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Creation of a Z-configuration Baseline Aircraft

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Technical Note

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19. Kurzfassung In this documents, the assumption and approaches used in order to design a Z-configuration baseline aircraft are described. As a first step, the preliminary sizing of the aircraft is carried out. Then, the geometrical description of its components and their location are estimated. Finally, an xml file is created for CEASIOM.		
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1 Design specifications

1.1 Aircraft configuration

The Z-configuration morphology is constructed by placing the starboard wing low at the forward fuselage, and, the port wing high at the aft fuselage. This morphology can be observed in Figure 1 and 2.

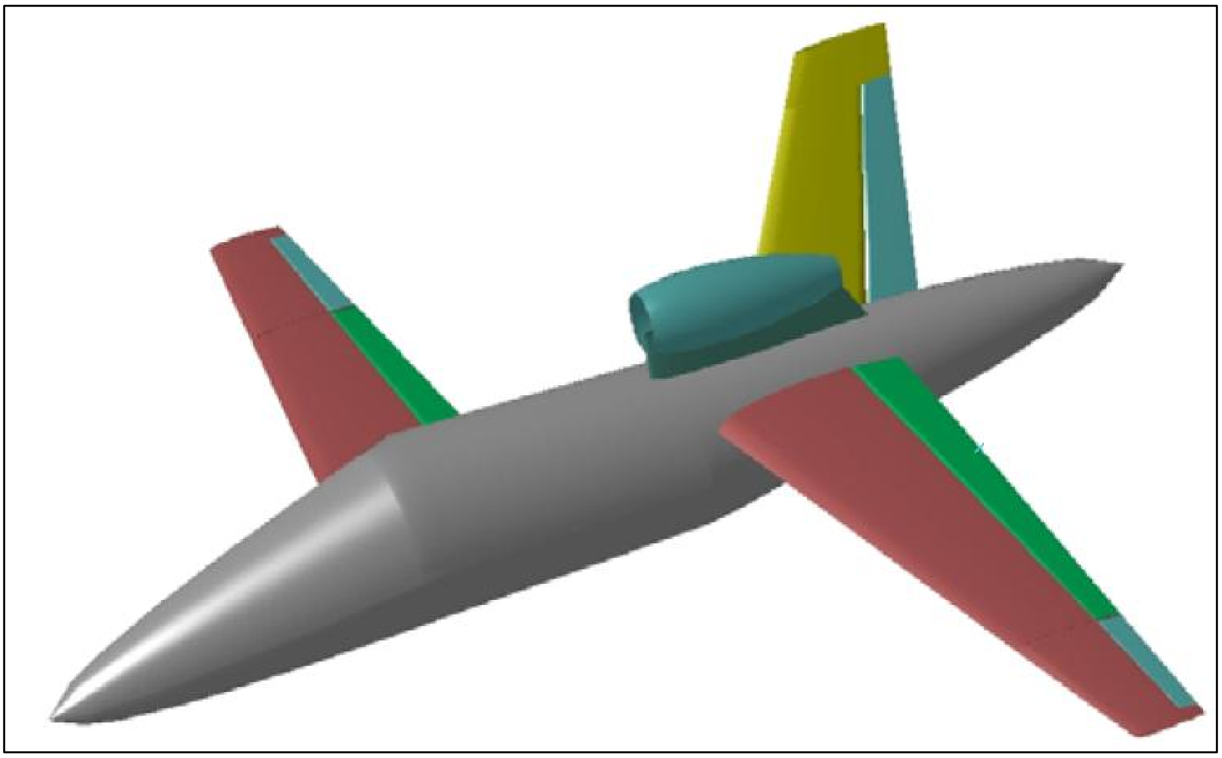

Figure 1 Z-configuration sketch (**Isikveren 2008**)

Figure 2 Z-configuration artistic view

1.2 Design Requirements

All the requirements for the design are obtained from the SimSAC report by Dr. Isikveren (**Isikveren 2008**) and summarized in Table 1. In addition to the design requirements, the motivations and innovations of the project are described in this document.

Table 1 Design Specifications

Parameter	Requirement
Passengers	Min. 5 (including pilot)
Cabin Volume [m^3]	At least 5.7
Passenger Weight [kg]	105
Cabin requirements	Lavatory, galley/stowage. 7000ft equivalent cabin altitude at service ceiling.
Design range, IFR, 1000nm altitude at 0.6 Mach [nm]	1500
Normal cruise Mach number	0.6
Maximum cruise Mach number	0.7
Take-off field length for ISA, sea level [ft]	Less than 3000
Take-off field length for ISA+20°C, 5000ft	Less than 5500

[ft]	
Approach speed [KCAS]	Less than 1000
ICA [ft]	At least 37000
TOC for ISA, MTOW, take-off (min)	Less than 25 min
Service Ceiling [ft]	41000
Service Life [cycles]	20000
Fatigue Life [cycles]	50000
Systems	FCS
Operational requirements	Accommodate 1+1 flight crew. Certified for single pilot operation.
Noise	Stage 4 requirements – 20 EPB *dB*
Operating Economics	Cash operating cost at least neutral with best comparable turboprop.
Certification Standards	FAR-23/CS-23 FAR135/JAR-OPS

1.3 Mission Definition

The IFR mission profile is defined in figure 3.

