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COMPILING THE SPACE SHUTTLE WIND TUNNEL DATA BASE:

AN EXERCISE IN TECHNICAL AND MANAGERIAL INNOVATIONS*

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ABSTRACT

Engineers evaluating Space Shuttle flight data and performance results are using a massive data base of wind tunnel test data. This data base is the result of years of extensive highly coordinated effort by NASA managers, NASA centers and contractors.

A wind tunnel test data base of the magnitude attained is a major accomplishment. It exists because of lessons learned from the Apollo program.

The Apollo program spawned an automated wind tunnel data analysis system called SADSAC developed by the Chrysler Space Division. An improved version of this system renamed DATAMAN was used by Chrysler to document analyzed wind tunnel data and data bank the test data in standardized formats.

These analysis documents, associated computer graphics and standard formatted data were disseminated nationwide to the Shuttle technical community. These outputs became the basis for substantiating and certifying the flight worthiness of the Space Shuttle and for improving future designs.

As an aid to future programs this paper documents the lessons learned in compiling the massive wind tunnel test data base for developing the Space Shuttle. In particular, innovative managerial and technical concepts evolved in the course of conceiving and developing this successful DATAMAN system and the methods and organization for applying the system are presented.

INTRODUCTION

Background

As early as 1970, farsighted NASA engineers of the Space Shuttle Aerothermodynamic Test Data panel resolved that regarding wind tunnel test data, circumstances of the Apollo program would not be repeated.

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As the Apollo program progressed to flight status, engineers substantiating flight data were hindered because of lack of corroborating wind tunnel data. This lack was not because data had not been acquired.

Extensive wind tunnel data had been acquired over the life of the program at a great expenditure of effort and money. The documentation and preservation of the test data, however, were not as extensive as the test program.

Changing Perceptions

Perceptions or attitudes regarding the value of documenting test data analyses evolved because of increased complexities, technical and managerial. Launch, reentry, cruise, and landing design conditions dictated a wind tunnel test program unparalleled in complexity and in data quantities. Engineers perceived the need for revamping the traditional approach of applying test results today and documenting tomorrow - or the day after that - or never.

Changing Circumstances

Performing the Space Shuttle engineering analyses were NASA and contractor personnel from coast to coast. Clearly, it was mandatory that a means be provided for accurately communicating and sharing the extensive wind tunnel data base that was to be the basis of a nationwide engineering development effort.

Purpose

For the Space Shuttle program, the engineers comprising the Aerothermodynamic Test Data panel proposed that all test data acquired would be collected at a central point, that these data would be put in standard forms for preserving and communicating these data to the technical elements of the Shuttle community, and that basic analyses of all tests would be performed, the results documented and disseminated as referenceable reports, and the data be put on file for ready accessing.

For the Space Shuttle they determined to be able to substantiate and certify the aerodynamic design data on the basis of documented and available wind tunnel data. For the Space Shuttle a comprehensive data base of both ground-based facility test results and flight measurements would be preserved as a basis for improving future designs. The objective was to obtain optimum benefits from the wind tunnel test program.

Current Applications

That these goals were attained is evidenced by ongoing flight data analysis work. Currently flight evaluation work is extensively referencing the wind tunnel test data base. The aerodynamic design data base (ADDB) is a synthesis of hundreds of wind tunnel test results, all of which are documented and referenceable.

Data for over 527 Phase C/D wind tunnel tests are in a data bank available to Shuttle design team members. These data are documented and the reports disseminated to the technical community. These wind tunnel test data have been preserved, documented and made widely available at a modest cost.

How did NASA manage to achieve those goals - and achieve them at a modest cost? That is the answer - they "managed" it.

COMPILING AND DOCUMENTING THE WIND TUNNEL TEST DATA BASE

The wind tunnel test data base is the product of highly coordinated efforts of NASA engineers, NASA and contractor test centers, and contractor engineers all working in the context of a system. A key factor in the success of the system is the innovative management approach implemented by NASA in directing these combined efforts. These NASA management concepts are discussed.

A particular innovation was the concept of a focal point for documenting and disseminating test data analyses. Chrysler Corporation's Data Management Services unit, selected as the focal point, also contributed advanced technical and managerial techniques to the effort.

A particularly innovative and advanced concept is the DATAMAN system, the computer system developed and used by Chrysler for automated data handling and computer graphics. This system is discussed, as are the organization and methods developed to perform the data documentation process. A brief description of some of the contributions of the data management operation to the Shuttle design effort and an evaluation of cost effectiveness are presented.

The managerial contributions of both NASA and Chrysler provided the essential environment which encouraged technical innovation. These management approaches are described as a prelude to the technical descriptions.

MANAGEMENT CONCEPTS

NASA Data Base Concepts

Major factors in the successful development of the wind tunnel test data base were the management concepts adopted by NASA. A principal concept was that of mutual interchange of all data acquired. Another was the commitment of documenting data analyses and disseminating data analysis reports to the technical community. Formatting all data to standards and preserving the data in a central data base were also key developments. These concepts were the outgrowth of deliberations of a central body of managers and engineers, the Aerothermodynamic Test Panel.

Aerothermodynamic Test Panel

The Aerothermodynamic Test Panel was established as a coordination and liaison body. Its role was to pull together and provide central direction to the diverse and multi-faceted efforts of NASA centers, the many wind tunnel complexes, the major contractors, and the engineers and managers of these entities in the pursuit of test data for supporting the aerothermodynamic design of the Space Shuttle.

The Aerothermodynamic Test Panel adopted the concept of developing a wind tunnel test data base, and assumed responsibility for achieving it. A commitment was made by all parties involved to cooperate to achieve a data base. A pivotal innovation was the decision to fully interchange all wind tunnel test data acquired.

Data Interchange

Each NASA center agreed to make all Shuttle data acquired in its facilities immediately available to a data center. Accordingly, these data would be converted to standard formats and displays and distributed to all parties involved in the Shuttle design and development.

For Phase B, all contractors participating in the Space Shuttle development were to make all wind tunnel data acquired at government expense available to NASA. These data were then made available to all NASA centers and participating contractors. Thus, the Shuttle development benefitted from a rich cross-fertilization of data uniformly available to all.

Similarly, for Phase C/D, all data were communal property of the Shuttle design and development team. The principals, Rockwell, the prime contractor, and NASA Centers (Ames, Johnson, Langley and Marshall) were provided uniformly all wind tunnel test data available. These participants were enabled to simultaneously and uniformly view wind tunnel data transformed to standardized analysis formats.

CENTRAL DATA BASE MANAGER

The Aerothermodynamic Test Panel selected Chrysler as the wind tunnel test data base documentation manager. Chrysler was selected on the basis of its development of an advanced computer-aided design system for analyzing wind tunnel test data.

The mission of the documentation manager was to be the wind tunnel test data acquisition/documentation/dissemination focal point. Chrysler was to establish standard data formats and presentation formats were established to accomplish a systematic and orderly dissemination of wind tunnel test data. Chrysler was assigned responsibilities for converting Shuttle data into the standard formats, compiling a data bank, analyzing and documenting the results, and making the data and documents available to the Shuttle design team.

For Phase B the panel assumed responsibility for ensuring cooperation of NASA centers and of participating contractors with the data base documentation manager. NASA/MSFC was the contracting agency, with Mr. C. Dale Andrews the COR. For the Phase C/D program, the data documentation contractor continued under NASA/JSC cognizance with Mr. W. C. Moseley, Jr., the COR. Figure 1 shows the relationship of the wind tunnel test program participants and the data base documentation manager.

In performing these responsibilities, the Chrysler unit continued the development of a unique system for data base management. The system is comprised of a committed engineering design team, highly advanced software systems and excellent hardware facilities, all operating in accordance with innovative management philosophies in applying advanced technical concepts.

Benefits of the NASA Management Approach

These concepts reaped many benefits for NASA. Principally, these were results of high volume data handling capability at low unit cost, benefits usually associated with mass production. It is rare that terms associated with economies of scale are applied to engineering projects. There are definite reasons, however.

The combination of the data pool, standard formatting and a central manager resulted in a synergistic high-volume data operation employing large-scale data systems operated by teams of specialists. The result was an extremely efficient data handling process with the attendant high productivity and cost effectiveness of high automated systems.

To acquire the benefits of a highly specialized organization and to develop efficient automation, the data documentation manager, Chrysler Data Management Services unit, had to be equally adept in innovating and applying advanced technical and management concepts.

Chrysler Management Precepts

The management concepts of the contractor can be put in a word: service. By Chrysler's definition, service has four aspects. These are: integrity, timeliness, usefulness, and cost efficiency.

The precepts are more than words. Their observance is mandatory because to violate any one would be to jeopardize the entire undertaking.

Foremost is concern for data integrity. Each NASA center is rightfully protective of its data to prevent misuse. Likewise, the user contractor is properly concerned about being provided compromised data. Accordingly, protecting data integrity is uppermost.

Timeliness is essential in terms of both schedule and usefulness. Hence, the data base service must speed up the user's work, not slow it down.

Usefulness is just that. The service must be an aid, not a hindrance, to the one being served. The man using the data base must perceive the data base as an improvement or an assist to his work.

Cost efficiency is reducing data analysis documentation costs and increasing productivity of the individual engineer.

Automation was perceived by Chrysler as central to attaining all aspects of the service philosophy. Accordingly, Chrysler concentrated its effort in two areas: developing a highly automated computer system for converting massive quantities of wind tunnel test data into a usable data base, and developing an organization to apply the system.

Translating these precepts into a working system and a functioning organization required extensive conceptual innovations in both computer software and engineering operations.

TECHNICAL CONCEPTS

Automated System

The Chrysler service philosophy is designed into an automated system called DATAMAN. A highly integrated computer aided design/computer aided graphics system, DATAMAN embodies unique technical concepts which continue to be state of the art.

The DATAMAN system is a pioneer in the computer aided process of converting wind tunnel data into report ready graphics. The system was initiated in 1966 as the System for Automatic Design for Static Aerodynamic Characteristics (SADSAC) under the auspices of the Saturn IB Apollo program. After the system was selected for the data base management role, the name was changed to DATAMAN to reflect the expanded role.

The DATAMAN system is fully integrated whereby all data manipulation programs and all computer graphics programs operate under a single unified system. Other design features characterize the DATAMAN system. These features and their particular contribution to the capabilities of the DATAMAN system are discussed in the following sections.

The Dataset - Key to the Unified System

The individual computational and graphics programs are unified by means of standardized data format. Communication between the generalized programs of the system is achieved through the "dataset."

