VOL. 11, NO. 5, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

HIGH ALTITUDE OPERATIONS WITH PISTON ENGINES POWER PLANT DESIGN OPTIMIZATION PART I: INTRODUCTION

Luca Piancastelli, Leonardo Frizziero, Simone Pica and Giampiero Donnici
Department of Industrial Engineering, Alma Mater Studiorum University of Bologna, Viale Risorgimento, Bologna, Italy
E-Mail: leonardo.frizziero@unibo.it

ABSTRACT

Diesel and spark-ignition piston engines are an ideal choice for long endurance, high altitude operations (10, 000m/33, 000ft) and extremely high altitude operations (20,000m-65,000ft). These systems are more complex than traditional applications that are normally limited to 5, 000-7, 000m (16, 000-23, 000ft). In fact, the air propulsion system (propeller or fan), the air intake, the fuel system, the turbo charging, the exhaust and the cooling system take part to the design optimization process. An integrated design is strictly necessary. Since prop-fan is currently under development, the design should start from the choice between propeller and fan. This choice will influence optimum cruise speed, critical altitude and aircraft design as a whole. The air induction system is extremely important to improve efficiency, endurance and critical altitude. At low altitude, a filtered induction system is used for takeoff. At high altitudes, the intake air is taken from high-pressure areas into an alternate, extremely optimized, path. This induction system recovers as much pressure as possible, air kinetic energy at cruise speed. In propeller systems, the intake is usually positioned in the lower part of the aircraft. On fan systems, a little amount of “high pressure” air is taken from the high-pressure area of the fan. The exhaust system is also critical with the choice between pressure recovery and thrust. Exhaust-pressure-recovery reduces backpressure and temperature at exhaust. However, the improvement in critical altitude is marginal. In more common, thrust driven exhaust systems, the exhaust energy is converted into speed and thrust. At the relatively high speed of high altitude cruise, also the cooling system adds a small amount of thrust through the Meredith’s effect. The piston engine power plant design is then extremely critical. Many different components should find the correct position for maximum performance. The power-plants of WWII water-cooled fighters and bombers are good examples, even if their design cruise altitude is below 10, 000m (33, 000ft). Modern turbofan and turbojet air intakes are also of help. However, the requirements of low weight, high reliability and long endurance HALE (High Altitude Long Endurance) UAVs (Unmanned Aerial Vehicle) requires further work on this specific subject.

Keywords: optimization, HALE, UAV, thruster, cooling, meredith effect.

INTRODUCTION

Propulsion system is a most difficult technical challenge in unmanned aircraft designed to fly subsonically >20, 000m (60, 000ft) for >4 hrs. In this flight regime, however, air breathing propulsion is difficult to achieve due to the small air density and pressure with altitude. Turbochargers (TC) are needed to supply most of the intake pressurization required to compress ambient air into the intake. Volume flow requirements increase with altitude, which translates to larger TC size. Pressure ratio requirements also increase with altitude, which translates to more TC stages. Since power is proportional to airflow for any air breathing engine, the powerplant size required to process airflow for a rated power will grow. Interstage and afterstage cooling is required for efficiency and power output. Weight is proportional to the cube of linear dimensions. Theoretically, heat exchanger sizing is driven upwards by the reduced convective heat transfer available, and the lower density ambient air. Practically, Meredith cooling duct will partially recover pressure and will output additional thrust. The very low OAT (Outside Air Temperature) of -56.5 DEC C also helps the cooling system. However, flying subsonically in low density air requires larger thruster "capture/actuator-disk" areas to achieve the propulsive efficiency that is needed to reduce fuel consumption and provide range. Mach 0.9 represents the approximate upper speed limit for a subsonic fan propelled aircraft, while Mach 0.4 represents the theoretical best efficiency aircraft speed. Subsonic slow flight at altitudes >20, 000m favour thrusters with relatively large actuator areas (i.e. a propeller driven aircraft), and the actuator size (i.e. propeller diameter) will approximately 3 times larger than medium altitude conventional aircraft (5, 000m).

Beyond certain power levels (≈200kW), the fan replaces the propeller. Because of the increased size and weight of the air handling system and thrust delivery components, a propulsion system optimized for high altitudes is significantly larger and heavier than its low altitude counterpart. Moreover, the HALE (High Altitude Long Endurance) vehicle needs more power to stay aloft. In fact, faster flight speeds are necessary to maintain dynamic pressure and support its weight in low density air. Therefore, the propulsion system claims greater fractions of the airplane's gross weight. This runs counter to the airplane's ability to carry the necessary fuel weight and payload. In this first part of the paper the choice between propeller and fan, the air induction, the exhaust and the cooling systems are discussed, since they are most critical for HALE UAVs optimization.

