REVITALIZATION OF A FLOW-CELL DEVICE FOR AIR INTAKE TESTING AND ITS INTEGRATION WITH WIND TUNNEL SYSTEMS

Dijana Damljanović[1], Djordje Vuković[2], Lazar Petrović[1]

[1] Experimental Aerodynamics Department, Military Technical Institute (VTI), Belgrade, Serbia
[2] Retired, Experimental Aerodynamics Department, Military Technical Institute (VTI), Belgrade, Serbia

Abstract

A flow-cell (mass-flow plug) device for testing of air intakes in wind tunnels was produced three decades ago to support tests during the development of the Yugoslav NA supersonic aircraft project. After the cancelation of the NA project, the flow cell was put in storage and never used again. Recent demands for wind tunnel tests of isolated supersonic air intakes brought attention back to the device, and an extensive modification was undertaken to revitalize it and make it suitable for the new requirements. Modifications comprise changes to the flow cell body, which also acts as a model support, new flow-plug control system, new pressure scanning system and provisions for the calibration of the device. Work on modifications is in progress.

Keywords: wind tunnel, air intake, flow-cell

1. Introduction

Flow-cells or mass-flow plugs [1]-[5] are devices for metering the airflow through wind tunnel models of air intakes, usually comprising a translating conical valve for regulating airflow through a duct and instrumented with pressure-measuring rakes. Military Technical Institute (VTI) in Belgrade, Serbia, has two such devices that were developed in early nineteen-nineties in the former Aeronautical institute Žarkovo to support the Yugoslav NA supersonic multirole airplane project. The smaller flow-cell [8], with engine-face duct diameter of 70 mm was intended for the 1.5 m × 1.5 m T-38 blowdown wind tunnel of VTI [10], while the larger unit, with duct diameter of 175 mm, was intended for the 4.3 m × 3.2 m large continuous low-speed T-35 wind tunnel. The NA project was cancelled before the flow-cell systems were quite finished so the partially configured devices were put in storage and not used afterwards.

Recently, however, VTI has received several inquiries about the possibilities for wind tunnel testing of isolated air intakes, in particular two-dimensional supersonic intakes [6]. It is of interest to be able to perform such tests, so the state of the smaller, 70 mm dia., flow-cell device and the possibilities of its use in future wind tunnel tests were reviewed. It was established that the device could not be used “as it was“, for several reasons. Since the production of the device, the control system and the data acquisition system of the wind tunnel have been replaced with new ones, and the new systems did not have any provisions for controlling a flow-cell. Also, the capability for measurements of pressure distribution, essential for tests with a flow-cell, was temporarily lost with the change of wind tunnel systems, because the old wind tunnel configuration incorporated a controller for electromechanical Scanivalve scanners, long ago proved to be inadequate for a short-run-duration blowdown wind tunnel, and the provisions for modern, much faster, electronic pressure scanners were not yet functional in the new wind tunnel configuration. The flow-cell device initially had a control unit based on a now-obsolete i486 personal computer which malfunctioned and could not be used anymore. Besides, analysis of the design of the flow-cell body, which was also a model support and intended mostly for subsonic and transonic tests [7], showed that its strength was insufficient for expected aerodynamic loads on the supersonic air-intake models, with dominant starting/stopping transient loads. Therefore, an extensive modification of the device was undertaken and required control systems were developed. Also, provisions for the calibration of the flow-plug were developed.

2. The Legacy Flow-Cell Device

The smaller of two VTI's flow-cell devices was designed for models with engine face diameter of 70 mm. Throat cross-section area of the duct in the flow cell is about 3500 mm^2 in fully-open position, and close to zero in fully-closed position. Wind tunnel model was supposed to be mounted on the flow-cell via a ∅134 mm circular flange face with six forward-facing M10 screws (Fig.1, left). The flow cell was designed for mounting on the model support mechanism of the T-38 wind tunnel using a ∅176 mm circular flange at its rear end (Fig.2, left).

A set of six total-pressure rakes with five probes on each rake was installed at the entry section to the flow cell (Fig.1, right). Also, there was a set of six static pressure taps on the duct walls downstream of the engine face section.

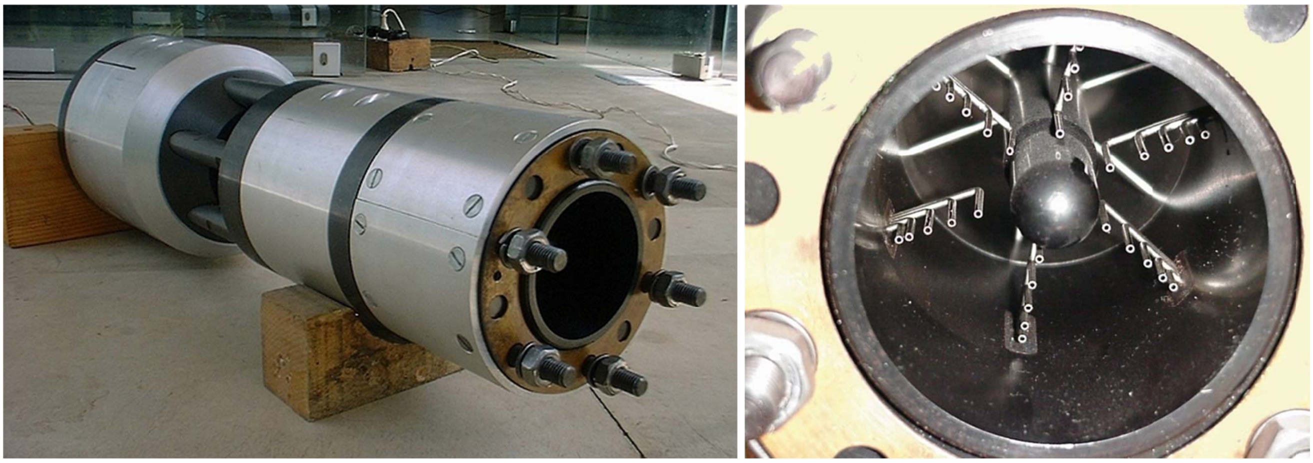

Figure 1 – Left: Existing 70 mm dia. flow-cell with covers installed; Right: Engine-face section of the flow-cell with total-pressure rakes.

