METODOLOGIE E TECNOLOGIE PER LO SVILUPPO DI UN NUOVO VELIVOLO

Highlights di progetto: Noise & Acoustics

2° Incontro - Napoli, 14 Giugno 2014

Scuola Politecnica e delle Scienze di Base
Piazzale V. Tecchio 80, 80125 Napoli

Noise & Acoustics nel Progetto Aeronautico

Perché considerare le problematiche Acustiche?

- **Le emissioni di Rumore di un aereo sono percepite come un grave inquinamento ambientale, specialmente nelle aree intorno agli aeroporti; esse sono quindi poste sotto stretto controllo da parte degli Enti di Certificazione:**
  - **La progettazione di un aereo non inquinante è un requisito fondamentale del progetto industriale (Eventuali limitazioni operative)**
  - **Inoltre gli specifici regolamenti aeroportuali penalizzano economicamente gli aerei rumorosi (Tasse anti-inquinamento)**
- **Il Comfort del passeggero è significativamente dipendente dai livelli di rumore e di vibrazione percepiti in cabina:**
  - **Una cabina rumorosa induce i passeggeri a percepire l'aereo come un prodotto di scarsa qualità (Quality Issue)**
  - **Il livello di rumore a bordo, insieme agli altri parametri di comfort, ha un significativo impatto sul successo commerciale del prodotto/Compagnia (Commercial Issue)**

Noise & Acoustics nel Progetto Aeronautico

Missione & Responsabilità nel Progetto del velivolo

- **Inquinamento**: assicurare bassi livelli di emissioni acustiche sulle aree sorvolate intorno agli aeroporti
- **Certificazione**: verificare di essere all'interno delle limitazioni dettate dalle Normative Internazionali
- **Sicurezza**: assicurare un livello acustico adeguato ai limiti imposti per la salvaguardia della salute e della operatività del personale di bordo
- **Comfort**: assicurare un elevato livello di comfort ai passeggeri minimizzando il costo ed il peso degli interventi insonorizzanti richiesti

External Noise (Certification)

Interior Noise (Comfort)

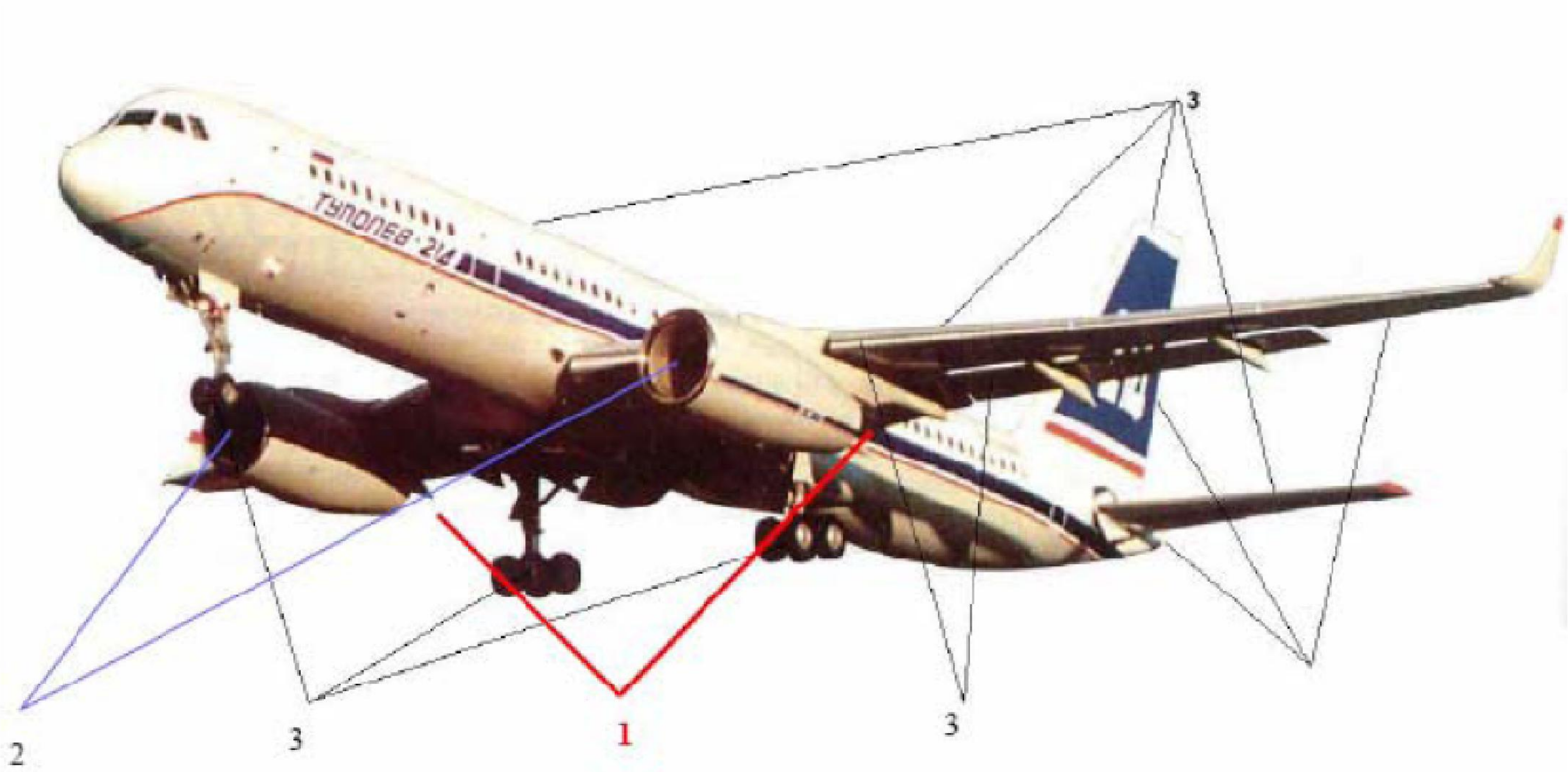
Noise & Acoustics nel Progetto Aeronautico

CONTENUTI:

- External Noise
  - Sorgenti di rumore aeronautiche
  - Certificazione Acustica
  - Sonic Boom

- Interior Noise
  - Comfort Acustico
  - Acustica & struttura
  - Trattamenti acustici
  - Fatica sonica

External Noise: Sorgenti di rumore



1. Jet noise; 2. Inlet and aft fan noise, turbine noise; 3. Airframe noise.

External Noise: Sorgeti di rumore

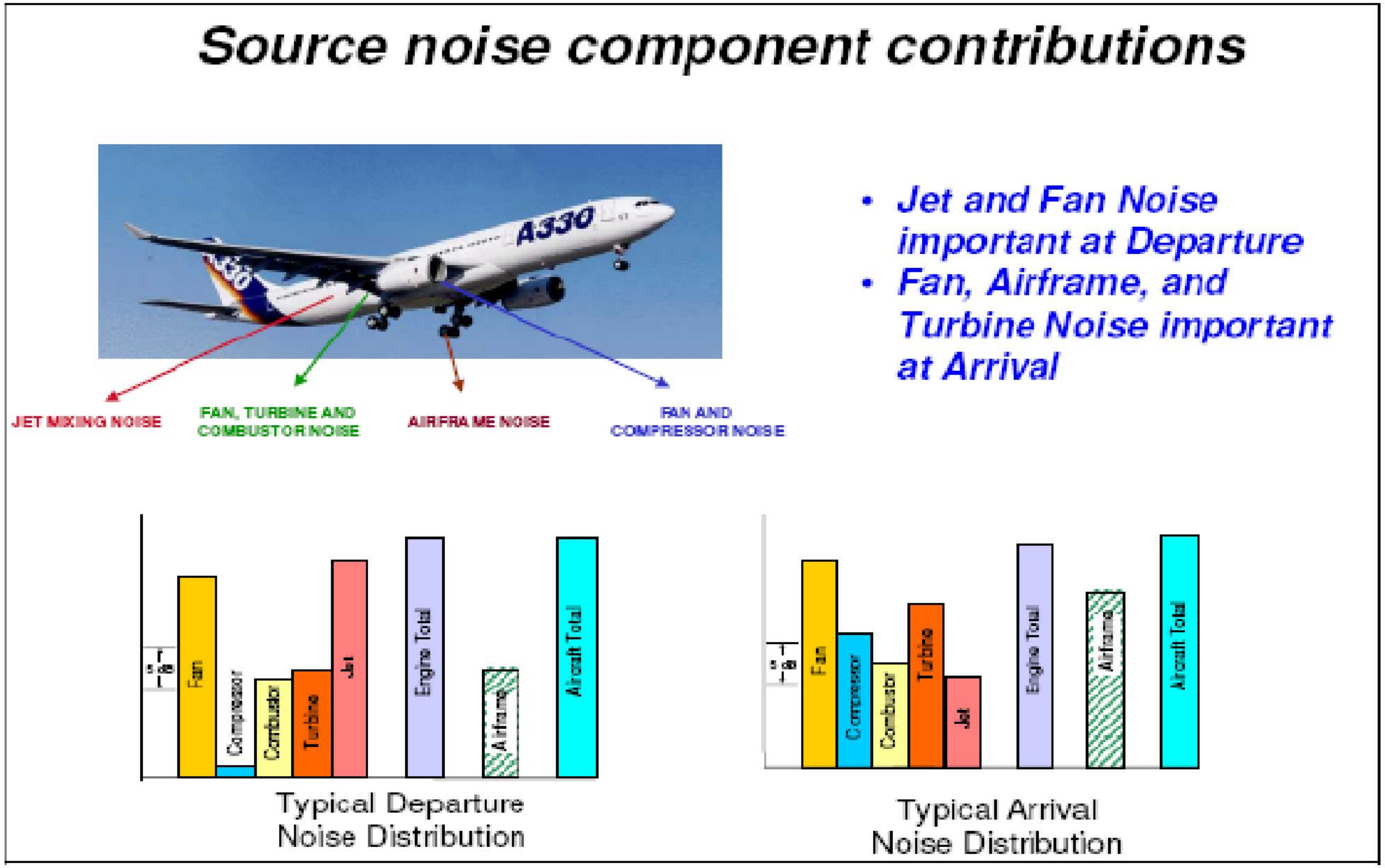


Figura da:

ICAO CAEP/7 WP34

Typical Component Contributions to Total Aircraft Noise for a Modern Turbofan-Powered Aircraft

External Noise: Sorgeti di rumore

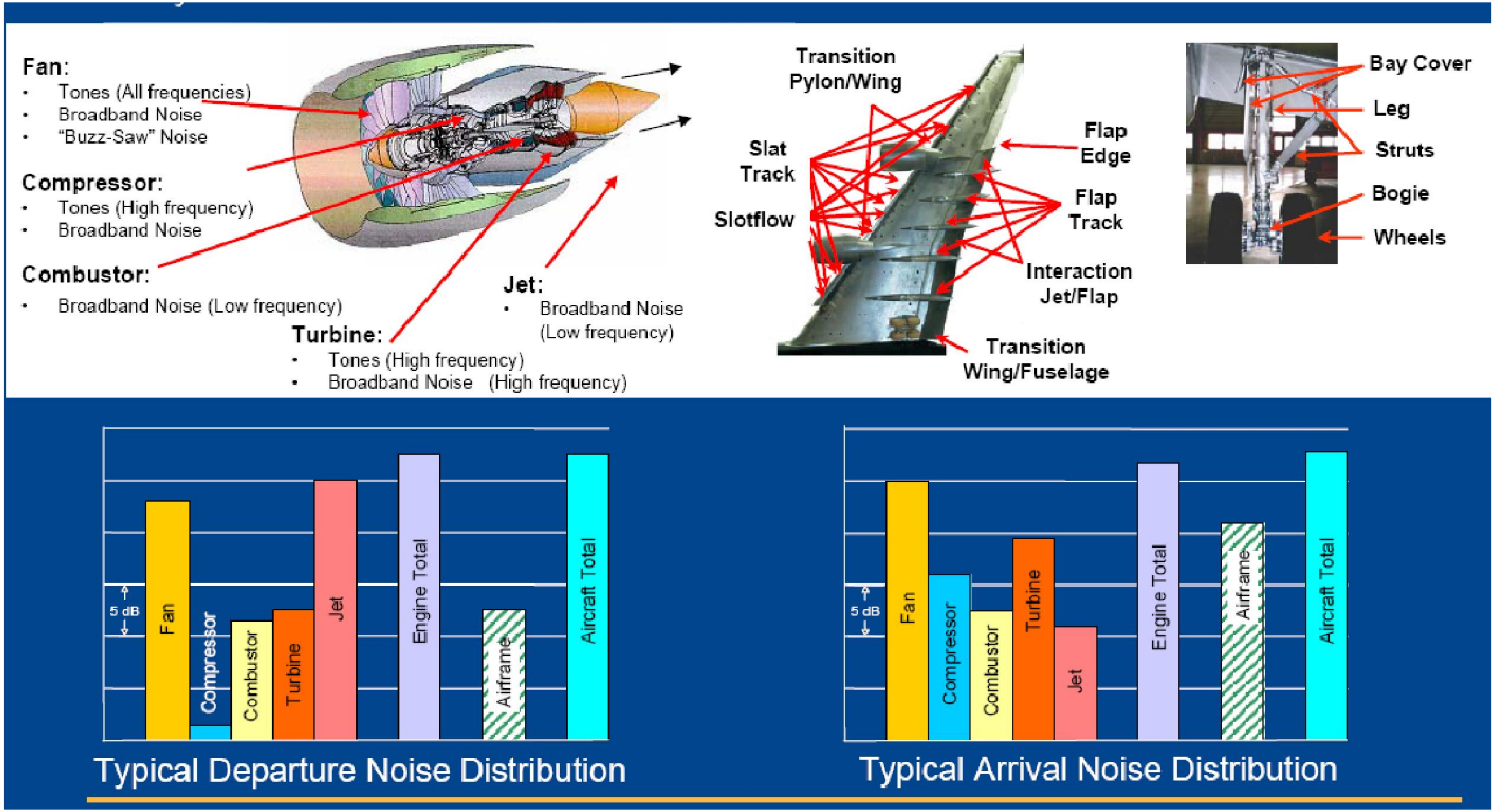


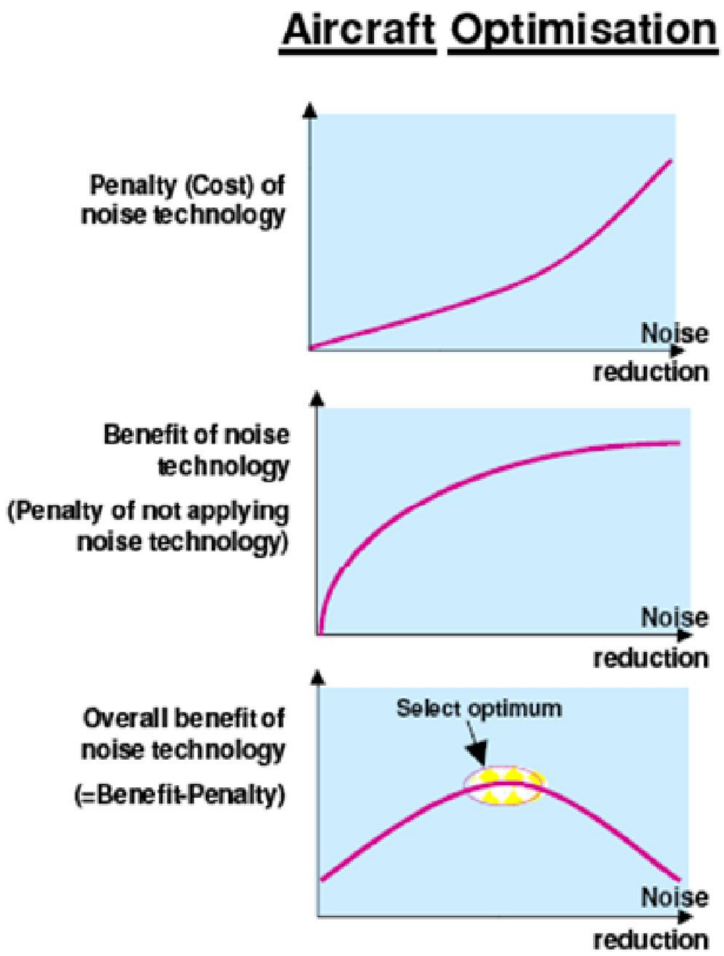
Figura da:

ICAO CAEP/7 IP/11

External Noise: Riduzione delle sorgenti di rumore

Figura da:
ICAO CAEP/7 WP/34

External Noise: Riduzione delle sorgenti di rumore



I Trattamenti acustici sono limitati dal loro impatto sui costi: carburante, emissioni, costi operativi, etc.

La capacità operativa del velivolo (quindi il valore) è accresciuta dalla sua bassa emissione acustica

Il giusto compromesso fra i due punti definisce l'ottimo del progetto

Figura da:
ICAO CAEP/7 WP/34

External Noise: Trattamenti acustici

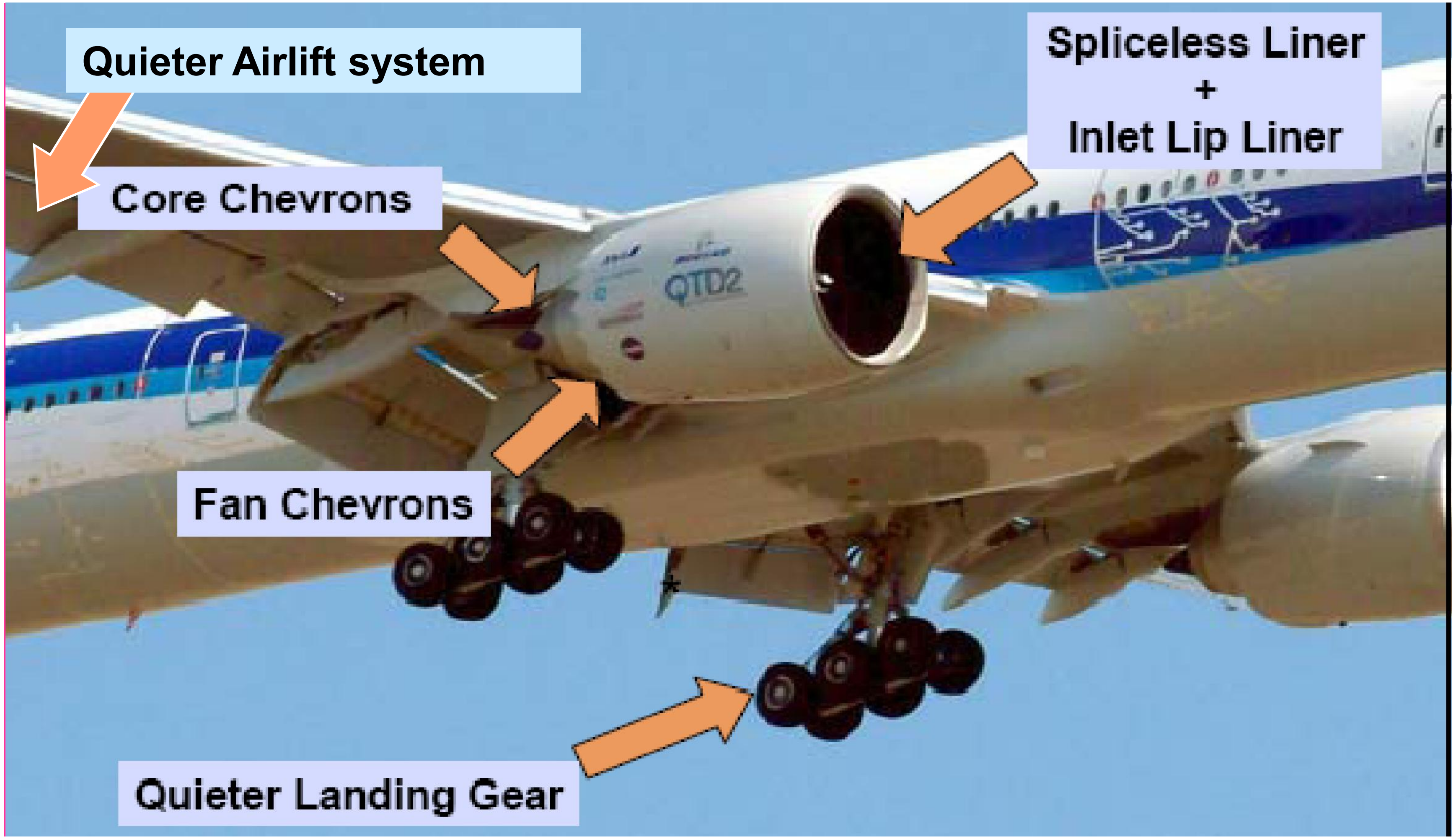


Figure from: CAEP/7 IP11

External Noise: Riduzione Sorgenti di rumore

Responsabilità:

- **Motoristi:** Disegnare e costruire motori con bassa generazione di rumore
- **Airframer:** Disegnare le superfici aerodinamiche ed installare trattamenti per l'attenuazione del rumore, ridurre gli effetti istallativi penalizzanti il rumore emesso

Inlet lining

Baseline Inlet

QTD-2 Inlet

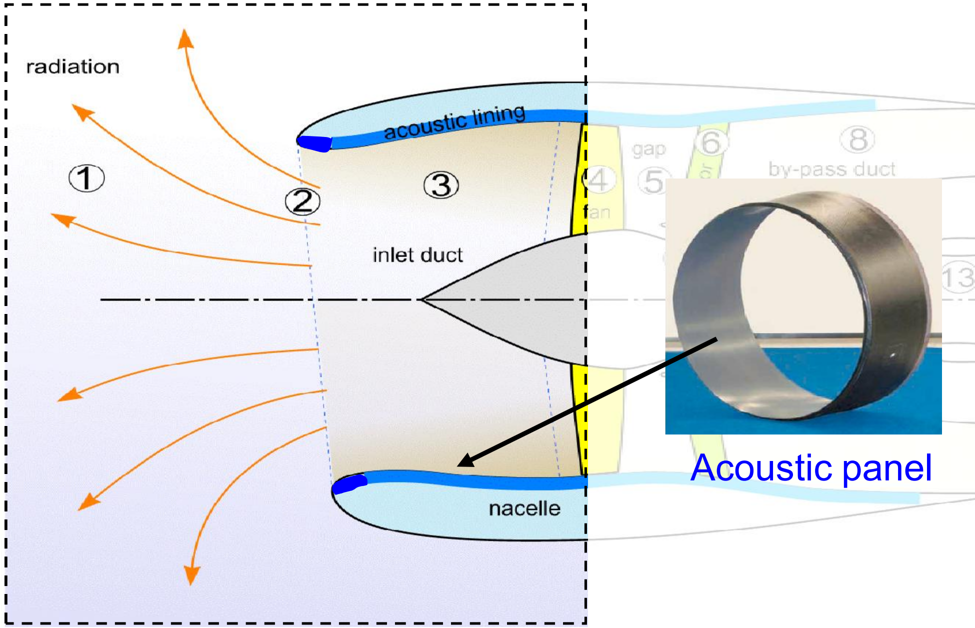
Fan Noise Reduction
(Forward swept fan, porous stators, variable area fan nozzle)