Propulsion system: propeller or fan

As part of the ERAST (Environmental Research Aircraft and Sensor Technology) 1987-2003 programs, NASA started developing an UAV (Unmanned Aerial Vehicle) for chemical analysis in the stratosphere. The requirements for the propulsion system, consisted in an altitude of 25.9 km, and an absorbed propeller power of 63.4 kW (85 hp), at a cruise velocity of Mach 0.4. A propeller was then designed with Glauert's momentum-blade element theory and with the ADPAC (Advanced Ducted Propfan Analysis Code) program, a CFD code.

The final design was a 4.6 meters diameter three-bladed propeller. The airfoil used for the sections was the Eppler 387, which is optimum for low Reynolds numbers, although it is slightly thicker than the modern transonic airfoils, with could create problems due to compressibility effects near the tip and to moisture/ice in air. The Eppler 387 was previously tested. The tests at the NASA Langley Low Turbulence Pressure Tunnel provided very high quality data in the range of 0.015–0.2 Mach. The 85.1% propeller efficiency of Glauert's theory was similar to the one obtained from CFD simulation (86.2%). However, a propeller of this size, although it presents a good efficiency, causes serious problems of installation.

In 2006, a contra-rotating propeller was designed for a vehicle capable of flying at an altitude of 25 km. The absorbed power can range from 110 kW to 220.5 kW at 0.4-0.7 M.

Table-1. Contra-rotating propeller data.

D (m)	**N** (rpm)	**P** (kW)	η_i
2.5	1,250	190	86%

The application of Theodorsen's theory for contra-rotating propellers led to the choice of a 2.5 m six bladed propeller, which can be observed in Figure-1. The propellers rotate at 1250 rpm and absorb a power of 183.75 kW, with an induced efficiency of 87.6%. This larger value of the induced efficiency is due to the higher value of the power and rotational speed, which could not be adopted with a single-rotating propeller, because of the excessive value of induced speed and the consequent decrease of efficiency. The other characteristics of the dual-rotating propeller are shown in Table-1. These evaluations were substantially confirmed by Solid Work CFD simulation, although the efficiency proved to be slightly lower (86%).

Figure-1. Propeller for 190kW/1250rpm/20km/0.4 M/ 2.5m diameter.

In order to simplify the construction the power was split into two propulsion units as shown in Figure-2. The quite large blended fuselage was due to the circular satellite communication antenna.

Figure-2. High altitude (20, 000m) UAV preliminary design with two contra-rotating propulsion units.

Theoretically, it is possible to design high-speed propellers, called propfans that NASA developed until 1990. This program saw recently new interest due to high fuel price. However, the propfan has encountered several problems of noise and turbulence that have not been solved. For practical reasons a (shrouded) fan is the best choice for power levels higher than 200kW@0.4M/25km. Figure 3 shows a fan designed for a 200kW-20, 000m-0.4M-UAV. The diameter of the fan is 0.29m (11-in.). This fan is based on NASA CR2003-212369 design. Propulsion efficiency is defined by equation (1)

$$\eta_p = \frac{2}{1+\frac{c}{v}} \tag{1}$$

While thrust T is given by equation (2).

$$T = \rho \frac{\pi D^2}{4} v(c-v) \tag{2}$$

ARPN Journal of Engineering and Applied Sciences

For the same thrust T, v_e is larger for the fan than for the propeller, since the diameter D of the fan is smaller than the diameter of the propeller for the same absorbed power (2). For this reason, in order to have the same propeller efficiency (1), the fan-propelled aircraft should be faster than the propeller-propelled aircraft. This fact affects aircraft design.

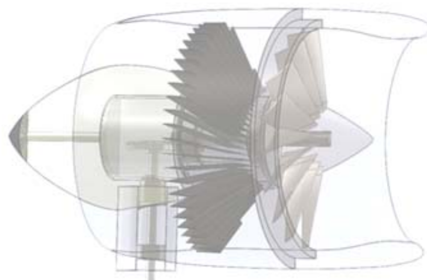

Figure-3. Fan for 200kW/20,000m/0.7M/0.65m diameter.

