applied to gas turbine pre-stall data. Finally, limitations and nuances of the program are given for reference. This format of discussion and example execution to dynamic engine parameters will be repeated for each program in Chapters 3 through 6. It is hoped that this will provide confidence in applying the analysis software.

3.1 Data Circumspection

Before application of the analysis software, it is important that an all too frequently encountered truism "Garbage In, Garbage Out", be considered. Results of an analysis can only be as good as the data input to the program. The user of the ISAS should be familiar with the acquisition and processing of the data to be analyzed from the time it was recorded to the time it was processed into an UFTAS C-file or B-file format. Things to be aware of include aliasing, time shifting, noise, and compression.

Aliasing is the phenomenon of high frequency energy being transferred into lower frequency energy when analog signals are sampled at improper rates. Aliasing can have detrimental and dramatic effects on analysis results. To prevent this phenomenon from occurring, an anti-aliasing filter should be placed before the sampling device. An anti-aliasing filter is an analog lowpass filter of appropriate cutoff frequency such that the higher frequency energy before sampling is not aliased into the lower frequency range of interest. A graphical approach to understanding and preventing aliasing is discussed in Reference 4.

A time shift of data may occur due to several sources. Sensors, instrumentation systems, anti-aliasing filters, and data sampling may contribute to a temporal shift of one signal relative to another. Also, data processing by the AFFTC Standard Analog to Digital System (SANDS) may result in a temporal shift of digital data. These effects can be corrected by the analysis software; however, the time shifts involved must be precisely known.

Noise always creates analysis problems. Noise contamination should be eliminated or controlled at the source. Some types of noise may be filtered from the contaminated signal. This can be accomplished by the digital filtering programs contained in the analysis software package. Again, it pays to closely follow data acquisition and handling.

Data dropout can originate from many sources. The instrumentation system or data handling operations may be at fault. This phenomenon can be difficult to eliminate; however, if the source and character of the dropout are known appropriate measures can be taken before processing the data. Data dropout has an adverse affect on most of the frequency analysis results and this cannot be tolerated. Data dropout is corrected by some of the data conditioning and handling programs.

3.1.1 Example:

A discussion of the acquisition and processing of the example test data before an analysis by the interactive signal analysis software is given below. Also, the background of the propulsion system instrumentation and post-flight data acquisition system is discussed. An understanding of these systems provides insight into the flight test data and any anomalies in the data such as aliasing, time shifting, noise, or compression.

Signals from pressure, temperature, rotation, and position sensors were recorded during propulsion system flight tests. The instrumentation installed on the augmented turbofan engine is shown in Figure 3. The various parameters were measured at the locations indicated in Figure 3. Data were recorded by a low frequency response pulse code modulation (PCM) system and a high frequency response frequency modulation (FM) system. These data streams were recorded on magnetic tape aboard the aircraft during the flight test. High frequency response parameters, such as the core and bypass duct flowpath pressures, main fuel pump pressure, and the augmentor segment fuel pressures, were recorded by the FM system. Only the FM parameters are analyzed for the examples of the analysis software. The various FM parameters were filtered before digitization to prevent aliasing errors.

Data from the engine instrumentation were processed by a series of digital computer programs which produced the flight data file. This process is illustrated in Figure 4. During this process the FM parameters were digitized at a rate of 1,000 samples per second. A data base was produced which was compatible with the digital data analysis software. The data base consisted of four C-files which collectively contained ten parameters. These C-files are represented by the block of data files at the top of Figure 5. Many of the parameters analyzed as examples in the following sections have coded names that are not indicative of their origin or identity. A listing of these parameter names along with the instrumentation nomenclature is given in Table 1.

The flight test results recorded on the example C-files characterize the engine flowpath and fuel pressure fluctuations experienced prior to engine stall. Figure 5 illustrates the methodology employed to analyze the pre-stall test data. The various analysis and data transfer paths employed in the examples

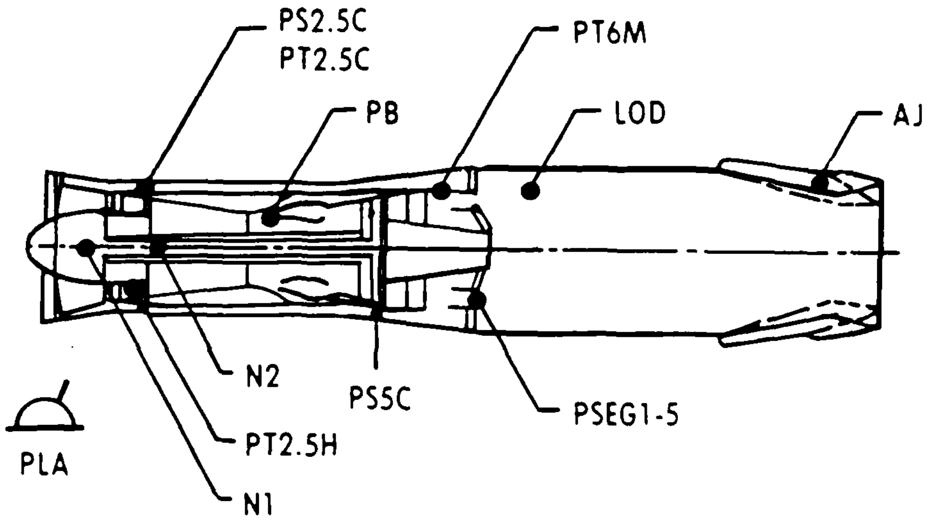


Figure 3 - Propulsion System Instrumentation

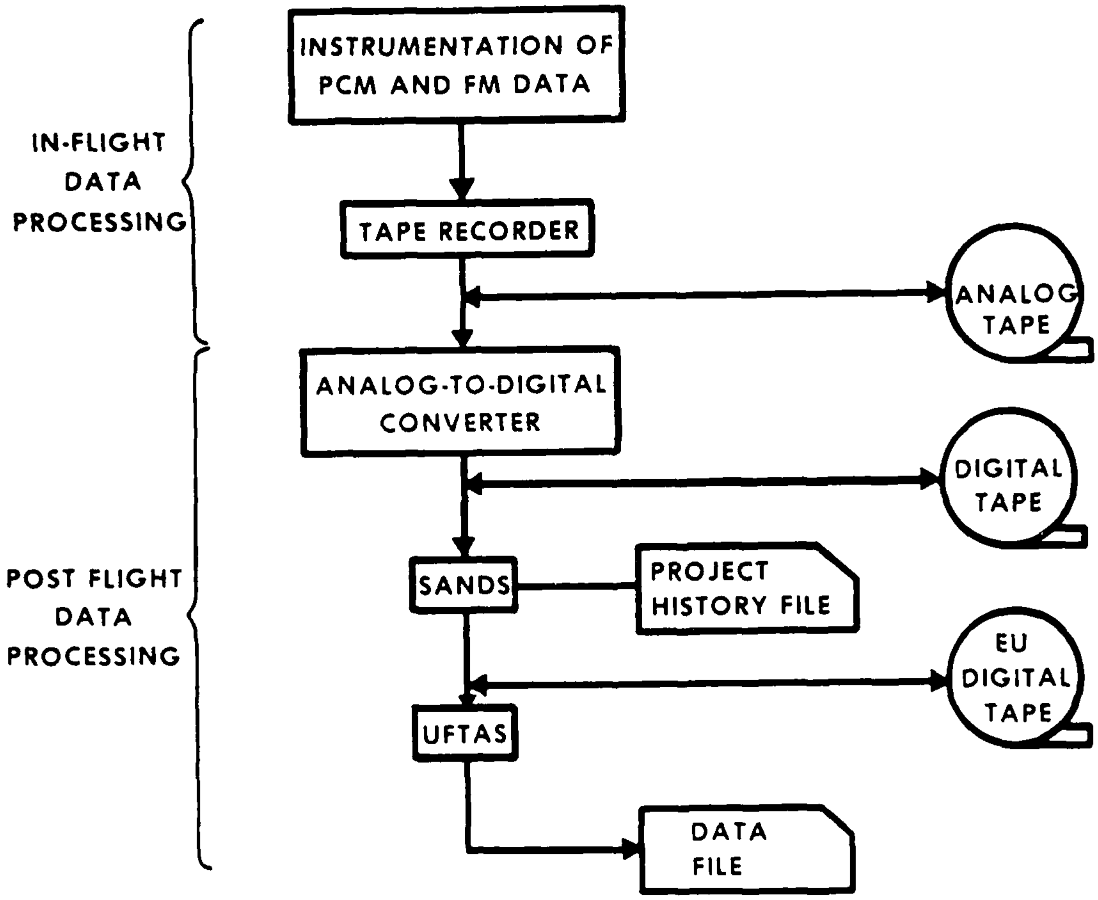


Figure 4 - Aircraft and Post-Flight Data Acquisition System

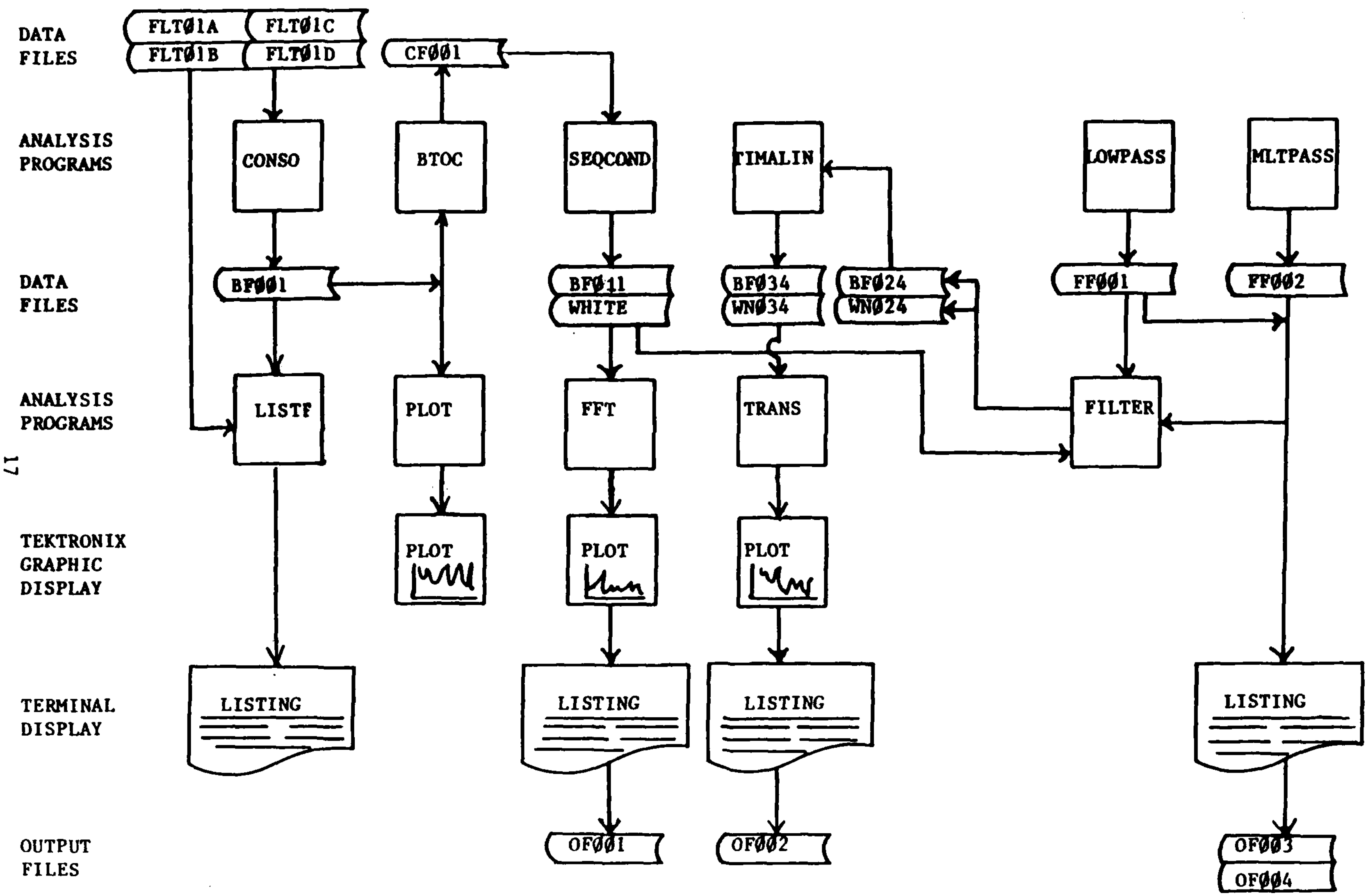


Figure 5 - Example Application of the Dynamic Signal Analysis Software

Table 1

Instrumentation and Data File Parameter Nomenclature

Instrumentation	Parameter	Description
AJ	---	exhaust nozzle area [percent]
LOD	---	augmentor light-off detector
N1	---	fan rotor speed [rpm]
N2	---	core rotor speed [rpm]
PB	PP073	core burner inlet pressure [psi]
PF4	PF4	core fuel pressure [psi]
PLA	---	power lever angle [degrees]
PSEG1	PP293	augmentor segment 1 fuel pressure [psi]
PSEG3	PP295	augmentor segment 3 fuel pressure [psi]
PSEG5	PP297	augmentor segment 5 fuel pressure [psi]
PS2.5C	PP230	fan duct static pressure [psi]
PT2.5C	---	fan duct total pressure [psi]
PT2.5H	PP227	fan core total pressure [psi]
PS5C	PP128	fan duct static pressure [psi]
PT6M	---	turbine discharge total pressure [psi]
VP025	VP025	gear box vibration [g]
VP058	VP058	power shaft vibration [g]

are indicated. These paths will be detailed by the discussion of the example application of the analysis software presented in this chapter and the following chapters.

The examples of the signal analysis software were conducted on a Tektronix graphic terminal to obtain a hard copy of the graphic display of the analysis results when appropriate. These displays augment the example discussions.

3.2 Consolidation of Parameters (CONSO)

CONSO provides the capability to consolidate several parameter time histories from one to ten C-files into one C-file or B-file. This capability is useful for combining parameter time histories which reside on many separate C-files due to previous data processing limitations or procedures. CONSO will correct moderate data dropout due to data compression.

3.2.1 Background:

CONSO was developed as the result of a requirement to consolidate parameter time histories that were resident on many separate C-files which spanned equal time periods. This situation resulted from the availability of a limited number of FM discriminators for the digititization of an analog tape. Also, CONSO was designed to correct data dropout due to data compression which may have occurred during the generation of UFTAS C-files. Data dropout due to compression was prevalent in the engine test data discussed in the examples below and resulted when a parameter did not change in value from one time point to the next. If possible, this problem should be addressed during the initial processing of data into a C-file format. However, this problem may persist and CONSO will correct moderate levels of data dropout.

The parameter merging philosophy of CONSO is illustrated in Figure 6. A maximum of ten C-files can be input to the program. The parameter time histories to be consolidated must reside on these C-files and span equal time intervals at identical sample rates. The parameter time histories can reside on any B-file section of the source C-files. A maximum of 200 parameters from the specified input B-file sections are then transferred from the input C-files and written over the common time interval to the specified output B-file or C-file. If a C-file format is chosen for the resultant time histories, the header record from the first input C-file is written as the header record for the output C-file. If data dropout is encountered during the process of transferring the parameter time histories, the previous value of the parameter is carried and used for the dropped time point. Thus, execution of CONSO will produce a consolidated timehistory data file which is free of data dropout for subsequent analysis techniques.

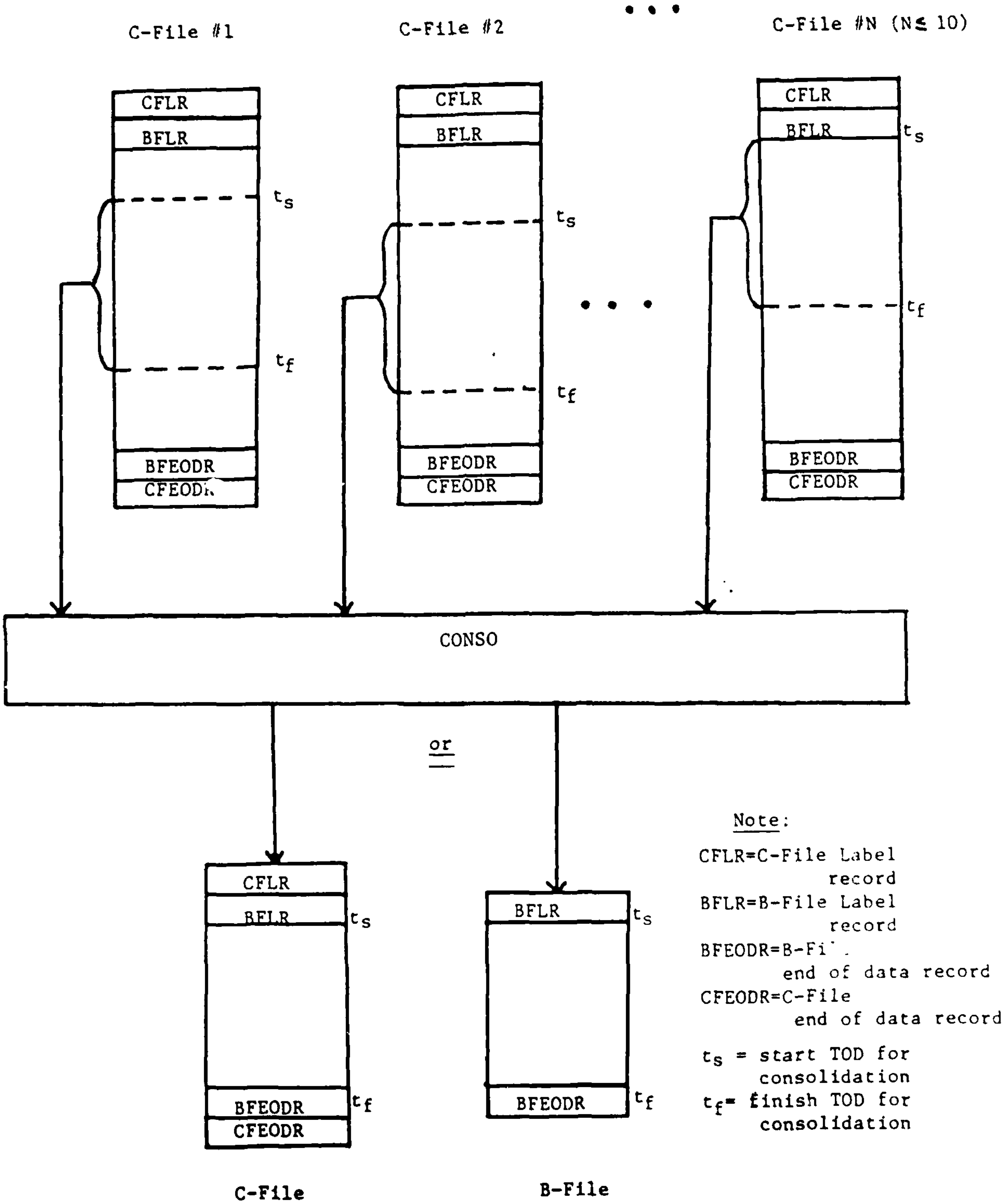


Figure 6 - C-File Consolidation Methodology Employed by CONSO

3.2.2 Input:

CONSO will consolidate parameter time histories which span identical time intervals. The parameter time histories to be consolidated must reside on C-files that are attached to the terminal local file space. These files are input to the program. Specifications requested by the program's interactive dialogue are:

- number of C-files to be consolidated
- start time-of-day for the time history interval of the parameters to be consolidated [seconds]
- finish time-of-day for the time history interval of the parameters to be consolidated [seconds]
- data sample rate [samples per second]
- names of the input C-files
- B-file section number which contains the parameters to be consolidated
- selection of a C-file or B-file output file format
- name for the output C-file or B-file

Another consolidation of parameter time histories can be performed upon consolidation of the specified C-files. If this option is selected, the above specifications must again be entered through the interactive dialogue. The utility C-file or B-file print program LISTF may be used to verify the data consolidation performed by CONSO.

3.2.3 Execution:

Interactive execution of CONSO is initiated by entering the name call load command:

CONSO

The program will respond by displaying at the terminal screen a statement of its capabilities and a prompt for an interactive dialogue. Termination of the interactive dialogue returns the terminal to the command level of NOS.

3.2.4 Output:

CONSO produces one C-file or B-file which contains the consolidated parameter time histories. This consolidated file is generated as a local file at the terminal. This file should be stored on a permanent storage device if it is desired to retain this file.

3.2.5 Example:

To facilitate handling of the engine pre-stall test data, it was desired to consolidate the parameters stored on the four C-files produced by SANDS onto one B-file. This was accomplished by utilizing CONSO as indicted by Figure 5. The parameter time histories from the four C-files named FLTØ1A, FLTØ1B, FLTØ1C, and FLTØ1D were consolidated onto one B-file named BFØØ1. This B-file was subsequently used to list, plot, and edit the parameter time histories.

The consolidation of the C-file parameters is given by a record of the interactive session with CONSO presented in Display 3. The parameter time histories from the four C-files were consolidated over the time-of-day interval from 75Ø15.ØØØ seconds to 75Ø18.5ØØ seconds. The four input C-files each consisted of one B-file section. During the consolidation and transfer of parameters, CONSO corrected data dropout. The resultant B-file named BFØØ1 was generated as a local file.

3.2.6 Limitations and nuances:

CONSO can consolidate a maximum of 2ØØ parameters. All parameters on the input C-files are consolidated onto the output C-file or B-file. Consequently, if the same parameter time history is present on more than one input C-file it will be repeated in the resultant data file.

```
*************************************************************************
*                                                                       *
*                           --- CONSO ---                               *
*                                                                       *
*       THIS PROGRAM WILL CONSOLIDATE PARAMETERS FROM MULTIPLE          *
*       C-FILE B-FILE SECTIONS. THE CONSOLIDATED PARAMETERS ARE         *
*       OUTPUT TO ONE B-FILE OR C-FILE. THIS CONSOLIDATION OCCURS       *
*       OVER A SELECTED TIME PERIOD COMMON TO ALL THE C-FILE B-FILE     *
*       SECTIONS. PROGRAM EXECUTION IS USER DIRECTED.                   *
*                                                                       *
*************************************************************************

 ENTER THE NUMBER OF C-FILES TO BE CONSOLIDATED:
? 4

 ENTER THE START TIME-OF-DAY FOR THE RESULTANT TIME HISTORY (SECONDS):
? 75015.000

 ENTER THE FINISH TIME-OF-DAY FOR THE RESULTANT TIME HISTORY (SECONDS):
? 75018.500

 ENTER THE DATA SAMPLE RATE (SAMPLES/SECOND):
? 1000

 ENTER THE NAME OF INPUT C-FILE NUMBER 1 ,
? flt01a

 ENTER THE SECTION NUMBER OF THE B-FILE TO BE CONSOLIDATED FROM C-FILE FLT01A  .
? 1

 ENTER THE NAME OF INPUT C-FILE NUMBER 2 .
? flt01b

 ENTER THE SECTION NUMBER OF THE B-FILE TO BE CONSOLIDATED FROM C-FILE FLT01B  ,
? 1

 ENTER THE NAME OF INPUT C-FILE NUMBER 3 ,
? flt01c

 ENTER THE SECTION NUMBER OF THE B-FILE TO BE CONSOLIDATED FROM C-FILE FLT01C  ,
? 1

 ENTER THE NAME OF INPUT C-FILE NUMBER 4 ,
? flt01d

 ENTER THE SECTION NUMBER OF THE B-FILE TO BE CONSOLIDATED FROM C-FILE FLT01D  ,
? 1

 OUTPUT DATA FILE FORMATS ARE

     1. B-FILE
     2. C-FILE

 ENTER THE NUMBER OF YOUR SELECTION
? 1
```

Display 3 - Example Application of the Parameter Consolidation Program CONSO

```
 ENTER A NAME FOR THE RESULTANT B-FILE.
? bf001

 CONSOLIDATED DATA WRITTEN TO LOCAL B-FILE BF001

 DO YOU WANT TO CONSOLIDATE OTHER C-FILES? (Y/N).
? n

 *** END OF PROGRAM ***

     7.250 CP SECONDS EXECUTION TIME.
/
```

Display 3 - Concluded

3.3 Conversion of a B-file to a C-file (BTOC)

BTOC converts an UFTAS data file from a B-file format to a C-file format.

3.3.1 Background:

This program is a modified version of the UFTAS utility program named BTOC which is documented in Reference 5.

3.3.2 Input:

A local file named BFILE is the primary input for BTOC. This file must contain the parameter time histories to be input in a B-file format. Additionally,a local file named INPUT can be used to specify information to be included on the output C-file header record. This information is read by BTOC through the following program records:

```
      READ (5,5,END=10) LIC,ITAIL,ITEST,FLT,DFLT,DREQ,DCOM
    5 FORMAT (A5,2X,I3,2X,I1,2X,A5,2X,A6,2X,A6,2X,A6)
      READ (5,'(10(A6))',END=20) (TITLE(I),I=1,10)
```

The variable names are documented in Reference 5. Default values for the header record parameters are:

```
LIC   = JON13
ITAIL = 123
ITEST = 1
FLT   = FLT13
DFLT  = 25DEC1
DREQ  = 25DEC1
DCOM  = 25DEC1
TITLE = THIS C-FILE CAME FROM BTOC
```

The program card of BTOC is given below for run time file substitution.

```
PROGRAM BTOC(BFILE,CFILE,INPUT,OUTPUT,TAPE1=BFILE,
        TAPE2=CFILE,TAPE5=INPUT,TAPE6=OUTPUT)
```

3.3.3 Execution:

Interactive execution of BTOC is initiated by entering the execution card statement as a command at the terminal. This name call load command is:

BTOC

Termination of BTOC returns the terminal to the command level of NOS.

3.3.4 Output:

Program messages are directed to the terminal screen.

3.3.5 Example:

It was desired to convert the consolidated engine stall time histories from a B-file to a C-file format. This format change is indicated in Figure 5. Data inspection through the data list and plot programs indicated that further data editing as well as the derivation of a new parameter was desirable before performing frequency analysis or digital filtering of the data.

Display 4 details the interactive session of BTOC which performed the data file format conversion. The B-file named BFØØ1 was converted to a C-file named CFØØ1. As Figure 5 shows, CFØØ1 was employed for further data processing.

```
btoc(bf001,cf001)
! ▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼
 ENTER BTOC (BFILE TO CFILE) UFTAS UTILITY PROGRAM


?

 NEW CFILE LABEL INFORMATION.
 JOB ORDER NUMBER =            JON13
 TAIL =                        123
 TITLE =                       THIS  CFILE CAME  FROM  BTOC
 TEST NUMBER =                     1
 FLIGHT NUMBER =               FLT13
 DATE OF FLIGHT =              25DEC1
 DATE OF REQUEST =             25DEC1
 DCOM =                        25DEC1
 EXIT BTOC (BFILE TO CFILE) UFTAS UTILITY PROGRAM
 ▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼
     2.799 CP SECONDS EXECUTION TIME
/
```

Display 4 - Example Application of the Data File Format Conversion Program BTOC

3.4 Conditioning and Derivation of Parameter Time Histories (SEQCOND)

SEQCOND conditions and derives parameter time histories from a standard UFTAS time history data file for further processing by frequency analysis, digital filter, or plot programs. Several data conditioning and manipulation options are available. These include:

1. Correction of data dropout in a time history
2. Transfer of a time history without manipulation
3. Termination of a time history with a cosine taper
4. Shift in a time history DC level
5. Amplification or attenuation of a time history
6. Generation of a derived parameter time history from the ratio or difference of two time histories

3.4.1 Background:

The data conditioning and manipulation capabilities listed above are implemented during the transfer of data from an input C-file to an output B-file. This transfer process is interactively directed by the user such that only selected parameters of interest over a specified time period are transferred to the output B-file. This strategy provides a resultant B-file which contains only time history data of interest in a form that is compatible with the various data analysis programs within the program group. The parameter time history conditioning and manipulation options of SEQCOND are discussed below.

Data dropout will be corrected automatically by SEQCOND. The program will fill in dropped data points at the appropriate data sample rate. The value of the dropped data point is set equal to the last valid data point. This procedure was adopted because data dropout has been found to be primarily due to data compression. Data dropout will be recovered if no more than 100 consecutive dropped data points are encountered. All parameter time histories which are transferred to the output B-file are corrected for data dropout.

SEQCOND provides an option to terminate a data sequence with a cosine taper which is characteristic of the signal dynamics under investigation. This feature is useful if "filter ringing" occurs upon implementation of a digital filter to a time history which has a step or spike in the signal level. Figure 7 illustrates the application of a cosine taper to a signal to eliminate a step in the signal level. The original signal is retained until the apex of the signal oscillation just prior to signal dropoff. Beyond this apex time point, the output time history consists of the cosine taper fit determined by the period and amplitude of the signal dynamics.

It may be necessary to shift the DC level of a parameter time history because of instrumentation or processing errors or for

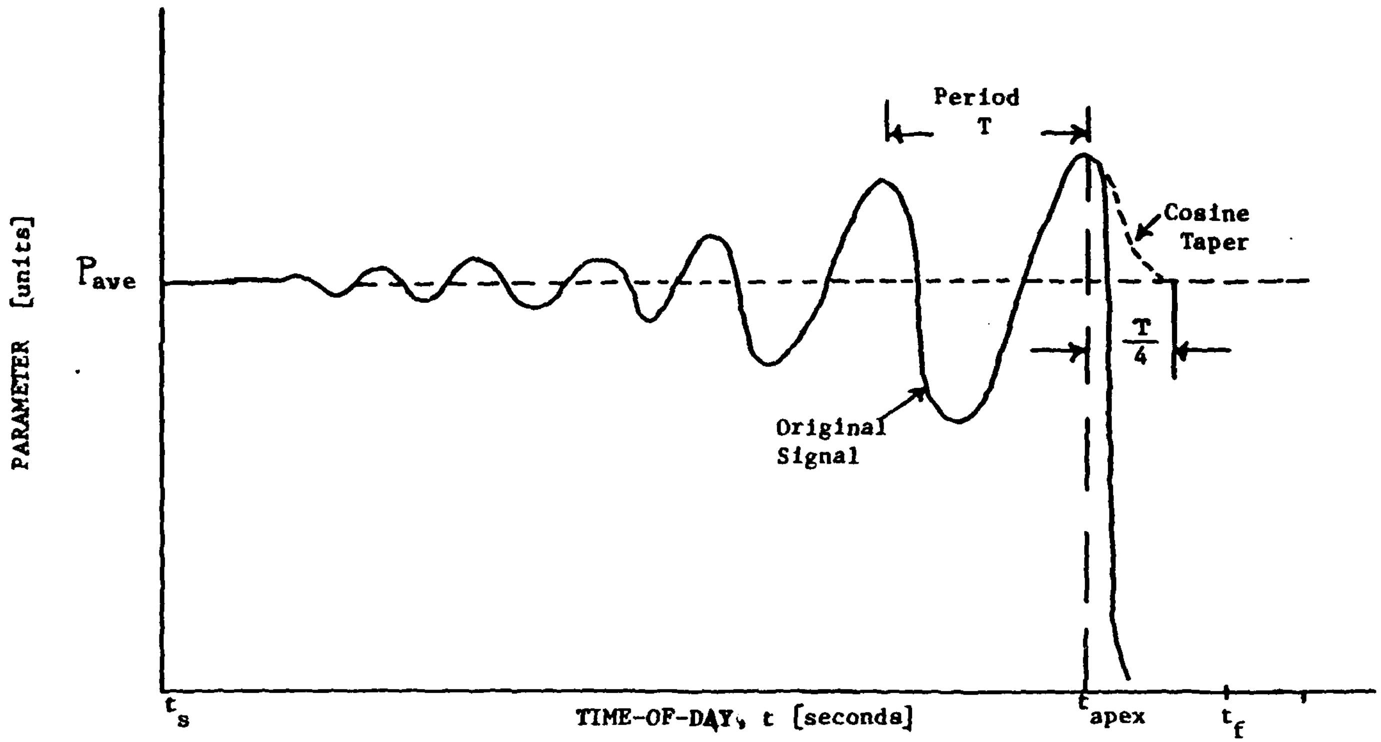


Figure 7 - Application of Cosine Taper to Signal Dropoff

comparative analysis with another signal. Similarly, a requirement may be to amplify or attenuate a time history sequence. SEQCOND provides this capability which is directed by the program user when the data time histories are transferred from a C-file to a B-file format. These time history conditioning options are only applied to the selected interval of the time history for output to the B-file.

SEQCOND also provides a means of deriving a parameter time history from existing parameter time histories. Currently, two options are available for deriving a parameter. These are the derivation of the ratio of two time histories or the difference between two time histories. The derived parameter time histories are appended to the transferred time histories on the output B-file.

