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EXPERIENCE LEARNED FROM ARIANE 5 WIND TUNNEL TESTS REGARDING AERODYNAMIC NOISE ON UPPER PART AND BUFFETING LOADS ON REAR PART

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ABSTRACT

Launch vehicles are subjected to steady and broadband unsteady pressure fields during transonic and maximum pressure dynamic phases. These pressure fields may be very severe in launch vehicle zones, which have relatively rapid local variations of geometry. These geometrical variations lead to adverse pressure gradients and separated flow in significant part of the launch vehicle. These aerodynamic loads may damage structures or subsystems and be dimensioning. Consequently, they have to be considered in the design of vehicles. This paper deals with the experimental analysis of: i) aerodynamic loads on the ARIANE 5 upper part (5- 2000 Hz, full scale), ii) buffeting loads on the ARIANE 5 rear part (5- 80 Hz full scale). The main point, which is discussed in this paper, concerns the way of defining full-scale aerodynamic noise and buffeting loads from reduced scale test results.

1 - INTRODUCTION

Upon lift-off and during ascent, the launch vehicles are subjected to external intense unsteady pressure fields, which excite the structures. The study of these excitations, of the resulting vibrations and noise transmission is of great importance for the design of subsystems, for defining acoustic environment of payloads and random vibration qualification levels at equipment. So it is required in the early design stage of launch vehicle programs to characterize the external pressure fluctuation field in order to analyze the response of structures. As mentioned before, the unsteady pressure field is broadband.
Roughly speaking, this external unsteady pressure field can be divided in two parts:

- The low frequency unsteady pressure field (frequencies lower than 80 Hz for the case considered here). The low frequency unsteady loads are called buffeting loads. Buffeting is a fluid structure interaction, the structure being considered rigid. As these loads have a low frequency content, they may be dimensioning and have to be taken into account in the launcher design,
- The high frequency pressure field (frequencies higher than 80 Hz). The high frequency loads are sometimes called aerodynamic noise or aeroacoustic loads.

2 - EXPERIMENTAL ANALYSIS OF AERODYNAMIC NOISE ON UPPER PART AND BUFFETING LOADS ON REAR PART

As there are no numerical tools available to predict unsteady pressure fields, tests in wind tunnels have to be performed. The purpose of this paper is to discuss two major reduced scale tests to characterize transonic unsteady pressure loads regarding ARIANE 5 launch vehicle:

- ARIANE 5 upper part tests performed on 0.025 scale rigid mock-up in NLR wind tunnel (Netherlands), [1] and [2], to measure the aerodynamic noise applied to external structures (5- 2000 Hz, full scale). The characterization of the aerodynamic noise applied to upper part external structures is required to estimate the acoustic environment of payloads [3] and the vibration levels at equipment mounting points of Vehicle Equipment Bay,

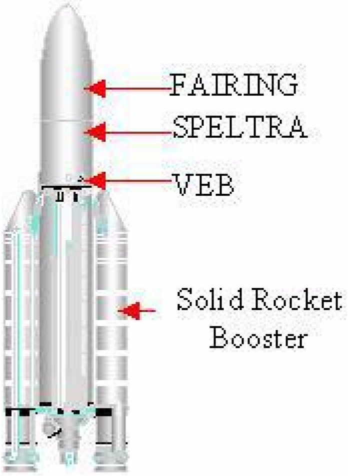

Figure 1: ARIANE 5 launch vehicle.

- ARIANE 5 rear part tests performed on 0.017 scale rigid mock-up in ONERA wind tunnel (France), [4], to measure the buffeting loads at rear part (5- 80 Hz full scale). The analysis of buffeting loads is of great importance in the case of ARIANE 5 rear part configuration because of, see figures 1 and 2:
  - Offset between the two solid propellant boosters (EAP) and one main cryogenic stage (EPC) nozzle exit planes,
  - Existing protuberances. Some subsystems are mounted on the external conical part of the thrust-frame,
  - EAP/EPC connection.

