POWER & PROPULSION

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THE TUBE-AND-WING ARCHITECTURE IS NOT DONE YET!

The Ultra Low-sweep Transonic Wing (ULTW) aircraft is designed with a tube-and-wing configuration that achieves a remarkable 50% increase in efficiency, primarily due to the innovative Boundary Layer Control (BLC) system integrated into the airframe. Historically, jet engines have been the key drivers of fuel efficiency improvements in aviation. However, the novel BLC system enhances performance by shifting the critical Mach number and drag divergence to the right, enabling a significant reduction in sweep angle (from 0 to 5 degrees for an aircraft cruising at Mach 0.82).

Figure 1. Artist illustration with a wing sweep angle of zero degree.

The ULTW aircraft promises at least a 50% improvement in fuel consumption. By employing this tube-and-wing architecture, it can attain the same fuel efficiency typically associated with blended wing body designs, leveraging the advantages of the BLC system to minimize sweep angle and skin friction drag. This approach allows for the use of existing manufacturing processes and tooling, facilitating a reasonable production timeframe that reduces costs and increases profit margins for OEMs and airlines. Additionally, current jet engines (such as the Pratt & Whitney GTF or GE Aerospace LEAP) will be compatible with an aircraft similar in performance to the Boeing 767-200ER. Despite a lower thrust rating, the aircraft can achieve the required climb performance due to drag reduction, a higher lift-over-drag ratio, and an enhanced aspect ratio. Importantly, the aircraft can be certified swiftly within the existing regulatory framework.

The Boundary Layer Control Technology

During the research program, a unique interaction was discovered between injected CO2 flow and specific microfeatures, leading to the development of a novel boundary layer control technology. Various types of tangential flow injections were tested, with two primary methods being explored in depth.

The first method involves high-energy flow to re-energize the boundary layer, primarily aimed at delaying flow separation, and has been implemented on several high-lift devices. However, the associated ram drag penalty from utilizing freestream fluid hampers the potential effectiveness of this approach.

The second method employs wall wake flow, where fluid injected at approximately 30% of the freestream velocity interacts with the skin of the vehicle, resulting in reduced skin friction drag. However, downstream mixing from the injection slots restricts drag reduction efficiency. Research indicates that while multiple slots can be employed with an optimal upper limit of ten slots to minimize friction coefficient, the ram drag penalty remains excessively high, even when using low-loss injected air.

The proprietary boundary layer control technology uniquely harnesses the interaction between injected CO2, at just 10% of the freestream speed, and specially designed microfeatures on a plastic film. Remarkably, this method requires only a single slot to achieve a 50% reduction in skin friction drag, with slot heights below 110 micrometers. Preliminary data suggests that the injection velocity might be further decreased to 2% of the freestream speed, potentially enhancing drag reduction even more. This technology is also designed to be resilient against external contaminants such as dust or insects.

Moreover, the boundary layer control technology holds great promise for enhancing the efficiency of propeller blades in EVTOL aircraft, potentially allowing for a 10-20% reduction in battery pack size. Additionally, it offers substantial fuel consumption reductions for general aviation and regional aircraft, as it is compatible with various engine types, including internal combustion, electric, and hybrid systems.

Commercial jetliners could be designed with lower wing sweep angles, thus increasing aerodynamic efficiency. Thanks to viscosity, the low-momentum CO2 flow virtually changes the airfoil camber by slowing down the adjacent freestream flow. One consequence is that the critical Mach number and drag divergence are pushed further to the right.

Fighter aircraft may also gain from this technology and applying it to engine nozzles could significantly decrease their infrared signatures. The technology presents opportunities for hypersonic vehicles as well, contributing to friction reduction, thermal management, and enhanced maneuverability. By selectively deactivating the system in certain zones, vehicles can utilize differential drag for steering without the need for fins.

Also, rocket engines' nozzle efficiency could be improved with a potential gain of up to 5%. The novel boundary layer technology could be a game changer for the aerospace sector.

