BRNO UNIVERSITY OF TECHNOLOGY

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF MECHANICAL ENGINEERING

FAKULTA STROJNÍHO INŽENÝRSTVÍ

INSTITUTE OF AEROSPACE ENGINEERING

LETECKÝ ÚSTAV

LIGHT SPORT AIRCRAFT ENGINE REPLACEMENT

REMOTORIZACE LEHKÉHO SPORTOVNÍHO LETOUNU

MASTER'S THESIS

DIPLOMOVÁ PRÁCE

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Specification Master's Thesis

Department:	Institute of Aerospace Engineering
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Pursuant to Act no. 111/1998 concerning universities and the BUT study and examination rules, you have been assigned the following topic by the institute director Master's Thesis:

Light sport aircraft engine replacement

Concise characteristic of the task:

The aim of the diploma thesis is the engine replacement of light–sport aircraft PS–28 Cruiser from the current engine to some of the more powerful type. The solution of the given problem includes a complex range of design tasks.

Goals Master's Thesis:

1) The search of available engines and comparison of performance parameters.
2) Mass and balance analysis for the selected engine.
3) Calculation of flight envelopes according to the selected regulation.
4) Engine mount design.
5) Engine mount test plan.

Recommended bibliography:

NIU, Michael Chun-Yung. Airframe structural design. 2nd ed. Hong Kong: Hong Kong Conmilit Press Ltd. ISBN 962-7128-09-0.

MATTINGLY, Jack D, Wiliam H HEISER and David T PRATT. Aircraft engine design. 2nd ed. Reston: AIAA American Institute of Aeronautics and Astronautics, 2002, 692 s. CD ROM. ISBN 1563475383.

GUDMUNDSSON, Snorri. General Aviation Aircraft Design: Applied Methods and Procedures. Elsevier Science, 2013. DOI: 10.1016/C2011-0-06824-2. ISBN 0123973082.

Deadline for submission Master's Thesis is given by the Schedule of the Academic year 2019/20

In Brno,

L. S.

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doc. Ing. Jaroslav Juračka, Ph.D. Director of the Institute	doc. Ing. Jaroslav Katolický, Ph.D. FME dean

Abstract

The thesis is focused to find optimal and new engine for PS-28 Sport Cruiser, for more power and thrust.

The Rotax 912 ULS is currently the only engine that the client of this work (Czech Aircraft Works, hereinafter CZAW) installs into Sport Cruiser aircraft. This four-cylinder power unit has a maximum take-off power of 100 hp. For more demanding customers, the offer will be expanded by Lycoming O-235-L2C, which is also four-cylinder engine with maximum take-off power 118 hp. Which means, company will have bigger option and client gonna be much more satisfied

Keywords

Current powerplant, New powerplant, Aircraft empty data, ROTAX 912 ULS, Lycoming O-235-L2C, Flight envelope, engine mount.

TOTOGASHVILI, Nikolozi. *Light sport aircraft engine replacement*. thesis. Tbilisi : Nikolozi Totogashvili, 2020.

I hereby declare that I am the sole author of this master's thesis and that I have not used any sources other than those listed in the bibliography and identified as references. I further declare that I have not submitted this thesis at any other institution in order to obtain a degree.

BEng. Nikolozi Totogashvili

Acknowledgement

I would like to say thanks to Ph.D Teimuraz Lomtadze from Georgian Technology University, who helped me financically to study in Brno University of Technology,

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Contents

Introduction

1.1 Objectives which should be achieve:

1) The search of available engines and comparison of performance parameters.

2) Mass and balance analysis for the selected engine.

3) Calculation of flight envelopes according to the selected regulation.

4) Engine mount design.

5) Engine mount test plan.

The aim of the diploma thesis is the engine replacement of light-sport aircraft PS-28 Cruiser from the current engine to some of the more powerful type. The solution of the given problem includes a complex range of design tasks.

The Rotax 912 ULS is currently the only engine that the client of this work (Czech Aircraft Works, hereinafter CZAW) installs into Sport Cruiser aircraft. This four-cylinder power unit has a maximum take-off power of 100 hp. For more demanding customers, the offer will be expanded by Lycoming O-235-L2C, which is also four-cylinder engine with maximum take-off power 118 hp.

Second stage is Cg, mass and balance analysis, for this calculations I used Excel.

On the third stage I calculated Flight envelope and the last level is engine mount design, for this design I needed Catia V5(6) software.

DESIGN OVERVIEW

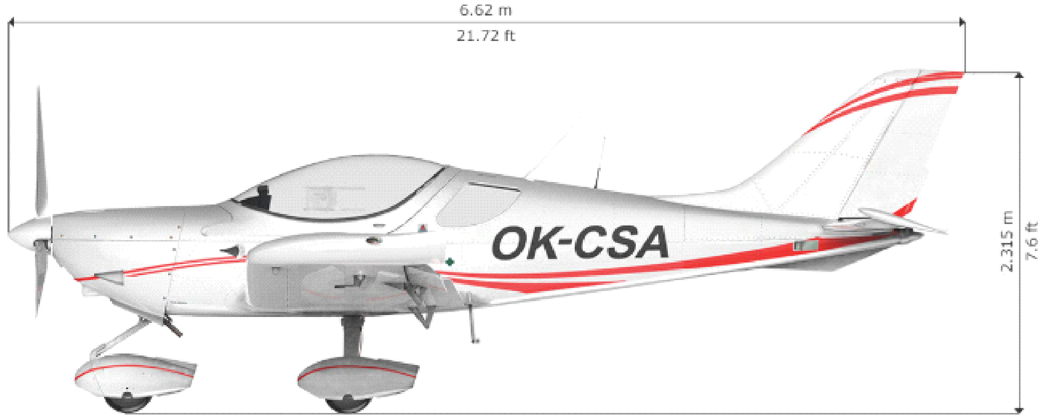
Chapter 2

2.1. BASIC DESIGN

The Sport Cruiser is used extensively for flight training around the world. It's a double-seat, all-metal aircraft, arranged as a low-wing monoplane with cantilevered wings and conventional empennage.

The aircraft has a tricycle fixed landing gear of nose type. The Sport Cruiser has been approved for operation in the USA and other countries in the LSA (Light Sport Aircraft) category according to the FAA (Federal Aviation Administration) Accepted ASTM Consensus Standards.

Drawing 1.



Drawing 2.

WING

The wings are of all-metal main spar structure with a rear spar. Each of the two wings is attached to the center section fuselage by means of 6 shear bolts. Fuel tank is located in each wing with a capacity of 57 litres. Unique lockable storage compartment is located in each wing with a load capacity of 10kg each.

The wing tips are made from carbon-glass composite. Both wings are equipped with electrically controlled flaps and ailerons. The right aileron is fitted also with electrical trim.

Position and strobe lights are installed in the wing tips.

TAIL UNIT

The aircraft tail unit consists of the vertical fin, the rudder, the horizontal stabilizer and the elevator with trim tabs. The elevator is well balanced by the electrically controlled trim of the elevator. The elevator is equipped also with a balance tab for aircraft better controllability and balance of the control forces.

FUSELAGE

The fuselage is designed as a semi monocoque conventional all-metal structure. The cockpit fixed frame and the movable frame are made from a composite. The main undercarriage is attached directly to the bottom part of the fuselage. The nose landing gear is attached to the firewall.

COCKPIT

The Sport Cruiser boasts by far the most spacious in its class, which provides utmost level of comfort and highly ergonomic arrangement to the flying crew.

The canopy window is made from plexiglass and is fitted with two openable side windows. There is a luggage compartment behind the pilot seats with the load capacity of 18 kg. The instrument desk consists of three panels. Thanks to dual flight controls and pedals the aircraft is fully controllable from both pilot seats. The cockpit is equipped with adjustable pedals. The first-class choice of materials used for the cockpit upholstery, advanced on-board climate control and defogging systems together with the easy flight control and high endurance of the aircraft provide for the Sport Cruiser being widely recognized also as a true cross-country aircraft.

With the unique baggage lockers integrated into both wings together with the spacious baggage compartment located in the rear part of the cockpit, the Sport Cruiser will always guarantee optimum flexibility for that weekend away.

TECHNICAL SPECIFICATION

Engine : Rotax 912 ULS2

Power: 100 HP (73.5Kw) at 5800 RPM

Fuel: Mogas RON 95, Avgas 100 LL, EN 228

Propeller: Sensenich Fixed 3-blade (*)

Wingspan: 28.22 ft (8.6 m)

Length: 21.72 ft (6.62 m)

Height: 7.60 ft (2.315 m)

Wing surface area: 132.4 sq ft (12.3 m²)

Cockpit width: 3.85 ft (1.17 m)

MTOW: 1,320 lbs (600 kg)

Empty weight: 855.4 lbs (388 kg)

Max. baggage weight in cockpit compartment: 40 lbs (18 kg)

Max. baggage weight in each wing locker: 22 lbs (10 kg)

Cruise speed at 3,000 ft and 75% power: 93 KIAS (172 km/h)

Max. horizontal speed: 119 KIAS (220 km/h)

VNE : 138 KIAS (255 km/h)

Stall speed VS0: 31 KIAS (55 km/h)

Climb rate: 825 ft/min (4.2 m/s)

Take-off distance to 50 ft (15 m):

Concrete: 1,270 ft (387 m)

Grass: 1,499 ft (457 m)

Braking distance:

Concrete: 479 ft (146 m)

Grass: 364 ft (111 m)

Range (30 min. reserve): 516 NM (953 km)

Endurance: 5 hours 25 min

Fuel capacity:

Average fuel consumption:

SPECIFICATIONS AND EQUIPMENT

EQUIPMENT

- Locking canopy
- Canopy lock signalisation
- Flight controls on left & right side
- Adjustable pedals (both seats) with breaks
- 4-point seat belts (both seats)
- Wing locker in each wing
- Locking fuel tanks (2x 57 litres)
- Electrical aileron trim
- Electrical elevator trim
- PTT & trim settings on control stick
- Electrical flap setting, indicator on MFD
- Dual hydraulic brakes
- Parking brake
- Spats
- Positional, strobe & landing light
- Canopy sunshade
- 12V jack plug
- BRS Parachute System (*)

AVIONICS AND INSTRUMENTS

- 2x SkyView SV-HDX1100 touch screen both with back-up battery SV-BAT-320
- SkyView Internal Autopilot (*)
- SV-AP-PANEL Autopilot control panel (*)
- SV-KNOB-PANEL Knob control panel (*)

- Primary air data, attitude, heading reference system, SV-ADAHRS-200
- Back-up air data, attitude, heading reference system, SV-ADAHRS-201
- SkyView SV-GPS-2020 built-in GPS
- SV-MAP-270 navigation software
- Transponder (S-Mode Class 2)
- SV-EMS-220 Engine Monitoring Module
- OAT Probe
- Pitch Trim Indicator on MFD
- Aileron Trim Indicator on MFD
- ADS-B receiver SV-ADSB-472
- VHF + NAV/COM Garmin GNC 255
- Intercom
- ELT
- Stall Warning
- GPS Garmin 796 (*)

2.2 Choice of coordinate system

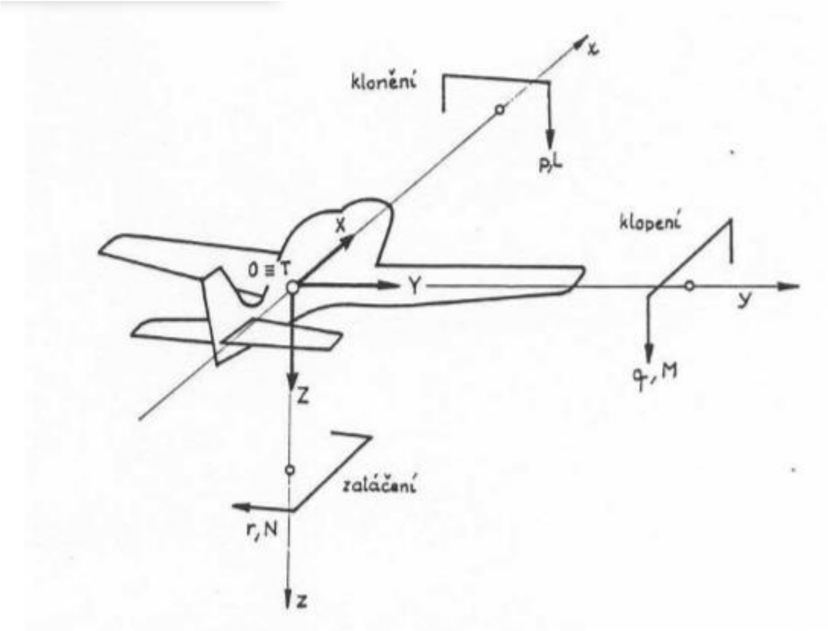
The coordinate system for easier orientation is chosen in accordance with the aircraft coordinate set (x, y, z)

The origin is placed in the center of gravity of the aircraft. This system is firmly connected to the aircraft. The x-axis is oriented in the direction of the fuselage axis, with its positive sense forward. The z-axis points down fros the aircraft. The y-axis is perpendicular to rhe previous twho axis with a positive sense on the pilot’s right hand side. All three axis are at right angle to each other.

