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FAKULTA STROJNÍHO INŽENÝRSTVÍ
LETECKÝ USTAV

ALTERNATIVE PROPULSION FOR AIRCRAFT OF GENERAL AVIATION CATEGORY
ALTERNATIVNÍ POHONY LETOUNŮ KATEGORIE VŠEOBECNÉHO LETECTVÍ

DOCTORAL THESIS
DOKTORSKÁ PRÁCE

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Abstract

Air transport as all other transport contributes in producing emissions greenhouse gases, which is the main reason of climate changes. The doctoral thesis is focusing on possibility of using alternative energy source (fuel, motor) in aviation in order to reduce emission produced by aircraft. The area that has been working on is general aviation in particular aircraft of categories LSA and VLA. Three options, alternative source of energy, will be discussed. First is using LPG fuel, another is electric motors, and last adding catalytic converter to the exhaust system. For each of them will be mentioned there advantages and disadvantage, the main change in aircraft propulsion or exhaust system, and the different in aircraft performance due to these changes.

Bibliographical citation

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Keywords

Airplane, alternative propulsion system, Delphi, Lpg, catalytic converter, electric motor, aircraft performance.

Statutory Declaration

I declare that I have developed and written the enclosed thesis completely by myself, and have not used sources or means without declaration.

Brno 30/11/2015

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Ing. Mirvat Kaddour

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أمي أبي وأخوتي، كنتم لي الدعم في كل مراحل حياتي، دعواتكم وتمنياتكم لي بالتفوق والنجاح رافقتني في كل سنوات دراستي وغربتي.

إليكم أقدم إهدائي ....

Mirvat kaddour

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1. LIST OF OBSERVATIONS

AFTF	Alternative fuels task force
AL_2O_3	Aluminum oxide
APU	Auxiliary power unit
ASTM F2245-12D	Standard Specification for Design and Performance of a Light Sport Airplane
Avgas UL	Aviation gasoline unleaded
Avgas	Aviation gasoline
BA 95	Natural Automotive Petrol
BTU	British thermal unit
C_3H_8	Propane
C_4H_{10}	Butane
CAA	Civil Aviation Authority
CAEP	Committee on Aviation Environmental Protection
Cat’s	Catalytic converter
CCS	Carbon capture and storage
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbone dioxide
CS VLA	Certification Specifications for Very Light Airplanes
DC/AC	Inverter
DC/DC	Voltage converter
DNL	Day-night level
ECCP	European climate change program
EEA	European economic area
EEC	European Economic Community

EFTA	European Free Trade Association
ETS	Emission Trading System
EU	European Union
FEGP	Fixed electrical ground power
GFAAF	Global Framework on Aviation Alternative Fuels
GHG	Greenhouse gas
HC	Hydrocarbons
HD5	Grade of propane
CH_4	Methane
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
ISA	Sea level conditions, for the given operating mode
KOH	Potassium hydroxide
LAQ	Local air quality
Li – Ion	Lithium- Ion batteries
Li – Pol	Lithium- Polymer battery
LL	Low leaded
LPG	Liquefied petroleum gas
LSA	Light sport aircraft
LTO	Landing take-off
MBM	Market-based mechanism
MOGAS	Motor gasoline
MON	Motor octane number
MSA	Clearwater metropolitan statistical area
N_2O	Nitrous oxide
Ni – CD	Nickel cadmium battery

Ni – MH	Nickel-metal hydride battery
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
NVPM	Non-volatile particulate matter
O_3	Ozone
OH	Hydroxyl radical
PCA	Pre-conditioned air
Pd	Palladium
PEM	Proton exchange membrane fuel cell
PT	Platinum
PM	Particulate maters
ppm	Parts per million
RF	Radiative forcing
RH	Rhodium
RON	Research octane number
RPKS	Revenue passenger kilometers
RTKS	Revenue ton kilometers
SARPs	Standards and recommended practices
SN	Smoke number
SO_2	Sulfur dioxide
SUSTAF	Sustainable Aviation Fuels Expert Group
SVOCS	Semi- volatile organic compounds
tg	Unit teragram
US	United States
UL 91	Unleaded
ULA	Ultra-light aircraft

UO	University of Defence Brno
VLA	Very Light Aircraft
VSB-TU	Technical University of Ostrava (Vysoká škola báňská - Technická univerzita Ostrava)
VZLU	National Center for Research, development and testing of aerospace (Výzkumný a zkušební letecký ústav)

2. LIST OF SYMBOLS

C_D [-]	Drag coefficient
$C_{L, LOF}$ [-]	Lift coefficient at the moment of lift of the ground
C_L [-]	Lift coefficient
C_{Lmax} [-]	Maximum lift coefficient
D[m]	Propeller diameter
DP	The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle
f*oo [N]	Rated thrust with afterburning applied
F [-]	Friction coefficient
F [N]	Thrust
F_{mid}[N]	Thrust at the mean value of flight speed
F_n [N]	Thrust in international standard atmosphere
foo [N]	Rated thrust
F_P[N]	Required thrust
F_V [N]	Available thrust
g [m/s^2]	Acceleration of gravity
G [N]	Force of gravity
h_p [m]	Height of obstacle
H [ft]	Height of flight
J [-]	Propeller speed ratio =V/nd
K	Light absorption coefficient
m [kg]	Airplane weight
m_{cuo}[kg]	Copper weight
m_{Feo} [kg]	Iron weight
n [rpm]	Speed
P_{cuo} [W]	Losses in copper

P_{Feo} [W]	Losses in iron
P_M[KW]	Engine power
P_P [KW]	Required power
P_V [KW]	Available power
S [m^2]	Wings area
$S_{A, L}$[m]	Length of airborne segment of landing path
$S_{A,TOF}$ [m]	Length of airborne segment take-off path
$S_{G,L}$ [m]	Length of ground segment of landing path
$S_{G,TOF}$ [m]	Length of ground segment take-off path
S_L [m]	Length of landing path
S_{TOF} [m]	Length of the take-off path
T [K]	Temperature
T_0 [K]	Temperature at 0 ft. altitude
U [m/s]	Climbing dpeed
V [m/s]	Flight speed
V_2 [m/s]	Speed at the height of obstacle
V_{lof} [m/s]	Lift off speed
V_P [m/s]	Approach speed
V_{REF} [m/s]	Reference speed
V_S [m/s]	Stalling speed
V_{S0} [m/s]	Stalling speed for landing configuration
V_{S1} [m/s]	Stalling speed for take-off configuration
X_L [m^{-1}]	Kriging absorption coefficient
X_p [m^{-1}]	Absorption coefficient
γ [^{0}]	Angle of climb
ΔP_M	Changing in engine power with altitude

η [-]	Propeller efficiency
λ [-]	Air excess factor
π_{OO}	Reference pressure ratio
ρ [kg/m^3]	Air density
ρ_0 [kg/m^3]	Air density at 0 ft. altitude

3. INTRODUCTION

3.1 Overview

The doctoral thesis focused on using alternative energy source (fuel, motor) in aviation in order to reduce emission produced by aircraft.

Air transport as all other transport contributes in producing emissions greenhouse gases, which is the main reason of climate changes. In 2005, it was estimated that the airlines industry produces 5% of total emission that affect global warming (CO_2 emission is 2-3%) and it is expected that this ratio will continue to rise due to the increasing in demand for air transport (passenger and cargo).

In recent years, it have been fought intensively against pollution, a number of programs have launched by the EU that introduce measures to help the member of states in the context of economical emission reduction and greenhouse gases.

On the other hand, the majority of aircraft engine burns one of two main fuel type, Avgas (100, 100 LL or Jet-A fuel. Both type of fuel are naturally made of petroleum, and this is the main disadvantage. Petroleum reserves are limited, its price has been growing throughlong term and the dependence on one source of energy from a strategic point of view is a mistake.

Since 2000, air transport is confronted with the problem of the huge increase in aviation fuel prices, while during 1990 these prices were very stable, as shown in Fig 1. Therefore, today there is an effort to find an alternative source of fuel to break away the dependence on petroleum.

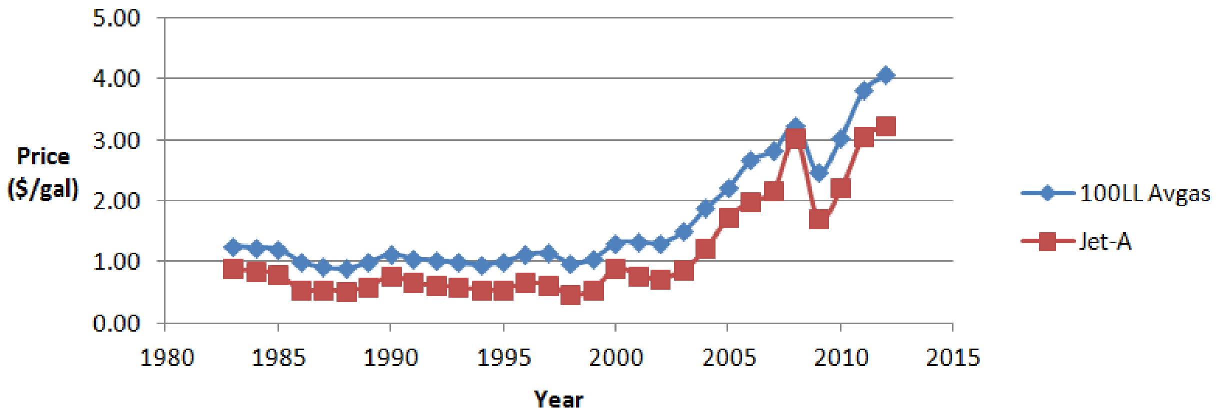


Fig 1 U.S. Jet fuel and Avgas prices 1983-2012 [12]

3.2 Motivation

This work is focusing on the area of general aviation in particular small aircraft their take-off weight is up to 1000 kg, which fall into the categories of LSA and VLA.

The reason for this choice is the fact that this category represents today a significant share of general aviation market, and this share is still rising. The advantages of these aircraft are relatively low operation cost, beneficial operation costs and relatively flexible rules for operation and construction, which can facilitate the uptake of alternative propulsion system in this category.

Another important aspect is that the aircraft of this group are very often used for flight training. Fuel costs today make up a significant portion of the total cost of flight training and that can be a reason for decreasing the interest in training. Operators of these aircraft must confront the rising in fuel prices, which is due to the high petroleum price and limited availability of some traditional aviation fuel such as Avgas.

These high prices along with relatively high fuel consumption and the effort to reduce emissions require to find an alternative source of energy (fuel/motors).

3.3 Goals of doctoral thesis

The main goals of this work are:

1. Mapping the global air traffic and exhaust emissions, and description the ICAO's initiative about emission standard
2. Statistical study using Delphi method on the views of experts group about the most effective alternative solution to reduce emission from aviation and minimize fuel consumption.
3. Measuring emission produced by aircraft.
4. Information about daily flight plan (flight time, number of take-offs, and number of individual flights) for several airplanes from the category of LSA, ULA.
5. Verifying the possibility of using alternative source of energy, and how that will effect on aircraft performance (three options were selected, LPG fuel, electric motors and adding catalytic converter to the exhaust system for aircraft with the current propulsion).

4. CURRENT STATE OF THE ART

Commercial air traffic, both passenger and freight, as well as business aviation are expected to continue to grow for the foreseeable future, bringing about benefits to people and economies in both developed and developing nations, and that will in turn increase the amount of contaminants emitted to the atmosphere.

The world's airlines carry around 2.3 billion passengers and 38 million tons of freight on scheduled services, representing more than 531 billion ton kilometers combined.

Passenger traffic is expected to grow at an average rate of 4.8% per year through the year 2036.

Overall, global trends of aviation noise, emissions that affect local air quality and fuel consumption predict an increase through the year 2036 at less than the 4.8% growth rate in traffic.

- In 2006, the global population exposed to 55 DNL aircraft noise was approximately 21million people. This is expected to increase at a rate of 0.7% to 1.6% per year through the year 2036.
- In 2006, 0.25 Mt of NO_x was emitted by aircraft within the LTO cycle globally. These emissions are expected to increase at a rate of between 2.4% and 3.5% per year.
- In 2006, aircraft consumed approximately 187 of fuel globally.
- International flights are responsible for approximately 62% of global aviation fuel consumption.
- Global aircraft fuel consumption is expected to increase at a rate of between 3.0% and 3.5% per year.

Environmental standards set by ICAO and the investments in technology and improved operational procedures are allowing aviation's noise, local air quality, and CO_2 footprints to grow at a rate slower than the demand for air travel.

4.1 Aviation traffic forecast

The world passenger traffic, expressed in terms of RPKS, is expected to grow from five billion to more than 13 billion RPKS over the 2010-2030 periods, at an average annual growth rate of 4.9%. Under that scenario, international traffic would grow at 5.1% cent per annum, while domestic traffic would grow at a slower rate of 4.4% per annum.

During the following ten years, 2030 to 2040, growth is expected to moderate to an average of 4.0% per annum, with international and domestic air traffic growing at the rates of 4.1% and 3.8% cent per annum, respectively.

As shown in Fig 2, international traffic's share of total traffic will increase from 64% in 2010 to about 68% in 2040. [22]

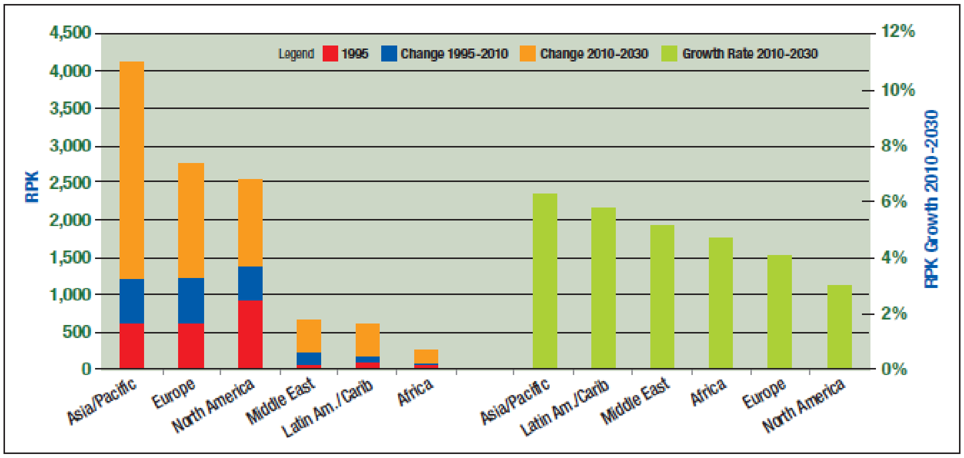


Fig 2 ICAO passenger traffic forecasts by ICAO statistical region [22]

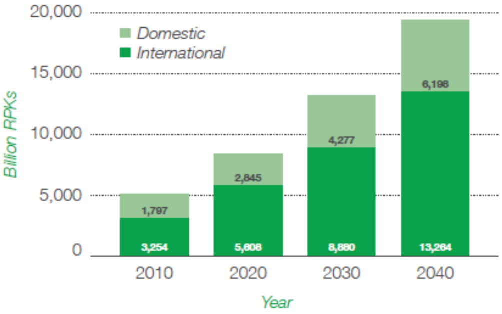


Fig 3 CAEP/9 passenger traffic forecast

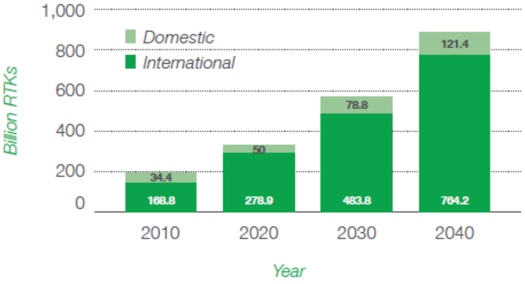


Fig 4 CAEP/9 cargo traffic forecast

With reference to Fig 5, the 2010 top five route groups in terms of passenger traffic volumes, domestic North America, Intra-Europe, North Atlantic, Intra-Asia/pacific, and domestic China/Mongolia, will remain at the top during the 2030 to 2040 period, although their relative rankings will change.

The combined share of these route groups in total RPKS will decline from about 52.4% in 2010, to 47.7% and 46.4% in 2030 and 2040, respectively.

The world air freight traffic, expressed in terms of RTKS, is expected to grow at an average annual growth rate of 5.2% from 2010 to 2030, and at 4.6% between 2030 and 2040.

As a result, as shown in Fig 4, therefore air freight traffic will increase from 203.2 billion RTKS in 2010, to 562 and 885 billion RTKS in 2030 and 2040, respectively. The largest increases in air freight traffic volumes over the forecast time horizon are expected to take place on international route groups: intra-Asia/pacific; Europe; other Asia/pacific (which includes Japan and Australia); Europe- China/Mongolia; and America-other Asia/pacific.

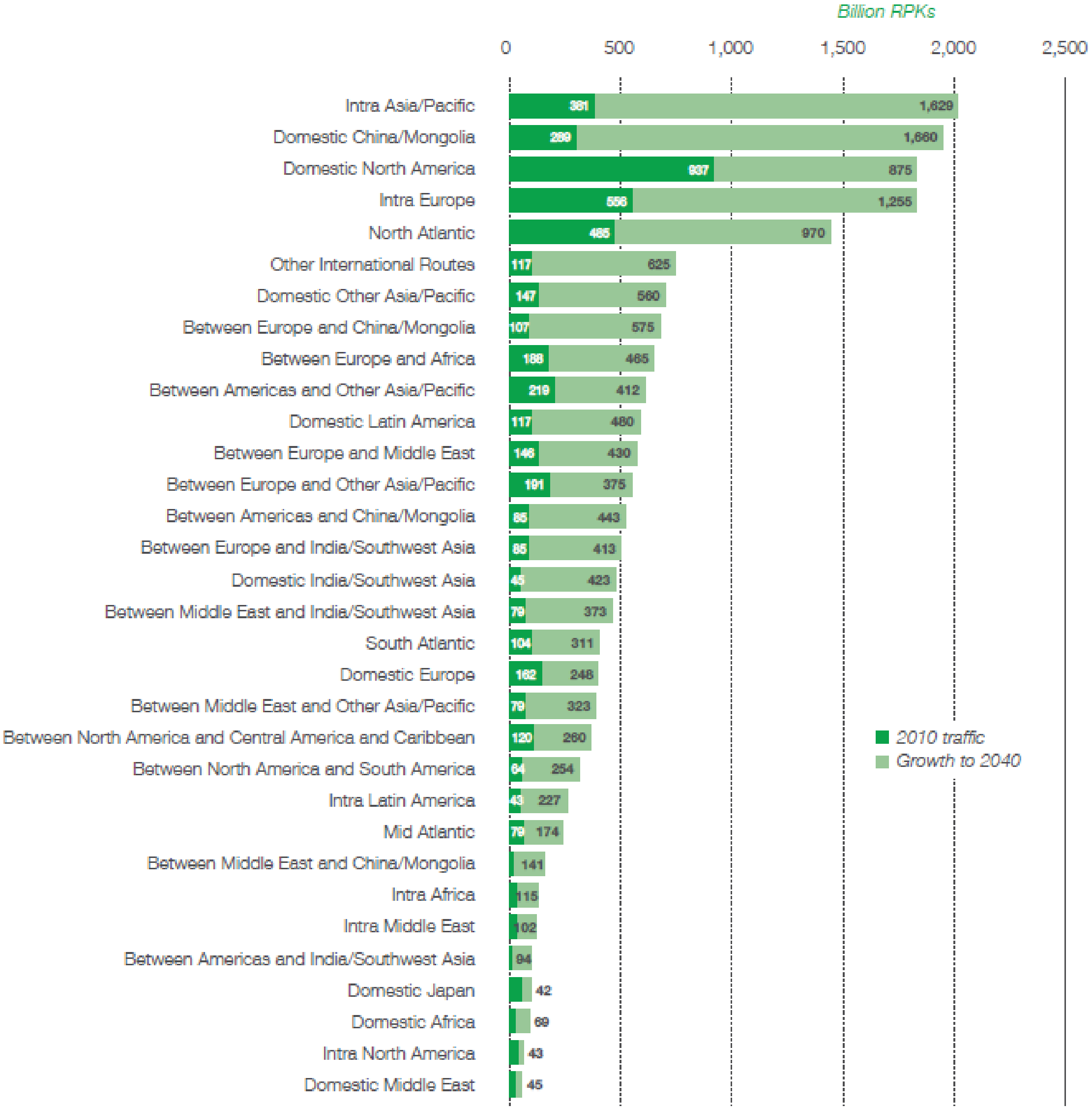


Fig 5 CAEP/9 passenger traffic forecast (central) by route group

4.2 Aircraft emissions

The technology of jet engines currently relies on fossil fuel combustion, which emits combustion products primarily at cruise altitudes. These emissions affect atmospheric composition differently than emissions from fossil-fuel combustion at the surface. In addition, aviation operations cause changes in cloudiness through contrail and contrail cirrus formation. Present and future changes in atmospheric composition and cloudiness from aviation have the potential to affect future climate.

Pollutants emitted by aircraft are:

- NO_x– which includes nitrogen oxide (NO) and nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Unburned hydrocarbons – which have almost been completed eliminated from the exhaust stream due to newer engine technologies

- Sulfur oxides
- PM – which leaves the exhaust as carbon black soot
- Volatile organic compounds (VOCS) – such as benzene and acrolein
- O_3– which is formed from the nitrogen oxides and volatile organic compounds emitted
- SVOCS
- Metals
- Noise

Airports also release contaminants from activities such as

- Ground service equipment
- Motor vehicles (parking, road traffic)
- Construction
- Boilers
- Generators
- Airport fire training facility
- Food preparation
- Engine testing
- Electricity
- De-icing
- Fuel storage facilities

4.3 Aviation emissions of CO_2

The only ‘greenhouse gas’ emissions from aviation are CO_2 and water vapor, other emissions, e.g. NO_x and particles result in changes in RF but are not in themselves ‘greenhouse gases’. Emissions of water vapor from current subsonic aviation are small.

Fig 6 shows the development of aviation fuel usage since 1940, along with RPKS. A number of events impacting the sector (oil crises, conflicts, disease) show a response in demand and in emissions, and that the sector is remarkably resilient and adaptable to a variety of external pressures.

The lower panel of Fig 7 shows aviation CO_2 emissions in context with total historical emissions of CO_2 from fossil fuel usage. Emissions of CO_2 (total) as an annual rate increased markedly in the late 1990s and early 2000s. This was not reflected in the early 2000s by the aviation sector, because of suppression of demand in response to the events of 9-11 etc. Another reason why an annual percentage contribution of aviation emissions to total CO_2 emissions can be misleading when not placed in a longer-term perspective. The lower panel of Fig 7 shows the growth in CO_2 emissions in tg CO_2 (per year) for all fossil fuel combustion and from aviation (left-hand axis), and the fraction of total anthropogenic CO_2 emissions represented by aviation CO_2 emissions (%) (Right-hand axis). [7]

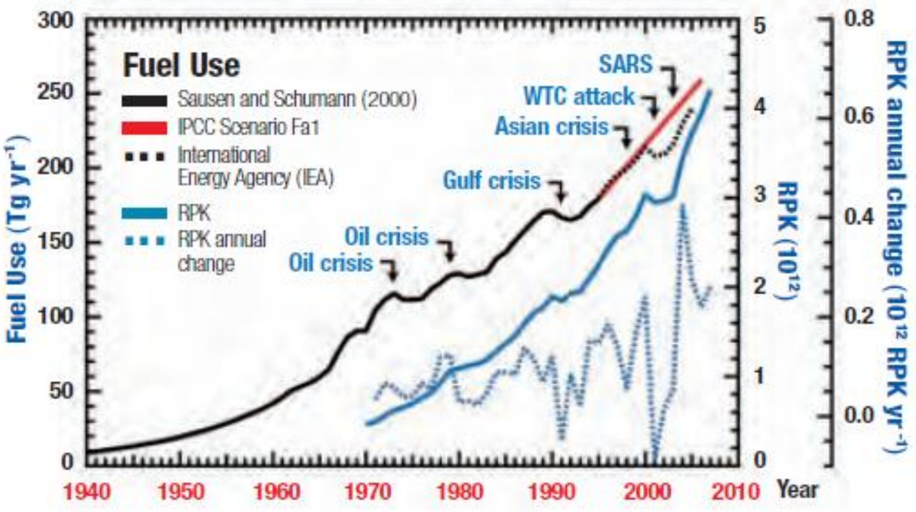


Fig 6 Aviation fuel usage, RPKS, and the annual change in RPKS [7]

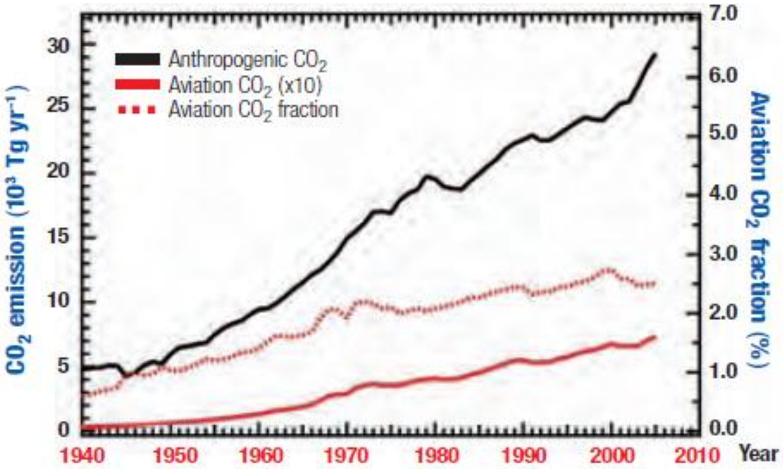


Fig 7 Changing aviation CO_2 emission from 1940 till 2010 [7]

4.4 Some impacts of aircraft emission on health

- CO carbon monoxide: cardiovascular affects, especially on those persons with heart conditions.
- HC:
    - Eye and respiratory tract infection
    - Headaches
    - Dizziness
    - Visual disorders

  - Memory impairment
- NO_x:
  - Lung irritation
  - Lower resistance to respiratory infections.
- O_3:
  - Lung function impairment
  - Effects on exercise performance
- PM:
  - Premature mortality
  - Changes in lung function
  - Cardiovascular disease

Aircraft and airport emissions can also have serious effects on the environment. These contaminants can affect crop productivity and ecosystem response. In particular, NO_x in the troposphere can contribute to ground-level ozone, excess nitrogen loads to sensitive water bodies, and acidification of sensitive ecosystems according to the U.S. Environmental protection agency.

Particulate matter contributes to visibility and soiling issues. They play a key role in creating the hazy smog often found surrounding cities on sunny, warm, dry days.

Vocs also contribute to ozone formation and damage plants, crops, buildings and materials when released at high levels.

Figure 8 presents full-flight CO_2 emissions for international aviation from 2005 to 2040, and extrapolated to the year 2050. This figure covers the CO_2 emissions associated with the combustion of jet fuel, assuming that 1 kg of jet fuel burned generates 3.16 kg of CO_2. As with the fuel burn analysis, this analysis considers: the contribution of aircraft technology, improved air traffic management, and infrastructure use. In addition, the range of possible CO_2 emissions for 2020 is displayed relative to the global aspirational goal of keeping the net CO_2 emissions at this level.

Interpretation of greenhouse gas trends

In 2010, international aviation consumed approximately 142 million metric tons of fuel, resulting in an estimated 448 million metric tons (MT, 1 kg x 109) of CO_2 emissions. Based on the GHG trend assessment assumptions described above, this equates to 522 million tons of net life cycle CO_2 emissions. It is projected that, by 2040 fuel consumption will have increased by between 2.8 and 3.9 times the 2010 value, while RTK are expected to increase 4.2 times under the central demand forecast. By extrapolating to the year 2050, it is estimated that fuel consumption will have increased four to six times the 2010 value, while revenue ton kilometers are expected to increase seven times under the central demand forecast

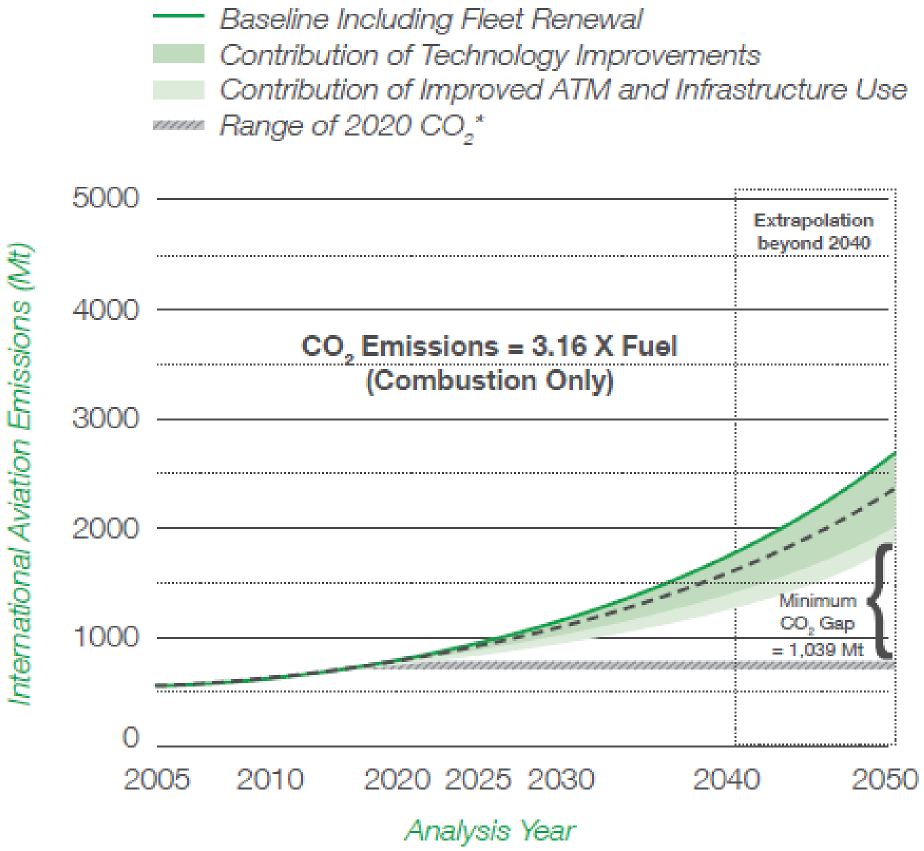


Fig 8 CO_2 emission trends from international aviation, 2005 to 2050 [22]

4.5 NO_x effects

Aircraft engines emit reactive nitrogen NO_x in the forms of NO and NO_2. While NO_x is not a greenhouse gas, it alters the abundance of two principal greenhouse gases, O_3 and CH_4, through a complex photochemical process.

NO_x acts as a catalyst to produce O_3 in the oxidation of CO, CH_4, and a variety of hydrocarbon compounds. The O_3 production efficiency is higher for NO_X emitted at cruise altitudes than at the surface due to atmospheric conditions in the upper troposphere.

Increased O_3 leads to a positive radiative forcing (warming). Another photochemical response to increased NO_x is an increase in the OH, which reacts with many atmospheric compounds including CH_4. The OH reaction with CH_4 reduces its atmospheric lifetime and, hence, atmospheric abundance.

4.6 EU aviation's contribution to climate change

Direct emissions from aviation account for about 3% of the EU's total GHG emissions. The large majority of these emissions come from international flights.

The overall impact is therefore estimated to be higher. The IPCC has estimated that aviation's total impact is about 2 to 4 times higher than the effect of its past CO_2 emissions alone. Recent EU research results indicate that this ratio may be somewhat smaller (around 2 times).

EU emissions from international aviation are increasing fast – doubling since 1990 – as air travel becomes cheaper without its environmental costs being addressed.

Emissions are forecast to continue growing for the foreseeable future. Emissions from aviation are higher than from certain entire sectors covered by the EU ETS, for example refineries and steel production. When aviation joins the EU ETS it is forecast to be the second largest sector in terms of emissions, second only to electricity generation.

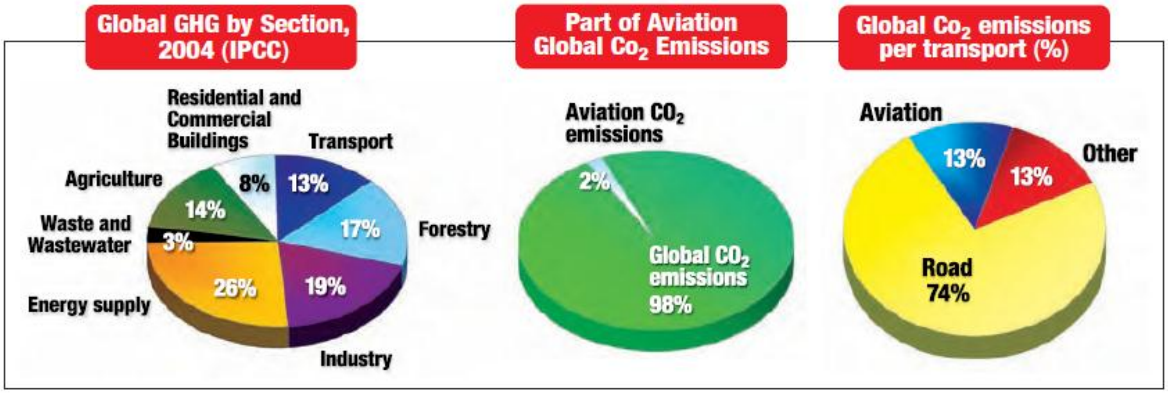


Fig 9 Aviation contribution to global CO_2 emission [22]

4.7 EU initiatives

Preventing dangerous climate change is a strategic priority for the European Union. Europe is working hard to cut its greenhouse gas emissions substantially while encouraging other nations and regions to do likewise.

In parallel, the European commission and some member states have developed adaptation strategies to help strengthen Europe's resilience to the inevitable impacts of climate change.

EU initiatives to reduce greenhouse gas emissions include:

- The European climate change program (ECCP).
- The EU emissions trading system.
- Adopting legislation to raise the share of energy consumption produced by renewable energy sources, such as wind, solar and biomass, to 20% by 2020.
- Setting a target to increase Europe's energy efficiency by 20% by 2020 by improving the energy efficiency of buildings and of a wide array of equipment and household appliances.
- Binding targets to reduce CO_2 emissions from new cars and vans.

- Supporting the development of (CCS) technologies to trap and store CO_2 emitted by power stations and other major industrial installingations.

The EU has agreed that at least 20% of its €960 billion budget for the 2014-2020 periods should be spent on climate change-related action. This represents around a threefold increase from the 6-8% share in 2007-2013.

The EU emissions trading system (EU ETS) is a cornerstone of the European Union’s policy to combat climate change and its key tool for reducing industrial greenhouse gas emissions cost-effectively.

The first - and still by far the biggest - international system for trading greenhouse gas emission allowances.

- Operates in the 28 EU countries and the three EEA-EFTA states (Iceland, Liechtenstein and Norway)
- Covers around 45% of the EU's greenhouse gas emissions
- Limits emissions from more than 11,000 heavy energy-using installingations in power generation and manufacturing industry, flights to and from the EU and the three EEA-EFTA states

A cap on the total emissions allowed within the scheme is set, and allowances adding up to the cap are provided to the companies regulated by the scheme. The companies are required to measure and report their carbon emissions and to hand in one allowance for each tone they release. Companies can trade their allowances, providing an incentive for them to reduce their emissions.

The current cap is set to fall by 1.74% annually to achieve a target of reducing emissions in 2020 to 21% below their level in 2005. In June 2011 the price of an allowance was around €16. The trade in permits is worth around $150bn annually, dwarfing other trading schemes (the clean development mechanism market established by the UN is valued at $1.5bn annually).

In a basic sense the ETS has worked. It has set a cap on half of Europe’s carbon emissions, which were previously unregulated, and the companies covered by the scheme are no longer free to pollute. Carbon has a price and this influences the economics of burning fossil fuels.

