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ABSTRACT

The aerospace industry is showing a growing interest to apply acoustic treatment in the exhaust ducts of turbofan engines to attenuate combustion and turbine noise. The design, optimisation and testing of hot stream liners require improved theoretical models and facilities to validate and evaluate the acoustic performances of these liners under realistic engine operating conditions. To extend the capabilities for liner testing, NLR has modified an existing burner rig. The main objective was to build a facility for hot stream liner testing up to a flow Mach number of 0.4 and a maximum temperature of 500 ºC, which has been met. Both insertion loss and in-situ acoustic impedance measurements can be performed at maximum sound pressure levels of about 145 dB. An overview is given of the design and commissioning of the new facility, the instrumentation and the measurement techniques. Furthermore a selection of results are presented on measured insertion losses and acoustic impedances.

**Nationaal Lucht- en Ruimtevaartlaboratorium**
National Aerospace Laboratory NLR

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# A new facility for hot stream acoustic liner testing

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This report is based on a presentation held at the Tenth International Congress on Sound and Vibration, Stockholm, Sweden, 7-10 July 2003.





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# A new facility for hot stream acoustic liner testing

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**Abstract**

The aerospace industry is showing a growing interest to apply acoustic treatment in the exhaust ducts of turbofan engines to attenuate combustion and turbine noise. The design, optimisation and testing of hot stream liners require improved theoretical models and facilities to validate and evaluate the acoustic performances of these liners under realistic engine operating conditions. To extend the capabilities for liner testing, NLR has modified an existing burner rig. The main objective was to build a facility for hot stream liner testing up to a flow Mach number of 0.4 and a maximum temperature of 500 ºC, which has been met. Both insertion loss and in-situ acoustic impedance measurements can be performed at maximum sound pressure levels of about 145 dB. An overview is given of the design and commissioning of the new facility, the instrumentation and the measurement techniques. Furthermore a selection of results are presented on measured insertion losses and acoustic impedances.

## INTRODUCTION

As a part of the project SILENCE(R), NLR specified, designed and manufactured a hot stream acoustic liner test facility, which is located at the NLR site in the Noordoostpolder. An existing burner rig of NLR's Structures and Materials Division, the so-called Compressor and Materials Test Installation (CMTI), was modified to facilitate this type of testing. This facility is additional to the Acoustic Flow Duct Facility (NLR-FDF), which has been extensively used over a period of 25 years for acoustic liner testing under ambient temperatures (Ref. 1). Before actual design, the test rig specifications were made in close co-operation with engine and liner manufacturers and a pre-test programme was carried out in the Acoustic Flow Duct Facility to investigate the acoustic measurement techniques.

## TEST RIG SPECIFICATIONS, DESIGN AND MANUFACTURE

### Test rig specifications

Besides industrial specifications, additional constraints had to be taken into account: (1) the power of the CMTI compressor driver system, (2) the gas burning capacity and (3) the consideration that the acoustic test panels for the new facility should be interchangeable with test panels of the Acoustic Flow Duct Facility. The latter requirement defined the hot stream test panel dimensions and therefore the test section dimensions. All considerations led to the following target parameters: a maximum temperature of 500 ºC, a maximum Mach number of 0.4, a maximum SPL of 145 dB and a test frequency range between 0.5 and 5 kHz. The acoustic challenges for the new facility compared to NLR-FDF were:

1. to conduct insertion loss measurements in the absence of reverberation chambers,
2. to conduct in-situ acoustic impedance measurements under hot conditions without means to tune the test section to resonance (the splitter-plate in NLR-FDF) and
3. to measure acoustic pressures with spurious combustion and flow noise.

**Test rig design**

The hot stream liner test rig was designed by NLR's design office. Starting point was the existing CMTI, which consists of a compressor, combustion or gas burning chamber, a contraction and a rectangular exhaust nozzle. Maximum compressor capacity is about 3000 $m^3$ /h, whereas maximum burner capacity is 500,000 kcal/h. The hot gases are flowing into the collector, with an inlet diameter of 1.2 m further into the contraction. The collector, the contraction, the rectangular duct and the exhaust nozzle were redesigned for two types of hot stream liner tests: insertion loss measurements and in-situ acoustic impedance measurements on liner facing sheets. The total axial dimension of these elements is about 2.0 m.