X-axis – longitudinal axis

Y- axis – lateral axis

Z –axis – perpendicular axis



Picture 1. 1 Aircraft coordinate system.

2.3 Curent Powerplant

ROTAX 912 ULS

100 hp

Picture 2. 1

DESCRIPTION :

• 4-cylinder

• 4-stroke liquid/air-cooled engine with opposed cylinders

• dry sump forced lubrication with separate oil tank, automatic adjustment by hydraulic valve tappet

• 2 carburetors

• mechanical fuel pump

• dual electronic ignition

• electric starter

• propeller speed reduction unit

• air intake system

Price : $18,878.

Picture 2. 2 proppeller : sensenich fixed 3- blade

Facts:

In comparison to the 80 hp version of the Rotax 912 series the 100 hp product line offers more power while keeping the weight. This engine series offers a time between overhauls of 2.000 hrs and the best power to weight ratio in its class - no surprise that this engine is the best selling 4-stroke engine. This series is available as non-certified (Rotax 912 ULS) and certified engine (Rotax 912 S) according to FAR33.

PERFORMANCE		
73.5 kW	100 hp	5800 1/min
TORQUE		
128 Nm	94 ft. lb.	5100 1/min
MAX RPM*		5800 1/min

Figure 2. 1. performance and torque

BORE		STROKE	
84.0 mm	3.31 in	61.0 mm	2.4 in
DISPLACEMENT		**FUEL**	
1352 ccm	82.6 cu in	min. MON 85 RON 95* min. AKI 91*	

Figure 2. 2. ***Bore, Stroke***

WEIGHT	KG	LB
Engine with propeller speed reduction unit i = 2.43	56.6	124.5
Overload clutch	1.7	3.7
Exhaust system	4.0	8.8
External alternator	3.0	6.6
Engine mount	2.0	4.4
Air guide hood	0.4	0.8

Figure 2. 3 weight

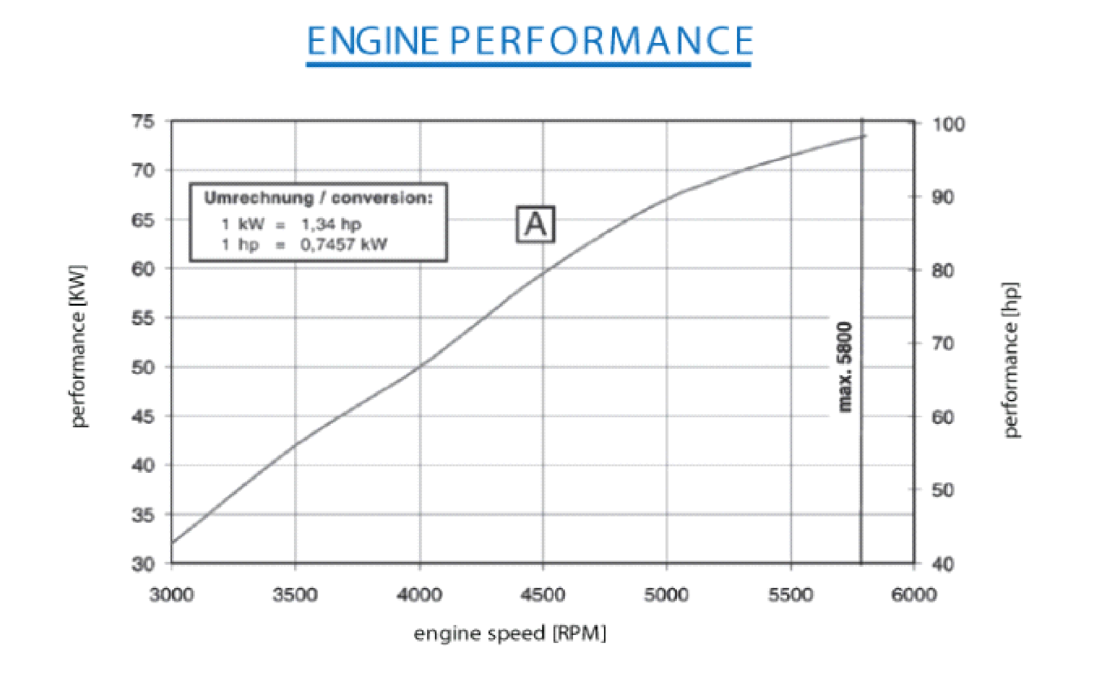


Figure 2. 4 engine performance

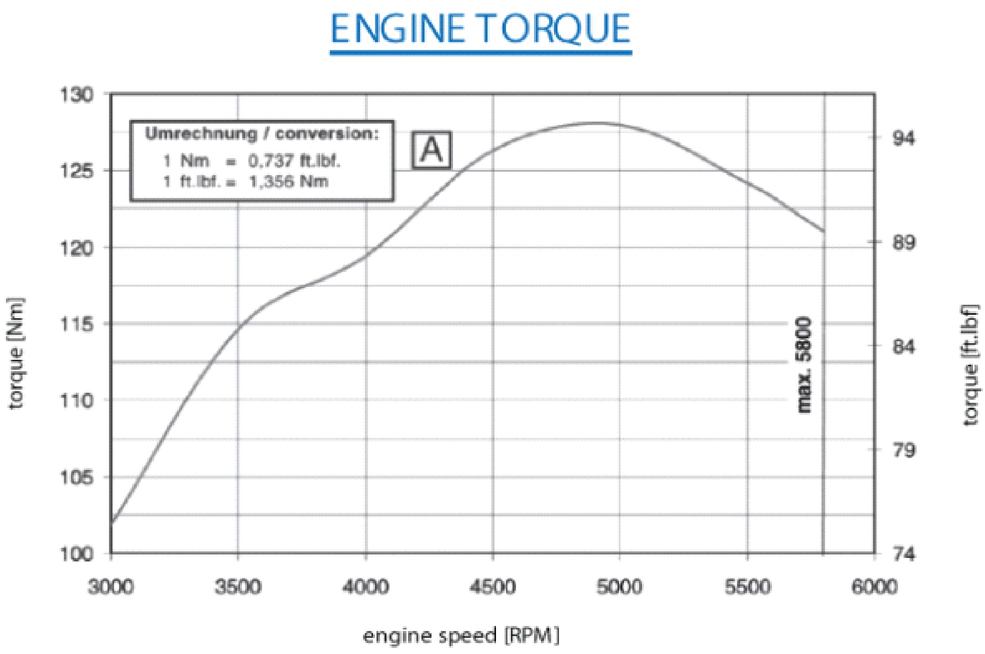


Figure 2. 5 Engine torque

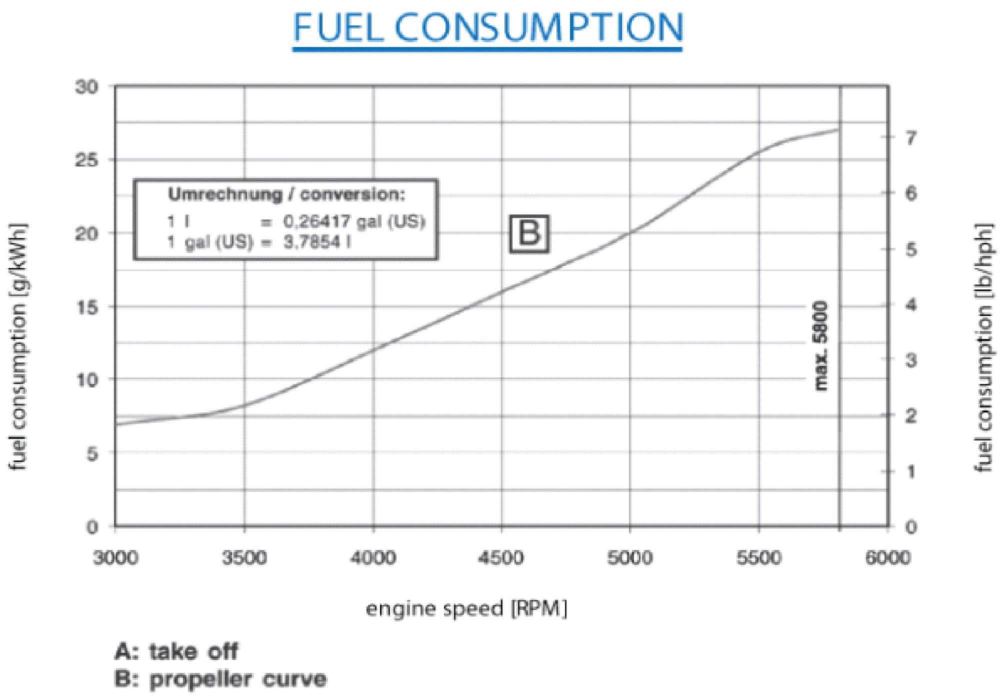


Figure 2. 6 Fuel consumption

2.4 Engine choises

Rotax 912 ULS/S	Rotax 914 UL	Rotax 915 iS	Lycoming IO-233-LSA	Lycoming O-235-L2C	Continental O-200-D
4-cylinder 4-stroke liquid-/air-cooled engine with Dry sump forced lubrication with sepa 2 carburetors Mechanical fuel pump Dual electronic ignition Electric starter Propeller speed reduction unit Air intake system (Purchased Separat	4-cylinder 4-stroke liquid-/air-cooled engine with With turbocharger With automatic waste gate control Dry sump forced lubrication with sepa Automatic adjustment by hydraulic va 2 carburetors Dual electronic ignition Electric starter Propeller speed reduction gearbox Engine mount assembly Air intake system Exhaust system	4-cylinder 4-stroke liquid/air-cooled engine with Dry sump forced lubrication with sepa Redundant electronic fuel injection an Engine management system (EMS) Electric starter (12 or 24 volt) Propeller speed reduction gearbox Air intake system with intercooler Turbocharger with stainless steel exh Service ceiling of 23,000 feet	4 valec, boxer, vzduchem chlazeny, mazani se suchou skrini, karburator nebo primy vstrik, bez reduktoru	4 valec, boxer, vzduchem chlazeny, mazani se suchou skrini, karburator, bez reduktoru	The 200 Series is a family of 4-cylinder, 4-stroke, spark ignitec air-cooled, horizontally opposed, direct-drive reciprocating aircraft engines designed for fixed pitch, ground adjustable, or electric constant speed propeller. The engines are made with a wet oil sump, carburetor with manual mixture control, continuous fuel injection, and Full Authority Digit Engine Control (FADEC) fuel cor
MOGAS EU - min. RON 95, EN 228 Super, EN 228 US - ASTM D4814 CA - min. AKI 91, CAN/CGSB-3.5 Quality 3 AVGAS US - AVGAS 100 LL (ASTM D910)	EU - min. MON 85 RON 85*, EN 228 US, CA - min. AKI 91* *leaded, unleaded, AVGAS 100LL or	EU - min. MON 85 / RON 95, US, CA - min. AKI 91	AVGAS 100 LL (ASTM D910 100LL), MOGAS 93 AKI (93 AKI ASTM D484	100/100LL (lisi se dle modelove rady)	100/100LL AVGAS (ASTM D910

