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Elaborato di laurea in Meccanica del Volo

Geometric modelling and analysis of performance, stability, and control of large military transport aircraft

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"If you hear a voice within you say
'you cannot paint,'
then by all means paint,
and that voice will be silenced."
-Vincent van Gogh

Abstract

The following work aims to compare the main parameters of stability and control, as well as the performance, of the Lockheed C-5 Galaxy and the Boeing C-17 Globemaster III, two of the largest military transport aircraft ever designed. A preliminary description is given in the first chapter. Firstly, thorough research is carried out to obtain the geometric features of the airplanes. These are needed to create the 3D models using JPAD Modeller, an integrated software, specialized in aircraft design, that allows to manage every component, from the fuselage and lifting surfaces to the powerplant and landing gear, with a unique level of detail. Moreover, flight performance is estimated thanks to a MATLAB script, provided by the thesis supervisor, which calculates the above-mentioned characteristics by reading the input data of the desired aircraft and flight conditions. Then, the stability and control analysis is performed through VSPAERO, a solver developed by NASA, capable of evaluating forces and moments by replacing the aircraft's surfaces with a discrete number of vortices, in accordance with the Vortex-Lattice method. Results are shown in every chapter to compare the characteristics of the aircraft.

Sommario

Il seguente lavoro ha lo scopo di confrontare i principali parametri di controllo e stabilità, nonché le prestazioni, di un Lockheed C-5 Galaxy e un Boeing C-17 Globemaster III, due tra i più grandi velivoli militari da trasporto mai progettati. Nel primo capitolo viene proposta una descrizione preliminare. Innanzitutto, è stata condotta un’approfondita ricerca per ricavare le caratteristiche geometriche degli aerei. Queste sono necessarie per creare i modelli tridimensionali con l’utilizzo di JPAD Modeller, un software integrato, specializzato nella progettazione di velivoli, che consente di gestire tutti i componenti, dalla fusoliera e le superfici portanti al sistema di propulsione e il carrello di atterraggio, con un livello di dettaglio unico nel suo genere. Inoltre, le prestazioni di volo sono ottenute grazie ad un codice MATLAB, fornito dal relatore, capace di fornire le sopracitate caratteristiche in base ai dati di input relativi all’aereo e alle condizioni di volo. In seguito, sono state svolte le analisi di stabilità e controllo tramite VSPAERO, un solutore, sviluppato dalla NASA, in grado di valutare le forze e i momenti generati, sostituendo le superfici del velivolo con un numero discreto di vortici, secondo il metodo Vortex-Lattice. In ogni capitolo vengono mostrati i risultati per confrontare le caratteristiche dei velivoli.

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1. Introduction

1.1 Purpose

Military aircraft are some of the most complex airplanes to design because they must be characterized by important levels of reliability and performance. Since the strategic transport airlifters presented in this work must often reach war zones, heavily loaded with supplies, armored vehicles, weaponry and soldiers, their design is critical. The purpose of this thesis is to analyze stability and control parameters and assess the flight performance of these airplanes, starting with the realization of the 3D models to have a faithful reproduction for the following studies.

1.2 Aircraft

1.2.1 Lockheed C-5 Galaxy

The Lockheed C-5 Galaxy is the largest strategic airlifter the United States Air Force is equipped with[1]. The assembly of the very first example was completed in 1968, since the U.S.A.F. was looking for a transport aircraft with a significantly higher load capacity than the ones already available, and Lockheed was able to offer a competitive design.

Figure 1.1 – Lockheed C-5 Galaxy

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[1] https://www.lockheedmartin.com/en-us/products/c-5.html

The load compartment is 37m long, 5.8m wide, with a total height of 4.1m. To avoid taking any risk, the cockpit is positioned above the cargo hold and not in front of it. This solution grants more longitudinal space to store the payload, and easier access to it, thanks to the nose door which, paired with the tail one, makes loading and unloading operations faster. Another interesting feature is the “kneeling” landing gear, which allows to lower the hold to truck-bed height. The crew usually consists of a pilot, a co-pilot, two flight engineers and three loadmasters. Nonetheless, the upper deck allows up to 73 passengers on board.

