PERFORMANCE EXPERIENCE WITH THE NEW JPL WIND TUNNEL DATA ACQUISITION SYSTEM*

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I. INTRODUCTION

In mid-1963 the Jet Propulsion Laboratory acquired a new digital data system for its wind tunnel facilities. This system is capable of performing the complete digital data function, from powering transducers to tabulating final test results. It was put into partial usage in January of 1964 and has been in full use since late in June of 1964. The purpose of this paper is to describe the general characteristics and to detail the performance experiences and the measured accuracies of this new data acquisition system. The methods used in selecting the system and the system builder are described more thoroughly in AGARDograph 85, to be published soon.

Prior to the installation of this new data system, all data collected in the two wind tunnels were processed by JPL-developed data acquisition equipment, vintage 1955. This system was typical of many developed during that period, in that it was quite limited in speed, somewhat limited in accuracy, and had become in recent years very difficult to maintain. New JPL testing techniques were, in several cases, incompatible with the equipment, and the laborious adaptation of general electronic equipment to the specific needs of the particular techniques was necessitated. Therefore, when it became obvious that the old equipment would have to be replaced, it was decided to develop a new system which had none of these defects.

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The system has several different types of operating modes. The basic interchannel sampling rate of the system has two modes; 2000 channels/sec and 5000 channels/sec. One sample of all channels is called a scan. Scanning has two modes; internally triggered and externally triggered. The internally triggered mode has two submodes; periodic and continuous scanning. The periodic mode permits a selected number of scans at a selected scanning rate to be preprogrammed; the continuous mode represents full-speed operation.

There are three types of signal channels in the system. One, which is called a strain gage channel, represents a very-high-accuracy analog channel and has an individual signal amplifier associated with each channel. The second type of signal channel is a (so-called) thermocouple analog channel, which has one amplifier associated with a group of 20 thermocouple channels. The basic reason for this differentiation is that it was felt that strain gages, in general, require signal amplifications of much greater accuracy that would thermocouple measurements.

The third type of signal channel accepts digital signals. Each strain gage channel is individually connected to a particular strain gage amplifier through a large patch panel. Each strain gage amplifier is, in turn, connected to a solid-state switching matrix (multiplexer) through the signal analog-digital converter supplied with the system. The individual thermocouple channels are connected through the patch panel to a low-level solid-state multiplexer and, in turn, to an amplifier. Each of these amplifiers is connected through a high-level solid-state multiplexer to the analog-digital converter. Thus, all of the analog channels terminate at the single analog-digital converter. In the total system, there are 40 strain gage channels, 200 thermocouple channels, and 18 digital channels. The outputs of the single analog-digital converter and the digital channels are connected to the computer.

The function of the computer is to sample the output of the single ADC according to the instructions specified in the computer sampling program. It must select those channels which are of interest to the specific site requesting a data sampling. It does this through a recording mask which inhibits the multiplexing of those channels of no interest to the site requesting the sampling. In addition, it must sample in the mode requested by the program. The computer then writes the sampled data

II. SYSTEM DESCRIPTION

Before the system was designed, a set of basic requirements was listed. These requirements, which specified that the system be reliable, accurate, versatile, able to serve three sites, and computer-integrated, were then detailed into a set of design specifications to guide the designers.

Reliability meant that the system was to be dependable. First-quality design techniques were essential, including component derating and redundance where applicable. Simplicity of operation, maintenance, and checkout was required.

Accuracy requirements near the upper limit of the state of the art were specified. These requirements are reproduced in Tables 1 and 2.

Versatility meant that the system should be sufficiently flexible to be compatible with a wide variety of electronic measuring instruments. Further, the sampling rate and mode of operation should be sufficiently variable to accommodate numerous testing techniques which were both dependent on and independent of time.

The three-site service was required since the wind tunnel complex consists of two wind tunnels and an area for balance calibration and test preparation. Because many test projects use all three sites, uniformity of equipment was desirable. Further, time-sharing of some components and system functions at a central location was suggested as a possible means of reducing costs.