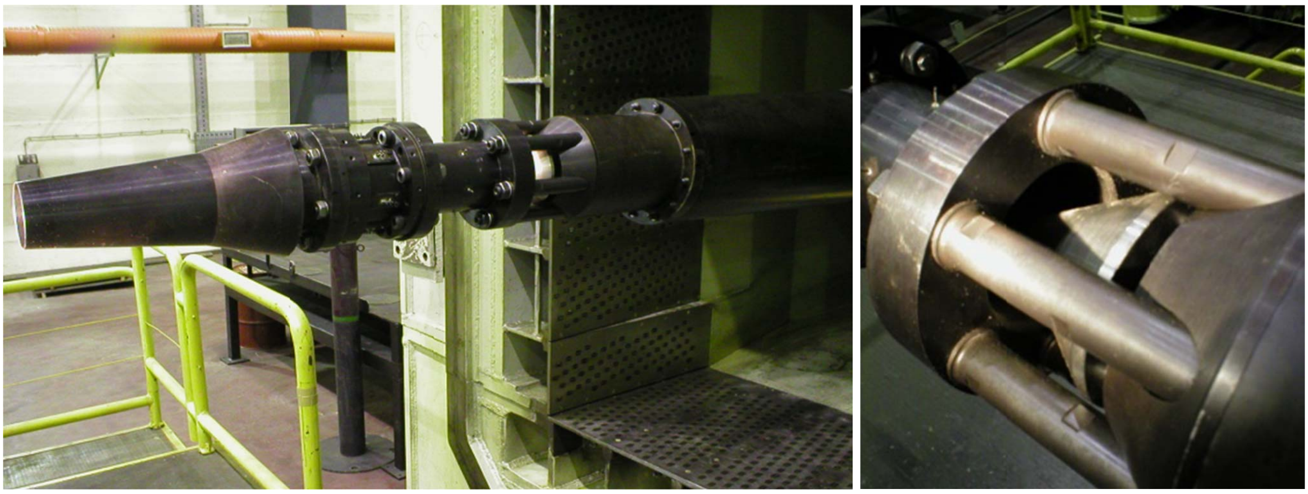

Figure 2 – Left: Existing 70 mm dia. flow-cell; with a simple pitot-intake model installed without covers on the model support mechanism in the T-38 wind tunnel; Right: flow-plug section exhaust with bars of the load-transferring cage.

Flow cell was assembled from several cylindrical sections connected by circular flanges (Fig.2, left) and with non-structural cylindrical covers (Fig.1, left). Exhaust around the conical plug was bridged by a cage made of six cylindrical bars (Fig.2, right) which transferred the loads from the model section to the stationary part of the system. Mass flow rate was regulated by a conical choke/valve driven axially by a ball-screw spindle on a stepper motor with a harmonic-drive reducer, Total travel of the flow plug was 47 mm and designed maximum travel speed was 5 mm/s Position of the conical flow-plug was determined by counting the steps of the drive motor starting from a "home" position determined by a limit switch.

3. Revitalization of the Flow-Cell

3.1 Structural modifications

The flow cell was designed so that its body acted at the same time as the support sting for the model with air intake being tested and, indeed, the geometries of the test section and the support system mechanism in the T-38 wind tunnel would hardly support any other arrangement. However, structural and functional analysis of the flow cell showed that the original arrangement was inadequate for the newly-intended purpose of testing supersonic air intake at airspeeds exceeding Mach 3, in the presence of high supersonic starting/stopping transient loads [9][11] that exist in the T-38 wind tunnel with high minimum operating pressures:

- For an intake model with typical dimensions of about 150 × 150 × 700 mm, supersonic transient loads are estimated, using established semi-empirical procedures [11], as a side force of approximately 6700 N, pitching/yawing moments of approximately 1050 Nm and rolling moments up to 200 Nm. Taking into account the loads on the body of the flow cell itself, transient loads rise to side forces of approximately 10000 N and bending moments of approximately 4150 Nm. Transients starting loads are significantly higher than aerodynamic loads expected during the measurement phase of a wind tunnel run.
- Body of the flow cell was basically a segmented cylindrical pipe with flanges, having inner diameter of 70 mm and outer diameter of 82 mm. Section moduli of pipe segments were insufficient and stresses in the body with estimated transient loads would have been close to the yield strength of the material used, with safety factor below 1.4. Also, because of the small section moduli, deflections of the assembly under expected aerodynamic loads would have been excessive.
- Strength of the bars in the cage around the exhaust was not sufficient, taking into account that, because the cage was assembled, it was improbable that loads would be smoothly distributed among the six bars. Safety factor was estimated to be about 1.2.
- Relatively large diameter of the fairing around the rear part of the flow-cell, immediately downstream of the exhaust, would have created adverse pressure gradients in the vicinity of the exhaust, hampering the flow.
- Pneumatic tubing and electric cabling from the rakes and other instrumentation in the front part of the flow cell was to be passed through the hollow bars of the cage around the exhaust. However, the provided space was insufficient for all cabling and tubing necessary in the new testing configurations.

