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

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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

1.2 Unexpected BWB Benefits

As design work at Douglas progressed, new benefits of the BWB were discovered. In almost every case the findings were favorable for the BWB relative to a Tube-and-Wing. The findings are summarized below:

- The airframe shields the community from most of the engine noise
- Supersonic flow above the cabin prevents forward-radiated noise entering the cabin
- The nacelles are protected from ground handling equipment
- Intake and exhaust hazards are eliminated for the ground personnel and equipment
- Thrust reversers do not blank the stabilizing surfaces, a major problem for today's transports on icy runways
- The fuel tanks are totally protected from rotor-burst
- The pressure vessel and passengers are totally protected from rotor-burst
- The primary wing structure is largely protected from rotor-burst
- Wingtip-stall is much improved since the elevons reduce air load near stall
- Maneuver-loads on the wing are reduced since the elevons are loaded opposite to the wing load in maneuvers
- Engine inlets are protected from stall at high angle-of-attack since the airframe directs the flow to the inlet
- The majority of the center-body is stall-free up to and beyond wing stall.
- The mid-span planform kink is stall critical to protect the wingtips from stall and the engines from distortion
- Passenger cabin loading, unloading, and emergency egress are faster due to multiple short aisles
- Ditching stability and integrity are improved by the large belly surface
- The traditional tails and associated systems are eliminated.
- The entire high lift flap system is removed
- No control surfaces are behind the wing where they are vulnerable to stalled wakes
- The wing shape and lack of tails reduces the size of the ice protection system.

2 Commercial Aviation Outlook

2.1 Dominance of the Single-Aisle Market

Boeing's 2016 market outlook predicts the single-aisle market will constitute 71% of sales in the 2016-2035 timeframe. Adding the 6% estimate for regional jet demand shows over 75% of total airline demand will come from the regional and single-aisle markets.

3 Motivation for the BWB in the Commercial Market

3.1 BWB Research Findings

Extensive research consistently shows the BWB species has significant performance and economic benefits compared to traditional Tube-and-Wing designs. The BWB configuration alone provides the majority of the performance improvements. The earliest studies at McDonnell Douglas (now Boeing) on a BWB concept sized for 800 passengers showed a 27% reduction in fuel burn when compared to a T+W configuration [4, 5].

Subsequent study focused on a 450 passenger capacity design, which showed 32% lower fuel burn per seat when compared to the Airbus A380-700 [5].

Some studies have shown lesser gains for the BWB. Especially noteworthy is reference [3] which showed an absolute fuel savings of only 12% relative to an advanced Tube-and-Wing. The study was excellent in every respect except the sizing rules for the center-body, which wrapped the landing gear in an additional sub-deck.

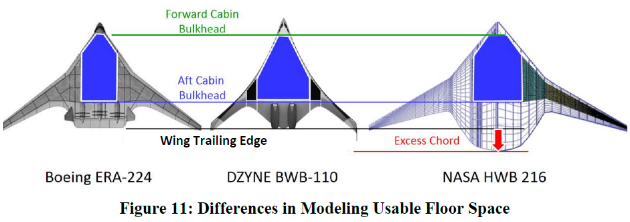

Figure 2. *Oversized Center-body from reference [3]*

Correcting the center-body size would add another 10% improvement in fuel savings for a total fuel savings of 22% relative to a Tube-and-Wing.

The BWB configuration offers great potential for community noise reduction. One key design element is airframe shielding afforded by top-mounted engines. Conventional wing mounted engines on T+W configurations are unshielded for forward radiated fan noise, and the aft-radiated jet noise is reflected downward by the wing and flaps. The BWB planform shields a large portion of radiated engine noise and prevents the downward reflection. A combination of high takeoff L/D and reduced takeoff thrust requirements helps to reduce noise further.

Overall, the BWB configuration is the most promising technology for achieving International goals of reduced fuel burn, emissions, and noise.

4 The Ascent1000 120 Passenger Super-Regional Jet

4.1 Ascent1000 Enabling Technology for a Small Single-Deck BWB

A small BWB must be single-deck. To date, commercial BWB's have been configured in two decks for optimal packaging. The lower deck is used for cargo and landing gear stowage. A single-deck BWB must find a new home for the landing gear and move the cargo outboard. If a single-deck BWB located its main gear in a traditional location, the gear wells would be giant boxes in the cabin, equal in size to all of the lavatories and galleys combined. This is why single-deck BWB configurations have been considered infeasible and uneconomical.

