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An Integrated Aeroacoustics Framework for Subsonic Aircraft and Engines

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Session: Environmental Friendly Technology

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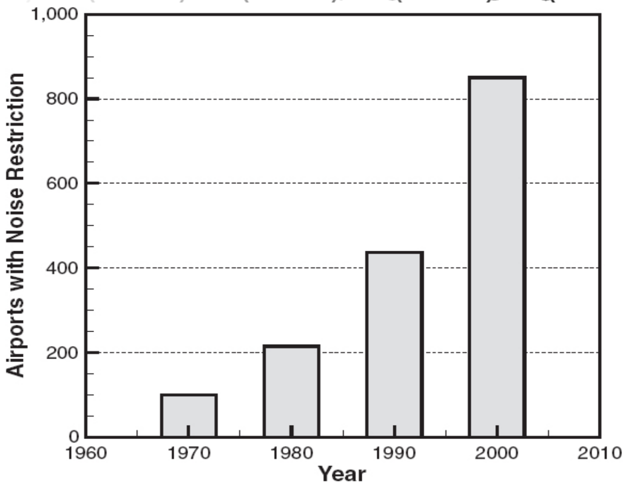
Outline

- Introduction – General Context
- ICAO – Balanced Approach
- Scope & Methodology
- Case Study & Results
- Concluding Remarks

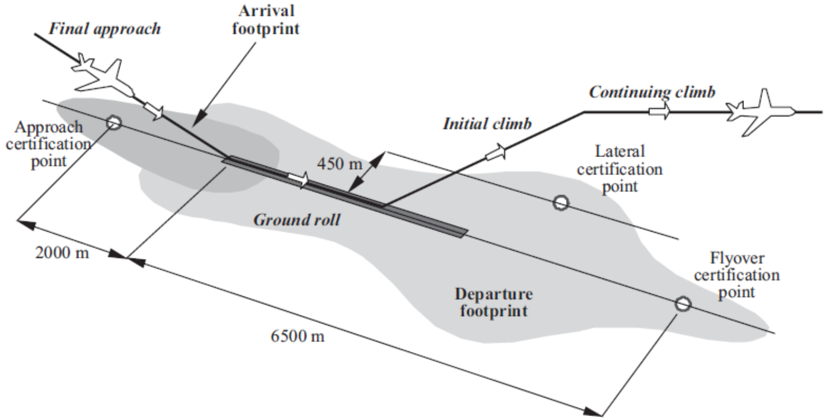
Introduction

Civil Aircraft Noise

- Aircraft noise and its adverse environmental effects is one of the major environmental concern that airports are facing nowadays.
- Generally aircraft noise at basic level is classed as "annoyance".
- Serious health-related effects are also reported through research.
- Aircraft Noise is therefore a high-profile issue that is being progressively addressed through combined efforts of global aviation community.



Evolution in airports with noise restrictions; from Ref. [2].

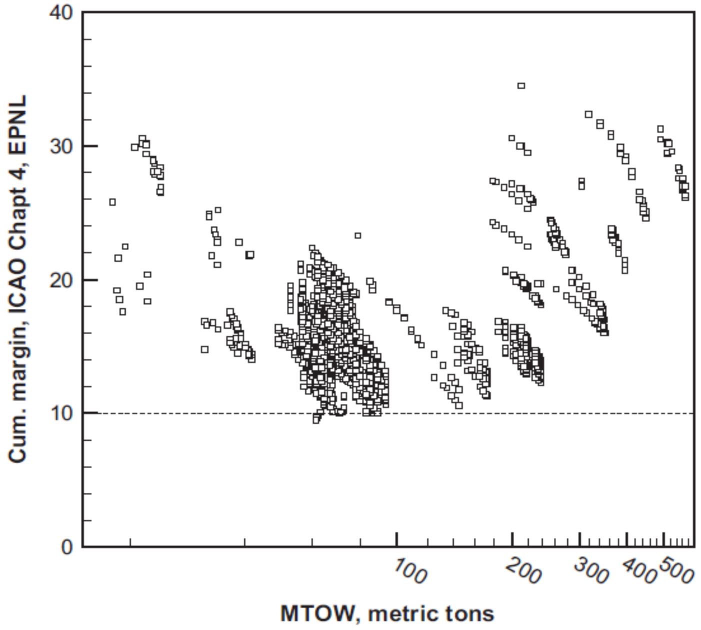


ICAO/FAR Community reference points for noise certification, adopted from [2]

- Regulated by the ICAO/FAR, and other organisations.
- ICAO - Chapter 4 - "Annex16"; first entered into force in1971.
- Upated regularly by ICAO – CAEP. Most recent updates enforced in 2006.

Civil Aircraft Noise Data

Analysis of the most recent certification data Indicates we are well below the current limits !!