In view of the listed shortcomings, extensive modifications were undertaken in order to improve the functionality of the device but minimize the procurement and production of new components. The main feature of the new concept is that a monolithic load-bearing outer shell is being produced (Fig.3) instead of multipiece covers/fairings, in order to increase model-loads capacity, increase rigidity, decrease frontal blockage, decrease planform area, and create more space for routing the instrumentation cables. All aerodynamic loads will be taken by the new shell. Basic components of the flow-cell- the pipe segments with total pressure rakes and static-pressure taps, and the conical valve with its step motor drive are retained (with minor modifications), while the non-structural covers and the load-bearing bars of the cage around the flow plug were discarded. Diameter of the rear end of the flow-cell was reduced to diminish unfavorable pressure gradients. The modified design permits manual rotation of the pressure rakes to different positions between wind tunnel runs. An external cable duct for instrumentation in the model will be added to the upper side of the flow cell. Particulars of the cable duct may vary from model to model.

Drive system for the conical flow plug is retained from the initial configuration of the flow cell, comprising a 0.6 Nm, 1.8º/step motor [12], with 1:100 harmonic-drive reducer driving a 25 mm dia. ball-screw spindle with 10 mm pitch. Design travel speed of the plug was 5 mm/s but recent tests have shown that speed of about 4 mm/s is a more likely maximum. It is recognized that, according to initial design, the step motor should operate at uncommonly high 10 kHz step rate, resulting in no more than about 20% of nominal torque, which should still be sufficient for driving the conical flow plug against expected aerodynamic loads. Travel limits of the plug are sensed by inductive limit switches [13] with 0.01 mm repeatability, replacing earlier-used mechanical contact switches.

Model is to be mounted on the front part of the flow cell and the aerodynamic loads are to be transferred to the base of the flow cell via the outer shell of the cell.

The flow-cell will be mounted on the wind tunnel pitch-and-roll model support system. However, because of the space constraints related to the positioning of the flow cell, the standard roll-angle drive in the wind tunnel model support will be removed and replaced with a shorter unit having a slightly larger diameter in order to provide necessary space for flow-cell drive motor and instrumentation.

Total- and static-pressure taps in the device are to be connected to an electronic pressure-scanner, such as an ESP or Scanivalve MPS, or to fast individual pressure transducers, depending on the type of the test. The scanners are to be located immediately behind the flow cell, in the space provided in the hollow shaft of the roll drive.

Figure 3 – New shell of the flow cell device being prepared for CMM control in VTI workshop

The new configuration of the flow cell with enhanced model support capability is shown in Fig.4. Fig.5. and Fig.6 show some of the produced new components.

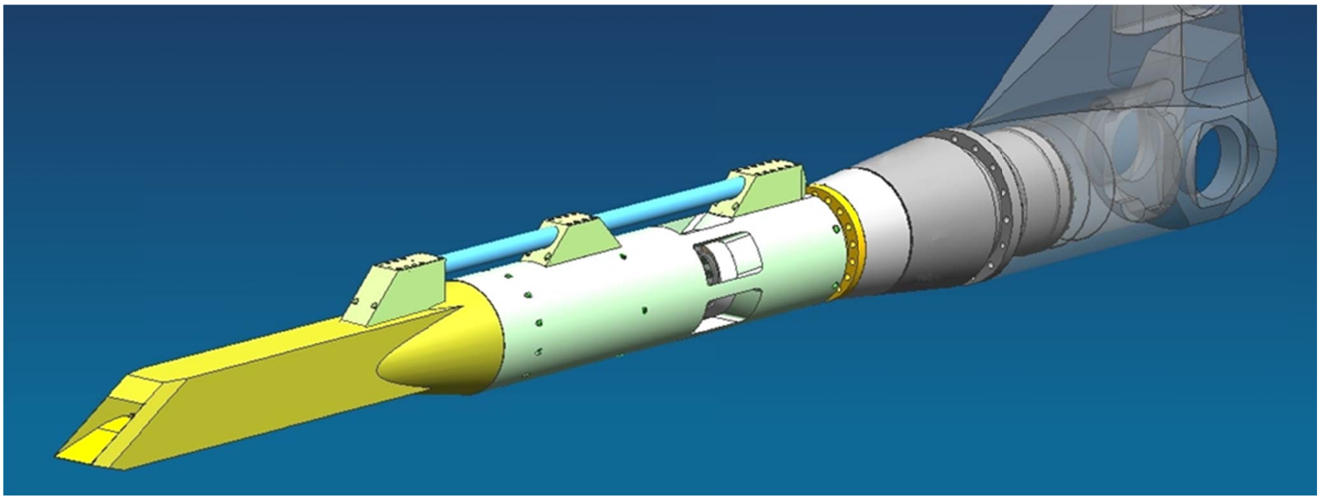

Figure 4 – CAD rendering of the modified flow-cell with a simplified hypothetical supersonic-inlet model, mounted on the pitch-and-roll support mechanism of the VTI T-38 wind tunnel. Attachments of the cable conduit on the upper side of the assembly will be adjusted to a particular model.

