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ATLLAS

Aerodynamic and Thermal Load Interactions with Lightweight Advanced Materials for High Speed Flight

SPECIFIC TARGETED RESEARCH PROJECT

Thematic Priority – 1.4
AERONAUTIC and SPACE

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M3 CAD- and mass-model

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

APPROVAL

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Nomenclature

Acronyms

CAD	Computer Aided Design
CoG	Centre of Gravity
DMR	Dry Mass Ratio
GDL	Gas Dynamics Ltd.
SART	Systemanalyse Raumtransport
STSM	Space Transportation Systems' Mass
VTP	Vertical Tail Plane

Symbols

a	distance of engines [m]
b	spanwise [m]
h	A/C height overall [m]
l	A/C length overall [m]
m	mass [kg]
x, y, z	coordinates

1 Executive summary

1.1 Scope of the deliverable

A 200-seat SST concept will be designed in work package 2.3 to meet an operational requirement of Mach 3 flight over a 5500 nm range [3]. The Mach 3 speed range allows consideration of established materials and newer materials. The Mach 3 vehicle will be designed along the principles outlined in WP2.1 and WP2.2 by GDL and system mass and payload fraction will be predicted by DLR-SART and GDL respectively [3].

DLR-SART provides the creation and the iterative adaptation of the semi-detailed CAD-representation of the Mach 3 SST-vehicle in support of the design process.

The objective of this report in support of deliverable D2.3.3 is the description of the semi-detailed CAD model for the M3 configuration. In addition to this model a mass estimation is done and a calculation and the CoG shifting is analysed.

1.2 Results

A semi-detailed CAD model (I-DEAS) of the Mach 3 configuration ATLLAS M3 is generated and IGES interchange format for CATIA of the vehicle's outer shape is provided to support CFD-analyses. The semi-detailed model includes structural components' preliminary designs (e.g. tanks). A mass estimation based on the CAD model which allows determining the gross lift of mass and CoG. In addition the CoG shifting is analysed.

1.3 Specific highlights

Not applicable.

1.4 Forms of integration within the work package and with other WPs

The Mach 3 vehicle has been designed along the principles outlined in WP2.1 and WP2.2 by GDL [3]. Within the work package 2.3 a CFD assessment based on Euler computations has been done for selected trajectory points where DLR-AS-RF computed the supersonic cruise case(s) and FOI the subsonic and transonic ones.

The aircraft concept and its associated thermal and structural loads have intended serving as a basis for the detailed material studies in WP3 [3].

1.5 Problem areas

None.

2 Introduction

M3 is a supersonic passenger airplane with a cruise velocity of Mach 3 proposed by GDL in the framework of the ATLLAS study [1]. To reach the required velocity, special propulsion concepts and fuel tank capacity are needed. Due to aerodynamic constraints high-speed aircrafts have unconventional shapes. Hence the integration of all structure components especially the tank accommodation into the fuselage is challenging.

The results of a following mass estimation are for example the gross lift off weight and the CoG. Both are determined by the components' accommodation. Due to the fact that the required fuel volume is less than the maximum volume available for the tank accommodation, different tank configurations are analysed regarding the shifting of the CoG.

2.1 Analyses of previous M3T rev.5 configuration by DLR-SART

2.1.1 Aerodynamic model

Figure 1 shows the geometrical model for the calculation of the aerodynamic coefficients shown in Figure 2. The lift to drag ratio C_L/C_D reaches a maximum value of 4.1 at Mach 3. The pressure point of the aircraft is at x = 44 m.

