CEAS - ASC Keynote Presentation

Broadband Noise : a Key Driver for Future Powerplant Systems

SAFRAN Snecma
Matthieu Fiack

Rolls-Royce
Nick Humphreys

Summary

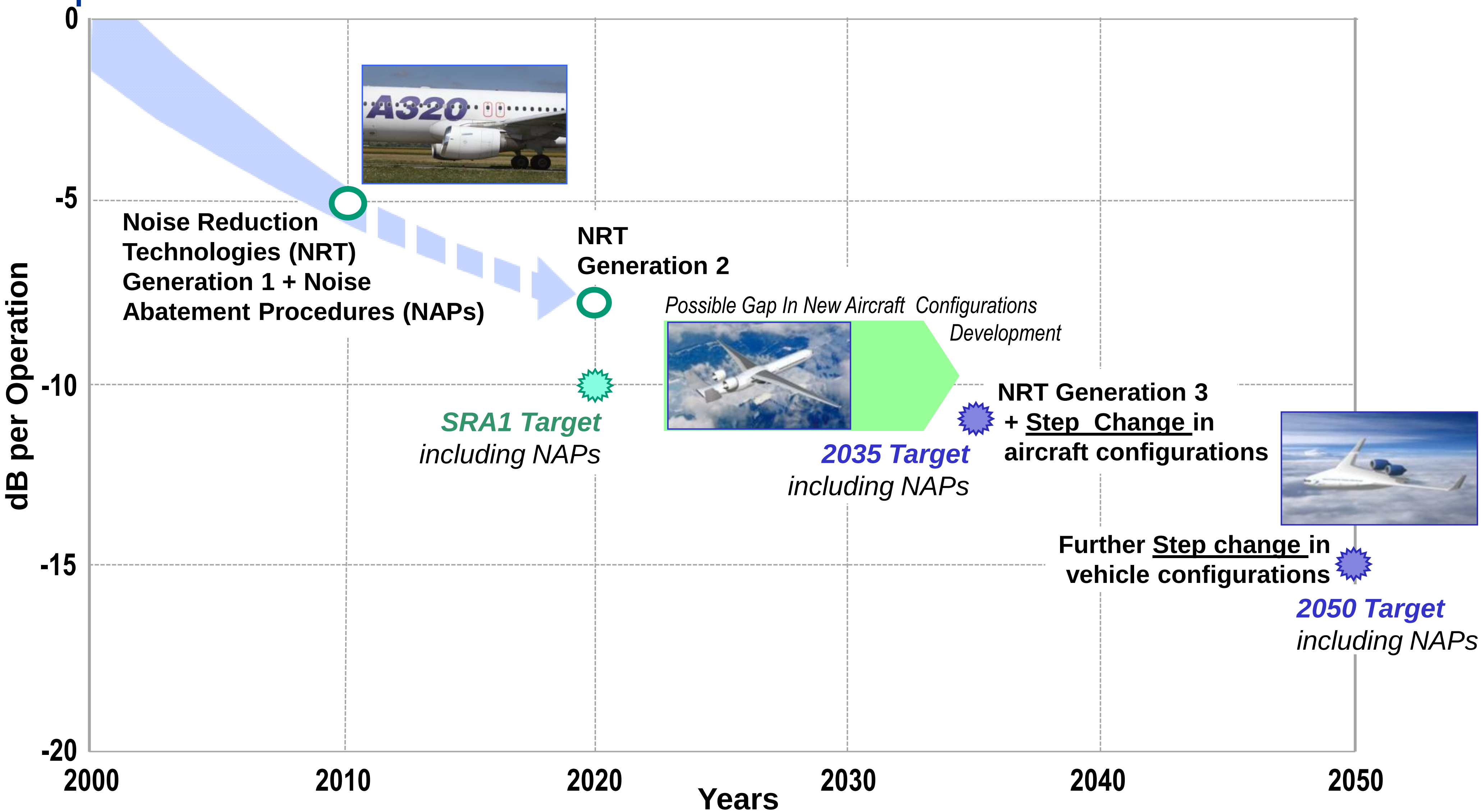
- Goals, achievements and perspectives
- Stakes of BBN for future Engines
  - Turbofan & Ultra High Bypass Ratio (UHBR)
  - Contra-Rotating Open Rotor engines
- A few words on other noise source

GOALS, ACHIEVEMENTS AND PERSPECTIVES

X-Noise

ACARE Noise Technology Goals Representation (Fixed Wing Aircraft)

X-NOISE EV



Take off Noise reduction achievement

- Powerplant turbomachinery tone and buzz saw noise reduced through
  - novel fan system
  - nacelle intake liner technologies
  - bypass duct technologies and application of multi disciplinary optimisation.

    → TurboNoiseCFD, RESOUND, SILENCE(R), OPENAIR
- Exhaust Installation effect understanding to enable low noise powerplant and airframe integration.

  → RAIN, JERONIMO* extends capability to UHBR

Approach Noise reduction achievement

- Approach noise dominated by broadband engine and airframe noise sources which have proved more difficult to understand and control.

  → PROBAND, FLOCON, OPENAIR, RECORD*
- Key Sources
  - Fan Broadband Noise
  - High Lift Device Broadband Noise
  - Landing Gear Noise
  - Combustor noise (approach and taxi)

* On going project

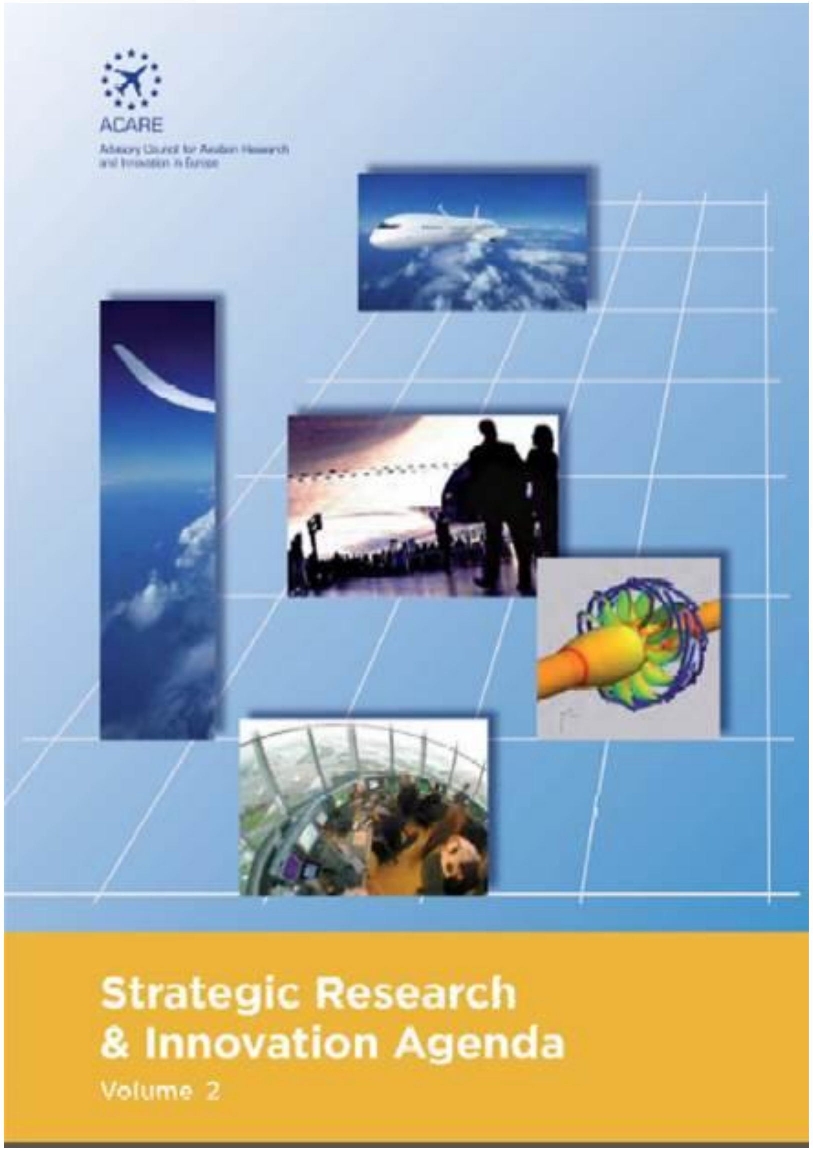
For Increased Bypass Ratio Turbofan :

- **Fan and airframe broadband noise** understanding, prediction and control
  - Take off
    - Noise reduction trend will not be maintained beyond 2020 without control of powerplant broadband noise
  - Approach
    - Noise reduction will not be possible beyond 2020 without control of both powerplant and airframe broadband noise.

Active and adaptive techniques for powerplant and airframe noise reduction :

- Continuous effort aimed at systems approach

ACARE SRIA 2035 (2050) Solutions



Generation 3 NRT

- **Advanced Source Modelling and Applications**
  - Powerplant system multi-disciplinary optimisation
  - Development of noise prediction and integrated system capability for UHBR and OR powerplants
  - Combustion and IP System Noise Source Control
  - Optimisation of propellers for turboprops and light aviation
- **Active / Adaptive Techniques**
  - Wake control to reduce interaction noise for fans (e.g. trailing edge passive) and open rotor (e.g. pylon blowing adaptive)
  - Flow control for reduced turbomachinery broadband noise
  - Acoustic active control : Active stators, Active / Adaptive Liners
  - Adaptive Nozzles including Variable Area Nozzle
  - Morphing structures for airframes, nacelles and engines
  - Landing Gear Noise Flow Control Technologies
- **Lightweight, Recyclable Acoustic Liners and Sound Absorbers**

Advanced Vehicle Architectures

- **Novel Aircraft Configurations (Tube & Wing, BWB) maximising noise benefits from masking effects: Airframe/nacelle/engine multi-disciplinary optimisation**

STAKES OF BBN FOR FUTURE ENGINES

Stakes of BBN for future engines

- Tonal noise successfully reduced in recent years (source and propagation)

- Necessity to assess broadband noise for future powerplant systems
  - Ultra High Bypass Ratio turbofans (UHBR) – EIS 2025+
    - Reduced SFC
    - Increased BPR
    - Lower fan tip speed
    - Short and slim nacelle
    - Reduced liners (depth and aera)
    - Structural and integrated OGV grids
  - Open Rotor engines – EIS 2030+
    - SFC further reduced
    - No nacelle
    - Increased propeller diameter
    - No liners, Free field radiation
    - Complexity of installation (pusher / puller)
    - Risk for cabin noise

Strong inflow distortion (UHBR items)

Strong installation effects (Open Rotor items)