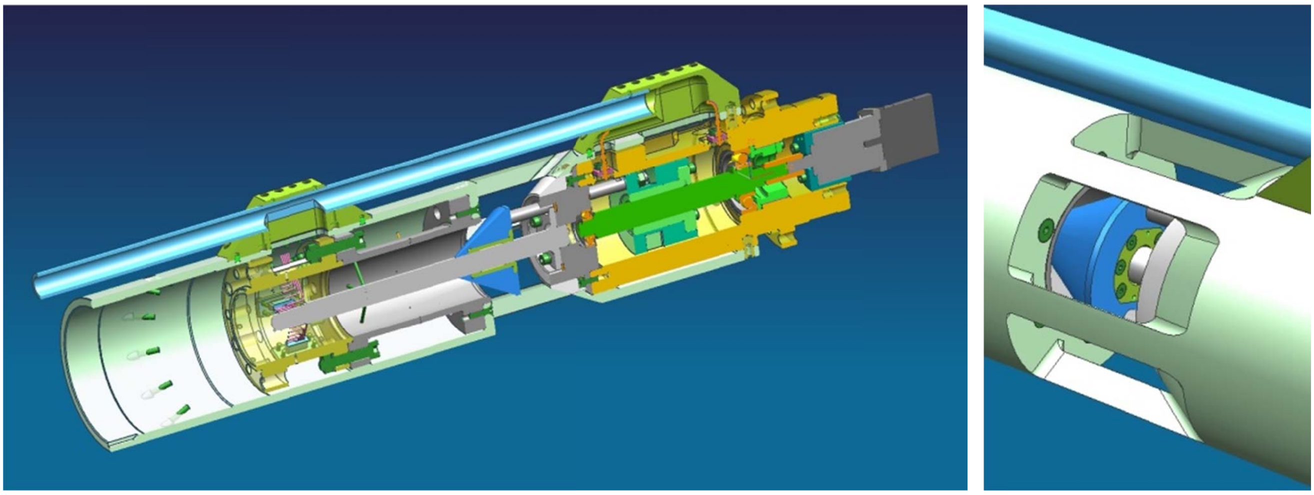

Figure 5 – Left: Cross-section through the modified flow-cell; Right: the new exhaust of the flow-plug

Figure 6 – Some components produced for the modified flow cell: Left: the bellmouth inlet for calibration; Middle: holders for cable conduit; Right: unfinished drive module and support flange

A negative side of the modification is that the diameter of the flow-cell device has been increased from 134 mm to 148 mm, increasing test section blockage by 0.14%. On the other hand, the diameter of the rear part of the flow-cell was decreased from 170 mm to 148 mm, decreasing blockage in that area by 0.24%, so the overall effect on blockage is expected to be beneficial.

3.2 Provisions for calibration

Mass flow rate through a flow-cell can be determined from integration of measurements of total pressures on the rakes in the flow-cell inlet and measurement of static pressures on the wall of the flow-cell duct. However, mostly because of the boundary layers and finite number of measurement points, this computation is not very accurate and a flow-cell should be calibrated in order to establish a relation between the actual mass flow rate and the choke-valve position. There are several methods by which this can be achieved. For example, a pitot intake with an inlet lip diameter of 58.6 mm (Fig.2, left) exists for this flow cell, for calibration in the wind tunnel using the attached shock-wave method. This method was adopted in the original design of the flow cell and the calibration was to be effected by observing a real-time schlieren visualization of the flow around the inlet lip in a supersonic wind tunnel run and by moving the flow-plug until the shock wave attaches to the lip of the inlet, at which point, knowing the test section flow conditions and the diameter of the inlet, mass flow rate could be established.

However, a more-conventional calibration setup for the flow-cell, similar to the one described in [3], was designed as well, and the components are being produced (Fig.7 left). The system utilizes the ejector-driven blow-off system for the transonic test section of the VTI T-38 wind tunnel. The blow-off system can provide sufficient pressure differential relative to atmosphere in order to establish desired flow conditions through the flow-cell which will be installed vertically at the inlet of one of the two blow-off pipes at the floor level of the T-38 wind tunnel hall (Fig.7 right). A 2 m long, 250 mm-dia. settling chamber, made from a PVC pipe, will be installed vertically above the flow-cell, with calibrated orifice(s) at the upper end of the chamber. Instrumentation in the rig will be connected to the nearby input patch panel of the wind tunnel data acquisition system.

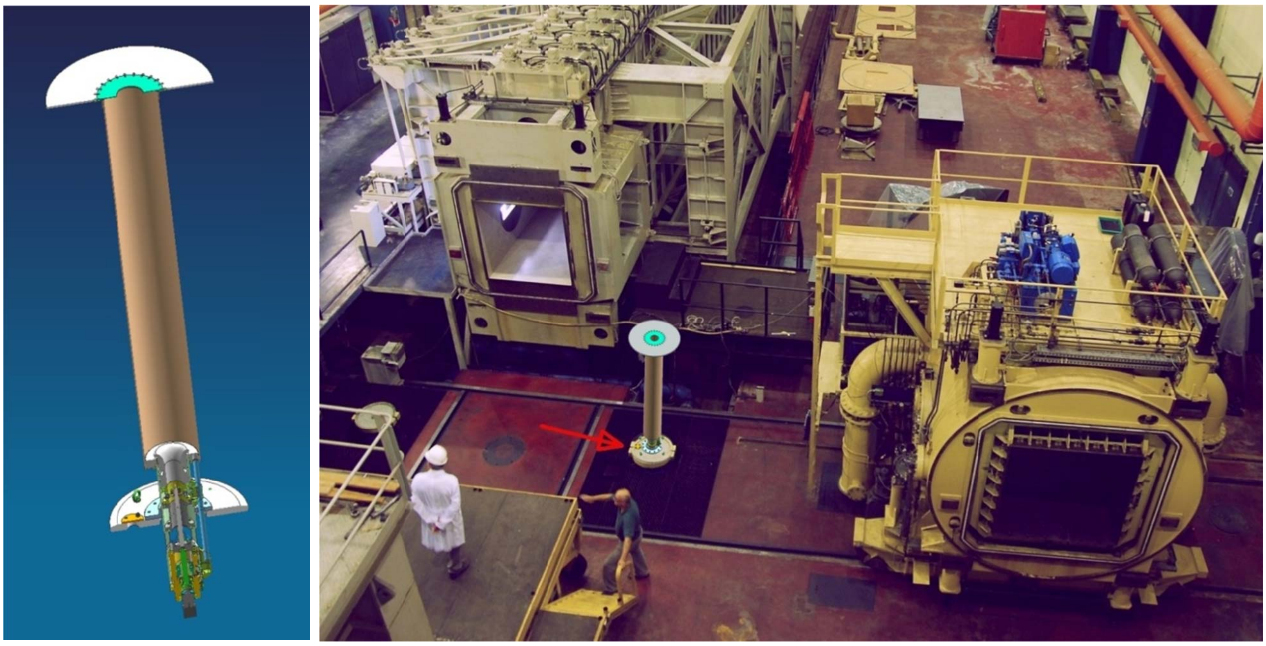

Figure 7 – Calibration setup for the modified flow cell: Left: cross section throught the setup showing the flow-cell, the settling chamber and the calibration orifice; Right: simulation of the installation of the setup on the right-hand blow-off inlet for the transonic test section of the T-38 wind tunnel.