Equation (3) approximates endurance (t) at cruise altitude.

$$t = (M_2 - M_1)\frac{\eta_p}{2C_D SFC}\sqrt{\frac{\rho C_L^3 A}{2g^3}} \quad (3)$$

Equation (4) holds for aircrafts.

$$M_1 = 0.221 L_{wingspan}^3 \quad (4)$$

Equation (3) indicates that for long endurance the lift is more important than drag. Propulsion efficiency and SFC (Specific Fuel Consumption) are equally important. From the definition of aspect ratio AR, it is possible to write equation (5).

$$t = 0.0781(r-1)L_{wingspan}^4 \frac{\eta_p}{C_D SFC}\sqrt{\frac{\rho C_L^3}{2g^3 AR}} \quad (5)$$

The Breguet's equation (5) demonstrated that also wingspan is fundamental to obtain good flight endurance. In the case of piston engines power and rpm are relatively free. Especially for diesel engines it is possible to obtain the same output power at different rpm with little SFC penalty. It is possible to optimize rpm with aircraft speed and to vary engine throttle without affecting SFC. If the installation is designed for off-design performance, acceptable propulsion efficiency can be retained even when slowing down. For this reason, in order to maximize the endurance, the UAV have to slow down as speed decreases. Practically, high altitude operations do not allow throttle control. Therefore, speed increases as fuel mass decreases at the same density altitude. It is also possible to reach higher density altitude where engine power output is reduced. An advantage of diesel over spark ignition engines that the efficiency is kept almost equal even at extremely reduced power output. In the case of spark-ignition engines efficiency is slightly reduced even at full throttle "overcritical" operations. The volume elaborated by the turbo charging system is kept constant. Turbocharger overspeed and over boost (for spark ignition engines) is controlled by the FADEC (Full Authority Digital Electronic Control). The debimeter (air mass flow meter) at the intake controls the air mass and reduces the fuel mass. The reduced efficiency of compressor at lower Reynolds is compensated by increasing the exhaust gas temperature (EGT). EGT is also controlled by the FADEC that controls fuel mass flow if EGT is too high. In spark ignition engines, the mixture is set to "lean" for high efficiency cruise. If the EGT is too high, the fuel flow is also increased to avoid knocking and to reduce EGT temperature. In this case fuel is used to cool down the air charge and (up to a certain extent) to improve combustion velocity. This mixture enrichment is detrimental for efficiency. On the contrary, in diesel engines the EGT is reduced by reducing fuel flow.

Given the payload and the approximate wingspan it is possible to calculate thrust. A propeller is better due to higher efficiency. However, over an absorbed power of 200kW per engine, only the fan is available. The choice between fan(s) and a propeller(s) changes completely the aircraft design and the engine installation.

Air intake

When optimizing engine altitude performance, the primary objective for the induction system is to deliver the higher total air pressure possible to the intake manifold. In high altitude engines, the pressure drop due to restrictions to airflow will hamper the performance of the forced induction system in a more important way than a naturally aspirated engine. In fact, the pressure ratio of the ram air intake, that recovers the airspeed-squared energy, is multiplied by the pressure ratios of the compressors (in serial arrangement). In any case, a forced induction system puts a greater demand on the induction system than does a naturally aspirated of the same displacement. This is due to the larger volumetric flow rates that are demanded by the compressor. Therefore, forced induction systems demand higher capacities out of an induction system. Every single component that performs some function in the induction system contributes some restriction to the airflow. The goal is to minimize all the restrictions, regardless of how large or small they are. The most common of the induction system aspects that affect the pressure drop are diameter of air ducting, surface finish of the air ducting, bends in the air ducting, filtration elements and, in general, any obstructions placed in the intake system. Therefore, the air filtering system is eliminated in the altitude air intake; an alternate, optimized induction system should be dedicated to high altitude operation. The high altitude turbocharger should be positioned in such a

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

way to have the reduce bends in a way similar to turbofan air intakes. This problematic was common in WWII. In figure 3 it is possible to see the evolution of the BF109 air intake from the Emil to the Friedrich. This latter air intake was kept up to the later Gustav and Konrad types.

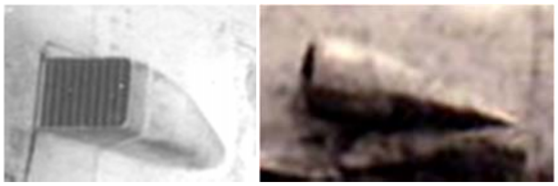

Figure-4. BF109 air intakes: left Emil (1940), right Konrad (1945).

