Status of Research and Development of the Hybrid Wing Body (HWB) Aircraft Concept

UTIAS Aviation and Climate Change Workshop

May 19, 2021

Presented by: Fayette Collier, Ph.D.

Part 1 - Introduction

The role of NASA and other global research organizations is to fill the technology pipeline to meet the needs of society (flyers and non flyers) in anticipation of driving market and regulatory and public and environmental SHIFTS

Airlines and OEMs are STILL Extracting Value from Conventional Tube and Wing

The incumbent configuration is dominant!

- For how much longer?
- How much more value is left?
- Will a shift to an alternate configuration occur?
- What forces will drive the shift?
- With the global pandemic, are we closer or farther to/from a shift?
- With climate change, are we closer or farther to/from a shift?

What forces are driving global research organizations to mature alternate configurations?

Anticipation of the incumbent tube and wing (TAW) reaching “performance” and capability and market limits, including extreme pressure to mitigate environmental impact!

- Carbon footprint
- Community noise footprint
- LTO NOx and particulate emissions
- Cost and rate of manufacture
- Passenger comfort (or lack thereof) and passenger acceptance
- Emerging alternative fuels and/or energy storage and/or propulsion/airframe integration concepts
- Operating costs (TAROC and CAROC and DOC+I)
- Rapidly growing cargo market

ALL of the above!

What alternative aircraft concepts are being investigated in response to drivers?

- Double Bubble Boundary Layer Ingestion (aka, the MIT/Aurora D8)
- Hybrid Wing Body (too numerous to list all)
  - Airbus
  - Boeing
  - China
  - DZYNE (Ascent 1000)
  - France (ONERA), Germany (DLR), England (Cranfield)
  - Lockheed
  - NASA
  - Russia
  - TU Delft/KLM (Blended Wing Body and Flying V concepts)
  - US Air Force
- Transonic Truss Braced Wing (Pfenninger/NASA/Boeing)
- Wright One All Electric Boundary Layer Ingestion (Wright Electric)
- Others

Chinese Journal of Aeronautics, (2019), 32(8): 1797–1827

Chinese Society of Aeronautics and Astronautics & Beihang University
Chinese Journal of Aeronautics
www.sciencedirect.com

Assessment on critical technologies for conceptual design of blended-wing-body civil aircraft

Zhenli CHEN[a,*], Minghui ZHANG[a], Yingchun CHEN[a,b], Weimin SANG[a], Zhaoguang TAN[b], Dong LI[a], Binqian ZHANG[a]

[a] School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China
[b] Shanghai Aircraft Design and Research Institute, Commercial Aircraft Corporation of China Ltd, Shanghai 201210, China

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KEYWORDS
Aerodynamic design;
Blended-wing-body;
Propulsion Airframe Integration;
Stability and control;
Structure

Abstract Civil aviation faces great challenges because of its robust projected future growth and potential adverse environmental effects. The classical Tube-And-Wing (TAW) configuration following the Cayley's design principles has been optimized to the architecture's limit, which can hardly satisfy the further requirements on green aviation. By past decades' investigations the Blended-Wing-Body (BWB) concept has emerged as a potential solution, which can simultaneously fulfill metrics of noise, emission and fuel burn. The purpose of the present work is to analyze the developments of critical technologies for BWB conceptual design from a historical perspective of technology progress. It was found that the high aerodynamic efficiency of BWB aircraft can be well scaled by the mean aerodynamic chord and wetted aspect ratio, and should be realized with the trade-offs among stability and control and low-speed performance. The structure concepts of non-cylinder pressurized cabin are of high risks on weight prediction and weight penalty. A static stability criterion is recommended and further clear and adequate criteria are required by the evaluations of flying and handling qualities. The difficulties of propulsion and airframe integration are analyzed. The energy to revenue work ratios of well-developed BWB configurations are compared, which are 31.5% and 40% better than that of TAW, using state-of-art engine technology and future engine technology, respectively. Finally, further study aspects are advocated.

* Corresponding author.
E-mail address: (Z. CHEN).
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1. Introduction

Rapid increasing demands of civil aviation are driven by the high-speed transport requirements of growing middle class, global economic growth and urbanization.[1] With growing urbanization, there is a greater demand to connect the world's cities. Since 1990, air transportation has grown at a fast

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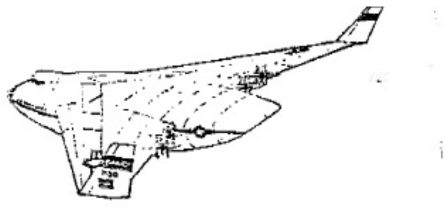
Why all the focus on the Hybrid Wing Body?



Vehicle Applications Panel Group E
National Research Council (NRC) Report on
Transport Technology
Memo to NASA (1984)

Bushnell's Subsonic Transport Aerodynamics
Renaissance Challenge Workshop (1989)

Transport Aircraft

Comparative Aerodynamic Possibilities

	Cruise Lift-to-Drag Ratio (L/D)	
Configuration	All Turbulent	with Laminar Flow
Current Conventional	19	
Advanced Conventional	21	23
Blended Wing Body	24	33
Strut-Braced Wings	28	45 (turbulent fuselage) 70 (all laminar)

Potential Impacts of Adv. Aero Tech on Air
Transportation System Productivity
(NASA TM-109154-1994)