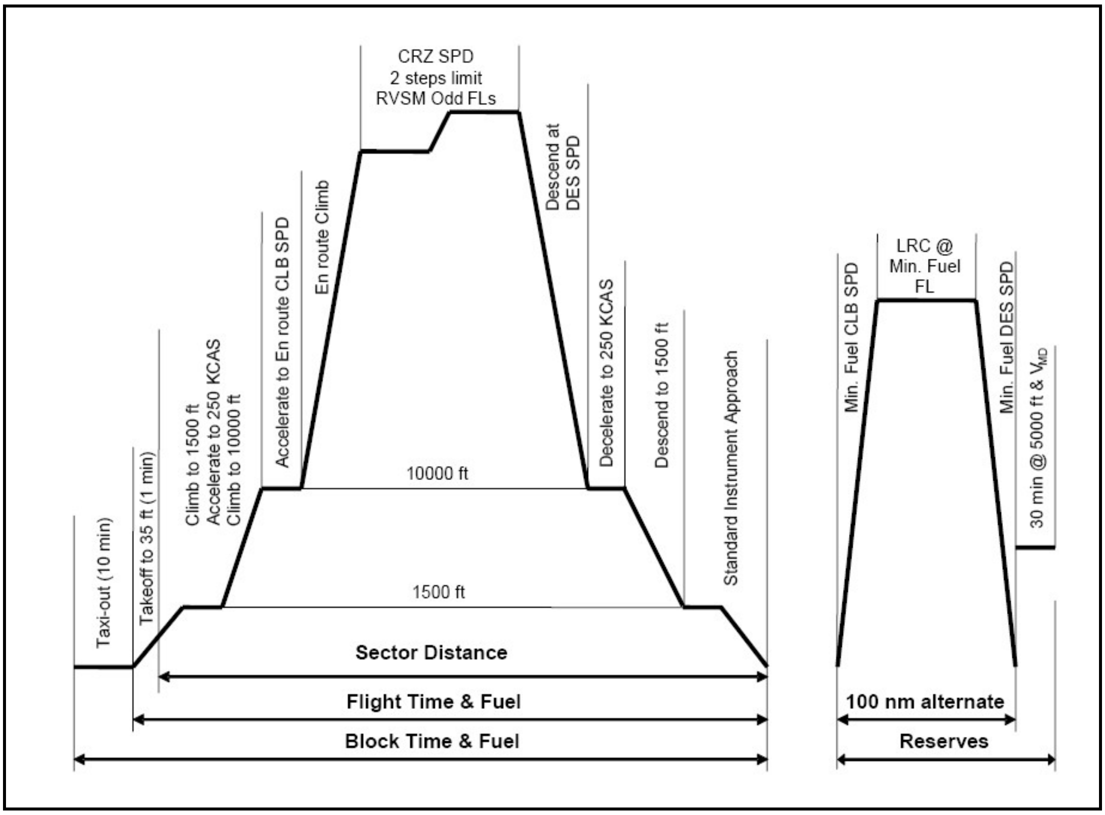

Figure 3 IFR Flight Profile

2 Selection of basic parameters

2.1 Methodology

Raymer methodology (**Raymer 1999**) will be used as main guideline for the selection of basic parameters. However, due to the special characteristics of the design, sometimes it will be more suitable to take data from similar mission aircrafts. For this purpose, Isikveren methodology (**Isikveren 2005**) will be used. Other parameters will be estimated according to Roskam approach (**Roskam 1985**). In addition, the preliminary sizing will be carried out using Loftin method (**Loftin 1980**) and the preliminary sizing tool from HAW (**Scholz 1999**).

All the abovementioned methods are based on statistical values or semi-empirical approaches, therefore, the results for unconventional configurations will not be accurate and a continuous evaluation of the results must be carried out. Assumption will be required when there is a lack of information.

2.2 Selection of aircraft parameters

2.2.1 Wing Characteristics

The first assumption in this design is that the aerodynamic behavior of the Z-configuration wing will be similar to a conventional wing, as shown in Figure 4. This means that the lift distribution along the spanwise will be similar to the conventional wings, so the current sizing methods can be used without urgent modifications. Later on, a two low aspect ratio wings approach could be used for results comparison.

In addition, Enebog (**Enebog 2008**) indicates that the sweep angles should be opposite in order to allocate the aerodynamic center close to the gravity center. Also, the port wing should have a low position and the starboard wing a high position for stability purposes.

Raymer's method provides the following possible values for the design:

Table 2 Recommended Wing Parameters

Parameter	Value	Source
Aspect Ratio	7.5 to 10	Raymer table 4.1
Taper Ratio	0.25 to 0.4	Raymer text p.61
Average Thickness [*t/c*]	0.14	Raymer fig. 4.14

Port wing dihedral angle [°]	3 to 7	Raymer table 4.2
Starboard wing dihedral angle [°]	-5 to 2	Raymer table 4.2
Twist angle [°]	3	Raymer text p.63
¼ Port wing Chord Sweep [°]	0 to -15	Raymer fig. 4.24
¼ Starboard Chord Sweep [°]	0 to 15	Raymer fig. 4.24
Wing Profile	0014	-