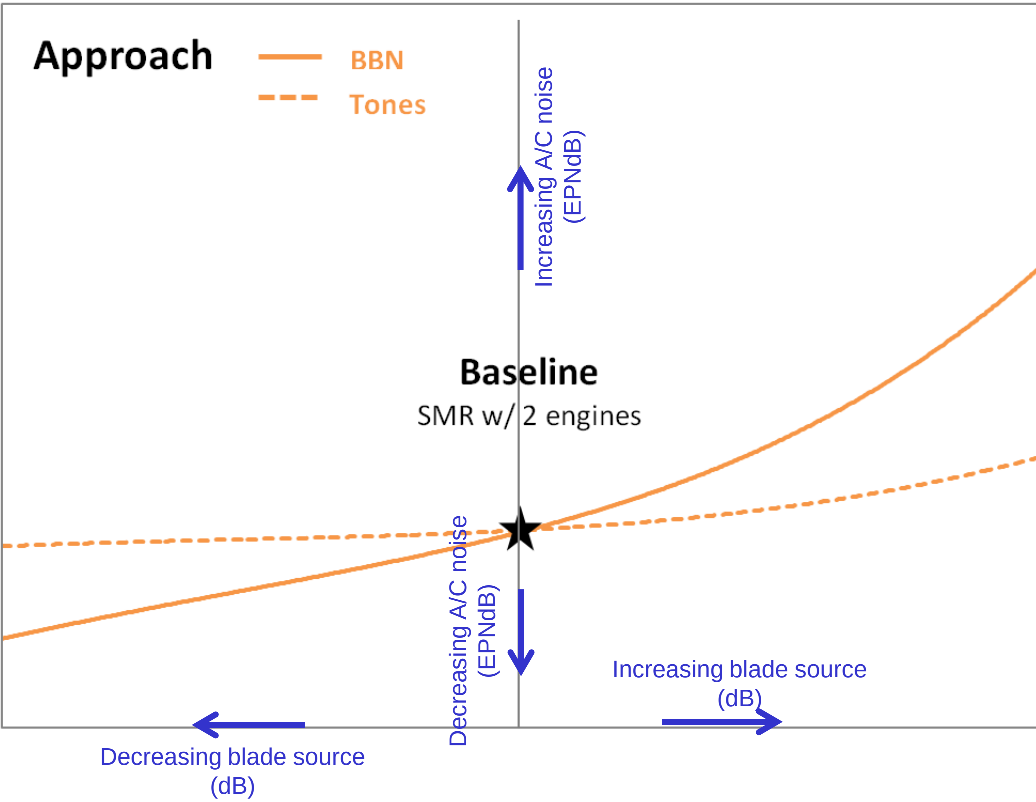
Change in noise source balance w.r.t. 2017 turbofans

- Long term need for methods with increasing degree of complexity
  - Overall major noise sources :
    - Fan stage, inlet / exhaust propagation
    - Often the main source of noise at most operating conditions
      - Rapid methods for preliminary design
      - Methods taking into account 3D geometries and complex swirling flows
  - Secondary noise sources in the by-pass and core flows (can be even more significant on biz-jet engines):
    - Bleed valves, heat exchangers in the by-pass, cavities, IGV, booster and interaction between all these elements
    - May significantly contribute to the overall noise radiation at a given operating condition
      - Modelling of devices self noise
      - Complex modelling accounting for possible interactions (e.g. local flow instabilities, turbulence generation) between various components.

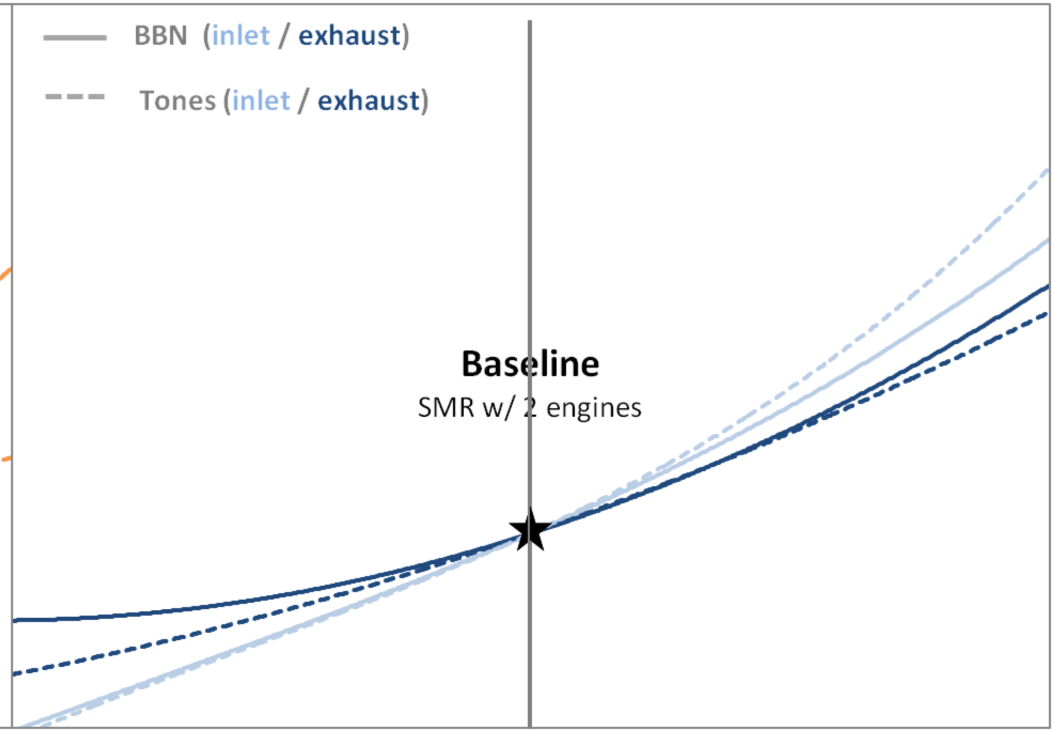
BBN Stake for future architectures

blades noise sensitivity at Approach

Open-Rotor



EIS 2017 Turbofans (BPR ~10)



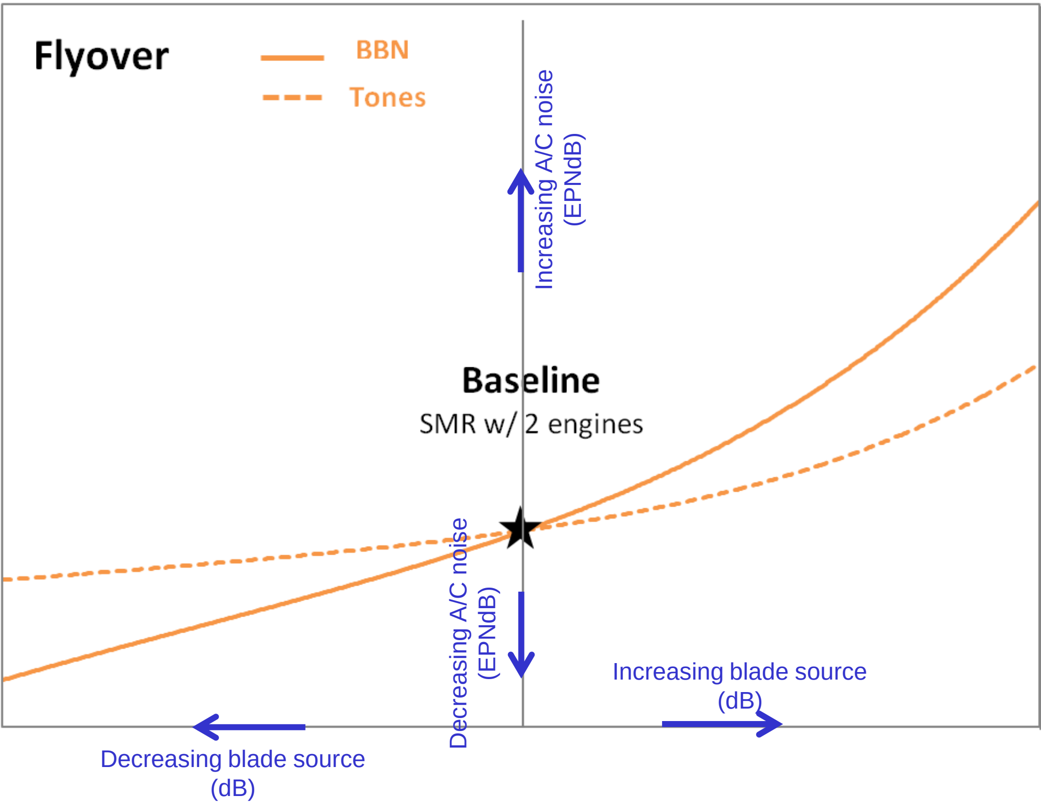
BBN is the major driver to control noise

Inlet TN and BBN are the main contributors

BBN Stake for future architectures

blades noise sensitivity at Flyover

Open-Rotor



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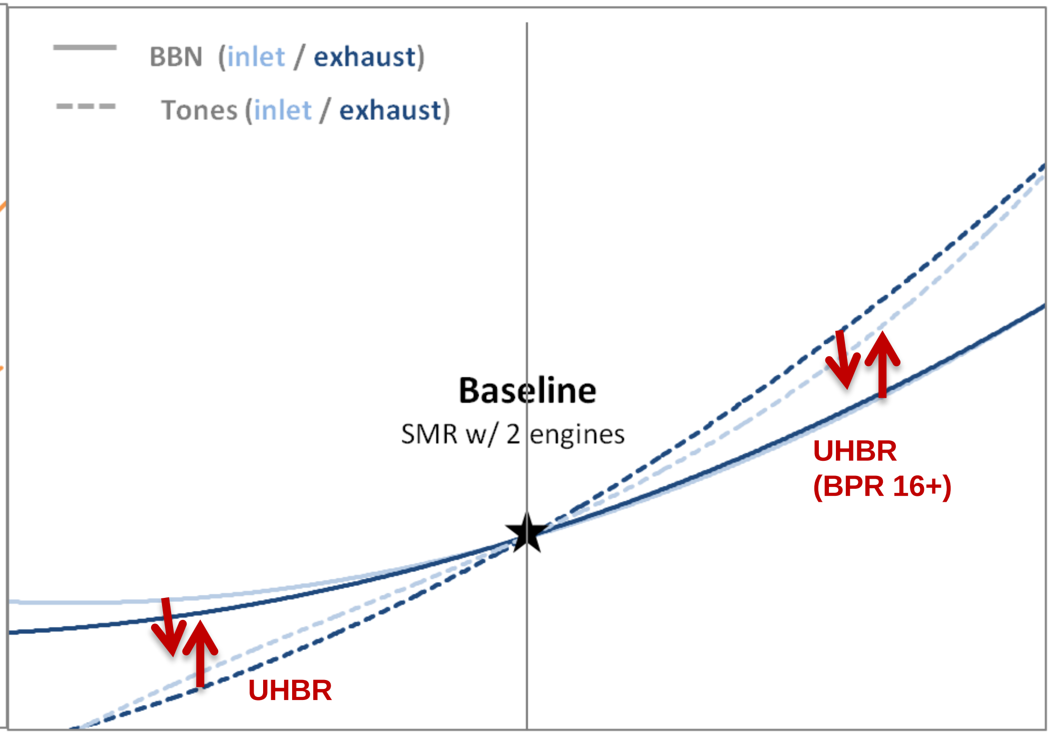
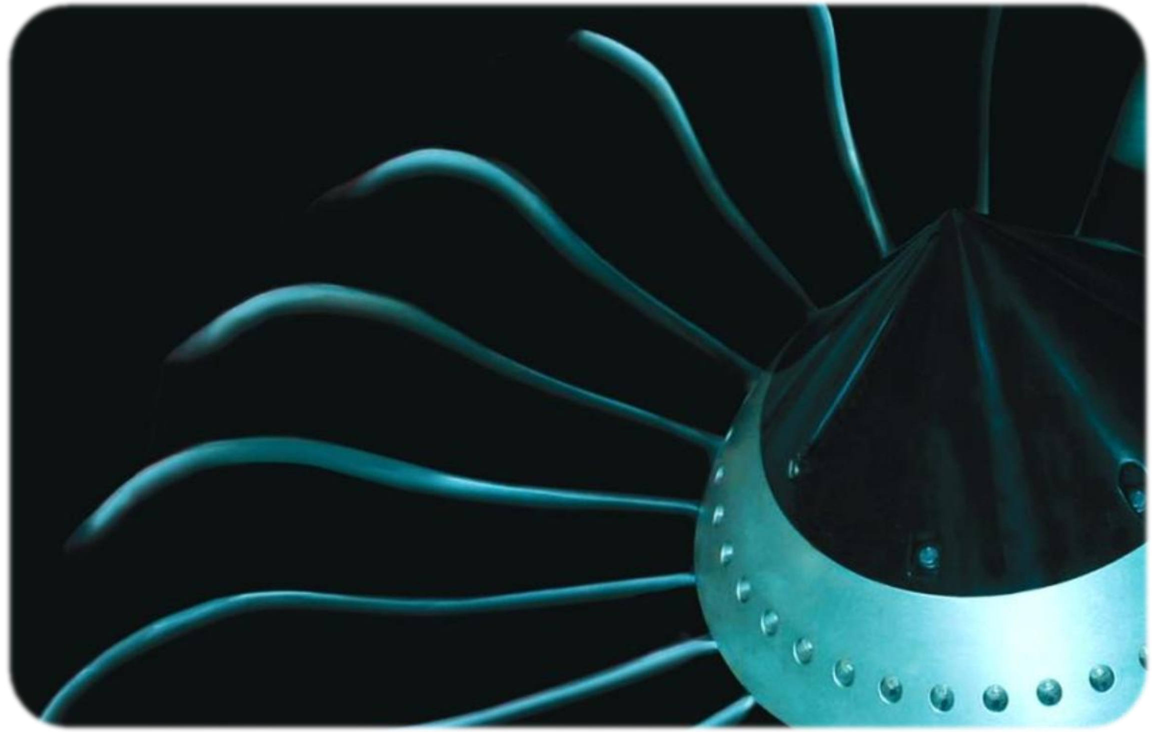


