A COMPUTER-CONTROLLED, ON-BOARD DATA ACQUISITION SYSTEM FOR WIND-TUNNEL TESTING

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Summary. A computer-controlled data acquisition system has been developed for the 40x80-Foot Wind Tunnel at Ames Research Center. The system, consisting of several small “on-board” units installed in the model and a data-managing, data-displaying ground station, is capable of sampling up to 256 channels of raw data at a total sample rate of 128,000 samples/sec. Complete signal conditioning is contained within the on-board units. The sampling sequence and channel gain selection is completely random and under total control of the ground station. Outputs include a bar-graph displays digital-to-analog converters, and digital interface to the tunnel’s central computer, an SEL 840MP. The system can be run stand-alone or under the control of the SEL 840MP.

Introduction. Ames Research Center has been the leader in large-scale aerodynamics research for many years. Ames, 40x80-Foot Wind Tunnel, the world’s largest such facility, has enabled researchers to study in detail full- or large-scale models of flight vehicles such as the F-14, SST, VSTOL, and STOL.

The tunnel’s increasing popularity had put tunnel time at a premium and created a need for a data system which could reduce preparation time and gain modification time once the model was in the tunnel. In addition, the system had to have enough flexibility to handle almost any type of model or experiment which came into the tunnel, while offering a relatively simple means of operation. Size, too, was a concern. Finally, since a large investment of capital was being made, the system had to have accuracies well beyond those found in current transducers. The system could not become the limiting factor as transducer technology improved.

A data acquisition system therefore has been developed, fashioned after the Airborne Integrated Flight Test Data System (AIFTDS) developed by Teledyne Controls for NASA Flight Research Center (FRC) and previously discussed by Borek\(^1\) and Trover.\(^2\) The modified AIFTDS system provides all the desired capabilities such as remote control, pretunnel set-up, and accuracy in flight-qualified units approximately the size of a telephone. The On-Board System (as it is called) contains the small remote multiplexer and digitizer units (RMDU’s) developed for FRC, along with dedicated presample filters and
shunt resistor strain gage calibration units (PAF’s and R-Cal units) for complete transducer excitation, signal conditioning, and on-board digitizing. Communication to a data management unit (DMU) in the tunnel control room is done through serializing the digitized data into a pulse code modulated bit stream. A bar-graph display and digital-to-analog converters within the DMU provide quick-look displays for the user and analog communication to other data systems in the 40x80 data system. IRIG standard PCM outputs to analog tape recorders and a digital interface to the tunnel’s central computer, an SEL 840MP, provide storage for later analysis.

**Testing Procedure in 40x80-Foot Tunnel.** The On-Board System has been designed to satisfy several unique problems of the 40x80-Foot Wind Tunnel. These restrictions can be better brought to light by understanding the procedure experimenters are expected to follow before and during a tunnel test.

Several months prior to the test, the experimenter, either from Ames, another government agency, or a government contractor, discusses with tunnel engineers the types of parameters to be examined during the test and the types of analysis which will be done on these data. The experimenter is then sent one or two sets of on-board signal conditioners with the appropriate I/O cards for the experiment. The experimenter also receives a portable checkout unit to enable him to connect the transducers and check every channel prior to his bringing the model into the tunnel. It is hoped that the experimenter can determine as closely as possible the gains of all channels at this time.

Once the model is set up, brought to Ames, and placed in the tunnel, connection to the OBS ground station is quick and simple. The communication cable previously used for the portable checkout unit is merely connected to the DMU cable from the tunnel control room and the model is ready for calibration and testing.

While in the tunnel, delays must be kept to a minimum. Minor changes to the data system, for instance, which would result in the tunnel being shut down, are generally compromised to reduce the time the model is kept in the tunnel and to allow for major modifications not prolonging the test beyond the proposed schedule. Off-line analysis is encouraged, when possible. Remote control of the RMDU’s is essential for efficient tunnel operation.

