

**“CONCEPTUAL DESIGN AND AERODYNAMIC STUDY OF
JOINED- WING BUSINESS JET AIRCRAFT”**

A Main project report submitted to the
SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY, CHENNAI

In partial fulfillment of the requirements for the award of the Degree of

BACHELOR OF ENGINEERING

IN

AERONAUTICAL ENGINEERING

Submitted by

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(DEEMED TO BE UNIVERSITY)**

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DEPARTMENT OF AERONAUTICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **B. SARATH CHANDRA (37260036)** and **V. SAI THARUN (37260034)** who carried out the project entitled **"CONCEPTUAL DESIGN AND AERODYNAMIC STUDY OF JOINED- WING BUSINESS JET AIRCRAFT"** under our supervision from SEPTEMBER 2020 to MARCH 2021

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Submitted for Viva voce Examination held on_____

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External Examiner

DECLARATION

I B. SARATRH CHANDRA (37260036) hereby declare that the Project Report entitled **“Conceptual Design and Aerodynamic Study of Joined- Wing Business Jet Aircraft”** done by me under the guidance of Dr. /Prof./ **Mr. VENKATESH S and Dr. VALARMATHI** at is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering / Technology degree in **Sathyabama institute of science and technology**.

DATE:4/3/2021

PLACE: Chennai

SIGNATURE OF CANDIDATE

DECLARATION

I **V. SAI THARUN (37260034)** hereby declare that the Project Report entitled “**Conceptual Design and Aerodynamic Study of Joined- Wing Business Jet Aircraft**” done by me under the guidance of Dr. /Prof./ **Mr. VENATESH S** and **Dr. VALARMATHI** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering / Technology degree in **Sathyabama Institute of Science And Technology**.

DATE: 04/03/2021

PLACE: Chennai

SIGNATURE OF THE CANDIDATE

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Abstract

For a medium-range box wing aircraft, a conceptual design optimization methodology was developed. A baseline conventional cantilever wing aircraft was optimized alongside a baseline box wing aircraft for the same mission and payload. By comparing traditional cantilever wings to the mass of the fore and aft wings of the box wing aircraft, an empirical formula for mass estimation of the fore and aft wings of the box wing aircraft was established.

A computational analysis was carried out as part of the technique to examine various wing/tip fin fixities using a statically loaded idealized box wing configuration. The best joint fixity was calculated by comparing stress distributions in finite element torsion box models with aerodynamic requirements. According to the results, the rigid joint is the better choice.

On the box wing aircraft, experiments were also conducted to explore the structural consequences of modifying only the tip fin inclinations. The angle the tip fin makes with the aircraft's vertical body axis is referred to as tip fin inclination. There were no major differences in wing structural design drivers as a result of tip fin inclination.

The methodology developed was used to perform stochastic and deterministic optimization routines on the baseline box wing aircraft, with the variables being wing area, average thickness to chord ratio, and sweep angle. The traditional aircraft design worked and acted similarly to the comparable in-service aircraft, providing some evidence for the methodology.

Longitudinal stability testing indicated that the box wing's extra fuel power in the fins could be used to minimize trim drag. The traditional cantilever wing aircraft's short duration oscillation was found to be adequate, but the box wing aircraft's oscillation was found to be unacceptable, necessitating the use of stability augmentation systems. The box wing's field and flight results were impressiv

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Introduction

Background

Aviation has improved dramatically in the last 40 to 50 years in terms of aerospace materials, theoretical aerodynamics, avionics, and jet engine performance. However, the search for the next potential airliner configuration that will result in much greater fuel efficiency gains as well as decreases in noise and noxious emissions is already ongoing⁵. This is because current civil transport aircraft types, such as the Boeing 707 (Fig. 1.1), seem to have hit their optimization limit, reigniting interest in innovative aircraft designs.

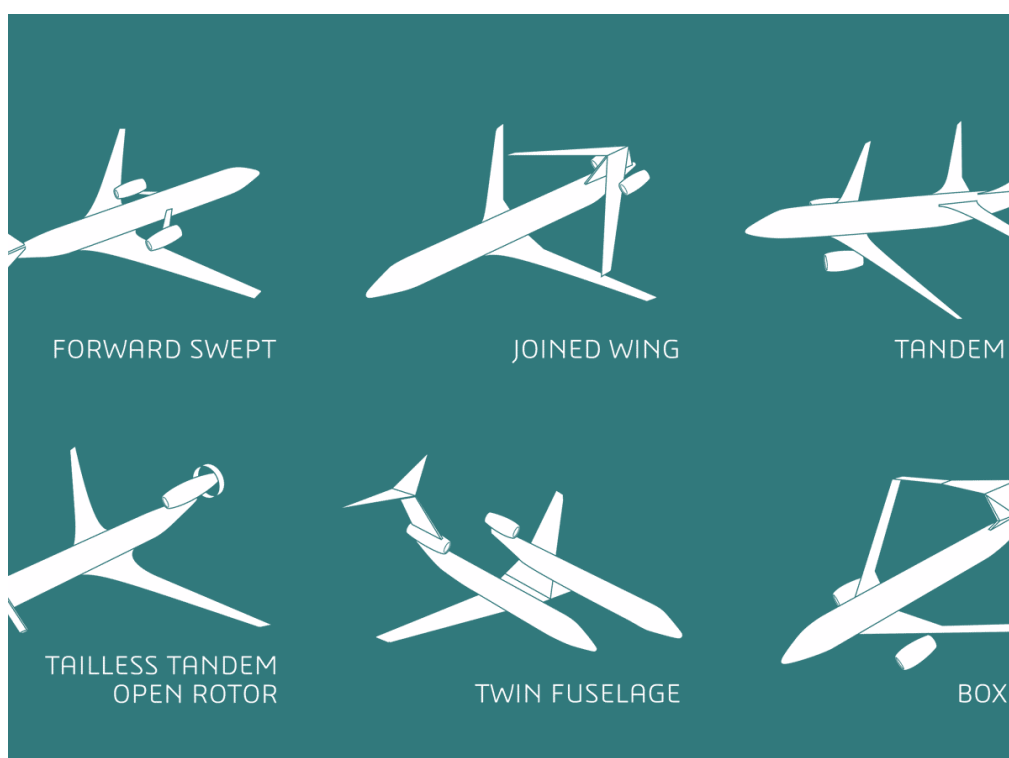


States, companies, and academics have all tried to forecast the future. In terms of aerospace materials, theoretical aerodynamics, avionics, and jet engine performance, aviation has improved significantly in the last 40 to 50 years. However, the hunt for the next possible airliner design that can result in much greater fuel efficiency benefits as well as noise and noxious emissions reductions is already ongoing⁵. This is due to the fact that existing civil transport aircraft types, such as the Boeing 707 (Fig. 1.1), seem to have reached their optimization limits, reigniting interest in new aircraft designs. Several efforts have utterly failed.



In the early twentieth century, Munk⁷ and Prandtl⁸ evaluated the box/joined wing aircraft configuration as well as other non-planar wing ideas. Non-planar lifting surfaces and box/joined wing aircraft configurations have been studied by researchers such as Wolkovitch⁹, Kroo¹⁰, Henderson¹¹, and Frediani¹² in recent years. The claimed potential of box/joined wing aircraft to minimize structural weight and direct operating costs has made it a contender for future consideration as a configuration. A 1% reduction in drag on an airliner saves 400,000 litres of fuel and thereby 5000 kg of toxic emissions, according to Schneider¹³. Research Objectives and Goals

The aim of this research is to provide a computational architecture and optimization approach for box wing transport aircraft. You'll need to consider the structural, aerodynamic, stability, and control issues that come with box wing designs in order to do so.



1. To provide a correction coefficient for box wing aircraft wing mass estimation.
2. To examine the fixity of the wing/tip fin joint in box wing aircraft.
3. To examine the orientation of a box wing aircraft's tip tail.
4. Develop a new MDO strategy for planes with box wings.
5. Examine the control and stability of box wing planes.
6. To study the economics of box wing planes.

The Structure of the Thesis

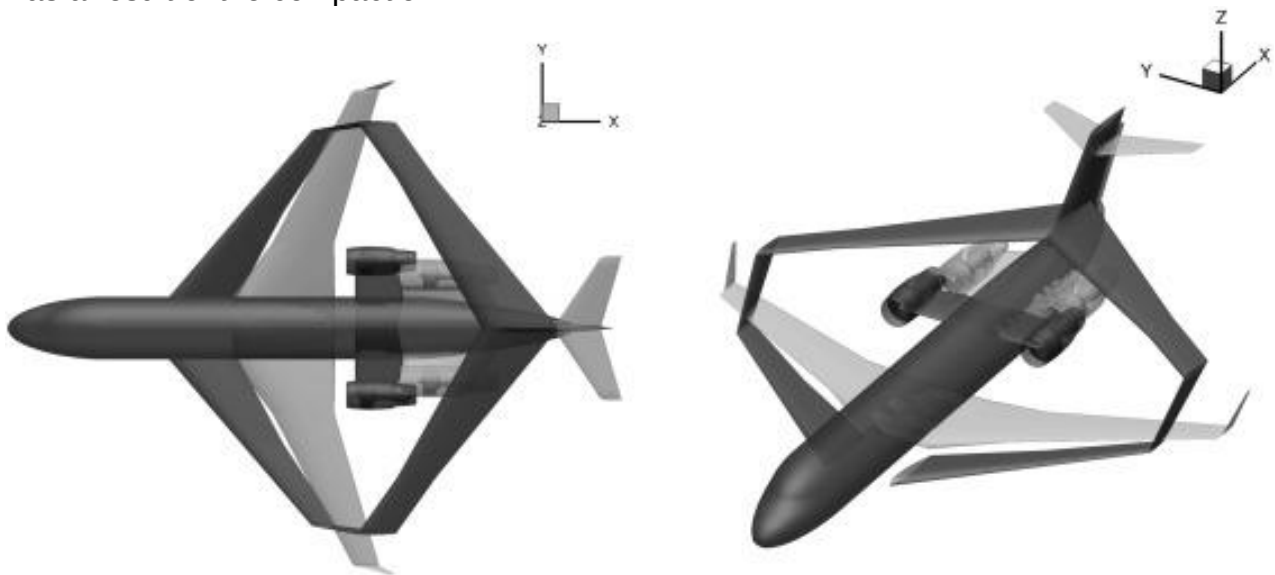
This thesis starts with an analysis of literature on joined/box-wing aircraft before introducing the wing mass calculation correction coefficient. Until looking at the wing/tip fin joint fixity, the structural implications of box wing tip fin inclination are analyzed. Then, using the developed design/optimization approach, case studies of MDO are presented. The stability and control inquiries of the box wing are discussed next, followed by the CAD implementation and debate. The paper ends with some conclusions and research proposals for the future.