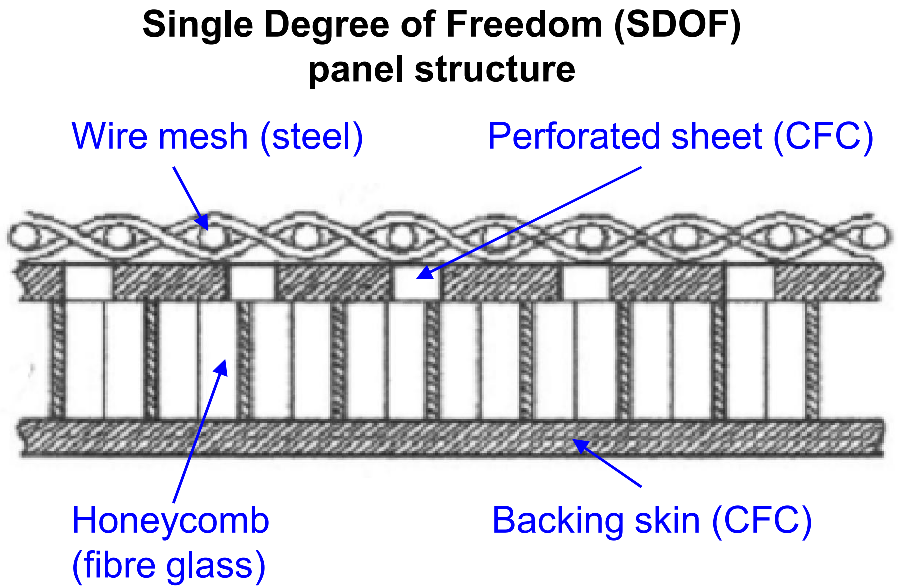
Active Fan Stator fitted with Piezo Actuators Facilty

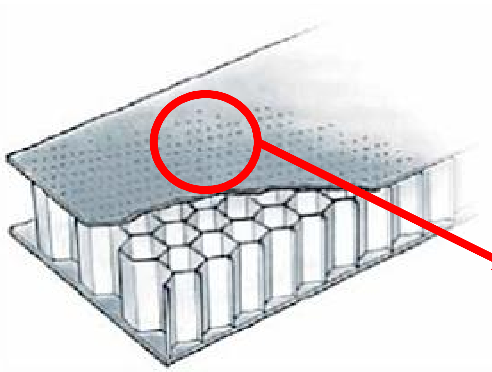
Figure from: CAEP/7 IP11

External Noise: Riduzione Sorgenti di rumore

Reducing fan noise by acoustic treatment

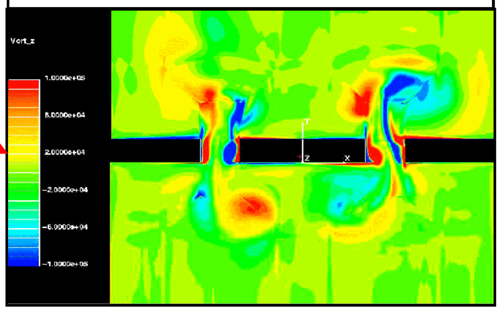


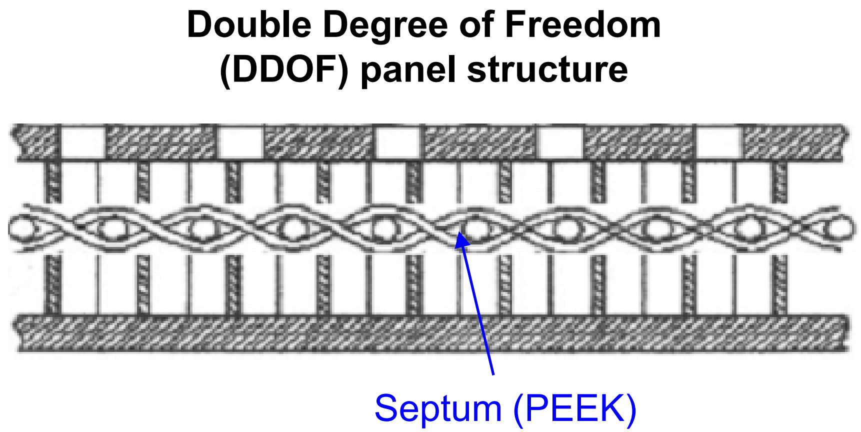




Acoustic panel structure

Noise interaction with the liner surface

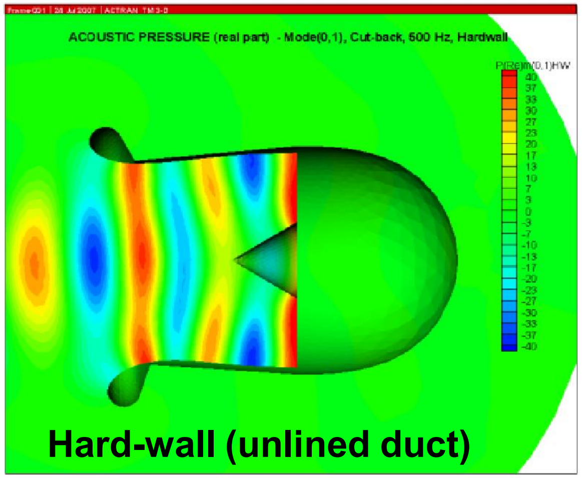


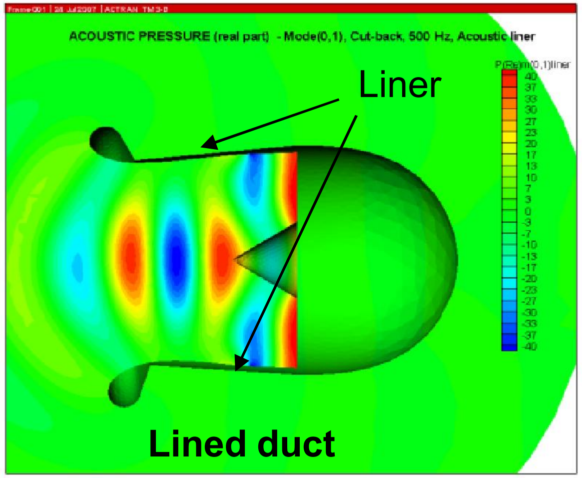


External Noise: Riduzione Sorgenti di rumore

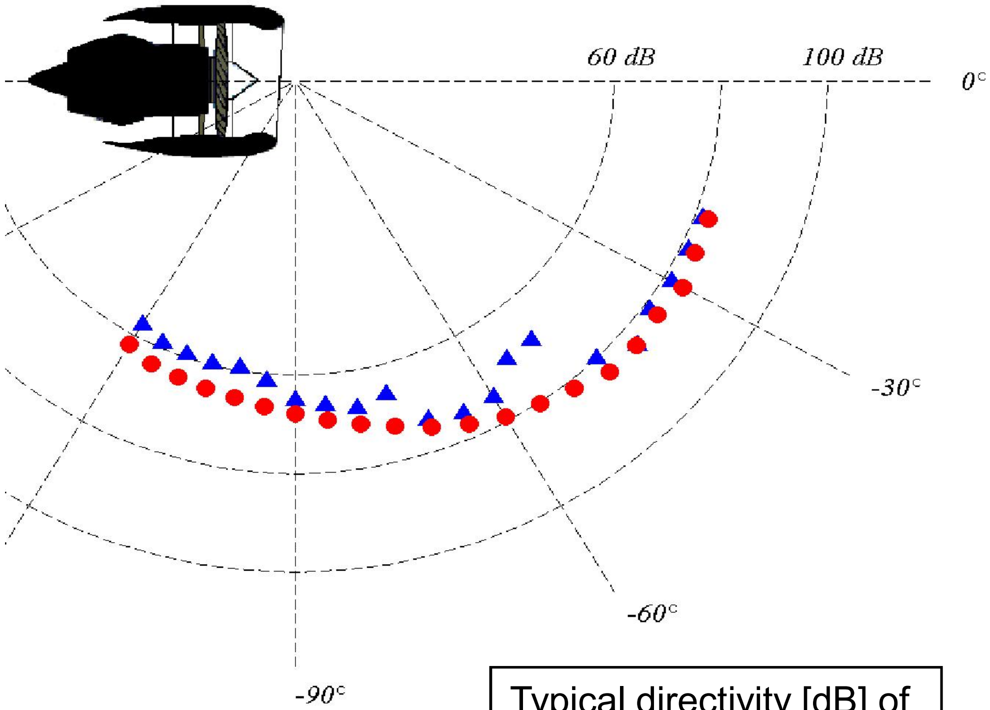
Reducing fan noise by acoustic treatment

Near-field engine noise reduction





Far-field engine noise reduction



Typical directivity [dB] of fan noise radiating through the air intake
▲ Acoustic liner
● Hard-wall

External Noise: Riduzione Sorgenti di rumore

INLET Lining: installazione di materiali assorbenti nella gondola anteriore per ridurre il rumore del fan

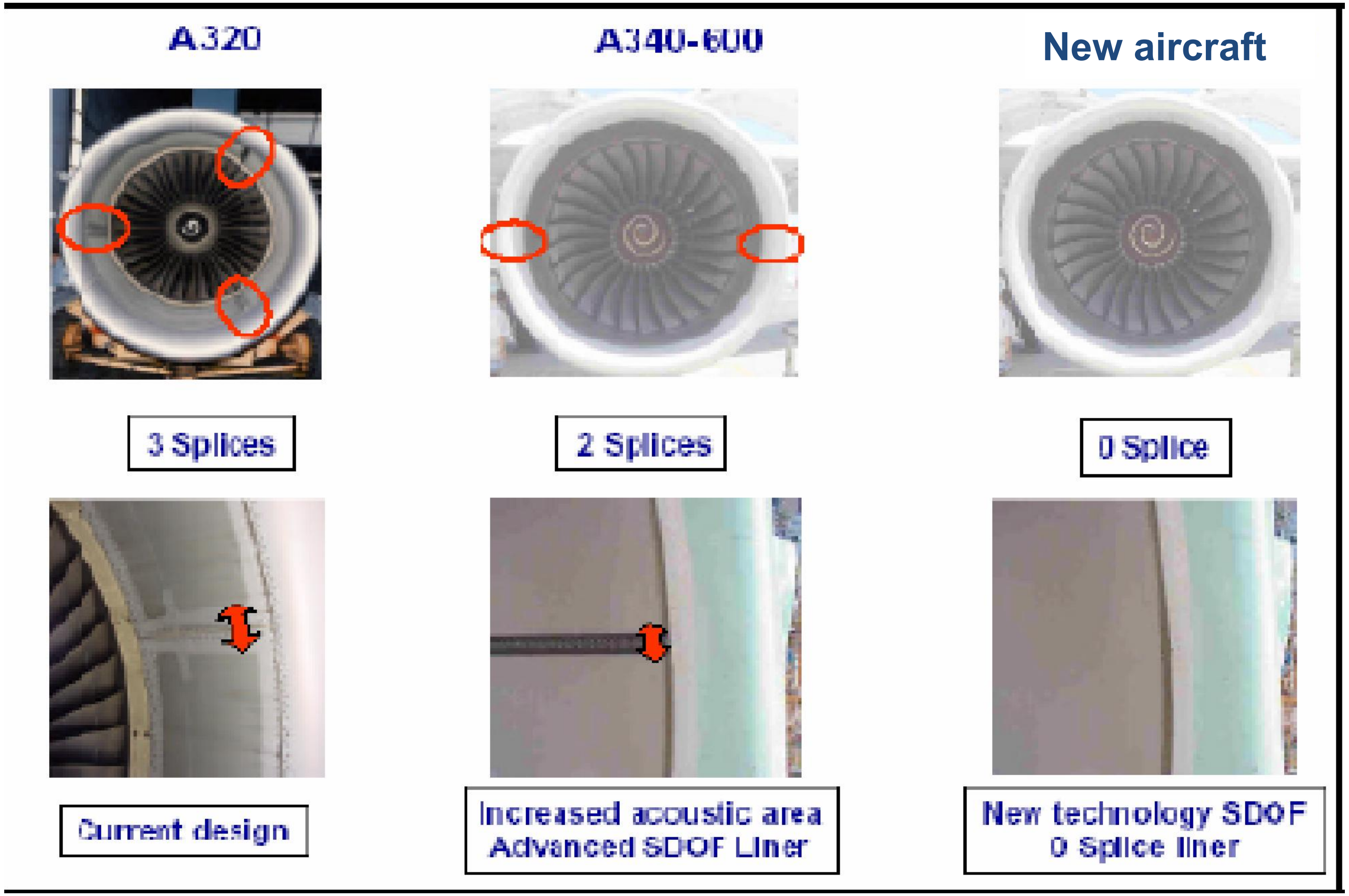


Figure from: CAEP/7 IP11

External Noise: Riduzione Sorgenti di rumore

Il tumore del getto: rappresenta la sorgente maggiore di rumore; la ricerca degli ultimi 20 anni si è focalizzata nel ridurne l'entità. Più di 20 dB di riduzione della componente getto sono stati ottenuti.

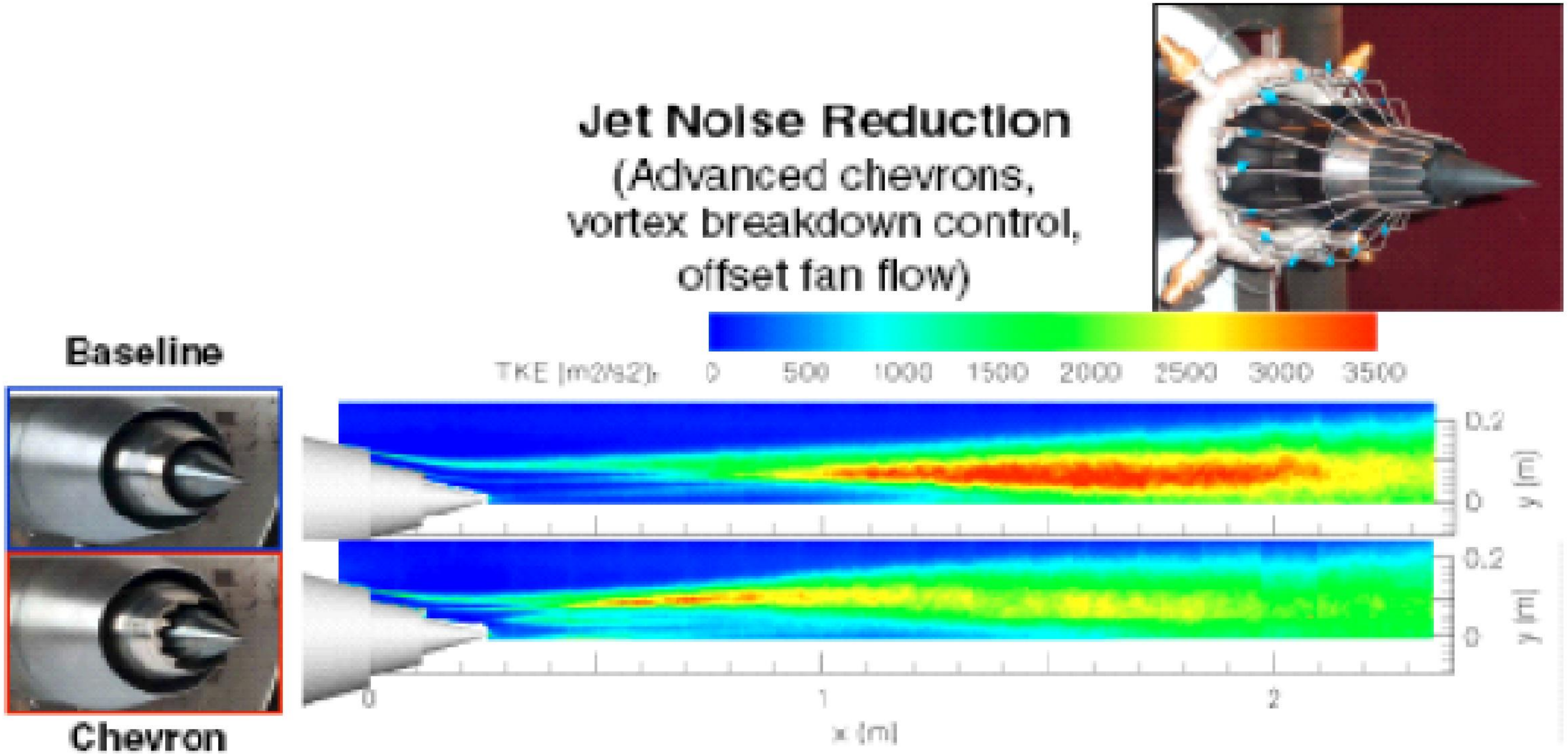
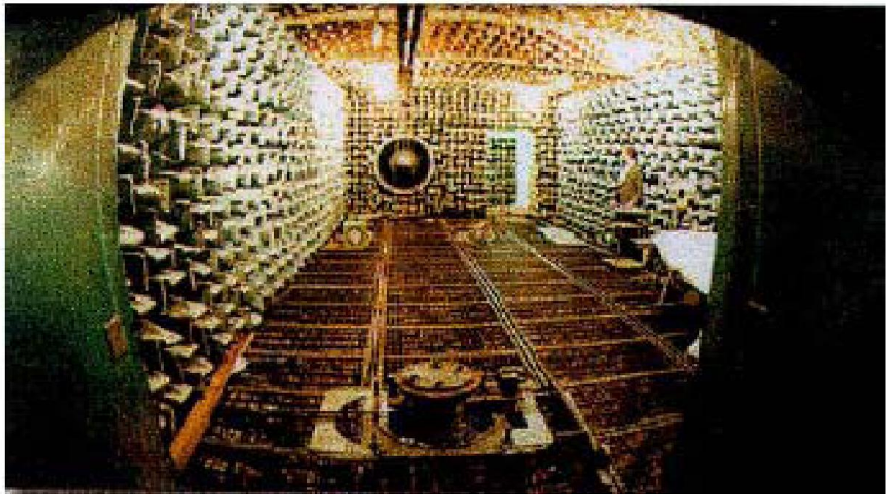


Figure from: CAEP/7 IP11

External Noise: Riduzione Sorgenti di rumore

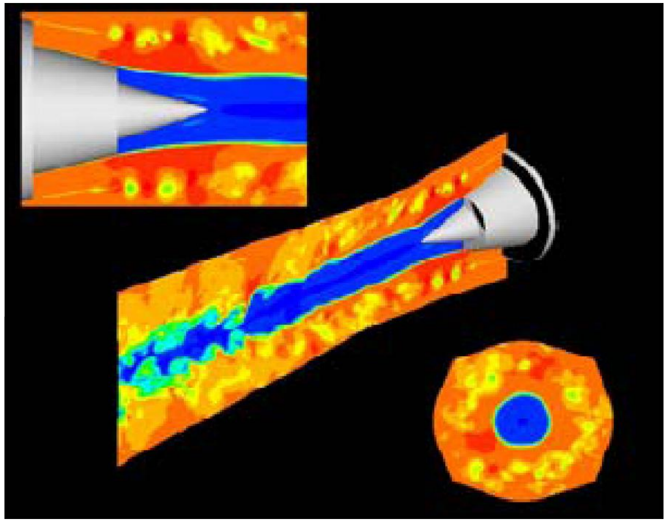
JET NOISE Study: simulazione numerica e sperimentazione di laboratorio

Experiment



Sperimentazione in camera anecoica di getto con flusso caldo

Theoretical Simulation



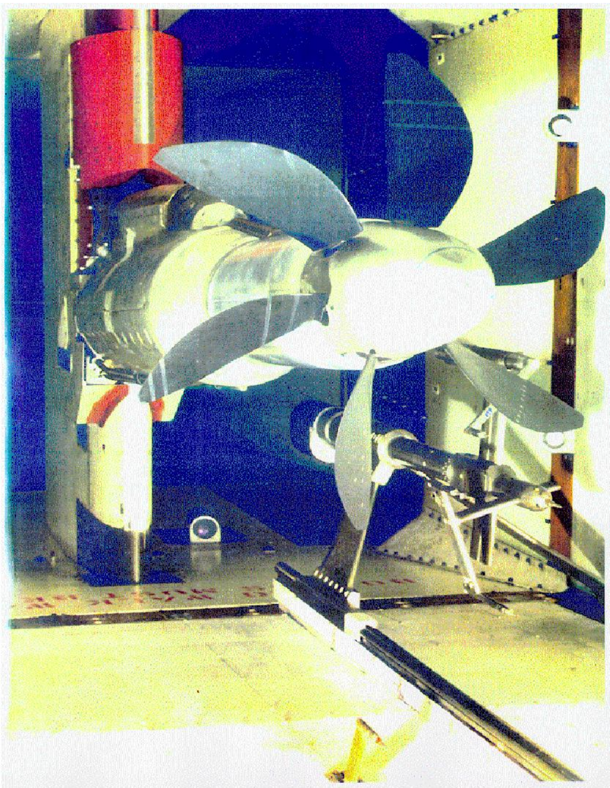
Simulazione getto coassiale mediante tecnica LES

Figure from: CAEP/7 IP11

External Noise: Riduzione Sorgenti di rumore

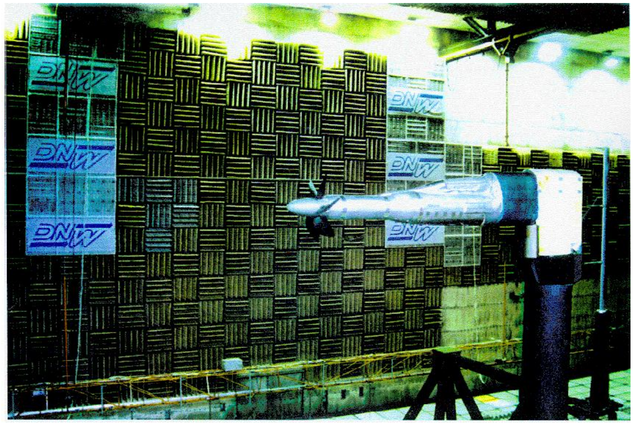
Rumore delle eliche:

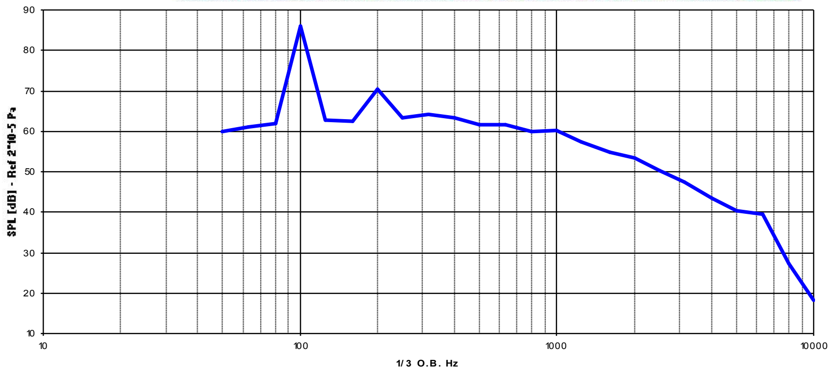
Nei velivoli propulsi ad elica (es. aviazione generale e regionali) la sorgente fondamentale di rumore è l'elica. Studi e ricerche di aeroacustica hanno prodotto notevoli riduzioni di questa componente di rumore (più di 30 dB): modificando la forma ed incrementando il numero delle pale, variandone profilo e velocità di rotazione.



