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Quiet Cruise Efficient Short Take-Off and Landing Subsonic Transport System

Ron Kawai
Boeing Technology/Phantom Works, Huntington Beach, California

April 2008

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Quiet Cruise Efficient Short Take-Off and Landing Subsonic Transport System

Ron Kawai
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Prepared under Contract NAS3–01140, Task Order 28

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

April 2008

Acknowledgments

This document summarizes the efforts of many participants, all of whom were essential to the successful development of a Cruise Efficient Short Take-Off and Landing (CESTOL) revolutionary very quiet airplane concept with transcontinental range capable of operating from regional airports. The airplane configuration incorporates innovative total engine noise shielding features that should result in very low flyover noise footprints. This study was conducted for the NASA Glenn Research Center under the technical direction of Mr. Hyun Dae Kim as a part of the Revolutionary System Concepts for Aeronautics (RSCA) Project. Funding was by Revolutionary Aero-Space Engine Research (RASER) Task Order # 28. The author gratefully acknowledges the participation and contributions of NASA Glenn Research Center personnel Hyun Dae Kim, the NASA Glenn Task Manager, Jeff Berton, Scott Jones, contractor to NASA Glenn, Jim Stone of Diversatech, NASA Langley Research Center personnel Karl Geiselhart and Lewis Owens, and Boeing Phantom Works personnel Peter Camacho, Bruce Kimoto, Jim Knight, Richard Odle, Alan Okazaki, David Pitera, Robert Seplak, Joshua Stengel, Jonathan Vass, and Sean Wakayama.

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Executive Summary

This study was conducted by the Boeing Technology /Phantom Works component of the Boeing Company as a part of the NASA Glenn Research Center Revolutionary Engine Research Task Order Number 28. This system study was conducted to explore the potential benefits from incorporating embedded distributed propulsion systems into a cruise efficient airplane in order to enable quiet operations from regional airports. The BWB, because of its inherent cruise efficiency, low noise characteristics, and large internal volume for embedding engines, was selected as the starting point. The configuration was developed for a 40K lb payload (170 pax) 3,000 nmi range airplane operable from 3,500 ft fields. The Boeing Phantom Works WingMOD multidisciplinary optimizer was used to define a planform with powered lift that is pitch controllable without an empennage. The WingMOD planform was then used to create a 3D model and then sized and mission performance data developed using the Advanced Design Boeing Integrated Vehicle Design System. These data were provided to NASA for a noise assessment. This study has created a revolutionary concept by using embedded distributed propulsion in the BWB incorporating fan bleed for a quiet internally blown flap powered lift system and with rapid mixing small engine exhaust nozzles for total engine noise shielding, including the jet noise.

This high degree of noise shielding in combination with increase take-off flight path and steeper approach glide path angles should result in a dramatic reduction in flyover noise footprints. This very low noise concept then has the inherent passive protection from potential terrorist threats from shoulder launched heat seeking missiles. While the noise analyses has not been conducted at the time of preparing this paper, and analysis on a larger CTOL quiet BWB concept incorporating jet noise shielding showed a potential noise level of Stage 3 cum minus 52 dB.

1.0 Introduction

Continuing air traffic growth is forecast by many organizations and agencies such as the FAA, IATA, Boeing and Airbus.

Figure 1 from reference 1 shows the Boeing air traffic growth forecast for the next 20 years. Historically, air travel as a discretionary item, has had growth as a multiple of Gross Domestic Products (GDP). With continuing increase in GDP, extrapolating beyond 2025 would result in a future 4X increase. Since population is increasing with economic growth, continuing growth in the passenger and freight air traffic will need to better distribute the departure and destinations using available airport assets.

A significant deterrent that is occurring, as shown in figure 2, is the exponential rise in noise rules, regulations and restrictions. In order to meet future traffic demand, revolutionary airplane concepts are needed to provide a dramatic reduction in flyover noise while operating with transcontinental range from short airfields. NASA, recognizing the need to identify aeronautics technologies to enable this future capability awarded Boeing this study contract for a Cruise Efficient Short Take-Off and Landing Subsonic Transport System. The concept should be able to cruise at Mach 0.8 in order to operate in transcontinental airspace. Further recognizing the need for revolutionary propulsion integration NASA specified this investigation should focus on use of embedded distributed propulsion for a quiet STOL. This report summarizes the results to conceive an airplane for the 2025+ time frame with very low noise design features than could operate around the clock from untapped regional airspace. NASA would retain responsibility for making the noise predictions.

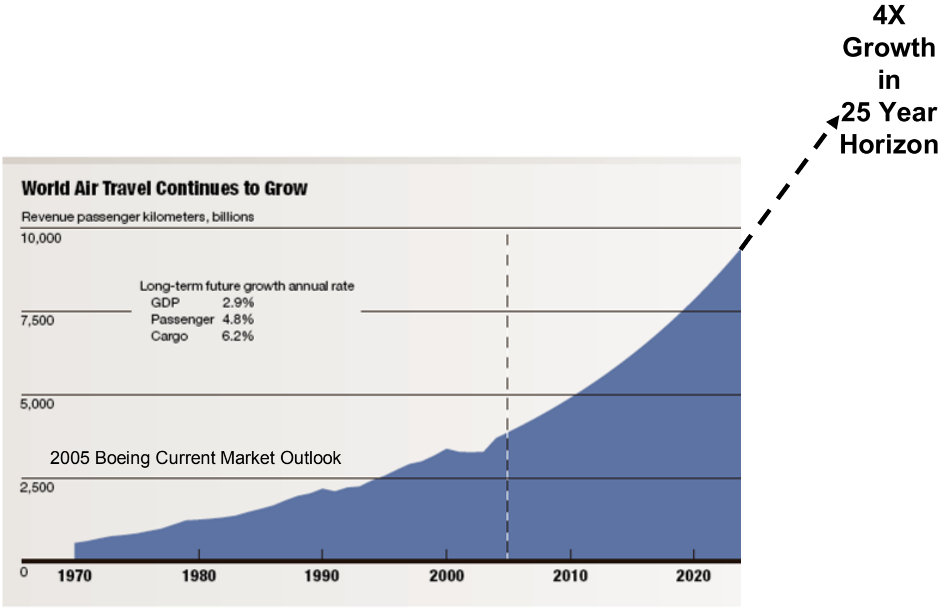


Figure 1.—Boeing air traffic growth forecast.