A Review of the Literature

Joined Wing

While Munk and Prandtl worked on related ideas prior to this time, they are credited with the bulk of the literature on joined/box wing aircraft. He is credited by most historians as having performed the first detailed study on the joined/box wing aircraft configuration. The joined/box wing aircraft configuration is regarded as a highly engineered system that combines structural and aerodynamic properties in novel ways. Light weight, high stiffness, reduced wetted area, and low transonic drag, as well as a high trimmed overall lift coefficient, mild induced drag, and less parasite drag, are all advantages of joined/box wing aircraft. According to the report, joined wing aircraft weigh 65 to 78 percent less than traditional planes with identical aerodynamics. Bell¹⁵ agrees, arguing that a joined wing's shorter span eliminates the aircraft's overall weight and reduces the bending moment on wings by shortening the moment-arm. Weight can be saved, according to Wolkovitch⁹, if the geometric parameters of the joined wing, such as sweep, dihedral, taper ratio, and joint direction, are correctly chosen (as a fraction of span). He goes on to say that as wing sweep is reduced, the joined wing's relative advantage increases. The susceptibility of structural weight in joined wing aircraft to wing sweep was investigated. It also claims that weight can be saved by maximising the internal wing arrangement, with the wing box covering the portion of the airfoil between 5% and 75% chord, and that the geometric chord of a joined/box wing should be taken into account.

to be about 65 percent of the conventional counterpart According to him, the bent plane of the joined wing would induce a forward bending moment around the vertical axis. To counteract this bending moment, Wolkovitch⁹ proposes that the structural material distribution be as far away from the inclined bending plane as possible. This necessitates that the upper leading edge and lower trailing edge of a joined wing have the most structural material available, as seen in Fig. 2.1. Blair and Canfield developed a 17-step integrated modelling method for producing high-fidelity models. Analytical weight calculations for joined wing concepts have shown that this design saves weight as a result of the compaction.



Airfoil Problems

He also recommends using natural laminar flow airfoils. Addoms¹⁸ agrees with this opinion. Biplane configurations, according to Addoms¹⁸, include airfoils with significantly different camber than monoplane configurations. Since biplanes use monoplane airfoils, they induce premature separation and, as a result, a low maximum lift. Wolkovitch⁹ summarises airfoil modelling technology in light of the emerging state of the art, arguing that using off-the-shelf monoplane airfoils for such configurations is inconvenient and unnecessary. Bell¹⁵ points out that when it comes to stalling, the rear wing causes an upwash on the forward wing, which causes a downwash on the back wing for joined/box wings. He claims that when the front wing has a higher angle of attack, it often stalls first, forcing the plane's nose to drop. The joined/box wing configuration has a number of advantages. Wolkovitch⁹ also argues that since the chord of a joined/box wing's airfoils determines its effective beam depth, d , as seen in Fig 2.2, the thickness of the airfoils is secondary, making joined/box wings suitable for thin airfoils. As a consequence, relative to a cantilever wing, there are less weight penalties. He suggests using twin fins that are about the same size.

A box-wing aircraft's structural configuration. The authors find that tip fin inclination has a significant effect on the torsional force, drag wise shear force, and drag wise bending moment ratios in the wings of a box-wing aircraft when five separate tip fin inclinations are considered. In comparison, tip fin inclination induced only slight changes in out-of-plane bending moment and shear force distributions. As a result, wing structural geometry drivers did not alter substantially as a result of tip fin inclination. Flutter and divergence analyses of the box-wing configuration, on the other hand, are recommended by the authors for a more detailed aeroelastic investigation of the elevator.

In plan view, Wolkovitch⁹ suggests that the fore and aft wing tips do not overlap, as this reduces aerodynamic efficiency. Bagwill and Selberg¹⁹, as well as Frediani¹², share this viewpoint. Filleting the fore wing and moving it forward on the fuselage was often suggested by Wolkovitch. Filleting the underside of the aft wing and the vertical tail is also recommended to reduce separation. Wolkovitch prefers wash-out for the fore wing and wash-in for the aft wing when it comes to wing twist. He also assumes that the aft wing should have less camber than the fore wing.

Cesnik and Brown²⁷ explored how new piezoelectric material technologies could be used to monitor induced strain and wing warping in a joined-wing aircraft configuration. This thesis used a proposed structure that takes into account the wing's nonlinear deflection behaviour, the effects of anisotropic piezoelectric composites embedded in the tissue, and the wing's unsteady subsonic aerodynamic forces. The value of the rear wing's abrupt lack of stiffness (or buckling), which undermines vehicle credibility in a joined wing configuration, is illustrated by their findings.

Joints between the wings

One of Wolkovitch's discoveries is that a 70 percent inter-wing joint position provides the lightest wing structure for the same span, while a tip-jointed arrangement produces a heavier wing structure. He also says that the tip-jointed design is 20% lighter than a conventional configuration due to the shorter span. To minimise the effective span/depth ratio, he recommends using high dihedral (both positive and negative) and low sweep angles (both positive and negative).

Aerodynamic issues are a normal occurrence.

Positively staggered joined wings are more aerodynamically efficient than negatively staggered joined wings, according to Bagwill and Selberg. When the upper wing is ahead of the lower aft wing, it is referred to as positive stagger, and when the opposite is true, it is referred to as negatively staggered. According to Mamla and Galinski, who agree with Bagwill and Selberg¹⁹, positive stagger joined wings are more aerodynamically efficient than negative stagger joined wings. Smith and Stonum analysed the aerodynamics of a variety of joined-wing aircraft in a wind tunnel. They discovered that joined wings have excellent aerodynamic performance, as well as enough stability and control over their entire flight path. In box wing aircraft, Schiktanz and Scholz studied the tension between aerodynamic performance and static longitudinal stability. To obtain inherent stability in their model, the fore and aft wing lift coefficient ratios were improved in favour of the fore wing, and the airframe, engines, fuel, and payload were all mounted near each other. Using lifting line theory and mild perturbation acceleration potential, Demasi³⁴ researched the conditions for reduced induced drag of closed wing systems and c-wings. He used analytical and experimental approaches to solve the problems, and his findings indicate that closed wing structures (such as biplanes) have about the same performance as open wing structures

The design of this research

Box wing, biplane, and diamond wing are all names for joined/box wing aircraft. The key difference is in the philosophy of wing design and function. To summarise, the key difference between the two aircraft configurations is that, although both wings in the box wing produce equal amounts of lift, the fore wing in the classic joined wing produces about 80% of the total lift. Frediani's research on the joined/box wing aircraft configuration was inspired by Prandtl's "best wing system," in which he showed that a closed rectangular lifting system can provide "the smallest possible induced resistance for a given span and height." If spans are equal, Prandtl⁸ finds that all biplanes have less induced drag than comparable monoplanes, and that biplane drag decreases as the wing gap increases." If Prandtl's "best wing system" is applied to current aircraft with a wing gap/span (h/b) ratio of 10-15%, Frediani¹² believes that induced drag reductions of up to 20-30% could be achieved. According to Frediani, a box wing's aerodynamic performance, Prandtl's "best wing system," or Plane, is closely linked to flight stability, and the challenge is to achieve a stable aircraft with equal lift on both wings. During a cruise in still air, induced drag accounts for approximately 43% of overall aircraft drag, according to Frediani. Consequently, if it is significantly decreased, it can result in benefits such as reduced aircraft weight and thrust requirements, as well as less negative environmental effects. Frediani's PrandtlPlane has already been flight tested at a scale of 1:5, with findings that fit the aircraft's mathematical model³⁹

Framework for Methodology

3.1 Tool for Design and Optimization

3.1 For this analysis, a design/optimization tool was developed. Microsoft Excel was used to create the design tool since it is a widely used programme that can be improved with Visual Basic for Application (VBA) algorithms. Using deterministic gradient search and stochastic non-gradient search algorithms, the tool was designed to solve multi-objective and multi-disciplinary optimization problems. The design tool's architecture is depicted in Figure 1.

Baseline architecture, geometry concept, wing structures, mass, aerodynamics, performance, and cost modules are all part of version 3.2. The arrows indicate the tool's optimization routines' direction and routes. The tool was initially developed for box wing optimization, but it was adapted and extended to traditional cantilever wing aircraft as well.

Takeoff distance, cruise speed, and landing distance are the constraints in the tool's MDO configuration, while the parameters are the number of engines, fuselage diameter, airfoils, and span. Wing sweep, thickness to chord ratio, wing area, and wing gap are design variables, while minimization of all up mass, fuel per passenger per nautical mile, and DOC per nautical mile are objective functions or measurements of merit.

The geometry specification module received initial design variables from the baseline designs, as shown by the arrows in Fig 3.1. The wing structures and aerodynamic modules were then fed these inputs. Loads were created by the aerodynamic module and fed into the wing structures module. The wing masses were fed into the mass module as outputs from the wing structures module. The aerodynamics module's outputs were the powers of lift and drag, all of which were entered into the output module. The mass module provided weight inputs to the output module as well. To satisfy the objective functions, local iterations were performed between the mass, aerodynamics, and performance modules. Cost optimization and stability and control were investigated using the computations from the output module

Module for Wing Structures

The wing structures module estimated the wing masses using inputs from the geometry description module and loads from the aerodynamics module. The required algorithms for estimating the wing mass of the box wing aircraft were determined using off-line finite element analysis. This was then incorporated into the wing structures module, the specifics of which can be found.

Module of Masses

The mass module is extended to include the zero-fuel mass and fuel mass submodules. The running empty mass and payload routines make up the zero-fuel mass sub module. The fuselage, nacelle, and power plant, tail fin, landing gear, tip fin, fixed equipment, wing mass, and empty mass routine are broken down into the fuselage, nacelle, and power plant, tail fin, landing gear, tip fin, fixed equipment, and empty mass routine.

Subroutines for manipulating surfaces. The wing mass inputs for the operating empty mass routine come from the wing structures module. The wing sweep angle, wing gap, and thickness to chord ratio subroutines all affect the wing mass. Howe 53 and Jenkinson 54 empirical mass estimation formulae are used in both modules and submodules. Using VBA codes, these modules are iterated until the best design is found. For the wing structures and mass modules, two codes were written. Range Seek, a macro one, optimises 741 aircraft samples, all of which are modifications of the baseline box wing aircraft according to the MDO outlined in Chapter 2.5. Select AUM, Macro two, stochastically selects samples from Macro one's output using predetermined cut-off parameters. Fore and aft wing sweep angles are the criteria. Appendix A includes information on the Spectrum Seek and Pick AUM macros one and two.

Module on Aerodynamics

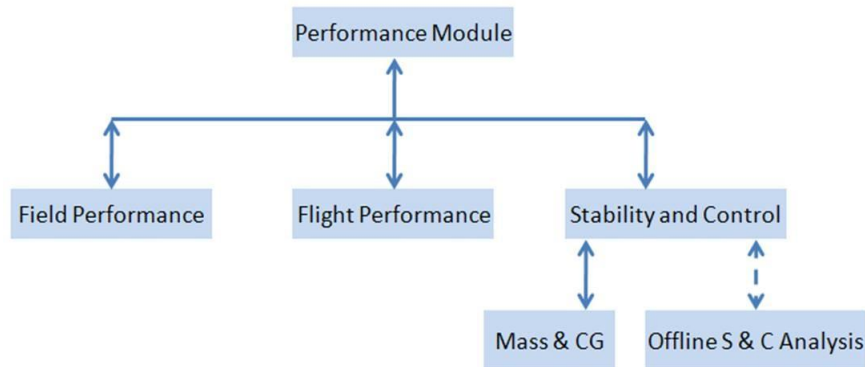
The lift loads and drag submodules make up the Aerodynamics module shown in Figure 3.3. The lift loads module generates lift loads on the wings using an off-line vortex lattice tool named Athena Vortex Lattice (AVL)⁵⁵. The zero lift (friction, shape, and interference drags) and induced drag routines make up the drag sub module. The wing gap subroutine is a feature of the induced drag routine. The Zero lift drag routine uses methods described in Hoerner⁵⁶, Roskam⁵⁷, and Jenkinson et al 54 to calculate the drag of components such as the fuselage, nacelle, engine pylons, landing gear blisters, tail fins, and tip fins. A factor that takes wing shield, secondary objects, and wave drag into account.

upwards The total sample drag is determined by adding the drag from the wings as a function of wing sweep (wing sweep subroutine) and thickness to chord (thickness to chord subroutine) ratios. A VBA macro called Pick Do is used to optimise zero lift drag as a function of sweep angle (see Appendix A). AVL is used to get induced drag inputs.

