IBM 1800 for Wind Tunnel Data Acquisition

IBM

Data Processing Application

INTRODUCTION

Recently, interest in slow-speed aircraft has increased. New demands for performance of these aircraft, as well as increased competition among aircraft companies, has led to an expanded research and development effort along these lines. Part of this expanded effort requires wind tunnel testing of new models, concepts, and aerodynamic designs. This testing requirement, the increased demands for the number of tests, the volume of the data, and the reduction and analysis of this data necessitates modern techniques for wind tunnel operation. More automatic equipment has been developed to perform many of these functions. The type of equipment used is based on considerations of the type of wind tunnel, the type of studies to be performed, and, of course, economical tunnel utilization, volume of work to be performed, and facility costs. The IBM 1800 system provides the necessary tool for the job.

In general, wind tunnels consist of six functional areas:

1. Power or driving section
2. Inlet and preconditioning section
3. Nozzle, orifice, or stream control section
4. Model or test section
5. Outlet or downstream section
6. Exhaust section

The power or driving source section is that area where the motors, propellers, or jet engines are mounted and provide the required gas velocity for lower-speed tunnels. High-pressure, large-capacity gas storage tanks can be used to supply a source of high-velocity gas for higher-speed tunnels. A small highly charged cylinder of gas usually provides the source for shock tube tunnels. In this case this is the primary source of gas (most often air) directed against the model.

The inlet and preconditioning section is designed to smooth the flow of gas moving down the tunnel toward the aerodynamic model. Temperature change and control is sometimes added to give high-temperature gas flow for some applications.

The throat or nozzle portion contains the constricted pipe section, which actually develops the desired gas characteristics (velocity and direction) to direct at the model under study.

The test or model portion contains the aerodynamic model, its mounting, and the major portion of the instrumentation from which data is to be collected.

The downstream or outlet section is used to move the gas away from the model with the least disturbance to the flow of the gas past the model. In some cases cooling equipment is installed in this section to reduce gas temperatures to tolerable levels before gas exhaust.

The exhaust section can be considered to be that portion of the tunnel where the expended gases are handled. In some tunnels the expended gases are simply exhausted to the atmosphere (through baffles, etc., if necessary to reduce the noise level). In others the exhaust section is a battery of vacuum chambers that are filled as the gas rushes past the model and into them.

Figures 1 and 2 show some examples of the types of wind tunnels, and the accompanying table provides some of the wind tunnel characteristics. The figures and the table do not represent the only facilities or parameters for each type of tunnel. Each tunnel usually has a certain uniqueness as well as many of the general classifications. The figures and the table merely provide a basic understanding of the application of data acquisition to wind tunnels.