3.4.2 Input:

Parameter time histories to be transferred, manipulated, or derived must reside on a single C-file. This C-file must be attached to the terminal local file space since this data file is input into SEQCOND. The program's interactve dialogue is divided into three sections. These three sections require input for general processing of the parameters, input for transferring of selected parameters, and input for deriving parameter time histories.

Specifications requested by the first section of the program's interactive dialogue which concerns general processing information include:

- name of the C-file which contains the parameter time histories to be processed
- section number of the B-file which contains the parameter time histories
- number of parameters to be transferred or manipulated
- number of parameters to be derived
- sample rate of the parameter time histories [samples per second]
- start time-of-day for the output B-file [seconds]
- finish time-of-day for the output B-file [seconds]
- name for the resultant B-file

Specifications requested by the second section of SEQCOND's interactive dialogue which concerns transferred parameter information are:

- name of the parameters to be transferred
- DC bias (if desired) [parameter units]
- amplification or attenuation factor (if desired)
- option of sequence termination with a cosine taper

If the cosine taper option is selected, additional requested specifications are:

- approximate time-of-day of the signal step or spike apex [seconds]
- approximate period of the signal dynamics [seconds]

Specifications requested by the third section of the program's interactive dialogue which concerns derived parameter information include:

- name for the derived parameter
- selection between a ratio of parameters or a difference between parameters to form the derived parameter time history
- reference parameter numbers (these are supplied by SEQCOND in the second section of the interactive dialogue)

Upon conditioning and manipulating specified parameters from the input C-file, other time histories may be conditioned and transferred to a B-file from another C-file. If this is desired, the above specifications must again be entered into the program.

3.4.3 Execution:

Interactive execution of SEQCOND is initiated by entering the name call load command:

SEQCOND

The program will respond with a statement of its capabilities and a prompt for an interactive dialogue. Termination of SEQCOND returns the terminal to the command level of NOS.

3.4.4 Output:

SEQCOND produces a B-file which contains the parameter time histories which were transferred, manipulated, or derived from the parameters available on the input C-file.

3.4.5 Example:

The parameter time histories contained in C-file CF001 were further conditioned and edited by SEQCOND. Also, SEQCOND was employed to derive a parameter from the ratio of two pressure parameters contained in CF001. A cosine taper was applied to the transferred parameter time histories to eliminate data dropoff and subsequently prevent filter ringing. The transferred time histories were trimmed in length to 1024 points which captured the pre-stall dynamics of interest. As Figure 5 indicates, the transferred and derived parameters were output on B-file BF011 which was used for input to the frequency analysis and digital filtering programs.

The execution and dialogue of SEQCOND is exemplified in Display 5 which is a record of an interactive session. In section 1 of SEQCOND, general specifications concerning the parameters to be processed were given. These parameters were input from section 1 of C-file CF001. Two parameters were transferred and one parameter was derived from these parameters. The sample rate of the B-file parameters was specified as 1000 samples per second. Also, start and finish times-of-day for the resultant time histories were specified to be 75017.001 seconds and 75018.024 seconds respectively. It was desired to name the output B-file BF011.

Section 2 of SEQCOND required specifications of the parameters that were to be transferred or manipulated from the input C-file. For each of the transferred parameters, PP128 and PP227, a DC bias level and amplification or attenuation factor was required. Parameters PP128 and PP227 were transferred unchanged with a DC bias of 0 and an amplification factor of 1 over the selected time period. However, a cosine taper was applied to these parameters. PP128 and PP227 were terminated with a cosine taper at an apex point of the signal dynamics which occurred at a time-of-day of 75017.802 seconds. The period of the signal dynamics at this point was approximately 0.019 seconds.

SEQCOND serially assigns a parameter number to the transferred time histories. This parameter number is referenced by section 3 of SEQCOND which calculates derived parameters.

Section 3 of SEQCOND required specifications for the parameter time histories that were to be derived from the transferred parameters. Parameter PD001 was derived from the ratio of transferred parameter numbers 1 and 2, PP128/PP227.

The three resultant parameter time histories were written to the specified B-file BF011. This B-file was output as a member of the terminal local file space. The effect of the cosine taper upon the termination of parameters PP128 and PP227 is illustrated by plots of their time histories which were obtained at the terminal through the plot program PLOT.

3.4.6 Limitations and Nuances:

Data transfer from the input C-file can include a maximum of 50 parameters. From these 50 parameters a maximum of 25 parameters can be derived parameters. This limitation is system dependent and may be alleviated in the future. Also, data dropout cannot exceed 100 successive samples in a parameter time history.

```
▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼
▼                                                                  ▼
▼                          --- SEQCOND ---                         ▼
▼                                                                  ▼
▼         THIS PROGRAM WILL MANIPULATE PARAMETER TIME HISTORIES INPUT ▼
▼         FROM A C-FILE AND RECOVER MODERATE DATA DROPOUT. SEQUENCE   ▼
▼         CONDITIONING OPTIONS AVAILABLE ARE,                      ▼
▼                                                                  ▼
▼              1. SHIFT IN SEQUENCE DC LEVEL                        ▼
▼              2. SEQUENCE AMPLIFICATION OR ATTENUATION             ▼
▼              3. RATIO OR DIFFERENCE OF DATA SEQUENCES             ▼
▼              4. SEQUENCE TERMINATION WITH COSINE TAPER            ▼
▼                                                                  ▼
▼         OUTPUT IS DIRECTED TO A USER SPECIFIED B-FILE            ▼
▼                                                                  ▼
▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼


THIS PROGRAM CONSISTS OF THREE SECTIONS WHICH ARE.

   1. INQUIRY FOR GENERAL DATA PROCESSING PARAMETERS.
   2. INQUIRY FOR TRANSFERRED PARAMETERS TO BE READ FROM A LOCAL C-FILE AND
      MODIFIED (IF APPROPRIATE). THESE PARAMETERS ARE THEN WROTE TO A LOCAL
      B-FILE.
   3. INQUIRY FOR THE DERIVATION OF PARAMETERS FROM PARAMETERS ON THE LOCAL
      C-FILE. THESE PARAMETERS ARE THEN WROTE TO A LOCAL B-FILE.


PRESS THE SPACE BAR AND THEN THE RETURN KEY TO CONTINUE.
?
```

Display 5 - Example Application of the Data Condition and Derivation Program SEQCOND

```
SECTION 1. GENERAL INQUIRY FOR PROCESSING PARAMETERS.

ENTER THE NAME OF THE LOCAL C-FILE WHICH CONTAINS THE PARAMETERS TO BE
MANIPULATED.
? cf001

ENTER THE SECTION NUMBER OF THE B-FILE WHICH CONTAINS THE DATA.
? 1

ENTER THE NUMBER OF PARAMETERS TO BE ANALYZED FROM THE B-FILE.
? 2

ENTER THE NUMBER OF PARAMETERS TO BE DERIVED FROM B-FILE PARAMETERS.
? 1

ENTER THE B-FILE PARAMETER SAMPLE RATE (SAMPLES/SECOND).
? 1000

ENTER THE DESIRED START TIME-OF-DAY (SECONDS) FOR THE RESULTING B-FILE.
? 75017.001

ENTER THE DESIRED FINISH TIME-OF-DAY (SECONDS) FOR THE RESULTING B-FILE.
? 75018.024

ENTER A NAME FOR THE LOCAL B-FILE WHICH RECIEVES THE RESULTANT DATA SEQUENCES.
? bf011
```

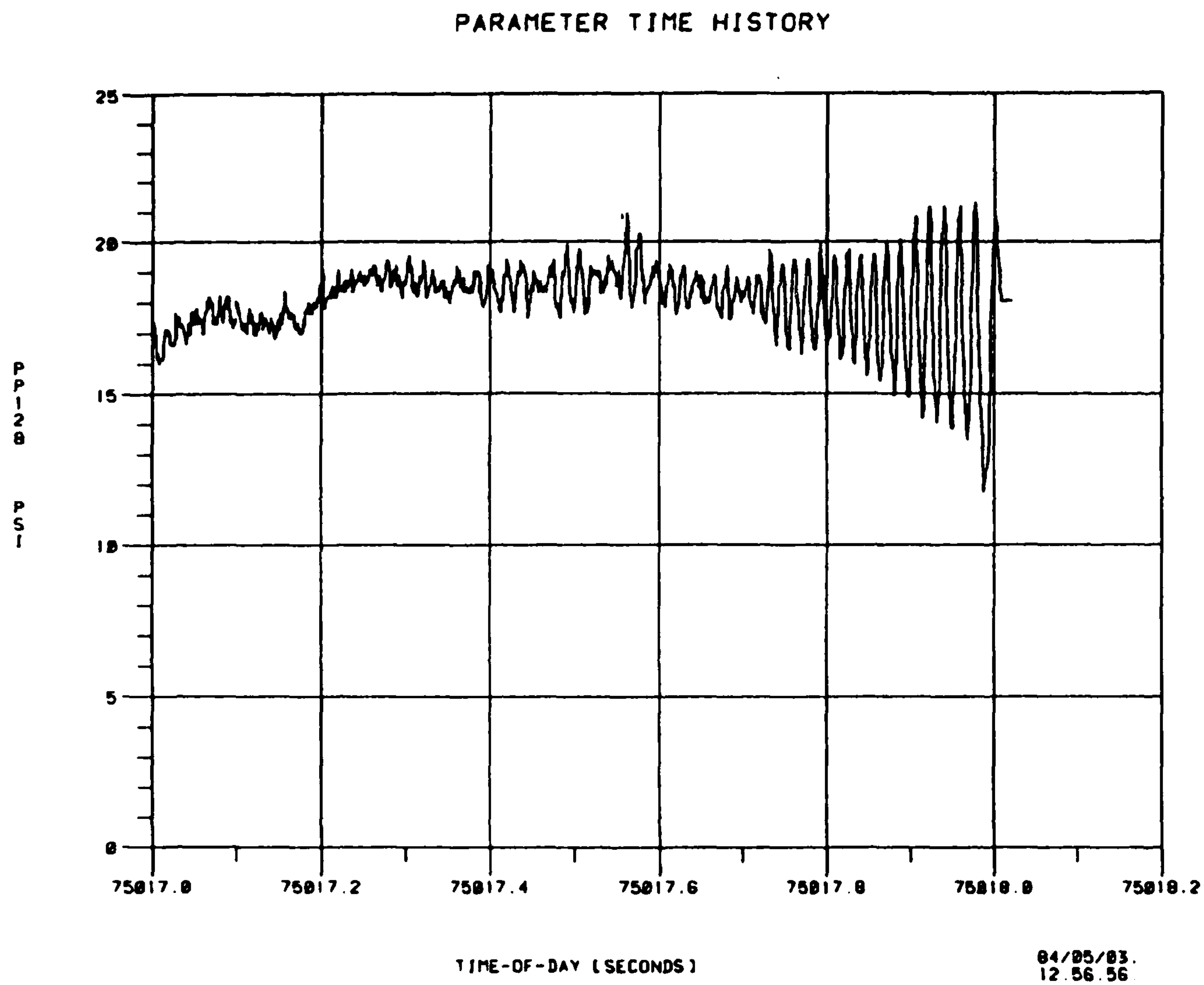
Display 5 - Continued

```
SECTION 2. INQUIRY FOR TRANSFERRED PARAMETERS.


TRANSFERRED B-FILE PARAMETER NUMBER 1 .

ENTER THE NAME OF THIS PARAMETER.
? pp128

ENTER A DC BIAS (0 IF NONE DESIRED).
? 0

ENTER THE VALUE OF AN AMPLIFICATION OR ATTENUATION FACTOR (1 IF NONE DESIRED).
? 1

DO YOU WANT SEQUENCE TERMINATION WITH A COSINE TAPER? (Y/N).
? y

ENTER THE TIME-OF-DAY OF THE SIGNAL APEX (SECONDS).
? 75018.002

ENTER THE APPROXIMATE PERIOD OF SIGNAL DYNAMICS (SECONDS).
? 0.019

TRANSFERRED B-FILE PARAMETER NUMBER 2 .

ENTER THE NAME OF THIS PARAMETER.
? pp227

ENTER A DC BIAS (0 IF NONE DESIRED).
? 0

ENTER THE VALUE OF AN AMPLIFICATION OR ATTENUATION FACTOR (1 IF NONE DESIRED).
? 1

DO YOU WANT SEQUENCE TERMINATION WITH A COSINE TAPER? (Y/N)
? y

ENTER THE TIME-OF-DAY OF THE SIGNAL APEX (SECONDS)
? 75018.002

ENTER THE APPROXIMATE PERIOD OF SIGNAL DYNAMICS (SECONDS).
? 0.019
```

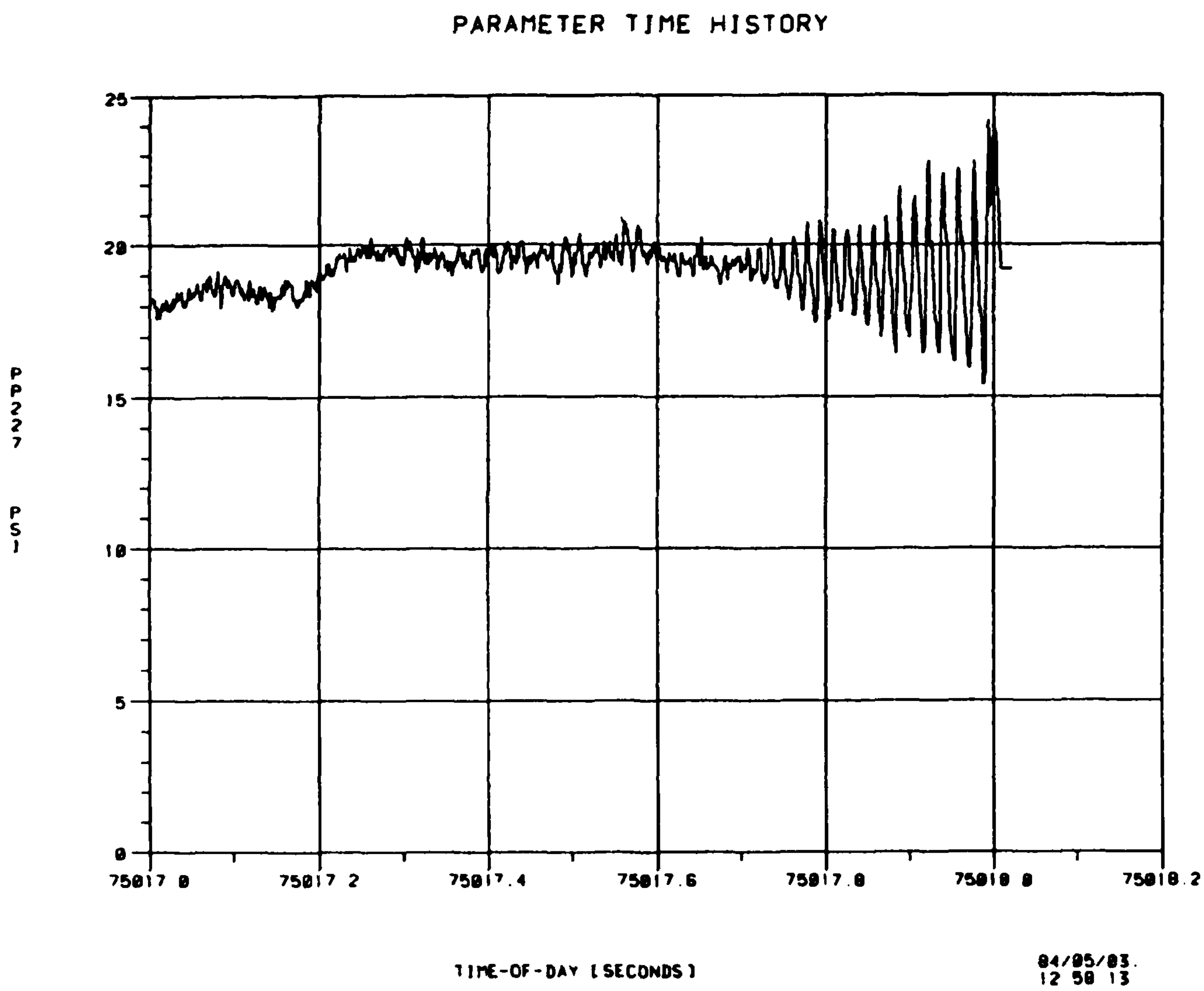
Display 5 - Continued

```
 SECTION 3. INQUIRY FOR DERINED PARAMETERS.


 DERIVED PARAMETER NUMBER: 1

 ENTER A NAME FOR THE DERIVED PARAMETER:
? pd001

 DATA MANIPULATION OPTIONS ARE:
     1. RATIO OF 2 PARAMETERS (A/B)
     2. DIFFERENCE BETWEEN 2 PARAMETERS (A-B)

 ENTER THE NUMBER OF THE DATA MANIPULATION OPTION:
? 1

 ENTER THE TRANSFERRED PARAMETER NUMBER FOR PARAMETER A:
? 1

 ENTER THE TRANSFERRED PARAMETER NUMBER FOR PARAMETER B:
? 2

 OUTPUT DIRECTED TO LOCAL FILE, BF011

 DO YOU WANT TO PROCESS ANOTHER C-FILE? (Y/N):
? n

  *** END OF PROGRAM ***

     2.238 CP SECONDS EXECUTION TIME.
/
```

Display 5 - Continued



Display 5 - Continued



Display 5 - Concluded

3.5 Temporal Alignment of a Data Sequence (TIMALIN)

TIMALIN provides a means of time shifting parameter time histories. This capability is useful for the temporal alignment of a time history to correct for time delays and phase lags introduced by instrumentation systems and unmatched filters.

3.5.1 Background:

TIMALIN is based upon a frequency response analysis (FRA) capability provided by the FRA program TSHFT which is documented in Reference 6. TIMALIN produces a time history which is lagged or advanced relative to the input time history. A time shift lead is given by,

$$x(t_o) = x(t_i+a)$$

where $x(t_o)$ is the output time history shifted by time a and $x(t_i)$ is the input time history. Similarly, a time shift lag is given by,

$$x(t_o) = x(t_i-a)$$

The temporal shift of the input time history is accomplished by first applying a fast Fourier transform to the time history. The resulting Fourier coefficients are then phase shifted according to the desired time shift. An inverse fast Fourier transform is then applied to the shifted Fourier coefficients to restore a time history of shifted data.

The input time history must be bandlimited. Also, TIMALIN requires that the input time history consist of a number of points which is a power of two. TIMALIN will automatically zero fill an input time history to the next power of two if this requirement is not met.

3.5.2 Input:

TIMALIN requires that the time history to be temporally shifted reside on a B-file at the terminal local file space. Specifications requested by TIMALIN through the interactive dialogue are:

- name of B-file which contains the parameter time history to be time shifted
- name of the parameter to be time shifted
- start time-of-day of the time history [seconds]
- finish time-of-day of the time history [seconds]
- sample rate of the time history [samples per second]
- desired time shift (positive for lead, negative for lag) [seconds]
- name of the output B-file to contain the shifted parameter
- option to write the shifted parameter as a unique

parameter or to overwrite the input parameter with the shifted parameter

If the shifted parameter is to be output as an unique parameter, additional requested information is:

- name of the shifted parameter time history

Upon time shifting one parameter, if it is desired to shift another parameter, the above specifications must be entered again.

3.5.3 Execution:

Interactive execution of TIMALIN is initiated by entering the name call load command:

TIMALIN

The program will respond with a statement of its capabilities and a prompt for an interactive dialogue. Termination of TIMALIN returns the terminal to the command level of NOS.

3.5.4 Output:

TIMALIN produces a local B-file which contains the shifted time history as a unique parameter.

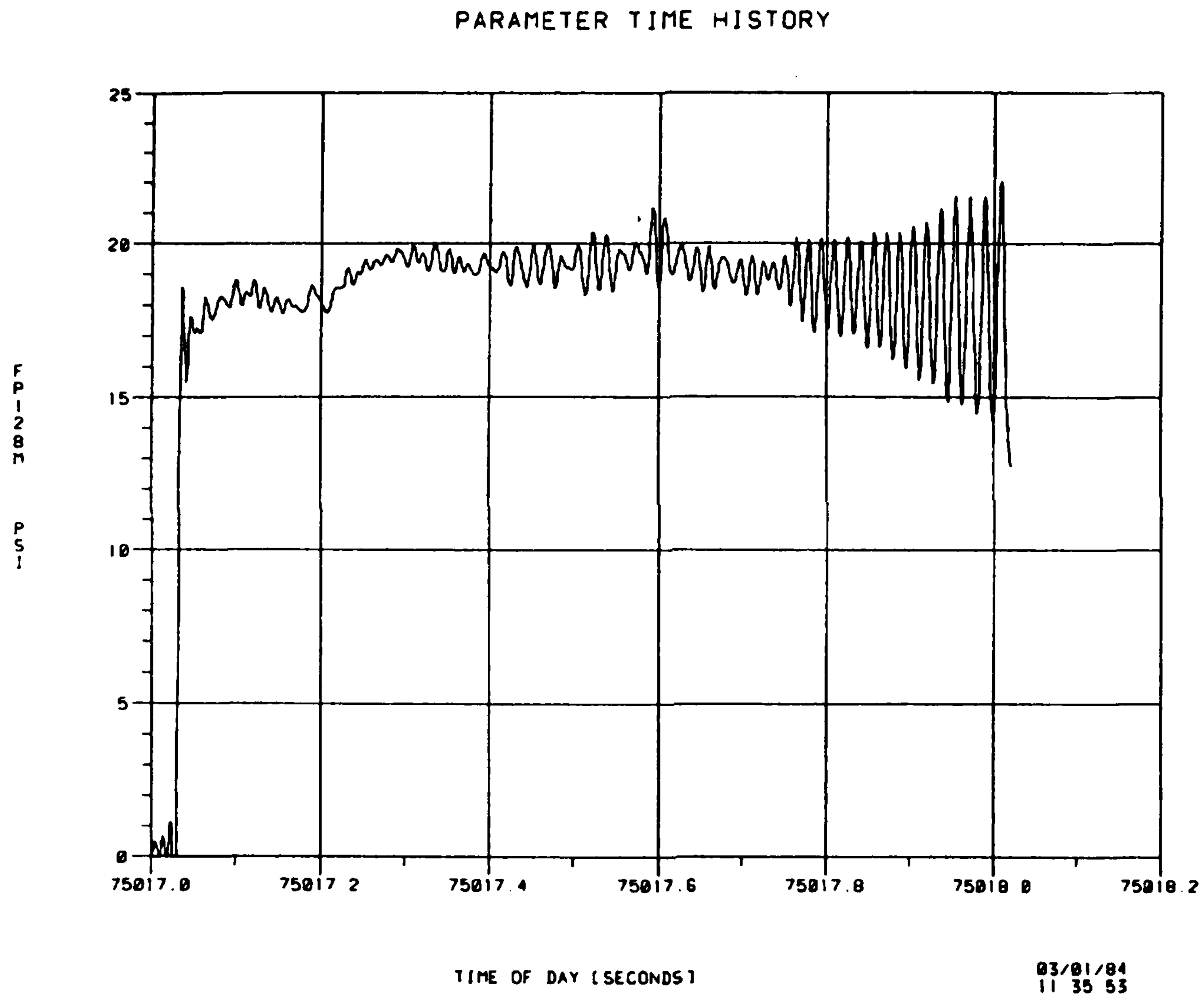
3.5.5 Example:

After the digital filtering of parameter time histories, it may be desirable to correct a time delay in the time histories due to the linear phase response of the filter. As Figure 5 indicates, the parameter time histories filtered by FILTER through the MLTPASS filter design were temporally realigned by TIMALIN. This restored the filtered parameter time histories into alignment with the unfiltered parameters. This facilitated analysis of the time histories in the time domain.

The execution and dialogue of TIMALIN is exemplified in Display 6 through its application to the filtered parameter FP128M contained on the B-file named BF024. FP128M was shifted by a time lag of 0.032 seconds over the interval time-of-day from 75017.001 seconds to 75018.024 seconds. As Sections 6.2 and 6.3 discuss, the application of the MLTPASS filter design to the parameter PP128 resulted in a time history FP128M that was shifted forward in time by 0.032 seconds relative to the input time history. The corrected time history was output as a unique parameter named SP128M and written to the local B-file BF031. The effect of TIMALIN is shown in the plots of parameters FP128M and SP128M which are presented in Display 6.

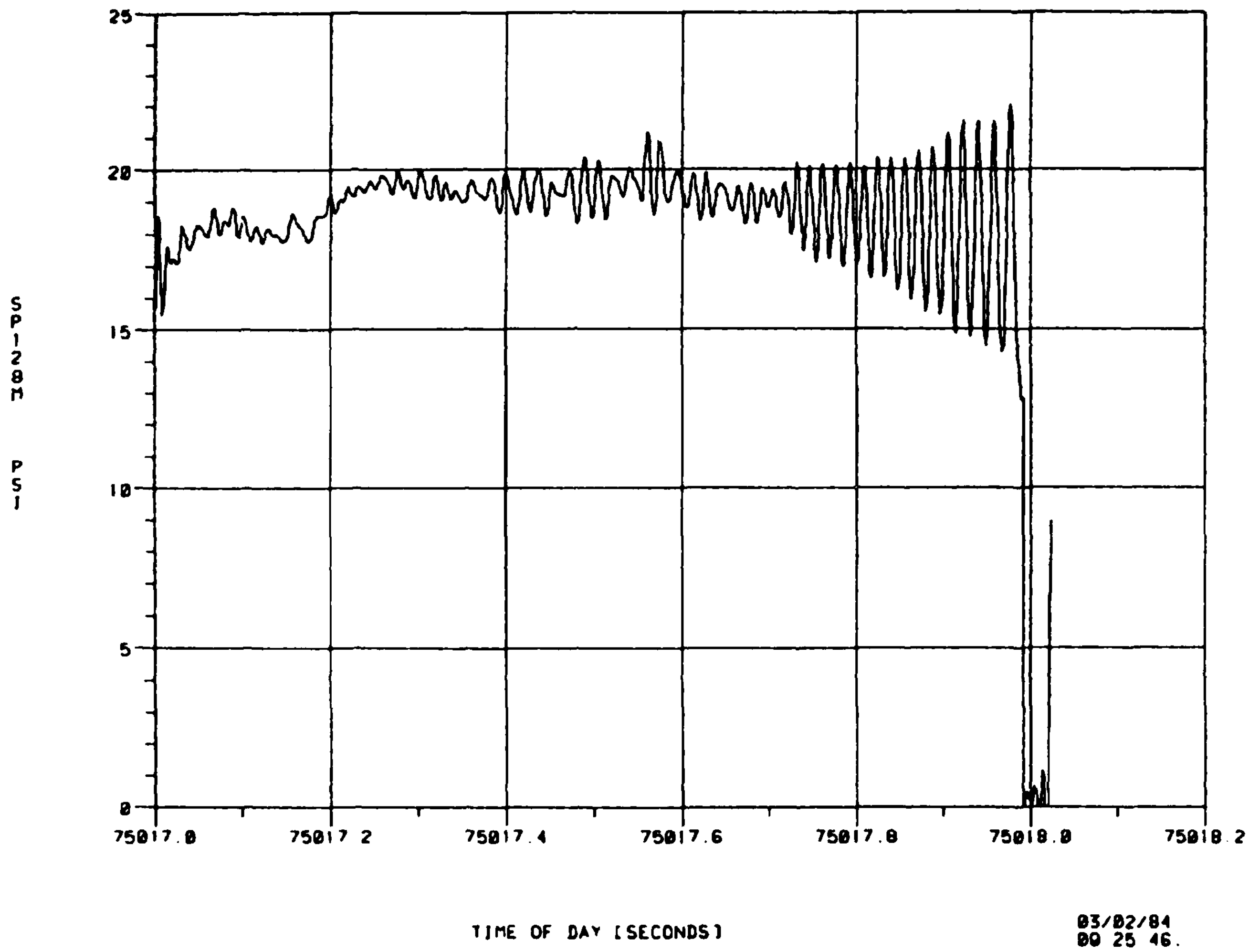
```
***************************************************************************
*                                                                         *
*                           --- TIMALIN ---                               *
*                                                                         *
*        THIS PROGRAM WILL PRODUCE AN OUTPUT TIME HISTORY WHICH IS        *
*        TIME SHIFTED RELATIVE TO THE INPUT TIME HISTORY. THE TIME        *
*        SHIFTED DATA CAN BE OUTPUT ON THE INPUT B-FILE AS AN ADDI-       *
*        TIONAL PARAMETER OR IT CAN BE WROTE OVER THE INPUT PARAMETER.    *
*        THE INPUT SIGNAL MUST BE BANDLIMITED AND NOT WINDOWED.           *
*        PROGRAM EXECUTION IS USER DIRECTED.                              *
*                                                                         *
***************************************************************************

 ENTER THE NAME OF  HE INPUT B-FILE
? bf024

 ENTER THE NAME OF THE PARAMETER TO BE TIME SHIFTED
? fp128m

 ENTER THE SEQUENCE START TIME-OF-DAY (SECONDS),
? 75017 001

 ENTER THE SEQUENCE FINISH TIME-OF-DAY (SECONDS):
? 75018.024

 ENTER THE SEQUENCE SAMPLE RATE (SAMPLES/SECOND),
? 1000

 ENTER DESIRED TIME SHIFT FOR FP128M      (SECONDS):
? 0.032

 ENTER A NAME FOR THE OUTPUT B-FILE:
? bf031

 THE SHIFTED DATA SEQUENCE WILL BE OUTPUT ON B-FILE BF031
 SEQUENCE OUTPUT OPTIONS ARE:

      1  WRITE THE OUTPUT SEQUENCE OVER THE INPUT SEQUENCE
      2  WRITE THE OUTPUT SEQUENCE AS AN ADDITIONAL PARAMETER

 ENTER THE NUMBER OF YOUR SELECTION:
? 2

 THE OUTPUT SHIFTED SEQUENCE WILL BE AN ADDITIONAL PARAMETER
 ENTER A NAME TO BE GIVEN TO THE SHIFTED SEQUENCE:
? sp128m

 DO YOU WANT TO SHIFT ANOTHER TIME SEQUENCE? (Y/N)
? n

 *** END OF PROGRAM ***

     1 754 CP SECONDS EXECUTION TIME
/
```

Display 6 - Example Application of the Temporal Alignment Program TIMALIN



Display 6 - Continued

PARAMETER TIME HISTORY



Display 6 -- Concluded

4 DATA LIST AND DISPLAY PROGRAM GROUP

The data list and display program group contains software which lists and plots parameter time histories. As Figure 2 indicates, these programs obtain parameter time histories from UFTAS C-files and B-files. These programs also produce output in the form of a graphical display at a Tektronix graphic terminal or a listing which can be displayed at the terminal screen and written to a local file for printing at a printer.

4.1 List of a Parameter Time History (LISTF)

LISTF is a C-file or B-file time history print program. LISTF will write a listing of the input file to the terminal screen or to a local file for printing at a remote site.

4.1.1 Background:

LISTF is a modified version of an UFTAS utility program named LISTBC. LISTBC is documented in Reference 4. LISTF provides options which enable the specification of the data print rate, the parameters to be printed, and the format of the printed data. These options are specified through an execution command. This command enables interactive execution of the program. Batch execution of LISTF is possible and is also documented in Reference 4.

4.1.2 Input:

Input to LISTF is provided through an execution command which is entered at the terminal and begins interactive execution of the program. The execution command is of the form:

```
LISTF (FILE,PR=n1,PC=n2,SD=n3)
```

where,

FILE = name of the local file which contains the parameters to be listed. Default is the local file named CFILE.

PR = print rate which specifies every n1th point to be printed. Default is n1=1 which prints every data point.

PC = flag to indicate that only specified parameters are to be printed. If n2=0 (default) all the parameters on the specified B-file or C-file are printed. If n2=1 the names of parameters to be printed are read from a local file named INPUT. The names of the parameters are specified on this file in free format in columns 1 through 80 with a blank or comma as terminators. An example for file INPUT is:

```
*EOR
P1 P2
P3,P4
P5
*EOR
```

This results in the parameters P1, P2, P3, P4, and P5 being printed, provided that they exist on the input local file.

SD = flag to indicate the number of significant digits for the printed data values. If n3=0 (default), 5 significant digits are printed.

The arguments of the LISTF execution command are optional.

4.1.3 Execution:

Interactive execution of LISTF is initiated by entering the execution command at the terminal. If execution defaults are invoked, then list is executed by entering the name call load command:

LISTF

A listing of the parameter time histories will be directed to the terminal screen. The program card of LISTF is given below for run time file substitution.

```
PROGRAM LISTF(CFILE,TAPE1=CFILE,INPUT,OUTPUT,
        TAPE5=INPUT,TAPE6=OUTPUT,TAPE99)
```

Termination of LISTF returns the terminal to the command level of NOS.

4.1.4 Output:

If run time file substitution is not employed, a formatted listing will be directed to the terminal screen.