Module of Performance

The ground, flight, and stability sub-modules, as well as the control sub-module, make up the performance module (see Fig. 3.4). Using Jenkinson⁵⁴'s sequence and process, the field performance sub-module includes routines for computing the field performance of selected outcomes from the mass and aerodynamic modules. The flight performance sub-module uses the Breguet range equation to determine flight performance and graphs the results.

Graph representing payload range Trim, short duration oscillation, and phugoid analysis are performed by the stability and control sub-module using off-line tools.



Module for Costs

The DOC, fuel per pax per nm, DOC per nm per seat, and aircraft market price sub-modules make up the cost module shown in Fig 3.5. The sequence and method outlined in Roskam58 are used in all sub-modules. A VBA code called Ac Cost is used to optimise the cost modules (see Appendix A). For all aircraft models in the envelope, the code performs an iterative sequence between the sub-modules to present the DOC, fuel per pax per nm, DOC per nm per seat, and aircraft market price.

Module of Stability and Power

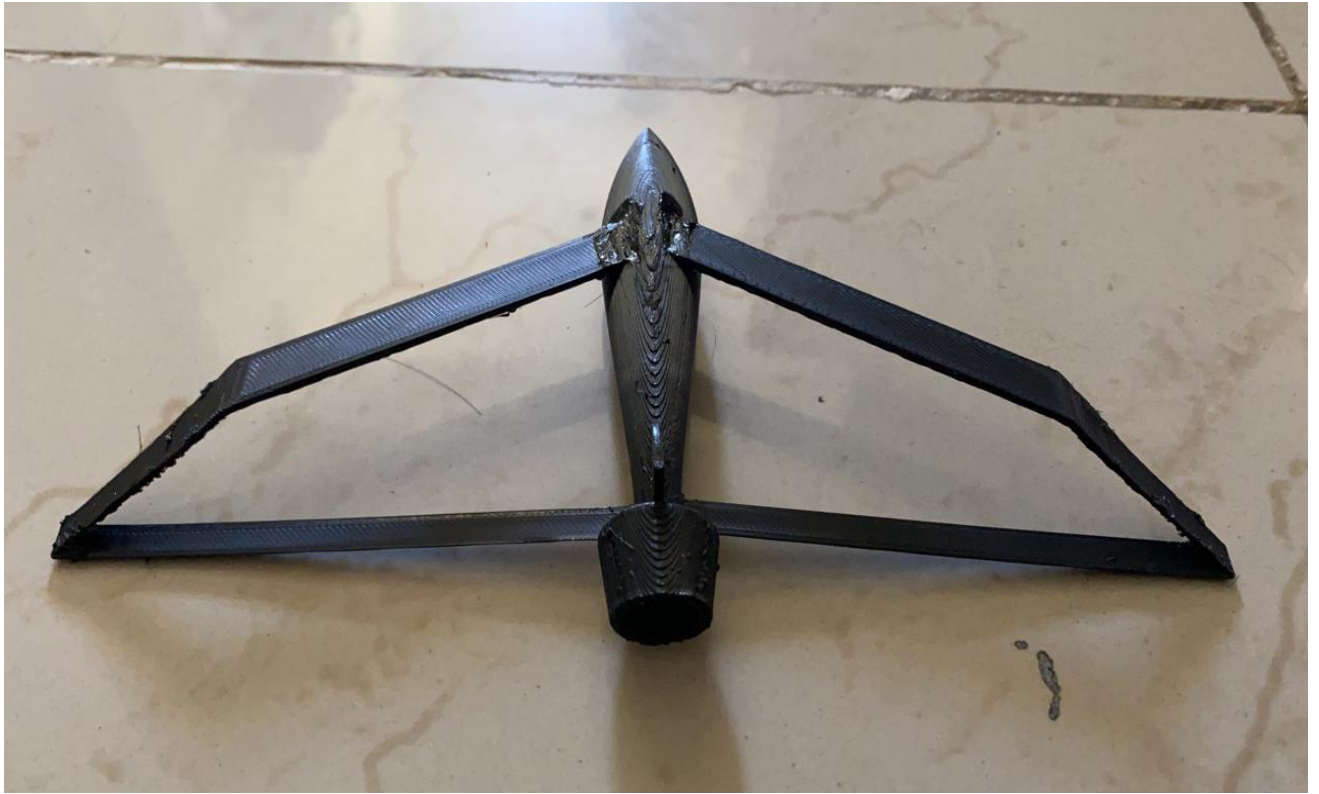
The trim analysis, phugoid analysis, and short time analysis submodules make up the stability and control module seen in Fig 3.6. It is not connected to the internet and receives data from the performance module. Trim, phugoid, and short term oscillation analysis is conducted in each module, as their names indicate. Only versions that could be trimmed were used for the phugoid and short term research. Section 3.7 contains further information about the stability and control tool that was used.

Aircraft with a Medium Scale Box Wing as a Starting Point

Smith and Jemitola's baseline aeroplane, which is adapted from Jemitola61 and seen in Fig 3.7, is used for this analysis. It's a box wing airliner with a gross takeoff mass of 127760kg and a wing span of 37.6m with a length of 4000 nautical miles. The gross areas of the fore and aft wings are 118.32m² each, with sweep angles of 40 and 25 degrees, respectively. The fuselage's overall length is 46 metres, and its full width is 5.6 metres. Appendix B includes background information on the baseline aircraft as well as other aircraft parameters.

Conventional Cantilever Aircraft as a Starting Point

A baseline conventional cantilever plane, Fig 3.8, was also obtained from Jemitola 61 for comparative purposes. It has a gross takeoff mass of 136000kg and a wing span of 47.0m, making it a 4000 nautical mile length airliner. The wing sweep angle is 30 degrees, and the wing gross area is proportional to the total of the fore and aft wings of the baseline box wing aircraft at 236.64m². The fuselage's overall length is 46 metres, and its full width is 5.6 metres. Appendix B contains additional aircraft parameters.



of a given aircraft geometry. It uses a vortex lattice model for the lifting surfaces, together

Loads that are aerodynamic

AVL provided the load distributions for the box and cantilever wings. The contributions to torsion from the airfoil section properties and the moment arm between the lift application point and the elastic axis of the torsion box were included in the load distributions. At sea level, at plan diving rpm, VD, and maximum take-off weight⁶⁴, a 2.5g case limit load was assumed. Other loading parameters, such as different potential variations of power deflections and gust loadings, should be analyzed in a final design report. However, the assumptions made in this preliminary analysis are thought to be satisfactory.

Tool for Finite Element Analysis

This study's finite element analysis was performed with Strand. An aircraft wing could be modelled using a variety of Strand⁷ components. For the wing finite element models, only beam, plate, and brick components were considered. Because of this, the beam part was selected.

Finite Feature Research and Aerodynamic Load

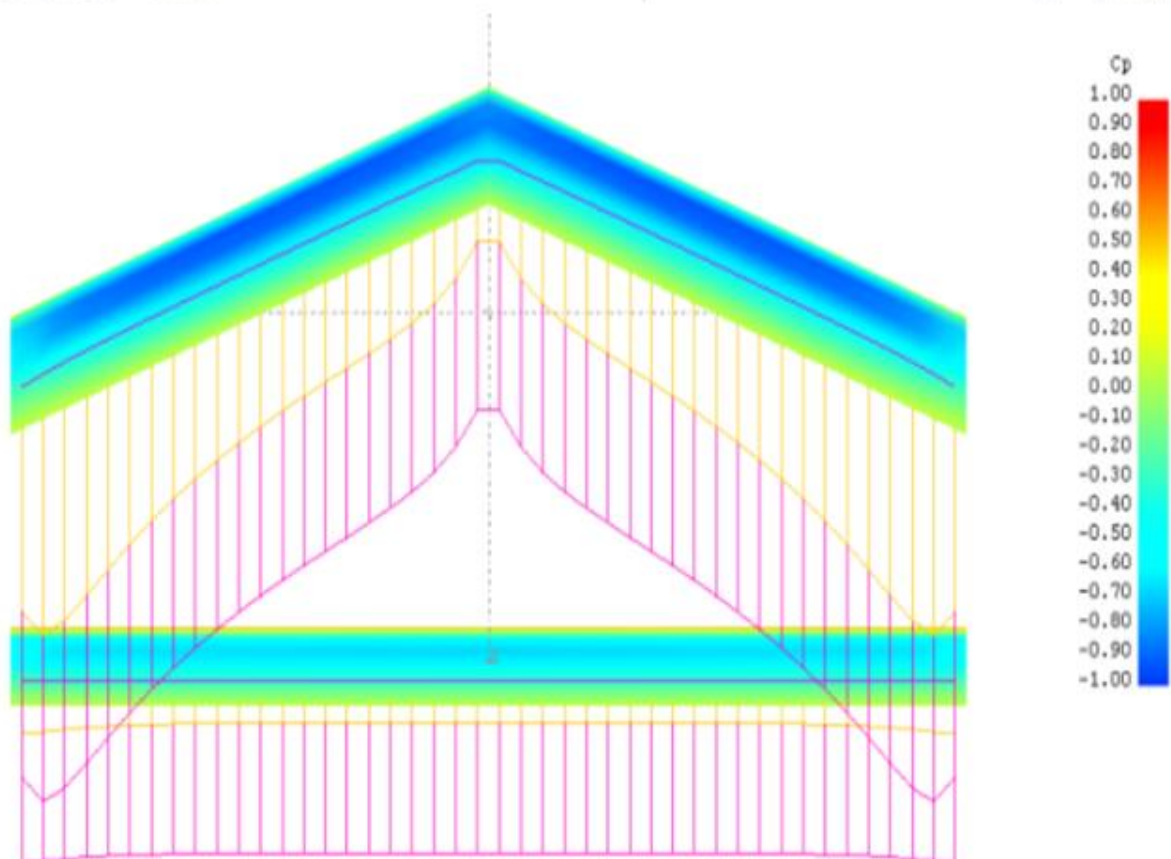
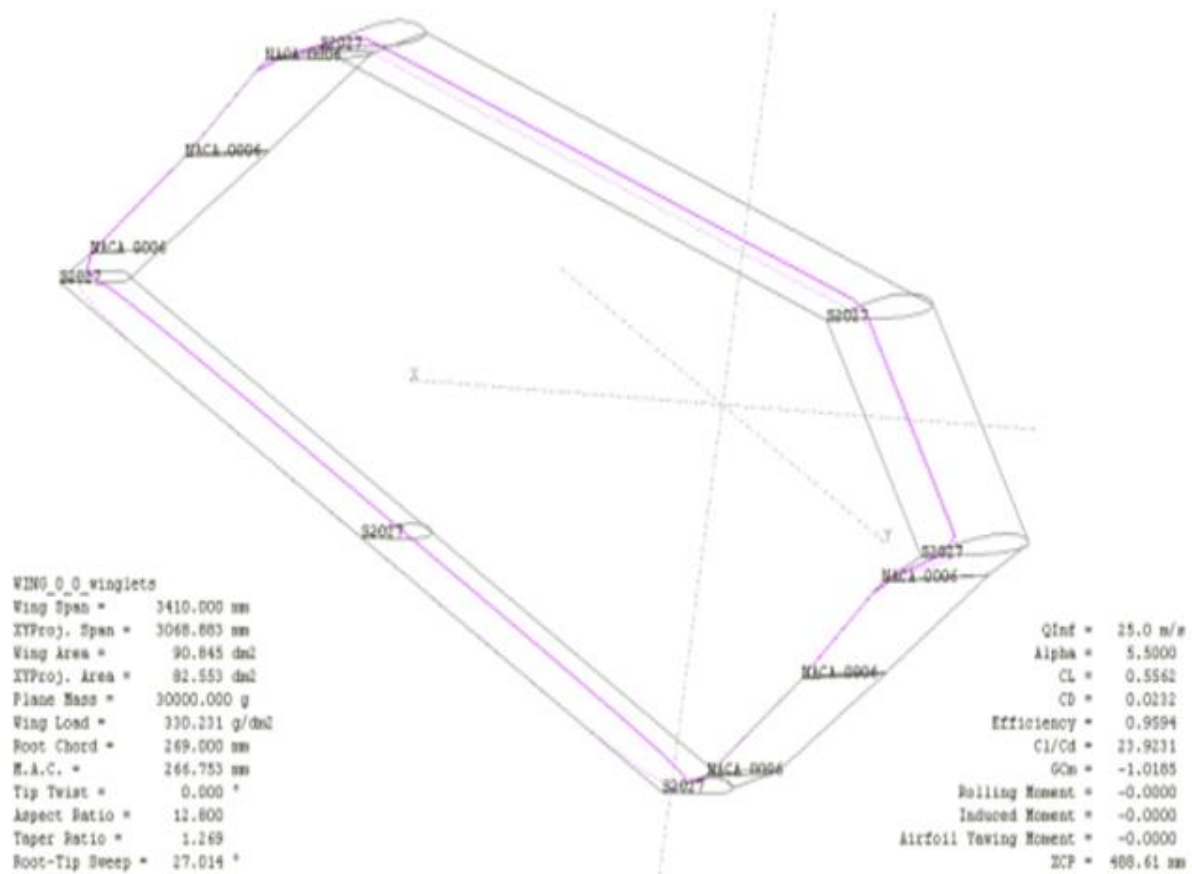
The aerodynamic loads that were used to investigate the wing/tip fin joint fixity are listed in Section 5 of Chapter 3. Similarly, the finite element analysis and structural sizing procedures used are described in Sections 6, 7, and 8 of Chapter 3.