3.3 Flow-cell control unit

Interfaces required to control the flow-cell are relatively simple and consist of a standard unipolar two-phase stepper-motor drive and signals from two inductive limit switches at the ends of the valve stroke. Position is to be established by counting the steps from the “home” position of the flow-plug. Also, in order to improve reliability against motor missteps, a miniature rotary encoder [14] is to be mounted on the output shaft of the harmonic-drive reducer. Pulse signals for the motor driver are generated by a locally developed single-board control unit based on a PIC microcontroller, which also monitors the limit switches and the rotary encoder, preventing driving beyond the physical valve-traverse limits. The microcontroller has to perform two basic functions: finding the start/limit/home position, and driving the step motor by the desired number of steps in either direction at the desired step rate. Also, In accordance with the requirements for the new tests, and in order to facilitate test procedures, the control unit can perform several higher-level functions, such as the initialization of the unit, during which the parameters for the subsequent movements are loaded, return to home position and stepping in the desired direction in the move-pause-move mode for a desired number of intervals and pause durations.

4. Integration of the Flow-Cell with Wind Tunnel Systems

VTI T-38 wind tunnel is a high-dynamic-pressure blowdown facility with limited run time (from 6 seconds up to about 45 seconds, depending on desired flow conditions). The consequences of a short run time are that a wind tunnel run sequence must be completely automated, and that data reduction takes place after a run. The wind tunnel control system (WTCS) and the data acquisition and recording system (DARS) of T-38 are two distinct systems. WTCS [19]-[21] is based on a high-power Windows workstation as a central control computer with locally-developed LabView-based control software, multiple subsystems based on National Instruments CompactRIO controllers [15], and a locally-built PLC compatible with I/O modules retained from the earlier-used Modicon Gould 584 PLC [22]. DARS is controlled by a Windows workstation running a locally-developed control application and comprises a Pacific Instruments PI6000 front end [16]. Besides PI6000, the DARS control application supports legacy Neff 620 [17] and Teledyne RMDU [18] systems in other wind tunnels of VTI. WTCS comprises its own minimalistic data acquisition system, sharing signals from some essential transducers between WTCS and DARS. A wind tunnel run sequence is completely under the control of the WTCS, which sends data-acquisition-related commands to DARS.

For certain site-specific reasons there cannot be a LAN connection between DARS and WTCS. Instead, during a wind tunnel run, WTCS sends commands to DARS via a serial connection. The commands comprise start run / stop run, start wind-on / stop wind-on, start data acquisition / stop data acquisition directives, etc. Also, additional information is sent via single-byte „event codes“, notifying of occurrences such as achieved stagnation pressure or Mach number, achievement of desired model position, etc. DARS control workstation records the acquired data and the received „events“, and, after a run, sends them to the data-reduction computer for processing.

Flow-cell device has a control unit, and it is obvious that a pressure-scanning system, with a control unit of some kind, must be active in an air-intake test. During the decades of wind tunnel testing in VTI, and also during the recent development of the control application for VTI's data acquisition systems, it was observed that there is often a need for such "auxiliary", sometimes-used, devices that are more or less closely coupled to the data acquisition system. Such devices comprise, for example:

- Control unit for the flow-cell
- Control unit for the pressure-scanning system
- Control unit for the video- and photo-recording system
- Control unit for a flow-probe or rake traversing or other device-traversing mechanism
- Control unit for the forced-oscillation apparatus for stability derivatives testing
- Control units for other, currently unspecified, auxiliary devices

It was also observed that, for all such devices, a very similar set of simple commands is required, and that the control units of auxiliary devices can, in most cases, be very simple and based on microcontrollers. Therefore, a simple communication protocol for issuing such commands was coded in the DARS control application and is, therefore, available in all wind tunnels of VTI. The protocol comprises a small set of commands, which are interpreted in device-specific ways (or ignored), depending on the controlled auxiliary device:

- Initialization of the auxiliary device: transfer of a fixed number of numeric parameters for subsequent operation of the device;
- Selection of the operating mode of the device: transfer of a single parameter for selecting a change of the operating mode of the device, if any;
- Run: starting a probe traverse or flow-plug traverse, or a pressure scan or a video recording, or forced oscillation;
- Stop: stopping a probe traverse or flow-plug traverse, a pressure scan or a video recording, etc.;
- Step: advancing the pressure scanner by a single port, taking a photo, etc.;
- Home: returning of the device to initial state or position, if applicable;
- End: shutdown of the device.

Serial interface (RS-485 or RS-232) was selected as the simplest solution for the communication medium between the devices and the DARS control computer, as it is implemented in most microcontrollers, easily programmed, and does not suffer from small-communication-distance limitation of the USB interface or the complexities related to Ethernet. All issued commands are simple one-byte messages except for the Init and Mode commands which contain fixed numbers of parameters for the configuration of the subsequent operation of the device. Run, Stop, Step and Home commands are issued upon occurrences of the “triggers” which are either selected from event codes received by the DARS from the WTCS or manual commands issued by the operator of the DARS system. Trigger events can be, for example, start of the wind-on run phase, end of phase, start of data acquisition, model on position, etc. In order to minimize communication overheads within the real-time DARS control computer, the communication with the controlled auxiliary devices is essentially one-way, only Init and Home commands initiating acknowledges from the devices.