4.1.5 Example:

As Figure 4 illustrates, UFTAS produced a data base compatible with the digital signal analysis software. This data base consists of C-files. A listing of the parameter time histories obtained from the engine pre-stall test data using LISTF was desired for a cursory inspection of the data. Data processing anomalies such as data dropout were detected from these listings. Also, at many intermediate steps in the example data analysis it was advantageous to obtain a listing of a parameter time history for inspection at the terminal screen.

Utilization of LISTF for the pre-stall data is indicated in Figure 5. List was employed to list the data base C-files as shown by Display 7. A listing of the parameters PP230 and PP127 contained on C-file FLT01B was obtained at the terminal screen at the specified print rate of 100 (i.e. print every 100th point). LISTF was also employed to confirm the consolidation of parameters performed by CONSO as discussed in Section 3.2. Display 8 is a record of the interactive usage of LISTF to produce a listing of the consolidated B-file BF001 at the terminal screen. The ten consolidated parameters are listed at a print rate of 1,000.

```
list(f(1);0lb,pr=100)

1
1

*******************************************************************************************************
ENTER LISTBC (LIST B OR C FILE) UFTAS UTILITY PROGRAM

------------------------------------------------------
THE PRINT RATE IS  100
------------------------------------------------------


CFILE LABEL RECORD INFORMATION.

JON=                   JON13
TAIL=                  123
TITLE=                 THIS      CFILE     CAME      FROM      BTOC
TEST=                     1
FLIGHT=                FLT13
FLIGHT DATE=           25DEC1
DATE REQUEST=          25DEC1

------------------------------------------------- SECTION NO.   1 -------------------------------------------------
SECTION=                  1
REMARKS=               FILE W    RITTEN    BY SA     MPLE

START TIME=      75015.000
STOP TIME=       75018.500
NUMBER OF PARAMETERS=    2


--- PARAMETER LIST ---
NUM   PARAMETER      STATUS
---   ---------      ------
  1   PP230          PRINTED
  2   PP127          PRINTED
1
 POINT      TIME          1 PP230       2 PP127



     1    75015.000        16.5988      274.8546
   100    75015.000        16.4727      272.5660
   200    75015.100        16.4411      267.8000
   300    75015.200        16.4727      267.2290
   400    75015.300        15.4321      267.8000
   500    75015.400        14.9590      260.9380
   600    75015.500        15.6843      263.2256
   700    75015.600        15.9681      261.7005
   800    75015.700        16.5988      260.9380
   900    75015.800        16.5673      266.2758
  1000    75015.900        15.9366      259.4120
  1100    75016.000        15.5897      265.7030
  1200    75016.100        15.7159      255.6001
  1300    75016.200        16.0043      267.0384
  1400    75016.300        16.5988      272.5660
```

Display 7 - Example Application of the Parameter Listing Program LISTF to a C-File

1500	75016.400	18.4411	267.0000
1600	75016.500	15.6043	262.4831
1700	75016.600	16.0637	250.6035
1800	75016.700	15.1700	261.1206
1900	75016.800	15.3050	264.1700
2000	75016.900	16.0627	264.1700
2100	75017.000	16.4411	270.2702
2200	75017.100	16.0511	272.3763
2300	75017.200	17.4502	270.6673
2400	75017.300	17.8206	277.1422
2600	75017.400	16.0511	283.2426
2600	75017.500	17.4818	282.4801
2700	75017.600	16.9467	281.5260
2800	75017.700	16.4727	276.3707
2000	75017.800	14.5006	282.4801
3000	75017.900	18.3647	246.4495
3100	75018.000	7.1071	224.5261
3200	75018.100	9.1253	240.3491
3300	75018.200	8.7784	248.1652
3400	75018.300	8.6523	244.9244
3500	75018.400	9.4001	252.5400

EXIT LISTBC (LIST B OR C FILE) UFTAS UTILITY PROGRAM
▼▼

1.491 CP SECONDS EXECUTION TIME.

Display 7 - Concluded

```
listf(bf001,pr=1000)

T
I

VVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVV
ENTER LISTBC (LIST B OR C FILE) UFTAS UTILITY PROGRAM

--------------------------------------------------
THE PRINT RATE IS 1000
--------------------------------------------------

BFILE LABEL RECORD INFORMATION.

-------------------------------------------------- SECTION NO.   1 --------------------------------------------------
SECTION=                1
REMARKS=              FILE V    RITTEN     BY SA    MPLE

START TIME=      75015.000
STOP TIME=       75018 500
NUMBER OF PARAMETERS=   10

--- PARAMETER LIST ---
NUM   PARAMETER      STATUS
---   ---------      ------
  1   PP073          PRINTED
  2   PP203          PRINTED
  3   VP025          PRINTED
  4   PP230          PRINTED
  5   PP127          PRINTED
  6   PP207          PRINTED
  7   VP058          PRINTED
  8   PP128          PRINTED
  9   PP227          PRINTED
 10   PP205          PRINTED
1
 POINT     TIME         1 PP073       2.PP203       3 VP025       4.PP230      5.PP127      6 PP207      7.VP058
 8.PP128



    1     75015 000      102 0025      166.7720          5351      16.5088     274.8546      16.8373       7 9563
   17.8574
 1000     75015.900       90.2267      246.6828        - 0430      15.9366     259.4120      12.8745       7 4213
   16.4731
 2000     75016 900       90.7804      250.8503       -1.9183      16.0627     264.1788      14.9858       8.8363
   17.3816
 3000     75017 900       96.3302      107.7234       -3 5887      18.3647     246.4405     237.5733       7.6213
   18.0305
1
 POINT     TIME         9 PP227      10.PP205
```

Display 8 - Example Application of the Parameter Listing Program LISTF to a B-File

```
      1    75815.000        18.3855       20.0000
   1000    75815.000        17.4830       23.1342
   2000    75816.000        18.1440      280.2414
   3000    75817.000        21.6746      266.1464

EXIT LISTBC (LIST B OR C FILE) UFTAS UTILITY PROGRAM
VVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVVV
     1.533 CP SECONDS EXECUTION TIME.
```

Display 8 - Concluded

4.2 Plot of a Parameter Time History (PLOT)

PLOT will display a plot of a B-file parameter time history on the screen of a Tektronix graphic terminal.

4.2.1 Background:

PLOT provides a plot of a B-file time history through interactive commands entered at a Tektronix graphic terminal. The user can dynamically modify the resultant plot. This capability provides a means to examine in detail many aspects of signal dynamics and to estimate characteristics of the dynamics such as the amplitude and period of oscillations.

4.2.2 Input:

The parameter time histories to be plotted must reside on B-files which are attached to the terminal local file space. These files are input to PLOT. Specifications required by the program's interactive dialogue include:

- model number of the Tektronix graphic terminal
- name of the B-file which contains the time history to be plotted
- name of the parameter to be plotted
- units of the parameter
- data sample rate [samples per second]
- plot start time-of-day [seconds]
- plot finish time-of-day [seconds]
- option to print a line of remark at the top of the plot
- option to invoke automatic scaling of the plot ordinate

If manual scaling of the plot was selected, additional required specifications are:

- maximum value of the plot ordinate
- minimum value of the plot ordinate

The maximum and minimum value of the plot abscissa are determined by the plot start and finish times-of-day.

4.2.3 Execution:

Interactive execution of PLOT is initiated by entering the name call load command:

PLOT

The program will respond with a statement of its capabilities and a prompt for an interactive dialogue. Termination of PLOT will return the terminal to the command level of NOS.

4.2.4 Output:

PLOT produces a plot of a parameter time history on the screen of a Tektronix graphic terminal. A copy of the plot can be obtained through the usage of a Tektronix hard copy unit.

4.2.5 Example:

Plots of the FM parameter time histories revealed details of augmentor transient phenomena which preceded engine stall. An understanding of the onset of pressure fluctuations was facilitated by the high digitization rate of 1000 samples per second.

The plot of two B-file parameters is exemplified by an interactive session of PLOT as given by Display 9. The parameters PP128 and PP227 were input from the B-file named BF001 and plotted on the screen of a Tektronix graphic terminal. This is indicated in Figure 5. The parameter time histories were plotted over a time-of-day interval from 75015.000 seconds to 75018.500 seconds. Automatic scaling was chosen for parameter PP128 while the plot ordinate of parameter PP227 was manually scaled from 0 psi to 25 psi.

The plots of Display 9 show the onset of pressure fluctuations in the fan duct which immediately preceded engine stall at approximately 75018 seconds. During this period of time, augmentor fuel system parameters indicated stabilized fuel flow. Also duct flow pressure oscillations were observed at the high pressure compressor inlet but not at the exit of the high pressure compressor. This information suggested that the large amplitude pressure oscillations may be associated with a combustion instability of the augmentor. This situation is summarized by a compilation of time histories presented in Figure 8. The elapsed time interval in Figure 8 corresponds to the times-of-day in Display 9 from 75017.200 seconds to 75018.200 seconds.

The augmentor transient time histories have suggested several phenomena which involve oscillations of the augmentor fuel delivery system and induced oscillations of the fan and core flowpath. These phenomena appear very similar, occur within short time intervals, and result in different operational anomalies. It was not certain by viewing the data time histories if the pressure oscillations in the engine flowpaths resulted from the same phenomena, coupled phenomena, or separate mechanisms. A quantitative method for analyzing the time history data was needed. One approach was to analyze the time history data in the frequency domain. This approach is exemplified in Chapter 5.

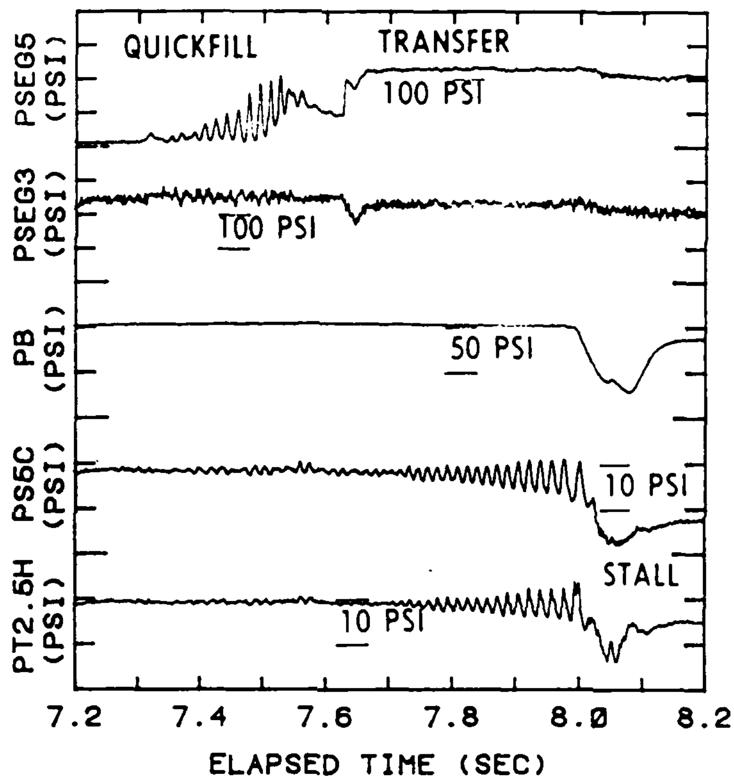
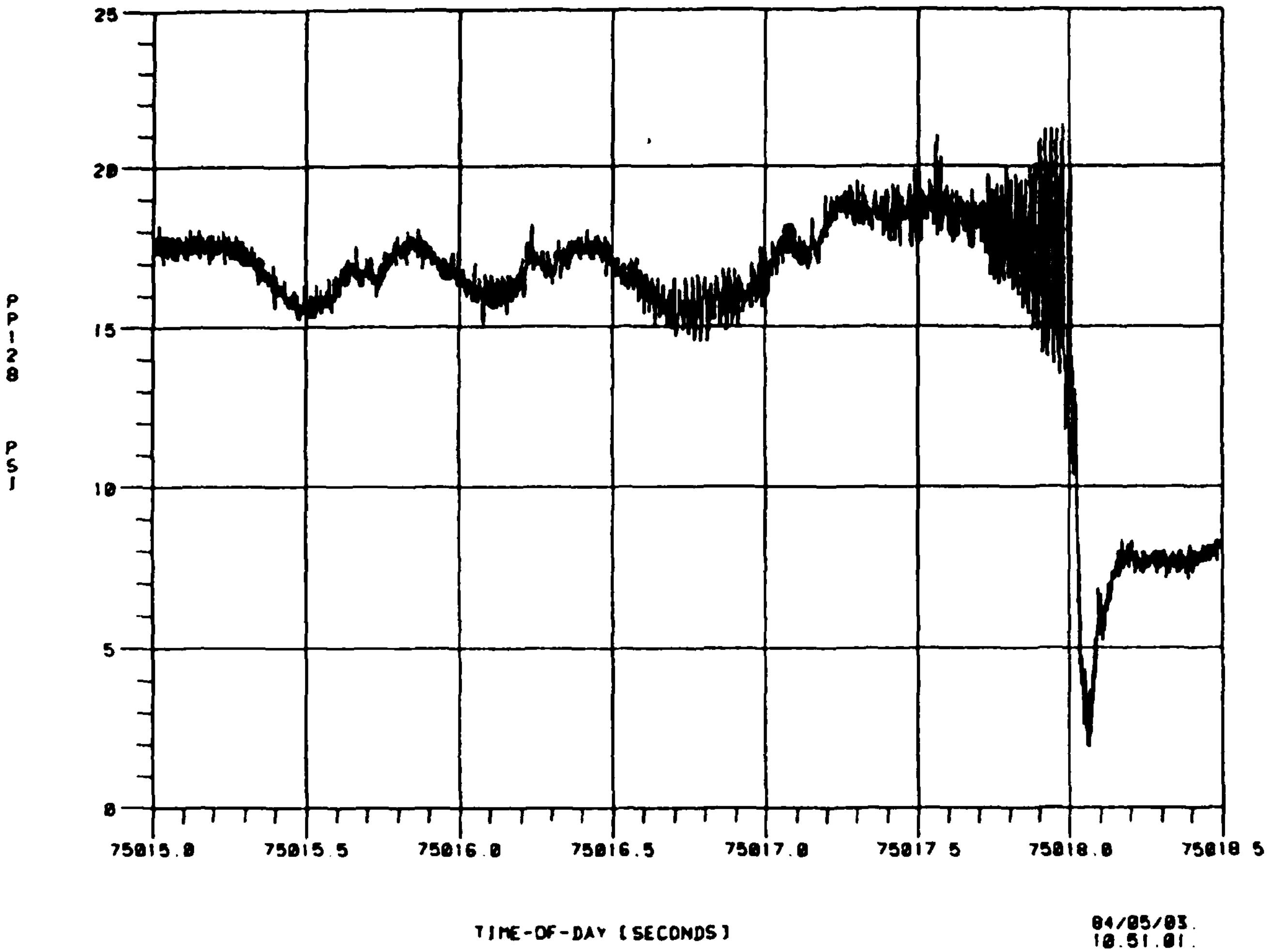


Figure 8 - Time History of FM Data Preceding Engine Stall

```
********************************************************************************
*                                                                              *
*                                --- PLOT ---                                  *
*                                                                              *
*        THIS INTERACTIVE PROGRAM WILL PLOT A USER SPECIFIED PARAMETER         *
*        SEQUENCE VERSUS TIME. THIS SEQUENCE MUST BE IN A B-FILE FORMAT.       *
*        PLOT PARAMETERS ARE USER DIRECTED.                                    *
*                                                                              *
********************************************************************************


                              *** PLEASE NOTE ***

A PLOT OF A B-FILE SEQUENCE TIME HISTORY CAN BE DISPLAYED ON YOUR SCREEN IF YOU
ARE USING A TEKTRONIX GRAPHIC TERMINAL. PLOTS ARE NOT DISPLAYED ON YOUR SCREEN
IF YOU ARE USING ANY OTHER TYPE OF TERMINAL (EG. TELERAY /11, ETC.) IF YOU ARE
NOT AT A GRAPHIC TEKTRONIX TERMINAL ABORT PROGRAM EXECUTION.


 ENTER THE MODEL NUMBER OF YOUR TEKTRONIX GRAPHIC TERMINAL :
? 4054

 ENTER THE NAME OF THE INPUT B-FILE CONTAINING THE DATA SEQUENCE TO BE PLOTTED:
? bf001

 ENTER THE NAME OF THE PARAMETER TO BE PLOTTED FROM B-FILE BF001 :
? pp128

 ENTER THE UNITS OF PARAMETER PP128
? psi

 ENTER THE DATA SAMPLE RATE (SAMPLES/SECOND)
? 1000

 ENTER THE PLOT START TIME-OF-DAY (SECONDS).
? 75015.000

 ENTER THE PLOT FINISH TIME-OF-DAY (SECONDS).
? 75018 500

 DO YOU WANT TO PRINT A LINE OF REMARK ON THE PLOT? (Y/N)
? n

 DO YOU WANT AUTOMATIC SCALING OF THE PLOT? (Y/N):
? y

********************************************************************************

             TO BEGIN PLOT VIEWING OR TO ADVANCE TO ANOTHER PLOT,
             PRESS THE SPACE BAR THEN THE RETURN KEY ONCE.

********************************************************************************
```

Display 9 - Example Application of PLOT to a B-File Parameter Time Histories

PARAMETER TIME HISTORY

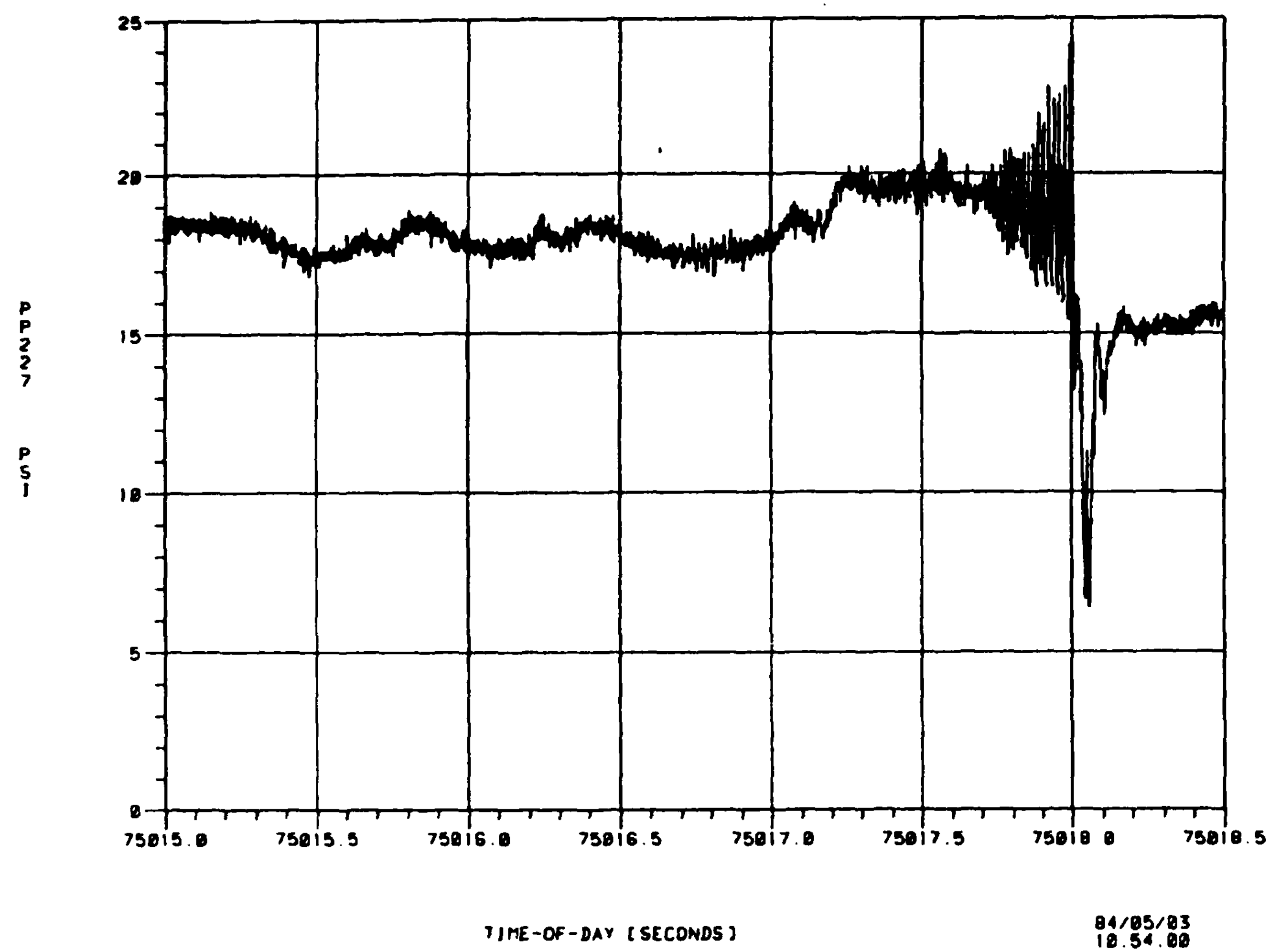


Display 9 - Continued

```
DO YOU WANT TO PLOT ANOTHER SIGNAL TIME HISTORY? (Y/N).
? y

ENTER THE NAME OF THE INPUT B-FILE CONTAINING THE DATA SEQUENCE TO BE PLOTTED.
? bf001

ENTER THE NAME OF THE PARAMETER TO BE PLOTTED FROM B-FILE BF001    .
? pp227

ENTER THE UNITS OF PARAMETER PP227        :
? psi

ENTER THE DATA SAMPLE RATE (SAMPLES/SECOND).
? 1000

ENTER THE PLOT START TIME-OF-DAY (SECONDS):
? 75015.000

ENTER THE PLOT FINISH TIME-OF-DAY (SECONDS):
? 75018.500

DO YOU WANT TO PRINT A LINE OF REMARK ON THE PLOT? (Y/N):
? n

DO YOU WANT AUTOMATIC SCALING OF THE PLOT? (Y/N).
? n

ENTER THE PLOT ORDINATE MAXIMUM VALUE FOR PP227        :
? 25

ENTER THE PLOT ORDINATE MINIMUM VALUE FOR PP227        .
? 0.

********************************************************************************

           TO BEGIN PLOT VIEWING OR TO ADVANCE TO ANOTHER PLOT,
           PRESS THE SPACE BAR THEN THE RETURN KEY ONCE.

********************************************************************************
```

Display 9 - Continued

PARAMETER TIME HISTORY



Display 9 - Continued

```
DO YOU WANT TO PLOT ANOTHER SIGNAL TIME HISTORY? (Y/N).
? n
 *** END OF PROGRAM ***
     0.112 CP SECONDS EXECUTION TIME.
/
```

Display 9 - Concluded

5 FREQUENCY ANALYSIS PROGRAM GROUP

Some characteristics of the mechanisms underlying dynamic data are not easily determined in the time domain. It can be more appropriate to transform the parameter time history into the frequency domain and analyze the data. The frequency analysis program group contains software which transforms time domain data into the frequency domain. This transformation provides a range of analysis capabilities. Two such capabilities are the determination of the variation of amplitude, phase, and power spectral density of a parameter time history with frequency and the determination of the transfer function between two parameter time histories.

5.1 Fast Fourier Transform (FFT)

FFT performs a transformation of a parameter time history into the frequency domain through the usage of the fast Fourier transform. The variation of amplitude, phase, and power spectral density (PSD) with frequency of a time history is determined by a fast Fourier transform of the parameter time history. FFT is based upon an algorithm documented in Reference 7 and implemented in Reference 6.

5.1.1 Background:

FFT performs a fast Fourier transform on a segment of a parameter time history. The fast Fourier transform results in a series of complex values known as the spectral components of the time history. These spectral components occur at discrete frequencies and are evaluated at n/2+1 points, where n is the length of the data sequence. The spectral components are complex with an amplitude and phase (real and imaginary part) associated with each spectral component. The amplitude squared spectrum is utilized to derive the power spectral density of the sequence which has the units of energy per unit frequency. The amplitude, phase, and PSD of a parameter time history are calculated over an appropriate frequency spectrum which is dependent upon the length of the data sequence.

The fast Fourier transform algorithm requires that the data sequence to be analyzed consist of a number of points which is equal to a power of two. If the input data sequence does not meet this requirement then two options are available. The first option is to truncate the parameter time history to a number of points equal to a power of two before analyzing the data sequence. The second option is to input the parameter time history unchanged and FFT will zero fill the time history to generate a data sqeuence with a number of points equal to two. FFT will automatically check for the power of two criterion and proceed will the zero fill if necessary.

Leakage of spectral estimates into adjacent frequencies results when a time history sequence that has been truncated is analyzed in the frequency domain. Data windows can be employed to reduce this leakage. Most time history data input into FFT will be truncated due to the power of two criterion. To compensate for this, FFT provides the option to apply a Hann window to the input data sequence to reduce the impact of truncation effects.

5.1.2 Input:

The parameter time history to be analyzed by FFT must be resident on a local B-file. This B-file is employed to transfer the data sequence to the analysis program. Specifications required by the interactive dialogue of FFT are:

- model number of the Tektronix graphic terminal (if employed)
- name of the input B-file
- name of the parameter to be analyzed
- units of the parameter
- data sample rate [samples per second]
- analysis start time-of-day [seconds]
- number of points to be analyzed (power of two)
- option to apply a Hann window
- option to plot and/or list results

Depending on the options selected, additional required specifications may include:

- name of a output file to contain analysis results
- selection between graphs of amplitude, phase, or PSD with frequency
- maximum value of the plot ordinate
- minimum value of the plot ordinate

Plots produced by FFT follow the conventions and format associated with the time history plot program PLOT discussed in Section 4.2.

5.1.3 Execution:

Interactive execution of FFT is initiated by entering the name call load command:

FFT

The program will respond with a statement of its capabilities and a prompt for an interactive dialogue. As indicated above, FFT can be executed at a Tektronix graphic terminal or a nongraphic type of terminal. Plots of the analysis results can only be obtained from a Tektronix graphic terminal. Beyond this restriction execution of FFT is not dependent on the type of terminal employed by the user.

5.1.4 Output:

FFT can be directed to output analysis results to the terminal screen and/or to a specified local output file. FFT can also display plots of the analysis results on the screen of a Tektronix graphic terminal. A permanent record of the plotted results can be obtained through the usage of a Tektronix hard copy unit.

5.1.5 Example:

FFT was employed to analyze the pre-stall engine data in the frequency domain. Figure 5 indicates the example application of FFT to the time history data contained in B-file BF024. Program output consisted of a listing and graphic display of the analysis results on the Tektronix terminal screen. Also, a listing of the results was directed to the output file OF001.

Display 10 details the example application of FFT. Parameter PP128 was input through B-file BF011. The sample rate of PP128 was specified as 1,000 samples per second. The fast Fourier transform analysis was initiated at the time-of-day equal to 75017.800 seconds and included 64 data points. This time interval captured the signal dynamics of interest. The data sequence did not require zero filling; however, a Hann window was employed to reduce leakage of the spectral estimates into adjacent frequencies. A listing of the analysis results was directed to the terminal screen and the output file. Display 10 presents the plots of the analysis results that were displayed on the terminal screen.

The plots of Display 10 show that pre-stall pressure oscillations were dominant at a frequency of 60 Hertz. It was suspected that the resultant fan stall was caused by an augmentor combustion instability which back-pressured the fan. A combustion instability of this type is typically characterized by longitudinal mode frequencies of 50 to 100 Hertz. Augmentor rumble was further suspected since the amplitude of the pressure fluctuations were measured to be greatest at station 5 in the fan duct. This is shown by Figure 9 which illustrates a comparison of power spectral density plots obtained at various engine locations.

A path of propagation of the pressure oscillations was suggested by a comparison of the amplitudes of the PSD at the characteristic frequency of the combustion instability for the various measured flowpath parameters. Figure 9 indicates that the source of the pressure oscillations was in the augmentor. The pressure oscillations propagated upstream in the fan duct. Upon reaching the fan face, the pressure oscillations propagated further upstream and downstream through the engine core components. However, the pressure oscillations were absorbed by the high pressure compressor. This resulted in stable pressure levels at the core burner inlet.

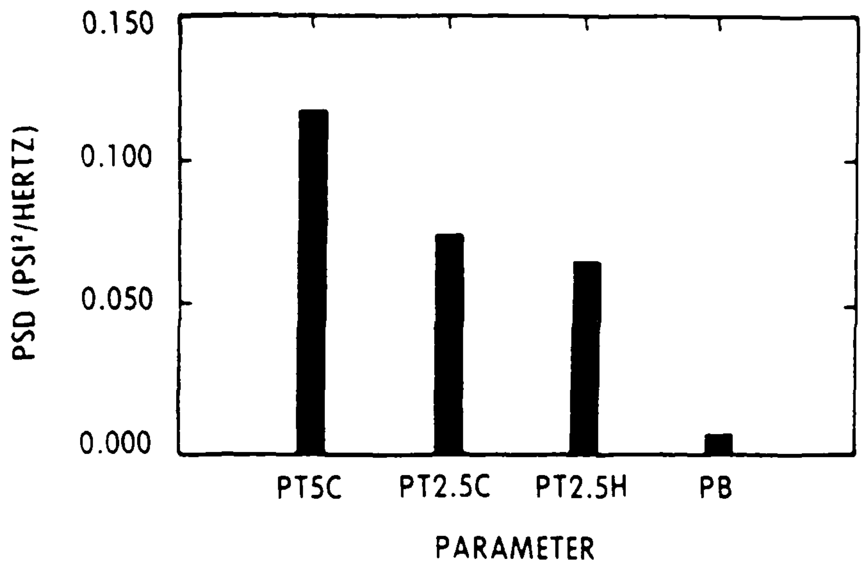


Figure 9 - Power Spectral Density of Fan and Core Flowpath Parameters Preceding Engine Stall

The utility of the FFT analysis program can be realized as a primer for the application of a digital filter to enhance the signal dynamics of interest. FFT was employed for the purpose of identifying the range of frequencies of interest in the engine pre-stall dynamics. As the plots of Display 10 indicate, this range of frequencies is from 20 Hertz to 100 Hertz. This information was utilized for the design of the lowpass and multiple pass digital filters in Sections 6.1 and 6.2.