The aerodynamic loads that were used to investigate the wing/tip fin joint fixity are listed in Section 5 of Chapter 3. Similarly, the finite element analysis and structural sizing procedures used are described in Sections 6, 7, and 8 of Chapter 3. The effects of a cantilever wing, which was tested alongside the other joint types, were included in the comparative study of the moments and forces in the four wing tip joint configurations studied. It was actually the fore wing of a box wing with the joint disconnected, and it offered a contrast to the box wing's patterns.

Before running the test, the trim load was measured and applied to the total mass of the aircraft. We were AVL55.

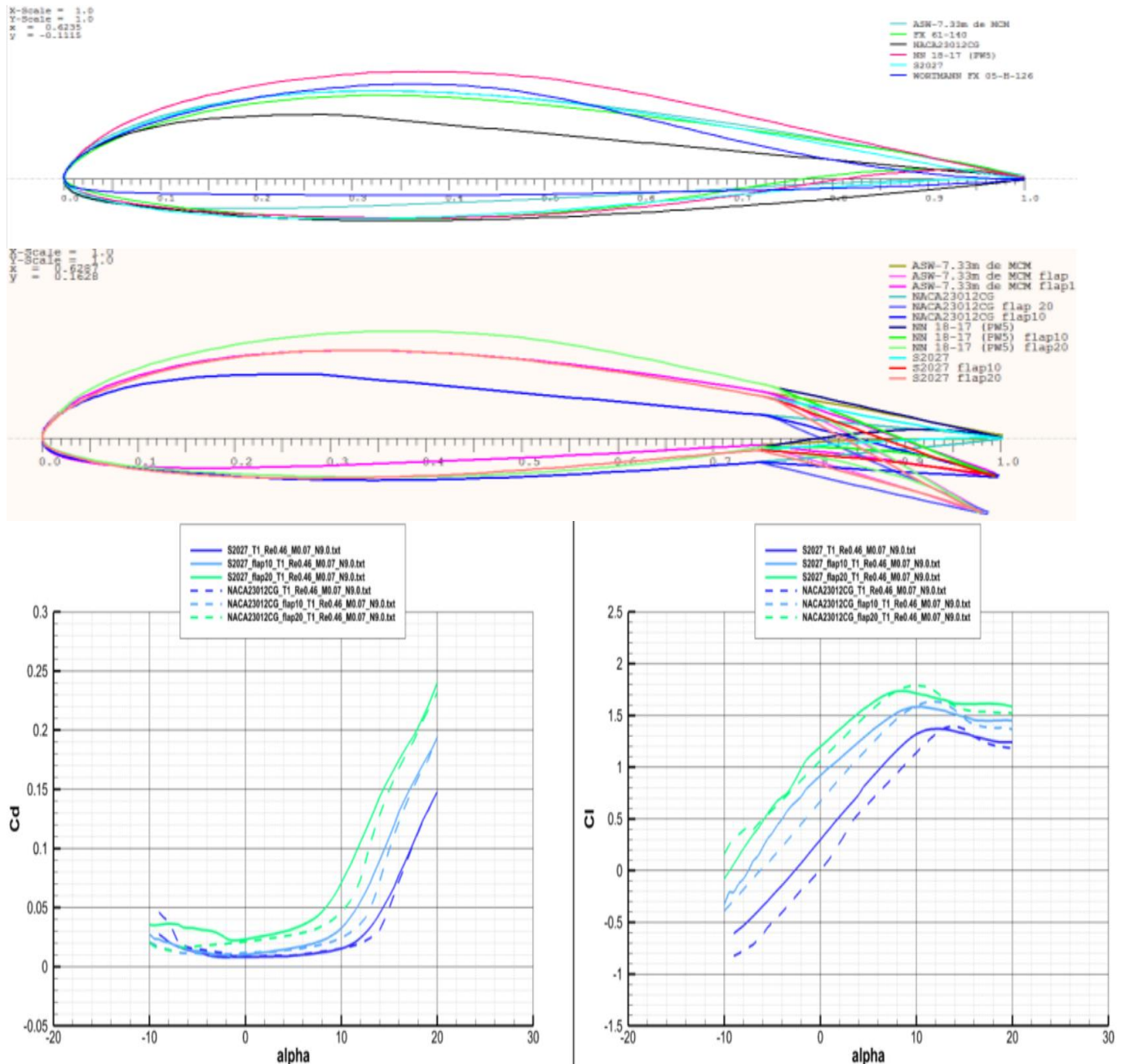
CFD ANALYSIS

A collection of geometrical features has been considered in CFD research conducted at The Institute of Aviation to determine their effect on aerodynamic characteristics. Since Warsaw University of Technology specified the wing structure and surfaces, we defined our collection as follows: airfoils and twist angles of both front and rear wings, form of a fuselage, fillets between fuselage and wings, shape of wingtip plates, influence of landing gear, influence of relation between rear wing, fuselage, and propeller duct. The shape of the center body (engine cover including propeller spinner) and its effect on separation within the propeller duct were also taken into account. Almost all configuration options are available.

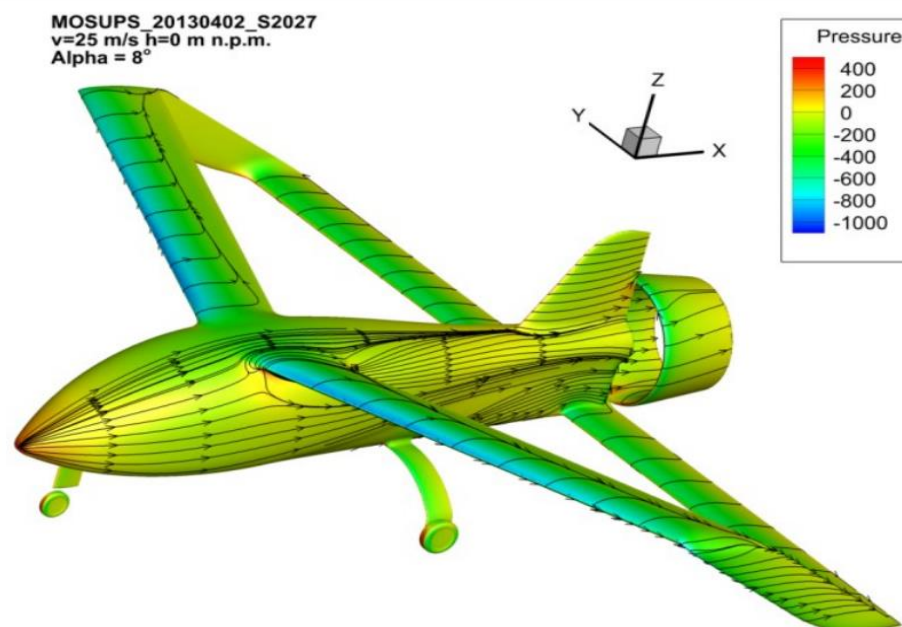
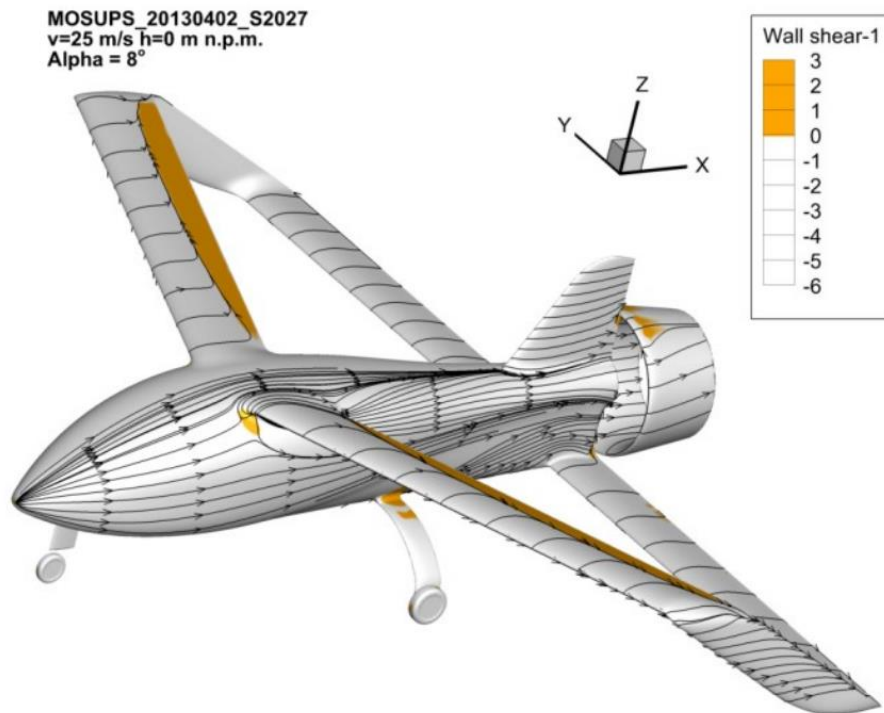


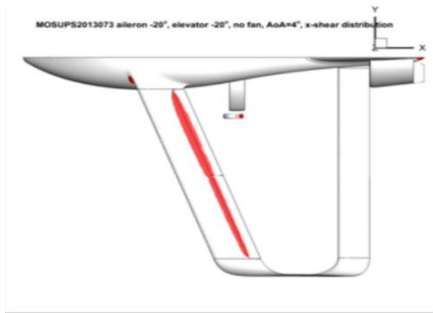
ANALYSIS OF AERFOIL

Maximum lift, separation, and the ranges of laminar and turbulent flows (drag bucket phenomena) are all well resolved this way. It's worth noting that laminar separation can occur on RC scale objects (for example, 0.1 - 0.2 m of chord), requiring such objects to withstand additional, and often more risky, flight conditions than normal "general aviation" aircrafts. This software has been tested against experimental data and has shown to be accurate in analysing the object size of RC models, which is the same size as our demonstrator.