General outline of the new set-up is given in figure 1. It consists of a new collector and contraction followed by a rectangular duct with cross-section dimensions of 0.15 x 0.05 $m^2$. The modular rig has the following elements: a collector/contraction of 900 mm length, a source section (300 mm), a liner test section with two boxes (400 mm), two acoustic and aerodynamic measurement sections upstream and downstream of the liner test section (2 x 140 mm) and an exit nozzle (100 mm). The rig is made of stainless steel plates of 3 mm thickness welded together. The elements are connected by flanges of 10 mm thickness. Loudspeakers are connected to the source section by two double wall air-cooled horns. The liner test panels for in-situ acoustic impedance measurements are placed at the side-wall of the source section opposite to the horns. The acoustic test panels for insertion loss measurements are placed in the boxes of the liner test section.

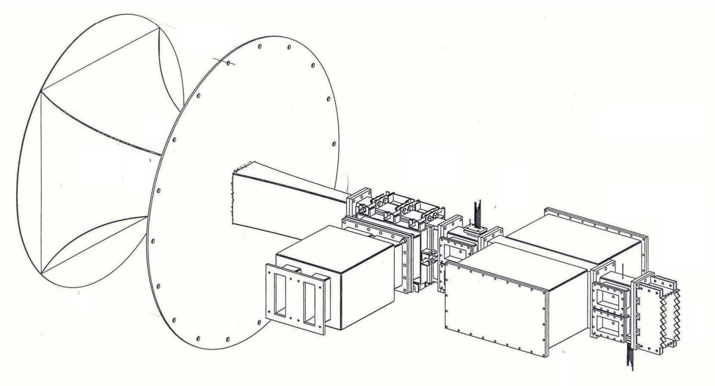

*Figure 1 Hot stream liner test set-up with collector/ contraction, source section, measurement section for the incident acoustic field, liner test section with two boxes, measurement section for the transmitted acoustic field and lined exit nozzle.*

**Test rig manufacture**

The cutting and the welding of the plates were out-sourced. NLR's workshop did the finishing work and installed the aerodynamic and acoustic instrumentation. The detached duct elements without the collector/contraction are shown in figure 2.