There are two fundamental conflicts between the BWB main gear and its payload compartment. The lateral conflict comes from the gear track limit for Group-III airports. If the gear were located outboard of all payload compartments (cabin and cargo) the gear-track would exceed the Group-III limit for future growth models. If the gear were located between the cabin and cargo compartments the center-body would need to grow in size adding weight and drag. The main gear must also be near the longitudinal center of gravity (CG) to rotate for takeoff. Moving the main-gear behind the cabin is very desirable since this space is unused. Unfortunately, this gear location is too far aft and would prevent takeoff rotation. This is why present BWB designs and all T+W designs locate the gear wells in a lower cargo deck near the airplane CG below the payload compartment.

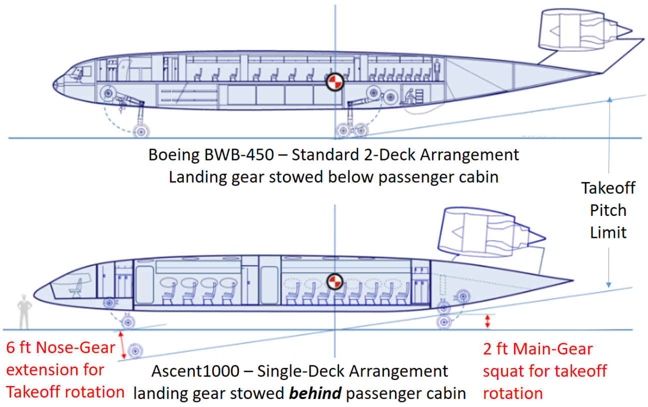

Figure 3. *Landing Gear Arrangement Comparison between the larger double-deck 450 passenger Boeing BWB-450 and the Single-Deck Ascent1000.*

DZYNE has solved the single-deck problem with a new type of landing gear (patent pending). This is the key enabling technology for a single-deck BWB in the regional and single-aisle markets. The new landing gear moves the main-gear behind the aft cabin bulkhead (also the rear spar) into unused volume below the engine mounts. To allow takeoff rotation, the main and nose gear are passively linked to create a virtual rotation point at the CG. Stated differently, the main-gear can squat and the nose-gear can extend a significant distance. This is a passive process and does not require pumps or actuators. The proprietary mechanism is not depicted.

This new gear reduces the pitch control needed for takeoff dramatically. The elevons are no longer required to produce a large downforce to rotate. This allows the lift off speed to be slower, reducing the demand for high takeoff thrust. One consequence of the new landing gear appeared to be a problem, but instead offered even more takeoff and landing performance gains. With the main gear tens of feet behind the CG, the nose gear is as heavily loaded and the mains. With this load moved from the mains to the nose gear, it was necessary to add brakes to the nose gear or pay a braking performance penalty. Today when brakes are applied by the main gear, the nose gear becomes heavily loaded. This so called “weight transfer” is why a car’s front brakes do most of the work. Without brakes on the nose gear the weight transfer cannot be exploited for better braking. With normal gear rigging the amount of weight transfer is insufficient to justify nose gear brakes, although these have been used on early model 727’s and combat aircraft. With the new landing gear, there is a 30% benefit to braking effect since weight transfer is harvested. The combination of improved braking and reduced lift off speed gives the Ascent1000 excellent field performance with small flight controls and smaller engines. But the largest benefit is the reduced volume needed to package the cargo, fuel, and landing gear. This allows the Ascent1000 to have a greater BWB benefit than double-deck BWB’s.

4.2 Ascent1000 Configuration

The single-deck arrangement requires the cargo holds to be on either side of the passenger compartment. The holds integrate very well because their height requirement is less than the cabin, allowing a smooth transition to the thinner outer wing. The cabin is divided into two 5-abreast bays. Each bay has 10 rows and seats 50 passengers. The galley and lavs are located at the cross-aisle for ready access by servicing personnel through the forward right door. The forward cabin is first and business class with seating for 20 and lavs located forward near the cockpit. The cockpit is a few steps up from the main deck to provide room for the new larger nose gear. An aft cross-aisle is provided for emergency egress through side doors beside the aft bulkhead. The outer wing is well above the cabin floor so passengers can exit the back standing fully upright. The engines are top-mounted to isolate them from ground debris kicked up by the gear and to provide acoustic shielding below the airplane for low community noise. The aft mounting eliminates rotor burst hazards in the cabin and fuel tanks and places them outside of the supersonic flow above the wing for low drag and good inlet performance.