This device-control protocol is already implemented and functional in the control of the video/photo-recording systems in VTI wind tunnels and tests of the communication with the flow-cell controller and the pressure-scanner controller are in progress. While the GigE-cameras video-subsystem controller is based on an industrial PC, the much-simpler new control units for the flow-cell and the pressure scanners are based on PIC microcontrollers.

The flow-cell controller creates step pulses for the flow-plug step-motor driver, and monitors limit switches for determining the initial and fully extended positions of the plug. Flow-plug position, based on either counted motor steps or encoder output, is presented in 16-bit parallel form and connected to a parallel digital input channel of DARS.

The pressure-scanner control unit, based on an idea [23] successfully tested with 32-port pressure scanners [24], utilizes the “sample clock“ signal from the data acquisition system to increment a counter and create parallel binary address signals for the scanners. Multiplexed output signals from the pressure sensors in the scanners are read by the analog input cards of the data acquisition system in wideband mode, and the scanner-port address is read by a parallel digital input channel, synchronously with all other channels sampled during a test. Therefore, the complex and expensive standalone control units for the electronic pressure scanners, usually deployed with pressure-scanning systems, are completely eliminated, simplifying the integration. It should be noted that a consequence of this approach is that the conversion of acquired scanner signals to pressure engineering units takes place on the data reduction computer, after the wind tunnel run.

Beside the electronic pressure scanners such as [24]-[27], the scanner control unit also supports legacy electromechanical Scanivalve scanners, which are still of interest for VTI’s continuous wind tunnels. Having the same DARS control application in all VTI wind tunnel means that the described concept of controlling auxiliary data-acquisition devices can be applied in any of them.

Final designs of the flow-cell control unit and the pressure-scanners control unit are being realized as single-slot boards in a 19” box located in the rack where the DARS front end is. DARS sample clock, needed for the scanners control unit, is already available in the box as it is needed for several site-specific microcontroller-driven digital-data-format converters located in the box. Serial connections to control units can be implemented either from physical serial ports on the DARS control computer or, in the case of a PI6000 system, from physical serial ports on the control data processor located in the front end rack and mapped through LAN as virtual remote ports on the DARS control computer. Both configurations have been successfully tested.

Fig.8 displays the interconnections of the components of the T-38 wind tunnel control and data acquisition systems with the auxiliary devices related to air intake tests.

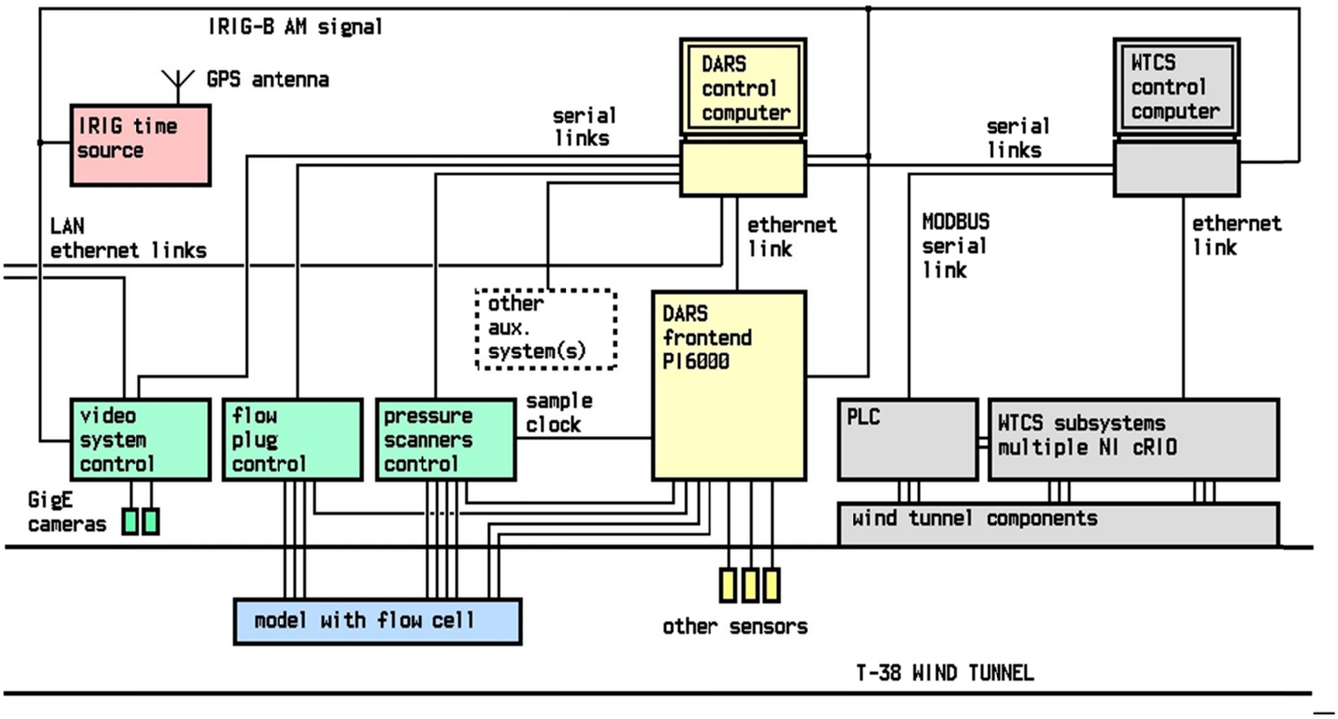

Figure 8 – Schematic representation of the integration of the flow-cell and its control components with other wind tunnel systems

5. The Data Acquisition System

All data during air-intake tests will be sampled and recorded by the Pacific Instruments PI6000 data acquisition system [16] which is the standard data acquisition equipment of the T-38 wind tunnel in VTI. Analog-to digital part of the system has a 16-bit resolution with the aggregate sampling rate exceeding 1 million samples/second. Nominal gain accuracy of the analog input channels in the system is 0.05% without recalibration. However, repeated checks have showed that the actual measurement accuracy after a daily-performed gain calibration is about 0.01%.

