Discussion

Question: In your opinion, is Daystrom's Heath analog computer adaptable for use in the system described? If so, wouldn't this simplify the system by eliminating the analog-to-digital converter?

Mr. Otis: While you are right in remarking that an analog computer would eliminate the use of an analog-to-digital converter, it would not meet the requirements in terms of reliability as well as computational accuracy, time sharing, and flexibility that we were able to design into the present system.

Question: Is the system described for a specific installation?

Mr. Otis: No, it isn't, although the first two are committed and will go in specific installations. The design is based on a study of many types of processes.

Question: Would you please repeat the arithmetic operation?

Mr. Otis: I assume by this you mean the speed of the machine. It is 1.3 milliseconds for addition and 10.1 milliseconds for a long multiplication and division. Shift commands fall into the 1.3 milliseconds or what we call the short commands.

Question: Is the coincident current memory the only memory? Is there any drum?

Mr. Otis: No, the coincident current memory is the only memory in this system. However, the machine is designed to work with a tape deck.

Question: In the presence of interaction in a process, how is optimum adjustment of the variables achieved? What criterion is established for behavior of multivariable systems?

Mr. Otis: It is a difficult question to answer in the sense that the criterion can only be established if you have a particular process that you are talking about. But, as I indicated in the paper, you usually have many sets of simultaneous equations and in solving them together, you take into consideration the interaction of the different variables.

It is this interaction between the different control variables that this equipment introduces into the control system. We want to take into consideration this interaction. The criterion is usually an economic one. You want to produce a product of a specific quality at minimum cost. This might be achieved by the use of minimum input power, the use of minimum raw materials, maximum catalyst life, or minimum processing time, whichever the criterion might be. You might have three or four criteria and go down the line until you find one that you will give you the best answer.

Question: Would you please repeat the type of your memory in your computer and mention its capacity?

Mr. Otis: It is a coincident current memory, transistor driven, and depending on the system we can have from 1000 to 16,000 words in this memory.

In other words, the computer has the circuits addressing up to 16,000 or 2^{15} words.

Real-Time Presentation of Reduced Wind-Tunnel Data*

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Introduction

THE effective use of wind-tunnel testing in determining aerodynamic properties of a body is very much dependent upon the reliability and speed with which wind-tunnel data can be reduced. The ability to provide reduced aerodynamic coefficients in real time, or on-line, greatly increases the operating efficiency of the wind tunnels and thereby reduces expensive wind-tunnel time required for each test. This paper describes a system for presenting reduced wind-tunnel data in real time for the two wind tunnels at the Jet Propulsion Laboratory (JPL).

The requirements for data-handling equipment and data-reduction procedures for wind tunnels throughout the country are quite diverse, and depend upon the wind-tunnel design and the type of tests for which they are used. The supersonic wind tunnels involved in this description are used for force tests, pressure tests, and miscellaneous research studies, and include a variety of force-balance systems. Consequently, the problems associated with on-line data reduction for these tunnels can be considered as representative of the problems associated with tunnels generally.

Real-time reduced-data presentation requires a system consisting of three major parts: 1) the instrumentation necessary to convert force, moment, pressure, and angular measurements into a form compatible with available computing equipment; 2) an operational system including the computer program and methods for accomplishing the data processing; and 3) a system for presenting reduced coefficients within a specified time interval in a form allowing use of test results to control the test program. An earlier data-reduction system providing reduced data on a daily basis has been described in the literature.[1] Most elements of the new on-line system have now been developed. The completion and installation of the new system will be accomplished step by step and will not involve wind-tunnel downtime. Prime considerations in developing the new on-line system have been economy in capital investment, high reliability, and flexibility in handling the variety of test types.

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[1] W. R. Hoover, J. J. Wedel, and J. R. Bruman, "Wind-tunnel data reduction using paper-tape storage media," *J. Assn. Computing Mach.*, vol. 3, pp. 101-109; April, 1956.

Wind-Tunnel Testing

Wind-tunnel tests are conducted by immersing an accurate scale model in the wind-tunnel air stream and recording a set of readings related to physical quantities such as forces, moments, pressures, or angles. Most tests requiring on-line presentation of reduced data are force tests or pressure tests. A point of force-test data consists of a set of forces and moments with respect to some reference system, the angles of attack and roll, the pressures necessary to specify tunnel operating conditions, and the free-stream Mach number. A point of pressure-test data consists of a set of readings giving the pressure at points on the body surface.