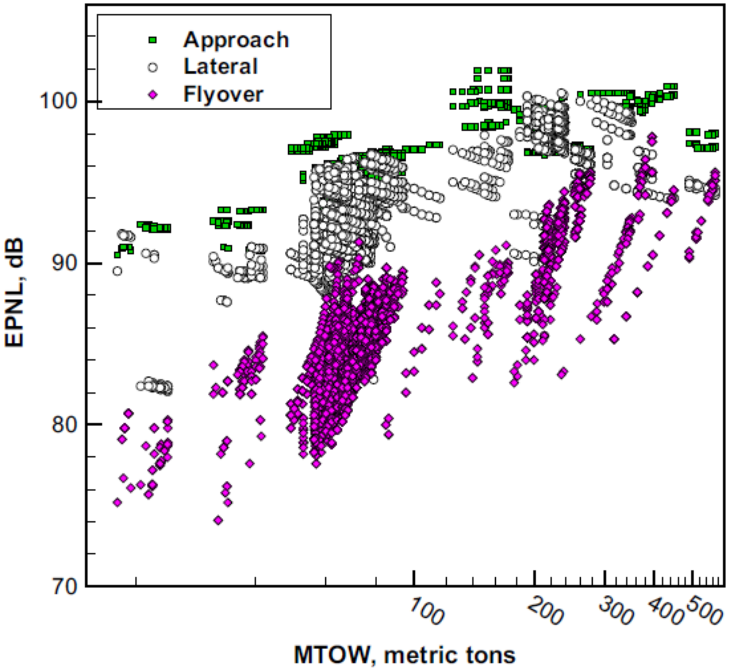


Cumulative noise margin (approach 5.1 , fly-over 6.9,lateral 3.6) of commercial aircraft over ICAO Chapter4 limits. Average 15 – 20 EPLN(dB). Data source: European Aviation Safety Agency. Ref. [2].

Demand for further cumulative reduction by 7 EPNL (dB) anticipated.

"Annoyance" Remain !

Approach noise level is always higher compared to other reference points; due to a combination of factors.



Recorded EPNL on approach, fly-over,lateral. Data source: EASA. Ref. [2].

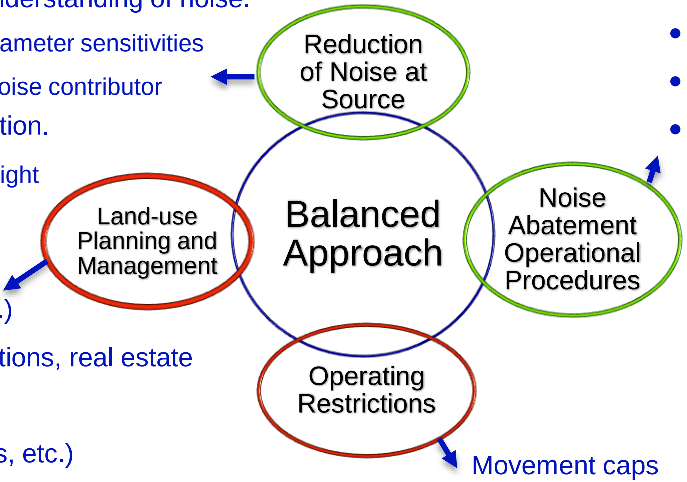
ICAO - Balanced Approach

In order to address noise issue and to propose a systematic, flexible and globally applicable solution. ICAO published a harmonised approach, usable on an airport-by-airport basis in 2001.

- System-level assessment and understanding of noise.
  - Design and operational parameter sensitivities
  - Identification of dominant noise contributor
- New technology potential/integration.

Support potential experiments and flight demonstration activities

- Planning (Zoning, easement, etc.)
- Mitigation (building codes, insulations, real estate disclosure, etc,)
- Financial (tax incentives, charges, etc.)



Movement caps
Noise quotas
Non-addition rules
Curfews

- Reduction/redistribution of noise around the airport
- Enable full use of modern aircraft capabilities
- Various departure & approach procedures:
  - Displaced thresholds (landing/takeoff positions)
  - Reduced power/drag and CDA (Continuous Descent Approach)
  - Limited engine ground running
  - Noise preferential routes/runways
  - SID[1]/STAR[2] and RNAV[3] procedures optimisation and design

[1]) SID = Standard Instrument Departure
[2]) STAR = Standard Terminal Arrival Route
[3]) RNAV = “Area Navigation” a method of instrument flight rules (IFR) navigation

Multidisciplinary knowledge of the aircraft noise serves as prerequisite to perform integrated noise assessment at aircraft operational level.

Scope

Scope of the presentation

- Propose a preliminary subsonic aircraft and engine noise assessment framework.
  - System level – source noise modelling
  - Propagation and atmospheric effects
  - Effective preceived noise level - EPNL (dB)
- Present assessment of aircraft certification noise
  - LTO cycle flight trajectory definition
  - Engine performance model integration
  - Aircraft flight performance model integration
- Present framework verification
  - Certification noise varification with ICAO data
  - Component level noise verification with available literature

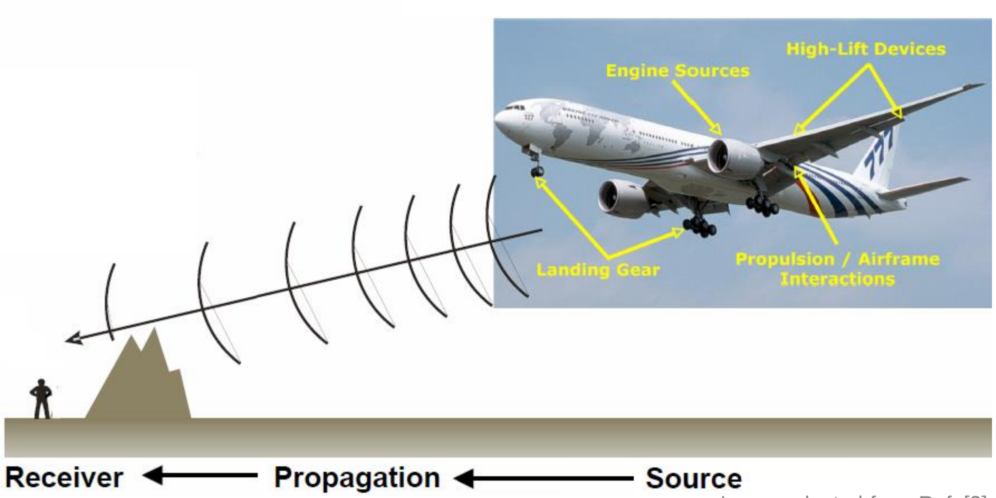


Image adopted from Ref. [3]

Methodology

Aircraft Performance Simulation

- Formulated based on aerodynamic LD Correlations.
- Verified through in-house data - Acquired based on industrial collaboration.
- Airframe manufacturers public reports.