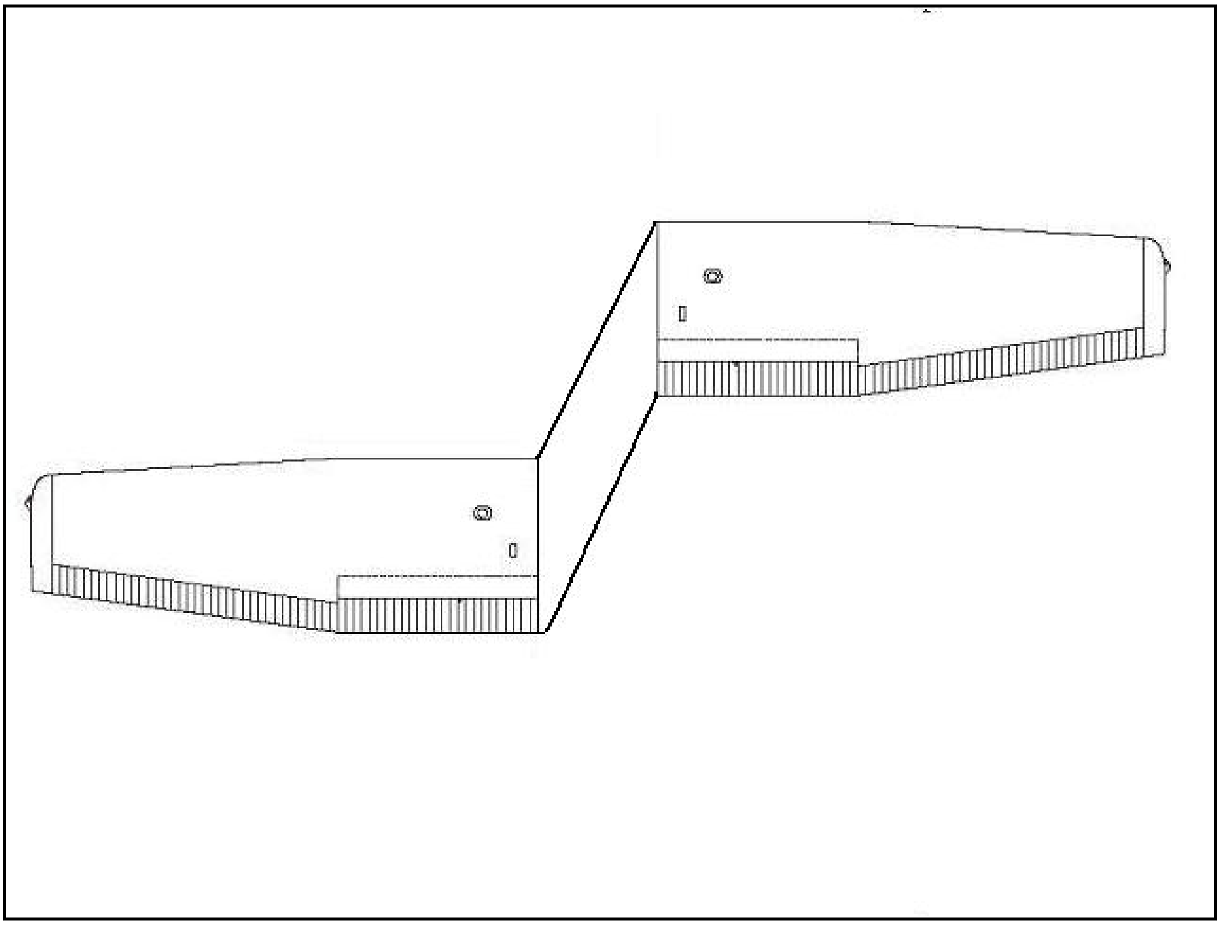

Figure 4 Assumption of the aerodynamic behavior of a Z-configuration wing for the preliminary sizing method.

2.2.2 Thrust over Weight ratio (*T/W*)

In Raymer's table 5.1, it is suggested a value between 0.25 and 0.4, recommending the highest value for one engine aircraft. Isikveren's data show that the similar missions aircraft have values between 0.335-0.427. The final Thrust over Weight ratio will be decided with the Loftin approach.

2.2.3 Wing Loading (*W/S*)

Raymer does not provide this information about very light jets and Isikveren's statistical data suggest that the wing loading should be between 195 and 268.95 kg/m^2.

2.2.4 Initial Sizing

The sizing has been carried out using the HAW preliminary sizing tool, which is based on Loftin methodology. Some modifications have been introduced in order to fulfill the one single engine certification requirements (**FAR 23, JAR 23**)

The required inputs for the sizing tool are shown on Table 3 while the matching chart T/W against W/S is shown in Figure 5.

Table 3 Input to the HAW preliminary sizing tool

Input Parameter	Value	Source
Approach Speed [KCAS]	100	Design Specification
Take-off field length for ISA, sea level [m]	920	Design Specification
Take-off field length for ISA+20°C, 5000ft [m]	1680	Design Specification
Landing field length, ISA, sea level [m]	914	Design Specification
Landing field length, ISA+20°C, 5000 ft [m]	1680	Design Specification
Aspect Ratio	8.8	Wing Characteristic
Landing – takeoff mass ratio	0.9	Roskam
Taper Ratio	0.28	Raymer
Average Thickness [t/c]	0.14	Raymer
Port wing dihedral angle [°]	4	Raymer
Starboard wing dihedral angle [°]	-3	Raymer
Twist angle [°]	3	Raymer
¼ Port wing Chord Sweep [°]	-9	Raymer
¼ Starboard Chord Sweep [°]	9	Raymer
Wing Profile	NACA 2412	-

