BOEING FLIGHT TEST PLANNING AND PROCEDURES

Lee H. Eccles
Boeing Commercial Airplane Group
Flight Test Engineering
Seattle, Washington

ABSTRACT

The Boeing Commercial Airplane Group uses a highly computerized Flight Test system. Everything from test planning to equipment control is handled through a large mainframe computer. This paper is an introduction to the structures which are necessary to efficiently run tests on many different airplanes at the same time, with a wide range of test requirements. This paper discusses the data bases required, the test planning and the procedures used to run a flight test program. Some data bases are common to all test programs while others are specific to a particular test program. The test planning begins with the Instrumentation Requirements estimating process. Then comes selecting parameters from the common data bases and marking them as required for a particular test program. New parameters are added to the common data bases as required. Once the process of identifying parameters to be recorded is started, the computer automatically generates airplane specific data bases and loads the information from the common data bases into them so that the other groups can select the specific instrumentation to be used to measure each parameter. As this planning is accomplished, information is added to the data bases so that they become more complete as the actual testing approaches, When the airplane enters it's testing phase, the data from these data bases is retrieved and provided to both the on-board data monitor system and the ground station to allow data to be acquired from the data acquisition system or from tape for data processing. As the testing is accomplished the computer data is updated to indicate the progress of the testing.

INTRODUCTION

The Boeing Commercial Airplane Group's Flight Test Operation is organized around a large mainframe computer. Test planning, data processing, and maintenance of records all center around information which is stored in this machine. This paper only discusses a limited subset of the overall system relating to instrumenting an airplane to acquire the data, with related topics mentioned as required. Even this subset of the total is a major operation. Not only is it necessary to plan the operation but we must be able to accurately reconstruct the exact configuration of the system for any test that was conducted as long as that model airplane is in use with a domestic airline. There are several different data bases which are maintained on the mainframe computer to allow all of this to be accomplished. These data bases and their uses are described in the following paragraphs.

INSTRUMENTATION REQUIREMENTS ESTIMATING

Well before a new or modified airplane is built, the planning and estimating for the test program is begun. To estimate the cost of instrumenting an airplane, a computer program is used which collects all of the known or likely test requirements and combines them so that the magnitude of the project can be determined. This process involves each test discipline making an estimate of the instrumentation required to test their particular area. These individual estimates are then combined with historical data to produce a projection of the amount of instrumentation required and how many people will be required to support the test program. These estimates are then used by management as part of their estimates for the cost of developing the new or modified product.

MEASUREMENT SPECIFICATION - MEAS SPEC

The measurement specification is a large data base which contains the specifications for each measurement that we make. Table I lists most of the information that is contained in the Meas Spec. This data base is a common data base used by all airplanes. Before a measurement can be requested for a given airplane its measurement specification must be entered into this data base. When it is entered into this data base an identifying measurement number and a measurement name are assigned. Historically, the measurement number has been the label by which this measurement is known for as long as it is in use. The measurement name is just now coming into use. Measurement specifications can be edited but once they are in use, they generally are not modified since any change may affect other airplanes, past or present.

TRANSDUCER CALIBRATION FILE - TC FILE

The transducer calibration file is, as the name implies, a file containing the calibration data for each transducer in use by Flight Test. When a new calibration is performed on a transducer, the new data, along with when the calibration was performed, is added to this file. The old calibration is not removed since it is still valid for tests which were run prior to the new calibration being performed. Thus, this data base contains a complete history of each calibration on each transducer used by Flight Test since the file was established. This data base is also independent of any particular test airplane.

Field Name	Function
Measurement Number	A unique number used to identify a parameter.
Measurement Nomenclature	A unique name used to identify a parameter.
Data Title	Text to be displayed with the parameter.
Measurement	Text describing the measurement.
Recording medium	Description PCM tape, Film, Calibrated Instrument, etc
Minimum Value	The lowest expected value.
Maximum Value	The highest expected value.
Units	The units to be displayed with the parameter.
Frequency/Sample Rate	The required data bandwidth or sampling rate.
Filter Characteristics	Filter Cutoff frequency.
Comments	Three lines of text.
Originator and date	The initials of the person creating the specification and the creation date.
Last person to revise & date	Initials of the last person revising this specification and the date.
Used On Airplane list	A list of the airplanes which have used or are using this measurement.
If ARINC-429 Bus data	
Bus Name	Title for the Bus
Label	Eight bit octal label for parameter.
SDI	Source Destination Index
Data Encoding	
Bits required from the word	
LSB Resolution	
About 15 other parameters.	

