Multidisciplinary Design Optimization of Low-Airframe-Noise Transport Aircraft

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Work sponsored in part by NASA Langley Research Center
Phoenix Integrations Inc. provided ModelCenter software

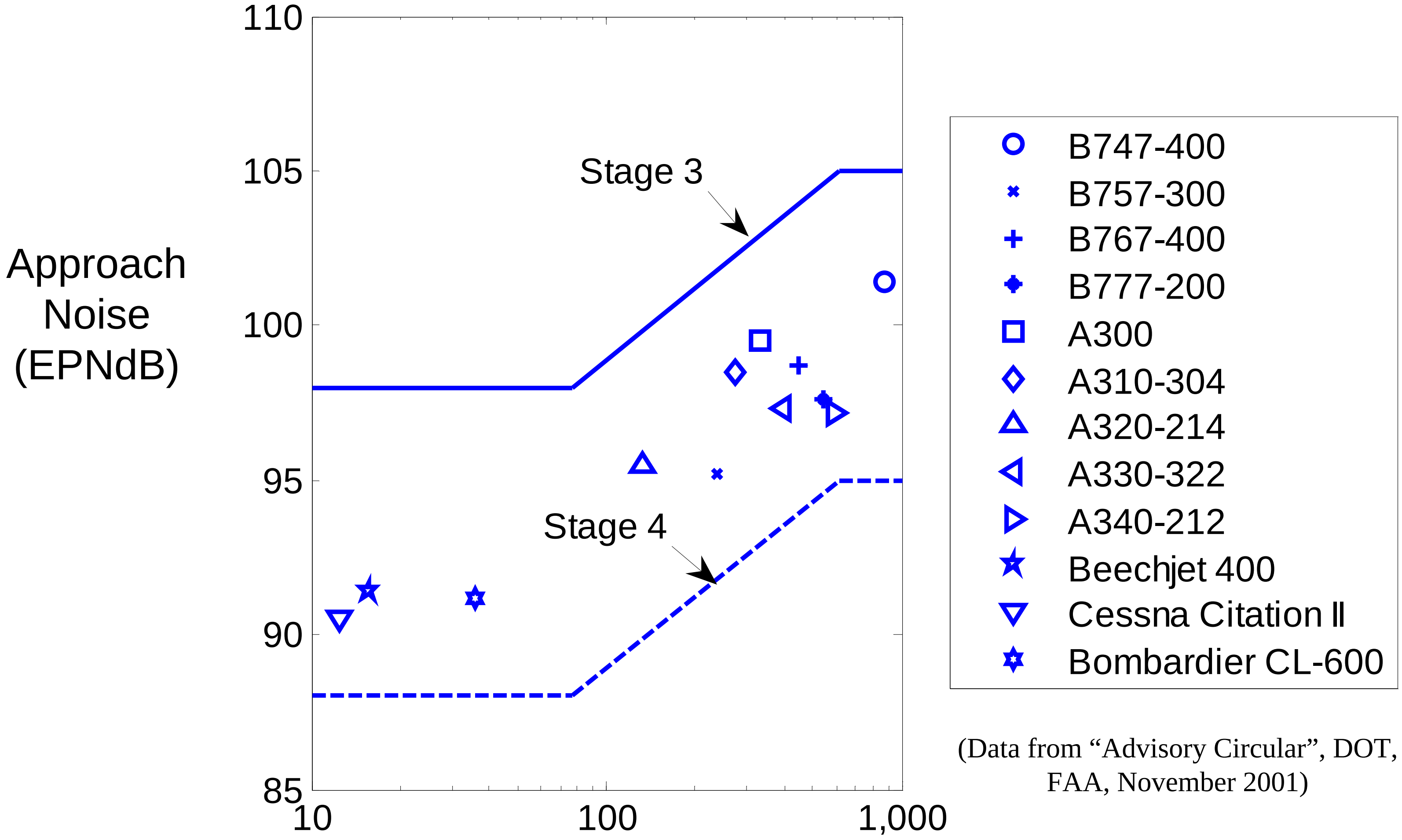
44th AIAA Aerospace Science Meeting and Exhibit, Reno
January 9, 2006

Outline

- Introduction
- Research objectives
- Methodology
- MDO formulation
- Design studies
- Conclusions
- Future work

(Source: www.airliners.net)

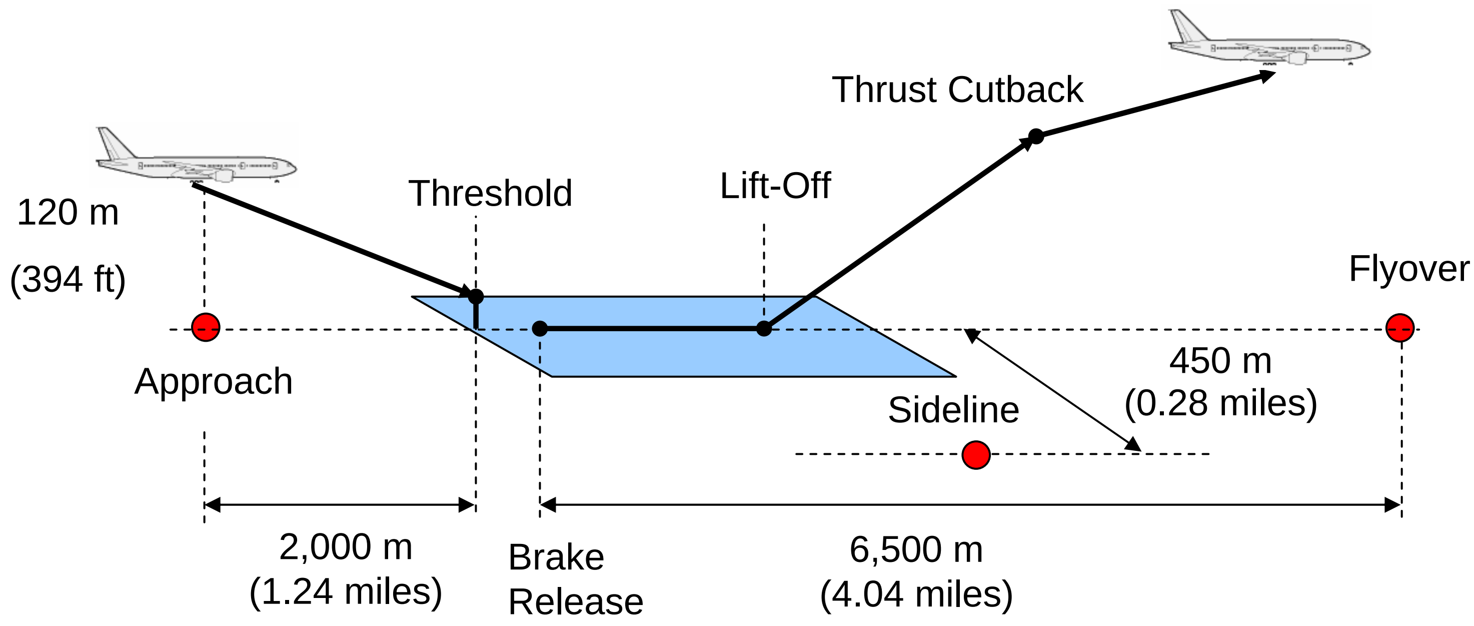
Aircraft noise is a growing problem



(Data from "Advisory Circular", DOT, FAA, November 2001)