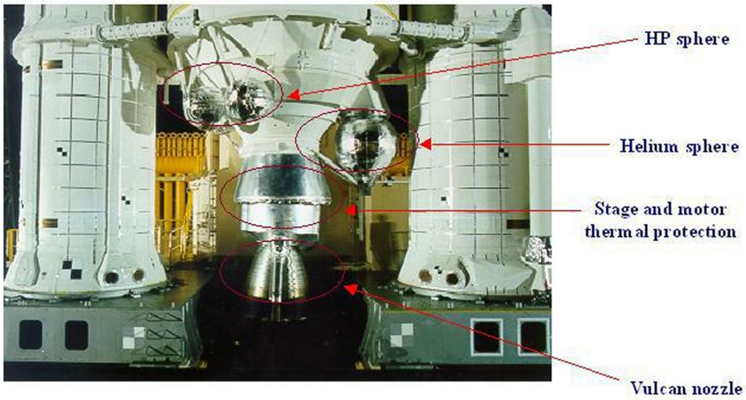

Figure 2: View of ARIANE 5 rear part and of subsystems.

It has been expected that these specific features would lead to intense steady and low frequency unsteady pressure fields at ARIANE 5 rear part. The unsteady pressure fields induce dynamic loads, which have to be taken into account in the design of structures. The buffeting loads have to be estimated at two levels:

- At subsystem level. The unsteady pressure fields induce dynamic loads on the Vulcain nozzle of main central engine EPC and on subsystems mounted on the rear part, see figure 2. These loads have to be estimated to check the design of subsystems (up to 80 Hz at one scale),
- At system level. The unsteady pressure loads excite the EPC actuators, which, in turn, excite the launch vehicle and acceleration levels are induced at the payload/launcher interface (up to 20 Hz at one scale).

For both test campaigns, the flight phase of concern is the transonic one.

3 - FULL SCALE TRANSPOSITION

The two above-mentioned experimental analysis are described in details in [1], [2] and [4]. The main point of interest in this paper is the full-scale transposition. How to get full-scale values from reduced scale test results? The unsteady pressure levels measured in wind tunnels are expressed as follows:

$$\mathbf{S_{adim}} = \frac{\mathbf{S_i U}}{\mathbf{q^2 L}} \text{ versus Strouhal number } \mathbf{f_{adin}} = \frac{\mathbf{fL}}{\mathbf{U}}$$

where

- $\mathbf{S_i}$ is the Power Spectral Density of pressure measured by i measurement,
- **U** is the free stream speed,
- **q** is the free stream dynamic pressure,
- **f** the frequency,
- **L** a characteristic length.

Consequently,

$$\mathbf{S_{i\ full\ scale}} = \mathbf{S_{i\ reduced\ scale}} \times \frac{\mathbf{q^2_{full\ scale}}}{\mathbf{q^2_{reduced\ scale}}} \times \frac{\mathbf{L_{full\ scale}}}{\mathbf{L_{reduced\ scale}}} \times \frac{\mathbf{U_{reduced\ scale}}}{\mathbf{U_{full\ scale}}}$$

The main problem is the choice of the characteristic length. This characteristic length is chosen as follows.

3.1 - Aerodynamic noise (high frequency excitation)

The characteristic length used for obtaining full-scale aerodynamic noise levels from reduced scale test measurements is the displacement boundary layer thickness. First, in the case of the ARIANE 5 upper pert, the boundary layer thickness has been calculated by the PROBSTEIN formula. Then the displacement boundary layer by the MICHEL formula. The ARIANE axisymmetrical shape of the upper part is taken into account using a shape coefficient obtained by analyzing the static pressure coefficient measured during wind tunnel tests (1,7% scale mock-up) at locations in and out of solid rocket boosters EAP planes.