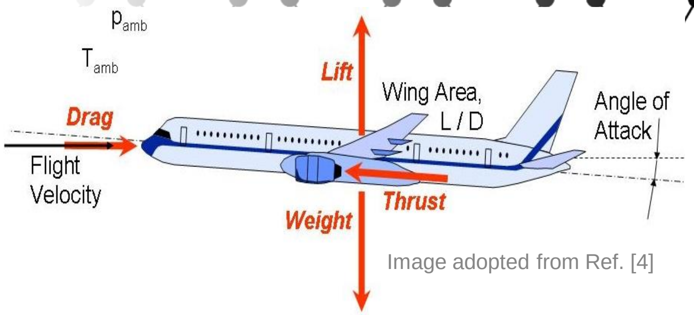
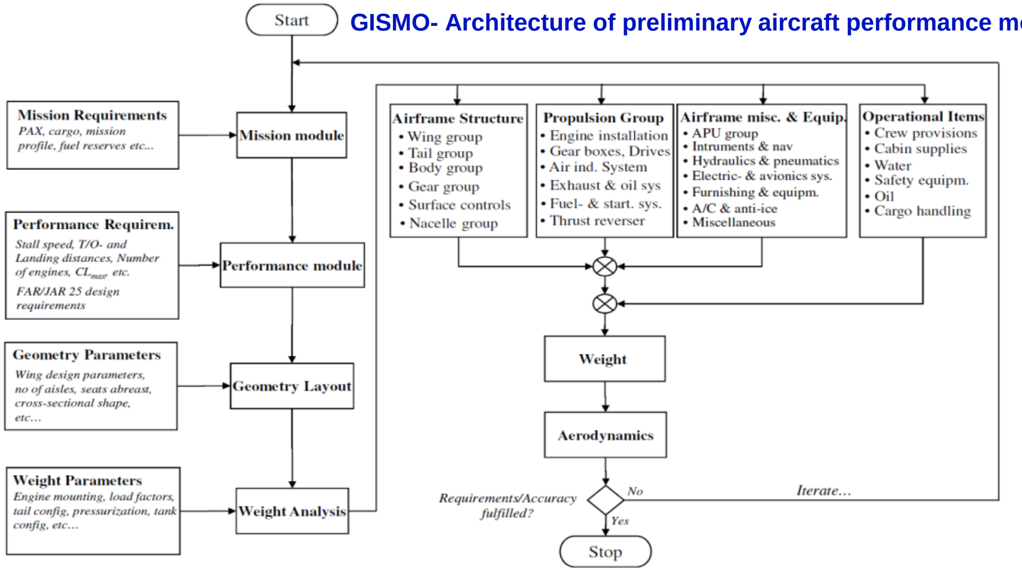
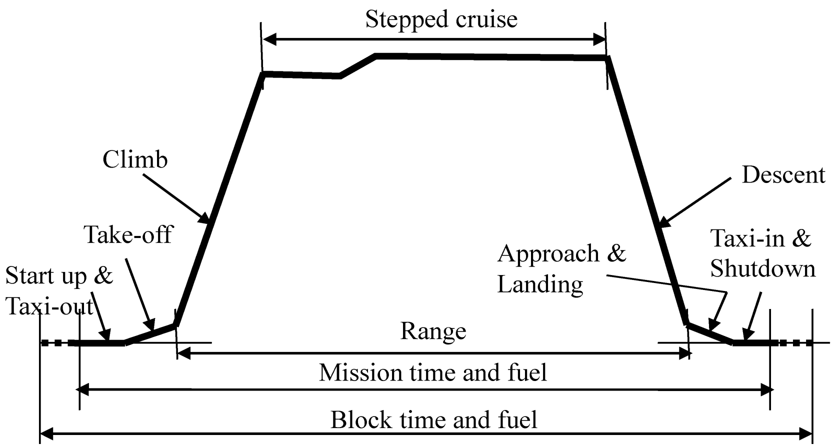


Image adopted from Ref. [4]

GISMO- Architecture of preliminary aircraft performance modelling.



Mission Task Elements



***Avellan, R**., “Preliminary Design of Subsonic Aircraft and Engines”, Proceedings of the International Society Of Air Breathing Engines. (ISABE-2007-1195), Chalmers University of Technology, Gothenburg, Sweden.

Engine Performance Simulation

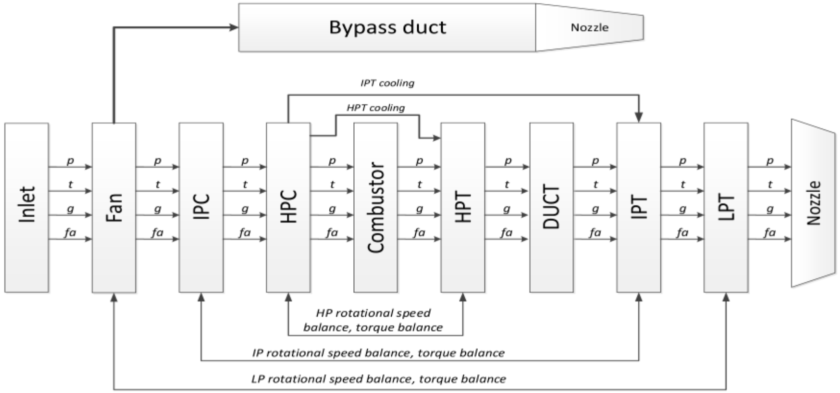
GESTPAN – General Stationary and Transient Propulsion Analysis

- Zero-dimensional aero-thermodynamic analysis employing discrete component maps
- Solves for the mass and energy balance between the various engine components
- Ability to simulate a wide range of aero-engines as well as industrial gas turbines

Image courtesy of CFM.