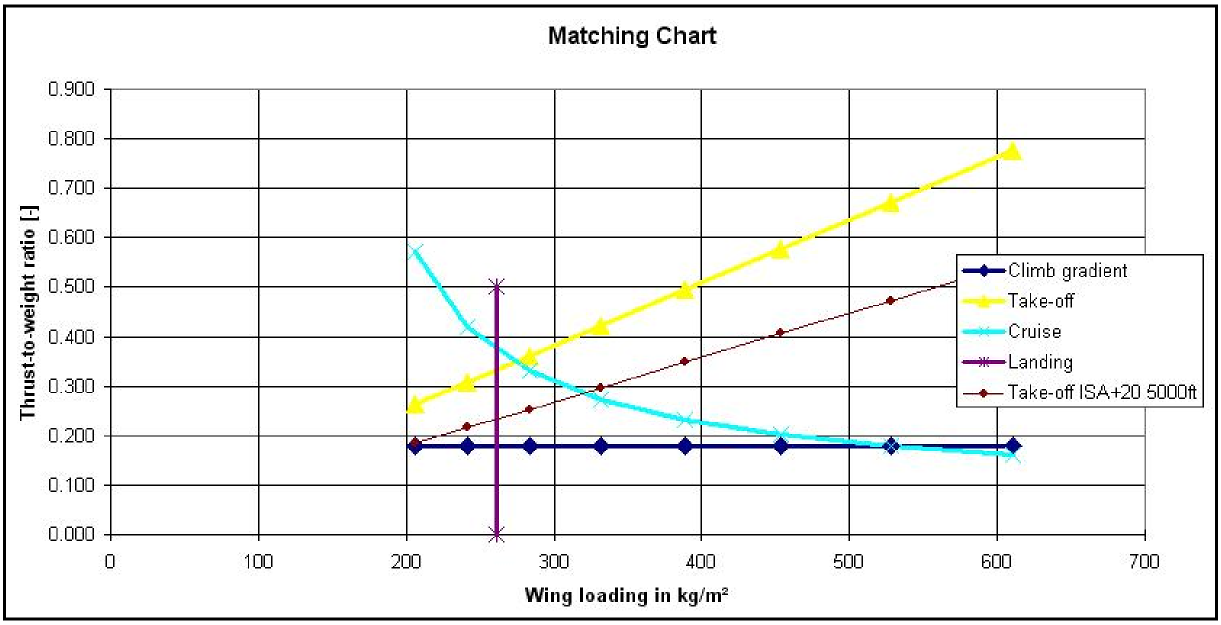

Figure 5 Matching Chart

The matching chart results are located within the recommend values by Raymer and Isikveren. These values are shown in Table 4.

Table 4 Aircraft Sizing Parameters

Parameter	Value
Thrust-to-weight ratio	0.38
Wing loading	261 kg/m^2

It is highly remarkable the high influence of the payload on the maximum takeoff weight in the Loftin method for typical very light jet weights. Therefore, the difference between BOW and OEW it is especially important. The reason for this is that for bigger aircrafts, the contribution of the cockpit crew to the OEW is small, but in the case of very jet lights it is a big contributions. Therefore, it is possible to include the cockpit crew in the payload as an assumption for this method in order to get reasonable results.

The detailed sizing calculations, taking into account the IFR mission profile, are included in the appendix A.

The main results are shown in Table 5 along with a comparison between the obtained data for the GAV and the available data from aircraft with similar missions. Particularly, the ratio between the payload and the maximum takeoff weight is fairly smaller than for the other aircrafts due to the very conservative assumptions.

Table 5 Comparison between GAV and similar aircrafts

Parameter	Unit	GAV	Citation Mustang	A-700	Eclipse 500
Crew	-	2	1 or 2	2	1 or 2
Capacity	-	5+lav	4 to 5	5 + lav	4 to 5
hmax	m	3.4	4.06	2.93	3.4
lmax	m	10.5	12.37	12.42	10.1
bmax	m	14.9	13.16	13.41	11.4
MTOW	kg	3889	3930	4250	2699
MLW	kg	3498	-	4091	
MZFW	kg	3425	-	-	
OEW	kg	2431	-	2718	1610
MPL	kg	785	-	-	1089
OEW/MTOW	-	0.62509643	-	0.639529	0.596517
PL/MTOW	-	0.20185138	-	-	0.403483
T/MTOW	N/kg	0.38	0.337	-	0.3025
Vs	knots	70.5	69	-	67
R	km	2778	2161	-	2084
Service ceiling	ft	44657	35000	-	41000
Takeoff distance	m	920	948	-	657
Landing distance	m	914	729	-	622

2.3 Aircraft Component Geometry

The following chapter describes the required assumptions that have been used in order to obtain the geometry of the aircraft.

2.3.1 Wing

From the sizing results and previous assumptions, the wing geometry is fully defined.

Table 6 Wing Geometry

Parameter	Value
Aspect Ratio	8.8
Taper Ratio	0.28
Average Thickness [t/c]	0.14
Port wing dihedral angle [°]	4
Starboard wing dihedral angle [°]	-3
Twist angle [°]	3
Port wing position	Low
Starboard wing position	High
¼ Port wing Chord Sweep [°]	-9
¼ Starboard Chord Sweep [°]	9
Wing Surface [m^2]	14.9
Semispan [m]	5.72
Root Chord [m]	2.03
Tip Chord [m]	0.57
MAC [m]	1.44
Wing Profile	NACA 2412

2.3.2 Fuselage and cabin

Due to the uncertainness of the results due to the unconventional configuration, it does not make sense to size an accurate fuselage with the available data. For this purpose, a cabin and a fuselage similar to the A-700 are proposed because it has the same requirement as the GAV.

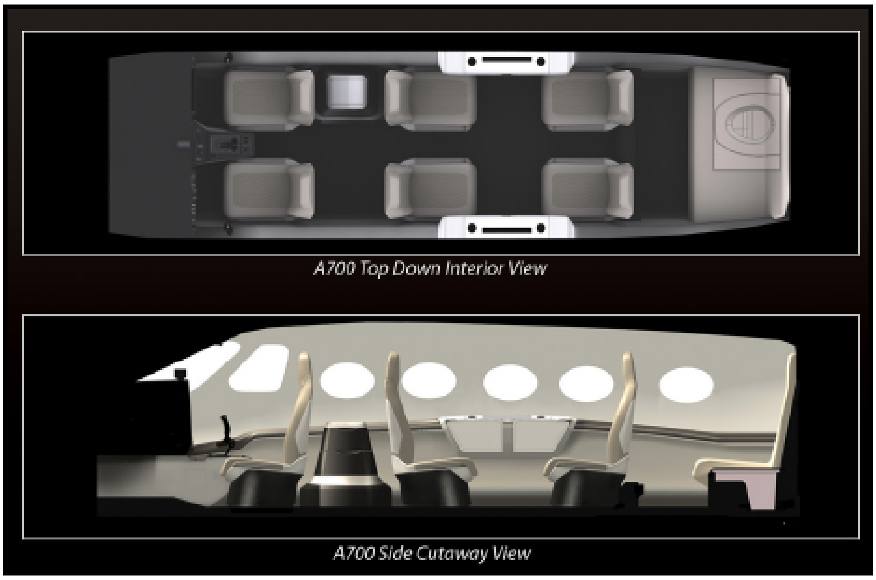

Figure 6 A700 Fuselage (**Adams 2009**)

