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Improved Aerodynamic Properties and Structural Design For Commercial Air-Liners.

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Fig.1.: The D8 " Double Bubble" concept aircraft

Abstract :
The D8 double-bubble aircraft – named for its complex, non-round fuselage shape – originated from NASA's N+3 Phase I study in which participants designed efficient commercial aircraft for market entry in the 2035 time frame .In this paper, the conceptual design of a D8 aircraft is presented: the aircraft is designed to comply with FAR 25 requirements and air transportation system constraints; airframe structural solutions for the unique configuration challenges of the D8 are presented; aircraft weight and balance and airline operations are analyzed; aerodynamic lofting and performance is accomplished with CFD; and performance of the boundary layer ingesting (BLI) propulsion system is investigated.
Results are presented for two D8 concepts transportation system analysis was completed using these aircraft and it is shown that the D8 configuration has the potential to reduce narrow body system fuel consumption by 52% and significantly reduce community noise impacts based on an analysis of the top 20 United States airports.
The description about the Body Layer ingestion and its integration in the aircraft is also discussed.

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I. INTRODUCTION AND HISTORY FOR D8

Revolutionary aircraft designs with aerodynamics in consideration started with DC 3 aircraft which introduced concepts of radial air cooled engines, retractable gears and variable pitch propellers. In 1956 Boeing 707 series introduced the jet propulsion engines thus causing a change in the airframe making it more Aerodynamic.
For the past 60 years' fuel efficiency was increased by focusing on propulsion systems.

D8 and its revolutionary designs of the fuselage and the Airframe caused decrease in fuel consumption levels increasing overall efficiency of the aircraft.

The 3 main criteria's proposed for the design included:
1. Fully integrated to leverage the virtuous cycle of interactions between subsystems in order to deliver revolutionary performance benefits in a short time frames;

2. Not dependent on high-risk technologies such as low-TRL materials or manufacturing methods; and
3. Capable of being integrated seamlessly into the existing global air transportation system.

II. NOMENCLATURE:

Mach Number(M): It is a dimensionless quantity representing the ratio of flow velocity past a boundary to the local speed of sound.

Angle of attack(α): It is the angle between the line of the chord of an aero foil and the relative airflow.

Co-efficient of lift(C_L): It is a dimensionless quantity relates to the lift generated by a lifting body to the fluid density around the body.

Co-efficient of drag(C_D): It is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment.

III. BOUNDARY LAYER INGESTION (BLI) IMPLEMENTATION IN D8 DESIGN

In physics and fluid mechanics, a boundary layer is the layer of fluid in the immediate vicinity of a bounding surface where the effects of viscosity are significant.

There are mainly 2 types of boundry layers depending on the flow of fluid over the surface

The laminar boundary is a very smooth flow, while the turbulent boundary layer contains swirls or "eddies." The laminar flow creates less skin friction drag than the turbulent flow, but is less stable. Boundary layer flow over a wing surface begins as a smooth laminar flow. As the flow continues back from the leading edge, the laminar boundary layer increases in thickness.

At some distance back from the leading edge, the smooth laminar flow breaks down and transitions to a turbulent flow. From a drag standpoint, it is advisable to have the transition from laminar to turbulent flow as far aft on the wing as possible, or have a large amount of the wing surface within the laminar portion of the boundary layer. The low energy laminar flow, however, tends to break down more suddenly than the turbulent layer.

Boundary layer suction is a boundary layer control technique in which an air pump is used to extract the boundary layer at the wing or the inlet of an aircraft. Improving the air flow can reduce drag.

Improvements in fuel efficiency have been estimated as high as 30%.

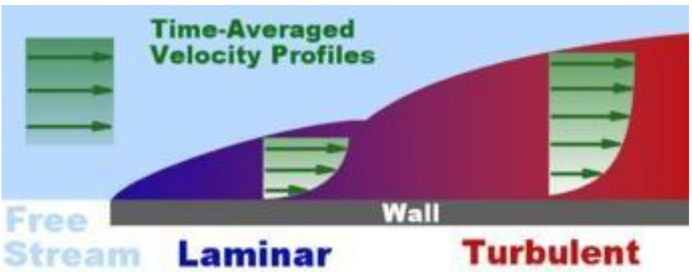


Fig.2.Boundary layer development and transition along a surface

Boundary Layer Ingestion – or BLI – is a promising idea NASA researchers are studying to reduce fuel burn in jet engines, thus reducing emissions and the cost of operating the aircraft.

At its simplest: With BLI, an airplane's engines are located near the rear of the aircraft so that air flowing over the aircraft body becomes part of the mix of air going into the engine and is then accelerated out the back.