The dataset is a packet of test data and associated descriptive information. It includes dimensional data required to initialize and index the system controls. The dataset contains all information and data required for program execution when accompanied by specific user instructions.

Communication between programs is accomplished when a program produces a dataset as output. That same dataset is then read as input by another program. Hence, information is communicated via the dataset.

Interface problems of data transfer between programs are eliminated. Once data are entered into the system, they can be automatically accessed for any application - computational or plotting.

Aerodynamic Data Orientation

The dataset concept is generalized in that the system is indifferent as to what data are incorporated into the dataset. Descriptions of the data and names of the variables are assigned by the user. However, the dataset structure is designed to accommodate aerodynamic related data.

Three dataset forms exist to accommodate three basic forms of aerodynamic data; force and moment data, distributed loads data, and pressure (or heat transfer) field data. This organization of the dataset is depicted in figure 2.

The dataset forms vary essentially in arraying of the variables. Force and moment datasets are bivariately arrayed, corresponding to the basic aerodynamic forcing functions, aircraft attitude and velocity. The same forcing functions apply to the loads and pressure datasets except these assume additional dimensions. Airloads datasets are trivariate - section loads distributed along a fuselage, wing, or panel axis. Pressure datasets are arrayed along an axis, as are distributed loads, and also around the body or panel.

Relationships between the aerodynamic datasets are such that integrating a pressure dataset produces a distributed loads dataset. Integrating a loads dataset results in a force and moment aero data set.

Recall that though the datasets do take the form of velocity-attitude driven vectors with up to 10 coefficients included (for the force and moment datasets), the dataset is generalized. The variables can be any systematically varying set of parameters or parameter matrix whose identities are assigned by the user.

Also, means are provided for manipulating these large sets or data matrices to conform one set to another, transpose or do arithmetic operations, or plot the data. These means provide for flexibility and versatility in doing a variety of tasks on large data blocks. Also, it is a very efficient means of handling significant data quantities because these means are in the context of an integrated system.

Integrated Subsystems

Major elements of the automated system consist of four interrelated subsystems. These subsystems are a program executive, a data handling system, a plotting system, and a file management system. These constitute an integrated system. A schematic arrangement of the integrated system is shown in figure 3.

These subsystems provide the framework for all functions required for a system. The executive system provides the user command and control over operations of the other systems. Within the other subsystems reside an array of callable modular programs for performing certain tasks.

Modularity

These modular programs provide the considerable flexibility of the system and greatly facilitate the addition of capability. This is because each modular program does only a specific task - a specific module for a specific requirement.

What this means is a given task can be programmed into a specific module. Only the specialized code would be required as the existing file management programs can be used to call and store the data. Existing listing and plotting routines can be used to display results. Modularity makes the system easily adaptable to many different applications that arise.

Similarly, the user applies modules selectively to process data as required. The modular programs of the force and moment data system are listed in figure 4. Note the array of categories of programs. Arithmetic, matrix handling, interpolation, and statistical are some of the generalized programs. Programs for specific tasks include those for flow field and air data systems applications. This list illustrates the versatility of the system.

With modularity, the task of data analysis becomes a "decomposition problem" - breaking the job down into a series of discrete basic arithmetic tasks. And doing the job in stepwise fashion enables the user to list or plot intermediate results for checking accuracy.

Also, because these modular functions are highly automated, they are easily set up or modified. Thus the modularity and automation of the system provide for low cost but flexible and versatile capability.

Automated Systems

Operation of the integrated subsystems is automated to a high degree. The design concept is to relieve the user of all repetitive burdens possible in favor of automated operation. Also, the system is designed to be transparent to the user.

The modularity enables the high degree of automation. As each module is restricted to specific tasks, automating these functions is simplified. Accordingly, applying the automated modules is simplified.

For computations (for example, say, interpolation) the user calls the interpolation program at the executive level. The only information required of the user is to name the identifier of the dataset to be interpolated and supply an identifier for the resultant output dataset and the values of the new variable arrays.

Similarly, for plotting, selecting a particular plot module calls for a particular preprogrammed plot format. The only user information required is the identifier of the input dataset. Plots will be generated automatically for all the variables in the dataset on self-scaled grids, a single frame on the page, with the axes labelled by the variable names imbedded in the dataset.

Options can be introduced by the user to custom tailor his plot to his particular needs. These include designated grid increments and ranges, frame layout, custom axes labels and plot titling.

The preprogrammed highly automated features of the system contribute significantly to the labor saving attributes of the system.

Data File Subsystem

File management functions are automated so that all output data of a program module are filed automatically for retrieval. Similarly, automated fetch operations are integral to each modular program for data input.

A key feature of the system is that data once on file are not altered. For a computation operation, data from the file are read into core but the data on the file remain. Operations on the data in core result in a different valued output dataset which is written out onto the file adjacent to the original input dataset.

Thus the input dataset and the output dataset coexist on the file and are available for comparison or checking. This feature provides an audit trail and is invaluable for verifying the accuracy of the analysis.

The file management system relies extensively on random accessing techniques. A file directory of data identifiers and the corresponding absolute address enables the efficient storage of large variable length data files.

Additionally, two other design features characterize the operation of the DATAMAN system. One is a heavy reliance on default mode of operations, the other, a no-fatal-error operation feature.

Default Mode Operation

Wind tunnel test data are very individual by nature. No means of preprogramming a data analysis algorithm is known that is universally applicable to any and all wind tunnel test data.

However, a generalized program with a number of options can do very well in satisfying the various analysis requirements. The DATAMAN system is extensively optioned, and the options are exercised generally by default.

This means that the program is designed to perform as many tasks as possible and the user must exercise an option to stop an operation. The bias is deliberate and is to encourage the user to get the most out of the system, trading off computer resources for man effort to increase the productivity of the engineer.

No-Fatal-Error

The system is designed to operate with minimum fatal errors. In the event of a nominal data error, missing data, data out of range, or an improper instruction, the system generally will make note of the discrepancy and continue.

The objective is to acquire for the user a complete run-through of his task and acquire a complete set of diagnostics and error messages. To stop a run at each incident, for large data volume runs, is not conducive to obtaining timely results.

With no-fatal-errors, a job runs to completion and the user with the aid of diagnostic messages debugs his setup and resumes processing. This feature contributes to the productivity, the throughput, of the system in a large data volume environment.

System Benefits

These subsystems and system features are designed with the service concepts - data integrity, timeliness, usefulness, cost efficiency - uppermost. How these subsystems and some other design features serve these precepts is described below.

Data Integrity

All program operations are under engineer control through the program executive. Data manipulations and graphics are done only on engineer command.

No potential runaway "black box" functions are permitted. All data manipulations are discrete one step operations.

Verification is attained by automatically preserving results of all data manipulations on the file. These results are accessible for reading or plotting for visual verification. Thus, there is an audit trail which enables the engineer or manager to review or check data manipulations step by step.

Data Timeliness

The system is designed with throughput as a major criterion to accomplish timeliness. Throughput is the result of a highly interrelated system.

Interrelatedness means that, for all functions (input, operations, storage and retrieval, output), the output of one function is, through automation, the input of another. This automation feature enables large jobs comprised of successive tasks to be set up and run with minimum elapsed time.

Data Usefulness

Data to be meaningful must be completely identified. All elements of identification must be associated with the data - proper nomenclature, source and reference characteristics (lengths, areas, moment references).

The dataset provides for associating identifying information with a collection of test data for a given configuration. The association is accomplished at the time of data entry. From initial input, all identifying data descriptions and names automatically appear on all outputs (plots or tabulations). Thus all output is completely identified for proper application.

Productive and Cost Efficient Process

The dataset also provides for the system interrelatedness. This enables the productive throughput capability. The dataset contains all matrix dimensional information required to initialize a program for operating.

Each data manipulation program generates initializing data and imbeds it into the output where it initializes the next successive program. Thus, one program is enabled to communicate to another without user intervention, thereby achieving the highly productive labor-saving automated system operation.

Heavy reliance on default operating modes is another system feature. The default mode enables fast job setup and execution with a minimum of input, and attendant labor saving. Another key system design concept in achieving maximum throughput and high productivity is the no-fatal-error concept.

The system is designed to continue operating to completion when errors are detected. This is to overcome time consuming consequences of jobs terminating because of sequential failures. Thus an engineer is enabled to evaluate the entire job in a single pass, saving considerable time and effort.

The labor saving automated systems not only increase engineering productivity, but contribute significantly to compressing engineering schedules. Thus the productivity increases extend far beyond the cost savings of reduced manhours alone.

Need for Right Methods

The DATAMAN computer system has demonstrated well its considerable power and versatility and the capability to handle high volumes of data efficiently and quickly. However, as with any tool, it needs to be used properly.

It has been stated that the DATAMAN operation is a mix of men, machines, and methods. The DATAMAN system is the machine. To be effective the machine must be used by the right men using the right methods.

OPERATIONAL CONCEPTS

Best Use of the System

To realize the benefits of the DATAMAN system it must be used in a way to exploit its capabilities. Hence, the means of using the system have been designed with the same care and attention to detail as with developing the system. The operational concepts and the resulting functional organization are described below.

Operating Strategies

The Chrysler service philosophy is embodied into the operational cycle in terms of operating strategies and practices. The same philosophy is carried over into the organization which conducts operations.

To apply the precepts of integrity, timeliness, usefulness, and cost efficiency to the operations, a disciplined and organized function is required. That means simply that the work must be done in a methodical, systematic manner. The DATAMAN strategy is to consider the wind tunnel data analysis and documentation task as a process, as in manufacturing operations.

As a process, systematic organized methods can be applied to execution. The types of controls associated with process operations can be used to monitor the performance, quality and costs aspects of an engineering operation.

The application of the process concept to the task of wind tunnel data analysis documentation is the basis for the method of operations. Also, it provides the rationale for developing the functional organization and the management systems for controlling the process.

Process Concept

Process is a term usually applied to procedural manufacturing or chemical operations. Engineering analysis, on the other hand, is a series of heuristic free association activities of analysis and synthesis.

These free association activities remain in the DATAMAN process. But these creative activities are implemented by using the computer system as a multipurpose tool to automatically perform the drudge work of data handling and data graphics.

In doing the work, there are certain procedures performed that are common to all tests, regardless of the diversity of the test. This collection or sequence of common procedures becomes the process and is defined as series of distinct steps, or stages. In this context the analysis is equivalent to a manufacturing process; the work is done in well defined stages. At each stage, as the analysis becomes more complete, it takes on "value." As the work progresses through the system you have "value added" until you acquire the completed product.