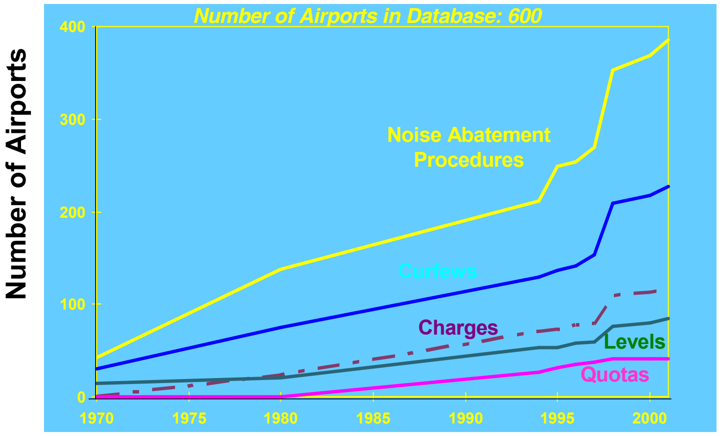


Figure 2.—Noise restrictions continue to grow.

Breguet 941 Demonstrated STOL capabilities

Deflected Slip Stream Turboprop

Figure 3.—The Breguet 941 deflected slipstream turboprop.

2.0 Study Approach

As noted, the Boeing task was to create a revolutionary quiet STOL transcontinental airplane with embedded distributed propulsion and outline foundational technology needs. The concept was to be configured for very low noise with the noise prediction to be conducted by another contractor. A review of past studies and related reports was conducted to determine the most suitable concepts for reducing take-off field lengths. Recent publications and internal Boeing investigations were used to conceive a potentially quiet STOL concept using embedded distributed propulsion. The Blended Wing Body (BWB) type of airplane was selected as the starting point since it is a cruise efficient and quiet airplane with large internal volume for embedding distributed engines The Boeing WingMOD multidisciplinary optimization code was used to develop a planform from which a 3D solid model was created. The Boeing Integrated Vehicle Design System (BIVDS) was then used for sizing and mission analyses. The foundational technologies needed for design for the 2025+ operational time frame were then outlined.

2.1 Review Related Report

A literature search for STOL Transports was conducted and reports selected from over 1000 titles from the Boeing Technical and AIAA Libraries. Selected reports were reviewed from which it was concluded that internally blown flap was the most efficient powered lift system for increasing C_L at low speeds.
The Breguet 941 deflected slipstream turboprop shown in figure 3 had good STOL capabilities and was used as an operational demonstrator by McDonnell-Douglas in the 1960s. Cruise speed was below

Prop Fans Developed for Cruise Efficiency at Mach 0.80

- **High TO noise**
- **Enroute noise**

GE36 on B727 and MD-80 in 1986-88

P&W/Allison 578DX on MD-80

Figure 4.—Ultra-high bypass ratio propulsors designed, built, and flight tested.

Mach 0.5 Other studies showed turboprop have a large thrust lapse with speed and altitude limited cruise speed to below Mach 0.70.

Following the energy crisis in the 1970s, the search for improving fuel efficiency led to NASA research determining that propellors could be designed for flight at Mach 0.80. This culminated in the engine companies developing experimental ultra high by-pass ratio unducted fans employing counter-rotating propfans.

Ultra high by-pass ratio propulsors designed, built and flight tested as shown in figure 4. They were fuel efficient however the complexity resulted in high recurring costs and concerns about maintenance cost. The blades had supersonic tip speeds resulting in high take-off noise, high cabin noise and noise that could be heard enroute. Studies were made optimizing for low noise predicting noise levels comparable to existing turbofans but not down to the level of lower noise turbofans today.

Numerous studies and investigations of turbofan powered STOL airplanes were conducted during the 1970s and 1980s leading into the Air Force prototype competition for the Advanced Medium STOL Transport (AMST). Investigations had show the most efficient powered lift system is the internally blown flap (IBF).

Figure 5 shows a comparison of lift coefficient at jet thrust coefficient of 2 where the thrust coefficient is thrust divided by freestream dynamic pressure times wing area. The internally blow flap and augmenter wing where flight tested. While efficient, they were judged to be complex and the winners in the AMST competition had selected simpler concepts without the hot ducting problems and issues of the IBF or the complexity of the augmenter wing.

The Boeing YC-14 used upper surface blowing while the McDonnell-Douglas YC-15 used the relatively simple externally blow flap (EBF). The prototypes shown in figure 6 had straight wings for which cruise speed was below Mach 0.70. In the following competition for a production program, the McDonnell-Douglas C-17 with the relatively simple EBF on a swept wing won. A factor was the Air Force requirements changed to a longer range strategic transport and engine availability was an issue requiring Boeing to go to more engines with a proposal for a trijet. Boeing later became the winner by merger.

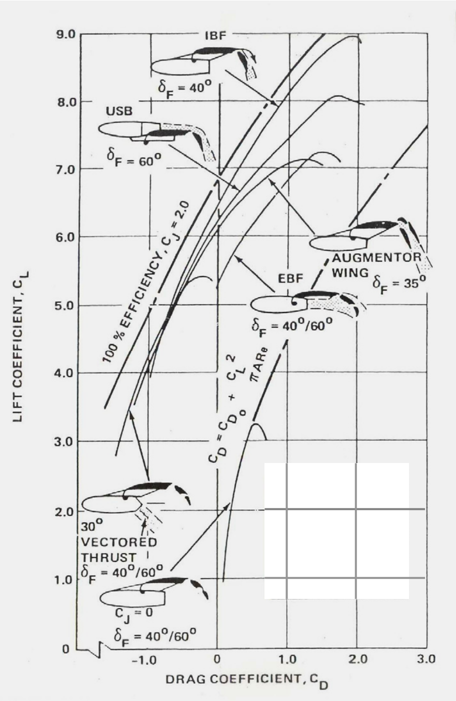


Figure 5.—Comparison of powered lift concepts.

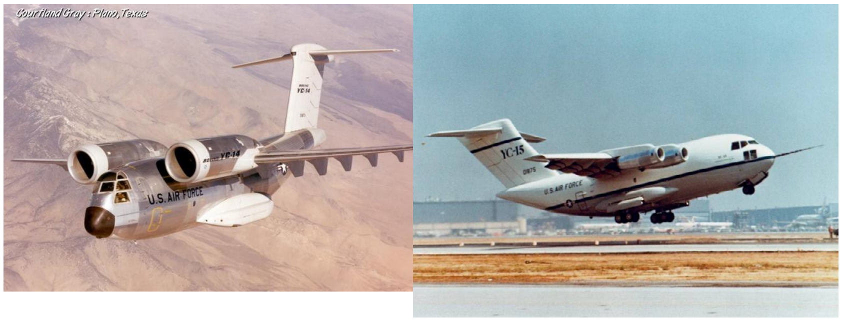


Figure 6.—Air Force AMST prototypes.

Figure 7.—Boeing C-17A.

The C-17 is shown in figure 7. First flight was Sept. 15, 1991 becoming the only successful large turbofan powered STOL transport in production. With a cruise speed of Mach 0.74 to 0.77 and a max payload range of 2750 nmi, it falls short of the speed and range selected for this study. While the EBF can meet Far 36 stage 3 noise levels, EBF is not the preferred concept for very low noise.