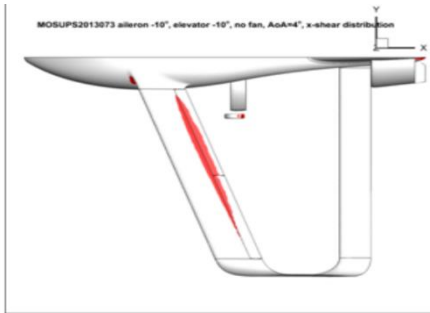


XFLR5 was used to achieve a precise CFD solution using a commercial ANSYS Fluent method that uses the Finite Airfoil characteristics. The NACA23012CG baseline airfoil, which has a flattened top surface, was compared to airfoils used in low-speed aircraft construction. Because of its stable and linear characteristics, thickness, and low decrease in abilities when fitted with flap, the S2027 has been chosen as the best suitable airfoil out of this group.

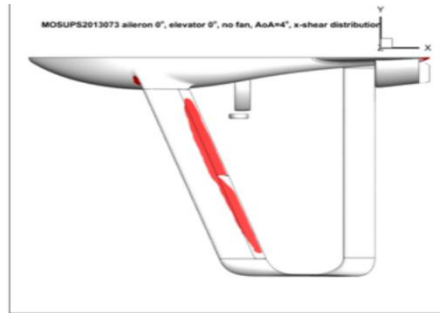




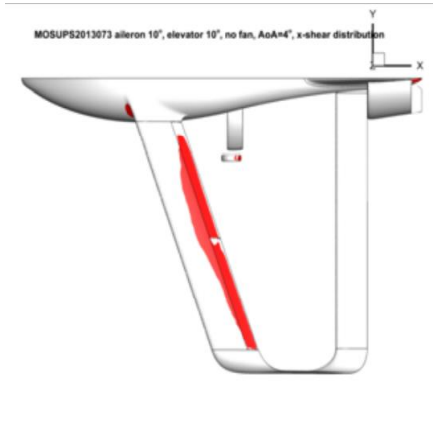
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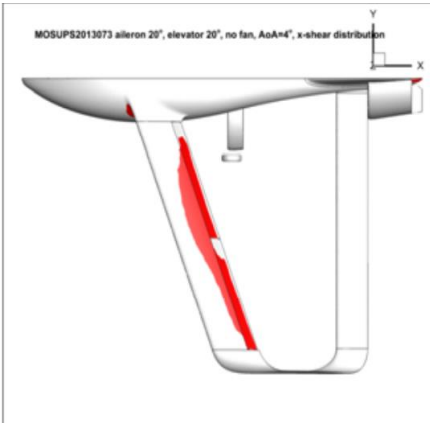
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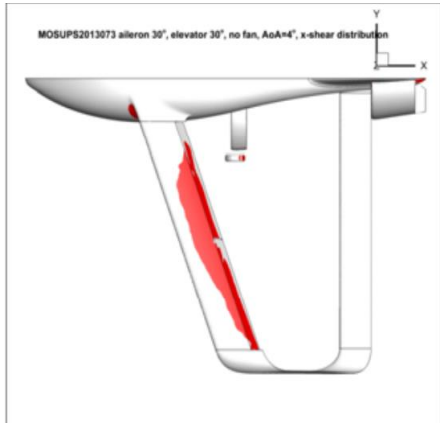
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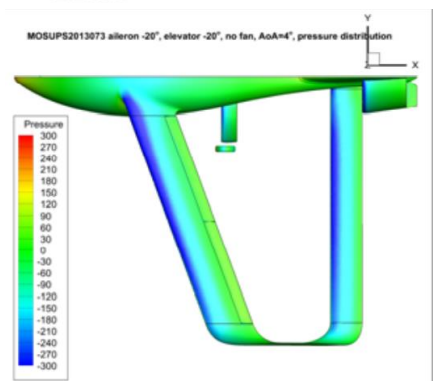
$\delta_{ELEVATOR} = 10^\circ$
 $\delta_{ELEVON} = 10^\circ$



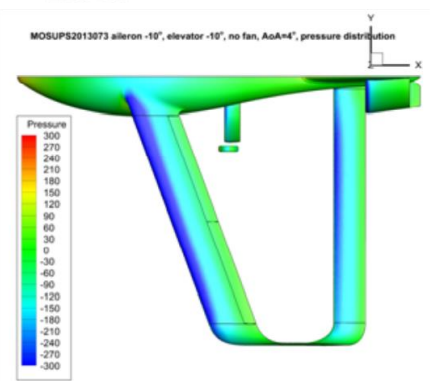
$\delta_{ELEVATOR} = 20^\circ$
 $\delta_{ELEVON} = 20^\circ$



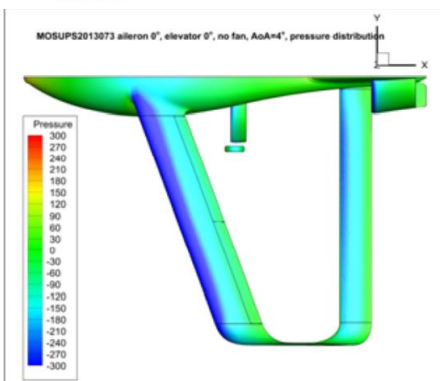
$\delta_{ELEVATOR} = 30^\circ$
 $\delta_{ELEVON} = 30^\circ$



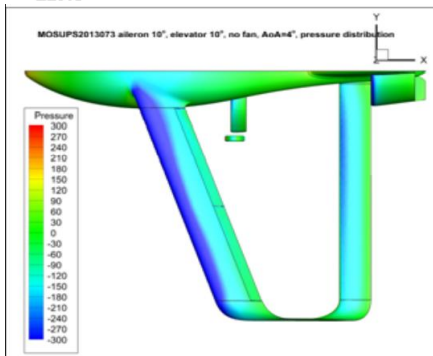
$\delta_{ELVTR} = -20^\circ$
 $\delta_{ELVN} = -20^\circ$



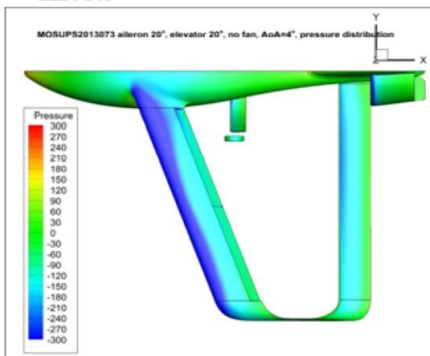
$\delta_{ELEVATOR} = -10^\circ$
 $\delta_{ELEVON} = -10^\circ$



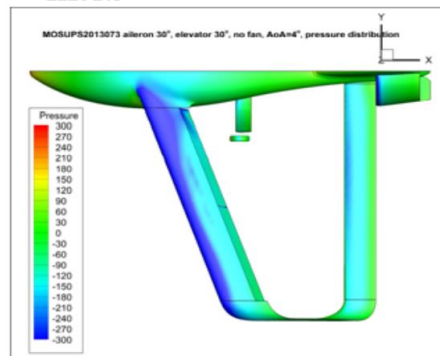
$\delta_{ELEVATOR} = 0^\circ$
 $\delta_{ELEVON} = 0^\circ$



$\delta_{ELEVATOR} = 10^\circ$
 $\delta_{ELEVON} = 10^\circ$

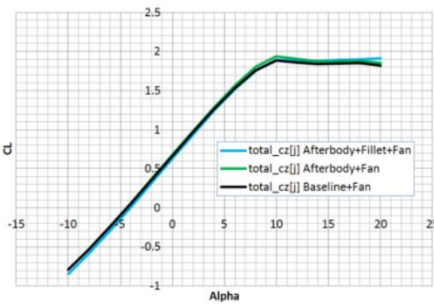
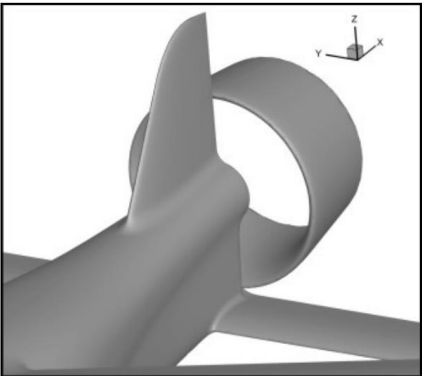


$\delta_{ELEVATOR} = 20^\circ$
 $\delta_{ELEVON} = 20^\circ$

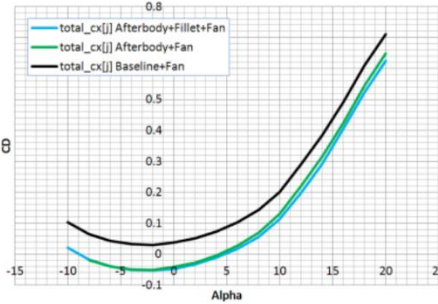
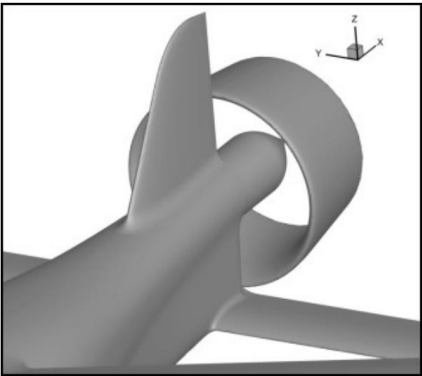


$\delta_{ELEVATOR} = 30^\circ$
 $\delta_{ELEVON} = 30^\circ$

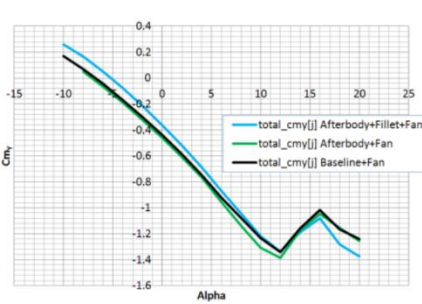
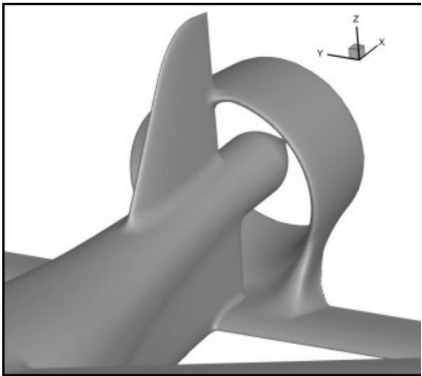
Baseline