Since the beginning of 2012, emissions from international aviation are included in the EU emissions trading system (EU ETS).

Like industrial installingations covered by the EU ETS, airlines receive tradable allowances covering a certain level of CO_2 emissions from their flights per year.

The legislation, adopted in 2008 N.2008/101/ES, applies to EU and non-EU airlines alike. Emissions from flights to and from Iceland, Liechtenstein and Norway are also covered.

From 2013 onwards, the cap on emissions from power stations and other fixed installingations is reduced by 1.74% every year. This means that in 2020, greenhouse gas emissions from these sectors will be 21% lower than in 2005. A separate cap applies to the aviation sector: for the whole 2013-2020 trading period, this is 5% below the average annual level of emissions in the years 2004-2006.

EU ETS: development in phases

2005-2007: 1st trading period used for ‘learning by doing.’ EU ETS successfully established as the world’s biggest carbon market. However, the number of allowances, based on estimated needs, turns out to be excessive; consequently the price of first-period allowances falls to zero in 2007.

2008-2012: 2nd trading period. Iceland, Norway and Liechtenstein join (1.1.2008). The number of allowances is reduced by 6.5% for the period, but the economic downturn cuts emissions, and thus demand, by even more. This leads to a surplus of unused allowances and credits which weighs on carbon price. Aviation brought into the system (1.1.2012).

2013-2020: 3rd trading period. Major reform takes effect (1.1.2013). Biggest changes are the introduction of an EU-wide cap on emissions (reduced by 1.74% each year) and a progressive shift towards auctioning of allowances in place of cost-free allocation. Croatia joins the ETS (1.1.2013).

2021-2028: 4th trading period.

4.8 Commission proposes limiting EU ETS to European regional airspace

In response to the ICAO outcome and to give further momentum to the global discussions, the European commission has proposed amending the EU ETS so that only the part of a flight that takes place in European regional airspace is covered by the EU ETS.

The change would apply from the beginning of 2014 until the planned global MBM enters into force.

The key features of the revised system would be:

- Emissions from flights between airports in the (EEA, covering the 28 EU member states plus Norway and Iceland) would continue to be covered.
- Emissions from flights to and from countries outside the EEA would be fully exempted for 2013.
- From 1 January 2014, flights to and from countries outside the EEA would benefit from a general exemption for the proportion of emissions that take place outside EEA airspace. Only the emissions from the proportion of a flight taking place within EEA airspace would be covered.
- To accommodate the special circumstances of developing countries, flights between the EEA and least developed countries, low-income countries and lower-middle income countries which benefit from the EU's generalized system of preferences and have a share of less than 1% of international aviation activity would be fully exempted from the EU ETS.

4.9 Total quantity of allowances for aviation

1. For the period from 1 January 2012 to 31 December 2012, the total quantity of allowances to be allocated to aircraft operators shall be equivalent to 97 % of the historical aviation emissions.

2. For the period referred to in article 11(2) beginning on 1 January 2013, and, in the absence of any amendments following the review referred to in article 30(4), for each subsequent period, the total quantity of allowances to be allocated to aircraft operators shall be equivalent to 95 % of the historical aviation emissions multiplied by the number of years in the period. This percentage may be reviewed as part of the general review of this directive.

3. The commission shall review the total quantity of allowances to be allocated to aircraft operators in accordance with article 30(4).

4. By 2 august 2009, the commission shall decide on the historical aviation emissions, based on are available data, including estimates based on actual traffic information.

Flights which depart from or arrive in an aerodrome situated in the territory of a member state to which the treaty applies. This activity shall not include:

(a) Flights performed exclusively for the transport, on official mission, of a reigning monarch and his immediate family, heads of state, heads of government and government ministers, of a country other than a member state, where this is substantiated by an appropriate status indicator in the flight plan;

(b) Military flights performed by military aircraft and customs and police flights.

(c) Flights related to search and rescue, firefighting flights, humanitarian flights and emergency medical service flights authorized by the appropriate competent authority.

(d) Any flights performed exclusively under visual flight rules as defined in annex 2 to the Chicago convention/

(e) Flights terminating at the aerodrome from which the aircraft has taken off and during which no intermediate landing has been made.

(f) Training flights performed exclusively for the purpose of obtaining a license, or a rating in the case of cockpit flight crew where this is substantiated by an appropriate remark in the flight plan provided that the flight does not serve for the transport of passengers and/or cargo or for the positioning or ferrying of the aircraft.

(g) Flights performed exclusively for the purpose of scientific research or for the purpose of checking, testing or certifying aircraft or equipment whether airborne or ground-based;. (h) Flights performed by aircraft with a certified maximum take-off mass of less than 5 700 kg.

(i) Flights performed in the framework of public service obligations imposed in accordance with regulation EEC no 2408/92 on routes within outermost regions, as specified in article 299(2) of the treaty, or on routes where the capacity offered does not exceed 30 000 seats per year.

(j) Flights which, but for this point, would fall within this activity, performed by a commercial air transport operator operating either:

— Fewer than 243 flights per period for three consecutive four-month periods; or

— Flights with total annual emissions lower than 10 000 tons per year. Flights performed exclusively for the transport, on official mission, of a reigning monarch and his immediate family, heads of state, heads of government and government ministers, of a member state may not be excluded under this point.

For commercial airlines, the ETS covers CO_2 emissions from flights within and between countries participating in the EU ETS. International flights to and from non-ETS countries are also covered, but the EU deferred the scheme's application to these for 2012 to allow time for agreement to be reached on a global framework for tackling aviation emissions.

In proposing the inclusion of aviation in the EU ETS in 2006, the commission concluded that this was the most cost-efficient and environmentally effective option for controlling aviation emissions following a wide-ranging consultation of stakeholders and the public and analysis of several types of market-based solutions.

Compared with alternatives such as a fuel tax, including aviation in the EU ETS provides the same environmental benefit at a lower cost to society - or a higher environmental benefit for the same cost.

In April 2013 the EU decided to temporarily suspend enforcement of the EU ETS requirements for flights operated in 2010, 2011, and 2012 from or to non-European countries, while continuing to apply the legislation to flights within and between countries in Europe.

In October 2013 the EU's hard work paid off when the ICAO assembly agreed to develop by 2016 a global MBM addressing international aviation emissions and apply it by 2020. Until then countries or groups of countries, such as the EU, can implement interim measures.

In response to the ICAO outcome and to give further momentum to the global discussions, the European commission has proposed amending the EU ETS so that only the part of a flight that takes place in European regional airspace is covered by the EU ETS.

The change would apply from the beginning of 2014 until the planned global MBM enters into force.

The key features of the revised system would be:

- Emissions from flights between airports in the (EEA, covering the 28 EU member states plus Norway and Iceland) would continue to be covered.
- Emissions from flights to and from countries outside the EEA would be fully exempted for 2013.
- From 1 January 2014, flights to and from countries outside the EEA would benefit from a general exemption for the proportion of emissions that take place outside EEA airspace. Only the emissions from the proportion of a flight taking place within EEA airspace would be covered.
- To accommodate the special circumstances of developing countries, flights between the EEA and least developed countries, low-income countries and Loir middle income

countries which benefit from the EU's generalized system of preferences and have a share of less than 1% of international aviation activity would be fully exempted from the EU ETS.

In October 2013 the international civil aviation organization (ICAO) assembly agreed to develop a global market-based mechanism to address international aviation emissions by 2016, and to apply it by 2020.

In response, and to give further momentum to the global discussions, the European commission has made a proposal to amend the EU ETS so that only the part of a flight that takes place in European regional airspace is covered by the trading system. The change would apply from the beginning of 2014 until the global measure enters into force.

The success of the EU ETS has inspired other countries and regions to launch cap and trade schemes of their own. The EU aims to link up the ETS with compatible systems around the world to form the backbone of an expanded international carbon market. The European commission has agreed in principle to link the ETS with Australia’s system in stages from mid-2015.

4.10 Targets up to 2050

EU leaders have committed to transforming Europe into a highly energy-efficient, low carbon economy. The EU has set itself targets for reducing its greenhouse gas emissions progressively up to 2050 and is working successfully towards meeting them.

Under the Kyoto protocol, the 15 countries that were EU members before 2004 ('EU-15') are committed to reducing their collective emissions to 8% below 1990 levels by the years 2008-2012.

For 2020, the EU has committed to cut its emissions to 20% below 1990 levels. This commitment is one of the headline targets of the Europe 2020 growth strategy.

The EU has offered to increase its emissions reduction to 30% by 2020 if other major emitting countries in the developed and developing world’s commit to undertake their fair share of a global emissions reduction effort.

In the climate and energy policy framework for 2030, the European commission proposes that the EU set itself a target of reducing emissions to 40% below 1990 levels by 2030.

For 2050, EU leaders have endorsed the objective of reducing Europe’s greenhouse gas emissions by 80-95% compared to 1990 levels as part of efforts by developed countries as a group to reduce their emissions by a similar degree.

4.11 Effect on air transport tickets

Including aviation in the EU ETS will not directly affect or regulate air transport tickets. However, aircraft operators may have to invest in more efficient planes or buy emission allowances in the market in addition to those allocated to them.

The impact on ticket prices will probably be minor. Assuming airlines fully pass on these extra costs to customers. By 2020 the ticket price for a return flight within the EU could rise by between €1.8 and €9. Due to their higher environmental impact, long-haul trips could increase by somewhat more depending on the journey length. For example a return flight to New York at current carbon prices of around €15 might cost an additional €12.

However, ticket price increases are in any case expected to be significantly lower than the extra costs airlines have passed on to consumers due to world oil price rises in recent years. Including aviation in the EU ETS will also have a smaller impact on prices than if the same environmental improvement were to be achieved through other measures such as a fuel tax or an emissions charge.

4.12 Local air quality and ICAO engine emissions standards

For many years, ICAO has been developing measures to reduce the impact of aircraft emissions on LAQ.

In particular, the ICAO CAEP and its predecessor, the committee on aircraft engine emissions, have, since the late 1970s, continually developed emissions standards for new engine types, their derivatives, and new production engines.

One of the principal results arising from the work of these groups is the development of the ICAO SARPs on engine emissions contained in volume ii of annex 16 to the convention on international civil aviation (the “Chicago convention”)1 and related guidance material and technical documentation.

These SARPs aim to address potential adverse effects of air pollutants on LAQ, primarily pertaining to human health and welfare. Among other issues, these provisions address: liquid fuel venting, smoke, and the main gaseous exhaust emissions from jet engines, namely; HC, NO_X, and CO.

Specifically, the annex 16 engine emissions standards set limits on the amounts of gaseous emissions and smoke allowable in the exhaust of most civil aircraft engine types. Over the past three years work has been conducted by CAEP to ensure the validity of the technical basis underpinning the ICAO SARPs associated with reducing the impact of civil aviation on LAQ. This work has included, inter alia: development of a (NVPM) standard, a NO_X technology review, and the publication of aircraft local air quality guidance material.

Gaseous emission levels when measured and computed must not exceed the regulatory levels determined from the following formulas:

HC: $dp /foo = 19.6$

Carbon monoxide (co): $dp /foo = 118$

Table 1 Gases emission levels

For engines of a type or model for which the date of manufacture of the first individual production model was before 1 January 1996 and for which the date of manufacture of the individual engine was before 1 January 2000		$Dp/foo = 40 + 2\pi oo$
For engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 1996 or for which the date of manufacture of the individual engine was on or after 1 January 2000.		$Dp/foo = 32 + 1.6\pi oo$
For engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 2004: 1) for engines with a pressure ratio of 30 or less:		
For engines with a pressure ratio of 30 or less	For engines with a maximum rated thrust of more than 89.0 KN	$Dp/foo = 19 + 1.6\pi oo$
	For engines with a maximum rated thrust of more than 26.7 KN but not more than 89. KN	$Dp/foo = 37.572 + 1.6\pi oo$ ⌐ $0.2087foo$
For engines with a pressure ratio of more than 30 but less than 62.5	For engines with a maximum rated thrust of more than 89.0 KN	$Dp/foo = 7 + 2.0\pi oo$
	For engines with a maximum rated thrust of more than 26.7 KN but not more than 89.0 KN	$Dp/foo = 42.71 + 1.4286\pi oo - 0.4013foo + 0.00642\pi oo \times foo$
For engines with a pressure ratio of 62.5 or more:		$Dp/foo = 32 + 1.6\pi oo$
For engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 2008 or for which the date of manufacture of the individual engine was on or after 1 January 2013		
For engines with a pressure ratio of 30 or less	For engines with a maximum rated thrust of more than 89.0 KN	$Dp/foo = 16.72 + (1.4080 * \pi oo)$
	For engine with a maximum rated thrust of more than 26.7 KN but not more than 89.0 KN	$Dp/foo = 38.5486 + (1.6823 * \pi oo) - (0.2453 * foo) - (0.00308 * \pi oo * foo)$
For engines with a pressure ratio of 82.6 or more		$Dp/foo = 32 + (1.6 * \pi oo)$
For engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 2014		
	For engines with a maximum rated thrust of more than 89.0 KN	$Dp/f00 = 7.88 + 1.4080\pi 00$

For engines with a pressure ratio of 30 or less	For engines with a maximum rated thrust of more than 26.7 KN but not more than 89.0 KN	$Dp/f00 = 40.052 + 1.5681\pi 00 - 0.3615 f00 - 0.0018\pi 00 f00$
For engines with a pressure ratio of more than 30 but less than 104.7	For engines with a maximum rated thrust of more than 89.0 KN	$Dp/f00 = -9.88 + 2.0\pi 00$
	For engines with a maximum rated thrust of more than 26.7 KN but not more than 89.0 KN	$Dp/f00 = 41.9435 + 1.505\pi 00 - 0.5823 f00 + 0.005562\pi 00 f00$
For engines with a pressure ratio of 104.7 or more:		$Dp/f00 = 32 + 1.6\pi 00$

4.13 ICAO engine emission standards

Concerns about local air quality in the vicinity of airports focus on the effects of aircraft engine emissions released below 3,000 feet (915 meters) and emissions from airport sources, such as airport traffic, ground service equipment, and de-icing operations.

The current ICAO standards for emissions certification of aircraft engines (contained in annex 16, volume ii) state that to achieve certification, it must be demonstrated that the characteristic emissions of the engine type for HC, CO, NO_X and smoke are below the limits defined by ICAO. The certification process is based on the LTO cycle, which is representative of the emissions emitted in the vicinity of airports.

The LTO cycle contains four modes of operation, which involve a thrust setting and a time-in mode. These are as follows:

- Take-off: (100% available thrust) for 0.7 minutes;
- Climb: (85% available thrust) for 2.2 minutes;
- Approach: (30% available thrust) for 4.0 minutes;
- Taxi: (7% available thrust) for 26 minutes.

4.14 Global aspirational goals

The initiatives constitute the key components of the basket of mitigation measures that has been developed by ICAO to provide its member states and the aviation industry with the means to reduce the climate impact of aviation operations. Through the implementation of these measures, ICAO aims toward the achievement of the global aspirational goal of 2% annual fuel efficiency improvement with objective of stabilizing global CO_2 emissions from international aviation at 2020 levels.

CAEP undertook the update of the CO_2 trends assessment by estimating the contribution of various categories of mitigation measures including: aircraft-related technology development, improved air traffic management and infrastructure use, and alternative fuels.

4.15 NO_x standard

The standard for NO_x was first adopted in 1981, and then made more stringent in 1993, 1999, and 2005. Most recently, the eight meeting of CAEP (CAEP/8) in February 2010 agreed on a new NO_x standard, which improves on the current standard by up to 15 per cent with an effective date of 31 December 2013, as well as a production cut-off of engines according to the current standard with an effective date of 31 December 2012.the ICAO engine exhaust emissions data bank (doc 9646), issued in 1995, contains a comprehensive database of aircraft jet engine emissions certification data.

Regarding PM emissions, CAEP/8 agreed to focus on non-volatile PM since the science is more advanced in this area, compared to volatile PM. Establishment of a certification requirement is targeted by 2013 and a certification standard by 2016.

The independent expert review for NO_x reduction technologies was completed in 2006 and subsequently updated for CAEP/8 in February 2010. The panel of independent experts decided to maintain the following goals established in 2006:

- Medium term goal (2016): CAEP/6 levels – 45%, ±2.5% (of CAEP/6) at an overall pressure ratio of 30
- Long term goal (2026): CAEP/6 levels – 60%, ±5% (of CAEP/6) at an overall pressure ratio of 30

The eighth meeting of the CAEP, held from 1 to 12 February at ICAO headquarters, also recommended NO_x standards up to 15 percent more stringent than the current levels, applicable to new aircraft engines certified after 31 December 2013.

4.16 Certification standards and technology goals

Aircraft are required to meet the environmental certification standards adopted by the council of ICAO. These are contained in annex 16 (environmental protection) to the *convention on international civil aviation*. This annex at present consists of two volumes, viz., and volume i: aircraft noise and volume ii: aircraft engine emissions. These certification standards have been designed and are kept up to date in order to respond to concerns regarding environmental impact of aviation on communities in the vicinity of airports as well as society at large.

More recently, ICAO, under the CAEP process, has undertaken an effort to establish medium and long-term environmental goals relating to three types of technologies, viz., noise, NO_X, and fuel burn. In addition, assessments of environmental improvements expected from operational initiatives in the medium and long term are also underway.

In October 2010 the 37th assembly (resolution a37-19) requested the development of an ICAO CO_2 emissions standard. On 11 July 2012, global aviation moved an important step closer to establishing the worldwide aircraft CO_2 emissions standard when the CAEP reached a unanimous agreement on a CO_2 metric system to underpin the CO_2 standard

In 2010, the 37th session of the ICAO assembly adopted the following goals for aviation:

- A global annual average fuel efficiency improvement of 2% until 2020 and an aspirational global fuel efficiency improvement rate of 2% per annum from 2021 to 2050; and
- A collective medium-term global aspirational goal of keeping the global net carbon emissions from international aviation from 2020 at the same level carbon neutral growth (CNG2020).

To achieve these goals, there needs to be a strong commitment from all stakeholders, including governments and non-governmental organizations working together through the four pillar strategy: improved technology, more efficient aircraft operations, infrastructure improvements, and properly-designed MBM to fill any remaining emissions gap. ICAO must continue to play the leading role in these efforts.

The aviation industry is contributing towards these goals by developing fuel efficient technology such as lighter weight materials and advanced engine technologies, improving operational efficiency, supporting the deployment of modernized infrastructure and the commercialization of sustainable alternative fuels.

In addition, the industry is also supporting the work of ICAO’s committee on aviation environmental protection (CAEP) on an aircraft CO_2 standard.

At the 38th general assembly of the ICAO, governments endorsed a comprehensive set of actions aimed at achieving an aspirational mid-term goal of zero carbon emissions growth for the aviation industry beginning in 2020. The October 4 accord brings together a number of measures being developed by ICAO, including: a certification requirement for a global CO2 efficiency standard for aircraft; support for an updated, more efficient air traffic control regime; continued development of sustainable biofuels; and updating national action plans laying out country strategies to reduce emissions.

The agreement reached October 4 states that ICAO “decides to develop a global market-based measure scheme for international aviation” to be considered at the next general assembly in 2016 and implemented in 2020. As a result, aviation would become the only major industry sector on a path toward a global market-based mechanism agreement to limit future greenhouse gas emissions.

4.17 Reduction of aviation emissions at airports

Airport operators can contribute to improvements in the aircraft activities of taxiing and APU usage with various mitigation measures including:

- Providing and enforcing the use of FEGP and PCA supply to aircraft at terminal gates that allow APU switch-off.
- Improving aircraft taxiways, terminal and runway configurations to reduce taxiing distance and ground and terminal area congestion.
- Implementation of departure management techniques, including holding aircraft at the gate (with APU switched off) until departure slot is ready.
- Use of arrival management techniques that provide gates for aircraft that are located to minimize taxiing distance after landing.

4.18 Conclusion

As a result of the global interest in reducing harmful emissions and the search for solutions in this area, the use of alternative fuel one effective solutions. Following is an overview of the Experience of flying on alternative fuel

Before the approval of the first alternative jet fuels, demonstration flights had already been performed by a number of airlines. The first flight took place in February 2008 when a Boeing 747 from virgin Atlantic flew from London to Amsterdam using a 20% blend of biofuel, made of coconut and babassu oil, to supply one of its engines. A total of nine demonstration flights using biofuels made from various vegetable oils was performed by July 2011 (three flights were also performed with fischer-tropsch gas-to-liquid, gtl, as a surrogate of biomass-to-liquid, btl, as the fischer-tropsch process was still under development for biomass). They demonstrated the performance and the safety of the fuels. In addition, numerous military aircraft flights were performed by the U.S. Air force that contributed to the validation of alternative jet fuels. [7]

The use of sustainable alternative fuels is a key part of the basket of measures under consideration by ICAO member states to achieve the aspirational goal of stabilizing emissions from international aviation at their 2020 levels.

ICAO is actively engaged in activities facilitating, on a global basis, the promotion and harmonization of initiatives that encourage and support the development of sustainable alternative fuels for international aviation.

The past achievements of ICAO in the field of alternative fuels:

1. February 2009: ICAO aviation and sustainable alternative workshop (Montreal)
2. November 2009: ICAO conference on aviation and alternative fuels (Rio de Janeiro)
3. 2010: creation of the global framework on aviation alternative fuels (GFAAF)
4. October 2011: ICAO workshop on sustainable alternative fuels (Montreal)
5. June 2012: rio+20 flight path initiative
6. July 2012: SUSTAF
7. November 2013: CAEP alternative fuels task force (AFTF)

Regarding states' initiatives in 2013, the Indonesian green aviation initiative was notable. Indonesia is indeed the first country that has set legally binding provisions for the use of biofuels in aviation, with the target to include 2% of biofuels in the aviation mix by 2016.

5. MEASURING OF AIRCRAFT EMISSIONS

In accordance with global trends to fight against pollution, Ministry of Transportation and Communications pursuant to 91 part of law No.56/2001 on conditions for operating vehicles on road and amending law No. 168/1999 on liability insurance for damage caused by vehicle, established decree about roadworthiness and vehicles emissions.

As the aircraft, in particular LSA and VLA, fly in the vicinity of the city, therefore they affect the atmosphere of the area as well as the road vehicle. However, they fly during very short times and most frequently, as will be shown in chapter 6, consequently their effect is concerning on specific area.

Therefore, aircraft of these categories must be included in the environmental policies for limiting emissions. This chapter provides information about environmental policy in Czech Republic. Moreover, there is a group of emissions measurement for aircraft of previously mentioned category.

5.1 Environmental policy and vehicles inspection in Czech Republic

Attachment No.1 for the decree N.201/2001 Sb about the permissible amount of emission from road vehicle in service.

a) Petrol engine
   1. Petrol engine with uncontrolled emission system

Permitted value CO at idle and at increased speed are determined by the manufacturer of the vehicle. If it is not determined, the CO content must not exceed the following limits for the vehicles registered or first put in service.

- Until 31.12. 1986 (4.5% vol)
- From 01.01.1987 (3.5 % vol)

Vehicle without emission system with catalytic converter are covered with this limits.

Permitted value HC (ppm vol) is determined by the manufacturer.

2. Petrol engine with controlled emission system and catalytic converter

Permitted value CO at idle and CO content and air excess coefficient at increased speed are determined by the manufacturer of the vehicle. If it is not determined, the CO content must not exceed the following limit.

- For vehicle registered or first put in service until 31.12.2002:

0.5 % vol at idle.

0.3 % vol for increasing speed, air excess coefficient must reach the values of +1/-0.03.

- For vehicle registered or first put in service until 01.01.2003:

0.3 % vol at idle

0.2 % vol at increasing speed, air excess speed must reach the values of +1/-0.03.

b) Diesel engine
   1. Diesel compression engine

The emission of visible pollutant (smoke) which expressed as light absorption coefficient K, must not exceed the following limit

- For vehicle manufactured until 31.02.1980 the value is 4 m^{-1}
- For vehicle manufactured from 01.01.1981 absorption coefficient value $K \leq X_P$

$X_p = X_L + 0.5$

X_L: kriging absorption coefficient (m^{-1})

X_P: absorption coefficient (m^{-1})

- Vehicles for which cringing absorption coefficient is not determined

For engines with naturally aspirated engine: 2.5 m^{-1}

For turbocharged engine: 3 m^{-1}

For vehicle first registered or first put in service from 01.01.2007 the limit value is 1.5 m^{-1}

2. Diesel gas engine and multi-fuel

Engine working on multi-fuel or gas must fulfill the requirement in accordance with section 1.

5.2 Measurement of aircraft emissions

I measured the gases emitted from ultra light aircraft engine at the airport of Medlanky using analyzer Bosch BEA050 which is shown in Fig 13.

Analyzer sensor was mounted to the exhaust pipe as shown in Fig 11, and the airplane was installed tightly to the ground Fig 10 and Fig 12.

Fig 10 Airplane install

Fig 11 Sensor connected to the exhaust pipe

Fig 12 Airplane engine (Rotax)

Aircraft used in measuring is TL-3000 Sirius. It has four-stroke engine Rotax 912 ULS 100 HP, shown in table2.

Table 2 Engine data

Performance	73,5 KW
Max speed	5800 rpm
Fuel	Leaded, unleaded, Avgas 100LL or ethanol 10
Weight	69,5 kg

Fig 13 Analyzer

Gases that were measured are: HC, CO, CO_2, NOx, and O_2 .

Measurement was done during four flight regime:

- Idle
- Cruise
- 75% power
- Full power

The results of exhaust gas measurement are listed in Table 3.

Table 3 Values of exhaust gases measurement

Mode	Λ	HC[ppm]	CO_2[%]	O_2[%]	NO_x[ppm]	CO[%]
Idling mode 1400 rpm	1.026	430	9.87	3.91	55	4.001
	1.075	423	11.38	3.78	61	1.695
	1.12	464	11.43	3.39	59	2.185
	1.113	423	11.08	3.85	58	2.041
	1.293	640	10.31	5.31	50	2.059
Average value	**1.125**	**476**	**10.8**	**4.04**	**56.6**	**2.39**
Cruise mode 4300 rpm	0.821	332	10.66	0.36	692	7.039
	0.815	261	10.45	0.23	769	7.404
	0.782	352	9.79	0.23	324	8.248
	0.779	342	9.41	0.22	334	8.435
	0.776	329	9.54	0.21	334	8.525
Average value	**0.79**	**323.3**	**9.97**	**0.25**	**490.6**	**7.93**
Mode 75% power 5000 rpm	0.805	250	10.38	0.18	506	7.253
	0.798	240	10.37	0.17	508	7.228
	0.791	235	10.42	0.16	527	7.159
	0.797	229	10.34	0.16	507	7.492
Average value	**0.79**	**238.5**	**10.37**	**0.16**	**512**	**7.2**
Full power mode (5600 reached)	0.81	214	10.59	0.16	905	6.971
	0.808	201	10.5	0.16	899	7.101
	0.811	199	10.6	0.16	933	7.218
Average value	**0.809**	**204**	**10.56**	**0.16**	**912.3**	**7.09**

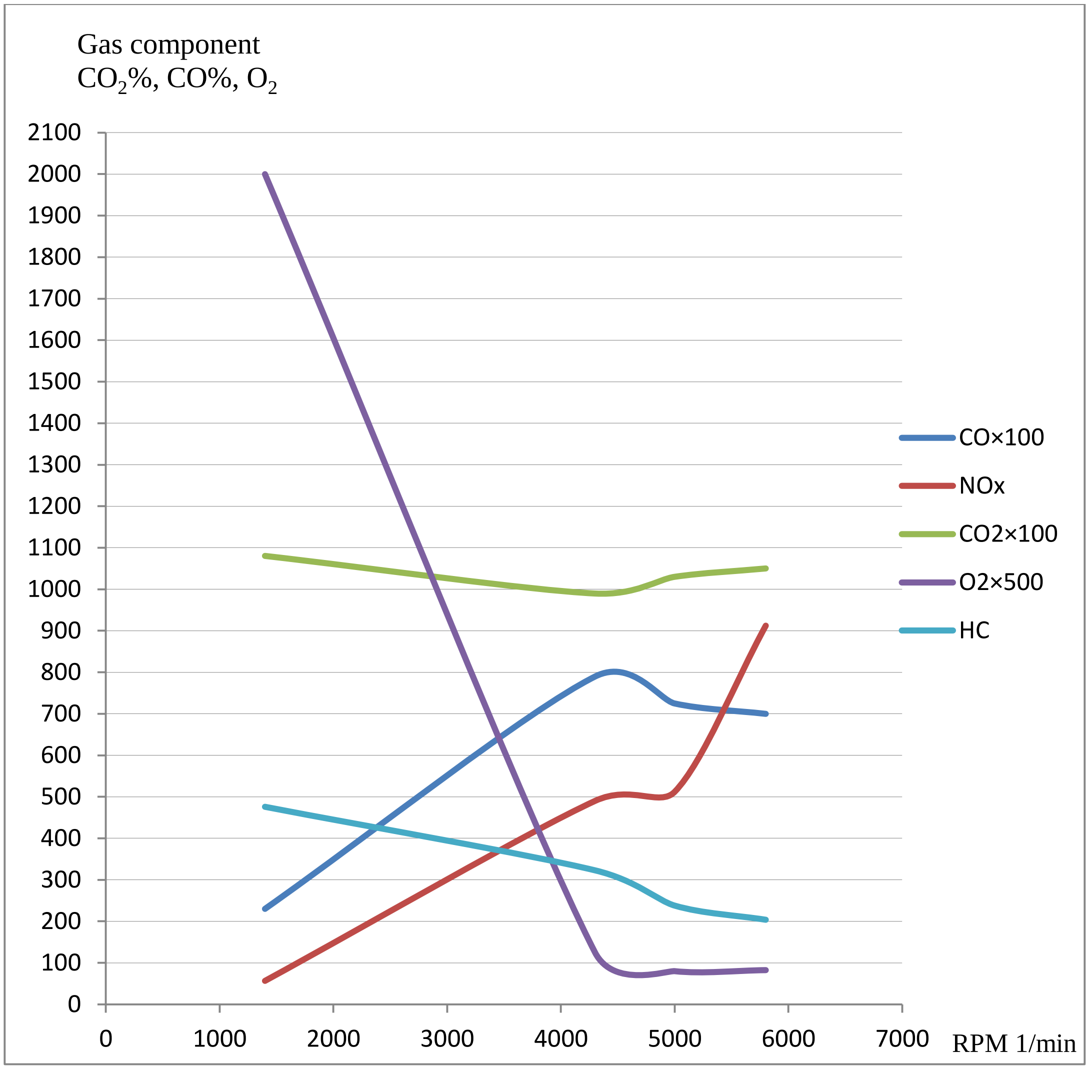


Fig 14 Exhaust gas composition depending on the speed (without cat's)

According to the plot in Fig 14, carbon dioxide ratio decreases with speed increasing till 50% of speed, then increases slightly. But carbon monoxide ratio increases significantly until the reach 50% of its speed, then starts decreasing gradually. On the other side hydrocarbon ratio decrease slightly with speed increasing.

5.3 Measurement for engine equipped with catalytic converter

Because of the difficulty of catalytic converter installation to the exhaust system, it was used an engine which is allready equipped with cat's and it is similar to the aircraft engine. It is 30 KW power engine, type Skoda 1.0 MPI , speed range 1500-4500 rpm. Measurement was made at the Institute of Automotive Engineering laboratory.

Fig 15 and Fig 16 show the engine equipped with catalytic converter.

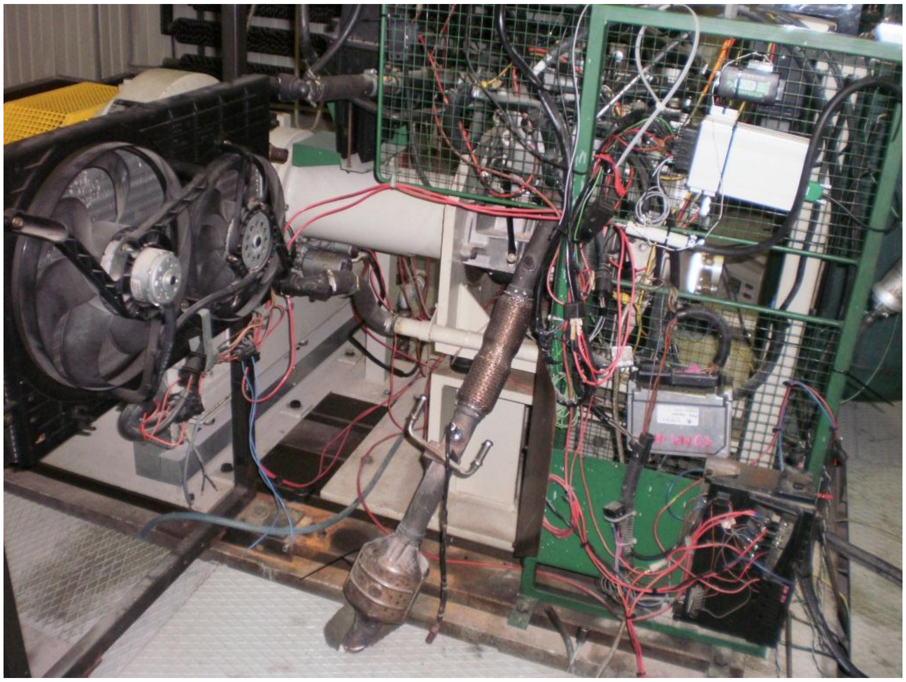


Fig 15 Catalytic converter connected to the engine

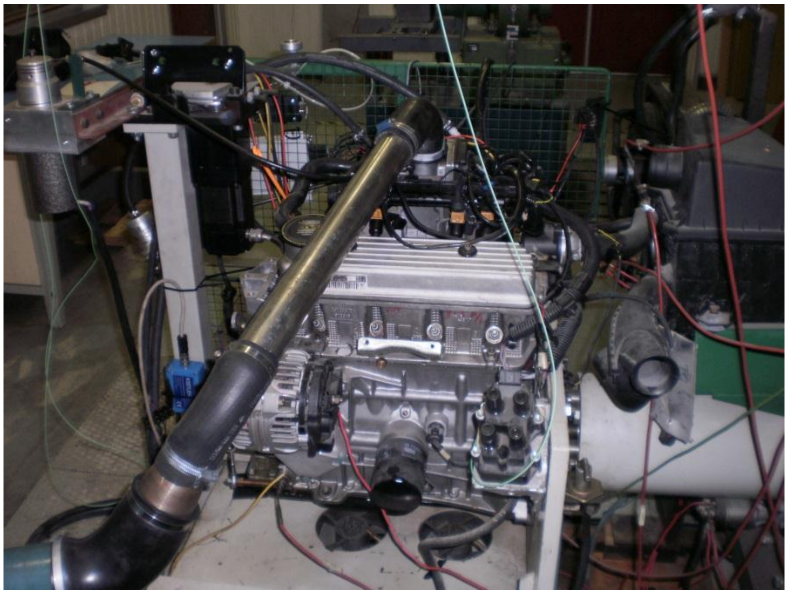


Fig 16 Engine Skoda 1.0 MPI

Table 4 Values of exhaust gases for engine Skoda1.0 MPI

Rpm	λ	HC[ppm]	CO_2[%]	O_2[%]	CO[%]
1500	1	228	12.7	3	0.5
2500	1	208	14.42	1.28	0.6
3500	1	203	14.48	1.29	0.52
4500	1	148	14.47	1.24	0.48

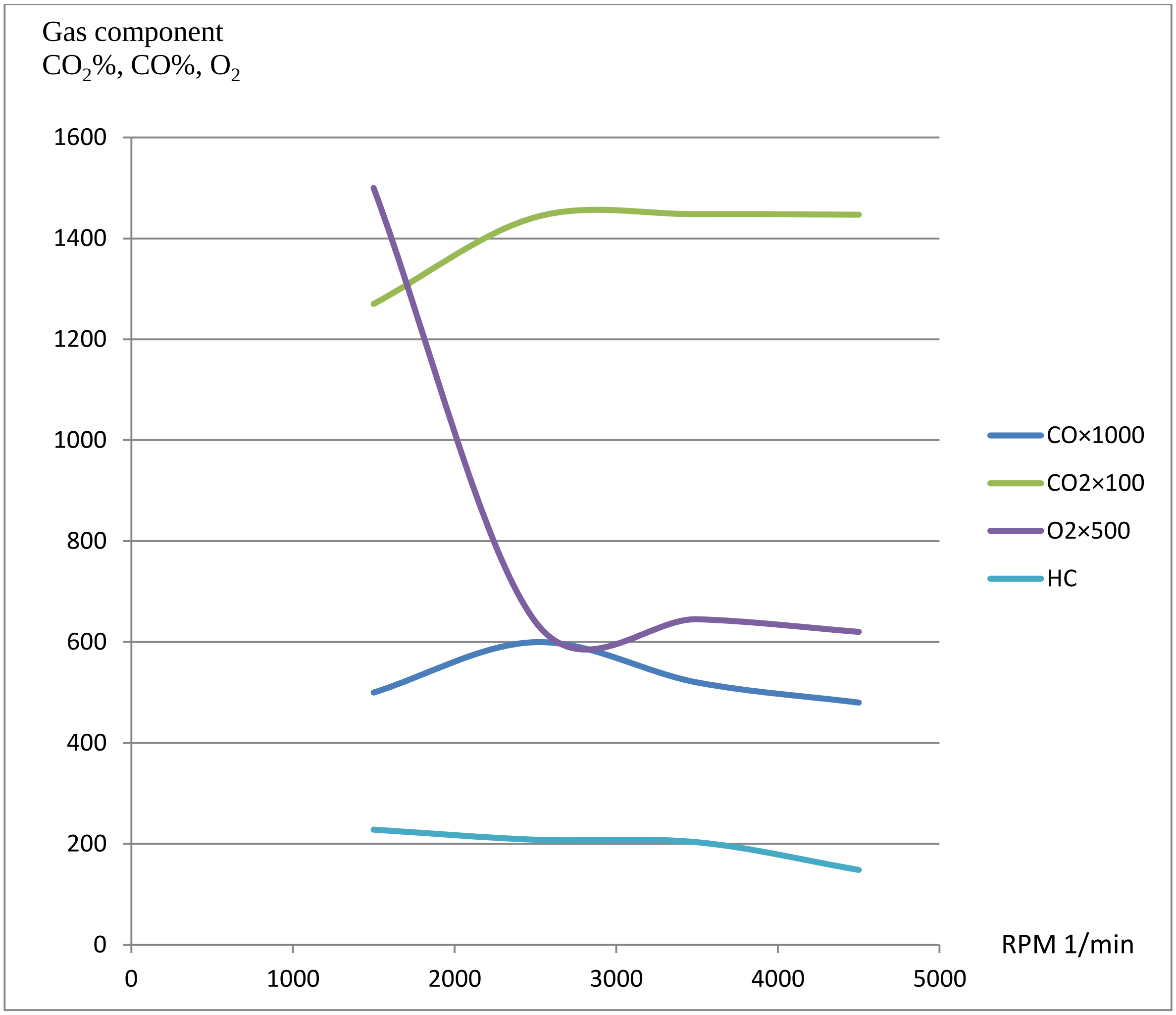


Fig 17 Exhaust gas composition depending on the speed (with cat's)

Engines emission with catalytic converter was measured at stoichiometric mixture λ=1.