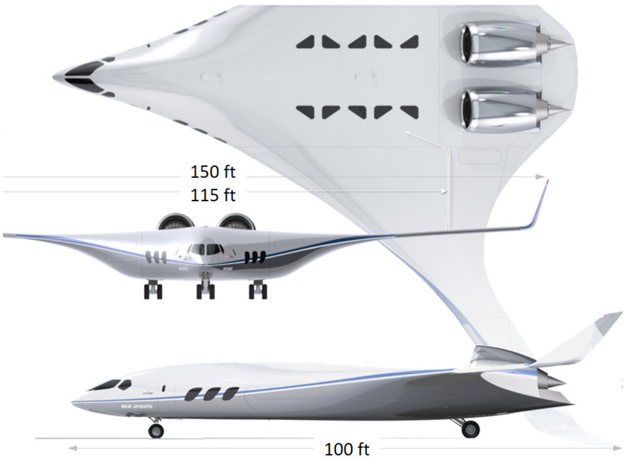

***Figure 4**. Ascent1000 3-View Diagram*

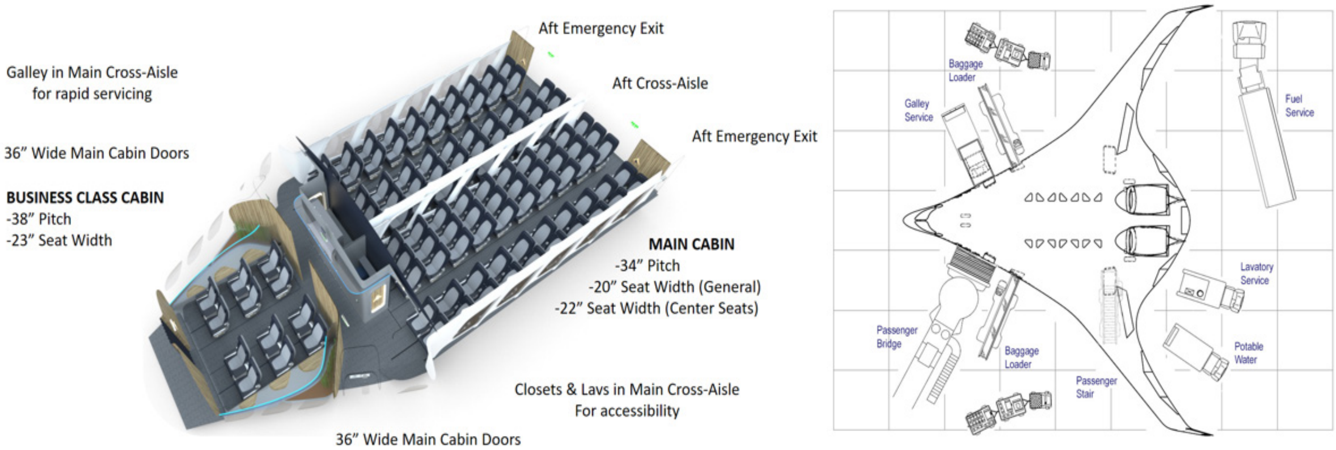

***Figure 5.** Ascent1000 cabin layout and ground servicing are conventional in many ways*

4.3 Ascent1000 Family

In the early days of BWB research, it was not clear how it could be grown for more capacity in a way that preserved most of the original airplane [12]. Later, a practical span-wise stretching concept was developed [13, 5] that used a centerline plug plus a mating collar. It was called a “T-plug” for its “T” shape. The outer wing, cabin, nose, and beavertail are preserved when growing the BWB. T-plugs increase floor space, wing area, and wing span in one step. A key benefit is gross weight can grow with little restriction. Today many aircraft families must preserve gross weight to re-use the wing and landing gear. This requires reducing range when capacity is increased. This constraint is largely absent with T-Plugs on a BWB. The structure is completely preserved, although the landing gear does require upsizing with increased gross weight.