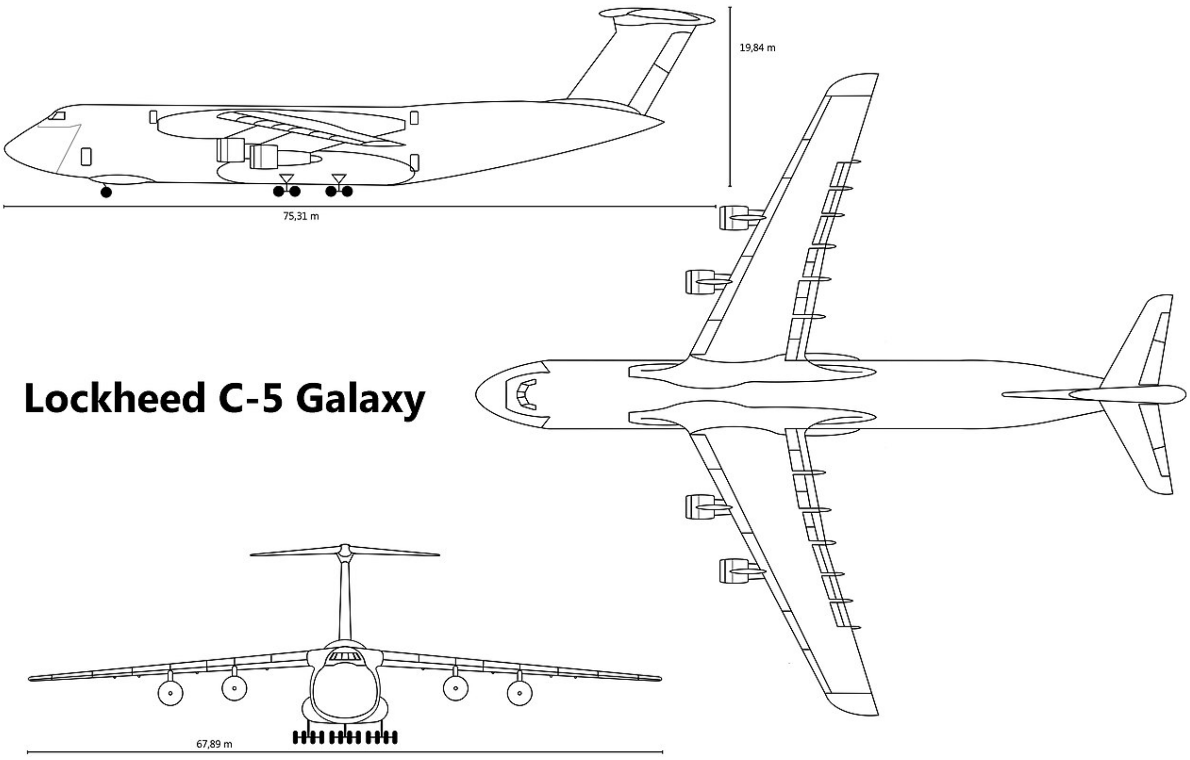

Figure 1.2 – Views and sizes of the Lockheed C-5 Galaxy

The C-5 Galaxy is the only aircraft considered by the U.S. Air Force displaying a T-tail. This configuration is more suited to a large cargo airlifter since it provides more space around the tail for the on-ground operations and enables higher stability and control thanks to the rearmost positioning allowed to the horizontal tail, hence generating a greater moment compared to the conventional tail. Moreover, at low angles of attack, the tail is less sensitive to the wake of the main wing and the jet blast, increasing the effectiveness of the elevator. Lastly, there is a minor improvement to the vertical stabilizer efficiency, since the horizontal tail works as an endplate, decreasing the induced drag generated when the rudder is actuated.

Of course, the T-tail implies a heavier structure for the last sections of the fuselage and the vertical stabilizer. The robust main wing sustains four General Electric TF-39 high-bypass turbofan engines which provide 193kN of thrust each, enabling the aircraft to take-off even at the maximum mass of 381000kg.

1.2.2 Boeing C-17 Globemaster III

The Boeing C-17 Globemaster III is designed as both a strategic and tactical airlifter, suited for long-distance transport and short missions within war zones. On September 15th, 1991, the maiden flight was accomplished, after 10 years of development and testing. Originally designed by McDonnel Douglas to meet the needs of the U.S.A.F., the C-17 was a versatile aircraft, able to intervene in many situations, from emergency evacuations to tactical airdrops. Moreover, the large cargo compartment, combined with the smaller overall size, made it suitable for replacing, in some operations, the larger C-5 Galaxy, which was having reliability issues at that time.

Figure 1.3 – Boeing C-17 Globemaster III

The aircraft, produced by Boeing since 1997, has a length of 53.04m and a fuselage diameter of 6.86m. Its wings, with a 51.74m span, are characterized by winglets, which modify lift distribution and significantly increase efficiency by reducing vortex intensity at the tip, whereas four Pratt & Whitney F117-PW-100 turbofan engines provide 179kN each and reverse thrust.

Figure 1.4 – Detail of winglet and engine

In addition, the lift coefficient, almost doubled thanks to the *blown flaps*[2], gives the C-17 excellent STOL[3] capabilities, making it able to take-off and land within just 1064m. Two pilots and a loadmaster are requested for ordinary operations, but the hold is equipped with 54 permanently installed seats on the sidewalls and 48 more stored on board, positioned in the centerline. Furthermore, the floor can be flipped from a flat surface for wheeled vehicles to rollerized conveyers for pallets.

1.3 Software and methods

1.3.1 JPAD Modeller

The main software used to prepare the geometry of the airlifters is JPAD Modeller, developed by SmartUp Engineering. The pre-processor is specifically designed for aircraft geometry management and allows the user to choose among three different options: to upload and modify an existing aircraft, to create a new one from scratch by assigning geometric features or to generate one thanks to the statistical design approach. Parametric modeling gives the opportunity to set the position of the wing in the user-defined reference frame, to shape the nose, cylindrical and tail trunks, as well as the engine pylons, winglets, nacelles, and fairings.

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[2] The high-mounted engines blowing on the double-slotted flaps of the wing enhance the lifting capabilities of the aircraft.

[3] Short Take-Off and Landing.

The designer has absolute control over the parts of the wing and the stabilizers, and features like sweep angle, panels and all the movables. A section is dedicated to the powerplant geometric and propulsive characteristics as well, whereas the CAD generation is managed by a specific menu. JPAD also has many export options like stl, iges, brep and step file formats for CAD software and analyses software like FlightStream, OpenVSP and any other code using the CPACS file format, allowing to easily evaluate the choices made in the conceptual design phase.

1.3.2 MATLAB live script

The study of performance was carried out with a MATLAB live script, divided into different sections. The script takes geometric, aerodynamic, propulsive, and operational data previously entered as an input by easily selecting the aircraft from a drop-down menu, and can calculate technical polar, climb, descent, glide and turn performance, take-off and landing distances, level flight characteristics and autonomies. All of this is possible thanks to previous, robust codes which use the well-known performance equations to obtain the requested results. A useful function, available since the 2022 release of the software, also allows to export all the output data, creating a report in Microsoft Word.

1.3.3 VSPAERO

VSPAERO is the solver used to estimate the stability and control characteristics of the 3-D models. As part of OpenVSP, a parametric geometry software focused on aircraft design and performance, VSPAERO gives outstanding information about forces, moments, and their distribution. The setup was chosen to acquire stability and control derivatives according to the Vortex-Lattice method, which simulates the aerodynamic disturbance of the bodies by replacing them with a grid of vortices, profoundly linking this method to the Lanchester-Prandtl wing theory. The intensity of each vortex is calculated with an iterative procedure, with the constraint of null normal velocity component on the walls. From the distribution and intensity of the vortices, it is possible to estimate the pressure distribution and velocity circulation along the analyzed geometries, hence, to extract the desired coefficients.

2. Models

In this chapter the geometric features of the aircraft are shown, to provide the reader with a comparison between every part of the developed models. The "Aircraft" section was used for the positioning of every component in the reference frame, whereas the "Canard" and "Landing gear" sections were not enabled since they are not useful for the purpose of this work. The information entered was obtained and compared using reliable sources, mentioned in the sitography, or identifying and converting the measures from the views of the aircraft.