Fig 17 shows that carbon dioxide ratio increases with speed increasing until it reaches 50% of speed then stop at this point, and carbon monoxide ratio increases till 50% of speed then starts decreasing gradually.

However, hydrocarbon ratio decreases slightly with speed increasing.

Table 5 comparing exhaust gas emission with and without catalytic converter

Rpm	HC[ppm]		CO_2[%]		O_2[%]		CO[%]	
	No cats	+cats	No cats	+cats	No cats	+cats	No cats	+cats
1400	476	230	10.8	12.5	4.04	3.08	2.39	0.485
4300	323.3	160	9.97	14.5	0.25	1.26	7.93	0.49
5000	238.5	115	10.37	14.5	0.16	1.2	7.2	0.46
5600	204	100	10.56	14.5	0.16	1.2	7.09	0.46

5.4 Conclusion

Table 5 compares the gases ration for engine equipped with cats and another without cats, at the same speed. All values are taken from Fig 14 and Fig 17, considering the difference of speed, so values were calculatED proportionally with speed. From this table we can conclude that using catalytic converter in the engine exhaust system leads to significantly less emission of hydrocarbons HC and carbon monoxide CO. This is due to the oxidation of CO, meanwhile, this is the reason of the decreasing of CO_2 emissions. While the increasing of oxygen ration in exhaust emission refers to the preserving a stoichiometric mixture during combustion using Lambda sensor.

6. DAILY FLIGHT PLAN FOR AIRCRAFT

At the end of 2007 a total of 6,066 aircraft were estimated to be in category LSA. The forecast assumes the fleet will increase approximately 930 aircraft per year until 2013 including both newly built aircraft and conversions from ultra-light trainers. Thereafter the rate of increase in the fleet tapers considerably to about 300 per year. By 2025 a total of 15,865 light sport aircraft are projected to be in the fleet.

The engine used in this kind of aircraft is piston engine (internal combustion engine) which burns aviation gasoline Avgas, eventually automobile gasoline Mogas. These aircraft, as will be shown in this chapter, is often used for training fly frequently for short periods and in the vicinity of the city. Therefore, they emit a significant amount of pollutants, which not only pollutes the air but also obscure the sun rays.

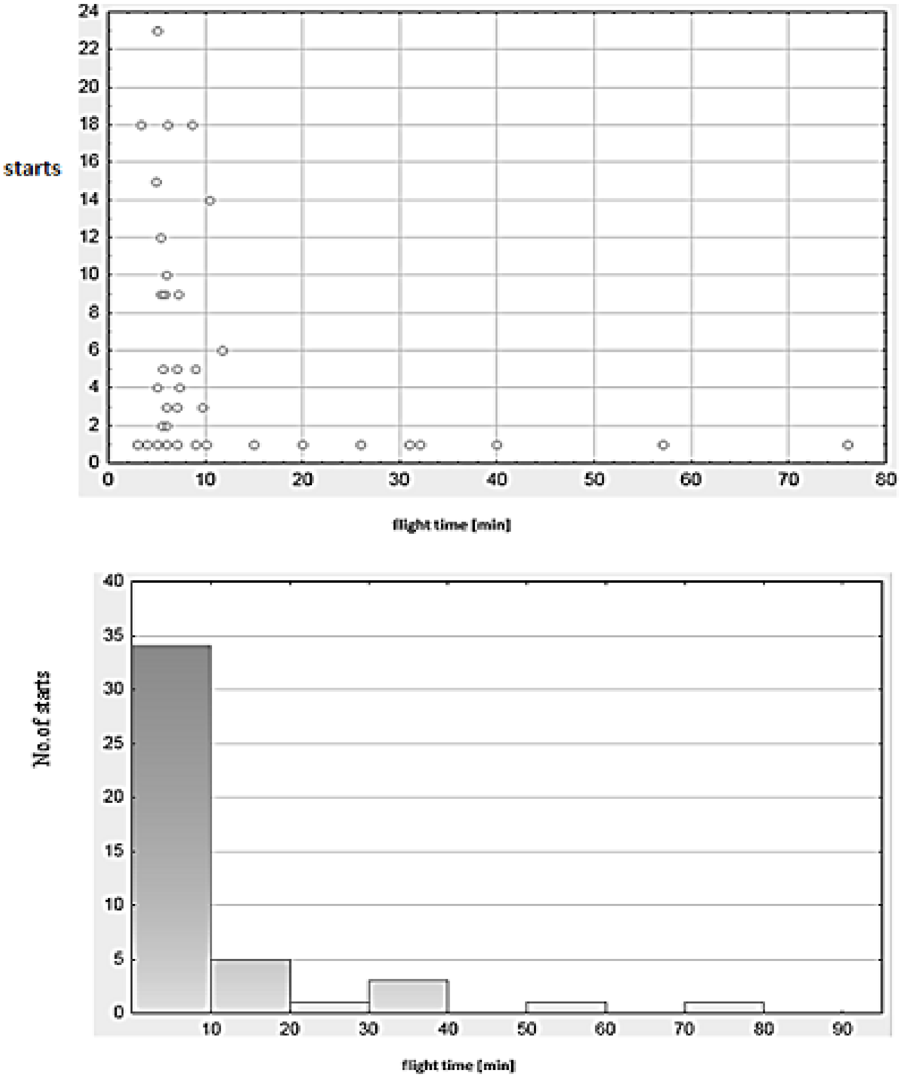


Fig 18 Histogram flight time [min] for airplane Z226 MS OK MGM, year 2013

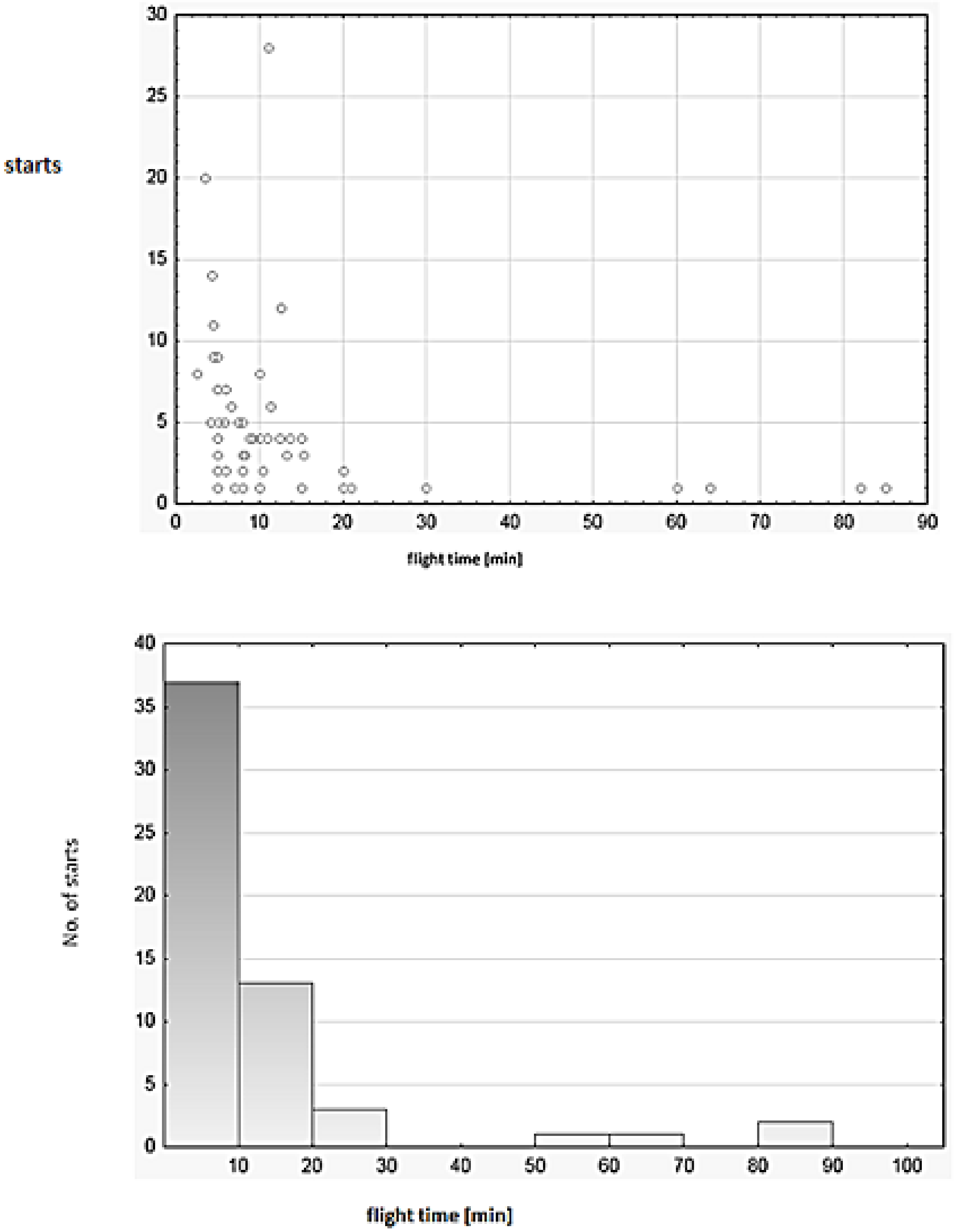


Fig 19 Histogram flight time [min] for airplane Z226 MS OK MGM, year 2012

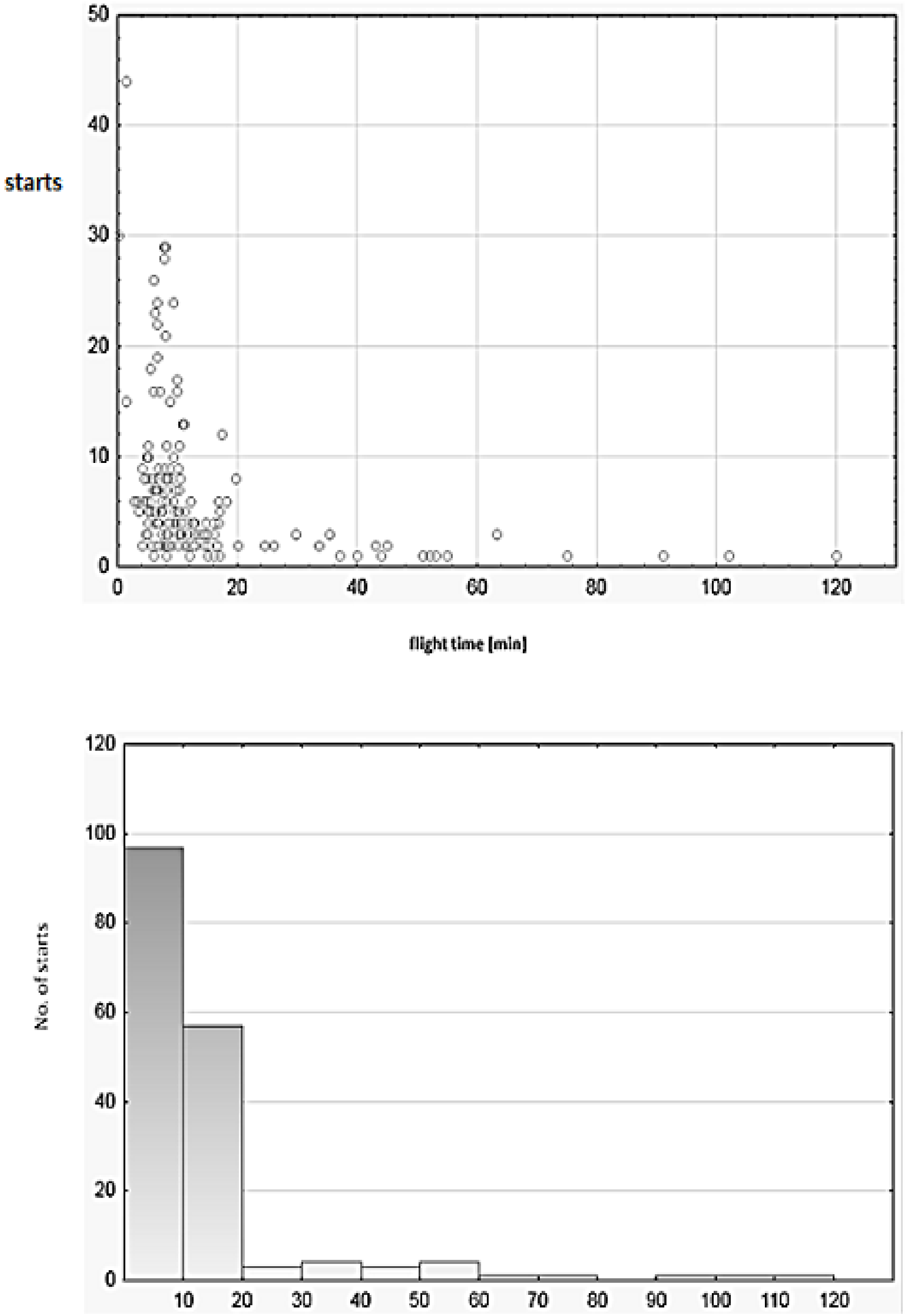


Fig 20 Histogram flight time [min] for airplane WT-9 OK-OUU, year 2012

Conclusion

In this chapter are details about daily flight plan (flight time, number of take-offs, and number of individual flights) for several airplanes from the category of LSA, ULA.

These timelines which are similar for all airplanes used for training, give us an idea about the most frequent flight time and the maximum probable one, and this allows the flexibility to change the maximum fuel amount in the airplane, or suggest another alternative motor which may be more suitable.

I chose airplanes which are used for training at the airport of Medlanky/ Brno, and made statistic for the flight period on 2012 and 2013. Daily flight plan for all examined airplanes are in Appendix A.

From the histograms in Fig 18, Fig 19 and Fig 20, we can notice that, the more number of occurrences is for the shorter flight time 0-10 min, and for 10-20 min, max flight time is between 100-120 min, and this means that these aircraft often fly at maximum power.

7. EXPERTS OPINIONS ABOUT ALTERNATIVE PROPULSION

Trying to reach the most suitable alternative solution for aircraft, there are several options that can be used as alternative propulsion for airplanes.

Taking into account the ecological aspect, it seems that the electric motor is the ideal option. However, considering the other aspects it was more complicated to decide which is the most appropriate option. Therefore, it was better to know the opinions of experts working in the field of aerospace. These opinions were statically examined using Delphi method.

Following is an overview about Delphi, hereafter the expert's opinions.

7.1 Delphi

The Delphi technique is a group of processes used to survey and collect the opinions of experts on a particular subject. Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem.

7.2 Areas of application

Linstone and turoff (1975) argued that Delphi has application in the following areas:

- Gathering current and historical data not accurately known or available.
- Evaluating possible budget allocations.
- Exploring urban and regional planning options.
- Planning university campus and curriculum development.
- Putting together an educational model.
- Delineating the pros and cons associated with potential policy options.
- Distinguishing and clarifying real and perceived human motivations.
- Exploring priorities of personal values, social goals, etc.

7.3 Characteristics of Delphi technique

Dalkey (1967) has identified the following basic characteristics of the Delphi technique:

1. Anonymity - - the use of questionnaires or other communication where expressed Responses are not identified as being from specific members of the panel allows for Anonymity.

2. Controlled feedback from the interaction - - controlled feedback allows interaction with a large reduction in discord among panel members. Interaction consists of allowing interaction among group members in several stages, with the results of the previous stage summarized and group members asked to reevaluate their answers as compared to the thinking of the group.

3. Statistical group response - the group opinion is defined as a statistical average of the final opinions of the individual members, with the opinion of every group member reflected in the final group response

7.4 Advantages of Delphi method

1. Anonymity of experts
2. The multi-round interviews with feedback on the previous round allows experts to change their mind
3. Ability to explore without emotion and objectively selected issues
4. Ideal for getting information about future general trends, phenomenon and ways to achieve it
5. It removes barriers to the achievement of consensus among experts in one location
6. It is independent on the personality’s experts.

7.5 Disadvantages

1. Delphi method has long term forecasting and their force thus cannot be verified
2. The Delphi technique is somewhat time consuming, which renders it ineffective when fast answers are needed
3. Possibility to get an extreme values
4. The success of the method depends on the appropriate selection of respondents.
5. It can be difficult for researchers to design an effective study. As with survey and other respondent-dependent research designs, the results from a Delphi study are determined in large part by how they are framed and conducted.

7.6 Applying Delphi for the case of two seats aircraft

A set of questions were sent to a group of 60 experts. These questions (written bellow) are about their opinions on the development of new engine or modification to drive two-seat sport aircraft category CS VLA.

Opinion about the development of new engine or modification to drive two-seat sport aircraft category CS VLA

Recommended numbers 1-7 (1 strongest, ..., 7 weakest)

☐ Using the current types of engines working on gasoline and focusing on increasing their efficiency, reliability, durability, weight reduction, emission and noise.

☐ Using the current types of engines equipped with catalytic converter.

☐ Modifying the current engines or developing new engines working on fuel gas such as LPG, natural gas or biogas with better emission ration.

☐ Developing a set of electric drive with rechargeable batteries, which will be charged from ordinary electrical outlet.

☐ Developing system of electric propulsion with hydrogen fuel cell.

☐ Developing hybrid drive (internal combustion engine + electrical motor working on battery)

☐ Other recommendation.

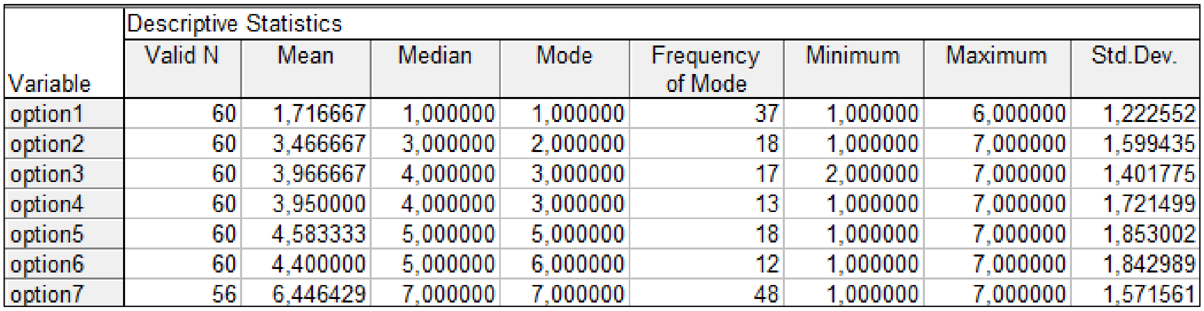
Is it appropriate to propose experimental aircraft that would allow easy installation of the first two recommendations (selected) drive species to measure the operating characteristics of these drives? (Delete what you do not agree with)

Yes No

The experts were asked to give each of the previous options a mark from 1 to 7. Expert's answers are in Appendix E,4.1.

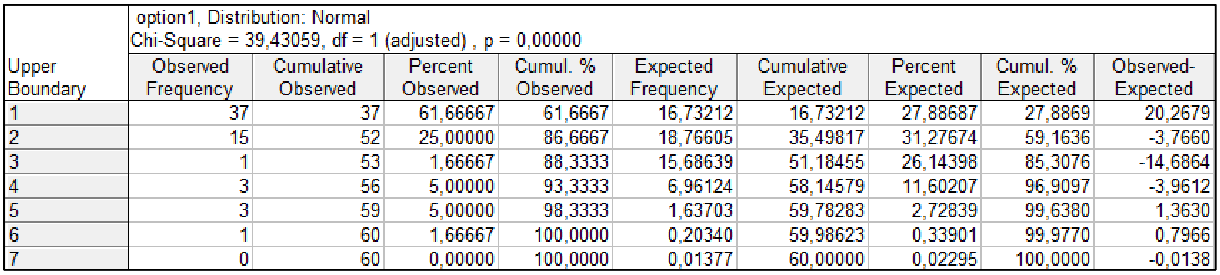
7.7 Result of statistical study

Table 6 Statistic table for the opinion about developing two seats aircraft



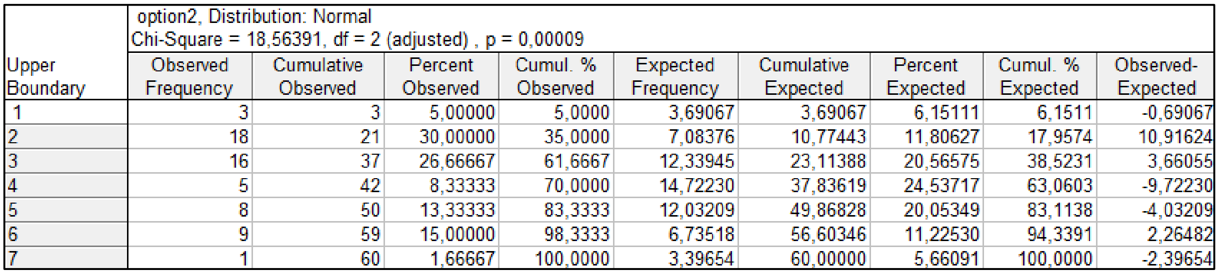
	Descriptive Statistics							
Variable	Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Std.Dev.
option1	60	1,716667	1,000000	1,000000	37	1,000000	6,000000	1,222552
option2	60	3,466667	3,000000	2,000000	18	1,000000	7,000000	1,599435
option3	60	3,966667	4,000000	3,000000	17	2,000000	7,000000	1,401775
option4	60	3,950000	4,000000	3,000000	13	1,000000	7,000000	1,721499
option5	60	4,583333	5,000000	5,000000	18	1,000000	7,000000	1,853002
option6	60	4,400000	5,000000	6,000000	12	1,000000	7,000000	1,842989
option7	56	6,446429	7,000000	7,000000	48	1,000000	7,000000	1,571561

Table 7 Fitting distribution and chi-square value for option 1 two seats aircrafts



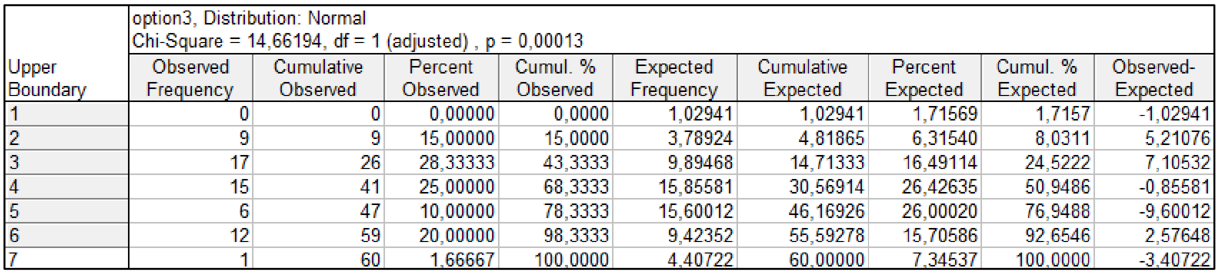
	option1, Distribution: Normal Chi-Square = 39,43059, df = 1 (adjusted) , p = 0,00000								
Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	37	37	61,66667	61,6667	16,73212	16,73212	27,88687	27,8869	20,2679
2	15	52	25,00000	86,6667	18,76605	35,49817	31,27674	59,1636	-3,7660
3	1	53	1,66667	88,3333	15,68639	51,18455	26,14398	85,3076	-14,6864
4	3	56	5,00000	93,3333	6,96124	58,14579	11,60207	96,9097	-3,9612
5	3	59	5,00000	98,3333	1,63703	59,78283	2,72839	99,6380	1,3630
6	1	60	1,66667	100,0000	0,20340	59,98623	0,33901	99,9770	0,7966
7	0	60	0,00000	100,0000	0,01377	60,00000	0,02295	100,0000	-0,0138

Table 8 Fitting distribution and chi-square value for option 2 two seats aircrafts



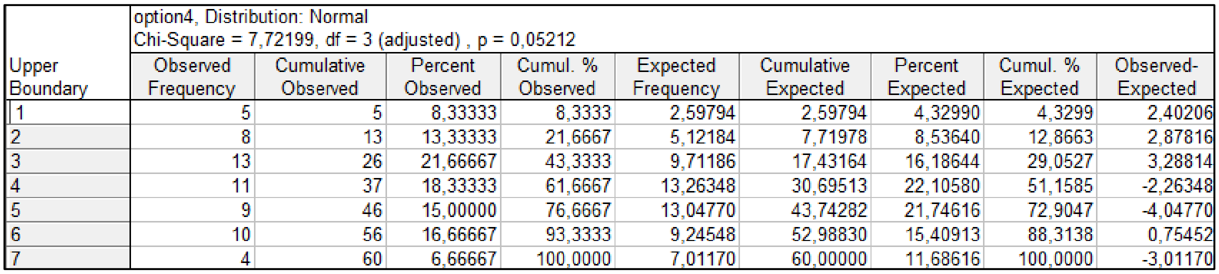
	option2, Distribution: Normal Chi-Square = 18,56391, df = 2 (adjusted) , p = 0,00009								
Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	3	3	5,00000	5,0000	3,69067	3,69067	6,15111	6,1511	-0,69067
2	18	21	30,00000	35,0000	7,08376	10,77443	11,80627	17,9574	10,91624
3	16	37	26,66667	61,6667	12,33945	23,11388	20,56575	38,5231	3,66055
4	5	42	8,33333	70,0000	14,72230	37,83619	24,53717	63,0603	-9,72230
5	8	50	13,33333	83,3333	12,03209	49,86828	20,05349	83,1138	-4,03209
6	9	59	15,00000	98,3333	6,73518	56,60346	11,22530	94,3391	2,26482
7	1	60	1,66667	100,0000	3,39654	60,00000	5,66091	100,0000	-2,39654

Table 9 Fitting distribution and chi-square value for option 3 two seats aircrafts



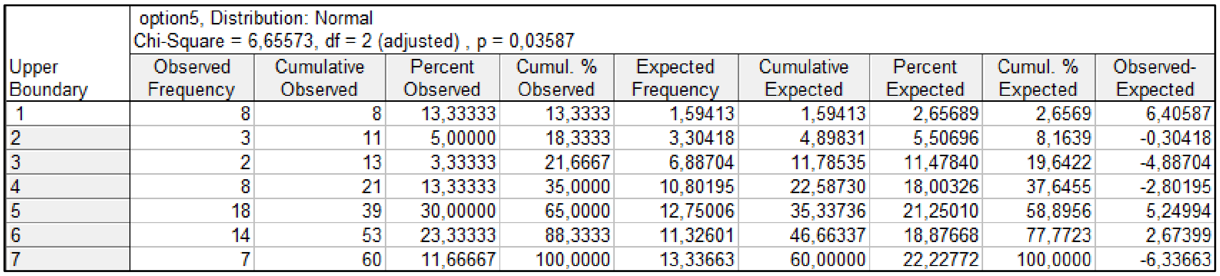
Upper Boundary	option3, Distribution: Normal Chi-Square = 14,66194, df = 1 (adjusted) , p = 0,00013								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	0	0	0,00000	0,0000	1,02941	1,02941	1,71569	1,7157	-1,02941
2	9	9	15,00000	15,0000	3,78924	4,81865	6,31540	8,0311	5,21076
3	17	26	28,33333	43,3333	9,89468	14,71333	16,49114	24,5222	7,10532
4	15	41	25,00000	68,3333	15,85581	30,56914	26,42635	50,9486	-0,85581
5	6	47	10,00000	78,3333	15,60012	46,16926	26,00020	76,9488	-9,60012
6	12	59	20,00000	98,3333	9,42352	55,59278	15,70586	92,6546	2,57648
7	1	60	1,66667	100,0000	4,40722	60,00000	7,34537	100,0000	-3,40722

Table 10 Fitting distribution and chi-square value for option 4 two seats aircrafts



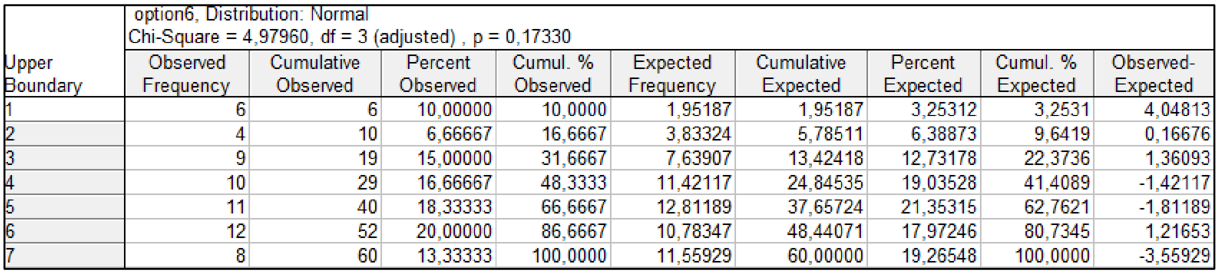
Upper Boundary	option4, Distribution: Normal Chi-Square = 7,72199, df = 3 (adjusted) , p = 0,05212								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	5	5	8,33333	8,3333	2,59794	2,59794	4,32990	4,3299	2,40206
2	8	13	13,33333	21,6667	5,12184	7,71978	8,53640	12,8663	2,87816
3	13	26	21,66667	43,3333	9,71186	17,43164	16,18644	29,0527	3,28814
4	11	37	18,33333	61,6667	13,26348	30,69513	22,10580	51,1585	-2,26348
5	9	46	15,00000	76,6667	13,04770	43,74282	21,74616	72,9047	-4,04770
6	10	56	16,66667	93,3333	9,24548	52,98830	15,40913	88,3138	0,75452
7	4	60	6,66667	100,0000	7,01170	60,00000	11,68616	100,0000	-3,01170

Table 11 Fitting distribution and chi-square value for option 5 two seats aircrafts



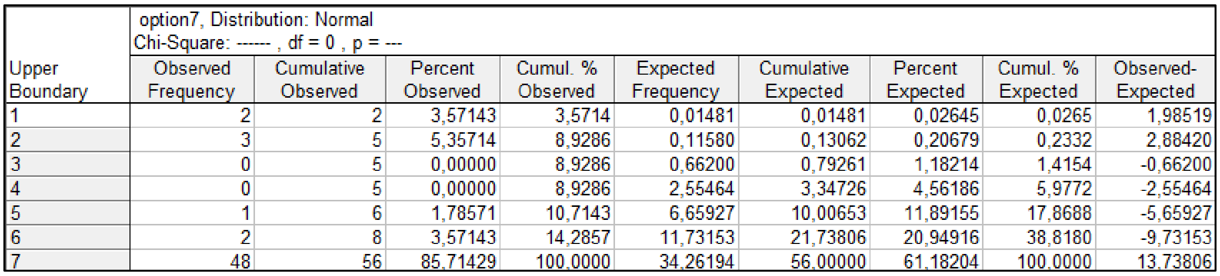
Upper Boundary	option5, Distribution: Normal Chi-Square = 6,65573, df = 2 (adjusted) , p = 0,03587								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	8	8	13,33333	13,3333	1,59413	1,59413	2,65689	2,6569	6,40587
2	3	11	5,00000	18,3333	3,30418	4,89831	5,50696	8,1639	-0,30418
3	2	13	3,33333	21,6667	6,88704	11,78535	11,47840	19,6422	-4,88704
4	8	21	13,33333	35,0000	10,80195	22,58730	18,00326	37,6455	-2,80195
5	18	39	30,00000	65,0000	12,75006	35,33736	21,25010	58,8956	5,24994
6	14	53	23,33333	88,3333	11,32601	46,66337	18,87668	77,7723	2,67399
7	7	60	11,66667	100,0000	13,33663	60,00000	22,22772	100,0000	-6,33663

Table 12 Fitting distribution and chi-square value for option 6 two seats aircrafts



Upper Boundary	option6, Distribution: Normal Chi-Square = 4,97960, df = 3 (adjusted) , p = 0,17330								
	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	6	6	10,00000	10,0000	1,95187	1,95187	3,25312	3,2531	4,04813
2	4	10	6,66667	16,6667	3,83324	5,78511	6,38873	9,6419	0,16676
3	9	19	15,00000	31,6667	7,63907	13,42418	12,73178	22,3736	1,36093
4	10	29	16,66667	48,3333	11,42117	24,84535	19,03528	41,4089	-1,42117
5	11	40	18,33333	66,6667	12,81189	37,65724	21,35315	62,7621	-1,81189
6	12	52	20,00000	86,6667	10,78347	48,44071	17,97246	80,7345	1,21653
7	8	60	13,33333	100,0000	11,55929	60,00000	19,26548	100,0000	-3,55929

Table 13 Fitting distribution and chi-square value for option 7 two seats aircrafts



option7, Distribution: Normal
Chi-Square: ------ , df = 0 , p = ---

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	2	2	3,57143	3,5714	0,01481	0,01481	0,02645	0,0265	1,98519
2	3	5	5,35714	8,9286	0,11580	0,13062	0,20679	0,2332	2,88420
3	0	5	0,00000	8,9286	0,66200	0,79261	1,18214	1,4154	-0,66200
4	0	5	0,00000	8,9286	2,55464	3,34726	4,56186	5,9772	-2,55464
5	1	6	1,78571	10,7143	6,65927	10,00653	11,89155	17,8688	-5,65927
6	2	8	3,57143	14,2857	11,73153	21,73806	20,94916	38,8180	-9,73153
7	48	56	85,71429	100,0000	34,26194	56,00000	61,18204	100,0000	13,73806

7.8 Applying Delphi for the case of four seats aircraft

Another group of question was sent to the experts about their opinions on the development new engine or modifications to drive four seat sport aircraft (category CS23-N).

