UDK: 533.6.071.3
COSATI: 01-01, 14-02

Design of a Flow Cell Device for the Validation of Quality of Air Intakes on Wind Tunnel Models in the T-38 Wind Tunnel

Aleksandar Vitić[1)]
Jovan Isaković[1)]

A description of a construction of airflow metering-flow cell device for the validation of quality of air intakes on wind tunnel models in the T-38 wind tunnel is given in this paper. The aircraft air intake performs a crucial role because it delivers the air to the engine. The airflow into an engine must be uniform so that the engine operates efficiently and reliably with the minimum possible requirements for maintenance. The air intake must perform its function throughout the operational envelope whatever the speed or attitude of the aircraft. Wind tunnel tests with airflow metering-flow cell devices are particularly important for the validation of air intake design. Wind tunnel tests provide a large quantity of high-fidelity data needed to quantify the level of distortion and separation in the airflow near the engine face throughout the operational envelope of the aircraft.

Key words: **wind tunnel, flow cell, air intake, calibration.**

Introduction

THE accurate measurement of air intake mass flow is very important for the overall performance of aircraft. A typical air intake test involves the design and manufacture of the front section of a model which will be tested. Behind the front section of the model, there is fixed a flow cell device for the regulation of mass flow through the air intake. Fig.1 shows three models for air intake studies for three different wind tunnel tests.

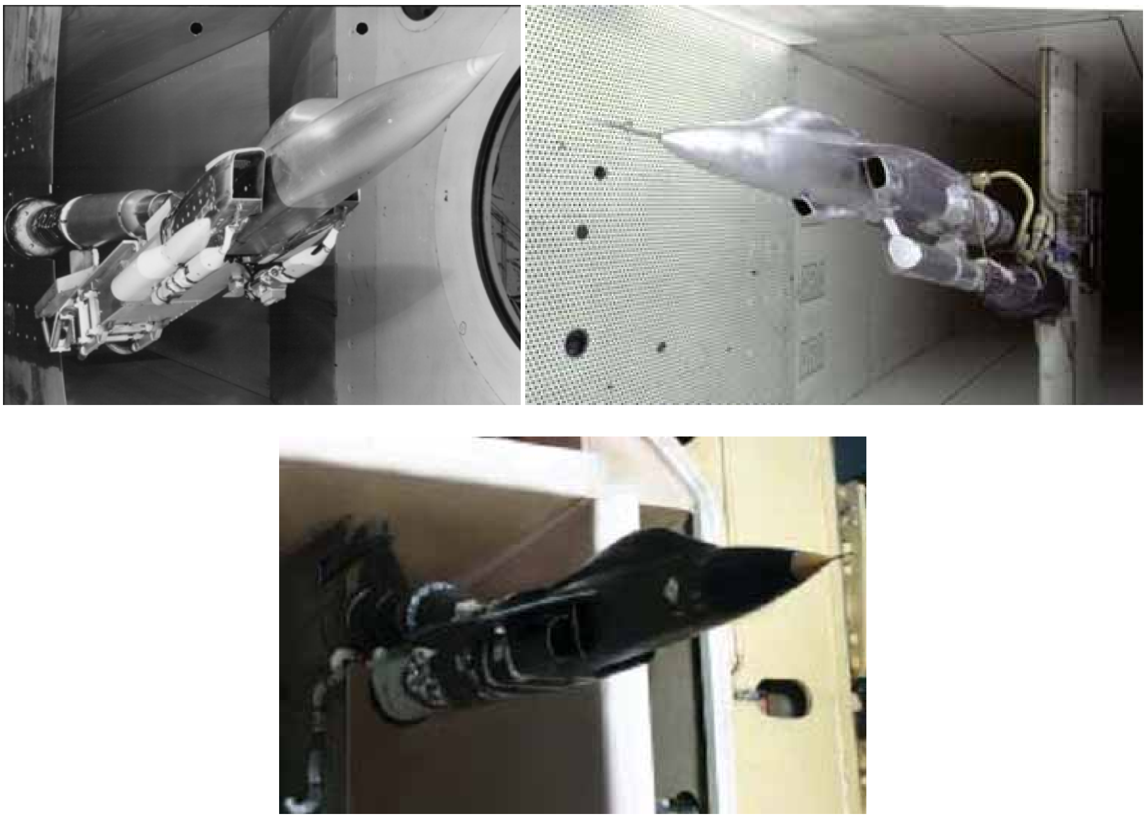


Figure 1. Air intake studies in 3m x 2.7m ARA trisonic wind tunnel, AEDC–USA wind tunnel and 1.2m trisonic wind tunnel NTAF Bangalore-India