Finally, once the test is over, the data system is quickly disconnected and the model removed both because other tests are waiting for tunnel time and because other models are waiting for on-board data acquisition units.
**OBS System.** To satisfy these constraints, the on-Board System must have the following characteristics:

1. set up and checkout capabilities away from the DKU
2. flexibility in configuration, both to type, gain, and sequence of channels
3. ease of connection of on-board units with ground station
4. ability for remote central computer or autonomous control of the DMU
5. ability for DMU control of the RMDU’s
6. sufficient displays and DAC’s for user viewing

The OBS system (fig. 1) has therefore been conceived in two major sections. The on-board section, consisting of remote multiplexer and digitizer units (RMDU), preamplifier and filter units (PAF), and R-Cal units, is a second generation of NASA-FRC’s AIFTDS system. The RMDU (figs. 2 & 3), which has been described in detail by Trover, is the prime signal conditioning unit. Transducers, such as strain-gage bridges, thermocouples, and pots, can be connected directly to the RMDU. The signals are then filtered, amplified, and digitized for transmission serially to the ground station.

Any of the up to 352 channels can be addressed and sampled within a 7.8 μs period, thereby enabling a sample rate of just over 128,000 samples per second. Channels can be sampled in a totally random nature within the 11 I/O cards/RMDU and up to 32 channels/card matrix. Eight gains (1, 2, 4, 8, 32, 128, 256, and 512) can be independently selected for each channel. Automatic, predigitizing downranging by a factor of 2 enables extended range with no loss in digital granularity. An 11-bit, 5.12-V A/D converter provides a neat 5-mV/count conversion.

Specialized I/O cards for digital signals, presample filtering, specific transducer interfacing, or analog output can be also inserted in any of the 11 card slots.

For those applications where significant filtering is needed, 32-channel or 64-channel PAF units provide fixed gain preamplification and 3-pole Bessel filtering. Each channel has its own preamp and filter. The output of the PAF is fed to an analog multiplexer card in the RMDU. In addition to the basic amplification and filtering, the 32-channel PAF unit provides full bridge excitation, completion, sensitivity, and balancing.
The 64-channel PAF unit provides only excitation and balancing. The R-Cal unit has been designed to provide a shunt resistor calibration for strain-gage bridge transducers. The R-Cal unit is remotely activated from the ground station. The 32-channel unit activates all channels simultaneously.

The ground station shown in figure 4 has two main functions. First, the ground station must direct the RMDU to sample each channel with the appropriate gain. This is accomplished by serial PCM transmission of gain and address information from the ground station to the RMDU every time a channel is to be sampled. The addresses and gains are determined by the user and entered into the ground station either through the CRT terminal or through the SEL 840MP computer.

In addition, the DMU is responsible for receiving the serially transmitted data from the RMDU’s, converting the data back to parallel, and distributing the data to all appropriate output devices such as two tape recorder ports, a bar-graph display, 16 digital/analog converters, and the SEL 840MP. The ground station, described in detail by Prichard, also contains five first-in, first-out (FIFO) memories, and a PDP-11/05 processor. The FIFO memories make up the output buffers for the various output devices. The FIFO concept enables the buffers to be filled at a sporadic rate and emptied at a constant interval. The PDP-11/05 processor provides the user with a means of instant analysis, data compression, or data supplementation. The PDP-11 also enables stand-alone, user conversational operation.

The OBS ground station further has the capability to accept data from an IRIG standard PCM data system. The ground station contains computer-controlled PCM bit and frame synchronizers which can input data into the OBS and out through all the appropriate FIFO buffers. The OBS system can “ping-pong” between its own computer-controlled RMDU’s and the IRIG units, sending to the SEL and the displays a combined set of data points. The ground station has the capacity to handle almost any on-board data acquisition unit currently available.

**Scannivalve Control.** Of particular interest to Ames has been the scannivalve control card developed for the RMDU. This card, shown schematically in figure 5, contains two counter circuits. The first counter enables the card to output one “advance” pulse to a photo-isolated. driver circuit every Nth time the first channel on the card is sampled. The second counter enables the card to output a “home” pulse every Mth “advance” pulse to resynchronize the system.

Both values are preset on the card by the user. The 8-bit N value gives sufficient range to advance the stepper as slow as 4 times/sec with the slowest subcom sample rate as high as
1000 times/sec. The 6-bit M value is more than sufficient to handle the traditional 24 and 48 port scannivalves.

Since continuous running of such steppers may significantly reduce their life, external controls such as counter reset, control disable, external advance, and external home have been included in the design. Scannivalve sampling only during “prime data” or “data collection” modes is thus possible.

Because of the complexity of the circuitry, only one such control circuit is available per card; however, as indicated previously, multiple drivers can be actuated via a single card. All scannivalves would be stepped at the same time. This restriction should cause no hardship to the user since the data system can sample the transducers at speeds far beyond the pressure stabilization. The ultimate limiter will always be pressure settling time.