2.1 Fuselage

In this section the nose, cylindrical and tail trunk, windshield, and cabin can be modified. Dimensions are listed and compared in Table 2.1.

	C-5 Galaxy	***C-17 Globemaster III***
Nose trunk length [m]	9.16	5.84
Cylindrical trunk lenght [m]	36.9	15.9
Tail trunk lenght [m]	24.5	26.9
Equivalent section diameter [m]	8.11	6.86

Table 2.1 – Fuselage main data

2.2 Wing

The "Wing" menu allows to set many parameters, such as:

- Position of spars.
- Height of the winglets.
- Position of the fuel tank.
- Span and chords of the panels.
- Flap type (plain, single slotted, fowler), size, position, and deflection.
- Size, position, and deflection of slats, ailerons and spoilers.

	C-5 Galaxy	***C-17 Globemaster III***
Total surface [m^2]	594	367
Total span [m]	68.0	51.6
Aspect ratio	7.78	7.26
Mean aerodynamic chord [m]	9.43	7.96
Winglets	No	Yes
Dihedral [deg]	-4	-4
Sweep at leading edge [deg]	27	29
Movables (half wing)	6 fowler flaps, 4 slats, 6 spoilers, aileron	2 single-slotted flaps, 4 slats, 4 spoilers, aileron

Table 2.2 – Wing main data

The selected airfoil for the C-5 Galaxy is the NACA 0012, since for the wing of this aircraft a slightly modified version of this symmetric airfoil was used.

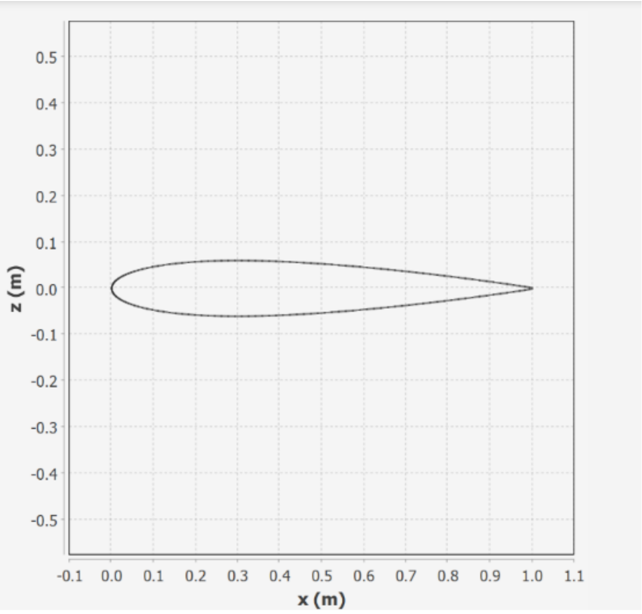

Figure 2.1 – NACA 0012 airfoil

The C-17 Globemaster III has a supercritical airfoil specifically designed for it[4], not available on public sources, so a similar airfoil was selected, the NASA SC (2)-0412. The JPAD library counts several types of airfoil, but this one was imported from Airfoil Tools website by copying its 2-D coordinates and organizing them in an Excel file, using the counterclockwise disposition requested by JPAD.

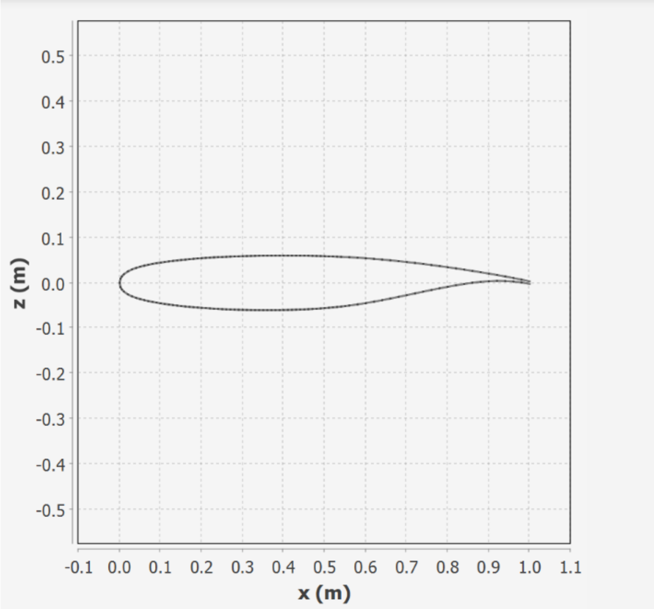

Figure 2.2 – NASA SC(2)-0412 airfoil

2.3 Horizontal tail

This section is dedicated to both the horizontal stabilizer and elevator. Just like the wing, it is possible to control the chordwise position of the spars, span and chords of the panels, and size, position, and deflection angle of the elevator. The airfoil chosen for the horizontal tail is the NACA 0012 for both aircraft.

The main parameters are listed below.

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[4] DLBA 142. The airfoil takes the name from the site of production of the aircraft, Long Beach, California.

	C-5 Galaxy	*C-17 Globemaster III*
Total surface [m^2]	91	76
Total span [m]	21.6	19.8
Aspect ratio	5.10	5.13
Mean aerodynamic chord [m]	4.51	4.18
Dihedral [deg]	-3	-3
Sweep leading edge [deg]	30	31

Table 2.3 – Horizontal tail main data

2.4 Vertical tail

The section which focuses on the vertical tail has the same options of the previous one. In this case the NACA 0012 airfoil was used too.

A comparison of the vertical tail geometries is presented in Table 2.4.

	C-5 Galaxy	*C-17 Globemaster III*
Total surface [m^2]	99	82
Total span [m]	11.4	9.8
Aspect ratio	1.31	1.18
Mean aerodynamic chord [m]	8.72	8.32
Sweep leading edge [deg]	35	40

Table 2.4 – Vertical tail main data

2.5 Nacelles and Powerplant

The last section of the Input Manager module is dedicated to the engines. The user is allowed to select the type of engine among piston engine, turbofan, and turboprop. Moreover, it is possible to choose nacelles geometric features with reference to the maximum diameter.