Afterbody



Afterbody+fillet



Data on Aircraft Aerodynamics

Angle of Attack	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16
Elevon Deflection																	
-16	-1.028	-1.030	-1.034	-1.018	-0.970	-0.942	-0.824	-0.748	-0.594	-0.429	-0.229	-0.117	0.023	0.159	0.292	0.427	0.531
-14	-0.997	-1.002	-0.998	-0.998	-0.914	-0.873	-0.776	-0.629	-0.490	-0.319	-0.146	-0.020	0.123	0.267	0.413	0.528	0.622
-12	-0.970	-0.967	-0.946	-0.911	-0.850	-0.766	-0.662	-0.543	-0.382	-0.174	-0.061	0.084	0.238	0.396	0.522	0.626	0.709
-10	-0.957	-0.940	-0.898	-0.852	-0.777	-0.685	-0.569	-0.434	-0.274	-0.078	0.047	0.206	0.370	0.512	0.629	0.721	0.790
-8	-0.927	-0.891	-0.881	-0.781	-0.700	-0.624	-0.469	-0.317	-0.135	0.024	0.167	0.335	0.496	0.624	0.729	0.807	0.868
-6	-0.884	-0.831	-0.782	-0.713	-0.622	-0.522	-0.350	-0.183	0.018	0.129	0.301	0.472	0.613	0.730	0.819	0.887	0.933
-4	-0.814	-0.762	-0.707	-0.615	-0.506	-0.378	-0.222	-0.048	0.143	0.258	0.442	0.595	0.722	0.825	0.901	0.960	0.996
-2	-0.753	-0.730	-0.611	-0.516	-0.425	-0.275	-0.092	0.115	0.218	0.402	0.568	0.707	0.836	0.926	0.992	1.039	1.062
0	-0.681	-0.609	-0.520	-0.425	-0.302	-0.133	0.056	0.229	0.314	0.538	0.689	0.816	0.920	0.995	1.050	1.082	1.094
2	-0.592	-0.537	-0.452	-0.302	-0.160	0.009	0.203	0.297	0.503	0.648	0.787	0.901	0.989	1.057	1.098	1.121	1.124
4	-0.512	-0.424	-0.342	-0.202	-0.033	0.134	0.288	0.349	0.614	0.748	0.877	0.976	1.053	1.105	1.136	1.149	1.143
6	-0.426	-0.327	-0.213	-0.073	0.080	0.231	0.348	0.549	0.716	0.839	0.951	1.039	1.106	1.148	1.171	1.174	1.160
8	-0.334	-0.228	-0.104	0.032	0.181	0.335	0.404	0.655	0.769	0.921	1.021	1.098	1.152	1.183	1.196	1.190	1.170
10	-0.247	-0.136	-0.009	0.130	0.267	0.391	0.580	0.716	0.895	0.993	1.082	1.151	1.193	1.215	1.219	1.201	1.174
12	-0.158	-0.046	0.081	0.209	0.344	0.448	0.639	0.802	0.923	1.062	1.139	1.194	1.227	1.239	1.234	1.212	1.174
14	-0.076	0.038	0.160	0.304	0.452	0.508	0.742	0.882	0.996	1.120	1.188	1.232	1.253	1.258	1.243	1.215	1.171
16	0.004	0.117	0.255	0.386	0.484	0.675	0.825	0.954	1.041	1.177	1.233	1.266	1.276	1.272	1.249	1.215	1.167

Variation in the Lift Coefficient of the Fore Wing

AoA	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16
Elevon deflection																	
-16	0.020	0.020	0.020	0.019	0.017	0.016	0.013	0.010	0.007	0.003	0.001	0.000	0.000	0.000	0.002	0.003	0.005
-14	0.018	0.019	0.018	0.018	0.015	0.014	0.011	0.007	0.004	0.002	0.000	0.000	0.000	0.001	0.003	0.005	0.007
-12	0.017	0.017	0.017	0.015	0.013	0.011	0.008	0.005	0.003	0.001	0.000	0.000	0.001	0.003	0.005	0.007	0.009
-10	0.017	0.016	0.015	0.013	0.011	0.009	0.006	0.003	0.001	0.000	0.000	0.001	0.003	0.005	0.007	0.010	0.012
-8	0.016	0.015	0.014	0.011	0.009	0.007	0.004	0.002	0.000	0.000	0.001	0.002	0.005	0.007	0.010	0.012	0.014
-6	0.014	0.013	0.011	0.009	0.007	0.005	0.002	0.001	0.000	0.000	0.002	0.004	0.007	0.010	0.012	0.015	0.016
-4	0.012	0.011	0.009	0.007	0.005	0.003	0.001	0.000	0.000	0.001	0.004	0.007	0.010	0.013	0.015	0.017	0.018
-2	0.010	0.010	0.007	0.005	0.003	0.001	0.000	0.000	0.001	0.003	0.006	0.009	0.013	0.016	0.018	0.020	0.021
0	0.009	0.007	0.005	0.003	0.002	0.000	0.000	0.001	0.002	0.005	0.009	0.012	0.016	0.018	0.020	0.022	0.022
2	0.006	0.005	0.004	0.002	0.000	0.000	0.001	0.002	0.005	0.008	0.011	0.015	0.018	0.021	0.022	0.023	0.023
4	0.005	0.003	0.002	0.001	0.000	0.000	0.002	0.002	0.007	0.010	0.014	0.018	0.020	0.023	0.024	0.024	0.024
6	0.003	0.002	0.001	0.000	0.000	0.001	0.002	0.006	0.009	0.013	0.017	0.020	0.023	0.024	0.025	0.025	0.025
8	0.002	0.001	0.000	0.000	0.001	0.002	0.003	0.008	0.011	0.016	0.019	0.022	0.025	0.026	0.026	0.026	0.025
10	0.001	0.000	0.000	0.000	0.001	0.003	0.006	0.009	0.015	0.018	0.022	0.024	0.026	0.027	0.027	0.027	0.025
12	0.000	0.000	0.000	0.001	0.002	0.004	0.008	0.012	0.016	0.021	0.024	0.026	0.028	0.028	0.028	0.027	0.025
14	0.000	0.000	0.000	0.002	0.004	0.005	0.010	0.014	0.018	0.023	0.026	0.028	0.029	0.029	0.029	0.027	0.025
16	0.000	0.000	0.001	0.003	0.004	0.008	0.013	0.017	0.020	0.026	0.028	0.030	0.030	0.030	0.029	0.027	0.025

Trimming the front wing drag

AoA	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16
Elevator deflection																	
-16	0.019	0.019	0.019	0.018	0.017	0.016	0.012	0.010	0.006	0.003	0.001	0.000	0.000	0.000	0.001	0.003	0.005
-14	0.017	0.018	0.017	0.017	0.015	0.013	0.011	0.007	0.004	0.002	0.000	0.000	0.000	0.001	0.003	0.005	0.007
-12	0.017	0.016	0.016	0.015	0.013	0.010	0.008	0.005	0.003	0.001	0.000	0.000	0.001	0.003	0.005	0.007	0.009
-10	0.016	0.016	0.014	0.013	0.011	0.008	0.006	0.003	0.001	0.000	0.000	0.001	0.002	0.005	0.007	0.009	0.011
-8	0.015	0.014	0.014	0.011	0.009	0.007	0.004	0.002	0.000	0.000	0.000	0.002	0.004	0.007	0.009	0.011	0.013
-6	0.014	0.012	0.011	0.009	0.007	0.005	0.002	0.001	0.000	0.000	0.002	0.004	0.007	0.009	0.012	0.014	0.015
-4	0.012	0.010	0.009	0.007	0.004	0.003	0.001	0.000	0.000	0.001	0.003	0.006	0.009	0.012	0.014	0.016	0.017
-2	0.010	0.009	0.007	0.005	0.003	0.001	0.000	0.000	0.001	0.003	0.006	0.009	0.012	0.015	0.017	0.019	0.020
0	0.008	0.007	0.005	0.003	0.002	0.000	0.000	0.001	0.002	0.005	0.008	0.012	0.015	0.017	0.019	0.021	0.021
2	0.006	0.005	0.004	0.002	0.000	0.000	0.001	0.002	0.004	0.007	0.011	0.014	0.017	0.020	0.021	0.022	0.022
4	0.005	0.003	0.002	0.001	0.000	0.000	0.001	0.002	0.007	0.010	0.013	0.017	0.019	0.021	0.023	0.023	0.023
6	0.003	0.002	0.001	0.000	0.000	0.001	0.002	0.005	0.009	0.012	0.016	0.019	0.021	0.023	0.024	0.024	0.024
8	0.002	0.001	0.000	0.000	0.001	0.002	0.003	0.008	0.010	0.015	0.018	0.021	0.023	0.025	0.025	0.025	0.024
10	0.001	0.000	0.000	0.000	0.001	0.003	0.006	0.009	0.014	0.017	0.021	0.023	0.025	0.026	0.026	0.025	0.024
12	0.000	0.000	0.000	0.001	0.002	0.004	0.007	0.011	0.015	0.020	0.023	0.025	0.026	0.027	0.027	0.026	0.024
14	0.000	0.000	0.000	0.002	0.004	0.005	0.010	0.014	0.017	0.022	0.025	0.027	0.028	0.028	0.027	0.026	0.024
16	0.000	0.000	0.001	0.003	0.004	0.008	0.012	0.016	0.019	0.024	0.027	0.028	0.029	0.028	0.027	0.026	0.024

Trim Drag on the Aft Wing

AoA	-16	-14	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16
Elevator deflection																	
-16	0.19	0.173	0.158	0.144	0.127	0.117	0.099	0.092	0.08	0.077	0.056	0.056	0.056	0.048	0.035	0.013	-0.009
-14	0.171	0.155	0.14	0.128	0.108	0.097	0.083	0.069	0.06	0.055	0.04	0.039	0.034	0.021	0.001	-0.019	-0.042
-12	0.154	0.136	0.119	0.103	0.087	0.072	0.059	0.049	0.04	0.024	0.022	0.019	0.007	-0.012	-0.032	-0.052	-0.073
-10	0.137	0.118	0.099	0.081	0.065	0.05	0.037	0.026	0.018	0.009	-0.001	-0.009	-0.027	-0.045	-0.067	-0.085	-0.111
-8	0.116	0.095	0.08	0.058	0.041	0.028	0.013	0.001	-0.008	-0.021	-0.027	-0.038	-0.06	-0.081	-0.099	-0.119	-0.144
-6	0.093	0.071	0.052	0.034	0.017	0	-0.015	-0.029	-0.03	-0.036	-0.063	-0.08	-0.097	-0.116	-0.135	-0.149	-0.175
-4	0.065	0.044	0.024	0.004	-0.015	-0.033	-0.048	-0.065	-0.075	-0.084	-0.095	-0.108	-0.13	-0.147	-0.166	-0.187	-0.206
-2	0.038	0.016	-0.007	-0.028	-0.052	-0.071	-0.082	-0.072	-0.097	-0.115	-0.131	-0.139	-0.165	-0.175	-0.199	-0.218	-0.235
0	0.006	-0.018	-0.04	-0.064	-0.089	-0.103	-0.108	-0.116	-0.11	-0.151	-0.157	-0.175	-0.19	-0.205	-0.221	-0.229	-0.255
2	-0.027	-0.054	-0.081	-0.096	-0.109	-0.123	-0.124	-0.141	-0.167	-0.174	-0.173	-0.197	-0.206	-0.222	-0.228	-0.248	-0.274
4	-0.061	-0.08	-0.112	-0.135	-0.15	-0.157	-0.155	-0.124	-0.188	-0.182	-0.194	-0.216	-0.214	-0.243	-0.251	-0.267	-0.289
6	-0.089	-0.112	-0.137	-0.161	-0.167	-0.141	-0.166	-0.202	-0.206	-0.201	-0.21	-0.233	-0.246	-0.245	-0.274	-0.27	-0.304
8	-0.121	-0.142	-0.162	-0.179	-0.193	-0.145	-0.163	-0.219	-0.209	-0.229	-0.238	-0.234	-0.244	-0.259	-0.272	-0.283	-0.3
10	-0.154	-0.18	-0.17	-0.208	-0.165	-0.112	-0.232	-0.219	-0.237	-0.227	-0.252	-0.249	-0.259	-0.272	-0.28	-0.297	-0.308
12	-0.177	-0.185	-0.216	-0.207	-0.204	-0.184	-0.225	-0.231	-0.235	-0.242	-0.25	-0.26	-0.271	-0.283	-0.295	-0.307	-0.317
14	-0.208	-0.209	-0.188	-0.232	-0.237	-0.173	-0.241	-0.243	-0.248	-0.252	-0.256	-0.27	-0.282	-0.292	-0.304	-0.314	-0.324
16	-0.228	-0.223	-0.247	-0.238	-0.201	-0.252	-0.251	-0.253	-0.252	-0.264	-0.271	-0.282	-0.288	-0.295	-0.311	-0.32	-0.329