3.2 - Buffeting loads (low frequency excitation)

The characteristic length is a geometric length.
In the following paragraphs, the above-presented techniques of full-scale transposition are validated in comparing in-flight measured values with predicted full-scale levels.

4 - FULL SCALE TRANSPOSITION FOR AERODYNAMIC NOISE

A 2.5 per cent scale ARIANE 5 upper part mock-up tested in NLR transonic wind tunnel was composed of:

- The short nose Fairing (9 transducers),
- The SPELTRA structure (8 transducers),
- The VEB (10 transducers),
- The EPC front shirt (8 transducers),
- The EAP front cones (11 transducers).

The estimate of the full-scale displacement boundary layer thickness differs from the test condition one by a factor of 2. The flight measurements regarding VEB and Fairing are compared with predicted noise levels in figures 3 and 4. The noise levels derived from wind tunnel test results, after full-scale transposition according to the technique presented early are quite close to the measured ones. The deviations are lower than 3 dB per one-third-octave band (5 dB by graduation on figures 3 and 4).

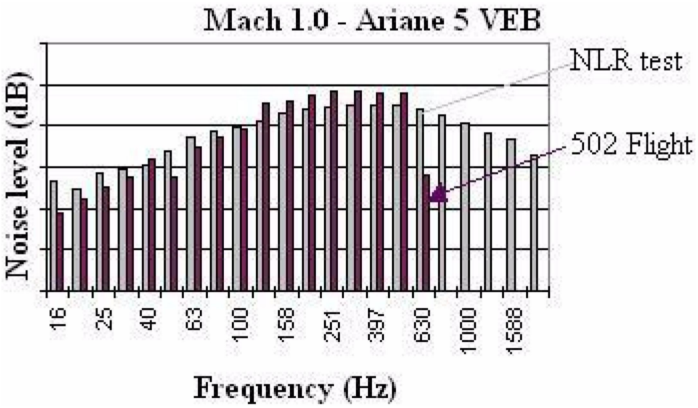

Figure 3: Comparison between flight measurement and predicted levels from wind tunnel tests after full scale transposition.

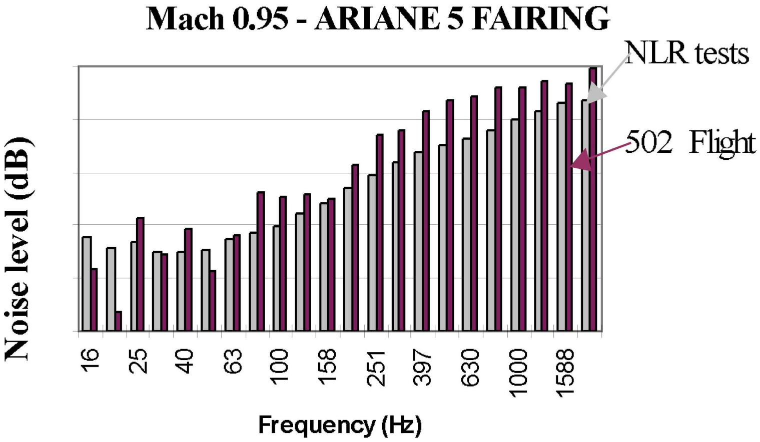

Figure 4: Comparison between flight measurement and predicted levels from wind tunnel tests after full scale transposition.

5 - FULL SCALE TRANSPOSITION FOR BUFFETING

A 0.017 scale model of the ARIANE 5 launcher, see figure 5, held by a lateral sting upwards EAP, has been tested from Mach =.5 up to 2. This mock-up was representative of the complex geometry of launch vehicle rear part (protuberances, EAP/EPC attachments). 28 steady pressure measurement and 27 unsteady pressure measurement (Kulite XCQL-062) have been, as usual, flash mounted. In flight, it is clearly not possible to implement a sufficient number unsteady pressure measurements, to characterize the aerodynamic environment. As a consequence the only way to check the validity of the full scale transposition and of the methodology of establishing unsteady loads before flight, is to compare the predicted effects of this loads on the launcher with the in flight measured ones, when measured. Comparisons between predicted and measured values during 502 ARIANE 5 flight have been made regarding:

- The loads induced in the two U and V actuators of the EPC Vulcain nozzle,
- The accelerations on the Vulcain nozzle.

