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Multi-fidelity Design Optimization of a Long-Range Blended Wing Body Aircraft with New Airframe Technologies

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Within the German Cluster of Excellence SE²A (Sustainable and Energy Efficient Aviation), three reference aircraft have been initially designed to study promising technologies for future sustainable air transport systems. In this paper, the design optimization of one of these reference aircraft, a long-range blended wing body aircraft, is presented. The design optimization is executed using the multi-fidelity aircraft design code SUAVE with a connection to the CFD code SU2. The conceptual design of the BWB aircraft is performed within the SUAVE framework, where the influence of the new technologies, such as hybrid laminar flow, active load alleviation, boundary layer ingestion, and new materials and structures on the aircraft performance and fuel consumption is investigated. In the second step, the initially designed BWB aircraft is improved by an aerodynamic shape optimization using the SU2 CFD code. In the third step, the performance of the optimized aircraft is evaluated again using the SUAVE code.

I. Nomenclature

α	=	angle-of-attack
C_D	=	drag coefficient
C_L	=	lift coefficient
$C_{D_{comp}}$	=	drag coefficient due to compressibility
C_p	=	pressure coefficient
M	=	Mach number
R_{LE}	=	Leading edge radius
Y	=	y-coordinate of a wing section
b	=	wing span
t	=	airfoil thickness
z	=	z-coordinate of a control point

II. Introduction

To meet the challenges of ambitious reduction in CO2, NOx and noise emission set by aviation authorities such as in Flightpath 2050 [1], a series of research activities have been carried out all over the world in the recent years. Among which one notable effort is the German Cluster of Excellence SE²A (Sustainable and Energy Efficient Aviation). The SE2A program is based on the previous joint research project "Energy System Transformation in Aviation, EWL [2]" that has been initiated between 2016 and 2018 in Germany to identify and investigate possible unconventional energy systems that can be used for civil transport aircraft in combination with game-changing aircraft configurations and airframe technologies.

The project has been inspired by a lot of relevant work that has been carried in recent decades. According to the research of Boeing, a blended wing body (BWB) concept for long-range commercial aircraft could lead to a fuel saving of 27% as compared to a conventional A380-like tube-and-wing (TAW) configuration [3]. Xu and Kroo [4] have investigated the benefits of load alleviation and natural laminar flow and have concluded that the combination

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of these two technologies to a Boeing 737-800 aircraft could bring a fuel saving of 18%. NASA-MIT D8 "Double-Bubble" Concept with boundary layer ingestion (BLI) and active load alleviation has conducted a fuel burn reduction of 70.87% as compared to a B737-800 baseline concept [5,6]. NASA Hybrid Wing Body (HWB) Concept (with N+3 airframe technology packages such as BLI and Distributed propulsion system) has conducted a fuel burn reduction of 54% as compared to a 777-200LR baseline [5,6]. The "Advanced Truss-Braced Wing" concept proposed by NASA and MIT with hybrid-electric propulsion has a 70% fuel burn reduction at a very low range condition [7]. Saeed et al. from Cambridge University have designed a flying wing concept with laminar flow control and has concluded that with 84% of the total wetted area being laminarised, they have achieved a 70% fuel savings when neglecting the system penalties [8].

Within the EWL project, several aircraft have been initially designed to represent technology integrator for these new technologies. In particular, the following technologies have been selected via system-level studies. Active flow control (boundary layer suction) was proposed to minimize friction drag, active load alleviation and new materials and structure concepts were introduced to minimize structural weight of aircraft, and boundary layer ingestion was proposed as a solution to improve propulsive efficiency [2].

The focus of the current manuscript is to present the multi-fidelity design and analysis of one of those reference aircraft, a long-range blended wing body (BWB) aircraft. Studies performed in Ref [2] determined initial configuration of the aircraft and estimated geometric properties based on mission requirements and several trade studies such as the wing aspect ratio, taper, sweep, and thickness. This study focuses on the aircraft mission analysis and optimization using a multi-fidelity approach. In this manuscript, first, the methods and tools that are used to carry out the overall aircraft design and optimization are described. Then, the outcome of the initial (conceptual) design of the BWB aircraft is presented. Finally, aerodynamic shape optimization results carried out with SU2 are also presented.

III. Methods and tools

As mentioned before, the goal of this research is to investigate the influence of the new technologies mentioned above on the fuel consumption of a long-range blended wing body aircraft. To achieve this goal a multi-fidelity design optimization is performed to design a long-range BWB aircraft equipped with the mentioned technologies. In this section, the utilized methods and tools to carry out the design optimization of the mentioned aircraft are introduced. Three open-source tools were used in this research. The overall assessment of the aircraft was executed using the Stanford University Aerospace Vehicle Environment (SUAVE) [9], which has been developed by the Aerospace Design Lab at Stanford University. Aerodynamic analysis and optimization of the aircraft were executed using the SU2 [10] CFD code. The SUAVE code was connected to the OpenVSP [11] code for automatic model and CFD-mesh generation for SU2 from the aircraft geometry defined in SUAVE. In the following subsection, each of these three tools is described in more detail.

A. SUAVE

SUAVE is an open-source, object-oriented aircraft design environment programmed in Python language with good flexibility, composability, and extensibility [9,12]. It enables multi-fidelity analyses of arbitrary aircraft and propulsion systems (both conventional and unconventional aircraft concepts as well as propulsion systems).

The performance of desired components in SUAVE is calculated by using individual design or analysis modules with multiple fidelities for different cases. For aerodynamics, both build-up methods (including AVL Vortex Lattice code for induced drag calculation), and higher-fidelity CFD approach (SU2 as solver and OpenVSP for CFD meshes) are used. The interfaces with Gmsh for generating mesh for SU2 are also available in SUAVE [13]. Currently, for structure and weight estimation, empirical and statistical methods or surrogates are used. A modular "energy network" has been implemented in SUAVE based on analytical methods that are used for both gas-turbine and electric energy systems (electric motor, fuel cells, batteries, etc.). The aircraft mission in SUAVE is analyzed by iteratively solving the equations of motion with a segment-based architecture [9]. By comparing SUAVE analysis results for Boeing 737-800, Embraer E-190, Concorde, and Boeing SUGAR Ray blended wing body with literature, the SUAVE tool has shown good accuracy for a wide range of transport aircraft [9].

It has to be noted that the aircraft geometry in SUAVE is described using representative parameters that can be used for simple aerodynamic/structural analyses such as VLM and Beam Theory. By using additional geometry converter, such as OpenVSP, the aircraft geometry parameterization in SUAVE can be further used to generate CFD meshes for high fidelity aerodynamic studies [14].

B. OpenVSP & Gmsh

To link SUAVE and CFD code SU2, the NASA OpenVSP [11] is used, in which the aircraft geometry is described in XML format, which can be easily connected to high fidelity analysis tools. For example, the surface triangulations in OpenVSP can be read by the open-source Gmsh tool with *MSH* output format. More recently, OpenVSP has also enabled the capability of creating CFD and FEM meshes directly from geometry data (.VSP3 file). Additional information on OpenVSP is available in references [11].

C. SU2

For high fidelity aerodynamic analysis, Stanford University Unstructured (SU2) [10] open-source CFD tool was selected. The SU2 uses both Euler and Reynolds-averaged Navier-Stokes Equations (RANS). The finite volume method is employed to discretize the Euler and RANS, with both explicit and implicit methods available for time integration. Via techniques such as free-form deformation (FFD), SU2 computes the deformation of 2D and 3D geometries within the computational mesh and the adjoint implementation of Euler and Navier-Stokes Equations also enables the high efficiency of SU2 in gradient-based aerodynamic shape optimization problems. More details on SU2 can be found in the literature [10,15].

IV. Conceptual design and assessment of the BWB aircraft

A. Top level aircraft requirements and initial design

The top-level aircraft requirements of the reference long-range aircraft SE^{2}A-LR are listed in Table 1, which were derived from the same category transport aircraft such as Boeing 777/787 or Airbus A330/350.