- 100% increase in noise related restrictions in the last decade
- NASA's goal is to reduce noise by 20 decibels in next 20 years

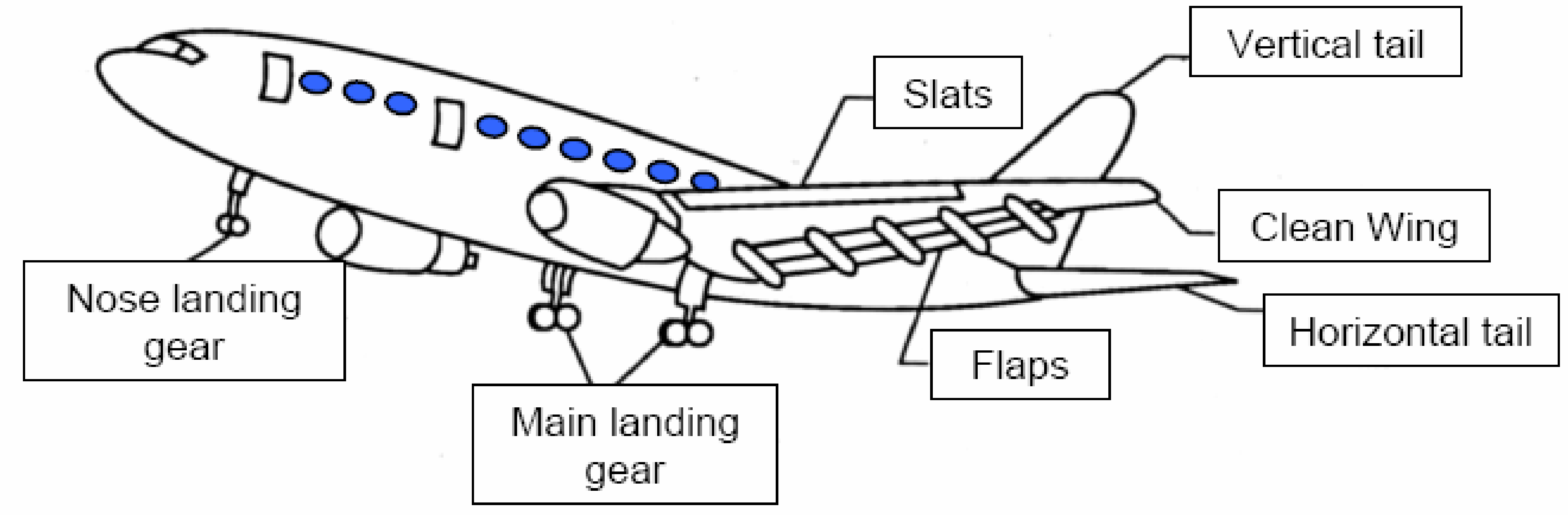
Aircraft Noise Certification



- Aircraft must be certified by the FAA and ICAO in terms of noise levels
- Certification noise is measured at flyover, sideline, and approach
- Based on aircraft max *TOGW* and number of engines, the noise level is limited
- Additionally, regulations limit the hours and the number of operations

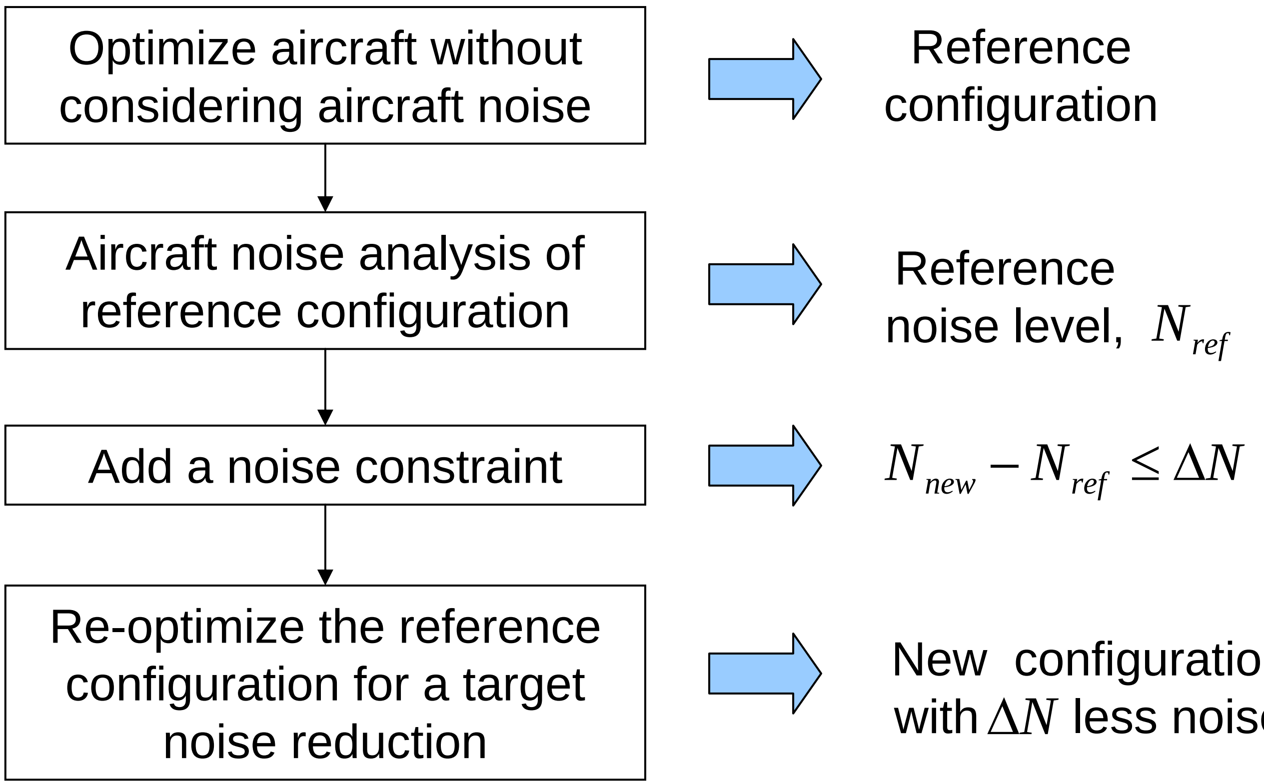
Research Objectives

- Include aircraft noise in the conceptual design phase
- Design *low-airframe-noise* transport aircraft using MDO
- Quantify change in performance w.r.t. traditionally designed aircraft