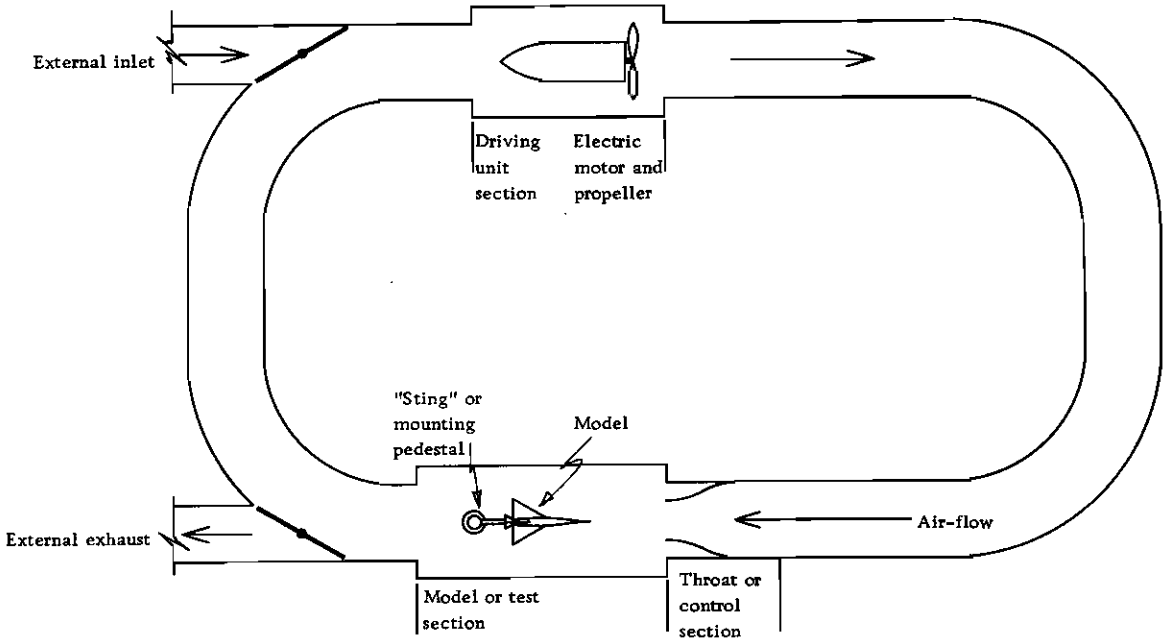


Figure 1. Subsonic closed-loop wind tunnel facility

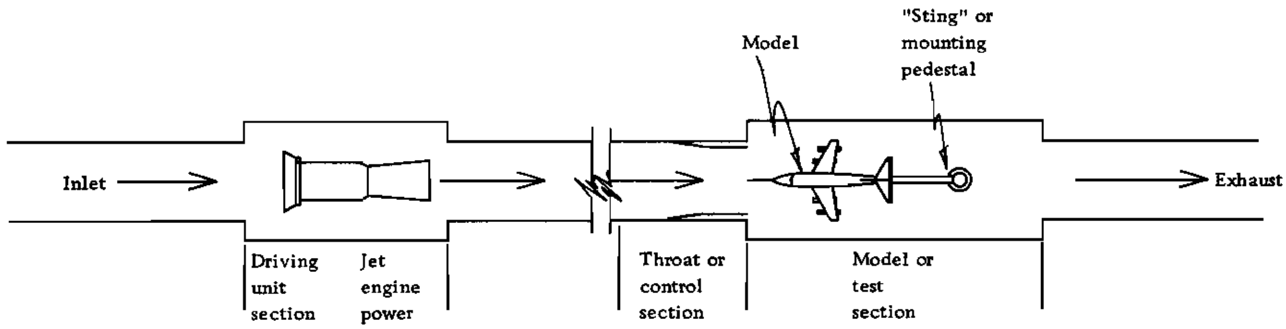


Figure 2. Subsonic open-ended wind tunnel facility

Wind Tunnel Characteristics					
Type	Gas Velocity	Gas or Air Movement Technique	Test Duration	Model Movement (during Test)	Test Characteristics
Subsonic	under 600 mph	Motor-driven propellers or jet engine exhaust	Up to hours in length	Can be extensive	Half low-speed data acquisition (100 sps*) and half high-speed (to 40KC sps). Variation of tunnel operations. Variation of aero-dynamic model altitudes. Essentially steady-state testing.
Supersonic	Mach 1 to mach 3-5	Pumped chambers or motor-driven	A few min-utes, depend-ing on velocity, tunnel size, and tank storage	Usually limited to one or two model changes.	High-speed data acquisition (5 to 50KC sps). Some variation of tunnel operations. Few model altitude changes.
Hypersonic	Mach 3-5 to mach 8 or more	Pumped chambers	Up to one or two minutes, depending on velocity, tun-nel size and tank storage	Usually limited to one or two model changes.	Same as supersonic
Shock wave		High-pressure change in sealed chamber	Very short — fractions of a second	No model changes	High-speed data acquisition only (10 to 50 KC sps). Start-stop test only.

* Samples per second

SUBSONIC WIND TUNNEL DESCRIPTION

The subsonic wind tunnel facility is a closed-loop cycle — that is, the air flowing in the tunnel is recycled from the driving section to the test section and back. Actually some air is exhausted and some fresh air added by means of controlled baffles. The tunnel changes about 10% of the air and recirculates 90%.

The tunnel section just upstream from the model section contains a constriction shaped so as to develop the air stream to a specific velocity and form. The test or model section contains most of the instrumentation as well as certain control devices and the model itself.

The model is heavily instrumented with pressure transducers and thermocouples. The model is mounted on a support ("pedestal" or "sting") which itself is instrumented. The support contains the force balance, which measures the forces acting upon the model in the three major axes and three major moments.

The tunnel operation is quite straightforward. The driving unit is started and run up. The driving unit is a large electric motor turning propeller blades to provide the movement of air through the tunnel. The throat section can be a fixed configuration set up before the test begins. In some large tunnels this throat is changeable by external sources and can be modified to change tunnel conditions during the test. As air is circulated at a controlled velocity by the motor, it passes through the throat, which constricts the passage area, thus increasing the air velocity to the desired level for the test. The effects of the airflow upon the model are recorded as pressure, temperature, and strain measurements.

The tunnel is also instrumented, primarily to measure flow, pressure, and temperature. In some tunnels heaters are used to increase the temperature of the air passing the model, and cooling coils are installed downstream to reduce the temperature (prevent overheating of the motor, etc.). Another variation among some tunnel facilities is the use of a jet engine to provide the driving force for the air circulation. This is seen in Figure 2, together with another type of tunnel construction in which the air is not recirculated — an open-ended tunnel taking air in at one end and exhausting it at the other. Actual tunnels generally do not intake air directly from, or exhaust it directly to, the surrounding atmosphere; they take it in through baffles and filters and exhaust it through baffles to reduce the operating noise level.

The length of time of a model run for most low-speed tunnels is unlimited except for the volume of data collected. The driving unit can supply a moving current of air for long periods of time. The test procedure itself is usually a series of tests. The model is positioned at some specified attitude and the air temperature, velocity, direction, etc., are brought to specific values. It may take five to ten minutes to stabilize the tunnel and model after a new set of operating conditions is initiated. During these intermediate periods, data from the tunnel and model is acquired only to determine when an equilibrium condition is reached.

At equilibrium a rapid series of measuring (as many as ten) is taken of the model, followed by a set of tunnel instrument readings as well as certain ambient conditions like barometric readings and humidity. This sequence may be repeated a number of times to ensure good data for the test.

