Experimental study of the efflux of an aero-engine in post-combustion regime: influence of the environmental conditions

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ABSTRACT

This study concerned the surrounding environment of the jet blast of a F16 on a trimpad in high and combustion regime. In particular, it was verified whether ambient conditions (wind, turbulence) have an impact on the jet. A numerical simulation was made of the trimpad and the plane releasing its jet, and the numerical results were validated through experiments taken on site of the trimpad.

INTRODUCTION

The reason for this study was an incident that happened on the F16 of the trimpad on the Belgian air force base of Florennes. The trimpad is used in order to work on the engine of the aircraft. The incident that is investigated is a dismantled plate that was subsequently placed somewhere in the trimpad, being pushed into the outlet tube of the trimpad when the F16 was releasing its jet into the outlet tube.

Fig 1: dismantled plate

Fig 2: view of trimpad

The purpose of this study was to determine possible causes for the incident through numerical simulation of the trimpad and the plane releasing its jet, and validating the numerical results through experiments taking on site of the trimpad.

In order to study this problem the following steps were taken:

1) identification of the measurement zones in the trimpad and choice of instrumentation
2) what is the effect of the jet on the surroundings, i.e. what is the pressure force applied on the plate if it were placed where it should have been
3) what are the effects of the ambient conditions, namely geometry and meteorological conditions

The measurement zones were determined by a numerical simulation. Firstly, a simulation of the trimpad was done in Fluent to determine the influence of the jet blast. For the modeling and meshing of the trimpad, the program Gambit was used. The simulation itself was performed in the program Fluent after importing the Gambit model. Since the exact position of the plate in the installation prior to the incident was not known, in the model the plate is poised near the wall next to the nozzle. The following dimensions are chosen for the plate: 2 m length x 2 m width x 4 mm thickness.

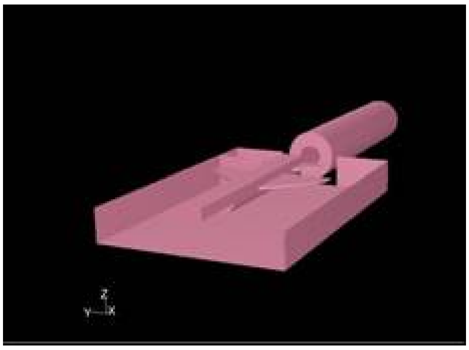


Fig 3: trimpad model

In the simulation, the airplane engine is treated as a black box since there is no interest in what happens within the engine. An engine intake velocity of 100 m/s and an engine jet velocity of 700 m/s with a jet temperature of 600 K were used as boundary conditions. This is equivalent with a mass flow through the airplane engine of approximately 50 kg/s in the symmetric model, which corresponds with a mass flow rate of 100 kg/s for the entire model.

The simulation was done for three cases: no wind entering the trimpad, and cases where a wind of respectively 10 mps and 25 mps were entering the trimpad.

After the first simulation, a second detailed simulation of the trimpad was performed, taking account the environmental conditions at the moment of the incident.

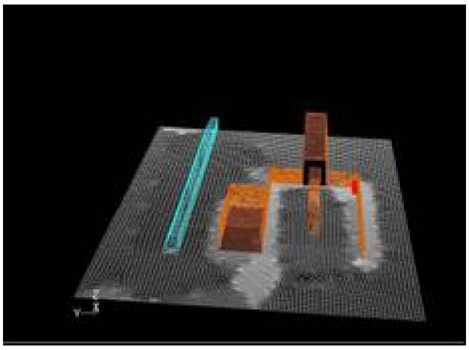


Fig 4: detailed trimpad model

Experimentally, the study was started with the engine on a jet engine test bench in a closed environment such that the flow around the engine is uniquely caused by the air intake and exhaust of the machine.

Secondly, the study was performed on the trimpad with a F16 airplane. The difference between the two situations is:

- presence of the body of the aircraft
- presence of surrounding walls
- presence of wind

The first simulation yielded as result that neither the air intake nor the jet blast caused a strong suction to be able to suck in the plate. To visualize the pressure existing over the plate during jet blast, pressure lines were defined in Fluent along which the pressure was determined. The pressure over the plate during jet blast was in all cases very low.

The second numerical simulation, which took into account the ambient conditions at the time of the incident (in particular the side wind at the moment of the incident), yielded as results that at the moment of the incident very few wind entered the trimpad, hence the trimpad is well shielded from side winds and therefore is unlikely to have been responsible for the incident.