AIAA A02-13493

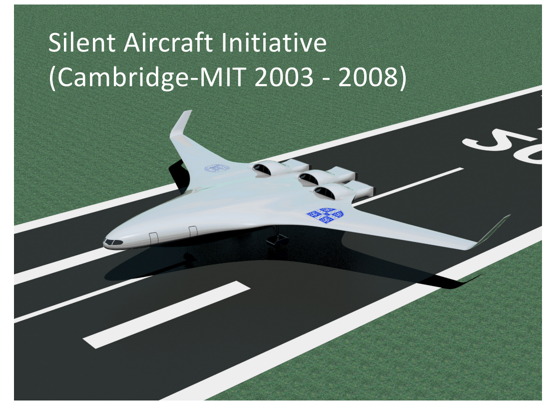
AIAA-2002-0002

Design of the Blended-Wing-Body Subsonic Transport

R. Liebeck
The Boeing Company
Long Beach, CA

40th AIAA Aerospace Sciences
Meeting & Exhibit
14-17 January 2002 / Reno, NV

Liebeck – AIAA Wright Brothers Lecture (2002)



- **149 passenger-miles per UK gallon of fuel**
- **Noise of 63 dBA outside airport perimeter**
- **http://silentaircraft.org/downloads**

<u>Themes Compared to TAW</u>
Lower wetted area
Higher cruise L/D
Low noise
Volumetrically efficient

Why all the focus on the Hybrid Wing Body?

Advantages	Contributing Design Feature
Carbon Footprint Reduction	
- Lower skin friction drag	- reduction of wetted area
- Trim drag during cruise can be avoided	- relaxed stability in pitch
- Interference drag reduction	- smooth transition of wing to center body
- Lift-induced drag reduction	- lifting body and improved spanwise lift distribution
- Wave drag reduction at high transonic speed	- better area-ruled shape
- Simplified high-lift devices	- reduced wing loading
- Wing weight reduction	- reduced wing loading
- Better high-altitude buffet margin	- reduced wing loading
- Local relief of aerodynamic loading	- reduced bending and shear loads on the structure
Community Noise Reduction	
- Greater noise shielding outside cabin	- optimized upper center body engine integration
Cost Reduction	
- Reduction in part count/manufacturing costs	- simplicity of the configuration

We began to realize that HWB Configurations may simultaneously SOLVE both carbon and noise footprint challenges!

Challenges associated w/Hybrid Wing Body

Advantages	Design Feature Challenges
Carbon Footprint Reduction	
- Lower skin friction drag	- may have weight penalty due to pressurized non-circular fuselage
- Trim drag during cruise can be avoided	- may have flying and handling quality issues
- Interference drag reduction	- may have recovery capability issues
- Lift-induced drag reduction	- may have less passenger comfort and acceptability (few windows)
- Wave drag reduction at high transonic speed	- may not be able to meet evacuation requirements
- Simplified high-lift devices	- may be sensitive to gust loads
- Wing weight reduction	- may be sensitive to gust loads
- Better high-altitude buffet margin	- may be sensitive to gust loads
- Local relief of aerodynamic loading	- may have issues with integration with airport
Community Noise Reduction	
- Greater noise shielding outside cabin	- may have degraded repairability due to upper body engine placement
Cost Reduction	
- Reduction in part count/manufacturing costs	- may be inconsistent w/family-oriented manufacturing concept

To achieve the potential of HWB, however, much work was (and still is) needed!

Part 2 – Mitigations and Confirmations

The role of NASA and other global research organizations is to fill the technology pipeline to meet the needs of society (flyers and non flyers) in anticipation of driving market and regulatory and public and environmental SHIFTS

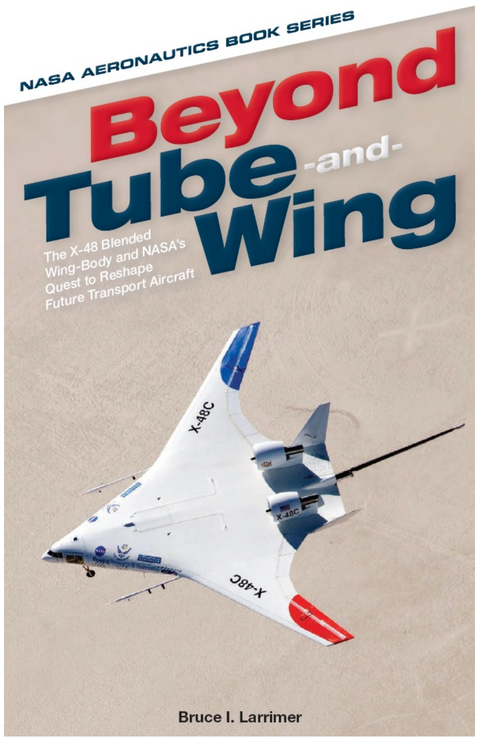
From 2005 to 2008, the need for sustainable aviation concepts in the US and the rest of the world reached a boiling point

NASA's Response – Transition promising technology from the enduring Subsonic Fixed Wing Project (now AATT) and Focus on technology maturation to enable Advanced Aircraft Concepts that mitigates aviation's impact on the environment

Part 2a – Mitigations and Confirmations

Challenge - The HWB may have flying and handling quality issues and may have recovery capability issues

Solution – Low-Speed HWB Ground and Flight Demonstrations – an 8-year RDTE campaign



<u>Campaign Objectives</u>

Assess stability & control characteristics of a HWB class vehicle in freeflight conditions:

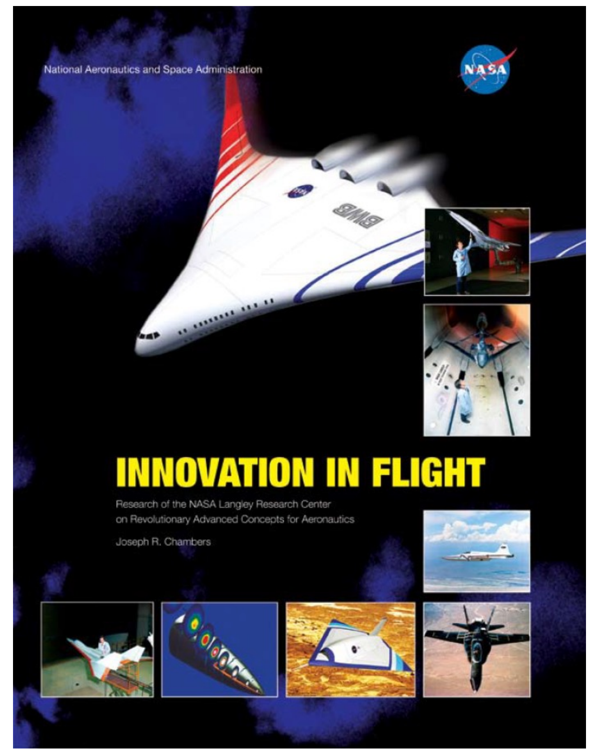
- Assess dynamic interaction of control surfaces
- Assess control requirements to accommodate asymmetric thrust
- Assess stability and controllability about each axis at a range of flight conditions

Assess flight control algorithms designed to provide desired flight characteristics:

- Assess control surface allocation and blending
- Assess edge of envelope protection schemes
- Assess takeoff and landing characteristics
- Test experimental control laws and control design methods

Evaluate prediction and test methods for HWB class vehicles:

- Correlate flight measurements with ground-based predictions and measurements

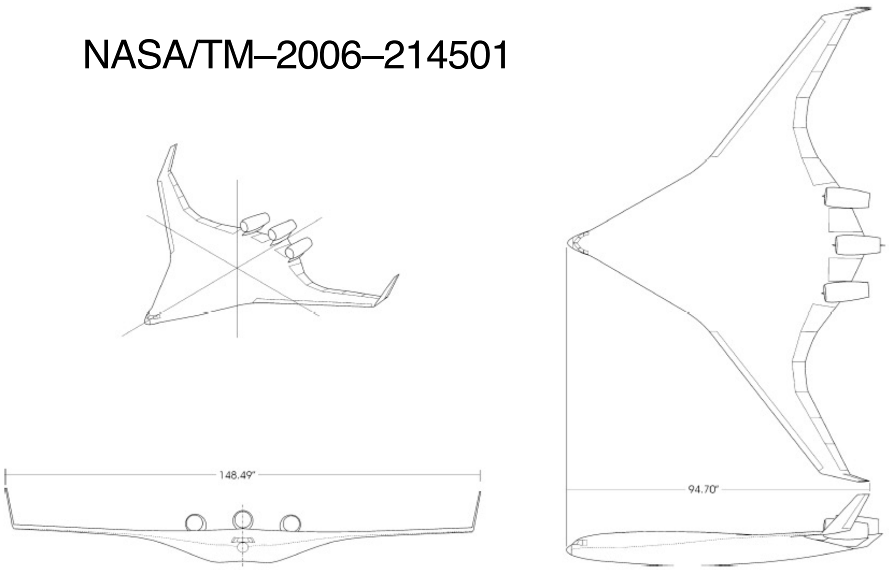


Part 2a – Mitigations and Confirmations

Challenge - The HWB may have flying and handling quality issues and may have recovery capability issues

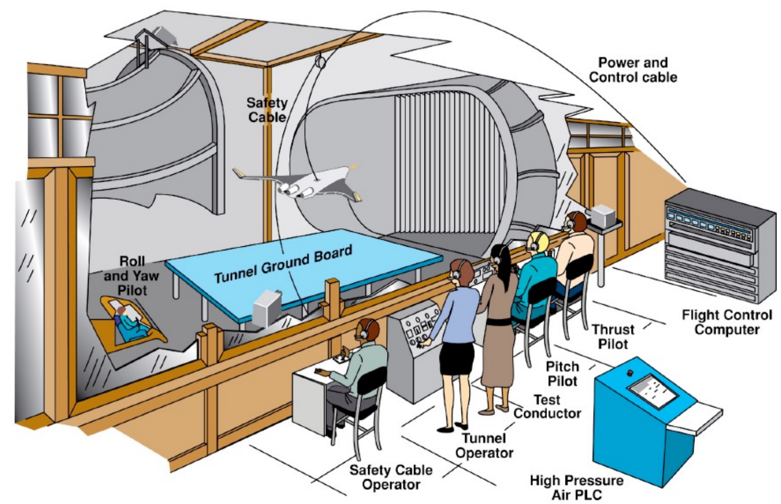
Solution – Low-Speed HWB Ground and Flight Demonstrations – an 8-year RDTE campaign

NASA/TM–2006–214501



HWB 5% Free Flight Wind Tunnel Model

This paper documents the control laws used in the free-flight tests of a 5% scaled blended-wing-body aircraft in the NASA Langley 30x60 Full-Scale Tunnel, conducted in the summer of 2005.



Free Flight Test Configuration of the 30x60 Full-Scale Wind Tunnel

The control laws described in this report, with the gain settings and schedules described herein, could be refined with additional testing. However, the pilots have indicated that the closed-loop vehicle flown during these tests was stable and controllable in all axes.

Part 2a – Mitigations and Confirmations

Challenge - The HWB may have flying and handling quality issues and may have recovery capability issues

Solution – Low-Speed HWB Ground and Flight Demonstrations – an 8-year RDTE campaign

ED06-0070-1

Researchers at NASA's Langley Research Center in Hampton, VA, tested the a 21-foot wingspan 8.5 percent scale prototype of a blended wing body aircraft in Langley's historic full-scale wind tunnel. Boeing Phantom Works partnered with NASA and the Air Force Research Laboratory to study the structural, aerodynamic, and operational advantages of the advanced aircraft concept, a cross between a conventional plane and a flying wing design.

The Air Force designated the prototype the X-48B based on its interest in the design's potential as a multi-role, long-range, high-capacity military transport aircraft. A second X-48B blended-wing body prototype arrived at NASA Dryden Flight Research Center in May, and after installation of test instrumentation and extensive checkout, began flight tests later that year.