The main propulsive and geometric parameters are listed in Table 2.5.

	C-5 Galaxy	*C-17 Globemaster III*
Engine type	Turbofan	Turbofan
Length [m]	7.92	6.26
Dry mass [kg]	3630	3311
Static thrust [kN]	193	180
By-pass ratio	8	6
Maximum diameter [m]	2.46	2.89

Table 2.5 – Main powerplant and nacelles data

2.6 Final models

Even though the C-5 Galaxy is larger than the C-17 Globemaster III, they have remarkably similar structures and configurations due to the mission profiles requested to both aircraft. The modelling results are shown and compared with the original views in the figures below.

2.6.1 C-5 Galaxy

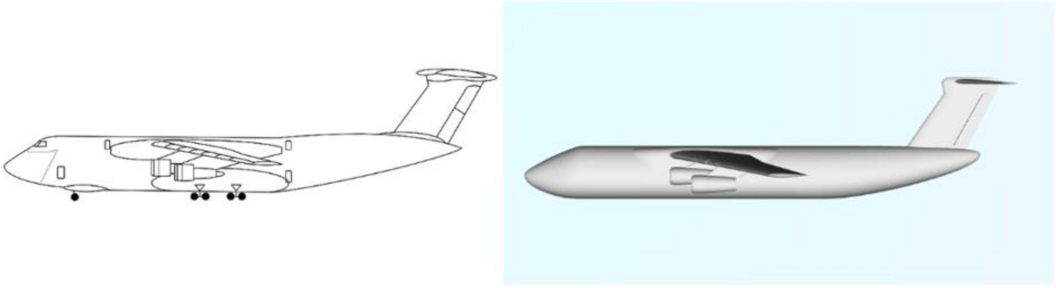


Figure 2.3 – C-5 side view

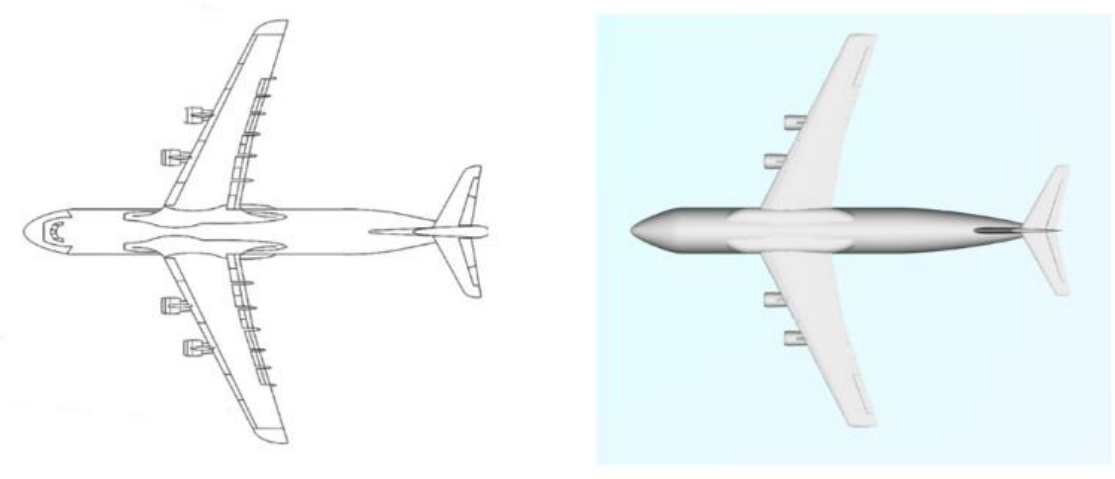


Figure 2.4 – C-5 top view

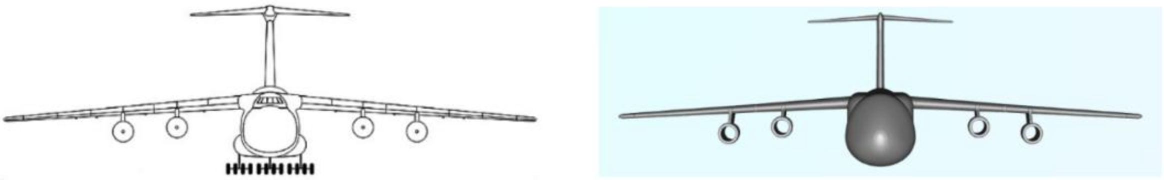


Figure 2.5 – C-5 front view

Figure 2.6 – C-5 generic view

2.6.2 C-17 Globemaster III

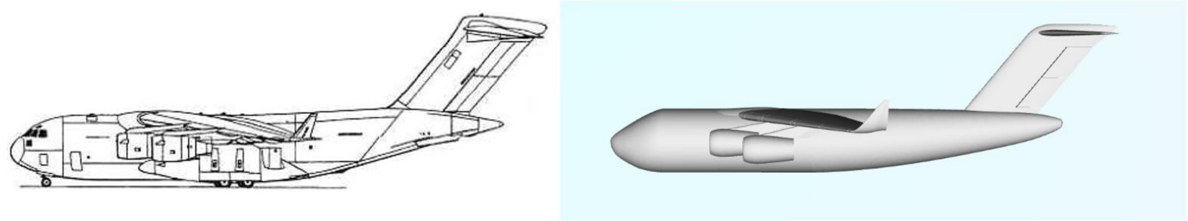


Figure 2.7 – C-17 side view

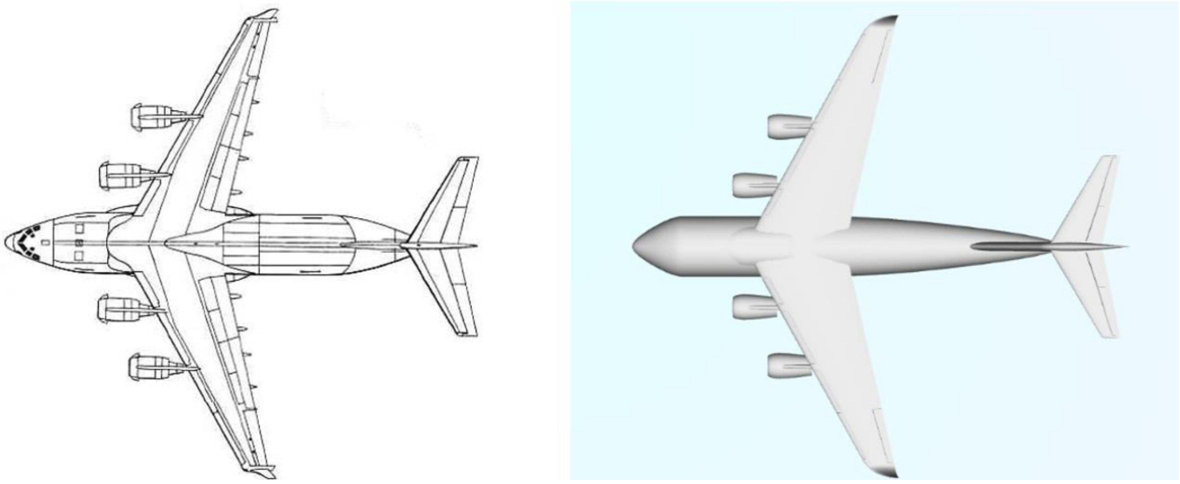


Figure 2.8 – C-17 top view

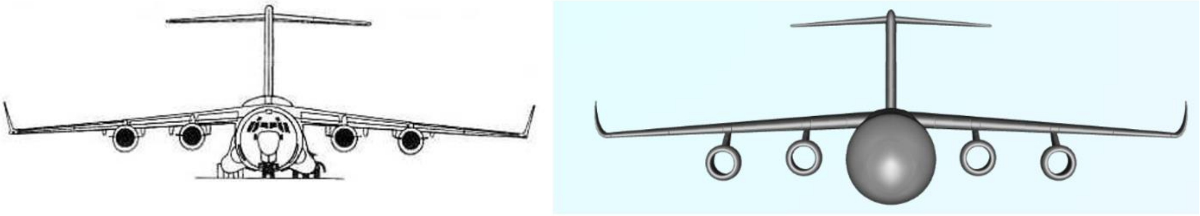


Figure 2.9 – C-17 front view

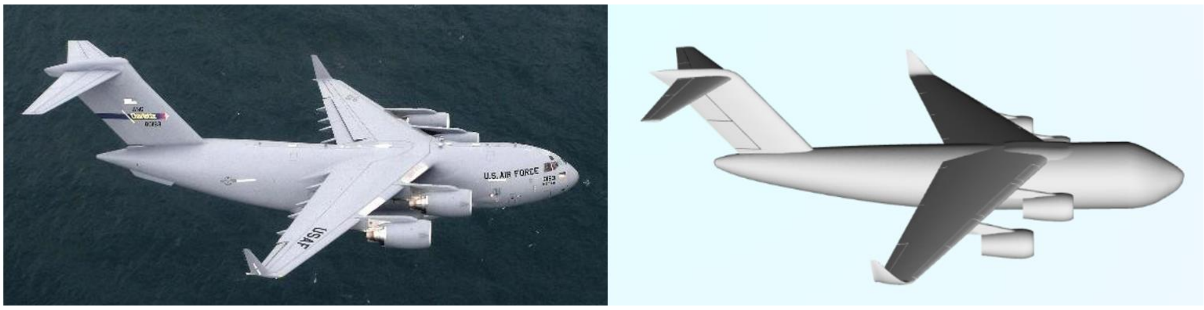


Figure 2.10 – C-17 generic view

3. Performance analysis

This chapter is dedicated to the examination of performance characteristics of the C-5 Galaxy and the C-17 Globemaster III. The results have been reported taking account of the official data available, to ensure their consistency.

3.1 Input data

	C-5 Galaxy	*C-17 Globemaster III*
Weight		
Take-off mass [kg]	348800	189375
Fuel mass [kg]	150820	82125