		1352			1211.2			1352
		84			79.5			84
		61			61			61
		10.8:1			9.0:1			8.2:1
		2.43:1			2.43:1			2.43:1
		NE			ANO			ANO
5800	98.5	**73.5**	5800	115	**84**	5800	141	**104**
5500	92.5	69	5500	100	73	5500	135	99
5100	94	128	4900	106	144			
		56.6			**64**			**74.23**
External alternator assy.		3	External alternator assy.		3	Cooling air baffle		0.38
Vacuum pump assy.		1.7	Vacuum pump assy.		1.7	PCV		0.35
~~Hydraulic governor assy.~~		0	~~Hydraulic governor assy.~~		0	Oil tank		1.5
HD-starter		0.43	HD-starter		0.43	Intercooler		1.65
Rectifier regulator		0.3	Rectifier regulator		0.3	ECU		1.13
Starter relais		0.145	Starter relais		0.145	Fusebox		2.02
Radiator		1	Radiator		1	Ambient sensors		0.06
Air guide hood		0.36	cooling air duct		0.8	Wiring harness		2.5
Airbox		1.3	Airbox		1.3	Intermediate flange with (		0.78
2 air filter		0.3	2 air filter		0.3	??? wtfff?		
Oil radiator		0.55	oil radiator		0.6	Radiator		1
Exhaust system		4	Exhaust system		4	oil radiator		0.6
Engine mount	X		Engine mount	X		Vacuum pump assy.		1.7
Overload clutch		1.7	Overload clutch		1.7			

		3823.1			3823.1			3
		111.125			111.125			10
		98.425			98.425			98
		8.1:1			8.5:1			8
		1:1			1:1			
		NE			NE			
2800	116	**86.5**	2800	118	**88.0**	2750	100	
2400	100	74.6	2400	105	78.3	2550	75	
		95			**112.5**			**7**
---		---	---		---	Vybaveni pro verzi D3B		
						Starter Skytec 12V		
						14.2V/50A Alternator		
						Magneto Champion 4301		
						Spark Plugs		
						Ignition Harness		
						Carburetor		
						Air Box (alu)		
						Oil Sump		
						Oil Cooler Adapter		

2000	2000	1200	2400	2400	2
$18,900	$30,700	$37,000	$13,500	$9	$11
1989 - doted'	1996 - doted'	2017 - doted'	2008 - doted'	1942 (posl. ver. 1983) - doted'	2004 - d
Vyrobce: https://www.flyrotax.com/produkte/de tail/rotax-912-uls-s.html Specifikace (cesky prodejce): https://teveso.cz/motory/ctyrtaktni-ne certifikovane/rotax-912-uls Specifikace (prodejce usa): https://www.cps-parts.com/catalog/rt xpages/912rotaxengine100.php Wiki: https://en.wikipedia.org/wiki/Rotax_9 12	Vyrobce: https://www.flyrotax.com/produkte/de tail/rotax-914-ul-f.html Specifikace (cesky prodejce): https://teveso.cz/motory/ctyrtaktni-ne certifikovane/rotax-914-ul Specifikace (prodejce usa): https://www.cps-parts.com/catalog/rt xpages/914rotaxengine115.php Clanek: https://www.aeroweb.cz/clanky/3557- vyrabime-letecky-motor-1-soucasny-t rh-s-leteckymi-motory Wiki: https://en.wikipedia.org/wiki/Rotax_9 14	Vyrobce: https://www.flyrotax.com/produkte/de tail/rotax-915-is-isc.html Specifikace (prodejce usa): https://www.cps-parts.com/catalog/rt xpages/915isrotaxengine140.php Wiki: https://en.wikipedia.org/wiki/Rotax_9 15_iS	Vyrobce: https://www.lycoming.com vyhledavani dle "233" nedava vysledky https://www.lycoming.com/search?se arch_api_views_fulltext=233 Specifikace, cena: http://www.paramotoraviation.com/pr oducts.php?product=Lycoming-IO%2 52d233%252dLSA-Aircraft-Engine Clanek: https://investor.textron.com/news/ne ws-releases/press-release-details/20 08/Lycoming-Engines-Launches-the- IO-233-LSA/default.aspx Clanek 2: https://generalaviationnews.com/201 0/10/13/first-flight-of-lycoming-o-233- lsa-powerplant/ Wiki: https://en.wikipedia.org/wiki/Lycomin	Vyrobce: https://www.lycoming.com/node/189 88	Vyrobce: https://www.continentalmotors.ae ngines/200.aspx Technicka dokumentace: https://www.manualslib.com/man 1476191/Continental-Motors-O-2 D.html Overhaul manual: http://veteranflyg.se/wordpress/w ontent/uploads/2017/03/Continer C75-C85-C90-O-200-Overhaul-M ual-Aug-2011.pdf Distributor: http://www.paramotoraviation.coı oducts.php?product=Continental 252d200%252dD-Lightweight-Ai t-Engine Wiki: https://en.wikipedia.org/wiki/Cont tal_O-200

Picture 3. 1 Engine choise

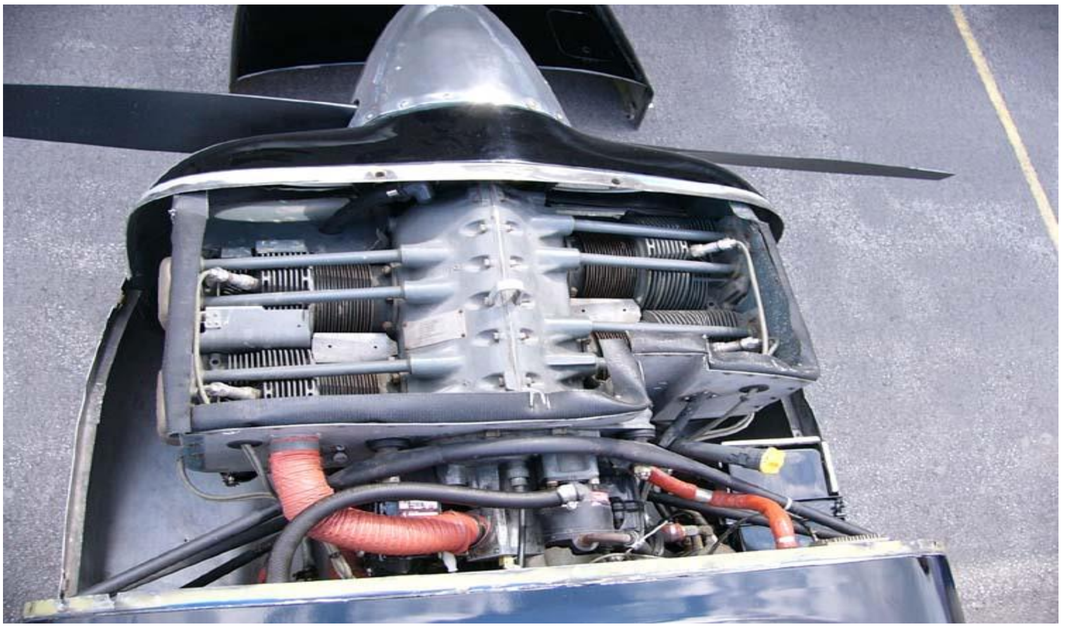
There are possible engines which was submitted in the company on the picture 3.

You can see specifications and prices which was available in internet. According to this paper “Czech sport aircraft “ choosed Lycoming O-235.

2.5 New Powerplant

Lycoming

O-235-L2C



Specifications

General characteristics

- **Type:** Certified piston aero-engine
- **Bore:** 103.17 mm
- **Stroke:** 98.425 mm
- **Displacement:** 233.3 in^3 (3.823 L)
- **Dry weight:** 108.9 kg
- Full Weight: 117.5 Kg

- **Fuel system:** carburetor
- **Fuel type:** 80/87 avgas
- **Cooling system:** air-cooled

Power output: 118 hp (88 kW) at 2800 rpm

Depending on our task, which means, that we need more powerfull engine we can compare those two engines and will see that Lycoming has better charatceristics, it's cheaper but heavier and bigger, Theoritically, because of this mass and dimensions I have different CG and different nose parts for aircraft, also it's important to reinforce nose landing gear.

Mass and balance analysis for the selected engine

(Chapter 3)

3.1. Three-view drawing

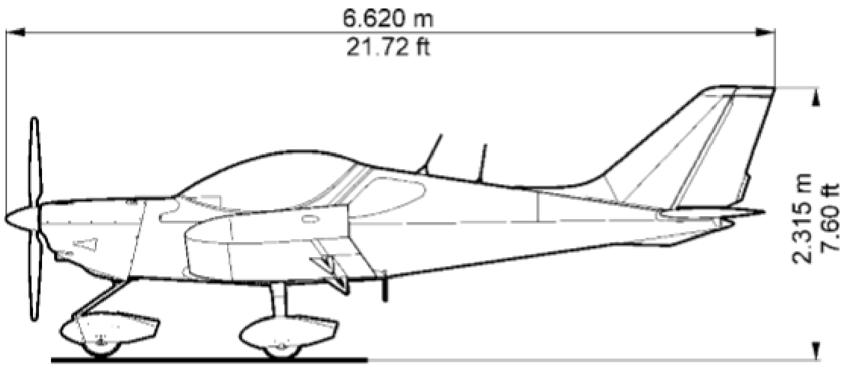


Figure 7.

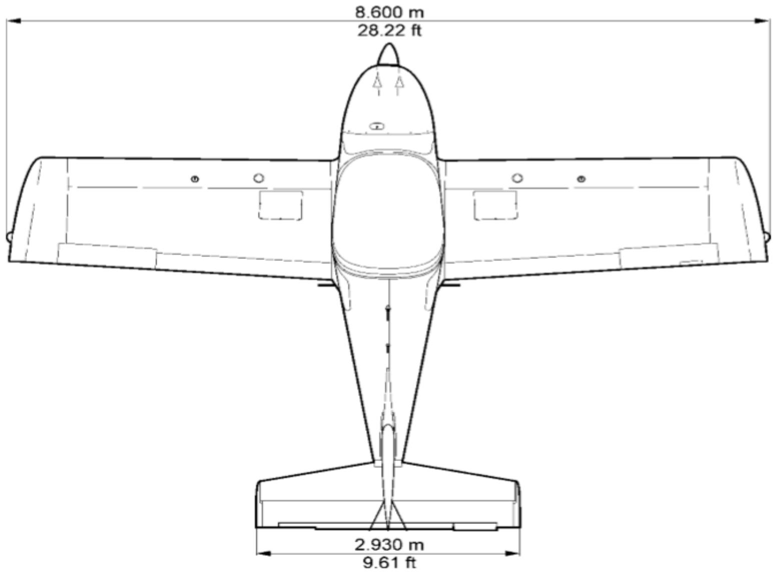


Figure 8.

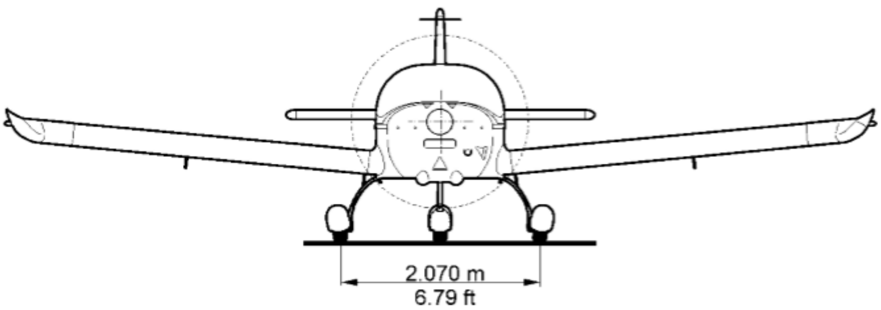


Figure 9.