May 2006

Note: Cranfield Aerospace constructed both X-48 vehicles and supported ground and flight tests. Was recognized with the prestigious RAeS Silver Award

HWB X-48B in the NASA/ODU Full Scale 30x60 ft Wind Tunnel

Part 2a – Mitigations and Confirmations

Challenge - The HWB may have flying and handling quality issues and may have recovery capability issues

Solution – Low-Speed HWB Ground and Flight Demonstrations – an 8-year	RDTE campaign

HWB X-48B Low Speed Flying Demonstrator on Lake Bed

This X-48B and C series of low-speed ground and flights (130 flight test sorties) yielded pilot comfort with the aircraft concept

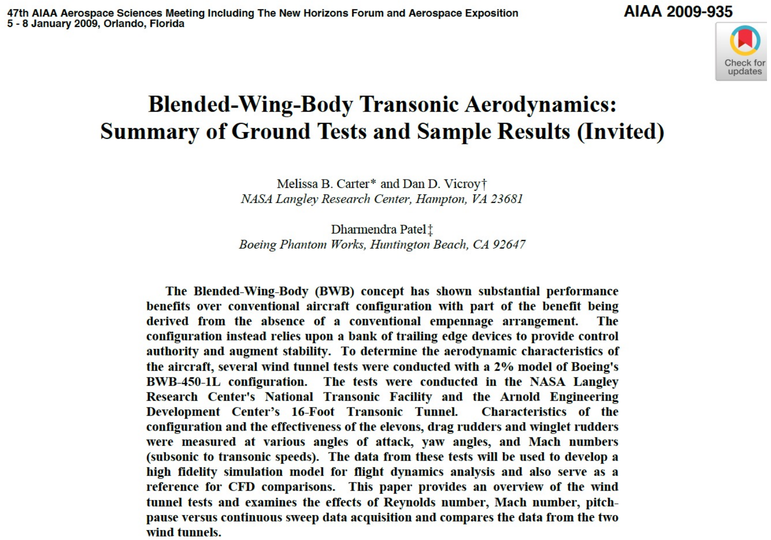
HWB X-48C Low Speed Flying Demonstrator in Flight

This series of low-speed ground and flight test results retired much S&C risk, allowing control law iterations

Part 2b – Mitigations and Confirmations

Challenge - The HWB may have flying and handling quality issues and may have recovery capability issues

Solution – High-Speed HWB Ground Demonstrations – Multi-year Simulator, NTF, AEDC 16T RDTE Campaign



47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition
5 - 8 January 2009, Orlando, Florida

AIAA 2009-935

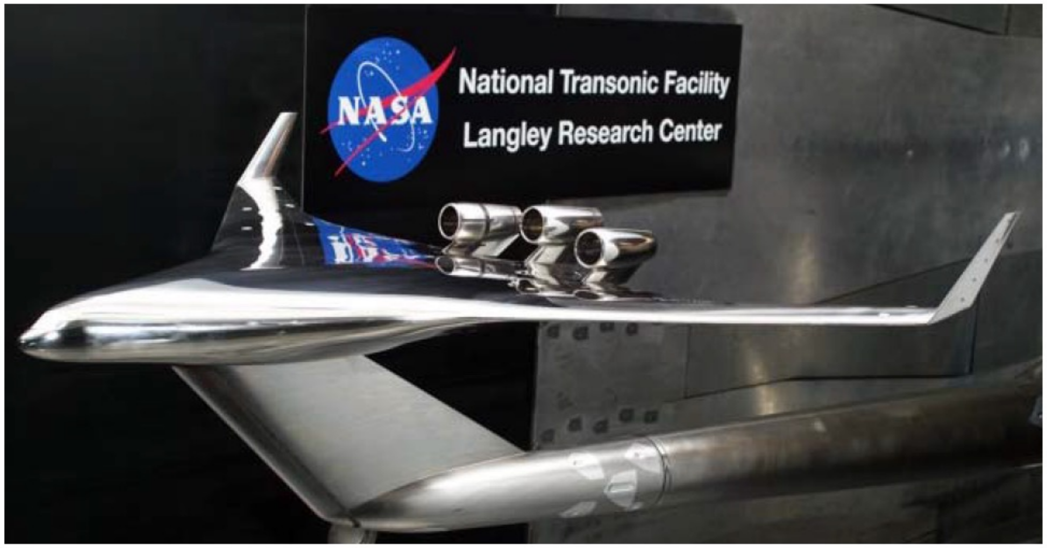
Blended-Wing-Body Transonic Aerodynamics: Summary of Ground Tests and Sample Results (Invited)

Melissa B. Carter* and Dan D. Vicroy†
NASA Langley Research Center, Hampton, VA 23681

Dharmendra Patel‡
Boeing Phantom Works, Huntington Beach, CA 92647

The Blended-Wing-Body (BWB) concept has shown substantial performance benefits over conventional aircraft configuration with part of the benefit being derived from the absence of a conventional empennage arrangement. The configuration instead relies upon a bank of trailing edge devices to provide control authority and augment stability. To determine the aerodynamic characteristics of the aircraft, several wind tunnel tests were conducted with a 2% model of Boeing's BWB-450-1L configuration. The tests were conducted in the NASA Langley Research Center's National Transonic Facility and the Arnold Engineering Development Center's 16-Foot Transonic Tunnel. Characteristics of the configuration and the effectiveness of the elevons, drag rudders and winglet rudders were measured at various angles of attack, yaw angles, and Mach numbers (subsonic to transonic speeds). The data from these tests will be used to develop a high fidelity simulation model for flight dynamics analysis and also serve as a reference for CFD comparisons. This paper provides an overview of the wind tunnel tests and examines the effects of Reynolds number, Mach number, pitch-pause versus continuous sweep data acquisition and compares the data from the two wind tunnels.