Table 7 Fuselage and cabin geometry

Parameter	Value
Cabin Volume	245 cu ft
Cabin Height	130.81 m
Cabin Width	137.16 m
Cabin floor With	1.14 m
Cabin Length	5.16 m
Front Baggage Bay Volume (Unpressurized)	27 cu ft
Internal Baggage Bay Volume (Pressurized)	6 cu ft

2.3.3 Engine

The GAV requires a thrust of approximately 3300 lbf. There are several engines in the market with such capabilities for VLJs. In particular, the Williams international FJ44 is a possible option.

Table 8 Engine Characteristics

Parameter	Value
Thrust Class	3600 lbf
Length	52.8 in
Diameter	25.3 in
Weight (dry)	650 lb

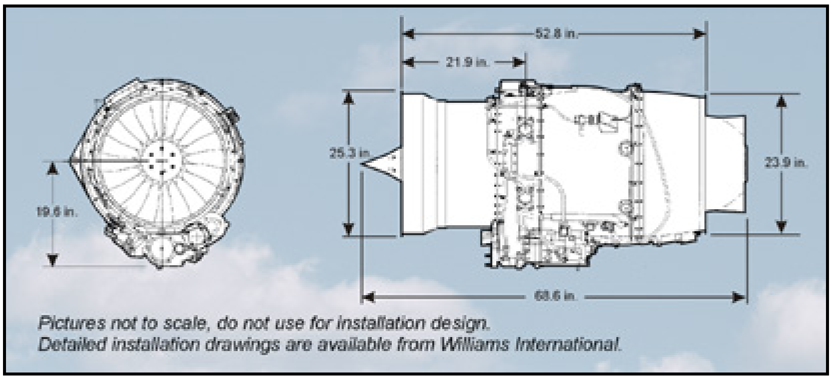

Figure 7 FJ44 Engine (Williams 2009)

2.3.4 Additional surfaces and control surfaces.

Preliminary calculation at Tornado with the above data and experimental results carried out by Enebog (**Enebog 2008**) indicate than a third surface is required for stability and control purposes. This effect can be seen in Figure 8 and 9. The lateral and longitudinal stability is highly coupled. It is noticeable that even for zero sideslip angle, as alpha increases, a lateral force and a rolling and yawing moment appear. In addition it is remarkable that this configuration is longitudinally stable.

The goal of this document is not the study in detail of the aerodynamic behavior of the Z configuration, so this calculation in Tornado are focused on providing a first scope of the stability characteristics of the aircraft in order to produce a better baseline aircraft.

Since the stability and control will be studied on CEASIOM environment, it is not necessary to design in detail the control surfaces. The classical guidelines indicated by Raymer and Scholz will be used for the baseline configuration.