Initial wind tunnel testing successfully completed

Figure 2. Test model.

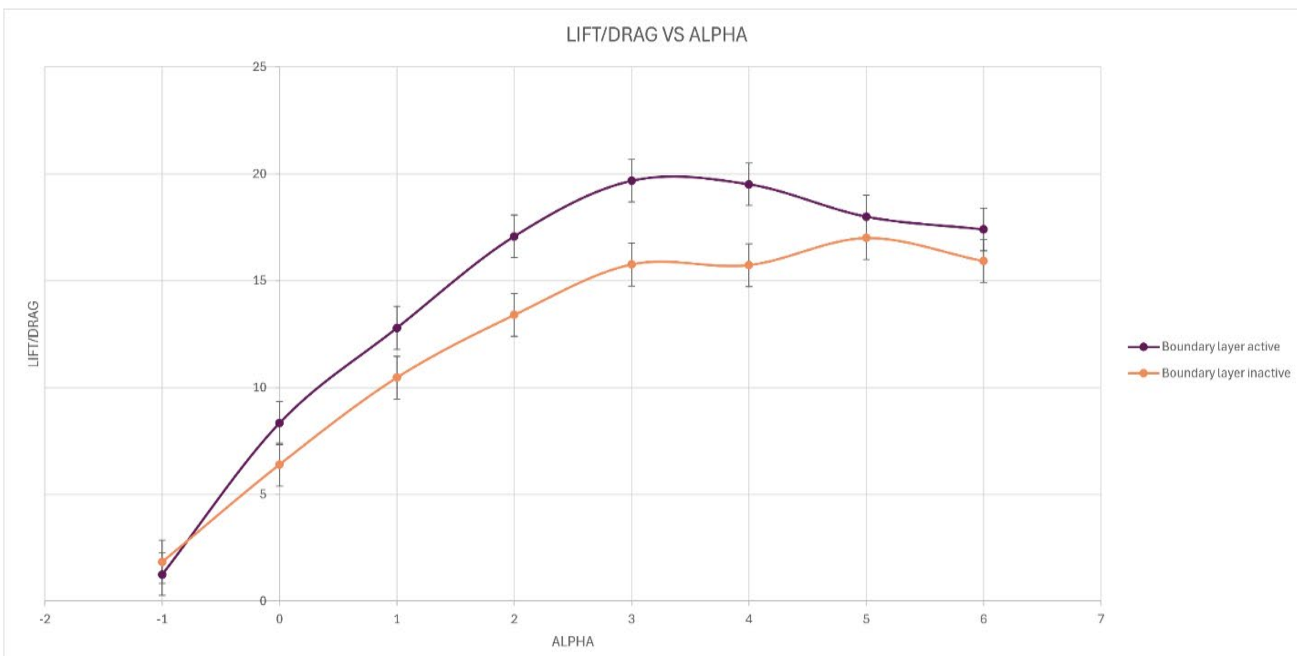

Figure 3. Lift over drag ratio versus angle of attack.

A wind tunnel test at subsonic speeds was conducted. A closed-circuit, double-return wind tunnel with an eight-foot by twelve-foot test section vented to the atmosphere was used. Each return duct contains a seven-bladed, fourteen-foot-nine-inch diameter fan. These mechanically synchronized and electrically driven fans are capable of developing wind velocities up to 200 miles per hour in the test section.

The results obtained exceeded expectations. More than 50% in skin friction reduction was achieved. The good surprise was the improved lift generated. The system was mainly designed to reduce drag. When comparing the lift-to-drag ratio curves, a 20% gain was realized thanks to the boundary layer control system at the optimal angle of three degrees. Further analysis of the data shows that the gain can be augmented.