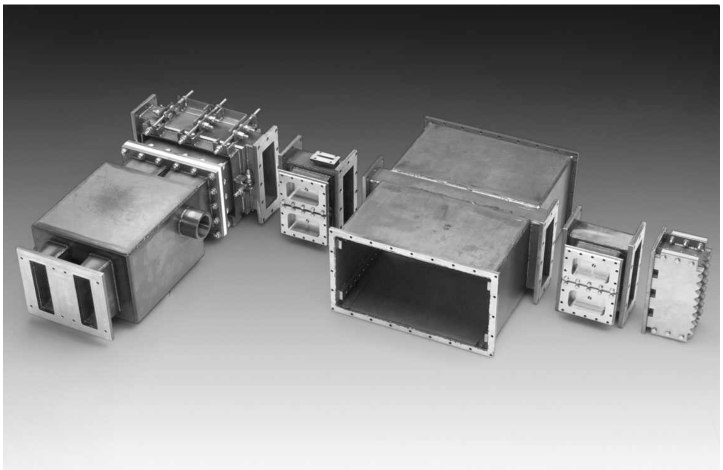

*Figure 2 Duct elements of the NLR hot stream liner test facility.*

## DEVELOPMENT OF MEASUREMENT TECHNIQUES

**Pre-tests in the Acoustic Flow Duct Facility**

Pre-tests to investigate the measurement techniques for insertion loss and in-situ acoustic impedance measurements were carried out in the Acoustic Flow Duct Facility. Note that the new hot stream facility does not have reverberation rooms, where the flow velocities are very low resulting in high acoustic signal to flow noise ratio's (SNR's). Results of conventional insertion loss results obtained from measurements in the reverberation rooms upstream and downstream of the liner test section were compared with results derived from wall and remotely mounted microphones. The latter are installed in lined cavities of 13 mm depth to increase the acoustic signal to boundary layer flow noise ratio (Figure 3). An increase in SNR was also investigated by deriving the insertion losses from measured crosspowers with various references instead of the conventional use of measured autopowers. The use of crosspowers significantly improves acoustic signal to flow noise ratio, however it gives strong fluctuations in measured insertion losses. The technique with remotely mounted transducers based on measured autopowers has been selected for the insertion loss measurements in the hot stream liner test facility.

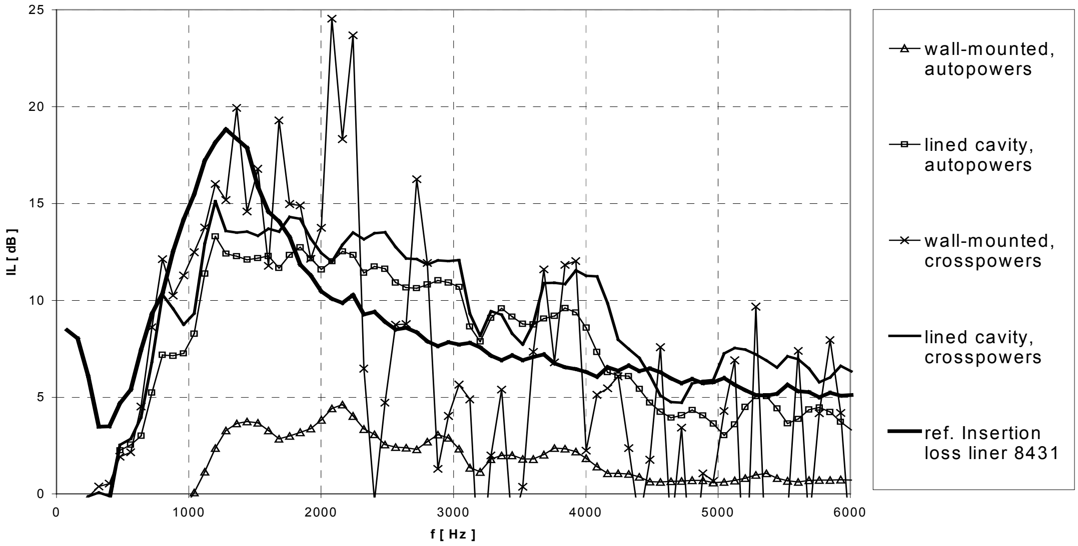


*Figure 3 Comparisons of various measured insertion losses in the NLR-FDF, reference liner 8431, flow Mach number is 0.35, broadband excitation, Δf = 80 Hz.*

For in-situ acoustic impedance measurements, two techniques were investigated and compared to the conventional in-situ microphone technique using miniature piezo-resistive Endevco types 8514 and 8507 pressure transducers at respectively the liner facing sheet and cell back wall. A test sample (Figure 4) was made with 3 instrumented cells with a linear (Perfolin) facing sheet and a cavity depth of 15 mm:

1. a reference cell instrumented with Endevco's for comparisons (14 mm inner diameter),
2. a large annular cell (12 mm inner and 45 mm outer diameter), instrumented with 5 water-cooled Kulite WCT-312 pressure transducers (1 at the facing sheet and 4 at the back wall) and
3. a cell (14 mm inner diameter) instrumented with probe microphones of 1 mm inner diameter and a length of about 0.6 m.