Maximum sampling rate on the analog-input channels is 10000 or 20000 samples/s per channel, depending on input-card module type, but a lower sampling rate (to be determined, probably about 5000 samples/s per channel) may be selected for air-intake tests. For pressure scanners with 32 ports, this rate would result in approximately 150 pressure scans per second (7 ms/scan), so that pressure scans could be performed even with the flow-plug moving. Various per-channel sample rates can be achieved by supercommutation in the scan list.

Recorded data are saved in a "raw" file using the de-facto standard telemetry data format, with sync words, data frames and subframes, each data frame including BCD-coded IRIG timebase data with 10 μs resolution. IRIG timebase data is also impressed in each frame of the video and photo recordings, so that a time correlation between the recorded signals and the video recordings can be established. Additional recorded files describe scan lists and channels configuration (gains, filters). After the completion of a wind tunnel run, all data are sent through the local network to the data-reduction computer.

6. A typical wind tunnel run procedure

A typical wind tunnel run procedure for testing the air-intake models in the T-38 will be as follows: model support with the test item will be placed at zero pitch angle and at the roll angle that will provide the desired sideslip angle at the desired angle of attack. A "pretare" measurement will be taken by the data acquisition system that will provide "zeros" of all differential pressure transducers and a comparison with atmospheric pressure for all absolute pressure transducers used in the test. The flow-cell controller will be initialized and the plug in the flow-cell will be traversed at this time to determine "home" (fully-closed) position. Flow through the wind tunnel will be started then. Upon achieving the desired stagnation pressure and Mach number, the model support will be moved to the pitch angle that will provide the desired angles of attack and sideslip. A certain time (a couple of seconds) for flow-stabilization will be permitted. Data acquisition and video recording (of the schileren flow visualization) will be started then. Flow-plug traverse will be started as well, with the plug travelling from the fully closed (or other desired initial position) to the desired final position, either continuously or with the desired number of pauses during the travel. Direction of the traverse will be reversed, and the plug will travel at the same speed back to the initial (or "home") position. Data acquisition and video recording will be stopped. Model support will be moved to the zero-pitch angle and the flow through the wind tunnel will be stopped. Run duration is estimated to be about 25 seconds. After the wind-on phase of the run and the shutdown of several wind tunnel systems, a "posttare" measurement will be made by the data acquisition system. Thereafter, recorded data will be transferred to the data-processing computer and data reduction will be performed. Also, video recording will be transferred from the camera to the computer where it will be stored. After a review by the test engineers, processed data will either be declared as valid or corrective actions will be taken.

Therefore, in one wind tunnel run, data will be taken only for one angle-of-attack/angle-of-sideslip combination (this is dictated by the limited run time of the blowdown T-38 wind tunnel).

7. Data processing

Acquired "raw" data from a wind tunnel run are automatically transferred through the network to the data-reduction computer at the end of each run and decommutated into file-per-measurement-channel form. Acquired measurement data are accompanied by sensor/channel settings data and by "run events" data, which guide the segmentation and averaging process.

After the test engineer enters the required data processing parameters (run identification, model configuration, etc.), data processing starts by converting the raw data-stream files into "normalized signals", segmented per each recording. Values pertaining to the primary measurement system (test section pressures, Mach number, temperature, etc.) are computed next, followed by the computation of the model attitude angles.

Processing of measurement of pressure distribution assumes that data were acquired using one or several pressure scanners in which measurements from a number of pneumatically connected pressure taps or probes are time-multiplexed to a single measurement channel per scanner, accompanied by port-address data on another measurement channel. Measurement of pressure distribution by individual, single point transducers is not currently supported. Pressures directly measured by each scanner are computed for each sample taken, using calibration data for the transducer(s) in the scanner, and averaged per each port. Computed data are then decommutated, using port-address data and user-defined interconnection tables ("plumbing tables") from arrays pertaining to scanners to arrays pertaining to "sections" (arrays of pressure taps or probes) on the model. As a pressure scanner is typically a differential device, reference pressure (usually test section static pressure or pitot pressure) is taken into account to compute absolute pressures at connected ports. If necessary, further processing is performed in order to obtain local Mach numbers or non-dimensional pressure coefficients for each measurement point on each section.

Processing of the data related to the air intake flow-plug tests takes as inputs the flow-plug position data, the flow parameters obtained through the primary measurement system and the per-section pressure-distribution data obtained in the processing of pressure measurements. Mass flow rate through the flow plug is calculated and corrected with respect to flow-plug calibration. Mass flow ratio is computed with respect to flow-plug position, as well as the pressure recovery at the downstream end of the air intake model. Mach number distribution and average Mach number at the downstream end of the air intake model is computed, using a weighted average of data from total-pressure probes on the rakes in the intake duct. Flow distortion is determined.

Calculations are performed for the flow in the intake (if it is instrumented) and in the flow-cell itself i.e. at the position of the total pressure rakes in the flow cell.