The system was also to be computer-integrated. It was recommended that the operations of the data system be controlled through an addressible logic system to provide the required operational versatility. This would make the operational flexibility dependent purely on programming the logic and independent of the hardware. Because a data reduction computer was required for the system, it was recommended that some of the logic of the computer serve a dual purpose in that it perform normal data reduction processes as well as the logic functions required by the data system. All of the above requirements were met by the manufacturer.

on magnetic tape and transmits a limited amount of data back to the test site paper tape punches for monitoring purposes. Complete tabulations of either recorded or reduced data are made using a 300-line-per-minute lister, which is part of the computer peripheral equipment.

The system is self-calibrating. A calibration request from the computer will activate the calibration sequence. For thermocouple channels, the sequence consists of applying regulated voltages to the thermocouple amplifiers in a prescribed manner and in prescribed steps. These voltages create signals at the analog-digital converter which then can be used to determine the sensitivity of each amplifier. For strain gage channels, shunt resistors are switched into the strain gage bridge. By comparing the bridge imbalance signals with the comparable signals produced during the strain gage calibration using identical resistors, the channel calibration can be determined.

III. PERFORMANCE EXPERIENCES

Since this system has been in full use for only a few months, it is rather difficult to give a high-reliability statistical evaluation of the performance of the system. The first several months of operation were devoted to eliminating minor engineering problems. However, quite recently more realistic evaluations of the system performance are becoming available. The performance is described here in terms of the original system requirements.

The reliability has been improving steadily over the past several months because of the elimination of most of the minor engineering problems that developed and because of the development of a realistic preventive maintenance schedule. The schedule currently in effect requires one day of maintenance for each 9-day period of use. With this schedule, the following reliability characteristics are being estimated:

Data system	100.0 operating hr/failure
	0.5 hr lost/failure
Computer*	165.0 operating hr/failure
	0.5 hr lost/failure
Total $T = \frac{1}{\frac{1}{D^2} + \frac{1}{C^2}}$	85.6 operating hr/failure
	0.5 hr lost/failure

The accuracy of the total system has been evaluated only during the acceptance calibration of the system. The results of this calibration are presented in Tables 1 and 2. In all cases, the measured accuracies are better than those originally specified.

The versatility of the system has not been fully explored as yet. However, it has been possible to conduct concurrently several different tests using widely idffering test techniques, with no changes to the hardware involved. Similarly, the advantages of having similar site equipment have been shown in a limited way by the ease with which tests have been moved from site to site.

The direct benefits of the computer control of the data system are reflected in system versatility. Secondary benefits in using the computer for dual purposes are reflected in initial and long-term cost reductions. The initial benefit is a saving in duplicate logic hardware estimated to be in excess of $50,000. The long-term benefit cannot be evaluated but arises from the fact that system flexibility precludes the necessity of using auxiliary data hardware and thereby delays system obsolescence.

One problem with this system is that, with the present control program, it is not possible to use the computer as a computer and a system controller simultaneously. This problem exists because of the size and complexity of the program. Attempts will be made to reduce the size of the control program to permit on-line computing.

IV. APPLICATION EXPERIENCE

At the present time, the new data system is being used to record the results from standard steady-state-type force tests, pressure tests, and temperature tests. In addition, it has been used to record the results from transient-type tests such as heat transfer.

In the future, it is expected that the system will be used to record the signals from telemetry receivers during free-flight wind tunnel tests. It is also planned to use the system to record the output of optical tracking equipment which is used in the wind tunnel during captive dynamic stability tests. A preprogrammed angle-of-attack drive system is being integrated with the new data system to automatically record wind tunnel test data using pitch and pause techniques.