Accordingly, the test data analysis process has distinct steps, each of which has an output. And the output is input to the next procedure in the sequence. Work is done on the input to increase its value. These procedures, or production activities, of the DATAMAN process and the corresponding work-in-process outputs are shown in figure 5.

The process is essentially a systematic procedure for bringing together the necessary inputs and activities required to convert wind tunnel test data to a documented analysis. This is the DATAMAN system which, though flexible, requires a high degree of discipline and methodology, which are brought about through organization.

ORGANIZATION

To systematically process wind tunnel test data into documented engineering analyses requires an organized and disciplined effort. The organization corresponds to the process functions in that the specific organizational elements are responsible for specific production phases.

Thus, the operating elements have well defined task assignments and are staffed with the corresponding specific skills. The organization is comprised of three operating elements: field engineering liaison, engineering data operations and computer systems.

Liaison is responsible for the preparatory and preprocessing phases. This includes all customer interface. This involves data coming into the organization and output going to the customer.

Engineering operations is responsible for the production phase. Operations performs the hands-on task of running data through the system to generate computer analyses and graphics. Operations also does the documentation and data banking.

Computer systems is a support function. Computer systems is responsible for all interface with the computer facility. It provides the systems for the line units: the preprocessing system for liaison to convert test data into standard formats, and the analysis system for operations to generate the applications data. Computer systems also supports the data base systems and the project management systems.

Details of the functions of the three operating units are presented in the following sections. The organizational elements and the corresponding production responsibilities are illustrated in figure 6.

OPERATIONS

The operation will be described in terms of the activities and the contributing functional organization. The outputs of each of these activities will be defined.

Quality assurance is an important element of any producing operation. And so it is in the DATAMAN operation. These quality control procedures will be detailed.

Also, tracking and monitoring systems and procedures are employed extensively to maintain schedules and control costs. These will be presented.

The relationships of the tasks, the outputs, and the quality assurance measures are shown in the network chart of figure 7. From this chart it is seen that the liaison unit begins the process by the planning and preparation activity.

Preparations

Liaison begins preparations at the time a test is scheduled. Test data and analysis requirements come through liaison which is also responsible for compiling test data information and developing analysis and graphics requirements. With these inputs liaison also develops the test data reformat specifications.

Preprocessing

Liaison, using the preprocessor computer system, converts the test data from the facility format into a standard DATAMAN format. Liaison forwards the standard formatted data and the analysis execution instructions to engineering operations for continued processing.

Computer Systems Support

Two data handling systems comprise the production systems. These are the preprocessor, the system which converts test facility data tapes into standard DATAMAN formatted tapes, and the DATAMAN system, which is the integrated data analysis system. Computer systems works hand in hand with liaison and operations to keep these systems in a high state of readiness in anticipating and preparing the ongoing test data handling requirements.

Computer systems maintains the systems to keep them current with the ongoing host facility upgrades and improvements. Additionally, with a commitment to automation there is always room for improvement - ways to save engineer time, save machine time, or improve the turnaround. So systems programmers have a continual challenge to improve the system in terms of capability, cost reduction or productivity.

Preliminary Analysis

Taking the reformatted test data tape and the analysis instructions, engineering operations conducts operations for producing the required data analysis and computer graphics. Operations engineers do the hands-on job of running the test data through the DATAMAN system.

Much of the work is checking. Analyzing the computer system diagnostic messages to make certain that good runs have been made and carefully evaluating the graphics and tabular data to make certain that the data results are valid and conform to customer specifications are part of this function.

When data results vary from plan, operations revises the analysis instruction set to correct the variance. For significant discrepancies, operations consults with liaison and the customer for direction before modifying the program instructions.

The operations engineer iterates the job to refine it to achieve the analysis and plot specifications. When satisfied that the analysis results and graphics are as specified, operations sends the output to liaison for review and forwarding to the customer.

Final Analysis

Frequently the data will not behave as the customer planned, or the customer discovers something about the data that requires different treatment or additional analysis.

This is standard operating procedure and is anticipated. The changes the customer desires are incorporated into the analysis instruction set and the job is recycled. The instruction setup is very flexible. Changes can be handled as rework or as add-on.

Operations will iterate the analysis/review cycle to satisfy the analysis and presentation requirements. Final confirmation is supplied by the customer.

Documentation Phase

Liaison is responsible for collecting the customer documentation input. Much of that comes from pretest documents - test plans, objectives, model information. The test engineer supplies commentary on test particulars. Standard facility descriptions are utilized.

Operations compiles the report, produces final computer graphics, complete with plot indexes, and integrates these and the liaison input into report format. Editing, final typing, and proofreading are all performed by operations.

Documentation Control

Report numbers are assigned by operations. Two report numbers are assigned. One is the internal document number. The other number is the contractor report number supplied by NASA. The reports are logged by STIF and listed in the STAR system by the contractor report number.

Document Distribution

Report copies are sent to designated members of the Shuttle design team. Participating NASA centers and the prime contractor are provided all documents for master files.

Reports are also sent to assigned NASA and contractor personnel according to the particular application of the data. For example, reports on orbiter heating data and ascent vehicle stability and control data will have different distributions. Distribution lists are provided by the contracting officer's representative (COR) who provides overall control of the distribution.

STIF is provided a master for further distribution on microfiche. Also, limited quantitites of reports are maintained locally for emergency distribution, again at the direction of the COR.

Data Bank

All the data are archived. Test data go into the data bank. Report material, masters, and notes go into archives.

Once the data are in the system they are always available for ongoing applications. All the test data and analysis data are maintained on magnetic tape. The data are easily accessed long after the analysis is completed. These are accessible for new applications, to compare to other tests, or to review the analysis.

Operations maintains the data bank. The data bank is always in a state of flux. It requires updating for new test data. It also requires periodic maintenance to validate current files and insure backup files. Tape library records are continually updated to reflect current data bank contents.

Test-in-Process Status Reports

Operations issues monthly processing status reports so that all involved always know the status of any tests - whether they are still in process or whether they are completed and in the data bank. Once the data enters the system, everyone is continuously made aware of its status.

Data File Contents Reports

After a test is documented, it is recorded in the Data File Contents Report. This report lists all tests and corresponding documents for completed tests.

These two documents, the Test-in-Process Status Report and the Data File Contents Report, are distributed throughout the Shuttle community. These reports provide current information on all Space Shuttle wind tunnel tests that have been conducted, the test particulars and the status and availability of the data.

These report contents are illustrated in figure 8.

Quality Assurance

As a test-in-process moves through liaison to operations, then back to liaison, quality reviews are made at each interface. Every time a work-in-process package is handed over to the next production phase, a quality review is made.

In-process quality checks result in minimized rework. Also, it is more efficient to inspect the work while it's evolving with reduced risk of overlooking a discrepancy.

Initial Quality Review

The first quality review occurs at the first interface between liaison and operations. Before liaison releases reformatted data, the liaison engineer carefully compares the reformatted data to insure an accurate translation and to insure compliance with the run collation specification. Also, he confirms that the analysis instruction set is consistent with data as collated. On completion, the output is released to operations as certified input.

In case of a discrepancy, a data discrepancy report is issued. This is a quality control document that becomes a permanent record of that test file.

Second Quality Review

As operations produce analysis data and presentation plots, they thoroughly review them for engineering accuracy and compliance with customer requirements. When satisfied, they release them to liaison for a final review and relay to the customer.

Documentation Quality Check

The final quality review is conducted at the documentation interface. As final analysis and graphics are produced, they are incorporated into a data report.

Before publication a double review is performed. The document is reviewed by both engineering operations and liaison, once before the report is sent to be printed and once after the report is printed. The review before printing is to insure compliance with customer specifications and compliance with sound engineering practice. The after-printing review is to insure that the report was printed "as prepared" and to insure legibility.

Tracking and Monitoring Work-in-Process

Tracking and monitoring a test in the documentation process is done using a test status log system. The summary status conditions are reported monthly by milestones. Costs are tracked and collected according to function and task.

Test Status Log

For each test a history is maintained detailing significant events in the processing life, good or bad. Dates of milestone events are recorded.

An automated status system develops a comprehensive status history report for all tests in the system. Also, it provides a milestone summary for all tests. This information is provided to the Shuttle community for data availability awareness.

Milestone Summary Report

The tests are categorized by milestone status in the processing cycle. A typical status summary report is shown in figure 9. Progress of a test is tracked by monitoring its movement from one milestone status to another.

Test status fluctuates between active and inactive as holds develop for inputs or for response to outputs. Status condition is evaluated by comparing the movement of a test status to planned norms which allow for holds.

It is difficult to establish norms as all tests are different. But expectations can be established for tests of similar complexity. Therefore, for each test an expected complexity level is established. The complexity level establishes the planning cycle norms and the budget plan for that test.

Cost Collection

Cost tracking comes from a companion system to the status monitoring system. Liaison is responsible for initiating all management controls. Tracking begins at the time a test is scheduled. At that time the test is assigned a test ID, a unique two-character identifier, which is imbedded in the label of every dataset.

The identifier preserves uniqueness for dataset names in the data file and prevents wrong data from being accessed. Liaison maintains a master log of ID's assigned and those to be assigned. The master log is prepared in advance, with ID preassigned to facilities and assigned as tests are scheduled at the facility.

Work Breakdown Structure

The work activities, the tasks that are performed by liaison and operations and the support provided by computer systems, have been described. These activities define the work breakdown structure.

The WBS task is related to a particular test through the test ID. The combination of WBS number and the test ID as a charge number is the basis for a cost collection system. The charge number associates the test being worked on with the kind of work being done. Daily time charges are compiled, collected and reported to provide cost analysis data for the work-in-process.

Task and Support Work

The WBS is two-tiered. One tier is for measuring effort expended on a specific test. The other tier is for measuring work expended in support.

Task effort is defined as work on a specifically identifiable test or task. Support effort is the myriad of activities from coordination meetings to logging data tapes to archiving accumulated test files.

Data base management tasks (maintaining the data base and servicing access requests) are also classified as support tasks, as are the test status reporting and project reporting tasks, the standard station-keeping chores that attend an organized activity.

Additionally, the automated DATAMAN systems require support personnel and support effort to maintain the systems. Support effort is also utilized to add new capability to meet user needs or improve efficiency.

The process operation also requires a highly coordinated stream of inputs. These coordination tasks with the various data sources are support activities.