The initial design of SE^{2}A-LR is based on the EWL project [2], where the thrust to weight ratio and wing loading values were determined by top-level aircraft requirements and design specifications derived from existing long-range transport aircraft such as Boeing 777. The outer wing of the blended wing body SE^{2}A-LR was designed via optimizing planform parameters such as wing aspect ratio, leading-edge sweep, thickness to chord ratio, taper ratio. The center body of SE^{2}A-LR was constrained by carrying 300 passengers with a multi-bubble concept. The supercritical DLR F15 airfoils were used for the initial design with different thickness to chord ratios at the center body and outer wing sections.

Figure 1 shows the 3-D view of the initial design from EWL. It has to be noted that for the initial design of SE^{2}A-LR, hybrid laminar flow control (80% of the blended wing area is laminarised), boundary layer ingestion (5% improvement in propulsive efficiency due to boundary layer ingestion), advanced structure design with composite materials (20% structure weight reduction as compared to baseline) as well as active load alleviation technologies (load factor is reduced to 1.5g) were included [2]. Table 2 gives a brief summary of the new airframe technologies applied to the reference long-range aircraft SE^{2}A-LR [16–19]. As such, significant fuel burn and MTOW reductions have been obtained compared to the current transport aircraft with similar top-level aircraft requirements, such as B777, A330 or even the new generation A350 and B787.

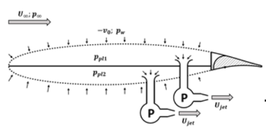
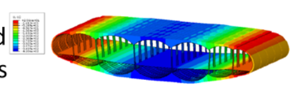
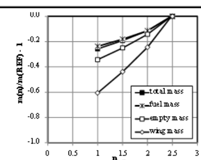
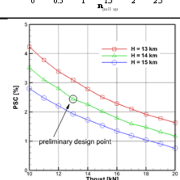
B. Assessment of the initial design using SUAVE

Since the initial design of the BWB aircraft in the EWL project has been done with an in-house tool (different from SUAVE), in the first step, we assessed the initial configuration of the SE2A-LR including the game-changing technologies in SUAVE. The results were comparable with those of the EWL project [2]. Table 3 shows the comparison between SE^{2}A-LR and baseline B777. From the table, the MTOW was reduced by 57.9% and block fuel was reduced by 75.3%. The detailed OWE mass breakdown is presented in Table 4. Figure 2 shows the aerodynamic performance of SE^{2}A-LR calculated using low/medium fidelity methods (AVL for induced drag and semi-empirical methods for wave drag and friction drag) of SUAVE. From the figure, the aerodynamics performance, especially the L/D, has been significantly improved due to the BWB configuration and also laminar flow control technology. Via boundary layer ingestion, the propulsive efficiency has been increased, with the total engine thrust being presented in Figure 3. Figure 4 gives the mission performance of SE^{2}A-LR including the information of altitude and weight changes through flight mission as well as the velocity data along the flight mission.

Table 1. Top level aircraft requirements of reference long-range aircraft SE^{2}A-LR

Parameter	Unit	Value
Design range	NM	8099
Design passenger number	-	300
Cruise Mach number	-	0.85
Cruise altitude	m	10600
Take-off field length (TOFL)	m	< 2200
Landing distance	m	< 1966

Table 2. A summary of new airframe technologies applied to reference long-range aircraft SE2A-LR

SE2A advanced airframe technologies		Description and integration into SE2A long range blended wing body aircraft
Laminar flow control		**Modelled through equivalent skin-friction coefficient which should further decided by the percentage of laminarization (Xfoil-suction, TAU, etc.)**
		BWB wing transition location at 80% via laminar flow control on both BWB center body and outer wing
Advanced structures		20% structure weight reduction based on advanced structure design and utilization of composite materials
Active load alleviation (1-g wing)		**Modelled with the structure mass of aircraft wing**
		Design load factor reduced from 2.5g to 1.5g through gust load alleviation and maneuver load alleviation
Boundary layer ingestion (BLI)		**Modelled with the propulsion efficiency**
		5% improvement in propulsive efficiency based on BLI power saving coefficient (PSC)

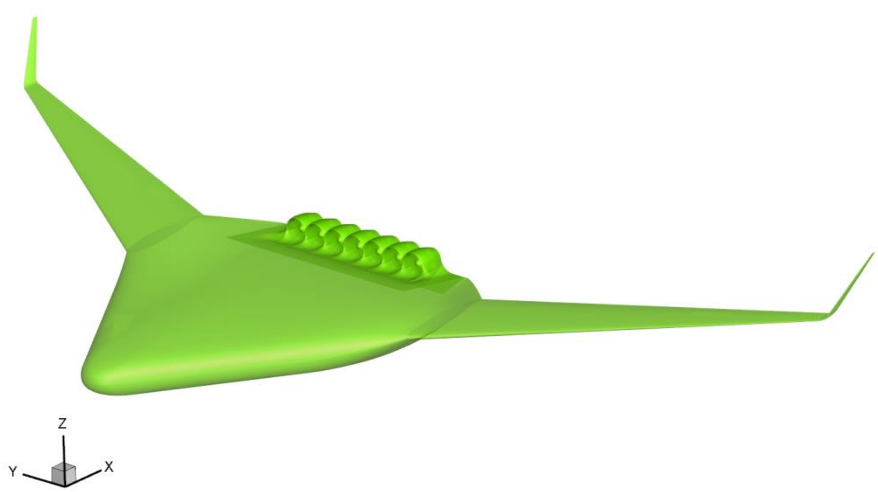


Figure 1. 3-D view of the initial reference long rang BWB aircraft with winglet

Table 3. Comparison of key aircraft parameters of reference long range aircraft SE^{2}A-LR and B777

	SE^{2}A - LR	B777	Relative change (%)*
MTOW (kg)	146249.0	347452.0	-57.9
OWE (kg)	83914.0	145150.0	-42.2
Block fuel (kg)	29334.0	109290.0	-73.2
Sea level static thrust (kN)	462.3	1026.0	-54.9
Fuel efficiency (kg/seat/100km)	0.65	2.72	-76.1

Table 4. Mass breakdown of reference long range aircraft SE^{2}A-LR

Mass items	Unit	Value
Operating Weight Empty (OWE)	kg	86308
Wing	kg	11061
Fuselage	kg	32549
Propulsion group	kg	13594
Landing gear	kg	5811
Systems (including opt. and furn.)	kg	23293
Breakdown of system mass		
Control systems	kg	2425
APU	kg	953
Hydraulics	kg	828
Instruments	kg	363
Avionics	kg	408
Optionals	kg	3810
Electrical	kg	1769
Air conditioner	kg	2041
Furnish	kg	10696