Table I Measurement Specification Contents

EQUIPMENT MANAGEMENT - FTEM

Flight Test also maintains a data base with the history of each piece of equipment that we own. When a new piece of equipment is accepted by Flight Test it is given a Flight Test property number, or FT number, and a record is created for it in the data base. Each time it moves from one place to another, such as from the store room to an airplane, that information is entered into the computer. Anytime a unit goes into a laboratory for service or modification, new entries are made into the data base. This system allows us to determine which equipment was on a given airplane at a given time and what it's configuration was. Transducers are also tracked using this system.

MEASUREMENT LISTS

There are two types of measurement lists that have developed over the years. The Quick Look Measurement Lists (QLML) were developed for use with the Airborne Data Analysis and Monitor System (ADAMS) on-board computer system. The quick look measurement lists are collections of up to twenty parameters identified by their measurement numbers to be displayed in one list. Since much of the testing on different airplanes requires the same disciplines, it was decided to maintain these lists on the large scale computer. Their use today goes beyond specifying a list of parameters for display. Each different test discipline maintains it's own QLMLs and uses them to specify what parameters to record as well. Coded Measurement Tables (CMT) have been developed as a method of identifying a set of related parameters which need to be specified as a group. Coded measurement tables are similar to quick took measurement lists except that they can be longer than twenty parameters and are not used to display data. For example, a CMT might specify which parameters need to be telemetered to the ground during a particular test.

TEST ITEM REQUIREMENTS LIST - TIRL

The test item requirements list (TIRL) is the first of the airplane-specific data bases to be created. It is developed by the analysis engineer as a planning tool to identify all requirements for testing a particular function on the airplane. Unlike the data bases that were previously discussed, TIRLs are created for each airplane and they are specific for that airplane. A TIRL must be created for each type of testing which is to be performed on a particular airplane. However, they are usually created by copying and then modifying a TIRL for an earlier airplane. It contains administrative requirements, test requirements and technical requirements. The administrative requirements include the number of flight and ground test hours required for the test. The technical requirements include a list of the QLMLs and CMTs which specify all of the parameters which need to be recorded for this set of tests. Also, included in the TIRL is a list of all of the application programs which will be required by the onboard computer system.

Transducer Calibration File	
Field	Description
Transducer Number	Property Number for the transducer
Calibration Date	When the calibration was performed
Input units	The units for the input variable
Output units	The units for the output variable
Transducer Excitation	Excitation Voltage used during calibration
Calibration type	Form of the calibration. For example Linear - Single Section or Polynomial - Multiple Section
Percent Deviation	The deviation of the transducer output from the published calibration.
Degree	Order of the equation.
Transducer Range	The input range of the transducer.
Input Resistance	Input resistance of a bridge transducer
Output Resistance	Output resistance of a bridge transducer
Shunt Cal Value	Resistor value used in shunt calibration
Shunt Cal Output	Expected change in output with shunt cal resistor applied.
Delay	Input to output delay in the transducer
Slope	Slope of the straight line fit of the data.
Intercept	Intercept for straight line fit of the data
Number of Sections	Number of sections necessary to fit a curve to the transducer within percent deviation.
Section Limit	Upper limit of this section. Lower limit of the next section.
Coefficients	Calibration coefficients

Table II Transducer Calibration File

Equipment Management		
Field	History	Description
Identifying Number	No	The property number for the equipment.
Nomenclature	No	The name of the Item.
Manufacturer	No	Manufacturer of the item. (Boeing if modified)
Model or Part Number	No	Manufacturers model number or Boeing P/N.
Serial Number	No	Original Manufacturers serial number.
Original Manufacturer	No	Original Mfgr's name if modified by Boeing.
Class Category	No	
Ownership	No	Program which purchased the item.
Procurement Documentation	No	Identification of documentation showing how and why the item was purchased.
Cost	No	Cost of the item.
Purchase Date	No	
Range Or Capacity	No	The range or capacity of the unit if applicable.
Weight	No	The weight of the item.
System	No	The system the item is used in if it is part of a larger system.
Service Cycle	No	How often the item needs to receive preventive maintenance and/or calibration.
Sort Codes	No	A set of entries used for sorting the data base.
Outstanding Change orders	No	A list of outstanding change orders for the item.
Latest Planned Part Number	No	P/N after all outstanding changes are made.
Current Location	Yes	Where the item is currently.
Location Date	Yes	Date the item was moved to this location.
Service Due date	No	Date that PM or calibration is due.
Accumulated Maintenance Hours	No	Hours spent maintaining the item.
Accumulated Maint Dollars	No	Cost of parts used to maintain the item.