**Remote Operation.** Despite its stand-alone capabilities, the OBS is expected to be used primarily under the control of the SEL 840MP computer in the 40x80 control room. Each function must be controllable through the 840MP as well as the graphic display keyboard on the PDP-11/05.

As shown in figure 6, the 40x80 Data system (FEDS) is a highly complex data acquisition system consisting of several subsystems. These subsystems, of which the OBS is just one, can be used autonomously or under control of the tunnel’s main computer. Coordination between the subsystems enables the user to record and examine any data point in a variety of mediums. Data from the OBS, for instance, can be directed to the Dynamic Recording System, the Dynamic Analysis System, the SEL 840MP, as well as to the various displays within the OBS itself.

All systems can be completely set up and controlled through user interaction with the SEL 840MP. Initially, the user submits a deck of IBM cards to the SEL 840MP describing set-up parameters for all the tunnel systems. Parameters for the OBS include the number of channels of dynamic data, the sample rate of the dynamic channels, the number of static data channels, and the sample rate of the static channels. The user also submits a complete list of every channel address and every channel gain in the order they are to be sampled. This “initialization table” is reformatted by the SEL 840MP and transmitted to the data management unit in the ground station.

After the initialization table is transmitted to the ground station and verified by the SEL, a second list is transmitted and verified by the SEL. This list of bad channels is determined by the user and entered into the SEL. These channels are, in the opinion of the user, malfunctioning in some manner and will be tagged by the OBS so that erroneous data will not be analyzed.
The OBS ground station then sets up the sampling format and enters the data monitoring mode. In this mode, data channels can be displayed on the bar graph or through the DAC’s to the chart recorder. Two PCM serial bit streams, one static channel and one dynamic channel, are also continuously output through the recorder buffers to analog tape recorders. Either Miller (delayed modulation) or biphase level codes are available.

Instructional communication between the SEL 840MP and the OBS ground station is performed through a single command word transfer. The SEL can command the ground station to accept the initialization table, retransfer back for verification, accept the “bad channel” table retransfer back for verification, enter the static standardization mode, enter the static calibration mode, enter the dynamic calibration mode, enter the static collection mode, enter the dynamic collection mode, or transfer data to the SEL.

Static standardization has been defined for all 40x80 subsystems as a voltage substitution for the transducer signal input to each amplifier. The RMDU provides a precision voltage source on every RMDU I/O card. Eight cards therefore provide enough sources for each of eight gains of the one RMDU gain programmable amplifier. The RMDU further provides a zero input to the gain programmable amplifier, a precision “high-level” voltage source at the input to the ADC, and a “power supply bite” word which gives the go-nogo status of all the power supplies in the RMDU.

Upon receiving the “static standardization” command from the SEL, the OBS will gather all the standardization points listed above. When the “transmit data to SEL” command is then received, the OBS will transfer to the SEL the 11 standardization points, the 11 expected values, and 11 in- or out-of-tolerance indicators. The OBS will then revert back to the “data monitor” mode.

Calibration has been defined as the calibration of the system with the transducer left in the system. Two static calibration points have been designed into the OBS system. An R-Cal point can be taken by placing a known resistance across one leg of a strain-gage bridge (see fig. 7). A zero calibration point can be taken by opening the power leads to the bridge and sampling the thermoelectric potentials in the system. The one dynamic calibration point which can be taken requires the R-Cal resistor to be placed across one leg of the bridge and a sine-wave function to be switched into the power lead of the bridge rather than normal power. This procedure gives a measure of the frequency response of the transducer as well as the data system.

Prior to every data collection sequence, the calibration data will also be taken. A typical sequence might include static calibration, dynamic calibration, dynamic data, and static data. The calibration and data points will be collected at a rate defined in the initialization table. The total number of “static” and “dynamic” frames will also be defined by the table.
Generally, static calibration and data points will be collected completely and then sent to the SEL while dynamic data points will be collected and simultaneously transmitted to the SEL in 10-sec runs. In each case, the SEL, through the command word, will inform the OBS ground station which mode to enter. After each “data point” (i.e., a complete calibration-collection sequence) is finished, the OBS will return to the data monitoring mode.