HSP in

ARA TWT & DNW





Tipico spettro di rumore generato da un turbopropulsore ad elica

APIAN EU Project

External Noise: Riduzione Sorgenti di rumore

OPEN ROTOR:

WT test per studiare la configurazione Regionale con propulsione Oen Rotor.

Test di aeroacustica per valutare gli effetti installativi della nuova propulsione.

Progewtto : JTI-WENEMOR

External Noise: Riduzione Sorgenti di rumore

Sorgenti aerodinamiche principali:

Landing gear **Airlift surfaces**

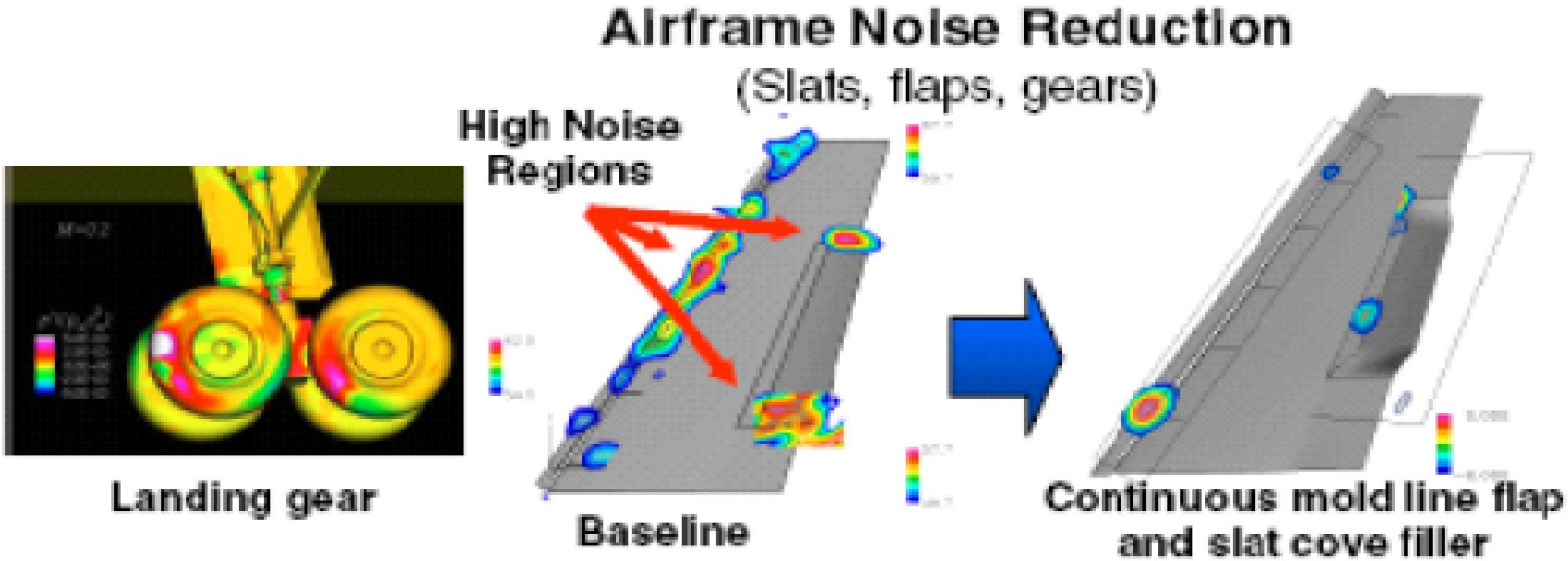
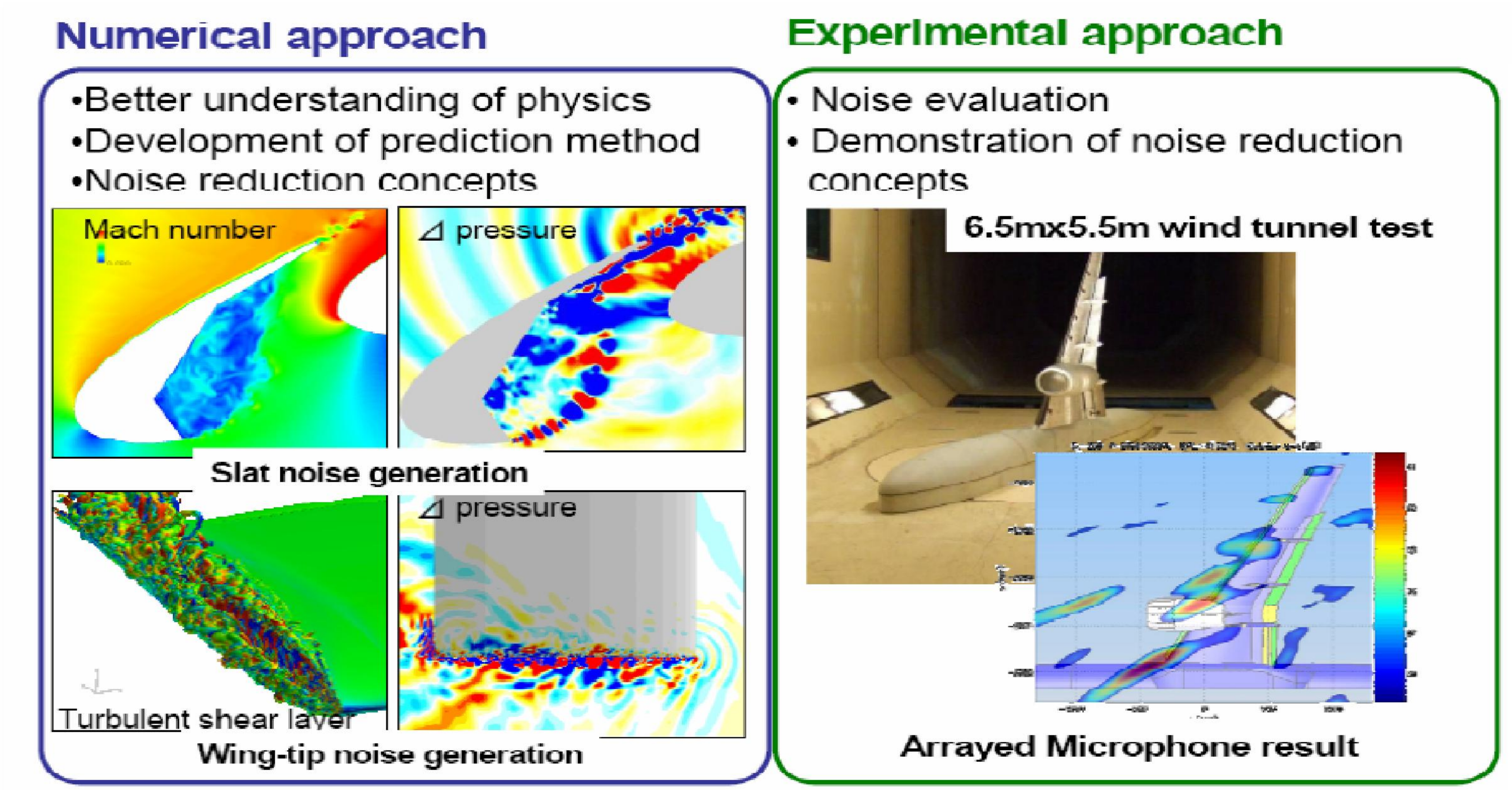


Figure from: CAEP/7 IP11

External Noise: Riduzione Sorgenti di rumore

Principali studi e modifiche, superfici aerodinamiche:

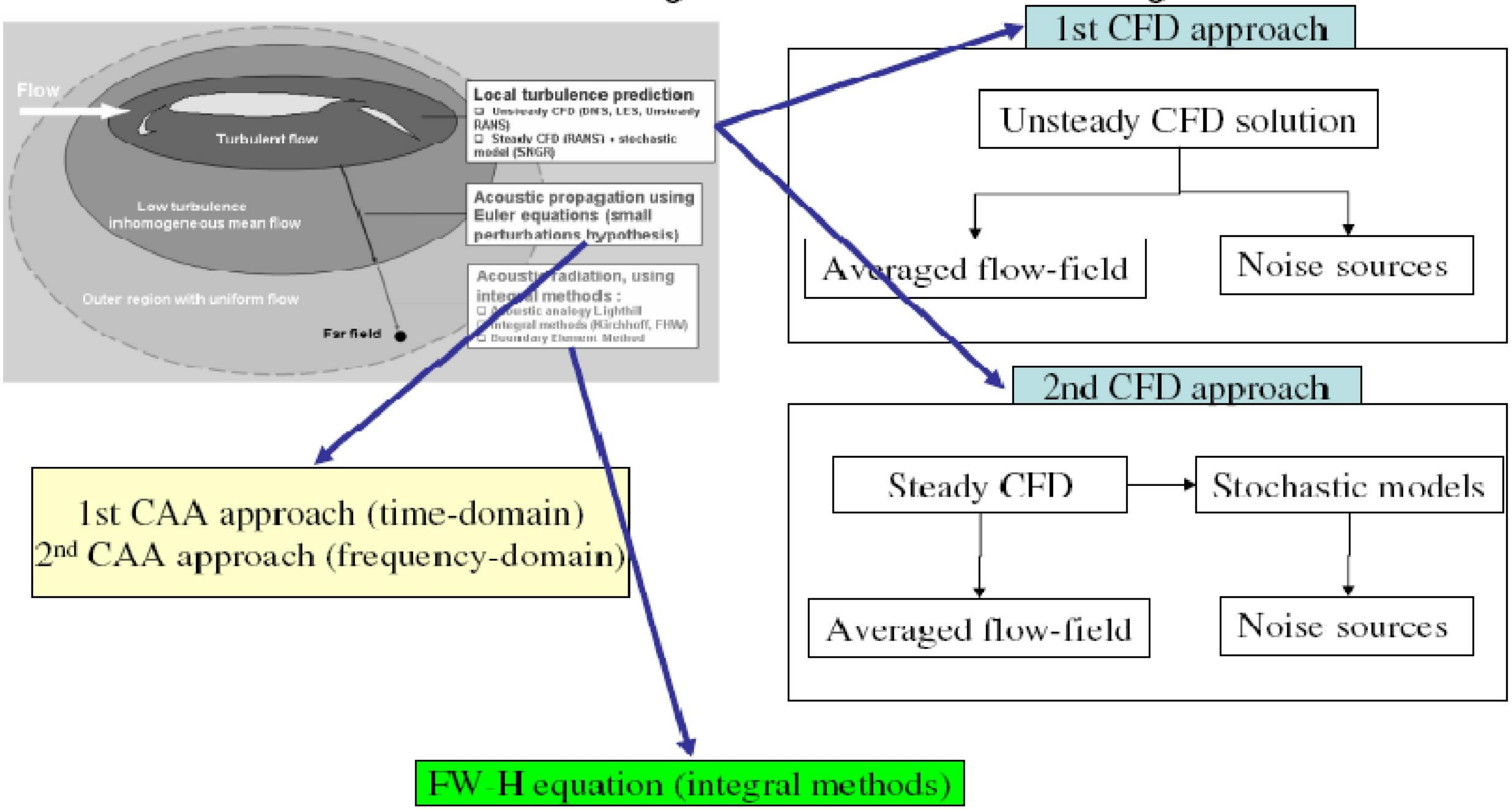


Detail of High Lift Devices (HLD) Noise Reduction Activities

Figure from: CAEP/7 IP11

External Noise: Sorgenti aerodinamiche modellazione

CFD-CAA state of the art in High Lift Devices noise modelling

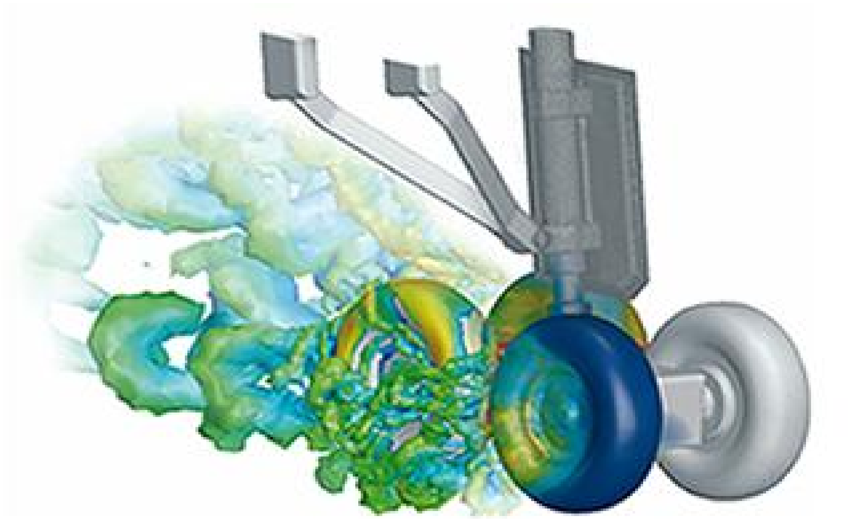


Slide Provided by CIRA

External Noise: Riduzione Sorgenti di rumore

Principali studi e modifiche, carrello:

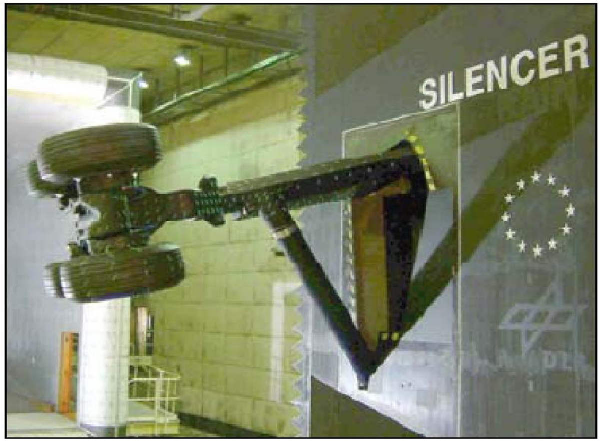
- ✓ Riduzione della separazione del flusso prodotta da cavi e tubi istallati sulla gamba carrello
- ✓ Riduzione delle Scie generate dalle ruote del carrello
- ✓ Riduzione dei flussi vorticosi generati intorno alle porte del carrello



External Noise: Riduzione Sorgenti di rumore

Principali interventi insonorizzanti:

- cover cups
- fairings
- clean roads
- shielding
- vortex generator



A340 main
equipped

SILENCER Configuration

Figure from: CAEP/7 IP11

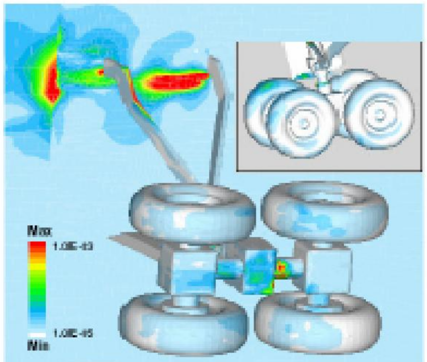
External Noise: Sorgenti aerodinamiche modellazione

CFD-CAA state of the art in Landing Gear noise modelling

- The pressure and velocity fields around the landing gear constitute the noise sources. → UNSTEADY NAVIER-STOKES EQUATIONS

On-line/Off-line data transfer

- The noise radiation to the far-field is computed in post-processing step via integral methods → ACOUSTIC ANALOGY: FW-H EQUATION



(b) 795 Hz

Fig. 8 FW-H source strengths plotted over the surface of the landing gear. The observer is 100 wheel diameters directly below the gear in a $M = 0.2$ flow.

Ref: AIAA 2003–3111
Aeroacoustic Analysis of a Simplified Landing Gear
(NASA Langley Research Center)

Slide Provided by CIRA

External Noise: Certificazione Acustica

Gli obiettivi degli enti di Certificazione Internazionale (ICAO, EASA, FAA) sono:

- Assicurare un basso livello di inquinamento acustico nelle aeree vicino agli aeroporti
- Assicurare che il livello tecnologico raggiunto dalla ricerca sviluppata sia adottata dai nuovi prodotti
- Fissare nuovi limiti di inquinamento in linea con lo sviluppo della ricerca e con la fattibilità tecnica dei nuovi prodotti
- Proteggere la salute degli abitanti nelle aree vicino agli aeroporti consentendo livelli di rumorosità adeguati e controllandone l'applicazione

External Noise: Certificazione Acustica

❑ A/C Category:

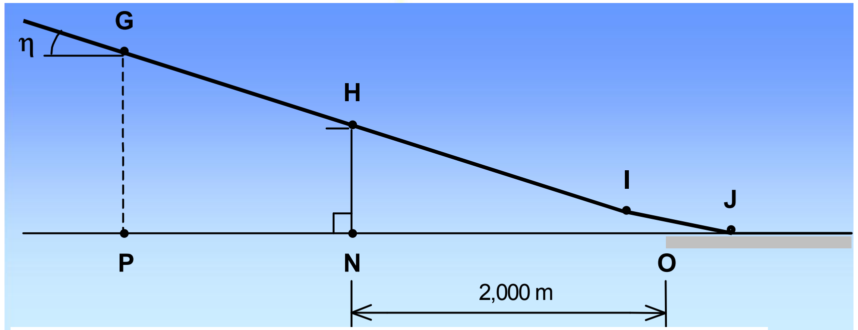
- Jet A/C and Large propeller aircraft (above 12500lb
- Light propeller aircraft (below 12500 lb)
- Helicopter

❑Regolamenti di riferimento:

- ICAO; ANNEX 16 VOL. 1 (International requirements)
- FAA : FAR 36 (USA requirements)
- EASA; CS36 (European requirements)

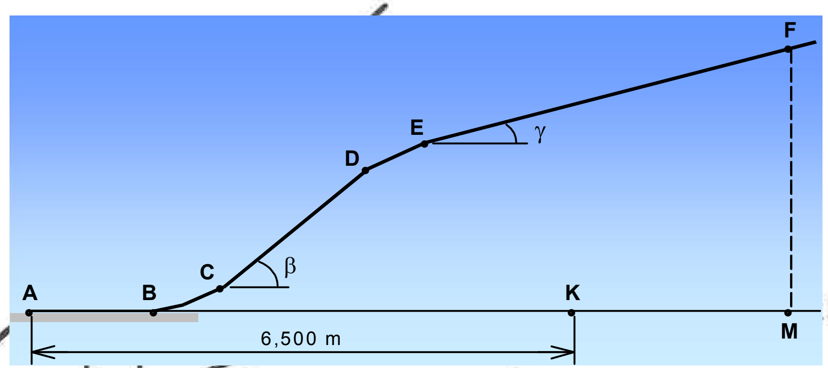
Le versioni delle normative FAR36 e CS36, applicabili attualmente, sono del tutto equivalenti alle normative ICAO Annex 16 Vol. 1

External Noise: Certificazione Acustica



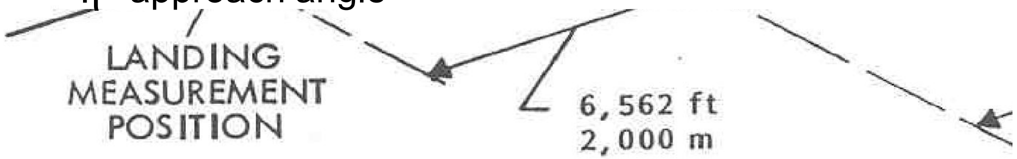
Typical Approach Flight Path

G start of noise certification approach flight path
N noise measurement station
O runway threshold
η approach angle