Key Capabilities

- Ability to introduce customised (user defined) component characteristics.
- Design, Off design and transient performance calculations



GESTPAN - Interconnected Engine Component Schematic of Turbofan

*Grönstedt, T., “Development of Methods for Analysis and Optimization of Complex Jet Engine Systems”, PhD Thesis, Department of Thermo and Fluid Dynamics, Chalmers University of Technology, 2000.

Noise Source Modelling Overview

- The noise sources are modelled based on a wide-range of **empirical and semi-empirical correlations** collected from the public domain literature.
  - The modelling is predominantly inspired by the work reported through the NASA "Aircraft NOise Prediction Program".

- **Fan, Compressor, Combustor and Turbine Model** – Empirical approach adopted from the NASA – "Improved NASA-ANOPP - Noise Prediction Computer Code for Advanced Subsonic Propulsion Systems, NASA Contractor Report 195480.

- **Jet Model** – Empirical approach reported in SAE "Gas Turbine Jet Exhaust Noise Prediction", SAE ARP876. Rev E, 2006.

- **Airframe Model** – Empirical approach and noise sub-component definition based on the 4.7% DC10 model and the 6.3% B767 model –NASA Contractor Report 213255, 2004 "Airframe Noise Sub-component Definition and Model".

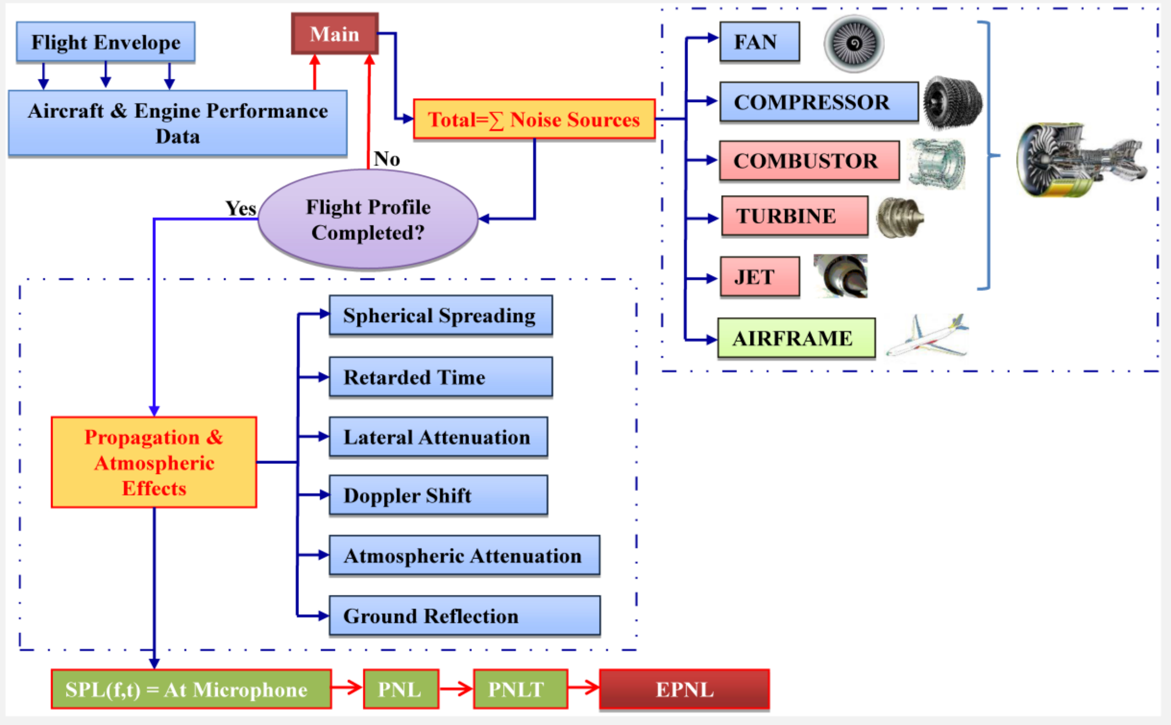
- **Landing Gear Model** – Semi-analytical and semi-empirical approach applied to three spectral component of the landing gear, low, medium and high frequency noise. NASA Contractor Report 213780, 2005. "Empirical Prediction of Aircraft Landing Gear Noise".

*F. Ali., D. Carlsson and L. Ellbrant., T. Gronstedt "A Noise Assessment Framework for Subsonic Aircraft and Engines" Proceedings of American Society of Mechanical Engineers Turbo Expo 2015: Power for Land, Sea and Air, June 13th - 17th, 2016 Seoul, South Korea GT2016-58012.

System Level Noise Modelling

- Developed integrated noise assessment framework: Architecture.

  - Aircraft flight definition (LTO Cycle)
  - Source Noise modelling
  - Propagation and Atmospheric Effects
  - Effective Precived Noise Level Calculation