[1)] Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA

A highly complex nature of the airflow around and through the air intake can be very dynamic with an intricate shock system, often with regions of separation [1],[2]. A numerical simulation performed on computers plays a very important part in intake design, but due to a highly challenging nature of the airflow, these simulations alone cannot provide designers with the level of confidence they require to proceed to a flight test. This is a reason why an array of measurement probes is used to record pressures and temperatures of the airflow as it approaches the position of the engine inlet-on the engine face. Because of the dynamic nature of the airflow, a high speed data acquisition system is needed to record several thousand points per second. A data processing suite of programs then converts the recorded data into useful engineering information.

Description of a flow cell for the YCA001 model

The basic dimensions of the flow cell were defined according to the YCA001 M-20 wind tunnel model which was to be designed in a scale 1:15 for testing in the wind tunnel T-38 (see Fig.2). The basic diameter of the mass flow duct, for a scaled model, was 70mm. The entry to the mass flow duct was provided with six screws for interfacing with the model.

Two tests ought to be carried out with the model and the flow cell. The first test ought to be carried out on the VTI static suction facility which has a capacity to choke the inlet [3], and the second test in the T-38 trisonic wind tunnel [4]. Static suction tests measurements should be made of engine face: total pressure recovery and flow distortion at the static conditions up to full engine-face flow. Transonic wind tunnel tests ought to be carried out over the full flight conditions from subsonic to supersonic Mach numbers. The main test objectives in the wind tunnel were to determine the effects of the shock/boundary layer interaction at the intake entry at high speeds. Both essential tests should validate the predicted performance of the air intake design for New aircraft.

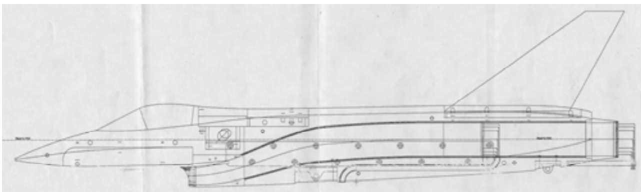


Figure 2. Sketch of the YCA001 M-20 model for the measurement and analysis of air intake

The flow cell device for the T-38 wind tunnel model can be used for investigating the performance of model air intakes. It consists of a pitot tubes support, a venturi part with six static holes, a movable cone, a step motor with a spindle and a control system connected to the wind tunnel control system (see Fig.3) [5]. The cone is moving from a close to fully open position, increasing area and air mass flow through the mass flow duct. There is a total of 30 pitot tubes connected to highly sensitive miniature and very fast pressure transducers. Pitot tubes are positioned at the face of the engine compressor. On the front part of the flow cell device there are six screws for connecting the front section of the model aircraft to be tested (see Fig.3). The rear part of flow cell device is connected to the model support system. This support provides pitch angles from -12^o to 19^o about the centre of rotation of the model.