Opinion about developing a new engine or modifications to drive four seat sport aircraft category CS 23 – N

Recommended no. 1-7 (1 the strongest,7 the weakest)

☐ Using the current types of gasoline engines and focusing on increasing their efficiency, reliability, durability, weight reduction, emissions and noise.

☐ Modifying the current engines or developing new engines working on fuel gas (LPG, natural gas, biogas) with acceptable emission ratio.

☐ Using turboprop engines with acceptable emission ratios.

☐ Developing a set of electrical drive with rechargeable batteries, which will be charged from ordinary electrical outlet.

☐ Developing system of electric motor and hydrogen fuel cell.

☐ Developing hybrid propulsion system.

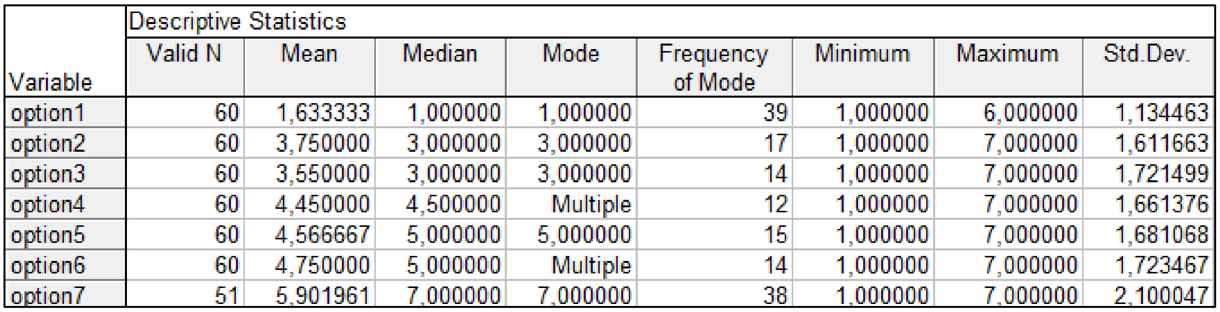
☐ Other recommendation.

Would be appropriate to hold a working meeting of responsible workers (representatives) selected manufacturing companies, VZLÚ, CAA, Czech Technical University in Prague, Brno UO, VSB-TU Ostrava, that focus on the issue of development of small aircraft with alternative drive? (Delete what you do not agree with)

Yes No

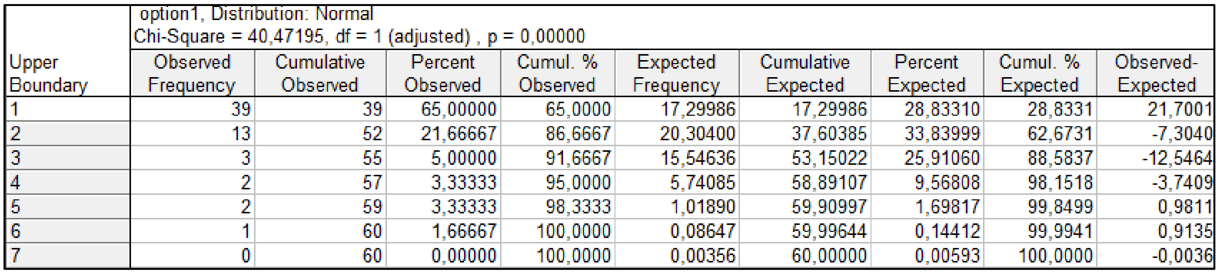
The experts were asked to give each of the previous options a mark from 1 to 7. Expert's answers are in Appendix E, 4.2.

Table 14 Statistic table of four seats aircraft



Variable	Descriptive Statistics Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Std.Dev.
option1	60	1,633333	1,000000	1,000000	39	1,000000	6,000000	1,134463
option2	60	3,750000	3,000000	3,000000	17	1,000000	7,000000	1,611663
option3	60	3,550000	3,000000	3,000000	14	1,000000	7,000000	1,721499
option4	60	4,450000	4,500000	Multiple	12	1,000000	7,000000	1,661376
option5	60	4,566667	5,000000	5,000000	15	1,000000	7,000000	1,681068
option6	60	4,750000	5,000000	Multiple	14	1,000000	7,000000	1,723467
option7	51	5,901961	7,000000	7,000000	38	1,000000	7,000000	2,100047

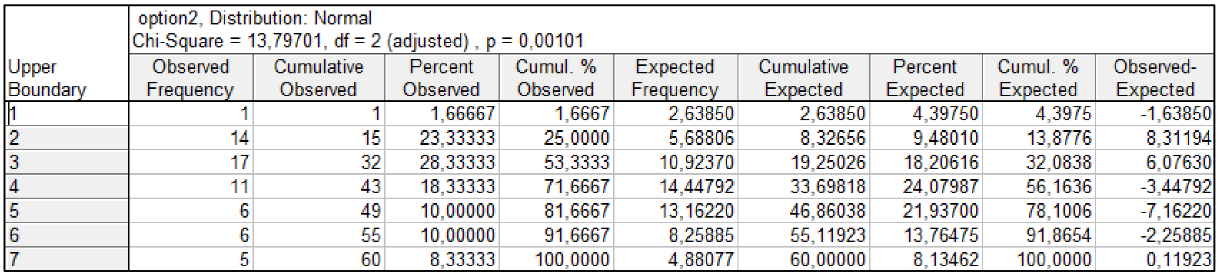
Table 15 Fitting distribution and chi-square value for option 1 four seats aircrafts



option1, Distribution: Normal
Chi-Square = 40,47195, df = 1 (adjusted) , p = 0,00000

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	39	39	65,00000	65,0000	17,29986	17,29986	28,83310	28,8331	21,7001
2	13	52	21,66667	86,6667	20,30400	37,60385	33,83999	62,6731	-7,3040
3	3	55	5,00000	91,6667	15,54636	53,15022	25,91060	88,5837	-12,5464
4	2	57	3,33333	95,0000	5,74085	58,89107	9,56808	98,1518	-3,7409
5	2	59	3,33333	98,3333	1,01890	59,90997	1,69817	99,8499	0,9811
6	1	60	1,66667	100,0000	0,08647	59,99644	0,14412	99,9941	0,9135
7	0	60	0,00000	100,0000	0,00356	60,00000	0,00593	100,0000	-0,0036

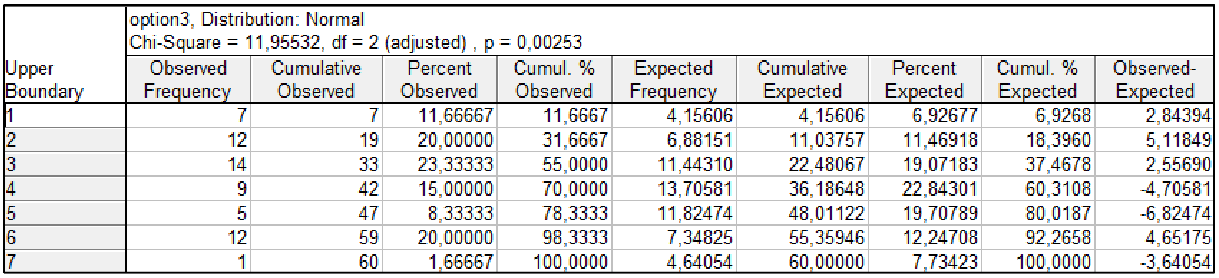
Table 16 Fitting distribution and chi-square value for option 2 four seats aircrafts



option2, Distribution: Normal
Chi-Square = 13,79701, df = 2 (adjusted) , p = 0,00101

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	1	1	1,66667	1,6667	2,63850	2,63850	4,39750	4,3975	-1,63850
2	14	15	23,33333	25,0000	5,68806	8,32656	9,48010	13,8776	8,31194
3	17	32	28,33333	53,3333	10,92370	19,25026	18,20616	32,0838	6,07630
4	11	43	18,33333	71,6667	14,44792	33,69818	24,07987	56,1636	-3,44792
5	6	49	10,00000	81,6667	13,16220	46,86038	21,93700	78,1006	-7,16220
6	6	55	10,00000	91,6667	8,25885	55,11923	13,76475	91,8654	-2,25885
7	5	60	8,33333	100,0000	4,88077	60,00000	8,13462	100,0000	0,11923

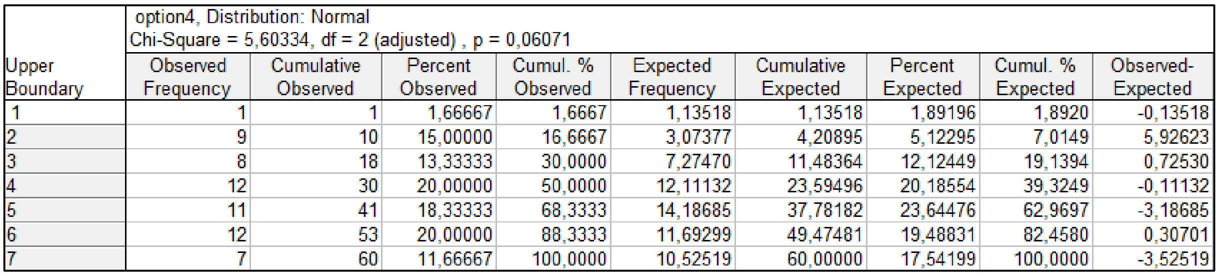
Table 17 Fitting distribution and chi-square value for option 3 four seats aircrafts



option3, Distribution: Normal
Chi-Square = 11,95532, df = 2 (adjusted) , p = 0,00253

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	7	7	11,66667	11,6667	4,15606	4,15606	6,92677	6,9268	2,84394
2	12	19	20,00000	31,6667	6,88151	11,03757	11,46918	18,3960	5,11849
3	14	33	23,33333	55,0000	11,44310	22,48067	19,07183	37,4678	2,55690
4	9	42	15,00000	70,0000	13,70581	36,18648	22,84301	60,3108	-4,70581
5	5	47	8,33333	78,3333	11,82474	48,01122	19,70789	80,0187	-6,82474
6	12	59	20,00000	98,3333	7,34825	55,35946	12,24708	92,2658	4,65175
7	1	60	1,66667	100,0000	4,64054	60,00000	7,73423	100,0000	-3,64054

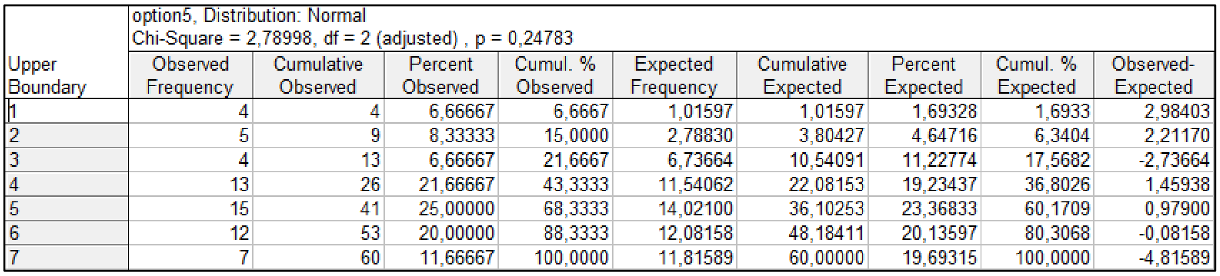
Table 18 Fitting distribution and chi-square value for option 4 four seats aircrafts



option4, Distribution: Normal
Chi-Square = 5,60334, df = 2 (adjusted) , p = 0,06071

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	1	1	1,66667	1,6667	1,13518	1,13518	1,89196	1,8920	-0,13518
2	9	10	15,00000	16,6667	3,07377	4,20895	5,12295	7,0149	5,92623
3	8	18	13,33333	30,0000	7,27470	11,48364	12,12449	19,1394	0,72530
4	12	30	20,00000	50,0000	12,11132	23,59496	20,18554	39,3249	-0,11132
5	11	41	18,33333	68,3333	14,18685	37,78182	23,64476	62,9697	-3,18685
6	12	53	20,00000	88,3333	11,69299	49,47481	19,48831	82,4580	0,30701
7	7	60	11,66667	100,0000	10,52519	60,00000	17,54199	100,0000	-3,52519

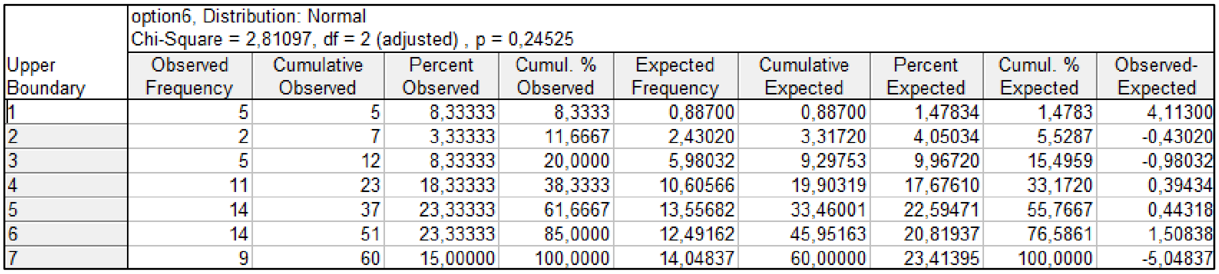
Table 19 Fitting distribution and chi-square value for option 5 four seats aircrafts



option5, Distribution: Normal
Chi-Square = 2,78998, df = 2 (adjusted) , p = 0,24783

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	4	4	6,66667	6,6667	1,01597	1,01597	1,69328	1,6933	2,98403
2	5	9	8,33333	15,0000	2,78830	3,80427	4,64716	6,3404	2,21170
3	4	13	6,66667	21,6667	6,73664	10,54091	11,22774	17,5682	-2,73664
4	13	26	21,66667	43,3333	11,54062	22,08153	19,23437	36,8026	1,45938
5	15	41	25,00000	68,3333	14,02100	36,10253	23,36833	60,1709	0,97900
6	12	53	20,00000	88,3333	12,08158	48,18411	20,13597	80,3068	-0,08158
7	7	60	11,66667	100,0000	11,81589	60,00000	19,69315	100,0000	-4,81589

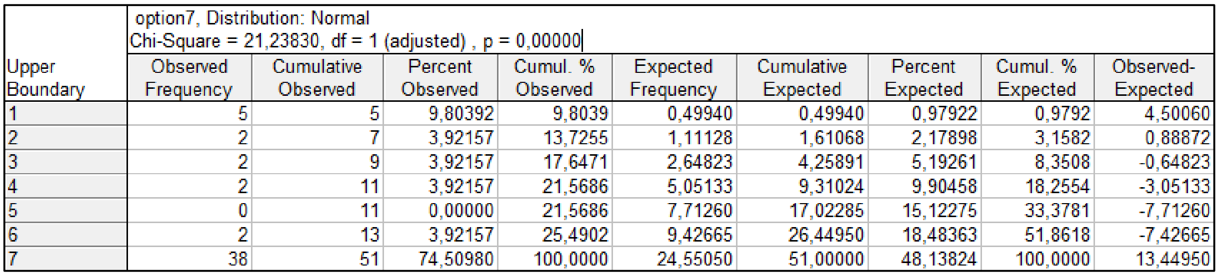
Table 20 Fitting distribution and chi-square value for option 6 four seats aircrafts



option6, Distribution: Normal
Chi-Square = 2,81097, df = 2 (adjusted) , p = 0,24525

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	5	5	8,33333	8,3333	0,88700	0,88700	1,47834	1,4783	4,11300
2	2	7	3,33333	11,6667	2,43020	3,31720	4,05034	5,5287	-0,43020
3	5	12	8,33333	20,0000	5,98032	9,29753	9,96720	15,4959	-0,98032
4	11	23	18,33333	38,3333	10,60566	19,90319	17,67610	33,1720	0,39434
5	14	37	23,33333	61,6667	13,55682	33,46001	22,59471	55,7667	0,44318
6	14	51	23,33333	85,0000	12,49162	45,95163	20,81937	76,5861	1,50838
7	9	60	15,00000	100,0000	14,04837	60,00000	23,41395	100,0000	-5,04837

Table 21 Fitting distribution and chi-square value for option 7 two four aircrafts



option7, Distribution: Normal
Chi-Square = 21,23830, df = 1 (adjusted) , p = 0,00000

Upper Boundary	Observed Frequency	Cumulative Observed	Percent Observed	Cumul. % Observed	Expected Frequency	Cumulative Expected	Percent Expected	Cumul. % Expected	Observed-Expected
1	5	5	9,80392	9,8039	0,49940	0,49940	0,97922	0,9792	4,50060
2	2	7	3,92157	13,7255	1,11128	1,61068	2,17898	3,1582	0,88872
3	2	9	3,92157	17,6471	2,64823	4,25891	5,19261	8,3508	-0,64823
4	2	11	3,92157	21,5686	5,05133	9,31024	9,90458	18,2554	-3,05133
5	0	11	0,00000	21,5686	7,71260	17,02285	15,12275	33,3781	-7,71260
6	2	13	3,92157	25,4902	9,42665	26,44950	18,48363	51,8618	-7,42665
7	38	51	74,50980	100,0000	24,55050	51,00000	48,13824	100,0000	13,44950

7.9 Conclusion

Tables 7-14 show that 61.6% of experts voted strongly for using the current types of engines working on gasoline and focusing on increasing their efficiency, reliability, durability, weight reduction, emission and noise.

30% said that adding catalytic converter for current aircraft is on the second place, 28% said that using LPG is in the third place and 21% gave it the fourth place.

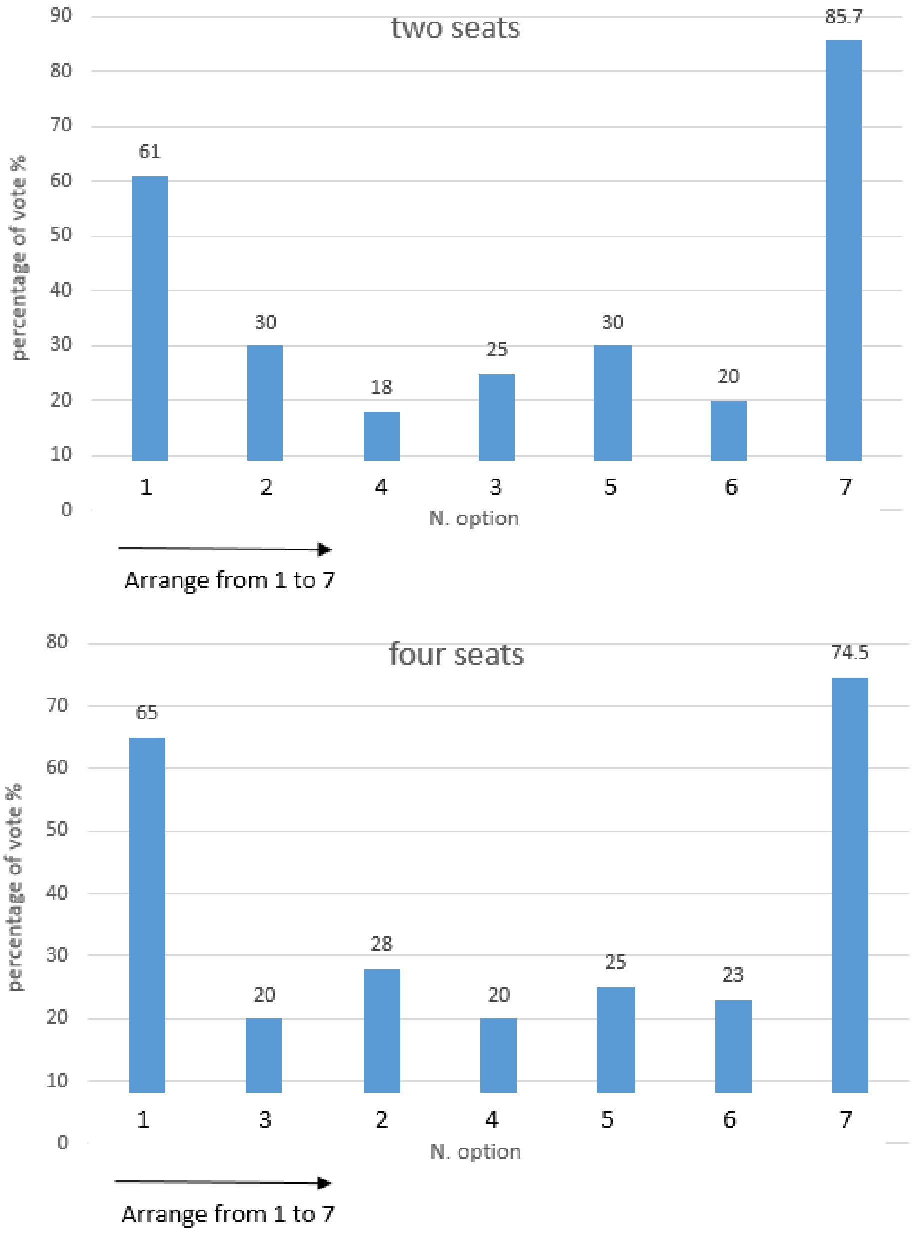


Fig 21 Percentage of vote for all option

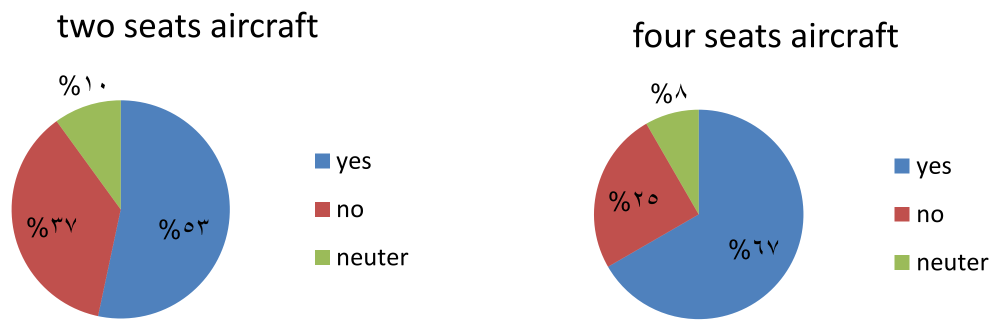


Fig 22 Experts opinions about proposing experimental aircraft (two seats) and using alternative fuel (four seats)

Fig 22 and Fig 21 show that 53% of experts think that it would be appropriate to propose experimental aircraft that would allow easy installation of the first two recommendations to measure their operating characteristics. 67% of experts think that it would be appropriate to hold a working meeting of responsible manufacturing companies focusing on developing small aircraft with alternative drive.

Tables 16-22 show that 65% of experts voted strongly for using the current types of gasoline engines and focusing on increasing their efficiency, reliability, durability, weight reduction, emissions and noise.

28.3% said that using turboprop engines with acceptable emission ratios is on the second place, 23.3 % said that using LPG is in the third place.

8. USING LPG AS ALTERNATIVE FUEL

LPG for internal combustion engines is labeled as HD5 and it requires minimum propane content (C_3H_8) of 90%.

LPG is a by-product from two sources, natural gas processing and crude oil refining. Natural gas, as extracted at the well-head, contains methane and other light hydrocarbons. The light hydrocarbons are separated in a gas processing plant using high pressures and low temperatures. The natural gas liquid components recovered during processing include ethane, propane, and butane, as well as heavier hydrocarbons. Propane and butane, along with other gases, are also produced during crude oil refining as a by-product of the processes that rearrange and/or break down molecular structures to obtain more desirable petroleum compounds.

8.1 Pollutants, greenhouse gases and emission factor

LPG is considered as "clean" fuel because it does not produce visible emissions. However, gaseous pollutants such as nitrogen oxides (NO_x), carbon monoxide (CO), and organic compounds are produced as are small amounts of SO_2 and PM.

Greenhouse gases (carbon dioxide (CO_2), methane (CH_4), and (N_2O) emissions) are all produced during LPG combustion. Nearly all of the fuel carbon (99.5 percent) in LPG is converted to CO_2 during the combustion process. This conversion is relatively independent of firing configuration. Although the formation of CO acts to reduce CO_2 emissions, the produced amount is insignificant compared to the amount of CO_2 produced. The majority of the 0.5 percent of fuel carbon not converted to CO_2 that is due to the incomplete combustion in the fuel stream.

Formation of N_2O during the combustion process is governed by a complex series of reactions and its formation is dependent upon many factors. Formation of N_2O is minimized when combustion temperatures are kept high (above 1475) and excess air is kept to a minimum (less than 1 percent).

Methane emissions are highest during periods of low-temperature combustion or incomplete combustion, such as the start-up or shut-down. Typically, conditions that favor formation of N_2O also favor emissions of CH_4.

Therefore, as shown in Table 22, the N_2O and CH_4 emission factor for LPG and Avgas is the same for energy unite, but it is less for the volume unite and it is due to the less calorific value of LPG comparing with Avgas (as shown in Table 24)

On the other hand. CO_2 factor for LPG is less than that for Avgas.

Table 22 Comparison emission factor LPG and Avgas

Fuel	CO_2 kg/mmbtu kg/MJ	CH_4 g/mmbtu, g/MJ	N_2O g/mmbtu, g/MJ	CO_2 kg/l	CH_4 g/l	N_2O g/l
Avgas	69.25/0.065	3/0.002	0.6/0.0005	2.19	0.095	0.018
LPG	61.71/0.059	3/0.002	0.6/0.0005	1.5	0.07	0.015

8.2 Advantages and disadvantages of using LPG fuel

LPG advantages:

- LPG is a hydrocarbon composed of C_3 and C_4. It is free of dust and can be completely combusted.
- LPG has relatively high octane number 104 and that increases the fuel efficiency.
- Because it burns in the engine in the gaseous phase, propane results in less corrosion and engine wear.
- Benefits associated with a maintenance
  - Less frequent oil and filter change
  - No formation of impurities in the engine
  - Longer life of exhaust parts
  - LPG cleans the spark plugs
  - Longer engine life

LPG disadvantages:

- The low vapor pressure of propane at low temperature could make a problem with starting in cold weather.
- LPG prices are higher than other fuel.
- LPG has less heat content/ dm^3 than jet fuel and Avgas.
- It damages the valves, resulting in a decrease of the engine life, because it doesn't use lead or any other substitute for combustion.
- Increasing in fuel consumption about 10%.
- Slight reduction in engine power by about 5%.

Table 23 LPG properties

Chemical formula		Propane C_3H_8	Butane C_4H_{10}
Boiling point of liquid at atmospheric pressure	°C	-42	0
Calorific value @ 60 °f (15 °C)	MJ/m^3	93.74	122.21
Latent heat of vaporization	Kcal/kg	102.9	105.9

Liquid weight/ density	kg/dm^3	0.508	0.576
Vapor volume from 1 dm^3 of liquid at 15 °C	m^3	0.272	0.234
Vapor volume from 1 kg of liquid at 15 °C	m^3	0.534	0.406
Amount of air required to burn 1 m^3 of gas	m^3	23.86	31.02
Ignition temperature in air	°C	490-550	480-540
Maximum flame temperature in air	°C	1980	1991
Octane number		Over 100	92

Table 24 Calorific value for various type of aviation fuel

Fuel	Calorific value [btu/gallon]	Calorific value [MJ/dm^3]
Jet fuel	125800	35.04
Biodiesel	117000-120000	32.58÷33.42
Avgas	112500	31.33
LPG	≈84000	23.39
Ethanol	≈80000	22.28
CNG(@ 3000 psi)	33000-38000	9.19÷10.58

8.3 LPG fuel system

LPG fuel system must consist of the following basic parts:

Pressure tank: which is made of steel or composite material (glass fiber and reinforced vinyl ester), and tested at pressure 67 bar and pressure pumping is 10 bar.

LPG tanks must never be filled to more than about 85% of the internal volume. When the valve of an LPG is opened, the pressure inside the cylinder is reduced and the liquid starts to vaporize (boil) at lower pressure.

The LPG tank is equipped with multi-valve that ensures filling the tank with LPG to max 80%. Is equipped with a pressure and a thermal fuse, which at elevated pressure releases gas outside the vehicle.

Vacuum fuel-lock filter: it has two primary functions:

- It prevents dirty fuel from reaching the carburetor.
- It shuts off the fuel flow automatically, regardless of the ignition being on or off.

Pressure regulator/vaporizer: It reduces fuel pressure in two stages and meter the fuel output in relation to a negative pressure signal (vacuum) from the carburetors, and convert the fuel from a liquid to a vapor.

8.4 Proposal of LPG fuel system

LPG system was proposed for airplane VUT-081 Kondor Fig 23 (this aircraft was designed, manufatured and tested in laboratory of aerospace engineering institute), which is a two-seat airplane of mixed construction with a conceptual layout representing the fuselage gondola tandem seat arrangement with thrust propulsion unite and tail hanging from the wing fuselage using two beams. The chassis is retractable, nose type with controlled front wheel.

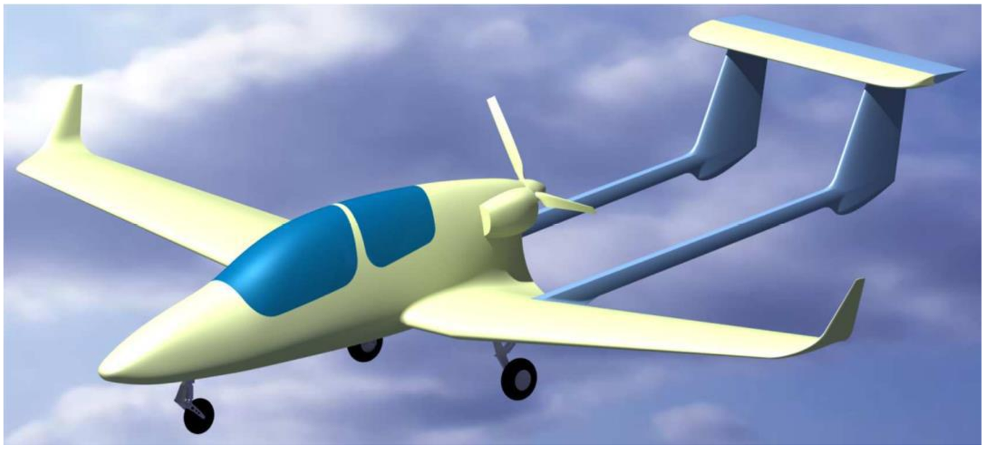


Fig 23 Airplane VUT-081 Kondor

The power unit consists of piston engine with fuel injection Rotax 912 IS (100 HP). Engine characteristic are shown in Table 25, Fig 24 and Fig 25.

Table 25 Engine characteristic

Regime	Power [KW]	Engine speed [rpm]	Propeller speed [rpm]	Consumption [lit/h]
Take-off	73.5	5800	2387	26.1
Permanent	69.8	5500	2263	23.6
75%	61.4	5000	2054	16.5

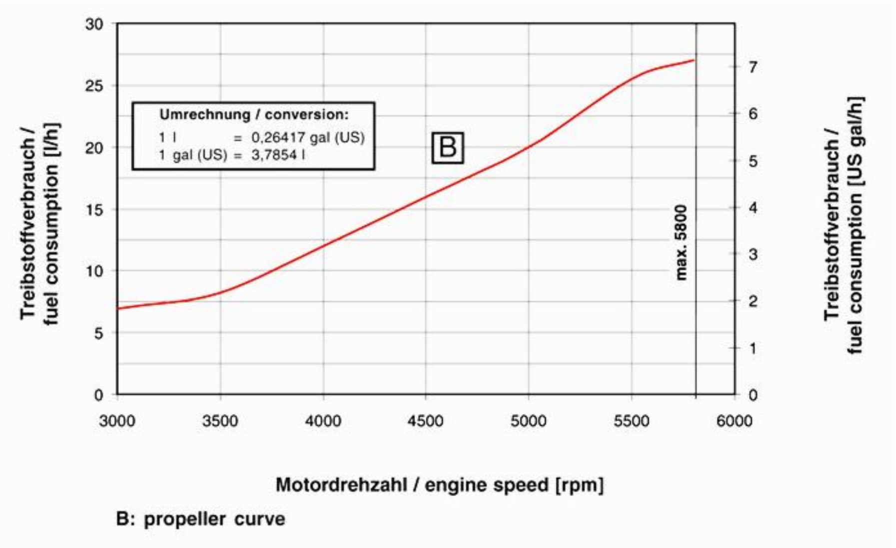


Fig 24 ROTAX engine fuel consumption for different engine speeds

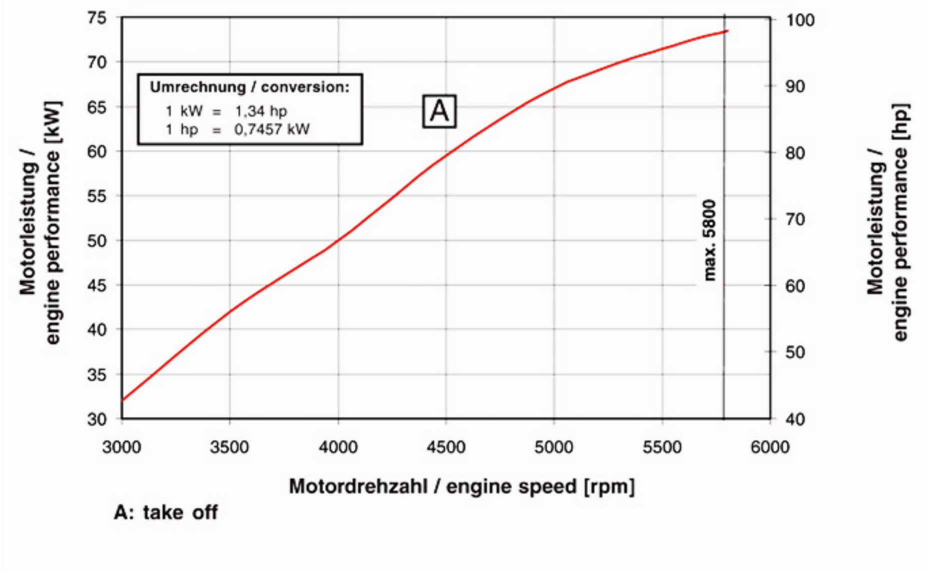


Fig 25 ROTAX engine performance for different engine speeds

The aircraft is equipped with a three-blade pusher propeller that is adjustable constant speed woodcomp SR-3000. Propeller diameter is 1650 mm.

Due to the lack of information on the propeller, it is used for the calculation a characteristics for propeller of similar category, hoffmann HO-V62R. Factor reduction in the efficiency of its buildings propeller airplane was set at 0.9058 . The effectiveness of the propeller is shown in the Fig 26.