The optimization was even more marked in Italian WWII fighters that used the same engine (Figure-5).

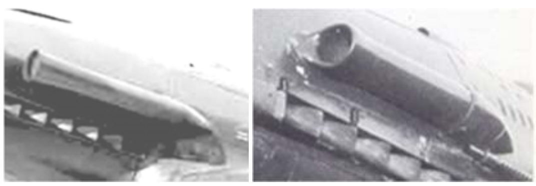

Figure-5. Air intakes: left Re2005, right M205N (1943).

In this case (Figures 4 and 5) the ram air intake is straight, outside the fuselage and enters directly into the compressor intake with a 90 DEG bend.

With respect to duct diameters, the intake track should gradually increase in size to match the inlet flange diameter of the first turbocharger. The Fanning equation (6) gives the friction loss for steady flow in circular pipes under isothermal conditions:

$$F = \frac{32\, f L_p Q_v}{\pi^2 \rho^2 D_h^5} \qquad (6)$$

The friction factor *f* is a function of the Reynolds Number (Re) for the system and the duct surface conditions. An n order of magnitude for the Re number for intake ducts is 10^5.

Bends in the intake duct strongly influences the airflow dynamics. Figure-6 shows the equivalent length of straight pipe that represents the bend's friction.

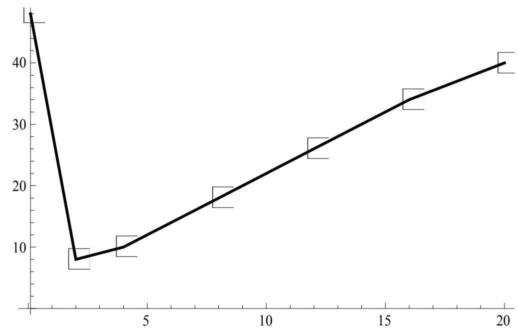

Figure-6. r/D vs. L/D for the fan of Figure-3.

It is then fundamental to keep the intake as smooth and straight as possible.

Since the aerial vehicle is in motion to generate lift, the airflow surrounding the vehicle and its influence on the induction system are fundamental. A good induction system takes advantage of the high-pressure zones and uses the pressure available to feed the induction system. Figure-7 shows the WWII Hurricane MKI and F16A air intakes in a high-pressure area with boundary layer separation.

Figure-7. Hurricane and F16 air intakes in high pressure areas.

In "Ram Air Intakes" the Bernoulli's equation can be rewritten as follows (7):

$$\Delta p = \frac{\rho\left(v_i^2 - v_u^2\right)}{2} \qquad (7)$$

For an “ideal” ram intake at 20,000m density altitude, with a compressor inlet velocity of 0.4M and an aircraft velocity of 0.6M the “ideal” pressure recovery ratio is 1.14. For high altitude operations, the aircraft will fly with “full continuous power”. If the engine slows down it is necessary to dive to lower altitude to regain full manifold pressure. In this type of mission, the worst condition is the last leg of the climb where the velocity is

VOL. 11, NO. 5, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

less than the cruise one and the air inlet pressure recovery is reduced.

In Figures 4, 5 and 6, different choices are shown. The German designers of Bf 109 choose an extremely short 90° inlet for the DB60X series engines. The limited size favored mass production. For the same engines, the Italian designers preferred a longer, more expensive and more efficient solution. The British designers were favored by the different arrangement of the RR Merlin engine and positioned the air intake in a higher-pressure area under the fuselage, just in front the Meredith's cooling duct. The additional drag is negligible is all cases. The more recent, F16 fighter air intake has been optimized through the years both for efficiency and for radar cross section. Figure-6 shows an early, efficiency aimed, development.

With the fan, inlet design is completely different. Fan converts energy into pressure and then pressure into speed and thrust. Therefore, inside the fan it is possible to find areas where pressure is higher than the atmospheric one.

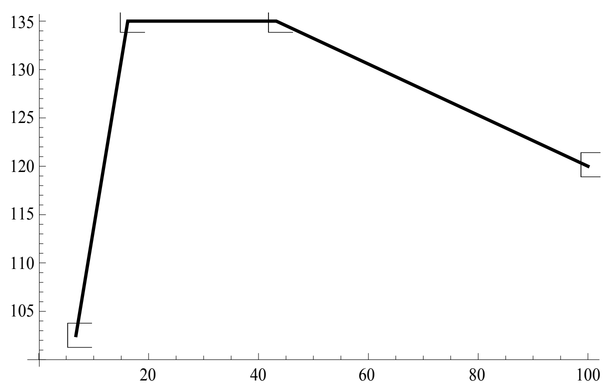

Figure-8. Pressure increment (%) vs distance from rotor inlet (%of fan length) for the fan of Figure-3.