At this point some of the significant data is usually hurriedly analyzed to determine whether the test is successful or should be repeated. At present it takes at least 10 to 20 minutes to perform this analysis. When the present test level has been considered successful, the next test level is initiated. This may be a change in the model attitude within the tunnel or a change in air velocity or temperature. The wait period takes place again. Data is observed to determine when equilibrium has been achieved, and the test cycle repeats itself until the entire series of conditions has been performed.

WHY A COMPUTER-ORIENTED DATA ACQUISITION SYSTEM?

A computer-oriented data acquisition system offers the ability to:

- Scan, sample, convert, and store a large number of inputs at high rates of speed with a high degree of accuracy and consistency.

- Monitor operating conditions (model and tunnel) to determine when a stable state has been reached for these test conditions and initiate an acquisition run.

- Control certain tunnel operations — for example, start up tunnel, modify model attitude, modify tunnel operating conditions, shut down tunnel.

- Provide quick-look data displays under program control or at operator request. The quick-look data will:

  1. Be corrected for calibration, nonlinearity, conversion factors, etc.

  2. Be computed from the inputs of a number of sources to give desired result.

- Monitor for dangerous conditions (for example, excess vibration in the power unit, or overload of force balance) and either notify the test operator or shut down to prevent damage to personnel or equipment.

- Provide quick turnaround of data reduction, analysis, and performance evaluation. Test engineers can determine.

  1. Whether the next test sequence should be performed or a rerun made.

  2. Whether the test setup can be torn down to prepare for the next test series, thereby maintaining effective use of tunnel facility.

WHY AN IBM 1800 COMPUTER SYSTEM?

The IBM 1800 system offers:

- An integral, compatible unit from computer to analog/digital signal terminations
- Highest performance/price ratio yet
- High-speed computer — down to 2-usec memory speeds
- High-speed converters — up to 20KC ADC, and up to 100 KC DAC
- High-speed overall data I/O — to 8 million bits per second
- Extensive interrupt system to provide extremely fast response to external stimuli
- Wide range of equipment and options to allow a tailored system from standard designs

IBM 1800 WIND TUNNEL DATA ACQUISITION SYSTEM

The configuration for an 1800 wind tunnel data acquisition system is shown functionally in Figure 3 and schematically in Figure 4. The 1800 has an analog-to-digital converter and a high-speed, solid-state multiplexor designed as an integral part of the computer system to select and convert analog signals to digital values. The 1800 system can select and convert signals at rates up to 20,000 sps (samples per second) over this analog input subsystem and store the values in programmable tables in the processor core storage. The analog input signals are transmitted from transducers both in the model under test and in the wind tunnel facility itself.

The most common transducers found in subsonic wind tunnels measure pressures and temperatures on the model and wind tunnel sections. Strain gages measure forces acting upon the model surfaces and also the force balance that supports the model in the air stream. The force balance gives the values of lift, drag, and side thrust, as well as moments (pitch, roll, and yaw). In some cases the wind velocity is measured directly by rotating impellors whose generated output is related to velocity either directly or after a frequency-to-analog conversion takes place.

The 1800 wind tunnel system can also accept digital or discrete data. This input data usually is acquired from thumbwheel switches giving noninstrumented data (barometic pressures, time of data, model and test I.D.) or shaft encoders giving positional data. The 1800 system accepts 16 bits of input at a time and can read multiple inputs at rates up to 8 million bits per second. The input of digital information is not limited to thumbwheels or rotary switches; it can be entered through an I/O keyboard printer (the actual means is determined by the overall system requirements). The digital input subsystem accepts dry contacts or binary voltage levels as a means of operation.