Ultra Low-sweep Transonic Wing aircraft

Skin friction drag accounts for nearly half of the total drag experienced by a jetliner flying at transonic speed. It is a function of the wetted area and the friction coefficient. At transonic speeds, the airflow is turbulent, leading to a friction coefficient that is three times higher than the aircraft would have experienced if the flow had been laminar. Also, the fuselage represents half of the aircraft's wetted area but is not covered by the boundary layer control technology. Only the top of the wing area, called extrados, is treated with the boundary layer control technology. This area represents around 20% of the total aircraft wetted area.

Furthermore, the boundary control technology does not cover the lower part of the wings. Extensive laminar flow could be maintained along the chord line due to the favorable pressure gradient and the significant reduction of crossflow instabilities with the elimination of the sweep angle, which are usually the two primary triggers for flow transition. This approach will limit the weight of the condenser in the engine used to generate the CO2 gas.

Figure 4. ULTW aircraft concept artist illustration.

Future evolution of the CO_2 recovery system could open the door for treating the fuselage area.

Thanks to the novel boundary layer technology, the wing sweep angle is eliminated due to a higher critical Mach number, which reduces the nose-down moment (present on swept wings with the lift generated behind the center of gravity). Thus, the trim drag is reduced.

Reducing the sweep angle provides multiple benefits. The reduced wing's sweep angle makes the front and rear spars straight, resulting in a stronger wing box (mainly dealing with bending stresses as torsion efforts are greatly reduced). Thus, the wingspan and aspect ratio can be increased for greater aerodynamic efficiency without a weight penalty. Weight savings could even be made as the length of the wing is reduced to match the same aspect ratio. Part of the wing is folded to fit existing airport gates. Also, the airfoil profile provides sufficient takeoff, climb, and low-speed performance. Thus, a slat system is not needed, resulting in weight savings.

Figure 5. Folded wingtips configuration.

Overall, the reductions in skin friction drag, induced drag, trim drag, form drag, and wave drag contribute to a total drag reduction of 36%. This significant decrease allows for the use of smaller core engines derived from existing narrowbody turbofans.

Moreover, the new wing design simplifies the trailing edge flap to a single-slotted flap panel. This adjustment permits a low approach speed, reduces noise, and accommodates a suitable landing attitude. The enhanced lift-to-drag ratio can lead to substantial weight savings or allow for additional payload. Notably, the elimination of the fuel center tank increases aircraft safety since no fuel is stored in the fuselage, and it frees up space for cargo.

Switching to a single slotted outboard flap panel on each wing also decreases the number of parts, which simplifies manufacturing, lowers costs, and reduces complexity. There's no need to account for certain failure modes that require redundancy and additional weight, such as slat asymmetry. Overall, the wing design is greatly simplified, and metallic materials are used for the airframe to facilitate high-rate manufacturing. Using composite materials, which are necessary for a blended wing body design, would hinder the ability to achieve those production rates.

The propulsion system with CO2 injection

This propulsion system leverages significant drag reduction to enable existing narrowbody engines, like the Pratt & Whitney GTF or CFM LEAP, to power aircraft the size of a Boeing 767. This setup allows compliance with the ICAO emissions standards set to take effect in 2027.

To prevent the accelerated airflow from interacting with the low-sweep wing and generating shock waves, the engine requires a nacelle. As a result, the open rotor concept has not been pursued for under-the-wing engine designs.

CO2 is essential for achieving aerodynamic benefits, ruling out the use of hydrogen as fuel. Instead, Sustainable Aviation Fuels or Jet A are the preferred fuel types.

Figure 6. ULTW Powerplant concept.

Water injection could be used with this powerplant concept. Like the Water Enhanced Turbofan (WET) engine, water recycling and injection could boost engine efficiency. However, the extra complexities and the size of the recycling system oriented the powerplant design toward CO2 injection instead. The condenser required will be smaller, and the design will be more compact. Furthermore, CO2 is a non-toxic, non-flammable, and non-corrosive gas.

The fan, compressor, and turbine blades incorporate boundary layer control technology to reduce losses and improve efficiency.