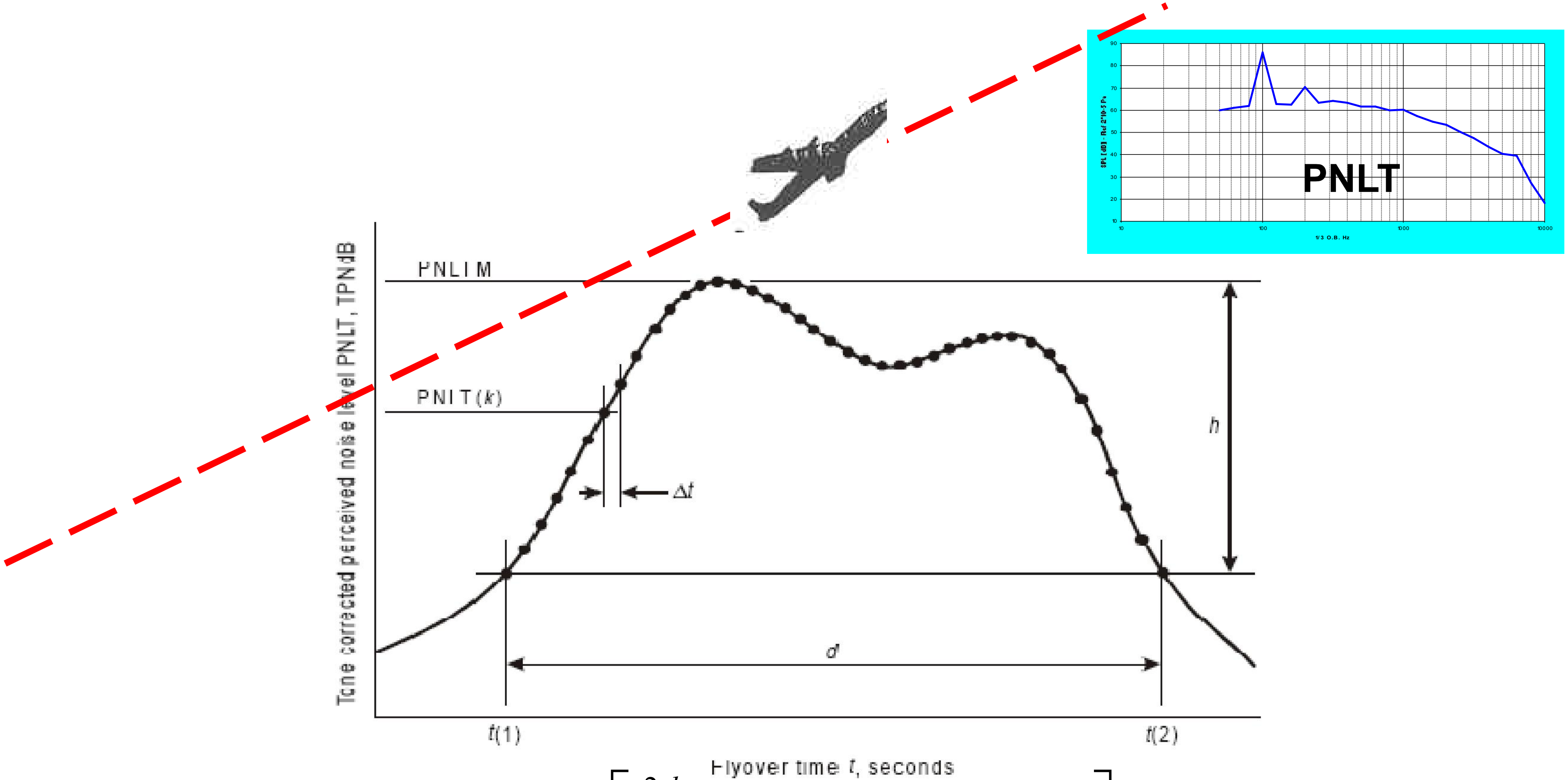
Typical Take-off Flight Path:

A start of take-off roll
B lift off
C start of 1st constant climb
D start of thrust cut-off
E start of 2nd constant climb
F end of noise certification TO flight path
K noise measurement station
β 1^{st} constant climb angle
γ 2^{nd} constant climb angle



LOCATION OF NOISE MEASUREMENT POSITIONS FOR CERTIFICATION MEASUREMENTS

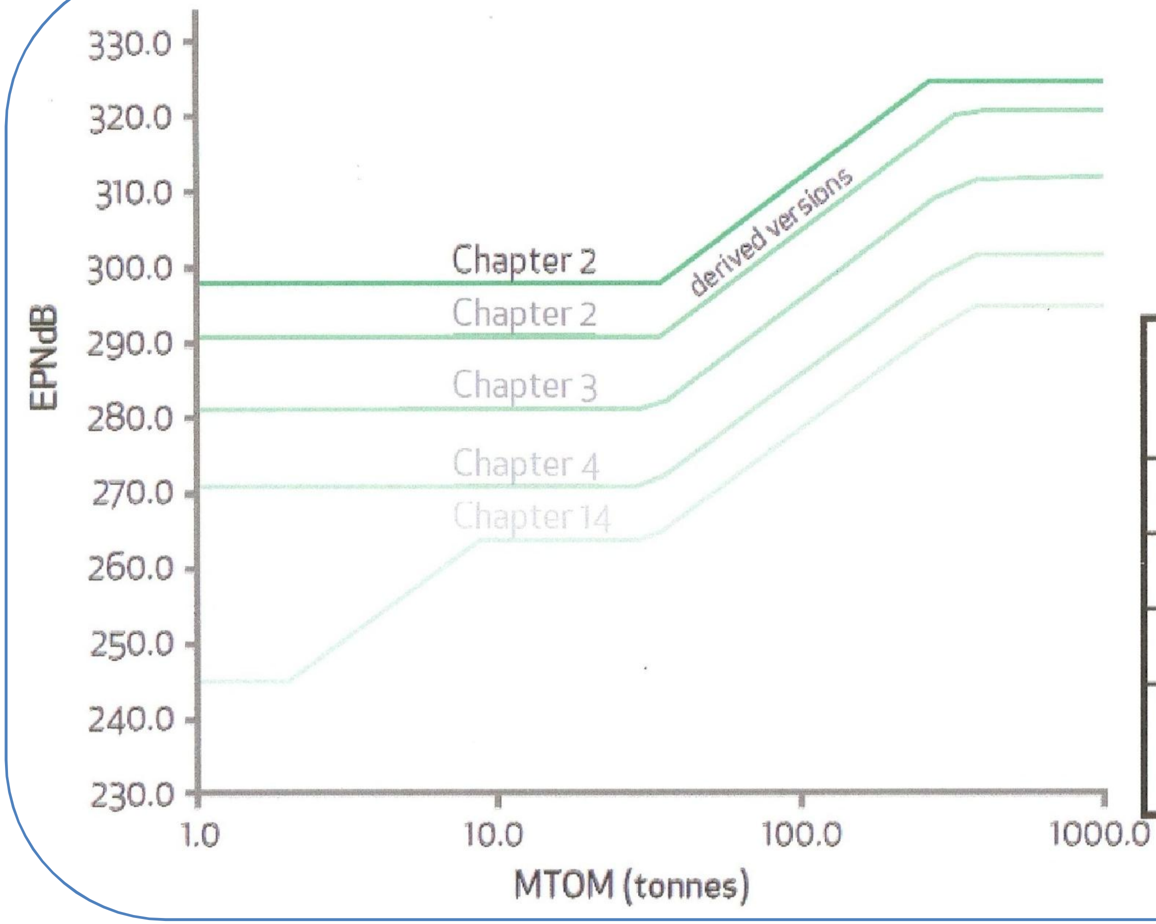
External Noise: Certificazione Acustica



$$EPNL = PNLM \underbrace{+10\log\left[\sum_{k=0}^{2d} anti\,\log\frac{PNLT(k)}{10}\right] - PNLTM - 13}_{\textbf{Duration}}$$

External Noise: Certification Limits

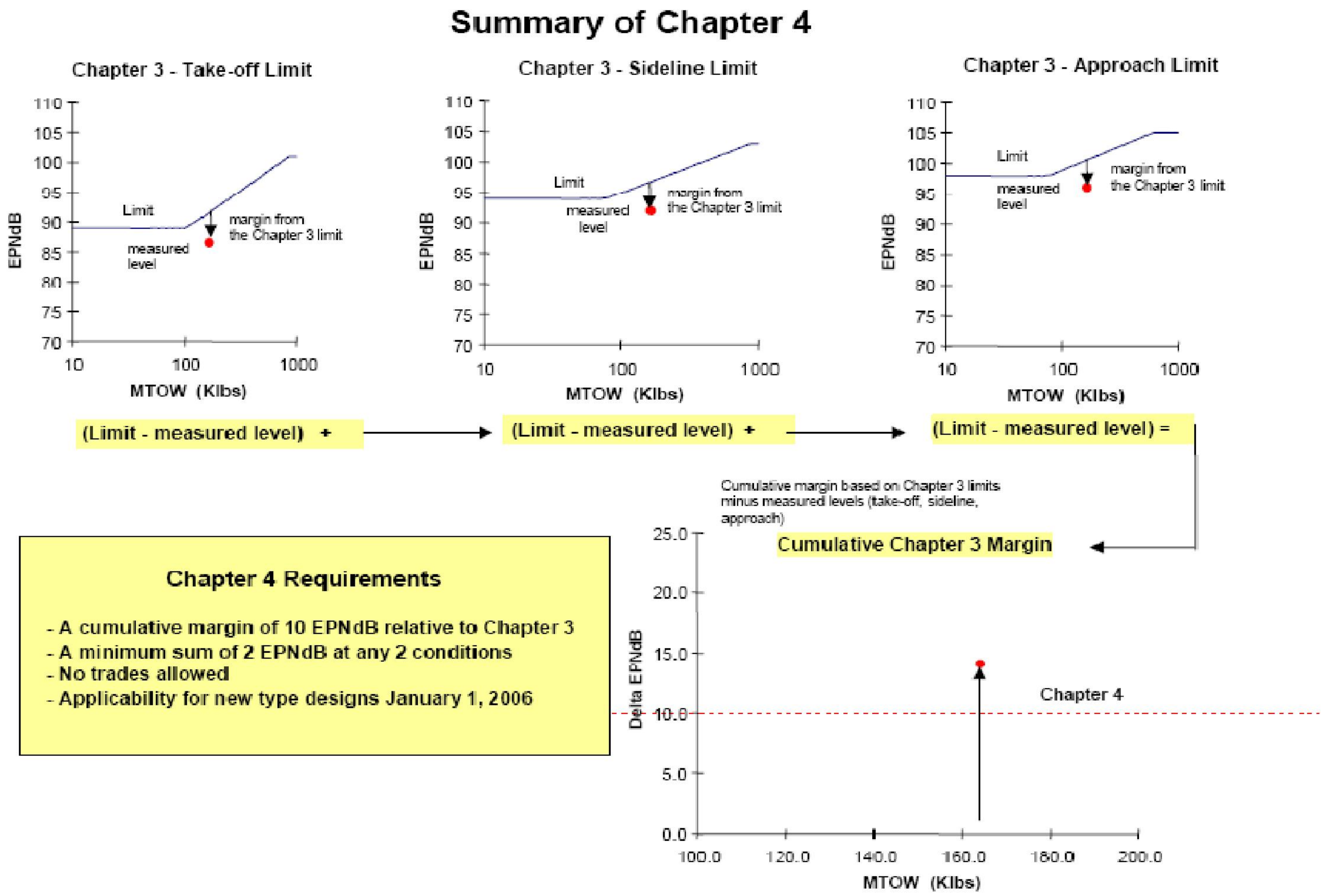
Evoluzione dei Limiti di certificazione : ICAO certification Chapters (Stages)



Stage 1 ; Applied 1969

Chapter	Applicable Year	Cum Margin (EPNdB)
2	1972	Ch. 3 ~-16
3	1978	0 (Ref)
4	2006	Ch. 3 +10
14	2017 & 2020	Ch. 3 +17 (Ch. 4 +7)

External Noise: Certificazione Acustica



External Noise: Certificazione Acustica

A/C Cumulative Certification Levels status

Figure 1: Cumulative certificated noise levels of twin-engined subsonic jets and heavy propeller driven aeroplanes

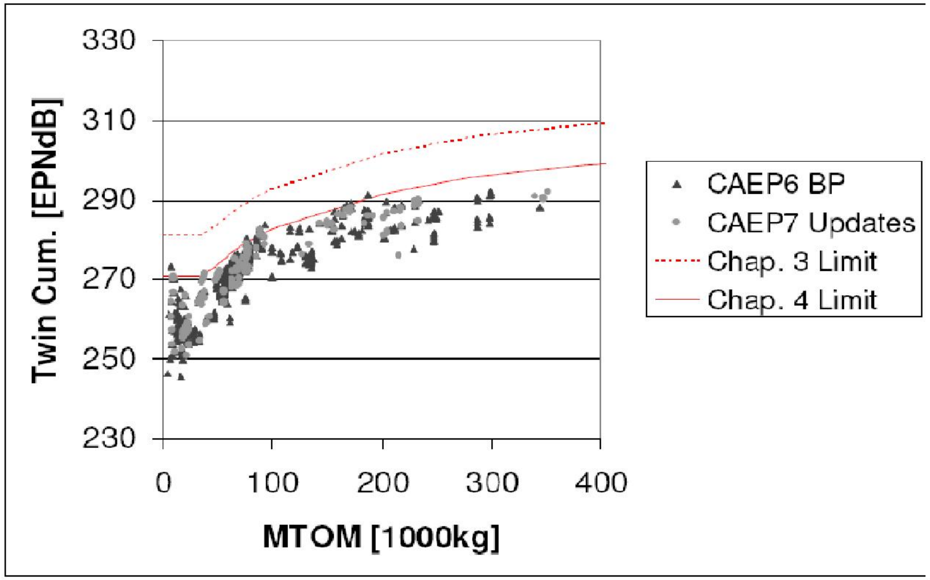
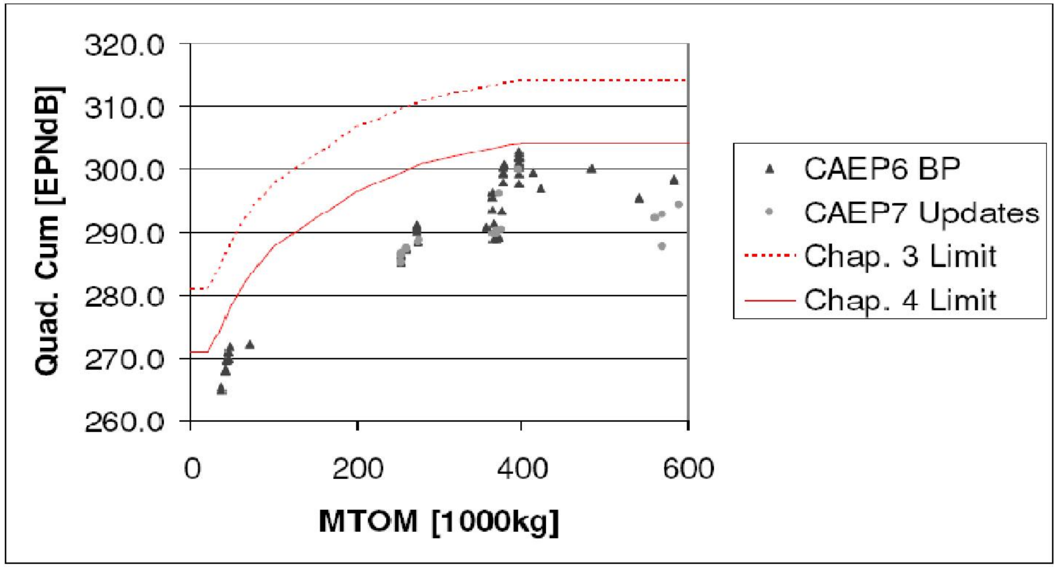


Figure 2: Cumulative certificated noise levels of four-engined subsonic jets and heavy propeller driven aeroplanes



Twine Engines

Four Engines

Figure from: CAEP/7 IP41

External Noise: Certificazione Acustica

A/C Cumulative Certification Levels status

Figure 3: Certificated noise levels of twin-engined light propeller driven aeroplanes and the original certification date of the aircraft type

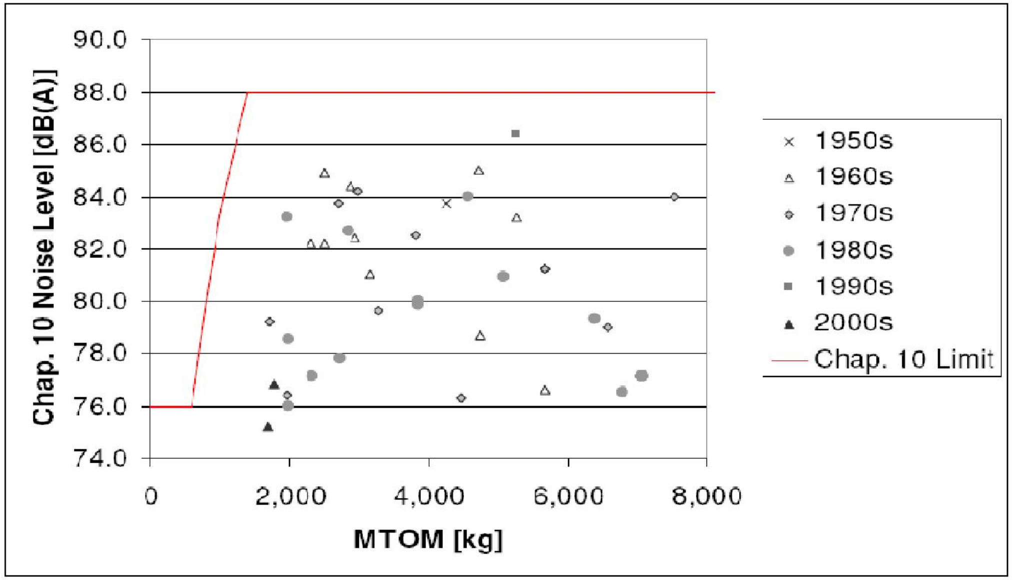
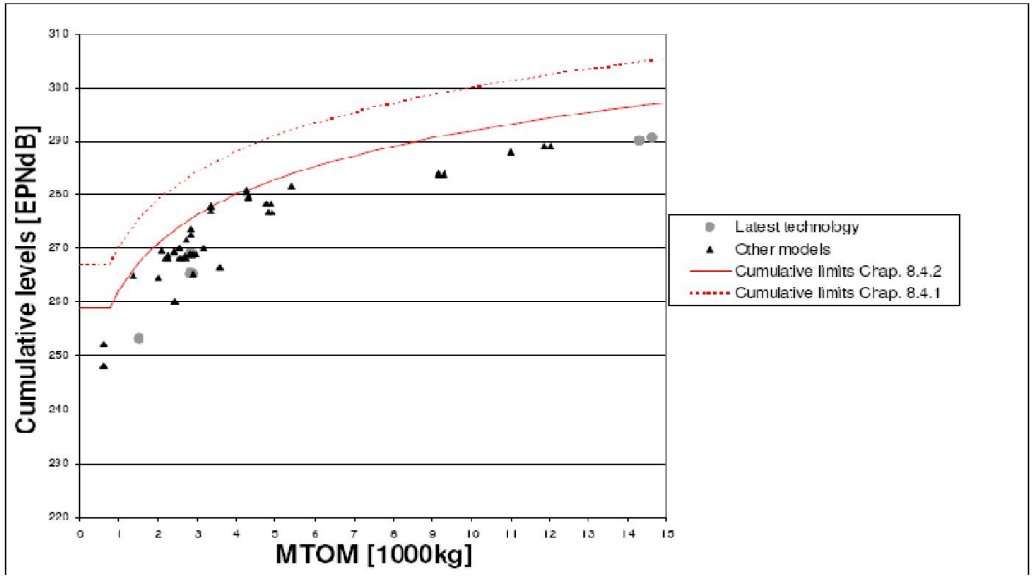