5.1 - Loads induced in the EPC actuators

Dynamic loads induced in the actuators of EPC nozzle in the frequency domain

The unsteady pressure environment induces dynamic loads on the EPC nozzle. These loads, in turn, induce forces and moment at gimbal point, which is the attachment of the EPC nozzle to the rear of the EPC main central stage. The loads applied to the nozzle have to be countered by the two U and V actuators. The pressure inside actuators is measured in flight. Consequently, knowing the actuator area, it is possible to estimate the in-flight forces in the actuators. The forces created by buffeting loads

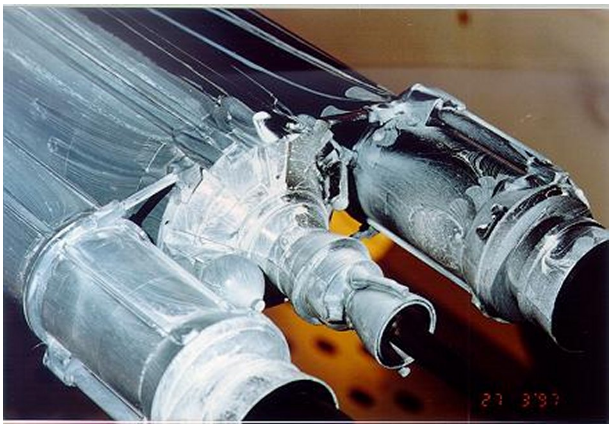

Figure 5: View of the mock-up in wind tunnel.

in actuators have been estimated before flight in a numerical closed loop analysis, using dynamic forces and moments at gimbal point estimated after the test analysis from the second campaign test results.

RATIO BETWEEN ESTIMATED DYNAMIC LOADS THROUGH AN CLOSED LOOP ANALYSIS AND ONES MEASURED IN 502 FLIGHT (Mach 0.8)	
Power Spectral Density of loads in V actuator RMS values between 5 and 18 Hz	Power Spectral Density of loads in U actuator RMS values between 5 and 18 Hz
1.18	1.01

Table 1: Comparison between dynamic loads measured in 502 flight and estimated ones.

The estimated loads are, consequently, very close to the measured ones. The frequencies, at which the levels are maximum, are also well restituted, as shown in table 2.

Mach 0.8	**502 flight**	**Closed loop calculation**
Pitch plane	9- 10.2 Hz	8.5 Hz
8.5 Hz	10.3 Hz	10.5 Hz

Table 2: Comparison between frequency of highest loads occurred in flight and estimated.

5.2 - Acceleration on the nozzle

The accelerations on some points of EPC nozzle have been measured during 502 flight. The table 3 presents a comparison between maximum measured and predicted accelerations levels. The acceleration levels before flight have been estimated through the calculation of the response of the EPC nozzle to the unsteady pressure field derived from the first campaign test results.

RATIO OF ESTIMATED ACCELERATION AND MEASURED ONES (dB)	
Transonic phase (ovalisation modes)	**1.7**
Transonic phase (frequencies up to 80 Hz)	**3.1**

Table 3: Maximum accelerations of the EPC nozzle.

The estimated values are satisfactory, taking into account the usual margin policy. The prediction is pessimistic too.

6 - CONCLUSION

The full-scale transposition chosen, which is to take:

- A characteristic length equal to the displacement boundary layer thickness for high frequency aerodynamic noise,
- A geometric length for low frequency buffeting loads, has been validated by the 502 ARIANE 5 flight measurements. The predicted levels are better, in most cases, than 3 dB, which is satisfactory.

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