3.2 Aircraft empty data:

Weight (without engine) ………………………….. 330.4 kg

Arm ……………………………………………….. 432.4 mm

Moment …………………………………………….. 142 864.96 kg mm

MAC ……………………………………………… 1 500 mm

Operating weights :

Pilot …………………………………………………. 85 kg

Passenger …………………………………………….. 65 kg

Baggage in cockpit …………………………………… 5 kg

Baggage in wing lockers …………………………….. 0

Fuel in tanks …………………………………………… (16.2 – 21 Kg)

For Cg calculation we need to find weights, arm and moment.

Arm can be determine with measurement. There are two kind of possibilities, 1) to measure from 0 point (in our case propeller) 2) to measure from leading edge.

I used second variant and got arms. Weights are given, so for moment and CG determination we can use

Formulas :

Moment (kg mm) = Weight (kg) x ARM (mm) ,

$$CG = \frac{M(total)}{W(total} \text{(mm).}$$

	CG Calculation with new engine for maximum loads :			
Item	Weight (kg)	ARM (mm)	MOMENT (kg mm)	
Empty Aircraft	311.3	432.4	134606.1	
Pilot	85	700	59500	
Passenger	65	700	45500	
Baggage	5	1310	6550	
Wing lockers	0	600	0	
Fuel in tanks	16.2	180	2916	
Engine	117.5	930.35	109316.1	
Total	600	415.1202	249072.1	
		27.67468		

Picture 4. 1 Cg calculation with new engine for max. loads.

You can see CG percentage (in green) for maximum loads on the Picture 4.

For Light Sport Aircraft (LSA) MTOW is 600 KG. In our case engine is 117.5 kg, which means 40-42kg more than Rotax. Because of this weight I desided to canceled wing lockers on maximum loads and decreased also baggage amount, which was 18 kg.

With 16.2 kg of fuel we can fly 1 hour with passanger. Which I think is quite enough.

		Weight (KG)	Xt (mm)	Zt (mm)	Center (
A	1 Pilot and 1 Passanger (85+65kg) + fuel + Baggage	600	2089.1	980.1	27.
B	1 Pilot and 1 Passanger (85+65kg) - fuel - Baggage	578.8	2101.6	985.4	27.
C	1 Pilot and 1 Passanger (65+65kg) + Fuel + Baggage	580	2063.1	972.1	2
D	1 Pilot and 1 Passanger (65+65kg) - Fuel - Baggage	558.8	2091.5	984.2	27.
E	1 Pilot (85 kg) + Fuel + Baggage	535	2024.2	961.9	25.
F	1 Pilot (85kg) - Fuel - Baggage	513.8	2067.5	981.5	25.
G	1 Pilot (65 kg) + Fuel + Baggage	515	2017.1	960.7	24.
H	1 Pilot (65kg) - Fuel - Baggage	493.8	2060.5	980.8	24.
I	1 Pilot (55 kg) + Fuel + Baggage	505	2007.5	959	24.
J	1 Pilot (55 kg) - Fuel - Baggage	483.8	2050.5	979.7	23.

Picture 5.1 1 All possibilities

We can find all possibilities for flight below 600 Kg on Picture 5.

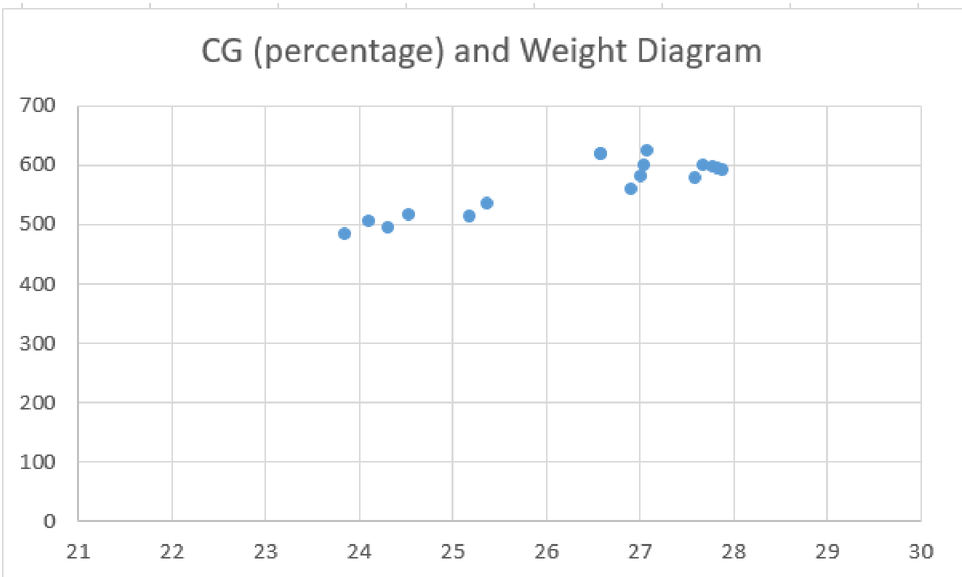


Figure 3. 1Cg and weight diagram

On the Figure 7. X axe is percentage and Y is Weights.

Which means that Cg varies between 23.8 - 27.6 %

We can fly 1 hour with passanger and baggage as I mentioned before, but aircraft weight is 535 kg if we don't have passanger, which means that we can use more fuel.

	CG Calculation for Aircraft with Fuel Pilot and Passanger			
Item	Weight (kg)	ARM (mm)	MOMENT (kg mm)	
Empty Aircraft	311.3	432.4	134606.1	
Pilot	85	700	59500	
Passenger	65	700	45500	
Baggage	0	1310	0	
Wing lockers	0	600	0	
Fuel in tanks	40	180	7200	(55.6 litre)
Engine	117.5	930.35	109316.1	
Total	618.8	398.8463	246806.1	
		26.58976		

Picture 6. 1 Cg calculation for aircraft with fuel, pilot and passanger

On the picture 6. You can see, that if we use 40 kg fuel MTOW is 618.8 Kg, which is 18.8 Kg more than 600 Kg.

	CG Calculation with Pilot, Passanger and 75% of Fuel		
Item	Weight (kg)	ARM (mm)	MOMENT (kg mm)
Empty Aircraft	311.3	432.4	134606.1
Pilot	85	700	59500
Passenger	65	700	45500
Baggage	5	1310	6550
Wing lockers	0	600	0
Fuel in tanks	12.15	180	2187
Engine	117.5	930.35	109316.1
Total	595.95	416.718	248343.1
		27.7812	

Picture 7. 1 Cg calculation with pilot, passanger and 75 % of fuel

There is shown 75% amount of Fuel and other max. loads on the Picture 4.

Calculation of flight envelopes according to the selected regulation.

(Chapter 4)

4.1 Input data

aircraft data		converted
Wing span m	8.6	
Wing area m^2	12.3	
MTOW kg	600	0
empty weight kg	428.8	
gravitaional acceleration m/s^2	9.80665	
power kW	88	
cruise speed [km/h]	197	54.72
stall speed [km/h] with flaps	57.8	16.06
max speed [km/h]	240	66.67
rate of climb [m/s]	4.4	
ni. Prop	0.85	
pi	3.141592654	
Oswald	0.8	
Cd0	0.039	
stall speed [km/h] without flaps	65.8	18.28
Load factor	4	
Fuel weight	21	
Specific fuel consumption c	7.08333E-08	
With out fuel W1	579	

Picture 8. 1Aicraft input data.

4.2 Power and Thrust estimation

To calculate power and thrust for given aircraft in different altitudes firstly find air densities through altitude in ISA table.

altitude [m]	0	2000	4000	6000	8000		8000	8000
density kg/m3	1.225	1.000	0.819	0.660	0.525			
Max power [Kw]	88.00	69.74	55.04	42.11	31.19			
stall speed at altitude Km/h	65.80	72.83	80.47	89.66	100.49			
max speed throught alltitude km/h	224	217	210	195	154		154	100.49

Picture 9. 1 Aircraft speed properties on different altitutes

Max power is calculated by:

$$P = P_{max} * \left(1.13 * \frac{\rho(h)}{1.225} - 0.13\right)$$

Next step is to calculate available power and thrust in different velocities in different altitude (results can be found in picture 11-12-13.) :

Speed				L	E	Propelef eff.
65.8	[KM/H]	18.27777778	[m/s]	0.33401	0.7201	0.612083264
84.2	[KM/H]	23.39444444	[m/s]	0.427513	0.8156	0.693258235
103	[KM/H]	28.51111111	[m/s]	0.521015	0.8831	0.75064515
121	[KM/H]	33.62777778	[m/s]	0.614518	0.9299	0.790437962
139	[KM/H]	38.74444444	[m/s]	0.70802	0.9617	0.817470622
158	[KM/H]	43.86111111	[m/s]	0.801523	0.9826	0.835217077
176	[KM/H]	48.97777778	[m/s]	0.895025	0.9950	0.845791273
195	[KM/H]	54.09444444	[m/s]	0.988528	0.9999	0.849947152
213	[KM/H]	59.21111111	[m/s]	1.08203	0.9966	0.847078653
232	[KM/H]	64.32777778	[m/s]	1.175533	0.9826	0.835219711
250	[KM/H]	69.44444444	[m/s]	1.269036	0.9542	0.811044261

Picture 10. 1

pa [kW] available						
53.8633	42.6839	33.690742	25.7757	19.0929	0	
61.0067	48.3447	38.158835	29.1941	21.6251	0	
66.0568	52.3466	41.317568	31.6108	23.4152	0	
69.5585	55.1216	43.507873	33.2865	24.6564	0	
71.9374	57.0067	44.995825	34.4249	25.4997	0	
73.4991	58.2443	45.972639	35.1722	26.0532	0	
74.4296	58.9817	46.554672	35.6175	26.3831	0	
74.7953	59.2715	46.783423	35.7925	26.5127	0	
74.5429	59.0715	46.625532	35.6717	26.4232	0	
73.4993	58.2445	45.972784	35.1723	26.0533	0	
71.3719	56.5586	44.642101	34.1543	25.2992	0	

Picture 11. 1

Thrust [N]					
2946.929755	2335.291477	1843.262463	1410.22	1045	0
2607.74411	2066.504159	1631.106687	1247.91	924	0
2316.87825	1836.007805	1449.174247	1108.72	821	0
2068.484606	1639.168515	1293.807571	989.852	733	0
1856.715608	1471.352389	1161.349088	888.512	658	0
1675.723686	1327.925525	1048.141227	801.9	594	0
1519.661271	1204.254024	950.5264157	727.218	539	0
1382.680794	1095.703984	864.8470838	661.668	490	0
1258.934683	997.6415053	787.4456597	602.45	446	0
1142.575371	905.432687	714.6645722	546.768	405	0
1027.755287	814.4436285	642.8462498	491.822	364	0

Picture 12. 1

Available power is calculated by formula:

$$P_{av} = P * Prop.eff$$

Thrust is calculated by formula:

$$F = \frac{P_{av}}{V}$$

4.3 Drag polar estimation

Next step calculation of Lift and drag coefficients through height and velocities by formulas:

$$C_L = \frac{2m_{tow}g}{\rho v^2 S}$$

$$C_D = C_{d_0} + \frac{C_L^2}{\pi * e * AR}$$

Lift coeficient						
2.33784	2.86385	3.49676	4.34114	5.45287	#DIV/0!	
1.42704	1.74812	2.13446	2.64987	3.32849	#DIV/0!	
0.9608	1.17698	1.43709	1.78411	2.24101	#DIV/0!	
0.69066	0.84606	1.03304	1.28249	1.61093	#DIV/0!	
0.52029	0.63735	0.77821	0.96612	1.21354	#DIV/0!	
0.40598	0.49732	0.60723	0.75386	0.94692	#DIV/0!	
0.32558	0.39884	0.48698	0.60458	0.75941	#DIV/0!	
0.2669	0.32696	0.39922	0.49562	0.62254	#DIV/0!	
0.22277	0.27289	0.3332	0.41366	0.5196	#DIV/0!	
0.18874	0.23121	0.2823	0.35047	0.44023	#DIV/0!	
0.16195	0.19839	0.24224	0.30073	0.37774	#DIV/0!	