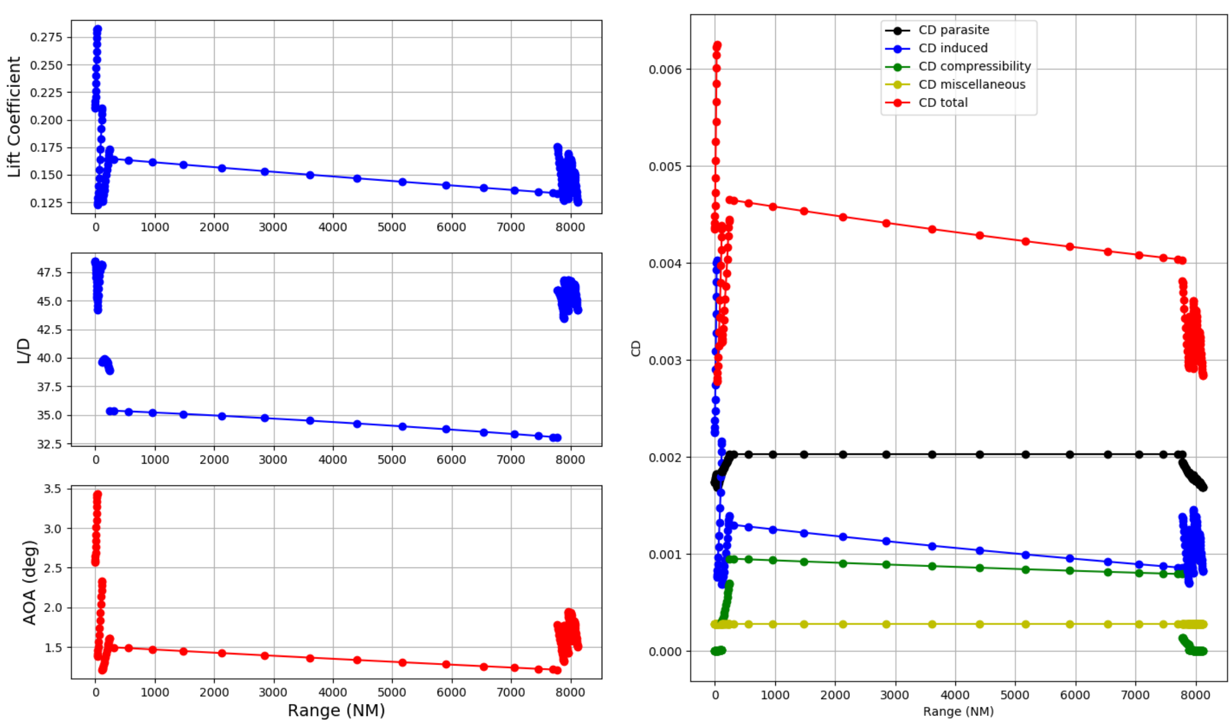


Figure 2. Aerodynamic performance of SE^{2}A-LR calculated using SUAVE

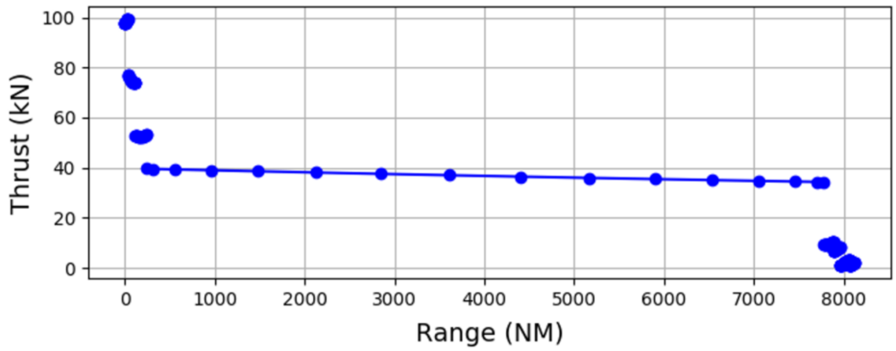
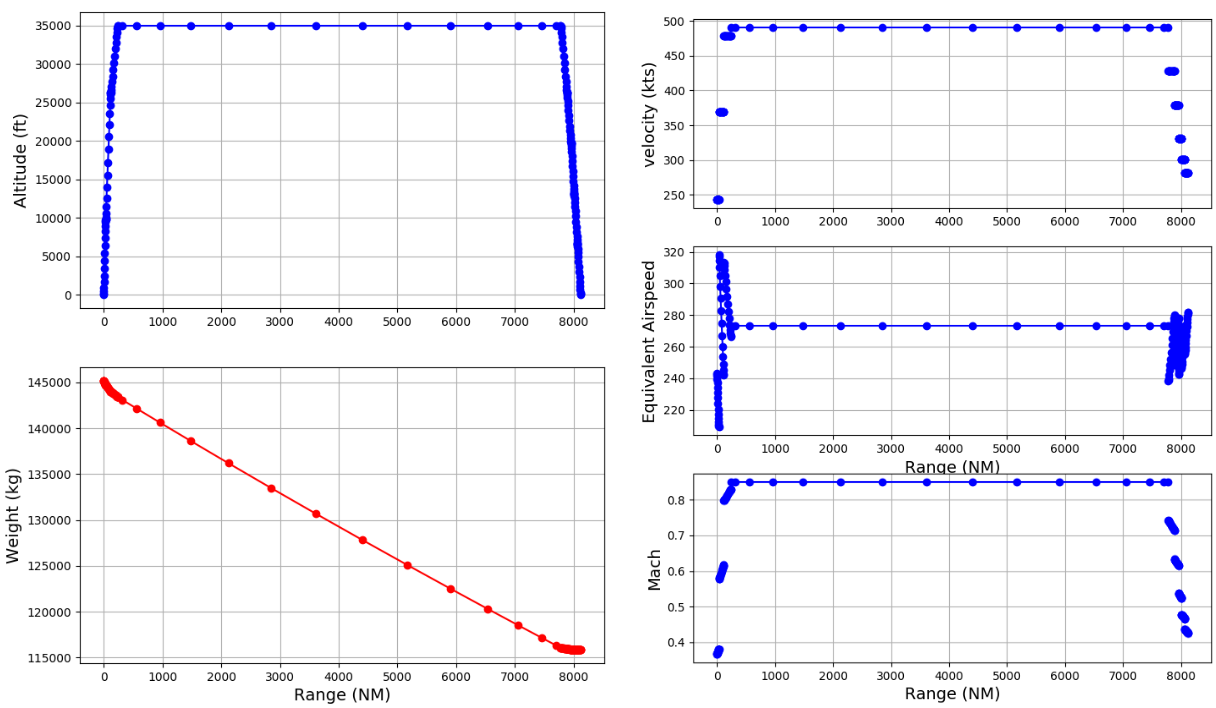


Figure 3. Thrust of SE^{2}A-LR



(a) Aircraft altitude and weight

(b) Aircraft velocity

Figure 4. Mission performance of SE^{2}A-LR

V. Mission performance analysis using SU2

In addition to the low/medium fidelity aerodynamic analysis of SUAVE, a higher fidelity aerodynamic analysis was considered in this research. As mentioned earlier, the SU2 CFD code was used for this purpose. Via an automatic link between SUAVE and SU2, the aerodynamic performance of the aircraft was evaluate using Euler analysis in SU2 (induced and wave drag) to improve the accuracy of the analysis. For the viscous drag estimation, the low-fidelity flat plate analogy method was used. To extract compressibility, drag from Euler analysis, the following formulation was used

$$C_{D_{comp}} = C_D - \left. C_D \right|_{M=0.3} \tag{1}$$

where $C_{D_{comp}}$ is the drag component due to compressibility and $C_D|_{M=0.3}$ is the drag at M = 0.3: the Mach number where compressibility effects are negligible. An additional SUAVE script was written to extract compressibility drag from SU2 and include it in the analysis as a surrogate. For the surrogate model, SMT-toolbox [11] was integrated in SUAVE. The RMTB B-spline method was used to fit the data.

The automatic link between SUAVE and SU2 was realized using two additional codes: OpenVSP and Gmesh. To generate proper inputs for SU2, the geometry parameterization in SUAVE was first transferred to the VSP format. Then, OpenVSP generated a CFD mesh using its internal generator. Finally, Gmesh was used to translate the mesh to the format applicable for SU2. Flight conditions such as Mach number from the reference aircraft were used to set the SU2 calculations up. For robustness and computational time constraint reasons, only Euler solver in SU2 was used to calculate the inviscid aerodynamic properties. The aerodynamic results calculated with SU2 were used to build up surrogates for SUAVE overall aircraft inviscid aerodynamic performance estimation. Figures 5 shows the link between SUAVE and SU2. Figure 6 shows the airframe geometry and an example CFD mesh of half of the SE^{2}A-LR aircraft geometry.

To accurately capture the compressibility effect, a mesh convergence analysis has been performed. Results of the drag coefficient sensitivity to mesh resolution at zero angle-of-attack and M = 0.85 are shown in Table 5. From the mesh convergence analysis, 660528 cells were used to combine accuracy and minimize computational costs.