When jet fuel is combusted, approximately 70% of the exhaust gases by weight are CO2, while 29% is water. The remaining 1% consists of unburned hydrocarbons, carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides, and soot. A portion of the exhaust gases from the engine core are redirected into the condenser, which uses fan air to separate CO2 from water. This process can begin at altitudes above 20,000 feet, depending on the external temperature, as temperatures rise post-fan. Only CO2 and a minimal amount of CO remain in the gaseous state and are extracted.

The liquefied CO2 is stored in a tank for use below 20,000 feet or during takeoff and go-around phases to enhance aircraft performance. This configuration resembles a hybrid system, but it employs lighter liquefied CO2 instead of heavy batteries and electric motors. Moreover, the stored CO2 could be utilized in the airplane's fire protection system.

Additionally, the engine nacelle could be treated using boundary layer control technology, allowing for an increased bypass ratio without significantly increasing drag.

While this approach may result in heavier engines, the weight savings from high lift systems or engine downgrades will offset the added weight of the nacelles and condensers. Overall, the expected fuel efficiency gain from the engine alone is around 10%.

When combining the efficiency improvements from the engine and the wing, the aircraft could achieve at least 50% greater fuel efficiency, considerably reducing the formation of contrails.

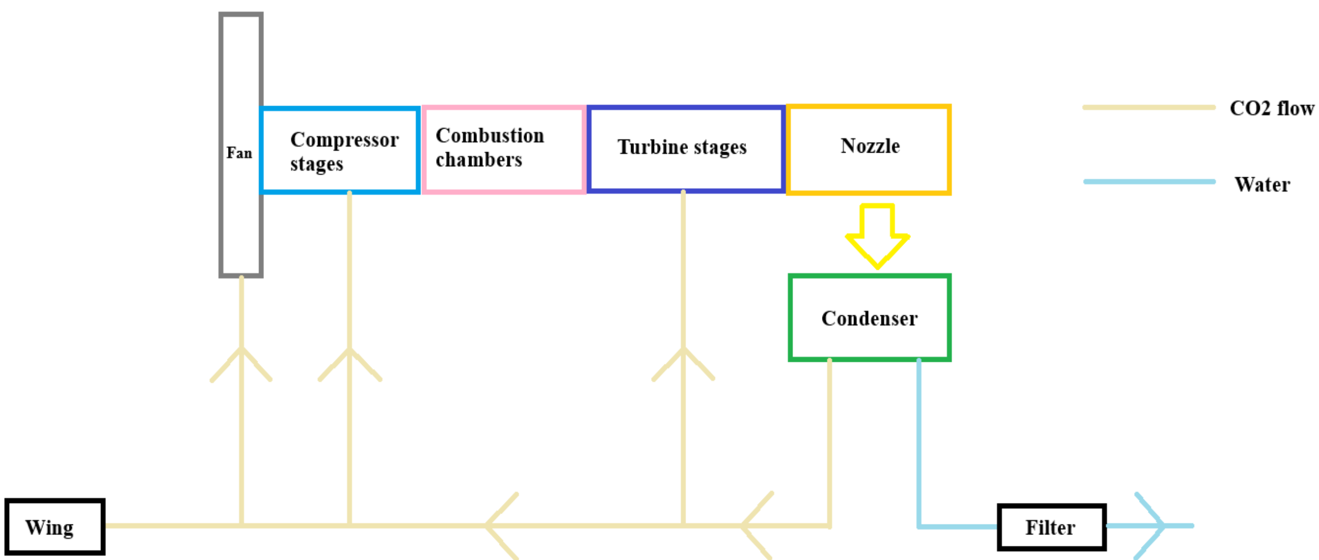

Figure 7. Diagram of the CO2 injection system.