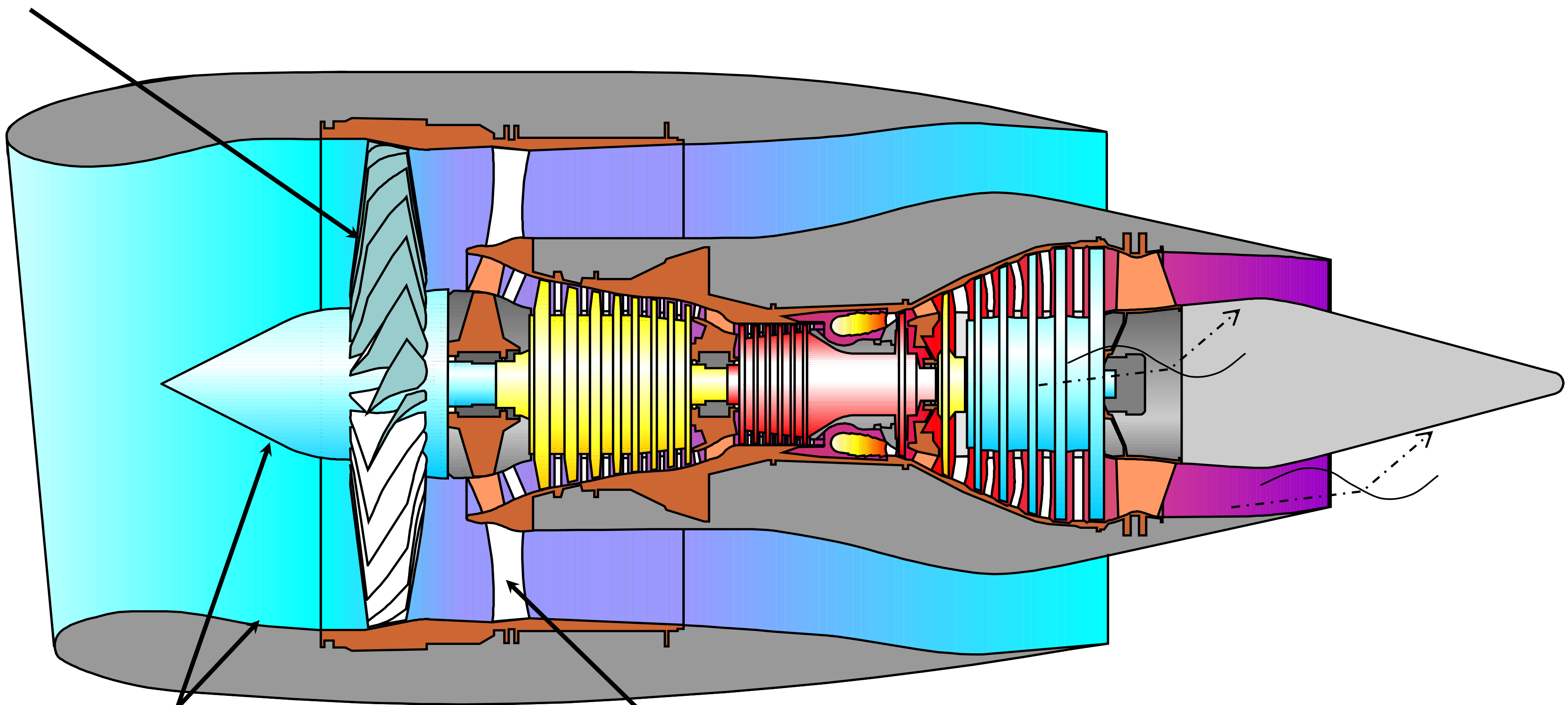
TN is the major driver to control noise

But TN/BBN breakdown highly modified for UHBR

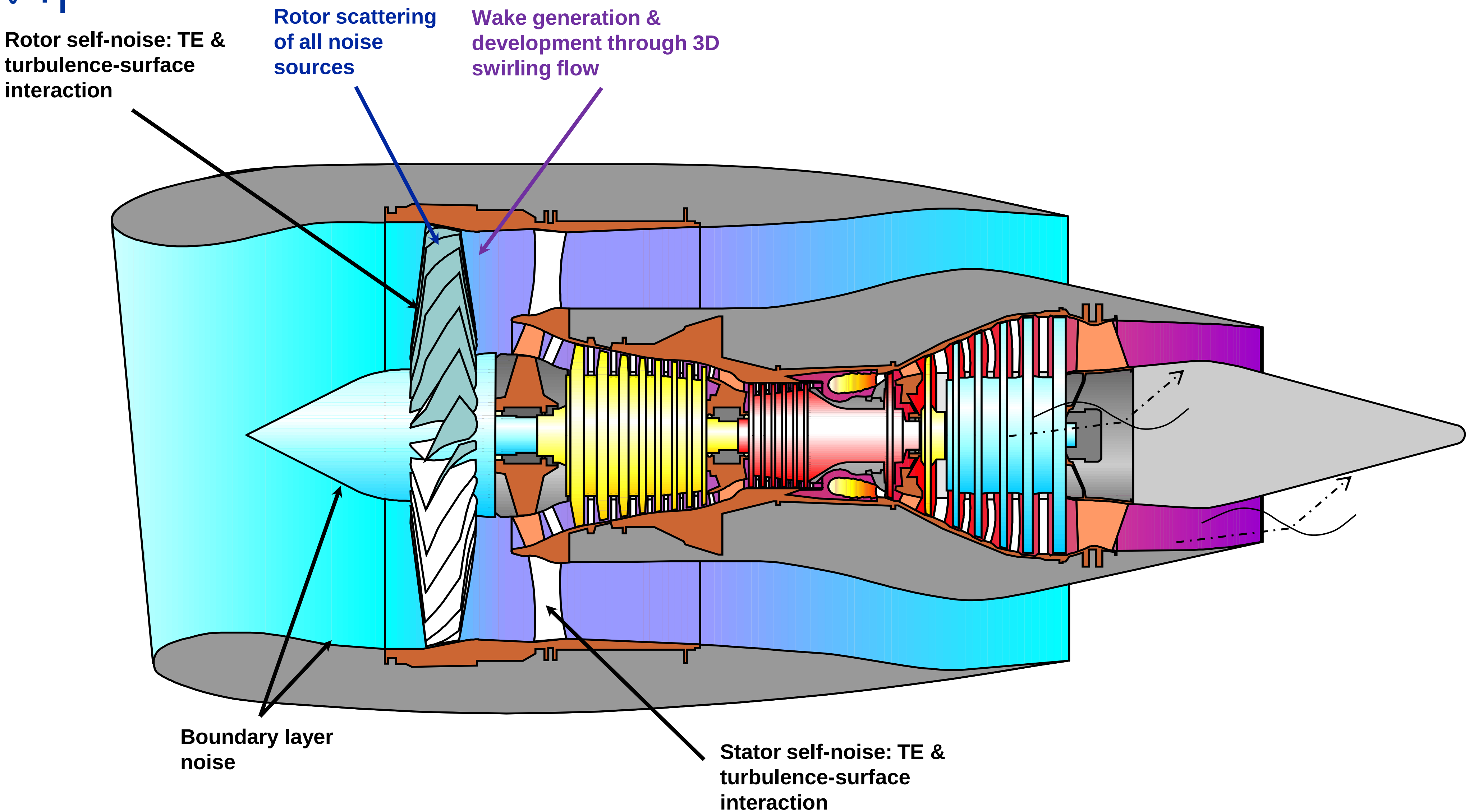


TURBOFAN &
ULTRA HIGH BYPASS RATIO (UHBR)