Figure 4: Cumulative certificated noise levels of Chapter 8 helicopters

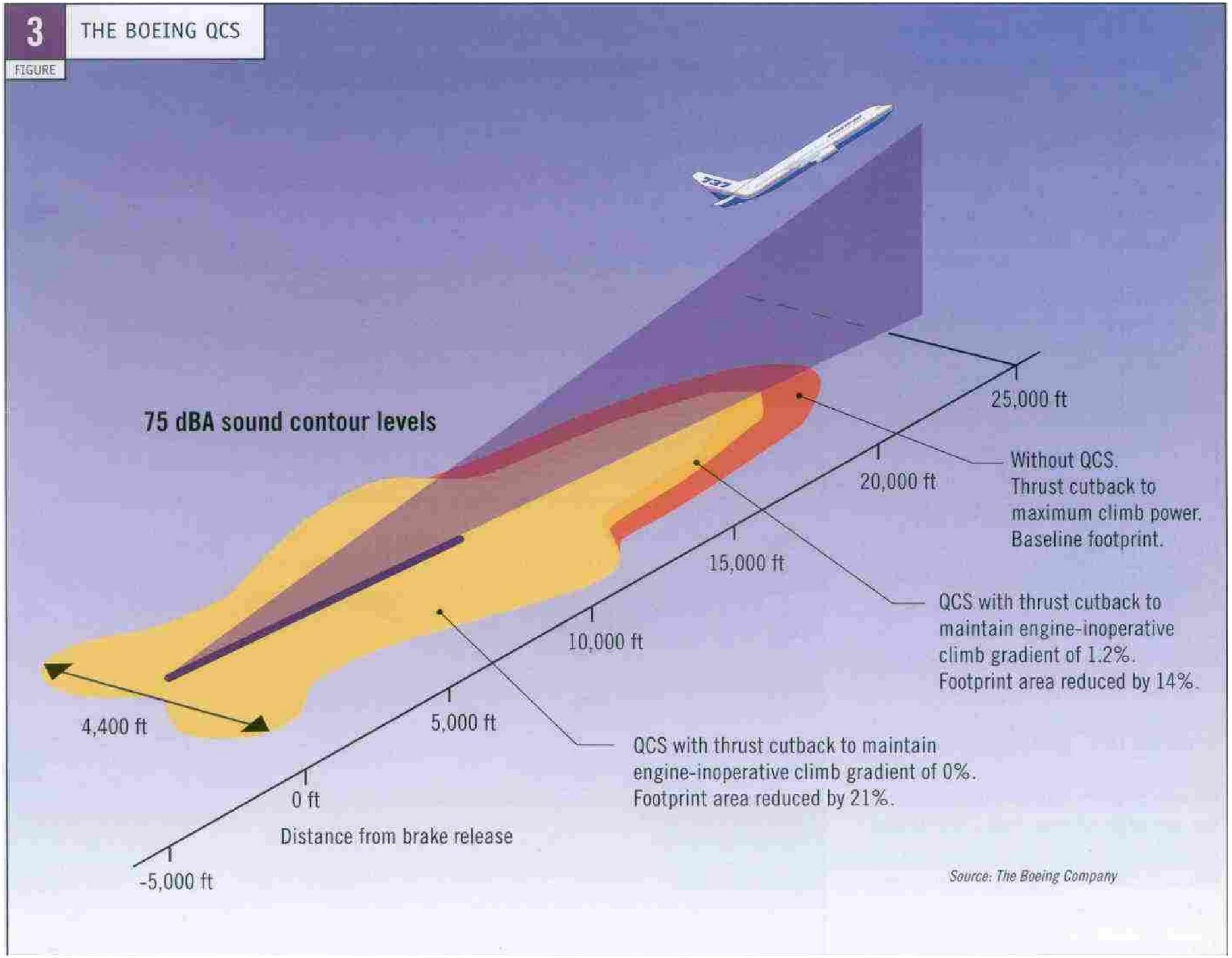


Light A/C less then 12500 lb

Helicopter

Figure from: CAEP/7 IP41

External Noise: Certificazione Acustica



External Noise: Certificazione Acustica

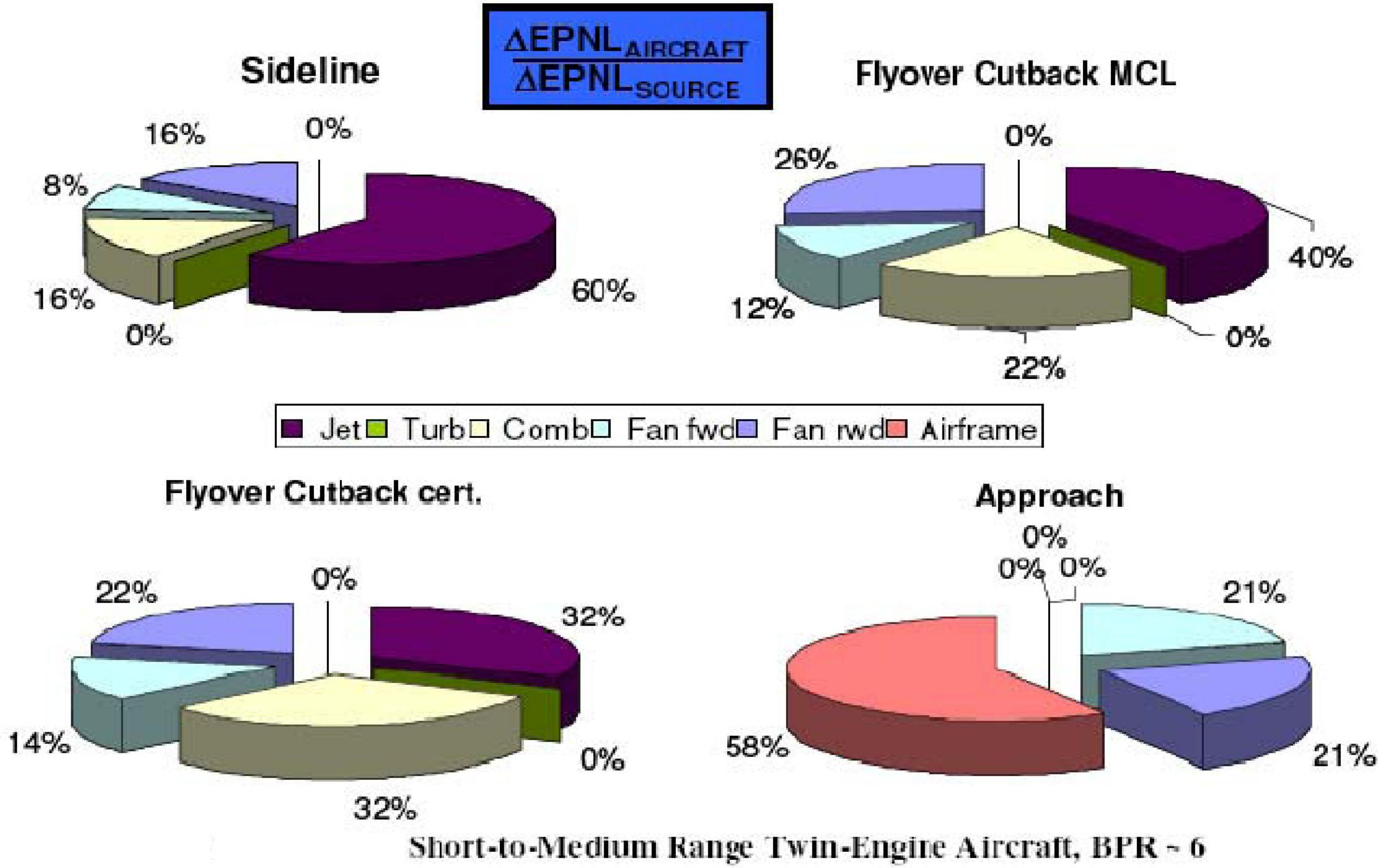


Figure from: CAEP/7 WP34

External Noise: Certificazione Acustica

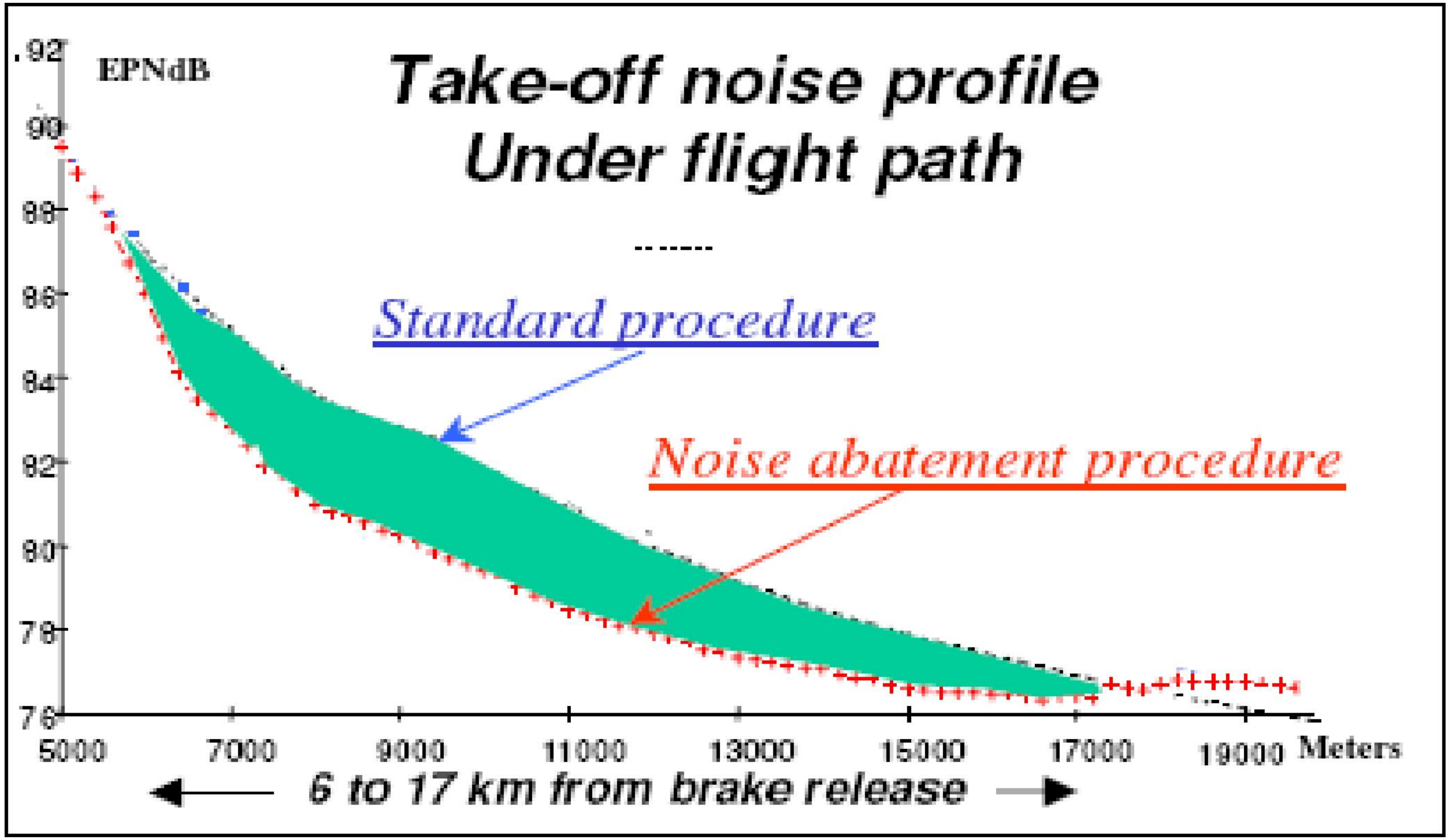


Figure from: CAEP/7 WP 34

External Noise: Sonic Boom

Il volo supersonico produce un notevolissimo fastidio prodotto dal Boom Sonico, questo contribuisce ad inibirne l'uso

- L'onda d'urto creata da un velivolo in volo supersonico si impatta al suolo su un'area larga diversi km producendo sia vibrazioni che rumore molto fastidiosi.
- L'onda di pressione (n-wave) generata è la sorgente del fastidio, la sua ampiezza e durata dipendono dalle dimensioni del velivolo e dalla sua velocità.
- Le ricerche in corso per ridurre l'intensità del boom sonico sono concentrate sul disegno di forme aerodinamiche che minimizzino i parametri dell' n-wave.

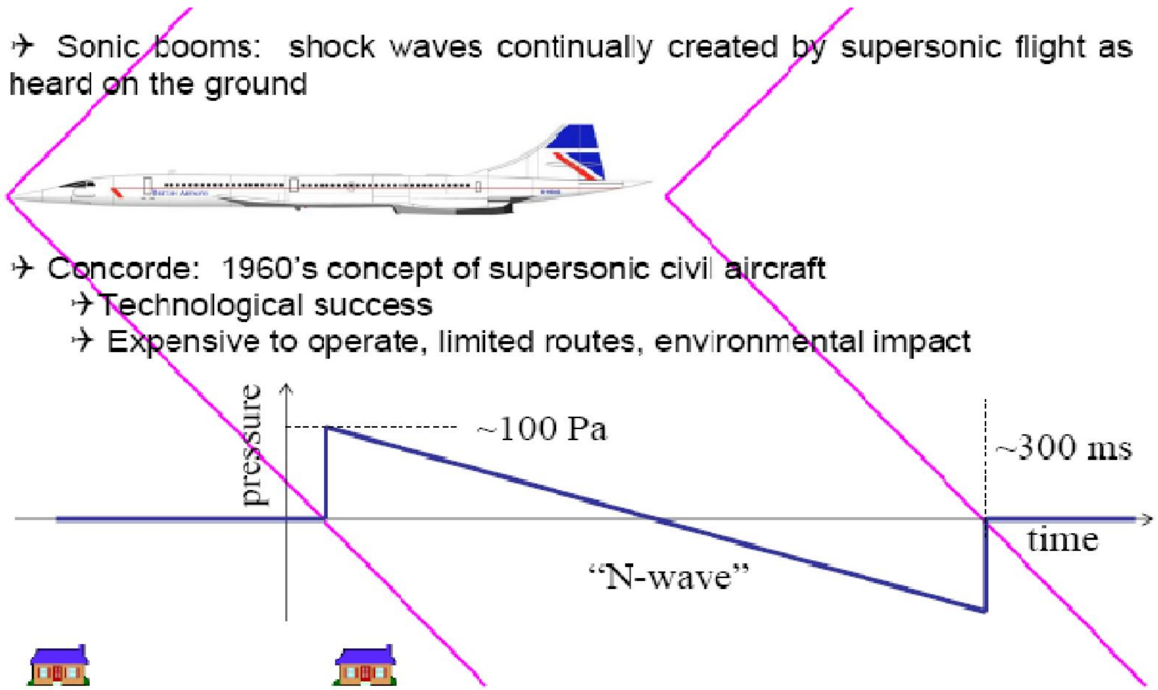


Figure from: CAEP/7 IP 18

External Noise: Sonic Boom

Esempi di dati da Boom Sonico:

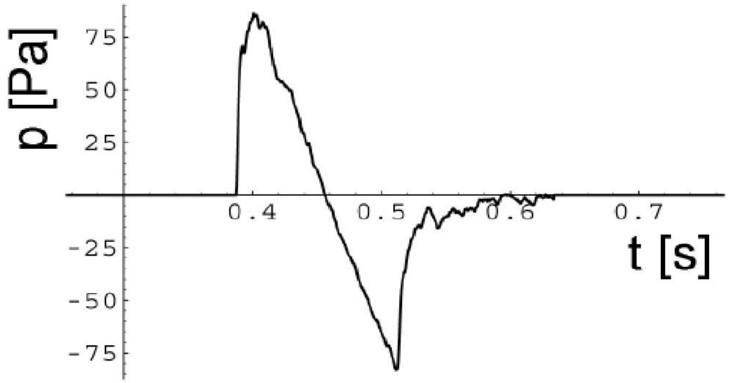


Fig. 1: Example measured waveform of F-15 aircraft. This particular waveform is somewhat rounded in shape.

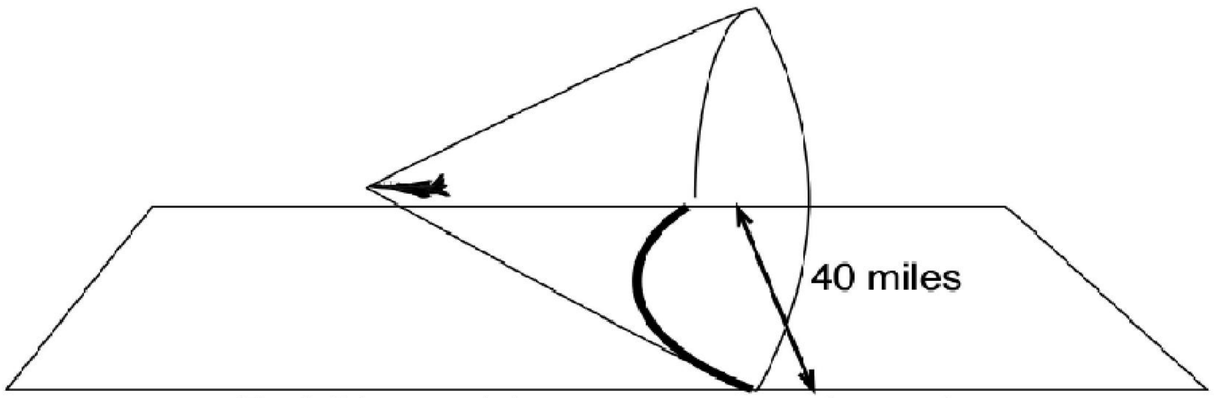


Fig. 2: Primary sonic boom carpet swept over the ground.

Figure from: CAEP/7 IP 18

External Noise: Sonic Boom

La riduzione del Sonic Boom richiede la modifica della N-wave di pressione (primary and secondary pichs).

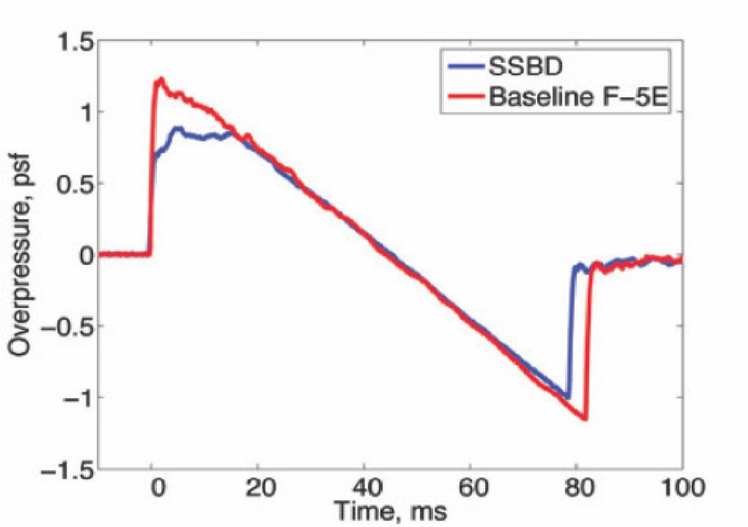


Fig. 4: Sonic booms compared for SSBD and F-5E. [Courtesy Northrop-Grumman Corporation]

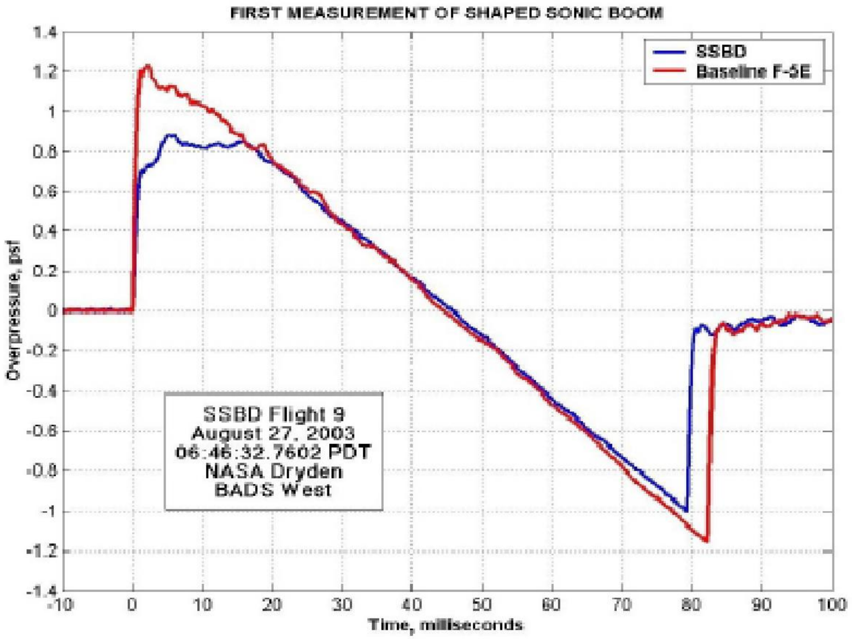
Figure from: CAEP/7 IP 18

External Noise: Sonic Boom

Esempi di dati da Boom Sonico:

- Boom shaping proven in flight for 1st time
  - Advanced computational fluid dynamics techniques and multidisciplinary design optimization needed to accurately predict shock structure close to aircraft

Unmodified F-5E and modified Shaped Sonic Boom Demonstrator (SSBD) aircraft. [DARPA /NASA /Northrop-Grumman]



Measured sonic booms from both aircraft [DARPA/NASA/Northrop-Grumman]

Figure from: CAEP/7 IP 18

Interior Acoustics: Cabin Comfort

Con il termine "Acoustic Cabin Comfort" si definisce il livello di comfort percepito dal passeggero durante le fasi di crociera, derivante dagli effetti combinati del rumore e delle vibrazioni percepite in cabina. In particolare:

- **Normalmente il passeggero non differenzia fra il fastidio generato dalle vibrazioni da quello generato da un livello troppo elevato di rumore**
- **I velivoli ad elica sono percepiti come meno confortevoli anche perché normalmente i livelli vibratori percepiti a bordo sono maggiori**
- **Gli elicotteri hanno il livello di comfort più basso poiché hanno livelli di vibrazione più alti e livelli di rumore a frequenze più basse e normalmente elevati, entrambi generati dalla propulsione del rotore**
- **Il livello di rumore propagato dall'impianto di condizionamento contribuisce significativamente al livello di comfort in qualsiasi aeromobile, in quanto questo rumore ha frequenze sovrapposte a quelle della voce umana. Quindi interferisce direttamente sulla percezione della parola**

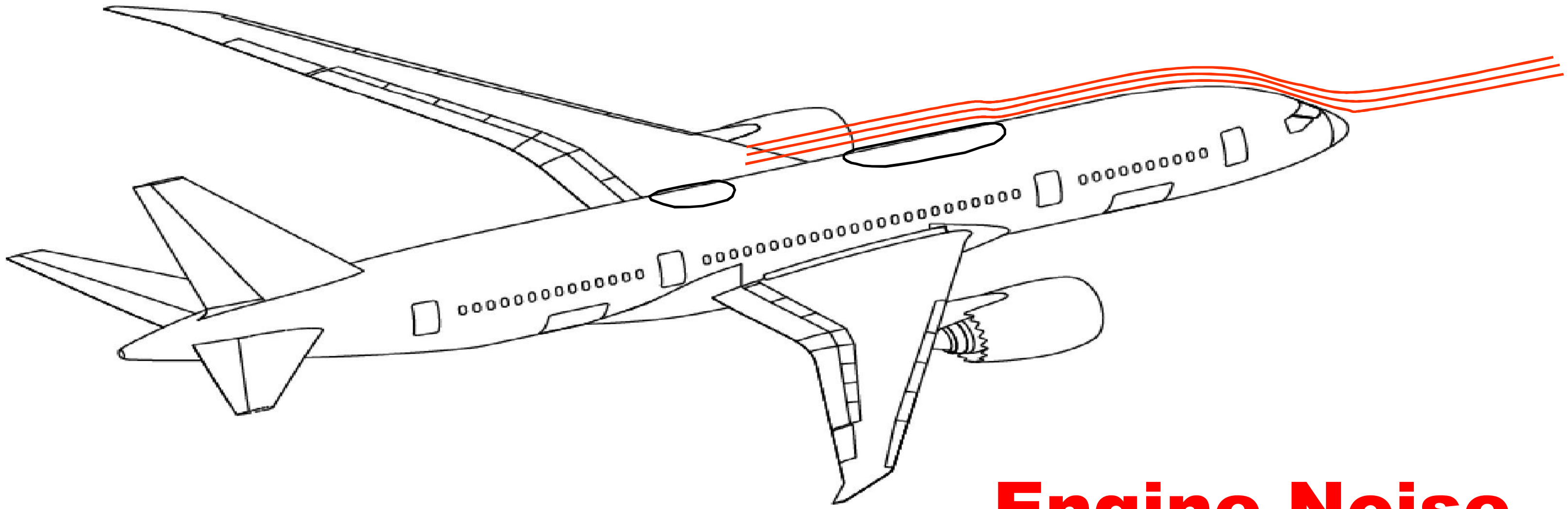
L'indicatore più utilizzato per misurare il livello di comfort è il dBA: misura l'energia sonora opportunamente pesata in frequenza per simulare la percezione del fastidio acustico dell'individuo medio.