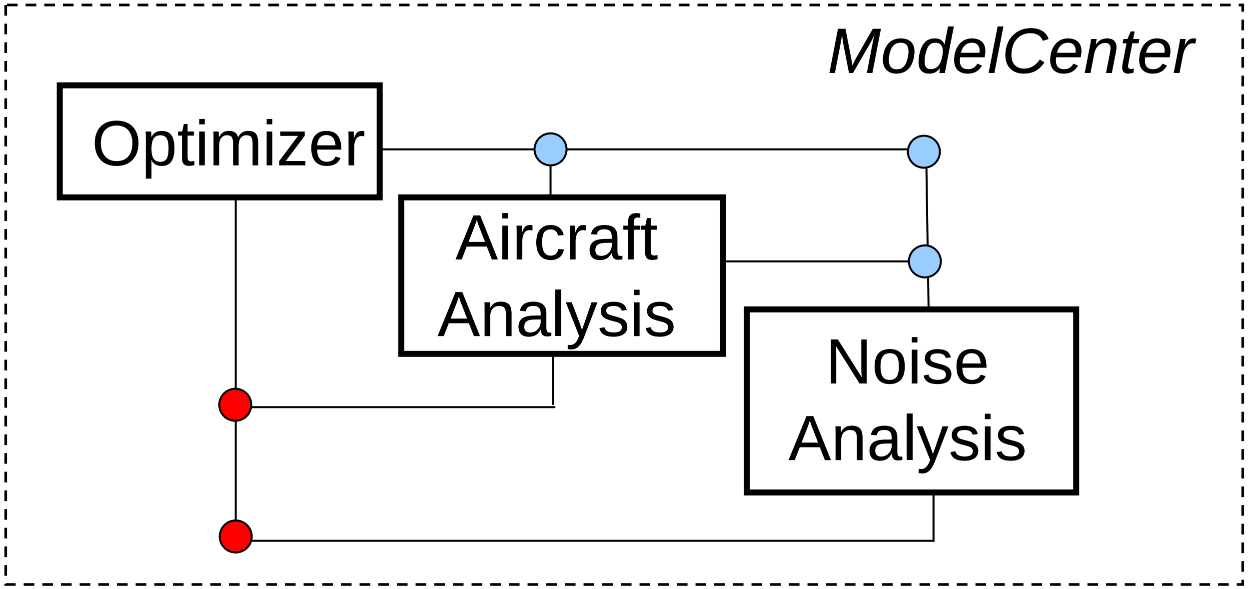


Airframe Noise Sources

Design Methodology: Noise as a Design Constraint



MDO Framework



- Aircraft analysis codes previously developed at Virginia Tech
  - High-lift system analysis module was added
- ANOPP used for aircraft noise analysis
- ModelCenter used to integrate the codes
- DOT is the optimizer; Method of Feasible Directions optimization algorithm

ANOPP Overview

- Semi-empirical code
- Uses publicly available noise prediction schemes
- Continuously updated by NASA
- The airframe noise module is component based
- Based on airframe noise models by Fink
- The general approach:

Far-Field Mean Square Acoustic Pressure

$$\langle p^2 \rangle = \frac{\Pi}{4\pi r_s^2} \frac{D(\theta,\phi) F(S)}{(1 - M_\infty \cos\theta)^4}$$

Acoustic Power

$$\Pi = K (M_\infty)^a G$$

ANOPP – Acoustic Power of Each Component

- Wing Trailing-Edge (Clean wing)

$$\Pi_{\text{Wing TE}} = K_1 \left(M_\infty\right)^5 \delta_w$$

← Turbulent BL thickness

$$\delta_w = 0.37 S_w \left(\frac{\rho_\infty M_\infty c_\infty S_w}{\mu_\infty b_w} \right)^{-0.2}$$

- Leading-Edge Slat
  - Increment on wing TE noise
  - TE noise of LE slat
- Trailing-Edge Flap