A surrogate model using the RMTB method was created to evaluate the aircraft performance in SUAVE. Figure 7 shows the aircraft pressure coefficient contours at the cruise conditions while Figures 8-10 present an updated mission analysis using SUAVE. Table 6 shows a modified comparison between the SE^{2}A-LR aircraft and B777 weights and fuel efficiency using higher-fidelity analysis.

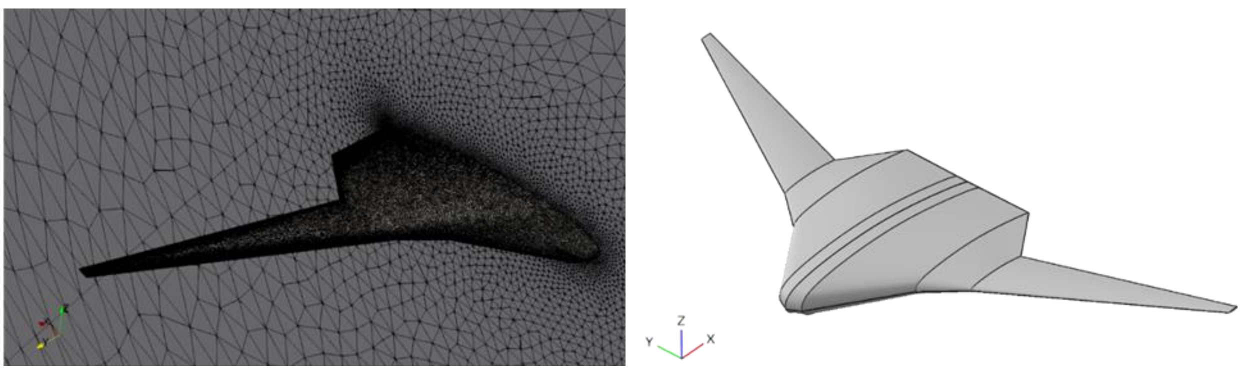


Figure 5. Sequential build-up from SUAVE geometry and to SU2 CFD analysis

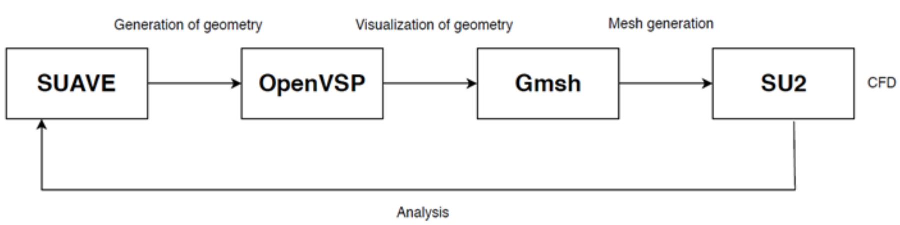


Figure 6. Airframe geometry of SE^{2}A-LR aircraft visualized in OpenVSP

Table 5. Mesh convergence study for the cruise configuration in SU2 ($\alpha = 0$ deg, M = 0.85)

Mesh number	Cells	C_D	Error (%)
1	343612	0.01733	9.02
2	660528	0.01673	5.25
3	835000	0.01670	5.03
4	1012683	0.01665	4.72
Extrapolation	∞	0.0159	0.00

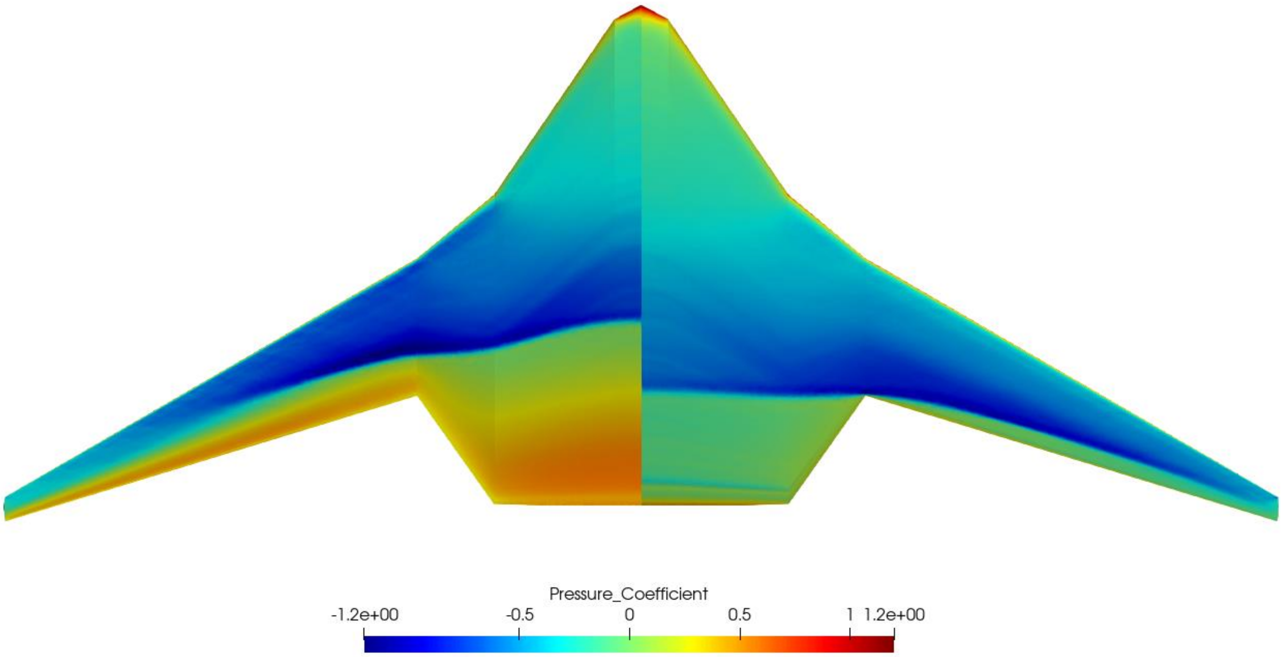


Figure 7. Pressure coefficient contours of lower (left) and upper (right) aircraft surfaces. ($\alpha = 0°$, M = 0.85)

Table 6. Comparison of key aircraft parameters of reference long range aircraft SE^{2}A-LR and B777

	SE^{2}A – LR (Higher fidelity)	B777	Relative change (%)*
MTOW (kg)	274392.0	347452.0	-21.0
OWE (kg)	98645.0	145150.0	-32.0
Block fuel (kg)	142747	109290.0	+30.6
Fuel efficiency (kg/seat/100km)	3.17	2.72	+16.5

Results presented above demonstrate a substantially higher compressibility drag due to the presence of shock waves along the aircraft span. Such behavior has not been captured by the low-fidelity analysis. In the low-fidelity analysis, a semi-empirical formulation was used to calculate drag due to compressibility. Although semi-empirical methods provide good accuracy without computational costs, they may have limitations when the analysis is done on an unconventional configuration. Consequently, increased aircraft drag predicted by SU2 increased the required fuel to complete the mission by 30.6% compared to the B777. The difference in fuel efficiency between the SE^{2}A – LR, and B777 became equal to 16.5%.