Interior Acoustics: Cabin Comfort

Sorgenti di rumore principali per il rumore interno

Aerodynamic Noise

- Turbulent Boundary Layer Excitation
- Fuselage Surface Protuberances, Steps, Gaps & Cavities

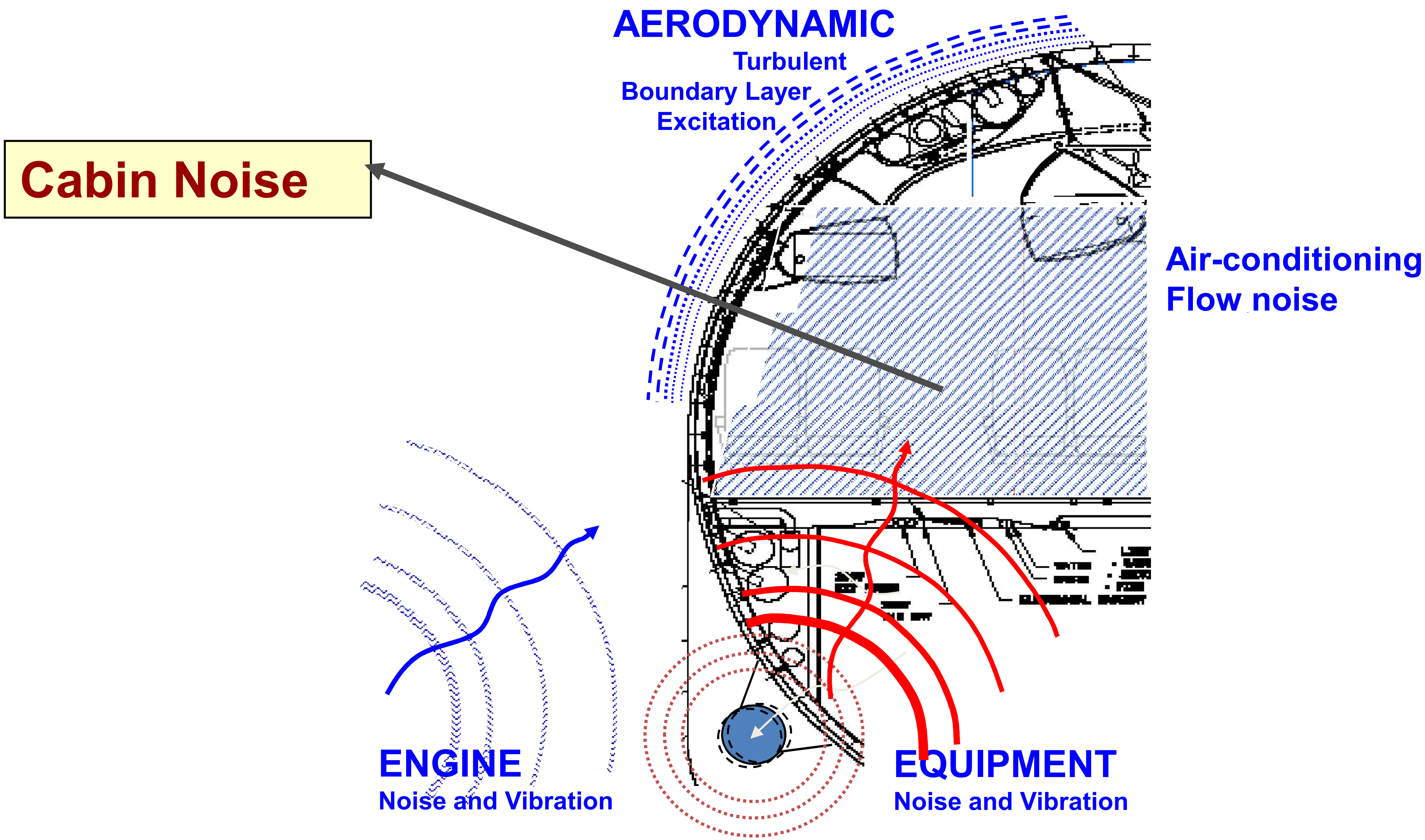


Engine Noise

- Fan noise, Jet noise
- Turbine noise

Interior Acoustics: Cabin Comfort

Sorgenti di rumore principali per il rumore interno

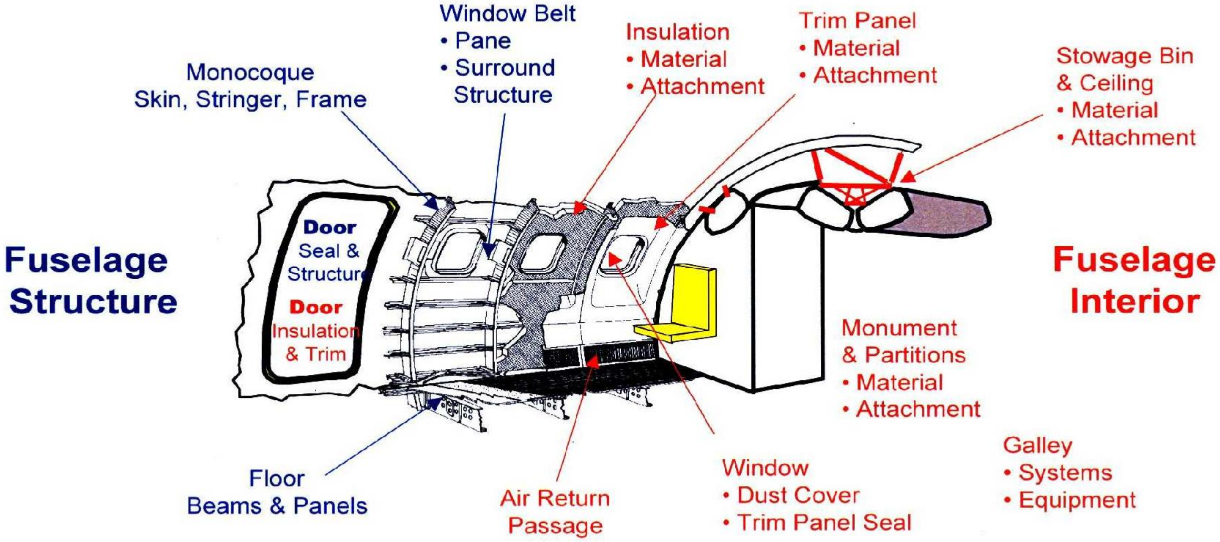


Interior Acoustics: Cabin Comfort

Aircraft Noise Generation & Transmission Components

FUSELAGE

- **Skin/Frame/Stringer**
- **Floor**
- **Door**
- **Window**
- **Antennas**



INTERIOR
(Cabin & Flight Deck)

- **Insulation**
- **Trim Panel**
- **Stowage Bin**
- **Ceiling Panel**
- **Seats**
- **Monument**
  (Lavatory, Galley, Crew Rest)

SYSTEMS

- **Transport Element**
- **Equipment**
  (ECS pack, fan, pump, flap drive, gear box, APU, vacuum Blower, etc……)

Interior Acoustics: Cabin Noise Treatments

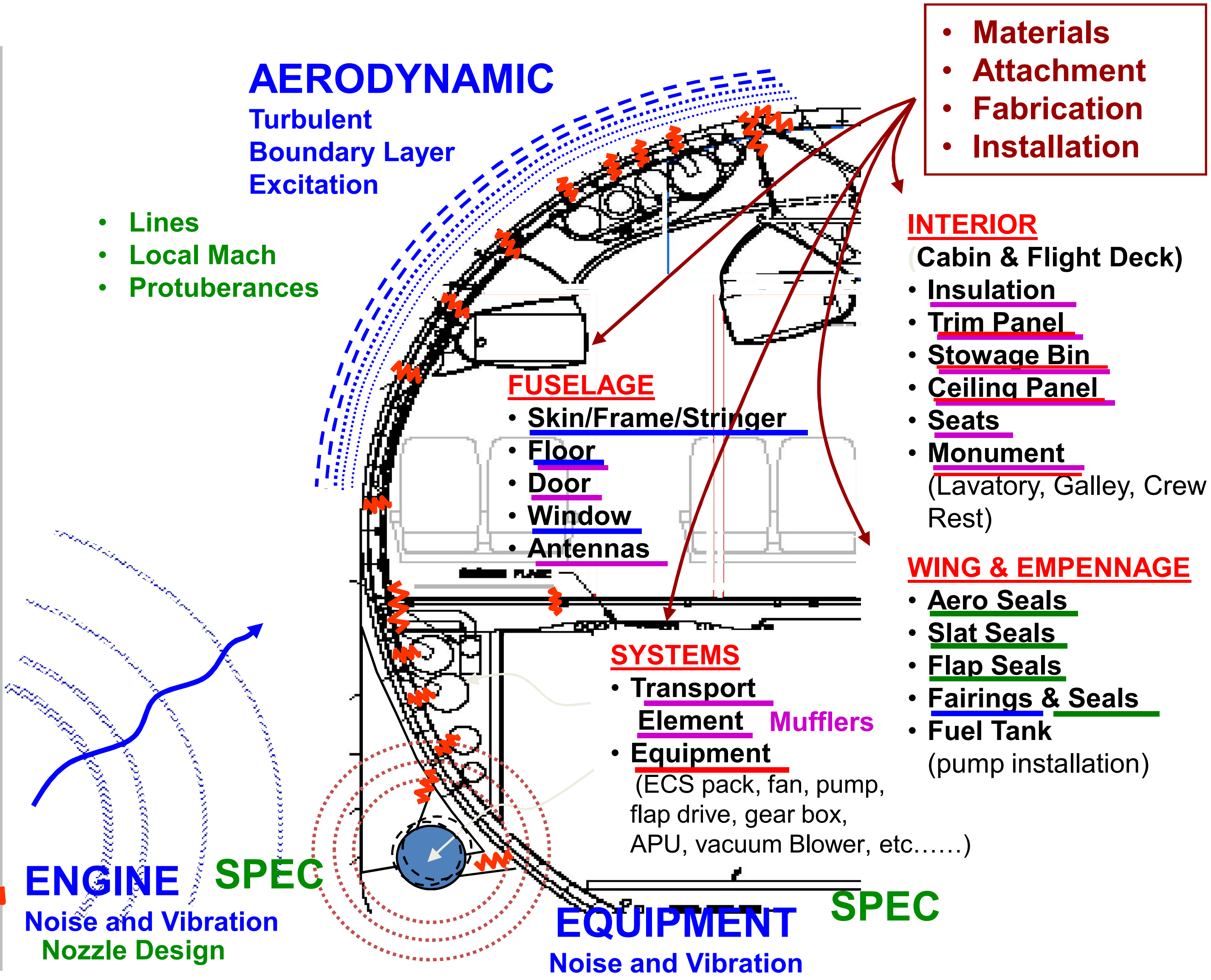
NOISE SOURCES

Major Affected Components

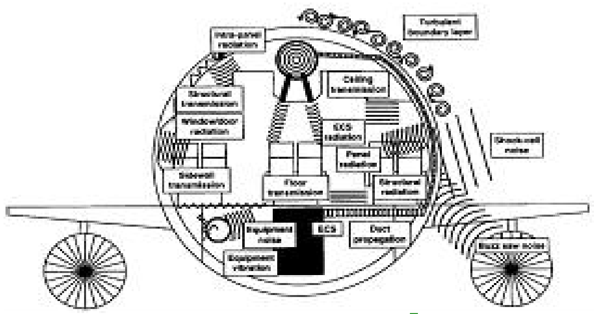
NOISE CONTROL

- At The Source
- By Design

- By Add-On Treatment
  - Structure Damping
  - Sound Absorption & Blockage
  - Vibration Isolator



Interior Acoustics: Cabin Low Noise Design



REQUIREMENTS

Model validation

Numerical Simulation

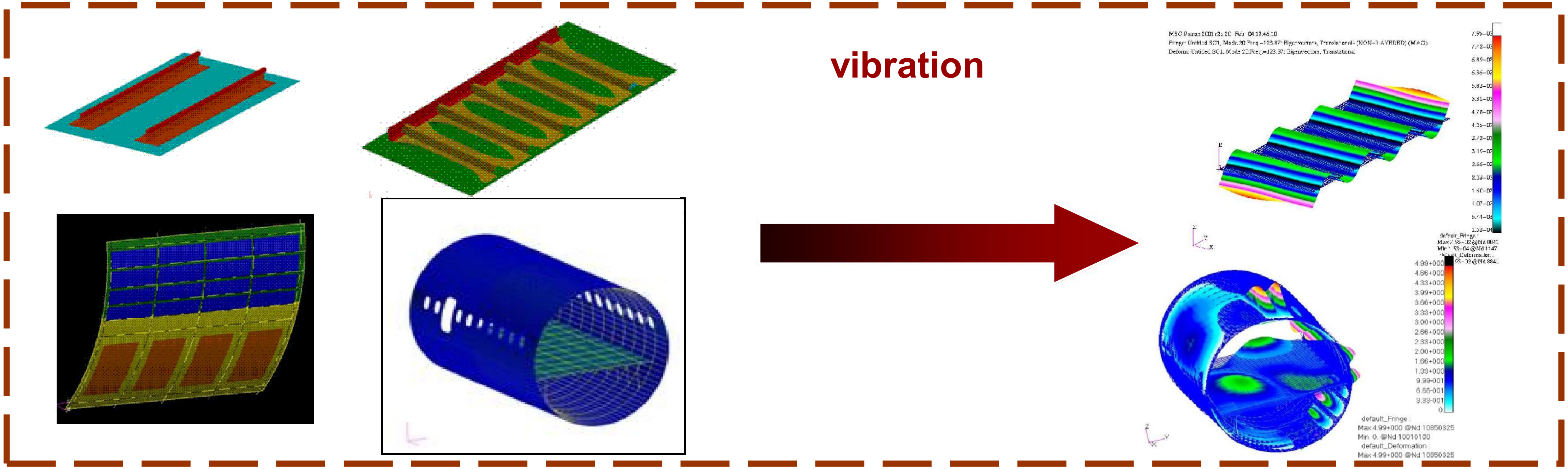
Component Lab Testing

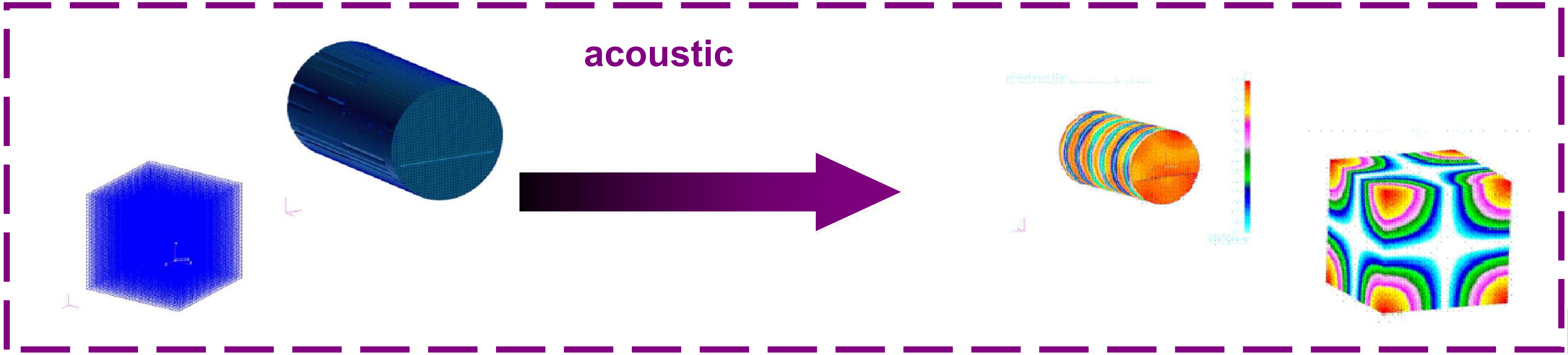
Structure/Interiors Design to Noise

Flight Test

Interior Acoustics: Cabin Low Noise Design

Interior Noise – Numerical Simulation





Interior Acoustics: Cabin Low Noise Design

Interior Noise – Testing Activity

Modal analysis

Acoustic analysis

Panel TL analysis

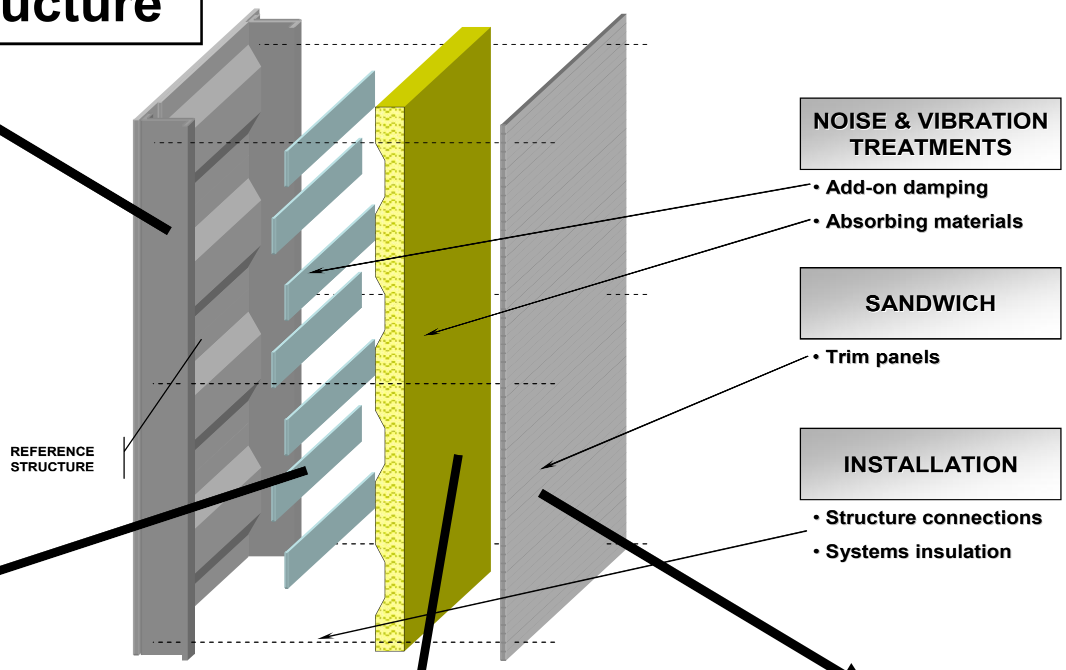
TL Transmission Loss

$$= 10 \ \mathrm{Log} \ (W_{inc} / W_{trasm})$$

Interior Acoustics: Cabin Low Noise Design

Fuselage structure

Progettare componenti ed installlazione per basso rumore



damping

Treatment

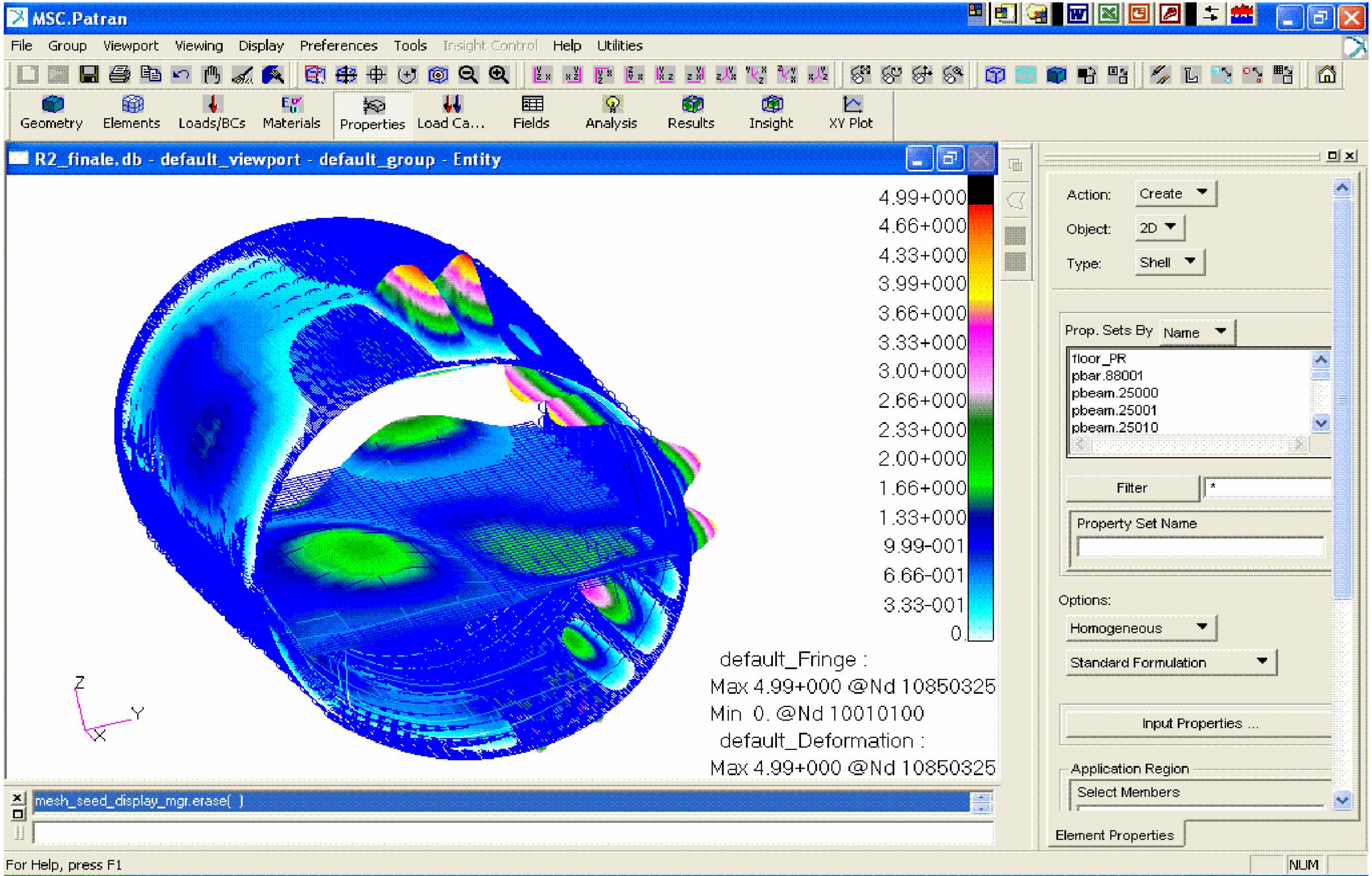
Insulation Blanket & improved installation

Light damped trim

Progetto integrato per ridurre la trasmissione acustico insieme con il peso ed il costo degli elementi insonorizzanti