5.1.6 Limitations and nuances:

FFT can accept a maximum of 512 points from a parameter time history.

```
*****************************************************************************
*                                                                           *
*                               --- FFT ---                                 *
*                                                                           *
*        THIS INTERACTIVE PROGRAM WILL PERFORM A FAST FOURIER TRANSFORM     *
*        ON AN INPUT B-FILE PARAMETER SEQUENCE WHICH IS A FUNCTION OF TIME. *
*        OUTPUT IS DIRECTED BY YOU TO BE LISTED OR PLOTTED.                 *
*                                                                           *
*****************************************************************************

                           *** PLEASE NOTE ***

A PLOT OF A B-FILE SEQUENCE TIME HISTORY CAN BE DISPLAYED ON YOUR SCREEN IIF YOU
ARE USING A TEKTRONIX GRAPHIC TERMINAL. PLOTS ARE NOT DISPLAYED ON YOUR SCIREEN
IF YOU ARE USING ANY OTHER TYPE OF TERMINAL (EG. TELERAY 711, ETC.). IF YOIU ARE
NOT AT A GRAPHIC TEKTRONIX TERMINAL, DO NOT REQUEST A PLOT OF THE RESULTS.

IF YOU ARE USING A TEKTRONIX GRAPHIC TERMINAL, ENTER THE MODEL NUMBER.
IF YOU ARE NOT USING A TEKTRONIX TERMINAL, ENTER 0.
? 4054

ENTER THE NAME OF THE LOCAL B-FILE WHICH CONTAINS THE DATA TO BE ANALYZED.
? bf011

ENTER THE NAME OF THE PARAMETER TO BE ANALYZED FROM B-FILE BF011    :
? pp128

ENTER THE UNITS OF PARAMETER PP128
? psi

ENTER THE DATA SAMPLE RATE (SAMPLES/SECOND).
? 1000

ENTER THE ANALYSIS START TIME-OF-DAY (SECONDS):
? 75017 800

ENTER THE NUMBER OF POINTS DESIRED FOR THE ANALYSIS SEQUENCE (MAXIMUM=512) .
? 64

DO YOU WANT TO APPLY THE HANN WINDOW FUNCTION? (Y/N)
? y

DO YOU WANT A LISTING OF THE FFT RESULTS? (Y/N)
? y

THE FOLLOWING LIST OPTIONS ARE AVAILABLE

     1  LIST TO THE TERMINAL SCREEN ONLY
     2  WRITE TO A LOCAL OUTPUT FILE
     3. LIST TO THE SCREEN AND WRITE TO AN OUTPUT FILE

ENTER THE NUMBER OF YOUR SELECTION:
? 3

ENTER A NAME FOR THE OUTPUT FILE.
? of001
```

Display 10 - Example Application of the Fast Fourier Transform Program FFT

```
******************************************************************************
*                                                                            *
*                     RESULTS OF FAST FOURIER TRANSFORM                      *
*                                                                            *
******************************************************************************
```

PARAMETER= PP120 SEQUENCE START TOD= 75017.000 SECONDS
SAMPLE RATE= 1000 SAMPLES/SECOND SEQUENCE LENGTH= 64 POINTS

FREQUENCY [HERTZ]	AMPLITUDE [UNITS]	PHASE [DEGREES]	PSD [UNITS SQRD/HERTZ]
.00000E+00	.26657E-01	.00000E+00	.45480E-04
.15625E+02	.70231E-01	.33016E+02	.31568E-03
.31250E+02	.72718E-01	-.17224E+02	.33842E-03
.46875E+02	.33014E+00	-.36825E+02	.69754E-02
.62500E+02	.80834E+00	-.41046E+02	.51648E-01
.78125E+02	.57066E+00	-.43345E+02	.20842E-01
.93750E+02	.40602E-01	-.37301E+02	.15746E-03
.10938E+03	.23753E-02	.32375E+02	.36108E-06
.12500E+03	.11656E-01	-.40967E+02	.86953E-05
.14063E+03	.24380E-01	-.81840E+01	.38067E-04
.15625E+03	.24805E-01	.31330E+02	.39379E-04
.17188E+03	.20800E-01	.36680E+02	.27713E-04
.18750E+03	.10624E-01	.36432E+02	.72231E-05
.20313E+03	.19178E-01	-.70595E+02	.23538E-04
.21875E+03	.15636E-01	-.35280E+02	.15646E-04
.23438E+03	.31102E-01	.71467E+02	.61910E-04
.25000E+03	.35234E-01	-.76274E+02	.70452E-04
.26563E+03	.22473E-01	-.35740E+02	.32322E-04
.28125E+03	.69074E-02	-.59476E+02	.30535E-05
.29688E+03	.29677E-01	-.45866E+02	.56365E-04
.31250E+03	.54016E-02	-.51263E+02	.18673E-05
.32813E+03	.32056E-01	-.41893E+02	.65764E-04
.34375E+03	.21157E-01	-.39125E+02	.28648E-04
.35938E+03	.70032E-02	-.31292E+02	.31389E-05
.37500E+03	.27702E-01	-.54244E+02	.49114E-04
.39063E+03	.36370E-01	-.61991E+02	.84657E-04
.40625E+03	.93307E-02	-.22060E+02	.55827E-05
.42188E+03	.19012E-01	.27285E+02	.23134E-04
.43750E+03	.28426E-01	-.86092E+01	.51713E-04
.45313E+03	.42061E-02	-.46887E+02	.11812E-05
.46875E+03	.23730E-01	-.22665E+02	.36038E-04
.48438E+03	.26680E-01	-.64484E+02	.45588E-04
.50000E+03	.38725E-03	.00000E+00	.05978E-08

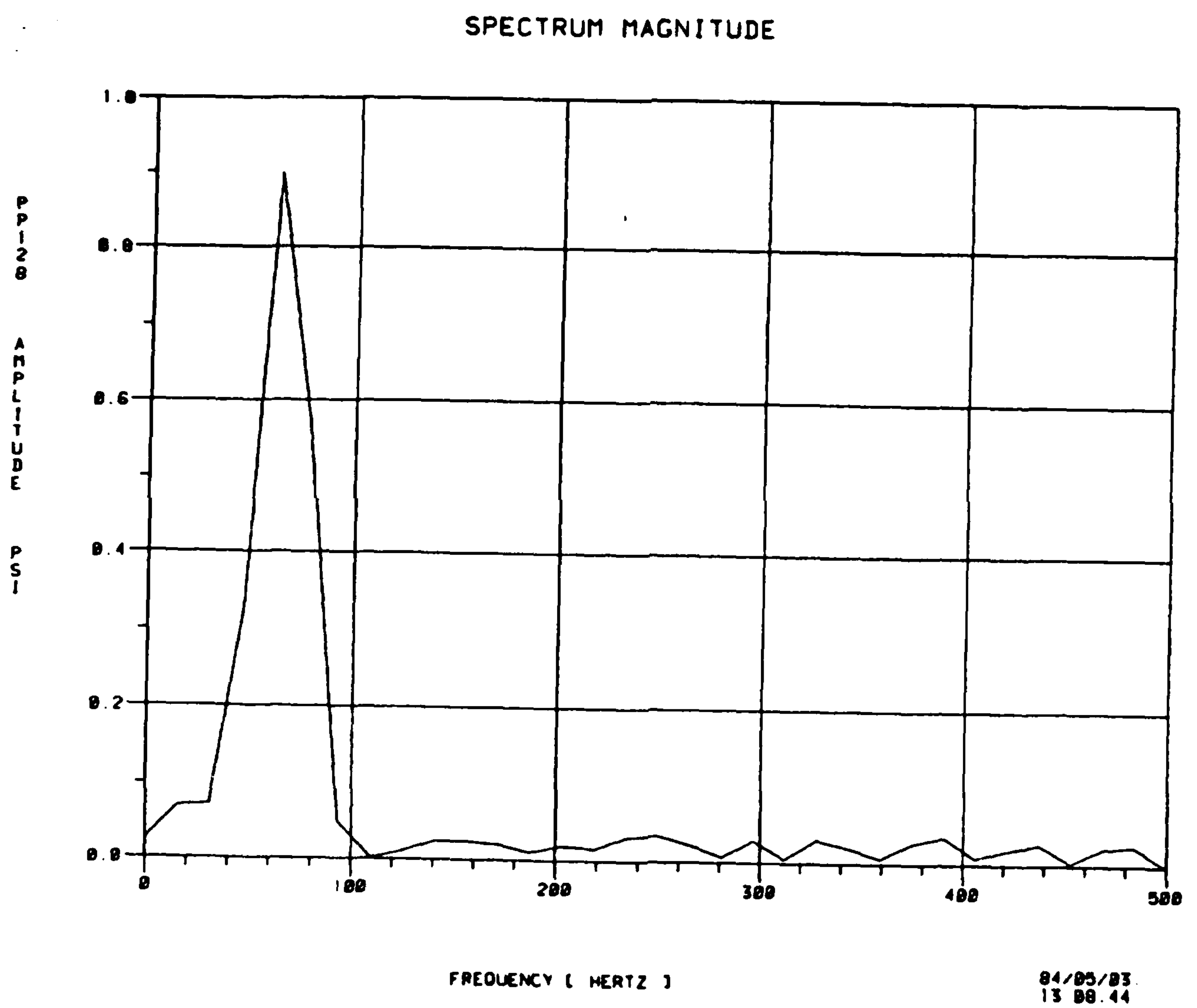
******************************** END OF LISTING ********************************

DO YOU WANT TO PLOT THE FFT RESULTS? (Y/N).
? Y

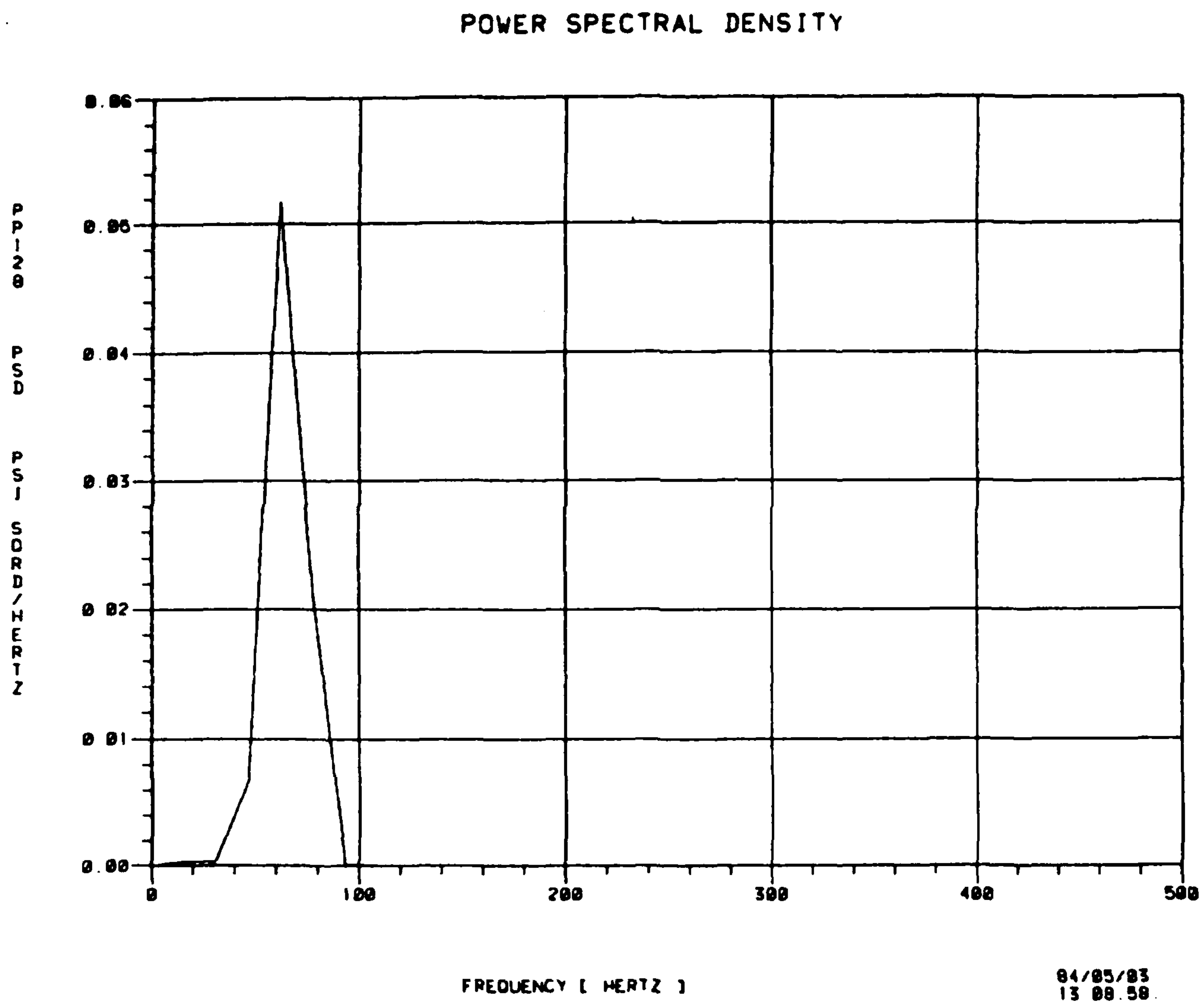
Display 1? Continued

```
THE FOLLOWING PLOTS ARE AVAILABLE.

     1. SPECTRUM MAGNITUDE VS FREQUENCY
     2. SPECTRUM PHASE VS FREQUENCY
     3. POWER SPECTRUM DENSITY VS FREQUENCY

ENTER NUMBER OF YOUR SELECTION.
? 1

DO YOU WANT AUTOMATIC SCALING OF THE PLOT? (Y/N).
? y

DO YOU WANT A LINE OF REMARK ON THIS PLOT? (Y/N).
? n

DO YOU WANT AN ADDITIONAL PLOT? (Y/N):
? y

ENTER NUMBER OF YOUR SELECTION:
? 3

DO YOU WANT AUTOMATIC SCALING OF THE PLOT? (Y/N):
? y

DO YOU WANT A LINE OF REMARK ON THIS PLOT? (Y/N):
? n

DO YOU WANT AN ADDITIONAL PLOT? (Y/N)
? n

**********************************************************************************

            TO BEGIN PLOT VIEWING OR TO ADVANCE TO ANOTHER PLOT,
            PRESS THE SPACE BAR THEN THE RETURN KEY ONCE.

**********************************************************************************
```

Display 10 - Continued



Display 10 - Continued



Display 10 - Continued

```
DO YOU WANT TO ANALYZE ANOTHER SIGNAL? (Y/N).
? n
*** END OF PROGRAM ***
    1.153 CP SECONDS EXECUTION TIME.
```

Display 10 - Concluded

5.2 Transfer Function (TRANS)

TRANS computes the magnitude and phase of the transfer function between two parameter time histories. This capability is particularly useful for determining relationships between parameters in the frequency and time domain. TRANS can also be used to determine the frequency response of a filter. Such a filter could result from the a design program documented in Chapter 6.

5.2.1 Background:

TRANS uses the fast Fourier transform algorithm to compute the frequency spectrum of the parameter time histories. Let the frequency spectrum of a time history represented by x(n), where n is a point of the data sequence, be given by X(w). Here w is a discrete frequency in the spectrum. Similarly, let the frequency spectrum of another data sequence y(n) be given by Y(w). Then the transfer function between these two parameters is represented as:

$$T(w) = Y(w)/X(w)$$

T(w) is a complex number whose value is representative of the transfer function between the two parameters at all frequencies in the spectrum. Since T(w) is a ratio of spectral components and can be expressed as a vector with magnitude and phase, the magnitude of T(w) is calculated as 20logT(w) and expressed in decibels. The phase is expressed in degrees.

5.2.2 Input:

The input data sequences should have a length equal to a power of two. This restriction is applied because the fast Fourier transform algorithm is used to compute the transfer function. If the input data sequences are not specified to be analyzed over a number of points equal to a power of two or the data sequence is not equal to a power of two, then the data sequence will be zero filled to the next power of two.

A B-file format is used to input the two parameter time histories for analysis. Both parameter time histories must be on the B-file and consist of the same number of points. Specifications required by the program through the interactive dialogue include:

- model number of the Tektronix terminal (if appropriate)
- name of the input B-file
- analysis start time-of-day [seconds]
- number of data points to be analyzed
- data sample rate [samples per second]
- name of parameter time history 1
- name of parameter time history 2
- option to plot and/or list results

Depending on the options selected, additional required specifications may include:

- name of the output file to contain analysis results
- selection between a graph of the amplitude or phase of the transfer function versus frequency
- maximum and minimum values of plot ordinate

Plots produced by TRANS follow the conventions and format associated with the time history plot program PLOT which is discussed in Section 4.2.

5.2.3 Execution:

Interactive execution of TRANS is initiated by entering the name call load command:

TRANS

The program will respond with a statement of its capabilities and a prompt for interactive execution. As with the program FFT, TRANS can be executed at a Tektronix graphic terminal or a nongraphic type of terminal. Plots of the transfer function can only be obtained on a Tektronix graphic terminal. Besides this restriction, execution of TRANS is not dependent on the type of terminal employed by a user.

5.2.4 Output:

TRANS can be directed to list analysis results to the terminal screen and/or to a named local output file. The listed analysis results consists of a tabulation of the magnitude and phase of the transfer function with frequency. This tabulation contains (n/2)+1 frequency samples at a spacing of f_s/n Hertz, where n is the sequence length and f_s is the sample frequency in samples per second.

A plot of the transfer function magnitude and phase versus frequency can be directed to the screen of a Tektronix graphic terminal. A permanent record of the plotted results can be obtained by a Tektronix hard copy unit.

5.2.5 Example:

Additional information concerning the mechanisms which drive dynamic systems may be obtained in the frequency domain by determining the transfer function between parameter time histories. As Figure 5 indicates, TRANS was employed to determine the magnitude and phase relationships of the spectral components of parameters contained on the input B-file BFØ34. The parameters contained on this input file were previously filtered to enhance the signal dynamics. TRANS produced a listing and graphic display of the analysis results on the Tektronix terminal screen as well as a listing of results which was directed to the output file named OF002.

Display 11 details an example application of TRANS to parameters SP128M and SP227M. The transfer function analysis was specified to begin at a time-of-day equal to 75017.400 seconds and to encompass 512 data points. The sample rate of the parameters was 1000 samples per second. Parameter SP128M was considered as the input signal and parameter SP227M was considered as the output signal. A listing of the analysis results was directed to output file OF002. Plots of the transfer function magnitude and phase versus frequency were obtained at the terminal screen and are given in Display 11.

TRANS is particularly useful in determining the frequency response of a digital filter. In this case, the two signals analyzed are the input and output of the digital filter. An example of this application of TRANS is presented in Section 7.1.

5.2.6 Limitations and nuances:

TRANS can accept a maximum of 512 points from a parameter time history.

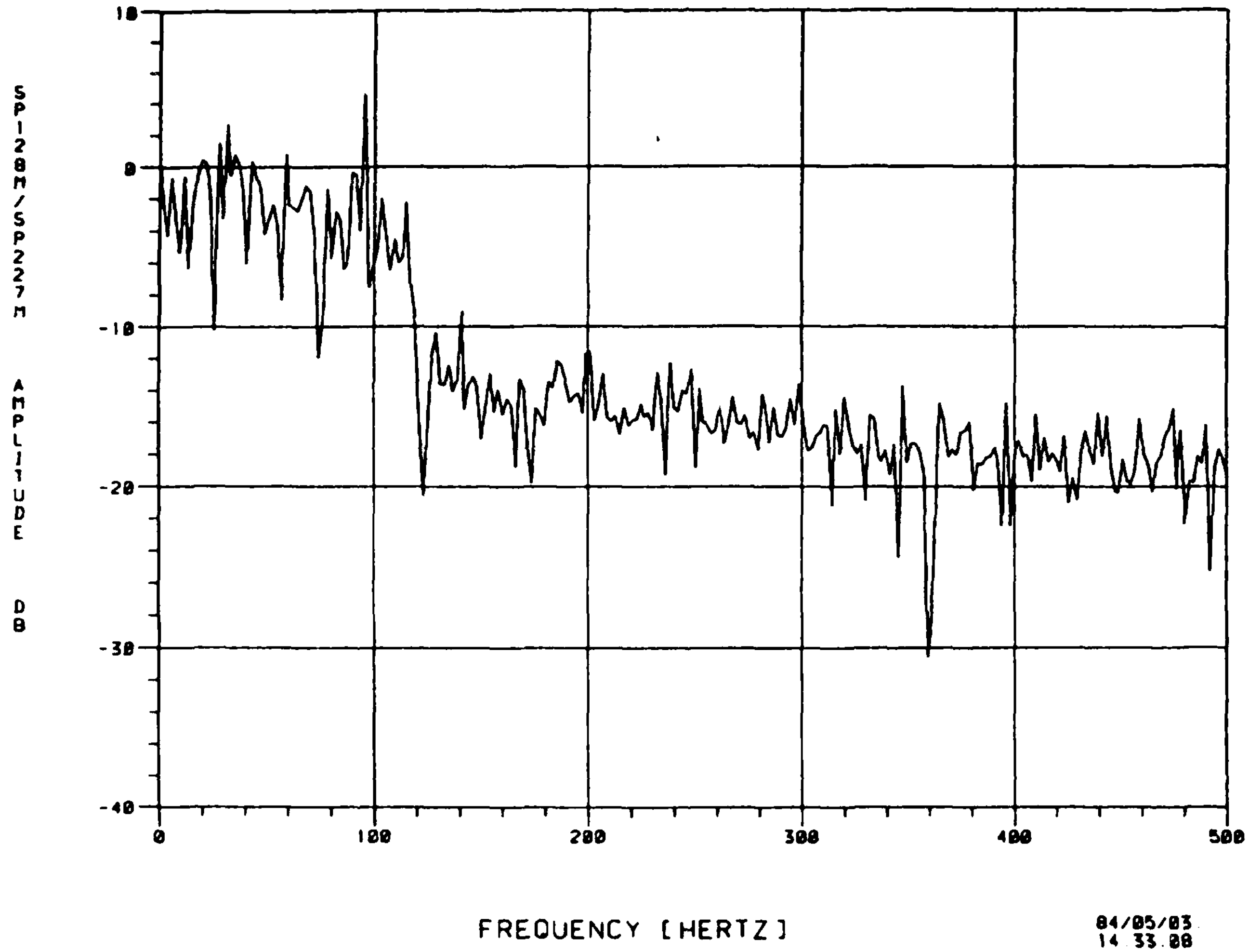
```
*****************************************************************************
*                                                                           *
*                               --- TRANS ---                               *
*                                                                           *
*       THIS PROGRAM COMPUTES A TRANSFER FUNCTION BETWEEN TWO SIGNAL        *
*       SEQUENCES. THE INPUT B-FILE MUST CONTAIN THE INPUT AND OUTPUT       *
*       SEQUENCES. OUTPUT IS USER DIRECTED TO BE LISTED OR PLOTTED          *
*                                                                           *
*****************************************************************************

                         *** PLEASE NOTE ***

A PLOT OF THE PROGRAM ANALYSIS RESULTS CAN BE DISPLAYED ON YOUR SCREEN IF YOU
ARE USING A TEKTRONIX GRAPHIC TERMINAL. PLOTS ARE NOT DISPLAYED ON YOUR SCREEN
IF YOU ARE USING ANY OTHER TYPE OF TERMINAL (EG  TELERAY 711, ETC.). IF YOU ARE
NOT AT A GRAPHIC TEKTRONIX TERMINAL, DO NOT REQUEST A PLOT OF THE RESULTS.

IF YOU ARE USING A TEKTRONIX GRAPHIC TERMINAL, ENTER THE MODEL NUMBER
IF YOU ARE NOT USING A TEKTRONIX TERMINAL, ENTER 0
? 4054

ENTER THE NAME OF THE LOCAL B-FILE WHICH CONTAINS THE DATA TO BE ANALYZED:
? bf034

ENTER THE ANALYSIS START TIME-OF-DAY (SECONDS):
? 75017 400

ENTER THE NUMBER OF DATA POINTS TO BE ANALYZED (MAXIMUM=512),
? 512

ENTER THE DATA SAMPLE RATE (SAMPLES/SECOND)
? 1000

ENTER THE NAME OF THE INPUT  SIGNAL PARAMETER:
? sp128m

VARIALBE IDENTIFIED AS PARAMETER NUMBER 8 ON INPUT BFILE.

ENTER THE NAME OF THE OUTPUT SIGNAL PARAMETER:
? sp227m

VARIALBE IDENTIFIED AS PARAMETER NUMBER 0 ON INPUT BFILE.

512 POINTS WILL BE ANALYZED FROM THE DATA SEQUENCES

DO YOU WANT A LISTING OF RESULTS? (Y/N),
? y
```

Display 11 - Example Application of the Transfer Function Program TRANS

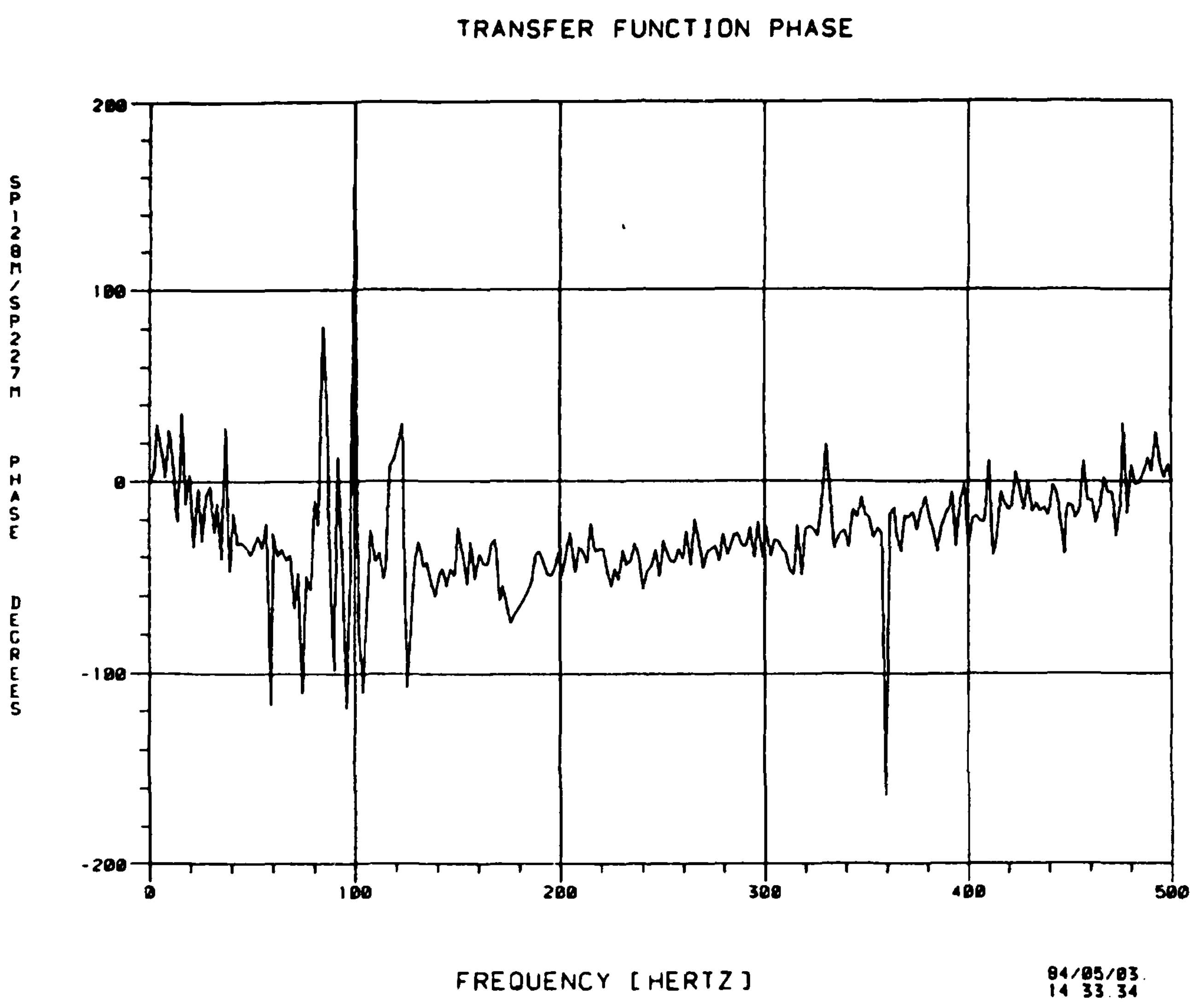
```
THE FOLLOWING LIST OPTIONS ARE AVAILABLE:

     1. LIST TO THE TERMINAL SCREEN ONLY
     2. WRITE TO A LOCAL OUTPUT FILE
     3. LIST TO THE SCREEN AND WRITE TO AN OUTPUT FILE

PLEASE ENTER THE NUMBER OF YOUR SELECTION:
? 2

ENTER THE NAME OF A FILE TO CONTAIN THE LISTING OF THE ANALYSIS RESULTS.
? of882

DO YOU WANT TO PLOT THE RESULTS? (Y/N):
? y

THE FOLLOWING PLOTS ARE AVAILABLE.

     1  TRANSFER FUNCTION MAGNITUDE VS FREQUENCY
     2  TRANSFER FUNCTION PHASE VS FREQUENCY

ENTER THE NUMBER OF YOUR SELECTION:
? 1

DO YOU WANT AUTOMATIC SCALING OF THE PLOT? (Y/N):
y
?
DO YOU WANT A LINE OF REMARK ON THIS PLOT? (Y/N):
? n

DO YOU WANT AN ADDITIONAL PLOT? (Y/N):
y
?
ENTER THE NUMBER OF YOUR SELECTION.
? 2

DO YOU WANT AUTOMATIC SCALING OF THE PLOT? (Y/N):
? y

DO YOU WANT A LINE OF REMARK ON THIS PLOT? (Y/N):
? n

vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv

          TO BEGIN PLOT VIEWING OR TO ADVANCE TO ANOTHER PLOT.
          PRESS THE SPACE BAR THEN THE RETURN KEY ONCE

vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv
```

Display 11 - Continued

TRANSFER FUNCTION MAGNITUDE



Display 11 - Continued



Display 11 - Continued

```
 DO YOU WANT TO ANALYZE ANOTHER PAIR OF SIGNALS? (Y/N).
? n

 *** END OF PROGRAM ***
     1.031 CP SECONDS EXECUTION TIME.
/
```

Display 11 - Concluded

6. DIGITAL FILTER PROGRAM GROUP

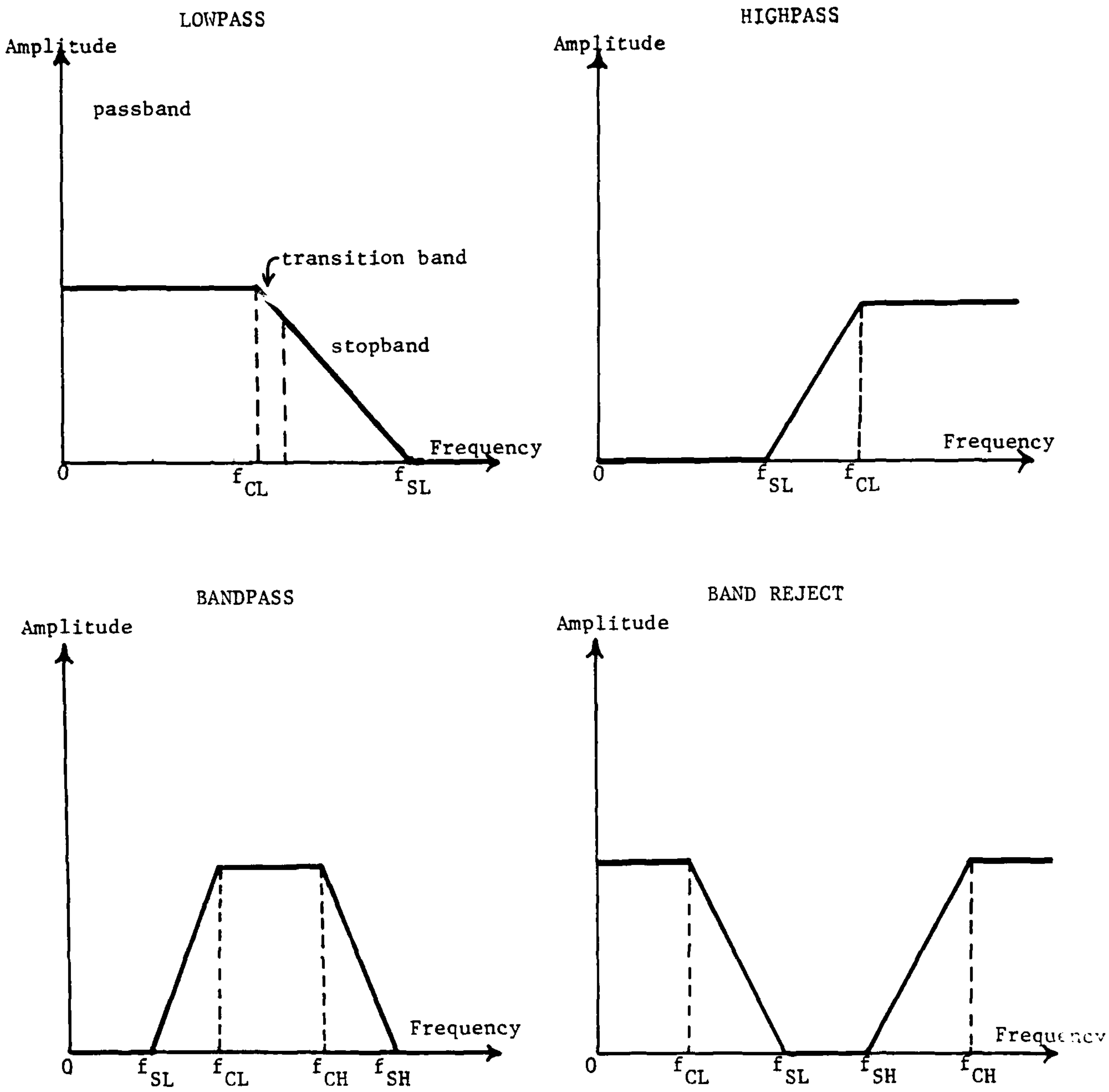
The digital filter program group provides the capability to design, analyze, and implement digital filters on a parameter time history. The software comprising this program group are modified versions of finite impulse response (FIR) filter design and implementation programs. These programs were obtained from the digital signal processing software package which is documented in Reference 2. The digital signal processing software package provides additional filtering capability; however, the filter design and implementation programs discussed below will meet most filtering requirements.

Much of the background discussion presented below and in the following sections is paraphrased from Reference 2. A more detailed discussion of digital filters is given in this reference. Additionally, an overview of digital signal processing terminology is given in Reference 8.

The frequency spectrum that a signal encompasses often represents the characteristics of the signal more explicitly than its time domain counterpart. When analyzing a signal in the frequency domain, spectral components are revealed that may be removed or enhanced by applying a digital filter. An example of this situation is noise due to a power supply which is at a discrete frequency. It would be desirable to eliminate this noise from the otherwise good signal. This can be accomplished by suppressing the components of the frequency spectrum which correspond to the frequency of the power supply noise. This capability is provided by the filter design programs discussed in this chapter.

The design of a digital filter is determined by a number of specifications which describe the intended function of the filter. These specifications designate the various pass bands and stop bands of the filter. The band of frequencies that are to pass essentially unattenuated through the filter is called the pass band. Similarly, the band of frequencies that are to be attenuated is called the stop band. A transition band is a range of frequencies which the filter will partially attenuate the frequency components. Although it is desirable to not specify a transition band, this is not obtainable for a real filter. Various combinations of the stop, pass, and transition bands produce typical filter designs as illustrated in Figure 10.