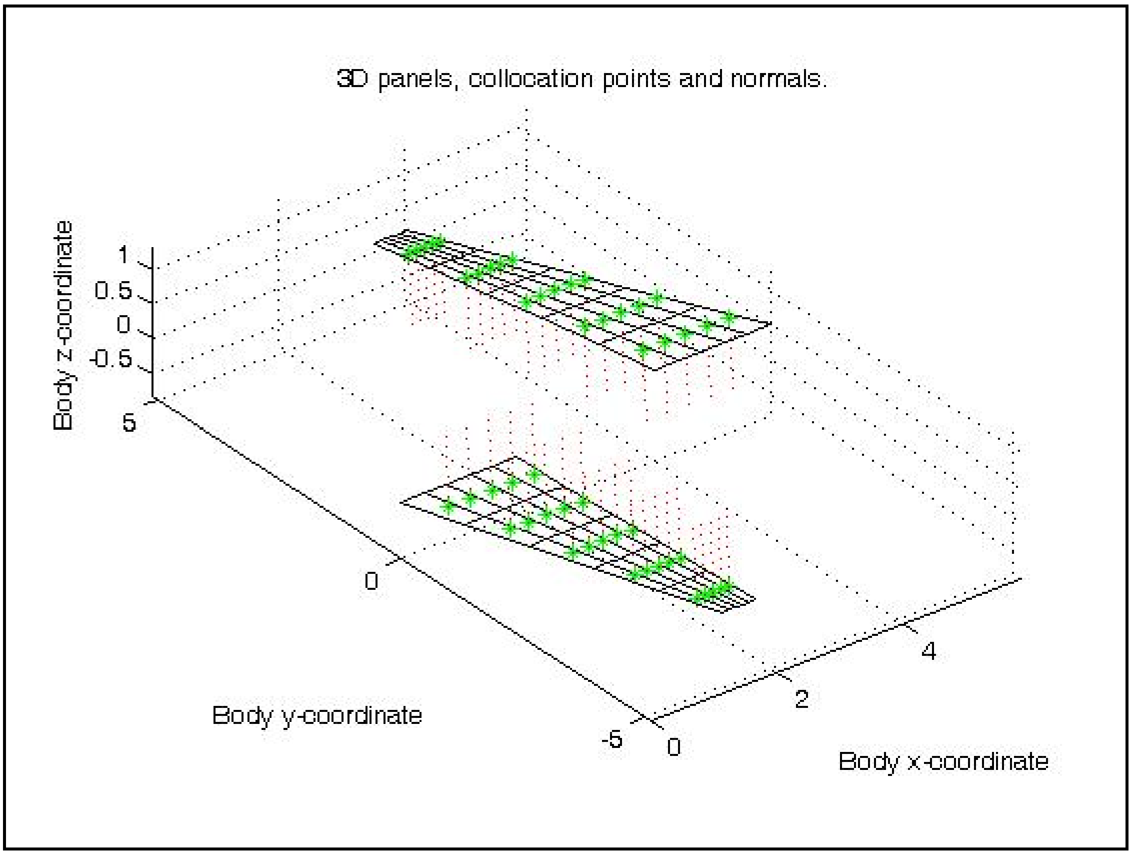

Figure 8 Basic aerodynamic model

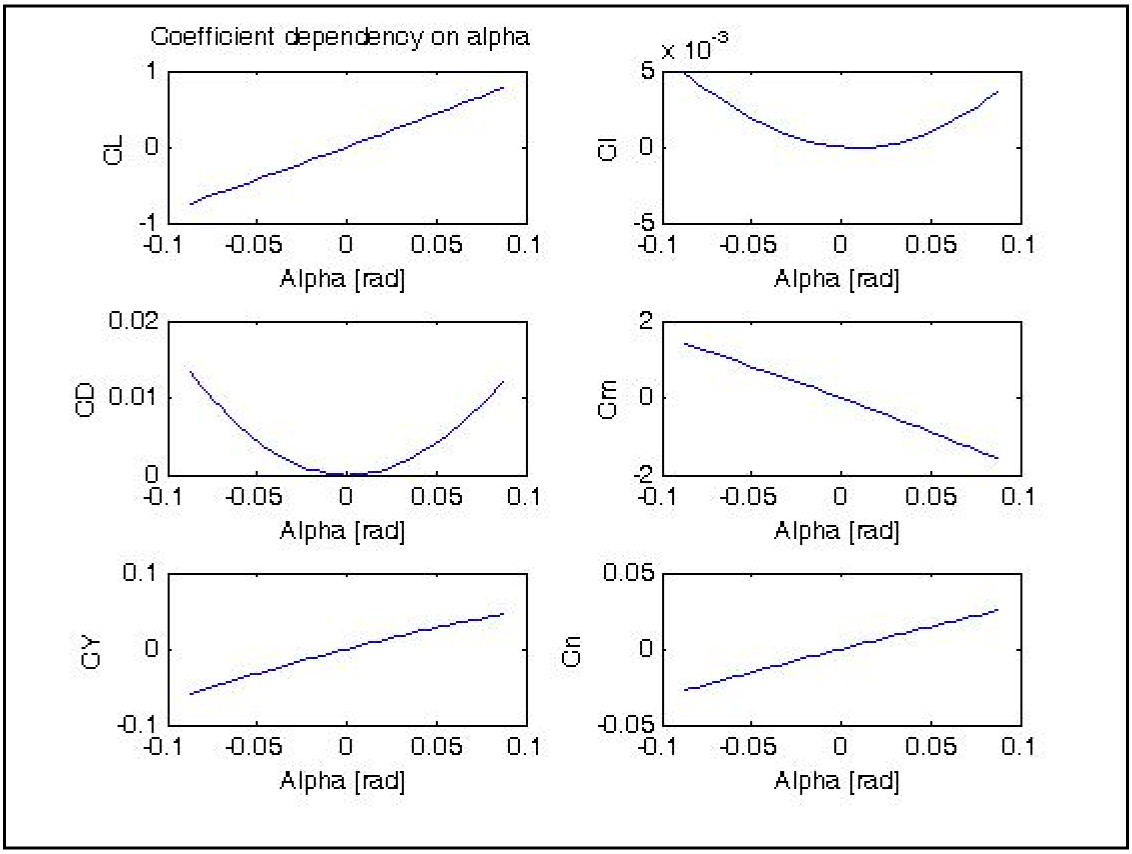

Figure 9 Basic aerodynamic model results at $\beta = 0$

2.4 Aircraft Synthesis Geometry

The two wings and the third surface need to be allocated along the fuselage. In order to this, a statistical tail volume coefficient approach has to be used. The reason for that is that this is the only available method at this stage with the available information.

For the horizontal stability, the distance from the two wings to the gravity center and the contribution of the third surface will produce the tail volume. This third surface will be treated as a one-single surface V-tail. The design philosophy consisting of the smallest number of lifting surfaces and the longitudinal-lateral stability coupling lead to this decision. In addition, the V-tail is beneficial to the engine integration. The V angle is set to 30 degrees in order to have influence on both longitudinal and lateral stability and allow the engine integration on the top of the fuselage. This angle shall be object of study later on and has to be considered as a parameter in the stability and control studies analysis in CEASIOM.

From simplicity, it is assumed that the two wings are located at the same distance from the gravity center in order to maintain the CG position, so their level arms have equal value:

$l_{PH} = -l_{sH}$. In addition, the CG will be located at 40% of the fuselage as a first approximation. These relationships are shown in Equation 1 and 2.

$$C_H = \frac{S_H \cdot l_H}{S_W \cdot c_{MAC}} = \frac{S_S \cdot l_{SH}}{S \cdot c_{MAC}} + \frac{S_P \cdot l_{PH}}{S \cdot c_{MAC}} + \frac{\sin(V) \cdot S_V \cdot l_V}{S \cdot c_{MAC}} \quad (1)$$

$$C_V = \frac{\cos(V) \cdot S_V \cdot l_V}{S_W \cdot b} \quad (2)$$

Raymer indicates recommended values for horizontal and vertical tail volume coefficients. Despite this, there are two equations and three unknown parameters, so an additional assumption is required. As it is suggested at Raymer, the 40% of the fuselage length will be used as the vertical arm. The results are shown in Table 9.