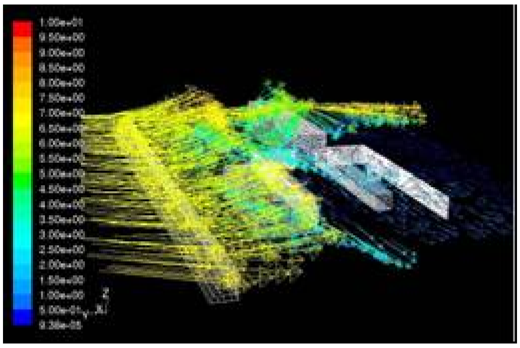


Fig 5: simulation of wind in trimpad

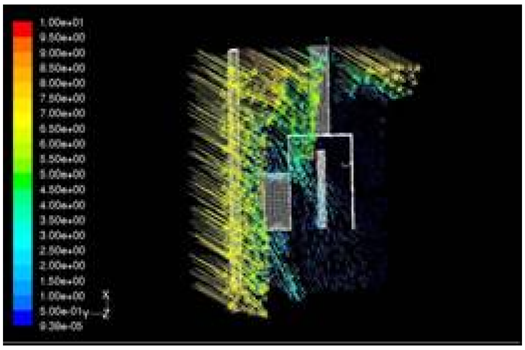


Fig 6: simulation of wind in trimpad

The numerical results were validated by measurements done with an ultrasonic transducer both on the trimpad with an airplane and in a testbench with a jet engine; measurements were performed in the corners of the trimpad and around the location where the plate was placed prior to the incident

The measurement device that was chosen to validate the numerical results was the WS425 ultrasonic wind sensor manufactured by the Finnish firm Vaisala.

Figure 1: WS425 ultrasonic anemometer

The WS425 ultrasonic wind sensor has an on-board microcontroller that captures and processes data and performs serial communications.

The wind sensor has an array of three equally spaced ultrasonic transducers on a horizontal plane. The sensor measures transit time, the time that it takes the ultrasound to travel from one transducer to another. The transit time is measured in both directions.

The transit time depends on the wind velocity along the ultrasonic path. For zero wind velocity, both the forward and reverse transit times are the same. With wind along the sound path, the upwind transit time increases whilst the downwind time decreases.

The microprocessor of the microcontroller calculates the wind speed from the transit times using the following formula:

$V_w = 0.5 \cdot L \cdot (1/t_f - 1/t_r)$

Where:

V_w = wind velocity
L = distance between two transducers
t_f = transit time in forward direction
t_r = transit time in reverse direction

Measuring the six transmit times allows wind velocity to be calculated for each of the three ultrasonic paths, which are offset to each other by 120°. The calculated wind speeds are independent of altitude, temperature and humidity because they cancel out with the six measurements even though the velocity of sound affects individual transit times.

The wind sensor can work in analog or serial mode; for the experimental validation the serial mode was chosen. In serial mode, the device can measure velocities up to 65 m/s and has a resolution of 0.1 m/s.

For the wind direction one transducer arm is permanently marked with an N for north and another with an S for south. By aligning this transducer arm with true north, a reference is obtained for the direction of the incoming wind.

Measurement locations

To validate the numerical simulation, measurements were taken on three locations in the trimpad: in the upper left corner, between a wing and the jet, and next to a wing.

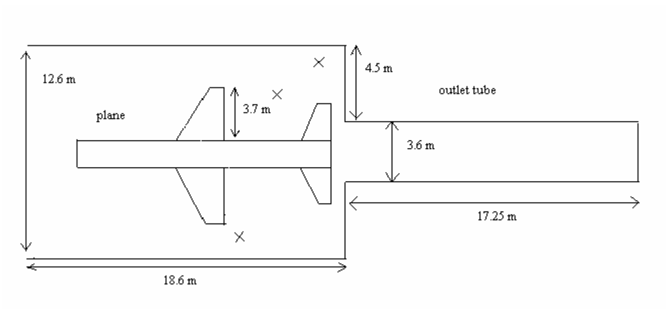
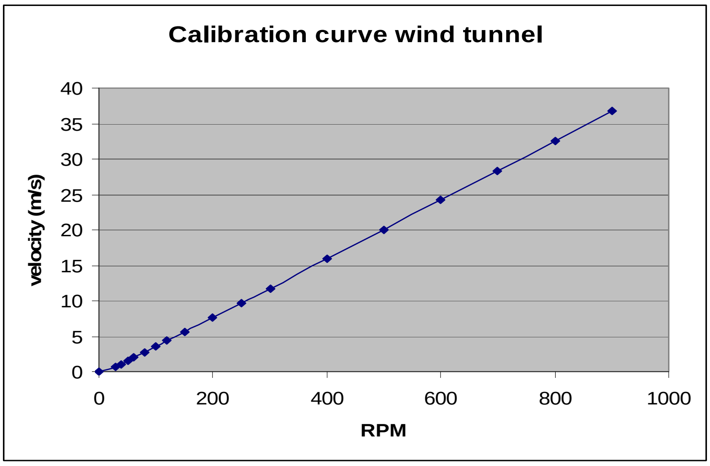