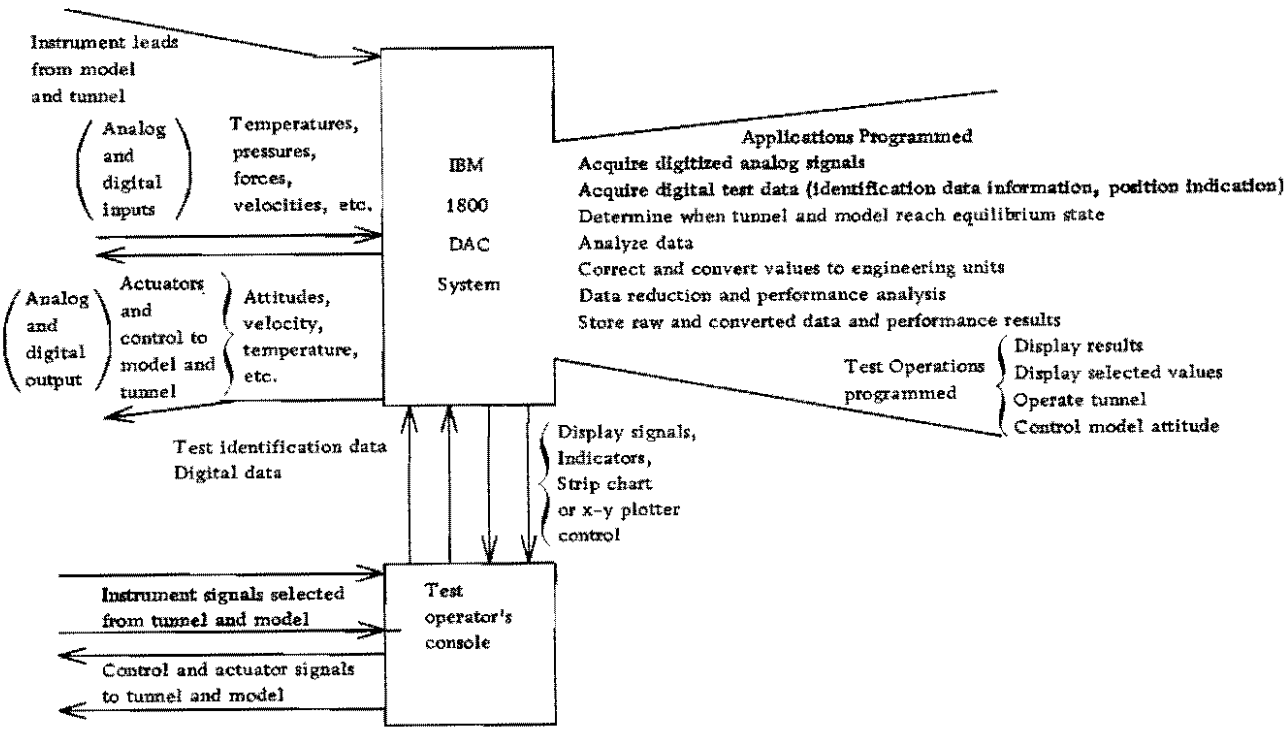


Figure 3. IBM Data Aquisition System-functional diagram

The digital input also accepts pulse inputs and counts them. The pulse counters are available in either 8-bit or 16-bit counters and operate at speeds up to 5000 pulses per second to each counter. These pulse inputs usually come from rate-type instrumentation such as turbines, or velocity meters whose pulse rate is proportional to flow or velocity.

The digital output subsystem of the 1800 is used to drive various types of displays, ranging from illuminated digital displays to indicator lights. In addition, a few of the digital output points will control various tunnel operations, motor startup, movement of model or of tunnel dampers, etc., through stepping motors, pulse duration signals, or will simply operate large magnetic contactors. The digital output consists of electronic contact operate points, similar to latching relays but capable of operation at electronic speeds, that can switch up to 450 milliamperes at 48 VDC.

In addition to these I/O capabilities, the 1800 configuration has input interrupt capability by which the computer program recognizes various external stimuli. These stimuli can come from selected pushbuttons or toggle switches in the test operator's console used to direct or alert the system, or from model or tunnel sensors such as limit switches, high-temperature switches, and vibration switches to notify the system of abnormal facility conditions.