"The data from these tests will be used to develop a high-fidelity simulation model for flight dynamics analysis and also serve as a reference for CFD comparisons"



HWB (Pylon Configuration) High Speed Wind Tunnel Test --- NASA National Transonic Facility

Part 2b – Mitigations and Confirmations

Challenge - The HWB may have flying and handling quality issues and may have recovery capability issues

Solution – High-Speed HWB Ground Demonstrations – Multi-year Simulator, NTF, AEDC 16T RDTE Campaign

WRIGHT-PATTERSON AIR FORCE BASE, Ohio -- AFRL researchers completed tests of a blended wing body (BWB) model in a 16-foot transonic wind tunnel at the Arnold Engineering Development Center (AEDC). The BWB model is a follow-on to previous wind tunnel tests conducted in the National Transonic Facility (NTF). The AEDC wind tunnel's larger cross-section enabled researchers to gather a broader range of data, including measurements of the model taken at higher Mach numbers than the earlier tests had allowed.

During testing, researchers investigated both Mach tuck and Mach buffet on the configuration. Mach tuck is a condition wherein the nose of the aircraft tends to pitch downward as the airflow around the wing reaches supersonic speeds. Mach buffet is a condition in which the wings begin to vibrate at supersonic speeds. The research team observed neither condition during the testing, which involved more than 250 data runs, covering 23 configurations and spanning a Mach number range of 0.5 to 0.97.

To permit a direct comparison of data, the researchers conducted the initial portion of this test under conditions mirroring those of the NTF tests. The team then performed the remainder of the testing at a lower tunnel air pressure, which is less expensive and thus allows more configurations to be tested.

The BWB airframe merges wings and a wind airfoil-shaped body, thereby generating lift and minimizing drag. In addition, it promises greater passenger or cargo capacity. Its potential may extend to various commercial and military applications as well, including tanker or transport aircraft.

HWB (Clean Wing Configuration) High Speed Wind Tunnel Test – USAF AEDC 16T Wind Tunnel

Part 2b – Mitigations and Confirmations

Challenge - The HWB may have flying and handling quality issues and may have recovery capability issues

Solution – High-Speed HWB Ground Demonstrations – Multi-year Simulator, NTF, AEDC 16T RDTE Campaign

Designing and Testing a Blended Wing Body with Boundary Layer Ingestion Nacelles

Melissa B. Carter[1], Richard L. Campbell[2], and Odis C. Pendergraft, Jr.[3]
NASA Langley Research Center, Hampton, VA 23681

Douglas M. Friedman[4] and Leonel Serrano[5]
Boeing Phantom Works, Huntington Beach, CA 92647

A knowledge-based aerodynamic design method coupled with an unstructured grid Navier-Stokes flow solver was used to improve the propulsion/airframe integration for a Blended Wing Body with boundary-layer ingestion nacelles. A new zonal design capability was used that significantly reduced the time required to achieve a successful design for each nacelle and the elevon between them. A wind tunnel model was built with interchangeable parts reflecting the baseline and redesigned configurations and tested in the National Transonic Facility (NTF). Most of the testing was done at the cruise design conditions (Mach number = 0.85, Reynolds number = 75 million). In general, the predicted improvements in forces and moments as well as the changes in wing pressures between the baseline and redesign were confirmed by the wind tunnel results. The effectiveness of elevons between the nacelles was also predicted surprisingly well considering the crudeness in the modeling of the control surfaces in the flow code.

"In general, the predicted improvements in forces and moments as well as the changes in wing pressures between the baseline and redesign were confirmed by the wind tunnel results."

HWB (Boundary Layer Ingestion Configuration) High Speed Wind Tunnel Test --- NASA National Transonic Facility

This series of high-speed test results allowed for calibration of design tools used in design iterations

Part 2c – Mitigations and Confirmations

Challenge - The HWB may have a weight penalty due to pressurized non-circular fuselage

Solution - Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) – a 10-year RDTE campaign

AIAA SciTech Forum
13-17 January 2014, National Harbor, Maryland
52nd Aerospace Sciences Meeting

10.2514/6.2014-0259

PRSEUS Structural Concept Development

Alex Velicki[1]
Boeing Research and Technology Group, Huntington Beach, CA, 92647

Dawn Jegley[2]
NASA Langley Research Center, Hampton, VA, 23681

A lighter, more robust airframe is one of the key technological advancements necessary for the successful launch of any large next-generation transport aircraft. Such a premise dictates that considerable improvements beyond current state-of-the-art aluminum structures is needed, and that improvements of this magnitude will require an extensive use of composite materials that are not only lightweight, but also economical to produce. To address this challenge, researchers at NASA and The Boeing Company are developing a novel structural concept called the Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) under the Environmentally Responsible Aviation (ERA) Project. It is an integrally stiffened panel concept that is stitched together and designed to maintain residual load-carrying capabilities under a variety of damage scenarios. In addition to improved structural performance, an important facet of this unique arrangement of stitched carbon fibers is its innovative manufacturing method that has the potential to lower fabrication costs by eliminating fasteners and autoclave cures. The rationale and development status for this new approach forms the basis of the work described in this paper. The test specimens described herein were fabricated, or are currently being fabricated, by The Boeing Company, while the structural analyses and testing tasks are being performed by NASA and Boeing personnel.

Nomenclature

BVID = barely visible impact damage
DLL = design limit load
DSD = discrete source damage
DUL = design ultimate load
EA = section modulus
EI = section stiffness

I. Introduction

To gain a competitive advantage in the marketplace, next-generation transport aircraft typically aim to achieve 20% better operating efficiency than incumbent designs. New airframe architectures, where improvements beyond aluminum structures can be achieved with the introduction of lightweight composite materials, are a significant contributor to the overall efficiencies of these new designs. Although lighter, the economic utility of composite primary structures is often diluted by their higher fabrication costs. Development of a new composite architecture that is not only inexpensive to fabricate, but also structurally superior, is the basis on which any next-generation composite structure will be judged. The fundamental premise of improving structural performance while simultaneously reducing fabrication costs forms the basis of how the design, manufacturing, and testing activities for the PRSEUS concept are being executed by NASA and Boeing researchers. A summary of this on-going work is described in the following sections.