Within each pass band and stop band, the affect of a filter may be characterized by the amplitude and phase response of the filter. The amplitude response of the filter is the ratio of the output signal to the input signal. The amplitude response is expressed in decibels at any component frequency. The phase response of the filter indicates the time delay of the output signal relative to the input signal. Phase response is expressed in degrees at any component frequency. The amplitude and phase response specify the frequency response of the filter.



f_{CL}: lower cutoff frequency

f_{CH}: upper cutoff frequency

f_{SL}: lower stopband edge frequency

f_{SH}: upper stopband edge frequency

Figure 10 - Typical Digital Filter Designs

Thefilter design programs contained in the ISAS produce a finite impulse response (FIR) filter. An FIR filter produces a linear phase response with frequency. This corresponds to imparting a constant time delay to the filter output time history relative to the input time history. However, this characteristic can be compensated through a temporal alignment of the parameter time history. This can be accomplished by using the data conditioning program TIMALIN.

The above discussion provides a basic understanding of digital filters. This information and that contained in the following sections should facilitate implementation of a digital filter with a reasonable level of confidence. Again, a more detailed discussion of digital filters is given in References 2 and 8.

6.1 Lowpass Filter Design (LOWPASS)

The filter design program LOWPASS generates a filter file for a maximally flat pass band and stop band FIR lowpass filter. The resultant filter file is used by the filter implementation program to filter a parameter time history.

6.1.1 Background:

LOWPASS is characterized by an ideal magnitude response that has a value of 1 within the pass band and a value of Ø within the stop band. Since the pass band and stop band cannot overlap, a transition band is employed. This transition band determines the steepness of the filter rolloff and the order of the filter. LOWPASS solves for a closed form expression of the filter response which yields filter coefficients. These filter coefficients comprise the filter description that is written to the filter file.

6.1.2 Input:

Input to the filter design program LOWPASS is accomplished only through an interactive dialogue with the program. Specifications required for the filter design are:

- sample rate of the data to be filtered [samples per second]
- center frequency of the transition band (less than 1/2 the sample frequency) [Hertz]
- transition band frequency width (greater than the sample frequency / 25) [Hertz]
- option to write the filter description to a filter file
- option to list the filter coefficients at the terminal screen or to an output file

Depending on the options selected above, additional required specifications may include:

- name for the filter file
- name for the output file

Upon completion of one filter design, another lowpass filter may be designed by reinitiating the program inquiry and providing the above specifications again.

6.1.3 Execution:

Interactive execution of LOWPASS is initiated by entering the name call load command:

LOWPASS

The program will respond with a statement of its capabilities and a prompt for an interactive dialogue. Upon termination of LOWPASS, the terminal is returned to the command level of NOS.

6.1.4 Output:

LOWPASS produces a filter description file which contains the filter coefficients. This file is input to the filter implementation program FILTER. Also, the filter description can be listed at the terminal screen or written to a local output file for saving on a permanent storage device or listing at a printer.

6.1.5 Example:

Digital data filtering techniques were applied to the parameter time histories obtained during transient augmentor operation. The filter pass band was specified to pass a band of frequencies which contained the characteristic frequency of the pre-stall flowpath pressure dynamics. Lowpass provided a filter design which would enhance the pressure oscillation data. Figure 5 indicates the application of LOWPASS to generate the filter file FF001 which was subsequently used by FILTER. Also, a listing of the filter description was directed to the local output file OF003.

Display 12 provides a record of an interactive filter design session which exemplifies the dialogue and execution of LOWPASS. The sample rate of the data to be filtered was specified as 1,000 samples per second. From the results of the fast Fourier transform analysis, it was determined that the characteristic frequency of the engine pre-stall dynamics was below 200 Hertz. Thus, the center frequency of the transition band width was specified as 250 Hertz and the transition band width was specified to be 60 Hertz. The resultant filter description was written to the filter file named FF001. Display 12 also shows the screen listing of the filter coeffifients that were directed to the output file OF003.

Application of the filter design to the parameter time histories is discussed in Section 6.3. Also, the LOWPASS filter design was verified by utilizing the white noise data file to drive the input of the filter design. The output of the filter thus indicated the frequency response of the filter. This procedure is presented in Chapter 7.

6.1.6 Limitations and nuances:

Some restrictions are imposed upon the design specifications for LOWPASS. These restrictions are:

1. The center frequency of the transition band must be greater than the sample frequency divided by 2.
2. The width of the transition band must be greater than the sample frequency divided by 25.

If these restrictions are observed, LOWPASS will normally converge on a filter design.

```
*********************************************************************
*                                                                   *
*                         --- LOWPASS ---                           *
*                                                                   *
*      THIS PROGRAM IS A DESIGN TOOL FOR THE GENERATION OF MAXIMALLY *
*      FLAT PASSBAND AND STOPBAND FINITE IMPULSE RESPONCE (FIR)     *
*      DIGITAL LOWPASS FILTERS. FILTER DESIGN IS USER SPECIFIED AND *
*      THE FILTER DESCRIPTION IS WRITTEN TO A DESIGNATED LOCAL FILE *
*      IN STANDARD FORMAT  THIS FILTER DESIGN HAS A LINEAR PHASE    *
*      WHICH IMPARTS A CONSTANT TIME DELAY TO THE FILTERED DATA.    *
*                                                                   *
*********************************************************************

 ENTER THE SAMPLING RATE OF THE DATA TO BE FILTERED (SAMPLES/SECOND):
? 1000

 ENTER THE CENTER FREQUENCY OF THE TRANSITION BAND (HZ).
? 250

 ENTER THE WIDTH OF THE TRANSITION BAND (HZ):
? 60

 DO YOU WANT THE FILTER DESCRIPTION WRITTEN TO A LOCAL FILTER FILE? (Y/N):
? y

 ENTER THE NAME OF THE FILE TO CONTAIN THE FILTER DESCRIPTION:
? ff001

 DO YOU WANT A LISTING OF THE FILTER COEFFICIENTS? (Y/N):
? y

 THE FOLLOWING LIST OPTIONS ARE AVAILABLE:

      1. LIST TO THE TERMINAL SCREEN ONLY.
      2. WRITE TO A LOCAL FILE ONLY.
      3. LIST TO THE TERMINAL SCREEN AND WRITE TO A LOCAL FILE.

 ENTER THE NUMBER OF YOUR SELECTION:
? 3

 ENTER THE NAME FOR A FILE TO CONTAIN THE LISTING OF THE FILTER COEFFICIENTS.
? of003
```

Display 12 - Example Utilization of LOWPASS for a Digital Filter Design

```
 *****************************************************************************
 *                                                                           *
 *                   RESULTS OF THE DIGITAL FILTER DESIGN                    *
 *                                                                           *
 *****************************************************************************
0TRANSITION BAND CENTER FREQUENCY=   .2500E+03 HZ
 TRANSITION BAND WIDTH=   .6000E+02 HZ
 NUMBER OF FILTER COEFFICIENTS=   70
0
 B(  1) =   .5000E+00
 B(  2) =   .3160E+00
 B(  3) =   .8577E-14
 B(  4) = -.9950E-01
 B(  5) = -.2174E-15
 B(  6) =   .5324E-01
 B(  7) = -.2250E-14
 B(  8) = -.3203E-01
 B(  9) =   .3736E-14
 B( 10) =   .1080E-01
 B( 11) =   .5293E-15
 B( 12) = -.1215E-01
 B( 13) =   .1165E-14
 B( 14) =   .7272E-02
 B( 15) =   .3263E-15
 B( 16) = -.4201E-02
 B( 17) =   .6113E-14
 B( 18) =   .2328E-02
 B( 19) =   .4547E-14
 B( 20) = -.1231E-02
 B( 21) =   .1387E-14
 B( 22) =   .6186E-03
 B( 23) =   .8930E-14
 B( 24) = -.2947E-03
 B( 25) =   .2249E-14
 B( 26) =   .1327E-03
 B( 27) = -.1031E-14
 B( 28) = -.5630E-04
 B( 29) =   .5594E-14
 B( 30) =   .2247E-04
 B( 31) = -.1325E-15
 B( 32) = -.8406E-05
 B( 33) = -.5763E-14
 B( 34) =   .2942E-05
 B( 35) =   .8576E-14
 B( 36) = -.9602E-06
 B( 37) =   .1071E-13
 B( 38) =   .2913E-06
 B( 39) =   .6459E-14
 B( 40) = -.8190E-07
 B( 41) = -.1721E-14
 B( 42) =   .2125E-07
 B( 43) =   .6109E-14
 B( 44) = -.5064E-08
 B( 45) =   .1639E-14
 B( 46) =   .1104E-08
 B( 47) = -.1732E-14
 B( 48) = -.2186E-09
 B( 49) = -.2552E-14
```

Display 12 -- Continued

```
 B( 50) =   .3010E-10
 B( 51) = - .4680E-14
 B( 52) = - .6267E-11
 B( 53) =   .8730E-15
 B( 54) =   .9004E-12
 B( 55) =   .1227E-13
 B( 56) = - .1112E-12
 B( 57) = - .1181E-13
 B( 58) =   .3146E-14
 B( 59) =   .7937E-15
 B( 60) =   .6354E-15
 B( 61) = - .4393E-14
 B( 62) = - .3387E-14
 B( 63) =   .8066E-14
 B( 64) =   .1422E-13
 B( 65) =   .7753E-14
 B( 66) = - .1407E-14
 B( 67) = - .9510E-15
 B( 68) =   .3961E-14
 B( 69) =   .3040E-14
 B( 70) = - .4060E-14
0
 ******************************  END OF LISTING  ******************************

 DO YOU WANT TO DESIGN ANOTHER FILTER? (Y/N):
? n

 *** END OF PROGRAM ***

     0.659 CP SECONDS EXECUTION TIME.
/
```

Display 12 - Concluded

6.2 Multiple Passband Filter Design (MLTPASS)

MLTPASS designs a finite impulse response filter based upon given specifications.

6.2.1 Background:

Many filter configurations may be designed by using the multiple pass band and stop band specifications of MLTPASS. The amplitude response of any filter is characterized by at least one pass band and one stop band with a transition band between these two bands. The lowpass and highpass filters are characterized by one pass band and one stop band. However, other filter designs may have more than one stop band and one pass band. For example, bandpass and band reject filters have two pass bands and stop bands. Figure 10 indicates the relationship between the pass band and the stop band frequencies for various types of filters. The need for the specification of the lower and upper cutoff frequencies as well as the the lower and upper stop band edge frequencies is dependent upon the type of filter.

MLTPASS uses an Remez exchange algorithm to determine filter values which minimize a weighted Chebyshev error function over a grid of frequencies. This means that the difference between the desired filter function and a trial filter function is calculated over a set of frequencies. The magnitude of this difference is then used to update the filter function. Also, the extent to which error influences the filter function in each of the specified bands is determined by the weighting value for that band. Thus, the value of the band weighting signifies the relative importance of the filter response.

6.2.2 Input:

Input to MLTPASS is provided through interactive dialogue with the program. Specifications required by MLTPASS are:

- filter length, i.e. the number of points to comprise the FIR filter (maximum is 128)
- number of frequency bands (disjoint pass bands and stop bands)
- grid density (nominal = 16)
- sample rate of the data to be filtered [samples per second]
- edge frequencies of the passbands and stop bands [Hertz]
- filter gain (1 for an ideal passband or 0 for an ideal stopband)
- relative weighting for each specified band
- option to write the filter description to a filter file
- option to list the filter coefficients at the terminal screen or to an output file
- gain of the filter for each specified frequency band

Depending on the options selected above, additional required specifications may include:

- name for the filter file
- name for the output file

Upon completion of one filter design, another filter may be designedby responding affirmatively to reinitiating the program inquiry and providing the appropriate specifications from those given above.

6.2.3 Execution:

Interactive execution of MLTPASS is initiated by entering the name call load command:

MLTPASS

The program will respond with a statement of its capabilities and a prompt for an interactive dialogue. The terminal is returned to the command level of NOS upon termination of program execution.

6.2.4 Output:

MLTPASS produces a filter description file which contains the filter coefficients. This file is input to the filter implementation program FILTER to actually filter a parameter time history. This filter description file can be listed at the terminal screen or written to a local output file.

6.2.5 Example:

The MLTPASS filter design program was utilized to design a digital filter which would enhance the pre-stall dynamic engine data. Figure 5 illustrates the utilization of MLTPASS for the generation of the filter file FF002 which was subsequently used by FILTER to filter the parameter time histories of interest.

Display 13 provides a record of an interactive filter design session which exemplifies the execution and dialogue of MLTPASS. A multiple pass band and stop band FIR digital filter was designed for the enhancement of data obtained during dynamic oscillations of the gas turbine engine. The data to be filtered is that which exemplified the execution of the Fourier analysis program FFT and the usage of the filter design program LOWPASS. Analysis of the dynamic data using FFT further determined the characteristic frequency of the pre-stall dynamics to be centered about a frequency of 60 Hertz. The MLTPASS filter design was specified to generate a pass band/stop band filter to further enhance the pre-stall dynamics. The pass band was specified to range from 0 Hertz to 100 Hertz and the stop band was specified to range from 120 Hertz to 500 Hertz. 500 Hertz was chosen as the upper cutoff frequency because this is the folding frequency corresponding to the data sample rate of 1000 samples per second. This filter design resulted in a transition band from 100 Hertz to 120 Hertz. The resultant filter design was saved on the filter file named FF002 for subsequent application through the filter implementation program FILTER.

Additional specifications were input to MLTPASS. The number of filter coefficients was chosen to be 64. Since one stop band and one pass band were desired, the total number of frequency bands specified was two. The filter grid density was set at the nominal value of 16. The sample rate of the parameter time history to be filtered was given as 1,000 samples per second. The gain of the pass band and the stop band were set equal to 1 and 0 respectively. The frequency bands were given a relative weighting of 10. A listing of the resultant filter description was directed to the terminal screen. Also, output was directed to an output file named OF004 for subsequent listing at a line printer.

Verification of the filter design produced by MLTPASS was accomplished by utlizing the white noise data file. This file was used as input to the filter design produced above. The resultant filter output indicated the frequency response of the filter. This verification process is presented in Chapter 7.

6.2.6 Limitations and nuances:

The extent to which error influences the filter function in each of the specified bands is determined by the weighting value of that band. Thus, the band weighting value signifies the relative importance of the filter response.

```
********************************************************************************
*                                                                              *
*                              --- MLTPASS ---                                 *
*                                                                              *
*         THIS PROGRAM IS A DESIGN TOOL FOR THE GENERATION OF EQUIRIPPLE       *
*         MULTIPLE PASSBAND AND STOPBAND FINITE IMPULSE RESPONCE DIGITAL       *
*         FILTERS. THE FILTER DESIGN IS USER SPECIFIED AND THE FILTER          *
*         DESCRIPTION IS WRITTEN TO A DESIGNATED LOCAL FILE IN STANDARD        *
*         FORMAT. THIS FILTER DESIGN HAS A LINEAR PHASE WHICH IMPARTS A        *
*         CONSTANT TIME DELAY TO THE FILTERED DATA.                            *
*                                                                              *
********************************************************************************

 ENTER THE DESIRED FILTER LENGTH (MAXIMUM= 128):
? 64

 ENTER THE TOTAL NUMBER OF PASSBANDS AND STOPBANDS:
? 2

 ENTER THE FILTER GRID DENSITY (NOMINAL= 16):
? 16

 ENTER THE SAMPLING RATE OF THE DATA TO BE FILTERED (SAMPLES/SECOND):
? 1000

 *** SPECIFICATIONS FOR THE PASSBANDS AND STOPBANDS FOLLOWS ***

 FILTER FREQUENCY BAND NUMBER 1:

 ENTER THE BAND LOWER EDGE FREQUENCY (HZ):
? 0

 ENTER THE BAND UPPER EDGE FREQUENCY (HZ)
? 100

 ENTER THE FILTER GAIN (1 FOR AN IDEAL PASSBAND, 0 FOR AN IDEAL STOPBAND):
? 1

 ENTER THE RELATIVE WEIGHT OF THIS BAND:
? 10

 FILTER FREQUENCY BAND NUMBER 2:

 ENTER THE BAND LOWER EDGE FREQUENCY (HZ)
? 120

 ENTER THE BAND UPPER EDGE FREQUENCY (HZ)
? 500
```

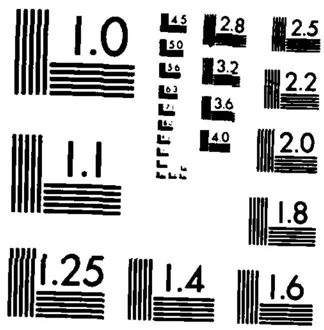
Display 13 - Example Utilization of MLTPASS for a Digital Filter Design

```
ENTER THE FILTER GAIN (1 FOR AN IDEAL PASSBAND, 0 FOR AN IDEAL STOPBAND),
? 0

ENTER THE RELATIVE WEIGHT OF THIS BAND:
? 10

DO YOU WANT THE FILTER DESCRIPTION WRITTEN TO A LOCAL FILTER FILE? (Y/N):
? y

ENTER THE NAME OF A FILE TO CONTAIN THE FILTER DESCRIPTION,
? ff002

DO YOU WANT A LISTING OF THE FILTER COEFFICIENTS? (Y/N),
? y

THE FOLLOWING LIST OPTIONS ARE AVAILABLE:

      1. LIST TO THE TERMINAL SCREEN ONLY.
      2. WRITE TO A LOCAL OUTPUT FILE ONLY
      3. LIST TO THE TERMINAL SCREEN AND WRITE TO A LOCAL OUTPUT FILE.

ENTER THE NUMBER OF YOUR SELECTION,
? 3

ENTER THE NAME FOR A FILE TO CONTAIN THE LISTING OF THE FILTER COEFFICIENTS:
? of004
```

Display 13 - Continued

AD-A146 999 INTERACTIVE SIGNAL ANALYSIS SOFTWARE (ISAS) USER'S MANUAL(U) AIR FORCE FLIGHT TEST CENTER EDWARDS AFB CA R M DAVINO JUL 84 AFFTC-TIM-84-4 2/2

UNCLASSIFIED F/G 9/2 NL


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

```
FINITE IMPULSE RESPONCE (FIR)
LINEAR PHASE DIGITAL FILTER DESIGN
REMEZ EXCHANGE ALGORITHM

BANDPASS FILTER

FILTER LENGTH = 64

***** IMPULSE RESPONSE *****
H( 1) = -.74638081E-02 = H( 64)
H( 2) =   .17760570E-01 = H( 63)
H( 3) =   .10578342E-01 = H( 62)
H( 4) =   .64373485E-02 = H( 61)
H( 5) =   .16326425E-02 = H( 60)
H( 6) = -.36818812E-02 = H( 59)
H( 7) = -.76371610E-02 = H( 58)
H( 8) = -.82880658E-02 = H( 57)
H( 9) = -.48420078E-02 = H( 56)
H(10) =   .15836887E-02 = H( 55)
H(11) =   .82625100E-02 = H( 54)
H(12) =   .11885595E-01 = H( 53)
H(13) =   .10154250E-01 = H( 52)
H(14) =    30380744E-02 = H( 51)
H(15) = -.68034347E-02 = H( 50)
H(16) = - 14032160E-01 = H( 49)
H(17) = -.16081855E-01 = H( 48)
H(18) = - 10037583E-01 = H( 47)
H(19) =    19723875E-02 = H( 46)
H(20) =    16337655E-01 = H( 45)
H(21) =    25302723E-01 = H( 44)
H(22) =    23430240E-01 = H( 43)
H(23) =    08594511E-02 = H( 42)
H(24) = - 14200107E-01 = H( 41)
H(25) = - 36517522E-01 = H( 40)
H(26) = - 46560002E-01 = H( 39)
H(27) = -.34824866E-01 = H( 38)
H(28) =   .21603508E-02 = H( 37)
H(29) =   .50684137E-01 = H( 36)
H(30) =   .12526528E+00 = H( 35)
H(31) =   .18243644E+00 = H( 34)
H(32) =    21560402E+00 = H( 33)

                     BAND  1        BAND  2
LOWER BAND EDGE       .0000000    120.0000000
UPPER BAND EDGE    100.0000000    500.0000000
DESIRED VALUE         1.0000000      .0000000
WEIGHTING            10.0000000     10.0000000
DEVIATION              .0377938      .0377938
DEVIATION IN DB        .3222215    -28.4515881

EXTREMAL FREQUENCIES--MAXIMA OF THE ERROR CURVE
     .0000000   16.6015625   33.2031250   49.8046875   65.4296875
   81.0546875   93.7500000  100.0000000  120.0000000  125.8593750
  139.5312500  154.1796875  169.8046875  185.4296875  202.0312500
  217.6562500  234.2578125  249.8828125  266.4843750  283.0859375
  298.7109375  315.3125000  330.9375000  347.5390625  363.1640625
```

Display 13 - Continued

```
 379.7656250 395.3906250 411.0021875 427.6171875 443.2421875
 459.0437500 475.4687500 402.0703125

▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼▼

DO YOU WANT TO DESIGN ANOTHER FILTER? (Y/N).
? n

▼▼▼ END OF PROGRAM ▼▼▼

    3.253 CP SECONDS EXECUTION TIME.
```

Display 13 - Concluded

6.3 Filter Implementation (FILTER)

FILTER filters a parameter time history by using a previously generated filter design.

6.3.1 Background:

The filtering of a parameter time history is accomplished by the convolution of the filter design with the data sequence. This convolution is accomplished by using a fast Fourier transform. The fast Fourier transform algorithm requires that the data sequence to be filtered consist of a number of points which is equal to a power of two. If the input data sequence does not meet this requirement then FILTER will zero fill the input data sequence to the next power of two.

6.3.2 Input:

A B-file format is employed to input the parameter time history to FILTER. Also, a filter file which has been previously generated is used to relay the particular filter design specifications to the program. Specifications requested by FILTER through an interactive dialogue are:

- nameof the B-file which contains the data sequence to be filtered
- name for the B-file generated by FILTER which will contain the filtered parameter time history
- name of the parameter to be filtered
- name for the filtered parameter
- selection of terminal entry or a filter file as thesource of the filter description

If a terminal entry was selected then additional requested specifications are:

- length of the filter
- filter sequence point number and gain for each non-zero filter value

If a filter file was selected as the filter description source then an additional requested specification is:

- name of the filter file

If it is desired to filter another parameter time history, the above specifications must be entered again.

6.3.3 Execution:

Interactive execution of FILTER is initiated by entering the name call load command:

FILTER

The program will respond with a statement of its capabilities and a prompt for interactive execution. Termination of FILTER returns the terminal to the command level of NOS.

6.3.4 Output:

FILTER produces a filtered parameter time history which is appended to the input time history and output on a B-file.

6.3.5 Example:

FILTER was employed to enhance the dynamic parameters of interest through filter designs supplied by the design programs LOWPASS and MLTPASS. Figure 5 illustrates the application of FILTER to the parameter time histories contained on B-file BF011. In this example, FILTER was employed twice, once with the LOWPASS filter design given by FF001 and again with the MLTPASS filter design given by FF002. The resultant filtered parameters were output on B-file BF024.

Display 14 provides an example application of the LOWPASS filter design to the time history of PP128. The filtered parameter time history FP128L was directed to an intermediate B-file named BF021. The result of filtering PP128 is illustrated in Display 14 by comparing the plots of the PP128 and FP128L. Qualitatively, the filtered parameter shows a reduction of the higher frequency oscillations which reflects the stopband specifications of the LOWPASS filter design. Also, the LOWPASS filter design does not impart a time delay to the filtered time history. Parameter FP128L is temporally aligned with the input time history PP128.

FILTER was also applied to parameter PP227 through the multiple bandpass filter design given by MLTPASS. The result of this filter application is shown in Display 14 by the plot of the filtered parameter FP227M. This plot can be compared to the plot of the input time history of parameter PP227. As the plot of FP227M indicates, The MLTPASS filter design imparts a time delay to the filtered parameter time history. This time delay may be corrected through the application of TIMALIN as given in Section 3.5.

The filtering of a time history by FILTER is accomplished by a convolution of the filter design with the data sequence. Since the filter has a finite length N, N/2 end points on each side of the filtered time history will be inaccurate. This is dramatically shown by the plot of FP227M. In this case, this effect is combined with the time lag due to the linear response of the filter design by MLTPASS.

The digital filter may uniformly attenuate the level of the signal. This characteristic is most pronounced by the implementation of the lowpass filter as is illustrated by FP128L. A good estimation of the expected attenuation can be determined by filtering a time history of white noise. A white noise data file is provided in the fileset for this purpose and is discussed in Section 7.1. The filtered white noise can then be compared to the original white noise in the frequency domain. This will determine the expected attenuation of a signal filtered with the filter design over a range of frequencies of interest.

The digital filtering techniques described above were applied to the dynamic parameters measured prior to engine stall. Figure 11 illustrates the digital filter processing results for the flowpath parameters PS5C, PT2.5H, PB, and the augmentor fuel manifold pressure PSEG5. These parameters were filtered in a frequency band from 40 Hertz to 70 Hertz and over a period of time which encompassed the dynamics of the fuel system and the core and bypass flowpaths. This period of time corresponds to elapsed times-of-day from 75017.200 seconds to 75018.200 seconds. The pressure oscillations of PSEG5 are clearly shown and are observed to influence the fan duct pressure PS5C and the core flowpath pressure PT2.5H. This influence was probably due to a combustion instability driven by oscillating fuel delivery rates to the augmentor.

Digital filtering techniques were employed to determine if the characteristic frequency of the augmentor instability was constant for the period of time immediately preceding stall. Figure 12 shows the results from filtering PS5C into four frequency bands which range from 30 Hertz to 70 Hertz. During the initial growth of the pressure oscillation, the higher frequency bands contained most of the frequency content. However, as the stall point approached, the characteristic frequency of the flowpath oscillation was shifted to the lower frequency bands where it was most pronounced before stall.

6.3.6 Limitations and nuances:

The end points of the filtered parameter time history will be inaccurate due to the finite length of the filter. The number of end points affected is dependent upon the length of the filter.

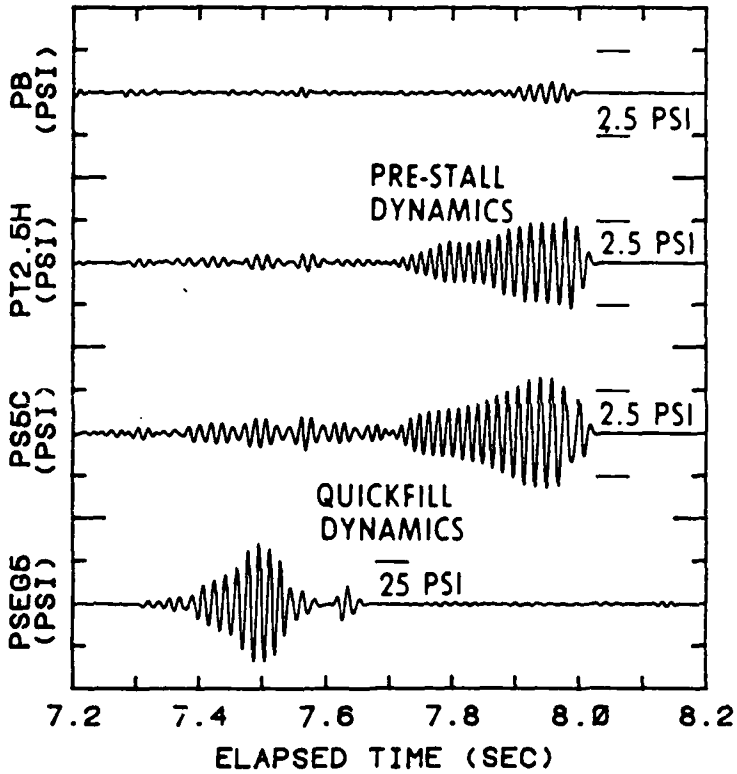


Figure 11 - Digital Filter Results of Flowpath and Fuel System Parameter Prior to Engine Stall

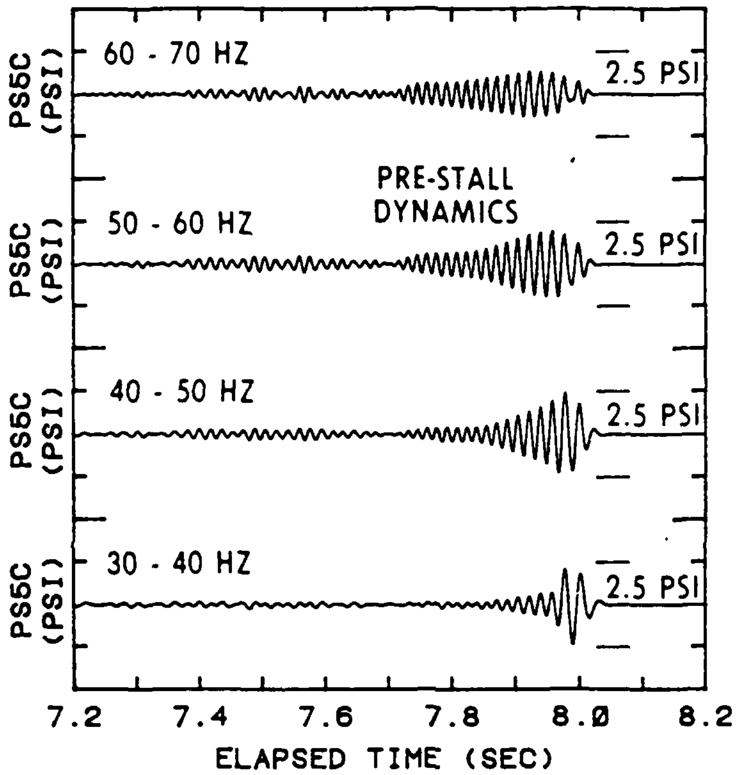
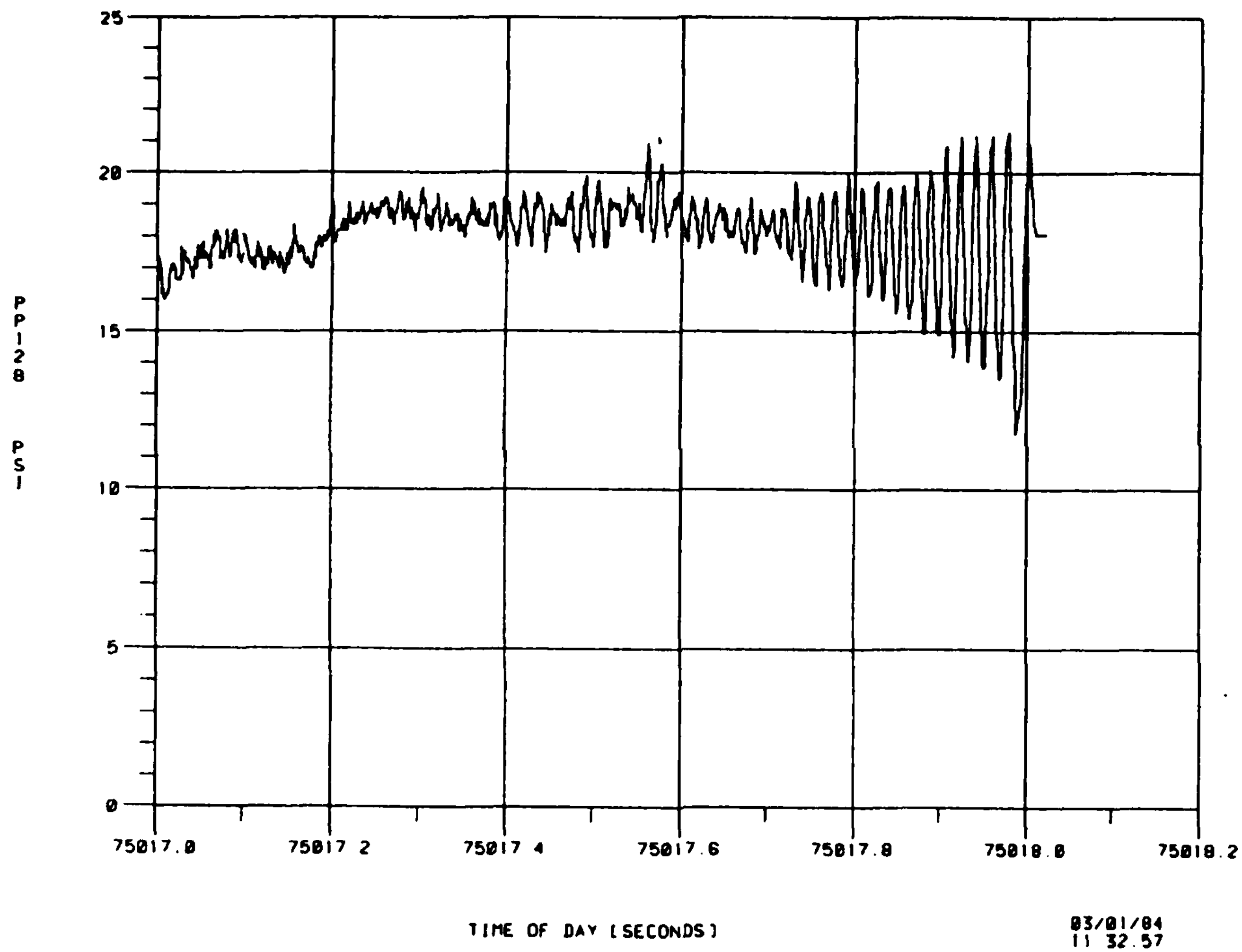