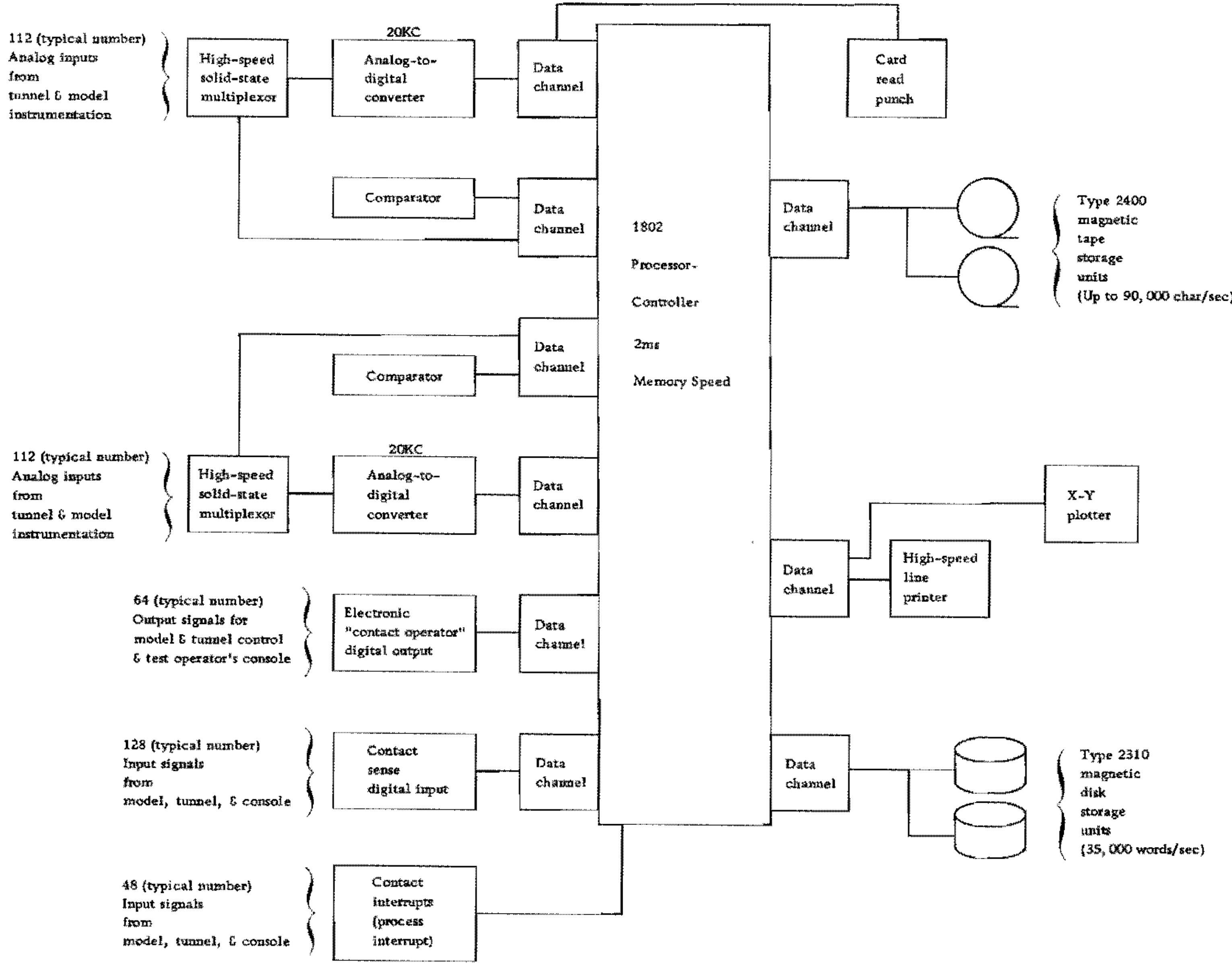


Figure 4. Wind tunnel configuration for IBM 1800 system

In addition to the instrument and console I/O features, certain standard data processing I/O functions are provided through:

- Magnetic tape units for gross storage of raw and converted data.
- Magnetic disk units used for data recording during high-speed runs and the storage of all system and application programs, constants, and tables.
- Card read punch for test program modification and the read-in of various engineering programs when the 1800 is used as a standard computer system.
- High-speed line printer for output of test results — the principal output device when the 1800 is used as a normal computer system.
- Keyboard printer used for operator-system communication, error and exception messages, etc.
- X-Y plotter for graphic output of performance data and for displays of instrumented variables and computed variables.

WIND TUNNEL SYSTEM OPERATION AND PERFORMANCE

The requirements for the analog input portion of the typical system were determined primarily by the maximum expected testing requirements. Two analog input systems were necessary to give the high-speed sampling required — up to 38,000 sps at 11-bit and sign conversion resolution. The wind tunnel instrument terminations for analog inputs might require that 100 points be actively monitored, although many additional system analog input terminations might be provided for flexibility and expansion. Of these 100 active inputs 50 would require high-speed sampling, the rest only periodic sampling. The high-speed and periodic inputs are divided between the two input systems, the distribution being determined by the requirements of a specific test. An estimated curve of input performance is shown in Figure 5.

If the 50 analog input points requiring high-speed sampling are distributed so that 20 are on the one analog input system and the remaining 30 are terminated on the second input system, the sampling rate per point is 950 sps on the 20-point and 633 on the 30-point group (see Figure 5). For this application it was felt that 5 samples per cycle were needed for good analysis results, so that in the above example the 20-point group could have frequencies up to 190 cps ($950 \div 5$) while the 30-point group could have frequencies up to 127 cps ($633 \div 5$). The aggregate sample rate for the entire wind tunnel configuration is still 38,000 sps ((30×633) + (20×950)). Using the technique in reverse, the number of channels capable of a specific sampling rate can be identified for correct termination assignment. For example, if 950 sps were necessary, it would be found that 20 inputs could be sampled at this rate and the remaining ones at 633 sps.