[1] Principal Design Engineer, The Boeing Company, Advanced Structures R&D, Associate Fellow, AIAA.
[2] Senior Aerospace Engineer, Structural Mechanics and Concepts Branch, Associate Fellow, AIAA.

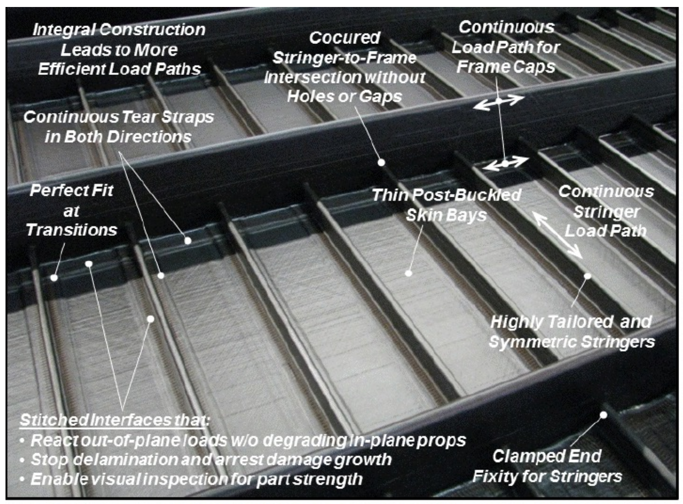


Figure 2. Structural advantages of PRSEUS panel construction.

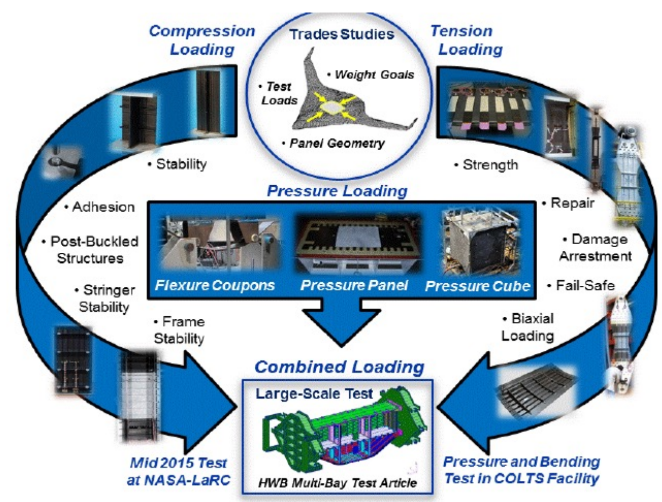


Figure 26. Development path leading to HWB large-scale test article.

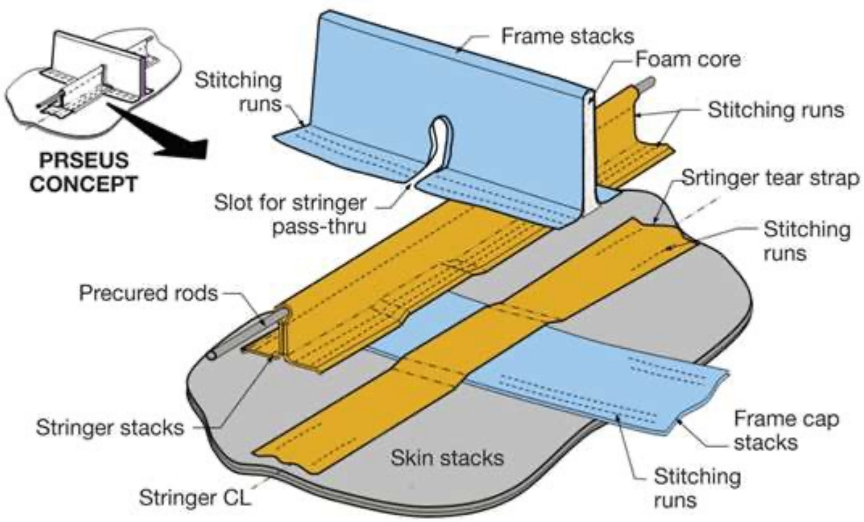
Velicki and Jegley, AIAA 2014-0259

"NASA calls on composites to enable a paradigm shift in future aircraft aerodynamics" --- Composites World 4/2015

Part 2c – Mitigations and Confirmations

Challenge - The HWB may have a weight penalty due to pressurized non-circular fuselage

Solution - Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) – a 10-year RDTE campaign



EXPLODED VIEW OF PREFORM ASSEMBLY

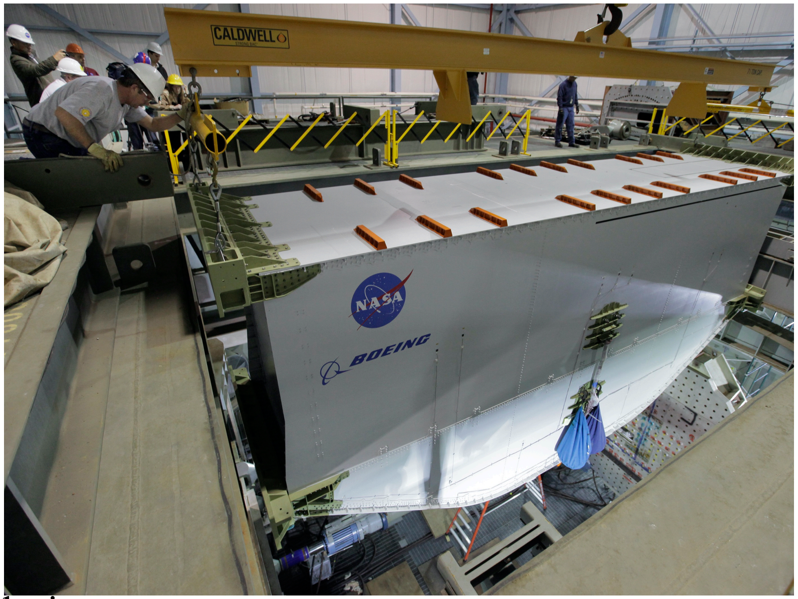
Similar panels were tested in the FAA FASTER facility (Bergan, et.al., Aircraft Airworthiness & Sustainment Conference, San Diego, California, April 18-21, 2011