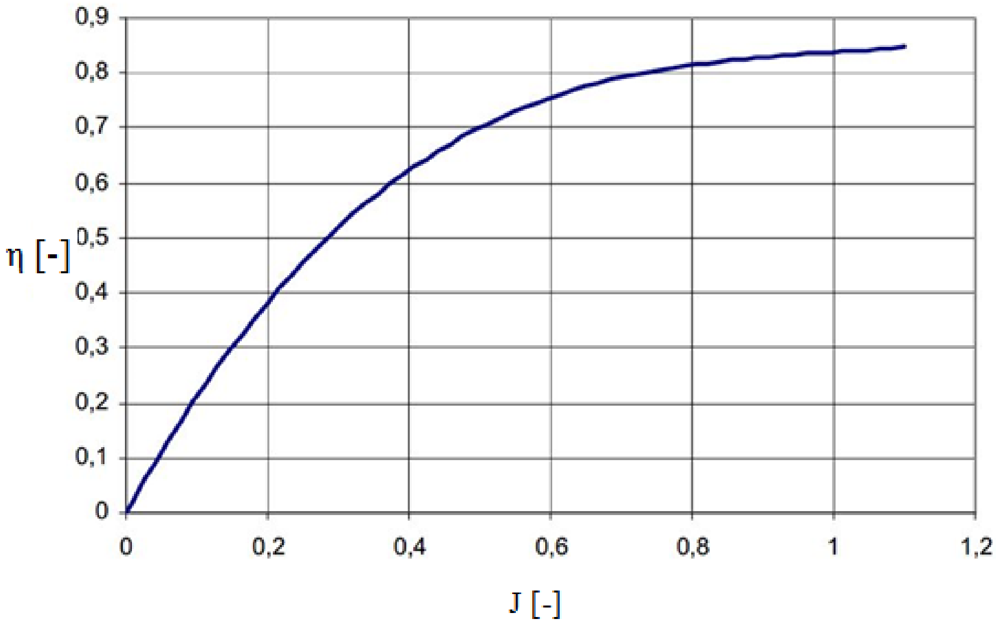


Fig 26 Propeller efficiency [15]

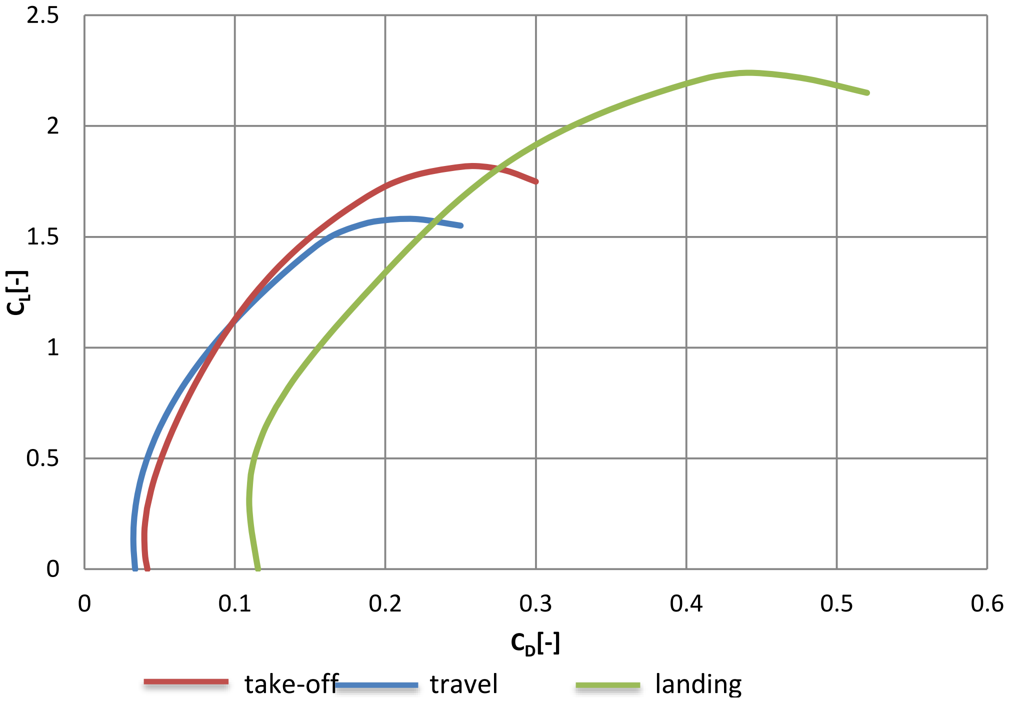


Fig 27 Airplane polar for different configuration [15]

Table 26 Max. lift coefficient

Configuration	Max. lift coefficient
Travel	1.58
Take-off	1.81
Landing	2.24

Basic geometry of airplane is shown in Fig 28, wing area S= 11,85 m^2.

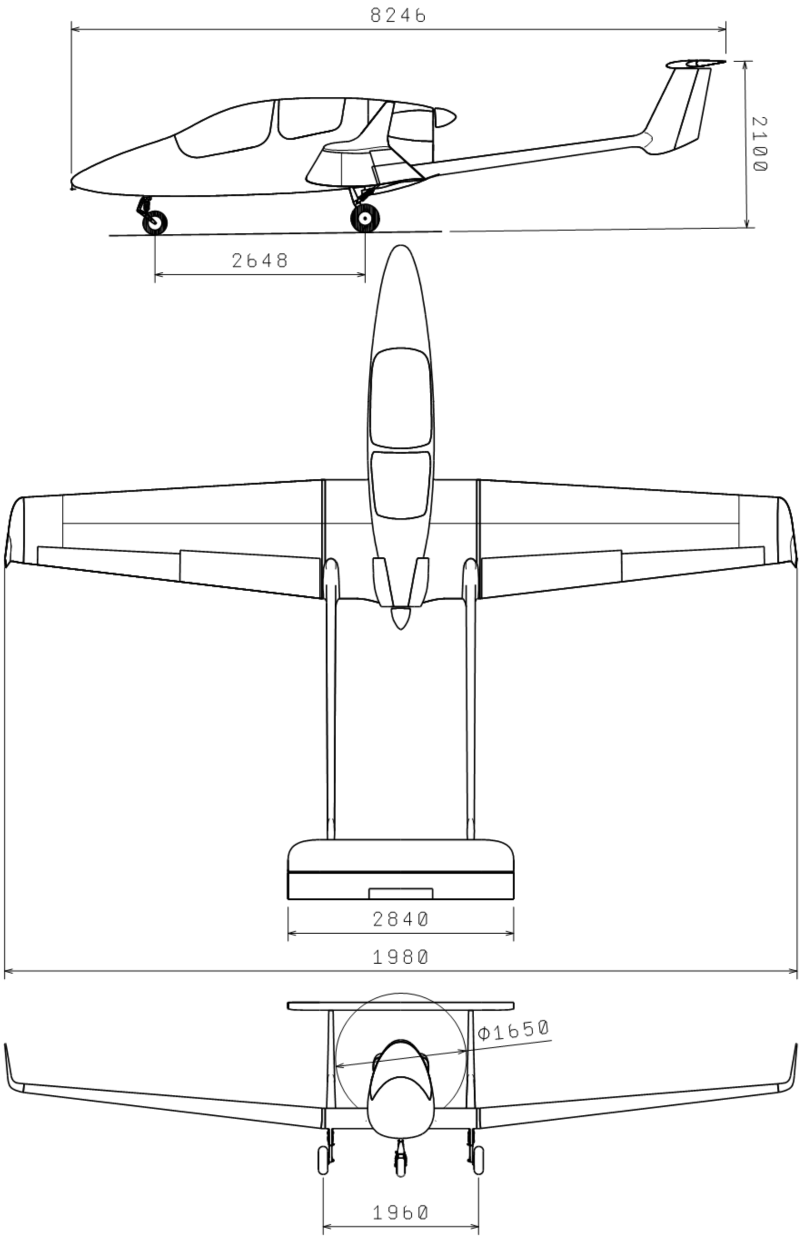


Fig 28 Airplane basic geometry [15]

8.5 Calculating LPG amount and tank capacity

LPG amount in the proposed system was calculated based on the energy produced by the maximum fuel of BA 95 used in the aircraft.

Energy content of Avgas: 31.33 MJ/dm^3

Energy content of LPG: 23.39 MJ/dm^3

Airplane Kondor have max. Fuel 120 dm^3

To produce amount of heat from LPG the same from Avgas will be needed

$\frac{31.33 \times 120}{23.39} = 160\ dm^3$ of LPG

Therefore the total max fuel of LPG will be 160 liter, I propose to use two tanks, each of them will carry half of fuel quantity. Because one tank must be filled maximum 80% so that the total capacity of each tank must be 100 dm^3 and the usable is 80 dm^3. Aircraft will be equipped with two pressure tanks, each of them has 102 liter capacity.

Scheme of LPG fuel system with two pressure tanks is shown in Fig 31. Tanks were selected from a group of torodial tank Stako which are shown in Fig 29 and Fig 30, according to the required capacity, all parameters of the selected tank are in Table 27.

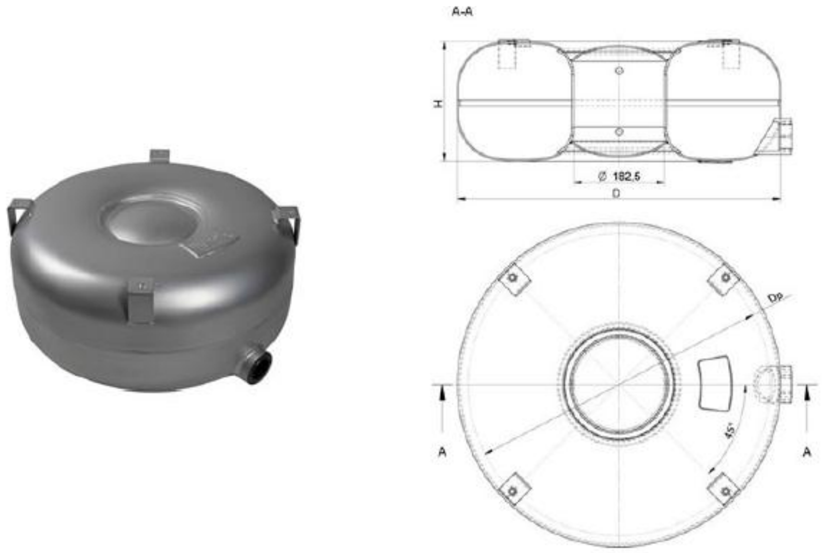
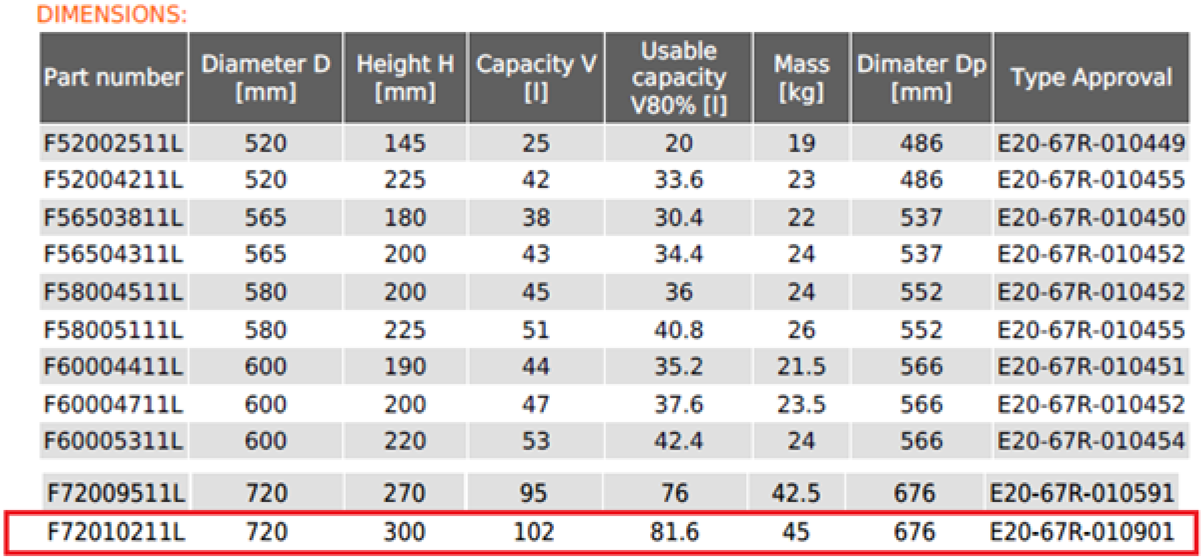


Fig 29 LPG tank dimension



DIMENSIONS:

Part number	Diameter D [mm]	Height H [mm]	Capacity V [l]	Usable capacity V80% [l]	Mass [kg]	Dimater Dp [mm]	Type Approval
F52002511L	520	145	25	20	19	486	E20-67R-010449
F52004211L	520	225	42	33.6	23	486	E20-67R-010455
F56503811L	565	180	38	30.4	22	537	E20-67R-010450
F56504311L	565	200	43	34.4	24	537	E20-67R-010452
F58004511L	580	200	45	36	24	552	E20-67R-010452
F58005111L	580	225	51	40.8	26	552	E20-67R-010455
F60004411L	600	190	44	35.2	21.5	566	E20-67R-010451
F60004711L	600	200	47	37.6	23.5	566	E20-67R-010452
F60005311L	600	220	53	42.4	24	566	E20-67R-010454
F72009511L	720	270	95	76	42.5	676	E20-67R-010591
F72010211L	720	300	102	81.6	45	676	E20-67R-010901

Fig 30 LPG pressure tank parameters

Table 27 Parameter of selected LPG pressure tank

Diameter [mm]	Height [mm]	Capacity [dm^3]	Usable capacity [dm^3]	Mass [kg]
720	300	102	81	45

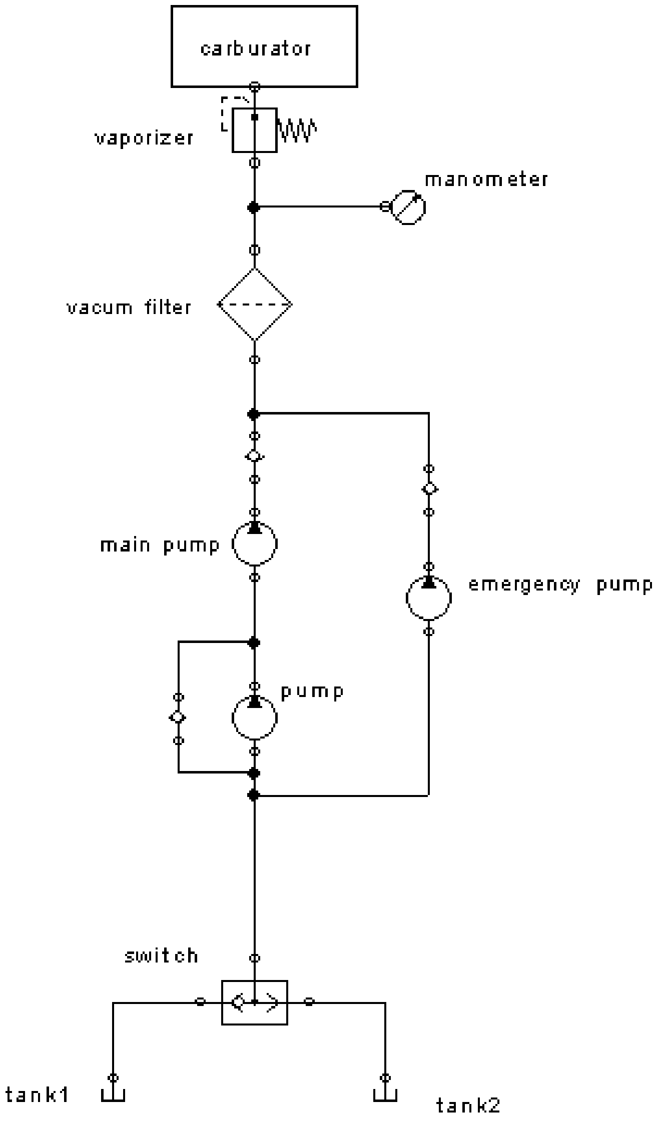


Fig 31 Scheme of LPG fuel system

In case of airplane Kondor (similar airplane), because of the lack of available place, it will be not possible to add two LPG pressure tank. Therefore I suggest LPG system with max fuel capacity 81dm^3, the aircraft will be equipped with one fuel tank. The position of pressure tank onboard the aircraft is in Fig 32.

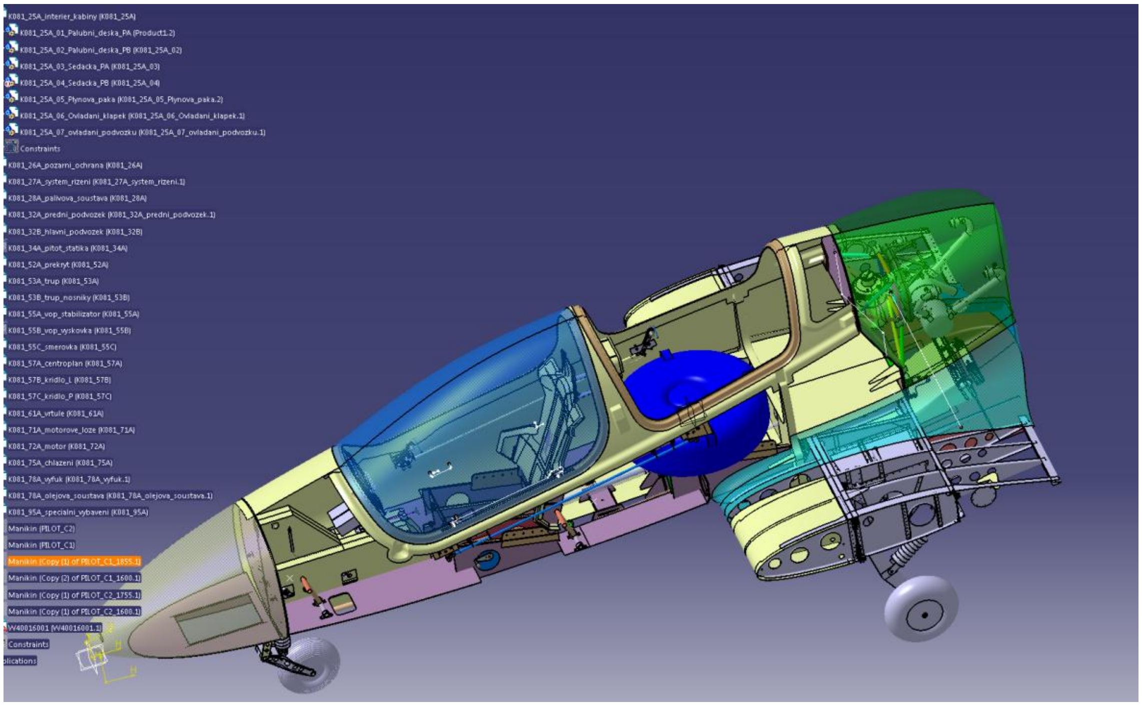


Fig 32 Position of LPG pressure tank on board airplane VUT 081 Kondor

8.6 Aircraft flight performance

Changing fuel system causes changes in max. take-off weight and engine power. therefore effects on aircraft performance. Aircraft with LPG will carry 45 kg Fuel, weight of pressure tank is 45 kg, so the max take-off weight is 600 kg.

Engine power decrease about 7% when using LPG fuel, and fuel consumption at this power will be 27 l/h. All detailed calculations are in Appendix B. All equations used in flight performance calculating are from [5].

8.6.1 Stalling speed

Stalling speed is the lowest speed at which the airplane is able to keep in a steady flight and is calculated according to the equation (8.1).

Stalling speeds were calculated for the max. Take-off weight 600 kg, at maximum lift coefficient and different configuration and altitude range from 0 to 8000 ft. MSA(step 2000 ft.). The values of max. Lift coefficient C_{Lmax} is taken from airplane polar Fig 27 and are listed in

Table 26.

$$V_s = \sqrt{\frac{2G}{C_{Lmax}\rho S}} \tag{8.1}$$

$$V_s = \sqrt{\frac{2 \times 600 \times 9.8}{1.58 \times 1.225 \times 11.85}} = 82.34\ km/h$$

Table 28 Stalling speed for different configuration and different flight altitudes

Configuration	Stalling speed [km/h]				
	Flight altitude [ft.]				
	0	2000	4000	6000	8000
Travel	82.34	84.79	87.37	90.15	92.92
Take-off	76.9	79.225	81.63	84.23	86.81
Landing	69.15	71.216	73.38	75.715	78.04

According to ELSA-A legislation, maximum stalling speed during landing configuration must not exceed 75 km/h. The landing configuration stalling speed is 69.1 km/h, this speed is lower than required speed as shown in Table 28.

8.6.2 Horizontal flight

Maximum speed in horizontal flight for travel configuration was determined as a steady mode, wherein required thrust and available thrust are equal - for different engine regime.

Fig 33 shows available and required thrust (F_P, F_V) for different configurations and different flight speeds. F_P, F_V are calculated according to the equations (8.3) and (8.4).

Speed at horizontal flight is calculated according to the equation (8.2)

Table 29 shows the maximum speed in horizontal flight for different modes of engine operation and at 0 ft. altitude.

$$V = \sqrt{\frac{2gm}{C_L\, \rho\, S}} \tag{8.2}$$

$$F_V = \frac{\eta P_M}{V} \tag{8.3}$$

$$F_P = \frac{C_D}{C_L} G \tag{8.4}$$

$$V = \sqrt{\frac{2 \times 9.8 \times 600}{0.212 \times 1.225 \times 11.85}} = 61.817 \frac{m}{s} = 222.54\ km/h$$

$$F_V = \frac{0.83 \times 68.355 \times 10^3}{61.817} = 919.86\ N$$

$$F_P = \frac{0.0329}{0.212} \times 9.8 \times 600 = 912.5N$$

Table 29 Maximum speed for different configuration and flight altitude 0ft

Configuration	Max.speed [km/h] Altitude [ft.] 0
Take-off	222
Permanent	220
75%	205

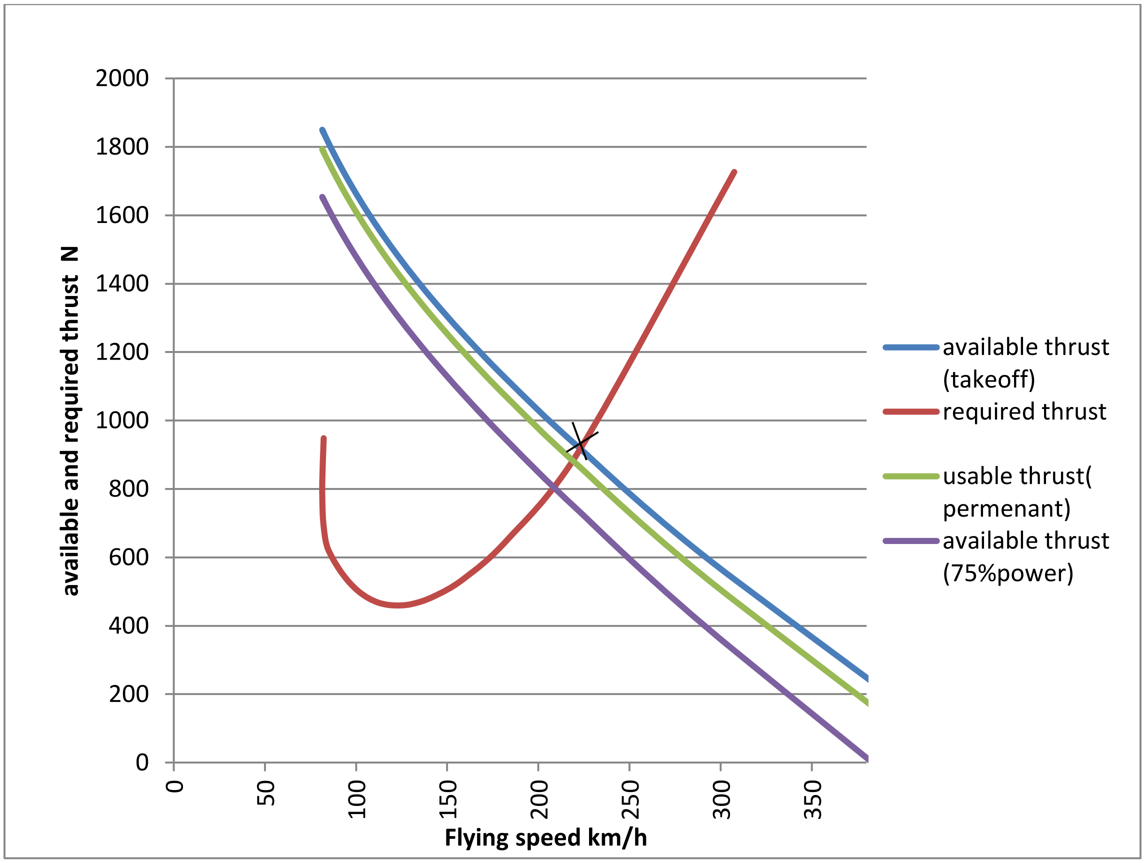


Fig 33 Available and required thrust at 0 ft. MSA

8.6.3 Climbing flight

Angle of climbing is calculating from equation (8.10), when V in the first step is calculating from equation (8.2), then repeating the calculation considering V resulting from equation (8.9) until reaching a stable value of flight speed

Required and available thrust in climbing flight are calculated according to equations (8.8) and (8.3).

Climbing speeds are calculated for different operation modes and different altitude according to the equation (8.5).

Table 30 shows max climbing speeds and corresponding flight speeds at different altitudes (0-8000) ft. Relationship between climbing speed and flight speed for different altitude and flight configurations is shown in Fig 34, Fig 35, and Fig 36.

Engine power changes depending on flight altitude according to equation (8.11).

$$U = \frac{\Delta P}{G} \tag{8.5}$$

$$\Delta P = P_V - P_P \tag{8.6}$$

$$P_P = F_P V \tag{8.7}$$

$$F_p = C_D \frac{1}{2} \rho S V^2 \tag{8.8}$$

$$V = \sqrt{\frac{2G\cos\gamma}{C_L \rho S}} \tag{8.9}$$

$$\gamma = arc\sin\frac{U}{V} \tag{8.10}$$

$$\Delta P_M = \left(1.11 * \left(\frac{\rho}{\rho_0}\right) * \sqrt{\left(\frac{T_0}{T}\right)}\right) - 0.11 \tag{8.11}$$

Following are calculation for take-off configuration and 0ft altitude, at C_L=0.617,C_D=0.0486.

$$V = \sqrt{\frac{2 \times 9.8 \times 600 \times \cos 0.1}{0.617 \times 1.225 \times 11.58}} = 35.98 \frac{m}{s} = 129.53\ km/h$$

$$F_P = 0.0486 \times \frac{1}{2} \times 1.225 \times 11.58 \times (35.98)^2 = 456.69N$$

$$P_P = 456.69 \times 35.98 = 16.432\ kW$$

$$F_V = \frac{0.755 \times 68.355 \times 10^3}{35.98} = 1435.665\ N$$

$$P_V = 1435.665 \times 35.98 = 51650\,W = 51.65\,KW$$

$$U = \frac{(51.65 - 16.432) \times 10^3}{9.8 \times 600} = 5.99\frac{m}{s}$$

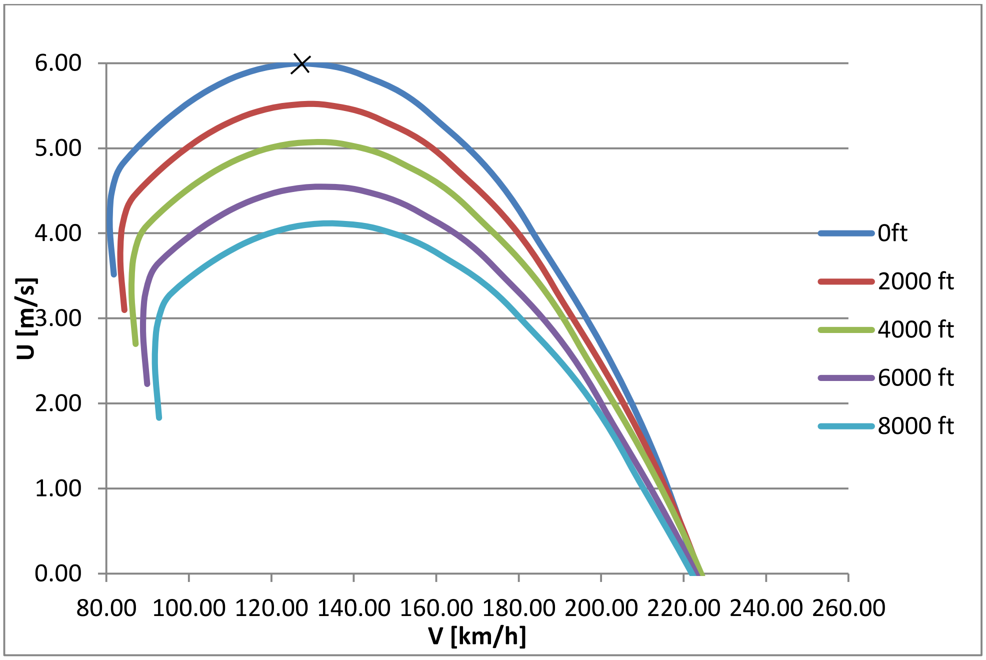


Fig 34 Climbing speed at take-off configuration for different flight altitude

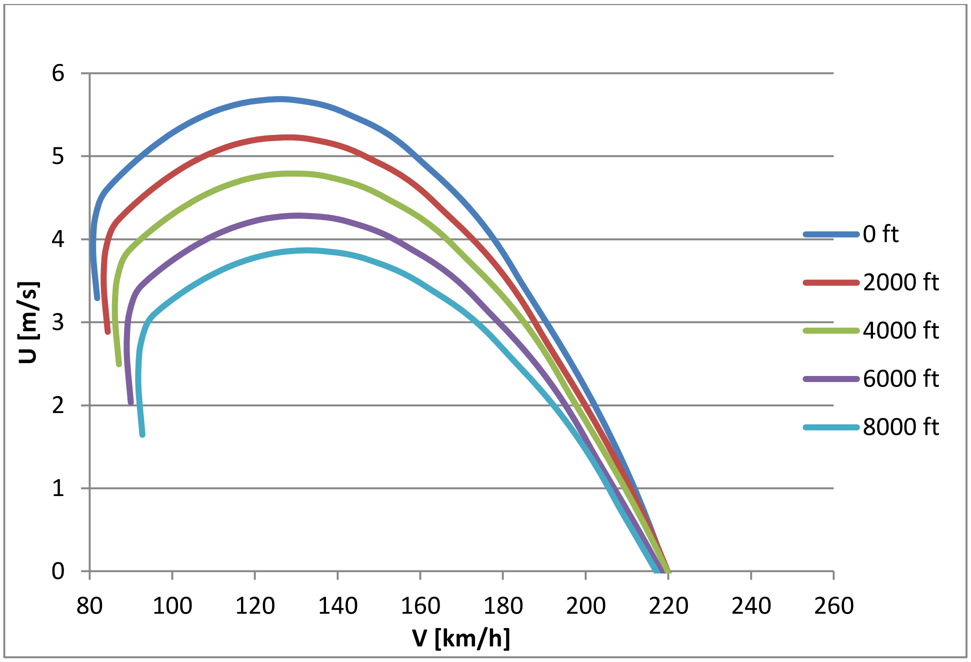


Fig 35 Climbing speed at permanent configuration for different flight altitude

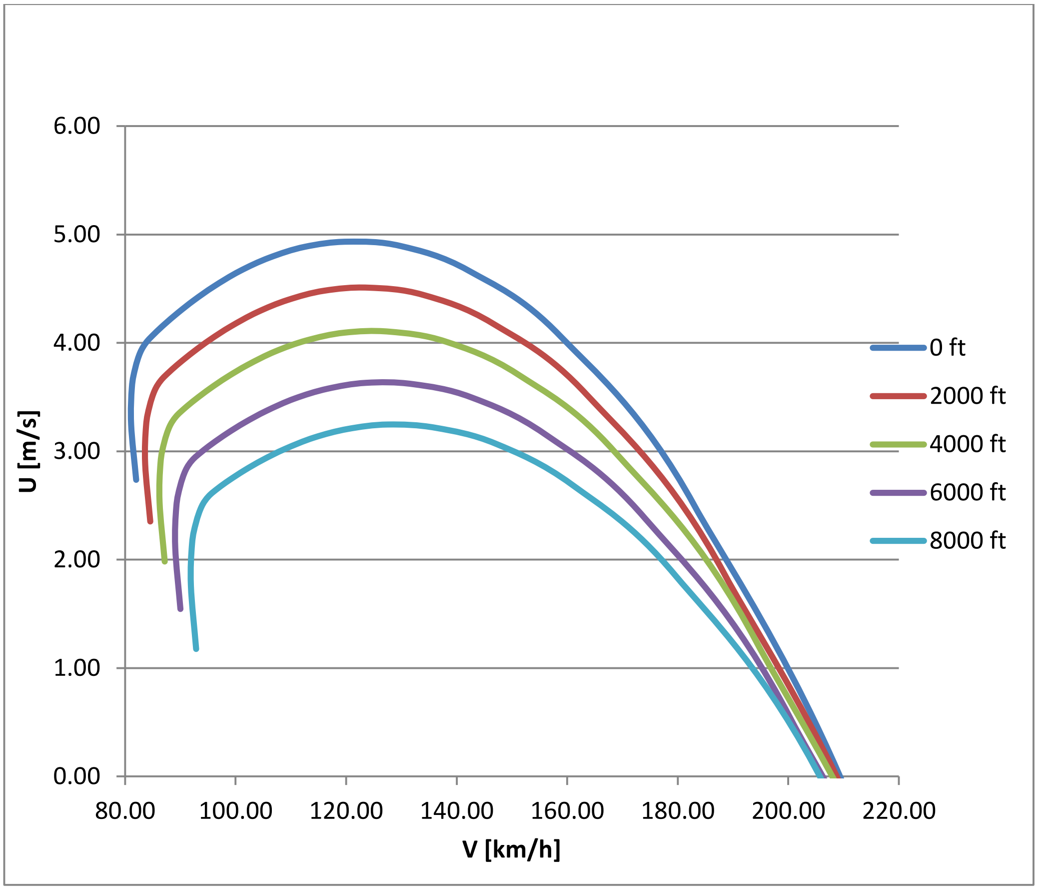


Fig 36 Climbing speed at 75% power for different flight altitude

Table 30 Climbing speed and corresponding flight speeds at different altitude and different configuration (1)

Engine mode	Climbing speed [m/s]/flight speed [km/h]				
	Flight altitude [ft.]				
	0	2000	4000	6000	8000
Take-off	5.99	5.51	5.08	4.5	4.11
	129.5	133.5	137.8	139	142
Permanent	5.6	5.2	4.75	4.21	3.77
	129.6	133.6	137.9	142.4	145
75%	4.89	4.44	4.02	3.5	3.2
	129.9	133.8	112	116	120

According to ASTM Norm F2245-12D climbing speed must be more than 1.6 m/s, the aircraft fulfill the requirement of climbing speed at all operation mode.

8.6.4 Ceiling

Theoretical ceiling is the altitude at which the climbing speed is zero, practical ceiling is the altitude at which the climbing speed is 0.5 m/s. Both are calculated based on the relationship between climbing speed and altitude shown in Fig 37.