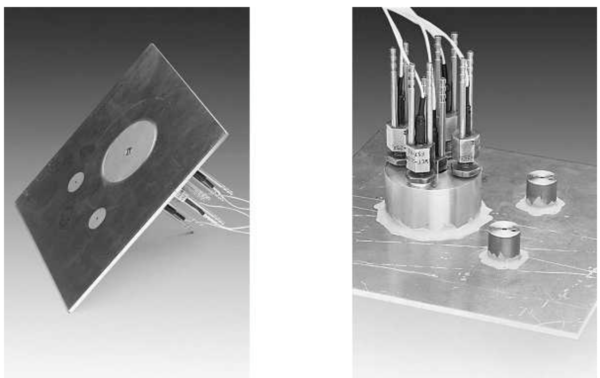

*Figure 4 Test sample to validate various in-situ acoustic impedance measurement techniques (reference cell, probe cell and large annular cell).*

The tests reveal that the measured impedance of the large cell nearly matches the value of the reference cell, except for a small and frequency independent correction factor caused by the blockage of the facing sheet mounted Kulite (Figure 5). Also the predicted cavity reactance is shown. The resistances derived from measurements with probe microphones are rather inaccurate, i.e. the measured value may be up to twice as high as the true value (R ≈ 2.5). Therefore the technique with the large annular cell instrumented with Kulite WCT-312 pressure transducers has been selected for the hot stream liner test facility. The technique with probe microphones remains optional.

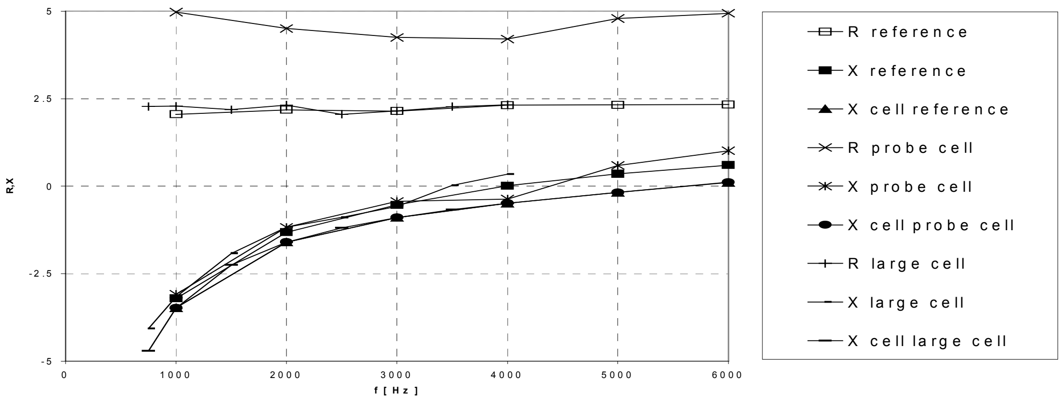


*Figure 5 Comparison between measured in-situ acoustic impedances with various techniques, $Z=R+iX$ ($X=X_{facing\ sheet}+X_{cell}$), $M = 0.3$, SPL = 120 dB, tonal excitation.*

**Instrumentation of the hot stream liner test facility**

Acoustic instrumentation for the determination of transmission and insertion loss and aerodynamic instrumentation is placed in two measurement sections upstream and downstream of the lined test section (the section with two boxes). Axial length is 140 mm (Figure 6). One side wall of each section has two chambers of 80 x 40 $mm^2$ cross section filled with metal foam RECEMAT of 13 mm depth. Two Kulite WCT-312 transducers are flush mounted at the back wall of the cavity at 13 mm distance from the flow boundary layer to enhance acoustic signal to flow noise ratio. At the upper/lower wall and second side wall aerodynamic instrumentation is mounted:

1. two total pressure rakes of 25 mm height (upper/lower wall and upper/lower side-wall) and four static pressure taps and
2. a total temperature probe and a thermocouple to measure the surface temperature.

Acoustic instrumentation for in-situ acoustic impedance measurements (see preceding section) is placed in the annular cell opposite to the horns of the source section. Furthermore several additional thermocouples and static pressure taps are distributed along the duct. Aerodynamic and acoustic data acquisition is done with the 128-channels GBM-system (Ref. 2).