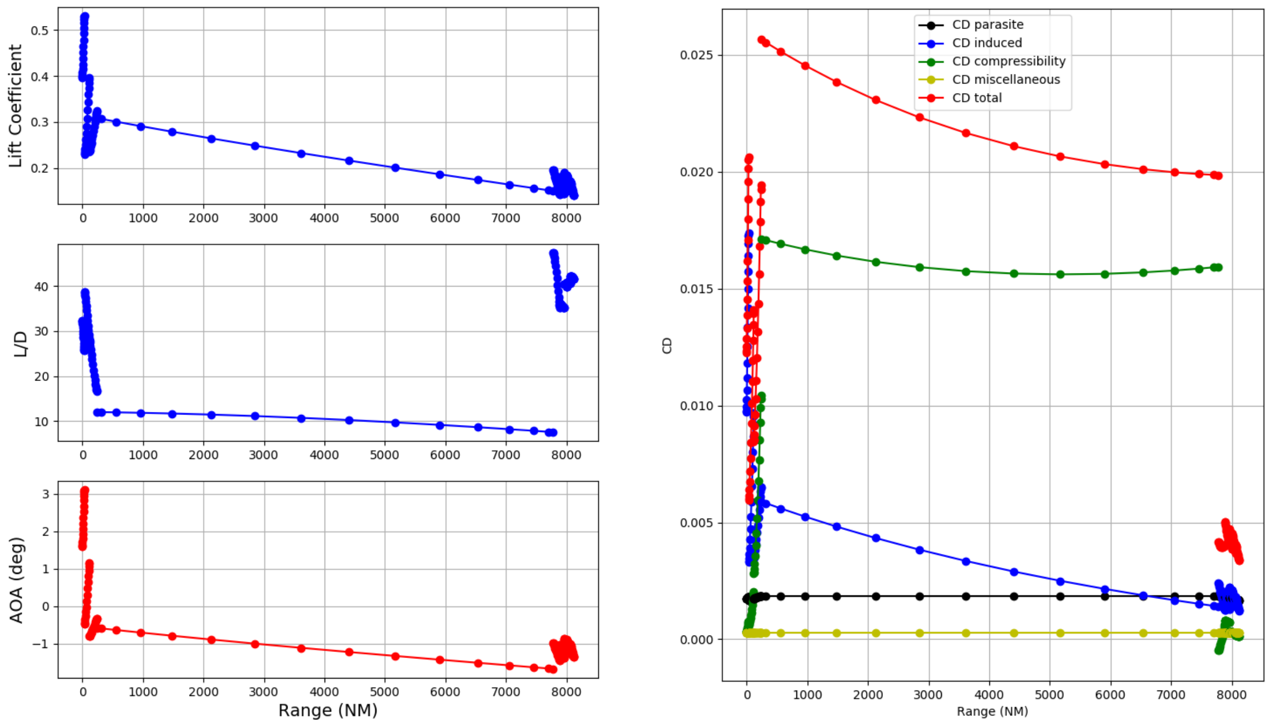


Figure 8. Aerodynamic performance of SE²A-LR calculated using SUAVE

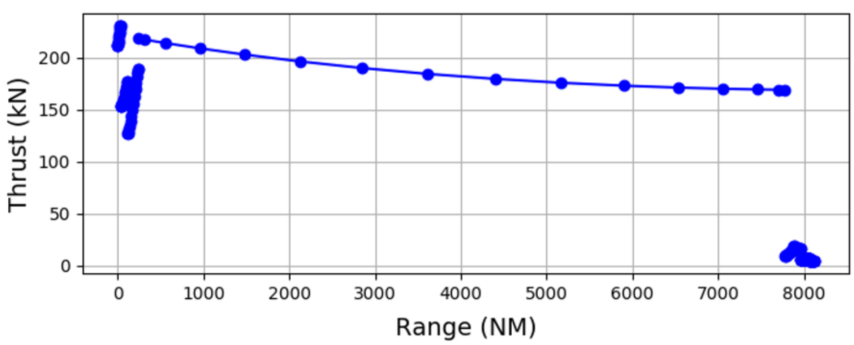
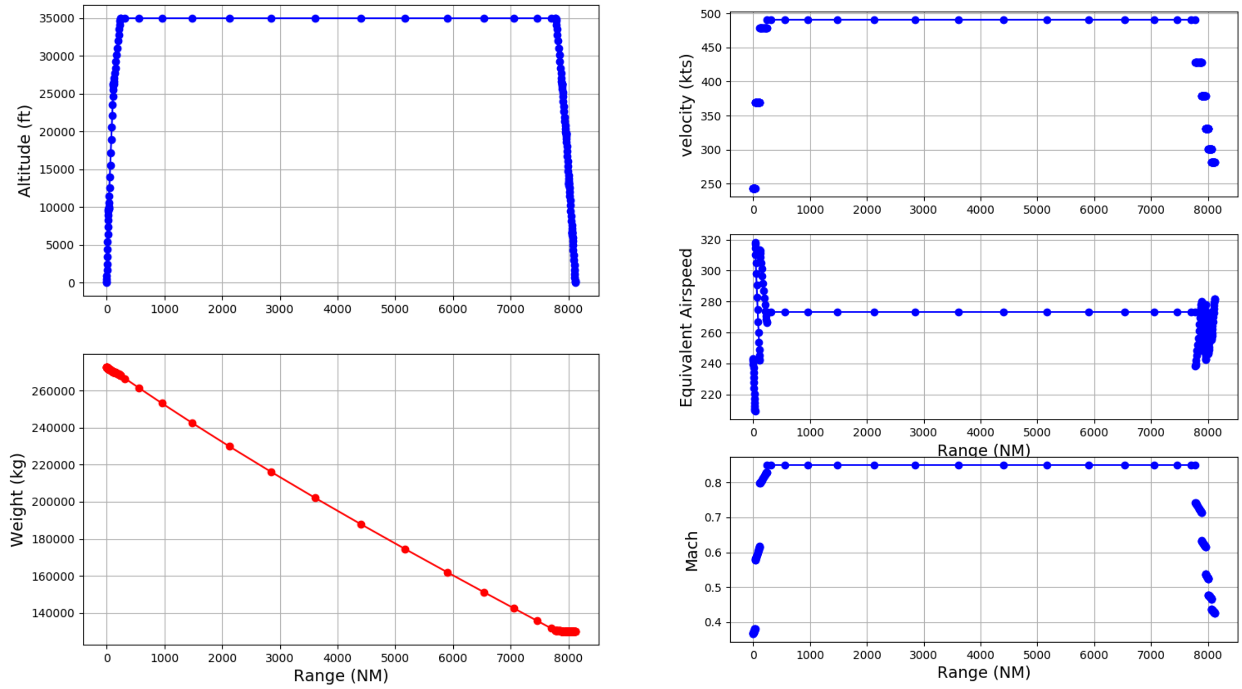


Figure 9. Thrust of SE²A-LR



(a) Aircraft altitude and weight

(b) Aircraft velocity

Figure 10. Mission performance of SE^{2}A-LR

VI. Aerodynamic shape optimization

To mitigate losses created by compressibility drag, a Discrete Adjoint aerodynamic shape optimization using SU2 was performed. For the present optimization problem, the SLSQP algorithm available through the Python interface Scipy [10] was used. At the moment, only a single-point optimization for an average cruise condition was considered. The objective function was to minimize the aircraft drag, subjected to geometric constraints for 10 selected sections along with the aircraft. A Free-From Deformation Box (FFD) with 15x11x2 (total of 330) points was used to modify the geometry at every optimization iteration. The optimization problem statement is summarized in Table 6 and the geometric representation of the FFD and constrained sections is shown in Figure 11.

The lift coefficient constraint is based on an average lift coefficient during the cruise. The thickness constraint was based on the initial selection of airfoils: initial thicknesses satisfied required volume for both passenger and fuel but were conservative. The reduction of maximum thickness by 20% still satisfies volume requirements for fuel and passengers. Finally, to avoid possibilities of sharp-edge sections generation, a constraint of leading edge radii reduction not exceeding 20% was imposed.

Figure 12 shows a comparison between the initial and optimizer geometries. From the figure, the shock wave strength was substantially reduced which caused a reduction in inviscid drag by 77%. Figure 13 demonstrates the distribution of pressure coefficient along 10 control sections of the geometry. Blue lines show initial sections while red lines demonstrate their modifications after optimization. From the figure, smoothening of all pressure coefficient curves is observed. In addition, three trends can be observed. First of all, the maximum thickness of inboard sections has not been substantially reduced, although a 20% reduction of thickness was imposed for all sections. Maximum thickness moved forward towards the leading edge making the aft part thinner. On the other hand, more significant thickness reduction is observed towards the wingtip. Second, the optimized wing demonstrates a 1 deg washout and increase the flight angle-of attack from -1.68 deg to -0.82 deg to reduce the shock wave strength and satisfy the lift coefficient requirements. Finally, a minor increase in the wing dihedral is observed. Figure 14 shows a comparison of lift distributions between initial and final designs and elliptical lift distribution. Results show that the optimized geometry approached elliptical lift distribution compared to the initial design which has a significant portion of lift produced by the fuselage and a mid-span loaded wing.