Velicki, etal were awarded two Gold Awards by the RAeS for well documented PRSEUS design/engineering approach

Part 2c – Mitigations and Confirmations

Challenge - The HWB may have a weight penalty due to pressurized non-circular fuselage

Solution - Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) – a 10-year RDTE campaign



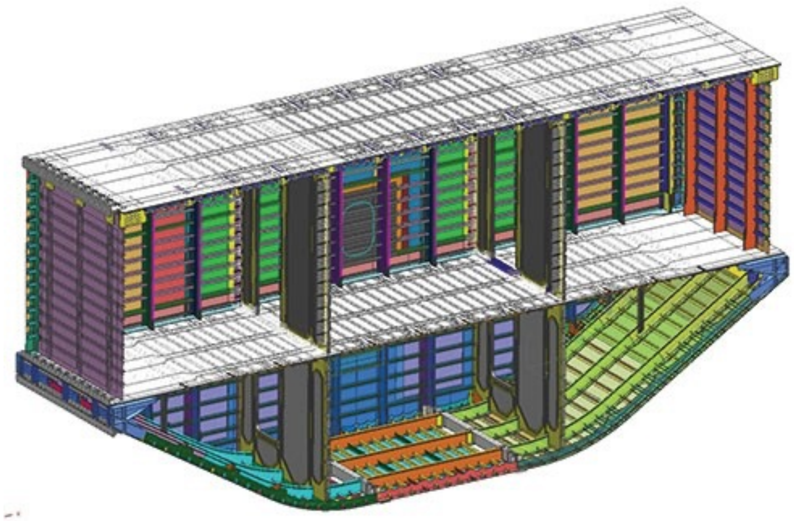
NASA/CR–2017-219668 – Multibay Box Design, Test and Analysis

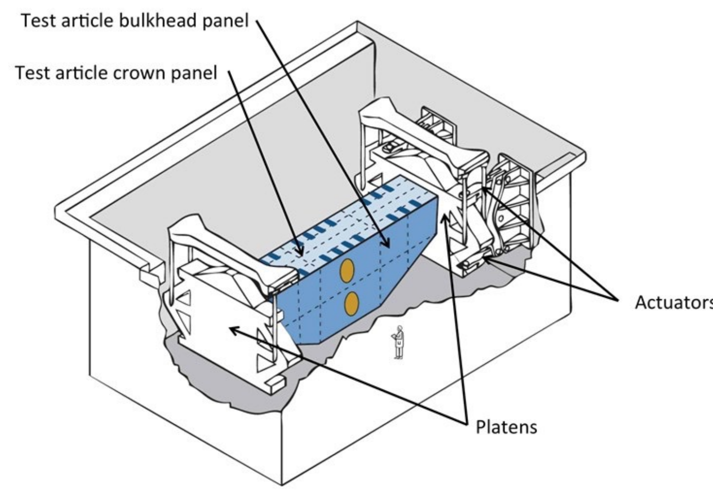
This 80-percent scale, 10,000lb piece of HWB center-body structure was constructed at the C-17 aircraft factory in Southern California and shipped to NASA Langley for testing in the COLTS

Part 2c – Mitigations and Confirmations

Challenge - The HWB may have a weight penalty due to pressurized non-circular fuselage

Solution - Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) – a 10-year RDTE campaign





The pressurized test was conducted at the NASA Langley Combined Loads Test System facility.
All pressurized test objectives were successfully achieved, including BVID and severe damage testing requirements.

PRSEUS test data supports component weight reduction yielding a system benefit: -20% to -30% OEW compared to SOA

Challenges associated w/Hybrid Wing Body

Advantages	Design Feature Challenges
Carbon Footprint Reduction	
- Lower skin friction drag	- may have weight penalty due to pressurized non-circular fuselage
- Trim drag during cruise can be avoided	- may have flying and handling quality issues
- Interference drag reduction	- may have recovery capability issues
- Lift-induced drag reduction	- may have less passenger comfort and acceptability (few windows)
- Wave drag reduction at high transonic speed	- may not be able to meet evacuation requirements
- Simplified high-lift devices	- may be sensitive to gust loads
- Wing weight reduction	- may be sensitive to gust loads
- Better high-altitude buffet margin	- may be sensitive to gust loads
- Local relief of aerodynamic loading	- may have issues with integration with airport
Community Noise Reduction	
- Greater noise shielding outside cabin	- may have degraded repairability due to upper body engine placement
Cost Reduction	
- Reduction in part count/manufacturing costs	- may be inconsistent w/family-oriented manufacturing concept

Where do we stand?

Part 2d – Mitigations and Confirmations

Challenge - The HWB may have less passenger comfort and acceptability (less access to windows)

Solution - Construct cabin mockups and test acceptance. Boeing did a cursory evaluation.

Challenge - The HWB may not be able to meet evacuation requirements

Solution - Run simulation software, such as AirExodus. Cranfield Aerospace did and met requirements.

Challenge - The HWB may have issues integrating with airports

Solution – Constrain designs to fit within current box. NASA and Boeing designs to date fit w/in the box.