Figure 12 - Multiple Frequency Band Filter Results of PS5C Prior to Engine Stall

```
**********************************************************************
*                                                                    *
*                           --- FILTER ---                           *
*        THIS PROGRAM PERFORMS THE FILTERING OF DIGITAL DATA BY EMPOYING
*        A FINITE IMPULSE RESPONSE (FIR) FILTER DESIGN PREVIOUSLY GENER-
*        ATED. A SPECIFIED B-FILE PARAMETER IS FILTERED AND APPENDED TO
*        THE INPUT B-FILE. THIS FILE IS OUTPUT AS A SEPERATE B-FILE.
*                                                                    *
**********************************************************************

ENTER THE NAME OF THE B-FILE WHICH CONTAINS THE PARAMETER TO BE FILTERED:
? bf011

THE FILTERED PARAMETER WILL BE APPENDED TO THE INPUT B-FILE AS A SEPERATE
PARAMETER. THIS APPENDED B-FILE WILL THEN BE OUTPUT AS A UNIQUE B-FILE.
ENTER A NAME FOR THIS OUTPUT B-FILE:
? bf021

ENTER THE NAME OF THE B-FILE PARAMETER TO BE FILTERED:
? pp128
VARIABLE IDENTIFIED AT POSITION 1.

ENTER A NAME FOR THE FILTERED PARAMETER WHICH WILL BE CONTAINED ON THE OUTPUT
B-FILE, BF021
? fp128l

WILL THE FILTER DESCRIPTION COME FROM A FILE OR TERMINAL ENTRY? (F/T):
? f

ENTER THE NAME OF THE FILTER DESCRIPTION FILE
? ff001

THE FILTER WILL BE TREATED AS LENGTH 128

DO YOU WANT TO FILTER ANOTHER PARAMETER? (Y/N):
? n

*** END OF PROGRAM ***

    1.780 CP SECONDS EXECUTION TIME
```

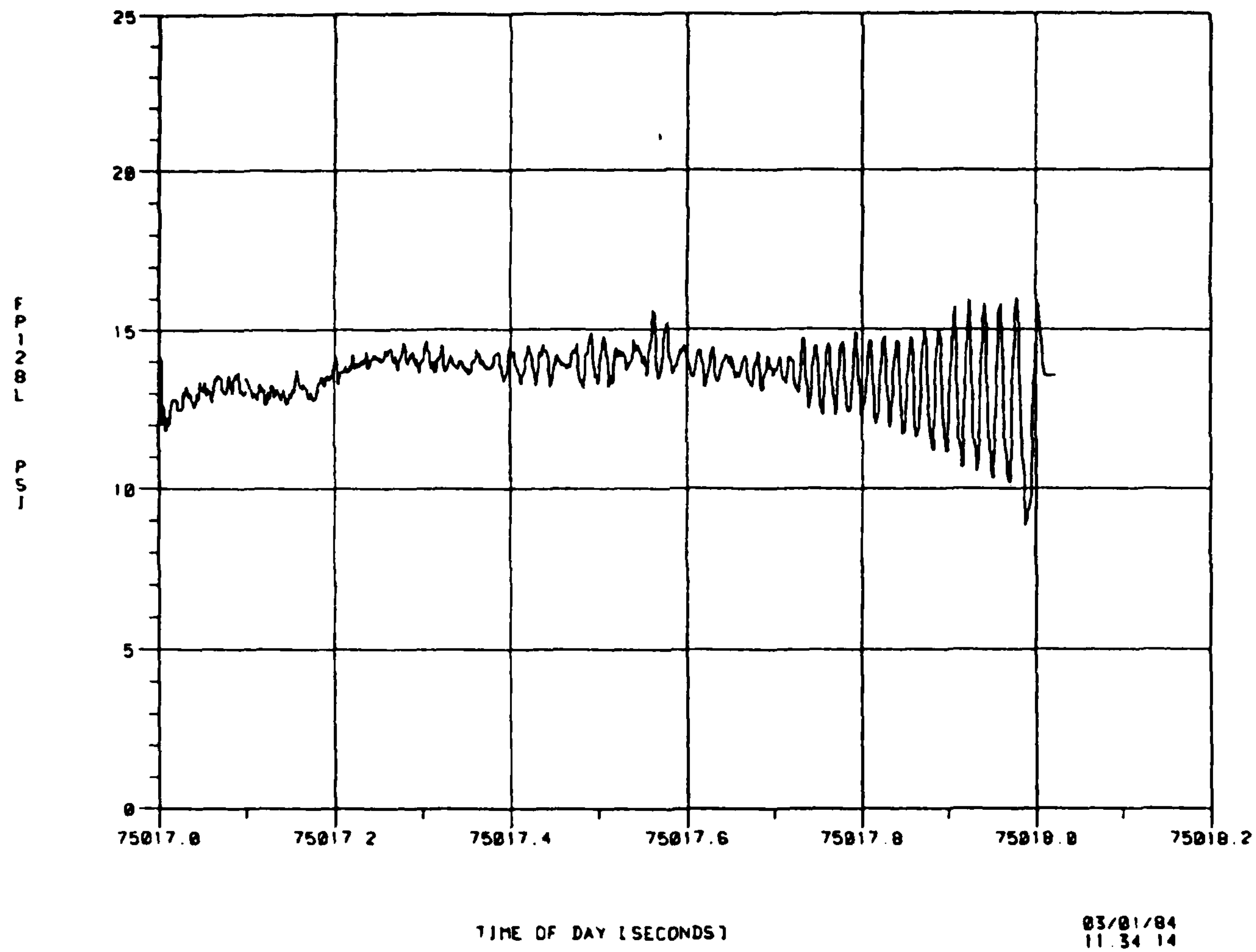
Display 14 - Example Application of FILTER Using LOWPASS and MLTPASS Filter Designs

PARAMETER TIME HISTORY



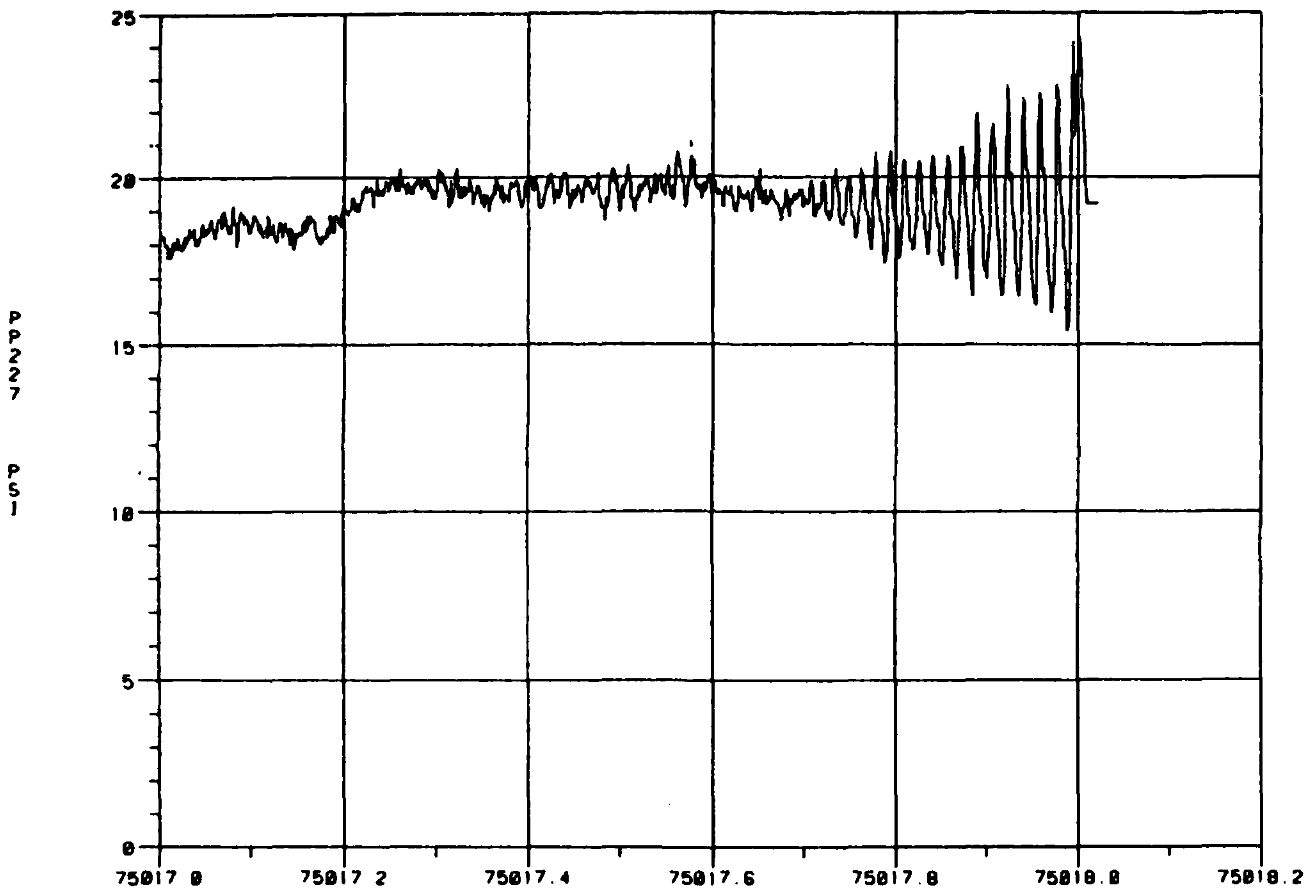
Display 14 - Continued

PARAMETER TIME HISTORY

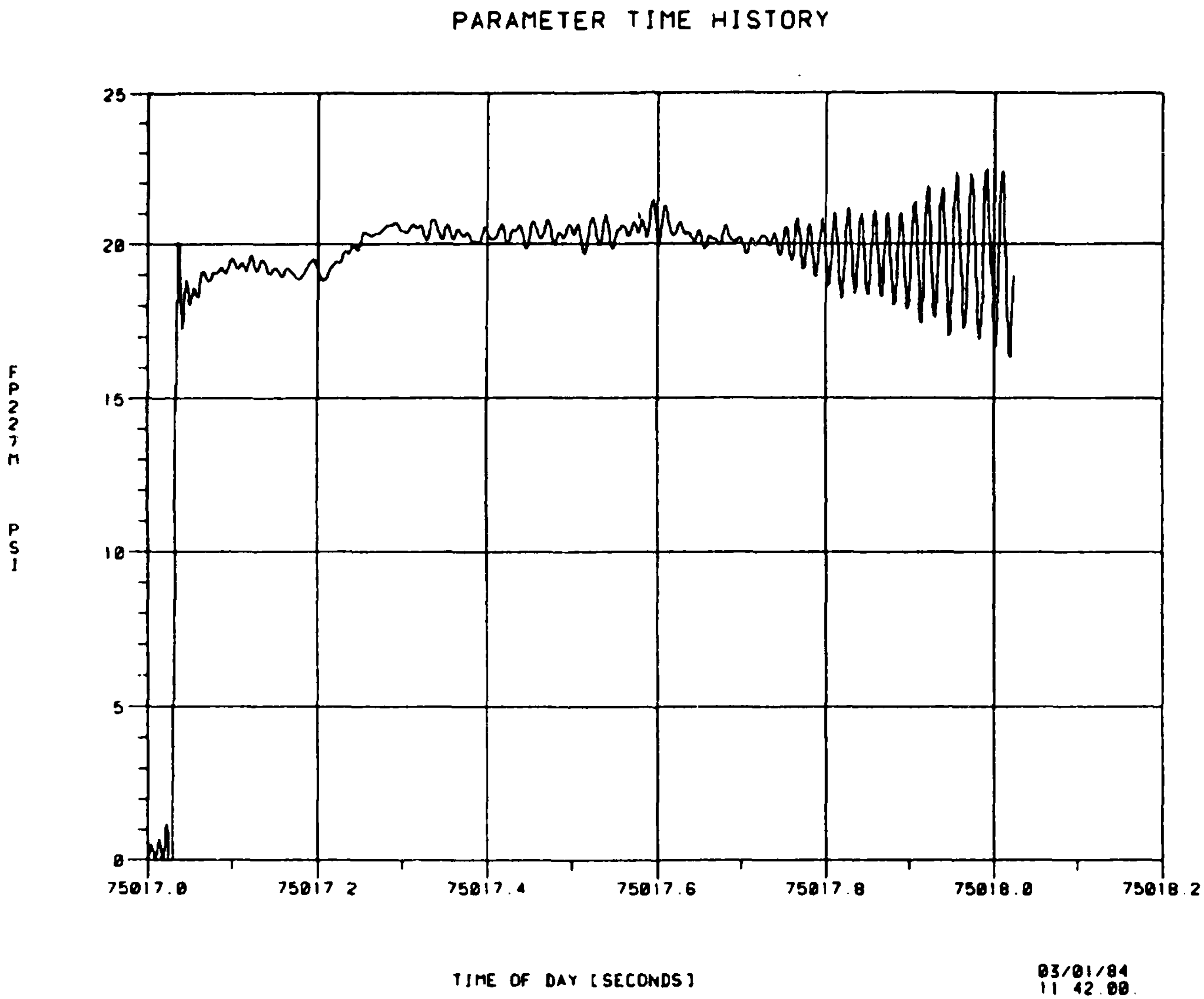


Display 14 -- Continued

PARAMETER TIME HISTORY



Display 14 -- Continued



Display 14 - Concluded

7. TEST SOURCE DATA FILES

Test source data files provide a means to test the output of an analysis program with a well defined input. Currently, one such data file is provided on the ISAS fileset.

7.1 White Noise (DATA/WHITE)

White noise is represented by a data sequence on the file named DATA/WHITE. This file is an UFTAS standard B-file with the fileset group name DATA and element name of WHITE. The white noise file provides a source test signal with frequency content spread across the sampled data spectrum. This signal may be used to drive the input of a digital filter under consideration so that the filter's output is an indication of the frequency response of the filter.

7.1.1 Background:

After a filter design has been generated, it is useful to examine the actual filter response and determine if the actual filter response meets the design specifications. A simple way to accomplish this is to provide a broad spectrum time history as input to the filter design and use a spectrum analysis tool to examine the output of the filter. Such a broad spectrum input is white noise which contains sinusoids of equal amplitude over a broad frequency range.

The fast Fourier transform may be used to analyze the frequency response of a system subjected to a particular signal. If a digital signal is composed of sinusoids evenly spaced across the frequency spectrum, the FFT will calculate frequency content within evenly spaced intervals across the spectrum. Also, if the N-point FFT of an sequence is calculated from the signal, the frequency content at(N/2)+1 positive frequencies is obtained by the fast Fourier transform. These frequencies are located between 0 and $f_s/2$ and have a spacing of f_s/N, where f_s is the sample frequency.

If the sinusoids of the test signal are located at precisely the center frequencies, no smearing of the frequency spectrum will occur. The frequency content of the signal will be accurately represented by a FFT. Correspondingly, the output of a linear system driven by this input will also have frequency content at only the center frequencies. The output of the system may be analyzed to determine the effectiveness of the system on the input signal. Thus the filtered output from a digital filter that had as input the white noise data file may be compared to this input to determine the effectiveness of the digital filter. This comparison is best conducted in the frequency domain by employing a frequency analysis program such as TRANS or FFT.

7.1.2 Data file specifications:

Specifications of the white noise data file are given below to facilitate the application of this test sequence in the digital filter and frequency analysis programs.

File name	- DATA/WHITE
File type	- B-file
Parameter name	- NOISE1 (this is the only parameter on the B-file)
Data sample rate	- 1,000 samples per second
Start time-of-day	- 0.001 seconds
Finish time-of-day	- 1.024 seconds
Signal length	- 1024 samples
Number of sinusoids	- 513 (including DC)
Sinusoid spacing	- 0.97656 Hertz between 0 and 500 Hertz

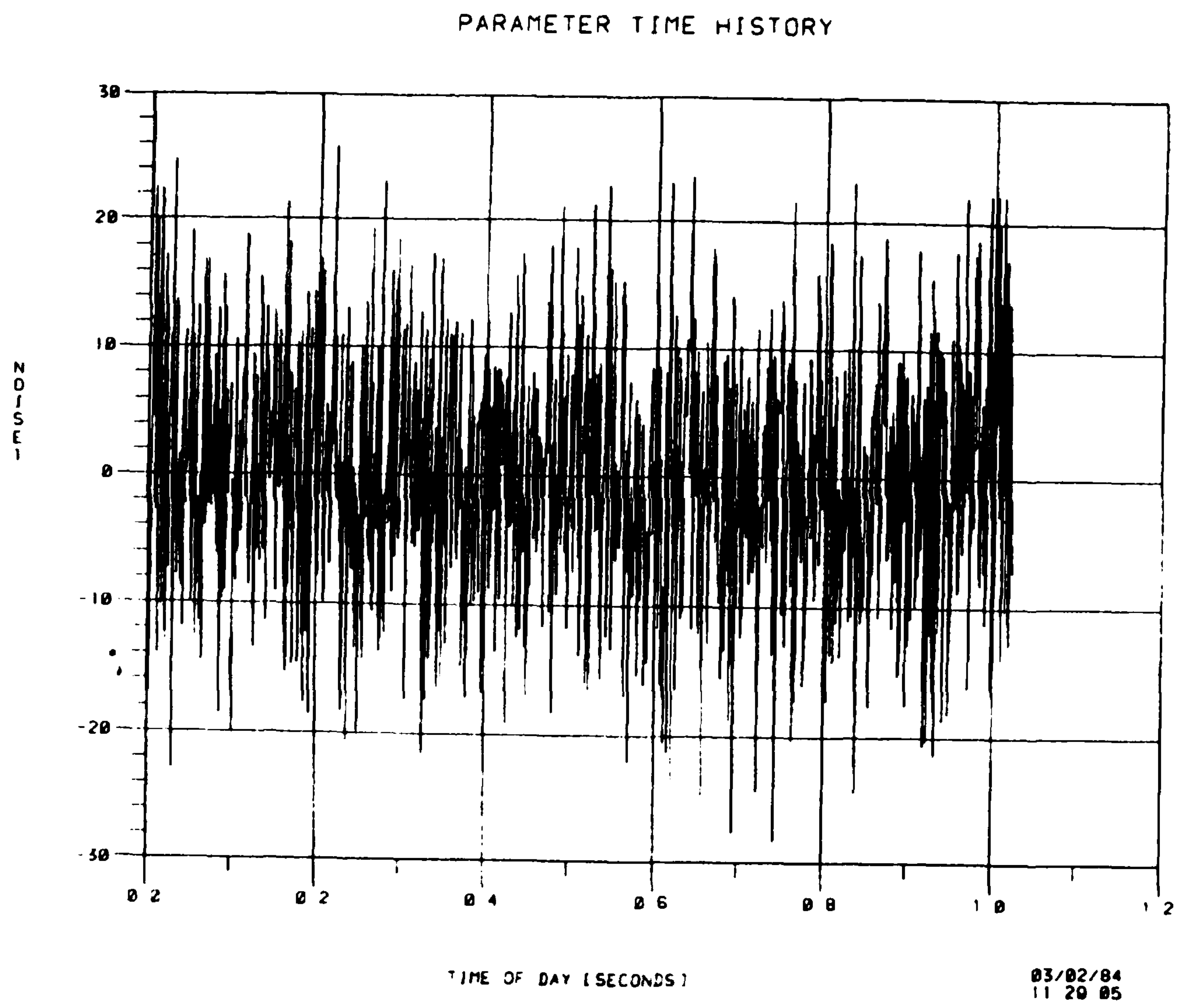
7.1.3 Example:

The data file named WHITE was employed to verify the digital filter designs detailed in Sections 6.1 and 6.2. This white noise B-file was generated through the UFTAS utility data generation program DATAGEN which is documented in Reference 5. Depending on the specifications of the filter design (e.g. data sample rate, frequency band range, etc.), it may be necessary to generate a white noise data file which reflects the sample rate and frequency content of the data to be filtered. The white noise data specifications given above were specified through DATAGEN to be compatible with the example test data. For reference, a plot of WHITE is given by Display 15 which was obtained from PLOT.

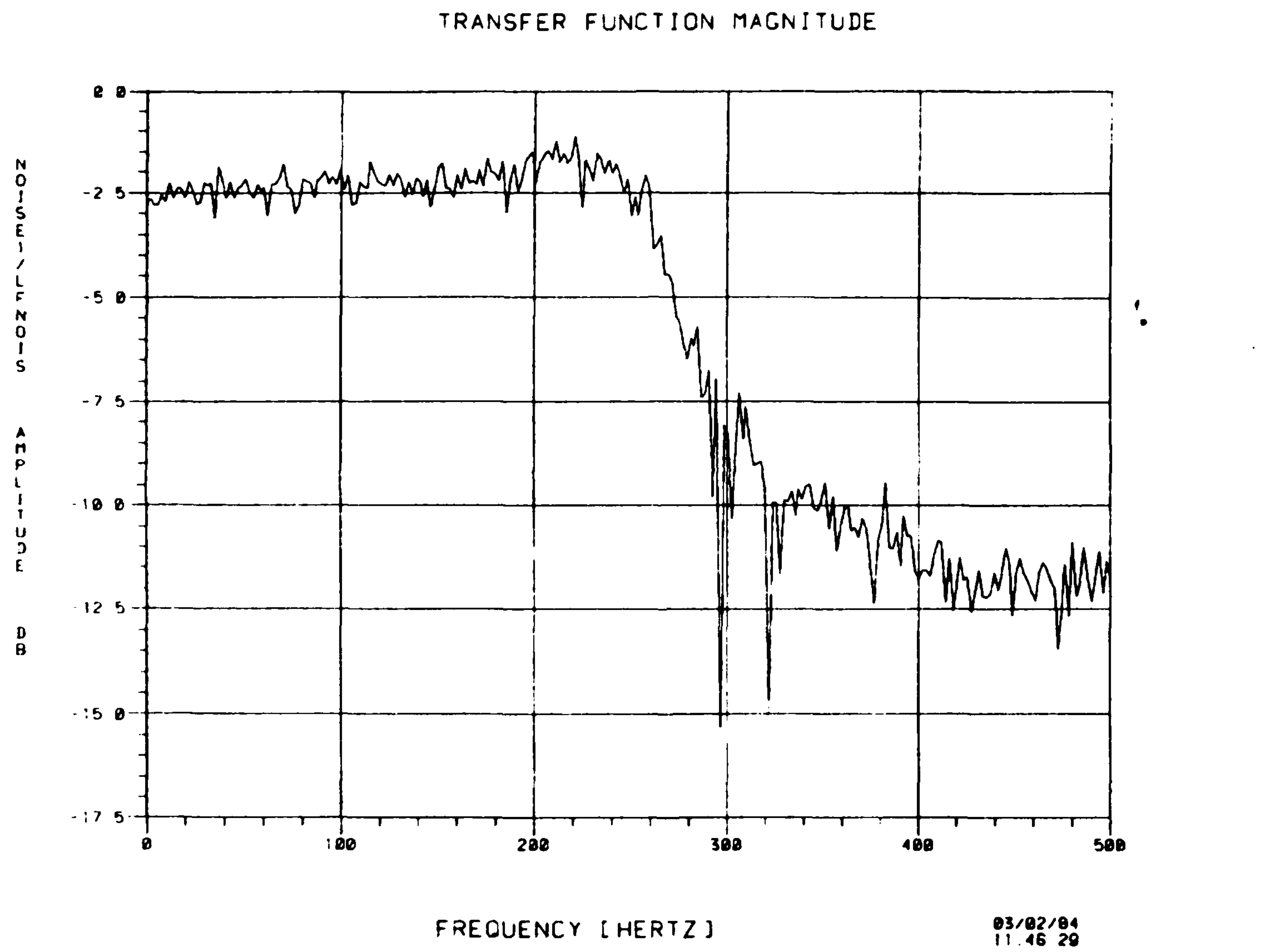
As Figure 5 indicates, WHITE was employed as input to the filter implementation program FILTER to verify the digital filter designs. The parameter NOISE1 was filtered according to the LOWPASS design specifications input through the filter file FF001. The filtered parameter time history named LFNOIS was output on the B-file WN024. This filtered time history was subsequently compared with the unfiltered time history NOISE1 in the frequency domain by TRANS. Display 16 shows the resultant plot of the transfer function magnitude of the transfer function between these two parameters. The effect of the LOWPASS filter design is evident and corresponds to the filter specifications. The pass band is present from 0 Hertz to 200 Hertz with the amplitude of the frequency components above 250 Hertz severely attenuated by the filter. However, Display 16 shows that the pass band frequency components are slightly attenuated by approximately 2 dB. This has been observed to be a consequence of the LOWPASS filter design and should be noted for reference.

In a similar manner, the white noise parameter NOISE1 was employed to verify the MLTPASS filter design. Display 17 shows a plot of the transfer function magnitude between NOISE1 and the filtered white noise parameter SFNOISE. The design specifications of the filter file FF002 are reflected in this plot of the transfer function magnitude. The pass band is predominant from 0 Hertz to 100 Hertz without any attenuation. The transition band displays rapid amplitude dropoff of the filtered parameter by approximately 25 dB. Also, the stop band is severely attenuated to the limiting frequency of 500 Hertz.

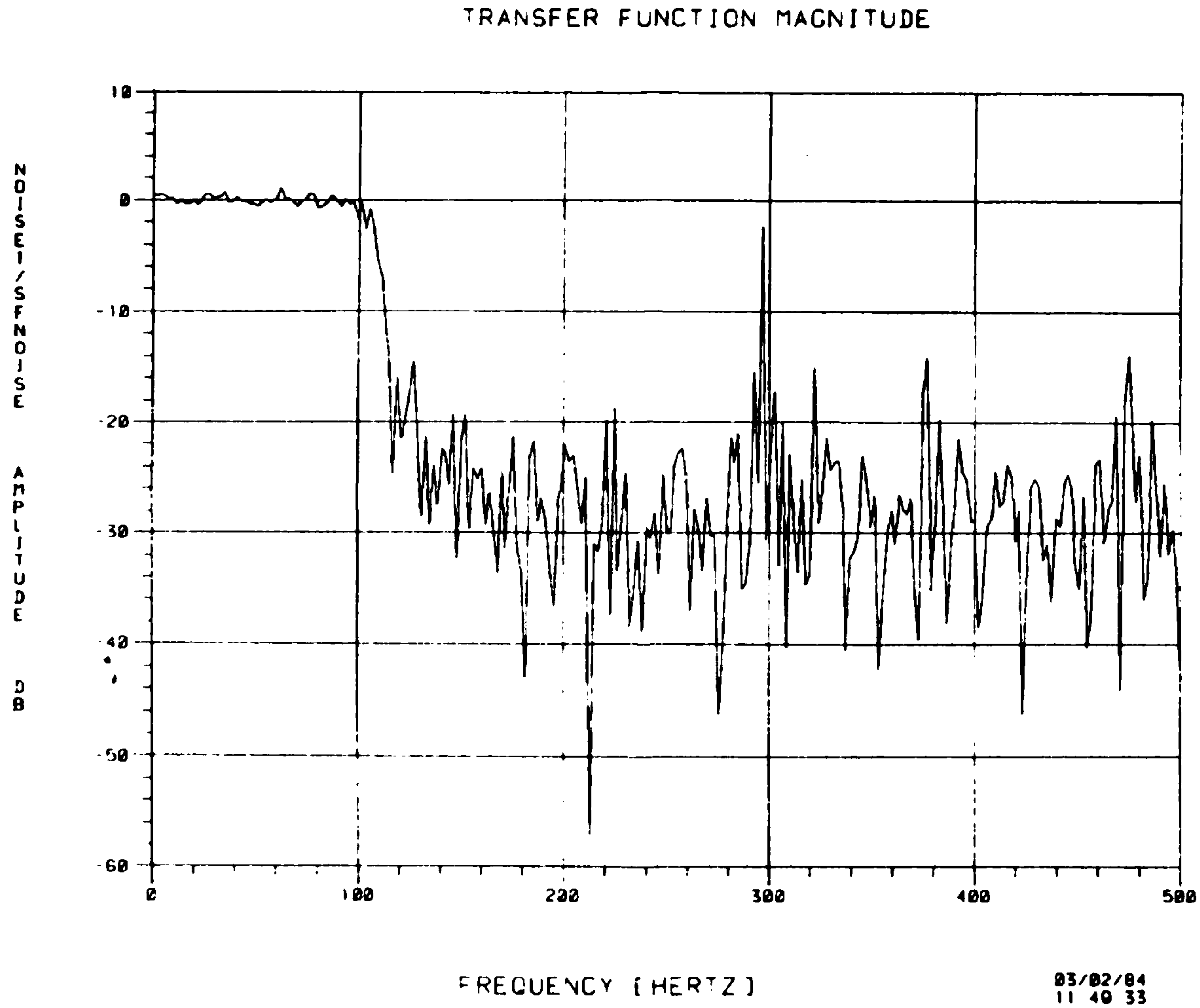
Verification of the filter designs employed to enhance the pre-stall test data through the above procedure provided confidence for the implementation of the filter designs to the test data. Also, insight was gained into the exact behavior of the filter over the spectral components of the white noise time history.



Display 15 - Time History Plot of White Noise Parameter NOISE



Display 16 - Plot of Transfer Function Magnitude Between Unfiltered and Filtered White Noise by LOWPASS



Display 17 - Plot of Transfer Function Magnitude Between Unfiltered and Filtered White Noise for NOTPASS

REFERENCES

1. Reference Manual, "Uniform Flight Test Analysis System (UFTAS)" , Computer Services Branch, 6521 Range Squadron, 6520th Test Group / AFFTC, Edwards AFB, CA, January 1984, pp. 2-1 to 2-5.

2. Louton, Steven E., "A User's Manual and Technical Overview of the Air Force Flight Test Center's Digital Signal Processing Software Package" , Flight Test Technology Branch Office Memorandum, January 1983.

3. Reference Manual, "Fileset User's Manual", Software Management Branch, Computer Sciences Division, 6520th Test Group / AFFTC, Edwards AFB, CA.

4. Reuter, Abigail L., "A Graphical Approach to Understanding and Preventing the Phenomenon of Aliasing", Flight Test Technology Branch Office Memo, February 1984.

5. Garbinski, Chuck and Johnson, Gary G., "UFTAS Utility Programs User's Guide" , Software Management Branch, Computer Sciences Division , 6520th Test Group / AFFTC , Edwards AFB, CA, July 1983.

6. Twisdale , Thomas , "Time Shifting Your Data : A New FRA Capability" , Flight Test Technology Branch Office Memo, October 1982.

7. Rabiner, L. R. and Gold, B., Theory and Application of Digital Signal Processing, Prentice-Hall, N.J., 1975, p.367.

8. Rabiner , L. R. , et al. , "Terminology in Digital Signal Processing", IEEE Transactions on Audio and Electroacoustics, Volume AU-20, Number 5, December 1972, pp. 332,336.

APPENDIX A

Analysis of Gas Turbine Engine Dynamic Instabilities

ANALYSIS OF GAS TURBINE ENGINE DYNAMIC INSTABILITIES

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Abstract

A method has been developed for the analysis of dynamic instabilities that have been observed in gas turbine engines during flight test. An investigation which exemplifies data analysis techniques was conducted on dynamic data recorded during augmentor transient operation. Signals from pressure transducers located in the engine gas path and fuel delivery system were recorded and digitized. Data analysis techniques included time history plotting of low and high frequency response data, Fourier Transform based spectral analysis, and digital filtering. Pre-stall dynamic instabilities were characterized by low frequency oscillations throughout many engine components. The analysis of component interactions identified the path of dynamic instabilities through the engine. A transfer of dynamic energy from one frequency band into another was also identified.