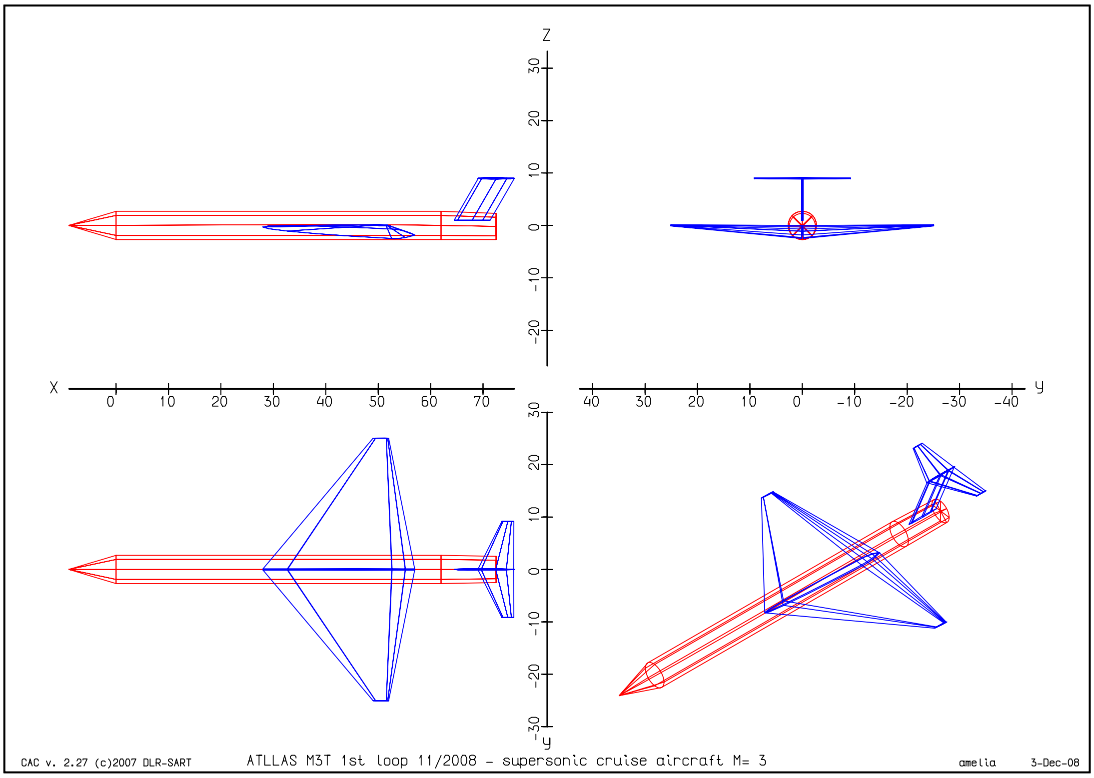


Figure 1: Homologous geometry of M3T rev.5 for aerodynamic calculation

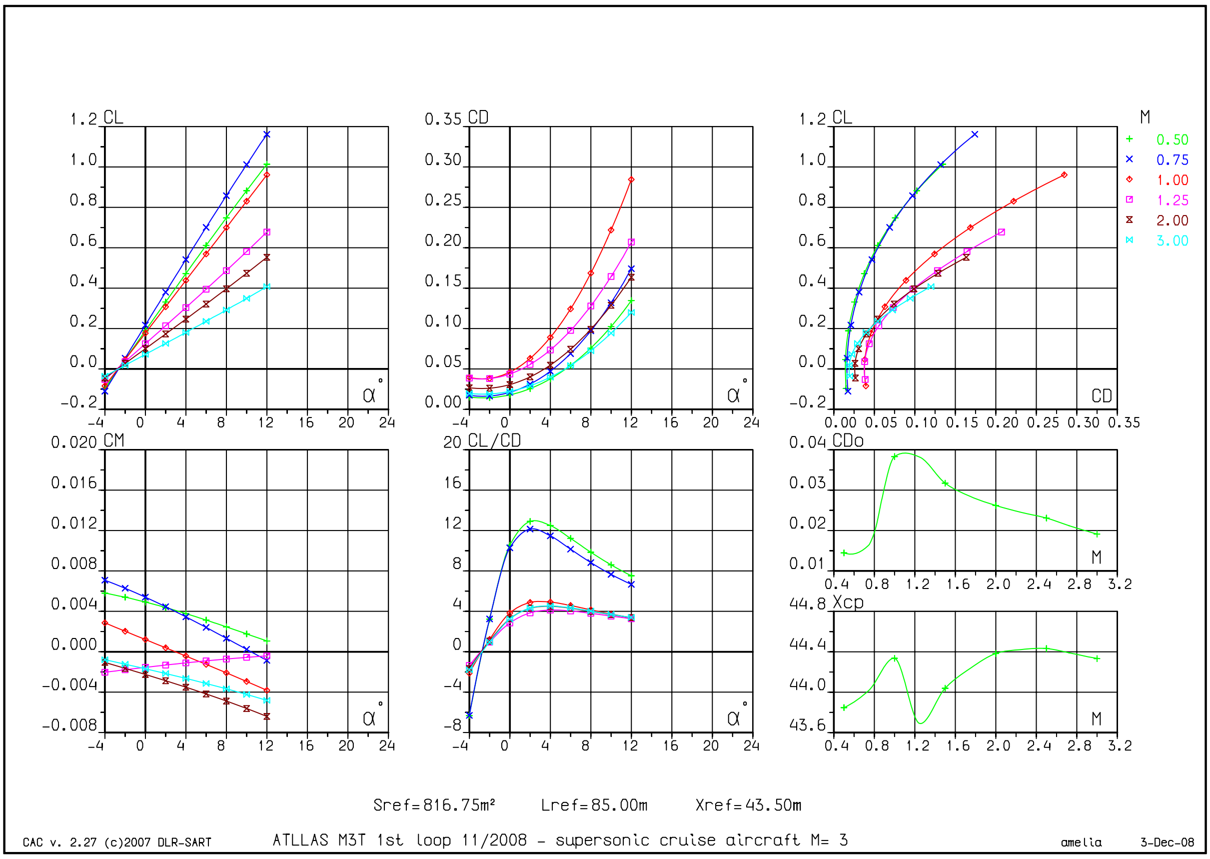


Figure 2: Aerodynamic characteristics of M3T rev.5

2.1.2 Mass and COG estimation

The mass estimated with STSM is given in Table 1. According to this estimation the empty aircraft weighs 108 t. Adding 97 t of propellant and 20 t of payload mass the lift-off mass of the aircraft is 225 t. The 97 t of propellant include 500 kg residuals and 500 kg reserve propellant.

GasDynamics states in [1] that the M3T weighs 84 t when empty. In comparison SART estimates a weight of 108 t, which is 24 t or 29 % more.

Table 1: Mass estimation of M3T rev.5 with STSM

		COG			
	m [kg]	X [m]	Y [m]	Z [m]	
Structure group:					
Fuselage	23464	33	0	0	
Take-Off Wing Structure	14338	45	0	-1,5	
Horizontal Stabilizer	1947	72,5	0	9	
Vertical Stabilizer	1050	70	0	5	
Wing Control Flaps	1606	53	0	-2	
Tank Seal	29	46	7	-1,25	
Tank Seal	29	46	-7	-1,25	
Thrustframe A/B-Engines	2000	9,5	0	0	*
Mass Structure group:w/o margins	44562				
Mass **Structure group**:including 10 % margins	**49018**				

Subsystem group:					
Propellant Supply	313	51	0	-2	
Propellant Supply	119	67	0	-2	
Take-Off Gear	4816	43	0	-1,5	
Electrics	1835	5	0	0	
Avionics	250	8	0	0	*
Hydraulics	1469	55	0	0	
ECS	800	37	0	0	*
Primary Power	1500	55	0	-1,5	*
Paint	239	35	0	0	
Air-Conditioning	3000	43	0	0	*
Furnishing	10000	38	0	0,5	*
Mass Subsystem group: w/o margins	24342				
Mass **Subsystem group**: including 10 % margins	**26777**				
Propulsion group:					
Airbreathing Engines Turbo	12500	8	0	0	*
Airbreathing Engines (SC)RAM	3750	50	0	-1	
Air Intake	5000	0	0	0	*
Airbreathing Engines Nozzle	3500	68	0	-1,5	*
Mass Propulsion group: w/o margins	24750				
Mass **Propulsion group**: including 10 % margins	**27225**				
Thermalprotection group:					
TPS	4105	36	0	0	
Mass Thermalprotection group: w/o margins	4105				
Mass **Thermalprotection group**: including 10 % margins	**4515**				
A/C Mass empty: (stage coordinates)	97823	34,49	0	-0,17	
A/C Mass empty incl.marg.: (global coordinates)	**107535**	**34,49**	**0**	**-0,17**	
A/C Structural Index:		1,11			
Ascent propellant:	96000				
Residual propellant:	500				
Reserve propellant:	500				
A/C Mass @ at end of flight:	**108535**				
Payload Mass (Passengers and Luggage):	20000				
Total Lift-off Mass w/o payloads:	204535				
Gross Lift-Off Mass including payload:	**224535**				

* user provided input

The Center of Gravity (COG) is at 34.5 m when the reference point is defined on the fuselage centreline and at the fuselage leading edge in axial direction.

Figure 3 and Figure 4 show the COG movement while the tanks are depleting during flight. The COG in x-direction moves from 40 m forward to 35 m during the flight. At the same time COG in z-direction moves from -0.6 m up to -0.1 m.

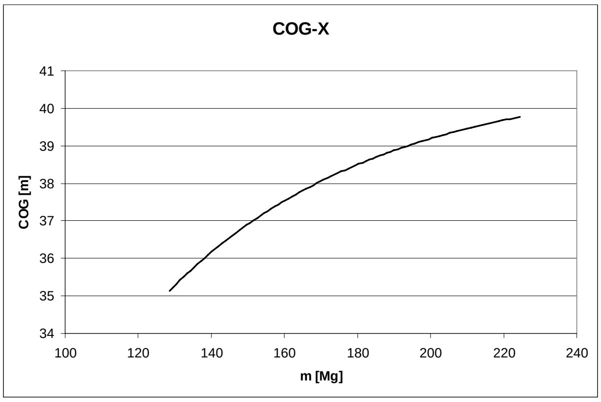


Figure 3: COG in x-direction of M3T rev.5

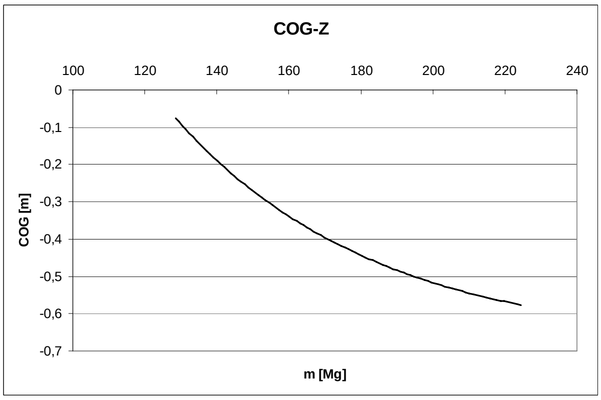


Figure 4: COG in z-direction of M3T rev.5

2.1.3 Discussion

The calculated COG in x-direction lies between 35 m and 40 m while the pressure point was calculated to be at 44 m. Although the aerodynamic calculations are based on very simple methods, any significant change of the centre of pressure is unlikely.

This means that the COG always is in a considerable distance in front of the pressure point. Thus, in the M3T rev.5 configuration the airplane is most likely not trimmable and hence the vehicle is not flyable.

3 M3T rev.6 configuration CAD model

3.1 Main overview

The semi-detailed CAD of the considerably updated model M3 T rev.6 [2] is generated in I-DEAS MS 11. Main dimensions of M3 are shown in Figure 5 and Figure 6. The values of the main dimensions of M3 are given in Table 2.

The CAD-file is saved in IGES format on the ATLLAS ftp-site at: ftp://ftp.estec.esa.int/documents/CAD/