2.2 Establish Mission Requirements

The revolutionary airplane creation process is for a 2025+ time frame. As such, the mission requirements and technology levels are projections into the future based on extrapolation of trend curves. As previously shown in figure 1, air traffic growth extrapolations of current forecasts would predict a 4X growth beyond 2025. Again from reference 1, the projections are for growth in departures and city pairs.

As shown in figure 8, while frequency and city pair growth increases, the prediction is that average airplane size remains relatively constant with the 90 to 175 passenger size. Since many airports today are congested and gate limited, meeting air traffic demand will require increasing operations using other airport assets. Many airports have shorter field lengths than the major airports.

The US airfield distribution is shown in figure 9 which was used in reference 2. Use of transport aircraft at smaller airports should maintain a reasonable runway width to allow turnarounds and lateral dispersion for landing in cross wind. Setting a 100 foot minimum width at Civil airports reduces the total but there are still 973 of which 84 percent or 813 have runway lengths of 5,000 ft or longer.

Expansion of departures in inhabited areas will clearly require very low flyover noise.

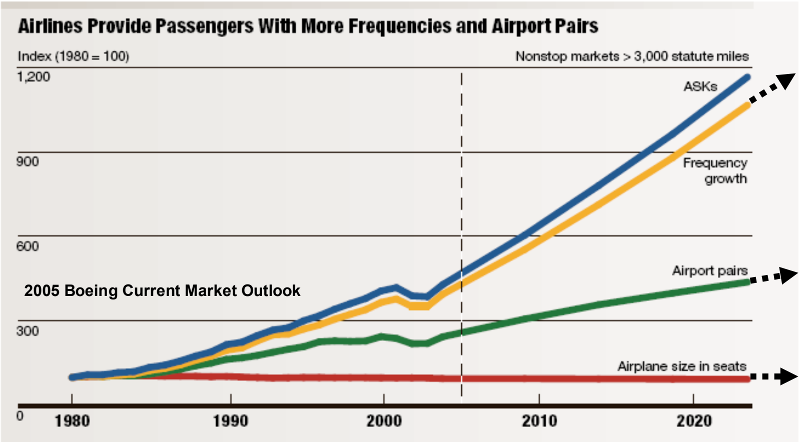
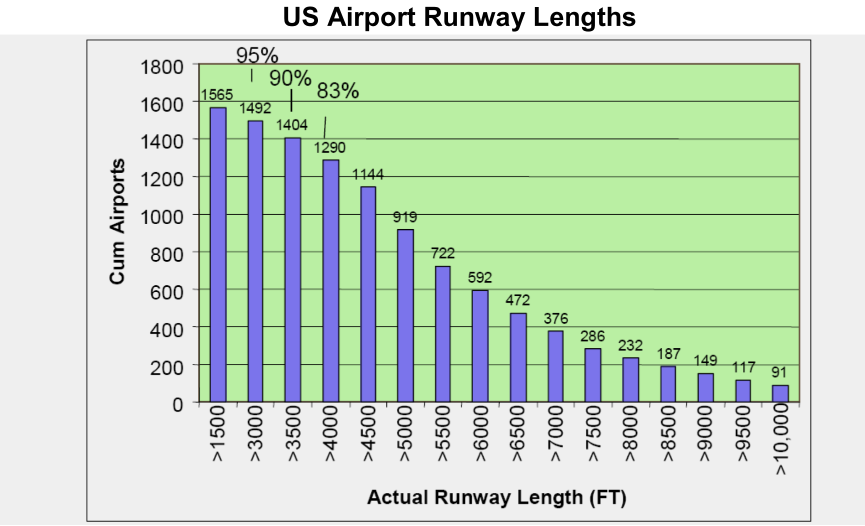


Figure 8.—Projected growth trends.



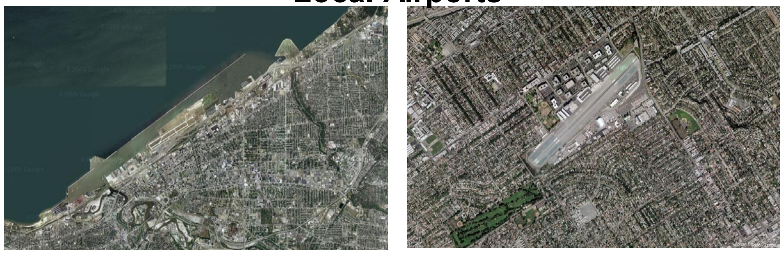
Constraining to Civil airports with a 100 ft width reduces total to 973 of which 84% or 813 have 5,000 ft + runways

Figure 9.—US airfield distribution.

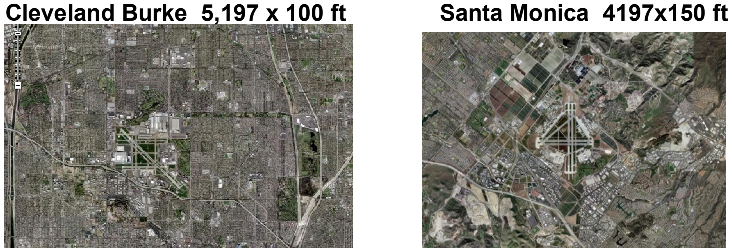
Figure 10 shows locations of some airports that offer convenience. Shorter runway airports such as Burke Lakefront in Cleveland, Ohio and Santa Monica, California could offer great convenience but are close or surrounded by inhabited areas and would require very low noise. Also to be noted is the landing and take-off measuring points in FAR 36 at 6,565 ft from the landing threshold and 21,325 ft from brake release are near 1 and 3 field lengths from a 5,000 ft runway into populated areas. Since Part 36 noise levels are based on TOGW and the neighborhood will be sensitive to noise regardless of the airplane gross weight, a maximum absolute noise level independent of gross weight should be considered. Other airports such as Long Beach, CA limit traffic growth. Long Beach limits airlines to 41 flights a day but this cap can be increased if quieter airplanes maintain the same total noise exposure. Also in Southern California, the El Toro marine base from which fighter jets operated was closed and attempts to use the base for commercial flights, including LAX airport attempt to purchase it to relieve congestion at LAX was denied.

Figure 11 shows the noise measurement locations for which STOL with a steeper approach and more rapid climb out would reduce the FAR 36 noise levels. The value of STOL then is important to reducing community noise footprints as much as being able to operate from regional and community airports.

Local Airports



Cleveland Burke 5,197 x 100 ft **Santa Monica 4197x150 ft**



Long Beach 41flts/day, 10-7 Curfew **El Toro Closure: Commercial Use Denied**

Figure 10.—Locations of some airports that offer convenience.