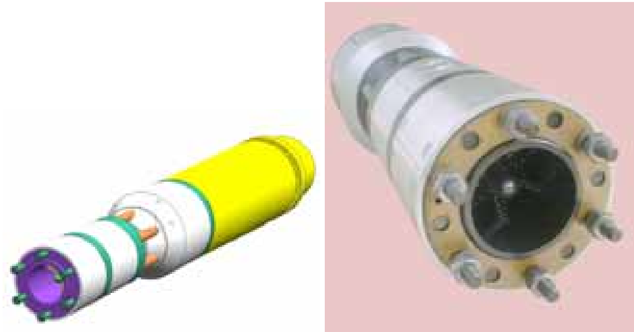
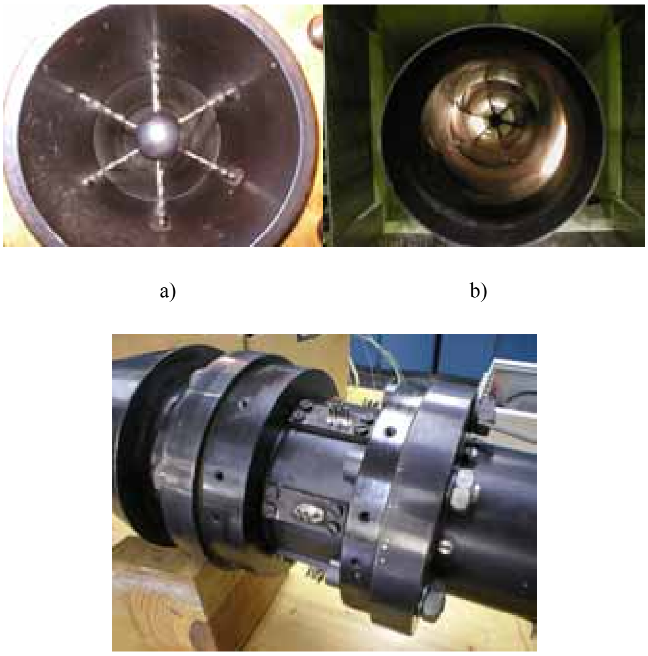


Figure 3. CAD representation of the flow cell and a real flow cell

Fig.4 shows the details inside a, b) and details outside c) of the pitot tube support. The end of each of total pressure tubes can be connected to the pressure transducers or to the pressure scanner system. What will be used depends on the type of the test.



a) b)

c)

Figure 4. Details of the total pressure rake at the engine face, inside a, b), and details outside c)

The speed of the cone is from 0 mm to 5 mm per second with an acceleration from 3 mm/s^2. The backlash is 0.01 mm. Fig.5 shows the cone in a closed a) and an open position b).

a) b)

Figure 5. Fully closed cone a) and fully open cone b)

A step motor, with harmonic drive, turns a spindle. A cone is fixed to a nut on the spindle. There are two limit switches for closed and fully open positions. In Fig.6 the step motor is shown.

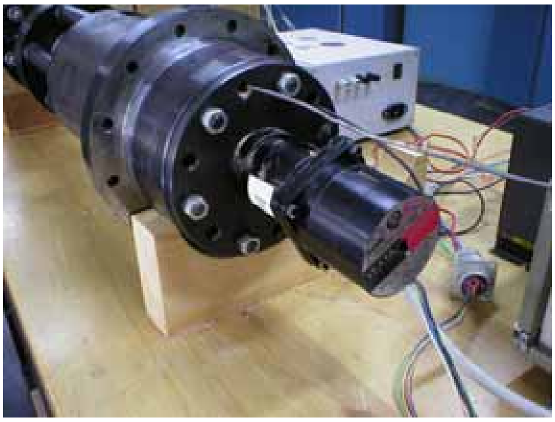


Figure 6. Step motor

The control of the flow cell device is synchronized with the wind tunnel control system (WTCS). The connection is performed via the RS-232 and a control-command computer (CCC). The software enables, via the menu, a choice of operations:

- Automatic mode operation
- Manual mode operation
- Setting constants in base data
- Displaying cone position and pressure at a throat of the pitot air intake.
- Exit from the program

Fig. 7 shows the control box of the flow cell device.

Figure 7. Control box of the flow cell

The T-38 wind tunnel test facility and a model with a flow cell

The T-38 wind tunnel test facility at the Military Technical Institute in Belgrade is a blowdown-type pressurized wind tunnel with a 1.5m x 1.5m square test section. For subsonic and supersonic tests, the test section is with solid walls, while for transonic tests, a section with porous walls is inserted in the tunnel configuration. The porosity of walls can be varied between 1.5% and 8% depending on Mach number, so as to achieve the best flow quality. Mach numbers in the range of 0.2 to 4.0 can be achieved in the test section, with Reynolds number up to 110 million per meter. In the supersonic configuration, Mach number is set by the flexible nozzle contour, while in the transonic configuration, Mach number is both set by sidewall flaps and the flexible nozzle, and actively regulated by blow-off system. Mach number can be set and regulated to within 0.3% of the nominal value. The model and the flow cell in the test section of the T-38wind tunnel are shown in Fig.8.