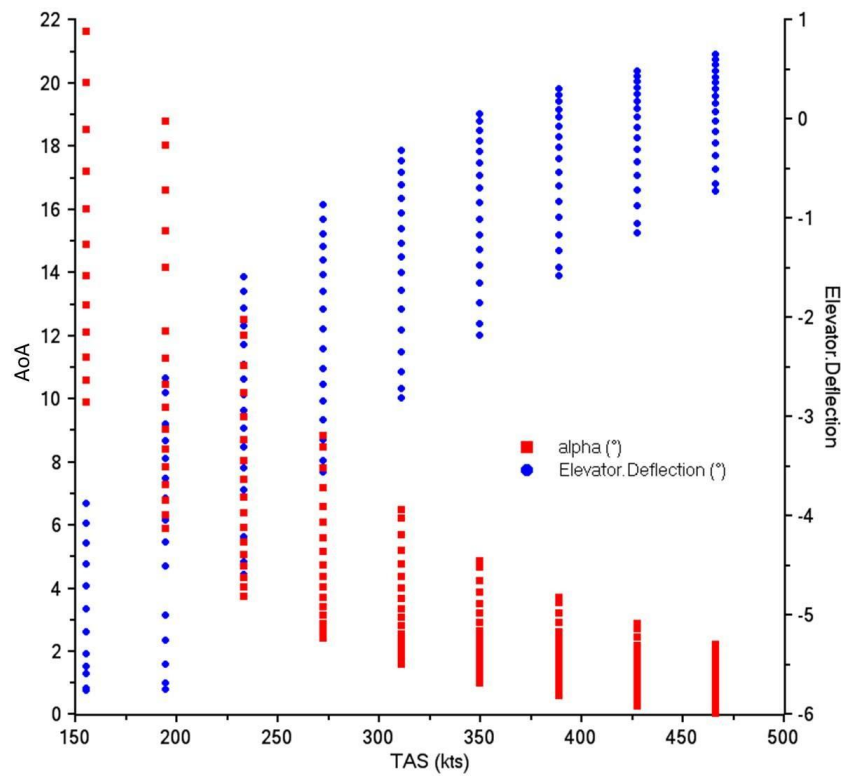
The Perfect Pitch

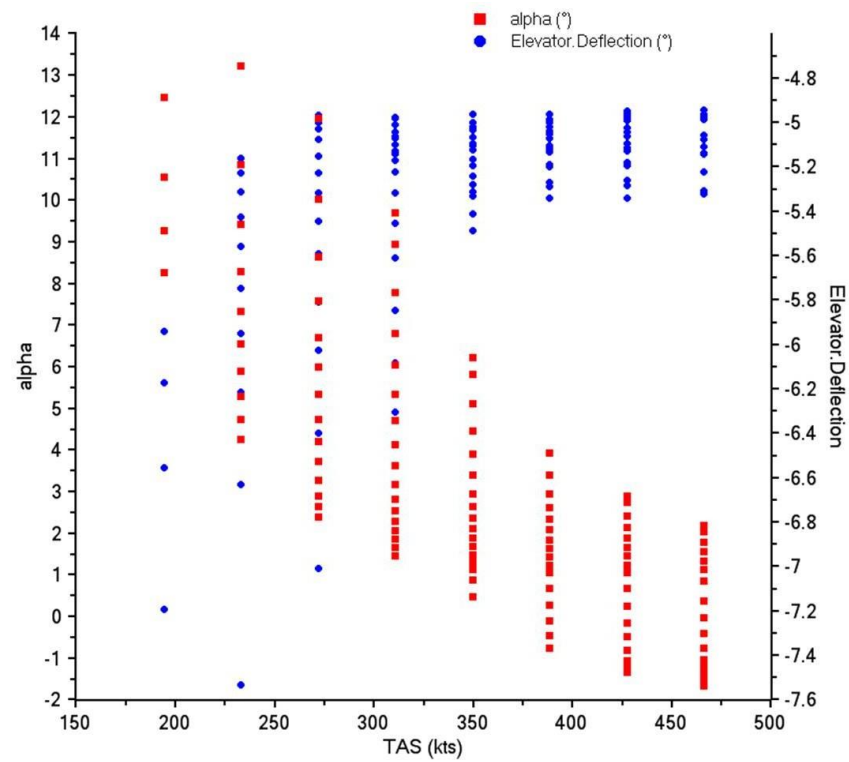
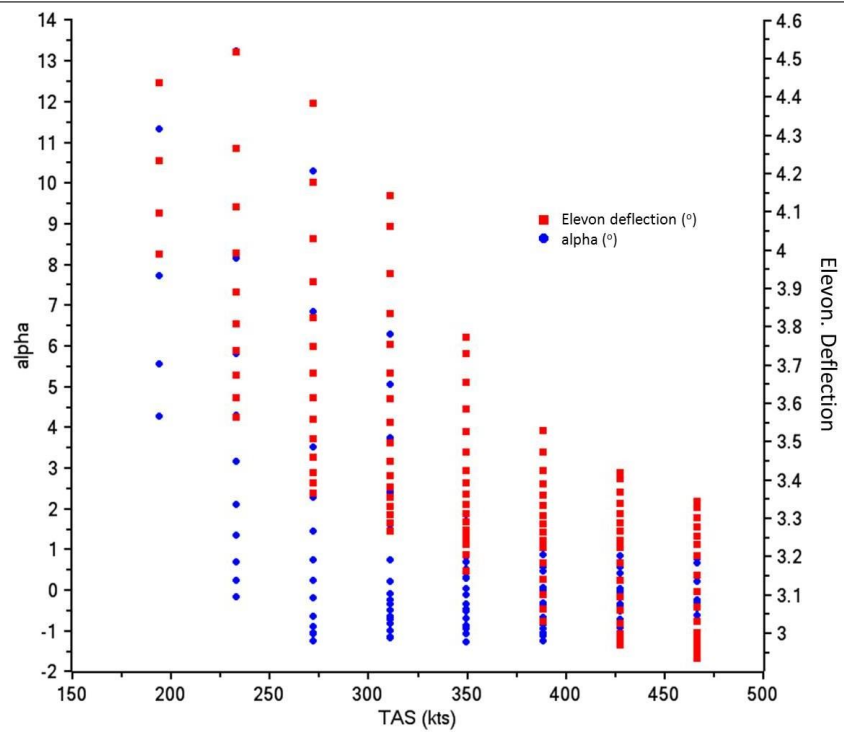
	Mach No	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.55	0.61	0.67	0.73	0.79
Relative Density	Altitude													
1	0	503913	473861	447003	423160	402152	383799	367922	354342	342879	333353	325587	319399	314466
0.9529	2000	489535	460341	434249	411086	390677	372848	357424	344231	333096	323842	316297	310286	305494
0.9075	4000	475405	447053	421715	399220	379400	362086	347107	334295	323481	314494	307167	301329	296676
0.8217	6000	447902	421191	397319	376125	357452	341139	327027	314956	304767	296301	289397	283897	279513
0.7812	8000	434523	408610	385450	364890	346774	330949	317258	305548	295664	287450	280753	275417	271164
0.7423	10000	421408	396277	373817	353877	336308	320960	307683	296326	286740	278774	272279	267104	262979
0.7048	12000	408503	384141	362368	343040	326009	311131	298260	287251	277959	270237	263941	258924	254926
0.6689	14000	395888	372278	351178	332446	315941	301523	289050	278381	269375	261892	255790	250929	247053
0.6012	16000	371336	349191	329399	311829	296347	282823	271123	261116	252669	245650	239926	235367	231732
0.5694	18000	359423	337988	318832	301825	286840	273750	262425	252739	244563	237769	232229	227816	224297
0.5389	20000	347744	327006	308472	292018	277520	264855	253899	244527	236617	230043	224684	220414	217010
0.5096	22000	336274	316220	298297	282385	268366	256119	245524	236461	228812	222455	217272	213143	209851
0.4549	24000	314127	295393	278651	263788	250691	239251	229353	220888	213742	207804	202963	199105	196030
0.4292	26000	303355	285264	269096	254742	242095	231046	221489	213313	206413	200678	196003	192278	189308
0.4047	28000	292843	275379	259771	245915	233706	223040	213814	205922	199260	193725	189211	185615	182749
0.3813	30000	282563	265712	250652	237282	225502	215211	206308	198693	192265	186924	182569	179099	176333
0.3589	31000	272483	256233	241710	228817	217457	207533	198948	191605	185406	180256	176056	172710	170043

