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**GTCP85-180**

**Non-aircraft Gas Turbine Engine**

Examples of gas turbine configurations: (1) turbojet, (2) turboprop, (3) turboshaft (electric generator), (4) high-bypass turbofan, (5) low-bypass afterburning turbofan

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber or area, called a combustor, in between.

The basic operation of the gas turbine is similar to that of the steam power plant except that the working fluid is air instead of water. Fresh atmospheric air flows through a compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity. The purpose of the gas turbine determines the design so that the most desirable energy form is maximized. Gas turbines are used to power aircraft, trains, ships, electrical generators, pumps, gas compressors and tanks.

**History**

Sketch of John Barber's gas turbine, from his patent

50: Hero's engine (aeolipile) — Apparently, Hero's steam engine was taken to be no more than a toy, and thus its full potential not realized for centuries.

1000: The "Trotting Horse Lamp" (Chinese: 走马灯) was used by the Chinese at lantern fairs as early as the Northern Song dynasty. When the lamp is lit, the heated airflow rises and drives an impeller with horse-riding figures attached on it, whose shadows are then projected onto the outer screen of the lantern.

1500: The Chimney Jack was drawn by Leonardo da Vinci: Hot air from a fire rises through a single-stage axial turbine rotor mounted in the exhaust duct of the fireplace and turning the roasting spit by gear-chain connection.

1629: Jets of steam rotated an impulse turbine that then drove a working stamping mill by means of a bevel gear, developed by Giovanni Branca.

1678: Ferdinand Verbiest built a model carriage relying on a steam jet for power.

1791: A patent was given to John Barber, an Englishman, for the first true gas turbine. His invention had most of the elements present in the modern day gas turbines. The turbine was designed to power a horseless carriage.

1861: British patent no. 1633 was granted to Marc Antoine Francois Mennons for a "Caloric engine". The patent shows that it was a gas turbine and the drawings show it applied to a locomotive. Also named in the patent was Nicolas de Telescheff (otherwise Nicholas A. Teleshov), a Russian aviation pioneer.

1872: A gas turbine engine was designed by Franz Stolze, but the engine never ran under its own power.

1894: Sir Charles Parsons patented the idea of propelling a ship with a steam turbine, and built a demonstration vessel, the Turbinia, easily the fastest vessel afloat at the time. This principle of propulsion is still of some use.

1895: Three 4-ton 100 kW Parsons radial flow generators were installed in Cambridge Power Station, and used to power the first electric street lighting scheme in the city.

1899: Charles Gordon Curtis patented the first gas turbine engine in the US ("Apparatus for generating mechanical power", Patent No. US635,919).

1900: Sanford Alexander Moss submitted a thesis on gas turbines. In 1903, Moss became an engineer for General Electric's Steam Turbine Department in Lynn, Massachusetts. While there, he applied some of his concepts in the development of the turbosupercharger. His design used a small turbine wheel, driven by exhaust gases, to turn a supercharger.

1903: A Norwegian, Ægidius Elling, built the first gas turbine that was able to produce more power than needed to run its own components, which was considered an achievement in a time when knowledge about aerodynamics was limited. Using rotary compressors and turbines it produced 11 hp.

1906: The Armengaud-Lemale turbine engine in France with water-cooled combustion chamber.

1910: Holzwarth impulse turbine (pulse combustion) achieved 150 kilowatts.

1913: Nikola Tesla patents the Tesla turbine based on the boundary layer effect.

1920s The practical theory of gas flow through passages was developed into the more formal (and applicable to turbines) theory of gas flow past airfoils by A. A. Griffith resulting in the publishing in 1926 of An Aerodynamic Theory of Turbine Design. Working testbed designs of axial turbines suitable for driving a propellor were developed by the Royal Aeronautical Establishment proving the efficiency of aerodynamic shaping of the blades in 1929.

1930: Having found no interest from the RAF for his idea, Frank Whittle patented the design for a centrifugal gas turbine for jet propulsion. The first successful use of his engine was in April 1937.