Geometry		
Wing surface [m^2]	594	367
Wingspan [m]	68.0	51.6
Aerodynamics		
Maximum lift coefficient	1.45	1.50
Maximum lift coefficient (take-off)	2.31	2.20
Maximum lift coefficient (landing)	2.60	2.60
Zero-lift drag coefficient	0.0184	0.0184
Δ zero-lift drag coefficient (take-off)	0.030	0.030
Δ zero-lift drag coefficient (landing)	0.042	0.05
Oswald factor	0.8	0.8
Drag-divergence Mach number	0.8	0.79
Powerplant		
Thrust [kgf]	19681	18343
TSFC [lb/lbh]	0.65	0.68
Engines number	4	4
Throttle in reverse thrust	40%	40%
Throttle during approach	20%	20%

Table 3.1 – Main input data for the MATLAB live script

3.2 Technical polars

The technical polars represent the relationships between the parameters of the aircraft, such as lift and drag coefficients, efficiency, thrust, power, and speed. On each curve, four characteristic points can be identified:

- E: maximum efficiency, minimum drag. At this point, a propeller-driven aircraft achieves the maximum range, whereas a jet aircraft maximizes its endurance.
- P: minimum power requested for level flight. This is the suggested configuration to maximize endurance on a propeller-driven aircraft.
- A: minimum drag-to-speed ratio. This trim should be selected for maximum range on a jet aircraft.
- S: minimum speed, maximum lift coefficient. A further increase of the angle of attack (a reduction of the flight speed) leads to an abrupt loss of lift.

The results shown below were calculated at sea level and cruise altitude, which was set as 7620m for the C-5 and 8500m for the C-17.