Interior Acoustics: Cabin Low Noise Design

Interazione acustico-strutturale - Simulazione Numerica



Interior Acoustics: Cabin Low Noise Design

Interazione acustico-strutturale - Simulazione Numerica

NASTRAN SOLVER per progetto Acustico-strutturale

SOL 103 → Real Modal Analysis

SOL 107, 110 → Complex Modal Analysis, direct or modal

SOL 108, 111 → Frequency Response, direct or modal

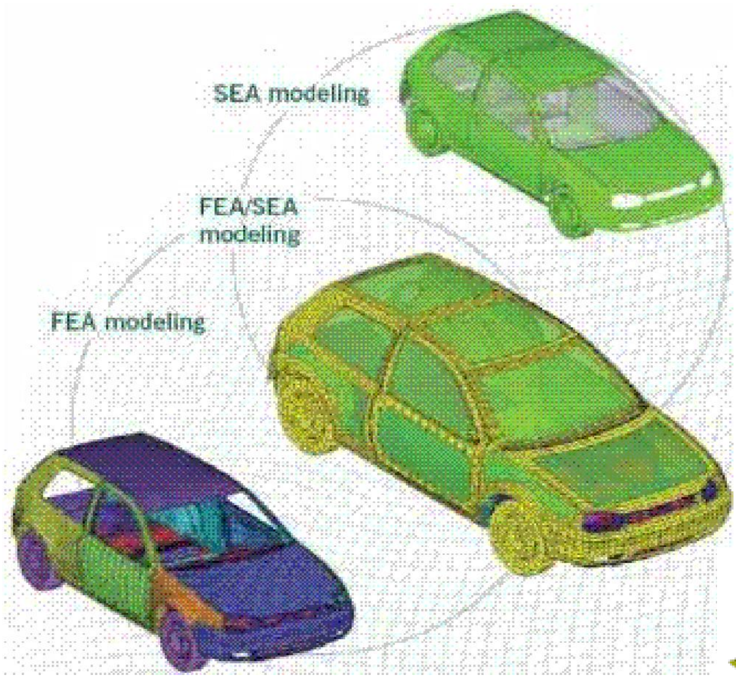
Fluid – Structure Interaction

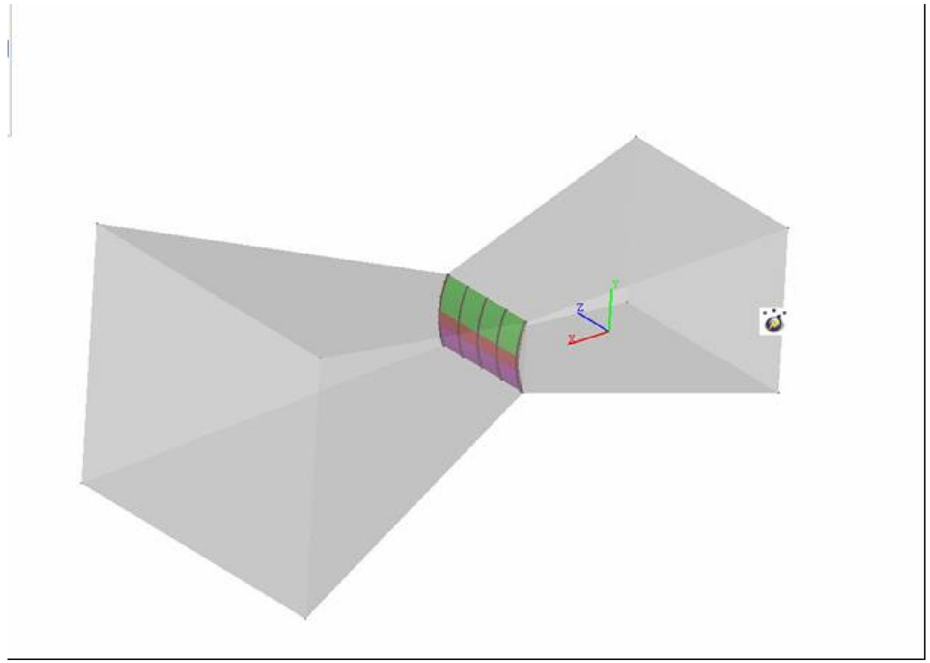
Acoustic Cavity

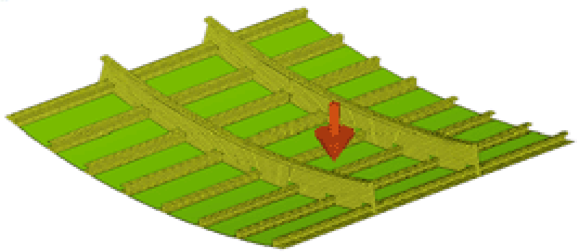
Interior Acoustics: Cabin Low Noise Design

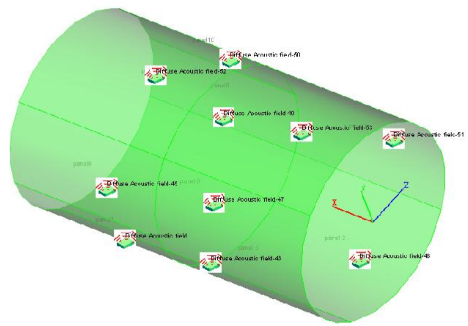
Statistical Energy Analysis – Simulazione Numerica

SEA Prediction





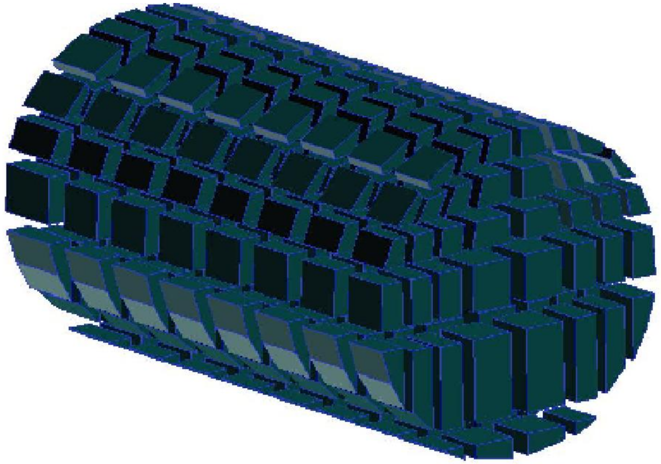


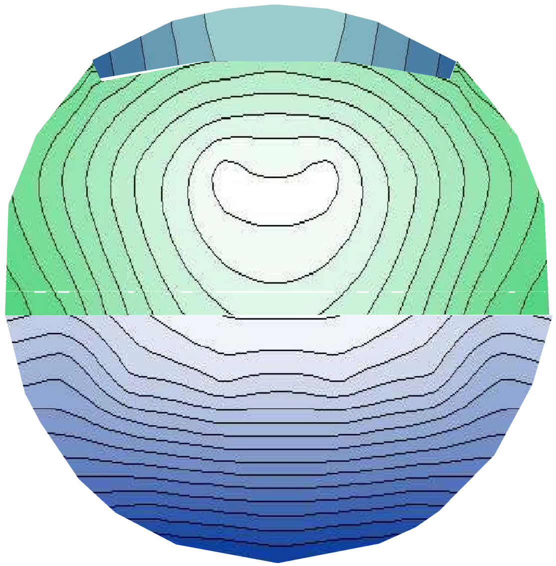


Interior Acoustics: Cabin Low Noise Design

Simulazioni semplificate di propagazione rumore in cabina

CABIN Noise Prediction (*)

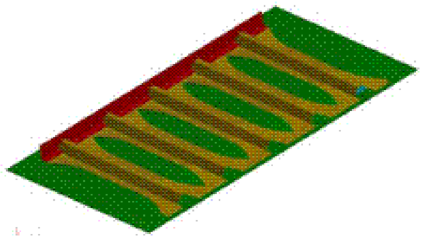




* Sviluppato da DIAS per Alenia (2006)

Interior Acoustics: Cabin Low Noise Design

Simulation OUTPUT



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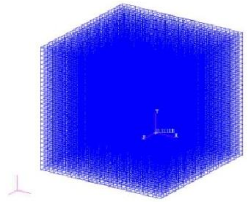

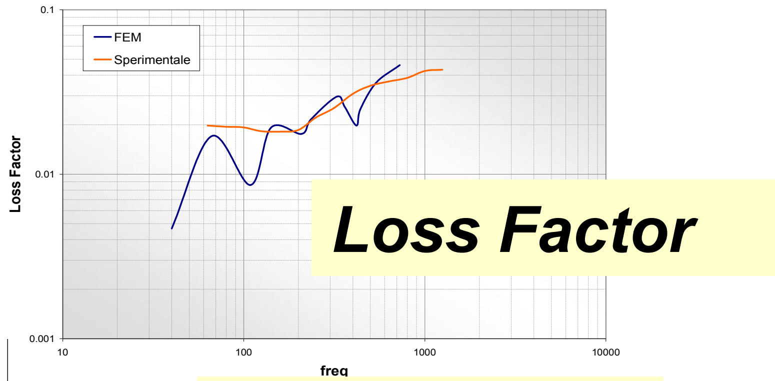

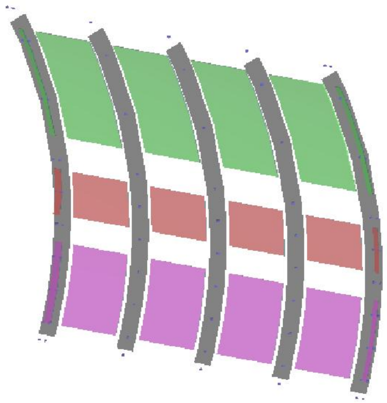

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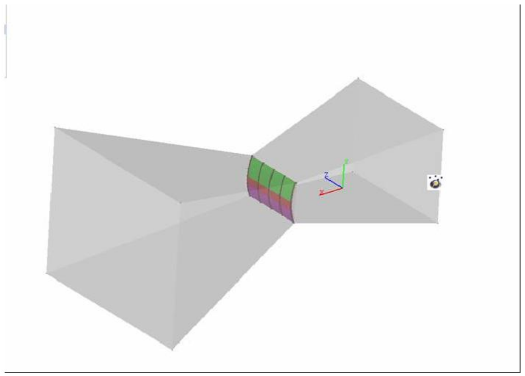
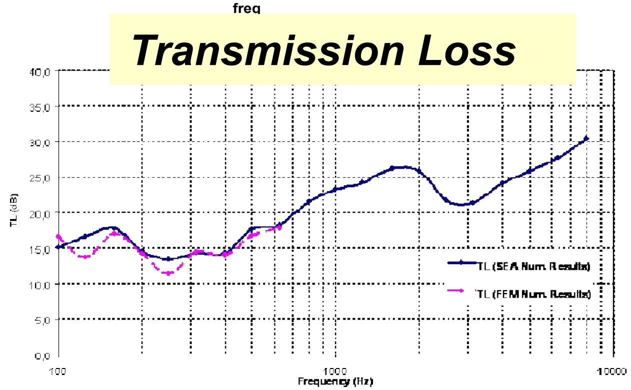
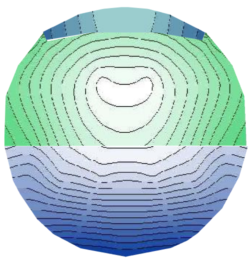






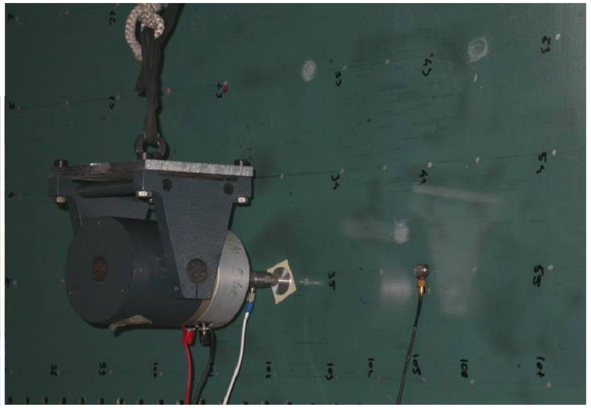
Cabin noise map:

- OASPL [dB]
- A-weighted OASPL [dBA]
- SIL [dB]

Interior Acoustics: Cabin Low Noise Design

Test Analysis

Modal Analysis



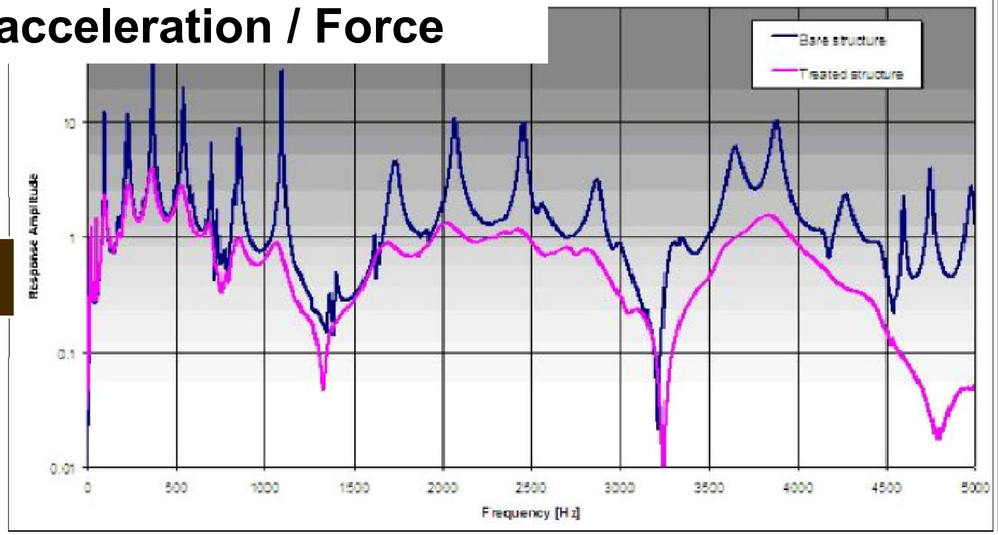
Excitation

Low-medium frequency 0-2000 Hz

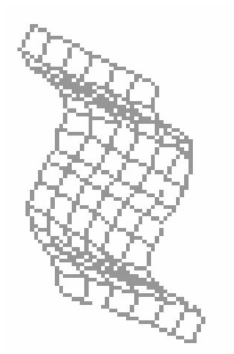
Acquisition

1 Accelerometer in different positions

FRF = acceleration / Force

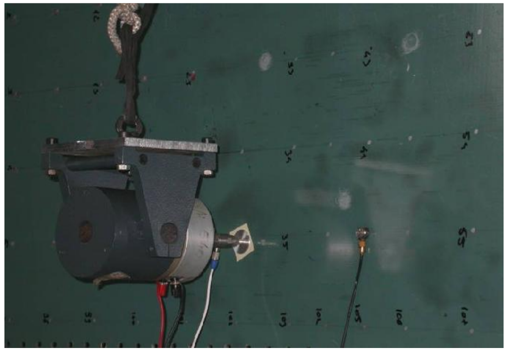


M.O.F.



Interior Acoustics: Cabin Low Noise Design

Damping Analysis



Excitation

Low-medium frequency $\Delta f = 0.125$ Hz

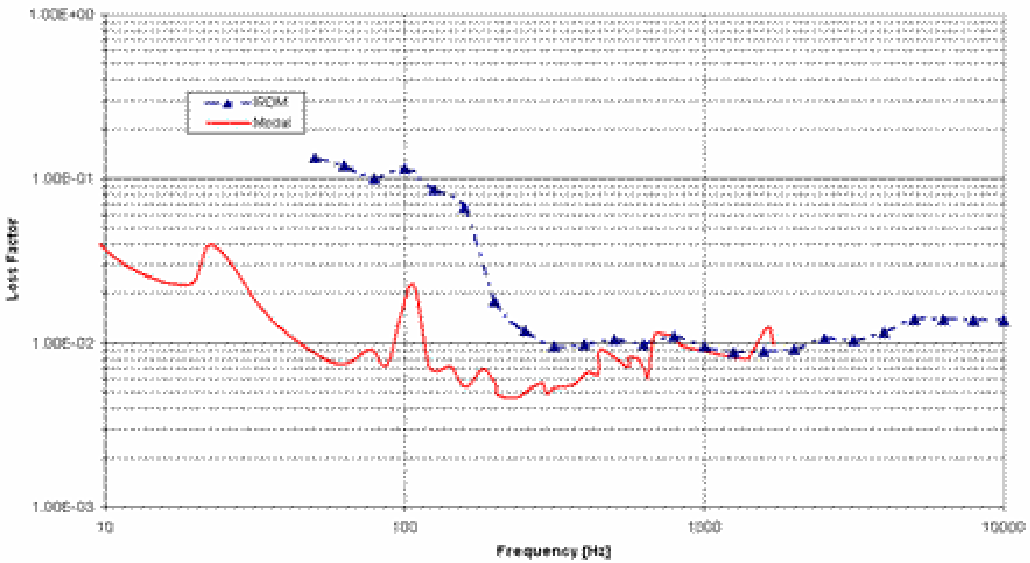
Medium-high frequency $\Delta f = 2$ Hz

Acquisition

1 Accelerometer 0-2000 Hz

0-10000 Hz

Climatic Chamber
Per analisi dinamica su coupons (damping)



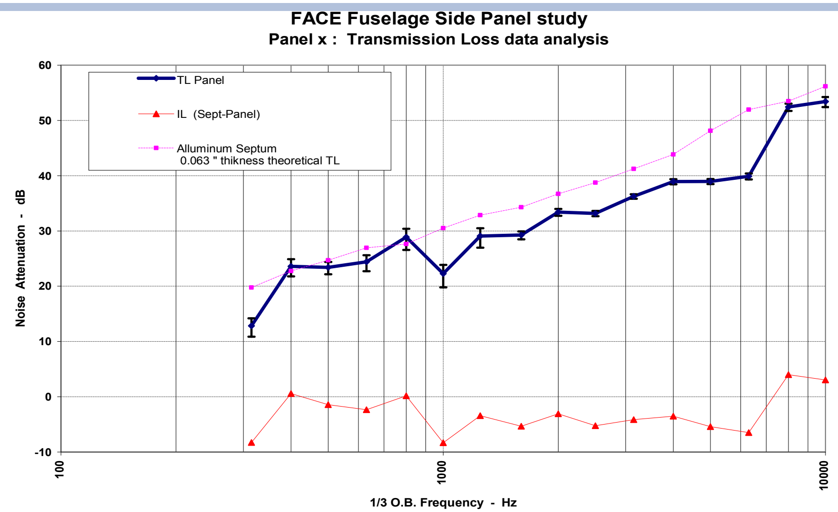
Data Extraction

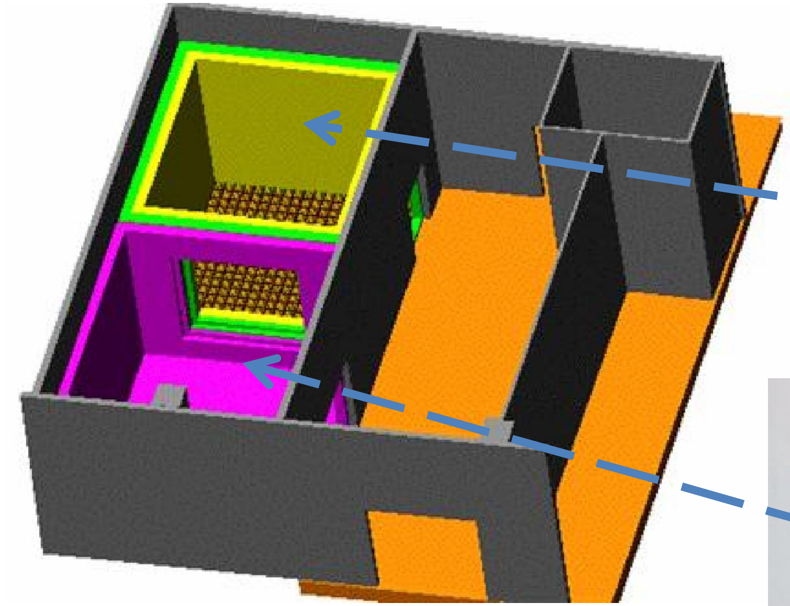
Half Power Bandwidth Method

Hilbert Transfer Method

Interior Acoustics: Cabin Low Noise Design

Noise transmission Test Analysis





Transmission Loss facility

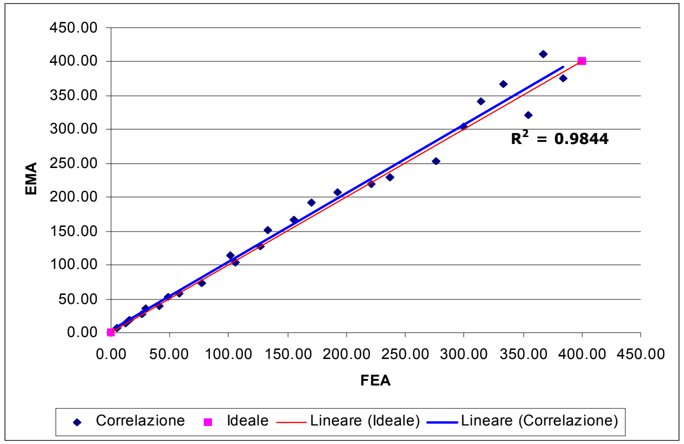
Camera Riverberante

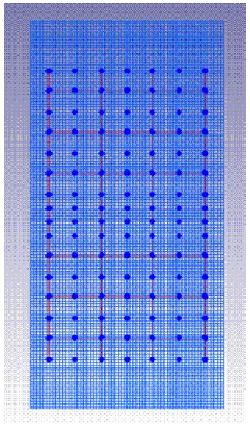
Camera Anecoica

Interior Acoustics: Cabin Low Noise Design

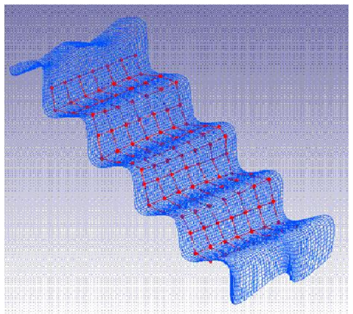
Numerical Experimental Correlation

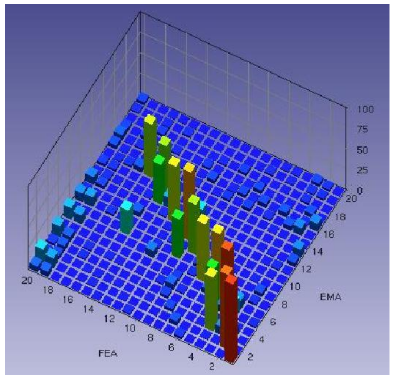
FEMtools
simulate > validate > update > optimize
Dynamic Design Solutions