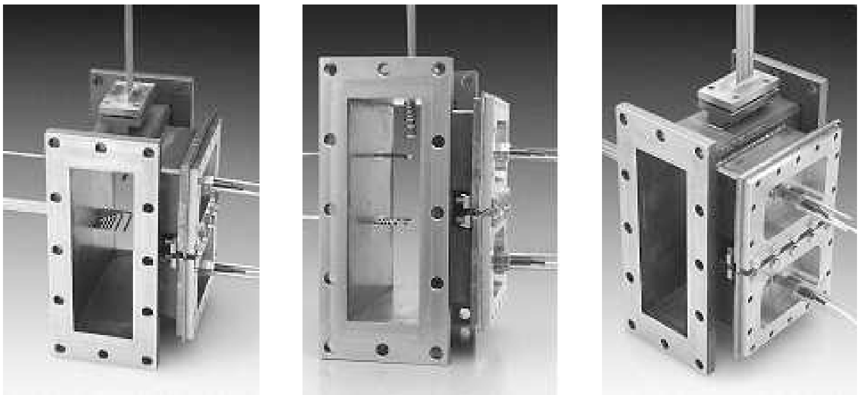

*Figure 6 Measurement sections with acoustic (Kulites at right side) and aerodynamic instrumentation for transmission and insertion loss measurements.*

**Test panel dimensions**

Dimensions of the test panels for transmission loss or insertion loss measurements are 300 x 170 $mm^2$. Maximum thickness is 150 mm and one or two panels are required. The panels will be clamped to the duct side wall. The metal boxes containing the liner test samples are designed to prevent leakage.

A facing sheet sample of 100 x 100 $mm^2$ is required for in-situ acoustic impedance measurements, which is brazed to the instrumented annular test cell. Optionally a liner sample of 170 x 170 $mm^2$ can be instrumented with probe microphones. Note that in the latter case the test results will be less accurate.

## TEST RESULTS

**Commissioning of the rig**

The rig was successfully commissioned in October and November 2002. Several aspects as (1) control of fan rotational speed, (2) adjustment of gas temperature, (3) gas technical aspects (oxygen supply and flame instabilities), stability and repeatability of aerodynamic and acoustic parameters have been investigated. Furthermore aerodynamic calibrations were carried out and the facility limits in terms of maximum temperature, flow Mach number and overall SPL were established. The maximum temperature is 500 ºC at a flow Mach number of 0.35, the maximum flow Mach number is 0.4 at a temperature of 440 ºC and the overall SPL is 145 dB. Minimum flow Mach number at hot conditions is 0.3. The cooling of the loudspeakers and Kulites with compressed air works well. Acoustic signal to flow noise ratio by maximum load on the loudspeakers is good (better than 10 dB, except at frequencies near 2900 Hz), however this maximum load seriously effects the working life of the loudspeakers. Typical acoustic spectra of the incident and transmitted sound fields in a hard-walled duct are given in figure 7.

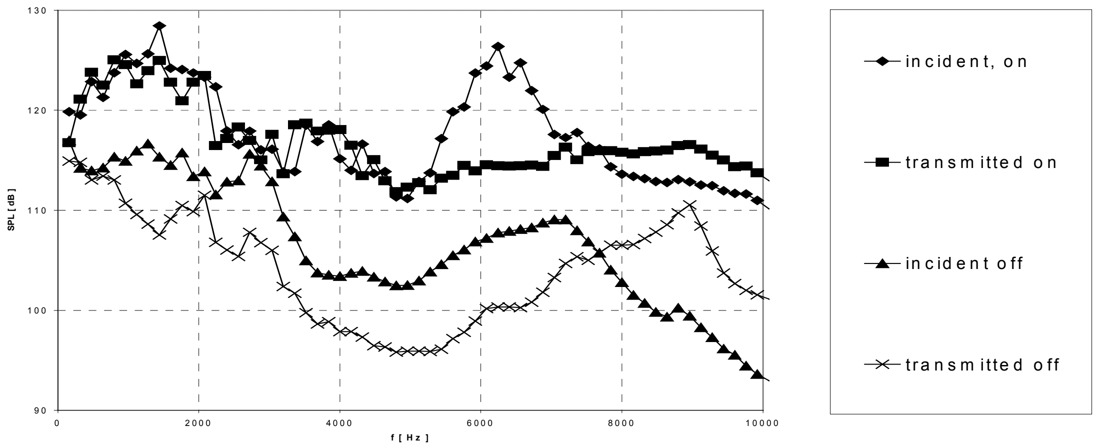


*Figure 7 Acoustic signal to flow noise ratio, hard-wall,T = 500 ºC, M = 0.35, loud-speakers are switched on or off (flow noise only), broadband excitation, Δf = 160 Hz.*