Drag coeficeient						
0.40065645	0.58171	0.8481	1.28603	2.00652	#DIV/0!	
0.17375313	0.24121	0.34047	0.50364	0.7721	#DIV/0!	
0.10008481	0.13067	0.17566	0.24963	0.37132	#DIV/0!	
0.07056437	0.08637	0.10962	0.14784	0.21072	#DIV/0!	
0.05691233	0.06588	0.07907	0.10076	0.13645	#DIV/0!	
0.04990615	0.05537	0.0634	0.07661	0.09833	#DIV/0!	
0.04601445	0.04953	0.05469	0.06319	0.07716	#DIV/0!	
0.04371389	0.04607	0.04955	0.05525	0.06464	#DIV/0!	
0.0422838	0.04393	0.04635	0.05032	0.05686	#DIV/0!	
0.0413572	0.04254	0.04427	0.04713	0.05182	#DIV/0!	
0.04073556	0.0416	0.04288	0.04498	0.04844	#DIV/0!	

Picture 13. 1 lift and drag coefficient in different altitude

From drag coefficient, Drag can be calculated by formula:

$$D = \frac{\rho v^2 S C_D}{2}$$

Drag [N]						
1008.39	1195.17	1427.09	1743.08	2165.16	#DIV/0!	
716.423	811.901	938.561	1118.33	1364.89	#DIV/0!	
612.925	653.227	719.212	823.266	974.936	#DIV/0!	
601.164	600.642	624.35	678.267	769.664	#DIV/0!	
643.63	608.199	597.872	613.682	661.587	#DIV/0!	
723.31	655.055	614.331	597.916	611.022	#DIV/0!	
831.579	730.646	660.825	614.956	597.853	#DIV/0!	
963.687	829.152	730.251	655.979	610.998	#DIV/0!	
1116.84	947.154	818.432	715.803	643.947	#DIV/0!	
1289.32	1082.53	922.784	791.218	692.67	#DIV/0!	
1479.99	1233.93	1041.64	880.153	754.565	#DIV/0!	

Picture 14. 1 Drag in different altitude

Next step is to calculate required power:

$$P_{req} = D * V$$

required power [Kw]				
18.43	21.845	26.08	31.86	39.57
16.76	18.994	21.96	26.16	31.93
17.48	18.624	20.51	23.47	27.8
20.22	20.198	21	22.81	25.88
24.94	23.564	23.16	23.78	25.63
31.73	28.731	26.95	26.23	26.8
40.73	35.785	32.37	30.12	29.28
52.13	44.853	39.5	35.48	33.05
66.13	56.082	48.46	42.38	38.13
82.94	69.637	59.36	50.9	44.56
102.8	85.689	72.34	61.12	52.4

Picture 15. 1Required power in different altitude

4.4 Analyzed flight regimes:

- **Horizontal flight**

Now we can graph available power-velocity and required power-velocity graph. From where we can find maximum service ceiling altitude speed by finding required and available power intersection. Minimum speed can be calculated by formula:

$$V_s = \sqrt{\frac{2m_{TOW}g}{\rho(H)C_L S}}$$

Climb

Climb speed is calculated by formula:

$$\omega = \frac{P_{av} - P_{req}}{W}$$

Climb velocity m/s				
6.02	3.54	1.29	-1.03	-3.48
7.52	4.99	2.75	0.52	-1.75
8.26	5.73	3.54	1.38	-0.74
8.39	5.94	3.83	1.78	-0.21
7.99	5.68	3.71	1.81	-0.02
7.10	5.02	3.23	1.52	-0.13
5.73	3.94	2.41	0.93	-0.49
3.85	2.45	1.24	0.05	-1.11
1.43	0.51	-0.31	-1.14	-1.99
-1.60	-1.94	-2.28	-2.67	-3.14
-5.34	-4.95	-4.71	-4.58	-4.61
Maximum climb speed in altitude [m/s]				
8.39	5.94	3.83	1.81	-0.02

Picture 16. 1 Climb speed in different altitude

Because in altitude density is decreasing climb speed is also decreasing.

Formula for climb gradient:

$$\gamma = \left(\frac{T}{W} - \frac{C_D}{C_L}\right) * 100\%$$

Climb gradient				
52.94	35.22	19.58	3.91	-11.96
49.84	35.34	22.84	10.67	-1.21
44.68	32.56	22.24	12.37	2.96
38.97	28.77	20.16	12.01	4.36
33.22	24.65	17.46	10.70	4.41
27.56	20.45	14.48	8.91	3.74
22.01	16.22	11.37	6.84	2.65
16.50	11.96	8.16	4.59	1.27
10.96	7.63	4.82	2.16	-0.33
5.26	3.13	1.31	-0.44	-2.14
-0.71	-1.60	-2.42	-3.26	-4.16

Picture 17. 1Climb gradient in different altitude

4.5 Gliding (descend)

To calculate Aircraft gliding regime we need to start lift coefficient with small value like 0.1 and linearly increase until it reaches maximum lift coefficient on stall speed without flaps, calculate gliding ratio, velocities and gliding angle for every Lift coefficient.

Formula for gliding ratio:

$$k = \frac{C_L}{C_D}$$

Formula for gliding angle:

$$\tan\left(\frac{C_D}{C_L}\right)$$

If during flight there will be opposite direction wind coordinate system will move to right same length as wind speed. It will be opposite in directional flight. To find best gliding ratio we need to make tangent line from origin of coordinate system to Hor. Speed vs Vert. speed curve

cl	cd	k		degree	V	RD	Vh
0.1	0.0397	2.521	0.64	21.63	291	29.7652	270.171
0.218	0.0421	5.168	5.82	10.95	202	10.6807	198.721
0.336	0.0465	7.224	17.51	7.881	164	6.23845	162.239
0.453	0.0526	8.619	33.68	6.618	141	4.51761	140.17
0.571	0.0606	9.427	50.75	6.055	126	3.68587	125.088
0.689	0.0704	9.785	65.96	5.835	115	3.23518	113.962
0.807	0.0821	9.83	77.96	5.808	106	2.97609	105.322
0.924	0.0956	9.675	86.53	5.901	98.9	2.82401	98.36
1.042	0.1109	9.4	92.09	6.073	93.1	2.73625	92.5921
1.16	0.128	9.06	95.21	6.299	88.2	2.68927	87.7095
1.278	0.147	8.69	96.49	6.564	84.1	2.66923	83.504
1.396	0.1679	8.313	96.44	6.859	80.4	2.6675	79.8301
1.513	0.1906	7.942	95.46	7.176	77.2	2.67851	76.5824
1.631	0.2151	7.585	93.84	7.511	74.3	2.69851	73.6826
1.749	0.2414	7.245	91.80	7.859	71.7	2.72494	71.0709
1.867	0.2696	6.925	89.51	8.218	69.4	2.75596	68.701
1.984	0.2996	6.624	87.07	8.585	67.3	2.79025	66.5365
2.102	0.3314	6.343	84.57	8.96	65.3	2.82687	64.548
2.22	0.3651	6.08	82.07	9.34	63.6	2.86507	62.7118
2.338	0.4007	5.835	79.60	9.725	61.9	2.90432	61.0083
		9.8304				2.6675	67.8578

Picture 19. 1

❖ Turning

Parameters limitating turns:

- ❖ Structural (load factor)-$n = 4$
- ❖ Aerodynamic ($C_{L_{max}}$)-$n = \left(\frac{V}{V_s}\right)^2$
- ❖ Propulsive (thrust)-$n = \frac{C_L}{C_D} * \frac{T}{W}$

Velocity [m/s]	Turning minimum radius [m] (1)	load factor (V/Vs) (2)	ust availab	Cd	Cl	Load factor Cl/Cd*Ta/W (3)	Turning minimum radius [m] (2
16.50	7.17	0.81	2865.64	1.40	4.53	1.58	#NUM!
18.00	8.53	0.97	2865.64	1.17	4.14	1.72	#NUM!
20.88	11.48	1.30	2471.84	0.75	3.28	1.83	53.0
25.96	17.75	2.02	2146.22	0.42	2.41	2.08	39.2
31.05	25.39	2.89	1878.14	0.26	1.82	2.25	36.3
36.14	34.39	3.91	1656.94	0.17	1.40	2.34	35.2
41.23	44.75	5.09	1471.97	0.11	1.07	2.33	34.7
46.32	56.48	6.42	1312.58	0.08	0.80	2.19	34.4
51.40	69.57	7.91	1168.12	0.06	0.55	1.85	34.3
56.49	84.02	9.55	1027.92	0.04	0.24	0.97	34.2
61.58	99.84	11.35					
66.67	117.02	13.30					

Picture 19. 2

❖ Range and Endurance

Next step is to calculate Range and Endurance. In this case height is constant (2000m).

Formula for range: $R = \frac{n*C_L}{g*C_p*C_d} * ln\left(\frac{W_{TOW}}{W_{fuel}}\right)$

Formula for endurance: $E = \frac{C_L^{3/2}*n}{C_D*C_p}\sqrt{2*\rho*S} * \left(\frac{1}{\sqrt{W_{TOW}}} - \frac{1}{\sqrt{W_{fuel}}}\right)$

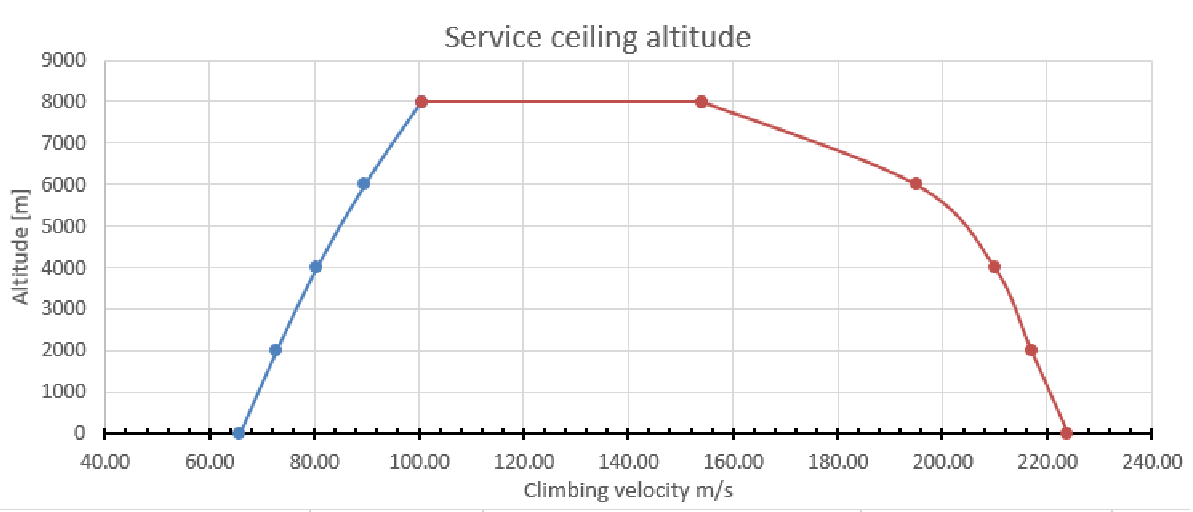
Speed for max endurance can be seen in req. power vs Speed graph where req. power is minimum

Speed for max range can be seen in Thrust vs speed graph, where thrust is minimum, because when there is minimum thrust there will be minimum fuel consumption.