Table 9 Aircraft synthesis geometry

Parameter	**Value**
Horizontal Tail Volume Coefficient	0.8
Vertical Tail Volume Coefficient	0.07
Vertical Tail Level Arm [m]	5.25
V-Surface [m^2]	1.28
V-angle (°)	30
Horizontal Tail Level Arm [m]	0.93
CG location (%)	40
Starboard Wing Apex location (%)	31%
Port Wing Apex location (%)	49%
V-Tail Apex location (%)	80%
Engine location (%)	70%

3 Results

With all the obtained results, there is enough information to create a model of the baseline aircraft under CEASIOM environment. An xml file containing all the information of the aircraft has been created. This file is shown in Appendix B and the final aircraft configuration can be seen on figure 10.

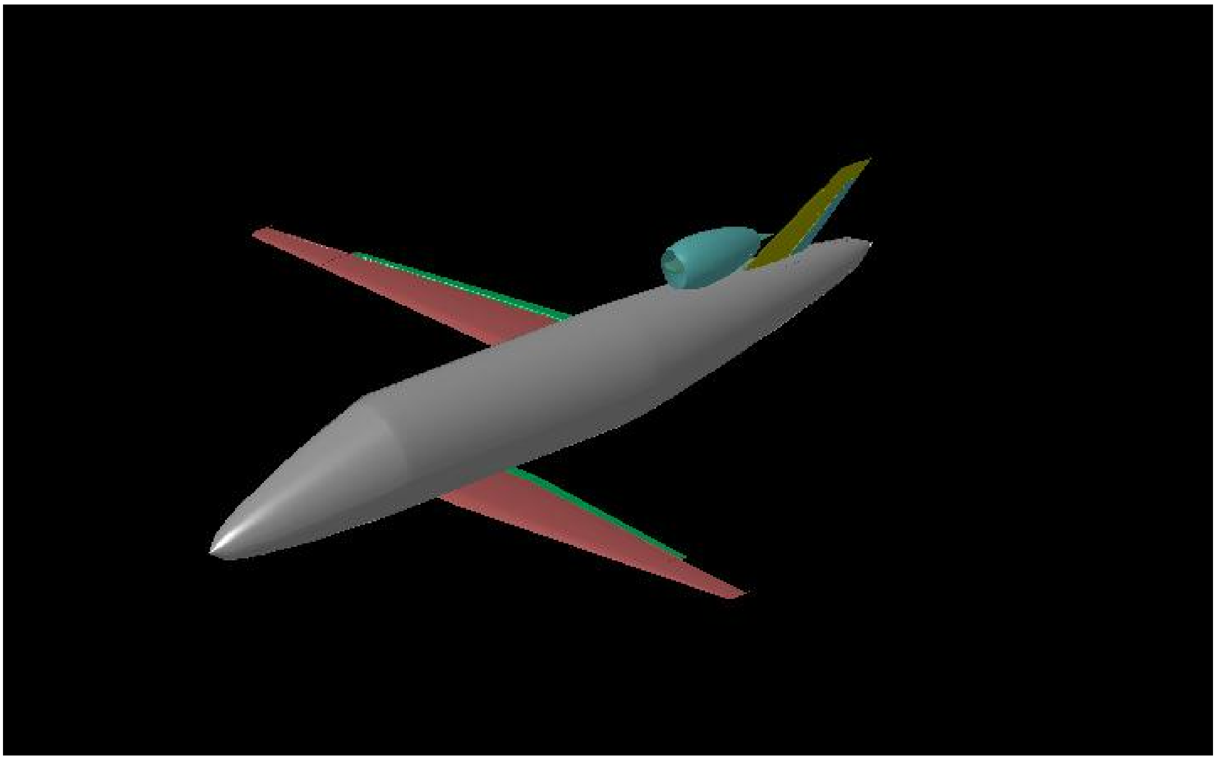

Figure 10 Baseline Aircraft Configuration

Now, further studies in detail about the stability properties and the possible control system of the aircraft can be carried out with this baseline configuration.

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Williams 2009 WILLIAMS INTERNATIONAL URL: http://www.williams-int.com/information.html?pid=1 (2009-02-14)

Appendix A – Preliminary Sizing Tool Results

Table A.1 Preliminary Sizing Tool Results

Wing loading	m_{MTO} / S_W	**261**		
Thrust-to-weight ratio	T_{TO} / (m_{MTO}*g)	**0.380**		
Thrust ratio	$(T_{CR}/T_{TO})_{CR}$	0.138		
Conversion factor	m -> ft	0.305m/ft		
Cruise altitude	h_{CR}	**13607m**		
Cruise altitude	h_{CR}	**44643ft**		
Temperature, troposphere	$T_{Troposphäre}$	199.70K	$T_{Stratosphäre}$	216.65K
Temperature, h_{CR}	$T(h_{CR})$	216.65		
Speed of sound, h_{CR}	a	295m/s		
Cruise speed	V_{CR}	**177m/s**		
Conversion factor	NM -> m	1852m/NM		
Design range	R	**1500NM**		
Design range	R	2778000m		
Distance to alternate	$s_{to\_alternate}$	100NM		
Distance to alternate	$s_{to\_alternate}$	185200m	**Reserve flight distance:**	
Chose: FAR Part121-Reserves?	domestic	**no**	FAR Part 121	s_{res}
	international	**yes**	domestic	185200m
Extra-fuel for long range		5%	international	324100m
Extra flight distance	s_{res}	185200m		
Spec.fuel consumption, cruise	SFC_{CR}	**1.60E-05kg/N/s**	typical value	1.60E-05kg/N/s
			Extra time:	
Breguet-Factor, cruise	B_s	21486496m	FAR Part 121	t_{loiter}
Fuel-Fraction, cruise	$M_{ff,CR}$	0.879	domestic	2700s

Fuel-Fraction, extra fliht distance	$M_{ff,RES}$	0.991	international	1800s

Loiter time	t_{loiter}	1800s
Spec.fuel consumption, loiter	SFC_{loiter}	**1.60E-05kg/N/s**
Breguet-Factor, flight time	B_t	121345s
Fuel-Fraction, loiter	$M_{ff,loiter}$	0.985