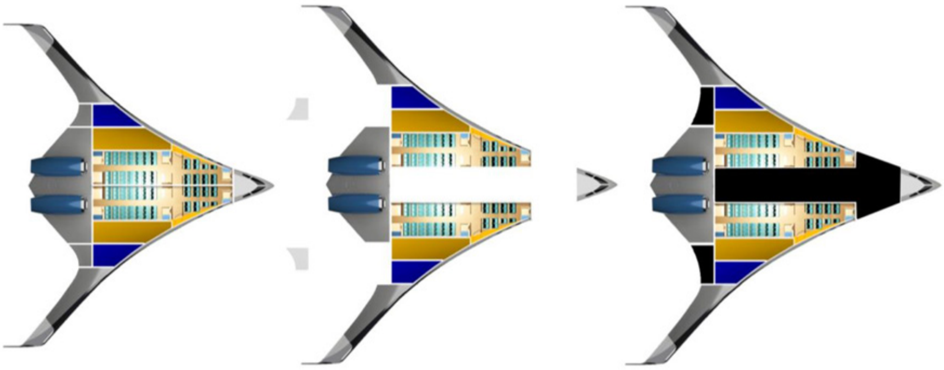

Figure 6. *A T-Plug grows the capacity while confining most changes to the T-Plug itself*

The Bombardier CS100 provides the best T+W comparison for the smallest BWB. It is also a new design with the latest geared turbo fan (GTF) engine technology and extensive use of composites. The following comparison in ***Figure 7*** assumes 2025 GTF technology that is expected to have 2% better specific fuel consumption than now installed on the CS100. The technology levels are otherwise the same. The Ascent BWB family growth model increases passenger capacity from 120 to 165 and increases range from 3,200 to 3,600 nmi. The final growth model has a capacity of 200 passengers and range to 3,800 nmi. BWB fuel savings are 30% while adding significantly more floor-space than the 737.

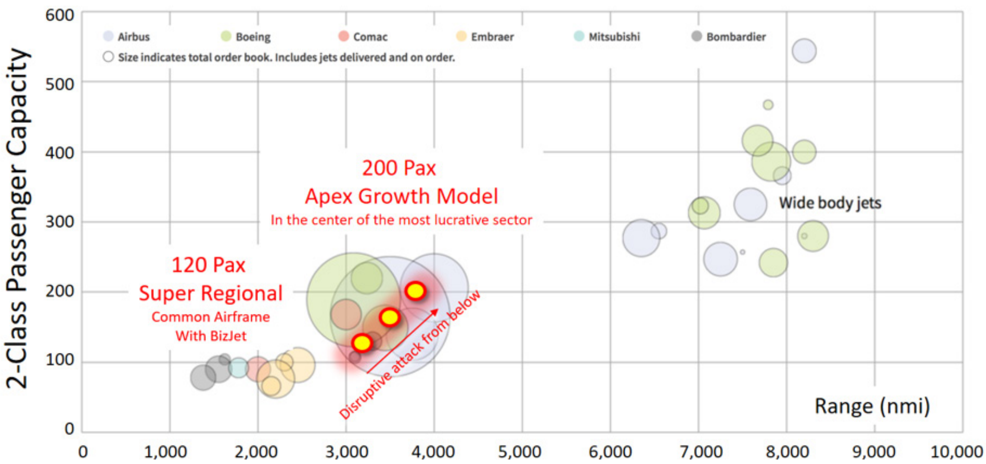

Figure 7. *The Ascent family can cover the entire Single-Aisle market (figure adapted from Embraer)*

Table 1: *Ascent Family Comparison – 30% fuel savings and greater floor space for the passengers.*

	BizJet		Regional Jet		160 pax JetLiner		200 pax JetLiner	
	G650	BWB BizJet	CS-100 max	Ascent1000	737 MAX 8	6ft Plug Ascent1600	737 MAX 9	11ft Plug Ascent2000
Passenger Provisions	18	18+	108	120	162	165	192	200
Mission Passenger Load	8	8	108	120	162	165	192	200
Range (nmi)	7,000	7,500	2,950	3,200	3,620	3,600	3,600	3,800
Cruise Mach	0.85	0.85	0.78	0.80	0.80	0.80	0.80	0.80
Takeoff Field Length (ft)	5,860	3,150	4,000	3,640	5,600	5,100	6,200	6,300
Floor Area / pax	Base	**Triple**	Base	**+5%**	Base	**+24%**	Base	**+25%**
Fuel Burn / pax-mile	Base	**-20%**	Base	**-30%**	Base	**-30%**	Base	**-31%**

4.4 Ascent1000 Comfort

For an airline, adding one extra seat in a 100 seat transport improves revenues 1%, but costs only 0.5% in additional fuel which translates into about 0.2% in increased operating cost. This simple math explains the intense motivation to fit more seats in airliners. Narrowing the seats is not a feasible strategy because seats would need to be narrowed 4 inches to add another seat in a row (20% less). However, adding an entire row to a 22 row airplane only costs only 1.3 inches in seat pitch (4% less). Little by little this pressure has created innovative thin seats, but also less comfort. The trends in seat pitch and obesity are in conflict as shown in ***Figure 8a and 8b.***