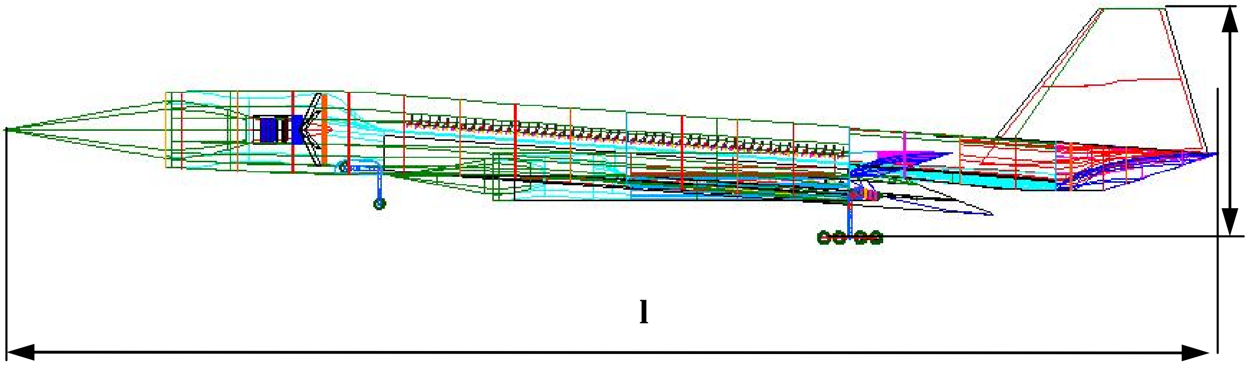


Figure 5: ATLLAS M3T rev.6 side view

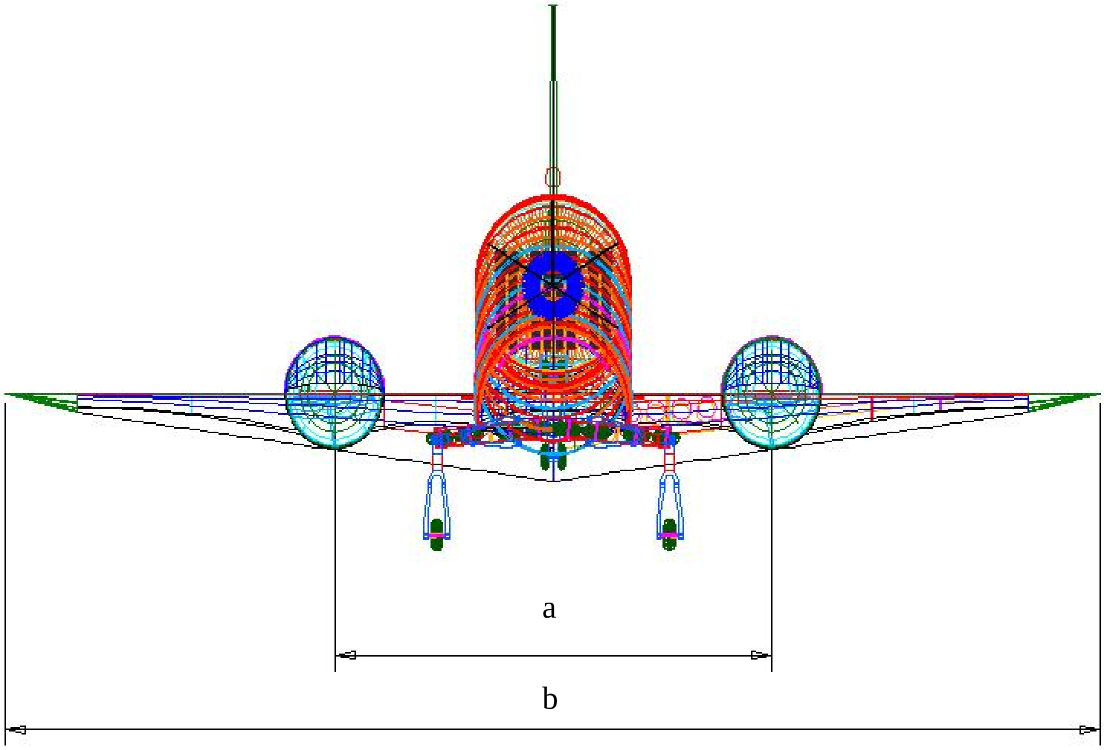


Figure 6: ATLLAS M3T rev.6 front view

Table 2: Main dimension of M3T rev.6 configuration

length overall	l	109.27 m
height overall	h	20.64 m
span	b	47.93 m
Distance between engines	a	19.15 m

In Figure 7 an overview of the internal components is given. The tanks, the pressurized cabin and the propulsion system as well as the nose and main landing gears are integrated into the fuselage.

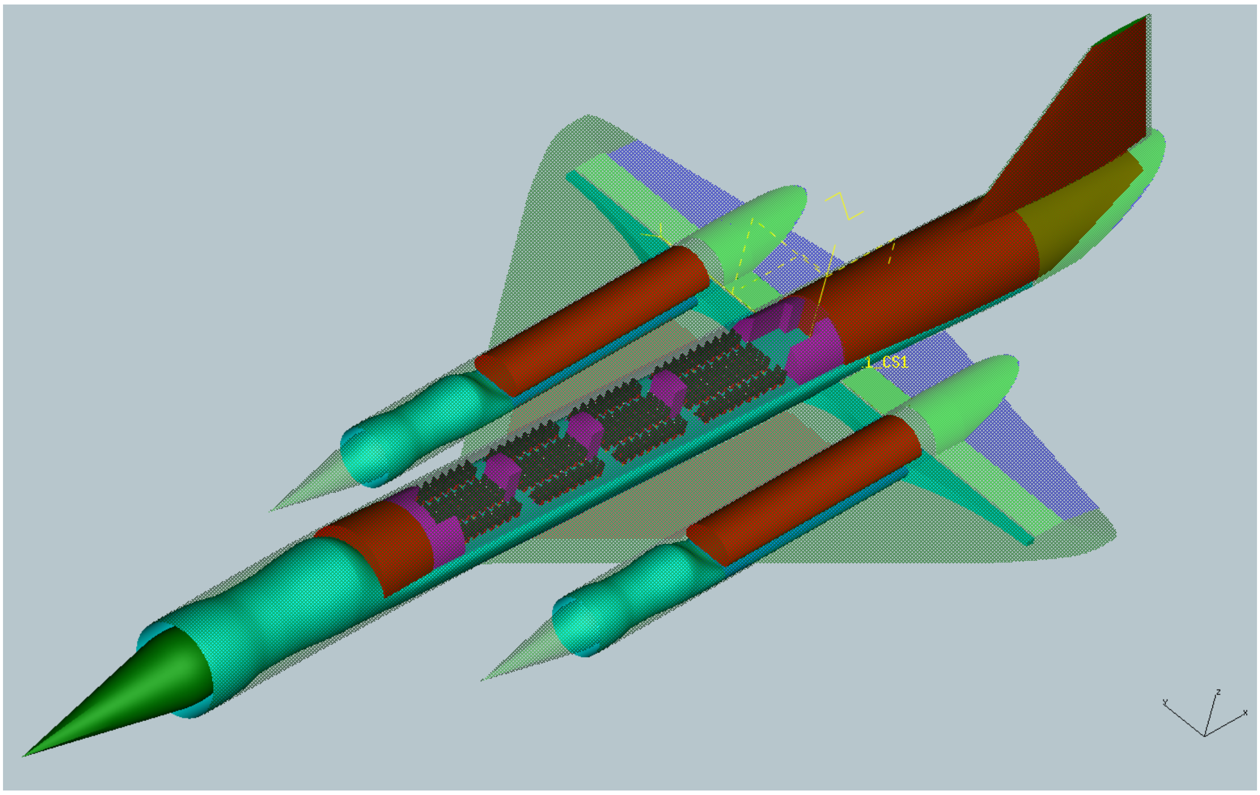


Figure 7: ATLLAS M3T rev.6 internal components overview

3.2 Propulsion System

The propulsion system is an air breathing one, realized by three turbofans. The inlet of the biggest one is placed at the nose of the fuselage. The second and third one are placed into auxiliary fuselages on each side. The engine ducts are shown in Figure 8.

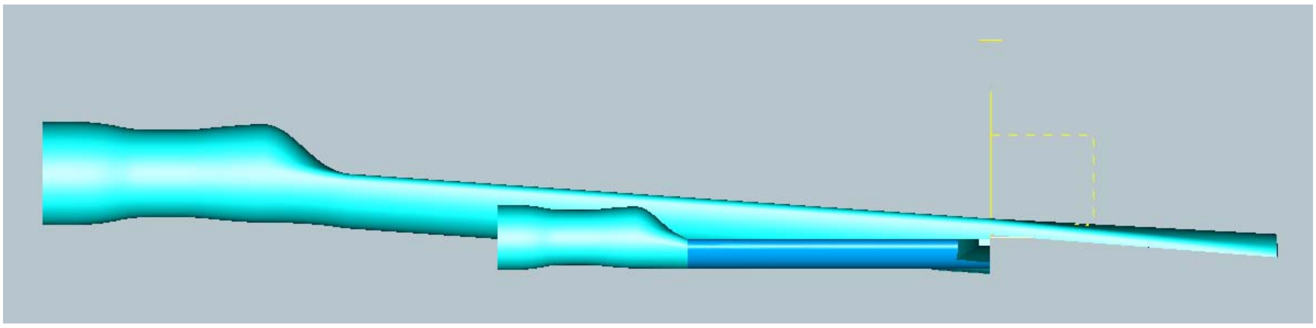


Figure 8: ATLLAS M3T rev.6 side view of engine duct

Figure 9 shows the integration of possible tanks (in red) and of the passenger cabin (in purple).