For example, in the fan of Figure-3, after the rotor the pressure recovery ratio is 1.35 (see Figure-8). This pressure will increase the critical altitude of the propulsion system and of the aircraft. This possibility affects the power-plant design.

Exhaust system

In 1932 it was shown that a significant increase in thrust is obtained with the exhaust stack of each engine is directed to discharge rearwardly. In this case the thrust is obtained by engine propeller plus jet. The jet contribution is relevant for airspeed exceeding 0.4 M due to high exhaust speed. Therefore, a jet exhaust increases propulsion efficiency. Another way to reduce fuel consumption and EGT is to slow down the exhaust gases for pressure recovery. This choice is most welcome in spark ignition engines where EGT tends to be very high. Maximum EGT allowed for continuous operation is about 1000 DEG C.

The only known ways to control it, in spark ignition engines at full throttle, is to enrich the mixture or to cool down air in the intake manifold. However, these operations increase fuel consumption in high altitude flight. With modern CFRP (Carbon Fibre Reinforced Plastic) it is possible to manufacture straight conical exhaust up to 1100 DEG C.

In this way it is possible to recover pressure at the exhaust outlet and to increase turbine-side pressure ratio. The lower backpressure increases scavenging efficiency and reduces specific fuel consumption.

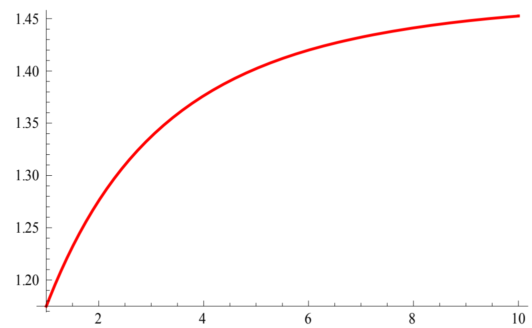

Figure-9. Pressure recovery ratio vs. cone length/outlet diameters.

Figure-9 shows the theoretical pressure recovery ratio from the exhaust outlet of the last turbine. In Figure-9 the cone length is given in exhaust diameters. It is not convenient to exceed a length of 4 diameters, since pressure recovery is negligible for longer diameters.

The Meredith's cooling system

Immediately before WWII, Meredith successfully designed a duct to convert engine cooling energy into jet thrust. The Meredith effect proved to be effective even at the relatively low speed of F1 racing cars. It then convenient to design the cooling system to provide additional jet thrust. Theoretically, the worst engine thermal condition is sea level steep climbing at maximum positive offset temperature. However, by using this working point the radiator will add excessive drag and weight. The heat rejection design point is 1.15 times the one at cruise condition. Climbing rate reduction controls the overheating in steep climbs at warm temperatures.

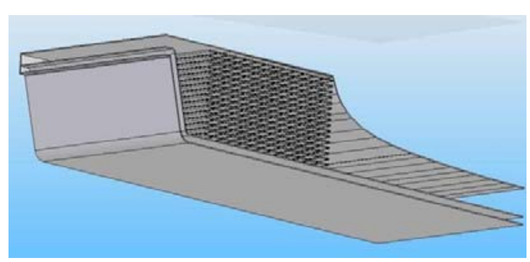

Figure-10. The Meredith's duct.

VOL. 11, NO. 5, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

The long trumpet-shape divergent duct converts the speed into pressure and reduces the radiator pressure drop that is proportional to the speed squared. Low aspect ratio, high permeability radiators are typical of aircraft design. The aftercooler and the intercoolers are cooled by the fresh air that afterwards cools the engine coolant and the lubricant. This arrangement maximizes heat transfer efficiency and exit air temperature.

In figure 10 old fashioned thick radiators are used. They are similar to the ones of Messerschmitt Bf 109. In more updated design F1 thinner, finned radiators are used instead. A convergent nozzle transforms the accelerated air pressure into speed. The typical efficiency (thrust x velocity/heat dissipated) of a well designed Meredith duct is around 20% overall. Better efficiencies can be obtained by integrating the duct inside the wing of the fuselage and cooling also the turbochargers with pressurized coolant.