Table III Equipment Management Data Base

Administrative Attributes	
Field	Function
Airplane Number	Identifies the Applicable airplane
Test Item Code	
EWA/Project Control Number	Authorization to perform the test
Title	Name of the test
Short Title	Abbreviated title
Purpose of Test	Field to describe the purpose of the test
Documentation Identifiers	Several fields used to identify documentation related to the test.
Personnel	Several fields used to identify responsible personnel
Test Readiness Date	
Data Required Date	
Test Item Completion date	
Estimated Flight Test Hours	
Estimated Ground Test Hours	
Actual Flight Test Hours	
Actual Ground Test Hours	
Percent of hours Complete	

Table IV Test Item Requirements List - Administrative Attributes

INSTRUMENTATION REQUIREMENTS - FTIR

Once one or more TIRLs have been entered, the system creates the instrumentation requirements file or FTIR. The system collects the information about each parameter called out in a QLML, CMT or application program in the TIRL from the measurement specification to create the FTIR. The information content is very similar to the Measurement Specification as shown in Table I. This file may then be edited as required. The instrumentation engineers take the requirements for the system from the FTIR and use them to design and install the data acquisition system for the airplane. Like the TIRL, the FTIR is for a specific airplane and becomes part of the permanent record for that airplane.

This data base is organized by measurement number with one record for each measurement required.

MEASUREMENT CONFIGURATION

Once the instrumentation engineer has an FTIR, a measurement configuration file is created. This file contains records which specify exactly how each parameter is to be measured. This data base is organized by measurement number with a record for each individual parameter. The exact hardware to be used, including the specific transducer, is included. The installation drawings for the transducer are referenced. The signal conditioning used is identified. The instructions for locating the data within the recorded data are found in this file. This file becomes part of the permanent record for that airplane.

Technical Requirements	
Quick Look Measurement Lists	Specifies parameters required for measurement and display
Coded Measurement Lists	Specifies parameters for recording
Application Programs	A list of the applications required for the on-board computer
Key file Tables	Function Key setups for On-board computer system
GC Equations	Equations to be used with the General Calculations Program
Plot Descriptors	Plot Program set up files
Direct Input Measurements	
Telemetered Measurements	
Test Outline	

Table V Test Item Requirements List - Technical Requirements

PREFLIGHT PLANNING

All of the files discussed so far are used for planning and record keeping purposes. What happens then, when after all these months of planning, it comes time to actually fly the airplane? The test operations engineer will examine all of the test items that need to be accomplished and select a subset of those, along with some alternatives, and plan a series of tests for a given flight. Based on the TIRLs for these tests, the instrumentation engineer will issue a request for instrumentation preflight, or RIP. The RIP processing will examine all of the TIRLs selected and issue a set of data bases which are used to set up the on-board data acquisition and data monitoring systems for a particular test. Currently the RIP does not select which parameters to record but it selects which parameters need to be preflight tested before the test. Some of these data bases are discussed in the following paragraphs.

ACQUISITION SYSTEM SETUP FILES

There has been one sub-system in our data acquisition system, the Advanced Digital Data Acquisition System (ADDAS), which could be readily programmed to select which parameters to record. ADDAS is used to acquire data from ARINC-429 data buses. Two new programmable sub-systems are being added to the data acquisition system. The remote analog/digital multiplexer (RMUX), which is to be used to acquire analog and discrete parameters outside of the airplane cabin, is one of these new systems. It will require a setup file to load all of its programmable features including which parameters to acquire for this specific flight. The other new sub-system is the central multiplexer or CMUX. The CMUX is the heart of the data acquisition system. It takes data directly from ARINC-629 and ARINC-429 data buses as well as from ADDAS, the RMUX and our existing PCM system and combines them into a single stream for recording. The CMUX will require a setup file to be used to select which parameters to record. All of these setup files are produced by the large scale computer based on the TIRLs selected for that series of tests. Once the setup files have been created they are loaded into the on-board computer system which is used to set up the acquisition system.