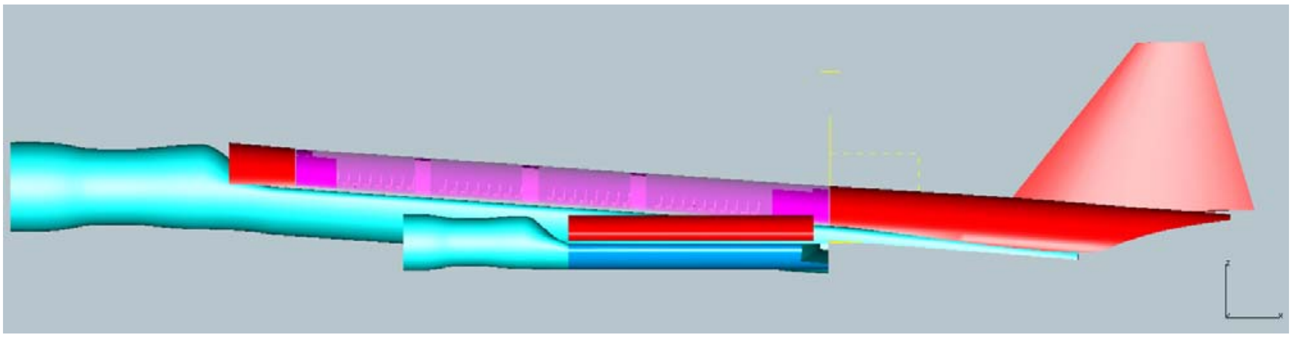


Figure 9: ATLLAS M3T rev.6 side view of engine duct, cabin and tanks

The turbofan inlets are equipped with movable spikes. Depending on the velocity the spike moves into or out of the engine duct to reach the optimum distance between the nose and the inlet. This allows regulating the airflow to the requirements of the turbofan. Keeping the shock attached to the inlet in all flight conditions is not possible. Three different positions of the spike can be seen in Figure 10. Note the change in throat cross sections. More data on the estimated intake performance is given in [4] on pages 26 and 27.

M < 1.6

M = 1.6

M = 3

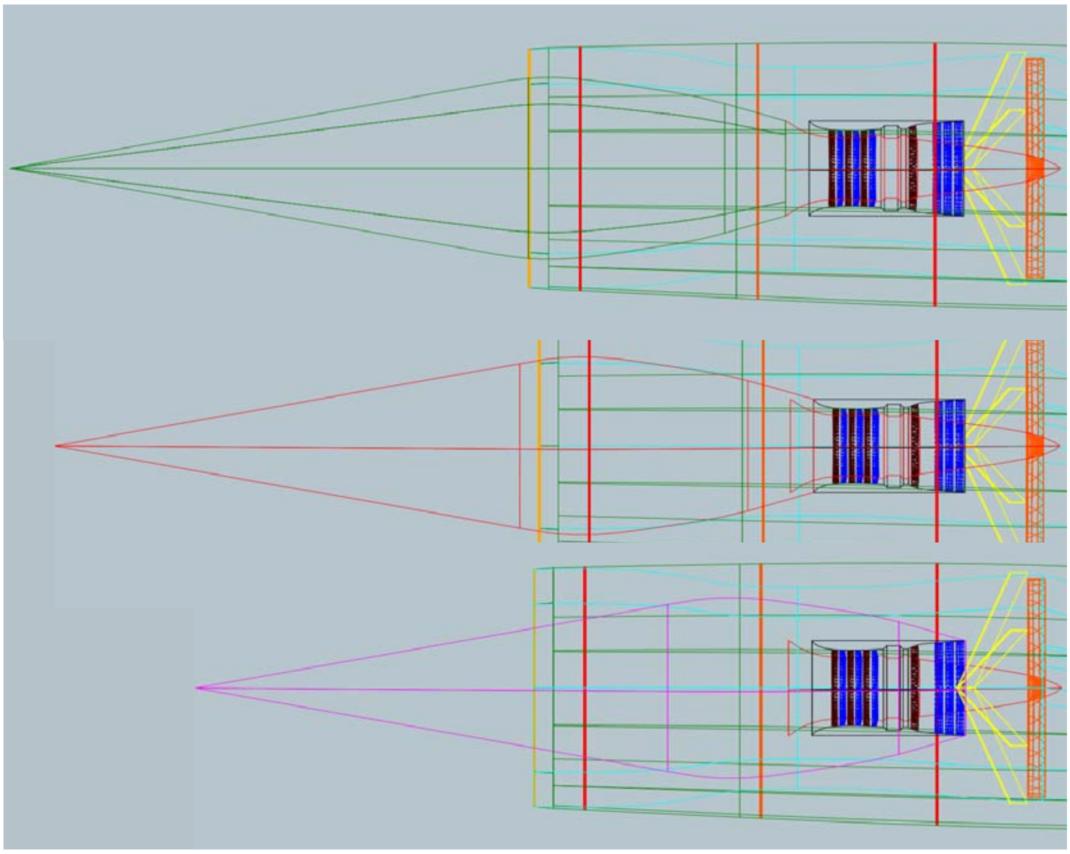
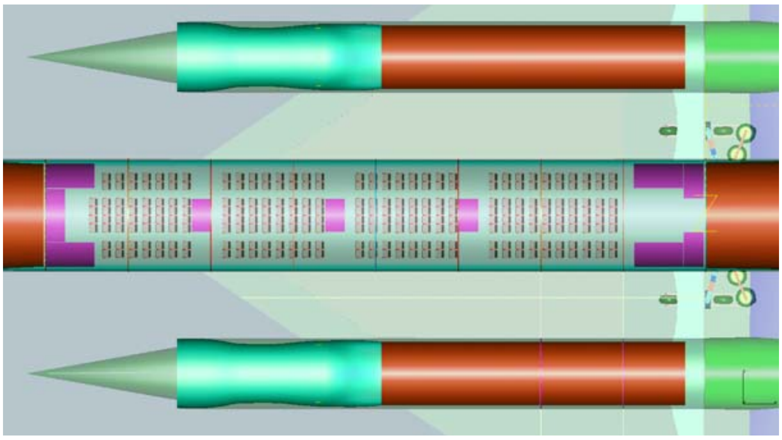


Figure 10: ATLLAS M3T rev.6 different positions of movable inlet spike

3.3 Passenger cabin

The pressurized cabin as well as the fuselage has a cylindrical shape. The passenger deck design was performed considering the integration of (emergency) exits, kitchens and toilets. In the chosen two aisles configuration, a total of 226 seats can be accommodated into the cabin (see Figure 11!).



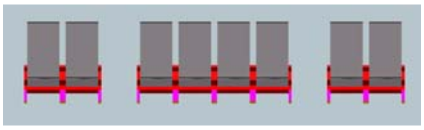


Figure 11: ATLLAS M3T rev.6 pressurized passenger cabin

3.4 Landing gear

Two main landing gears with four wheels each are proposed. The landing gears will be retracted into the fuselage during the flight. Both positions of the main gear are shown in Figure 12 and Figure 13.