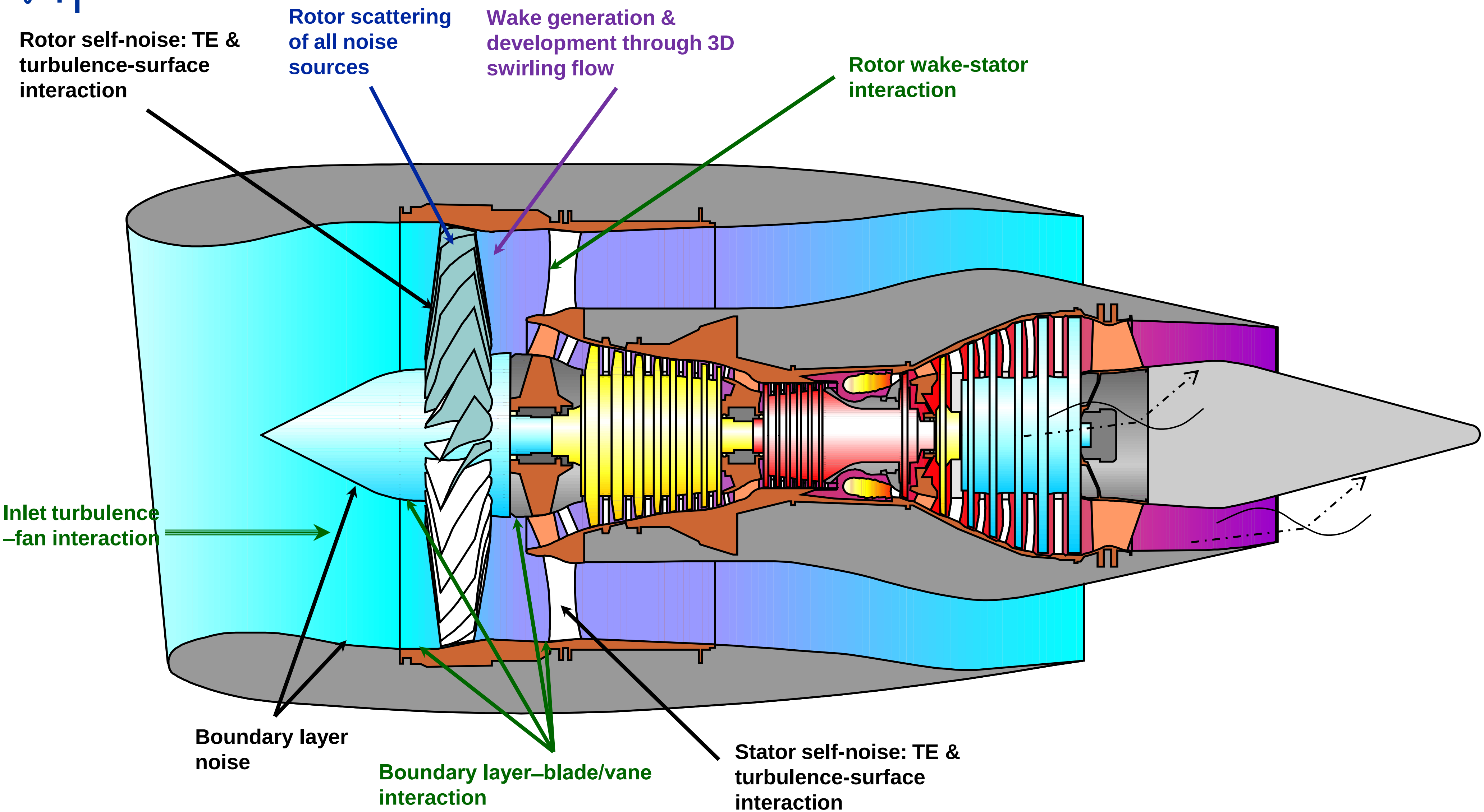
Fan Stage Broadband Noise Sources



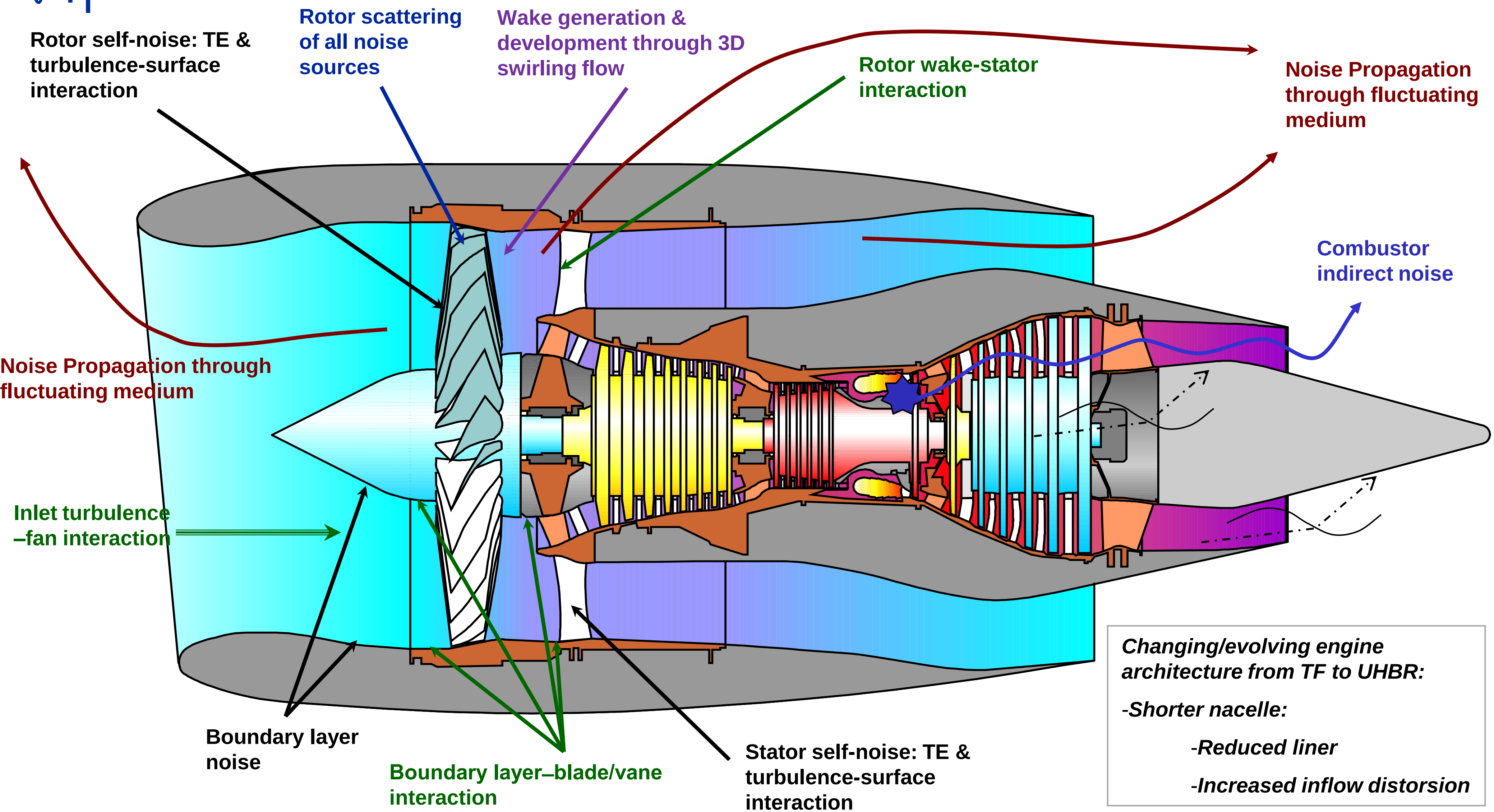
Fan Stage Broadband Noise Sources



Fan Stage Broadband Noise Sources



Fan Stage Broadband Noise Sources



Changing/evolving engine architecture from TF to UHBR:

-Shorter nacelle:

-Reduced liner

-Increased inflow distorsion

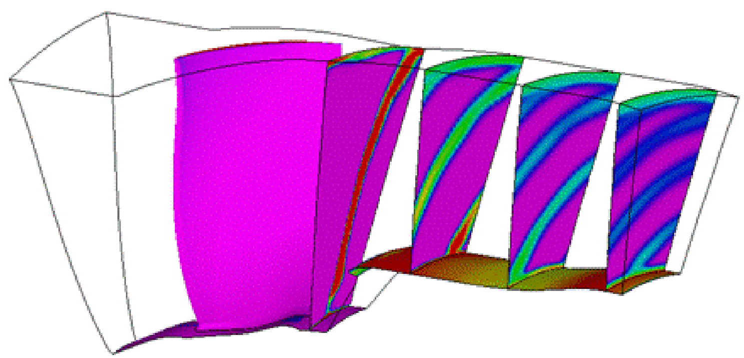
Modelling

1. PROBAND :
- Accelerated understanding and 2D modelling

2. National Programmes and Global Benchmarking Programme
- Modelling taking into account 3D geometrical OGV shaping.
- Emerging source and propagation modelling taking into account 3D flow field downstream of fan.

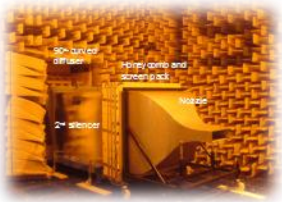
Example from FLOCON application - Rolls-Royce HYDRA 3D RANS using the k-ω/SST turbulence model.

Solution Domain and Example Result for Turbulence Energy on planes downstream of the Fan Rotor blade

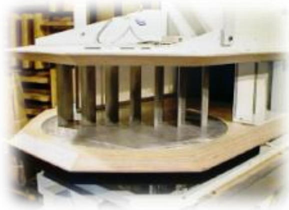


Lower Technology Readiness Level Achievements

Control



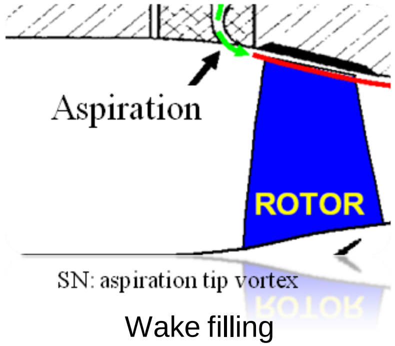
ISVR isolated airfoil rig


ECL cascade rig

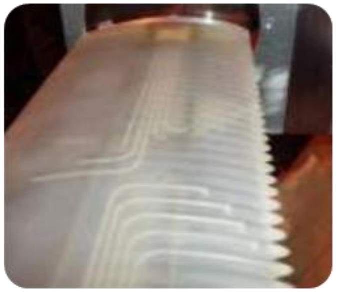

DLR fan rig

1. FLOCON :

- Most promising technology relates to OGV leading edge shaping however more work to do on fan trailing edge / wake filling. Fan tip liner treatments interesting but not fully understood.
- Static rigs provide high quality static results
- Rotating rigs used in this programme limited due to not representing aerodynamic or acoustic effects. Used in future for novel instrumentation demonstration ?



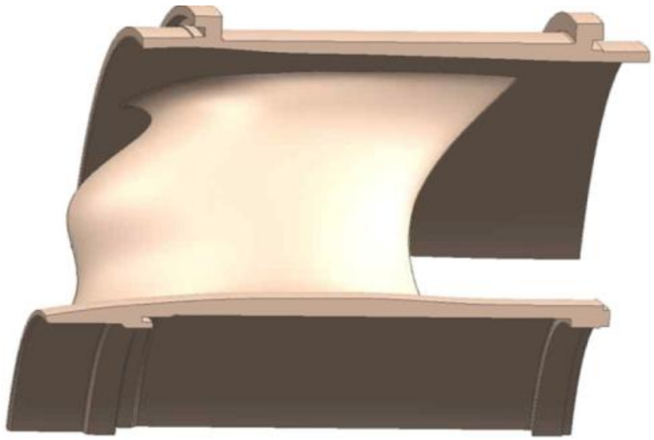
Wake filling


LE treatment
TRL3 achieved

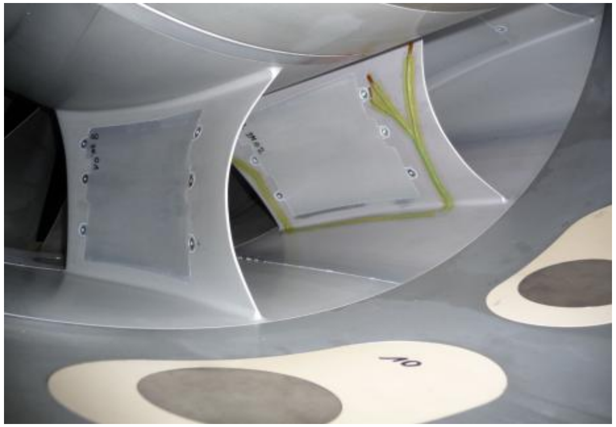

TE treatment
TRL 3 achieved


TE fiber
TRL 2 achieved

2. VITAL / OPENAIR :



- Investigation of low count Outlet Guide Vanes (OGVs) within the Fan System
- Rolls-Royce, DLR and University of Cambridge designed low count OGVs including using multi disciplinary optimisation (MDO) of the leading edge.
- GKN and Chalmers University designed low count OGVs including acoustic liner and highly swept leading edge shape.
- For both designs the AneCom modular fan rig (UFFA) engine representative test showed that Broadband noise reduced significantly as expected due to the reduced number of OGVs demonstrating that this was a dominant fan broadband source.