Table 31 Theoretical and practical ceiling for different engine mode (1)

Engine mode	Ceiling [ft.]	
	Theoretical	Practical
Take-off	29941.5	27441.5
Permanent	28406.5	25906.5
75%	24685.5	22185.5

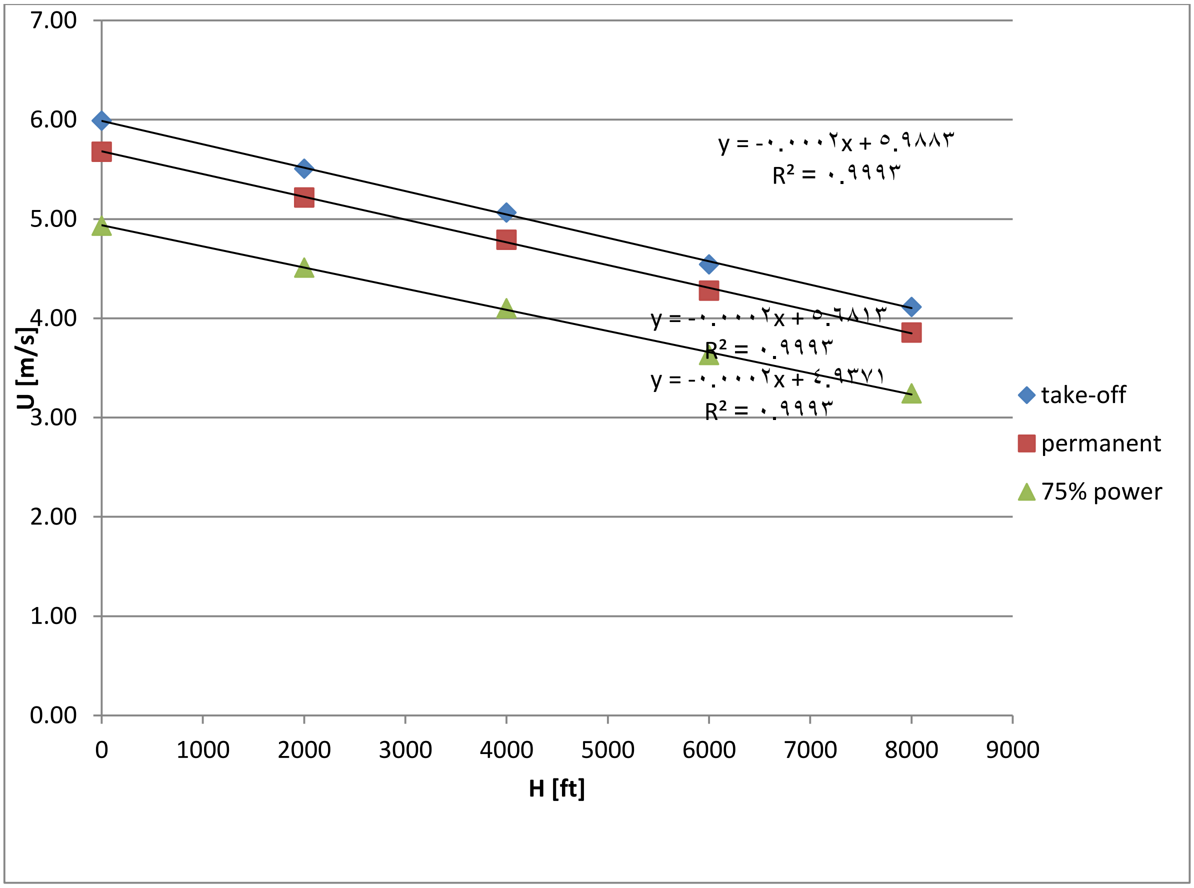


Fig 37 Flight altitude for different climbing speeds

8.6.5 Range and endurance

Range and endurance were calculated for max. take-off weight 600 kg, max fuel 81 dm^3, pilot weight 2x90 kg. Motor speed 4600 rpm.

From the curve of required power Fig 38 we can get that max. range is at flight speed 120 km/h, max. endurance at speed 100 km/h. At these speeds cannot achieve equivalent between required and available power.

Endurance and range are defined when the required and available power are equal, this equivalent can be obtained at engine speed 4600 rpm (according to the Fig 38). At this point flight speed= 210 km/h, engine fuel consumption is determined based on engine speed from Fig 38.

Fuel consumption = 14 l/h

$$Endurance = \frac{\max fuel}{fuel\ consumption} = \frac{81}{14} = 5.8\ \text{h}$$

$$Range\ = endurance \times speed = 5.8 \times 210 = \ 1215\ km$$

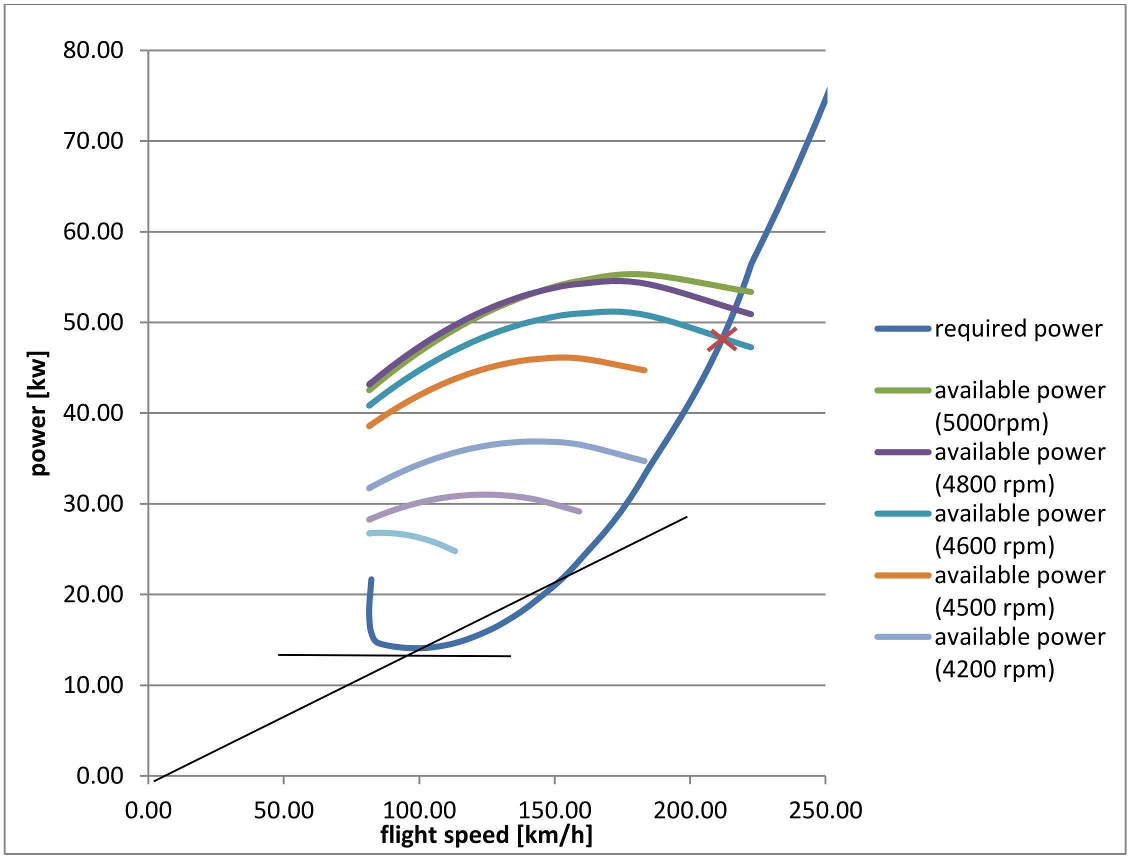


Fig 38 Available and required power for different flight speeds and different engine speeds

8.6.6 Take-off

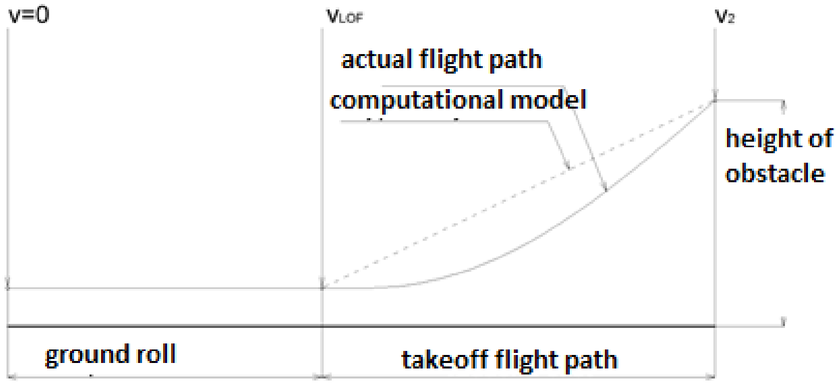


Fig 39 Take-off path

Ground segment of Take-off starts at speed V = 0 until V_{LOF}, then starts airborne phase until V_2. At this speed airplane climbs to the height of obstacle 15m. Speeds for take-off segments are calculated according to equations (8.12) (8.13).

The calculation was made considering max.take-off weight 600 kg, take-off at altitude 0 ft. MSA, friction coefficient f = 0.04, height of obstacle h_P is 50 ft. (15m).

Throughout take-off flaps are set for take-off mode, and engine operates at take-off mode, pitch angle is 0^o, at this angle $C_L = 0.539$, $C_D = 0.055$.

Length of take-off segments are calculated according to equations (8.14) (8.15) (8.16).

Table 32 Length of take-off path (1)

Segment	Segment length [m]
$S_{G,TOF}$	116
$S_{A,TOF}$	105
S_{TOF}	221

$$V_{LOF} = 1.1\,V_{S1} \tag{8.12}$$

$$V_{LOF} = 1.1 \times 76.93 = \frac{84.6km}{h} = 23.5m/s$$

$$V_2 = 1.3V_{S1} \tag{8.13}$$

$$V_2 = 1.3 \times 76.93 = 103.5\ \mathrm{km/h} = 27.78\ \mathrm{m/s}$$

$$C_{L,LOF} = \frac{2gm}{\rho S V_{LOF}^2} = \frac{2 \times 9.8 \times 600}{1.225 \times 11.85 \times 23.5^2} = 1.46$$

$$F_{mid} = F_V at\ V_{mid}: V_{mid} = \frac{V_{LOF} + V_2}{2} = 25.64\ m/s$$

From Appendix B. 2.3, $F_{mid} = 1727\ N$

$$S_{G,TOF} = \frac{1}{\rho g} \frac{G/_S}{C_D - fC_L} \ln \left| \frac{\left(\frac{F_{mid}}{G} - f\right)}{\left(\frac{F_{mid}}{G} - f\right) - \frac{C_D - fC_L}{C_{L,LOF}}} \right| \tag{8.14}$$

$$S_{A,TOF} = \frac{G}{(F-D)_{mid}} \left(\frac{V_2^2 - V_{LOF}^2}{2g} + h_p \right) \tag{8.15}$$

$$S_{TOF} = S_{G,TOF} + S_{A,TOF} \tag{8.16}$$

8.6.7 Landing

Airborne phase of landing starts at altitude h_P=15m and reference speed V_{REF} until V_P approach speed then starts ground phase till speed V=0. Speeds at landing segment are calculated according to equations (8.17) and (8.18)

Pitch angle is 0^o, therefore lift coefficient C_L=1.066, drag coefficient C_D=0.1635, and friction coefficient will be consider 0.4.

Length of landing segments are calculated according to equations (8.19) (8.20) (8.21).

$$V_{ref} = 1.3\ V_{s0} \tag{8.17}$$

$$V_P = 1.15\ V_{S0} \tag{8.18}$$

$$S_{A,L} = \frac{G}{D_{mid}} \left(\frac{V_{ref}^2 - V_P^2}{2g} + h_p \right) \tag{8.19}$$

$$S_{G,L} = \frac{1}{g} \int_0^{V_P} \frac{VdV}{f + (C_D - fC_L)\frac{\rho V^2 S}{2\,G}} \tag{8.20}$$

$$S_L = S_{G,L} + S_{A,L} \tag{8.21}$$

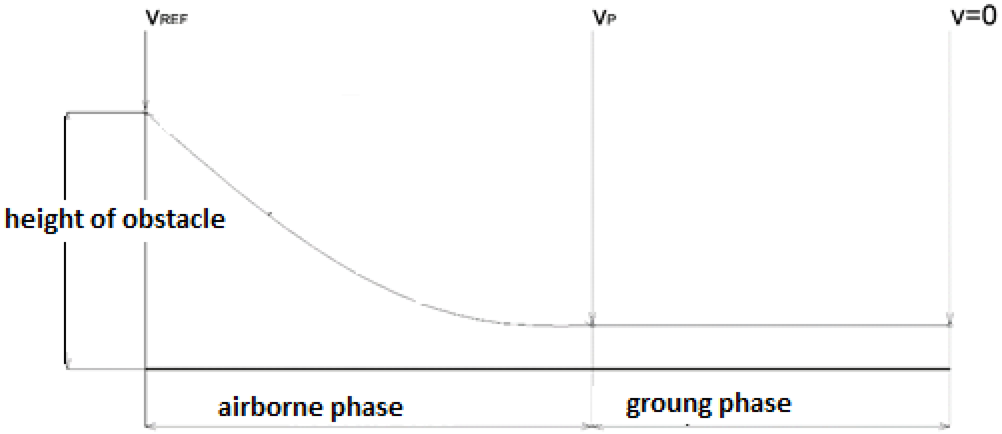


Fig 40 Landing path

Table 33 Length of landing path (1)

Segment	Segment length [m]
$S_{A,L}$	229
$S_{G,L}$	71
S_L	300

9. APPLYING CATALYTIC CONVERTER

9.1 Using catalyst for reducing emission

Catalyst construction

Catalyst is thin layers of precious metals ex. (palladium, platinum and rhodium) applied on the grid of catalyst, which induce and speed the reaction of products imperfect combustion and their decomposition to less dangerous products.

Catalysts are produced in many technical designs, which are different in durability endurance, cleaning quality and flow. In automotive industry, it is used catalyst with steel carrier, which is suitable in intensive conditions, because of their low flow resistance and high mechanical and thermal resistance. The thin wavy film of high-alloy steel is rolled into the shape of the letter "S", which significantly reduces internal stresses at high temperature changes. Layers of film are soldered to each other and to the outer cylinder casing. "S" shape with two centers also prevents degradation carrier's telescopic effect, which sometimes happens with catalysts simpler structure. On metal wall rack is coated lining of (AL_2O_3). It is a highly porous material to which it is applied only own catalytic layer of precious metals (platinum, rhodium, palladium). This makes the reaction area of the catalyst larger.

Optimum working temperature inside catalyst is 250-800 ˚C. In the period before the temperature reaches 250 ˚C the catalyst is ineffective. That is in the status of cold start shortly 30-60 second after start. At lower temperatures (to 600˚C, it is recognized clogging the active area of catalysts, with slow thermal aging. At temperature range (600-800 ˚C) the catalyst clogging reduces, but the thermal aging increases.

9.2 Two-way and three-way catalyst

Two-way catalyst (oxidation) catalysts are able to reduce emissions HC and CO, three- way catalyst (oxidation-reduction) reduces emissions HC, CO and NO_x. Since the oxidation catalysts are not used in modern petrol engines.

In order that the three-way catalyst works properly, it must be enough amount of oxygen in emission. These catalysts work at combustion of exactly stoichiometric mixture fuel- air, (1kg fuel+ 14.8 kg air) when excess air coefficient =1.

In order to achieve stoichiometric mixture fuel-air, it is used so-called lambda sensor, which measures the oxygen amount in the emission. According to this amount, the amount of fuel into the cylinders is regulated. Three-way catalyst is ineffective without lambda sensor, because the default mixture richness is not corresponding to the requirement of current combustion conditions. The catalyst body should also be enough warmed to fill its function.

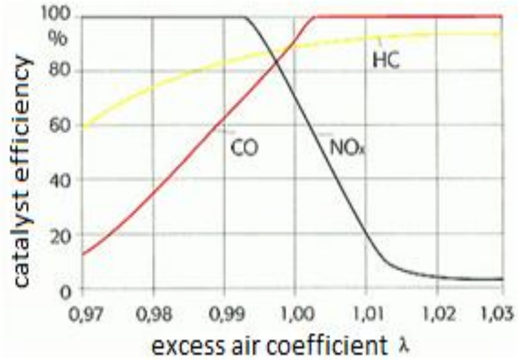


Fig 41 Influence of excess air coefficient on catalyst efficiency

9.3 Influence of catalyst on aircraft emissions

Using three-way catalyst in petrol engine reduces CO emission 15 ×, HC and NO_x to 10×. CO and HC are oxidized to CO_2, which is one of greenhouse gases that cause global warming. Petrol engine with catalyst produces three of six greenhouse gases listed in Kyoto protocol, which are (CO_2, CH_4 and N_2O). Although methane content is reduced when using catalyst, but in the same time the content of carbon dioxide increases with increasing conversion efficiency of co, HC and CH_4 to CO_2. In term of greenhouse gas emission, that will be positive, because methane contributes in global warming 21× more than carbon dioxide. Moreover, the modern three-way catalysts cause greater amount of N_2O, whose greenhouse effect is 310 times greater than CO_2. The greatest amount of N_2O is created when using RH, PT, PD (three-way catalyst). Whereas using RH and PT (two-way catalyst) produces the smallest of N_2O. However, with catalyst aging this amount increases, probably with the thermal connection. N_2O produced in presence of PD catalyst persists even at high temperatures above 500 ° C.

Using catalytic converter in engines working on leaded fuel (Avgas 100, 100LL) is not possible, because the lead deactivate the main catalyst elements (platinum). Therefore, catalyst can be used in aircraft engines that work or may work on unleaded Avgas (UL91) or unleaded Mogas.

To the motors working on unleaded Mogas belongs Rotax 912 IS, 912 S/ ULS. All engines already approved to use unleaded Mogas RON 95 (MON 85) in accordance with standard EN228:2008 are deemed as suitable for operation with UL 91. To the motors that can work on motor gasoline belong Lycoming O-290/ O-320 and others. aircrafts permitting to use motor gasoline are listed by UK CAA.

9.4 Proposal catalytic converter for airplane VUT-081 Kondor

Catalytic converter will be proposed for airplane VUT-081 Kondor, their characteristics are presented in chapter 0.

Choosing catalytic converter depends on design specification from manufacturer take in account engine power, exhaust system dimension, and emission level.

Given that there is no design specifications determines, the catalytic converter model will be chosen according to the exhaust pipe dimensions,shown in Fig 42, and emission level.

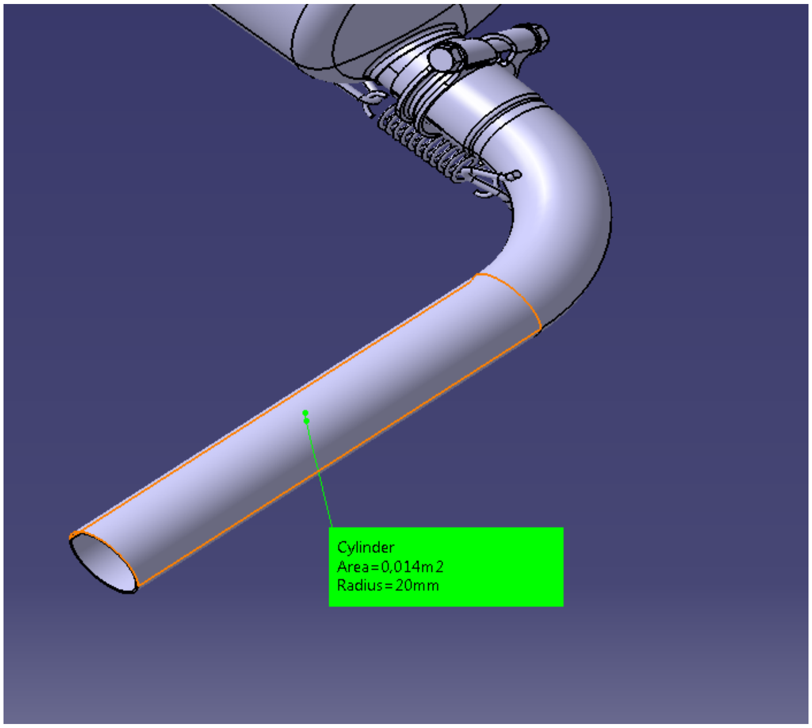
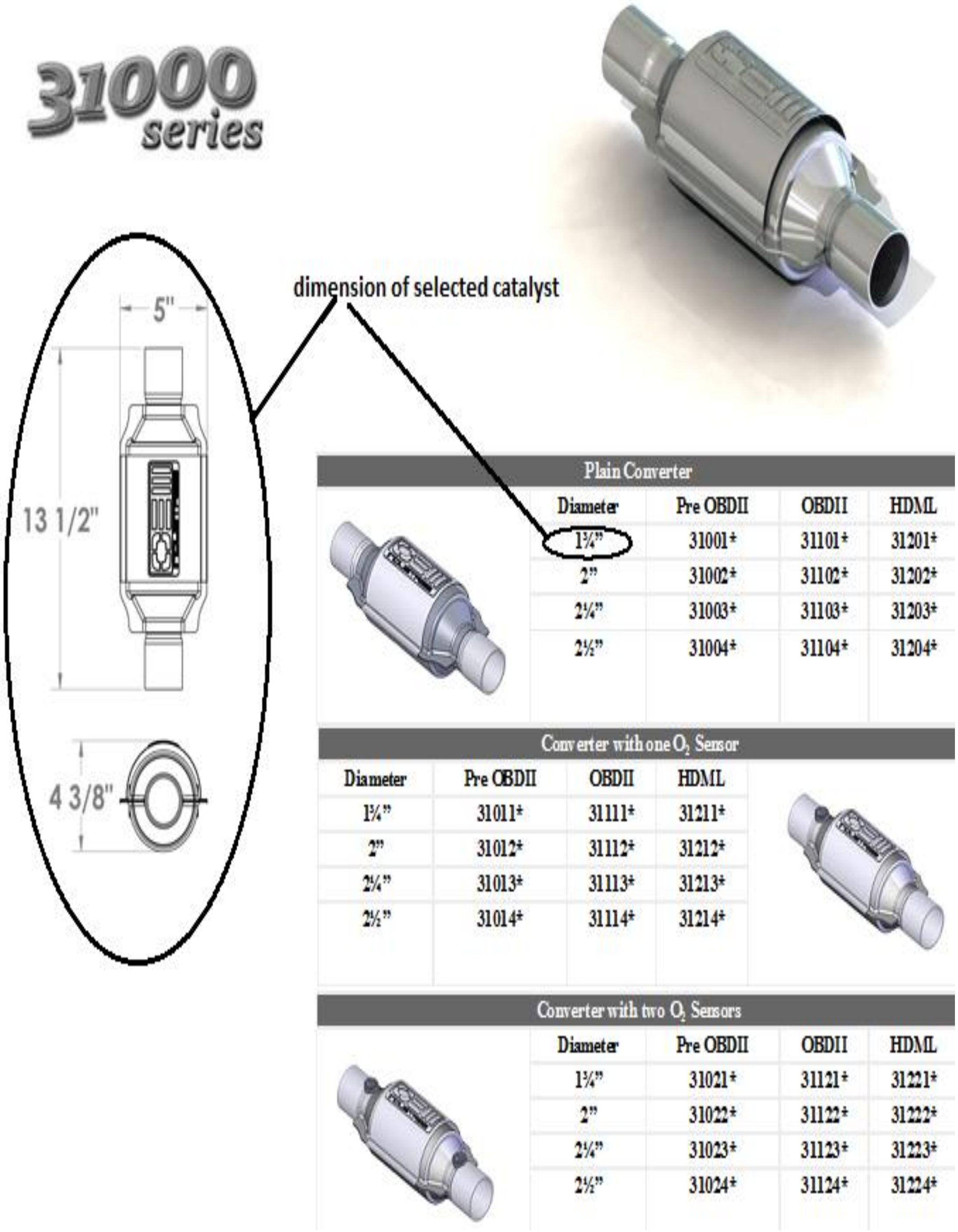


Fig 42 Dimension of exhaust pipe



Plain Converter

Diameter	Pre OBDII	OBDII	HDML
1¼"	31001*	31101*	31201*
2"	31002*	31102*	31202*
2¼"	31003*	31103*	31203*
2½"	31004*	31104*	31204*

Converter with one O_2 Sensor

Diameter	Pre OBDII	OBDII	HDML
1¼"	31011*	31111*	31211*
2"	31012*	31112*	31212*
2¼"	31013*	31113*	31213*
2½"	31014*	31114*	31214*

Converter with two O_2 Sensors

Diameter	Pre OBDII	OBDII	HDML
1¼"	31021*	31121*	31221*
2"	31022*	31122*	31222*
2¼"	31023*	31123*	31223*
2½"	31024*	31124*	31224*

Fig 43 Parameters of selected catalytic converter [29]

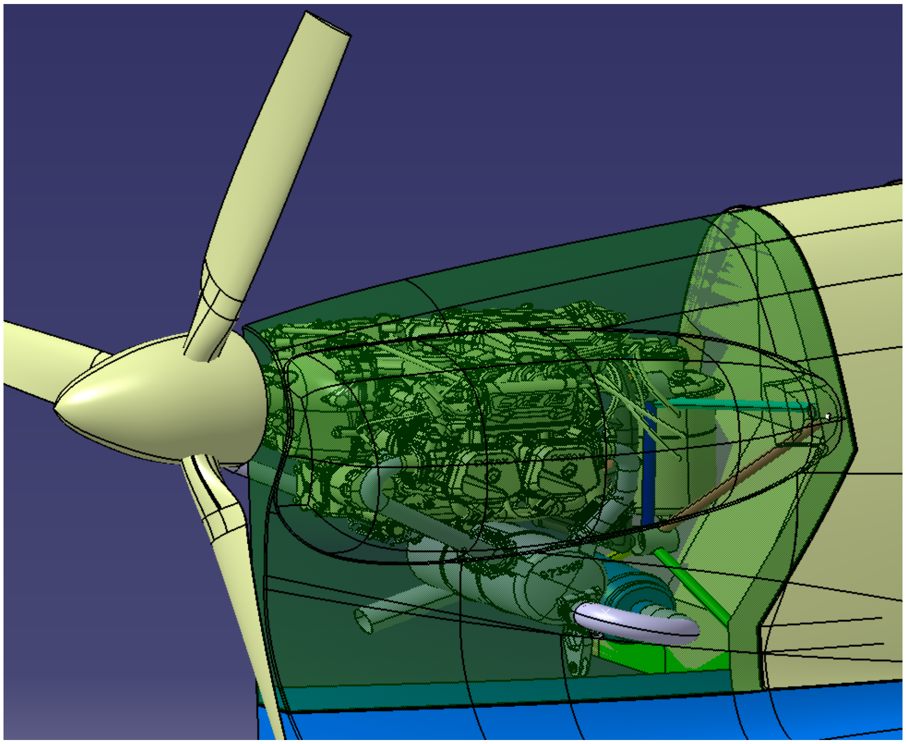


Fig 44 Placement of catalytic converter in the airplane (1)

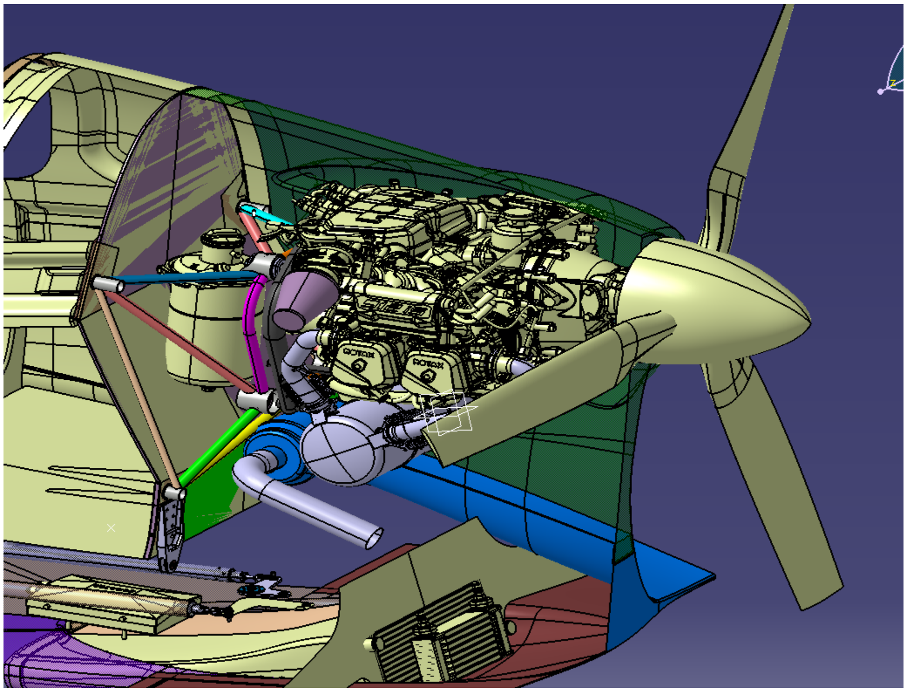


Fig 45 Placement of catalytic converter in the airplane (2)

9.5 Aircraft flight performance with catalytic converter in the exhaust system

Adding catalytic converter to the aircraft exhaust system reduces engine power about 11%, and that causes changing in aircraft performance.

All equations used for calculating flight performance are mentioned in chapter 0 (8.6).

Detailed calculations are listed in Appendix C.

9.5.1 Stalling speed

Stalling speeds were calculated for the max. take-off weight 600 kg, at maximum lift coefficient and different configuration and altitude range from 0 to 8000 ft. MSA(step 2000 ft.)

Table 34 Stalling speed for different configuration and different flight altitude

Configuration	Stalling speed [km/h]				
	Flight altitude [ft.]				
	0	2000	4000	6000	8000
Travel	82.34	84.8	87.3	90.1	92.9
Take-off	76.93	79.22	81.6	84.23	86.8
Landing	69.1	71.2	73.38	75.7	78.04

According to ELSA-A legislation, maximum stalling speed during landing configuration must not exceed 75 km/h. The landing configuration stalling speed is 69.1 km/h, this speed is lower than required speed.

9.5.2 Horizontal flight

Maximum speed in horizontal flight for travel configuration was determined as a steady mode, wherein the required and available thrust are equal - for different engine regime

The table below shows the maximum speed in horizontal flight for different modes of engine operation and at 0 ft. altitude.

Table 35 Maximum speed for different configuration and flight altitude 0ft

Regime	Max.speed [km/h] Altitude [ft.] 0
Take-off	220
Permanent	215
75%	202

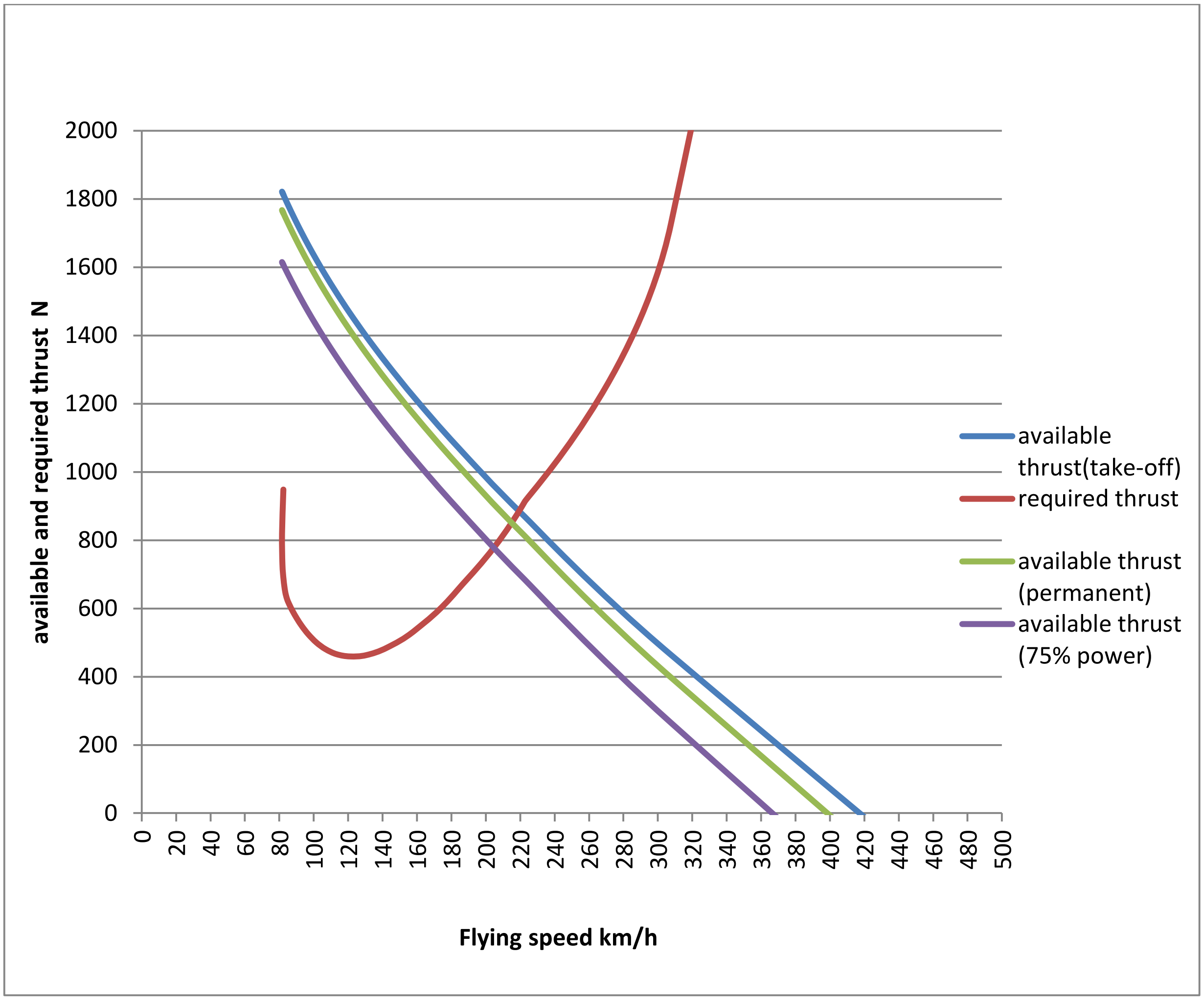


Fig 46 Available and required thrust at 0 ft. MSA for different flight speeds

9.5.3 Climbing flight

Climbing speeds are calculated for travel configuration for different operation modes and different altitude.

Max climbing speed and corresponding flight speed are in Table 36.