			Phase	M_{ff} per flight phases [Roskam]	
				transport jet	business jet
Fuel-Fraction, engine start	$M_{ff,engine}$	**0.990<<<< Copy**	engine start	0.990	0.990
Fuel-Fraction, taxi	$M_{ff,taxi}$	**0.995<<<< values**	taxi	0.990	**0.995**
Fuel-Fraction, take-off	$M_{ff,TO}$	**0.995<<<< from**	take-off	0.995	0.995
Fuel-Fraction, climb	$M_{ff,CLB}$	**0.998<<<< table**	climb	0.998	0.998
Fuel-Fraction, descent	$M_{ff,DES}$	**0.990<<<< on the**	descent	0.990	0.990
Fuel-Fraction, landing	$M_{ff,L}$	**0.992<<<< right !**	landing	0.992	0.992

Fuel-Fraction, standard flight	$M_{ff,std}$	0.857
Fuel-Fraction, all reserves	$M_{ff,res}$	0.965
Fuel-Fraction, total	M_{ff}	0.827
Mission fuel fraction	m_F/m_{MTO}	0.173

Realtive operating empty mass	m_{OE}/m_{MTO}	0.625	acc. to Loftin
Realtive operating empty mass	m_{OE}/m_{MTO}	**xxx**	from statistics (if given)
Realtive operating empty mass	m_{OE}/m_{MTO}	**0.625**	**<<<< Choose according to task**

Choose: type of a/c	short / medium range	**yes**	**<<<< Choose according to task**
	long range	**no**	

Mass: Passengers, including baggage	m_{PAX}	105.0kg	in kg	Short- and Medium Range

Number of passengers	n_{PAX}	**7**	m_{PAX}	93.0
Cargo mass	m_{cargo}	**50kg**		
Payload	m_{PL}	**785kg**	1727lb	
			0	
Max. Take-off mass	m_{MTO}	**3889kg**	8555.960868lb	
Max. landing mass	m_{ML}	**3500kg**	7700.364781lb	
Operating empty mass	m_{OE}	**2431kg**	5349.186734lb	
Mission fuel fraction, standard flight	m_F	**673kg**	1479.774133lb	
Wing area	S_W	**14.9m²**		
Take-off thrust	T_{TO}	14498N	**all engines together**	
Take-off thrust	T_{TO}	3259lb	**all engines together**	
Fuel mass, needed	$m_{F,erf}$	721kg		
Fuel density	ρ_F	800kg/m³		
Fuel volume, needed	$V_{F,erf}$	**0.901m³**	(check with tank geometry later on)	
Max. Payload	m_{MPL}	**785kg**		
Max. zero-fuel mass	m_{MZF}	3216kg		
Fuel mass, all reserves	$m_{F,res}$	136kg		
Check of assumptions	check:	m_{ML}	>	$m_{MZF} + m_{F,res}$
		3500kg	>	3352kg
			yes	
			Aircraft sizing finished!	

Appendix B – XML CEASIOM FILE


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    <quarter_chord_sweep_midboard idx="1" type="double" size="1 1">-9</quarter_chord_sweep_midboard>
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    <LE_sweep_midboard idx="1" type="double" size="1 1">0</LE_sweep_midboard>
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    <dihedral_midboard idx="1" type="double" size="1 1">-3</dihedral_midboard>
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    <thickness_kink2 idx="1" type="double" size="1 1">0.14</thickness_kink2>
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```
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    <LE_sweep_outboard idx="1" type="double" size="1 1">0</LE_sweep_outboard>
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    <Z_locale idx="1" type="double" size="1 1">0</Z_locale>
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    <taper_tip idx="1" type="double" size="1 1">0</taper_tip>
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    <Z_locale idx="1" type="double" size="1 1">0.68</Z_locale>
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    <Fore_wing_spar_loc_kin2 idx="1" type="double" size="1 1">0.088</Fore_wing_spar_loc_kin2>
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    <Baggage_combined_length idx="1" type="double" size="1 1">1</Baggage_combined_length>
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  </Baggage>
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    <Passenger_accomodation idx="1" type="double" size="1 1">5</Passenger_accomodation>
    <Seats_abreast_in_fuselage idx="1" type="double" size="1 1">2</Seats_abreast_in_fuselage>
    <Seat_pitch idx="1" type="double" size="1 1">1.29</Seat_pitch>
    <Maximum_cabin_altitude idx="1" type="double" size="1 1">7000</Maximum_cabin_altitude>
    <Max_pressure_differential idx="1" type="double" size="1 1">7.4586284760521</Max_pressure_differential>
  </cabin>
  <miscellaneous idx="1" type="struct" size="1 1">
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    <Spoiler_effectivity idx="1" type="double" size="1 1">100</Spoiler_effectivity>
    <Undercarriage_layout idx="1" type="double" size="1 1">0</Undercarriage_layout>
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  <weight_balance idx="1" type="struct" size="1 1">
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    <Manufacturer_weights_tolerance idx="1" type="double" size="1 1">872</Manufacturer_weights_tolerance>
  </weight_balance>
  <flight_envelope_prediction idx="1" type="struct" size="1 1">
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    <VMO_Flight_envelope idx="1" type="double" size="1 1">285</VMO_Flight_envelope>
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    <increment_fuselage_fairing idx="1" type="double" size="1 1">0</increment_fuselage_fairing>
    <increment_wings idx="1" type="double" size="1 1">0</increment_wings>
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    <increment_Vertical_tail idx="1" type="double" size="1 1">0</increment_Vertical_tail>
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    <increment_powerplant idx="1" type="double" size="1 1">0</increment_powerplant>
    <increment_Horizontal_tail idx="1" type="double" size="1 1">0</increment_Horizontal_tail>
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