Aerodynamics

- 3D high Mach number swirling unsteady flow characteristics and interaction with turbomachinery.
- 3D high speed fan and OGVs
- 3D flow inlet and bypass duct.

Acoustics

- 3D acoustic response
- 3D scattering / diffraction effects through turbomachinery and inlet / bypass duct
- Propagation through 3D aerodynamics
- Multi-disciplinary, integrated low noise fan stage design

Requirements - Fan Broadband Noise Understanding

Modelling

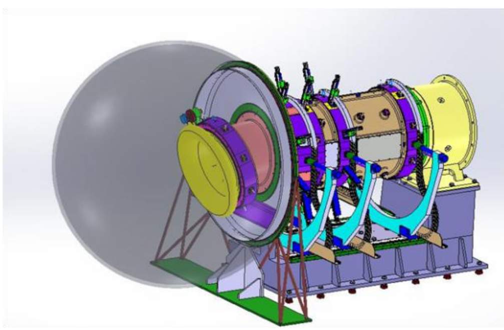
- Rapid assessment tools for prelim design.
- 3D assessment and component design capability

Control

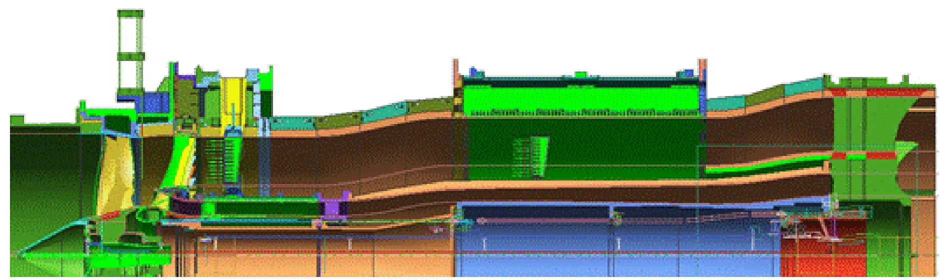
- Novel flow / acoustic control to reduce fan system broadband noise
- Optimised / novel acoustic liners

Understanding and Validation

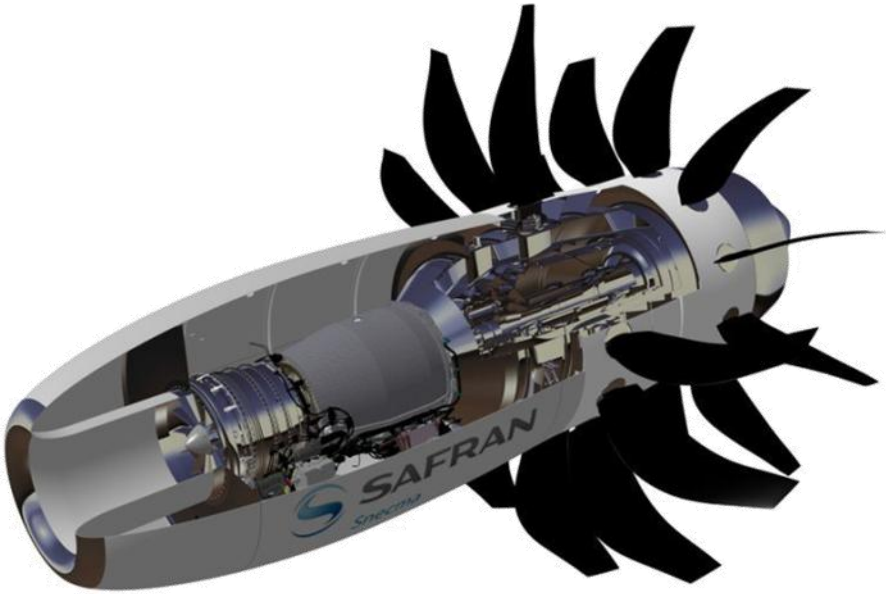
- Instrumented rig for rapid assessment of novel technologies - must have representative Mach numbers and 3D engine unsteady flows.
- Instrumented large scale engine representative fan rig for high TRL understanding and validation.
- Challenges of measurement, source analysis and source identification / separation on realistic mock up and full scale engines

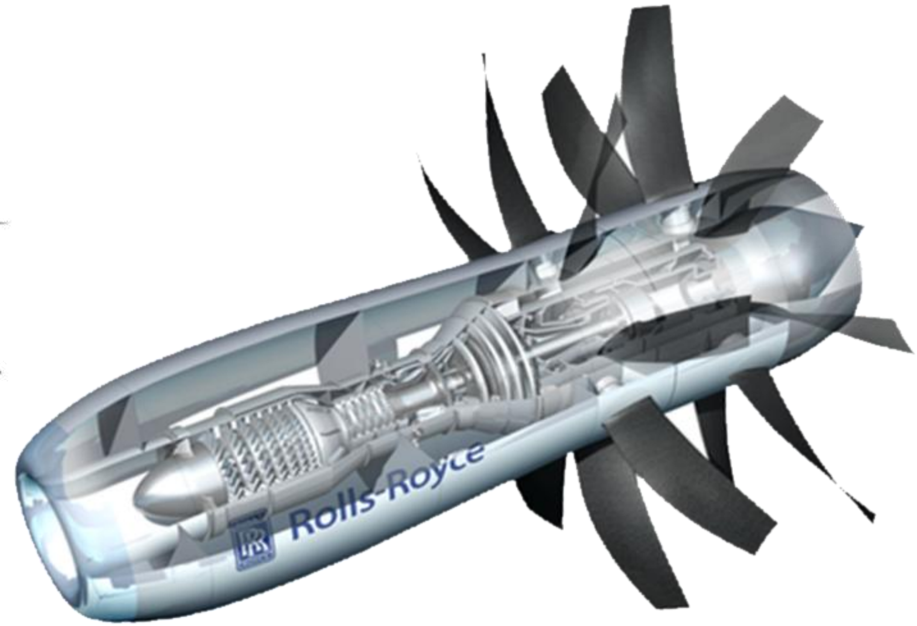


MARLYSA / PHARE2 (modular fan rig)



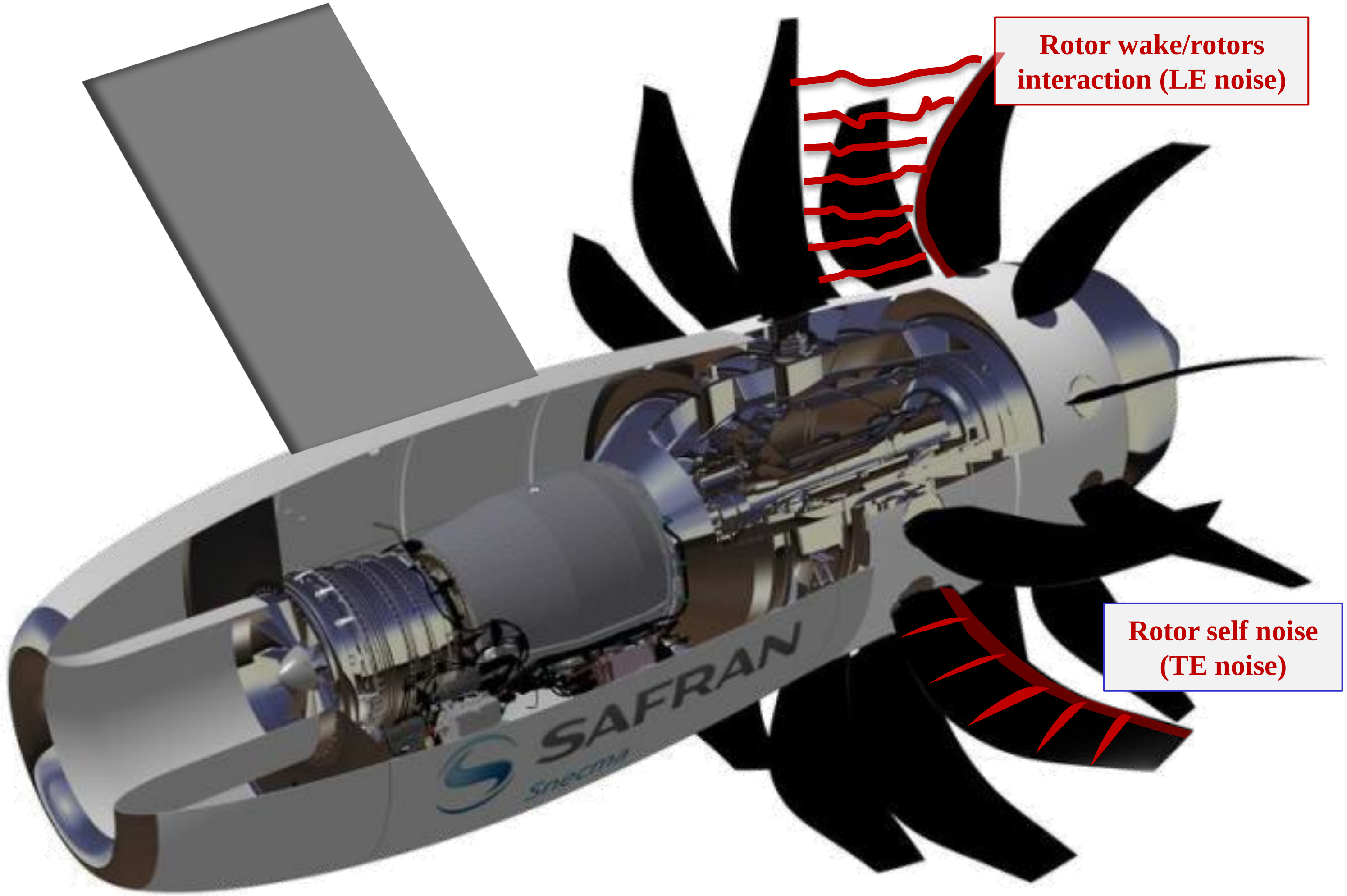
AneCom UFFA (modular fan rig)