Fig 7: choice of measurement locations

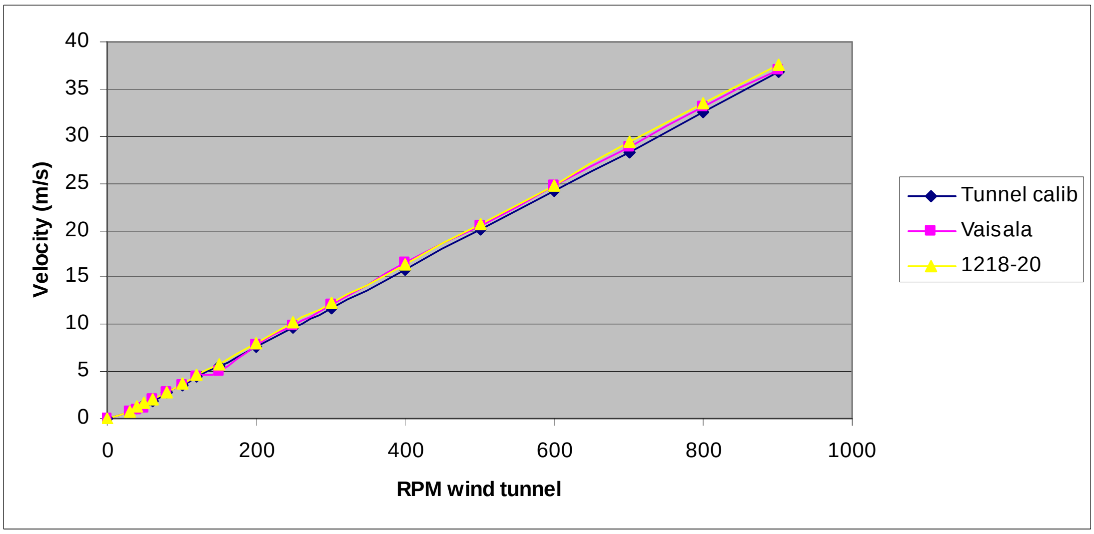
The instrument was calibrated in the firm, but this calibration was tested in the subsonic open circuit wind tunnel of the Royal Military School. The WS425 was installed in the test section of the wind tunnel and used to measure the known wind speeds occurring in the test section. Comparison was also made between the measurements of the WS425 and the measurements of a 1218-20 hot film probe in the test section.

The calibration curve of the subsonic wind tunnel is as follows:



The above measurements data were gathered with a Pitot tube in the test section of the wind tunnel.

Comparing the calibration speeds of the wind tunnel with the speeds measured by respectively the hot film probe yielded the following:



One can conclude the WS425 is on par with the calibrated wind speeds and the wind speeds measured with the hot film probe.

RESULTS AND DISCUSSION

1) <u>Results in left corner</u>

The meteorological conditions at the base during measurements (27 November 2007) was as follows:

Temperature: 2.6 – 4.9°C
Wind speed: 22 km/h
Wind direction: west

This means that on the time the measurements were performed, the wind blew to the trimpad from the left (as on the day of the incident). First measurements with an idle airplane engine showed a very few wind in the trimpad, namely 1 m/s. This confirms that the trimpad is well protected from incoming wind by means of the walls and the talud. Hence, this situation corresponds to the simulation case as described in section 3.1, namely the case where there is no wind in the trimpad.

With the airplane releasing its jet, the maximum speed measured in the left corner was 2.8 m/s, which corresponds well with what the simulation suggested, namely speeds between 2.25 m/s and 3.0 m/s.

2) Results in vicinity of wing

With the airplane releasing its jet, the maximum speed measured around the wing was 4 m/s, which corresponds well with what the simulation suggests, namely a speed around 3.0 m/s.

3) Results between left corner and wing

With the airplane releasing its jet, the maximum speed measured was 2.6 m/s, which corresponds well with what the simulation suggested, namely speeds between 2.25 m/s and 3.0 m/s.

4) Results in test bench

Measurements in the test bench were only possible with the engine in idle mode; it was found that for maximum thrust the anemometer did not measure any valid data. This is due to the fact that a jet engine produces both infrasonic and ultrasonic noise; due to the closed space of the hangar the ultrasonic noise of the jet engine disturbs the ultrasonic sensors of the anemometer, rendering measurements impossible.

The measurements in idle mode of the engine showed a maximum speed of 2.1 m/s. This is comparable to the measurements in the trimpad under ambient conditions, since the trimpad is very well ‘isolated’ from side wind so that few wind enters the trimpad.

Measurements were also performed (with the same measuring device) in the test bench of the airbase of Florennes, in order to investigate the influence of the jet in the absence of ambient conditions as in the trimpad. The test bench is basically a hangar where the engine of a F16 is positioned. From the control room next to the hangar, the engine can be turned on from idle to maximum thrust and monitored.

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Problems that occurred during the measuring on the trimpad were vibrations and high frequency noise; the vibrations required the device on which the wind meter was installed to be held steadfast.

A significant problem that occurred, was high frequency noise: a jet engine is a broad band sound source, and henceforth radiates from infrasound (<2 Hz) up to ultrasound (>20 kHz) at near distance. The WS425 anemometer operates at frequency of 100 kHz. Thus the jet engine at proximity of an anemometer acted as a temporal disturbing sound source, so that the anemometer did not take measurements when the jet engine of the F16 worked at maximum power.

REFERENCES

[1] User’s Guide Vaisala WINDCAP® Ultrasonic Wind Sensor WS425
[2] DASH/F16 confidential report