Seat width is built into the airplane design, but seat pitch is not. DZYNE selected a baseline pitch of 34 inches to design the Ascent1000 floor. However, this still allows another row to be added which would reduce pitch to today's average of 31inches. Fortunately, further reductions would be commercially impossible. The added row would increase capacity from 120 to 130 and improve the fuel efficiency by 6% per seat-mile. So forfeiting comfort to the same level as today's airliners would yield a 36% BWB benefit to fuel-burn. Ironically, if the main cabins were shortened for a 33inch pitch, it would practically inoculate the plane against reduced pitch in the future. This will be an interesting point of negotiation with the airlines.

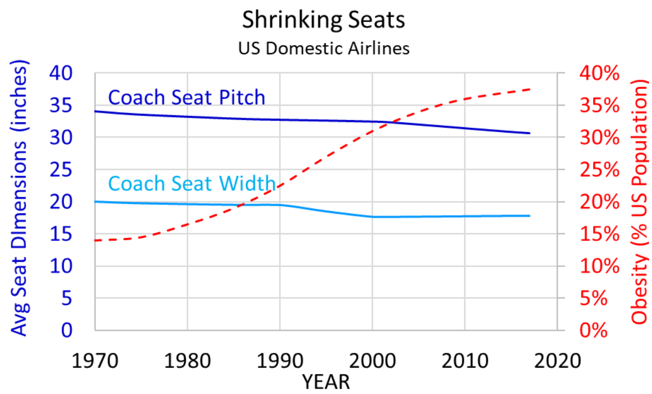

Figure 8a. *The competing trends of seat size and passenger size and the promise of more comfort.*

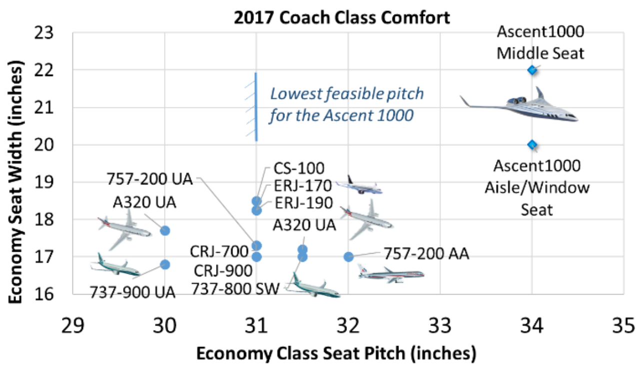

Figure 8b. *The competing trends of seat size and passenger size and the promise of more comfort.*

The BWB offers new options to the interior designer. First, the sidewalls are vertical which increases the perception of space. Second, the cost of cabin width is much less for a BWB than a cylindrical fuselage. Widening the BWB center-body does not require the attendant increase in height needed for cylindrical bodies.

This roughly halves the cost of seat and aisle width. The cost of 10% more seat width (nearly 2 inches more) is less than 0.9% in takeoff weight and costs only 0.8% in fuel-burn. Increasing seat pitch is also less expensive for a BWB since reducing thickness/chord-ratio benefits drag more than the same reduction in a slender body's diameter/length-ratio. Increasing seat-pitch by 10% increases takeoff weight 0.2% and fuel-burn by 0.8% for the Ascent1000. In addition, the middle seat received special attention. The intent was to make all seats equally appealing. At 22 inches wide, the extra 2 inches helps counter the reduced private space in the middle seat of today's airliners. Note that the CS100 adds an extra half inch for similar reasons.

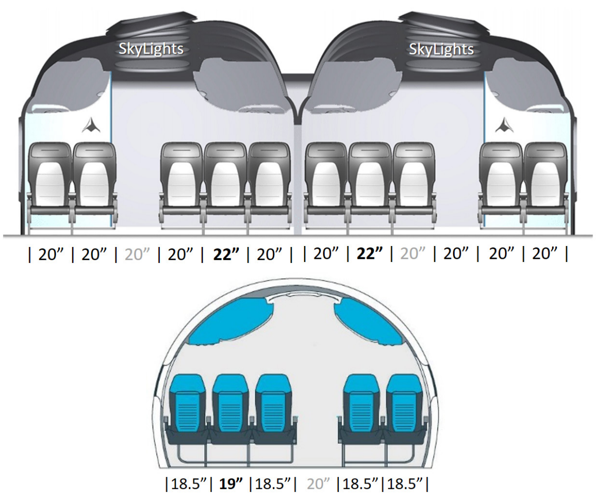

Figure 9. *Ascent1000 coach cabin (top) compared to the best-in-class CS100 (bottom)*