At JPL, force and moment measurements are usually made using two types of balance systems. The six-component external balance system resolves three independent components of force and three independent components of moment about a reference system fixed with respect to the tunnel. The strain-gauge system isolates forces and moments about a reference system fixed in the model. The readings from the two balance systems are four-digit numbers. The external balance readings require a code digit to indicate the set of balance constants needed in the data-reduction process.

Pressure tests are conducted by measuring the pressure at fixed positions on the body surface. Measurements are made by connecting each point with a pressure transducer which transmits a signal to the automatic pressure readout system.

The system is capable of digitally recording as many as 192 pressure readings and of automatically ratioing each reading to a prescribed pressure.

The purpose of force-data reduction is to convert test readings from the balance coordinate system to a coordinate system suitable for engineering purposes. This process involves a sequence of changes of scale, rotations, and translations to obtain dimensionless aerodynamic coefficients. A general data-reduction scheme has been evolved utilizing a sequence of vector by matrix products which includes the transformations for both the external and internal balance systems. In reducing the data, two classes of constants exist, those fixed for a complete test and those changing as the test progresses. The air-off zero correction is a point taken with air off and at zero angle of attack and indicates the balance condition for zero forces and moments. The static tare is the change in balance readings under air-off conditions caused by movement of the model center of gravity during model pitch angle rotations. Moment transfer distances are dependent upon the model configuration.

Pressure-test data reduction consists of computing ratios for all model pressures to a set of known pressures, in addition to computing profile averages, local Mach numbers, drag, and other aerodynamic forces. In general, pressure-test data reduction is much simpler than the force-test reduction used at JPL.

System Requirements

One of the primary considerations in the presentation of wind-tunnel data is the selection of the proper form of raw-data record. Accumulated experience with the paper-tape storage system has verified the advantages previously claimed,[1] and the real-time data-reduction system will retain this feature. The large volume of data output from wind-tunnel operations requires fast and reliable data accumulation equipment which does not limit the operational speed of the wind tunnel. The system must accept information from either of two wind tunnels and convert it to a standard form for data reduction and presentation; also, the system must be flexible enough to handle all categories of force tests presented by a wide variety of engineering requirements.

Real-time presentation of reduced wind-tunnel data requires that all of the final data be presented before normal model or tunnel conditions are changed for a succeeding run. It is desirable that all data-handling units be integrated and utilized in such a manner that real-time results used for monitoring the test correspond to the final coefficient tabulations and plots required for engineering reports.

System requirements necessitate tabulating and plotting directly from the raw-data record. This first inspection serves to determine whether raw data appear reasonable and sufficient (curves are smooth and defined); also, it provides sufficient information to allow testing to proceed on the basis of raw-data presentation in the event of computer breakdown.

The operating rate of the wind tunnel is 15 seconds per point; this is an average time required to change an independent variable in the test procedure, allow the tunnel to reach a stable condition, digitize the balance readings, and punch a point of raw data into tape. A run of data includes a series of related points; for each run of data, there is an additional two minutes available, thus increasing the average time available for computing purposes on a run basis to 25 seconds per point.

The basic computer system to be used is an ElectroData Model 202. To increase the efficiency of the system for use on data-reduction problems, several modifications were required. A second photoreader and input order were added to the computer, giving the system two independent input stations which are internally controlled and can be actuated either manually or by programmed command words. A second teletype punch with independent output commands was added to the system. Presentation of wind-tunnel data in both tabulated and plotted form from paper tape requires two output tapes with different data organization for use in the plotter and tabulator, respectively.

Instrumentation

Force Tests

The six components of force sensed by the external hydraulic balance are measured on an automatic servo-controlled beam balance. The balance position is converted to digital form by means of a shaft-position digitizer. The force components obtained from the internal strain-gauge balance are measured by a strain-gauge bridge with servo follow-up which also drives a shaft-position digitizer.

The digitizers employed are the double-brush decimal encoders manufactured by the Coleman Engineering Company. These devices require a set of readout relays before the digital data can be transmitted to the tape punch. In order to ease the interpretation of raw data, it is necessary that the output readings be recorded in both plus and minus values. The conversion of digitizer readings to correct plus and minus decimal numbers is a relatively complex operation requiring a sequence of relay closures. Since the readout relays are time-shared among the digitizers, the relay cycling time would be prohibitively long and would slow the scanning rate if it were not for a novel method of readout devised at JPL which requires only one relay closure time per digitizer, approximately 15 msec.