$$\Pi_{\text{Flap}} = K_2 \left(M_\infty\right)^6 S_f \sin^2 \delta_f$$

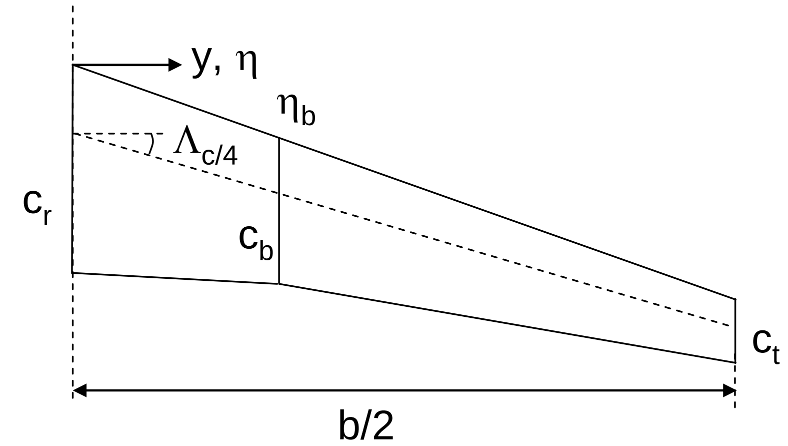
- Landing-Gear

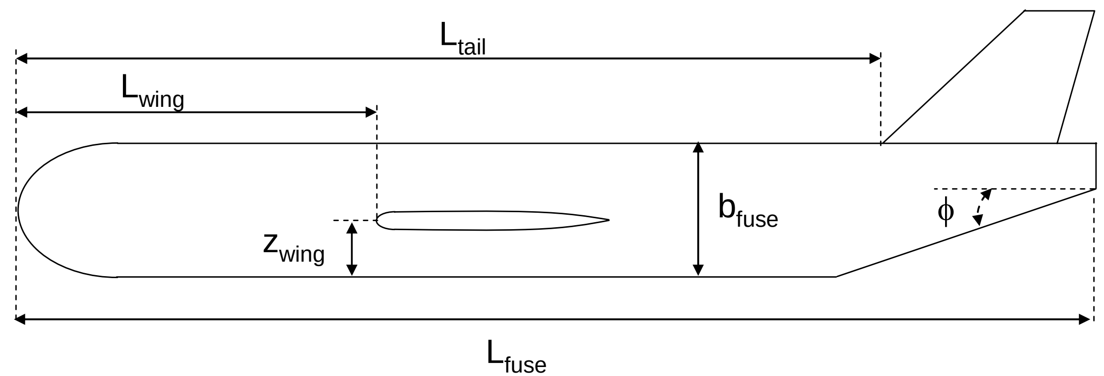
$$\Pi_{\text{Landing gear strut}} = K_3 \left(M_\infty\right)^6 d\, l$$

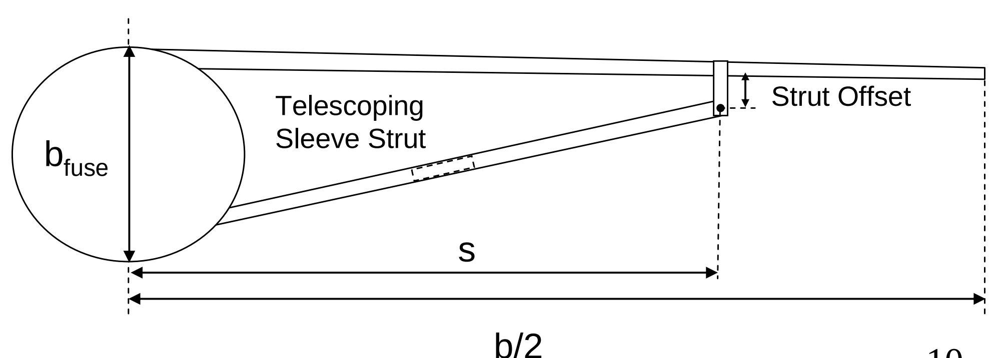
$$\Pi_{\text{Landing gear wheels}} = K_4 \left(M_\infty\right)^6 d^2 n$$

MDO Formulation

- Objective function
  - *Min Takeoff Gross Weight*
- Design variables (17-22)
  - Geometry
  - Average Cruise Altitude
  - Sea level static thrust
  - Fuel weight
- Constraints (16-17)
  - Geometry
  - Performance
    - Takeoff, Climb, Cruise, Landing
- Parameters
  - Fuselage geometry