Case Study

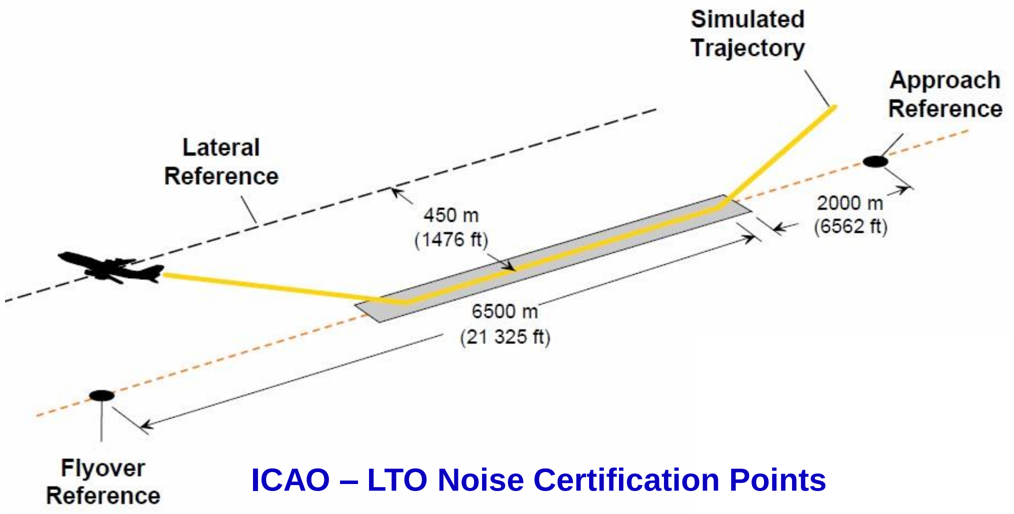
Aircraft Model

Image courtesy of Boeing

Engine Model: Inspired by CFM 56-7B27

Image courtesy of cfm

Parameter	Value	Units
Mass flow	427.00	Kg/sec
BPR	5.10	-
FPR	1.71	-
CPR	10.71	-
OPR	28.63	-
TET	1608.00	K
Thrust	121.50	kN



ICAO – LTO Noise Certification Points

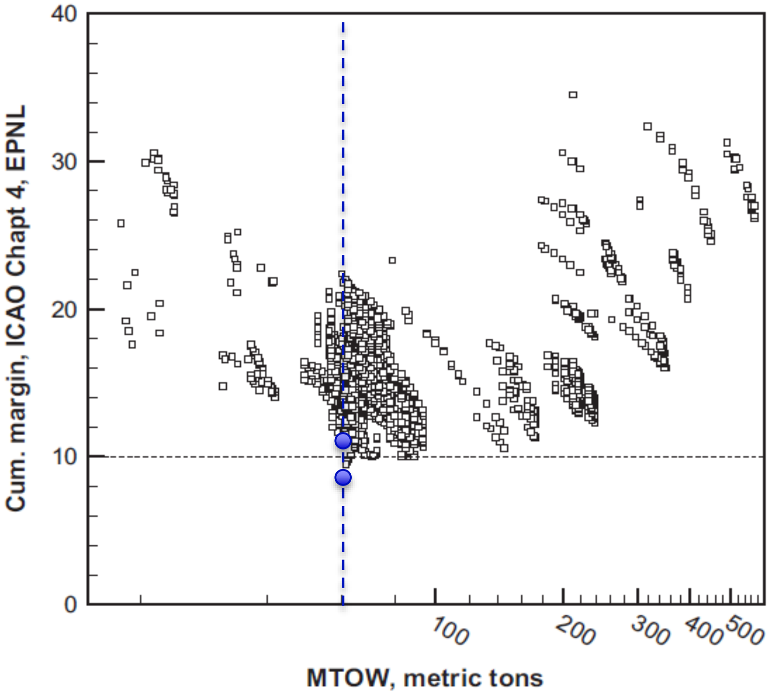
- Community/Flyover with noise abatement cutback.
- Approach (3deg glide slope).

Results

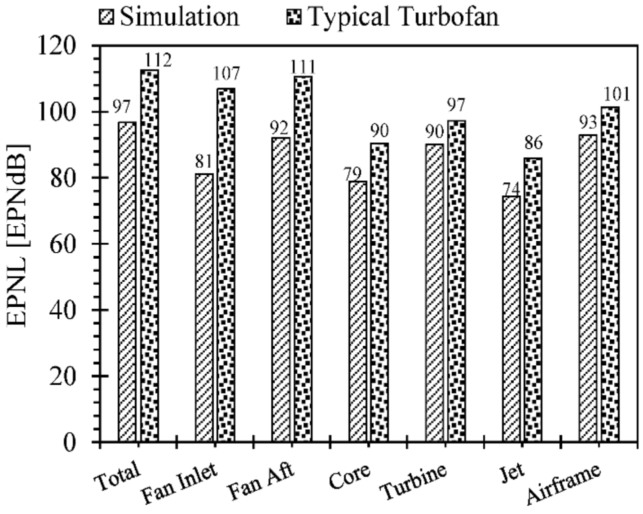
Certification Noise Results

ICAO Data Vs Model Prediction

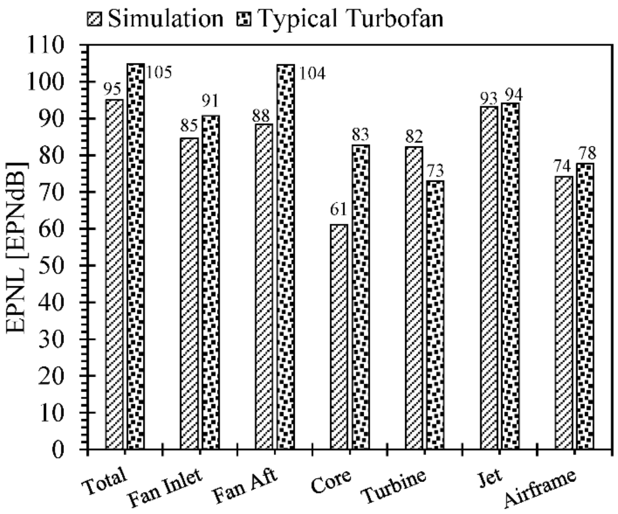
ICAO Measured Noise Level				
Noise Level	**Lateral Full power**		**Flyover**	**Approach**
Measured Noise level	94.70		87.00	96.50
Noise Limit	97.00		91.90	100.70
Margin	-2.30		-4.90	-4.20
Cumulative Margin		**-11.40**	-	-
Framework - Simulated Noise Level				
Noise Level	95.10		89.80	96.80
Margin	-1.90		-2.10	-3.90
Cumulative Margin		**-7.90**	-	-
$\Delta_{M\&Sim}$	**≈0.5%**		**≈3.0%**	**≈0.5%**