The WBS is further divided into subtasks. Manhour expenditures are collected by function (liaison, operations, or programming) and by level (task or support, including the specific subtask). The WBS subtask matrices for task and support levels are shown in figure 10.

Cost Control

Cost control is aided by awareness of the distribution of manhour expenditures. Also, this knowledge provides guidance in determining need for improved or additional automation. A third contribution of the cost collection system to management is that cost data provide essential forecasting and planning information.

Similarly, computer resource costs are compiled according to task activity and test ID. Knowing the manhours and computer resources expended provides a basis for controlling current expenditures and forecasting future costs.

Knowing what test or what task is consuming manhours or computer time enables the manager to spot opportunities for improvement, either in personnel or procedures or in systems.

These management tools, in conjunction with the automated DATAMAN systems and systematic operations, have enabled Chrysler to provide a highly productive, low-cost data analysis service in behalf of the Space Shuttle.

These contributions to the Space Shuttle design effort will be examined in detail in a following section. But one more vital element in the production process will be detailed and that element is the computer facility.

COMPUTER FACILITIES

Capable computer facilities and facility operations are essential to successful data management services. The NASA Slidell Computer Complex is the capable facility utilized by DATAMAN services.

Management Philosophy

A fundamental reason why the Slidell Computer Complex is termed capable is the resident NASA management and their management philosophy. The management philosophy, in a word, is service.

Because of their particular circumstances as a satellite center servicing the remote sites of Michoud and the Mississippi Test Facility, the NASA management clearly perceives its primary duty as providing service. The service philosophy is manifested equally in the two major operating elements, excellent facilities and effective operators.

Computer Equipment

UNIVAC 1100 series mainframes are the CPU systems used for data base operations. These systems have been continuously upgraded beginning with the advanced 1108 (Exec 8) system in 1970 to the current top line system 1100/82.

Graphics

The computer graphics device in use at the Slidell center is the Information International FR 80 system. Coupled with the FR-80, which produces fiche, is the Xerox 970 copier, which produces hard copy from fiche.

The combined capacity of the FR-80/Xerox is measured in tens of thousands of frames daily. This is adequate for data base operations.

Peripherals

Careful management attention to seemingly mundane incidentals contributes significantly to facility efficiency. Two of these lesser items which contribute are peripheral systems.

One peripheral provides for automated job instructions. The other provides automated plot tape labels and instructions, including those for multi-reel files.

These peripherals, long in use at SCC, effectively automate the job control operation and overcome a production bottleneck that continues to plague many computer sites.

Facility Operations

The NASA management influences facility operations in quality day-to-day service and fast response priority service in emergency situations.

Management enforced high performance standards imposed on contractor operations provide the right climate for service oriented data base operations. Rapid NASA management attention is directed to the rare operations breakdown. Similarly, priorities are readily granted on proper justification for unusual or schedule-critical situations.

The efficiency of the SCC computer facility is attested to by the fact that no significant delays in providing data base services have ever been attributed to lack of computer support. This record has been established while the facility simultaneously supported data reduction for Skylab operations, External Tank development, Shuttle engine test programs, and Shuttle flights.

In addition to an efficient facility, another key factor is the support of the resident NASA management. These gentlemen collectively and unstintingly have seen to it that the DATAMAN operation received proper support and that this was done in a highly responsible, uncompromising manner.

EVALUATING DATAMAN OPERATIONS PERFORMANCE

Automated data systems, a skilled, integrated organization using systematic procedures, constitute the DATAMAN operation. How effectively did these elements function? What was accomplished and how well was it accomplished?

Recalling the Mission

The primary mission of the DATAMAN operation was to document and disseminate wind tunnel test data analyses. To act as a central clearing house for all wind tunnel test data, to conform the data to standard formats and to make it available to the Shuttle team were other aspects of the mission.

As the high volume DATAMAN system capabilities became known, secondary responsibilities developed. These were special considerations, usually schedule critical tasks where the special system capabilities were sorely needed. These activities were reduced, however, in 1977 because of budget constraints.

Performance can be measured in terms of shear output volume. Another performance indicator would be productivity; that is, what was accomplished with resources available. Also to be answered is how well the system responded to the varied demands of the design effort.

These performance parameters are provided below.

Data Documentation Results

Since January 1973, DATAMAN has handled over 527 NASA series number tests. These correspond to a total of 57,800 wind tunnel occupancy hours (through 1979), conducted by the prime contractor and by NASA in independent tests.

For these tests over 800 data analysis reports will be published, considering the work-in-process. These reports will involve approximately 500,000 pages. Additionally, 348 special request studies were conducted and these results documented. The total documents then will exceed 1148.

In addition to documented analyses another output was provided the Shuttle community. This was the advance data releases, principally preliminary data plots. The purpose of these preliminary plots was twofold, one, for timeliness, to make the data readily available to the user for advance applications, and the second to involve the user in evaluating the data, for data integrity. Over three million preliminary evaluation plots were delivered.

These significant output volumes, taken at face value, affirm the overall effectiveness of the Chrysler data management operation. An indicator of the system productivity is a comparison of the task load and the corresponding manning. This comparison is presented in the following section.

Task Loading

Task frequency, the number of new tasks submitted per month for handling, was highly irregular but increasing through 1976. The average task input frequency during this period exceeded 12 per month, and for three quarters of 1976 it averaged 15 per month.

The corresponding manning level for this period averaged 23. Task frequency and man levels are shown in figure 11. The task load per man then averages out to be a new task every two months per man. The implication is that with the system, a man completes a task every two months. This is a rough but reasonable indicator that the system is cost effective.

The inference is that a man analyzes a wind tunnel test, produces preliminary data plots, then final data plots, and documents and publishes the results - in two months. That same man is also performing the liaison, system maintenance and data bank station-keeping duties.

System Versatility

Volume and productivity are not the only factors, however, in evaluating system performance. The Shuttle aerothermodynamic test program involved a variety of aerodynamic and thermodynamic tests for a variety of configurations. The ability to handle the wide range of conditions encountered is a measure of system effectiveness.

Aerodynamic tests were conducted for every Shuttle configuration (ascent, external tank, SRB, orbiter entry, landing and mated carrier). These configurations were exposed to a host of perturbations - separation, proximity, component loads, pressure loads, probes, boundary layer rakes, air data system devices, blowing RCS jets, exhaust plumes, flaps, and flexible and rigid controls.

For aerothermoheating, similar tests were performed on the ascent vehicle, external tank, and SRB, both separated and in proximity. The tests included interstage heating, orbiter entry, base heating, and hot jet tests, pressure distribution tests, and obtained pressure distributions for wings, panels, flaps, control surfaces, nozzles, tail cones, external tank, and interstage.

All of these varied kinds of data were handled with the DATAMAN system. The capability of the system to contend with the array of configurations, the varied and extensive types of data and equally varied and extensive applications demonstrates that the DATAMAN system is exceedingly versatile.

The demonstrated performance verifies that the concept of the generalized dataset, a means of organizing any systematically varying collection of data, and the generalized modular data handling subprograms are sound concepts that work exceedingly well, and they work in a most challenging number of situations.

Special Applications

As the wind tunnel test program matured, the test configurations became very involved and complex. Extensive pressure measurements involved thermocouple layouts, instrumented panels, multiple-balance models, and separation/proximity tests.

Essentially, large quantities of data were being taken. Schedules were tight, resources were scarce and available manpower resources of the prime contractor and supporting NASA centers were being taxed to analyze and apply the data within the tight program schedules.

DATAMAN operations was authorized by NASA in mid-1973 to assist the prime and support groups by applying the automated data systems to perform special data applications tasks. The need was so great and the DATAMAN system capability so useful that by 1977 the special task load was larger than the test load.

Examining the list of special applications reveals the range of DATAMAN involvement. Virtually all the design areas using wind tunnel test data benefitted. These areas were the aerodynamic analyses, aerodynamic loads, aerothermodynamic analysis, air data systems, aero design data book development, RCS studies, and local flow. An extensive but not exhaustive list of various applications is compiled in figure 12.

The list shows the applications of the DATAMAN system, but it does not show the time frame or schedule considerations. Several, if not most, of the applications were in response to extremely time constrained situations in support of critical program milestone schedules.

At the end of 1977, budget factors caused a reduction in the level of special support. Funding constraints forced a choice between continuing a very effective and valuable contribution to the ongoing design effort at a high level but jeopardizing the continuation of the mainline test data analysis documentation and data base effort. The analyses documentation and data bank service were the priority choice. As a result, the special request support was severely reduced.

Special applications contributed significantly to the Shuttle design effort. These contributions were pervasive extending to virtually every design area which utilized wind tunnel data. A few samples are given to illustrate the range of application.

Aerodynamic Analysis

A typical data bank application is illustrated by the comparison curves of wing/elevon coefficients for various tunnel entries shown in figure 13(a). Datasets containing outboard hinge moment coefficients for four different tests of similar configurations have been retrieved from the data bank for operations.

These coefficients have been interpolated to common Mach, pitch, sideslip, and control surface deflection conditions. The results have been comparison plotted for evaluation.

These presentations enable the design engineer to quickly assess the relative data merits and expedite the analysis.

Thermodynamic Analysis

A data presentation method for quickly assessing interference heating effects is illustrated in figure 13(b).

Heating distributions are presented for

1) ET alone

2) ET in the presence of the orbiter and SRB's

3) Theoretical heating for the ET alone at the given test conditions

4) Interference to undisturbed heating ratios, h_i/h_u, for test to theory and for test to test.

Note that these data are a mix of measured rates and theory base computed rates.

The heating rates for undisturbed ET are presented with the rates for the ET in the presence of the orbiter. Also presented is the computed ratio of the interference data and undisturbed (h_i,h_u).

Localized areas of high heating can be quickly identified by scanning the h_i/h_u display. Thus, design engineers, after rapidly identifiying potential problem areas with the aid of the displays, are enabled to concentrate effort on solving the problems.

Pressure Load Integrations

Computed delta pressure increments across a rudder panel presented in figure 13(c) show the chordwise aerodynamic loads on a rudder panel.

These load distributions provide first order estimates for design applications.

Integrated panel pressures are integrated to produce local loads. The distributed elevon panel load variation with angle of attack is presented in figure 13(d).

The Mach number crossplot of the same elevon distributed load is presented in figure 13(e).

These two presentations of local loads enable the designer to rapidly determine potentially critical load conditions.

Wing pressures are integrated to obtain wing panel forces and moments. Figure 13(f) shows a wing root normal shear force carpet plotted for a pitch-sideslip matrix.