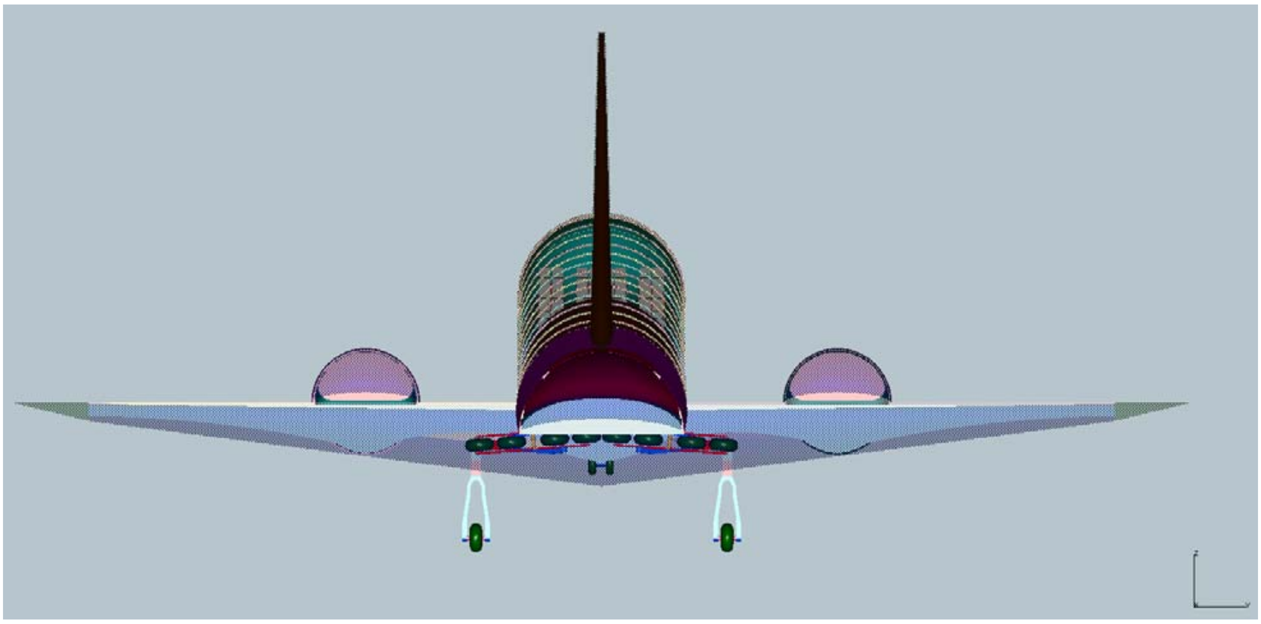


Figure 12: ATLLAS M3T rev.6 back view with integration of landing gear

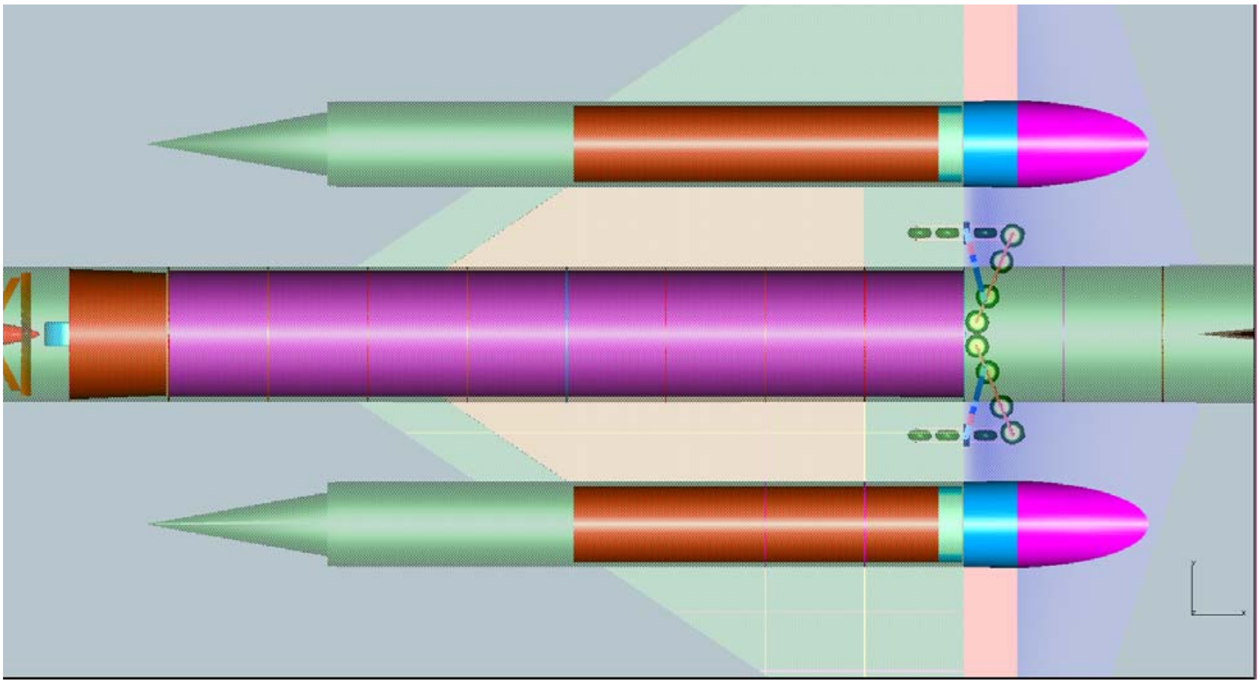


Figure 13: ATLLAS M3T rev.6 top view with integration of main landing gear

In addition, for aerodynamic reasons the nose landing gear cannot be stored outside of the fuselage. Consequently a volume has to be accommodated in the engine duct for the nose landing gear. The nose gear's position and its housing (as shown in Figure 14) is already at an ambitiously compact design. Nevertheless, this shape directly behind the fan rotor significantly disturbs the flow in the duct (Figure 15).