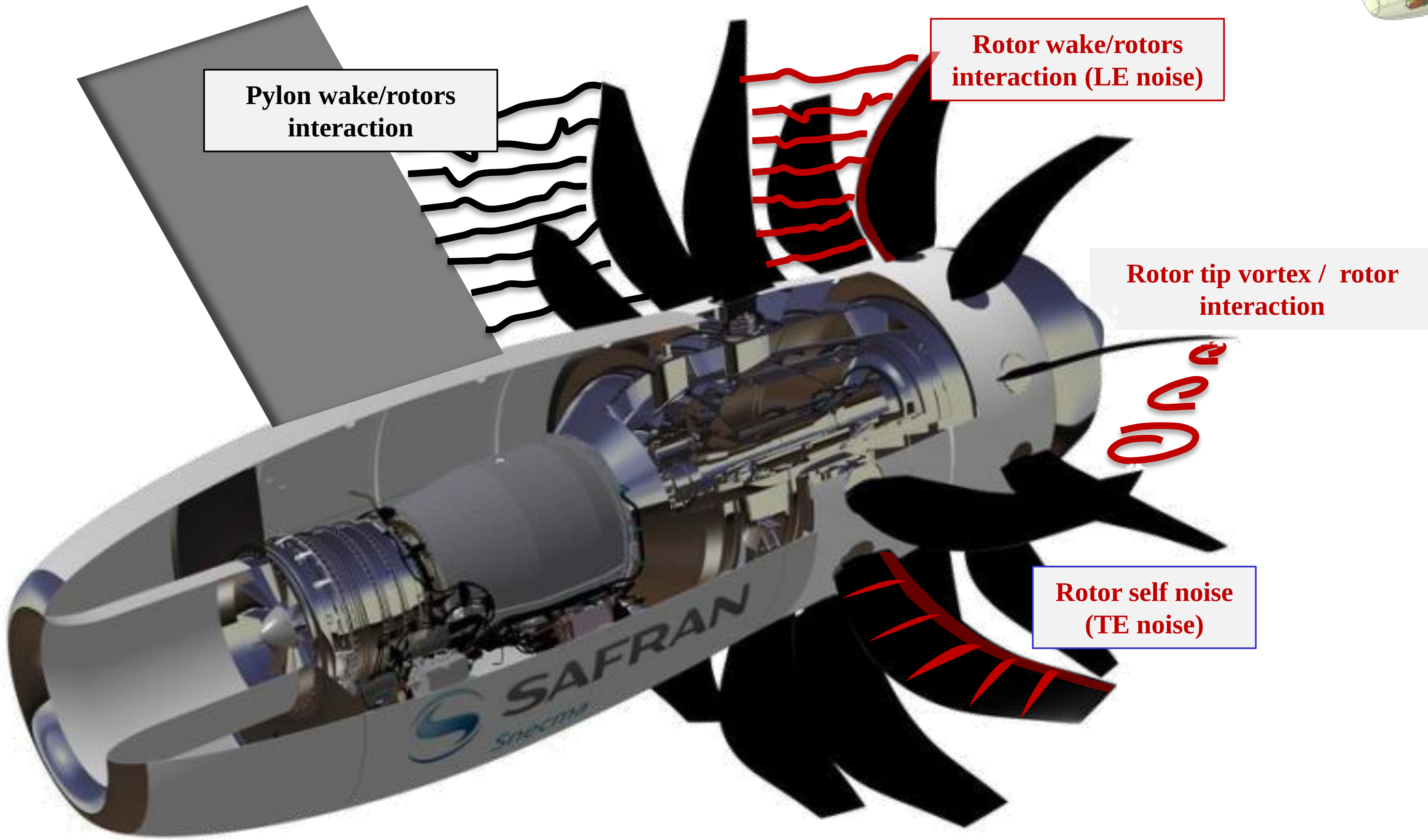


CONTRA-ROTATING OPEN ROTOR ENGINES

CROR Broadband Noise Sources



CROR Broadband Noise Sources



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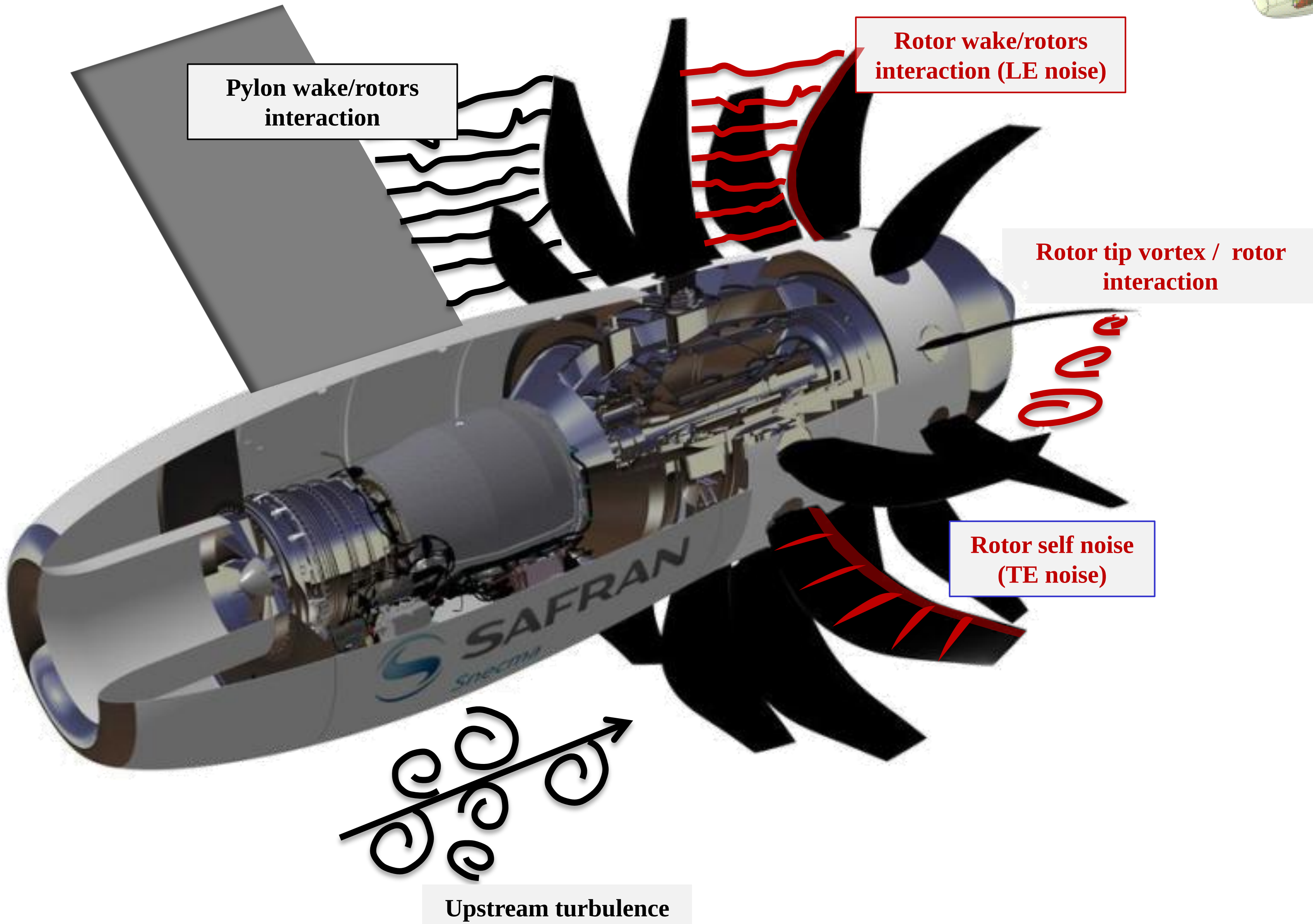
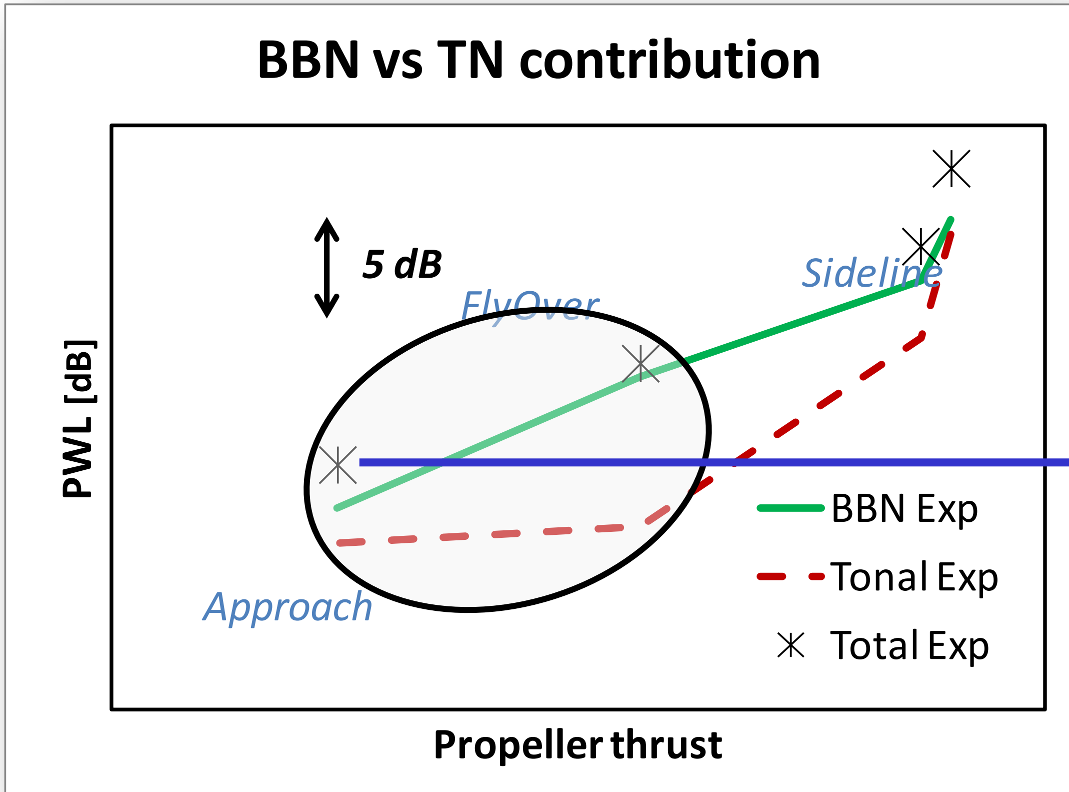
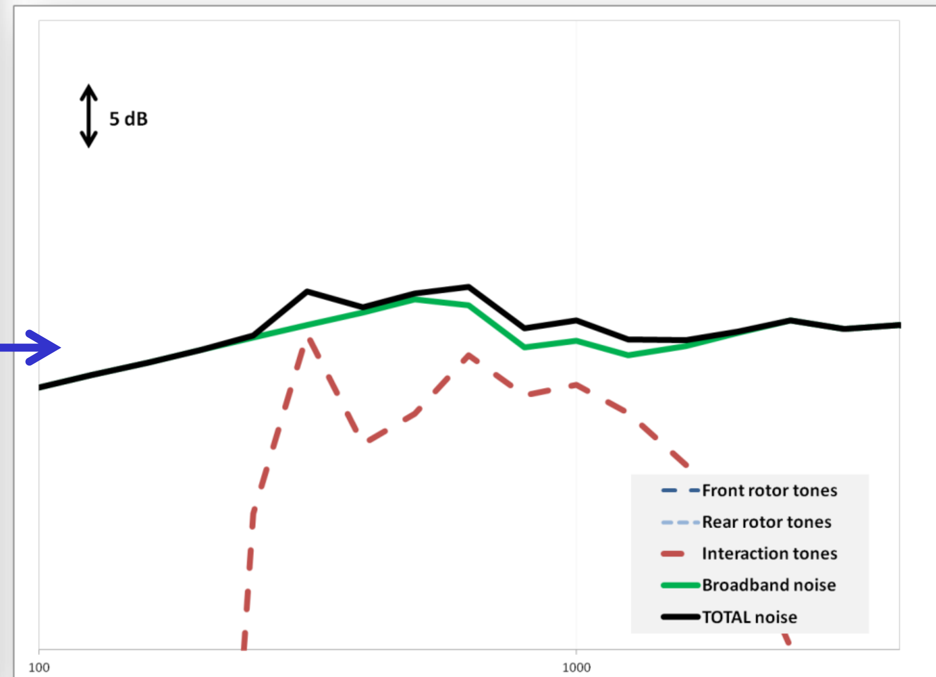