The scanner records the digitizer and keyboard readings on a punched paper tape using a Teletype BRPE-2 60-digit-per-second punch. The slow-speed scanning of data-source words is accomplished by telephone-type stepper switches while the high-speed scanning of individual digits is accomplished electronically using magnetron beam switching tubes and transistor switches.

The data are recorded on punched tape and then verified on a tabulator; in addition, selected words in the scan are plotted on an automatic tape-controlled plotter (the raw-data plotter indicated in Fig. 1). The raw-data plotter can plot as many as twelve components on a single 30- by 30-inch sheet of paper. After the data have been displayed on the tabulator and plotter, the tape can be read on a high-speed tape reader which is controlled by and transmits information to the computer. After data reduction, the final data tapes are read by tape readers located near the computer's output punches, and these readers are controlled by and transmit information to the final data tabulating and plotting facilities. The tabulating machine is a Burroughs Sensimatic used as a word-at-a-time printer. The data for a word are assembled in a magnetic-core memory which together with associated circuitry controls the type bars of the Sensimatic. The final data are plotted by three Electronic Associates, Inc., Model 1100D Variplotters. These plotters use 11- by 17-inch graph paper and employ programmable symbol printers.

Pressure Tests

The data from pressure tests are recorded on a multipressure measuring system developed at JPL.[2] This system scans as many as 192 pressure sources by means of pressure selector tubes. The unknown pressures are channeled to a single pressure transducer; the transducer reading is converted to a binary-encoded four-digit decimal number in a high-speed analog-to-digital converter, and the data are subsequently recorded on punched paper tape. The 192 pressures can be scanned in approximately 40 seconds. For a lesser number of pressure tubes the scan time is correspondingly shorter. The output of the pressure transducer can be scaled to any arbitrary value, thus obviating much of the data reduction. As an example, if it is required that all model pressures be recorded as a ratio to stagnation pressure, it is a simple matter to calibrate the system by feeding stagnation pressure into the machine and adjusting the encoder to read 1000. The accuracy of the multipressure measuring system is better than 0.2 per cent of full scale. This accuracy is achieved by the use of a single pressure transducer, allowing detailed observation of any transducer zero drift or calibration shifts. In addition, the method of scanning provides for the gauge to be connected to a vacuum system before each reading, thus eliminating a major source of gauge error, the hysteresis effect.

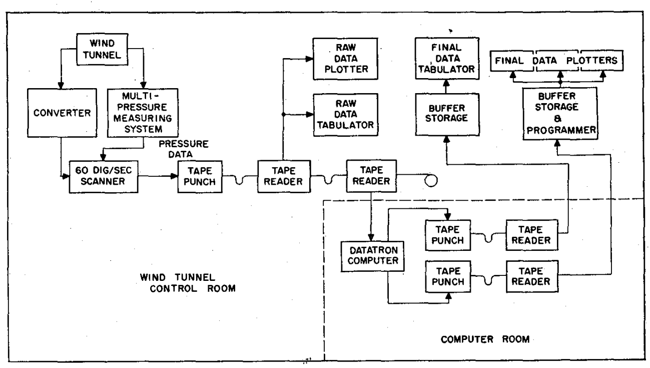

Fig. 1—Block diagram of wind-tunnel data-reduction system.

After being punched the tape is fed to a high-speed tape reader controlling the Burroughs Sensimatic printer. Selected pressures can be plotted on the Electronic Associates Variplotter for the presentation of pressure contour curves.

Data Reduction of Force Tests

The computer program is written to conform to a standard reduction procedure which converts information from the coordinate system of the force balance to aerodynamic coefficients in any or all of four coordinate systems which may be specified in a test. The same program is used to reduce data from either internal or external balance systems; the procedure accounts for characteristics which are functions of the tunnel, suspension, balance, and readout system.

The basic program for reduction of force tests consists of eleven steps, each written as a separate routine or subroutine. Essentially, each of the steps is written as a matrix-by-vector multiplication, and any change required usually consists of a minor alteration of a matrix at a particular step. In some instances it is necessary to bypass or reprogram a step completely; either type of change

[2] M. B. Bain, "A multipressure measuring system," IRE Trans. on Instrumentation, vol. I-6, pp. 18-22; March, 1957.

affects only an isolated portion of the entire program. This program structure minimizes the amount of pretest programming and checkout prior to the test date.