1932: BBC Brown, Boveri & Cie of Switzerland] starts selling axial compressor and turbine turbosets as part of the turbocharged steam generating Velox boiler. Following the gas turbine principle, the steam evaporation tubes are arranged within the gas turbine combustion chamber; the first Velox plant was erected in Mondeville, Calvados, France.

1934: Raúl Pateras de Pescara patented the free-piston engine as a gas generator for gas turbines.

1936: Hans von Ohain and Max Hahn in Germany were developing their own patented engine design.

1936 Whittle with others backed by investment forms Power Jets Ltd

1937 The first Power Jets engine runs, and impresses Henry Tizard such that he secures government funding for its further development.

1939: First 4 MW utility power generation gas turbine from BBC Brown, Boveri & Cie. for an emergency power station in Neuchâtel, Switzerland.

1946 National Gas Turbine Establishment formed from Power Jets and the RAE turbine division bring together Whittle and Hayne Constant's work. In Beznau, Switzerland the first commercial reheated/recuperated unit generating 27 MW was commissioned.

1963 Pratt and Whitney introduce the GG4/FT4 which is the first commercial aeroderivative gas turbine.

2011 Mitsubishi Heavy Industries tests the first >60% efficiency gas turbine (the M501J) at its Takasago, Hyōgo, works.

Theory of operation

In an ideal gas turbine, gases undergo four thermodynamic processes: an isentropic compression, an isobaric (constant pressure) combustion, an isentropic expansion and heat rejection. Together, these make up the Brayton cycle.

**Brayton cycle**

In a real gas turbine, mechanical energy is changed irreversibly (due to internal friction and turbulence) into pressure and thermal energy when the gas is compressed (in either a centrifugal or axial compressor). Heat is added in the combustion chamber and the specific volume of the gas increases, accompanied by a slight loss in pressure. During expansion through the stator and rotor passages in the turbine, irreversible energy transformation once again occurs. Fresh air is taken in, in place of the heat rejection.

If the engine has a power turbine added to drive an industrial generator or a helicopter rotor, the exit pressure will be as close to the entry pressure as possible with only enough energy left to overcome the pressure losses in the exhaust ducting and expel the exhaust. For a turboprop engine there will be a particular balance between propeller power and jet thrust which gives the most economical operation. In a jet engine only enough pressure and energy is extracted from the flow to drive the compressor and other components. The remaining high-pressure gases are accelerated to provide a jet to propel an aircraft.

The smaller the engine, the higher the rotation rate of the shaft(s) must be to attain the required blade tip speed. Blade-tip speed determines the maximum pressure ratios that can be obtained by the turbine and the compressor. This, in turn, limits the maximum power and efficiency that can be obtained by the engine. In order for tip speed to remain constant, if the diameter of a rotor is reduced by half, the rotational speed must double. For example, large jet engines operate around 10,000 rpm, while micro turbines spin as fast as 500,000 rpm.

Mechanically, gas turbines can be considerably less complex than internal combustion piston engines. Simple turbines might have one main moving part, the compressor/shaft/turbine rotor assembly (see image above), with other moving parts in the fuel system. However, the precision manufacture required for components and the temperature resistant alloys necessary for high efficiency often make the construction of a simple gas turbine more complicated than a piston engine.

More advanced gas turbines (such as those found in modern jet engines or combined cycle power plants) may have 2 or 3 shafts (spools), hundreds of compressor and turbine blades, movable stator blades, and extensive external tubing for fuel, oil and air systems. To reach optimum performance in modern gas turbine power plants the gas needs to be prepared to exact fuel specifications. Fuel gas conditioning systems treat the natural gas to reach the exact fuel specification prior to entering the turbine in terms of pressure, temperature, gas composition and the related wobbe-index.

Thrust bearings and journal bearings are a critical part of design. They are hydrodynamic oil bearings or oil-cooled rolling-element bearings. Foil bearings are used in some small machines such as micro turbines and also have strong potential for use in small gas turbines/auxiliary power units.