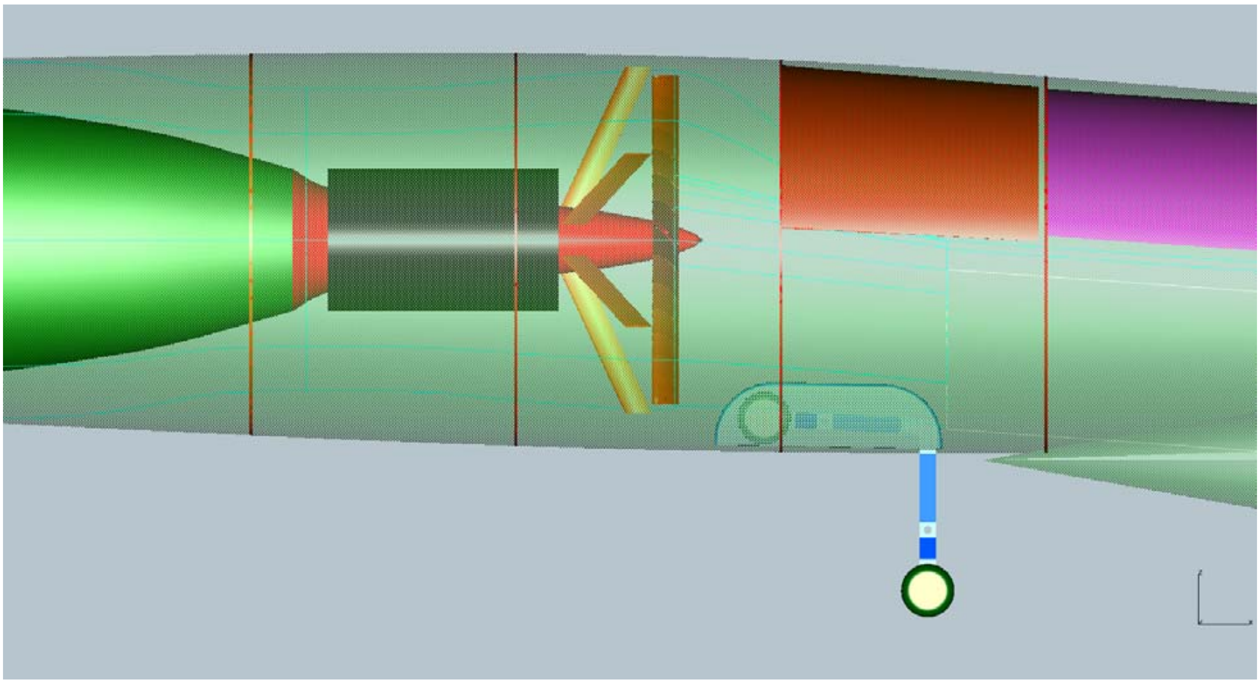


Figure 14: ATLLAS M3T rev.6 nose landing gear stored in fuselage

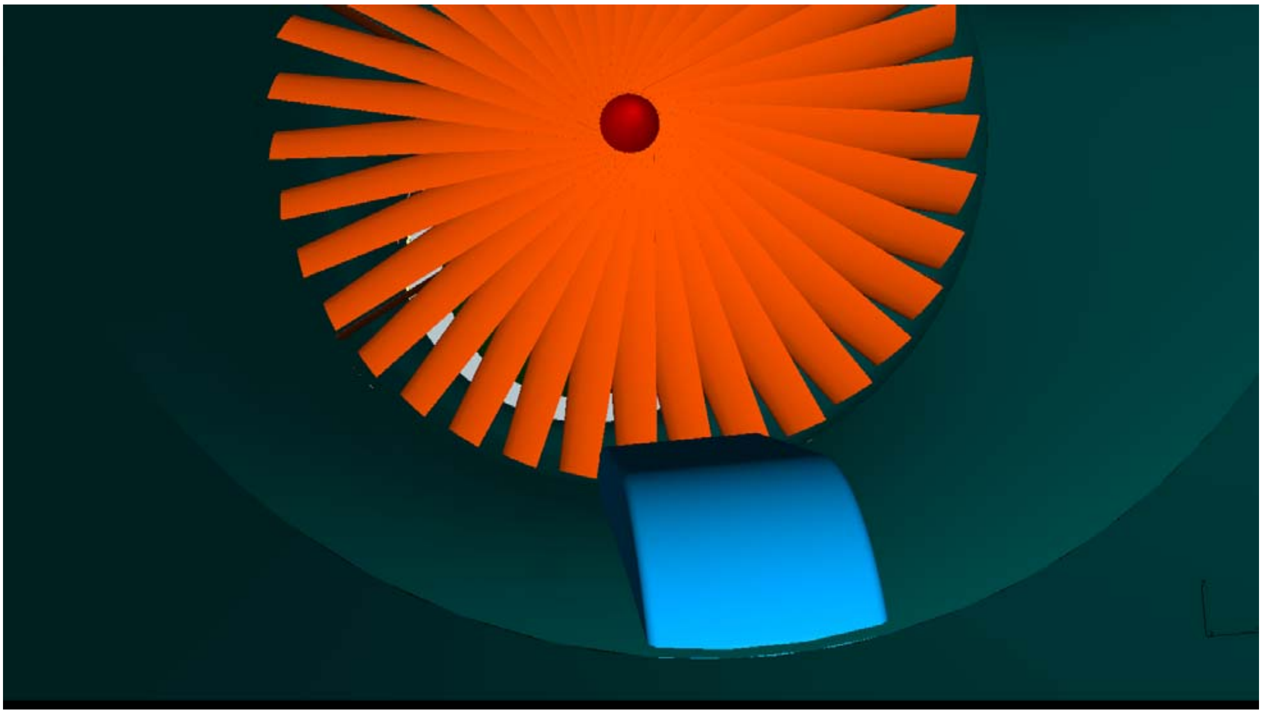


Figure 15: ATTLLAS M3T rev.6 nose landing gear housing reaching into the engine duct

3.5 Tanks

In the M3 configuration the tanks are integrated into the fuselage as well as into the wings and into the VTP. The tanks, which are located in the fuselage, have a cylindrical shape, while the design of other tanks depends on the structure's shape of the parts in which they are integrated. Figure 16 shows how the different tanks (front, auxiliary, wing, aft and methane tank) are accommodated.

The required fuel volume is less than the maximum volume available for the tanks accommodation. This leads to different possible tank filling configurations.

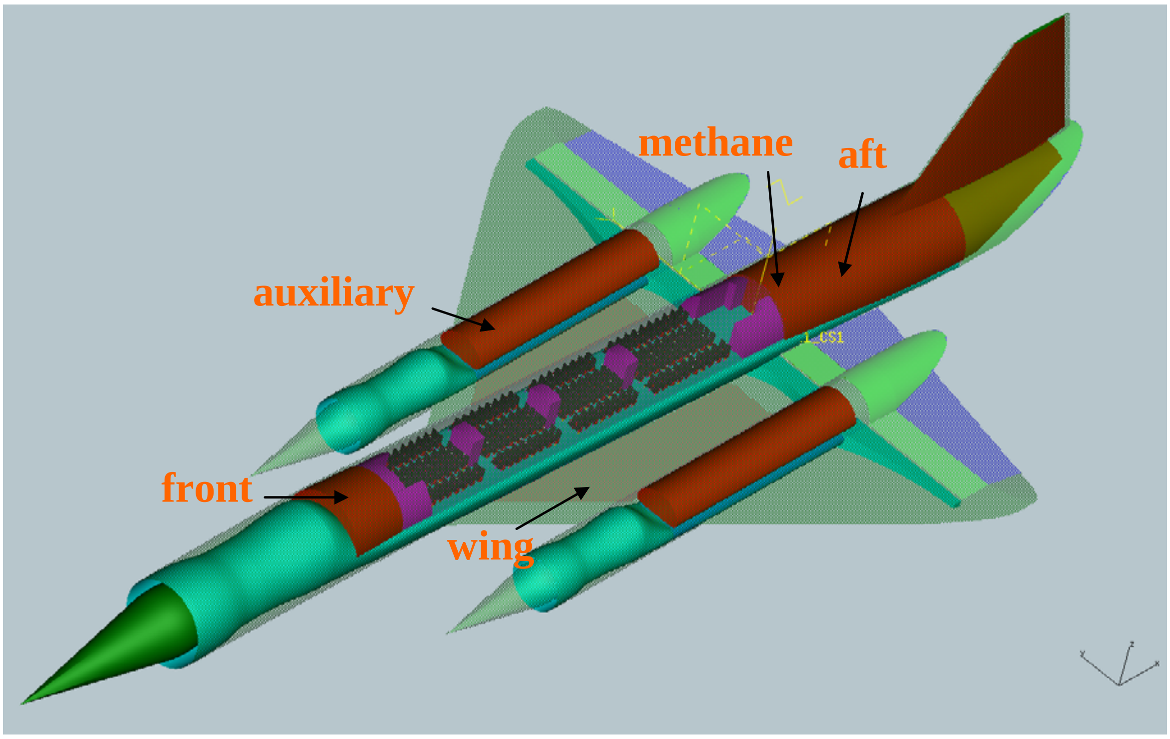


Figure 16: ATLLAS M3T rev.6 tank accommodation

4 Mass and CoG analyses

4.1 Vehicle dry mass estimation

The mass was estimated with the help of the DLR-SART tool STSM for different tank configurations. The position of the CoG is given as the distance from the leading edge of the fuselage in the direction of the x-axis (the coordinate system is shown in Figure 17).

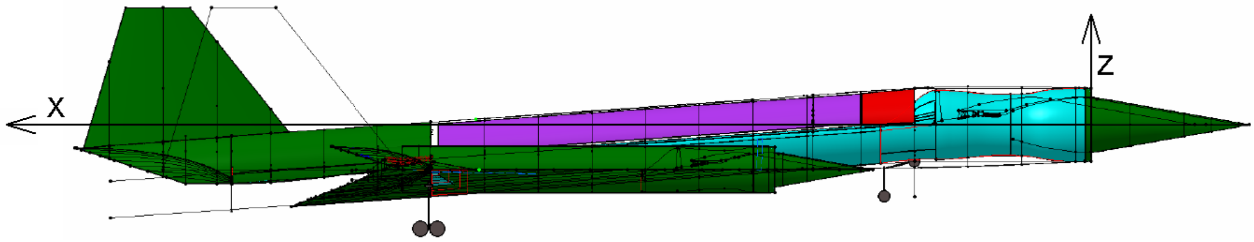


Figure 17: ATLLAS M3T rev.6, x- and z-axis orientation for CoG calculation

In Table 3 a detailed mass breakdown estimation for the front tank configuration is listed. This example was chosen because the maximum change in CoG position is the smallest of all options with less than 2.5 m (from 42 m to 44.3 m) as will be shown in the next section 4.2.

According to this estimation, the empty aircraft weighs 154 t. Adding 149 t of propellant and 62 t of payload gives a lift-off mass for the aircraft of 365 t. The 149 t of propellant include 500 kg residuals and 500 kg reserve propellant. A mass margin of 10 % is added to all estimated component masses. This value for such an advanced Mach 3.5 airplane with its unconventional shape is seen as the absolute minimum to take care for the risk of mass growth during development.

Table 3: Mass breakdown estimation for the front tank configuration M3T rev.6

			COG				
		m [kg]	**X [m]**	**Y [m]**	**Z []m]}**	**DMR [%]**	
1.1	*Structure group:*						
1.1.1	Fuselage	30844	40.0	0.0	-1.7	22.0	
1.1.2	2ndary engine body structure right	2665	44.6	9.6	-4.4	1.9	
1.1.3	2ndary engine body structure left	2665	44.6	-9.6	-4.4	1.9	
1.1.4	Take-Off Wing Structure	19392	57.2	0.0	-5.5	13.8	
1.1.5	Vertical Stabilizer	3878	85.3	0.0	3.0	2.8	
1.1.6	Wing Control Flaps	2117	70.0	0.0	-8.0	1.5	
1.1.7	Tank	584	18.9	0.0	1.8	0.4	
1.1.8	Tank Seal	35	45.3	4.4	-4.7	0.0	
1.1.9	Tank Seal	35	45.3	-4.4	-4.7	0.0	
1.1.10	Tank, methane	355	64.4	0.0	-0.9	0.3	
1.1.11	Thrustframe A/B-Engines, main	1125	12.4	0.0	0.0	0.8	*
1.1.12	Thrustframe A/B-Engines, 2ndary right	438	37.1	0.0	-4.4	0.3	*
1.1.13	Thrustframe A/B-Engines, 2ndary left	438	37.1	0.0	-4.4	0.3	*
	Mass Structure group w/o margins	64570					
	Mass Structure group incl. 10% margins	**71027**				**46.0**	
1.2	*Subsystem group:*						
1.2.1	Propellant Supply, kerosene to main engine	535	26.9	0.0	-2.2	0.4	
1.2.2	Propellant Supply, kerosene to 2ndary engines	338	68.7	0.0	-6.0	0.2	