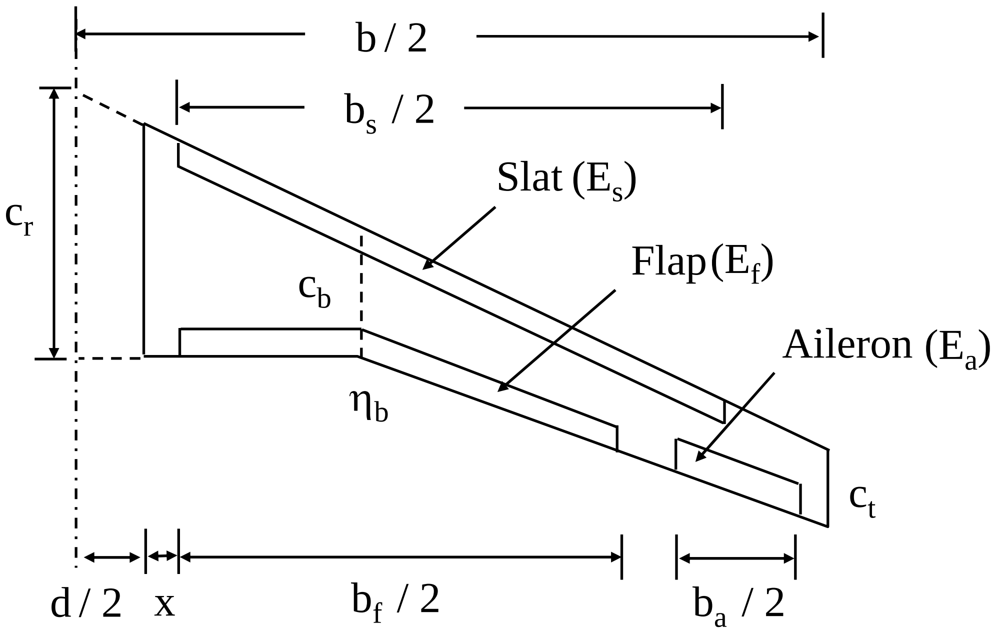




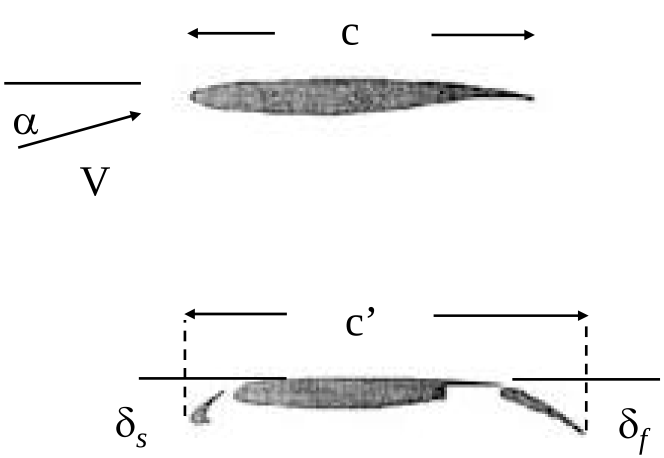


High-Lift System Configuration

Planform View

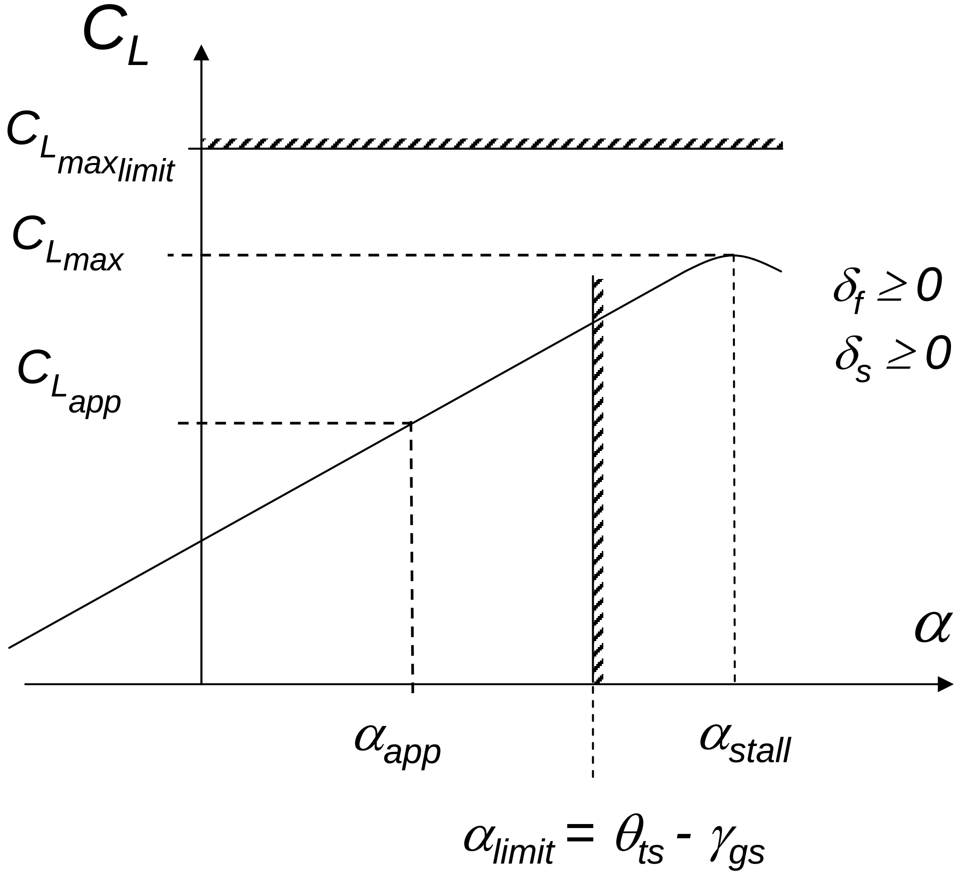


Section View



- High-lift analysis model based on semi-empirical methods by Torenbeek
- Model validated by analyzing a DC-9-30 and comparing with published data

High-Lift Design Limits and Requirements



FAA Design Requirement: $C_{L_{\max}} \geq 1.3^2 C_{L_{app}}$

MDO Formulation for the High-Lift System

MDO

DV's: $b_f/2$, E_f

Constraints:

$$C_{L_{\max}} \geq 1.3^2 C_{L_{app}}$$

$$C_{L_{\max}} \leq C_{L_{\max\,\mathrm{limit}}}$$

$$\alpha_{app} \leq \alpha_{tailscrape} - \gamma_{glideslope} = 15 \ \mathrm{deg}$$

$$\eta_{f_o} \leq 0.75$$

Flap Deflection:

$$\min_{0 \leq \delta_f \leq 30} \left| 1.3^2 C_{L_{app}} - C_{L_{\max}}(\delta_f) \right|$$

Side Constraint: $0 \leq b_f / 2 \leq 80$ ft

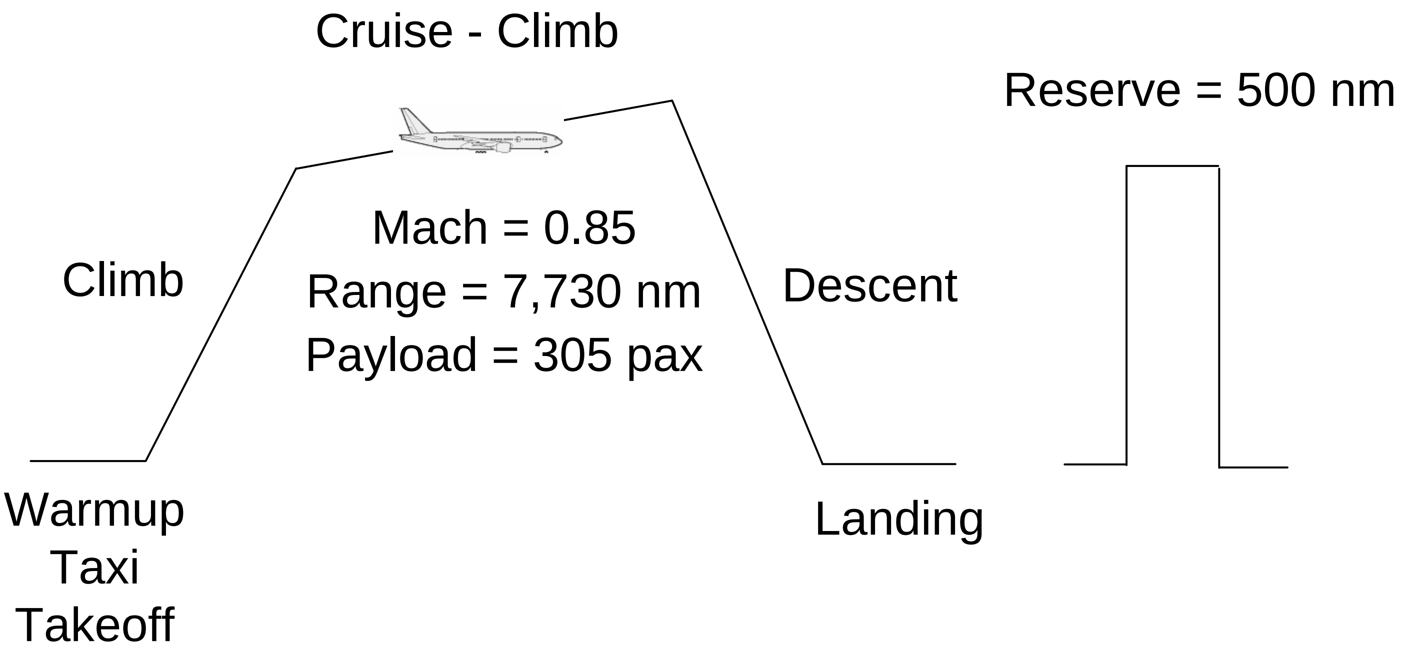
Parameters: $C_{L_{\max\,\mathrm{limit}}}$ V_{app} E_a , E_s