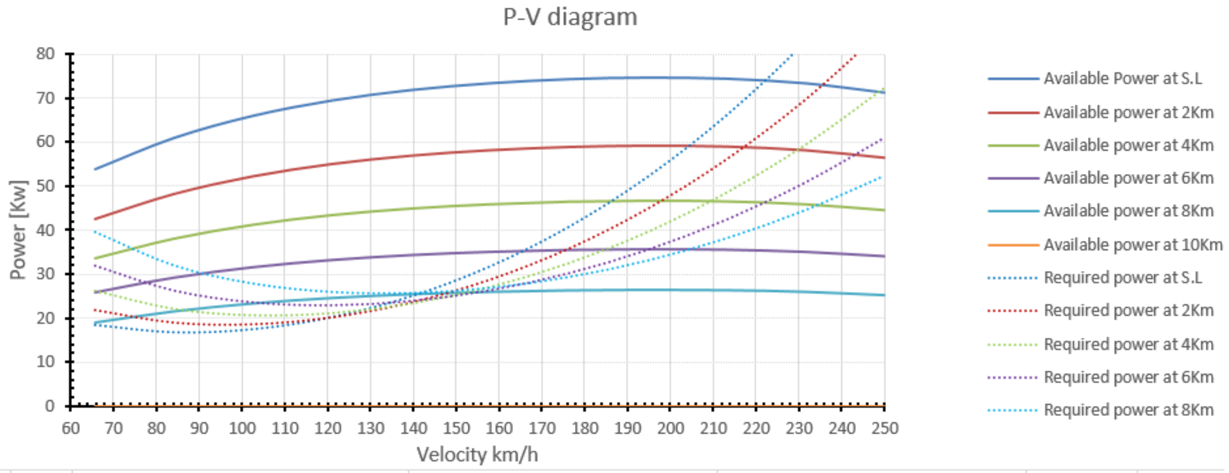
From this graph we can determine maximum range velocity which is minimum drag in drag vs velocity. Maximum endurance will be minimum power in power required vs speed in altitude.

Endurance at 2000m [h]	Range at 2000m [km]
2.348826435	155
3.059652804	258
3.378697773	347
3.280550488	397
2.908104271	406
2.436883274	385
1.981298425	349
1.588538651	309
1.266172158	270
1.005433095	233
0.793432833	198

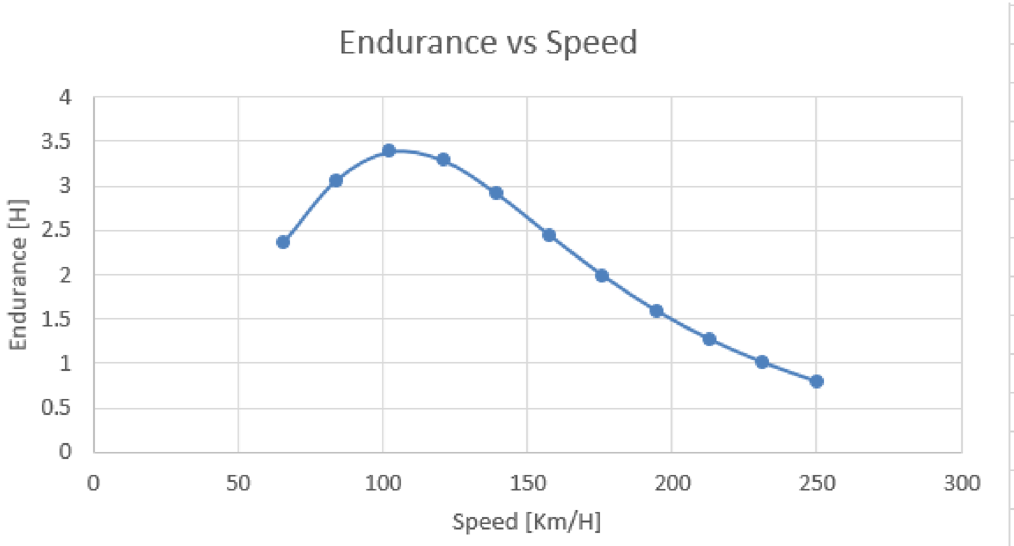
Picture 20. 1



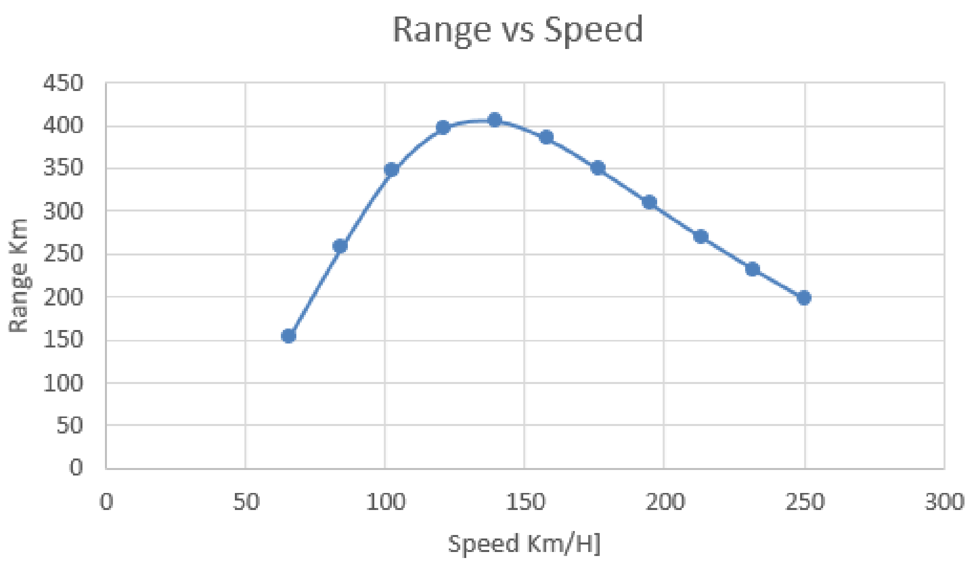
Picture 21. 1Service ceiling altitute



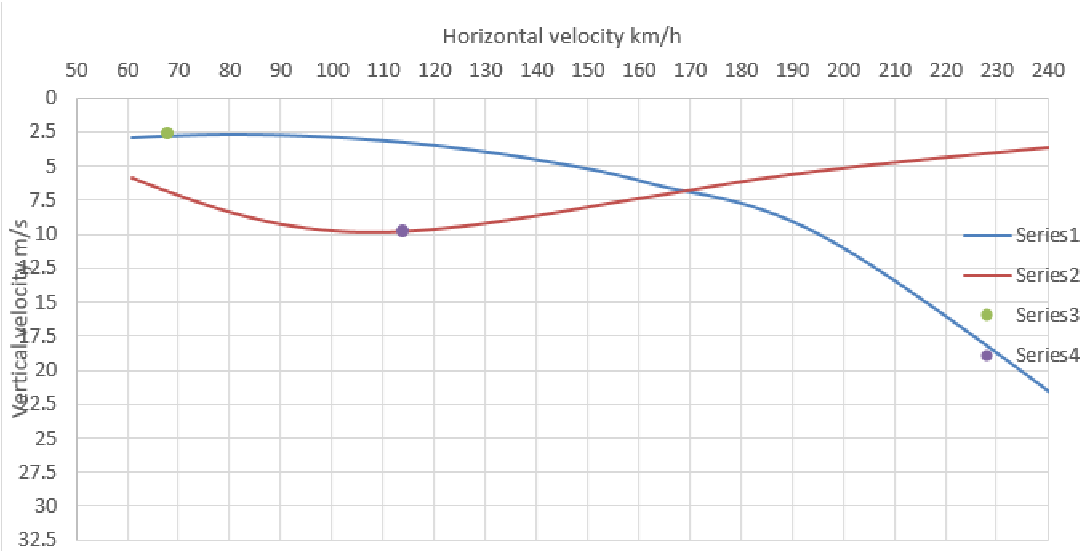
Picture 22. 1P-V Diagram



Picture 24.



Picture 25.



Picture 26.

4.6 Flight Envelope Diagram

maneuver	calculated	choosen in knots	m/s	ft/s
Vc not less than	104.3083447	110.47	56.83039	186.451404
Vc not more than	116.630712			
Vc min	110.3801105			
Vd not less then	154.5321547	200	102.8888	337.561691
Va not less then	73.67485625	92.07	47.36599	155.400224
Va not more Than	110.47			
vb	50.53240683			
Vf	49.74083884	80		

Picture 27.

Limit maneuvering load factor for normal category airplane:

$2.1 + \frac{24000}{W+1000} = 4.06$ Where W = design maximum take-off weight lb.

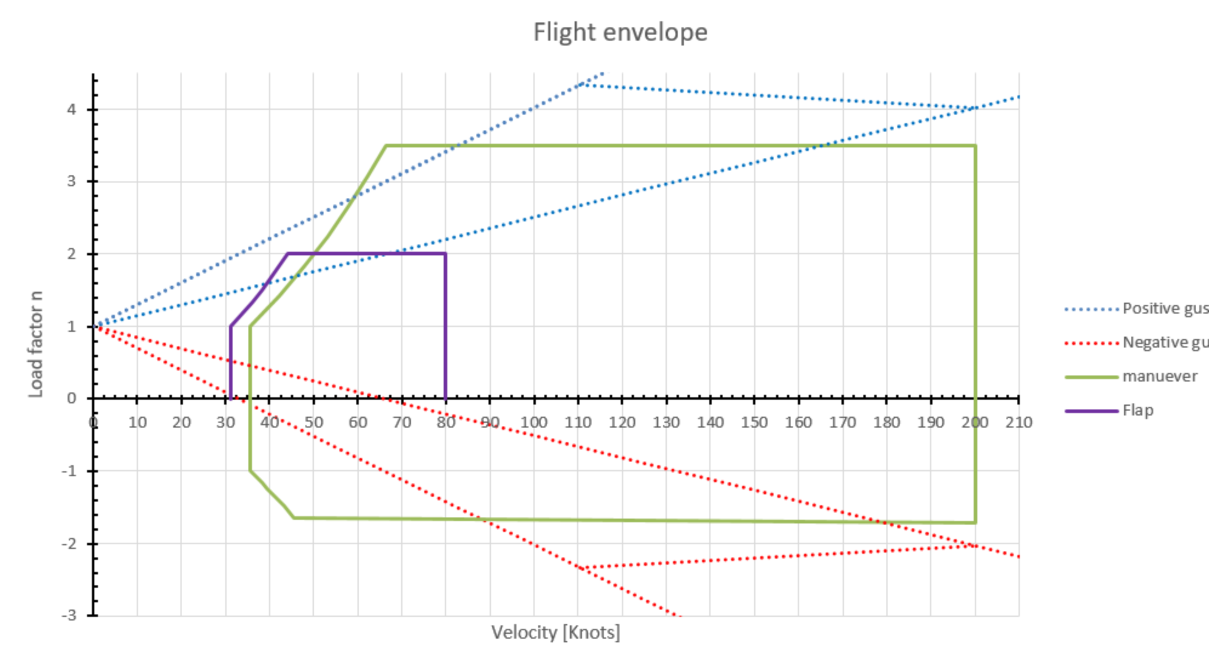
Gust load factor: $n = 1 \pm \frac{k_g \rho_0 UdeVa}{2^W/_S}$ where: $k_g = \frac{0.88\mu g}{5.3+\mu g} = gust\ alleviation\ factor;$

$\mu g = \frac{2(^W/_S)}{\rho \bar{C} ag} = aeroplane\ mass\ ratio;$

Ude = Derived gust velocities referred to in CS 23.333 (c) (m/s);
ρo = Density of air at sea-level (kg/m3)
ρ = Density of air (kg/m3) at the altitude considered;
W/S = Wing loading due to the applicable weight of the aeroplane in the particular load case (N/m2);
C = Mean geometric chord (m);
g = Acceleration due to gravity (m/sec2);
V = Aeroplane equivalent speed (m/s);
a = Slope of the aeroplane normal force coefficient curve CNA per radian if the gust loads are applied to the wings and horizontal tail surfaces simultaneously by a rational method. The wing lift curve slope CL per radian may be used when the gust load is applied to the wings only and the horizontal tail gust loads are treated as a separate condition.

ude	m/s	
50fps for vc	15.24	
25fps for vd	7.62	
U	4.352461588	
nig	10.21046317	
kg	0.57929976	
n gust	4.33935978	4.022878643
	-2.33935978	-2.022878643

Picture 28.



Picture 29

Engine mount design

Chapter 5

Last chapter for my thesis is Engine mount design. For 3D modeling I used Catia V5.