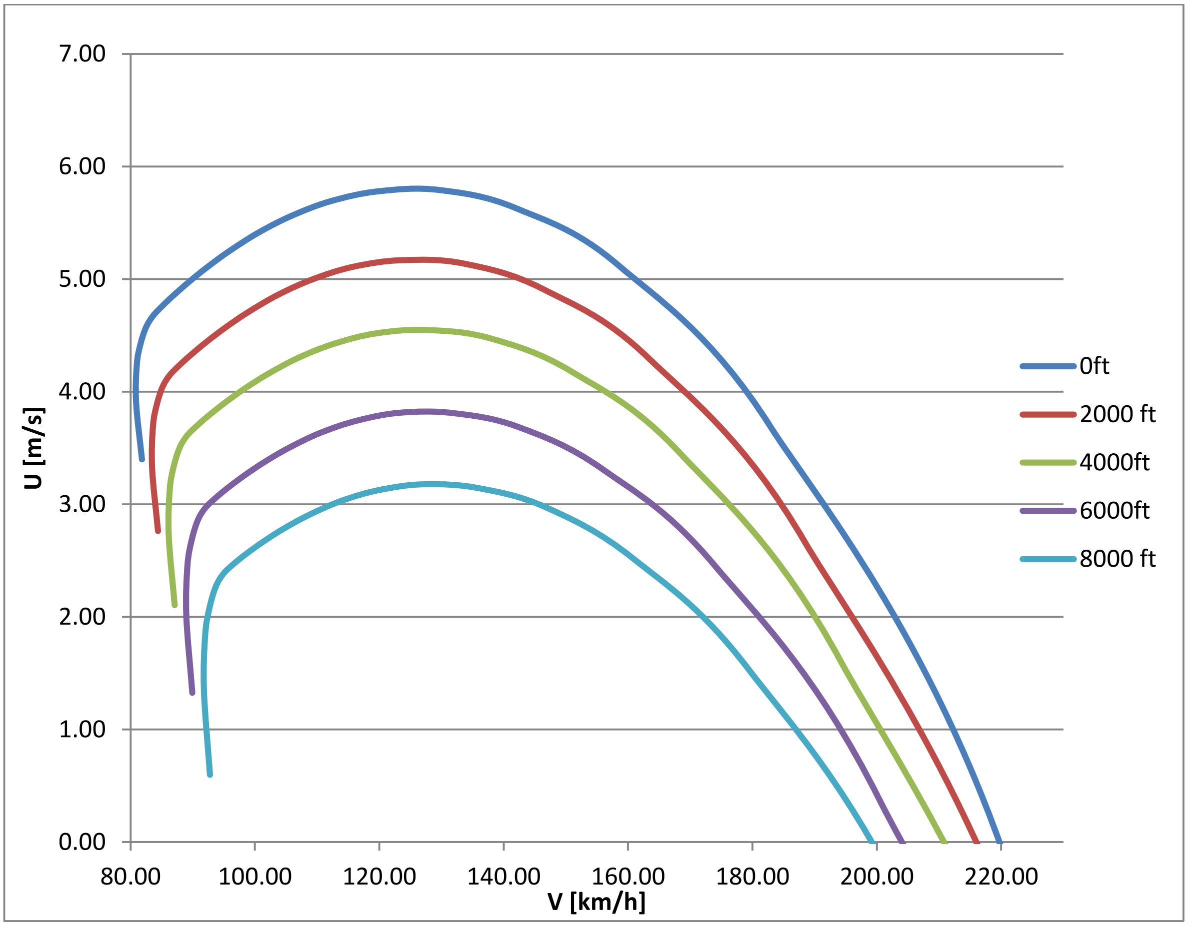


Fig 47 Climbing speed at take-off configuration for different flight speeds and flight altitudes

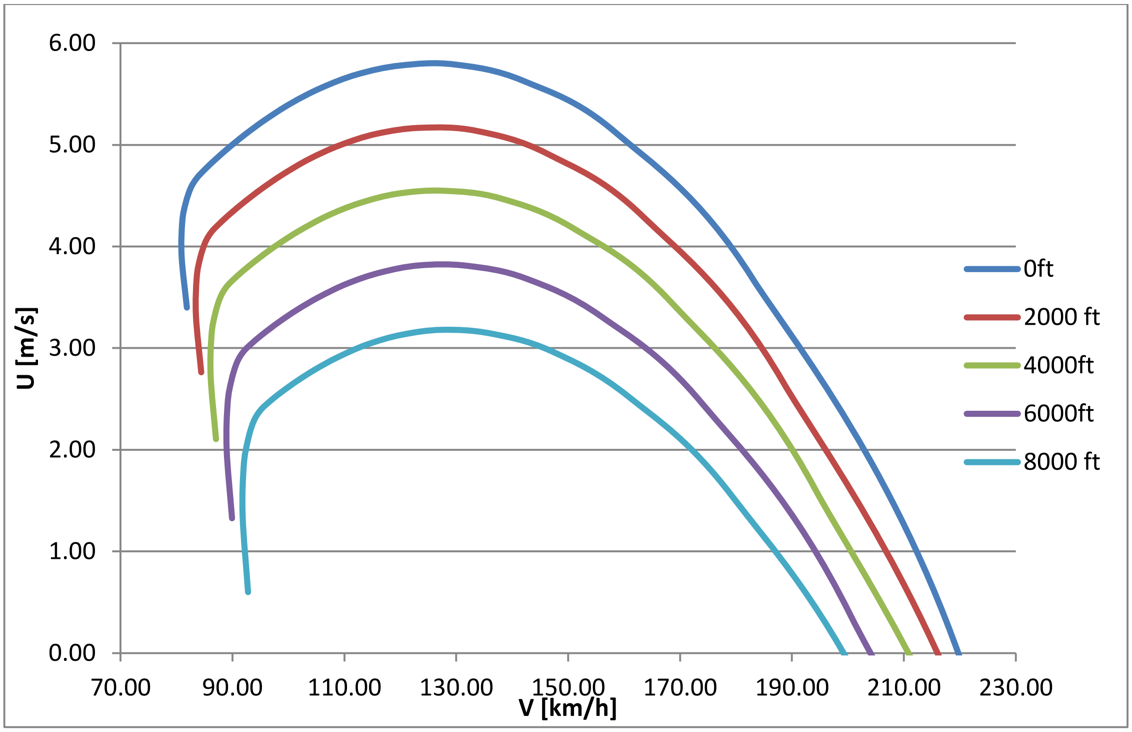


Fig 48 Climbing speed at permanent flight for different flight speeds and flight altitudes

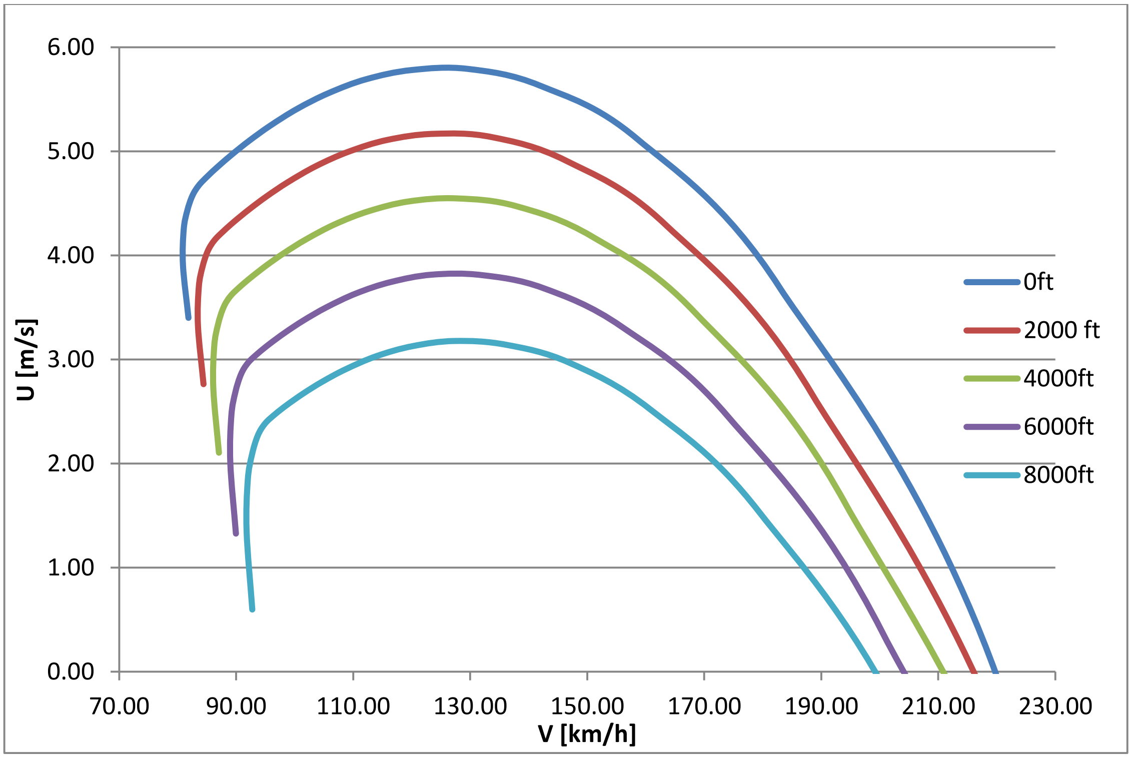


Fig 49 Climbing speed at 75% power for different flight speeds and flight altitudes

Table 36 Climbing speed and corresponding flight speeds at different altitude and different configuration (2)

Engine mode	Climbing speed [m/s]/flight speed [km/h]				
	Flight altitude [ft.]				
	0	2000	4000	6000	8000
Take-off	5.63	5.2	4.55	3.8	3.18
	129	133	137	139	140
Permanent	5.79	5.2	4.55	3.81	3.18
	125	127	129	130	135
75%	5.79	5.2	4.55	3.81	3.14
	129	128	127	131	136

According to ASTM norm F2245-12D climbing speed must be more than 1.6 m/s, the aircraft fulfill the requirement of climbing speed at all operation mode.

9.5.4 Ceiling

Theoretical ceiling is calculated at 0 m/s speed, practical ceiling is calculated at rate of climb 0.5 m/s, and both are shown in Table 37.

Table 37 Theoretical and practical ceiling for different engine mode (2)

Engine mode	Ceiling[ft.]	
	Theoretical	Practical
Take-off	19386	17719
Permanent	18392	16725
75%	15792	14126

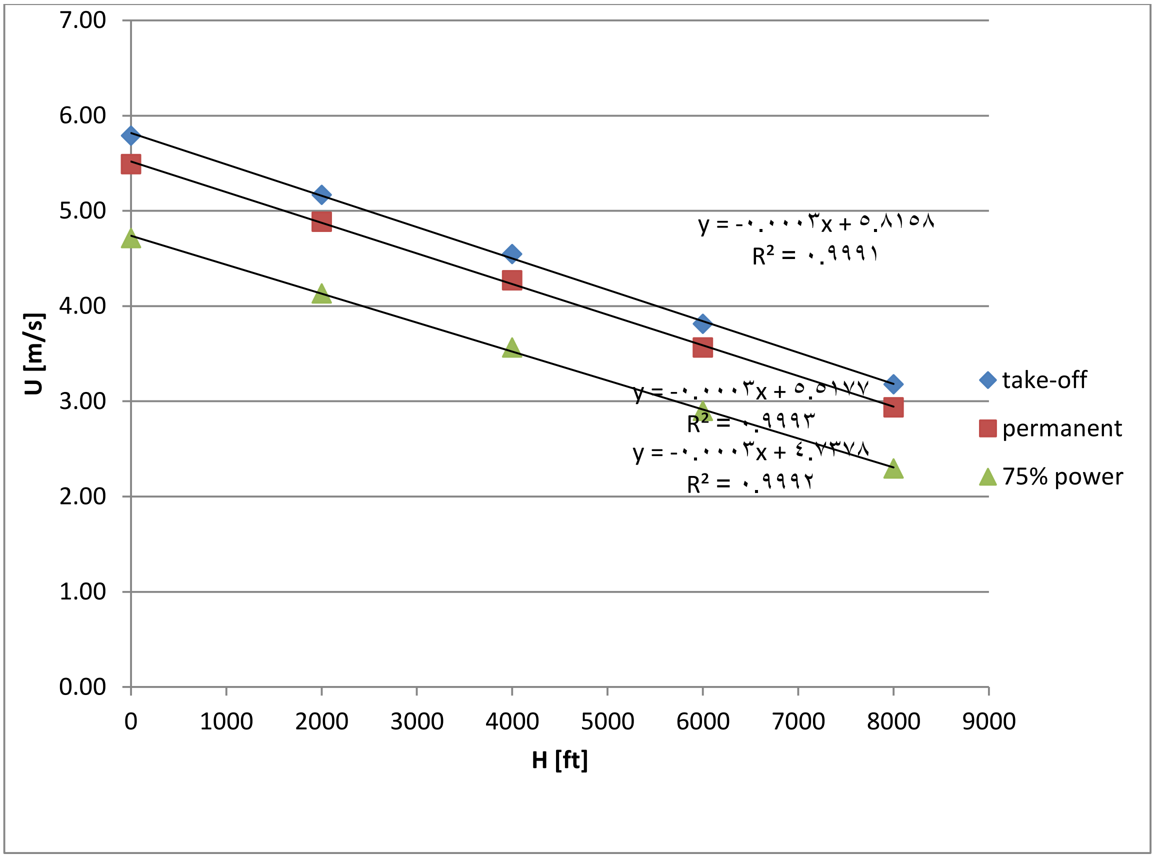


Fig 50 Flight altitude for different climbing speeds

9.5.5 Range and endurance

Range and endurance were calculated for max. take-off weight 600 kg, max fuel kg, pilot weight 2x90 kg and motor speed 4500 rpm. From the curve of required power we can get that max. range is at flight speed 100 km/h, max. endurance is at 125 km/h speed. At these speeds cannot achieve equivalent between required and available power.

Endurance and range are defined when require and available power are equal and for engine speed 4500 rpm (according to the Fig 51). At which the flight speed will be 202 km/h. At this regime the engine fuel consumption will be 11 l/h.

Endurance = 10.9 h

Range = 2203 km

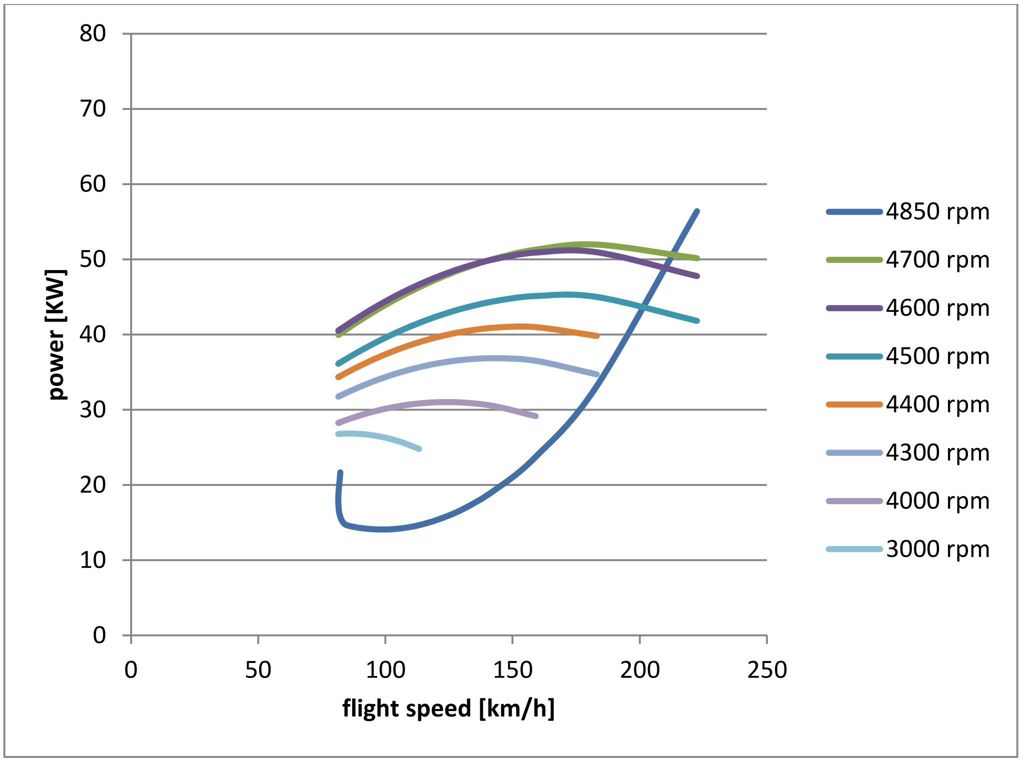


Fig 51 Required and available power for different flight speeds and different engine speeds

9.5.6 Take-off

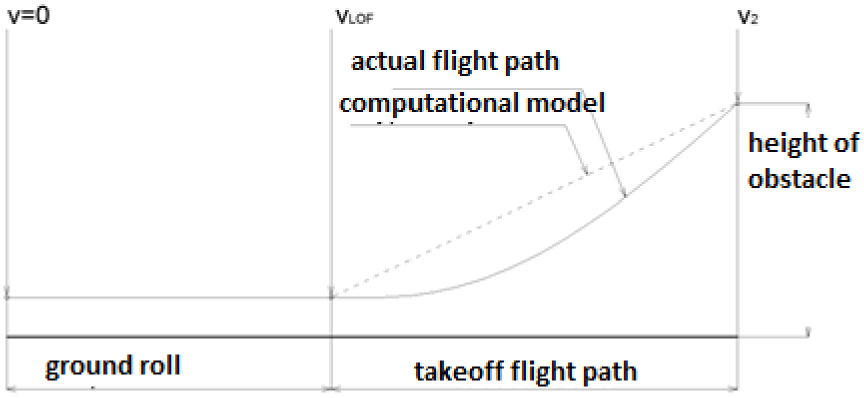


Fig 52 Take-off path

The calculation was made considering max.take-off weight 600 kg, and take-off at altitude 0 ft. MSA, and friction coefficient 0.04, height of obstacle is 50ft (15m)

Table 38 Length of take-off path (2)

Segment	Segment length [m]
$S_{G,TOF}$	118
$S_{A,TOF}$	107
S_{TOF}	226

9.5.7 Landing

Airborne phase of landing starts at altitude h_P=15m and reference speed V_{REF} until V_P approach speed then starts ground phase till speed V = 0. Speeds at landing segment are calculated according to equations (8.17) and (8.18)

Pitch angle is 0^o, therefore lift coefficient C_L = 1.066, drag coefficient C_D = 0.1635, and friction coefficient will be consider 0.4.

Length of landing segments are calculated according to equations (8.19) (8.20) (8.21).

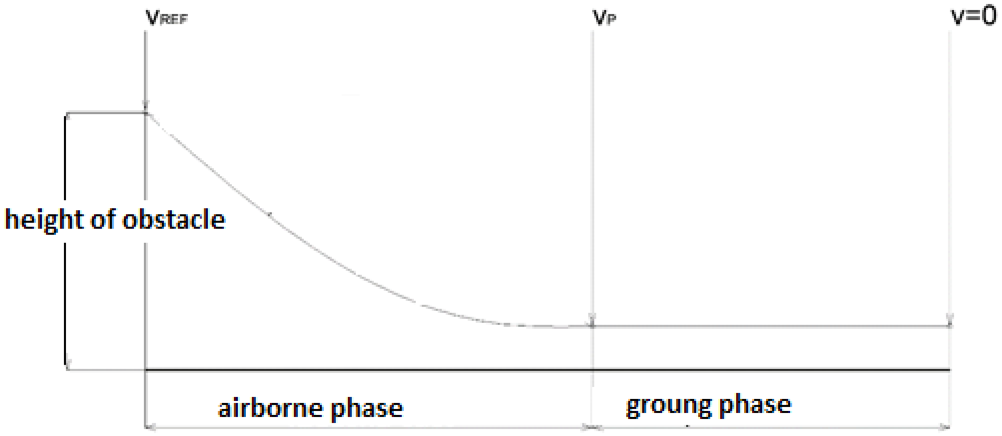


Fig 53 Landing path

Table 39 Length of landing path(2)

Segment	Segment length [m]
$S_{A,L}$	224
$S_{G,L}$	71
S_L	295

10. ELECTRIC MOTORS

There are two variants for using electric motors in aviation:

- Electric motors working on fuel cells.
- Electric motors working on battery.

10.1 Electric motors working on fuel cells

Fuel cells are classified primarily by the type of electrolyte. Currently we distinguish the following five systems :

- AFC’s - alkaline fuel cells in which the electrolyte is usually diluted KOH.
- PEFC’s - proton exchange fuel cells in which the electrolyte is a solid organic polymer.
- PAFC’s - phosphoric acid fuel cells which is appointed by the acid electrolyte (HPO_3).
- MCFC 's - molten carbonate fuel cells in which the electrolyte consists of a mixture of molten carbonates
- SOFC’s - solid oxide fuel cells where the electrolyte is oxides of selected metal.

The first fuel cell powered aircraft flew on 04.02.2008. It was the installation of hydrogen power to the aircraft HK36 Super Dimona, manufactured by Diamond Aircraft. The drive was created from the PEM Fuel Cell propulsion system with an output of 50 KW.

Another hydrogen-powered aircraft is Antares DLR H2. It is a modified motorized glider, which was originally powered by batteries. Fuel cells could generate power 25 KW, hydrogen tanks are under slung beneath the wing in aerodynamic nacelles.

Hydrogen Production:

Hydrogen can be produced in many ways from a wide range of feedstock. The global hydrogen production is currently dominated by production from fossil sources. Every day the world produces about 1.4 billion Nm^3 , or 127 thousand tons of hydrogen .

The use of hydrogen thus produced locally can help reduce the production of certain health - damaging substances globally would not only lead to less economical use of primary energy and the associated increase in the production of carbon dioxide. Therefore, it is necessary to look for other ways to produce hydrogen. One possibility is obtaining hydrogen from water electrolysis, gasification or pyrolysis of biomass.

Power consumption for producing 1 m^3 H_2 nowadays is about 4.8 KWh , or about 53 KWh/kg. Producing hydrogen by electrolysis costs about 90 CZK per kilogram.

Schematic of aircraft fuel cell system is shown in Fig 54.

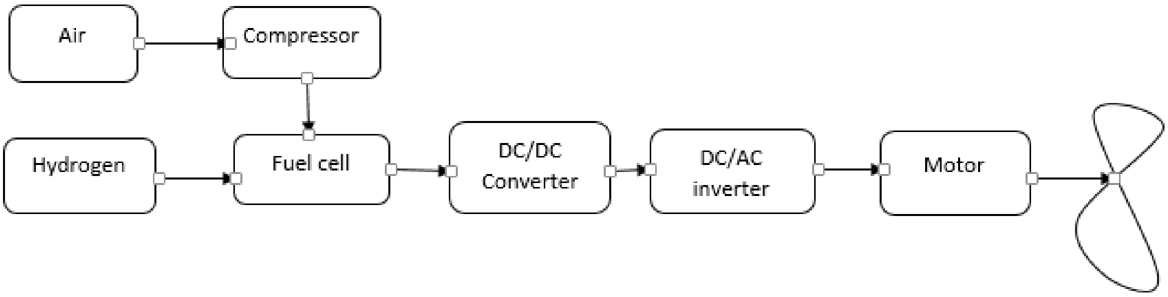


Fig 54 Scheme hydrogen fuel cell propulsion system

Advantages of using hydrogen cell:

- Hydrogen is abundant and readily available.
- Hydrogen is non-toxic gas and does not produce any toxic emission.
- Hydrogen energy is efficient; it produces more energy per pound of fuel than other fuel.

Disadvantages of using hydrogen fuel cell:

- Hydrogen gas is expensive and time-consuming to produce.
- It is hard to storage and move around.
- Though hydrogen energy is renewable and its environmental impacts are minimal, it still needs other non-renewable sources like coal, oil and natural gas to separate it from oxygen.
- Hydrogen cells produce a big amount of heat, so that radiator is always needed in fuel cell system.

10.2 Electric motors working on battery

Batteries store energy and provide it to the motor via controller. The most important characteristic of batteries for airplanes is their energy density, usually measured in watt-hours per pound or kilogram (Wh/lb. or Wh/kg).

Battery types:

Following are most known kind of batteries, their advantages and disadvantages, characteristics of all battery types are shown in Table. 40.

Table. 40 Characteristic of all battery types

	NiCd	NiMH	Lead Acid	Li-Ion	Li-Pol
Energy Density(Wh/kg)	45-80	60-120	30-50	110-160	100-130
Cycle Life (to 80% of initial capacity)	1500	300- 500	200- 300	500-1000	300- 500
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h
Overcharge Tolerance	moderate	Low	high	very low	low
Self-discharge/ Month (room temperature)	20%	30%	5%	10%	~10%
Cell Voltage (nominal)	1.25V	1.25V	2V	3.6V	3.6V
Operating Temperature (discharge only) °C	-40÷60	-20÷ 60	-20÷ 60	-20÷60°C	0 ÷ 60
Maintenance Requirement	30-60 days	60-90 days	3- 6 months	not req.	not req.
Typical Battery Cost (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)
Cost per Cycle(US$)	$0.04	$0.12	$0.10	$0.14	$0.29
Commercial use since	1950	1990	1970	1991	1999

Lead-acid batteries

Lead acid was the first rechargeable battery for commercial use. Today, the flooded lead acid battery is used in automobiles, forklifts and large uninterruptible power supply (UPS) systems. They have a small energy density which means that they are heavier for the same capacity, therefore they are not suitable for using on board aircraft. Lead-acid batteries are used as ground power for aircraft.

Advantages of lead-acid batteries:

- Inexpensive and simple to manufacture
- Low self-discharge
- Low maintenance requirements

Disadvantages of lead-acid batteries:

- Lead-acid battery cannot be stored in a discharged condition.
- Low energy density, poor weight-to-energy density limits use to stationary and wheeled applications.
- Environmentally unfriendly, the electrolyte and the lead content can cause environmental damage.
- Thermal runaway can occur with improper charging.

Lithium -Ion batteries

Lithium is the lightest of all metals, and has the highest negative standard potential. The first aircraft with electric drive, which has received a certificate of airworthiness is Antares 20E Fig 55 and Antaras 23E. It is an electric glider with a 42 KW brushless motor and Li-Ion batteries. The Antares 20E is equipped with a battery-system utilizing Li-Ion cells of the type SAFT VL41M

Fig 55 The Antares 20E

Fig 56 Li-Ion battery type SAFT VL41M [20]

Advantages of Li-Ion batteries:

- High energy density due to volume.
- It is low maintenance battery.
- They have almost no self-discharged.

Disadvantages of Li-Ion batteries:

- The need for electronic protection for the individual cells during charge and discharge, specified level of final voltage must not be exceeded during charging or discharging.
- The battery is aging, thus losing the maximum capacity regardless of it is used or not, the speed of aging increases with higher temperatures, higher state of charge, and a higher discharge current (load). It is, therefore, not suitable for appliances with power consumption at high intensity.
- Battery Production is quite expensive.
- Liquidation of battery in very demanding.

Lithium- polymer batteries (Li-Pol):

The Li-polymer differentiates itself from other battery systems in the type of electrolyte used. This electrolyte resembles a plastic-like film that does not conduct electricity but allows an exchange of ions. The polymer electrolyte replaces the traditional porous separator, which is soaked with electrolyte.

Advantages of Li-Pol batteries:

- Compared with the type Li-Ion Li-Polymer for the same capacity it is about 10-15 % lighter.
- It has more resistance to overcharge.

Disadvantages of Li-Pol batteries:

- They are very brittle. Cell package is formed from a metal foil which has less mechanical resistant.
- There is a risk of fire and poisoning because of the expanding gases when the battery is damaged. For safe storage, transport and charging it is good to use a security package that is self- extinguishing

Nickel Cadmium batteries:

The nickel–cadmium battery (NiCd) is a type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes.

Wet-cell nickel-cadmium batteries were invented in 1898. Among rechargeable battery technologies, NiCd rapidly lost market share in the 1990s, to NiMH and Li-ion batteries; market share dropped by 80%. Ni-Cd battery has a terminal voltage during discharge of around 1.2 Volts which decreases little until nearly the end of discharge.

NiCd battery has low internal resistance, its main disadvantage is that, it is prone to damage by overcharging. Moreover it has low energy density than Li- Ion battery.

The Nickel-Metal Hydride (NiMH) battery has higher energy density than Ni-Cd battery, but it has high self-discharge.

10.3 Suggestion of electric propulsion system for airplane VUT-081 Kondor

As it mentioned in the previous chapters, the airplane VUT-081 Kondor was selected to be the sample, on which all alternative propulsion will be applied.

Herein electric motor will be applied on Kondor, all its parameter are listed in chapter 0 (8.4).

Required thrust:

To determine the parameters of electric system, at first the required thrust must be calculated.

Required thrust and power for horizontal flight are calculated according to equations (8.4) (8.7). detailed calculations are shown in Table 41.

Table 41 Required thrust and required power

M	P	n [rpm]	C_D	C_L	D [mm]	V [km/h]	J	η	F_p	P_p
600	1,225	2387	0,22	1,58	1,65	81,52	0,34	0,58	818,73	18,54
600	1,225	2387	0,18	1,546	1,65	82,41	0,35	0,58	684,61	15,67
600	1,225	2387	0,1371	1,363	1,65	87,77	0,37	0,60	591,45	14,42
600	1,225	2387	0,1127	1,21	1,65	93,15	0,39	0,62	547,67	14,17
600	1,225	2387	0,0752	0,92	1,65	106,83	0,45	0,66	480,63	14,26
600	1,225	2387	0,0486	0,617	1,65	130,45	0,55	0,72	463,16	16,78
600	1,225	2387	0,0379	0,313	1,65	183,15	0,78	0,81	711,99	36,22
600	1,225	2387	0,0329	0,212	1,65	222,54	0,94	0,84	912,51	56,41

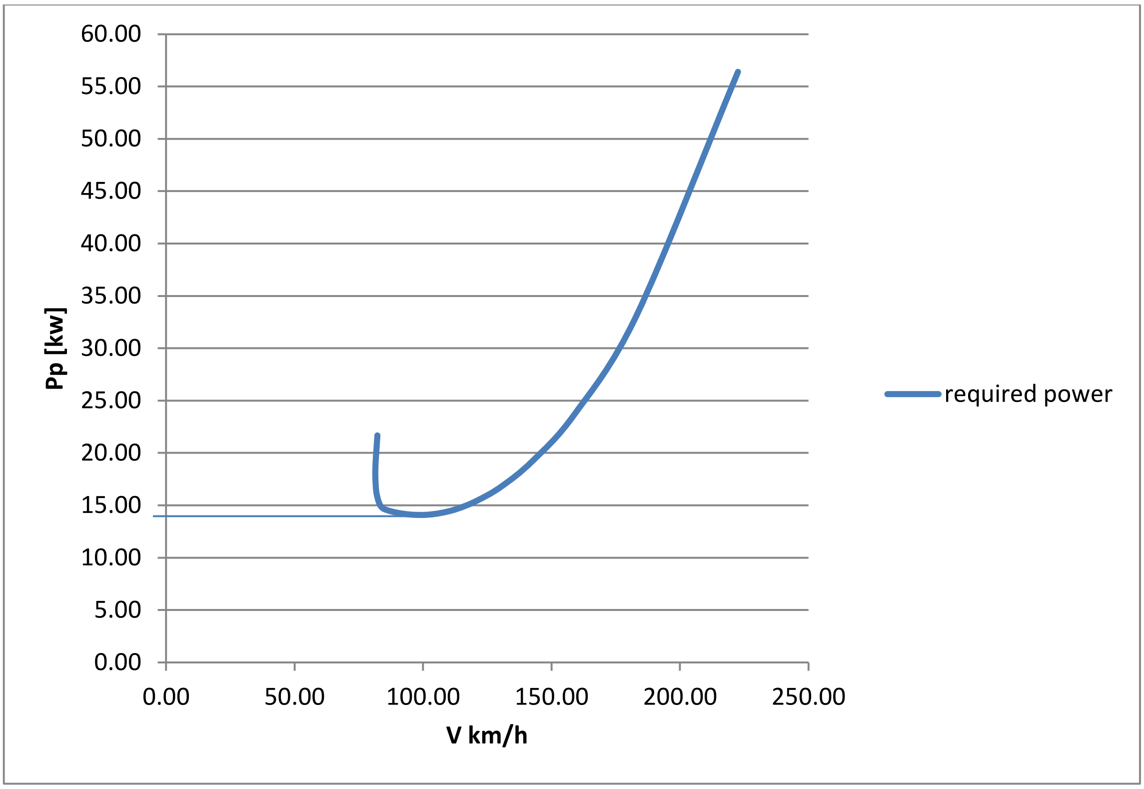


Fig 57 Required power

<u>Power for climbing flight</u>

Required power for climbing flight is calculated according to the equation (9.1)

$$P_{p.c} = P_{Pmin} + \Delta P \qquad (9.1)$$

The difference between available and required power ΔP can be calculated from equation (7.5) assuming the climbing speed as its minimum value according to ASTM norm F2245-12D.

Table 42 Minimum required power

m [kg]	U [m/s]	Pmin [KW]	ΔP [KW]	Pv [KW]
600	1,5	14	8,82	22,82

<u>Definition of flight type:</u>

Flight type was determined the same in aircraft VUT051 RAY according to the

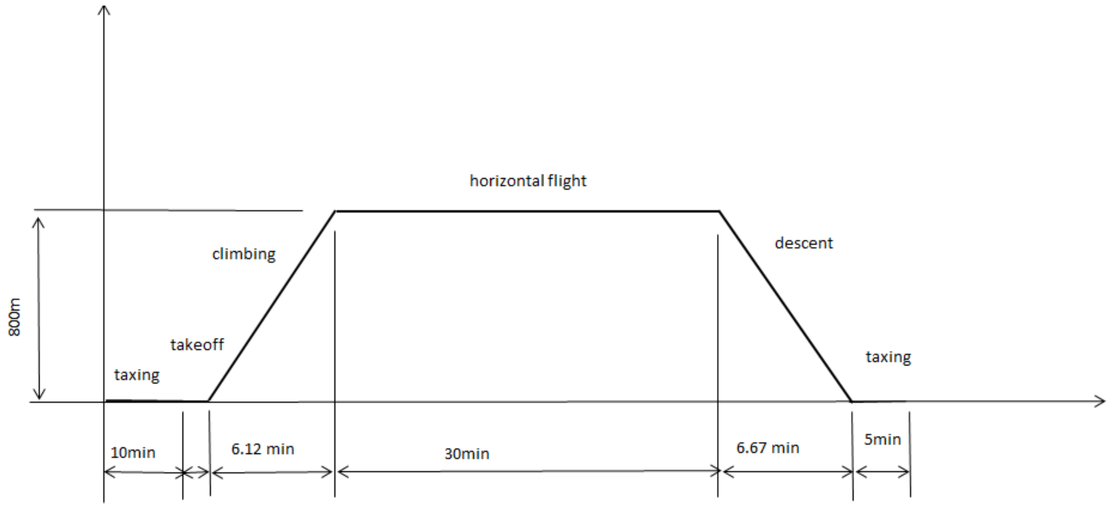


Fig 58 Flight type

Thermal dimensioning of electric motor:

Optimal choice of electric motor is based on two criteria's:

1- Motor temperature must not exceed 150 C° in all working cycle.
2- The weight of motor and battery must be the minimum.

Based on motor dimensioning for aircraft VUT051 RAY it will be used the same reference motor with 40 KW power and 2000 rpm speed, motor parameter are in Table 43.

Fig 59 shows the changes of motor temperature during all working cycles and for different power. It can be observed that temperature of 30 KW motor exceeds 150 C^O at specific work phases.