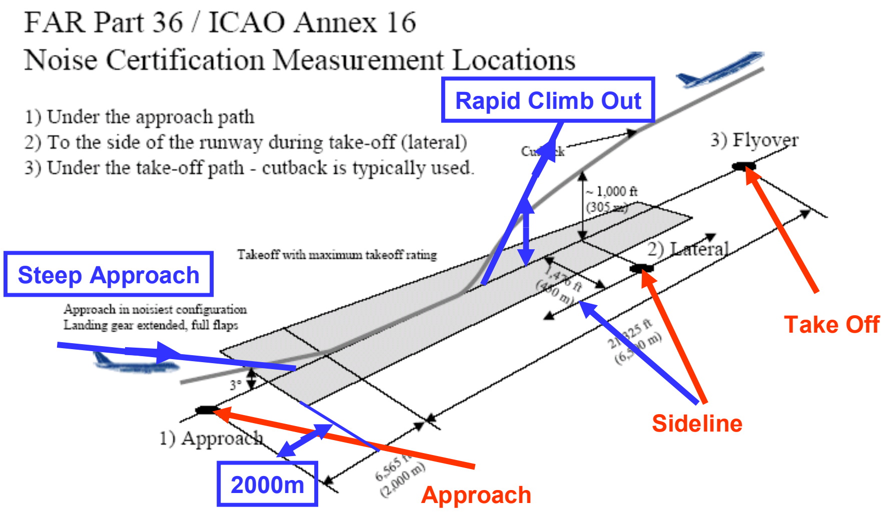


Figure 11.—STOL to reduce noise footprints.

- **Payload weight and volume to accommodate 170 pax (40,000 lb)**
- **3,000 nmi range**
- **Long range cruise speed at least Mach 0.8, 30,000 ft alt**
- **FAR Part 25 field length ≤ 5,000 ft w/critical engine inoperative**
- **Climb at Std +15C atmosphere**
- **Landing flare for passenger comfort.**

Figure 12.—Mission requirements.

Figure 13.—Blended wing body is a future 2025 concept for improved efficiency and lower noise.

The study mission requirements are listed in figure 12. The mission requirements were established as a payload weight and volume that would accommodate the higher end of the projected passenger size at 170. The range of 3,000 nmi was shown in reference 3 to enable travel from Seattle to any point in the 50 states with 85 percent annual winds and a 5 percent range factor. Similarly, any point in the continental U.S. from Boston or Miami and allow coverage of all intra Western Europe. Mach 0.8 at an altitude of at least 30,000 was selected for operation in traffic lanes with intermix using FAR rules and a hot day climb. Landing flare is also used to preclude hard landing with a 6° glide slope.

2.3 Create a New Concept With Embedded Distributed Propulsion

The starting point selected for this study was the Blended Wing Body (BWB) because the cruise efficiency, low noise characteristics and greater internal volume for embedded distributed engines.

Studies of the blended wing body, described in references 4 and 5 have been on going at Boeing providing a broad data and technology base for this study. As shown in figure 13, a current study version for a multi-role platform has low noise characteristics. The upper aft engine location provides forward noise shielding, no wing or horizontal tail aft downward noise reflecting surface, being flapless has no flap noise, low approach thrust noise because of a high approach L/D, and studies have shown the body suppresses flow velocities around the main landing gear reducing landing gear noise.

In addition to a review of reports, literature and internet information, internal Boeing concept studies were used to then asses how to conceive a revolutionary concept to provide a potential breakthrough for noise reduction. Other investigations such reported in references 6 and 7 and as on the websites of reference 8 and 9 for the Greener by Design and Silent Aircraft Initiative have identified the BWB has beneficial for forward noise shielding and no aft noise reflections. In general studies had concluded that the limiting factor for reducing flyover noise was jet noise and increasing by-pass ratio with geared fans was necessary. However, an internal Boeing BWB study conducted collaboratively with NASA LaRC identified that moving the engines forward, adapting rapid mixing nozzles, and moving the verticals inboard could be used to shield jet aft and sideline noise. The predicted noise reduction potential was a cum minus 52 dB from FAR 36 stage 3. Using embedded distributed propulsion was identified as a means to capitalize on this revolutionary concept to create a total engine noise shielded configuration. Further, since IBF was the most efficient powered lift system, adaptation using fan bleed as to hot high pressure compressor bleed avoided hot ducting issues and the lower pressure cold bleed should have low noise. The USB, while efficient, has the engines located forward with external scrubbing creating high internal cabin noise. At Mach 0.80 cruise, the fan exhaust pressure ratio will be supercritical resulting in supersonic scrubbing. The interior noise was measured in the YC-14 and is presented in reference 10. The peak interior sound pressure level was measured as 115 dB between 70 and 100 Hz. This low frequency noise would be very challenging to attenuate.

Geometric configuration studies were conducted to evolve a concept a very quiet powered lift concept with total engine noise shielding using embedded distributed propulsion. Initial studies identified limiting factors and the need for a very shore propulsion system for embedding was recognized. Propulsion envelope sizing was then done judgmentally based on related investigations and experience. Envelope contours for a short boundary layer ingesting offset diffuser was established from the investigations of references 11 and 12 and consultation with investigators at NASA GRC, NASA LaRC, Boeing Technology Phantom Works St. Louis working on boundary layer ingestion inlet flow control. The inlet diffuser length and offset is within what investigators have shown can meet an inlet DC60 distortion index of less than 0.05 with fixed vane vortex generators or pulsating active flow control.

Engine companies were consulted and studies had been made for lift fans and cruise fan versions of these revolutionary concepts. The cruise fan versions were shown to have over all engine length to diameter ratios within unity. This length criterion was thus used where the engine diameter is based on fan diameters for high by-pass ratio engines. The fan flow diverter for bleeding one-half of the fan flow during powered lift operation was based on thrust reverser design experience. The variable area nozzle could be similar to a semi circular section of those commonly used in fighters.

3.0 Results of Analysis

3.1 Initial Planform

To recap, the initial configuration was based on the BWB because of cruise efficiency and low noise characteristics with internal volume for integrating embedded distributed propulsion. The powered lift system selected because of the highest efficiency was the IBF. Distributed propulsion with aft engines would enable using fan bleed for low pressure cold air that would not have the hot duct issues and be subsonic to keep the powered lift noise down. The revolutionary concept is the use of distributed embedded propulsion for quiet IBF powered lift with total engine noise shielding, including jet noise shielding. The CESTOL concept combines total engine noise shielding with rapid climb out and steep descent to provide a very low noise footprint. While the noise is not presented here, a previous study for which Boeing provided the Very Quiet BWB concept for noise assessment by NASA Langley resulted in an estimated potential for a cum Stage 3 noise reduction of more than 50 dB. This was done by moving engine exhaust forward with rapid flow mixing nozzles to move the jet source noise forward to provide afterbody jet noise shielding and locating vertical tail surface mid span to provide sideline noise shielding.