Nomenclature

AC	type of oscillating signal employed by masking technique
AJ	exhaust nozzle area, percent
EPR	engine pressure ratio
EU	engineering units
FFT	Fast Fourier Transform
FM	frequency modulated signal
LOD	augmentor light-off detector
MASK	type of constant signal employed by masking technique
N1	fan rotor speed, rpm
N2	core rotor speed, rpm
ORIG	type of dynamic signal employed by masking technique
Pb	core burner inlet pressure, lbf/in^2
PCM	pulse code modulated signal
PLA	power lever angle
Pseg1	fuel pressure in augmentor segment 1, lbf/in^2
Pseg2	fuel pressure in augmentor segment 2, lbf/in^2
Pseg3	fuel pressure in augmentor segment 3, lbf/in^2
Pseg4	fuel pressure in augmentor segment 4, lbf/in^2
Pseg5	fuel pressure in augmentor segment 5, lbf/in^2
Ps2.5c	fan exit duct static pressure, lbf/in^2
Pt2.5c	fan exit duct total pressure, lbf/in^2
Pt2.5h	fan exit core total pressure, lbf/in^2
Ps5c	fan duct static pressure, lbf/in^2
Pt6m	turbine discharge (mixed core and fan stream) total pressure, lbf/in^2
SANDS	Standard Analog to Digital System for processing data
t	elapsed time, seconds
UFTAS	Uniform Flight Test Analysis System

Introduction

A continuous technological challenge exists for high performance aircraft capable of executing multiple mission roles. This challenge has driven the design of the aircraft gas turbine engine throughout its history of development. Today's typical high performance gas turbine engine is an augmented turbofan engine with features such as variable compressor vane geometry, variable exhaust nozzle area, and a hydromechanical or electronic control system. Such a design provides a high thrust-to-weight ratio and optimum performance over a wide range of operating conditions. Continuing gas turbine technological advancements coupled with aircraft integration through the engine control system have resulted in complex designs to meet operational requirements.

The complex design of the modern gas turbine engine often harbors operational anomalies. Operation of the aircraft's propulsion system at extreme regions of the flight envelope can cause components of the gas turbine engine to operate off their design point. Components, such as the high-pressure compressor, can experience rotating stall or surge which adversely affects other engine components. The transient processes which occur during a rapid advance of the throttle from an idle or military power setting to a maximum power setting may induce combustion instabilities in the afterburner and its control system. Combustion instabilities often inherent in high performance thrust augmentation systems can result in large amplitude pressure oscillations. These pressure oscillations can stall the compression components of the engine or induce augmentor blowout. Transient processes resulting from a throttle excursion can also impose unmeetable demands on the engine control system. Phenomena and processes

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of these types within the gas turbine engine restrict operation of the aircraft over a region of its flight envelope and reduce the effectiveness of its mission.

Operational difficulties accompanying engine component off-design performance and throttle excursions can be minimized through an understanding of the underlying physical principles and characteristics of the encountered anomaly. An understanding of the driving mechanisms behind unstable engine operation can prompt hardware modifications to reduce or eliminate the source of the instability. Component coupling can reinforce unstable operation of several components of the engine. An understanding of the coupling mechanism can result in design modifications to alleviate reinforcement of the instability. Dynamic instabilities and time delays of the engine control system can be identified and minimized during transient operation. An understanding of the phenomena underlying unstable engine operation is facilitated through performing appropriate propulsion system flight tests and applying methodical post-flight data analysis.

Propulsion system evaluation and testing of high performance aircraft are conducted at the Air Force Flight Test Center. During recent propulsion system flight tests, dynamic engine instabilities have been observed to result from throttle excursions which involve transient augmentor operation. These instabilities were recorded by pressure transducers located in the engine core and bypass flowpaths, and in the gas generator and augmentor fuel delivery systems. Measurements from typical augmentor transients were chosen for analysis and for the generation of a data base of the dynamic engine instabilities. These instabilities were characterized by engine stall or stagnation, augmentor rumble or blowout, and pressure oscillations in the fuel flow metering and distribution system. Existing data analysis procedures were extended and new techniques were developed for the analysis of engine instabilities recorded in the data base. Procedures were defined which aided the identification and characterization of phenomena typical of unstable augmentor transient operation. The analysis techniques revealed basic mechanisms underlying the dynamic instability as well as a coupling between engine components. Hardware design modifications were determined to alleviate specific dynamics of the fuel delivery system and improve transient augmentor operation.

Propulsion System Description

The data analysed were obtained from a propulsion system which is typical of a modern high performance augmented turbofan engine. Figure 1 illustrates a cross sectional schematic of this type of propulsion system. Primary engine stations and components are indicated. The engine is typical of a low bypass ratio and high-pressure ratio design. The multiple-stage fan is driven by a multiple-stage, low-pressure turbine. Similarly, the compressor is powered by a multiple-stage, high-pressure turbine. Variable compressor vanes are utilized to help maintain high performance over a wide range of power settings. The engine core combustor is typically of the annular type. The engine is also equipped with a full length annular fan duct and a mixed flow augmentor. The augmentor is terminated by a variable-area, convergent-divergent nozzle. The augmentor contains multiple spray manifolds or segments which deliver fuel to the afterburner combustion area for afterburner operation. These manifolds are located in the core and bypass flowpaths behind the low pressure turbine.

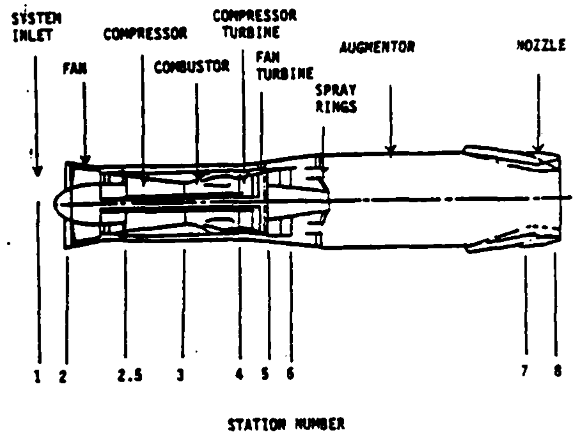

Fig. 1 Cross sectional view of typical propulsion system with component and station identification.

Modulation of the augmentor fuel delivery system is typically accomplished by an integrated afterburner and nozzle control system. The afterburner control system has the primary function of governing the fuel delivered to the afterburner manifolds, and maintaining a correct pressure level in the afterburner by varying the nozzle throat area. The control sytem is also responsible for sequentially supplying the fuel to the various segments of the augmentor. This process normally consists of initially filling the manifolds at a high rate of fuel flow (quickfill) and then transferring the manifold fuel flow to a precisely metered rate of flow. The augmentor fuel control is particularly important during throttle excursions which involve transient augmentor operation.

Data Acquisition

Signals from pressure, temperature, rotation, and position sensors were recorded during propulsion system flight tests. The instrumentation installed on the augmented turbofan engine utilized for flight test is shown in Figure 2. The various parameters were measured at the locations indicated in Figure 2. Data were recorded by a low frequency response pulse code modulation (PCM) system and a high frequency response frequency modulation (FM) system. These data streams were recorded on magnetic tape aboard the aircraft during flight test for post-flight processing. Low frequency response parameters such as the power lever angle (PLA), augmentor light-off detector (LOD), percent nozzle area (AJ), and the rotational speed of the high and low pressure rotors, were recorded by the PCM system. High frequency response parameters, such as the core and bypass duct flowpath pressures, main pump fuel pressure, and the augmentor segment fuel pressures, were recorded by the FM system.

The various parameters were filtered by the PCM and FM instrumentation systems before digitization to prevent aliasing errors.

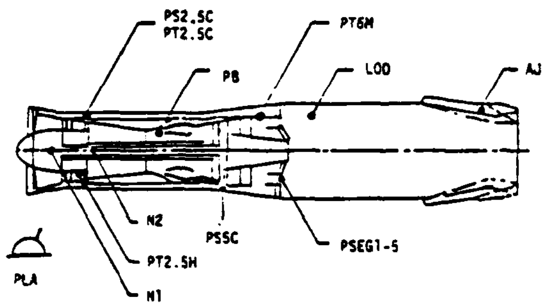

Fig. 2 Propulsion system instrumentation.

Data from the aircraft and engine instrumentation recorded on the aircraft tape were processed by a series of digital computer programs which produced the flight data file. This process is illustrated in Figure 3. The analog aircraft tape was converted into a digital tape by an analog-to-digital converter. During this process the FM parameters were digitized at a rate of 1,000 samples per second. The data were then converted into engineering units and various computations were performed with direction from the project history file. At this time instrumentation errors were corrected, and derived parameters, such as the engine pressure ratio and compressor pressure ratio, were calculated. This processing was conducted by the Air Force Flight Test Center's Standard Analog to Digital System (SANDS) for data analysis which produced a digital data tape with the parameters expressed in engineering units. Further processing, such as data smoothing and editing, was performed by the Uniform Flight Test Analysis System (UFTAS) at the Flight Test Center. UFTAS produced a data base compatible with digital data analysis software. The digital data base was subsequently referenced by digital computer programs which performed analysis tasks to identify and characterize the measured augmentor transient phenomena.

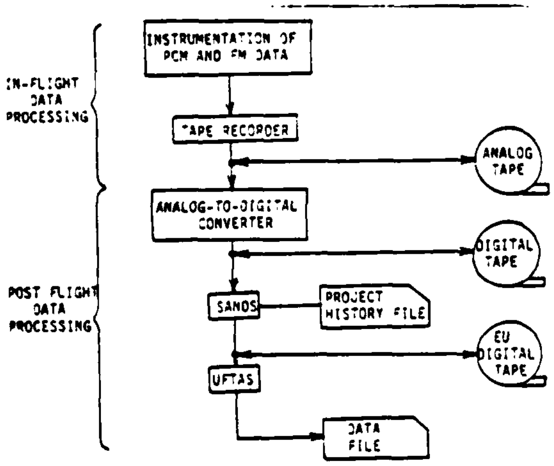

Fig. 3 Aircraft and post-flight data acquisition system.

Throttle snaps from idle to maximum power were performed at relatively high altitudes and low Mach numbers. Figure 4 shows a portion of the aircraft flight envelope and the augmentor operating envelope. The augmentor operating envelope is divided into three regions which are based on the probability of afterburner transient success. Unrestricted afterburner operation is permitted in region 1 and all augmentor transients are expected to be successful. However, afterburner mislights, light-off stalls or blowouts, and stalls related to rumble, may occur during throttle transients. Augmentor transients performed in region 3 are likely to be unsuccessful. Also, afterburner rumble and blowout are possible during steady-state operation. Figure 4 shows a region of the augmentor operating envelope where combustion instabilities such as rumble have been experienced. This region is indicated by the cross-hatched area.

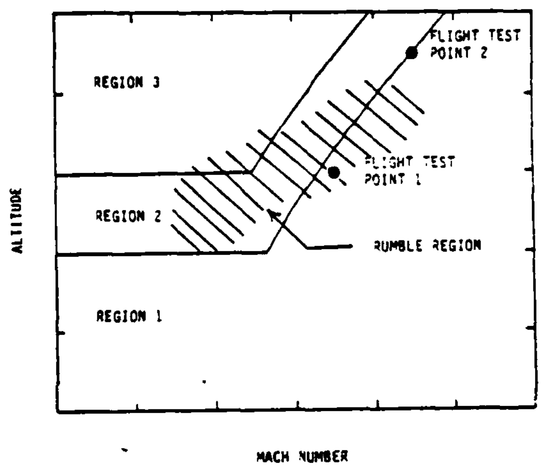

Fig. 4 Augmentor operating envelope.

Flight test results were obtained from throttle snaps from idle to maximum power at operating points in regions 1 and 2 and near the interface between regions 2 and 3. Idle to maximum power snaps were generally successful in region 1. However, some throttle snaps attempted in region 2 led to engine stall or augmentor blowout. Throttle snaps to maximum power in region 3 frequently resulted in similar operational anomalies. From unsuccessful augmentor transients, typical flight test data were chosen to exemplify transient phenomena and develop data analysis techniques. Two such flight test points are indicated in Figure 4. A throttle snap was attempted at flight test point 1. This augmentor transient resulted in an engine stall. A similar throttle snap was attempted at flight test point 2. This augmentor transient resulted in an augmentor blowout. Data obtained from these transient events were recorded and processed through the post-flight data processing system for further analysis.

Data Analysis Procedure

Data analysis consisted of processing the parameter time histories of the digital data file through a group of digital computer programs. Figure 5 illustrates a block diagram of the data analysis software. This software is organized into four groups of functionally similar programs. These groups are the data consolidation and editing program group, the data display and list program group, the frequency analysis program group, and the digital filter program group. The data analysis software utilized the UFTAS data file structure for the communication of data between the individual analysis programs. Also, formatted output files were employed to transmit analysis results to hard copy devices.

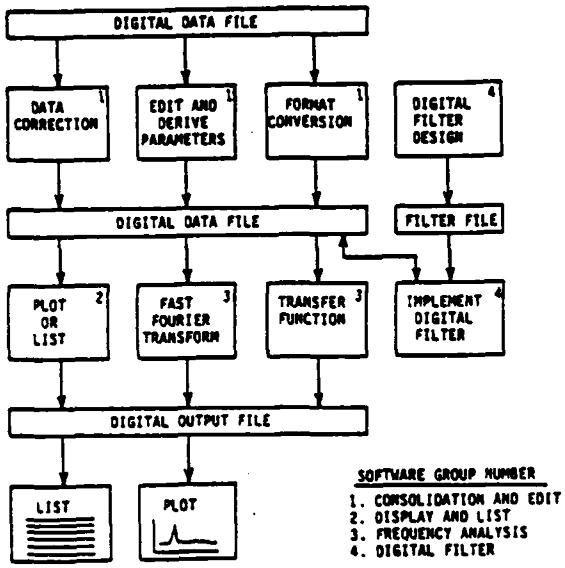

Fig. 5 Block diagram of data analysis software.

The various analysis software groups contain programs which perform specific tasks of data reduction. The data consolidation and editing group of programs performed operations such as the consolidation of parameter time histories, the correction of instrumentation and digitizing errors, the generation of derived parameters, and format conversion of data files. Parameter time histories could be plotted or listed in a specified format through the usage of software in the display and list program group. The frequency analysis program group provided the capability to analyze data in the frequency domain. A Fast Fourier Transform (FFT) of a dynamic parameter or the frequency domain transfer function between two parameters could be determined. The software of the digital filter program group facilitated the design and implementation of low-pass and multiple-band, finite-impulse-response digital filters. A description of the digital filter was represented by its impulse reponse which was stored on the filter description file. The software programs within the four program groups generated analysis results in the form of listings, plots, or output files which could be directed to a plotter or line printer.

Data Analysis Results

Results from various data analysis techniques that were applied to augmentor transient data are presented and discussed below. Data analysis techniques that are discussed include PCM and FM data time history plots, Fourier Transform based spectral analysis, and digital filtering. These analysis tools assisted in revealing the characteristics and physical basis of dynamic instabilities of augmentor operation that were observed during flight test.

PCM Data Time Histories

The time histories of engine parameters recorded by the PCM data acquisition system provided a comprehensive record of a transient event during flight test. An advantage of this data acquisition system is that many parameters could be input to the PCM data stream. Therefore, an interaction or coupling between engine components could be discerned during analysis. PCM data of the engine parameters were recorded during the augmentor transient flight tests. Figures 6 and 7 present PCM data obtained from flight test points 1 and 2. Various parameters are presented over a 10 second time interval which captures the transient processes leading to a stall or blowout.

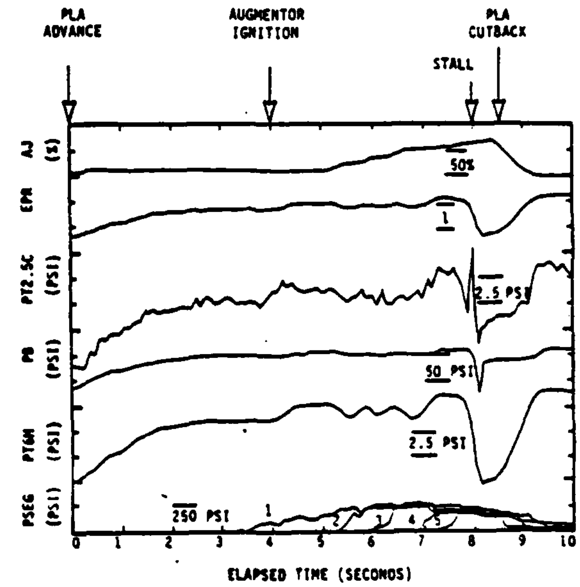

Fig. 6 Time history of PCM data obtained during augmentor transient at flight test point 1.

The transient processes which occurred during the throttle snap to maximum power at flight test point 1 resulted in an engine stall. These transient processes are characterized by the parameter time histories given in Figure 6. The PLA was advanced to the maximum power setting at the elapsed time of t = 0 seconds. Approximately 8 seconds later, after full thrust augmentation was achieved, an engine stall was experienced and the PLA was cutback to an intermediate power setting.

The parameter time histories presented in Figure 6 summarize the sequence of events which occurred between the throttle snap and the incipient stall.

Various pressures in the fan and core duct, as well as the exhaust nozzle percent area variation, are shown along with the augmentor fuel manifold pressures. At t = 0 seconds the PLA request resulted in an increase of the fan duct pressure (Pt2.5c), core flow pressure behind the high pressure compressor (Pb), and pressure in the mixed flow region behind the low pressure turbine (Pt6m). The rise in the engine flowpath pressures gradually increased until t = 3.5 seconds. At this time the augmentor fuel control began to sequentially pressurize the augmentor fuel spray rings which consisted of segment 1 through segment 5. Augmentor ignition at t = 4 seconds was deduced from the rapid increase in Pt6m and confirmed by the LOD. After segment 1 was stable, the fuel control quickfilled segment 2 at t = 5.3 seconds and then transferred segment 2 to metered flow. This process was continued for segments 3 through 5 and terminated with segment 5 on metered flow at approximately t = 7.7 seconds. The core and fan flowpath pressures increased and decreased in amplitude during this process in response to backpressure generated by the augmentor stepped combustion processes and modulation of the exhaust nozzle. Pt6m and Pt2.5c experienced substantial variations in amplitude during the sequential activation of the augmentor segments. However, any increase in backpressure to the fan up to t = 7 seconds was accommodated by the fan's stall margin. Also, the nozzle area adjusted to maintain the correct engine pressure ratio (EPR). After the quickfill and transfer to metered flow of segment 5, a pressure pulse was generated which had sufficient amplitude to increase the fan pressure ratio to a value above its steady-state stall line. This resulted in a fan stall at t = 8 seconds. The stall was evidenced by a rapid increase in Pt6m and a severe oscillation of Pt2.5c. Immediately following the stall, the PLA was brought to an intermediate power setting, the fuel flow was sequentially stopped to the augmentor segments, the nozzle was closed, and the engine recovered at t = 9.5 seconds.

An augmentor blowout was also experienced during a throttle excursion from idle to maximum power. The blowout occurred at flight test point 2. Figure 7 summarizes the time histories of the PCM parameters during 10 seconds of time which captured the event. The five augmentor segment fuel pressures are shown along with the pressures measured in the fan and core flowpath and the percent exhaust nozzle area variation.

At t = 0.8 seconds of elapsed time, the throttle was snapped from an idle power setting to the maximum power setting of the PLA. Again, the throttle advance resulted in an increase in the amplitude of the core and fan flowpath pressures. At t = 4 seconds the augmentor segments were sequentially pressurized. Ignition of the augmentor was detected at t = 4.5 seconds. Segments 2 through 5 proceeded through a sequence of quickfills and transfers to metered flow until t = 8.5 seconds when segment 5 was supplied with metered fuel flow.

Substantial variations in the amplitude of the fan duct pressures were induced due to pressure pulses from the augmentor transient fuel flow. However, the stall margin of the fan was not exceeded and the nozzle adjusted to maintain a constant engine pressure ratio. One second after segment 5 was transferred to metered flow, at t = 9.5 seconds, an augmentor blowout was experienced. The cause of this blowout was difficult to determine from the PCM data alone.

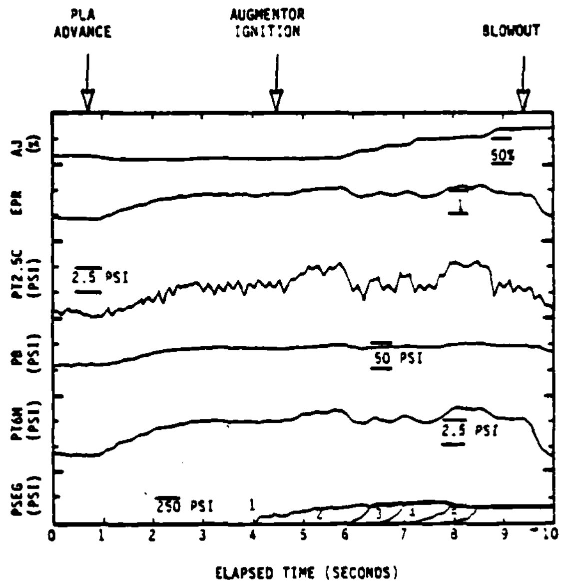

Fig. 7 Time history of PCM data obtained during augmentor transient at flight test point 2.

The PCM data acquisition system provided a comprehensive summary of the variation of many engine parameters during augmentor transients. The interaction between engine components was described by a large number of parameters over a long period of time. However, the lower sample rates associated with the PCM data system limited the ability to identify rapid fluctuations in parameter values. From the PCM data, it was difficult to determine the phenomena which induced the pressure oscillations that resulted in an engine stall and blowout. A better understanding of the augmentor transient events was obtained through the FM time history data.

FM Data Time Histories

The FM data acquisition system provided parameter time histories which could be digitized at a high rate. A digitizing rate of 1,000 samples per second was employed. Characteristics of several augmentor transient phenomena in the gas flowpath and fuel delivery system were revealed at this high sample rate.

The FM Data revealed details of augmentor transient phenomena which preceded the engine stall that occurred at flight test point 1. The time histories of several FM parameters are given in Figure 8 for the stall event. These time histories span a period of 1 second in time which corresponds to an elapsed time of the PCM data presented in Figure 6 from t = 7.2 seconds to t = 8.2 seconds. The quickfill of the augmentor segments, as exemplified by segment 5 at t = 7.4 seconds, is shown to consist of high amplitude pressure fluctuations which diminished in amplitude when the segment transferred to a metered flow rate. The dynamics associated with the quickfill of the augmentor manifolds were transmitted to segments already supplied with metered fuel flow due to the common delivery system. This is realized by comparing the quickfill of segment 5 and the resultant pressure oscillations in the metered fuel flow of segment 3. Also, the transfer to metered fuel flow was not smooth and was revealed to be characterized by a pressure spike. This pressure spike has been reported to create a pressure pulse in the fan duct flowpath of sufficient amplitude to induce a fan stall. The segments already on metered flow also experienced a pressure drop since they are supplied by the common fuel delivery system.

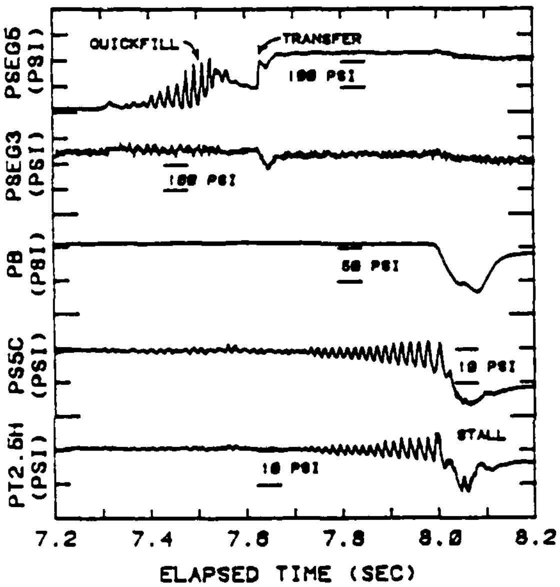

Fig. 8 Time history of FM data preceding engine stall at flight test point 1.

The quickfill and transfer to metered flow of the augmentor segments were observed to induce pressure oscillations in the engine fan duct as shown by Figure 8. This phenomenon is exemplified by the variation of the duct static pressure at station 5, Ps5c, during the quickfill of segment 5. The induced pressure oscillations in the fan flowpath became more severe as the quickfill process was applied by subsequent manifold segments. This is due to the common fuel delivery system of the manifolds. The induced gas flowpath pressure oscillations were observed with reduced amplitude by other flowpath pressures measured in the fan duct and also by Pt2.5h which was measured in the core flowpath behind the fan. However, no influence was observed in Pb measured downstream of the high-pressure compressor. This suggests that the flowpath pressure oscillations were not transmitted through the compressor.

Figure 8 also shows the onset of pressure oscillations in the fan duct at t = 7.7 seconds which immediately preceded stall. These pressure oscillations reached an amplitude which caused the fan to stall at t = 8 seconds. During this period of time, the augmentor fuel delivery system appeared to be stabilized with all segments on metered flow. These pressure oscillations in the gas flowpath were observed through the fan duct and also at the high-pressure compressor inlet. However, the duct flow pressure oscillations were not observed at the exit of the high-pressure compressor as shown by Pb. Again, the pressure oscillations were observed to be readily transmitted through the fan but not through the high-pressure compressor. This information suggests that the large amplitude pressure fluctuations may be associated with a combustion instability of the augmentor which occurred after segment 5 stabilized with metered fuel flow. Combustion instabilities of this type can be driven by a coupling between an acoustic oscillation at a resonant mode of the augmentor and the heat addition process.

The transient phenomena preceding the augmentor blowout experienced at flight test point 2 are characterized by the FM parameters presented in Figure 9. These data correspond to two periods of time recorded by the PCM data system and plotted in figure 7. These time periods correspond to elapsed times from t = 8.2 seconds to t = 8.7 seconds and from t = 9.2 seconds to t = 9.7 seconds. The data presented in Figure 9 from t = 8.2 seconds to t = 8.7 seconds demonstrate the affect of a modification to the augmentor quickfill system which reduced the amplitude of pressure oscillations in the fuel delivery system. The time history of Pseg5 shows a reduced pressure oscillation due to quickfill and a smoother transfer to metered flow. Also, the variation of Pseg3 indicates that pressure oscillations are no longer readily transferred through the fuel delivery system of the augmentor.

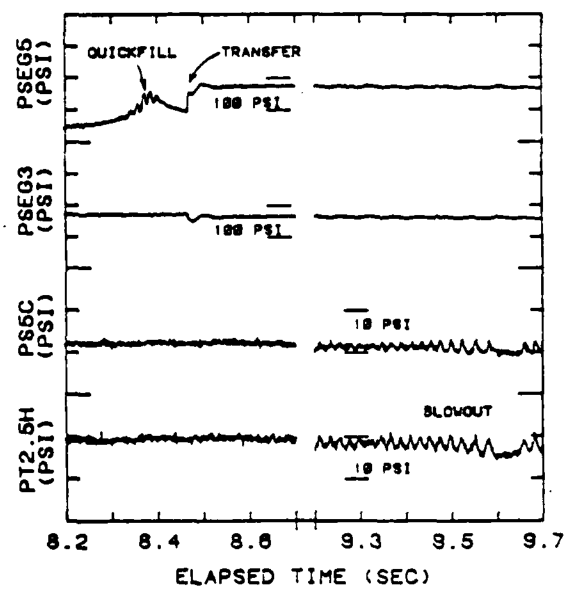

Fig. 9 Time history of FM data preceding augmentor blowout at flight test point 2.

The fan duct pressure oscillations which preceded augmentor blowout are also shown in Figure 9 during the period of elapsed time from t = 9.2 seconds to t = 9.7 seconds. During this period of time, the augmentor fuel delivery system had stabilized and all the segments were on metered flow. However, pressure oscillations were observed in the fan duct and at the compressor face with diminished amplitude. As with flight test point 1, these time history plots suggest that a combustion instability of the augmentor had induced the blowout during the throttle transient.

The above augmentor transient time histories have suggested several phenomena which involve oscillations of the augmentor fuel delivery system and induced oscillations of the fan and core flowpath. These phenomena appear very similar, occur within short time intervals, and result in two different operational anomalies: an engine stall and an augmentor blowout. It is not certain by viewing the data time histories if the pressure oscillations of the fuel system and flowpath result from the same phenomenon, two coupled phenomena, or separate mechanisms. A quantitative method for analyzing the time history data was needed. One approach was to analyze the digitized FM data in the frequency domain.

Power Spectral Density Analysis

Some characteristics of the mechanisms underlying dynamic data are not easily determined in the time domain. It can be more appropriate to transform the parameter time history into the frequency domain and analyze the signal. The digitized FM parameter time histories of flight test point 1 were transformed into the frequency domain and power spectral densities of the data were obtained. These power spectral densities identified component frequencies of the signal oscillations and the relative amplitude of the oscillations at various engine locations.

Power spectral density plots of Ps5c were obtained during the augmentor quickfill and immediately preceding stall. Figure 10 shows that the characteristic frequency of the fuel pressure oscillation during quickfill differs from the characteristic frequency of the fan flowpath dynamics prior to stall. The fuel pressure dynamics are shown to be characterized by pressure oscillations at approximately 45 Hertz. This phenomenon was observed throughout the augmentor fuel delivery system, transmitted through the augmentor combustion process and resulted in pressure oscillations in the fan duct. The fuel system dynamics associated with the quickfill process were reduced in amplitude after segment 5 transferred to metered fuel flow as shown in Figure 8. Immediately following segment 5 transfer to metered flow, Figure 10 indicates that pressure oscillations, at a characteristic frequency of 60 Hertz and lesser amplitude compared to quickfill, immediately preceded the fan stall. It is suspected that an augmentor combustion instability, which is characterized by longitudinal mode frequencies from 50 to 100 Hertz, induced this fan stall.

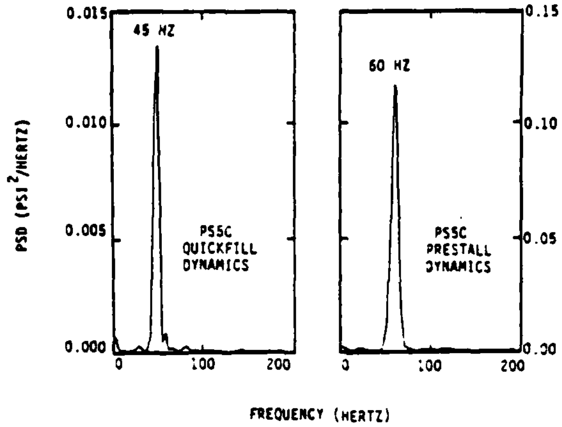

Fig. 10 Power spectral density of Ps5c during augmentor quickfill and pre-stall dynamics at flight test point 1.

Augmentor rumble was further suspected since the amplitudes of the pressure oscillations were greatest at station 5 in the fan duct. Figure 11 illustrates a comparison of power spectral density plots obtained from measurements at various engine stations. The pressure oscillation measured by Ps5c had reduced in amplitude at the fan exit plane as shown by Pt2.5c. The amplitude of the pressure oscillation was reduced further when measured in the core flowpath at station 2.5. Also, the amplitude of the spectral density plot of Pb shows that the pressure oscillation was not readily transmitted through the compressor.

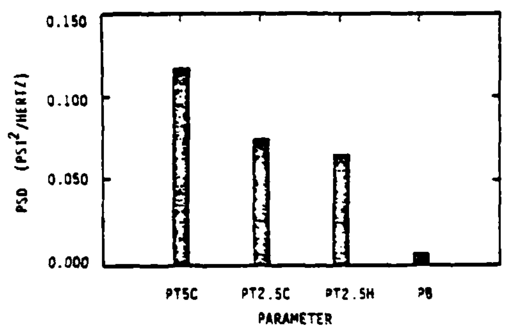

Fig. 11 Power spectral density of fan and core flowpath parameters preceding engine stall at flight test point 1.

A path of propagation is suggested by the amplitude of the power spectral densities at the characteristic frequency of the combustion instability. The source of the pressure oscillation due to rumble was in the augmentor. This pressure oscillation propagated upstream in the fan duct. Upon reaching the fan face, the pressure oscillation propagated further upstream and was also transmitted through the fan core flowpath. However, the pressure oscillation was absorbed by the high-pressure compressor. This resulted in stable pressure levels at the core burner inlet.

Digital Filter Processing

The frequency spectrum of a signal often represents the characteristics of the signal more explicitly than its time domain counterpart. The removal or enhancement of signal characteristics in the frequency domain can help identify the phenomena under investigation. An example of this is the removal of noise due to a power supply from otherwise clean and desirable data. By filtering the band of frequencies that contain the noise or a similar undesirable band of frequencies, a more useful signal can be restored. This signal can then be analyzed without confusion or interference from irrelevant frequency content.

Digital data filtering techniques were applied to the parameter time histories obtained during the augmentor transient operation. Application of the digital filter to the time history data required some knowledge of the characteristics of the data as well as the specifications of the filter to be employed. The dynamic parameters measured during the augmentor transients, were analyzed in the range of frequencies of interest. This range of frequencies was determined by the power spectral density of the parameter. The digital filter passband was specified to pass a band of frequencies containing the characteristic frequency of the fuel system quickfill pressure oscillations, pre-stall flowpath pressure dynamics, and the dynamics of the flowpath pressures before blowout. A 3-pole Butterworth filter was designed and implemented with a forward and reverse pass through the data to cancel any phase shift due to the filter.