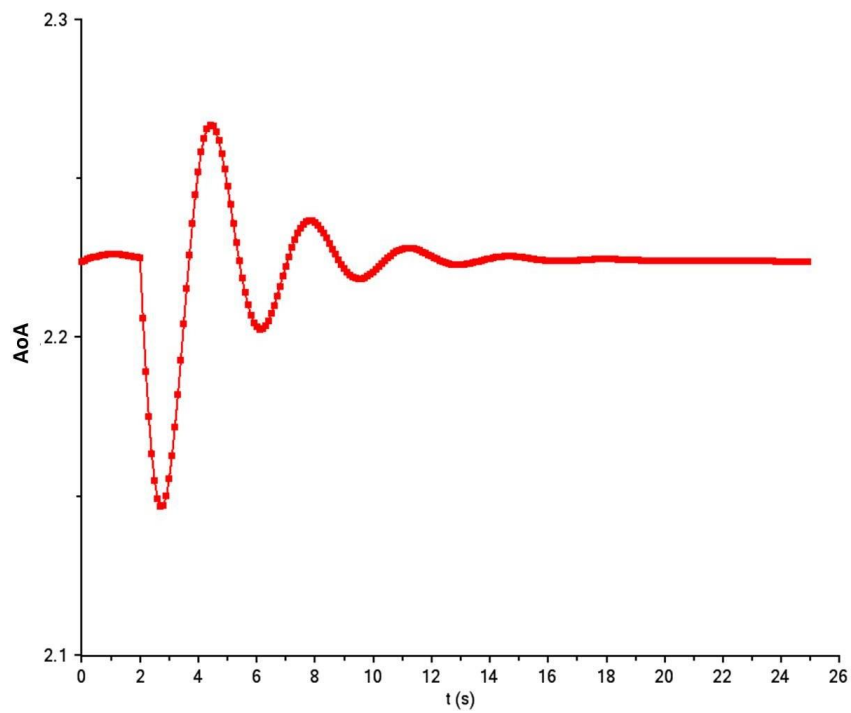
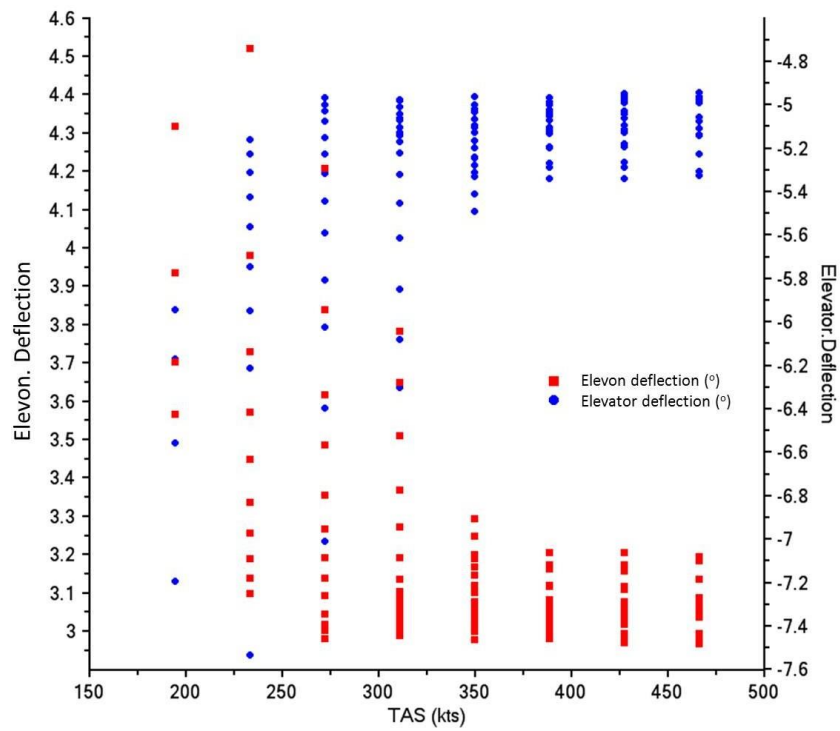
Maximum Thrust of an Engine as a Function of Altitude and Mach Number

	Mach No	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.55	0.61	0.67	0.73	0.79
Relative Density	Altitude													
1	0	438185	412053	388699	367965	349697	333738	319932	308123	298155	289873	283119	277738	273449
0.9529	2000	425683	400296	377608	357466	339719	324216	310804	299332	289648	281602	275041	269814	265647
0.9075	4000	413395	388742	366709	347148	329913	314857	301832	290691	281288	273473	267102	262025	257979
0.8217	6000	389480	366253	345494	327066	310828	296643	284371	273875	265015	257653	251650	246867	243055
0.7812	8000	377846	355313	335174	317296	301543	287782	275877	265694	257099	249957	244133	239493	235794
0.7423	10000	366442	344589	325058	307719	292442	279096	267550	257675	249339	242412	236764	232265	228678
0.7048	12000	355220	334036	315103	298295	283486	270549	259357	249784	241703	234989	229514	225152	221674
0.6689	14000	344250	323720	305372	289084	274732	262194	251347	242070	234239	227732	222426	218199	214829
0.6012	16000	322901	303644	286434	271155	257693	245933	235759	227057	219712	213609	208632	204667	201506
0.5694	18000	312542	293903	277245	262456	249426	238043	228196	219773	212664	206756	201939	198101	195041
0.5389	20000	302387	284353	268237	253929	241322	230309	220781	212632	205754	200038	195377	191664	188704
0.5096	22000	292412	274974	259388	245553	233362	222712	213499	205618	198967	193439	188932	185342	182479
0.4549	24000	273154	256864	242305	229380	217992	208044	199438	192076	185863	180699	176489	173135	170461
0.4292	26000	263787	248056	233996	221515	210517	200910	192599	185490	179489	174503	170437	167198	164616
0.4047	28000	254646	239460	225888	213839	203223	193948	185925	179062	173270	168456	164531	161404	158912
0.3813	30000	245707	231054	217958	206332	196088	187140	179398	172776	167187	162543	158756	155738	153333
0.3589	31000	236942	222811	210183	198972	189093	180464	172998	166613	161223	156744	153092	150183	147863

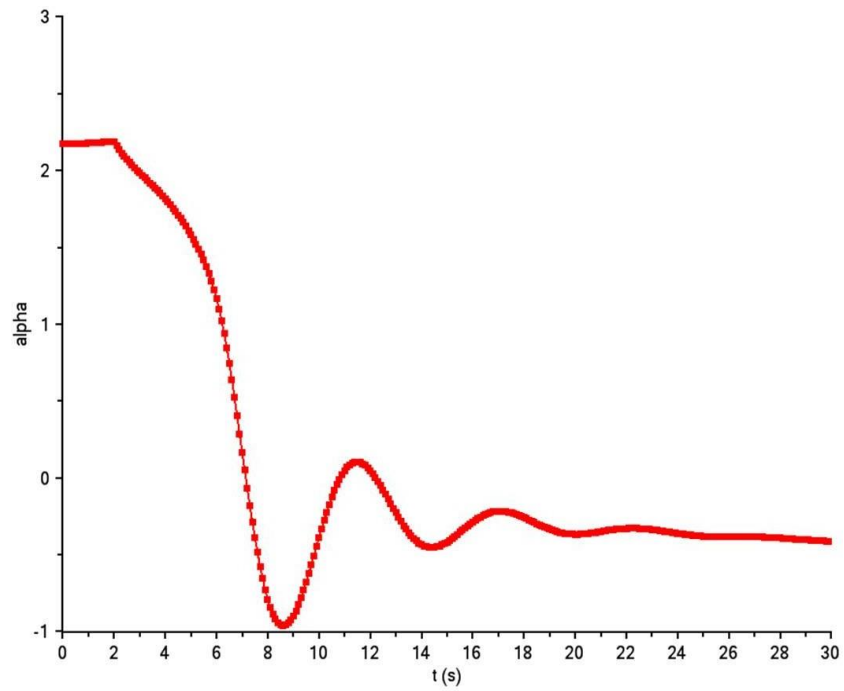
Thrust of the engine as a result of altitude and Mach number



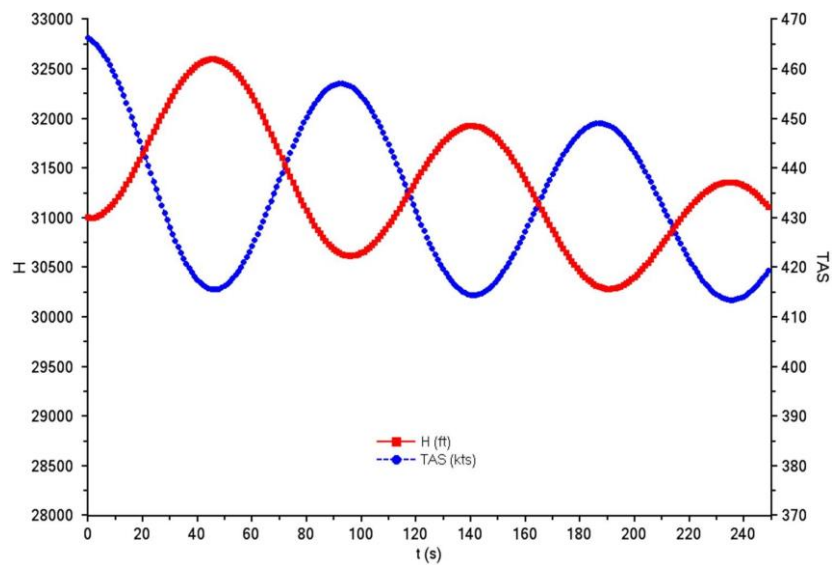




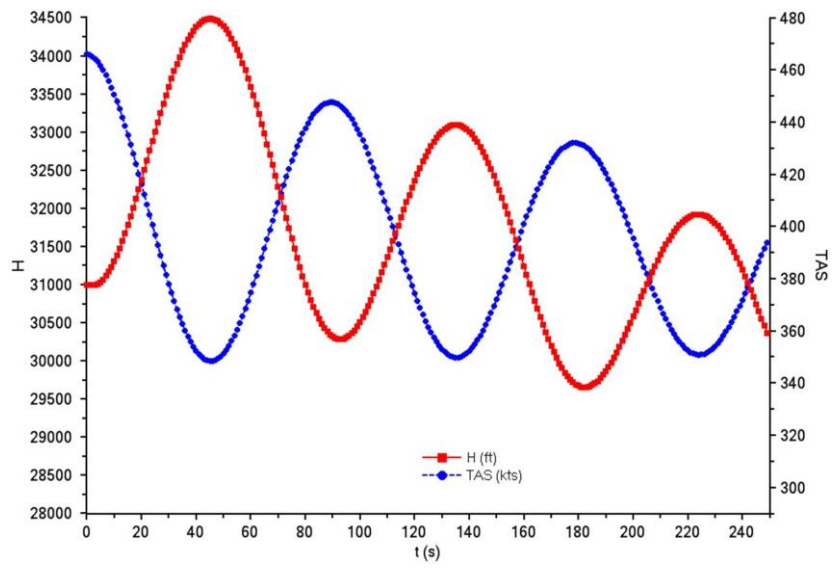
66 percent Payload - Short Duration Oscillation



66 percent payload for Box Wing Short Period Oscillation



66% of the payload



66 percent payload for the Box Wing Phugoid

Result and Outcome

Conclusions The 0.28 wing mass determination coefficient calculated for the fore wing was found to be identical to that calculated for the aft wing. Since the wings are jointly bracing each other and the same set of restrictions is applied to them, it was expected that their coefficient would be the same since they bear the same load and are bound by tip fins. The meaning of this is that a medium-range box-wing aircraft's aft wing would be lighter than the fore wing. Since the sweep angle of the aft wing on a medium-range box wing aircraft is usually less than that of the fore wing (with the same wing area), the resultant mass of the aft wing will be less. The 0.28 wing mass determination coefficient calculated for the fore wing was found to be identical to that calculated for the aft wing. Since the wings are jointly bracing each other and the same set of restrictions is applied to them, it was expected that their coefficient would be the same since they bear the same load and are bound by tip fins. The meaning of this is that a medium-range box-wing aircraft's aft wing would be lighter than the fore wing. The explanation for this is that the sweep angle of the aft wing on a medium-range box wing aircraft is normally less than that of the fore wing. As a result, the aft wing's mass will be reduced. Based on the information presented here, the joined-wing configuration aircraft is 5.0716 percent lighter and provides 1.3629 times more lift than the Reference Conventional Business Jet (RCBJ). The average drag of the Joined-Wing Business Aircraft (JWBJ) configuration is 3.5 percent smaller than the RCBJ configuration after considering the decrease in vortex drag due to the joined-wing configuration. As a result, the goals of This project's goal was accomplished, namely improved aerodynamic efficiency in terms of higher lift and decreased drag, as well as a lighter construction when compared to similar-sized comparison aircraft. The joint arrangement of this joined-wing configuration aircraft results in a lack in wing tip vortices, which is one of its main advantages. This decreases the risks of wake turbulence, the creation of vapour contrails, which absorbs Earth's radiation, noise emissions, and the recovery of 30-40% of power loss induced by drag due to lift in traditional wing designs.