Case study Middle of the Market MoM airplane: Boeing 767 with the ULTW concept

Figure 8. Boeing 767 200ER

With the ULTW concept, a new MoM aircraft based on the Boeing 767 can be developed. The program is expected to cost between $4 billion and $6 billion, including the engine program. The OEM could gain a significantly higher profit margin from this initiative. The timeline for the program is three years, and airlines can expect an aircraft that achieves at least a 50% reduction in fuel consumption. The expected range will be between 4,000 and 6,000 nautical miles.

As a rule of thumb, a 1% improvement in lift-to-drag ratio corresponds to an increase of 3,000 lbs in takeoff and landing weights for a 350,000 lbs airplane, as maximum lift capabilities are also improved. Additionally, a 1% reduction in aircraft weight can lead to a 0.35% to 0.5% improvement in fuel consumption. The useful payload for widebody aircraft is generally about 20% of their maximum takeoff weight (MTOW), while for narrowbodies, it is around 30%.

For the Boeing 767 utilizing the ULTW concept, the useful payload will be a minimum of 30% of the MTOW. The existing CF6 or JT9D engines will be replaced with Pratt & Whitney GTF or CFM LEAP engines. The CF6 80C2B2 engine that powers the 767 200ER has a thrust rating of

52,500 lbs, but under the ULTW concept, the required thrust is reduced to 33,600 lbs, which is achievable with either the GTF or LEAP engines. The CF6 80C2B2 weighs 9,500 lbs and has a fan diameter of 93 inches, while the GTF weighs 6,900 lbs with an 81-inch fan diameter. An additional 1,200 lbs will be added for the condenser and related systems, bringing the total weight of the GTF engine for the 767 ULTW concept to 8,100 lbs.

The current Boeing 767 wing features three-position leading-edge slats, an outboard single-slotted flap, and an inboard double-slotted flap. However, the ULTW concept only requires an outboard single-slotted flap, which allows for the elimination of the slats and inboard flaps, saving at least 5,000 lbs. Since the wing manufacturing cost represents 20% of the aircraft's production cost, these reductions contribute to cost savings. The wing's aileron, flap, and slat systems account for half of the wing’s cost. Considering the engines and high-lift system, total weight savings can reach up to 7,800 lbs. This means the aircraft's gross weight could decrease by about 15,600 lbs (with a sensitivity factor of around 2 for a commercial airliner), leading to an estimated 3% gain in fuel efficiency.

Additional fuel savings may come from reducing the size of the engine nacelle. Moreover, redesigning the vertical and horizontal stabilizers could lower both weight and drag, as their dimensions are traditionally dictated by engine failure scenarios during takeoff and the aircraft's nose-down moment. With lower thrust and trim force requirements, these components can be downsized. Overall, total fuel savings could potentially reach 60%, significantly reducing aviation emissions, given that widebody aircraft constitute 30% of the global fleet but account for more than 50% of the industry's emissions.

Perspective for a new narrowbody airplane based on the ULTW concept

Figure 9. A320 family.

Narrowbody aircraft make up 70% of the global fleet, presenting a significant opportunity for redesign. The approach used for the Boeing 767 could also apply to the A220, A320, and Ejet families. By improving payload capacity and lowering fuel consumption, airlines can enhance their profit margins while also reducing their carbon footprints. The A321 XLR utilizing the ULTW concept would achieve the same range without the need for an additional fuel tank. The Boeing 737 family could undergo redesign, although the absence of an Engine Indication and Crew Alerting System (EICAS) or a fly-by-wire system (except for the spoilers on the MAX family) could hinder certification efforts for such an aircraft. Further studies are currently ongoing internally.

Perspective for a new fighter jet based on the ULTW concept

Figure 10. F35

The ULTW concept could also pave the way for developing a new fighter aircraft at a reduced cost. For instance, the F-35 could be enhanced by integrating boundary layer control technology into its airframe and engine, significantly improving maneuverability. Additionally, the infrared signature of the F135 engine could be minimized, and CO_2 injection could be implemented to boost performance. This would not only enhance power and reduce fuel consumption but also potentially enable supercruise capabilities.