I searched lot's of modifications of LSA engine mounts and the most popular and optimal chose for me was "rectangular" modification with 4 main hinges, where the engine should be fixed and than with 4 main tubes need to be fixed on first cross section

Figure 4. 1 Engine mount design in Catia V5

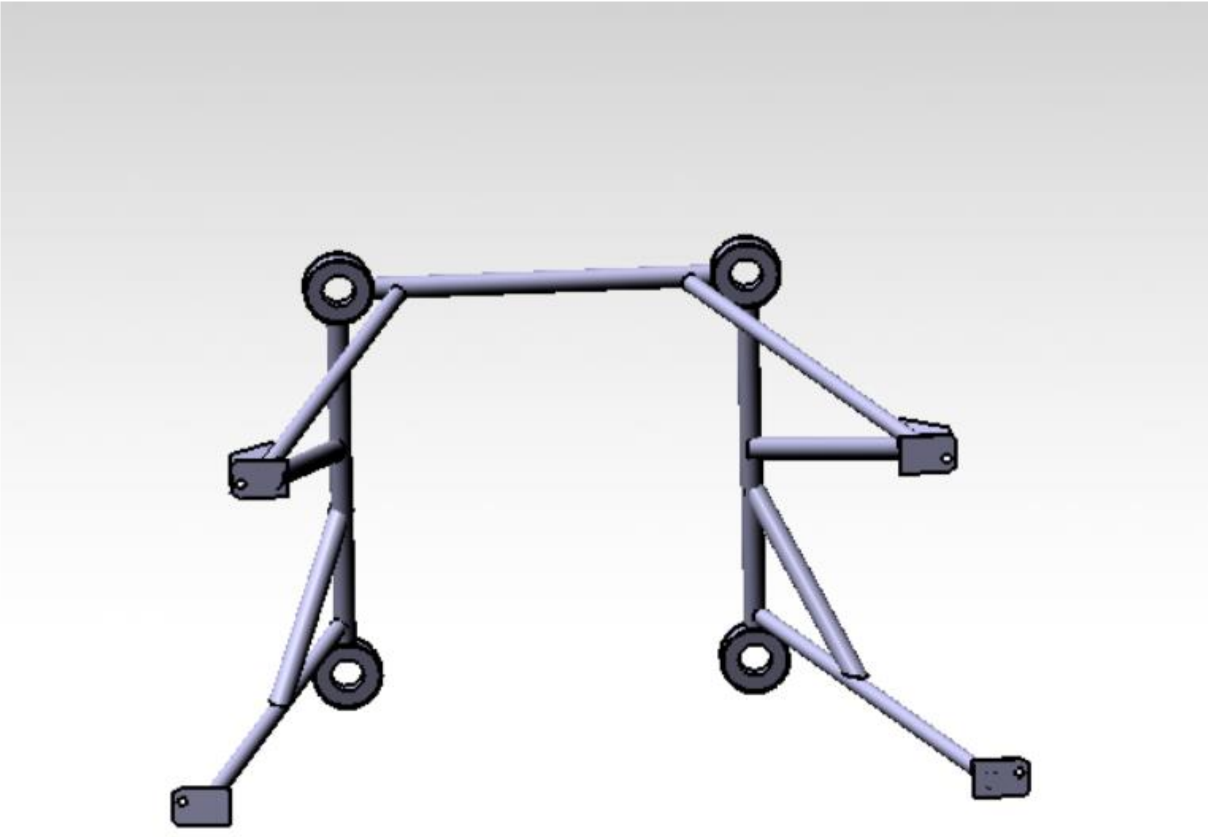


Figure 5. 1

On the figure 5.1 you can see back view. From where need to be fixed on the first cross section.

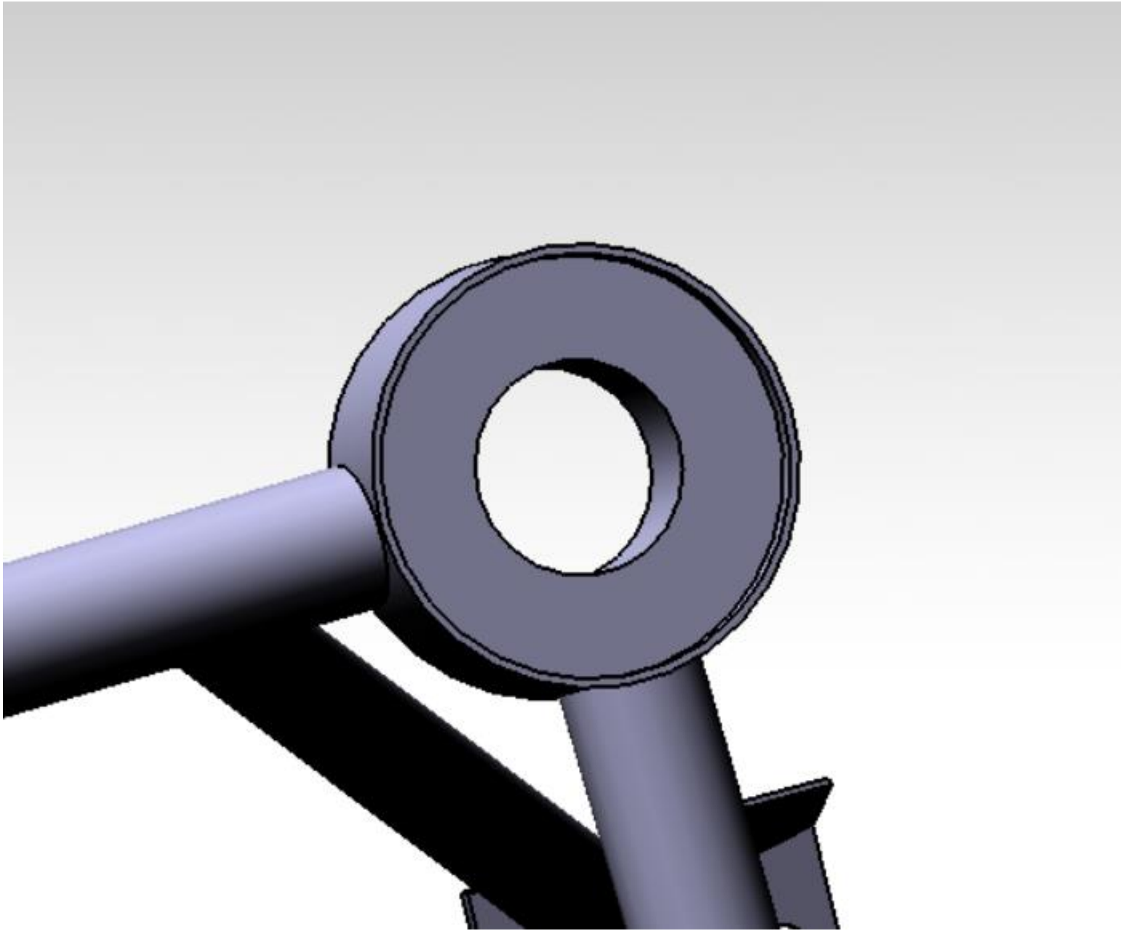


Figure 6. 1

On the figure 6.1 you can see main hinge, it is on 90 degree position but it depends on situation, if it’s needed we can fix on the tubes with some other possible angle. (To be rotated according to engine hinge)

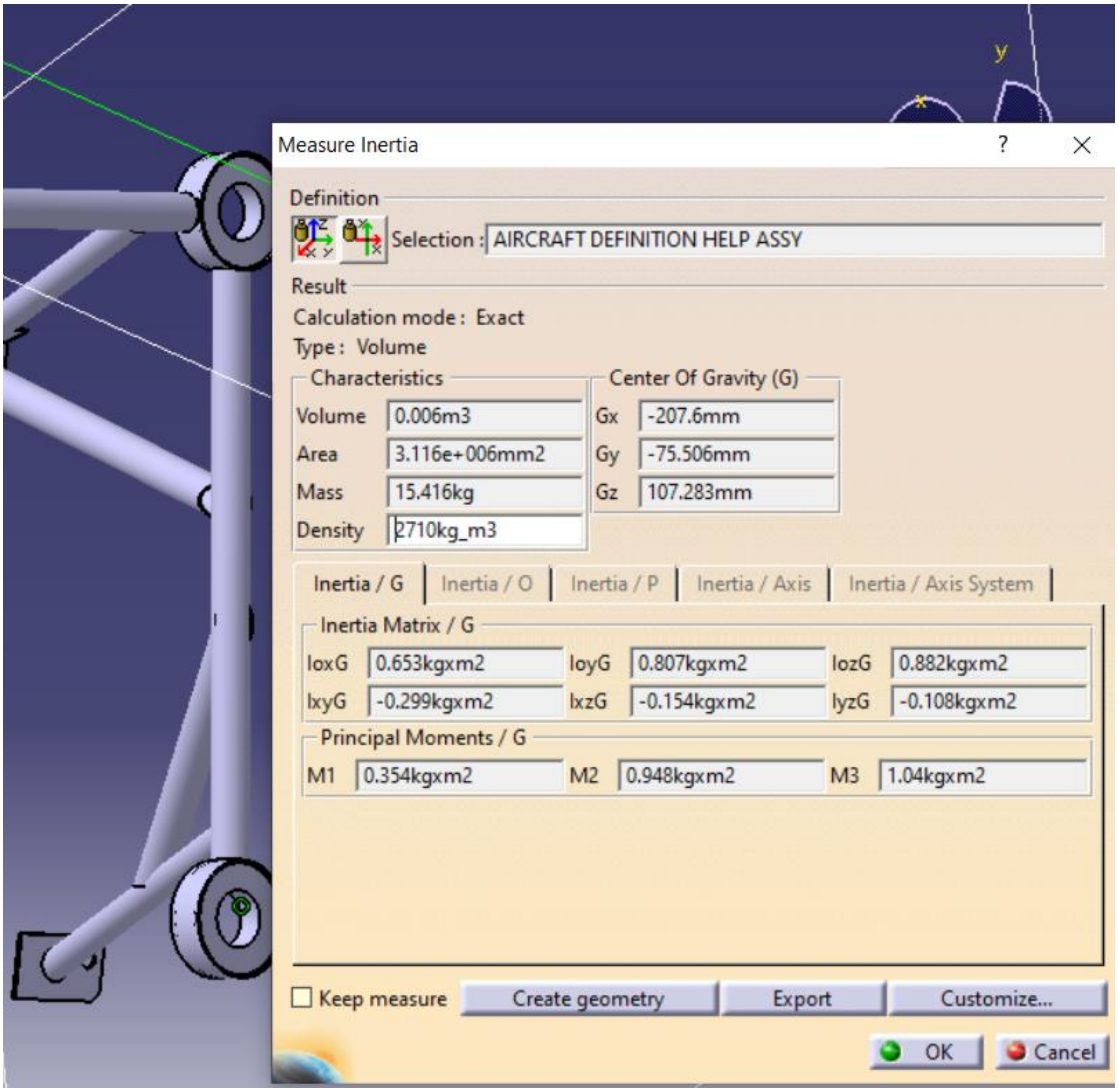


Figure 7. 1Engine mount mass

According to the Catia, Engine mount weight is 15.4 kg which is quite good mass, but Lycoming engine mass is 117.5 kg, its almost twice heavy than rotax, which means, that we need praqtical and calculations in lab to be sure, that this engine mount will be okay.

This is first operations and first calculations.