Table 43 Parameters of reference motor

Iron weight m_{Feo}[kg]	21
Copper weight m_{cuo} [kg]	10
Temperature at full power [C^o]	150
Losses in iron P_{feo} [W]	600
Losses in copper P_{cuo}[W]	910

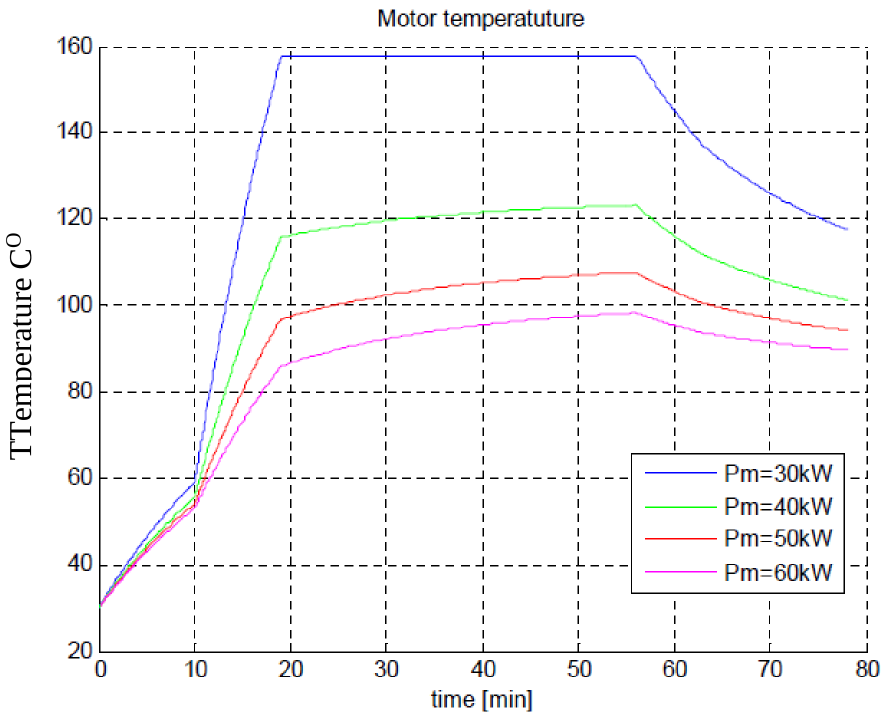


Fig 59 Motor temperature in all flight stages and for different power [30]

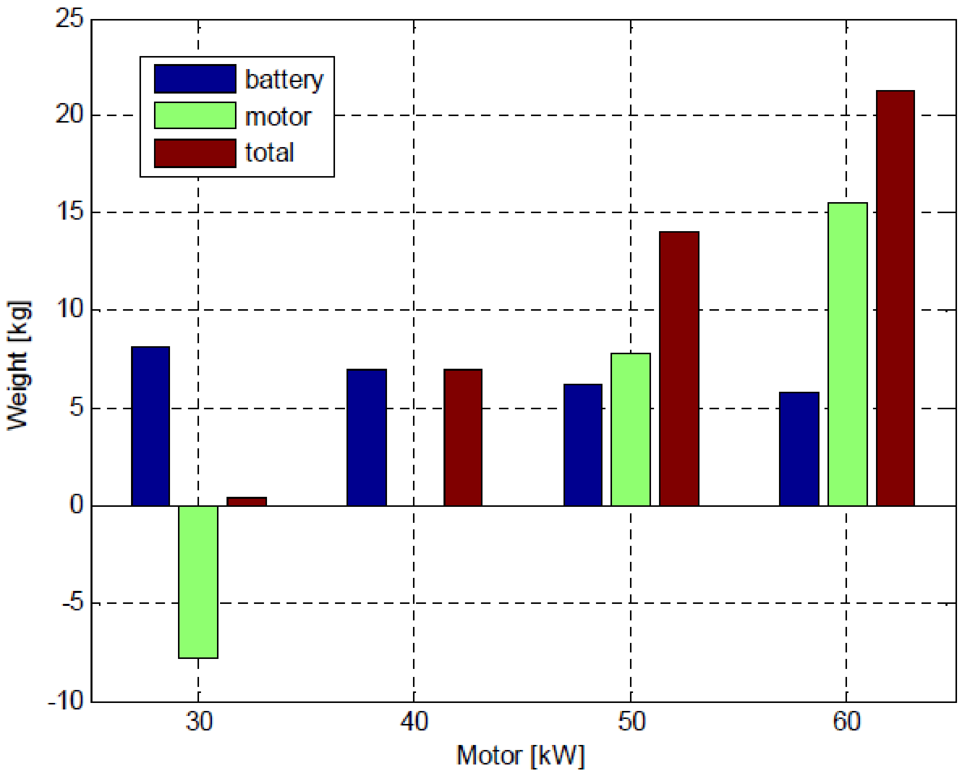


Fig 60 Addition weight for loses compensation [30]

From Fig 59, Fig 60 it can be noticed, that motor with power over than 40 KW will achieve the criteria of temperature. However the weight of motor + battery combination will be increase with motor power increasing.

I suggest to use the same electric motor that was used in airplane VUT 051 RAY, which is HS 019 00 Aveko, 53 KW power and 2300 rpm speed.

According to the selected motor, available and consumed power for all flight phases is shown in the Table 44

Table 44 Motor powers for all flight phases

Flight phase	T [min]	T [sec]	P_m [KW]	P_t [KWh]
Taxing	10	600	15	2.5
Take-off	0.83	50	52.4	0.73
Climbing	6.12	367	52.4	5.34
Horizontal	30	1800	29.6	14.8
Descent	6.67	400	9.4	1.04
Taxing	5	300	15	1.25
Total	53.62	3217		24.41

Powered consumed during all flight phases is 24.41 KWh on the motor shaft. Power losses in 40 KW motor during flight type is about 1.1 KWh. Inverter efficiency is assumed to be about 0.95.

The total required energy stored in battery can be calculated from equation (9.2)

$$W_{bat} = \frac{P_t + energy\ losses}{\eta_{inv}} = \frac{24.41+1.1}{0.96} = 26.58\ KWh \tag{9.2}$$

The value of stored energy using to suggest the battery is 27KWh. A combination of 3041 battery Panasonic NCR18650A will be the ideal option. It is lithium-ion battery with energy density 27 KWh, all its parameters are listed in Table 45.

Table 45 Parameters of the selected combination of battery

Type battery	Voltage [V]	Capacity [Ah]	Battery weight [kg]	Density [Wh/kg]	No. battery	Weight of all battery	D [mm]	H [mm]
NCR18650A	3.7	2.4	0.045	197.33	3041	136.845	18.2	64.7

I suggest to use two battery package. The first one consists of two series-connected pack and every pack is consisting of 5 block each of them contains 102 battery. The second pack consists of four series-connected packs and every pack is consisting of 5 blocks each of them contains 102 batteries. Total number of used battery will be 3060.

The first battery pack will be placed behind the seat of the airplane, so I recommend replacing the second seat with this battery pack, and the secod pack in the rare of the plane

The two battery package and their dimensions are illustrated in Fig 61, Fig 62, and Fig 63.

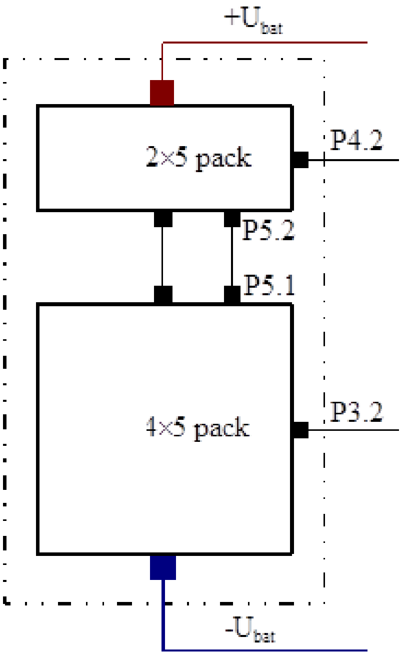


Fig 61 Block diagram of battery [3]

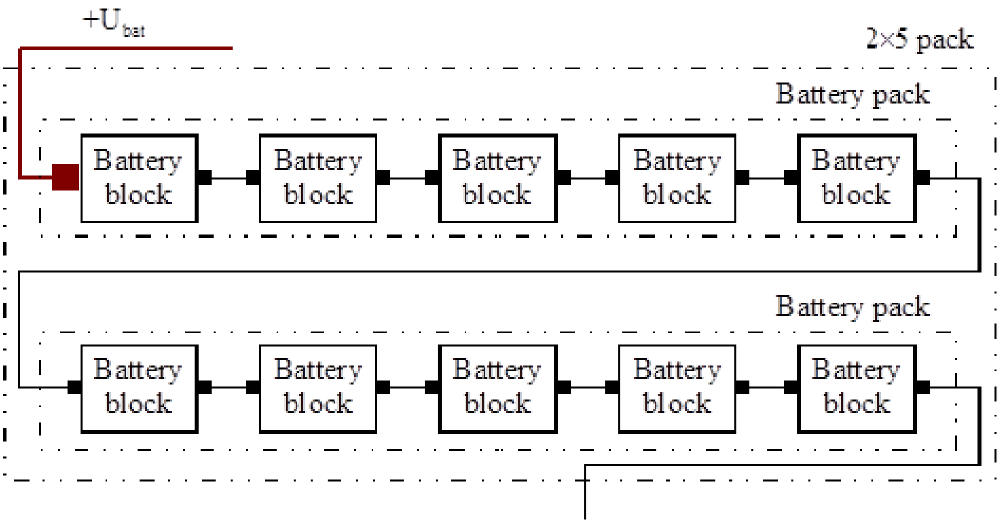


Fig 62 Block diagram of package 2×5 pack [3]

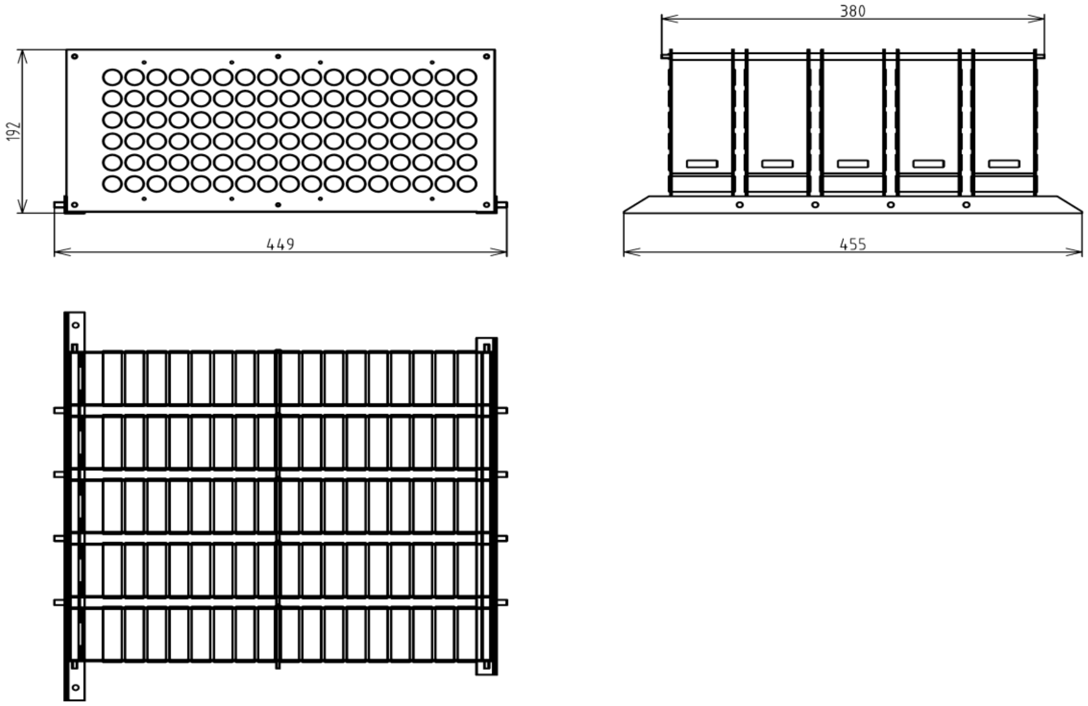


Fig 63 Basic dimension of battery pack [3]

10.4 Aircraft flight performance

Table 46 shows the weight of each component of aircraft with motor Rotax and the aircraft with electric motor. For max take-off weight, it is considered one pilot (weight 90kg) and all other weights are according to the weight listed in [31].

Table 46 Weight of aircraft component

Max take-off weight (with piston engine)	**600 kg**
Pilot weight	2×90 kg
Kits and rescue equipment weight	20 kg
Engine weight	73 kg
Propeller and fuel system weight	50 kg
Fuel weight	90 kg
Electric propulsion weight (electric motor + propeller + inverter)	49 kg
Weight battery + surrounding system	170 kg
Weight of attachment elements + cables	10 kg
Weight of LCD panel + controlling elements	4 kg
Max take-off weight (with electric motor)	**530 kg**

Results performance airplane are calculating according to the same equations listed in chapter 8 (8.6).

10.4.1 Stalling speed

Stalling speeds were calculated for the max. take-off weight 530 kg, at maximum lift coefficient and different configuration and altitude range from 0 to 8000 ft. MSA(step 2000 ft.). The values of max. lift coefficient C_{Lmax} is taken from airplane polar Fig 27 and are listed in Table 26.

Table 47 Stalling speed for different configuration and different flight altitude

Configuration	Stalling speed [km/h]				
	Flight altitude [ft.]				
	0	2000	4000	6000	8000
Travel	77.4	79.7	82.1	84.7	87.33
Take-off	72.3	74.4	76.7	79.1	81.6
Landing	65	67	69	71.1	73.4

According to ELSA-A legislation, maximum stalling speed during landing configuration must not exceed 75 km/h. The landing configuration stalling speed is 65 km/h, this speed is lower than required speed.

10.4.2 Horizontal flight

Maximum speed in horizontal flight for travel configuration was determined as a steady mode, wherein required thrust and available thrust are equal - for different engine regime.

Fig 64 shows available and required thrust (F_P, F_V) for different configuration and different flight speeds. F_P, F_V are calculated according to equations (8.3) and (8.4).

Table 48 shows the maximum speed in horizontal flight for different modes of engine operation and at 0 ft. altitude.

Table 48 Maximum speed for different configuration and flight altitude 0 ft

Configuration	Max.speed [km/h] Altitude 0 [ft.]
Take-off	185
Permanent	215

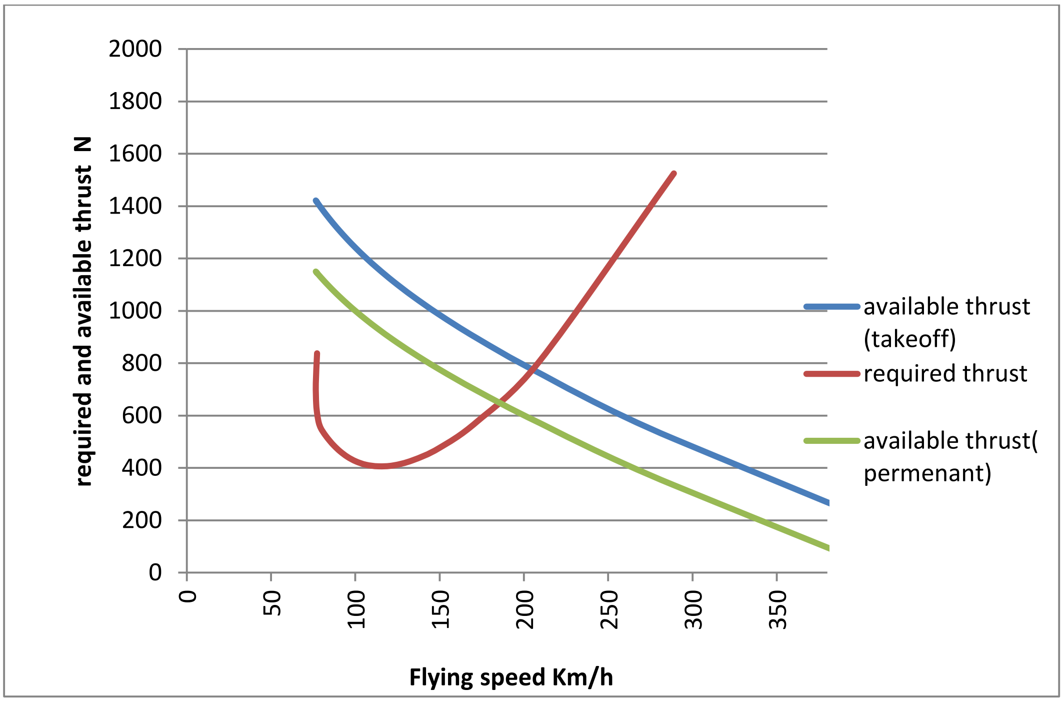


Fig 64 Available and required thrust at 0 ft. MSA

10.4.3 Climbing flight

Table 49 shows max climbing speeds and corresponding flight speeds at different altitudes (0-8000) ft. Relationship between climbing speed and flight speed for different altitude and flight configurations is shown in Fig 65 and Fig 66.

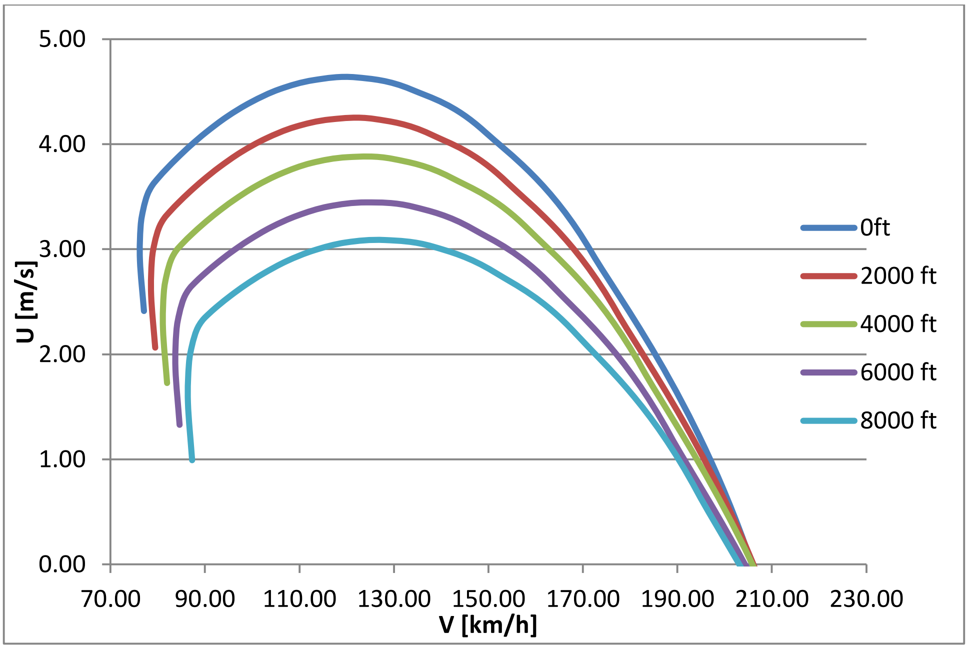


Fig 65 Climbing speed at take-off configuration for different flight altitude

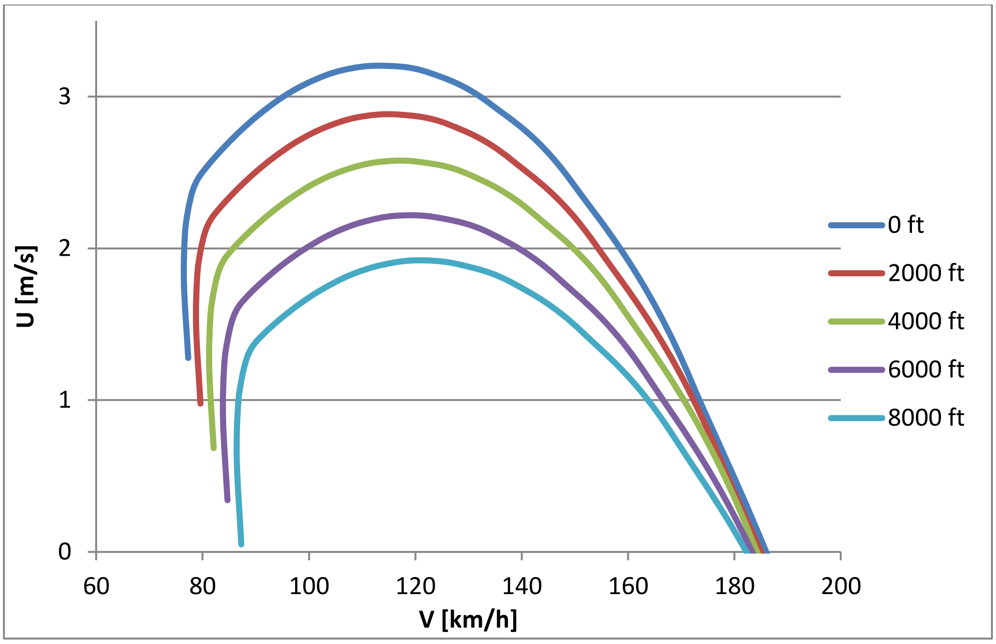


Fig 66 Climbing speed at permanent configuration for different flight altitude

Table 49 Climbing speed and corresponding flight speeds at different altitude and different configuration (1)

Engine mode	Climbing speed [m/s]/flight speed [km/h]				
	Flight altitude [ft.]				
	0	2000	4000	6000	8000
Take-off	4.64	4.24	3.88	3.44	3.09
	122	125.78	120	124	128
Permanent	3.2	2.88	2.57	2.21	1.92
	113.35	166.8	112.7	116.3	119.98

According to ASTM norm F2245-12D climbing speed must be more than 1.6 m/s, the aircraft fulfill the requirement of climbing speed at all operation mode.

10.4.4 Ceiling

Theoretical ceiling is the altitude at which the climbing speed is zero , practical ceiling is the altitude at which the climbing speed is 0,5 m/s. Both are calculated based on the relationship between climbing speed and altitude shown in Fig 37.

Table 50 Theoretical and practical ceiling for different engine mode (1)

Engine mode	Ceiling [ft.]	
	Theoretical	Practical
Take-off	23150	20650
Permanent	16000	13500

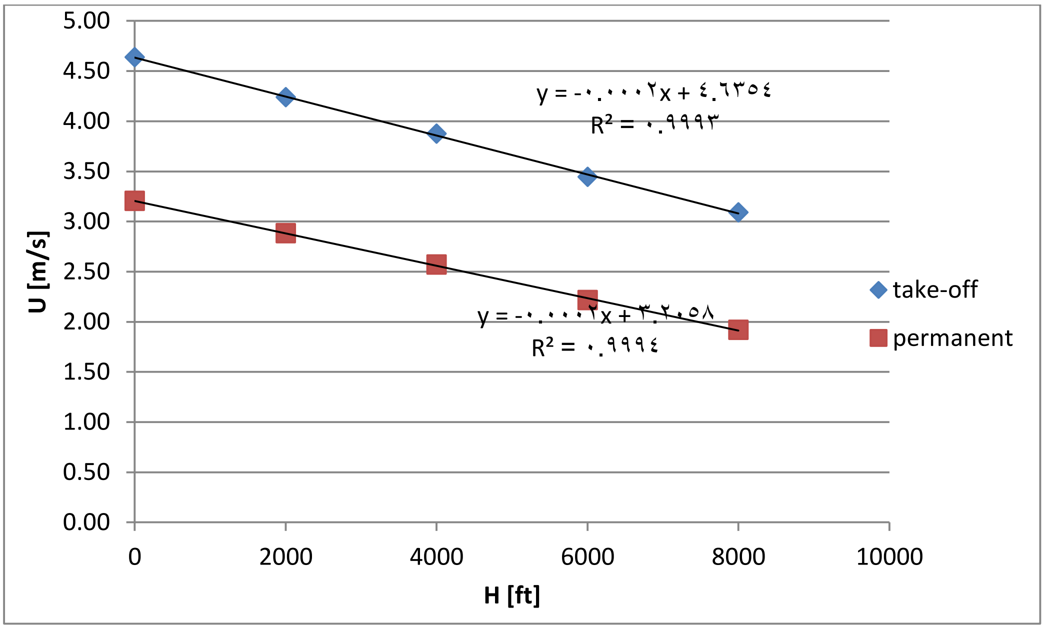


Fig 67 Flight altitude for different climbing speeds

10.4.5 Range and endurance

Calculated for max. take-off weight 530 kg, pilot weight 90 kg, motor effeciency is 0.97, and inverter efficiency is assumed to be 0.95.

$$Endurance = \frac{battery\ energy \times motor\ effeciency \times inverter\ efficiency}{required\ power}$$

$$Endurance = \frac{27 \times 0.97 \times 0.95}{14} = 1.77\ h$$

$$Range\ \ = endurance \times speed = 1.77 \times 110 =\ 194.7\ km$$

10.4.6 Take-off

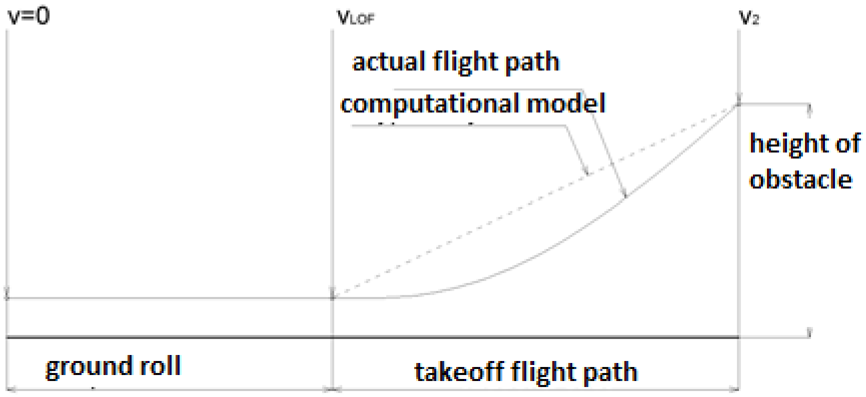


Fig 68 Take-off path

Ground segment of take-off starts at speed V= 0 until V_{LOF}, then starts airborne phase until V_2. At this speed airplane climbs to the height of obstacle 15m.

The calculation was made considering max.take-off weight 530 kg, take-off at altitude 0 ft. MSA, friction coefficient f = 0.04, height of obstacle h_P is 50 ft. (15m).

Throughout take-off flaps are set for take-off mode, and engine operates at take-off mode, pitch angle is 0°, at this angle C_L=0.539.

Table 51 Length of take-off path (1)

Segment	Segment length [m]
$S_{G,TOF}$	122
$S_{A,TOF}$	118
S_{TOF}	240

10.4.7 Landing

Airborne phase of landing starts at altitude h_P=15m and reference speed V_{REF} until V_P approach speed then starts ground phase till speed V=0.

Pitch angle is 0°, therefore lift coefficient C_L=1.066, drag coefficient C_D=0.1635, and friction coefficient will be consider 0.4.

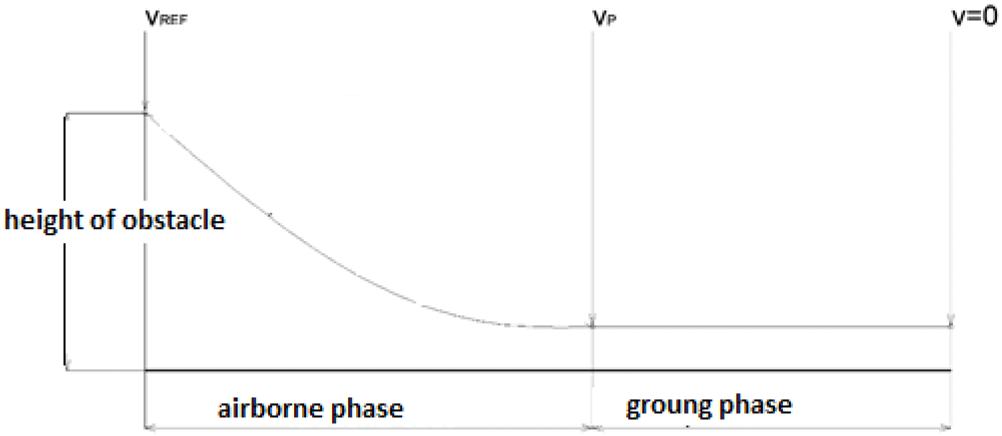


Fig 69 Landing path

Table 52 Length of landing path (1)

Segment	Segment length [m]
$S_{A,L}$	218
$S_{G,L}$	63
S_L	281

11. CONCLUSION

In this thesis there are ten chapters. The first chapter, after the introduction, contains an overview about aviation traffic and aircraft emissions. It also contains information about EU aviation's contribution to climate change and different EU and ICAO initiatives to reduce greenhouse gas emissions.

This is followed by the measurements made at Medlanky airport and the Institute of Automotive Engineering laboratory, for Rotax engine without catalytic converter and engine, type Skoda 1.0 MPI which is equipped with catalytic converter. These measurements revealed the clear effect of using catalytic converter in exhaust system.

In the fifth chapter were presented daily flight plan for aircraft of categories LSA, ULA, during a year. The analysis of the most frequent flight time of the aircraft and the difinition of the maximum probable one, allows the flexibility to change the maximum fuel amount in the airplane, or suggest another alternative motor which may be more suitable.

Further in the following chapter, I made a statistic study for the experts‘ opinion about their opinions on the development of new engine or modification to drive two-seat sport aircraft category CS VLA. Also about development new engine or modifications to drive four seat sport aircraft (category CS23-N). This study gave an idea about the alternative propulsion option which can be considered the closest to optimal from the viewpoint of experts working in this field.

In the last three chapters, three options among all options presented as alternative propulsion or alternative solution to reduce aircraft emissions were examined. These options are, using LPG fuel, replacing the traditional engine with electric one, and adding catalytic converter to the aircraft exhaust system.

These options were examined individually, taking into account the advantages and disadvantages of each of them, choosing the component of fuel system or all propulsion system. Finally, there was presented the effect of using each one on aircraft performance by calculating aircraft speeds, ceiling, endurance, range and take-off and landing path.

After reviewing the emissions rates from air traffic and the programs of EU in collaboration with ICAO to limit the emissions, I found that it is worthwhile to search in the field of new solutions which will support the process of reducing emission and at the same time it can be economically viable and doable.

In order to support the research with practical and realistic views, I made the statistical study on the use of all possible solutions in this area. The results of this study was, that 61.6% of experts thinks that using current types of engines working on gasoline stays the most effective propulsion for two seats aircraft. However, the solution can be in focusing on increasing their efficiency, reliability, durability, weight reduction, emission and noise.

Whilst, 25 % of them thought that adding catalytic converter to the exhaust system is the better solution. I can expect that this option is relatively good at first from ecological point of view. Whereas, as shown in 0, engine for airplane equipped with catalytic converter produces significantly less hydrocarbons and carbon monoxide emissions. It must take into account a very important factor which is, adding catalytic converter to exhaust system reduces the engine power of about 11% . So that I calculated all aircraft performance for airplane VUT-081 Kondor for which was applied catalytic converter.

A slight decrease in max. speed at horizontal flight was recognized. Climbing speeds at different altitudes also changed, but all performance details still fulfill the corresponding norms. A comparison between all calculated performance is listed in Table 53.

Returning to the expert's opinions 28% said that using LPG is in the third place and 21% gave it the fourth place. It seems at the first glance that, engine which burns liquefied petroleum, produces significantly less emissions. This idea appears from the facts that visible emission (soots) does not exist in products of LPG combustions.

In fact, LPG emits all greenhouse gases producing by traditional fuel, but this rate is a little less for carbon dioxides. Here it should be noted that LPG has less heat content/ dm3 than jet fuel and avgas, which means Increasing in fuel consumption about 10%, and this is its main disadvantages.

Using LPG as fuel causes also reducing of engine power about 5%. Moreover, LPG fuel system has a greater weight than the other of Avgas for the same airplane. That's because this fuel needs a pressure tank to save it in a liquid form.

After applying LPG on Kondor airplane again, the calculated amount of fuel is significant so that will be no enough places for the pressure tank to be equipped. Based on this, and on the information provided by flight plan for some similar airplane in chapter 6. I decided to decrease the fuel amount carried by aircraft and calculated performance changes according to the new criterias.

A slight decrease in max. speed at horizontal flight was recognized. Climbing speeds at different altitudes also changed, but all performance details still fulfill the corresponding legislation.

Table 53 Camparing flight performance for all proposed systems [1]

Dicreption	Traditional motor	LPG system	+ cat's	Electric motor
Stalling speed [km/h] at 0 [ft] altitude and travel configuratio	82.34	82.34	82.34	77.4
Max. speed at horizontal flight [km/h] at 0 [ft] altitude and take-off configuration	228.16	222	220	185
Climbing speeds [m/s] / flight speed [km/h] at 0 altitude and take- off configuration	6.07/127	5.99/129.5	5.63/129	4.64/11
Theoretical/ practical ceiling [ft] at take-off configuration	25675/ 23556	29941/ 27441.5	19386/ 17719	23150/ 20650
Length of take-off path [m]	197	221	226	240
Length of landing path	276	300	295	281

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[1] Flight performance for airplane Kondor equipped with traditional motor is taken from reference [15]

12. LIST OF FIGURES

13. LIST OF TABLES

14. REFERENCE

1. (23. august 2010). American Fuels.
2. CHIA-CHIEN, A. (2007). The Delphi Technique: Making Sense Of Consensus. *Practical Assessment Research & Evaluation, 12*(10).
3. CIPIN, R. (2010). *Battery system for driving aircraft VUT 051 RAY*. Brno: Department of Power Electrical and Electronics.
4. *Courses*. (15. june 2012). National Programme on Technology Enhanced Learning: http://nptel.ac.in/courses/112104033/pdf_lecture/lecture15.pdf
5. DANEK, V. (2009). *Mechanika letu 1*. Brno: CERM, s.r.o.
6. *Environmental Policy*. International Air Transport Association: http://www.iata.org/policy/environment/Documents/atag-paper-on-cng2020-july2013.pdf
7. *Environmental Protection* . (2010). International Civil Aviation Organization: http://www.icao.int/environmental-protection/Documents/EnvironmentReport-2010/ICAO_EnvReport10-Outlook_en.pdf
8. *EU action on climate*. European comission, CLIMATE ACTION: http://ec.europa.eu/clima/policies/brief/eu/index_en.htm
9. HROMADKU, J. (2011). *Internal Combustion Engine*. Prague: Grada.
10. ICAO. *Aviation Aoutlook*.
11. IMRAN, Y. (2007). The Delphi Technique. *20*.
12. *Jet fuel*. (2. August 2012). The Strengle Angel: http://stengelangle.com/tag/jet-fuel/
13. KADDOUR, M. (2013). Using Catalyst for Reducing Emission in Aviation. *New Trends in Civil Aviation 2013*. Zelina: Academic Publisher CERM, s.r.o. Brno.
14. KADDOUR, M. (2014). Properties of Alternative Motors in Aviation. *32*(2).
15. LAJZA, O. (2014). *Flight performance of airplane VUT 081 KONDOR*. Brno.
16. *LPG fuel systems*. LPGC: http://www.lpgc.co.uk/index_files/TypesofLPGsystems.htm
17. *LPG Systems & Manufacturers*. Gas 4 Car: http://www.gas4cars.com/index.php?option=com_content&view=article&id=47&Itemid=66
18. *LPG toroidal tank F11L*. (2010). STAKO: http://www.stako.pl/index.php?id=product&prod=6&kat=1&alias=F11L&lang=en
19. *Mandatory Requirement for Airworthiness*. (2012). CIVIL AVIATION AUTHORITY.

20. *Medium power lithium-ion cells VL M cells*. (March 2005). houseofbatteries: http://www.houseofbatteries.com/documents/VL41M.pdf
21. *Reducing emissions from aviation*. European comission, CLIMATE ACTION: http://ec.europa.eu/clima/policies/transport/aviation/faq_en.htm
22. Secretariat, I. (2010). *Aviation Outlook.* ICAO.
23. SEIDEL, S. *Steve Seidel's blog.* CENTER FOR CLIMATE AND ENERGY SOLUUTIONS: http://www.c2es.org/blog/seidels/efforts-limit-aviation-emissions-advance-icao
24. SHARP ARTHUR, G. *Delphi Technique*. Načteno z Reference for Business: http://www.referenceforbusiness.com/encyclopedia/Cos-Des/Delphi-Technique.html
25. STENGEL, M. (2014). *general aviation*. the stengle angle: http://stengelangle.com/tag/general-aviation/
26. *Technika.* (20. september 2004). HONDA CLUB: http://www.hondaclub.cz/default.aspx?a=610
27. *Technology Transfer Network Clearinghouse for Inventories & Emissions Factors.* Environmental Protection Agency: http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s05.pdf
28. *The EU Emissions Trading System (EU ETS).* European comission, Climate action: http://ec.europa.eu/clima/policies/ets/index_en.htm
29. *Universal Catalytic Converters.* OEM catalytic converters: http://www.oemcatalyticconverters.com/universal-catalytic-converters.html
30. VOREL, P. BENCALIK, K. . (2010). *Specification electric motor VUT 051 RAY.* Brno: Department of Power Electrical and Electronics.
31. VOREL, P. et el. (2010). *Specifications for propulsion system with batteries VUT 051 RAY.* Brno: Department of Power Electrical and Electronics.