Table 6. Objective function definition

	Function/variable	Description	Quantity
minimize	C_D	Drag coefficient	
with respect to	z	FFD control point z-coordinates	330
Subject to	$C_L = 0.15$	Lift coefficient constraint	1
	$t > 0.8t_{base}$	Maximum thickness constraint for a given section	10
	$R_{LE} > 0.8R_{LE_{base}}$	Leading-edge radius constraint for a given section	10

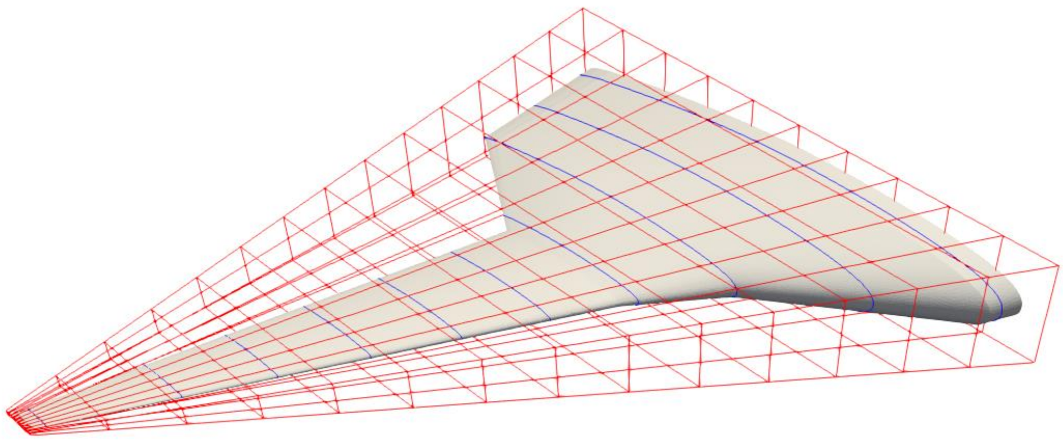


Figure 11. FFD Box (red) and control sections (blue) of the SE ²A-LR aircraft geometry

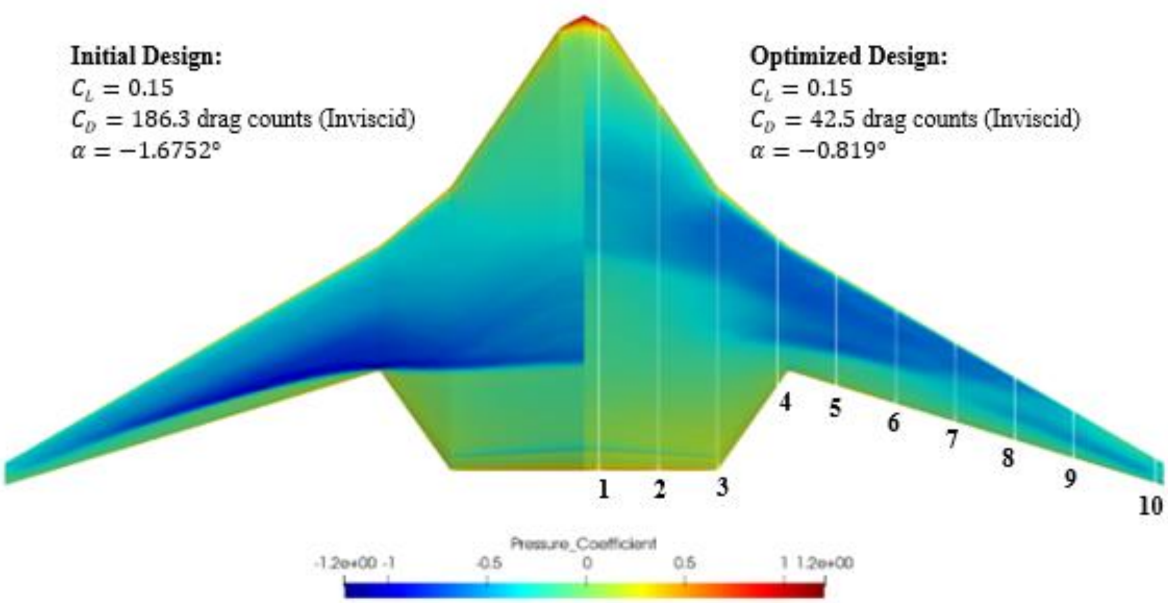
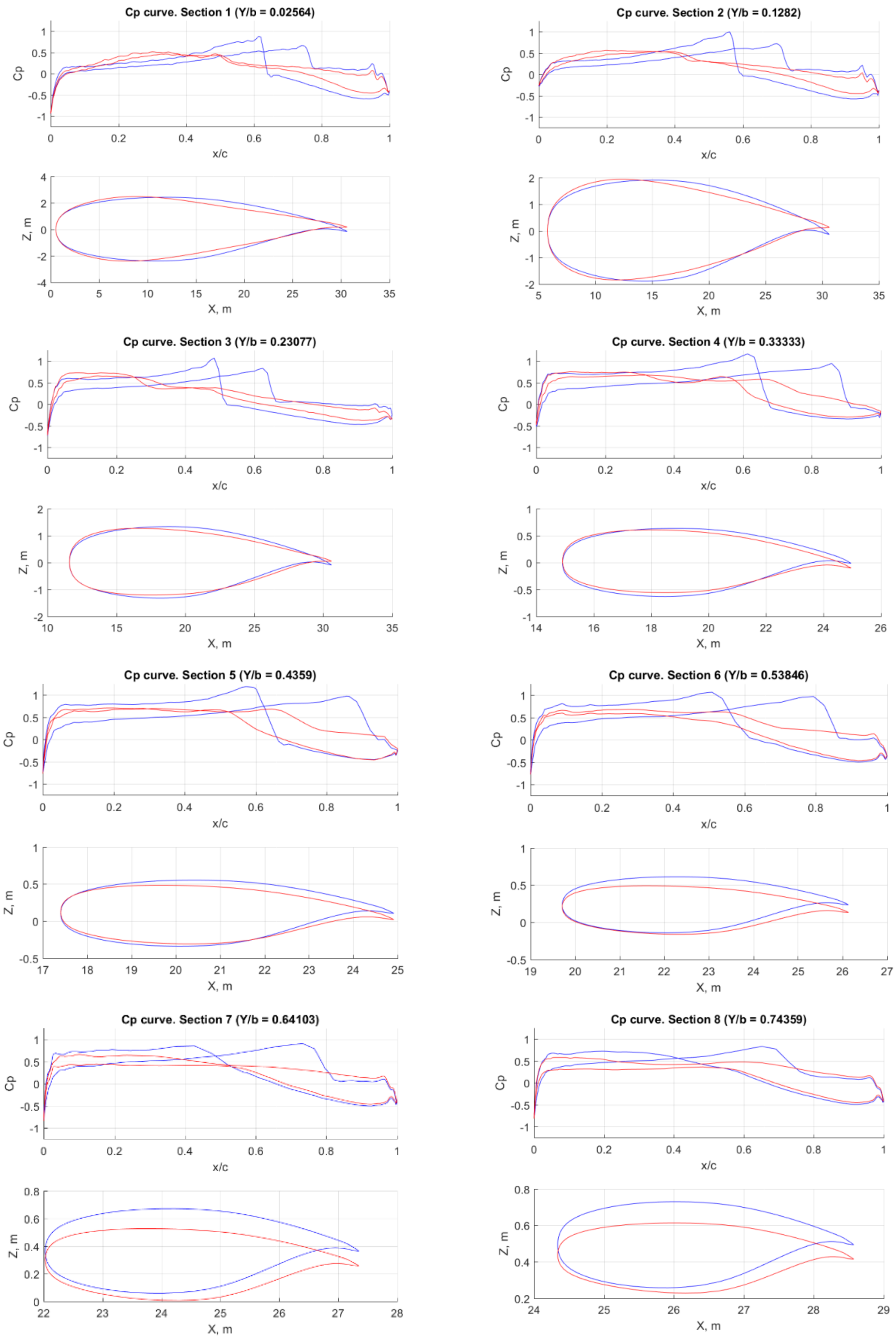