Point E

	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	0.60	0.04	16.3	125	210	26290	0.37
C-17 Globemaster III	0.58	0.04	15.8	119	118	14093	0.35

Table 3.2 – Point E at sea level

Point E

	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	0.60	0.04	16.3	187	210	39272	0.60
C-17 Globemaster III	0.58	0.04	15.8	188	118	22168	0.61

Table 3.3 – Point E at cruise altitude

Point P							
	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	1.04	0.07	14.1	95	242	23066	0.28
C-17 Globemaster III	1.00	0.07	13.6	91	136	12365	0.27

Table 3.4 – Point P at sea level

Point P							
	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	1.04	0.07	14.1	142	242	34457	0.46
C-17 Globemaster III	1.00	0.07	13.6	143	136	19450	0.47

Table 3.5 – Point P at cruise altitude

Point A							
	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	0.35	0.02	14.1	165	242	39951	0.48
C-17 Globemaster III	0.33	0.02	13.6	157	136	21416	0.46

Table 3.6 – Point A at sea level

Point A							
	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	0.35	0.02	14.1	202	242	59681	0.79
C-17 Globemaster III	0.33	0.02	13.6	192	136	33688	0.81

Table 3.7 – Point A at cruise altitude

Point S							
	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	1.45	0.13	11.5	81	297	23936	0.24
C-17 Globemaster III	1.50	0.14	10.6	74	175	13029	0.22

Table 3.8 – Point S at sea level

Point S							
	CL	**CD**	**E**	**V[m/s]**	**D[kN]**	**Pr[kW]**	**M**
C-5 Galaxy	1.45	0.13	11.5	120	297	35756	0.39
C-17 Globemaster III	1.50	0.14	10.6	117	175	20494	0.38

Table 3.9 – Point S at cruise altitude

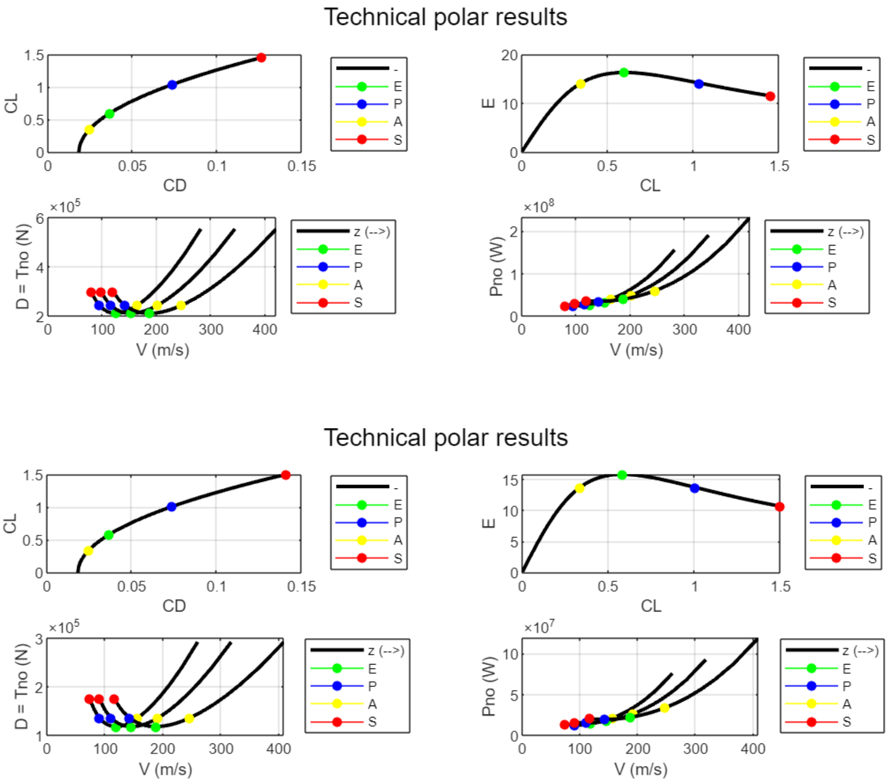


Figure 3.1 – Technical polars of the C-5 (top) and the C-17 (bottom)

3.3 Propulsive characteristics

Considering a cruise rating, five hours of flight with the throttle at 80%, and a speed of 200 m/s, the propulsive characteristics are shown in Table 3.10.

	Thrust [kN]	**Power [kW]**	**Fuel [L]**
C-5 Galaxy	197	39313	81426
C-17 Globemaster III	183	36642	79396

Table 3.10 – Propulsive characteristics

3.4 Climb and level flight

The climb performance is evaluated at sea level, whereas the level flight maximum speed refers to cruise altitude, with the effects of compressibility reported in Figure 3.2.

	Rate of climb [m/s]	Maximum speed [m/s]
C-5 Galaxy	6.4	248
C-17 Globemaster III	15.8	254

Table 3.11 – RC and maximum speed

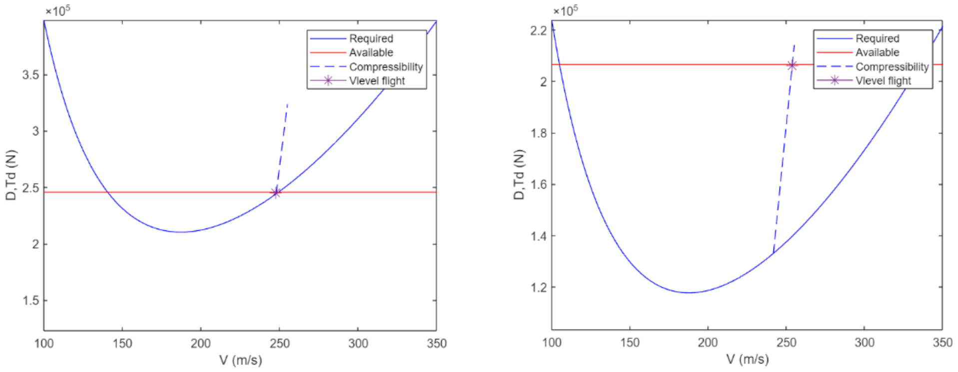


Figure 3.2 – Power available and required in level flight condition

The gap between the two rates of climb is due to the significant difference in weight, paired with a comparable powerplant and higher drag-to-speed ratio of the C-5.

3.5 Autonomies

	Maximum endurance [h]	Maximum range [km]
C-5 Galaxy	14.2	9485
C-17 Globemaster III	13.2	8387

Table 3.12 – Aircraft autonomies (constant flight altitude)

As the reader can see, the autonomies are comparable, but it should be kept in mind that the C-17 is also used as a tactical airlifter, so the actual mission profile usually halves the range requested.

3.6 Turn

Turn performance, in take-off rating at 4000m, is shown in Table 3.13.