This matrix display visualizes component forces enabling the designer to rapidly assess the data for critical wing loads.

Demonstrated Utility

These selected samples indicate the ability of the system to handle applications of a wide range. The versatility is extremely useful in fast response, schedule-critical situations.

The system is demonstrably versatile. It is capable of very high volume operations. It contributes significantly to increasing engineering productivity.

A complete assessment of the DATAMAN contributions must include consideration of cost. What did it cost to provide these contributions, and was it worth the candle?

COST PERFORMANCE

What has it cost to analyze and document the wind tunnel test data and to provide the data bank services? For perspective, an equally important question is how much it has cost to acquire the data being analyzed and documented. Accordingly, data analysis and documentation costs are presented relative to data acquisition costs.

Assessments of input over output provide direct cost parameters. DATAMAN manhours and contract costs are the input. Data reports are the output. The distribution of manhours for the various production tasks provides insight on the productivity of the system. Therefore, an analysis of the manpower utilized is presented.

The cost data presented substantiate the claims made for the DATAMAN operation; it is an efficient system, and it does provide a low-cost means of data transfer.

Wind Tunnel Test Program Cost Estimates

Estimates for contractor model fabrication and estimated tunnel occupancy costs are $73.3 million through 1979 (reference 2). The total occupancy hours are 57,800 for tests processed by the DATAMAN system. These hours reflect 21,600 occupancy hours logged by NASA in independent efforts. No cost estimates are available for the NASA independent effort.

Note that the cost estimates are partial costs only. No manpower costs are included for model design nor for test planning or test conducting. Neither are any NASA manpower costs included.

Baseline Reference Costs

Model costs and occupancy hours, though they do not reflect total test program costs, are reasonably well behaved parameters for planning and estimating purposes. Accordingly, cost ratios of data analysis documentation costs show that every contractor dollar expended for model fabrication and tunnel occupancy required an additional 10 cents to be expended for data analysis documentation, or about one dollar for data analysis documentation for every $10 the contractor expended for model fabrication and wind tunnel occupancy (through 1979).

The corresponding manhour factor for data analysis documentation (the number of manhours required per tunnel occupancy hour) is five. For every wind tunnel occupancy hour, five manhours were required to place the test analysis documentation in the hands of the technical community.

These factors are for purposes of perspective. Perhaps a more reliable indicator would be in terms of the output; namely, the data analysis, corresponding documentation and the data bank services.

Input Over Output Factors

The total projected number of NASA series number tests to be handled exceeds 527. These, in turn, resulted or will result in approximately 800 data report volumes. Additionally, 348 special analysis tasks have also been performed and documented.

Average contract costs for these 1148 documents were $7,700 per document for the period 1973-1983. In terms of manhours, approximately 275 manhours, or about 1-3/4 man months, were required per report document.

Note that these cost parameters include not only the production costs of the data analyses, production of graphics, documentation and distribution, but included also the field liaison support and the computer programming support. Also provided for the same cost were ancillary services which included the extensive cataloging, status reporting and data base management functions. File releases of data reports, data base tapes and preliminary plot packages were also continuing activities in moving analysis data from wind tunnel to user. The costs reported include all these services.

Note that these are contract costs. Facility costs are not included. These include computer services and occupancy costs. Occupancy costs are office and utility costs. Occupancy also includes printing services of a government printing office field shop.

The distribution of costs between the data graphics production documentation and data base management activities can be seen in the WBS breakdown presented in the following section.

WBS Manhour Distributions

Manhour allocations between the various WBS functions are shown in figure 14. These allocations show where the 275 manhours were expended to analyze and document the average wind tunnel test.

The spread of effort between the production activities shows that the principal effort is data operations. Note the relatively low effort required for documentation. This is because the output of the automated data operations effort, the computer graphics and computer-generated plot indexes and legends, is incorporated directly into the document.

Note also the division of effort between two categories, task effort and support effort. The data base management functions and the status reporting functions are support only. The production functions also involve support, however.

The highly automated, highly specialized p[illegible] requires expenditures of effort to maintain the automated systems and to c[illegible]nate the work flow to prevent bottlenecks in a high volume operation. These costs are compiled and identified as support costs. The hours identified as task are those expended directly on moving data through the system and out the door.

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Just how effective, then, is the DATAMAN system if it requires such support? The answer is, very.

What might appear to be buzzwords or cliches are words that accurately describe a throughput oriented process using a highly automated analysis system.

The result is a high quality product that is delivered in a timely manner, a very useful product which saves money. A conservative estimate places the savings in a range of 2-4 over alternate techniques.

SUMMARY

The wind tunnel test data analysis documentation effort has contributed significantly to the development of the Space Shuttle. The technical design and development of the Space Shuttle has been materially enhanced by the ready availability of documented wind tunnel test analysis data. Additionally, the DATAMAN operation has aided the Space Shuttle design team through timely deliveries of special data analysis to support schedule-critical program milestones.

Summarized in the following sections are the major highlights of the wind tunnel test data base effort and advancements and contributions, management and technical, realized as a result of the DATAMAN systems and operations.

NASA Management Developments

NASA centers exhibited a high degree of cooperation in participative interchange of the data via the data base. The NASA centers also benefitted by the unprecedented ready uniform availability of useful data.

NASA managers also demonstrated uncommon leadership in keeping the data base function an independent and thereby viable operation. Correspondingly, the contractor operating on service based principles provided a beneficial highly responsive service.

Technical Developments

Attaining the data base was the result of a significant number of conceptual technical innovations.

Central to the data base service is the advanced computer-aided design/graphics DATAMAN system. The conceptual design of the system and the high degree of system integration remain unduplicated.

The engineering productivity increases realized because of the system capabilities resulted in an unprecedented availability of analyzed test data to the design team (unprecedented in terms of both schedule and volume).

Organizational Developments

The very productive automated DATAMAN system enabled the analysis of wind tunnel test data at an unprecedented rate and volume. Adopting high volume production methods to utilize the system capacity resulted in an engineering analysis organization resembling a production organization.

Similarly, production-type management controls and systems and procedures enhanced operating effectiveness and abilities to operate in fast turnaround schedule-critical modes.

Data Awareness

Another result of the data base system was continuously available awareness of the existence and availability of the wind tunnel test data acquired. This information enhanced (optimized) the overall usefulness of the test data.

Data Availability

The most important result of the data base function is that the data were readily available and accessible by the Shuttle design team. Adhering to the original concepts, the test facilities consistently provided to DATAMAN operations timely test data for interchanging.

The DATAMAN operation in turn rapidly converted these data from the variety of facilities, for an array of different kinds of tests and configurations, into standardized formats and displays. These displayed data were uniformly available simultaneously to all Shuttle design participants. Thus, the data base service provided an unprecedented channel of communication for the interchange of data.

The DATAMAN capability was also utilized to provide special data operations for expediting design applications of the data. These special operations contributed significantly in attaining program milestones on a time critical schedule.

Lessons Learned

The lessons learned in compiling the Space Shuttle wind tunnel test data base can be summarized as follows:

1) The centralized data base function, responsive to both prime contractor and NASA, has successfully provided the following benefits to the success of the Space Shuttle design:

   - full and free interchange of data between all participating in Space Shuttle development

   - uniform availability of analyzed test data in a referenceable document for all Shuttle design team members

- standardized formats for enhanced usefulness of test data from over 44 facilities
- guaranteed preservation of test data for flight certification and future design applications.
- enhanced Shuttle design team through special data studies to support schedule-critical program milestones
- benefits accruing from a unified data base (i.e., extensive data retrieval, special data handling and data visualization, test-to-test comparisons, and extended test data analyses)
- complete awareness of total wind tunnel program through management information regarding test status and data

2) Maintaining the data base function as an independent entity (reporting to NASA, not a subordinate prime contractor activity) resulted in the following organizational benefits:

   - single purpose mission which enhanced certainty of achieving goals of a complete data base
   - high degree of responsiveness to all data users
   - high visibility of test data status for improved management and control

3) Centralizing the data base function with the resultant large data volumes has provided the following technical benefits:

   - impetus for developing the large-scale highly efficient data handling system (DATAMAN)
   - significant cost savings because of efficient systems and economies of scale
   - productivity improvements not only in the analysis of wind tunnel test data but corresponding improvements in application of test data

CONCLUSION

In conclusion, the revolutionary productivity increases in data delivery brought about by the automated DATAMAN system and the DATAMAN organization have not only significantly contributed to the successful design of the Space Shuttle, but have provided a means of low-cost data transfer which is applicable and beneficial to any wind tunnel test activity.

This has also resulted in an unprecedented accumulation of ground based facility data by which to verify the vehicle flight characteristics. Also, all the wind tunnel test data, acquired at considerable expense, are available to the technical community as a basis for improved and future designs.

When embarking on the development of the next aerodynamic systems, one question that must be asked is, "Which procedures used on the Shuttle program should be done again?" One of the answers should be the wind tunnel test data analysis/documentation, the DATAMAN system. That should be done again.

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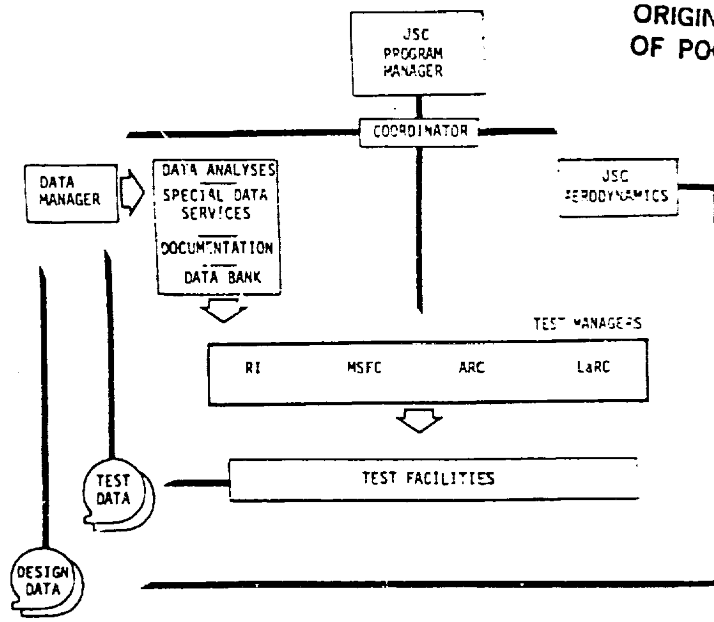

Figure 1.- Chrysler as the data analysis documentation manager services the Space Shuttle design team under the direction of JSC.