Figure 12. Pressure coefficient contours of the upper aircraft surfaces for initial and optimizer configurations



Cp curve. Section 1 (Y/b = 0.02564)
Cp curve. Section 2 (Y/b = 0.1282)
Cp curve. Section 3 (Y/b = 0.23077)
Cp curve. Section 4 (Y/b = 0.33333)
Cp curve. Section 5 (Y/b = 0.4359)
Cp curve. Section 6 (Y/b = 0.53846)
Cp curve. Section 7 (Y/b = 0.64103)
Cp curve. Section 8 (Y/b = 0.74359)
Cp
x/c
Z, m
X, m

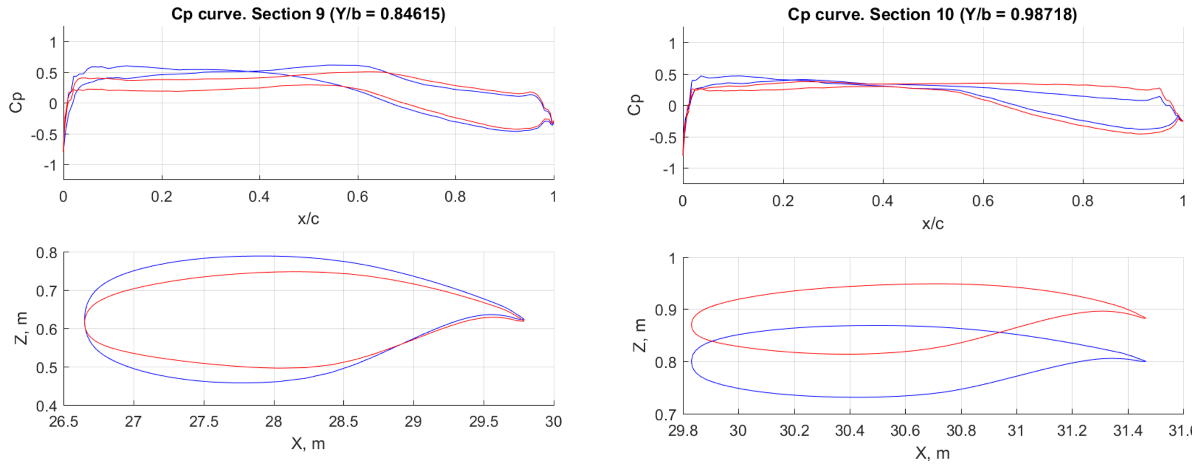


Figure 13. Pressure coefficient and geometry sections. Blue curves represent the initial design, and red curves represent the optimized design

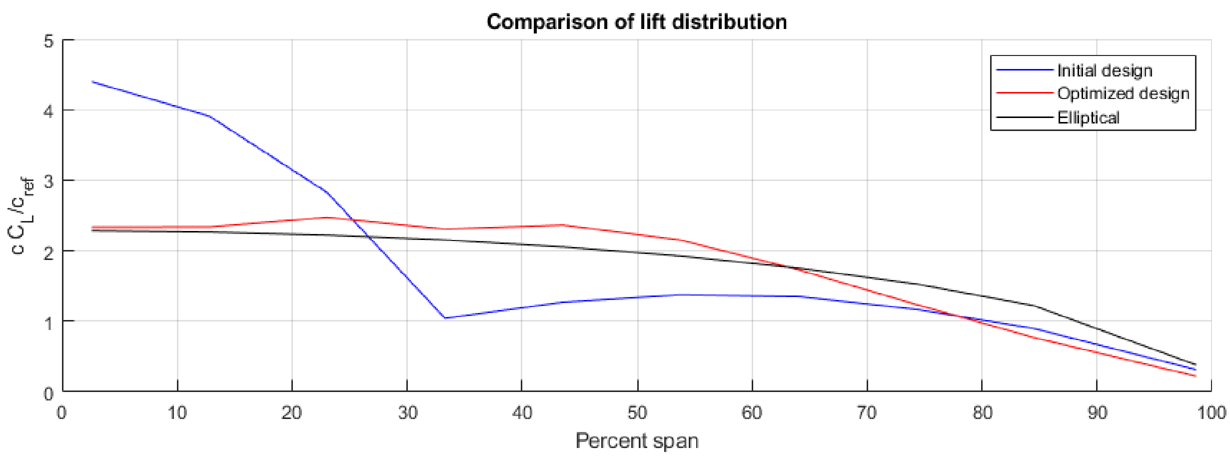


Figure 14. Comparison of lift distribution between initial and optimized designs

VII. Mission performance analysis of the optimized geometry

After a single-point optimization, the mission was calculated again to obtain modified results with the account of high-fidelity aerodynamics. Table 7 provides comparison of relative changes among low/medium fidelity, high-fidelity unoptimized and optimized high-fidelity results with respect to B777 results while Figures 15-17 show simulation results.

Results show substantial improvements in mission analysis. However, improvements caused by new technologies do not match the low-fidelity analysis. Fuel efficiency improvement does not exceed 61% for the analysis using higher fidelity tools. This shows that higher fidelity analysis plays an important role in initial stages of design and should not be avoided if the design considers unconventional configurations.

Table 7. Comparison of relative changes in key aircraft parameters with respect to B777

	Initial SE^{2}A – LR, Low/Medium fidelity (%)	**Initial SE^{2}A – LR, High fidelity (%)**	**Optimized SE^{2}A – LR, High fidelity (%)**
MTOW (kg)	-57.9	-21.0	-51.6
OWE (kg)	-42.2	-32.0	-40.3
Block fuel (kg)	-73.2	+30.6	-55.7
Fuel efficiency (kg/seat/100km)	-76.1	+16.5	-60.4