Approach, flyover after cutback :

→ **BBN is dominant**

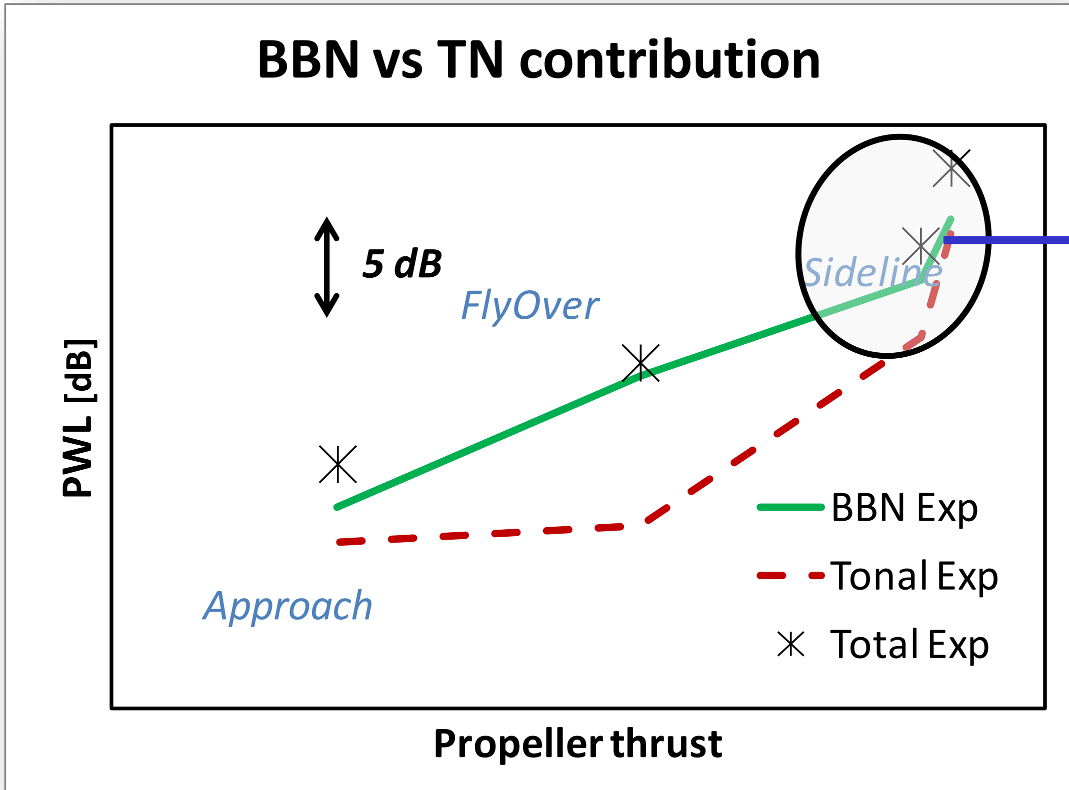


1/3 octave aft spectra at approach conditions (Snecma HERA measurements @ ONERA S1MA)

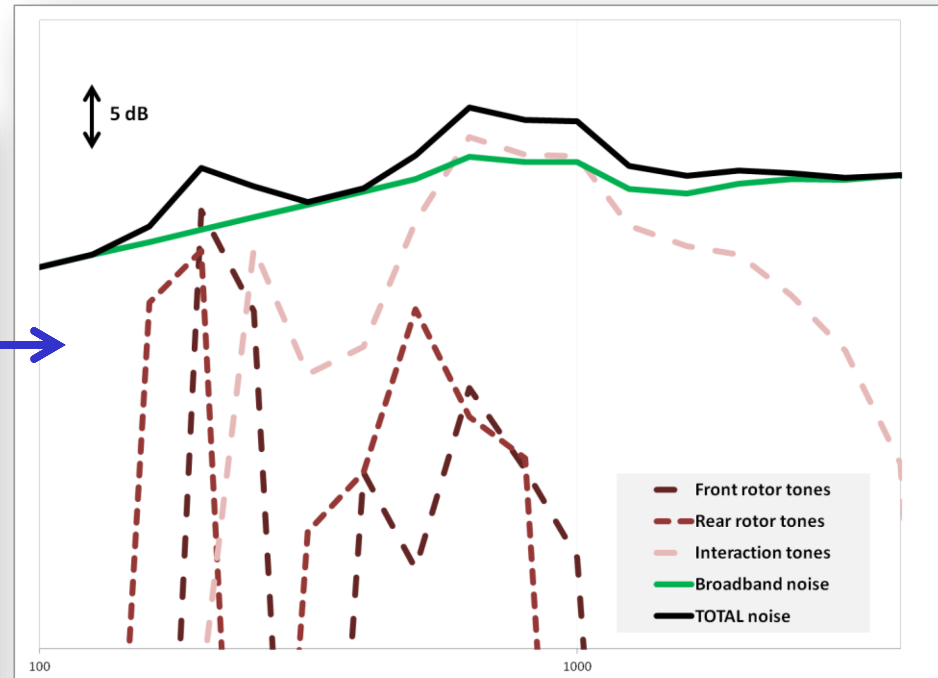


Sideline and T/0 :

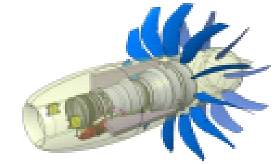
→ **BBN and TO contribute similarly**



1/3 octave aft spectra at T/O conditions (Snecma HERA measurements @ ONERA S1MA)



CROR - Blade design
Evaluating BBN

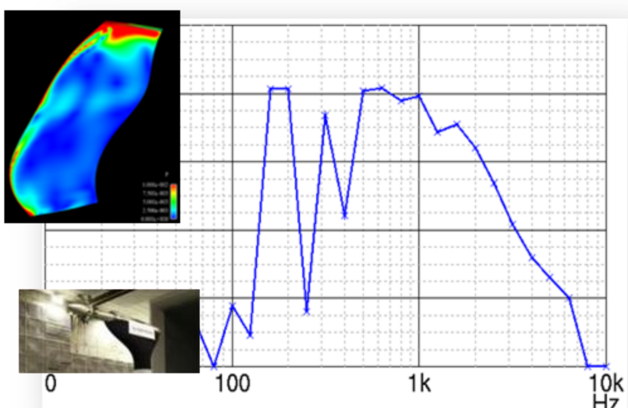


Objective : evaluate the in-flight acoustic performance from blade design stages

→ **TN Prediction using conventional uRANS computations or in-flow measurements**
- uRANS → Computing the unsteady wall pressure on the blades
- Acoustic radiation → Tonal noise predictions

→ **Addition of a BBN taken from in-flow measurements or analytical models**
- Extraction of BBN spectra from measured data (from isolated configurations, i.e. Onera & DNW), corrected from wind-tunnel background noise
- BBN levels scaling of autospectra
- Linear interpolation of the levels in the database @ target thrust
- Interpolation of the levels at microphone positions

→ **Total noise radiation (tonal and broadband noise components) for flight path projection**



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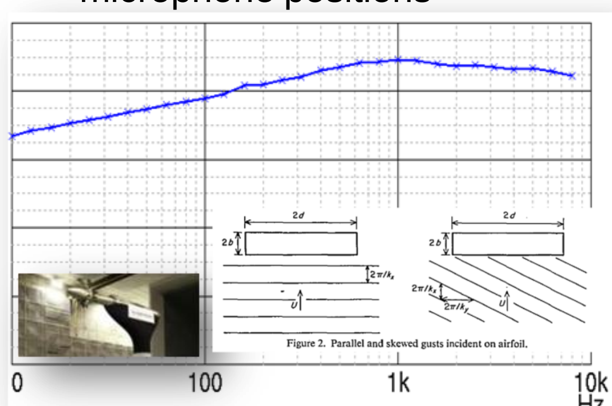

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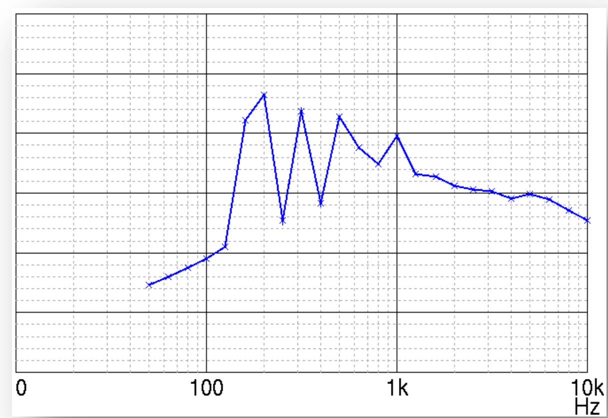
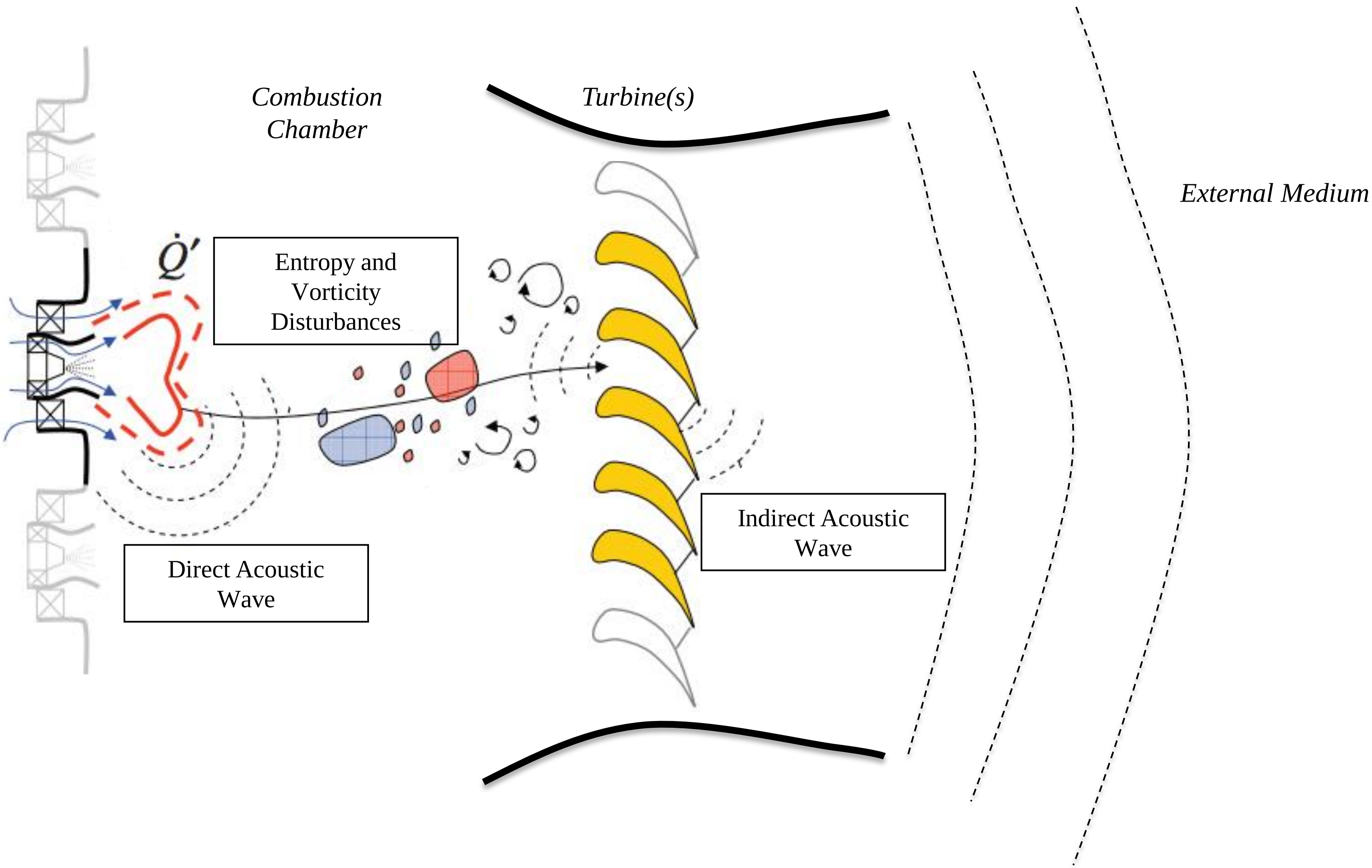