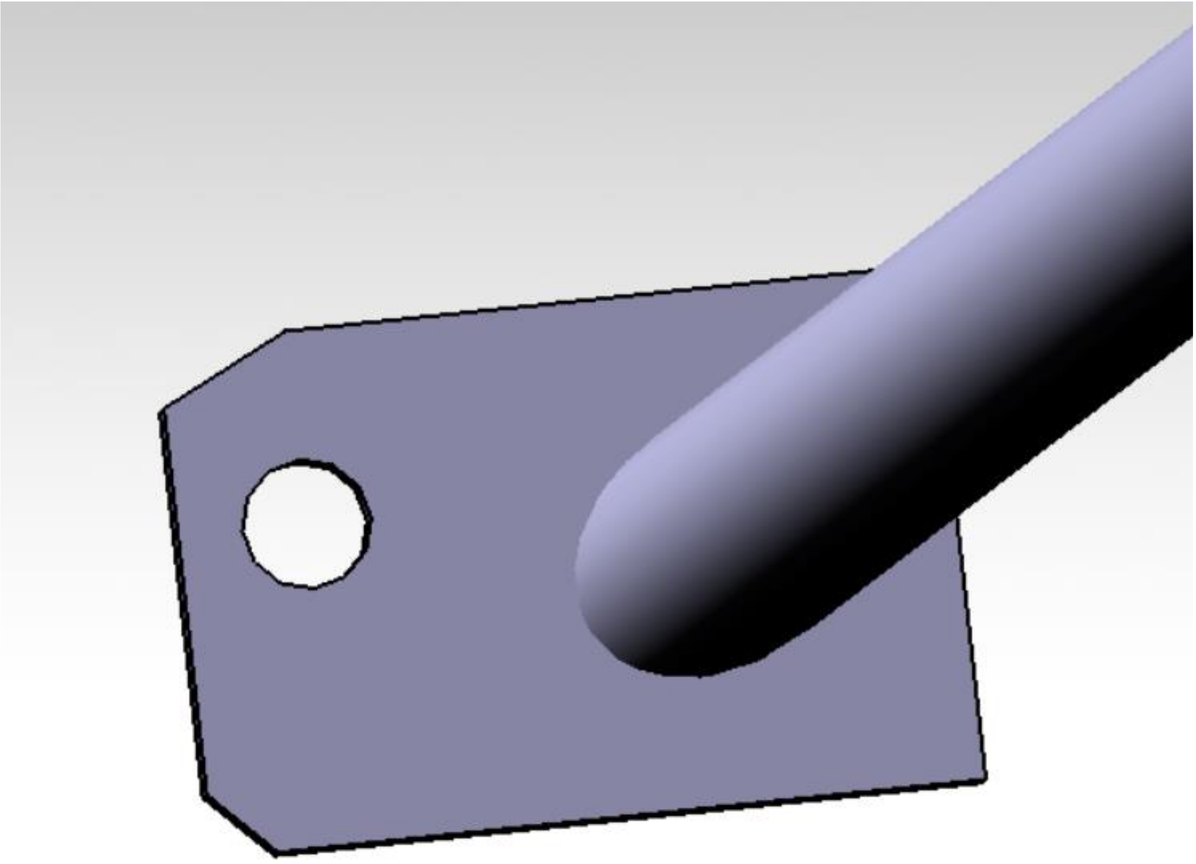


Figure 8.1

Hinge, from where need to fix engine mount on the first cross section with bolts.

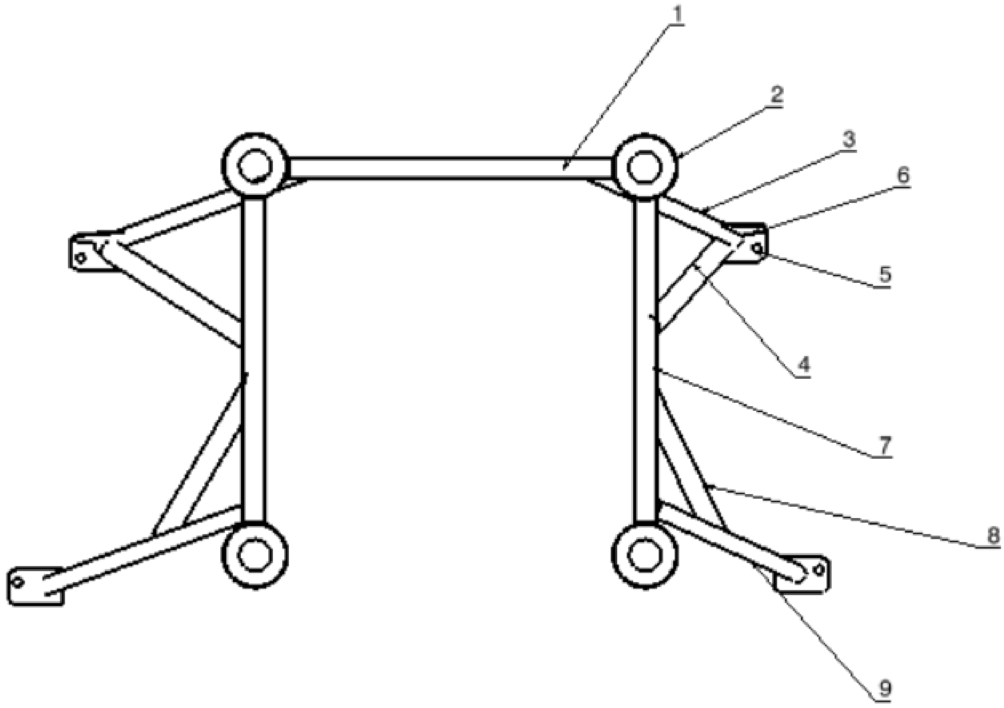


Figure 9. 1Engine mount assembly drawing (Front view)

Engine mount Test Plan

Chapter 6

This chapter will explain the engine bed test procedure, for all cases load according to regulation LSA-I.part.

6.1 Test scheme

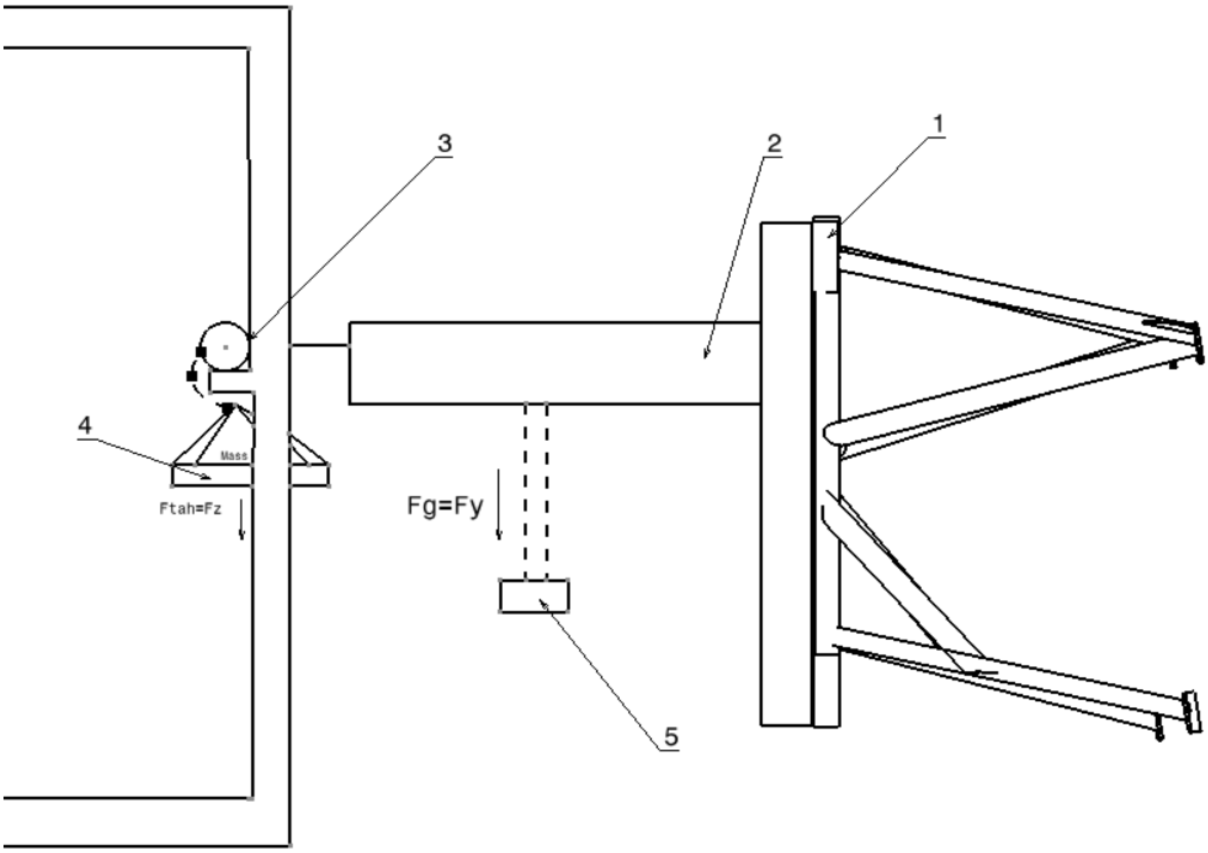


Figure 10. 1Test plan

1) Engine mount
3) pulley
5) weight with an accuracy 1kg
2) Engine imitation (117.5 kg)
4) Trolley with weight

The tesnsile force FTAH is derived drom the weight on the trolley (4), which is fixed via a pulley (3) to the engine model (2) The weight is pre-weighed and then loaded onto a cart

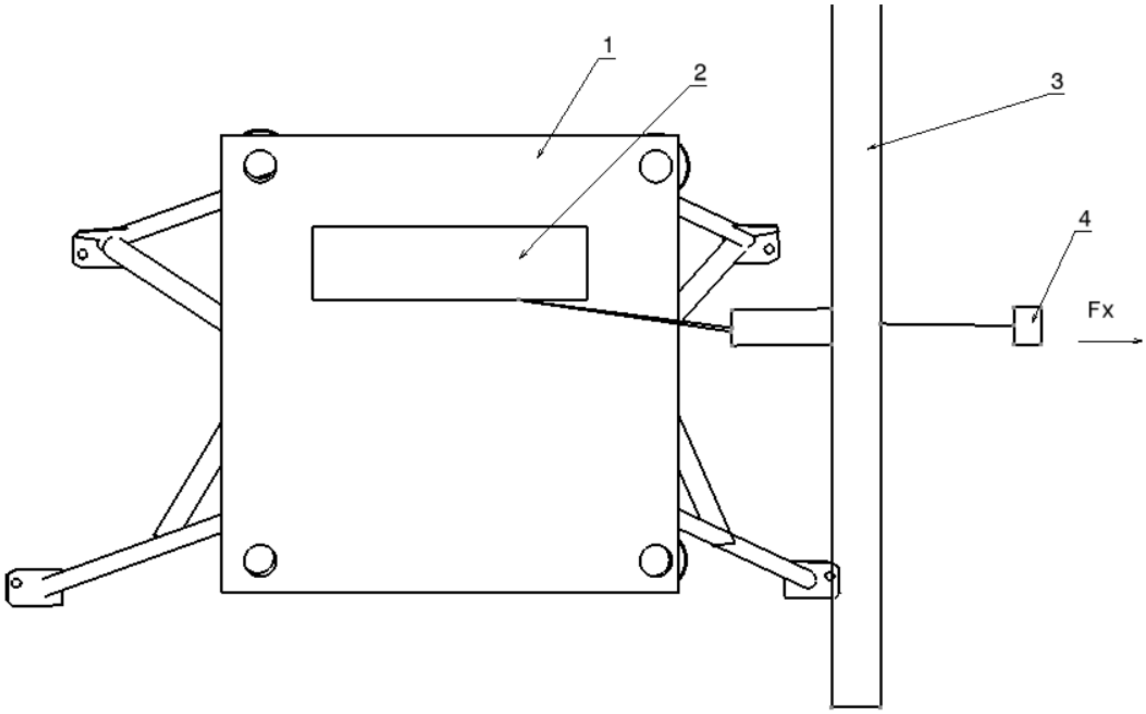


Figure 17.

1) Engine mount

2) Engine imitation (117.5 kg)

3) Stand

4) Weight with an accuracy 1kg

The lateral load Fx is derived to the side, again the weight is used to correctly determine the force, the force Gx acts from the same place on the engine imitation as the force Fy

Conclusion

"Czech sport aircraft" needed to change engine on aircraft PS-28 Sport cruiser, which would be more powerfull.

Curent engine was Rotax 912 ULS, which is very common aircraft 4 cylinder engine with 100 hp.

Because of this I choosed Lycoming O-235 also 4 cylinder engine with 118-120 hp.

The main problem was weight, which is in total 117.5 kg (almost twice more than Rotax).

According to EASA, LSA max. take of weight should be 600kg, in my case only powerplant was 117.5 kg, only construction was 330 kg. So I decided to made some changes, which means, that I canceled wing lockers and decreased baggage comparision in the aircraft, also decreased fuel amount and all these gave me possibility to fixed Lycoming in the aircraft.

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