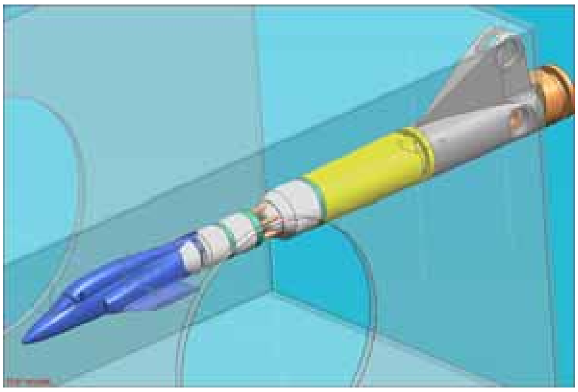


Figure 8. CAD representation of the model with the flow cell in the T-38 wind tunnel test section

Each flow cell test run is to be performed at the constant angle of attack and roll angle. For all runs pre and post tare will be taken. At the beginning, after total pressure and Mach number have been achieved, run should be at one second wait; after that data acquisition starts and the cone is moved. A typical movement of a cone is from 15 to 20 seconds. The speed of the cone depends on Mach number and total pressure. The start position of the cone depends on Mach number and total pressure as well. After the cone reaches the last position, data acquisition and wind tunnel run will be finished.

If static suction tests are not performed, the flow cell and instrumentations should be calibrated and checked. The calibration is done using Pitot air intake in the wind tunnel test section [6]. The primary purpose of the flow cell calibration is to determine the effective exit area versus a cone position. The engine face total pressure is measured by a six arm rake of six pitot tubes each and four wall static pressures downstream the engine face rake. All pressures are measured using transducers or a pressure scanner. Fig. 9 shows the flow cell with Pitot intake in the T-38 wind tunnel test section a) and alone Pitot air intake b). During this procedure, the Schlieren system is active, for the visualization of the flow around the Pitot air intake.

Figure 9. The flow cell with the Pitot air intake in the T-38 wind tunnel test section a) and Pitot air intake b)

Instrumentation, data recording and reduction

The data acquisition system consists of a Teledyne 64 channel "front end" controls by a PC Compaq computer. For transducers, a filter of 30 Hz and a channel gain of 1024 can be set. The applied supply voltage depends on the transducers. Date sampling rate can be set up to 1kHz data/s per channel.

Data reduction is performed after each run, using the standard T38-APS software package in use with the wind tunnel facility. It is done in several stages, i.e.:

- data acquisition system interfacing and signals normalizing
- determination of the main flow parameters, primary the measuring system (PMS),
- determination of the model attitude, the angle of attack and the roll angle, the cone position,
- determination of the mass flow through the air intake, total pressure recovery and distortion.

Each stage is performed by a different module.

The Schlieren system will be active for observing and analyzing the flow around the air intake. The Schlieren pictures will show the oblique shock waves and the shock/boundary layer interaction.

Conclusion

In preparation for the fighter aircraft project a flow cell device was designed and manufactured. This device is capable of controling mass flow through an air intake. The system can record more than forty channels of individual pressure transducers, temperatures or other instrumentation devices. A typical run may use all or only a portion of this capability. Data sampling rate, number of data points, throttle cone, and angle of attack are all selectable as desired for each test. The flow cell and instrumentations must be calibrated and checked before the run. During the run, the yaw angle is fixed and can be changed during the wind off. The airflow parameter (AFP) depends on mass flow through the air intakes, total temperature and total pressure and must be the same for the model and the aircraft which is obtained from real engine characteristics. Flow cell device can be used for all fighter models with diameter of the mass flow duct from 70mm.

References

[1] WELTE,D., Dornier GmbH, Friedrichshafen, Federal Republic of Germany, *Experimental analysis of a Pitot type air intake*, J. Aircraft, Vol.23, No.4,1986.