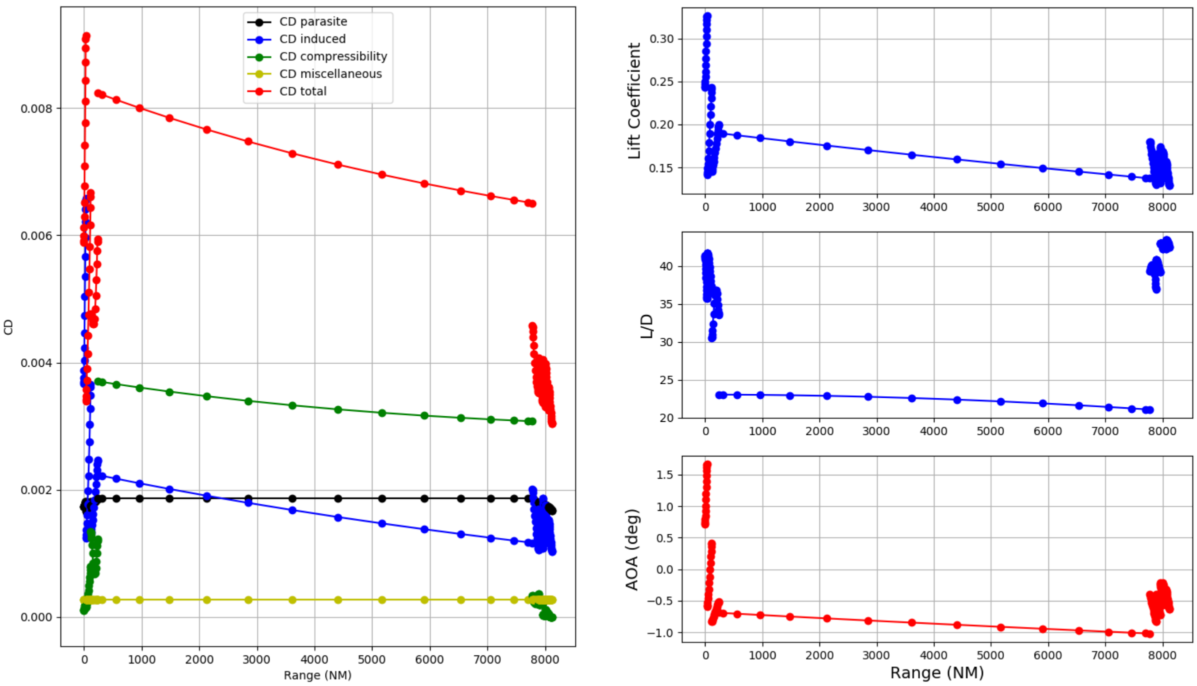


Figure 15. Aerodynamic performance of SE^{2}A-LR calculated using SUAVE

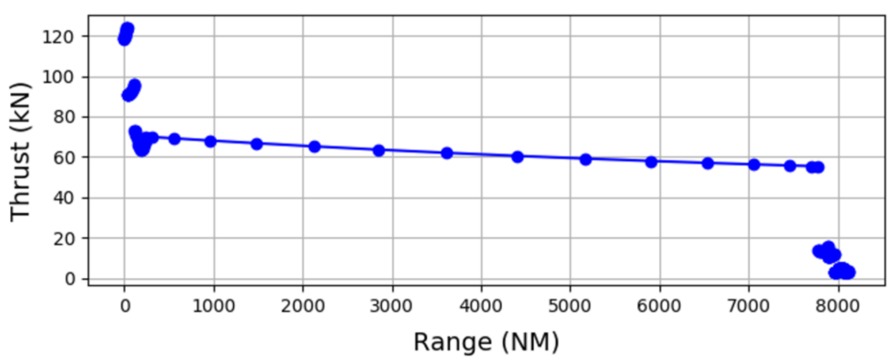
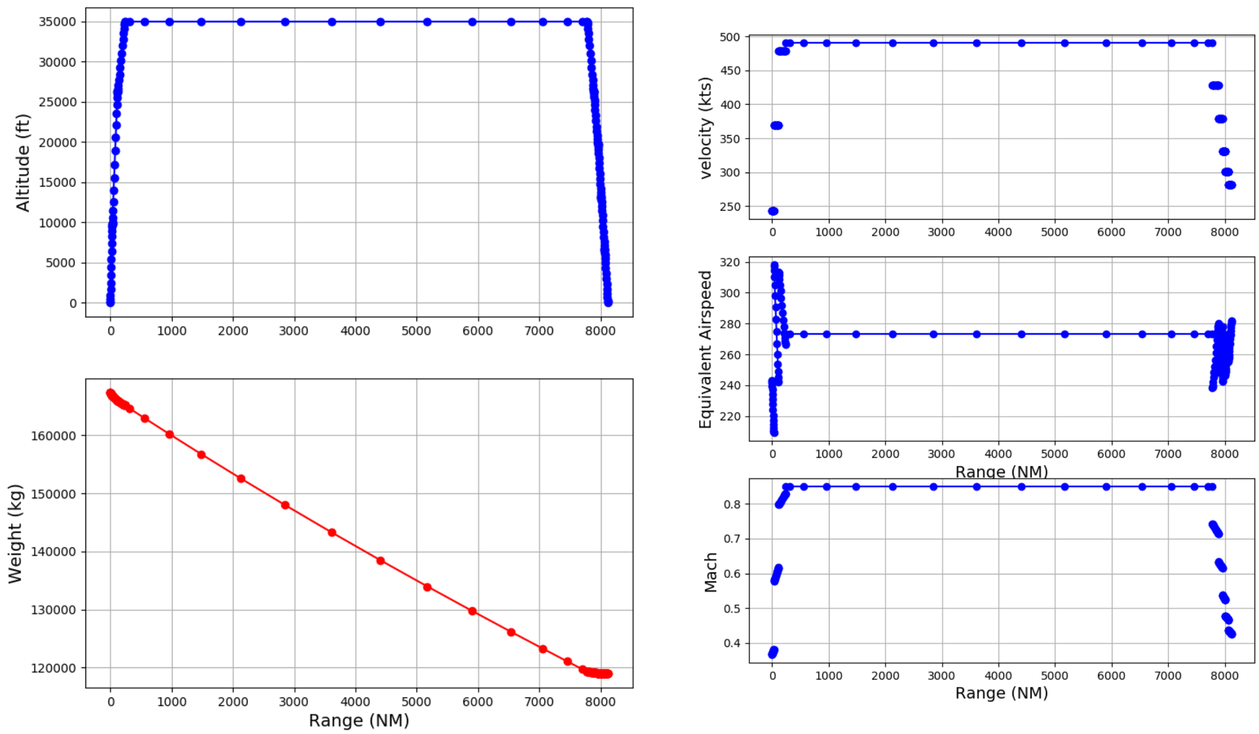


Figure 16. Thrust of SE^{2}A-LR



(a) Aircraft altitude and weight

(b) Aircraft velocity

Figure 17. Mission performance of SE^{2}A-LR

VIII. Summary and conclusion

The present manuscript describes a multi-fidelity design approach used under the SE^{2}A project to design a high-efficiency energy-sustainable aircraft. To increase the aircraft efficiency and minimize negative environmental impact, multiple novel technologies have been integrated at the conceptual design phase: active flow control (boundary layer suction), active load alleviation, boundary layer ingestion, and new materials and structure concepts. Presented approach was introduced for one of three aircraft concepts - the long-range blended wing body (BWB).

To increase design accuracy and, a multi-fidelity approach has been introduced. Stanford University SUAVE aircraft design environment with integration of novel technologies module was used for the mission analysis, OpenVSP and Gmesh were used for geometry modeling and mesh generation, and AVL and Stanford University SU2 were used for aerodynamic analysis. Euler equations CFD analysis was used to minimize computational costs and capture transonic aerodynamic effects.

Low-fidelity/medium approach (using AVL for CFD) has shown significant improvement in fuel efficiency of a potential long-rage aircraft – almost 76% increase in fuel efficiency compared to B777. However, mission analysis using SU2 demonstrated substantial increase in drag due to compressibility which has not been captured by the lower fidelity analysis. Large increase in drag reduced fuel efficiency by 16.5% compared to B777.

To minimize adverse effects of the wave drag, high-fidelity discrete-adjoint aerodynamic shape optimization using SU2 was performed. FFD approach was used to modify the aircraft geometry, and a SLSQP algorithm was used for optimization. The objective function was to reduce drag for an average cruise condition and geometric constraints of maximum thickness not being less than 80% compared to the initial design. Results showed reduction of inviscid drag by 77% compared to the initial configuration.

A modified mission analysis with an optimized aircraft and higher fidelity aerodynamic analysis significantly improved fuel efficiency compared to the initial design: fuel efficiency changed from +16.5% to -60.4% compared to B777. However, an optimized solution did not match the lower fidelity analysis which indicates desire to introduce higher fidelity tools as early in the conceptual design stage as possible to have more accuracy during design of unconventional aircraft configurations.

Future work will focus on multiple tasks. First, a new design iteration with focus on stability and control, weights and balance, system layouts will be performed. Second, an improved technique for the FFD definition will be implemented in SU2 to distribute control points more uniformly along the aircraft geometry and increase accuracy and flexibility of the shape optimization.

The present manuscript only covers very preliminary results based on the methods developed at the first stage of the project. The design will face multiple iteration with progressively increasing level of design and analysis accuracy, fidelity, and depth.

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