Inside the 8' x 6' wind tunnel at NASA Glenn, engineers recently tested a fan and inlet design, commonly called a propulsor.

So, more specifically, what exactly is BLI and how does it lead to potential economic and environmental benefits?

When an airplane is flying, it has four major forces acting on it – thrust, drag, weight and lift. Thrust makes an airplane go forward, while drag tries to slow it down. Lift offsets the weight to keep an airplane in the sky.BLI deals specifically with the drag part of the equation by, ultimately, trying to reduce the total drag an airplane experiences in the sky.

It all starts with the fact that as an airplane flies through the air, a layer of slower moving air begins to build up along the skin of the fuselage and wings, which is fittingly called the boundary layer. This slower moving air causes additional drag. At the front of the airplane the thickness of the boundary layer is zero, but as the air flows back over the surface of the airplane's fuselage and wings, the layer grows thicker. By the time it gets to the rear of the airplane it can be a foot or more deep.

In a conventional tube and wing airplane, where the jet engines are hung beneath the wings, that's the end of the boundary layer story. The slower, drag-inducing airflow just continues off the rear of the airplane to mix with the undisturbed air there.

2. Reducing Drag:

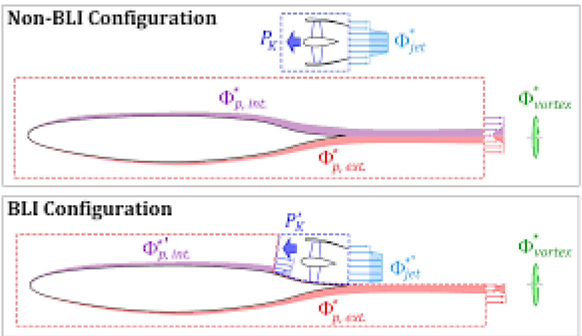


Fig.3.Comparison of air-flow for BLI and Non-BLI body configuration.

The story changes when the airplane's engines are put in the path of the boundary layer, for example, by placing them at the extreme rear of the airplane. Not mounted on either side of the tail on short pylons as seen on some airliners or business jets today, but directly atop or behind the main fuselage.

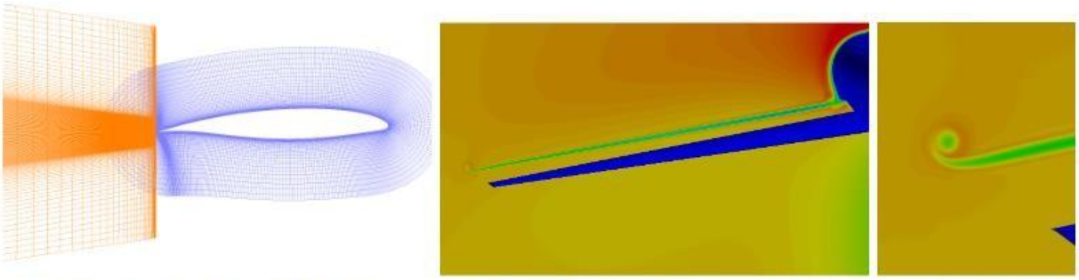
With the engines in this location, the slower, boundary layer air enters the engine – or is ingested, as in boundary layer ingestion – and is then accelerated with the rest of the air passing through the engine and exhausted out the back.

It doesn't matter if the incoming boundary layer air winds up being compressed, mixed with fuel and burned to become part of the hot jet exhaust, or if the air flow bypasses around the engine core, through the fans and out the back.

And the ingested boundary layer of air doesn't make the engines more, or less, powerful.

One of the advanced design concepts – the D8 or "double bubble" – is now a subscale model being tested in a wind tunnel at MIT. The design, developed for NASA by a team led by Massachusetts Institute of Technology, has a very wide fuselage to provide extra lift, low-swept wings to reduce drag and weight, and engines sitting above the fuselage and aft of the wings to block some noise from reaching the ground.

What does change?



(a) 2D slice of a wing and wake grid. (b) Planar cut behind the wing showing the wake and tip vortex. (c) Zoom-in view of the tip vortex.

Fig.4.:Specialized mesh for capturing wake and tip vortex.

The total amount of drag created by the slower air moving over and behind the whole airplane body is decreased because some of that slower air has been sped up again by passing through the engines.

And that's the benefit. With less total drag the engines need less thrust to push the airplane forward, which means they don't have to burn as much fuel, which reduces emissions and saves on fuel expense. It all works out very nicely on paper, but there still is an engineering challenge to overcome.