1.2.3	Propellant Supply, methane	94	63.8	0.0	-0.5	0.1	
1.2.4	Take-Off Gear	6707	54.0	0.0	-3.4	4.8	
1.2.5	Electrics	2787	22.0	0.0	0.0	2.0	
1.2.6	Avionics	250	22.0	0.0	1.6	0.2	*
1.2.7	Hydraulics	2103	40.3	0.0	-2.1	1.5	
1.2.8	ECS	800	22.0	0.0	-2.1	0.6	*
1.2.9	Primary Power	1500	19.6	0.0	-1.4	1.1	*
1.2.10	Paint	371	50.0	0.0	0.0	0.3	
1.2.11	Air-Conditioning	3000	40.2	0.0	0.0	2.1	*
1.2.12	Furnishing	10000	40.2	0.0	-1.4	7.1	*
1.2.13	Cockpit	500	22.0	0.0	1.5	0.4	*
	Mass Subsystem group w/o margins	28987	35.0	0.0	0.0		
	Mass Subsystem group incl. 10% margins	**31886**				**20.7**	
1.3	*Propulsion group:*						
1.3.1	Airbreathing Engines Turbo, main	5000	11.5	0.0	0.0	0	*
1.3.2	Airbreathing Engines RAM, main	1000	76.3	0.0	-3.3	0	*
1.3.3	Air Intake, main	5000	0.0	0.0	0.0	0	*
1.3.4	Airbreathing Engines Nozzle, main	3000	96.6	0.0	-4.7	0	*
1.3.5	Airbreathing Engines RAM, on wing	2000	61.4	0.0	-1.0	0	*
1.3.6	Airbreathing Engines Nozzle, on wing	3000	94.0	0.0	-5.7	0	*
1.3.7	Airbreathing Engines Turbo, 2ndary right	3000	38.5	0.0	-4.4	0	*
1.3.8	Air Intake, 2ndary right	2000	29.4	0.0	0.0	0	*
1.3.9	Airbreathing Engines Nozzle, 2ndary right	1170	65.3	0.0	-1.5	0	*
1.3.10	Airbreathing Engines Turbo, 2ndary left	3000	38.5	0.0	-4.4	0	*
1.3.11	Air Intake, 2ndary left	2000	29.4	0.0	0.0	0	*
1.3.12	Airbreathing Engines Nozzle, 2ndary left	1170	65.3	0.0	-1.5	0	*
	Mass Propulsion group w/o margins	31340					
	Mass Propulsion group incl. 10% margins	**34474**				**22.3**	
1.4	*Thermalprotection group:*						
1.4.1	TPS	5618	40.0	0.0	0.0	0.0	
1.4.2	Cryogenic Insulation, methane tank	55	73.8	0.0	-1.9	0.0	
1.4.3	Cabin Insulation	9800	40.2	0.0	0.0	0.0	*
	Mass Thermalprotection group w/o margins	15473					
	Mass Thermalprotection group incl. 10% margins	**17020**				**11.0**	
	A/C Mass empty w/o margins	140370	44.5	0.0	-2.2		
	A/C Mass empty incl.marg.	**154407**	44.5	0.0	-2.2		
	Structural Index		1.0				

2.1	*Fluids*							
2.1.1	Propellant (kerosene)	136000						
2.1.2	Residual propellant (kerosene)	500						
2.1.3	Reserve propellant (kerosene)	500						
2.1.4	Methane	12000						
	Mass **Liquids**	**149000**						
2.2	*Crew:*							
2.2.1	Pilots (2)	160						
2.2.2	Cabin Crew (4)	320						
	Mass **Crew**	**480**						
	Total Lift-Off Mass w/o payload	303887						
	Mass **Payload**: Passengers and luggage	**61749**						
	Gross Lift-Off Mass incl. payload	**365156**						

4.2 Tank position dependent CoG movement along flight mission

As already shown in Figure 16 sufficient volume is available for the tanks for accommodation of the total fuel loading. This allows for different possible tank filling configurations with different CoG movement during the nominal flight mission. Such CoG shift can be simulated using STSM to support the selection of the most promising configuration with respect to flight dynamic requirements.

Table 4 presents the empty vehicle, kerosene, payload and total mass distribution for different tank configuration. Due to different tank configurations, the CoG shifting during the flight is different. This can be seen in Figure 18 to Figure 22. The vehicle empty mass slightly differs due to the different tank types used in the five configurations. As a result also the available payload mass for a fixed take-off mass is not identical.

Table 4: Vehicle, kerosene, payload and total masses distribution for different tank configurations M3T rev.6

Conf. Nr.	Configuration	Vehicle empty mass	Kerosene mass				Payload mass	Total mass
			Front tank	Wing tank	Aft tank	Aux tank		
1	Front + wing	154.4 t	40 t	2 x 48.5 t			61.7 t	365 t
2	Aux	156 t				2 x 68.5 t	60.1 t	365 t
3	Aft	155.5 t			137 t		60.7 t	365 t
4	Aft + aux	156.1 t			40 t	2 x 48.5 t	60.0 t	365 t
5	Aft + wing	154.4 t		2 x 48.5 t	40 t		61.7 t	365 t