Preparation of a test for reduction consists mainly of setting up an efficient method for handling run parameters such as configuration constants, roll angles, Mach numbers, and deflection constants. As standard practice, all combinations of constants are prestored in computer memory and programming changes are provided to select and check proper constants as the run number changes. Infrequently, the schedule of constant changes overtaxes the limited memory capacity and a second photoreader is used to introduce required changes.

Fig. 2 is a flow diagram outlining the sequence of operations on a point of raw data as executed by the computer program. Assuming that the basic program, the required program alterations, and all fixed constants have been prestored in the computer, the input is actuated for read-in of the first data point from the accumulation system. The raw data are permuted to a fixed order, and a check is made to determine whether the point is an air-off-zero point. (If the point is an air-off-zero it is flagged and stored in memory for later reference.) Introduction of an air-off-zero point indicates the necessity for changing run parameter constants; selection of such constants is made either from memory or from an external photoreader tape. A coded word structure is used to flag input of points from a static-tare run; pitch and rolling-moment data from these points are used to form a static-tare table which is in general applicable to a series of related runs. Upon read-in of an air-on point, the static tare for the raw-data angle of attack is determined and corrections for air-off zero and static tare are applied to the raw data. The corrected raw data are then reduced through the body-axis coordinate system. A set of code words is used to determine to which of the coordinate systems the reduction is to be carried and the form of the aerodynamic coefficients, which are punched on two separate output tapes; one tape is for tabulation on a Burroughs word printer and the other drives automatic plotters for final data plots.

The pointwise reduction program as written reduces six-component external balance data to body-axis coefficients in 15 seconds. Results are presented with no increase in inaccuracy and with all anomalies accounted for. Extension of the reduction to additional coordinate systems requires approximately 2 seconds for each system desired. These times include the operations necessary to scale and otherwise adjust all output to forms acceptable to the listing and plotting equipment.

In the proposed system, the total data-handling time for a typical point of tunnel data will be approximately 23 seconds. Operating times of system blocks are as follows. 1) Digitizer, scanner, and punch require 1½ seconds per point; during this period the independent variable for the next point may be set in the tunnel. 2) Raw-data tabulation and plotting will require 12 seconds; if the computer is ready to accept a point of data when readout is completed, the raw data point will first be read into the computer and then into the raw-data tabulating and plotting system in such a manner that reduction and raw-data presentation operate concurrently. 3) Computer read-in, reduction, and punchout of final tabulating and plotting tapes require 18 seconds per point. 4) Tabulating and plotting of final results require 3 seconds per point.

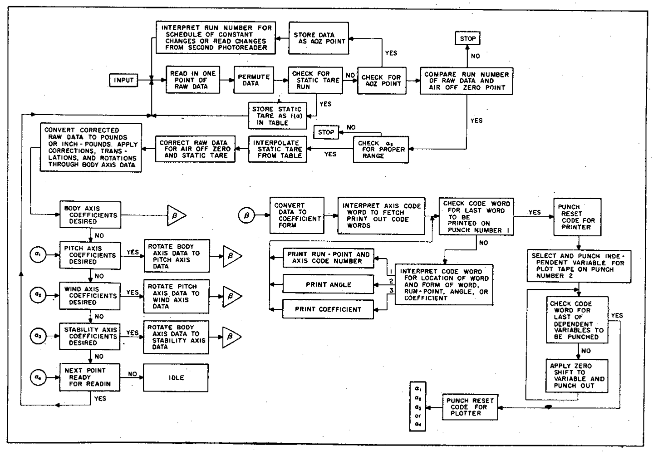

Fig. 2—Flow diagram of reduction program operations.

In the actual data presentation process the system will always lag tunnel output by one or two points; however, model pitch-down time incurred during the course of each run will allow the system to "catch up" by the time the run is actually completed. The times listed are basic times; varying requirements of test procedures may necessitate compromise between the amount and rate at which data are taken and final results presented.

Conclusions

The system described for the real-time presentation of reduced wind-tunnel data at JPL provides the broad flexibility required by the varied test programs conducted. The system utilizes components now in operation with the present data-processing system. Much of the necessary computer programming has been accomplished and the over-all system design has been completed.

The system will provide a real-time tabulation and plot of reduced data for most standard tests and will have the ability to provide reduced data with a time delay of one run for most of the possible variations on the standard reduction.