8. Conclusion

After receiving multiple requests for wind tunnel tests of supersonic air intakes, the status of a stored 70 mm dia. legacy flow-cell (mass-flow-plug) device in VTI was reviewed. It was conclued that the device could not be used „as it was“ because various components of the system have either become non-functional, incompatible with the since-upgraded wind tunnel systems of VTI, or structurally inadequate for the new requirements. Ether a new flow-cell device with accompanying systems had to be produced or the existing one had to be extensively modified. Constrained by the need to minimize procurements and production of new components, and, generally, to minimize costs, it was decided to modify the existing device, so only a small number of new components is produced and some other are being modified to that end. Simple low-cost controllers for the flow-plug and the pressure-scanning system are being devloped and tested. A flexible concept of controlling various such systems from the control computer of the wind tunnel data acquisition system was developed, has been successfully tested and is expected to be of use in a number of future tests. Because of the unified DARS control application, the concept can be used in all wind tunnels at the site. The developed concept of controlling the pressure-scanning system is particularly interesting as it eliminates commonly used but complex and expensive standalone pressure-scanner control units. Unfortunately, because of some non-technical delays, the systems are not yet finalized, but are expected to be in the following months. It was also noted that, in order to fully utilized the flow-cell device, some modifications to the data-reduction software should be performed.

9. Acknowledge

This project is supported by the Military Technical Institute (VTI) Belgrade and the Ministry of Science, Technological Development and Innovation of Republic of Serbia (Project number 451-03-66/2024-03/200325).

10. Contact Author Email Address

mailto: dijana.damljanovic@vti.vs.rs, didamlj@gmail.com, vdjole@sbb.rs

11. Copyright Statement

References

[1] Sheldon J. *Intake Aerodynamics*. Blackwell Publishing ltd. 1999

[2] Goldsmith E.L, Cater E.C. *A review of methods for the representation of engine flows in high speed wind tunnel testing*. Technical report 72012, Royal Aircraft Establishment, 1972

[3] McGregor I. The characteristics and calibration of two types of airflow metering device for investigating the performance of model air intakes. Technical report 71212, Royal Aircraft Establishment, 1971

[4] Sasson J. *Small Scale Mass Flow Plug Calibration*. NASA/CR-2015-218820, NASA Glenn Research Center, Cleveland, 2015

[5] D.Corriveau et al. Wind tunnel tests on two-dimensional air intakes at DRDC Valcartier

[6] Anon: *Air Intakes for High Speed Vehicles*, AR-270, AGARD Advisory Report 270, AGARD, 1991

[7] Welte D, Dornier GmbH and Friedrichshafen. Experimental analysis of a Pitot type air intake. *J. Aircraft*, Vol. 23, No.4, 1986.

[8] Vitic A and Isakovic J. Design of a Flow Cell Device for the Validation of Quality of Air Intakes on Wind Tunnel Models in the T-38 Wind Tunnel. Scientific Technical Review, 2012, Vol.62, No.1, pp.23-27

[9] Pope A and Goin KL. *High-speed wind tunnel testing*. New York, NY: John Willey and Sons, Inc, 1965

[10] Medved B and Elfstrom G. The Yugoslav 1.5m trisonic blow-down wind tunnel. *AIAA aerodynamic testing conference*, AIAA, Reston, VA, 1986, paper no. AIAA-86-0746-CP.

[11] Vuković Dj, Ćurčić D, Marinkovski D, Damljanović D, Samardžić M, Vitić A. Living with supersonic starting loads in the T-38 trisonic wind tunnel of VTI. Proceedings of the 29th congress of the international council of the aeronautical sciences (ICAS). ICAS2014_0138, 2014.

[12]Anon. *Operating Manual, Stepping motor PK series, PH series, PX series*, HM-601-17, Oriental Motor Co. Ltd. 2011

[13] Anon. *Small-diameter Proximity Sensor E2E*, Omron Corporation, 2019

[14] Anon. *ID1102C Dual Channel Rotary Encoder Kit*. ID1102C-DS-V2D, POSIC, 2020

[15] Anon. Product Flyer CompactRIO Controllers, National Instruments, 2017

[16] Anon. *6000DAS Transducer Data Acquisition & Control System Operating Manual*. Pacific Instruments, 2021

[17] Anon. *Handbook and Selection Guide for Computer-Based Data Acquisition & Control Systems*. Neff Instruments Corporation, 2007

[18] Anon. *Operating Instructions, CPP/VTI Data Acquisition and Reduction System (DARS),* Technical Manual TM847800, Teledyne Controls, 1983

[19] Ilić B. *Hibridni sistem upravljanja strujanjem u aerotunelima velikih brzina* (*A hybrid system for flow control in high-speed wind tunnels;* in Serbian), PhD dissertation, Engineering faculty, University of beograd, Serbia, 2017

[20] Ilić B, Miloš M, Milosavljević M and Isaković J. Model-based Stagnation Pressure Control in a Supersonic Wind Tunnel. *FME Transactions 44 No.1*, pp 1-9, 2016

[21] Ilić B and Milosavljević M. FPGA-based Embedded System for Wind-Tunnel Variable-Geometry Nozzle Positioning, *Scientific Technical Review*, Vol.69 No.1, pp. 3-9, 2019

[22] Anon. Gould 584 PC System Reference Manual. GM-584R-REF Rev.A, Gould Electronics, 1985

[23] Vuković Đ. Integracija elektronski skaniranih davača pritiska sa aerotunelskim sistemom za prikupljanje podataka (Integration of electronically/scanned pressure sensors with a wind tunnel data acquisition system; in Serbian) *Proceedings of the Vazduhoplovstvo '93 (Aeronautics '93) conference*, Engineering Faculty, University of Belgrade, 1993

[24] Anon: *Pressure Sensor Array MSP-32A*, Institute for Microelectronic technologies and Monocrystals, University of Belgrade, 2002

[25] Anon: *Model 4164 Miniature Analog Pressure Scanner*, Datasheet No. G-480, Scanivalve Corporation, 2019

[26] Anon: *Model ZOC22B Electronic Pressure Scanning Module*, Datasheet No. G-436, Scanivalve Corporation, 2012

[27] Anon: *Miniature Electronic Pressure Scanners, ESP-16HD/32HD/64HD*, datasheet, Measurement Specialties Inc., 2018