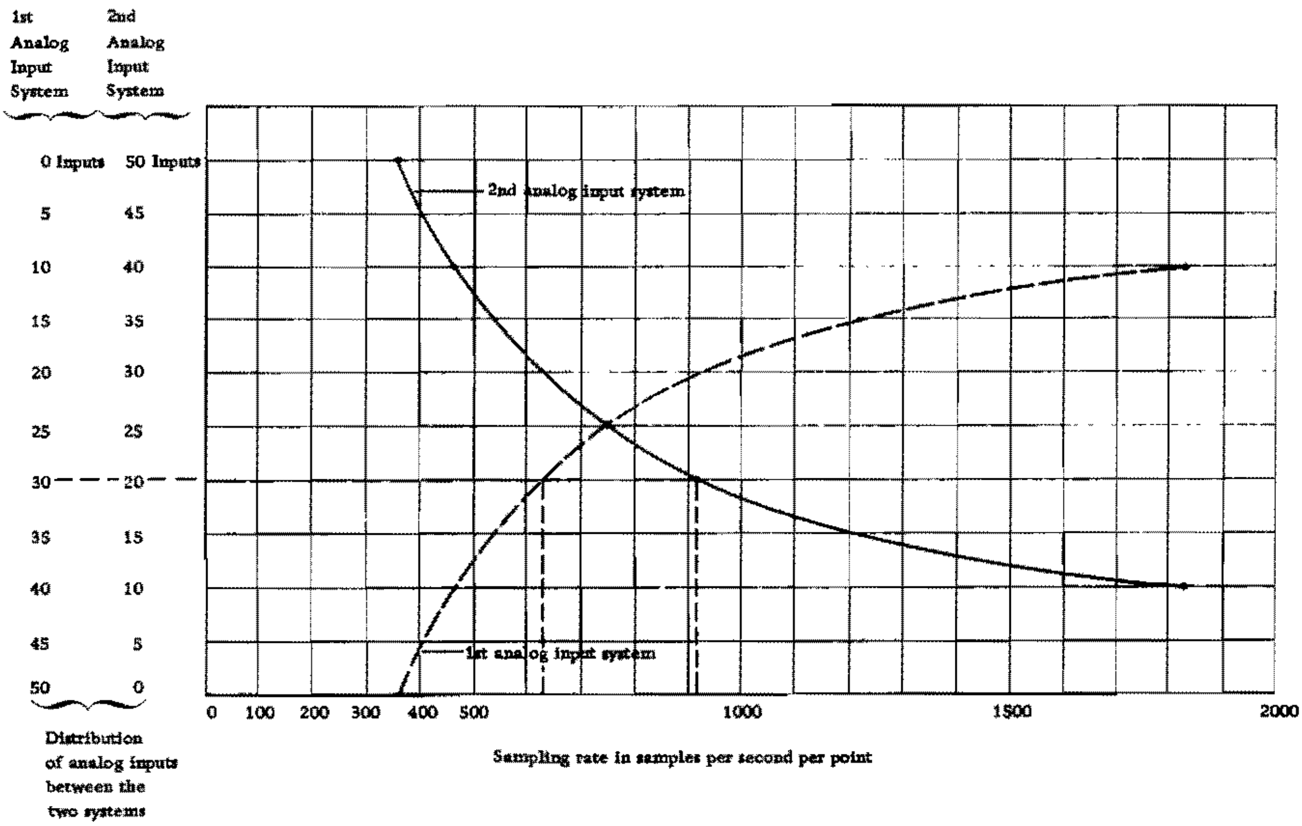


Figure 5. Estimate of system sampling rate vs distribution of analog input terminations

In addition, a second modification is possible if more inputs must be sampled at 950 sps. Using the random sampling capability of the IBM 1800, a table of multiplexor addresses can be described so that some points are sampled more often than others. For example, the group of 30 inputs could be sampled according to the order shown below:

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30.

This would result in the first 10 inputs being sampled twice as often as the last 20. The sampling rate is then 950 sps for 10 inputs and 475 sps for the remaining 20 inputs. For the overall system, this results in 30 analog inputs sampled at 950 sps while 20 points are sampled at 475 sps. The versatility of this technique can result in a variety of sampling rates among the inputs. This was the approach used to obtain 30 analog inputs having a maximum frequency of 190 cps while 20 inputs could have a maximum input frequency of 95 cps (a requirement for the maximum case input to the system).

The second problem to be solved involves the storage of data during such a high-speed sampling run. The estimated effective transfer rate of magnetic tape and the magnetic disk files were analyzed for long-term steady-state operation (including such delays as interrecord gaps, access mechanism movement, etc.). Figure 6 shows the estimated effective record rate of the magnetic tape unit, and Figure 7 shows the estimated effective record rate of the magnetic disks while changing the record block size. To obtain 38,000 words stored per second on the magnetic tape requires a block size of about 1300 words. One disk file develops a rate of 20,900 words per second with a 300-word record size and, of course, two disks will write 41,800 words per second to be stored for a total block of 600 words (300 in each of two blocks) if each disk operates with its own data channel. Since the actual core storage required is much greater using the magnetic tape to keep up with the input, it was decided to use the disk files to store the data during the acquisition run and later record it on the magnetic tape.

The requirements of the system are to record data at high speed in five one-second bursts from the 50 high-frequency inputs and four scans of the 50 low-speed inputs between the five high-speed bursts. The total data thus acquired amounts to 191,000 converted input values, which are transferred to the disk files. Certain data is then analyzed and presented to the test operator to decide whether the test run was successful. This data is stripped out as it is entered, and the computations (calibration factors, engineering conversion, calculation of a number of inputs to arrive at significant data) are performed essentially in real time. When the operator confirms that the test results are satisfactory, he signals the system to step to the next test stage. This requires a change in the model conditions (altitude, for example) or tunnel conditions (air velocity, for example). The system causes the changes to take place by activating various digital outputs and monitoring the conditions until a stable operation again exists. This is expected to take five to ten minutes. The system displays the conditions to the test operator. He decides whether the correct conditions have been selected and pushes a button on the console to tell the system to begin another high-speed acquisition run. During this waiting period while the facility's conditions are sampled to ascertain when stable conditions have been achieved, all the data stored on the disk files is formatted and stored on the magnetic tape, clearing the disks for the next run. Thus the system proceeds through the entire test series.

The handling of all data twice, as this technique seems to be doing, serves as an advantage. During the five- to ten-minute stabilizing periods, a more complete analysis and reduction of the data can be made. Since the results are still stored on the disk files, the quick access of data from disk rather than from the tape records makes the reduction and the analysis of data reasonable. In addition to this extended analysis between runs, the test engineer may want to request certain specific analyses. The disk files provide the storage for a large number of special programs as well as operating system routines.