$$C_{L_{app}} = \frac{W_{landing}}{\frac{1}{2}\rho V_{app}^2 S_{ref}}$$

Limited by ANOPP

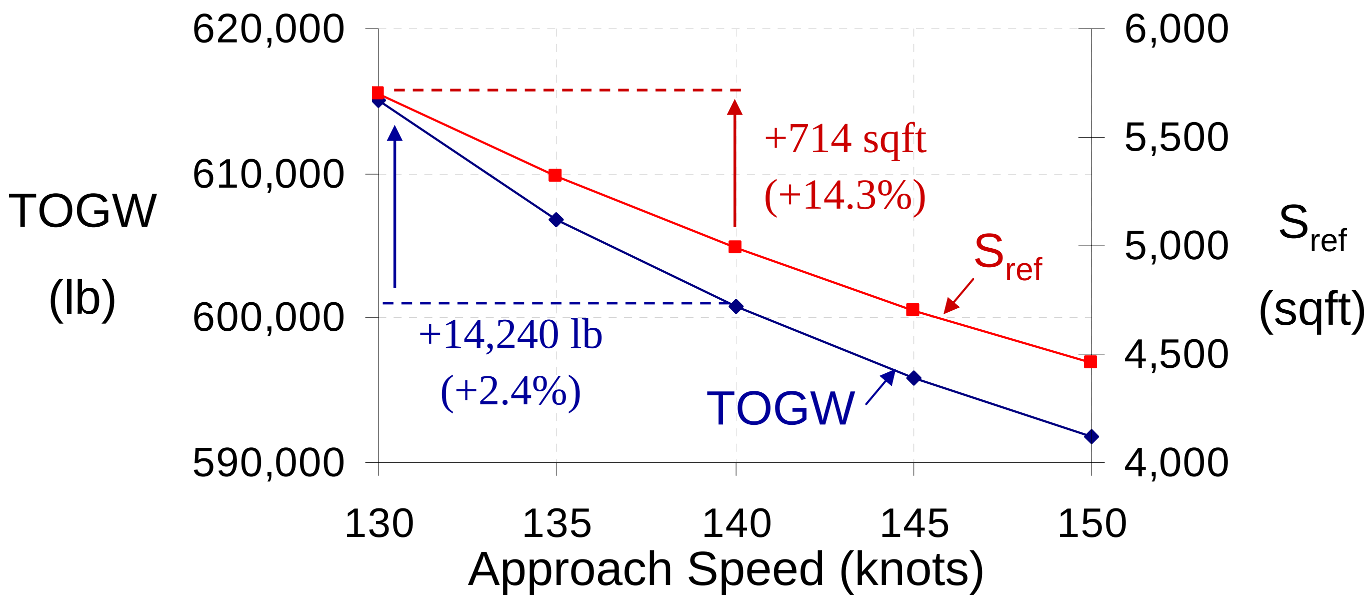
Design Studies

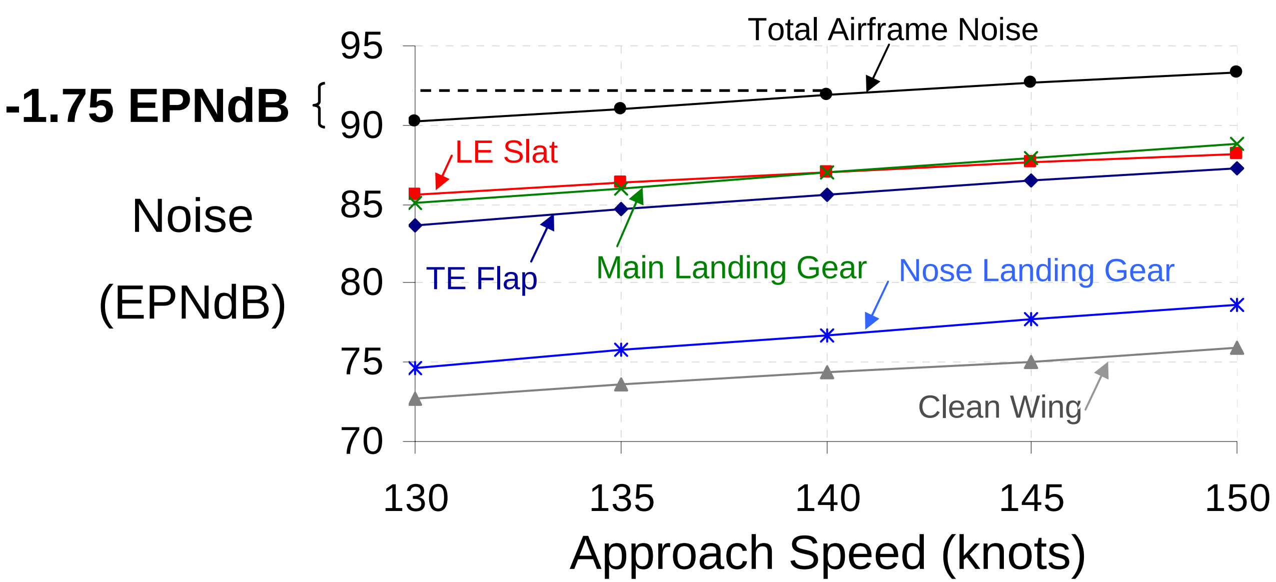
1. Approach speed study
2. TE flap noise reduction
3. Airframe noise analysis of cantilever wing vs. SBW



Study 1: Approach Speed Study

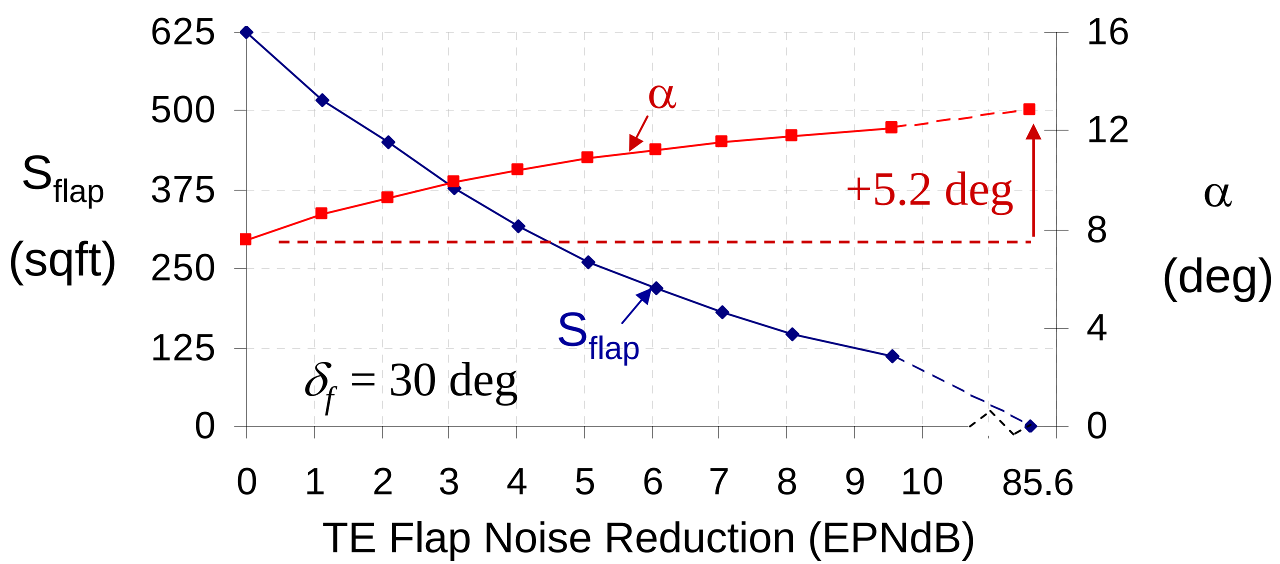
Reducing airframe noise by reducing approach speed alone, will not provide significant noise reduction without a large weight penalty