The study was conducted using goal levels for 2025+ engines. Engine performance was based on projecting improvement in SFC into the 2025 time frame. Recognizing the challenges, the SFC for 2025 is used as a goal to have small engines SFC levels at current large engine levels.

SFC trends are shown in figure 14. The cruise SFC goal was set at 0.52 for Mach 0.80, 35,000 ft alt. Similarly, the engine thrust to weight ratio goal was set based on current large engines but reduced 20 percent for the revolutionary concepts that are very short. These data were used in the Boeing Phantom Works WingMOD multidisciplinary optimization code.

The WingMOD optimizer is outlined in figure 15. It uses a vortex lattice model with empirical adjustments and calibration with CFD and wind tunnel data for the BWB.

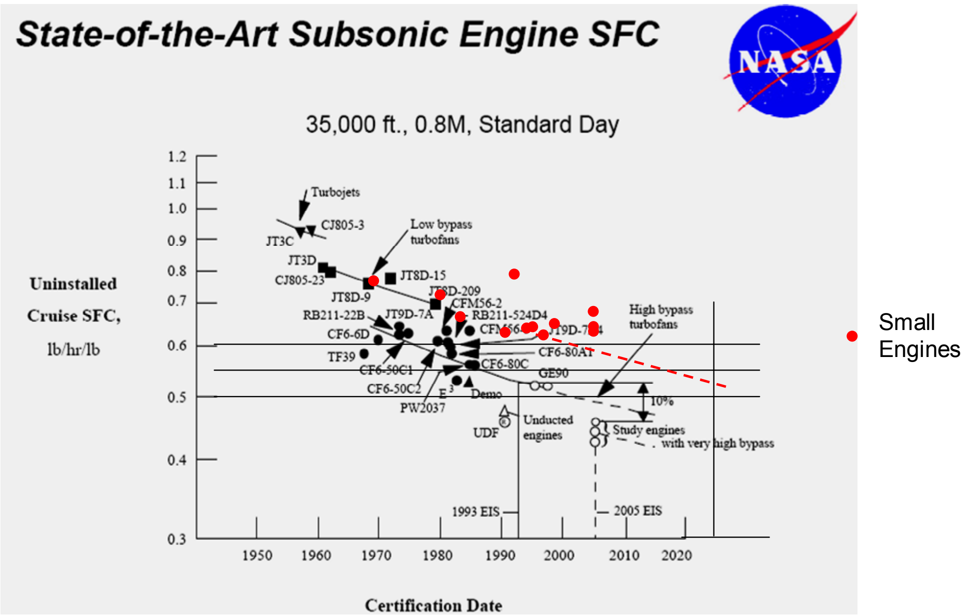

State-of-the-Art Subsonic Engine SFC

Figure 14.—SFC trends.

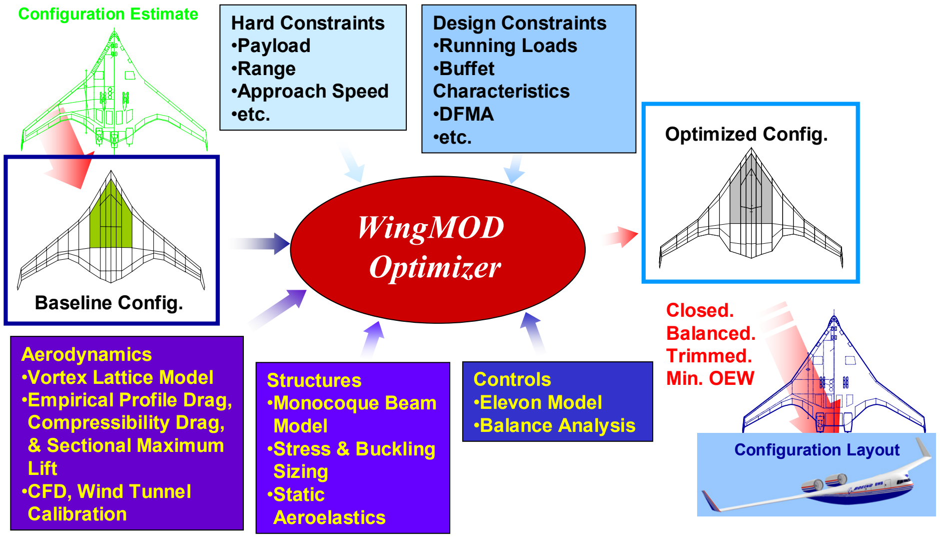

WingMOD: Multidisciplinary Optimization

Figure 15.—The WingMOD optimizer.

A starting point configuration shown in figure 16 was defined using the CFE738 engine. It was quickly determined that the propulsion system length for embedded engines was driving the length of the wing chord resulting in excessively large wings. A more aggressive technologies were needed and as described above after consultation with engine companies, the use of “square” engines with a length to fan diameter of one used. The engine centerline was also canted to reduce the inlet diffusion. 100 optimizer iterations were made to develop a planform controllable in pitch.

The final WingMOD planform is shown in figure 17.

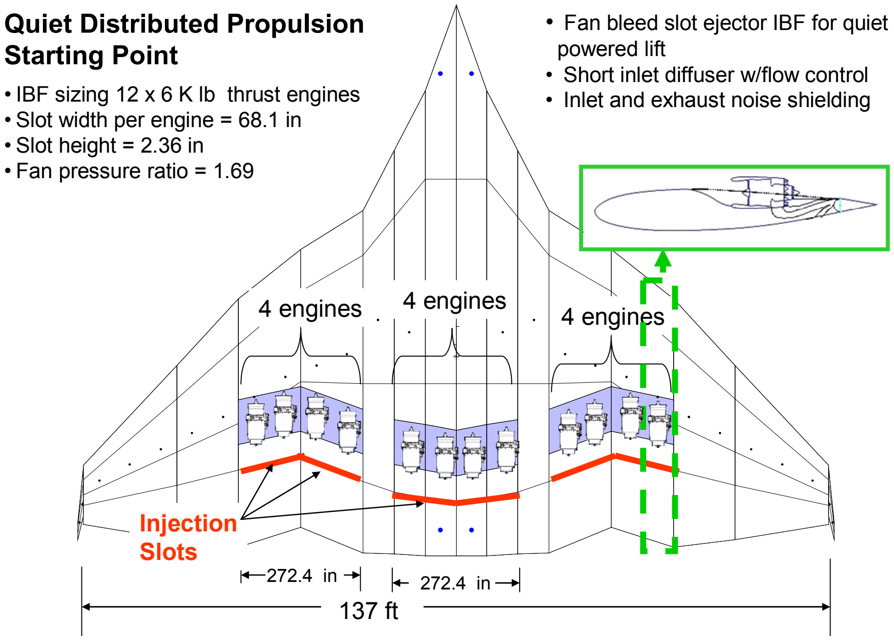


Figure 16.—Starting point configuration.