Two other differences are worth noting. First, the average ceiling height is higher in the BWB. Height at the rear bulkhead is less. Both are a result of the airfoil shaped cabin. Next, the overhead baggage space is about 50% greater. This design choice was motivated by the desire to eliminate gate checked bags. Gate checking is disruptive to passenger flow and requires additional airline personnel to manage. Eliminating gate checking will further improve the turn time benefits of the BWB layout.

4.5 Ascent1000 Breakthrough Community Noise Reductions

As described earlier, the BWB configuration offers extraordinary reductions in community noise. The largest benefit comes from airframe shielding of engine noise. The semi-buried engine arrangement improves shielding from the beavertail. DZYNE's Ascent1000 eliminates leading edge high lift devices, such as slats or Krueger flaps which is a significant noise on today's T+W aircraft.

DZYNE and the Georgia Institute of Technology Aerospace Systems Design Laboratory (ASDL) assessed the Ascent1000's noise with NASA's Aircraft Noise Prediction Program (ANOPP) which included modules calibrated specifically for BWB noise prediction. A potential cumulative noise reduction of 39dB below Stage IV was found. This exceeds the NASA N+2 threshold of 32 dB below Stage IV.

5 Barriers to BWB Adoption – Contrived and Real

The lack of BWB adoption for passenger travel has been discussed in the press and social media. A common misconception is the BWB has "no windows". Another misconception is motion-sickness for passengers located far from the centerline. And finally, there has been speculation that emergency egress is hindered in BWB's. All three are untrue. There are common-sense answers to these concerns, but there is also published research that shows the significance and insignificance of these concerns.

5.1 BWB's Have Windows in Every Cabin

Concerns have been expressed about the lack of windows in BWB aircraft, but in fact, BWB's can have windows in every cabin just like any other transport. The weight penalties are the same as in Tube-and-Wing aircraft. Today's Tube-and Wing aircraft have windows located at the seated shoulder height of the passengers for a downward view when seated. During a flight, most passengers can see only 2 windows and normally they are closed throughout the flight. During boarding and de-boarding, the windows are fully open by law, and most passengers can see many windows now at elbow-level when standing in the aisles. The forward cabin of a

BWB will have the same side-windows but can also add overhead skylights. Dimmable skylights provide natural light, and a sense of open-ness. But a key is visual motion cues that correlate with motion perception. This is important in preventing motion-sickness. Just like the side-windows of today's jets, you can sense the beams of light tilting along with airplane banking even if you can not actually see the window itself. The beams of light provide all the cues the brain needs. Skylights provide the motion-cue more effectively than today's side-windows. While side-windows are not impossible in the aft cabin, they would cost about 2% of the BWB's 30% benefit. Given the pace of display development, electronic virtual windows are a clear solution. Aft-cabin skylights will provide natural light and motion cues through dimmable panes.

Figure 10. *In many ways the BWB interior is no different, its familiar, but will have more natural light in all cabins*

5.2 BWB's Will Have Excellent Ride Qualities Just Like Tube-and-Wing Aircraft

There has been speculation that lateral distance from centerline is somehow different than longitudinal distance from the CG for motion detection. This is untrue especially for the most common Dutch roll motion. Motion sickness is caused by periodic variation of linear and angular acceleration. Normally, these accelerations arise from upsets due to turbulence, and the resulting airframe oscillations. Historically, poor yaw damping of the Dutch roll mode has been the principal culprit. Passengers who have flown in the back of older 747's will remember poorly damped Dutch roll motion. Those passengers seated in the back were most susceptible because they were furthest from the CG. The aft-most passenger in a 747-200 was 42 feet from the CG. That is further from the CG than a BWB passenger in the same size airliner. A 777-sized BWB would place the outermost passenger 24 ft. from the CG. Today's 777 locates the furthest passenger five times further at 120ft. Reference [16] found minor motion issues with a very large BWB layout (1,000 passengers) which had twice the width of the subject Ascent1000. For 200 passenger BWB's and smaller, motion discomfort can be dismissed by inspection. The Ascent1000 will have the same cabin width as the A380, which has double the cabin width of the 737 and no motion issues. Geometry of these smaller BWB's will not expose passengers to objectionable motion.