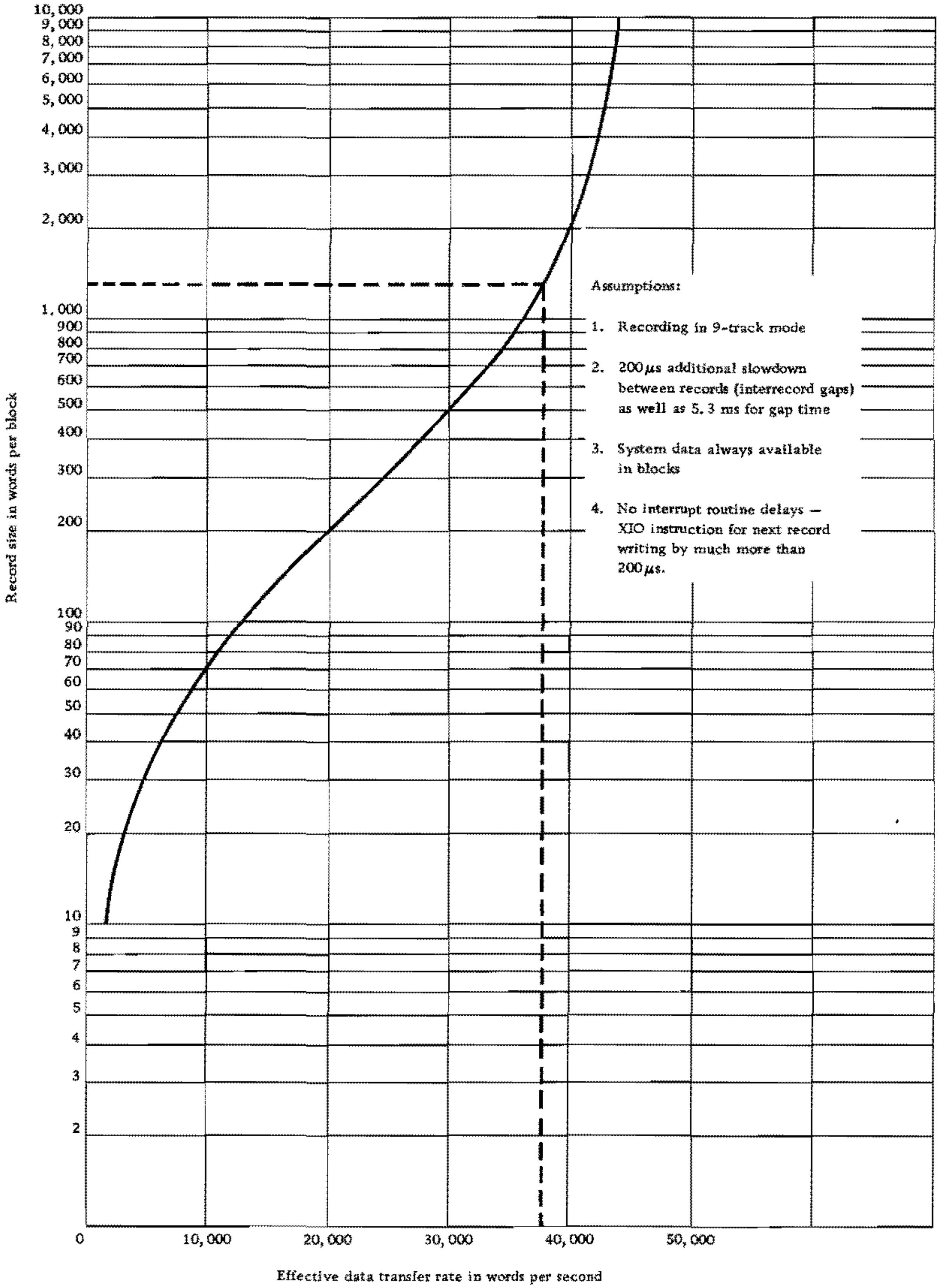
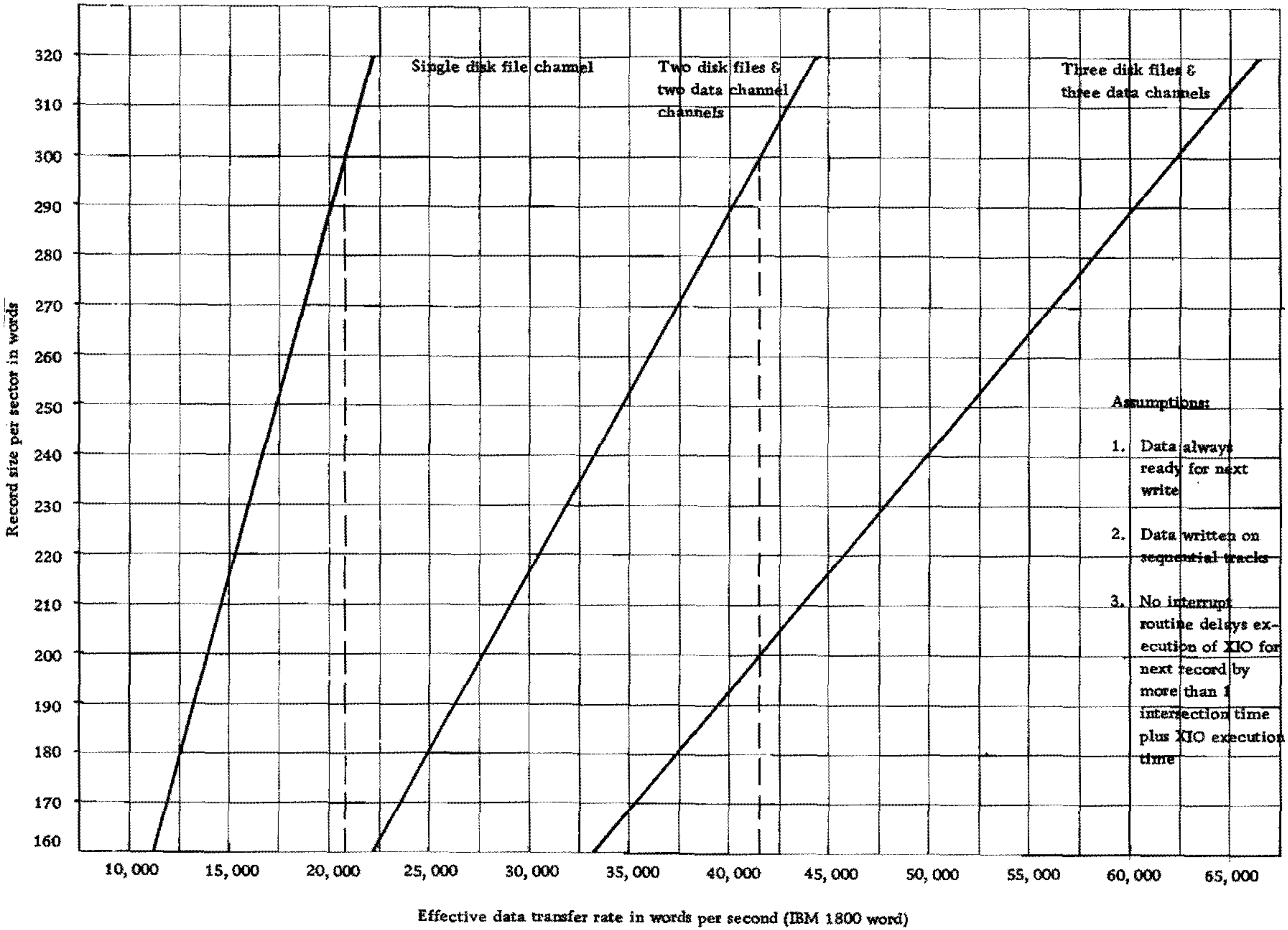