Property	Value
Max Takeoff Weight (lb)	208,900
Max Landing Weight (lb)	160,006
Operating Empty Weight (lb)	100,046
Design Payload (lb)	39,957
Design Fuel (lb)	68,897
Ballast (lb)	1,357
Property	Value
Number of Engines	12
Engine SLS Thrust (lb)	4,973
Design Range (nm)	3,000
Takeoff Field Length (ft)	5,000
Rotation Speed (kn)	110
Approach Speed (kn)	111

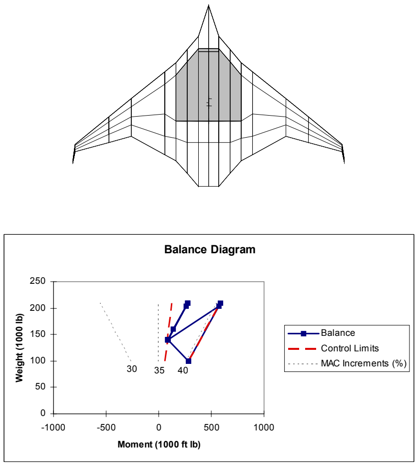
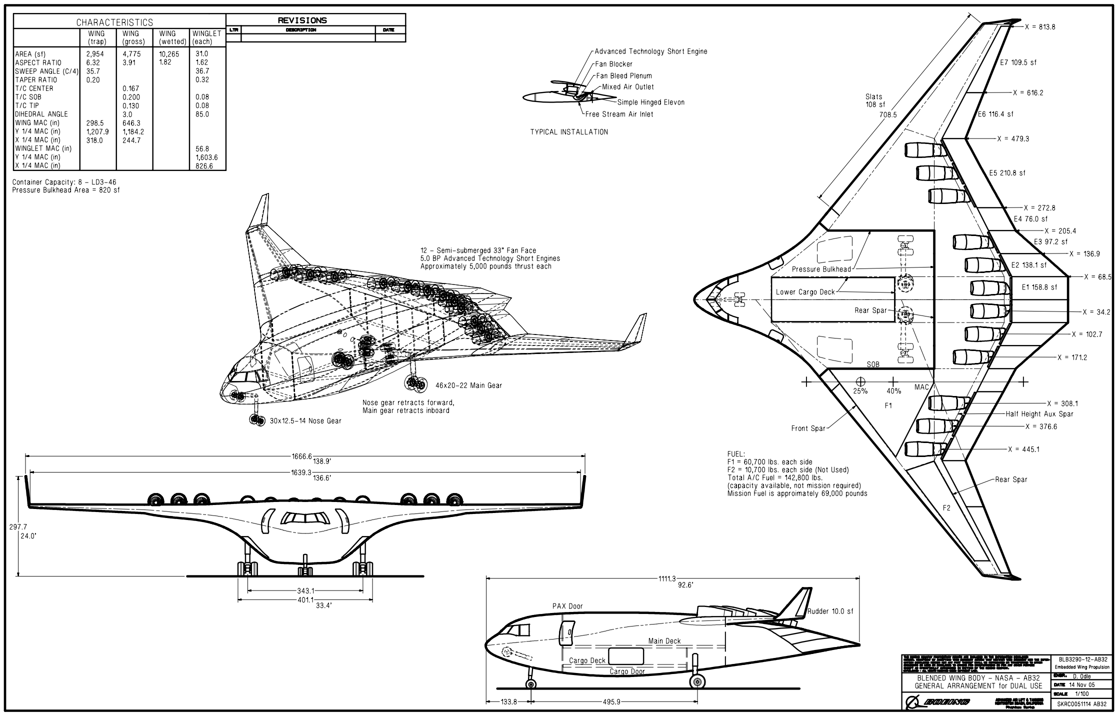


Figure 17.—CESTOL configuration from WingMOD.

3.2 Configuration Development

The WingMOD planform was then used to create a 3D model incorporating normal airplane configuration requirements. The 3 view drawing is shown in figure 18. This configuration was then used in the Advanced Design Boeing Integrated Vehicle Design System.

The BIVDS process is shown in figure 19. A drag build up and mass properties for the configuration is developed. The powered lift increment was from NASA data for C_L versus C_μ. The engine performance model data was provided by NASA GRC.



CHARACTERISTICS	WING (trap)	WING (gross)	WING (wetted)	WINGLET (each)
AREA (sf)	2,954	4,775	10,265	31.0
ASPECT RATIO	6.32	3.91	1.82	1.62
SWEEP ANGLE (C/4)	35.7			36.7
TAPER RATIO	0.20			0.32
T/C CENTER		0.167		
T/C SOB		0.200		0.08
T/C TIP		0.130		0.08
DIHEDRAL ANGLE		3.0		85.0
WING MAC (in)	298.5	646.3		
Y 1/4 MAC (in)	1,207.9	1,184.2		
X 1/4 MAC (in)	318.0	244.7		
WINGLET MAC (in)				56.8
Y 1/4 MAC (in)				1,603.6
X 1/4 MAC (in)				826.6

REVISIONS		
LTR	DESCRIPTION	DATE

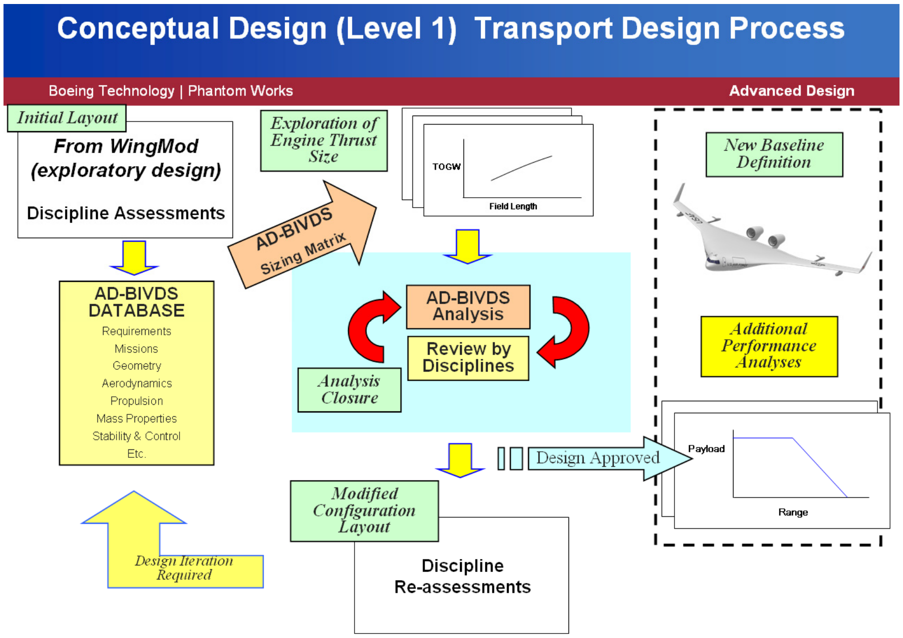
Container Capacity: 8 – LD3-46
Pressure Bulkhead Area = 820 sf

FUEL:
F1 = 60,700 lbs. each side
F2 = 10,700 lbs. each side (Not Used)
Total A/C Fuel = 142,800 lbs.
(capacity available, not mission required)
Mission Fuel is approimately 69,000 pounds

BLENDED WING BODY – NASA – AB32
GENERAL ARRANGEMENT for DUAL USE

BLB3290-12-AB32
Embedded Wing Propulsion
ENGR. D. Odle
DATE 14 Nov 05
SCALE 1/100
SKRC0051114 AB32

Figure 18.—NASA CESTOL configuration drawing.