[2] WELTE,D., Dornier GmbH, Friedrichshafen, Federal Republic of Germany, *Design, wind tunnel testing and rational analysis of a ventral Pitot type air intake*, AIAA 2nd Applied Aerodynamics Conference, august 21-23 1984/ Seattle Washington, AIAA'84.

[3] McGREGOR,I.: *The characteristics and calibration of two types of airflow metering device for investigating the performance of model air-intakes*; RAE (Royal Aircraft Establishment) Technical Report 71212, November 1971.

[4] GOLDSMITH,E.L., CARTER,E.C. (ARA): *A review of methods used for the representation of engine flows in high speed wind tunnel testing*, RAE (Royal Aircraft Establishment) Technical Report 72012, November 1972.

[5] E.E.A., june 1987. Mass flow cells, specification No.87030, NUTEM LTD. International centre Spindle Way Crawley West Sussex RH10 1TH ,England

[6] GOLDSMITH,E.L., HAYWARD,R., HYDE,D.: *The internal performance of Pitot intakes at supersonic and subsonic speeds*, RAE technical Memorandum Aero, 1979

Received: 21.02.2012

Projekat merne ćelije za ocenu kvaliteta uvodnika vazduha na modelima u aerotunelu T-38

U radu je dat opis konstrukcije merne ćelije za ocenu kvaliteta uvodnika vazduha na modelima u aerotunelu T-38. Uvodnik vazduha na avionu ima vrlo značajnu ulogu zato što napaja motor vazduhom. Vazdušna struja u motoru mora biti uniformna tako da motor radi efikasno i pouzdano sa minimumom zahteva za održavanjem. Uvodnik vazduha mora vršiti svoju funkciju u svim anvelopama leta pri svim brzinama i visinama aviona. Aerotunelski testovi sa mernom ćelijom su posebno važni za ocenu dizajna uvodnika za vazduh. Aerotunelski testovi obezbeđuju veliki broj tačnih podataka potrebnih da se oceni nivo distorzije ili odvajanja struje vazduha u blizini čela motora u celoj anvelopi leta aviona.

Ključne reči: **aerodinamički tunel, merna ćelija, uvodnik vazduha, kalibracija.**

Проект измерительной ячейки для оценки качества воздухозаборника в моделях в аэродинамической трубе Т-38

В данной работе описывается конструкция измерительной ячейки для оценки качества воздухозаборника на моделях в аэродинамической трубе Т-38. Воздухозаборник на самолётах имеет очень важную роль, потому что снабжает двигатель воздухом. Воздух поступающий в двигатель должен быть хорошо сжатым, так что двигатель работает эффективно и надёжно даже с минимальными требованиями к обслуживанию. Воздухозаборник осуществляет свои функции на всех режимах полёта, на всех скоростях и на всех высотах. Испытания в аэродинамической трубе с измерительной ячейкой имеют особо важное значение для оценки качества конструкции воздухозаборника. Испытания в аэродинамической трубе обеспечивают большое количество точных данных, необходимых для оценки уровня скошения или разделения струи воздуха около лба двигателя для всех режимов полёта самолёта.

Ключевые слова: **аэродинамическая труба, измерительная ячейка, калибровка, воздухозаборник.**

La conception de la cellule de mesurage pour la validation de la qualité d'admission d'air chez les modèles dans le tunnel aérodynamique T-38

La description de la construction de la cellule de mesurage pour la validation de la qualité d'admission d'air chez les modèles dans le tunnel aérodynamique T-38 a été exposée dans ce papier. L'admission d'air chez l'avion joue un rôle significatif car elle alimente le moteur de l'air. Cet air qui entre dans le moteur doit être si bien conditionné que le moteur marche avec efficacité et fiabilité avec les exigences minimales de l'entretien. L'admission de l'air doit fonctionner pour toutes les enveloppes du vol à toutes les vitesses et à toutes les altitudes. Les tests dans le tunnel aérodynamique avec la cellule de mesurage sont très importants pour valider la conception d'admission d'air. Ces tests assurent aussi un grand nombre de données nécessaires pour évaluer le niveau de distorsion ou la séparation de l'air à proximité du front de moteur pour toutes les enveloppes du vol d'avion.

Mots clé: **tunnel aérodynamique, cellule de mesurage, calibrage, admission d'air.**