V. PROBLEMS

No insurmountable problems have been encountered during the period of implementation of the new data system. The major difficulties encountered were in trying to obtain legitimate estimates of the time required to bring the system into full usage. The system development time took approximately twice as long as was originally anticipated. The amount of time required to develop the system control program was considerably longer than that originally predicted. These delays were not results of unforeseeable design, construction, procurement, or programming difficulties. The estimates were simply overly optimistic. The system designers and programmers (both JPL subcontractors) were not totally at fault. During contract negotiations JPL indicated that very rapid delivery of the total system was extremely desirable, and it appears, in retrospect, that this may have influenced the time estimators in the direction of overly optimistic estimates.

During the latter months of development, it became increasingly obvious that the original data-accumulating equipment and computer were rapidly approaching a condition of total breakdown. Two weeks prior to the release of the new system to full usage, the old computer was declared by the manufacturers to be not repairable.

VI. CONCLUSIONS

Because of insufficient padding of the time-to-free-usage estimates, the wind tunnels were almost left without a data system. The total development time took two years, almost twice as long as the most conservative early estimates.

Our experience thus far has shown this new data acquisition system to be a highly accurate and reliable device. We find that the flexibility is already proving it to be valuable in the number of different types of tests which can be conducted. Our experience with the adaptability of this system to the various types of test techniques currently under development at the Jet Propulsion Laboratory indicates that the system will have a long useful life.

Table 1. Actual system accuracy: strain gage channels

1. Common mode rejection:

   Greater than 10^6 to 1 at 100 cps (not measureable with balanced inputs)

2. Cross talk:

   Less than 0.01% (not measurable for 50 mv dc or 100 mv peak-to-peak ac at 60-cps cross-talk voltage)

3. Accuracy (maximum signal = 4000 quanta):

   a. Short term (8 hr)

Full scale (mv)	Error (quanta) (3σ) filter cutoff frequency (cps)							
	2.5		5		20		100	
	Meas.	Spec.	Meas.	Spec.	Meas.	Spec.	Meas.	Spec.
2.5	nm	4.4	1	4.4	3	6.0	11	12.0
5	nm	4.0	1	4.0	2	5.2	nm	8.0
10	nm	4.0	nm	4.0	1	4.4	nm	6.0
30	nm	4.0	nm	4.0	nm	4.0	1	4.8
50	nm	4.0	nm	4.0	nm	4.0	nm	4.0

nm = not measured.

   b. Long term (7 days)

Full scale (mv)	Error (quanta) (3σ)	
	Meas.	Spec.
2.5	10	12
5	2	8
10	3	6
30	2	4
50	2	4

Table 1. (Cont'd)

c. Repeatability (1 hr)

Full scale (mv)	Error (quanta) (3σ) filter cutoff frequency (cps) 2.5		5		20		100	
	Meas.	Spec.	Meas.	Spec.	Meas.	Spec.	Meas.	Spec.
2.5	1	2	1	2.4	3	3.2	5	6.4
5	1	2	1	2	1	2.4	2	4.0
10	1	2	1	2	1	2	2	2.8
30	1	2	1	2	1	2	1	2
50	1	2	1	2	1	2	1	2

Table 2. Actual system accuracy: thermocouple channels

1. Common mode rejection:

   Greater than 10^6 to 1 at 100 cps (not measurable with 30 Ω unbalance)

2. Cross talk:

   Less than 0.01% (not measurable for 50 mv dc or 100 mv peak-to-peak ac at 60-cps cross-talk voltage)

3. Accuracy (maximum signal = 4000 quanta):

   a. Short term (8 hr)

Full scale (mv)	Error (quanta) (3σ)	
	Meas.	Spec.
5	4	15.2
10	2	8.8
20	1	6
50	1	4

   b. Long term (7 days)

Full scale (mv)	Error (quanta) (3σ)	
	Meas.	Spec.
5	4	20
10	2	12
20	2	8
50	2	8

Table 2. (Cont'd)

c. Repeatability (1 hr)

Full scale (mv)	Error (quanta) (3σ)			
	2 kc		5 kc	
	Meas.	Spec.	Meas.	Spec.
5	5	8	8	12
10	3	4.8	3	6
20	1	2.4	2	4
50	2	2	2	2.8