5 .Designing Engines for BLI

Let's go back to the conventional wing and tube design with the engines hanging off the bottom of the wings. In that configuration, with the airplane cruising along, the engine inlets are exposed to a nice, clean, uniform stream of air entering the engine, where the airflow is slowed down a bit to encounter the first set of fan blades.

This is ideal for engine designers because, as the fan blades turn, they experience the same environmental conditions – the same air pressure and speed – with each revolution.

But with the rear-mounted engines in the path of the boundary layer, the engine's fan blades are exposed to additional stresses every time they pass through the distorted airflow.

To better understand how to design and build an engine inlet and fan blades capable of safely withstanding those additional stresses, a NASA-led research team has been testing a BLI engine configuration in the 8' by 6' wind tunnel at Glenn.

Early results show a proper design can be achieved, but more work needs to be done to ensure the solution – which could require a heavier, less aerodynamically efficient engine design – doesn't cancel out the fuel burn efficiencies that come from reducing overall drag through BLI.

NASA's aeronautical innovators and its industry partners are studying several airplane concepts that could take advantage of BLI's contributions to reducing fuel burn.

One or more of those designs that includes BLI could be incorporated into a series of X-planes NASA hopes to build and fly within the next decade to demonstrate advanced technologies and accelerate their adoption by industry.

Fig.5: BLI engines for D8 confugiration

D8 Background:

D8 concept originated from NASA N+3 phase 1 study.

The aim was to develop a conceptual configuration based on system optimization studies for an ultra efficient passenger transport aircraft, to develop aircraft that would substantially reduce fuel consumption, noise and emissions of commercial aircraft.

The aircraft has a twin-aisle lifting body fuselage with integrated Boundary layer Ingesting propulsion, due to which the drag reduced significantly leading to better fuel economy.

The experimental investigation on D8 concept aircraft validated up to 8% power benefit as compared to commercial aircrafts with early conceptual tool estimates.

Configuration and conceptual design:

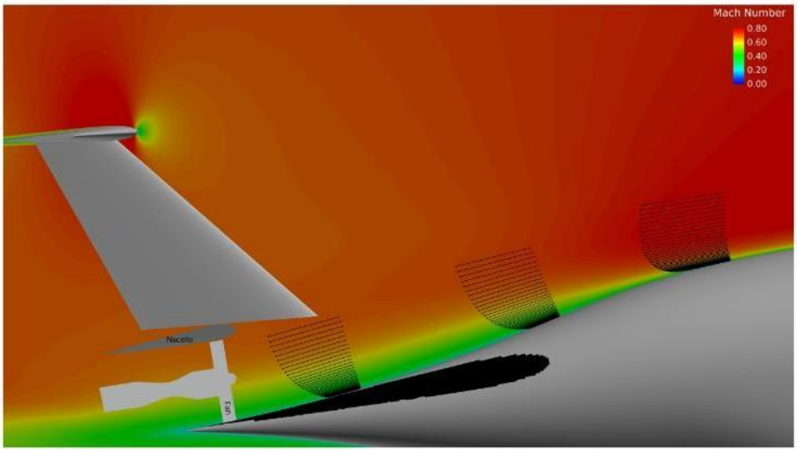


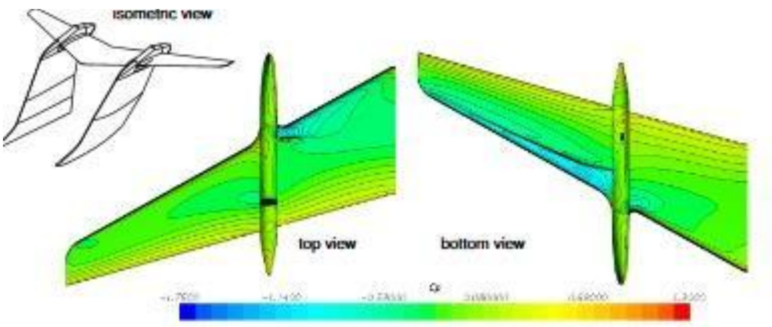
Fig.6.:A close up of the aft end of the D8 aircraft in free-air at M=0.72,α= 4◦showing that the shape of the fuselage in the rear acts as a diffuser for the flow entering the fan.

The studies regarding the conceptual design for the aircraft set an approximate speed at 0.8 Mach. However the experimental observations put the approximate speed between 0.78-0.8 Mach.

