Free Shock Separation with Downstream Excitation

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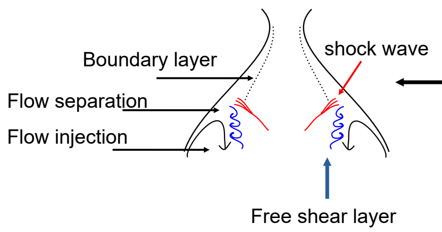
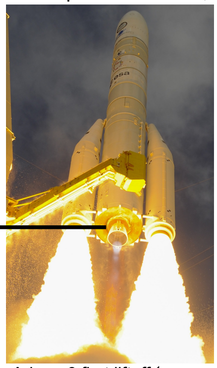
1. CONTEXT

The Vulcain Engine is designed to operate at high altitude where the pressure is low. During the liftoff, Vulcain is not adapted to operate at 1 atm, leading to flow separation inside the nozzle.

Free Shock Separation (FSS) - without flow reattachment:





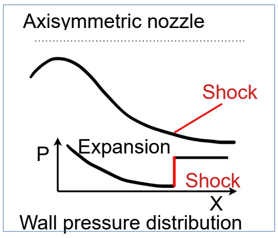
Ariane 6 first liftoff [1]

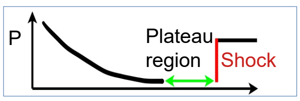
2. OBJECTIVES

- The nozzle is axisymmetric, however, a new 2D experimental setup developed by Demni (PhD 2022, CNES)[2] enables the study of FSS. The main goal is to extend Demni's setup to also allow **controlled acoustic excitation** downstream of the FSS region.
- Does the shock's response to a downstream acoustic wave depend on the flow state (whether it is attached or detached) and on the frequency (transfer function)?

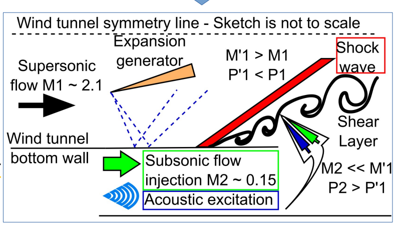
3. SKETCH OF THE 2D MODEL

The nozzle accelerates the flow, reducing its pressure through expansion waves. At the shock position, there is a pressure jump. The 2D model aims to mimic this pressure distribution.



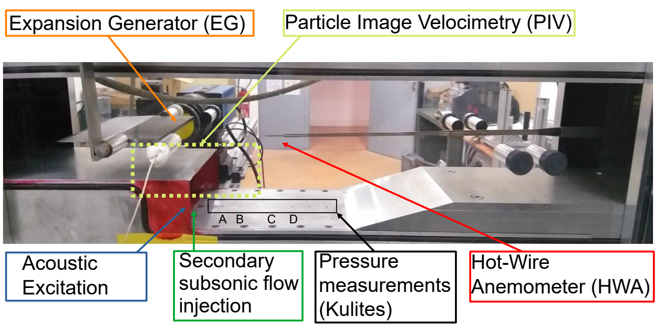


The plateau region is created by shifting the Expansion Generator (EG) farther upstream of the shock.



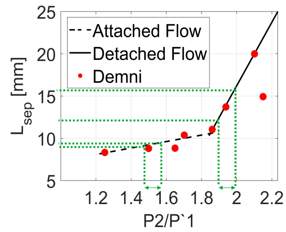
4. THE EXPERIMENTAL SETUP

The experiments were conducted in the supersonic wind tunnel at IUSTI lab., Marseille. The incoming flow conditions are M = 2.1, U_∞ = 522 m/s, δ* = 1.67 mm, θ = 0.55 mm, Re_θ = 4850.



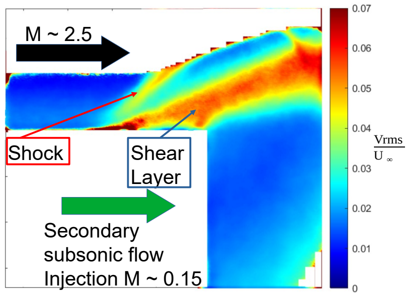
5. PREVIOUS WORK

Demni (PhD 2022, CNES)[2]: For the same small variation in pressure, the separation length (L_{sep}) varies significantly more for the detached flow case.



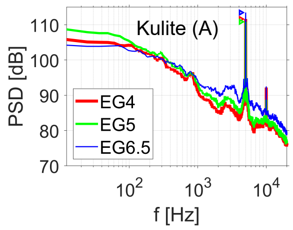
Where:
- P'1 is the static pressure upstream of the shock.
- P2 is the static pressure downstream of the shock.

The PIV result for the EG6.5 case shows the separated free shear layer induced by the shock.



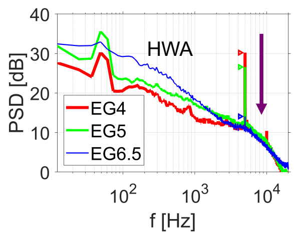
6. RESULTS: Acoustic excitation at 5 kHz

The Power Spectra Density (PSD) is presented for three different Expansion Generator (EG) angles: 4° (attached - EG4), 5° (incipient - EG5) and 6.5° (detached – EG6.5). All three cases are subjected to the same acoustic excitation at 5 kHz.



The kulite placed at the exit of the secondary flow injection (sensor A, see Fig. In Experimental Setup) measures the pressure fluctuation, and its PSD (left Fig.) gives approximately the same max. peak ~110dB at 5 Khz for all three cases.

The HWA placed at the mean shock position, used to measure the shock's response, shows a decrease in the PSD peak (right Fig.) as the flow separation increases.



7. CONCLUSION + FUTURE WORK

The downstream acoustic excitation generates **the same air displacement and acoustic pressure perturbation** for all three cases. As the shock displacement is greater for detached flow compared to attached flow, the acoustic excitation becomes relatively weaker as flow separation increases, resulting in a reduced shock response.

The next step is to study how the shock behaves at different excitation frequencies and to identify a transfer function between the controlled downstream acoustic excitation and the shock displacement.

8. REFERENCES

1) https://www.esa.int/ESA_Multimedia/Missions/Ariane_6

2) Demni, N. (2022). Etude expérimentale d'un décollement supersonique ouvert (Doctoral dissertation, CNES).

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