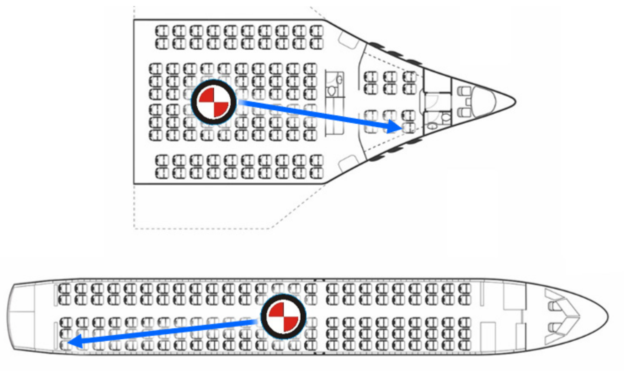

Figure 11. *Ascent1000 passengers are a little closer to the CG, not further, it's the total distance that matters for motion comfort*

5.3 BWB's Have Faster Loading and Emergency Egress than Tube-and-Wing Aircraft

Reference [15] reviewed the boarding and de-boarding process and found a benefit for BWB's. Similar physics are at work for emergency egress. For the small Ascent1000, the BWB benefit is easy to discern. Single-aisle aircraft have more rows between the most remote seat and the nearest exit. For example, The CS100 has 8 rows to the nearest exit, while the Ascent1000 has only 5 as shown in ***Figure 12.***

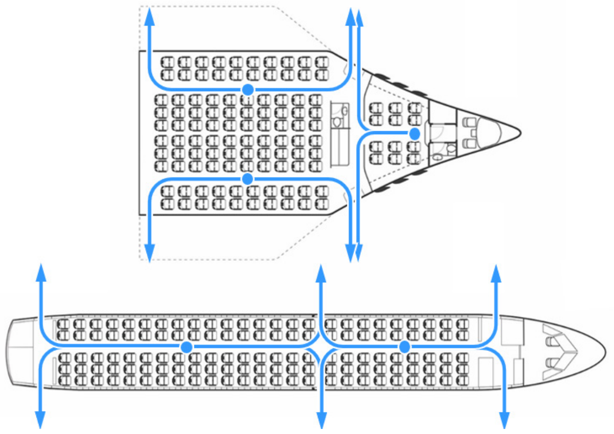

Figure 12. *The Ascent1000 passengers are closer the exits and have fewer rows between them and the exits*

The Ascent1000 will have 2 aisles of 10 rows and 50 passengers each, plus an additional aisle that is only 4 rows deep with 20 passengers. The multiple paths prevent one person from stopping the entire airplane's flow while they wrestle with carry-on baggage. The average number of rows a passenger must cross to enter or exit the BWB is only 5, compared to 22 for the 737-700. This difference has a significant effect on ease and speed of boarding and de-boarding that is estimated to shorten turn-time. These benefits are even more compelling in an emergency. Each exit route will have 4 times less obstruction from abandoned luggage and struggling passengers. The BWB will not have a loading or emergency egress penalty; it will have an improvement in both.

6 Conclusions – The Real Barriers to Entry for a BWB Transport

The Real Barrier to Entry – Incumbent Builders Do Not Need BWB Technology – Everyone Else Does

The technical and economic benefits for the BWB have been presented. There are significant environmental and comfort benefits as well. With 25 years of study by NASA and the major manufacturers, the feasibility has been long-established, and most developmental risks are retired as well. This was achieved by decades of aerodynamic computational fluid dynamic (CFD) analysis, structural (finite element analysis (FEA), and piloted simulator studies. There have been numerous low-speed wind tunnel tests that thoroughly explored the following: performance, stall characteristics, gear effects, control mixing, stability & control, control hysteresis, control failures, power effects, engine inlet distortion, nacelle rigging, belly-flaps, ground-effects, spin and tumble, tethered flight dynamics, and aeroacoustics. High speed testing has explored: aero performance, nacelle integration, inlet distortion, full-scale Reynolds number, aero loads, stability & control, transonic control reversal, Mach-buffet, and Mach-tuck. NASA and Boeing built the X-48B and C models to evaluate pilot-on-the-loop flight control for terminal area operations. That program demonstrated takeoff and landing flying qualities, stall, stall recovery, engine-out, degraded control modes, and power effects, and even acoustics. An 85% scale cabin structure was built and tested against all of the key flight and pressurization load cases. Then the structure was tested with various levels of damage which validated the general configuration and the specific PRSEUS fabrication process. The remaining chores will demand diligent engineering as would be done for any new airplane, plus a little extra for this new species of airplane, but the heavy-lifting is done. BWB technology is ready for introduction.