	C-5 Galaxy	*C-17 Globemaster III*
Minimum turn speed [m/s]	109	127
Minimum turn radius [m]	1689	979
Maximum rate of turn [deg/s]	3.7	7.4
Maximum bank angle [deg]	36	59

Table 3.13 – Turn performance

As for the rate of climb, the difference between turn performance is given by the weight of the C-5 Galaxy, which doubles that of the C-17, while having similar engines.

3.7 Take-off and landing

Take-off and landing distances in standard atmospheric conditions are summarized in Table 3.14.

	Take-off distance [m]	**Landing distance [m]**
C-5 Galaxy	1805	892
C-17 Globemaster III	990	1020

Table 3.14 – Take-off and landing distances

As mentioned in 1.2.2, the C-17 has enhanced take-off capabilities, also given the lower weight. On the other hand, more weight allows for a shorter approach phase, reducing the overall landing distance of the C-5.

4. Stability and control analysis

The last analysis performed aims to estimate stability and control derivatives using VSPAERO, the solver implemented in OpenVSP for aerodynamic analyses. In this chapter, the setup and the results for both aircraft are shown.

4.1 VSPAERO setup

After importing the OpenVSP file from JPAD Modeller, the solver was given the instructions necessary to carry out the analysis. Firstly, the Vortex-Lattice method was selected, then the reference area and lengths were entered, considering the wing surface, wingspan and mean aerodynamic chord. As for the longitudinal position of the center of gravity, it was calculated considering the following formula:

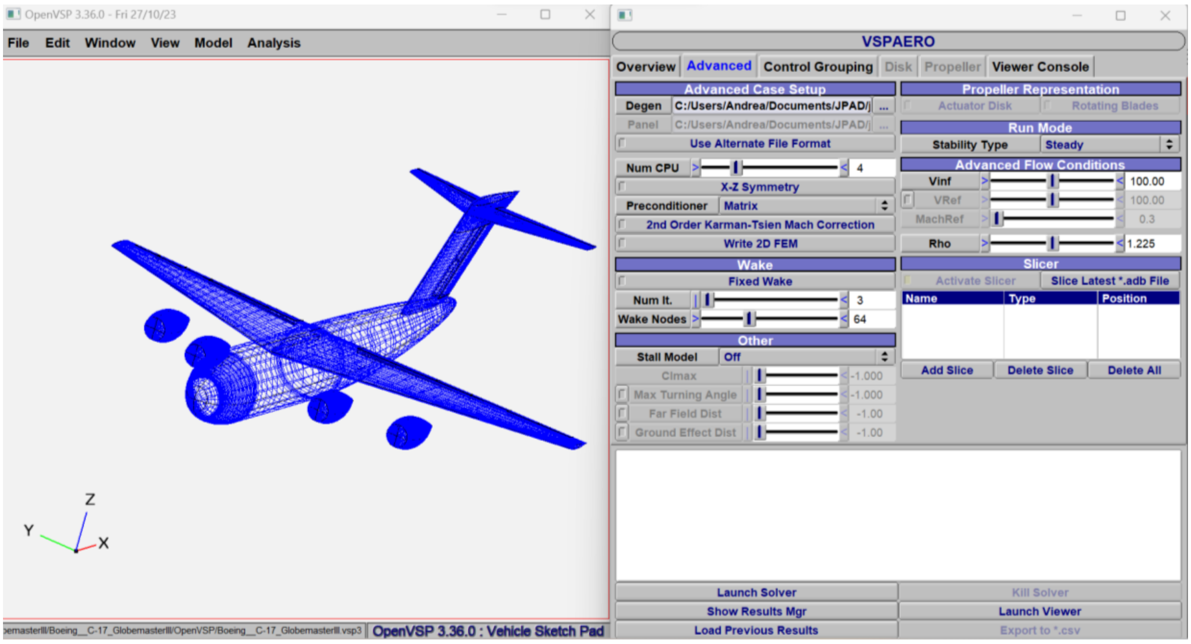
$$x_{CG} = X + x + \bar{x} \tag{4.1}$$

in which X is the distance between the apex of the fuselage and that of the wing, x is the coordinate of the apex of the mean aerodynamic chord with reference to that of the wing, and $\bar{x}$ is the position, with respect to the apex of the m.a.c., where the center of gravity is located. The stability study was conducted considering a variation of 1 deg of the angle of attack and sideslip angle, which were initially set to 0°.

	C-5 Galaxy	**C-17 Globemaster III**
Reference area [m^2]	594	367
Reference wingspan [m]	67.0	51.6
Reference chord [m]	9.43	7.96
X [m]	20.7	12.8
x [m]	7.28	5.75
$\bar{x}$ [m]	2.36	2.23
CG longitudinal position [m]	30.3	20.7

Table 4.1 – Reference area, lengths, and CG position

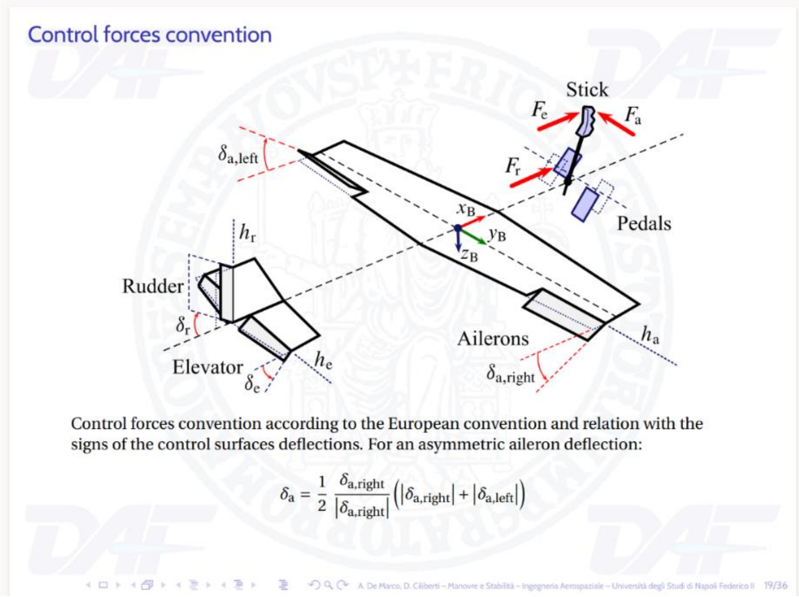
The position of the center of gravity, considering the geometry and mass distribution, was set as 25% of m.a.c. for the C-5 and 28% of the m.a.c. for the C-17. In the advanced settings, the desired number of CPUs was selected, as the number of iterations for the wake. The X-Z symmetry was left disabled since the variation of the sideslip angle would not allow for such an assumption. The stability type was set to steady, then the flow conditions were entered, like the speed of 100 m/s and density of 1.225 kg/m^3.