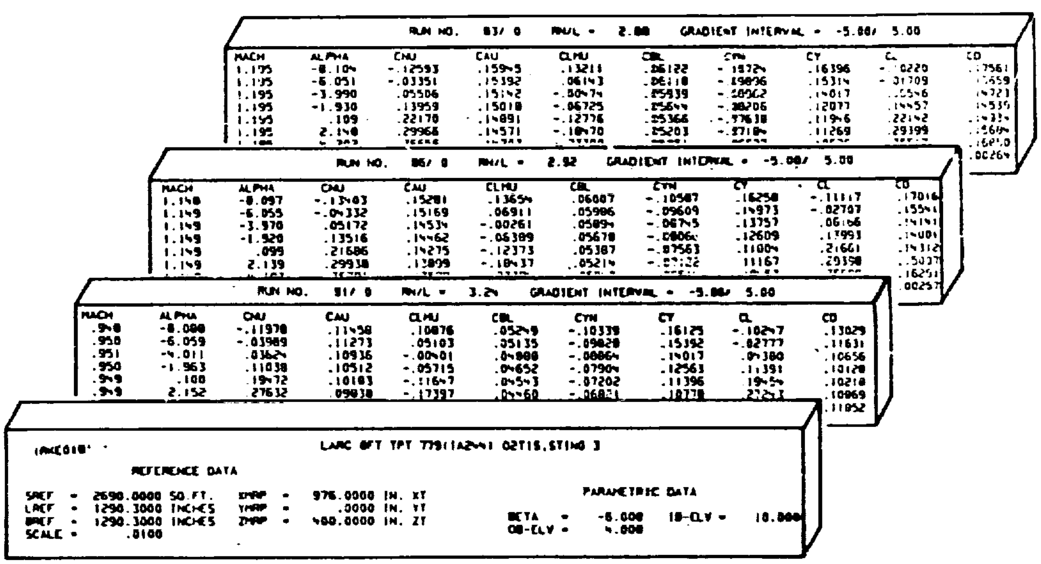

Figure 2.- The dataset is a collection of wind tunnel runs for the same configuration. Associated with the data are supplied identifying descriptive information and dimensional data to complete the packet.

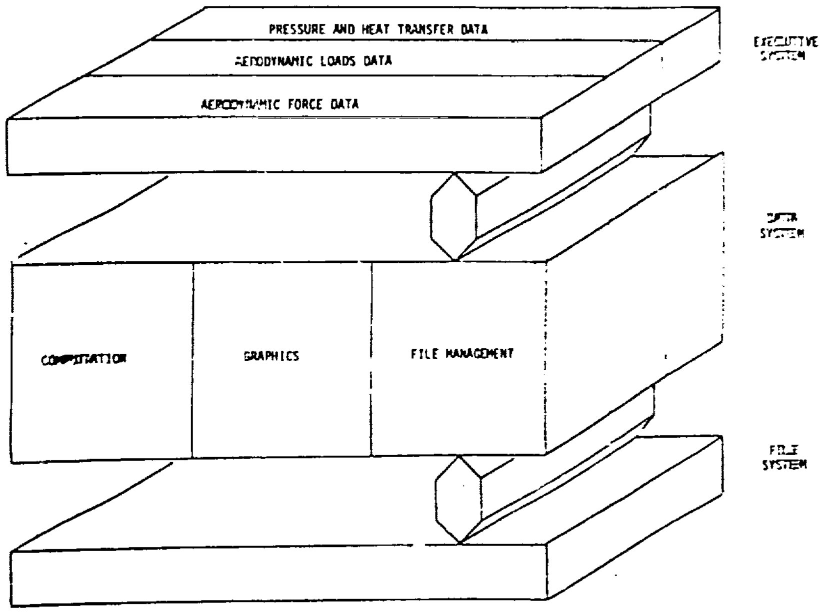

Figure 3.- The DATAMAN system is an integrated system consisting of a system executive, data systems, and a file management system. It is also a unified system for processing aerodynamic pressure or heat transfer data, aerodynamic loads, and aerodynamic force data.

Arithmetic Operations

FCOMBN
FCOMPR
FCONVT
FDERIV
FDSIGN
FPARAM
FRATIO

Matrix Operations

FADJON
FADVAR
FPSWCH
FSTACK
FSWTCH
FTRANS

Edit

FCDMOD
FCELIM

Utility

FDSDAT
FPPCON
FPUNCH

Interpolation

FANTRP
FINTRP
FPWTRP
FSMTRP

Statistical

FPOLYN
FMSTAT
FREGRS
FSIGMA
FSTATS

Aerodynamic Applications

FAXIAL
FSCALE
FCAXIS
FXTRCT

Flow Field Applications

FBLAYR
FLOCAL
FPRCAL
FPROBE

Air Data Systems

FADSAA
FBENCH

I/O Operations

FCDATB
FCDATD
FCDUMP
FCLIST
FCUPDT

Figure 4.- The modular programs of the FORCE DATA SYSTEM illustrate the range of capability and versatility of the system.

	Activity	Result
ENGINEERING ANALYSIS	o Planning	o Collation Plan o Analysis Specifications
DATA ENTRY	o Data Initialization o Analysis System Input	o Formatted Data Tape
DATA ANALYSIS OPERATIONS	o Engineering Analysis o Computer Graphics	o Preliminary Analysis Data o Preliminary Data Plots
ANALYSIS EVALUATION	o Inhouse Review o Customer Review	o Confirmed Analysis Data o Confirmed Data Plots
DOCUMENTATION	o Compiling/Editing o Publication/Distribution	o Engineering Report
DATA BASE MANAGEMENT	o Data Base o Document Archives	o Retrievable Data Files o Data Bank Contents Report o Status Reports

Figure 5.- The data analysis documentation operations is a systematic production process of well defined activities and outputs.

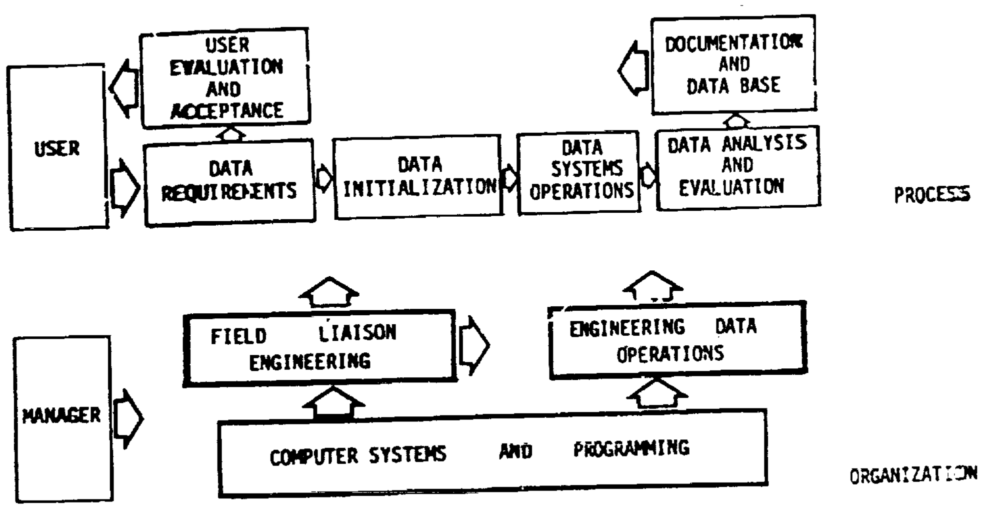

Figure 6.- The DATAMAN organization parallels the analysis production process.

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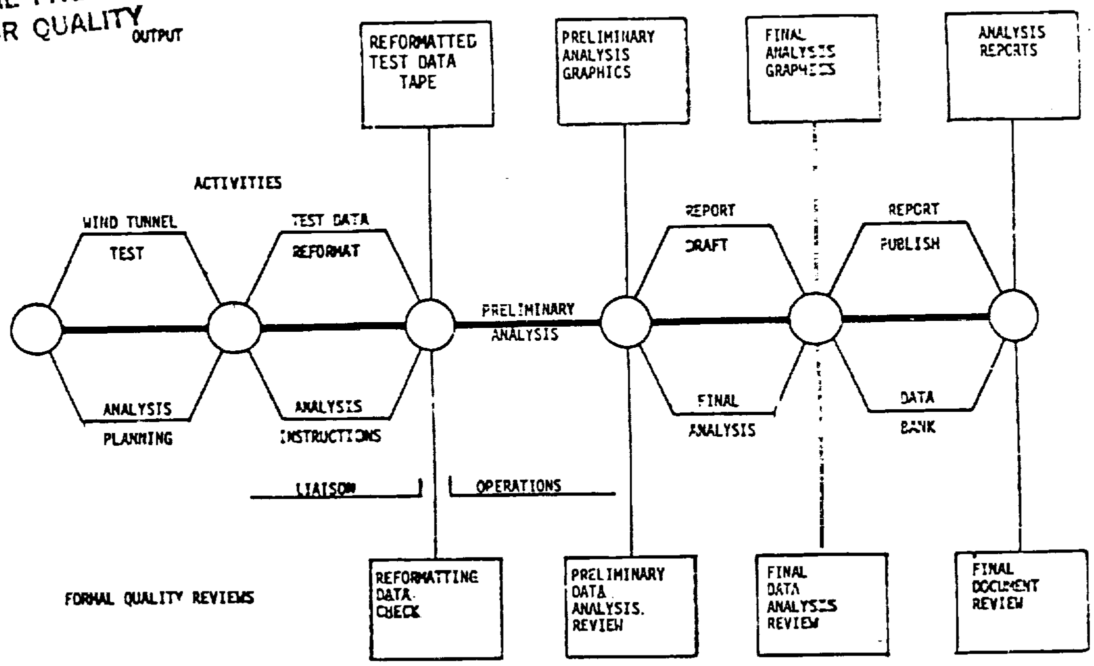


Figure 7.- The network chart shows the relationships of the data analysis and documentation activities to the operational elements.