The inlet of the cooling duct should be positioned in a high pressure part of the aircraft. The boundary layer is separated from the main flow (Figure-10). A vortex may take place in the diffuser due to pressure differential. The radiator net frontal area is then reduced. A flap is normally added as a correction (see Figure-11).

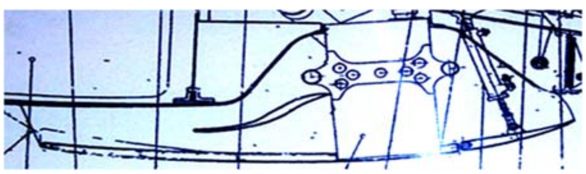

Figure-11. Re 2005 cooling duct with the flap in the short diffuser.

The flap makes it possible to reduce diffuser length with a small penalty in internal efficiency. In the Re 2005 WWII fighter cooling duct, the mobile flap of the nozzle was usually kept fully open. In an analogous design of the Macchi 205 the mobile flap was eliminated in production aircrafts. Figure-12 shows the Meredith duct of a successful Ferrari Formula 1 car.

Figure-12. 1996 Ferrari F1, Meredith duct air intake.

In this racing car the air inlet was displaced on the side to find fresh air and pressure. In this case the Meredith duct follows the “coca cola bottle” shape of modern F1 cars. The radiators are thin and inclined to obtain a low aspect ratio and to reduce diffuser vortex (Figure-13).

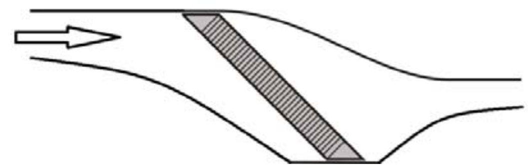

Figure-13. F1 inclined radiator.

The thin radiator has a very low pressure drop and the Meredith jet has more energy at low speed (< 0.3 M).

Figure-14. F1 radiator inclined along the pitch axis.

Fuel and lubrication systems

Fuel system is critical due to low temperature and pressure. Fuel icing is a major risk. For this purpose it is possible to divert a little amount of air from the compressor outlet. This solution is simple but expensive since it will reduce the maximum density altitude of your aircraft. Russian WWII fighters used the filtered engine exhaust to pressure and warm up the fuel tanks. This solution reduces also fire hazard since the air is replaced by CO_2. Airspeed venting is also an option. Provisions should be made to check and prevent fuel icing on valves and filters. Finally, the capacity of the oil sump/reservoir is increased for the long endurance mission and the crankcase is pressurized to avoid oil pump cavitation and unacceptable flow degradation.

CONCLUSIONS

Turbocharged diesel and spark-ignition piston engines are an ideal choice for long endurance, high altitude operations (10,000m/33, 000ft) and extremely high altitude operations (20, 000m-65, 000ft). In fact, piston engines SFC (Specific Fuel Consumption) is independent from altitude. However these propulsion systems are more complex than traditional ones that are normally limited to 5, 000-7, 000m (16, 000-23, 000ft). In fact, the air-side propulsion system (propeller or fan), the air intake, the fuel system, the turbocharging, the exhaust and the cooling system take a more important than in traditional "power pack" systems. An integrated design is strictly necessary. Since prop-fan is currently under development, the design starts from the choice between propeller and fan. This choice will influence optimum cruise speed, critical altitude and aircraft design as a whole. At high altitudes, the intake air is taken from high-pressure areas into an alternate, extremely optimized, path. In propeller propulsion systems, the induction system diffuser converts the air kinetic energy at cruise into pressure. In fan systems, a little amount of "high pressure" air is taken from the high-pressure area of the fan. The exhaust system is also critical with the choice between pressure recovery and thrust. Exhaust-pressure-recovery reduces backpressure and temperature at exhaust. However, the improvement in critical altitude is marginal. In more common, thrust driven exhaust systems, the exhaust energy is converted into speed and thrust. At the relatively high speed of high altitude cruise, also the cooling system adds a small amount of thrust through the Meredith's effect. The piston engine power plant design is then extremely critical. Many different components should find the correct position for maximum performance. The power-plants of WWII water-cooled fighters and bombers are good examples, even if their design cruise altitude is below 10,000m (33,000ft). Modern turbofan and turbojet air intakes are also of help. However, the requirements of low weight, high reliability and long endurance HALE (High Altitude Long Endurance) UAVs (Unmanned Aerial Vehicle) requires further work on this specific subject.