Conceptual Design (Level 1) Transport Design Process

Boeing Technology | Phantom Works

Advanced Design

Initial Layout

From WingMod (exploratory design)

Discipline Assessments

AD-BIVDS DATABASE
- Requirements
- Missions
- Geometry
- Aerodynamics
- Propulsion
- Mass Properties
- Stability & Control
- Etc.

Design Iteration Required

Exploration of Engine Thrust Size

AD-BIVDS Sizing Matrix

AD-BIVDS Analysis

Review by Disciplines

Analysis Closure

Design Approved

Modified Configuration Layout

Discipline Re-assessments

New Baseline Definition

Additional Performance Analyses

Figure 19.—The BIVDS process.

	EWP Design	500 nm	150 nm
Range (nm)	3,000	500	150
Payload (lb)	40,000	40,000	40,000
Takeoff Gross Weight (lb)	189,140	157,874	152,835
Landing Weight (lb)	152,548	151,052	150,866
Total Fuel (lb)	44,098	12,832	8,793
Block Fuel (lb)	37,723	7,946	4,098
Block Time (h)	6.92	1.48	0.68
Initial Cruise Altitude (ft)	39,000	43,000	31,000
Takeoff Field Length (ft)	2,452	1,772	1,694
Landing Field Length (ft)	3,477	3,457	3,454
Takeoff C_{Lmax} Liftoff	1.66	1.80	1.83
Takeoff C_{Lmax} Obstacle	1.57	1.65	1.66
Landing C_{Lmax}	1.06	1.06	1.06

Figure 20.—BIVDS evaluation and mission performance.

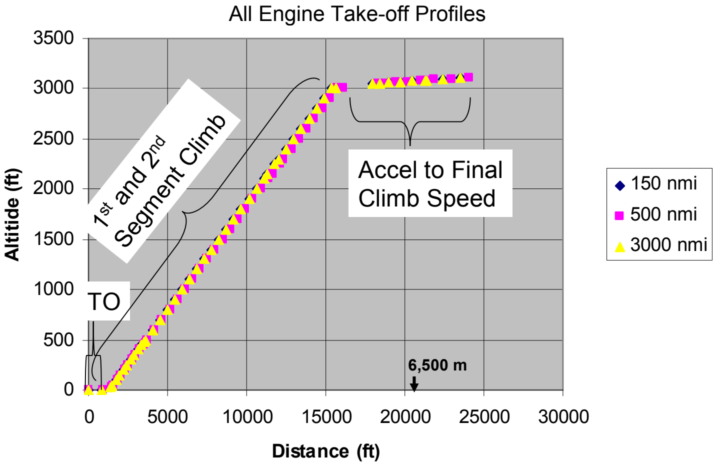


Figure 21.—Take-off flight profiles.

3.3 Mission Performance

The sizing and mission performance from BIVDS is shown in figure 20. The take-off field length is the actual for obstacle clearance with all engine operating. The engine out length would also be longer. Note that the landing field length is 3,500 ft which includes the 1.67 factor on stopping distance. Therefore, 3,500 ft would be the operating field length for the configuration defined. It is believed that use of the variable area nozzle for improved powered lift during approach would enable shortening the field length.

The take-off flight profiles are shown in figure 21 for the 3 ranges. The BIVDS performance was based on no power cut back and flap retraction and clean up at 3,000 ft. For minimum noise, depending on the footprint characteristics desired, other schedules can be used.

4.0 Discussion of Results

The CESTOL concept created has very low noise features (fig. 22). The embedded distributed propulsion enables use of low pressure fan bleed for an IBF system for STOL while keeping the powered lift noise down. The STOL capability then offers rapid climb and descent to reduce noise footprints. The

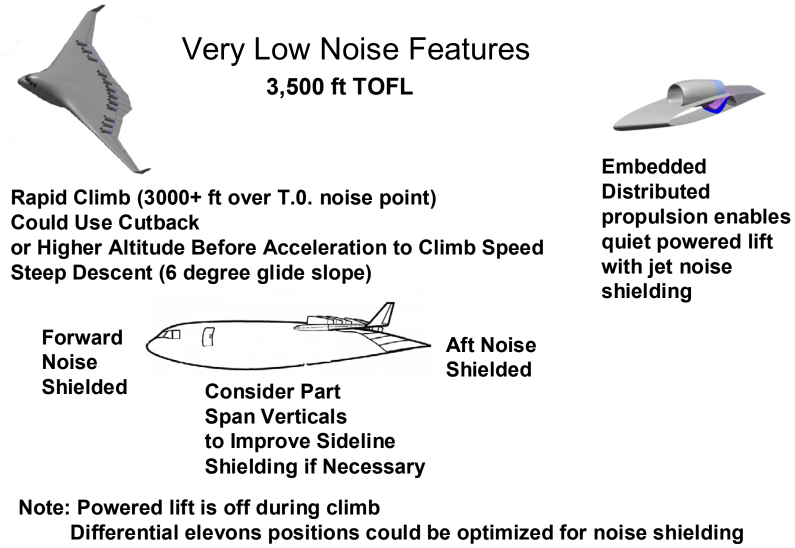


Figure 22.—The CESTOL concept created has very low noise features.