DZYNE's single-deck BWB is poised for introduction into the regional and single-aisle markets. These markets burn half of fuel of the worldwide fleet today. The Ascent family offers a 30% fuel benefit, profound noise reductions, significantly higher safety, more comfort, and faster gate turns. These benefits may be the only way for airlines to realize the environmental targets set by ICAS, ICAO, NOAA and others.

The key enabling technology for smaller single-deck BWB is the new landing gear, which allows the BWB access to the largest portion of the airline market, the single-aisle segments, and give the public the greatest outcomes in efficiency, emissions, and noise.

7 Acknowledgments

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8 References

[1] Boeing Commercial Airplanes, *Current Market Outlook 2016-2035*. Retrieved from: http://www.boeing.com/resources/boeingdotcom/commercial/about-our-market/assets/downloads/cmo_print_2016_final_updated.pdf

[2] *New Aviation Horizons Initiative and Complementary Investments*. NASA, 2016.

[3] Nickol, C.L. and Haller, W.J. *Assessment of the Performance Potential of Advanced Subsonic Transport Concepts for NASA's Environmentally Responsible Aviation Project*. AIAA SciTech 2016, San Diego, CA, January, 2016, AIAA 2016-1030.

[4] Liebeck, R.H., Page, M.A., Rawdon, B.K. *Blended-Wing-Body Subsonic Commercial Transport*. AIAA 98-0438, January, 1998.

[5] Liebeck, R.H. *Design of the Blended Wing Body Subsonic Transport*. Journal of Aircraft, Vol. 41, No. 1, January-February 2004.

[6] *Aviation Emissions, Impacts & Mitigation: A Primer.* FAA Office of Environmental and Energy, January 2015.

[7] Thomas, R.H., Burley, C.L., and Nickol, C.L. *Assessment of the Noise Reduction Potential of Advanced Subsonic Transport Concepts for NASA's Environmentally Responsible Aviation Project*. AIAA SciTech 2016, San Diego, CA, January, 2016, AIAA 2016-0863.

[8] Christensen, Clayton M. *The Innovator's Dilemma.* New York, NY: Harper Business, 2011.

[9] Lauke, T., Lummer, M., Wilhelm, R. *Assessment of Sound Radiation of Semi-Buried Engine Intakes.* Aeroacoustics of New Aircraft and Engine Configurations (Impact of Aircraft Noise on Future Design) Conference, Budapest, November, 2004.

[10] Godard, J. *Semi-buried Engine Installation: The Nacre Project Experience.* 27th International Congress of the Aeronautical Sciences, Nice, France, September 2010.

[11] Velicki, A. and Jegley, D. *PRSEUS Development for the Hybrid Wing Body Aircraft.* AIAA Centennial of Naval Aviation Forum "100 Years of Achievement and Progress". Virginia Beach, VA.

[12] Liebeck, R.H., Page, M.A., Rawdon, B.K., Scott, P.W., and Wright, P.A. *Concepts for Advanced Subsonic Transports.* NASA CR-4624, September, 1994.

[13] Page, Mark A., Whitlock, Jennifer P., and Wilks, Matthew W., Boeing Company, Long Beach, CA, U.S. *Patent for a Variable size blended wing body aircraft.* Patent No. 6,568,632, filed 4 April 2001.

[14] Carter, M. B., Shea, P. R., Flamm, J. D., Schuh, M. J., James, K., Sexton, M. R. Tompkins, D., and Beyar, M., *Experimental Evaluation of Inlet Distortion on an Ejector Powered Hybrid Wing Body at Take-off and Landing Conditions (Invited).* 54th AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, (AIAA 2016-0010)

[15] *A Generic Approach to Analyze the Impact of a Future Aircraft Design on the Boarding Process*

Bekir Yildiz 1 ID, Peter Förster 1 ID, Thomas Feuerle 1 ID, Peter Hecker 1,* ID , Stefan Bugow 2 ID and Stefan Helber 2 ID Energies **2018**, 11, 303; doi:10.3390/en11020303

[16] *PASSENGER ACCEPTANCE OF BWB CONFIGURATIONS*

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