Figure 6. Estimate of effective data transfer rate for 2401 Magnetic Tape Unit, Model 3 (90KC)


Record size per sector in words
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
55,000
60,000
65,000
Effective data transfer rate in words per second (IBM 1800 word)
Single disk file channel
Two disk files & two data channel channels
Three disk files & three data channels
Assumptions:
1. Data always ready for next write
2. Data written on sequential tracks
3. No interrupt routine delays execution of XIO for next record by more than 1 intersection time plus XIO execution time

The I/O typewriter enables the test operator to enter special code requests for calling out stored routines for special analysis. The random access capability of the disk files enables these special routines to quickly locate and use some or all of the test data from the last run, since it will be stored on the disk until the next high-speed acquisition run begins.

During all testing runs the computing capability of the 1800 can be used in real time to test for conditions exceeding any prestated limits. This technique enables the system to take corrective action quickly, if necessary, by operating various digital outputs or at least bringing the conditions to the attention of the test engineer. Further, the system maintains indicator lights on the operator's console showing the present status of the system (in good working order, performing high-speed acquisition, tunnel conditions at a stable level, etc.).

After the test series has been completed, the 1800 system can be programmed to do a thorough formatting, reduction, and analysis of all the data acquired. The disk files provide a convenient data storage area for massaging this data during the post-test analysis and formatting the output report of the test results. The high-speed line printer is then used for this large-volume, final test report of the tunnel and model performance. The X-Y plotter is also of significant value in developing graphic results such as plotting lift versus angle of attack, drag versus model attitude, etc.

SUMMARY

The IBM 1800 configuration discussed here will perform the acquisition requirements for a wind tunnel application. The flexibility of sampling sequence, the hardware comparator to detect out-of-limits values, the programmable resolution of the analog-to-digital converters provide the desired input characteristics for this application. The computer speed and instruction set provide the capability to perform most, if not all, of the data reduction and analysis needs of this application. In addition, the system can be used in an offline manner as a standard data processor for any engineering, scientific, or data processing programming desired. The disks and tapes provide a large useful storage space for accepting raw and converted test data (up to 9 million words can be stored on one magnetic tape reel and up to 1 million words can be stored on the two disk files).

The digital input and output features provide binary input sensing of tunnel and model limits, operator information (start acquisition run, step to next operating state, barometric pressure, etc.) and output to various tunnel controls (start up control, modify model conditions) and test console indicators (system on, tunnel at stable point, excess force on model).