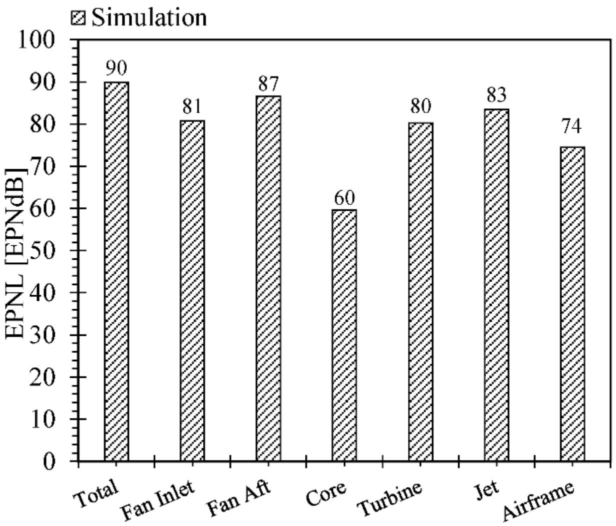
Component Level Noise



Approach



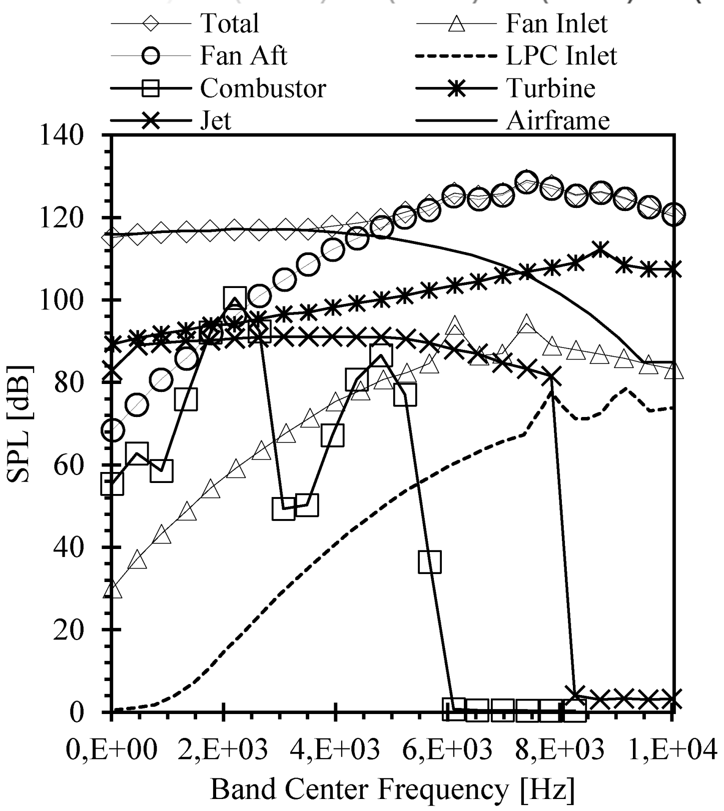
Lateral



Flyover

Component Level Approach Spectrum

- Airframe noise is the most dominant component for lower frequencies.
- The airframe noise at approach is greatly influenced by the turbulent wakes that arise from the airframe components:
  - landing gear and high-lift surfaces
  - controls surfaces
  - speed brakes
- Airframe is significantly greater compared to the characteristics of the engine, therefore noise generated by the airframe is of larger length scales which translate to lower frequencies.
- At higher frequencies the fan and turbine exhibit greater influence.
- Predominantly dependent on the
  - Rotational speed of the rotor
  - Number of blades



Approach condition simulation results: Spectrum at 1m radius (120 deg) for baseline aircraft.

Concluding Remarks

- An integrated framework capable of computing the noise sources corresponding to aircraft airframe, engine component and flight propagation effects at all three ICAO defined noise certification points has been developed and successfully deployed.
- The proposed model exhibits reasonable accuracy in predicting the certification and component level noise to support conceptual design assessment.
- The model development work gather most relevant literature and noise data from different sources into a multidisciplinary method for aircraft noise estimation.
- The model allows an effective implementation into an aircraft design process by evaluating the risks of new technologies on the environmental noise impact.