Some dynamic parameters required conditioning with a masking technique before being filtered. This reduced any induced ringing of the filter from rapid data drop-off. Parameter Ps5c obtained at flight test point 1 exhibited this rapid drop-off of amplitude immediately following the dynamics of interest. Figure 12 illustrates the application of a masking signal to parameter Ps5c before being filtered. A masking signal (MASK) was generated and subtracted from the original signal (ORIG) to produce an oscillating type of signal (AC) which was free of data drop-off for processing. The masking signal consists of a constant amplitude signal until the point of data drop-off where a copy of the original signal is used to terminate the signal. The resultant AC signal was filtered into the various bands of interest without error due to filter ringing.

The digital filtering technique described above was applied to the dynamic parameters measured at flight test point 1. Figure 13 illustrates the digital filter processing results for the flowpath parameters Ps5c, Pt2.5h, Pb, and the augmentor fuel manifold pressure of segment 5. These parameters were filtered in a frequency band from 40 Hertz to 70 Hertz and over a period of time which encompassed the quickfill dynamics of the fuel system and the pre-stall flowpath dynamics. This period of time corresponds to an elapsed time in Figure 6 from t = 7.2 to t = 8.2. The pressure oscillations in Pseg5 due to the quickfill process are clearly shown and are observed to influence the fan duct pressure, Ps5c, and the core flowpath pressure, Pt2.5h. This influence was probably due to a combustion instability driven by oscillating fuel delivery rates to segment 5 of the augmentor. The pre-stall dynamics observed in flowpath pressures are shown in Figure 13. During this period of time, Pseg5 was stable and was being supplied by metered flow. These pre-stall dynamics are probably associated with an augmentor combustion instability such as rumble. Flowpath pressure oscillations were measured at station 5 in the fan duct (Ps5c) with the largest amplitude. As the pressure oscillations propagated up the fan duct to the fan face and downstream through the fan, they were measured by Pt2.5h in the engine core flowpath at a reduced amplitude. These oscillations were not substantially transmitted through the high pressure compressor, as Pb indicates. This analysis enhanced the signals of interest.

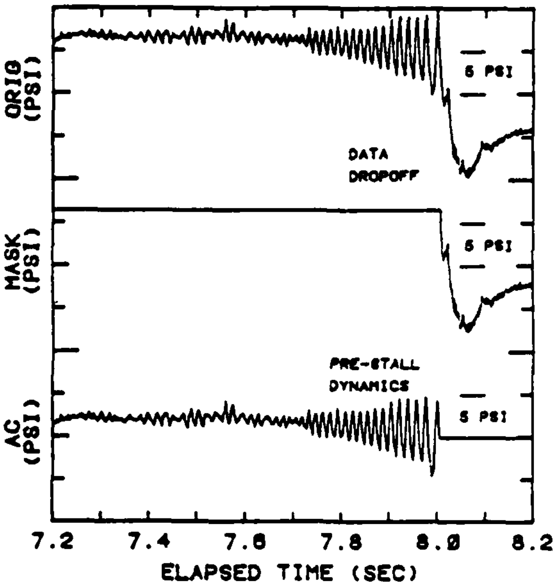

Fig. 12 Example of digital filter technique.

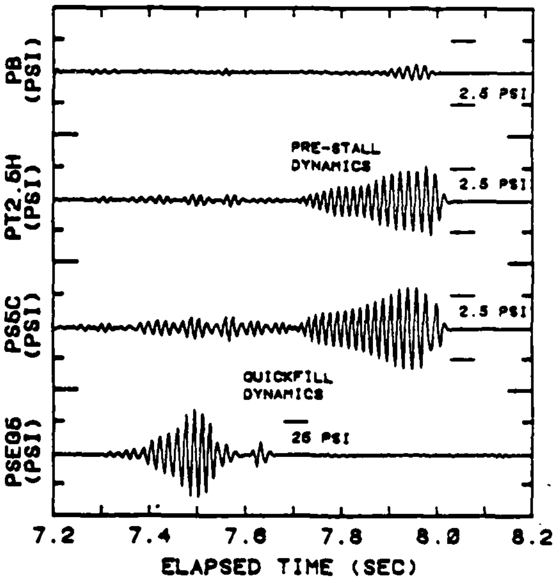

Fig. 13 Digital filter results of flowpath and fuel system parameters at flight test point 1.

A similar digital filtering analysis was conducted on pressure parameters measured in the augmentor fuel delivery system and gas flowpath prior to the blowout encountered at flight test point 2. The results shown in Figure 14 correspond to an elapsed time from t = 8.5 seconds to t = 9.5 seconds. During this period, the augmentor fuel pressure was stable. However, as Figure 14 illustrates substantial pressure oscillations were experienced in the gas flowpath. Parameters Ps5c and Pt2.5h experienced these oscillations and their relative magnitudes suggest that the source was an augmentor combustion instability. This relationship is easily determined through the enhanced signals produced by the digital filtering procedure.

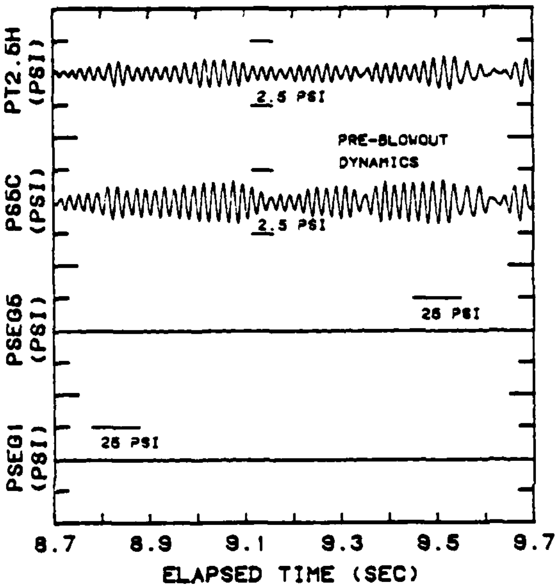

Fig. 14 Digital filter results of flowpath and fuel system parameters obtained at flight test point 2.

Digital filtering techniques were employed to determine if the characteristic frequency of the augmentor instability was constant for a period of time immediately preceding stall. Ps5c was analyzed during an elapsed time of t = 7.2 seconds to t = 8.2 seconds for the augmentor transient experienced at flight test point 1. Figure 15 shows the results from filtering Ps5c into four frequency bands which range from 30 Hertz to 70 Hertz. During the initial growth of the pressure oscillation, the higher frequency bands contained most of the frequency content. However, as the stall point approached, the characteristic frequency of the flowpath oscillation was shifted to the lower frequency bands and was most pronounced just before stall. The shift in characteristic frequency was also revealed by a frequency analysis of the duct pressure fluctuations immediately preceding stall. Figure 16 illustrates this frequency shift preceding stall. The characteristic frequency is seen to shift to a lower frequency just prior to stall.

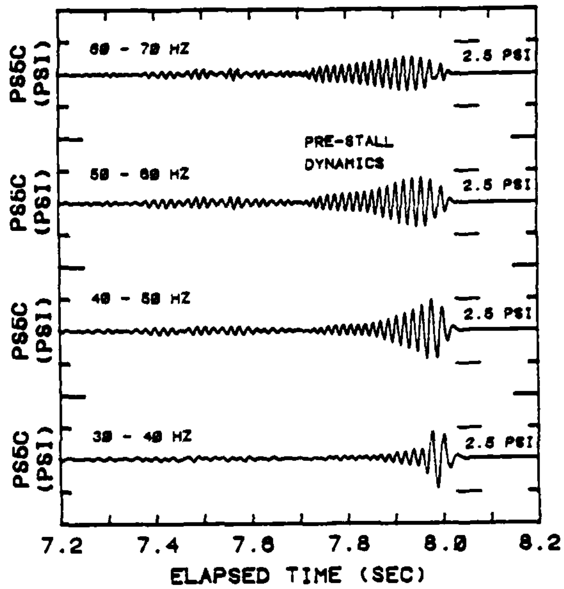

Fig. 15 Multiple frequency band digital filter results of Ps5c during pre-stall dynamics at flight test point 1.

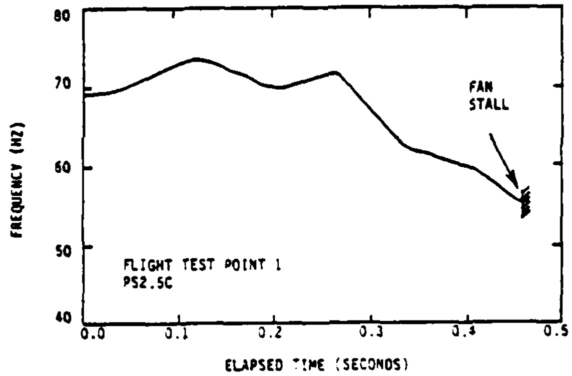

Fig. 16 Variation in characteristic frequency of pre-stall dynamics at flight test point 1.

The shift in characteristic frequency occurred when the augmentor was suspected to be experiencing rumble. This frequency shift may indicate that the frequency of the combustion instability was approaching a resonant mode of the augmentor system. Just prior to stall, this resonant mode coupled with an acoustic oscillation to produce large pressure oscillations, which subsequently stalled the fan.

Concluding Remarks

A method has been developed for the analysis of gas turbine engine dynamic instabilities that have been observed during transient augmentor operation. These instabilities were characterized by engine stall or stagnation, augmentor rumble or blowout, and pressure oscillations in the augmentor fuel distribution system. Existing data analysis procedures were extended and new techniques were developed for the analysis of these engine instabilities which were recorded by pressure sensors located in the engine flowpath and fuel delivery system. Analysis procedures, included parameter time history analysis of low and high frequency response data, Fourier Transform based spectral analysis, and data filtering. These analysis techniques revealed mechanisms underlying the dynamic instabilities and interactions between engine components.

A comprehensive history of augmentor transient events was summarized by low frequency response data obtained through the PCM data acquisition system. Many parameters were input to the PCM data stream which captured the overall transient processes and component interactions preceding a fan stall or augmentor blowout. However, due to the low data sample rate, details of the observed anomaly were not obtained by the PCM data acquisition system.

The FM data acquisition system provided parameter time histories which could be digitized at a high sample rate. Detailed parameter time history analysis has suggested several phenomena which involve oscillations of the augmentor fuel delivery system and the augmentor combustion process. The augment manifold quickfill process was determined to induce fuel pressure oscillations which were transmitted through the fuel delivery system to other manifold segments. Also, these fuel pressure oscillations induced flowpath pressure oscillations through the augmentor combustion process. Augmentor rumble was indicated through large amplitude pressure oscillations in the engine core and fan flowpath.

Analysis of the digitized FM parameter time histories in the frequency domain provided a method of discerning the characteristic frequency of the augmentor operating anomaly. Different characteristic frequencies, for the fuel system dynamics and combustion instability preceding stall or blowout, suggested that the fuel system dynamics were not directly related to the augmentor combustion dynamics. A propagation path of the core and fan duct pressure oscillations, which originated in the augmentor, was determined by the amplitude of the parameter power spectral densities at the characteristic frequency of the combustion instability.

Removal or enhancement of signal characteristics in the frequency domain was performed by utilizing digital filtering techniques. The enhanced parameter time histories revealed the influence of fuel system pressure oscillations on the gas pressures in the fan and core flowpaths. Augmentor combustion pressure oscillations were shown to be easily transmitted through the fan but not through the compressor. The characteristic frequency of the augmentor combustion instability was shown to be time dependent. The frequency shift prior to stall indicated a coupling of a resonant mode of the combustion instability with an acoustic oscillation to produce large pressure oscillations in the fan duct.

APPENDIX B

Fileset Documentation

CONVERSION OF A B-FILE TO A C-FILE

****

PURPOSE:

BTOC CONVERTS AN UFTAS DATA FILE FROM A B-FILE FORMAT TO A C-FILE FORMAT. THE PROGRAM ENABLES THE SPECIFICATION OF THE C-FILE HEADER RECORD INFORMATION.

REQUIRED INPUT:

BTOC CAN BE RUN BOTH INTERACTIVELY AND BATCH. INTERACTIVE EXECUTION IS DOCUMENTED HERE. A LOCAL B-FILE NAMED BFILE IS THE PRIMARY INPUT FOR BTOC. THIS FILE MUST CONTAIN THE PARAMETER TIME HISTORIES IN A B-FILE FORMAT FOR THE CONVERSION TO A C-FILE FORMAT. CONTROL OF PROGRAM EXECUTION IS OBTAINED THROUGH AN EXECUTION CARD STATEMENT WHICH IS ENTERED AT THE TERMINAL AS A COMMAND. THE FORMAT OF THIS COMMAND IS:

```
BTOC
```

OPTIONAL INPUT:

A LOCAL FILE NAMED INPUT CAN BE USED TO SPECIFY INFORMATION TO BE INCLUDED ON THE OUTPUT C-FILE HEADER RECORD. THIS INFORMATION IS READ BY BTOC THROUGH THE FOLLOWING PROGRAM RECORDS:

```
    READ (5,5,END=10) LIC,ITAIL,ITEST,FLT,DFLT,DREQ,DCOM
  5 FORMAT (A5,2X,I3,2X,I1,2X,A5,2X,A6,2X,A6,2X,A6)
    READ (5,'(10(A6))',END=20) (TITLE(I),I=1,10)
```

OUTPUT:

BTOC PRODUCES A C-FILE NAMED CFILE WHICH CONTAINS THE INPUT PARAMETER TIME HISTORIES IN A C-FILE FORMAT.

CONSOLIDATION OF C-FILE PARAMETERS
****

PURPOSE:

CONSO CONSOLIDATES TIME HISTORY PARAMETERS FROM MULTIPLE C-FILE B-FILE SECTIONS AND OUTPUTS THESE PARAMETERS TO ONE B-FILE OR C-FILE. THIS CONSOLIDATION OCCURS OVER A SELECTED TIME PERIOD WHICH MUST BE COMMON TO ALL B-FILE SECTIONS OF THE INPUT C-FILES. MODERATE DATA DROPOUT DUE TO DATA COMPRESSION IS AUTOMATICALLY CORRECTED.

REQUIRED INPUT:

1. NUMBER OF C-FILES TO BE CONSOLIDATED.
2. START TIME-OF-DAY FOR THE RESULTANT B-FILE (SECONDS).
3. FINISH TIME-OF-DAY FOR THE RESULTANT B-FILE (SECONDS).
4. DATA SAMPLE RATE (SAMPLES/SECOND).
5. NAMES OF THE INPUT C-FILES TO BE CONSOLIDATED.
6. SECTION NUMBER OF THE B-FILES TO BE CONSOLIDATED.
7. NAME FOR THE OUTPUT B-FILE OR C-FILE.

OUTPUT:

1. B-FILE OR C-FILE WHICH CONTAINS THE CONSOLIDATED PARAMETERS.

MANIPULATION AND CONDITIONING OF PARAMETER SEQUENCES

****

PURPOSE:

SEQCOND MANIPULATES PARAMETER TIME HISTORIES THAT ARE INPUT FROM A C-FILE AND RECOVERS MODERATE DATA DROPOUT DUE TO COMPRESSION FROM SANDS PROCESSING. DATA SEQUENCE CONDITIONING CAPABILITIES INCLUDE: AMPLIFICATION OR ATTENUATION OF THE SEQUENCE AND ITS DC LEVEL, THE DERIVATION OF NEW PARAMETERS, AND THE APPLICATION OF A COSINE TAPER TO THE END OF A SEQUENCE. THE RESULTANT PARAMETER TIME HISTORIES ARE OUTPUT TO A SPECIFIED LOCAL B-FILE.

REQUIRED INPUT:

1. NAME OF THE INPUT C-FILE.
2. B-FILE SECTION NUMBER CONTAINING THE PARAMETERS TO BE MANIPULATED.
3. NUMBER OF PARAMETERS TO BE CONDITIONED.
4. NUMBER OF PARAMETERS TO BE DERIVED.
5. DATA SAMPLE RATE (SAMPLES/SECOND).
6. START TIME-OF-DAY FOR THE RESULTANT TIME HISTORIES (SECONDS).
7. FINISH TIME-OF-DAY FOR THE RESULTANT TIME HISTORIES (SECONDS).
8. NAME FOR THE B-FILE WHICH RECEIVES THE CONDITIONED DATA.
9. FOR EACH THROUGHPUT PARAMETER TO BE CONDITIONED:
   A. PARAMETER NAME.
   B. DC BIAS (IF DESIRED).
   C. ATTENUATION FACTOR (IF DESIRED).
   D. COSINE TAPER (IF DESIRED).
10. FOR EACH DERIVED PARAMETER:
   A. PARAMETER NAME.
   B. CHOICE OF THE DERIVED PARAMETER TO BE A RATIO OR DIFFERENCE OF PARAMETERS.

OPTIONAL INPUT:

1. SELECTION OF A COSINE TAPER REQUIRES:
   A. TIME-OF-DAY OF THE SIGNAL APEX (SECONDS).
   B. APPROXIMATE PERIOD OF THE SIGNAL DYNAMICS (SECONDS).

OUTPUT:

1. LOCAL B-FILE WHICH CONTAINS THE MANIPULATED DATA SEQUENCES AS A TRANSFERRED OR DERIVED PARAMETER.

TIME SHIFT OF A B-FILE PARAMETER SEQUENCE
****

PURPOSE:

TIMALIN PRODUCES A B-FILE TIME HISTORY WHICH IS SHIFTED IN TIME RELATIVE TO THE ORIGINAL TIME HISTORY. THE SHIFTED PARAMETER SEQUENCE CAN BE APPENDED TO THE INPUT B-FILE AS AN ADDITIONAL PARAMETER OR WROTE OVER THE INPUT PARAMETER. THE INPUT SIGNAL MUST BE BAND LIMITED AND NOT WINDOWED.

REQUIRED INPUT:

1. NAME OF THE LOCAL B-FILE WHICH CONTAINS THE PARAMETER TO BE TIME SHIFTED.
2. NAME OF THE PARAMETER TO BE SHIFTED.
3. START TIME-OF-DAY FOR THE PARAMETER TIME HISTORY (SECONDS).
4. FINISH TIME-OF-DAY FOR THE PARAMETER TIME HISTORY (SECONDS).
5. DATA SAMPLE RATE (SAMPLES/SECOND).
6. DESIRED TIME SHIFT (SECONDS).
7. NAME FOR THE LOCAL B-FILE WHICH CONTAINS THE RESULTANT PARAMETER TIME HISTORY.
8. SELECTION OF THE RESULTANT TIME HISTORY TO BE A NEW OR OLD PARAMETER.

OPTIONAL INPUT:

1. SELECTION OF THE RESULTANT TIME HISTORY TO BE A NEW PARAMETER REQUIRES:
   A. NAME FOR THIS NEW PARAMETER.

OUTPUT:

1. B-FILE WHICH CONTAINS THE TIME ALIGNED PARAMETER TIME HISTORY AS A NEW OR OVERWRITTEN PARAMETER.

B-FILE OR C-FILE LISTING OF PARAMETERS
****

PURPOSE:

LISTF IS A MODIFIED VERSION OF AN UFTAS UTILITY PROGRAM WHICH PRINTS THE CONTENTS OF A B-FILE OR C-FILE. THE PROGRAM ENABLES A SELECTION OF THE DATA PRINT RATE, PARAMETERS TO BE LISTED, AND THE DATA FORMAT.

REQUIRED INPUT:

LISTF CAN BE RUN BOTH INTERACTIVELY AND BATCH. INTERACTIVE EXECUTION IS DOCUMENTED HERE. CONTROL OF PROGRAM EXECUTION IS OBTAINED THROUGH AN EXECUTION CARD WHICH IS ENTERED AT THE TERMINAL AS A COMMAND. THE FORMAT OF THIS COMMAND IS:

LISTF(FILE)

WHERE FILE IS THE NAME OF A LOCAL FILE WHICH CONTAINS THE PARAMETERS TO BE LISTED. THE DEFAULT NAME IS CFILE.

OPTIONAL INPUT:

LISTING OPTIONS ARE INVOKED THROUGH AN ARGUMENT LIST ON THE EXECUTION CARD. THIS IS SPECIFIED AS:

LISTF(FILE,PR=N1,PC=N2,SD=N3)

WHERE:

1. PR IS THE PRINT RATE. N1 IS A NUMERICAL VALUE SPECIFYING EVERY N1TH POINT TO BE LISTED. DEFAULT IS PR=1.
2. PC IS A FLAG FOR PARAMETER SPECIFICATION. IF N2=0, ALL PARAMETERS ARE PRINTED. IF N2=1, A LIST OF PARAMETERS IN FREE FORMAT IS READ FROM A LOCAL FILE NAMED INPUT. ONLY THESE PARAMETERS ARE LISTED. DEFAULT IS PC=0.
3. SD IS A FLAG FOR THE NUMBER OF DATA VALUE SIGNIFICANT DIGITS. IF SD=0, 5 SIGNIFICANT DIGITS ARE LISTED. IF SD=1, 7 SIGNIFICANT DIGITS ARE LISTED. DEFAULT IS SD=0.

OUTPUT:

THE LISTING OF DATA VALUES IS WRITTEN TO A LOCAL FILE NAMED OUTPUT.

PLOT OF A B-FILE PARAMETER TIME HISTORY
****

PURPOSE:

PLOT DISPLAYS A PLOT OF A SPECIFIED PARAMETER TIME HISTORY ON THE SCREEN OF A TEKTRONIX GRAPHIC TERMINAL.

REQUIRED INPUT:

1. MODEL NUMBER OF THE TEKTRONIX GRAPHIC TERMINAL.
2. NAME OF THE B-FILE WHICH CONTAINS THE DATA SEQUENCE TO BE PLOTTED.
3. NAME OF THE B-FILE PARAMETER TO BE PLOTTED.
4. UNITS OF THE B-FILE PARAMETER.
5. DATA SAMPLE RATE OF THE SEQUENCE (SAMPLES/SECOND).
6. PLOT START TIME-OF-DAY (SECONDS).
7. PLOT FINISH TIME-OF-DAY (SECONDS).

OPTIONAL INPUT:

1. STATEMENT OF A PLOT TITLE OR REMARK.
2. SELECTION OF MANUAL PLOT SCALING REQUIRES:
   A. PLOT ORDINATE MAXIMUN VALUE.
   B. PLOT ORDINATE MINIMUM VALUE.

OUTPUT:

1. PLOT OF THE B-FILE PARAMETER TIME HISTORY ON THE SCREEN OF A TEKTRONIX GRAPHIC TERMINAL.

FAST FOURIER TRANSFORM OF A B-FILE PARAMETER
****

PURPOSE:

FFT PERFORMS A FAST FOURIER TRANSFORM ON AN INPUT B-FILE PARAMETER TIME HISTORY. THE FFT RESULTS CAN BE LISTED AT THE TERMINAL SCREEN, WRITTEN TO AN OUTPUT FILE, OR PLOTTED ON THE SCREEN OF A TEKTRONIX GRAPHIC TERMINAL.

REQUIRED INPUT:

1. MODEL NUMBER OF THE TEKTRONIX TERMINAL (IF APPROPRIATE).
2. NAME OF THE B-FILE WHICH CONTAINS THE DATA SEQUENCE TO BE ANALYZED.
3. NAME OF THE PARAMETER TO BE ANALYZED.
4. UNITS OF THE PARAMETER.
5. DATA SAMPLE RATE (SAMPLES/SECOND).
6. ANALYSIS START TIME-OF-DAY (SECONDS).
7. NUMBER OF POINTS TO BE ANALYZED.
8. SELECTION OF THE FORMAT FOR THE FFT RESULTS.

OPTIONAL INPUT:

1. APPLICATION OF A HANN WINDOW TO THE DATA PRIOR TO ANALYSIS.
2. SELECTION OF OUTPUT FORMAT REQUIRES:
   A. CHOICE OF TERMINAL SCREEN OR OUTPUT DUMP FILE.
3. SELECTION OF GRAPHIC DISPLAY OF RESULTS REQUIRES:
   A. SELECTION OF THE TYPE OF PLOT (MAGNITUDE,PHASE,OR PSD VS. FREQUENCY).
   B. SELECTION OF AUTOMATIC OR MANUAL SCALING.
4. STATEMENT OF PLOT A REMARK.

OUTPUT:

1. TABULATION OF FFT RESULTS ON THE TERMINAL SCREEN OR ON A SPECIFIED OUTPUT FILE.
2. PLOT OF FFT RESULTS AT THE TERMINAL SCREEN.

TRANSFER FUNCTION BETWEEN TWO B-FILE PARAMETERS
****

PURPOSE:

TRANS COMPUTES THE TRANSFER FUNCTION BETWEEN TWO B-FILE PARAMETER TIME HISTORIES. RESULTS CAN BE LISTED AT THE TERMINAL SCREEN, DUMPED TO A LOCAL FILE, OR PLOTTED AT THE SCREEN OF A TEKTRONIX GRAPHIC TERMINAL.

REQUIRED INPUT:

1. MODEL NUMBER OF THE TEKTRONIX GRAPHIC TERMINAL (IF APPROPRIATE).
2. NAME OF THE LOCAL B-FILE WHICH CONTAINS THE PARAMETERS TO BE ANALYZED.
3. ANALYSIS START TIME OF DAY (SECONDS).
4. NUMBER OF POINTS FOR THE ANALYSIS.
5. DATA SAMPLE RATE (SAMPLES/SECOND).
6. NAMES OF THE PARAMETERS TO BE ANALYZED.
7. SELECTION OF AN OUTPUT FORMAT FOR THE ANALYSIS RESULTS.

OPTIONAL INPUT:

1. CHOICE OF RESULTS LISTED AT THE TERMINAL SCREEN OR DUMPED TO A LOCAL OUTPUT FILE.
2. SELECTION OF GRAPHIC DISPLAY OF RESULTS REQUIRES:
   A. TYPE OF PLOT (MAGNITUDE OR PHASE VS. FREQUENCY).
   B. CHOICE OF AUTOMATIC OR MANUAL SCALING OF THE PLOTS.

OUTPUT:

1. TABULATION OF TRANS RESULTS AT THE TERMINAL SCREEN OR ON A SPECIFIED OUTPUT FILE.
2. PLOTS OF TRANS RESULTS ON THE SCREEN OF A TEKTRONIX GRAPHIC TERMNAL.

DESIGN OF LOWPASS DIGITAL FILTERS
****

PURPOSE:

LOWPASS IS A DESIGN TOOL FOR THE GENERATION OF MAXIMALLY FLAT PASSBAND AND STOPBAND FINITE IMPULSE RESPONSE (FIR) DIGITAL LOWPASS FILTERS. THE FILTER DESIGN IS USER SPECIFIED AND THE RESULTANT FILTER DESCRIPTION IS WRITTEN TO A FILTER FILE IN STANDARD FORMAT. THIS FILTER DESIGN HAS A LINEAR PHASE VARIATION WITH FREQUENCY WHICH IMPARTS A CONSTANT TIME DELAY TO THE FILTERED DATA.

REQUIRED INPUT:

1. SAMPLE RATE OF THE DATA TO BE FILTERED (SAMPLES/SECOND).
2. CENTER FREQUENCY OF THE TRANSITION BAND (HZ).
3. WIDTH OF THE TRANSITION BAND (HZ).
4. NAME FOR THE FILTER DESCRIPTION FILE.
5. SELECTION OF LISTING OPTIONS FOR THE FILTER COEFFICIENTS.

OPTIONAL INPUT:

1. SELECTION OF A LISTING OF THE FILTER COEFFICIENTS REQUIRES:
   A. CHOICE OF A TERMINAL LISTING OR DUMP TO A SPECIFIED LOCAL FILE.

OUTPUT:

1. LOCAL FILTER FILE FOR SUBSEQUENT APPLICATION TO DATA THROUGH THE FILTER IMPLEMENTATION PROGRAM.
2. IF CHOSEN, A LOCAL FILE WHICH CONTAINS A LISTING OF THE FILTER COEFFICIENTS AND THE FILTER DESCRIPTION.

DESIGN OF MULTIPLE PASSBAND & STOPBAND DIGITAL FILTERS
****

PURPOSE:

MLTPASS IS A DESIGN TOOL FOR THE GENERATION OF EQUIRIPPLE MULTIPLE PASSBAND AND STOPBAND FINITE IMPULSE RESPONSE (FIR) DIGITAL FILTERS. THE FILTER DESIGN IS USER SPECIFIED AND THE RESULTING FILTER DESCRIPTION IS WRITTEN TO A SPECIFIED LOCAL FILE IN STANDARD FORMAT. THE RESULTANT FILTER DESIGN HAS A LINEAR PHASE VARIATION WITH FREQUENCY. THIS IMPARTS A CONSTANT TIME DELAY TO THE FILTERED DATA.

REQUIRED INPUT:

1. FILTER LENGTH.
2. TOTAL NUMBER OF PASSBANDS AND STOPBANDS.
3. FILTER GRID DENSITY.
4. SAMPLE RATE OF THE DATA TO BE FILTERED (SAMPLES/SECOND).
5. SPECIFICATIONS FOR EACH PASSBAND AND STOPBAND:
   A. BAND LOWER EDGE FREQUENCY (HZ).
   B. BAND UPPER EDGE FREQUENCY (HZ).
   C. GAIN OF THE BAND.
   D. RELATIVE WEIGHT OF THE BAND.
6. NAME FOR THE FILTER DESCRIPTION FILE.
7. SELECTION FROM LISTING OPTIONS FOR A DESCRIPTION OF THE FILTER SPECIFICATIONS.

OPTIONAL INPUT:

1. SELECTION OF THE FILTER DESCRIPTION TO BE WRITTEN TO A FILTER FILE REQUIRES:
   A. NAME FOR THE FILTER FILE.
2. SELECTION OF A FILTER DESCRIPTION LISTING REQUIRES:
   A. CHOICE OF A TERMINAL LISTING OR LISTING ON A LOCAL FILE.

OUTPUT:

1. LOCAL FILTER FILE WHICH CONTAINS THE FILTER DESCRIPTION AS REQUIRED BY THE FILTER IMPLEMENTATION PROGRAM.
2. IF CHOSEN, A LOCAL OUTPUT FILE WHICH CONTAINS A LISTING OF THE FILTER DESCRIPTION AND THE FILTER COEFFICIENTS.

DIGITAL FILTER IMPLEMENTATION
****

PURPOSE:

FILTER PERFORMS THE FILTERING OF DIGITAL DATA BY EMPLOYING A FINITE IMPULSE RESPONSE (FIR) FILTER DESIGN WHICH HAS BEEN PREVIOUSLY GENERATED. A SPECIFIED B-FILE PARAMETER IS FILTERED AND APPENDED TO THE INPUT B-FILE. THIS FILE IS OUTPUT AS A UNIQUE B-FILE.

REQUIRED INPUT:

1. NAME OF THE B-FILE WHICH CONTAINS THE PARAMETER TO BE FILTERED.
2. NAME FOR THE OUTPUT B-FILE.
3. NAME OF THE PARAMETER TO BE FILTERED.
4. NAME FOR THE FILTERED PARAMETER.
5. SELECTION OF THE FILTER DESCRIPTION TO COME FROM A FILTER FILE OR TERMINAL ENTRY.

OPTIONAL INPUT:

1. SELECTION OF THE FILTER DESCRIPTION FROM A FILTER FILE REQUIRES:
   A. NAME OF THE FILTER FILE.
2. SELECTION OF THE FILTER DESCRIPTION FROM THE TERMINAL REQUIRES:
   A. LENGTH OF THE FILTER.
   B. FILTER GAIN FOR EACH SEQUENCE POINT.

OUTPUT:

1. B-FILE CONTAINING THE FILTERED PARAMETER AS AN APPENDED PARAMETER TO THE INPUT B-FILE.

WHITE NOISE DATA FILE
****

PURPOSE:

WHITE IS A WHITE NOISE DATA B-FILE WHICH PROVIDES A SOURCE TEST SIGNAL WHICH IS CHARACTERIZED BY FREQUENCY CONTENT UNIFORMLY SPREAD ACROSS THE SAMPLED DATA SPECTRUM. THIS TIME HISTORY CAN BE USED TO TEST A DIGITAL FILTER DESIGN UNDER CONSIDERATION. THE IMPLEMENTATION OF THE FILTER TO THIS WHITE NOISE FILE YIELDS OUTPUT WHICH INDICATES THE FREQUENCY RESPONSE OF THE FILTER.

SPECIFICATIONS:

1. CONTAINS ONE PARAMETER NAMED NOISE1.
2. DATA SAMPLE RATE IS 1000 SAMPLES/SECOND.
3. START TIME-OF-DAY OF THE SEQUENCE IS 0.001 SECONDS.
4. FINISH TIME-OF-DAY OF THE SEQUENCE IS 1.024 SECONDS.
5. LENGTH OF THE SEQUENCE IS 1024 SAMPLES.
6. NOISE1 CONTAINS 501 COMPONENT SINUSOIDS (INCLUDES DC).
7. FREQUENCY SPACING BETWEEN SINUSOIDS IS 1.0 HZ BETWEEN 0 AND 500 HZ.

END

FILMED

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