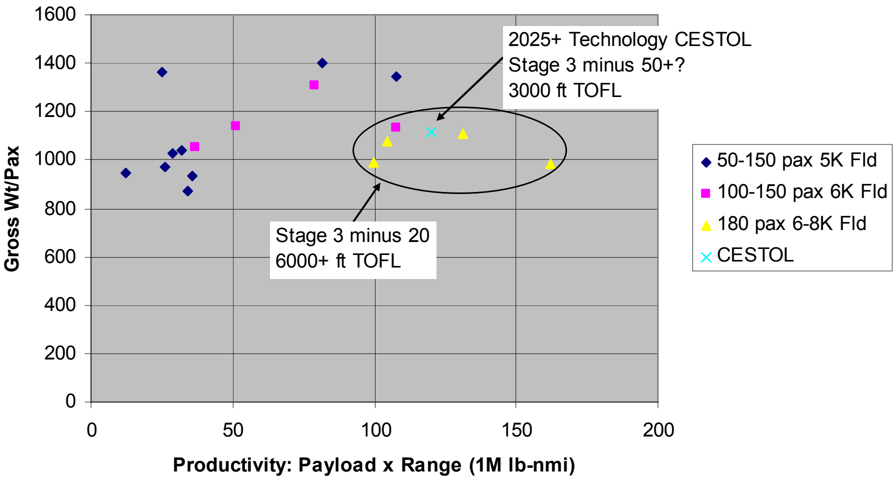


Figure 23.—CESTOL comparison to current aircraft in productivity.

smaller diameter engines have forward noise shielding and employ mixer nozzles to increase the jet noise frequency and move the jet noise source forward. The forward jet source noise can then be shielded by airframe surfaces to reduce aft and sideline noise. If deemed beneficial, the vertical control surfaces can also be positioned and sized to further reduce sideline noise.

Figure 23 shows how the CESTOL compares with current aircraft in productivity. The gross weight per passenger for the same payload time range is seen to be competitive with current aircraft however current aircraft do not have the short field or low noise features. Aggressive foundational technologies will be needed to have a new airplane in the 2025+ time period possible to meet noise in infra structure needs for projected future air traffic demand.

Foundational technologies needed are depicted in figure 24. These technologies are needed to enable design and evaluation of highly noise shielded configurations and sizing systems for quiet powered lift using low pressure fan air. The noise shielding also provides passive IR shielding against ground launched heat seeking missiles for which the media has reported a million have been produced and several attempts by terrorists to acquire them have been reported. Foundational technologies would thus be dual use for military platforms.

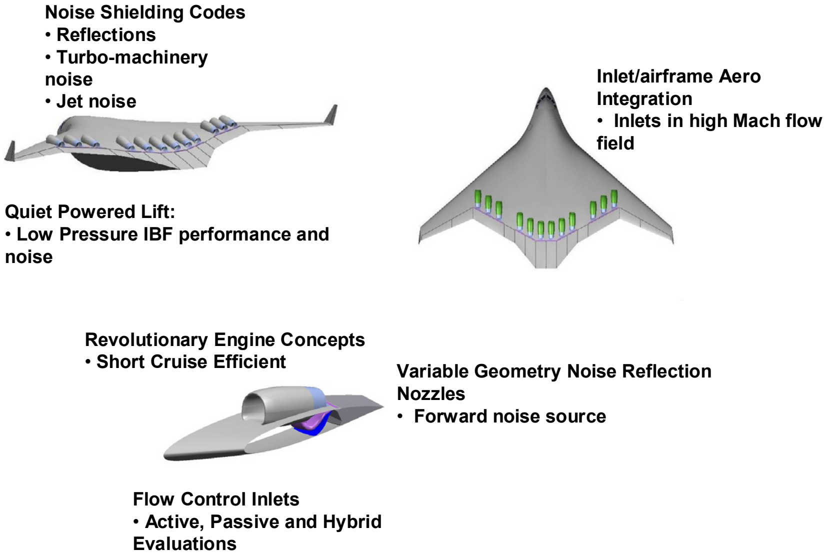


Figure 24.—Foundational technologies needed.

Continuing growth in air travel demand is forecast. This growth is expected to increase daily departures operating from an increasing number of city pairs.

This growth is forecast to go with increasing GDP providing a need for very quiet airplane operating from regional airports which can have current economics

Studies have shown eliminating noise reflections while providing noise shielding can significantly reduce flyover noise

Extending these principals to jet noise source downstream in the exhaust wake should provide more dramatic noise reductions

Large surface area planforms such as the BWB provides opportunities for increased source noise shielding

Embedded distributed propulsion offers the potential for quiet powered lift with jet noise shielding for small noise footprints operating from regional airports

Configuration studies were made to evolve a BWB STOL planform that is trimmable with total noise shielding

Low noise footprints would also have low IR footprints for passive protection from terrorists

Development of foundational technologies are needed that would be generic and dual use

Figure 25.—Conclusions.

5.0 Conclusions

The conclusions are summarized in figure 25.

This was a conceptual study embodying features that should enable quiet STOL for traffic expansion in the 2025+ time frame. Basic aero-propulsion and acoustic technologies are needed. It is difficult to imagine with current airport congestion and growing noise restrictions how a multiple growth factor can occur without such a revolutionary concept.

Appendix—Symbols

ASKs	Available Seat Kilometers
alt	Altitude
AMST	Advanced Medium STOL Transport
BIVDS	Boeing Integrated Vehicle Design System
BPR	Bypass Ratio
BWB	Blended Wing Body Aircraft
dB	Decibel
C	Centigrade
CFD	Computational fluid dynamics
C_L	Lift Coefficient
C_μ	Thrust Coefficient
EBF	Externally Blown Flap
FAR	Federal Air Regulations
ft	Feet
GDP	Gross Domestic Products
GRC	(NASA) Glenn Research Center
Hz	Hertz
IBF	Internally Blown Flap
IR	Infra Red
kts	nautical miles per hour
LaRC	(NASA) Langley Research Center
lb	pound
L/D	Lift to Drag ratio
M	Mach number
MTOW	Maximum Take-Off Weight
NASA	National Aeronautics and Space Administration (USA)
nmi	Nautical mile
pax	passengers
RASER	Revolutionary Aero-Space Engine Research
RSCA	Revolutionary System Concepts for Aeronautics
SFC	Specific Fuel Consumption
SLST	Sea Level Static Thrust
std	Standard
STOL	Short Take-Off and Landing
TOFL	Take-Off Field Length
TOGW	Take-Off Gross Weight
WingMOD	Boeing multi-interdisciplinary optimization code

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This NASA funded study conceived a revolutionary airplane concept to enable future traffic growth by using regional air space. This requires a very quiet airplane with STOL capability. Starting with a Blended Wing Body that is cruise efficient with inherent low noise characteristics from forward noise shielding and void of aft downward noise reflections, integration of embedded distributed propulsion enables incorporation of the revolutionary concept for jet noise shielding. Embedded distributed propulsion also enables incorporation of a fan bleed internally blown flap for quiet powered lift. The powered lift provides STOL capability for operation at regional airports with rapid take-off and descent to further reduce flyover noise. This study focused on configuring the total engine noise shielding STOL concept with a BWB airplane using the Boeing Phantom Works WingMOD multidisciplinary optimization code to define a planform that is pitch controllable. The configuration was then sized and mission data developed to enable NASA to assess the flyover and sideline noise. The foundational technologies needed are identified including military dual use benefits.

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