References

1) **Airbus Market Forecast** 2015 – 2034.
2) **Antonio Filippone** “Aircraft Noise Prediction” Progress in Aerospace Sciences 68 (2014) 27 -63.
3) **Marcus, H**., “Interim Prediction Method for Fan and Compressor Source Noise”, NASA Technical Memorandum X-71763, 1979.
4) **Janardan, B., Kontos**, K., and Gliebe, R., “Improved NASA-ANOPP - Noise Prediction Computer Code for Advanced Subsonic Propulsion Systems, NASA Contractor Report 195480.
5) **Gliebe, P**., Mani, R., Shin, H., Mitchell, B., Ashford, G., Salamah, S., and Connell, S., “Aeroacoustics Prediction Codes”, NASA Contractor Report 210244, August 2000.
6) **Krejsa, A**,. “Interim Prediction Method for Turbine Noise”. NASA Technical Memorandum 73566, 1976.
7) **Smith, T**., and Bushell, W., Turbine Noise - Its Significance in the Civil Aircraft Noise Problem. In ASME Paper, 69-WA/GT-12. SAE, Nov 1969.
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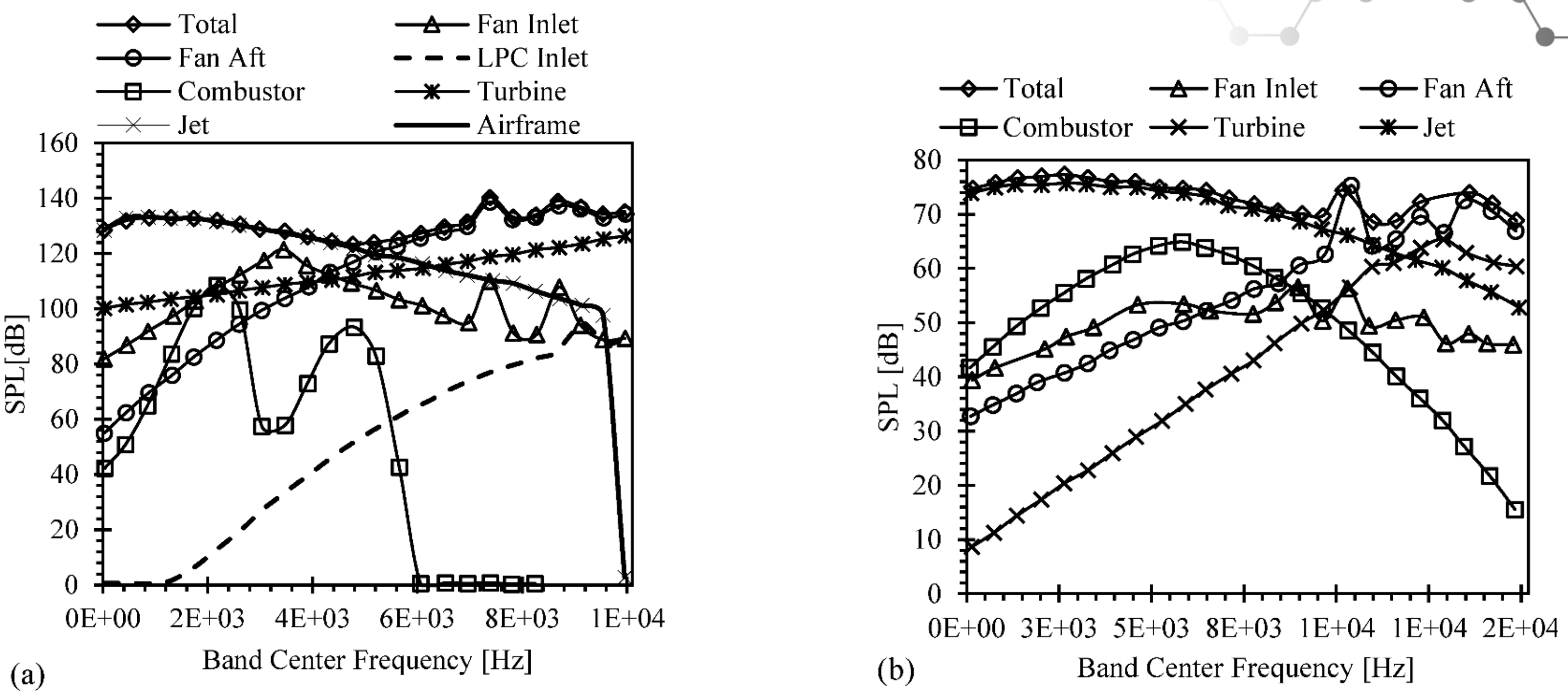
9) **SAE Report**., “Prediction of Single Stream Jet Mixing Noise from Shock-free Circular Nozzles”, In Gas Turbine Jet Exhaust Noise Prediction, SAE ARP876. Rev E, 2006.
10) **SAE Report**., “Prediction of Coaxial Jet Mixing Noise”, In Gas Turbine Jet Exhaust Noise Prediction, SAE ARP876. Rev E, 2006.
11) **SAE Report**., “Prediction of Single Stream Shock-associated Noise”, In Gas turbine jet exhaust noise prediction, SAE ARP876 Rev. E, 2006.
12) **Guo, Y**., “Empirical Prediction of Aircraft Landing Gear Noise”, NASA Contractor Report 213780, 2005.
13) **Sen, R**., “Airframe Noise Sub-component Definition and Model”, NASA Contractor Report 213255, 2004.
14) **Avellan, R**., “Preliminary Design of Subsonic Aircraft and Engines”, Proceedings of the International Society Of Air Breathing Engines. (ISABE-2007-1195), Chalmers University of Technology, Gothenburg, Sweden.

Thank you for your attention.



Lateral condition spectra at 120 degree results: (a) simulation for baseline aircraft; (b) trends based on theory.

Fan & Compressor Noise

The model employed was initially developed by Boeing Company in collaboration with NASA Ames, and further improved by Heidmann based on full-scale fan test performed at NASA lewis.

- The procedure involes predicting spectrum shape, level, and directivity for each of the following components:
  - Inlet broadband, discrete tone, and multiple-pure tones
  - Exhaust broadband and tone noise

- Four key parameters are required to predict basic spectrum level
  - Mass flow (specific power)
  - Total temperature rise across the stage (specific work)
  - Design and operating point values for relative tip mach number

- The acquired basic levels are then corrected for:
  - Presence of IGV, rotor-stator spacing,
  - Inlet flow distortions, and cuttoff.

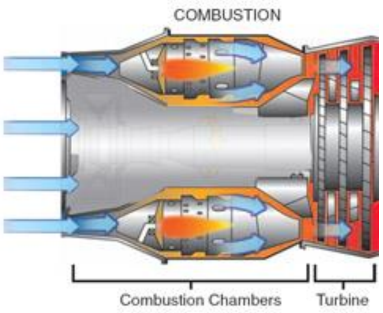
Images courtesy of Jet Art Aviation.