**Flight Testing Hardware.** In addition, a corollary system - a stand-alone firmware controlled PCM data system with erasable read-only memories has been developed for Ames. This system consists of the same flight-qualified, on-board units found in the 40x80 OBS, but replaces the DMU communication card and the DMIJ in the ground station with a stand-alone timing card which contains the four E-PROM memories. The PROM’s, which can be erased using ultraviolet light and then reprogrammed, are used to control the RMDU sampling sequence and gain selection. The stand-alone RMDU enables the user to set up a sampling program, with subcommutation, in the RMDU memories and modify any or all of the program, including gains, in a matter of minutes once the system is back on the ground.

The stand-alone RMDU has the capability for outputing NRZ, biphase or delayed modulation PCM codes at any of 256 programmable rates up to 125K words/sec with 5 programmable word lengths. The unit is identical to the RMDU used in the wind-tunnel application except for the different overhead card and can accept any of the I/O cards used in the tunnel. Filtering and R-Cal operation is the same as in the wind-tunnel case.

The stand-alone RMDU therefore enables Ames to perform complete testing on, for instance, the tilt-rotor aircraft. This aircraft currently under contract by NASA and the Army to Bell Helicopter, Fort Worth, Texas, will use the AIFTDS system throughout all phases of testing. The Tilt-Rotor Data System (TRDS)(fig. 8) consists of two stand-alone RMDU’s, two 64-channel PAF’s, and five R-Cal units. Analog voltage, digital, strain-gage, and scannivalve I/O cards will be used throughout. The 250-channel system will output two PCM bit streams to a MARS 1414 airborne tape recorder at a 480K bit/sec rate (12 bits at 40K words/sec).

Once the TRDS is fixed in the aircraft, no out-of-plane modifications or adjustments will need to be made to it. The stand-alone TRDS system will first be used during aircraft ground test operations at Bell. By merely changing the digital processing module in the RMDU from a stand-alone timing module to a DMU communication module, the same data system will then be used for the wind-tunnel phase of testing at the Ames 40x80-Foot Wind Tunnel. Finally, after tunnel testing, the system will again be used in the standalone configuration for actual flight testing. Throughout, a minimum of technician effort will be needed to reconfigure the system for tunnel or flight testing. Furthermore, since each
RMDU is capable of handling far more than the 125 channels/box maximum expected for the tilt-rotor testing, all transducers to be used in any phase of the testing can be wired up originally and programmed in as needed. The data system and transducers therefore can be completely installed during the early, less hectic phases of operation without any rewiring necessary.

The tilt-rotor aircraft will thus become the first plane configured with a data system of such flexibility that it can be used throughout its experimental testing program.

**OBS Expansion Capabilities.** Currently configured as a 256-channel system, the Ames on-board system has expansion capabilities up to a staggering maximum of over 9000 channels. More realistic needs therefore are well within system hardware capabilities. The AIFTDS production model RMDU’s have a maximum channel capacity of 352 low-and/or high-level analog channels. More elaborate signal conditioning reduces this number. The Ames version of the AIFTDS data management unit, though currently expected to service 2 RMDU’s, has the ability to handle 4 and expansion capability up to 29 RMDU’s. The stand-alone RMDU’s also can be multiplexed together so that 4 units can produce a single PCM output.

More elaborate signal conditioning than described here is currently available. Thermocouple, scanivalve, synchro, frequency-to-digital, and pulse-sensitive demodulator signal conditioning cards are among those now in production. Others axe or can be designed.

The OBS is therefore an almost infinitely expandable system perfectly suited to the unlimited demands of aircraft research. As described, it has been designed to be user oriented at the researcher and technician levels. Even instructional aspects of the system reflect this state of mind. Ames has attempted to divide training courses into selected topic areas and video tape each topic separately, thereby enabling personnel to view courses only in their area of interest.

The portable checkout unit alluded to earlier is an English language device that allows a technician or experimenter to easily select a channel and a gain and quickly read back a decimal and/or binary value for that channel.

In the final analysis, the Ames OBS is expected to become an integral part of the 40x80 data analysis concept. As familiarity and understanding of the system by Ames personnel increase, the OBS is expected to replace older systems. As demands increase, more and more of the OBS’s capabilities will be explored. Its long-term applications can only be left to speculation.
References


Figure 1.- Ames On-Board System
Figure 2.- Schematic of the RMDU

Figure 3.-AIFTDS RMDU
Figure 4.- OBS Ground Station

Figure 5.- Scannivalve Control Card
Figure 6.- 40x80 Data System

Figure 7.- Strain-Gage Excitation and Calibration
Figure 8.- Tilt-Rotor Data System