Degen C:/Users/Andrea/Documents/JPAD/j
Panel C:/Users/Andrea/Documents/JPAD/j
Num CPU 4
Preconditioner Matrix
Num It. 3
Wake Nodes 64
Stall Model Off
Clmax -1.000
Max Turning Angle -1.000
Far Field Dist -1.00
Ground Effect Dist -1.00
Stability Type Steady
Vinf 100.00
VRef 100.00
MachRef 0.3
Rho 1.225
emasterIII/Boeing__C-17_GlobemasterIII/OpenVSP/Boeing__C-17_GlobemasterIII.vsp3

Figure 4.1 – VSPAERO user’s interface

Lastly the control surfaces were grouped. This was done autonomously by the software which, based on the position of the movables, created three groups containing, respectively, ailerons, elevator, and rudder. The flaps, which are detected as control surfaces, were disabled for the calculation of derivatives. In addition, the rotation of movables was modified such that the rudder would deflect on the left, while looking the airplane from behind, and the elevator would rotate down, since the standard option sets an antisymmetric deflection.



Control forces convention

Control forces convention according to the European convention and relation with the signs of the control surfaces deflections. For an asymmetric aileron deflection:

$$\delta_a = \frac{1}{2}\,\frac{\delta_{a,right}}{|\delta_{a,right}|}\left(|\delta_{a,right}| + |\delta_{a,left}|\right)$$

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Figure 4.2 – Positive deflections of control surfaces

4.2 Results

Before showing the results, it must be said that, as shown in Figure 4.1, the reference frame used by OpenVSP is different from the body frame of reference. This is not negligible, because the stability and control derivatives are obtained considering OpenVSP frame, so the signs for some of them change. To be clear, the reported values are already converted in the body frame. The stability and control derivatives determine the aircraft response to variations of the angle of attack, sideslip, and control surfaces deflection. An aircraft is considered “longitudinally stable” when a higher angle of attack generates a reduction of the pitching moment coefficient, hence:

$$\frac{\mathrm{d}C_{My}}{\mathrm{d}\alpha} < 0 \qquad (4.2).$$

It is said “directionally stable” when a positive sideslip induces a positive yawing moment that lowers said angle, which leads to:

$$\frac{\mathrm{d}C_{Mz}}{\mathrm{d}\beta} > 0 \qquad (4.3).$$

Stability and control derivatives are summarized in Table 4.2.

	C-5 Galaxy	*C-17 Globemaster III*
Stability derivatives		
$dC_L/d\alpha$	4.94	5.02
$dC_{My}/d\alpha$	-1.41	-1.60
$dC_{Mx}/d\beta$	-0.0218	-0.0526
$dC_{Mz}/d\beta$	0.0178	0.00166
Control derivatives		
$dC_{My}/d\delta_e$	-1.41	-1.99
$dC_{Mx}/d\delta_a$	-0.120	-0.133
$dC_{Mx}/d\delta_r$	0.0249	0.0318
$dC_{Mz}/d\delta_r$	-0.0863	-0.0890

Table 4.2 – Stability and control derivatives (rad^{-1})

Based on the previous definitions, both aircraft are longitudinally and directionally stable. The control derivatives also have a coherent sign with respect to the European convention. Lastly, VSPAERO gives as an output the position of the neutral point and the static stability margin, reported in Table 4.3.

	C-5 Galaxy	*C-17 Globemaster III*
Static stability margin	0.286	0.318
Neutral point position [m]	33.02	23.27

Table 4.3 – SM and neutral point longitudinal position

The static stability margin is calculated as:

$$SM = \hat{x}_N - \hat{x}_{CG} \quad (4.4),$$

which is exactly the opposite of the conventional definition. $\hat{x}_N$ is the position of the neutral point as percentage of the mean aerodynamic chord. This is the aft limit for the position of the center of gravity, since in this point the aircraft’s equilibrium in pitch is neutrally stable, hence $\frac{\mathrm{d}C_{My}}{\mathrm{d}\alpha} = 0$. Moving the center of gravity further back would lead to an unstable equilibrium in pitch.

5. Conclusion

The goal of this work was to assess stability, control, and performance of two large military transport airlifters using three-dimensional models created in JPAD Modeller. The analyses of performance have demonstrated consistency with official data available, meaning that the modelling of characteristic parameters is robust. Stability and control derivatives are aligned with the principles of flight mechanics and give important information about the configuration of the aircraft.

The study which was carried out could be improved with a more accurate modelling of the fuselage in JPAD Modeller, which doesn’t yet allow for the specification of peculiar fuselage sections[5] and nose geometry, critical for aerodynamic analyses, and tail, which can lead to problems in the definition of linking sections of the vertical tail. Additionally, the wingtip geometry is less easy to manipulate than the other features of the wing, which can sometimes make it necessary to simplify this part of the main lifting surface. On the other hand, the managing of the movables is absolutely advanced, and the geometric configuration of the wing fairing can replicate very precisely the link between the fuselage and the wing itself. Regarding VSPAERO, it makes possible to start a calculation and examine results in a matter of minutes, even though the default settings and conventions can lead to mistakes if unnoticed. Finally, the MATLAB script is straightforward and gives a complete overview of the most relevant performance of an aircraft, allowing for a quick and rich evaluation of desired parameters in a hypothetical design phase. It could be an interesting development to compare the characteristics of these airlifters with a fighter aircraft, to highlight the differences between the various military applications of flight mechanics and dynamics.

In conclusion, this thesis gives a contribution to the understanding of important parameters for the type of aircraft presented, by effectively combining theoretical knowledge with the latest engineering tools and technologies.

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[5] For example, the airlifters presented in this work have uncommon fuselage sections where the landing gear is located.

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