**Creep**

A major challenge facing turbine design is reducing the creep that is induced by the high temperatures. Because of the stresses of operation, turbine materials become damaged through these mechanisms. As temperatures are increased in an effort to improve turbine efficiency, creep becomes more significant. To limit creep, thermal coatings and superalloys with solid-solution strengthening and grain boundary strengthening are used in blade designs. Protective coatings are used to reduce the thermal damage and to limit oxidation. These coatings are often stabilized zirconium dioxide-based ceramics. Using a thermal protective coating limits the temperature exposure of the nickel superalloy. This reduces the creep mechanisms experienced in the blade. Oxidation coatings limit efficiency losses caused by a buildup on the outside of the blades, which is especially important in the high-temperature environment. The nickel-based blades are alloyed with aluminum and titanium to improve strength and creep resistance. The microstructure of these alloys is composed of different regions of composition. A uniform dispersion of the gamma-prime phase – a combination of nickel, aluminum, and titanium – promotes the strength and creep resistance of the blade due to the microstructure. Refractory elements such as rhenium and ruthenium can be added to the alloy to improve creep strength. The addition of these elements reduces the diffusion of the gamma prime phase, thus preserving the fatigue resistance, strength, and creep resistance.

**Types**

**Jet engines**

typical axial-flow gas turbine turbojet, the J85, sectioned for display. Flow is left to right, multistage compressor on left, combustion chambers center, two-stage turbine on right

Airbreathing jet engines are gas turbines optimized to produce thrust from the exhaust gases, or from ducted fans connected to the gas turbines. Jet engines that produce thrust from the direct impulse of exhaust gases are often called turbojets, whereas those that generate thrust with the addition of a ducted fan are often called turbofans or (rarely) fan-jets.

Gas turbines are also used in many liquid propellant rockets, gas turbines are used to power a turbopump to permit the use of lightweight, low-pressure tanks, which reduce the empty weight of the rocket.

Turboprop engines

A turboprop engine is a turbine engine that drives an aircraft propeller using a reduction gear. Turboprop engines are used on small aircraft such as the general-aviation Cessna 208 Caravan and Embraer EMB 312 Tucano military trainer, medium-sized commuter aircraft such as the Bombardier Dash 8 and large aircraft such as the Airbus A400M transport and the 60 year-old Tupolev Tu-95 strategic bomber.

Aeroderivative gas turbines

Diagram of a high-pressure film-cooled turbine blade

Aeroderivatives are also used in electrical power generation due to their ability to be shut down and handle load changes more quickly than industrial machines. They are also used in the marine industry to reduce weight. The General Electric LM2500, General Electric LM6000, Rolls-Royce RB211 and Rolls-Royce Avon are common models of this type of machine.

Amateur gas turbines

Increasing numbers of gas turbines are being used or even constructed by amateurs.

In its most straightforward form, these are commercial turbines acquired through military surplus or scrapyard sales, then operated for display as part of the hobby of engine collecting. In its most extreme form, amateurs have even rebuilt engines beyond professional repair and then used them to compete for the Land Speed Record.

The simplest form of self-constructed gas turbine employs an automotive turbocharger as the core component. A combustion chamber is fabricated and plumbed between the compressor and turbine sections.

More sophisticated turbojets are also built, where their thrust and light weight are sufficient to power large model aircraft. The Schreckling design constructs the entire engine from raw materials, including the fabrication of a centrifugal compressor wheel from plywood, epoxy and wrapped carbon fibre strands.

Several small companies now manufacture small turbines and parts for the amateur. Most turbojet-powered model aircraft are now using these commercial and semi-commercial microturbines, rather than a Schreckling-like home-build.

Auxiliary power units

APUs are small gas turbines designed to supply auxiliary power to larger, mobile, machines such as an aircraft. They supply:

compressed air for air conditioning and ventilation,

compressed air start-up power for larger jet engines,

mechanical (shaft) power to a gearbox to drive shafted accessories or to start large jet engines, and

electrical, hydraulic and other power-transmission sources to consuming devices remote from the APU.

Industrial gas turbines for power generation

GE H series power generation gas turbine: in combined cycle configuration, its highest thermal efficiency is 62.22%

Industrial gas turbines differ from aeronautical designs in that the frames, bearings, and blading are of heavier construction. They are also much more closely integrated with the devices they power— often an electric generator—and the secondary-energy equipment that is used to recover residual energy (largely heat).