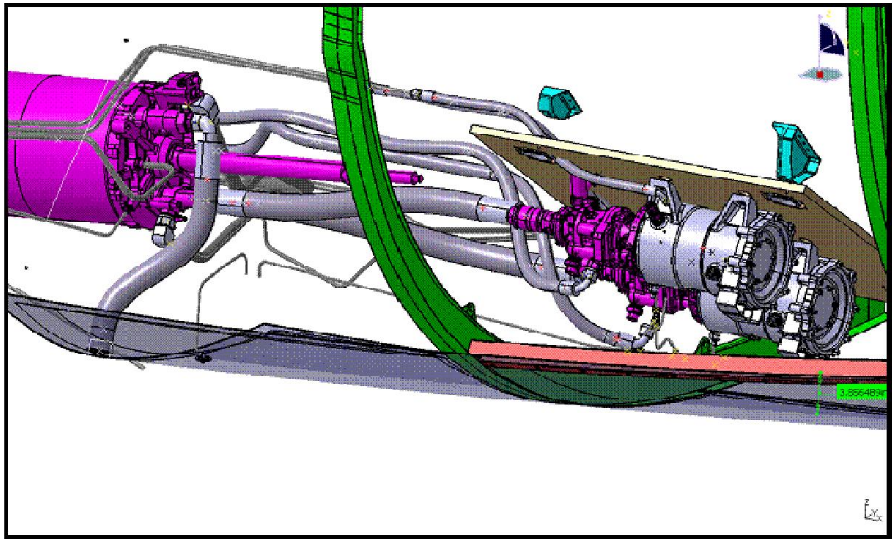
	FEA	Hz	EMA	Hz	Error	MAC
1	7	5.70	1	7.09	-19.55	73.40
2	8	12.60	2	13.57	-7.15	91.40
3	9	15.49	3	17.92	-13.60	83.70
4	10	25.98	4	26.36	-1.47	82.50
5	11	29.93	5	35.19	-14.95	31.20
6	12	40.78	6	39.65	2.87	92.70
7	13	48.77	7	53.45	-8.75	38.10
8	14	57.73	8	57.83	-0.17	73.00
9	16	77.73	9	73.68	5.50	61.60
10	18	102.03	10	114.33	-10.76	67.30
11	20	105.52	11	102.98	2.46	39.80
12	21	126.60	12	127.99	-1.09	89.50
13	22	133.23	13	150.89	-11.70	90.60
14	23	155.43	14	165.76	-6.23	92.50
15	26	170.20	15	192.49	-11.58	71.20
16	27	193.05	16	206.45	-6.49	88.50
17	28	220.99	17	218.35	1.21	93.70
18	30	236.98	18	229.76	3.14	90.20
19	32	276.44	19	252.41	9.52	84.50
20	33	299.59	21	303.21	-1.19	58.80
21	34	314.93	23	341.99	-7.91	46.20
22	35	333.92	24	366.31	-8.84	47.30
23	37	354.77	20	321.66	10.30	30.20
24	38	367.86	25	411.45	-10.59	43.10
25	42	384.00	22	375.41	2.29	41.40

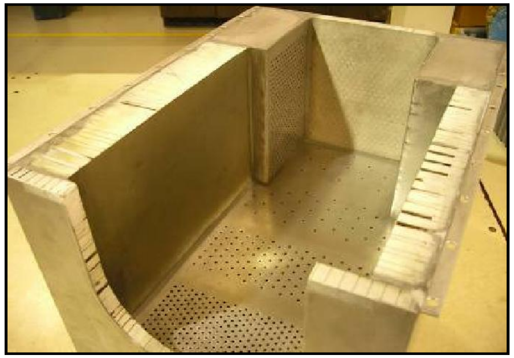




Interior Acoustics: Cabin Noise Treatments

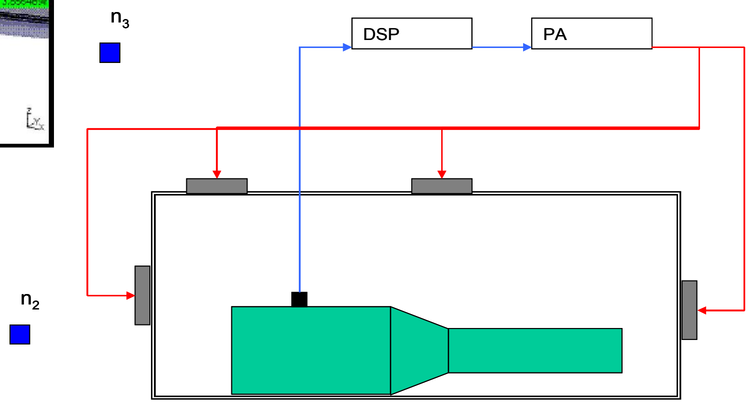
SYSTEM TREATMENTS





Electric Motor Pump

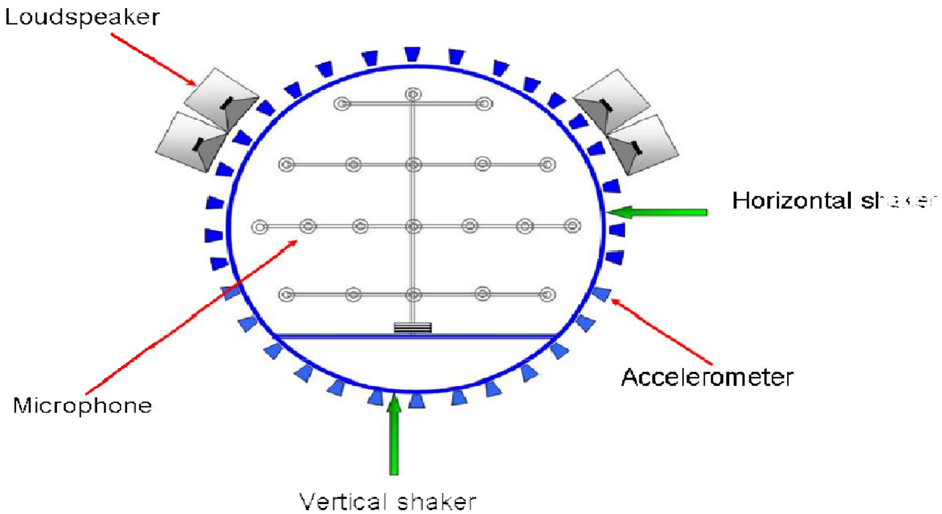
- Covered by an enclosure
- Passive treatment (heavy solution)
- Active treatment (lighter solution)

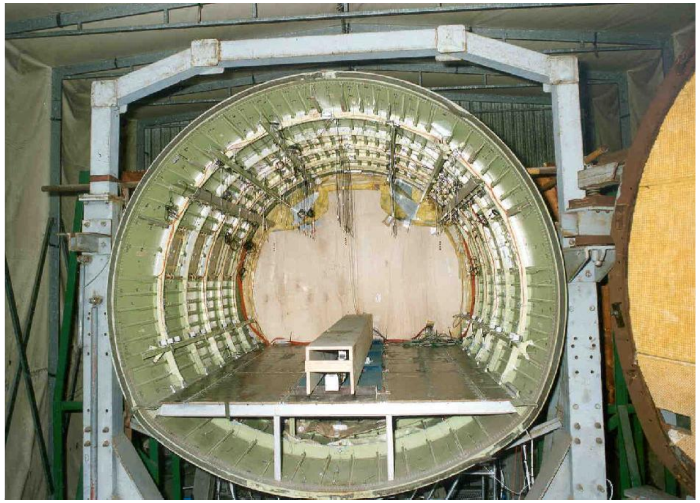


- **feed-forward active control architecture using the signal from a single accelerometer placed on the motor**
- **Piezo actuators placed on the enclosure surfaces**
- **DSP optimized using adaptive signal processing to minimize the radiated noise**

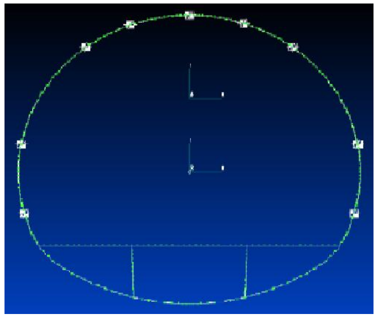
Interior Acoustics: Propeller Aircraft
DVA Cabin Noise Treatments

Direct Approach:
Measurements in ATR Mock-up (Alenia)



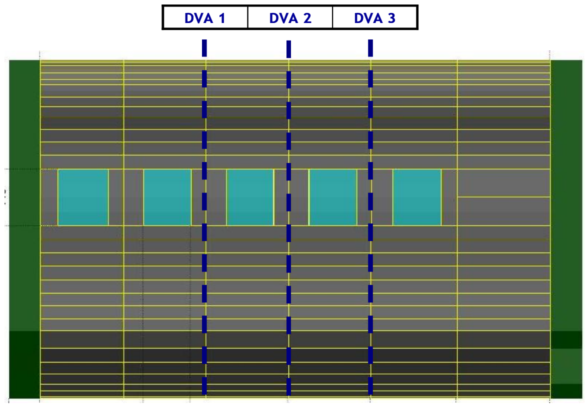


ATR MOCK-UP



DVA OPTIMISED CONFIGURATION

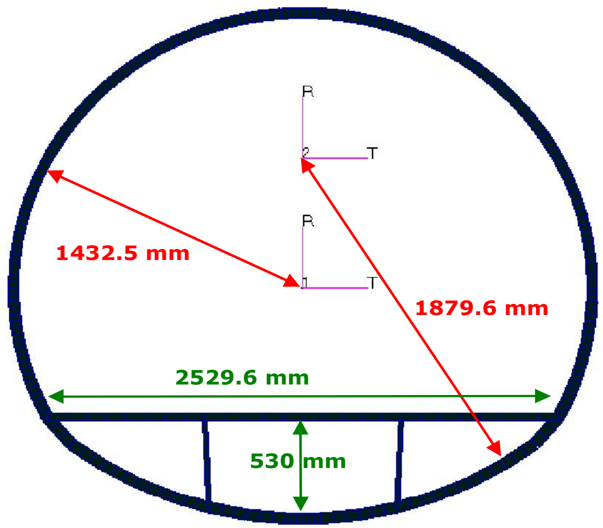
Mock-up Frame instrumented



(*) dal progetto europeo CREDO

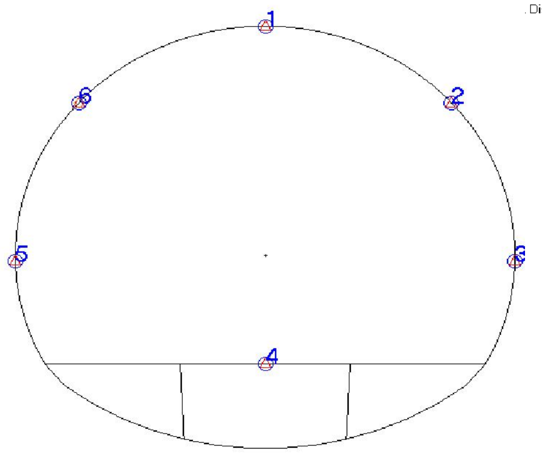
Interior Acoustics: DVA Cabin Noise Treatments

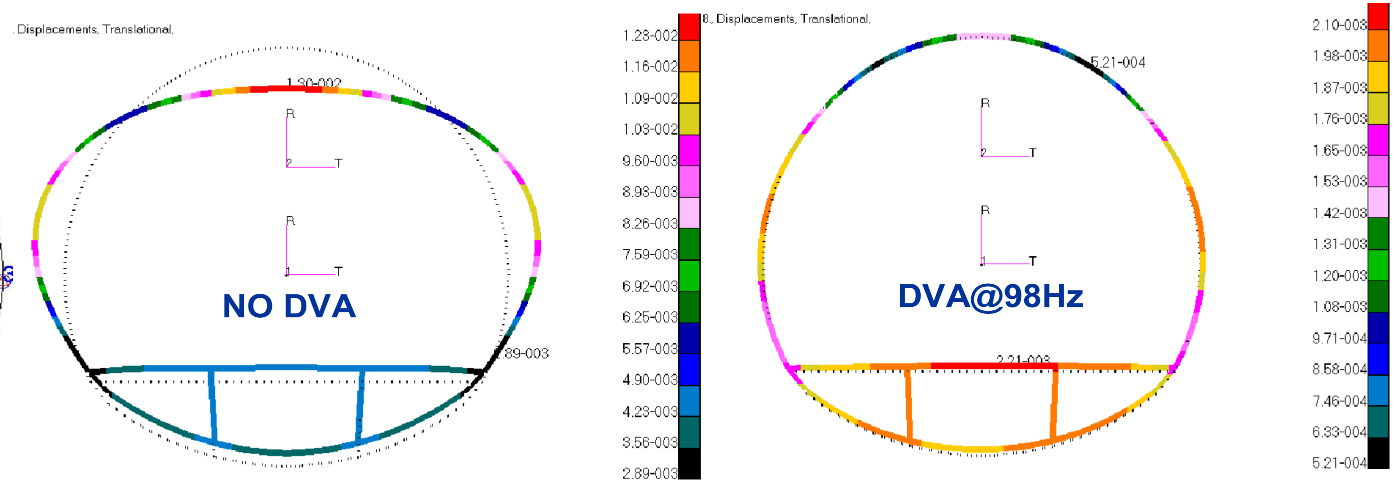
Esempio di progettazione trattamento acustico strutturale per basse frequenze: DVA treatment on ATR 72 (*)



Direct Approach 2D FE Model

- 2-D model of a typical ATR72 frame
- Application of DVA (concentrated mass linked to the structure by spring elements)
- 3 different DVAs configurations
- Modal Analysis



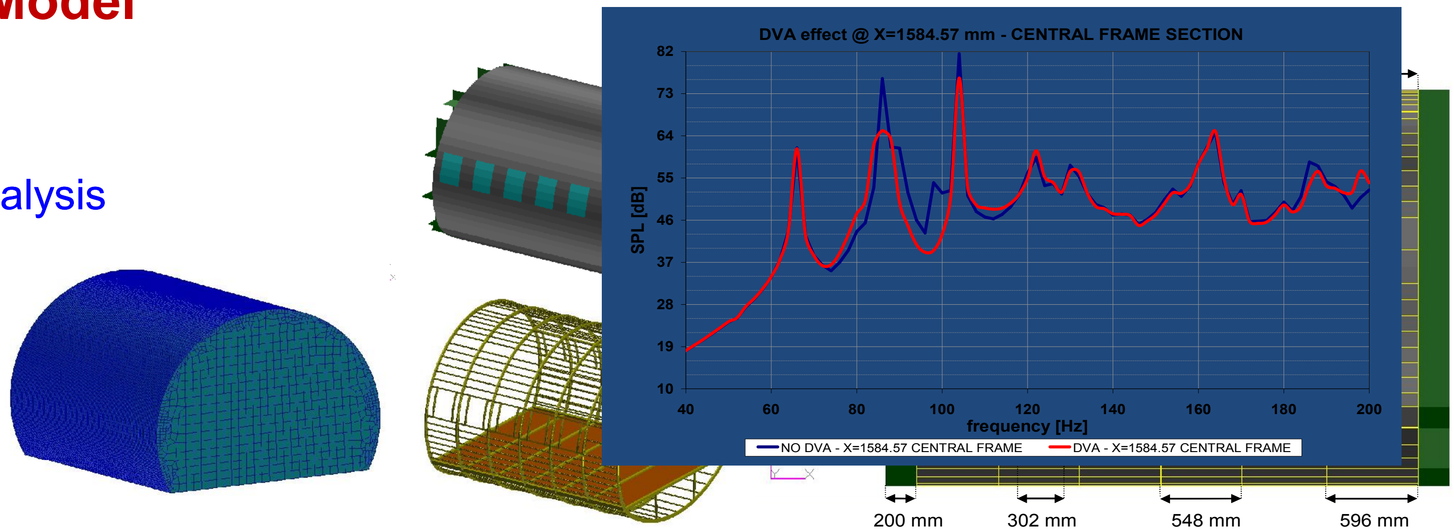


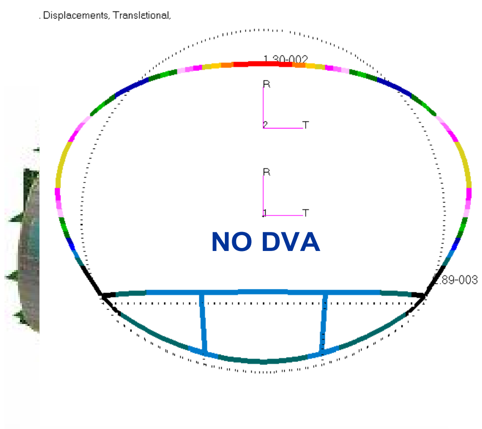
(*) dal progetto europeo CREDO

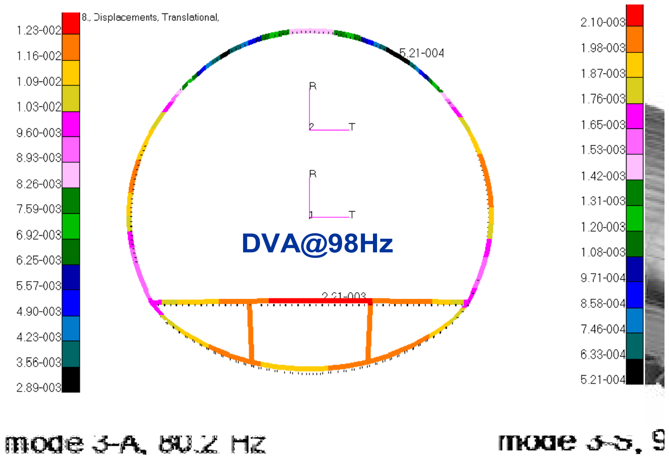
Interior Acoustics: DVA Cabin Noise Treatments

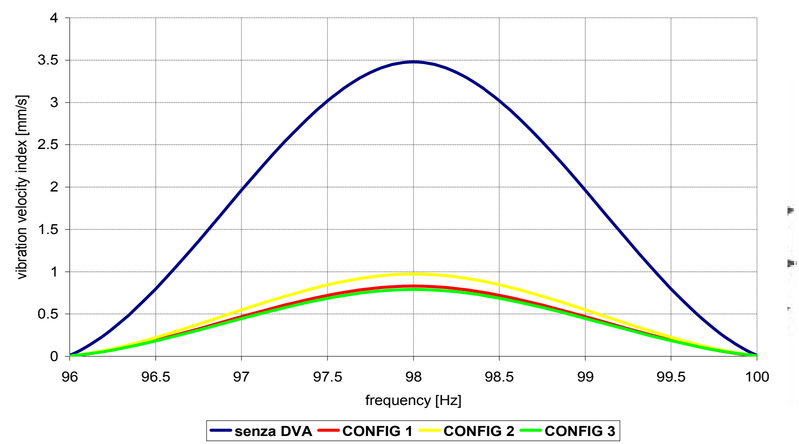
Direct Approach FE Model

- Modeling
- Modal Analysis
- Frequency Response Analysis
- DVA effects









(*) dal progetto europeo CREDO

Interior Acoustics: DVA Cabin Noise Treatments

Experimental testing on ATR Barrel (Alenia):
- procedures and model calibration with and w/o treatments
- validation of inverse numerical method

ATR BARREL

Horizontal Shaker

Loudspeaker

Loudspeaker

Vertical Shaker

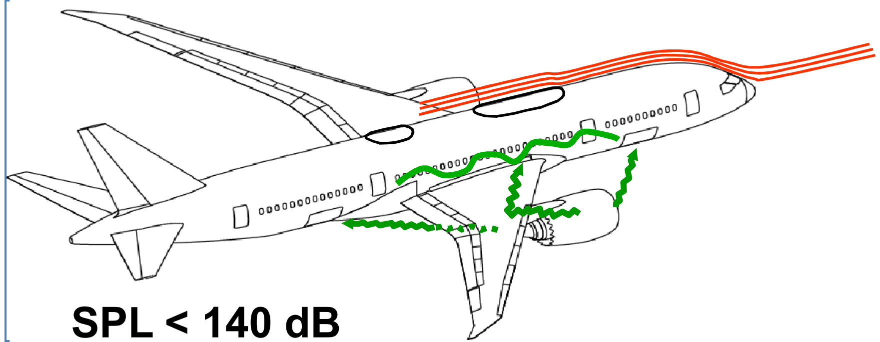
(*) dal progetto europeo CREDO

Interior Acoustics: Fatica sonica

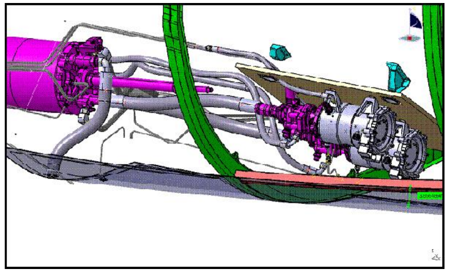
Descrizione del problema:

- **Componenti strutturali sollecitati da liveeli di rumore superiori ai 140 dB**
  - Analisi FEM
  - Tecnica S.E.A.
  - Test in “Acoustic Fatique facility”

- **Componenti di sitema sollecitati da livelli di rumore superiore ai 130 dB**
  - Test funzionali
  - Test a resistenza



SPL < 140 dB
NO SONIC FATIGUE PROBLEM



SPL < 130 dB
NO SONIC FATIGUE PROBLEM

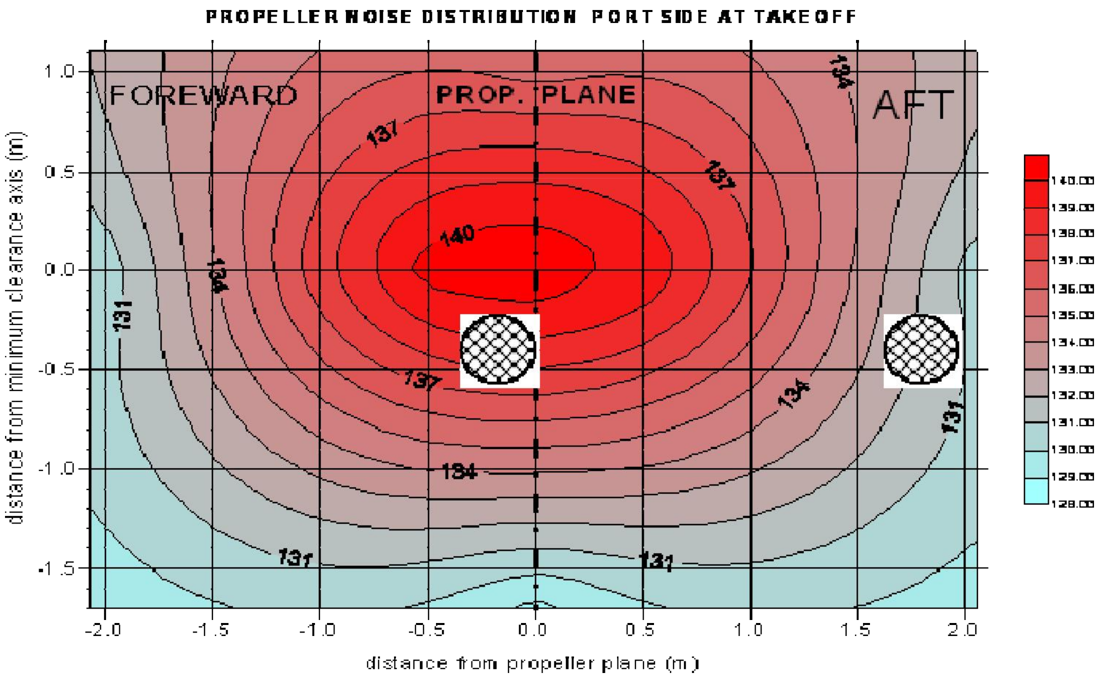
Interior Acoustics: Fatica sonica

Problem Solving

Structural parts:

Structure Procedures

- Fundamental Frequency Method
- Nomogram method
- S.E.A. technique



Equipments Standards:

- Civil: DO160
- Military: MIL STD-810E

DOMANDE ?

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