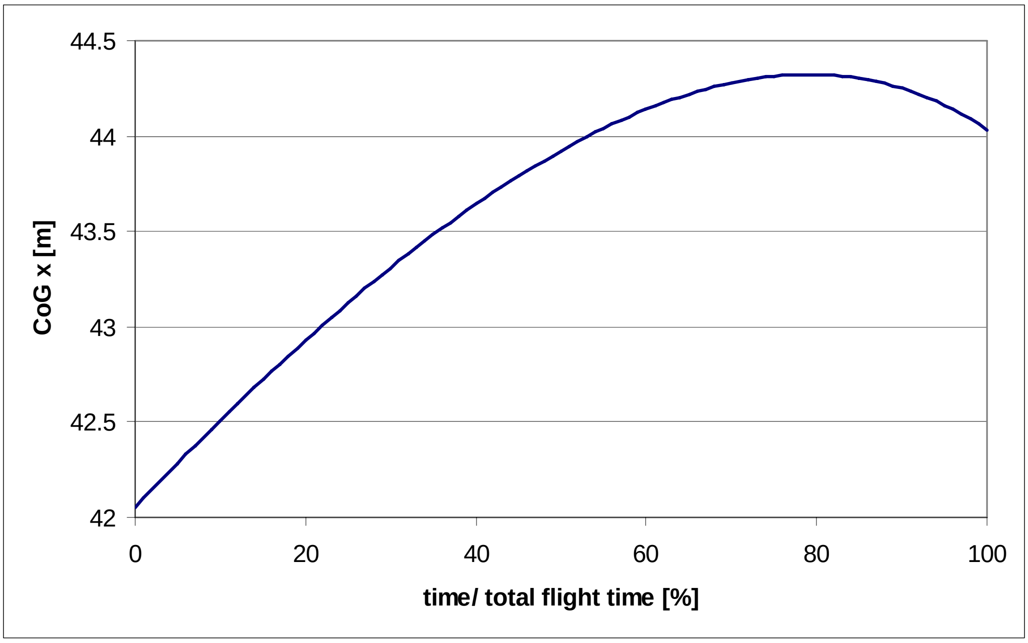


Figure 18: ATLLAS M3T rev.6, configuration 1 - CoG drift

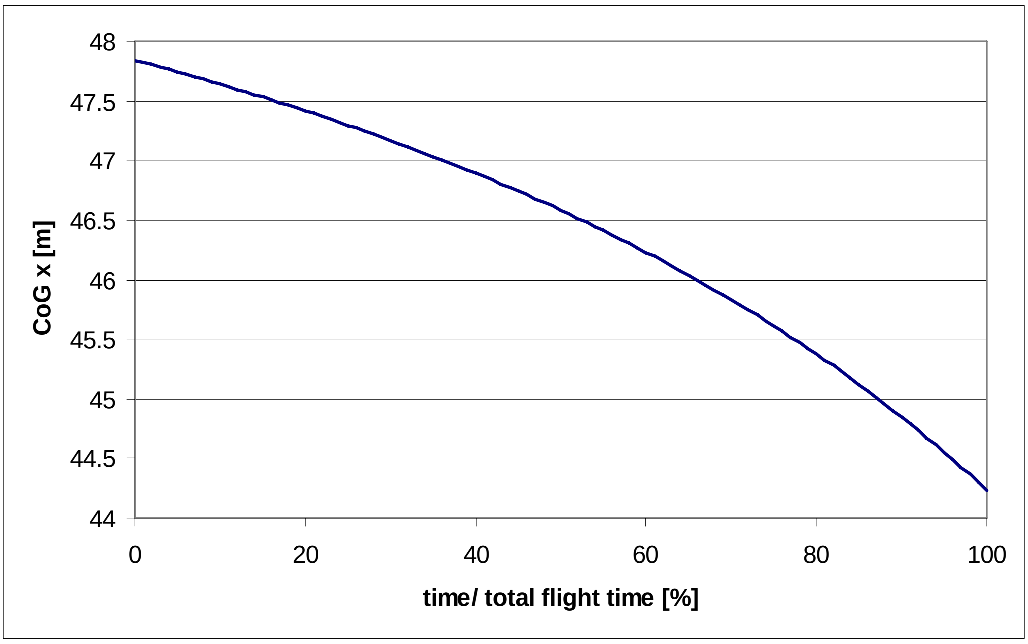


Figure 19: ATLLAS M3T rev.6, configuration 2 - CoG drift

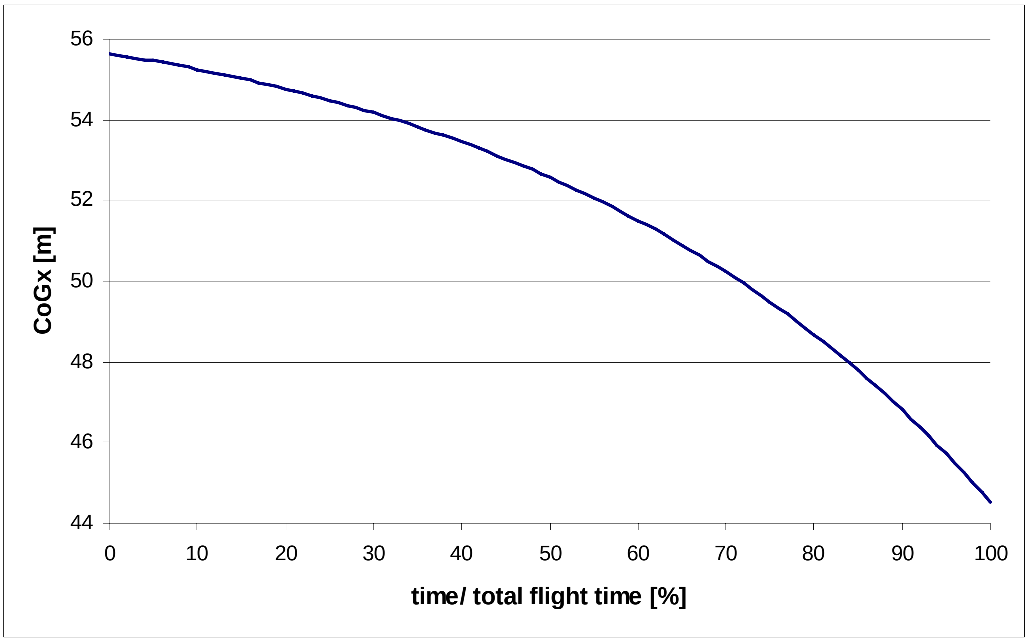


Figure 20: ATLLAS M3T rev.6, configuration 3 - CoG drift

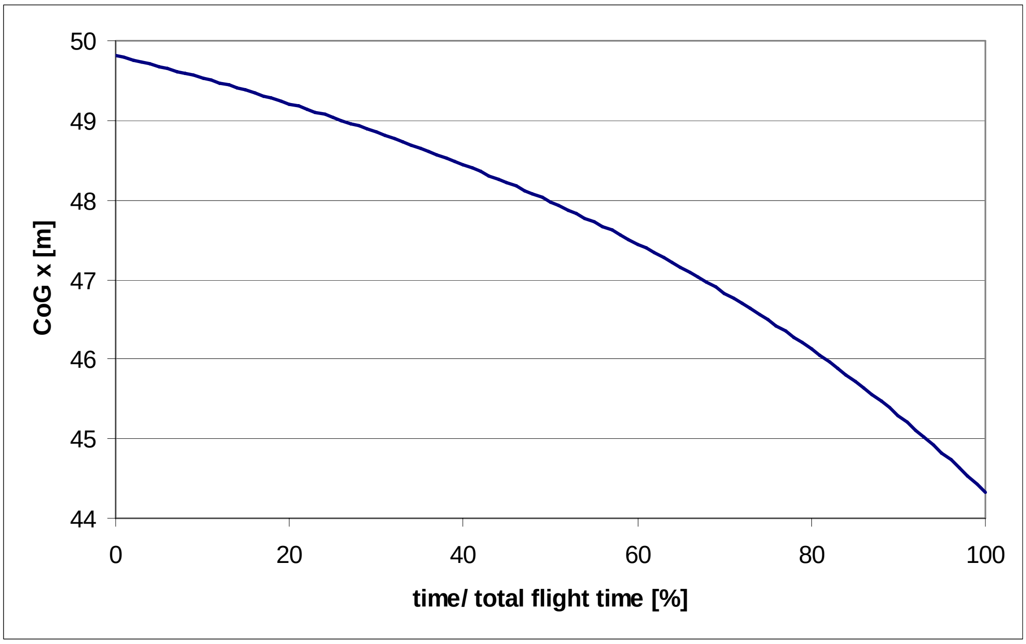


Figure 21: ATLLAS M3T rev.6, configuration 4 - CoG drift

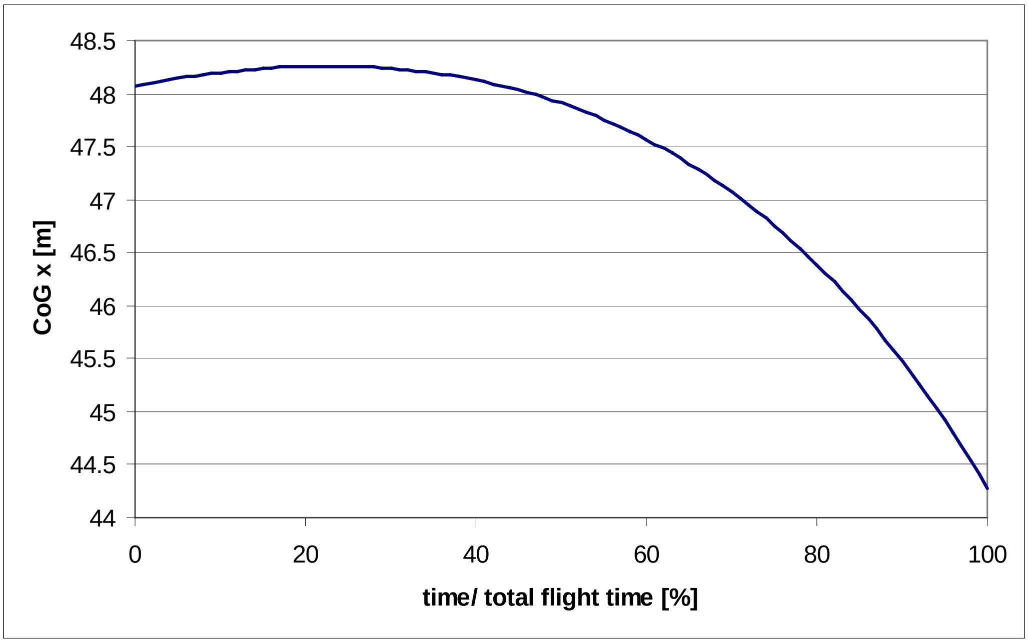


Figure 22: ATLLAS M3T rev.6, configuration 5 - CoG drift

5 Conclusions

An overview of the main dimensions and main components of the M3 configuration was given with the help of a CAD-model. The integration of the propulsion system, the passenger cabin, the tanks and the landing gears into the fuselage is shown. Due to the fact that the required fuel volume is smaller than the available volume for the tank accommodation, different tank configurations are possible. Based on the CAD-model, the mass is estimated for the different configurations. In addition the drift of the CoG during the mission is shown for each configuration.

The best tank configuration depends on the position of the aerodynamic centre of pressure in the subsonic and supersonic flight regimes and the corresponding requirements to achieve a fully trimmable configuration under all, even adverse conditions. This selection is part of the system work to be done by GDL.

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