MONITOR SYSTEM SETUP FILES

There are a number of files used to set up the on-board monitor system. Perhaps the most obvious are the programs themselves. The TIRL specify which application programs are required for the particular series of tests, but it is more common just to load all available programs as long as disk space is not at a premium. The second set of files are the data bases which describe the parameters being recorded. Two of these data bases are discussed here. Information from the Measurement Specification, the TC File and the Configuration File is combined to form the Measurement Data Table or MDT. The MDT contains all the information needed to locate, calibrate and display any parameter being recorded. This file is installed on the system and then run through a compiler. This generates an expanded MDT which contains the instructions necessary for the preprocessor in the system to convert a parameter to engineering units. The other major file is the configuration file. This file contains all of the information about how a particular measurement is set up on the system. The operator can display this information on the airborne work-station instead of using a large paper document. Several other small data bases are used to set up specific areas in the system.

Test Requirements	
Test Outline	
Testing Prerequisites	Tests which must be performed before this test.
Airplane Configuration Comments	Specific Airplane Configuration required for this test.
Instrumentation Comments	Special instrumentation requirements for this test
New Data Reduction Requirements	Anything non-standard required for data acquisition and reduction.
Unique Support Equipment & Facilities	Any non-standard facilities or support equipment required for this test.
Outside Lab Support	Any support required from labs other than Flight Test.
Testing Limitations	Any affect on normal Airplane operations. (Flight envelope limits, Cockpit procedures, etc)
Method of Evaluation & Reporting Requirements	Requirements for reporting and evaluating the data.
Test Success Criteria	What is required to successfully complete this test.
Engineers Comments	

Table VI Test Item Requirements List - Test Requirements

PREFLIGHT

Most testing is done on first shift, but there are people working on the airplane all three shifts. Second shift is used to troubleshoot problems which were observed on an earlier test and to install new measurements. Third shift has the responsibility to preflight the airplane and have it ready for an 8:00 a.m. release for the day’s testing. The data bases loaded onto the system each night typically contain more parameters than are required for the day’s testing. A special group of QLMLs are generated by the computer for use by the instrumentation engineer. These lists group the measurements by category, with each category having two classes. The categories might be “Left wing strain gages” or “Engine pressures.” The two classes are “Required for flight” and “Not required for flight.” The instrumentation engineer uses these lists to check each parameter on the airplane and to verify that they are working correctly. As each parameter is checked it is marked in the system to verify that it was checked. It is not necessary to check each parameter which is taken off of one of the airplane buses. However, at least one parameter from each bus is checked.

IN FLIGHT

The monitor system is used by both analysis and instrumentation engineers during a test flight. The analysis engineer is interested in observing the conduct and the results of the test. The instrumentation engineer is primarily interested in the health of the system. The analysis engineer may be running up to twenty different programs to analyze what is happening and to verify that all of the conditions needed for the specific test are met. The results of this analysis may be used to decide if it is safe to proceed with the next test point or if the airplane is performing as specified. The instrumentation engineer uses a different terminal to scan through the parameters being recorded to verify that everything is still working properly. All of the displays use the data bases generated before the test to acquire, format and display the data. The parameters for display are specified by measurement number and the operator does not need to know how the data are being acquired to be able to display the parameters as long as everything is working properly. If a problem occurs then the data bases can be accessed to determine the exact configuration for that parameter.

POST FLIGHT

After the flight the analysis engineer submits data requests while instrumentation is having the data tapes delivered to the ground-based Tape Data Retrieval System (TDRS). When the data request is submitted, the mainframe computer identifies the parameters which are required for that data request. The information about those parameters are collected into an “Arrangement and Calibration” file which is passed to TDRS along with the times for which the data are desired. TDRS receives and processes the data requests, extracts the data from the flight tape, converts it to engineering units and passes the data, on a computer tape, back to the mainframe computer. The mainframe computer then places this data into an on-line data store and processes the data as requested in the data request. The results of this processing are then passed to the analysis engineer, one of the airplane design groups or a sub-contractor for further analysis or for inclusion into a report.

CONCLUSIONS

The Boeing Commercial Airplane Group’s Flight Test Organization has been using computers in all aspects of it’s operations for several years now. The computer has proven to be an indispensable tool. They are used in both data analysis as well as in test planning. The computers allow data from all airplanes to be acquired efficiently and make it possible to retrieve data from both present and past airplane test programs. Manual processes would not be able to keep up with the volume of data involved.