REFERENCES

[1] Wolfer H. Ignition Lag in Diesel Engines VDI-Forchungsheft 392, 1938, (English Translation, RAE Farnborough, Lib. No 359, UDC 621-436 - 047, Ig5g).

[2] E Mancaruso, S. S. Merola, B. M. Vaglieco. 2008. Study of the multi-injection combustion process in a transparent direct injection common rail diesel engine by means of optical techniques, International Journal of Engine Research. 01/2008; 9(6):483-498. DOI: 10.1243/14680874JER01308.

[3] H. Bettes. 2003. Flow bench applications and techniques, Superflow.

[4] Kalitzin G. and Iaccarino G. 2002. Turbulence Modeling in an Immersed-Boundary RANS-Method, Center for Turbulence Research Annual Research Briefs, Stanford University, California. pp. 415-426.

[5] Shuvom G. 2011. Practical Flow Simulation at Highway Speeds. http://blog.capinc.com/2011/06/practical-flow-simulation-at-highway-speeds/.

[6] Franke R. 1982. Scattered data interpolation: Tests of some methods. Math. Comput. 38, 181-200.

[7] Ferziger J. H. and Peric M. 2002. Computational Methods for Fluid Dynamics. Springer-Verlag, third-edition.

[8] Lam C. K. G. and Bremhorst K. A. 1981. Modified Form of Model for Predicting Wall Turbulence. ASME Journal of Fluids Engineering. 103: 456-460.

[9] Wilcox D. C. 1994. Turbulence Modeling for CFD. DCW Industries.

[10] L. Piancastelli, L. Frizziero. 2014. Turbocharging and turbo compounding optimization in automotive racing. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(11): 2192-2199, EBSCO Publishing, USA.

[11] L. Piancastelli, L. Frizziero, G. Donnici. 2014. The common-rail fuel injection technique in turbocharged di-diesel-engines for aircraft applications. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(12): 2493-2499, EBSCO Publishing, USA.

[12] L. Piancastelli, L. Frizziero. 2015. Supercharging systems in small aircraft diesel common rail engines derived from the automotive field. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 20-26, EBSCO Publishing, USA.

[13] L. Piancastelli, L. Frizziero. 2015. Accelerated FEM analysis for critical engine components. Published by Walailak Journal of Science and Technology The Walailak Journal of Science and Technology, Institute of Research and Development, Walailak University, ISSN: 1686-3933, Thasala, Nakhon Si Thammarat 80161. 12(2): 151-165, Thailand.

[14] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Turbo matching of small aircraft diesel common rail engines

derived from the automotive field. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 172-178, EBSCO Publishing, USA.

[15] L. Piancastelli, L. Frizziero. 2015. Multistage turbocharging systems for high altitude flight with common rail diesel engines. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 370-375, EBSCO Publishing, USA.

[16] L. Piancastelli, L. Frizziero. 2015. A new approach for energy recovery and turbo compounding systems for high altitude flight with common rail diesel engines. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(2): 828-834, EBSCO Publishing, USA.

[17] L. Piancastelli, L. Frizziero. 2015. Mapping optimization for common rail diesel conversions from the automotive to the flying applications. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(4): 1539-1547, EBSCO Publishing, USA.

[18] L. Piancastelli, L. Frizziero. 2015. GA based optimization of the preliminary design of an extremely high pressure centrifugal compressor for a small common rail diesel engine. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(4): 1623-1630, EBSCO Publishing, USA.

[19] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Common rail diesel-electric propulsion for small boats and yachts. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(6): 2378-2385, EBSCO Publishing, USA.

[20] L. Frizziero, I. Rocchi. 2013. New finite element analysis approach. Published by Pushpa Publishing House. Far East Journal of Electronics and Communications. ISSN: 0973-7006, 11(2): 85-100, Allahabad, India.

[21] L. Piancastelli, L. Frizziero, E. Pezzuti. 2014. Kers applications to aerospace diesel propulsion. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(5): 807-818, EBSCO Publishing, USA.

[22] L. Piancastelli, L. Frizziero. 2015. Diesel ecu mapping optimization for aircraft and helicopter applications. JP Journal of Heat and Mass Transfer. ISSN 0973-5763, 11(2): 151-167, Pushpa Publishing House, India.