A FEW WORDS ON OTHER NOISE SOURCES : COMBUSTION

Combustor Noise (RECORD)

Combustion noise generation and Propagation mechanisms

(Safran / CERFACS)



Combustor Noise (RECORD)

Combustion noise generation and Propagation mechanisms

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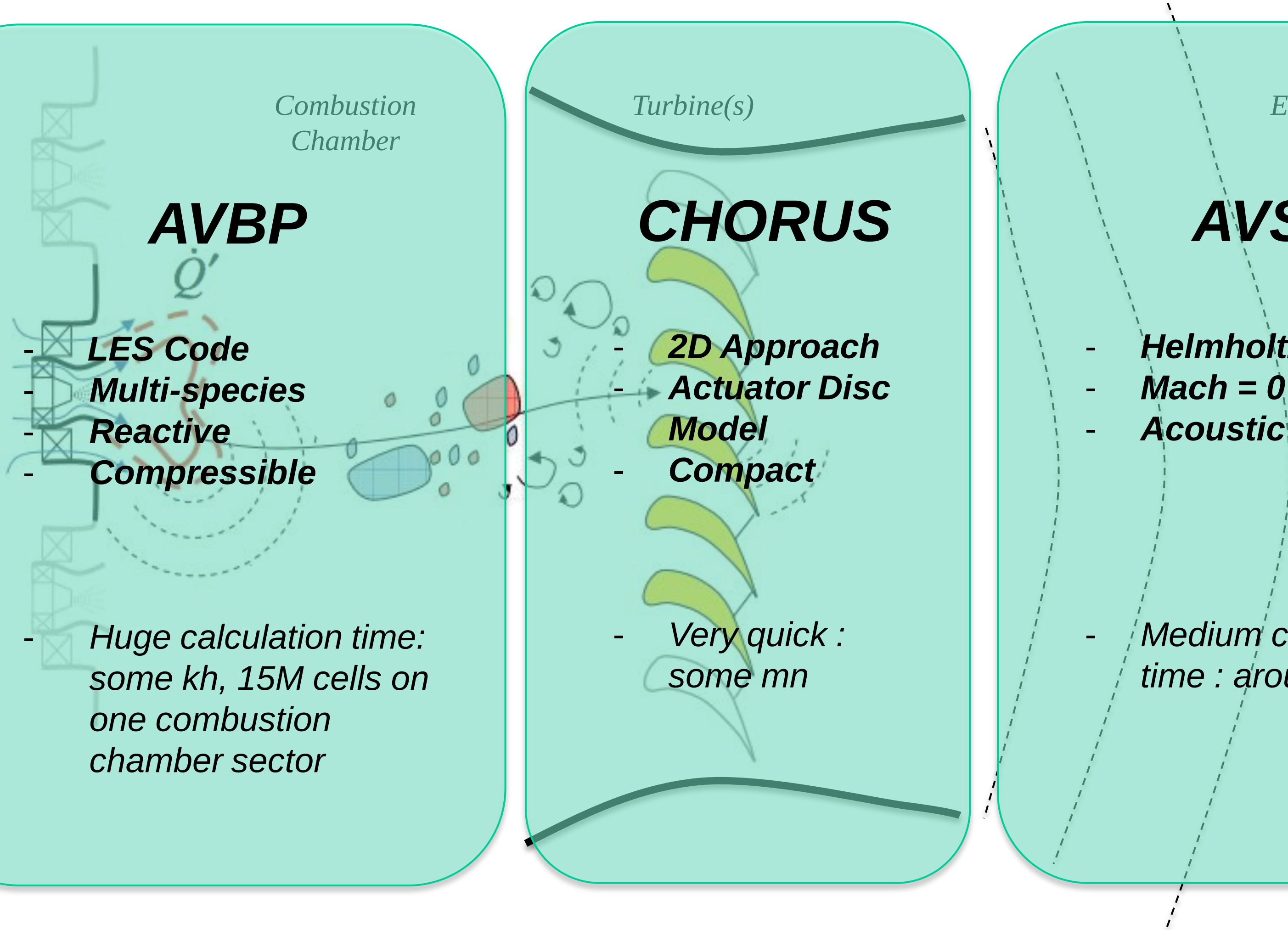


AVBP

- ***LES Code***
- ***Multi-species***
- ***Reactive***
- ***Compressible***

- *Huge calculation time: some kh, 15M cells on one combustion chamber sector*

CHORUS

- ***2D Approach***
- ***Actuator Disc Model***
- ***Compact***

- *Very quick : some mn*

AVSP-f

- ***Helmholtz Eq. Solver***
- ***Mach = 0***
- ***Acoustic Excitation***

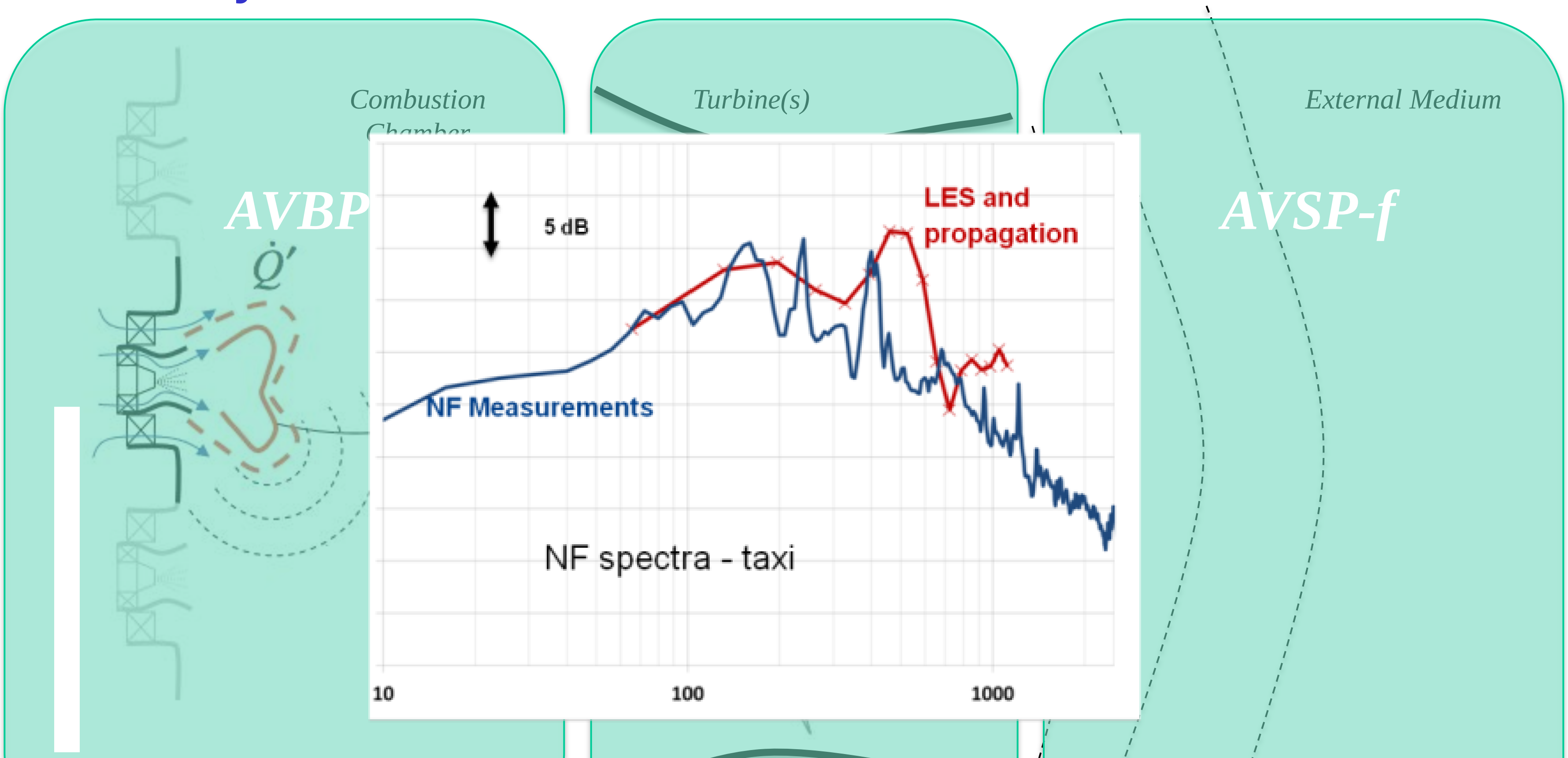
- *Medium calculation time : around 1h*

Combustor Noise (RECORD)

Combustion noise generation and Propagation mechanisms

(Safran / CERFACS)

➔ Preliminary results



Very good agreement between calculation and measurement…
…but large effort required (LES) to produce good quality results

- **BBN modelling is**
  - An enabler to free a new level of creativity within the next ten years, allowing more and more complex models to be computed
  - Mandatory in order to meet long-term « Flightpath 2050 » Noise objectives
- **Challenges for Aeroacoustic modelling**
  - More and more integrated systems, leading to more and more heavy models (e.g. inlet + fan + bypass duct + pylon)
  - Necessity to take into account secondary sources (bleed valves, by-pass heat exchangers, cavities,IGV, booster, …) for community noise but also cabin noise
  - Accessibility to industry of state-of-the-art computation methods (complexity and cost)

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