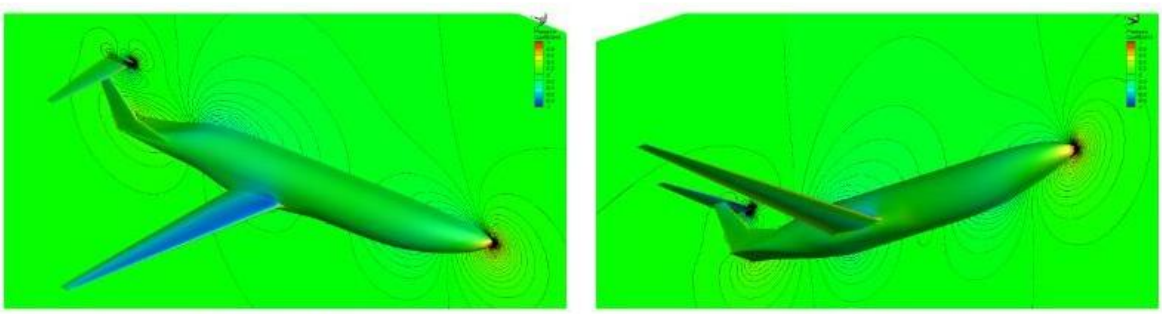
The operation ceiling for the aircraft is about 20,000 ft. with key features including the 250 KIAS speed restriction under 10,000ft. Further studies on the aircraft showed that for D8 conceptual design with 200 mile cruise to alternate of 20,000 ft. and 30 min. hold at 1500 ft., the total fuel reserve mission turns out to be 10% as compared to other aircraft having 20%.

Main features include, pi-tail, double –bubble fuselage, wide body, which results to more gliding effect increasing the efficiency and overall performance of the aircraft.

Aerodynamic design and analysis:

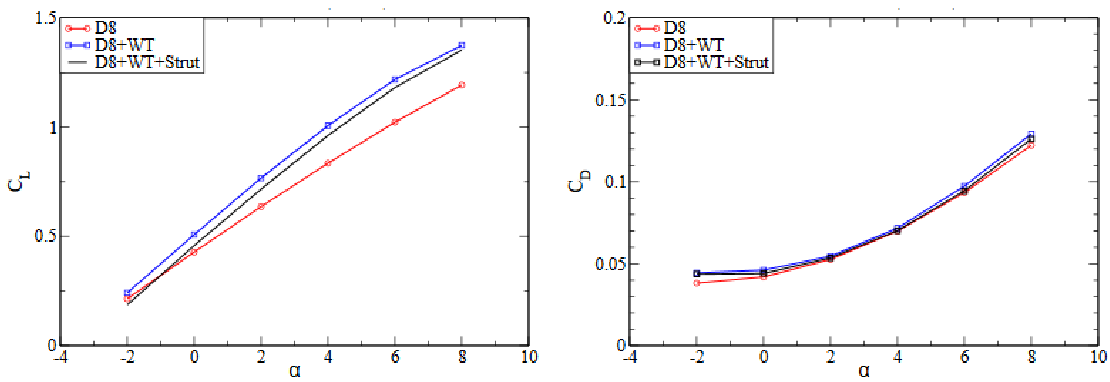


a.



(a) View of top. (b) View of bottom.

b.



(a) C_L (b) C_D

Fig.7.: (a)Analysis of Pi-tail design; Top view of static pressure coefficient contours on the horizontal tail (vertical tail hidden), Bottom view of static pressure coefficient contours on the horizontal tail (vertical tail hidden). (b)Simulations depicting pressure contours on D8 design and comparison of lift and drag coefficients.

The aircraft has up-swept nose and wide body for less air drag and better carryover lift as compared to straight nose derived from Boeing 787 max aircraft.

The aircraft uses beaver-tail to ensure clean aerodynamics as well as the fuselage contributes roughly to 17.8% of the overall lift which also reduces the noise significantly.

The aircraft has a unique tail design, pi-tail design which is a forward swept tail which manages the drag at transonic speeds while maintaining the structural integrity of the aircraft.

IV. Conclusion:

A conceptual design of a 0.78M, double-bubble, boundary-layer ingesting D8 aircraft was completed to provide higher fidelity estimates for weight and performance. There is a clear need to continue development of the D8 concept, which is potentially a viable replacement for the current generation of single-aisle tube-and-wing aircraft. Further development is required to mature the concept, especially in regard to the BLI propulsion system, its integration with the airframe, and the details of the double-bubble fuselage design and manufacturer. These studies should be initiated in the near future. One potentially necessary risk reduction activity is thought to be the design and eventual manufacturer of a prototype aircraft, or X-Plane. A D8 X-Plane would demonstrate the D8 configuration performance and operability across the flight envelope, which is one of the largest remaining challenges associated with the configuration.

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