**Insertion loss**

The insertion loss is defined as the difference in measured transmission losses with and without a liner installed in the test section. The transmission loss is the difference in SPL's measured upstream (incident sound field) and downstream (transmitted sound field) of the liner test section. The tests reveal desired attenuation rates between 5 and 20 dB at both half and fully lined configurations (not too much attenuation, which would lead to low SNR's and not too less attenuation which would lead to problems in ranking the liners). The insertion loss of the NLR reference liner is given in figure 8a as example. (T = 440 ºC and M=0.3). This liner has a perforated facing sheet of 22% porosity, a cell depth of 13 mm and is filled with porous metal foam.

**In-situ acoustic impedance measurements**

Liner samples of various types (linear and perforate) have been tested. The results reveal that the measurement technique works very well for these air-filled cavity liners. The measured impedance of a perforate type of liner (porosity 10%, cell depth 15.0 mm) is given in figure 8b as an typical example (T = 440 ºC and M=0.3).

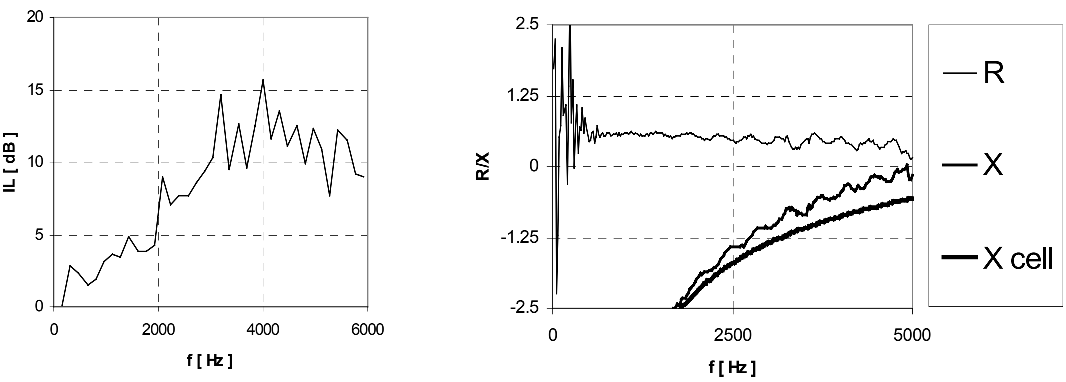


*Figure 8a+b Insertion loss (left) and in-situ acoustic impedance, T = 440 ºC, M = 0.3, broadband excitation, Δf = 160 Hz (a) and Δf = 20 Hz (b).*

## CONCLUSIONS

A new hot stream liner test facility has been successfully designed, built and commissioned at NLR. Insertion loss and in-situ acoustic impedance measurements have been carried out up to:

1. a maximum temperature of 500 ºC at a flow Mach number of 0.35,
2. a maximum flow Mach number of 0.4 at a temperature of 440 ºC,
3. and at an overall SPL of 145 dB.

Minimum flow Mach number at hot conditions is 0.3. During a short period tests have been carried out at 600 ºC, but these require replacement of current isolation material at the combustion chamber wall with isolation material with a higher maximum temperature. Improved measurement techniques for both types of testing have been developed and applied under hot stream conditions. The new rig will be operated besides the existing Acoustic Flow Duct Facility and enhances NLR's capabilities on acoustic liner testing for aerospace industry.

Maximum temperature and flow Mach number can be further increased, the latter by a decrease of the flow duct cross-section. The possibility to exchange test samples between both liner test facilities at NLR will then be lost.

## ACKNOWLEDGEMENT

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