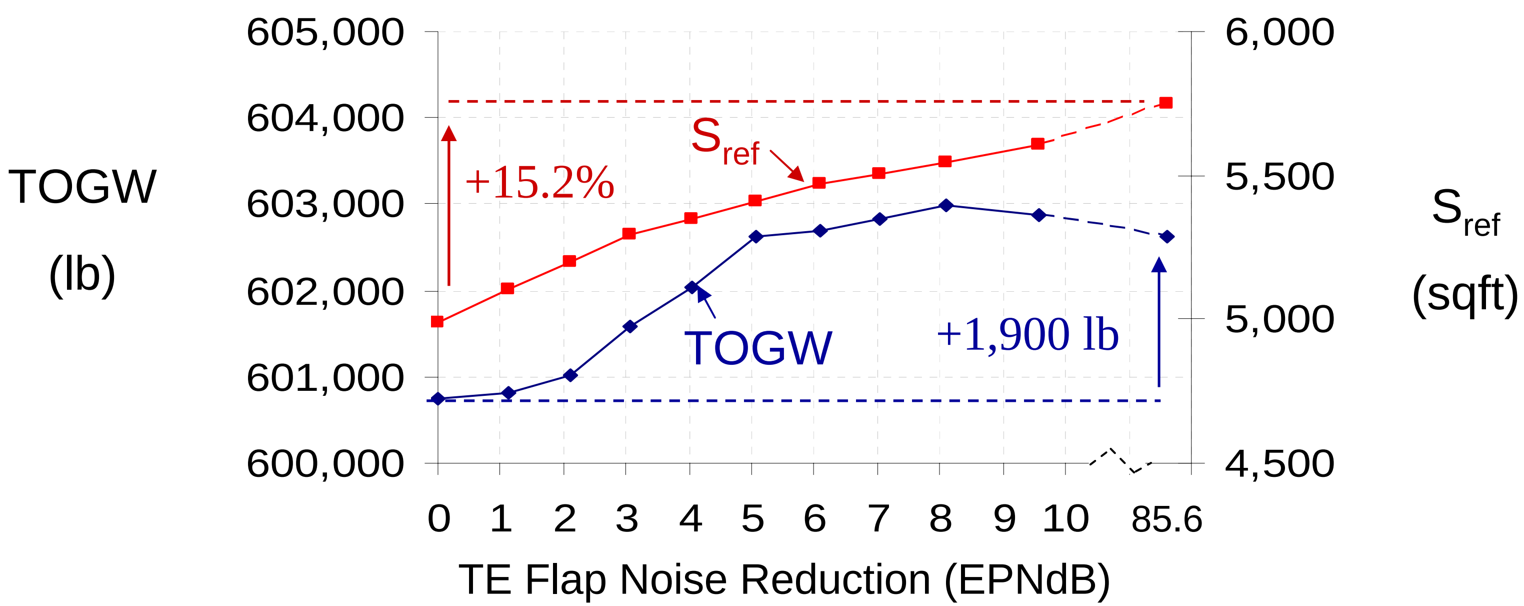




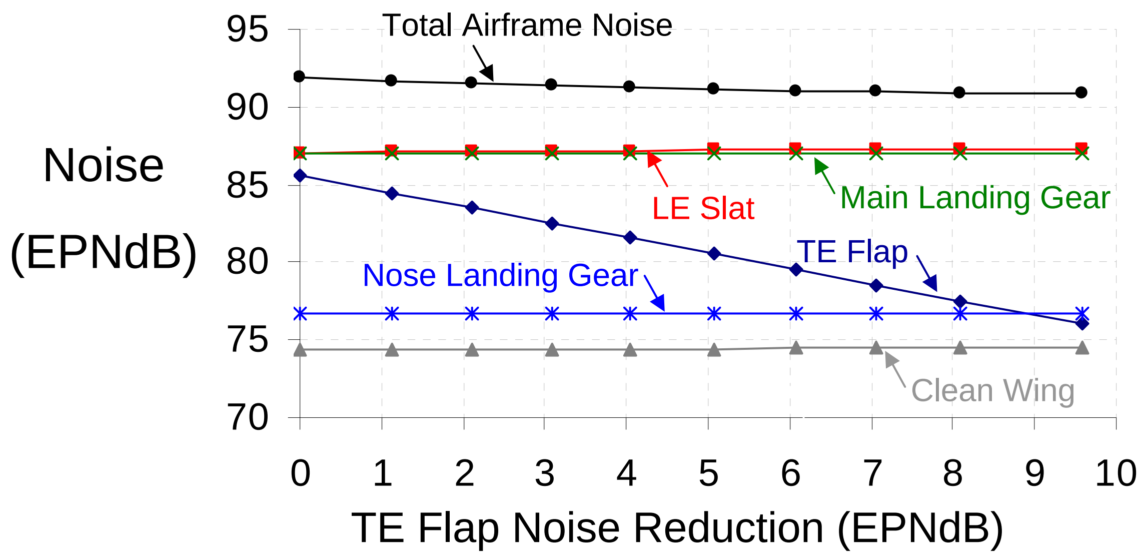
Study 2: TE flap noise reduction

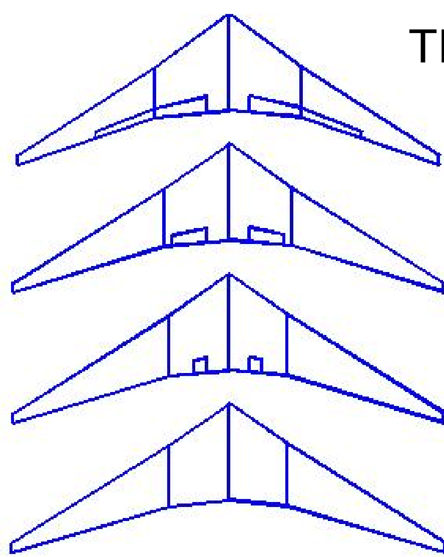
Eliminate TE flaps by increasing S_{ref} and α without incurring significant weight penalty