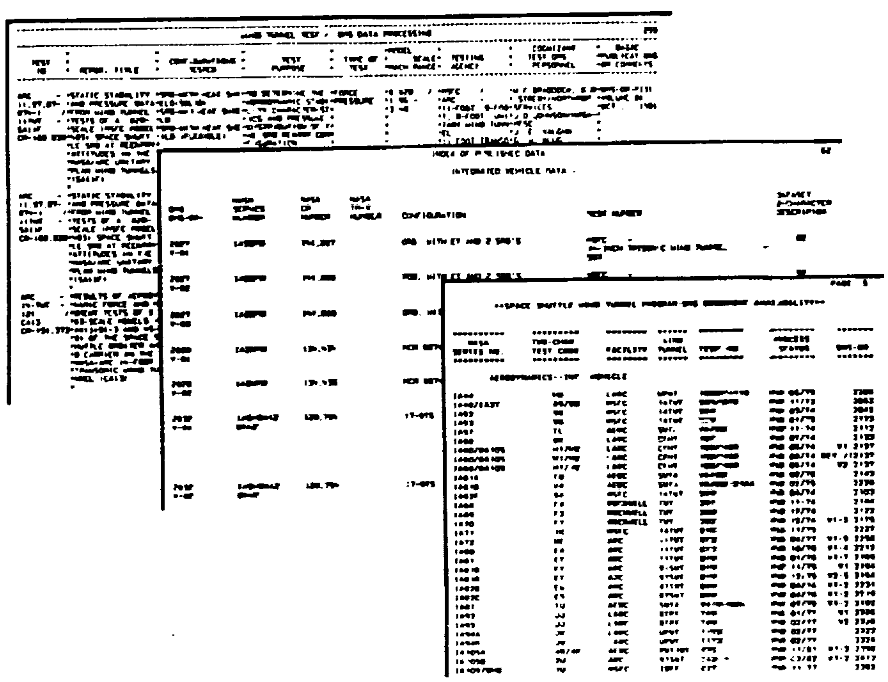


Figure 8.- The Shuttle technical community is continually made aware of data available by data bank contents reports. (From Ref. 3.)

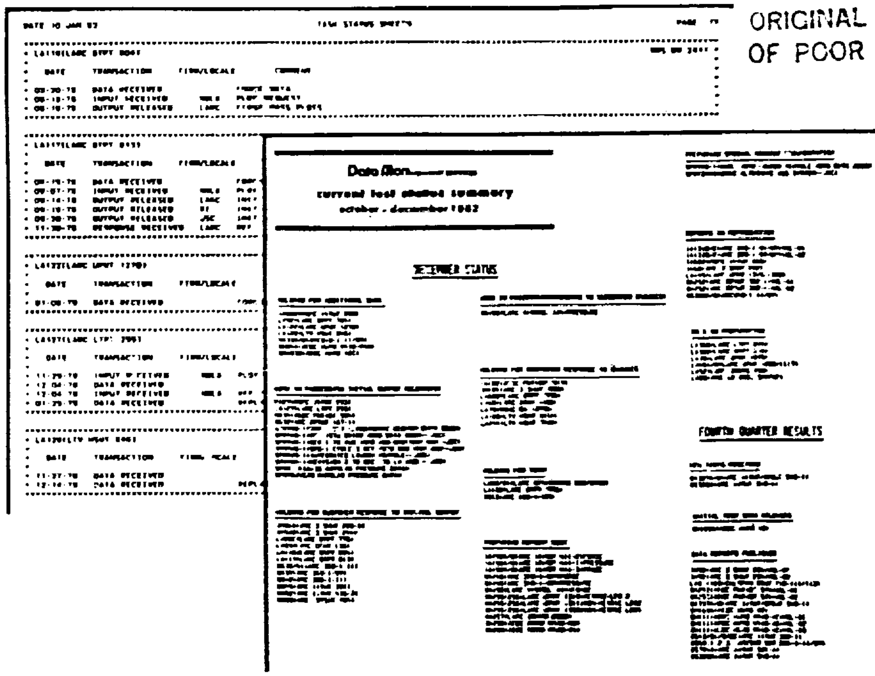


Figure 9.- Work-in-process status is communicated regularly to the Shuttle design team. (From Ref. 4.)

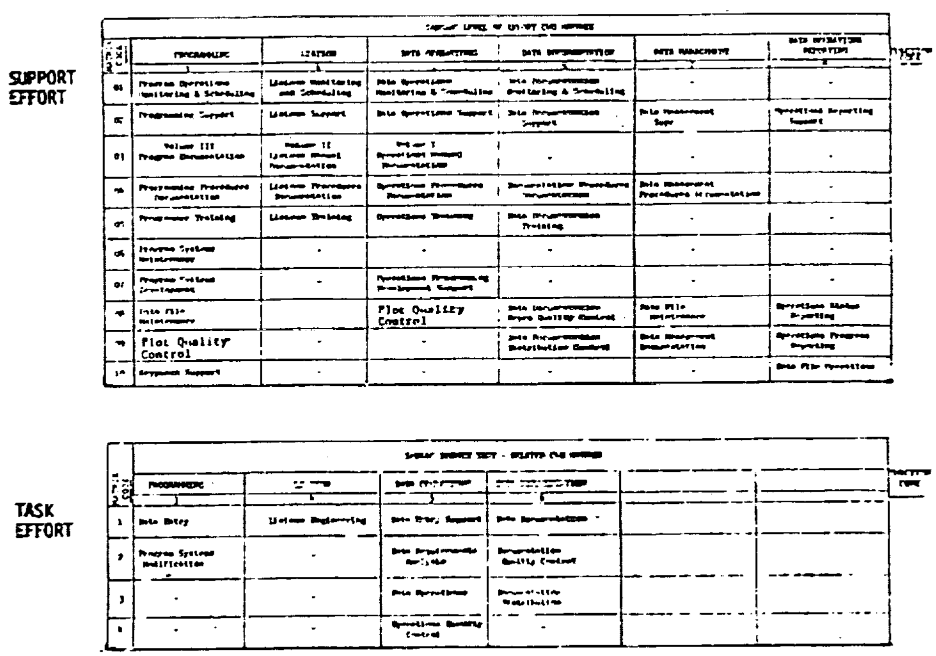
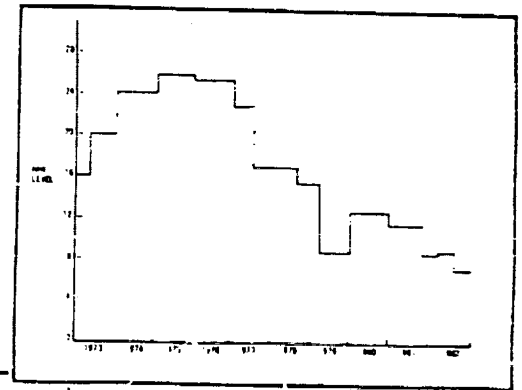


Figure 10.- Manpower applications are tracked and collected by function and task for cost control and forecasting.



MANNING LEVEL FOR WIND TUNNEL TEST DATA ANALYSIS DOCUMENTATION

WIND TUNNEL TEST DATA ANALYSIS TASK LOADING

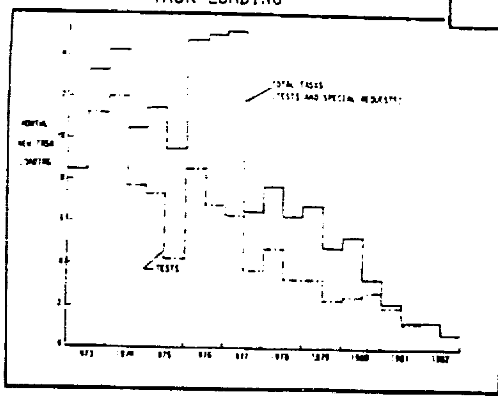


Figure 11.- Comparing manning level to task loading provides indicator of DATAMAN productivity.

AERODYNAMIC ANALYSIS

- o Test to Test Comparisons
- o Control Surface Effectiveness
- o Derivatives
- o Control Surface Interactions
- o Ground Height Increments
- o Power Increments
- o Hysteresis Displays
- o Post-test Blockage and Tare Corrections

PRESSURE LOAD INTEGRATIONS

- o Control Surface Hinge Movements
- o Protuberance Loads
- o Vehicle Component Loads
- o Nozzle Loads
- o Tailcone Loads
- o Input to NARSLAG Program

THERMODYNAMIC ANALYSIS

- o Development of Analysis Techniques
- o Test-to-Test Comparisons
- o Comparison to Theoretical
- o Mirror-Image Calculations
- o Special Displays

AIR DATA SYSTEMS

- o Algorithm Development
- o FTP Data Analysis Techniques
- o Parametric Analysis of Flush Mounted Ports
- o Composite ADS Test Databases

DESIGN DATA APPLICATIONS

- o Substantiation and Applications
- o Total and Component Coefficient Calculations
- o Update Comparisons
- o Pre-test Predictions

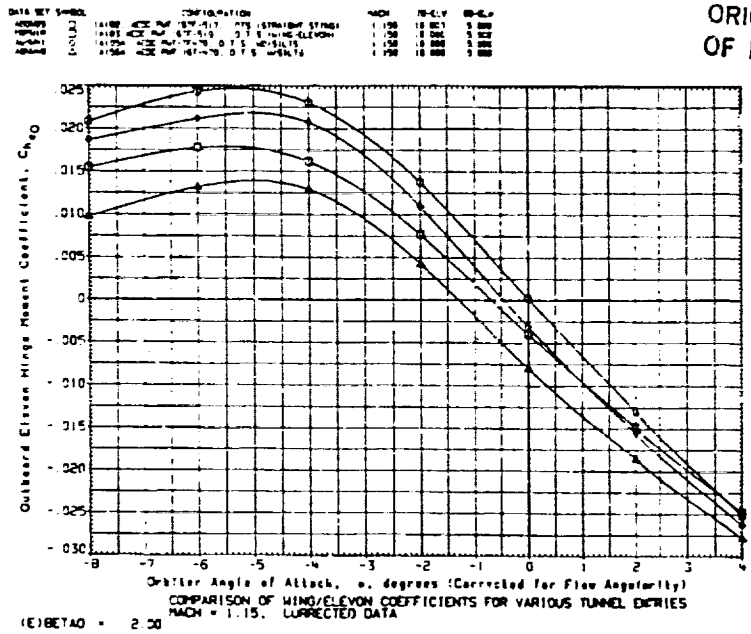
SPECIAL

- o Statistical Error Analysis of RCS
- o RCS Interaction Incrementing
- o Mini-Probe Calibration
- o Protuberance Flow Field Survey