Images courtesy of GE.

Janardan, B., Kontos, K., and Gliebe, R., “Improved NASA-ANOPP - Noise Prediction Computer Code for Advanced Subsonic Propulsion Systems, NASA Contractor Report 195480.

Combustor Noise

- The empirical models emplyed for combustor noise are derived based on the full-scale engine static tests on several modern low emissions commercial turbofans.
    - CM56-80C2, CM56-5B, CM56-7B, and GE90
- The test data was acquired for both single and dual annular combustors noise levels through data decomposition.
    - SPL correlations were derived as a function of the following parameters:
        - Combustor geometry
        - Cycle conditions
        - Spectral frequency content
        - Measured directivity angle
- **Turbine** noise source is modelled using similar approach as employed for compressor.



Images courtesy of Jet Art Aviation.

Krejsa, A,. "Interim Prediction Method for Turbine Noise". NASA Technical Memorandum 73566.

Jet Noise

- The jet noise model employed originates from the experimental findings reported in [5], performed by NASA.

- Three dedicated noise sub-models are scheduled as following:
  - Single Stream Jet (SSJ) mixing noise
  - Coaxial Jet mixing noise

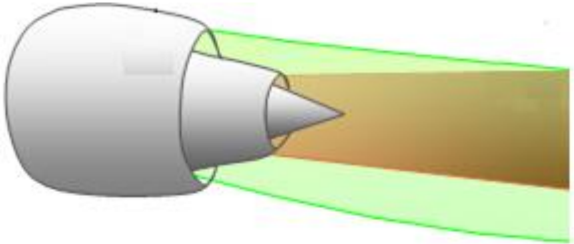


Image adopted from Ref. [2]

- For SSJ the jet velocity is the most dominent factor, calculated using nozzle design and performance parameters e.g nozzle PR and temperature.

  - Static OSPL as a function of angle to the inlet axis is then computed based on the correlation derived using experimental values.
  - A subtraction of the difference between the static and the flight case is made in order to obtain the in flight overall sound pressure level.

SAE Report., “Prediction of Single Stream Jet Mixing Noise from Shock-free Circular Nozzles”, In Gas Turbine Jet Exhaust Noise Prediction, SAE ARP876. Rev E, 2006.

Jet Noise Cont'd

- Employed model for coaxial jet mixing is divided into three sub-models
  - Primary (Core flow)
  - Secondary (Bypass flow)
  - Shear layer between above corresponds to mixed source

- The most important parameters are following:
  - Velocity and density differences between the core and the bypass
  - Bypass and the ambient flow
  - Geometry of the core and bypass

SAE Report., "Prediction of Coaxial Jet Mixing Noise", In Gas Turbine Jet Exhaust Noise Prediction, SAE ARP876. Rev E, 2006.

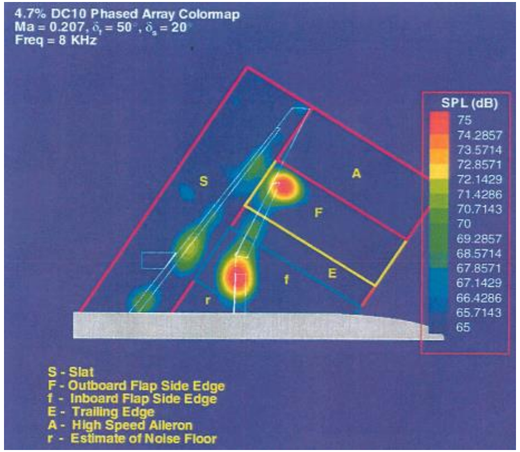
Airframe Noise

- NASA performed elliptic mirror acoustic measurements of the scaled DC10 and B767 fuselage models.

- Through the regression analysis of the mesured data empirical correlation for each noise sub-regions were established corresponding to:
    - Leading edge slats
    - Outboard flap
    - Inboard flap edge
    - Trailing edge and ailerons

- The model requires the geometric and aerodynamic parameters as an input corresponding to each noise source. E.g. Cl, Cd, angle of attack, ´flight velocity, chord.

- What all noise sources have in common is that with increase in angle of attack and the effective area leads to increase in noise level.



Definition of the noise source sub-regions for airframe [13]

Sen, R., “Airframe Noise Sub-component Definition and Model”, NASA Contractor Report 213255, 2004.

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Landing Gear Noise

- The model is based on a composite of semi-analytical and semi-empirical correlations applied to three spectral components of landing gear.
  - Low frequency – Wheels
  - Medium frequency – Struts
  - High frequency – complex small features

- The amplitudes are determined by geometric and flow quantities unique to each component together with common functional dependencies, such as:
  - Mach Number
  - Spherical speading
  - Convective amplification and atmospheric absorbtion

- The most dominet sources for the LG noise are the the surface pressure fluctuations
  - Deterministically determined for low and medium frequency components
  - Statistical description is employed for high frequency components

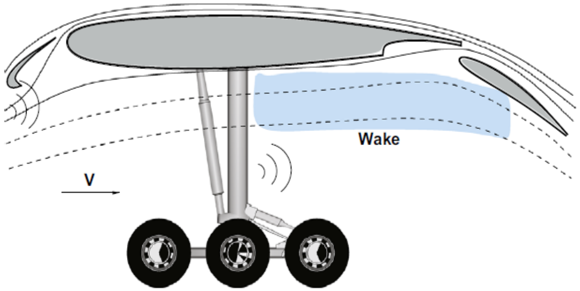

Image adopted from Ref. [1]

Guo, Y., "Empirical Prediction of Aircraft Landing Gear Noise", NASA Contractor Report 213780, 2005.