Challenge - The HWB may be inconsistent w/family-oriented manufacturing concept

Solution – Develop design features that allow viable HWB configurations at all seat classes, such T-plug.

Challenge - The HWB may have degraded repairability due to upper center body engine integration

Solution – NASA has not addressed this challenge.

Part 2d – Mitigations and Confirmations

ICAS2018-0390

31st Congress of the International Council
of the Aeronautical Sciences
Belo Horizonte, Brazil; September 09-14, 2018

SINGLE-AISLE AIRLINER DISRUPTION WITH A SINGLE-DECK BLENDED-WING-BODY

M. A. Page, VP and Chief Scientist
E. J. Smetak, Program Manager
S. L. Yang, Program Manager
DZYNE Technologies Incorporated, Irvine, California 92618, USA
Key Words: Blended Wing Body, BWB, Efficient, Quiet, Safe, Comfort

Abstract

DZYNE Technologies Incorporated (DZYNE) has been studying a disruptive application of Blended-Wing-Body (BWB) technology to the single-aisle market (100 to 200 passengers). Today the single-aisle market is dominated by the Boeing 737 and the Airbus A320. These aircraft are in extraordinary demand and both manufacturers have near decade-long backlogs despite being older models (737 first flight in 1967, and A320 first flight in 1987). In the mean-time, 25 years of Blended-Wing-Body research has matured the concept, and the first company to introduce it will enjoy a sizable business advantage over conventional Tube-and-Wing competitors. A new entrant in the super-regional class with 120 passengers falls below the smallest Boeing 737 MAX 7, which carries 138-153 passengers. Later, the plane can grow upward to 200 passengers in capacity. However, planes sized for under 200 passengers were believed to be too small for a BWB. If BWB technology could be applied to a 100 passenger Super-Regional JetLiner, it would create a compelling business case for introducing the first passenger carrying BWB. DZYNE Technologies Incorporated has been developing a technology that makes a small single-deck BWB possible. Surprisingly the admitting technology is a new type of landing gear that can be stowed far from the payload compartment. The Ascent1000 BWB JetLiner would address the most pressing issues in today's Airliner fleet: new stringent emissions and noise standards from ICAO, operating cost, maintenance cost, and the newest problem – declining passenger comfort. This is why DZYNE believes there is both a business and technology opportunity for the BWB. The proposed Ascent1000 would burn 30% less fuel than today's newest Airliners using the same engine technology.

Figure 1. *DZYNE Ascent1000 Super-Regional JetLiner*

1 Early BWB History

1.1 Development at McDonnell Douglas

McDonnell Douglas coined the term "Blended-Wing-Body" (BWB) in the 1987 paper that introduced its first incarnation. In 1992, NASA funded further research evolving the airplane to the now familiar configuration where both the structure and aerodynamics are blended. The BWB was benchmarked against a Tube-and-Wing (T+W) with equal technology.

The findings for an 800 passenger BWB flying 7,000 nmi were impressive:

Takeoff Gross Weight	15.2% less
Lift to Drag Ratio (L/D)	20.6% higher
Fuel-Burn	27.5% lower
Empty Weight	12.3% lower
Thrust Required	27% lower
Operating Cost	13% lower

Many of these challenges is addressed by Mark Page in his iconic paper presented at ICAS 2018

Challenge - The HWB may have less passenger comfort and acceptability (less access to windows)

Solution - Construct cabin mockups and test acceptance. Boeing did a cursory evaluation.

Challenge - The HWB may not be able to meet evacuation requirements

Solution - Run simulation software, such as AirExodus. Cranfield Aerospace did and met requirements.

Challenge - The HWB may have issues integrating with airports

Solution – Constrain designs to fit within current box. NASA and Boeing designs to date fit w/in the box.

Challenge - The HWB may be inconsistent w/family-oriented manufacturing concept

Solution – Develop design features that allow viable HWB configurations at all seat classes, such T-plug.

Challenge - The HWB may have degraded repairability due to upper center body engine integration

Solution – NASA has not addressed this challenge.

https://youtu.be/InOBg0OsmLo This link provides a video of Mark and his perspective on Hybrid Wing Body.

Concluding Remarks

- "The most important lesson learned from the X-48 HWB flight test program is that the aircraft flies like an airplane! We do not say that lightly and are willing volunteers to pilot the manned demonstrator version"

  —Michael Sizoo and Dan Wells, X-48B/C test pilots

- Extensive enabling Research & Development has been performed
  - An advanced Composite Aircraft Structure was developed
  - Extensive Low Speed Flight Dynamics and Control experience was gained
  - Low-speed operability issues were investigated and put to bed
  - Design tools were calibrated at low and high speeds

- Performance Metrics Confirmation
  - The HWB configuration change provides 15-percent in mission fuel burn reduction when compared to advanced TAW at same technology levels - Reference AIAA 2016-1030, Nickol, etal
  - The same HWB has a 20 to 25 EPNdB cumulative community noise advantage over the advanced TAW at same technology levels – Reference AIAA 2016-0863, Thomas, etal

The HWB will have an even bigger advantage over TAW with eventual transition to LNG or LH2 due to volumetric efficiency of the HWB

Summary

- NASA has proven the HWB concept aircraft as viable and credible and has matured enabling technologies over a period of 30 years
- Many organizations are seriously exploring the transition of the HWB technology as a transformational commercial venture

  Available now
  - Commercial transport for people – ultra efficient and ultra low carbon footprint
  - Commercial/military transport for cargo – ultra quiet for 24 x 7 operations

  Available with Additional Research
  - Viable platform for very low or no carbon footprint
  - Viable platform for containing all objectionable community noise within airport boundary
  - Viable platform across all seat-classes with maturation of non-intrusive landing gear concepts such as the pivot piston concept being explored by DZYNE/BWAI

Questions