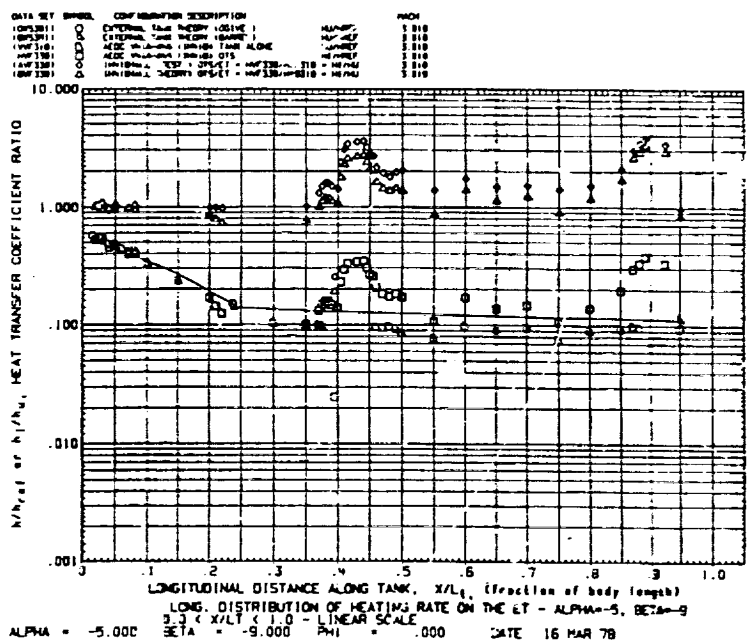
MISCELLANEOUS

- o Punched card inputs to NASA programs
- o Data Tape Inputs to ADAP II
- o Data Tape Inputs to JSC/Structures
- o Data File/Data Base Releases
- o Inputs to NASA Technical Reports
- o Microfiche Documentation

Figure 12.- The DATAMAN operation provided high priority special design applications support to almost every activity using wind tunnel data.

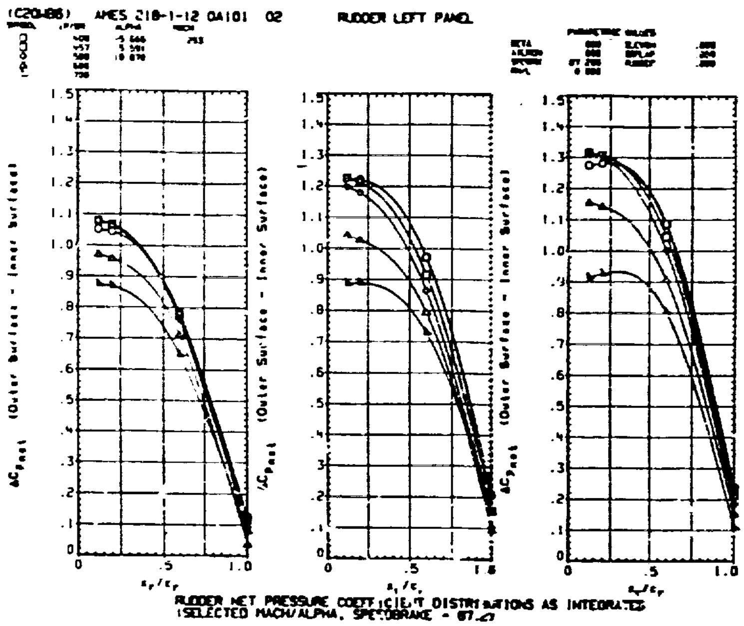


(a) Retrieved data of four tests adjusted to common conditions for comparing data for tunnel effects. (From Ref. 5.)

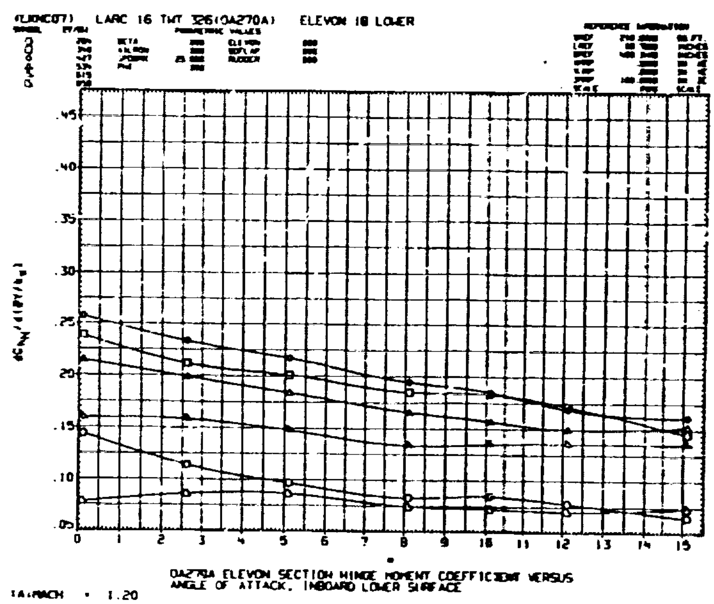


(b) Heating ratios (test and theory) computed for rapid identification of interference heating problems. (From Ref. 6.)

Figure 13.- Special applications of DATAMAN which contributed to Shuttle design effort.

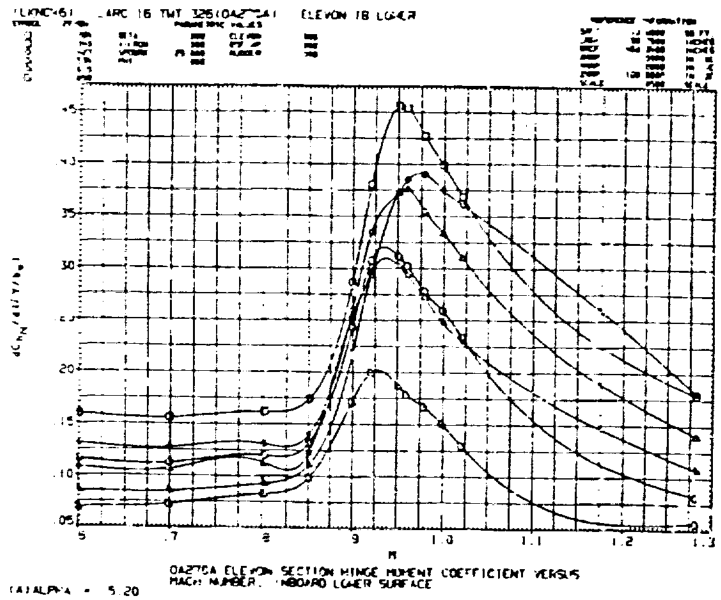


(c) Delta pressure calculations provide rapid estimates of airload distributions. (From Ref. 7.)

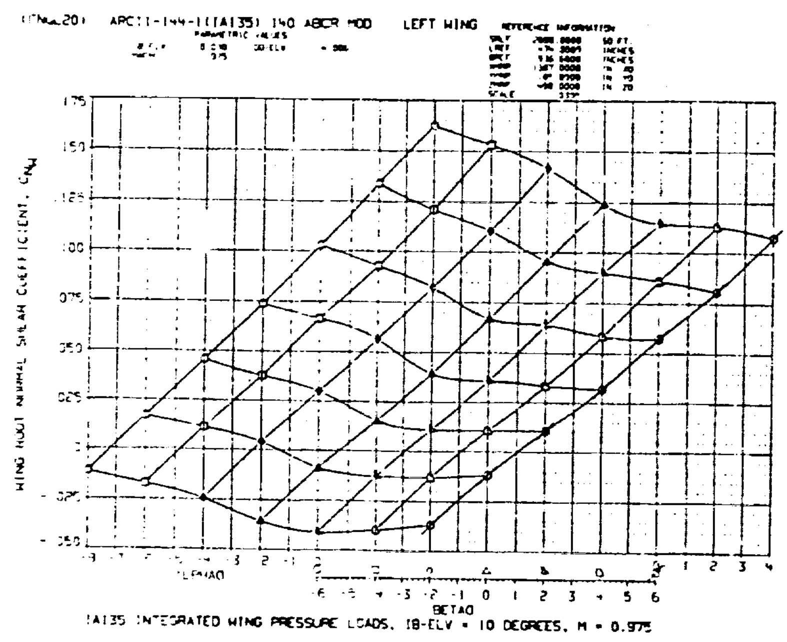


(d) Local distributed loads developed from pressure and displayed for evaluation. (From Ref. 8.)

Figure 13.- Continued.



(e) The same distributed loads crossplotted with Mach to ascertain potentially critical conditions. (From Ref. 8.)



(f) Wing forces developed from pressure integrations carpet displayed to visualize the wing loads in the pitch-sideslip matrix. (From Ref. 9.)

Figure 13.- Concluded.

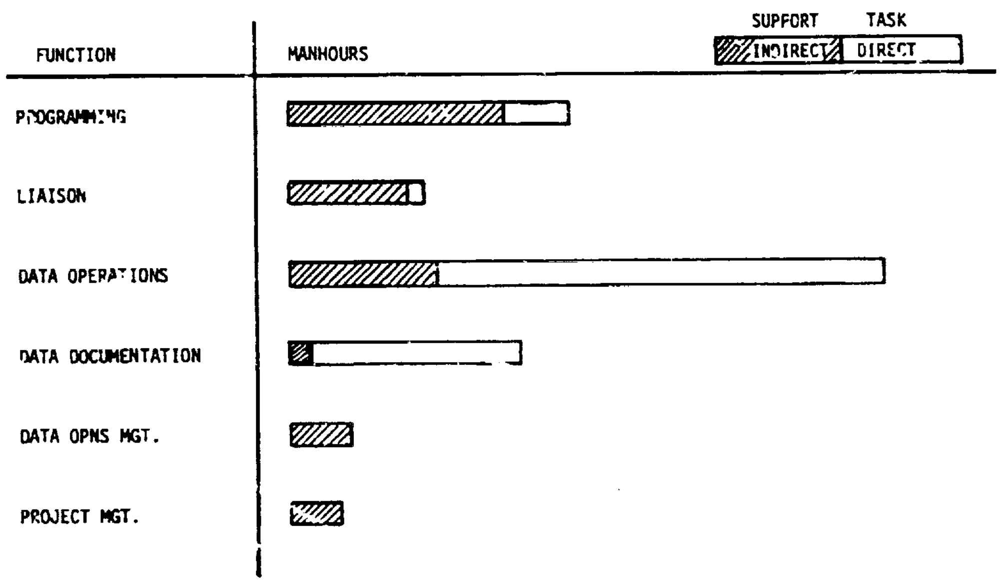


Figure 14.- Typical manhour allocations between task functions are shown for the average test.