Thus, eliminating any noise associated with TE flaps

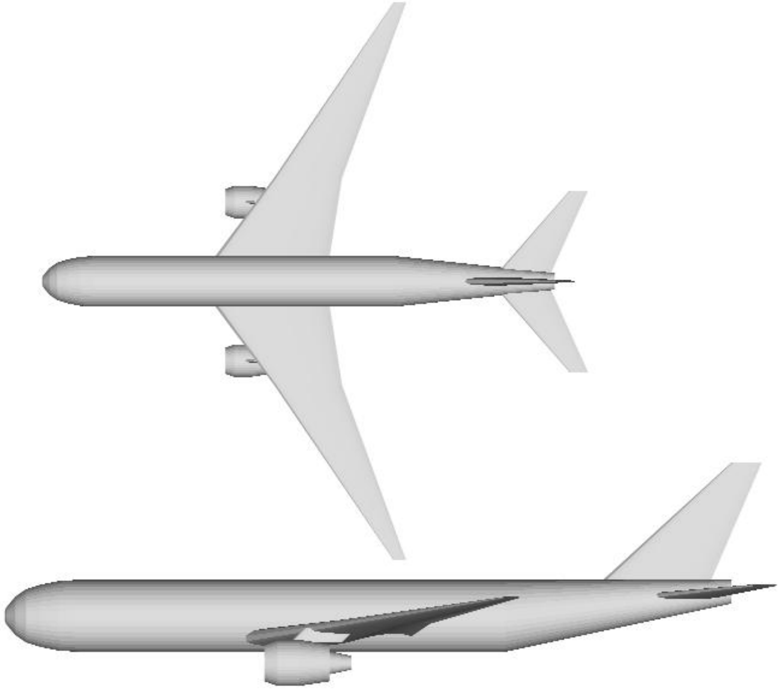




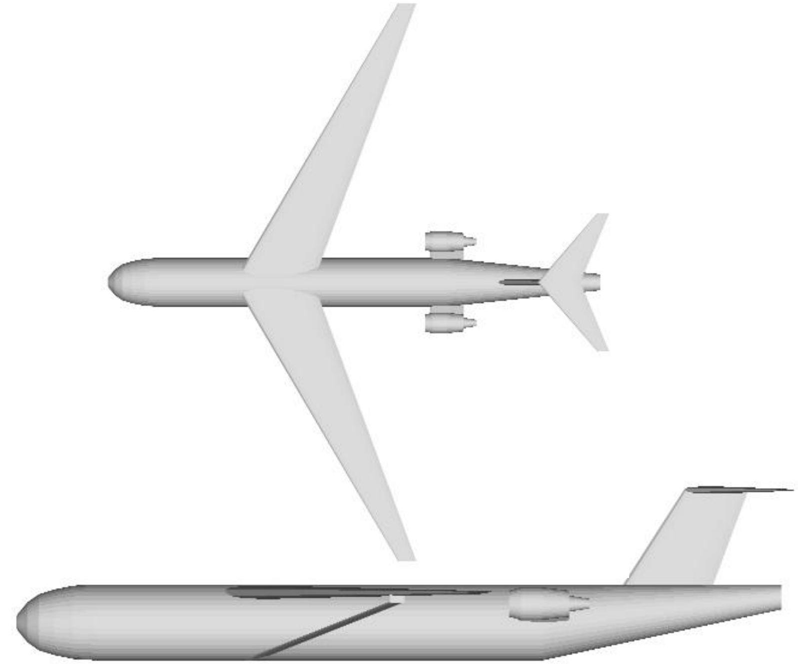
TE Flap Noise Reduction (EPNdB)
0
5.07
9.58
No TE Flap

Study 3: Airframe noise analysis of cantilever wing and SBW

SBW shows a significant improvement in weight & performance compared to a cantilever wing



$\alpha_{app} = 7.7^o\ ,\ \delta_f = 30^o$



$\alpha_{app} = 5.8^o\ ,\ \delta_f = 30^o$

Design Parameter	Cantilever Wing	SBW	Difference
TOGW (lb)	601,901	543,066	-9.8%
Fuel Weight (lb)	230,614	196,236	-14.9%
Wing Weight (lb)	90,044	81,492	-9.5%
Aspect Ratio	9.91	11.42	15.2%
L/D at Cruise	21.14	23.54	11.4%
Specific Range (nm/1000 lb fuel)	31.25	37.59	20.3%

SBW has a similar or potentially lower total airframe noise than a cantilever wing aircraft

Component	Cantilever Wing (EPNdB)	SBW (EPNdB)	Difference (EPNdB)
Main Landing Gear	87.02	85.21	-1.82
LE Slat	87.06	87.02	-0.04
TE Flap	85.54	85.33	-0.21
Nose Landing Gear	76.76	76.76	0.00
Wing TE	74.31	74.41	0.09
Strut	-	67.16	-
Total	**91.89**	**91.27**	**-0.63**

- Main landing gear
  - Cantilever with 6 wheels; SBW with 4 wheels and ½ the strut length
- Wing strut modeled as wing TE noise

Conclusions

- A methodology for designing *low-airframe-noise* aircraft has been developed and implemented in an MDO framework
- Reducing airframe noise by reducing approach speed alone, will not provide significant noise reduction without a large weight penalty
- Therefore, more dramatic changes to the aircraft design are needed to achieve a significant airframe noise reduction
- Cantilever wing aircraft can be designed with minimal TE flaps without significant penalty in weight and performance
- If slat noise and landing gear noise sources were reduced (this is being pursued), the elimination of the flap will be very significant
- Clean wing noise is the next ‘noise barrier’
- SBW aircraft could have a similar or potentially lower total airframe noise compared to cantilever wing aircraft

Future Work

- Important topics
  - Effects of reduced runway length
  - Effects on other noise sources
    - Increased drag at approach => Increased engine noise for same speed
- SBW's and BWB's should be considered in future studies
  - Clean wing noise model by Hosder et al.