[23] L. Piancastelli, L. Frizziero. 2015. Fuel consumption reduction and power downsize via robotized multiple speed gearbox and automatic selection system for an automotive application. JP Journal of Heat and Mass Transfer. ISSN 0973-5763, 12(2): 197-210, Pushpa Publishing House, India.

[24] L. Piancastelli, L. Frizziero, G. Donnici, G. Di Giacomo, A. Gatti. 2015. Optimized FSI flow simulation using modern up-to-date software systems: A direct comparison between simulated and tunnel results. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(20): 807-818, EBSCO Publishing, USA.

[25] L. Piancastelli, R.A. Bernabeo, L. Frizziero. 2015. UAV remote control distraction prevention trough synthetic augmented virtual imaging and oculus rift-style headsets. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(10): 4359-4365, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[26] L. Piancastelli, L. Frizziero, 2015. Different approach to robust automatic control for airplanes. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(6): 2321-2328, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[27] L. Piancastelli, M. Forghieri, L. Frizziero, L. Chinni, M. Cremonini. 2015. Large HSDI CR diesel engines multiple injections and multiple swirls concept. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(18): 7919-7928, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[28] L. Piancastelli, A. Gatti, L. Frizziero, L. Ragazzi, M. Cremonini. 2015. CFD analysis of the Zimmerman's V173 stol aircraft. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(18): 8063-8070,

EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[29] L. Piancastelli, A. Castagnoli, L. Frizziero. 2015. Design and optimization of an aircraft propeller for tuned torsional vibration damping. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(16): 6725-6731, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[30] L. Piancastelli, A. Castagnoli, L. Frizziero, G. Donnici, S. Pica. 2015. Direct comparison of fsi optimized theodorsen and larrabee propellers. Asian Research Publishing Network, ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(16): 7250-7258, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[31] L. Piancastelli L., Frizziero G. Donnici. 2015. Common rail diesel - Automotive to aerial vehicle conversions: An update (Part I). Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(6): 2479-2487, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[32] L. Piancastelli, L. Frizziero, A. Rotondi. 2015. Optimum installation of a common rail diesel engine on a “classical” helicopter: The UH1. JP Journal of Heat and Mass Transfer. 12(1): 45-64, 2015.

[33] L. Piancastelli, L. Frizziero, G. Donnici. 2015. A new concept for low inertia electric turbocompounding in racing spark ignition engines. JP Journal of Heat and Mass Transfer. 12(1): 1-14.

[34] L. Piancastelli, L. Frizziero. 2015. Preliminary optimization of a common rail direct injection diesel alternative to the AE2100 class turboshafts. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(11): 4738-4747, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[35] L. Frizziero, I. Rocchi, G. Donnici, E. Pezzuti. 2015. Aircraft diesel engine turbocompound optimized. JP Journal of Heat and Mass Transfer. 11(2): 133-150.

[36] L. Piancastelli, L. Frizziero, G. Donnici. 2015. The meredith ramjet: An efficient way to recover the heat wasted in piston engine cooling. Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(12): 5327-5333, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[37] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Common rail diesel - automotive to aerial vehicle conversions: An update (Part II). Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(8): 3286-3294, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[38] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Common rail diesel - automotive to aerial vehicle conversions: An update (Part III). Asian Research Publishing Network. ARPN Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(14): 5823-5830, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

Symbols

Symbol	Description	Unit	Value
D	Propeller diameter	m	-
N	Propeller angular speed	rpm	-
P	Power	kW	-
η_i	Thruster efticiency	-	-
η_p	Propulsive efficiency	-	-
v	Aircraft velocity	m/s	-
c	Thrust air velocity	m/s	-
T	Thrust	N	-
ρ	Air density	kg/m3	-
M_2	Max Take Off Mass	kg	-
M_1	Landing Mass	kg	-
C_d	Drag Coefficient	-	-
g	Gravity acceleration	m/s^2	9.81
C_L	Lift Coefficient	-	
SFC	Specific Fuel Consumption	gr/kWh	
L	Wingspan	m	-
r	M_2/M_1	-	-
A	Lifting area	m^2	-
AR	Aspect Ratio	-	-
t	Flight time	s	-
Q_v	Volumetric flow	m^3/s	-
f	Friction coefficient	-	-
L_p	Pipe equivalent length	m	-
D_h	Hydraulic diameter	m	-
v_i	Inducer inlet air velocity	m/s	-
v_u	Inducer exit air velocity	m/s	-