They range in size from portable mobile plants to large, complex systems weighing more than a hundred tonnes housed in purpose-built buildings. When the gas turbine is used solely for shaft power, its thermal efficiency is about 30%. However, it may be cheaper to buy electricity than to generate it. Therefore, many engines are used in CHP (Combined Heat and Power) configurations that can be small enough to be integrated into portable container configurations.

Gas turbines can be particularly efficient when waste heat from the turbine is recovered by a heat recovery steam generator to power a conventional steam turbine in a combined cycle configuration. The 605 MW General Electric 9HA achieved a 62.22% efficiency rate with temperatures as high as 1,540 °C (2,800 °F). Aeroderivative gas turbines can also be used in combined cycles, leading to a higher efficiency, but it will not be as high as a specifically designed industrial gas turbine. They can also be run in a cogeneration configuration: the exhaust is used for space or water heating, or drives an absorption chiller for cooling the inlet air and increase the power output, technology known as Turbine Inlet Air Cooling.

Another significant advantage is their ability to be turned on and off within minutes, supplying power during peak, or unscheduled, demand. Since single cycle (gas turbine only) power plants are less efficient than combined cycle plants, they are usually used as peaking power plants, which operate anywhere from several hours per day to a few dozen hours per year—depending on the electricity demand and the generating capacity of the region. In areas with a shortage of base-load and load following power plant capacity or with low fuel costs, a gas turbine powerplant may regularly operate most hours of the day. A large single-cycle gas turbine typically produces 100 to 400 megawatts of electric power and has 35–40% thermal efficiency.

Industrial gas turbines for mechanical drive

Industrial gas turbines that are used solely for mechanical drive or used in collaboration with a recovery steam generator differ from power generating sets in that they are often smaller and feature a dual shaft design as opposed to single shaft. The power range varies from 1 megawatt up to 50 megawatts. These engines are connected directly or via a gearbox to either a pump or compressor assembly. The majority of installations are used within the oil and gas industries. Mechanical drive applications increase efficiency by around 2%.

Oil and Gas platforms require these engines to drive compressors to inject gas into the wells to force oil up via another bore, or to compress the gas for transportation. They're also often used to provide power for the platform. These platforms don't need to use the engine in collaboration with a CHP system due to getting the gas at an extremely reduced cost (often free from burn off gas). The same companies use pump sets to drive the fluids to land and across pipelines in various intervals.

Compressed air energy storage

Main article: Compressed air energy storage

One modern development seeks to improve efficiency in another way, by separating the compressor and the turbine with a compressed air store. In a conventional turbine, up to half the generated power is used driving the compressor. In a compressed air energy storage configuration, power, perhaps from a wind farm or bought on the open market at a time of low demand and low price, is used to drive the compressor, and the compressed air released to operate the turbine when required.

Turboshaft engines

Turboshaft engines are often used to drive compression trains (for example in gas pumping stations or natural gas liquefaction plants) and are used to power almost all modern helicopters. The primary shaft bears the compressor and the high speed turbine (often referred to as the Gas Generator), while a second shaft bears the low-speed turbine (a power turbine or free-wheeling turbine on helicopters, especially, because the gas generator turbine spins separately from the power turbine). In effect the separation of the gas generator, by a fluid coupling (the hot energy-rich combustion gases), from the power turbine is analogous to an automotive transmission's fluid coupling. This arrangement is used to increase power-output flexibility with associated highly-reliable control mechanisms.

Radial gas turbines

Main article: Radial turbine

In 1963, Jan Mowill initiated the development at Kongsberg Våpenfabrikk in Norway. Various successors have made good progress in the refinement of this mechanism. Owing to a configuration that keeps heat away from certain bearings the durability of the machine is improved while the radial turbine is well matched in speed requirement.

Scale jet engines

Scale jet engines are scaled down versions of this early full scale engine

Also known as miniature gas turbines or micro-jets.

With this in mind the pioneer of modern Micro-Jets, Kurt Schreckling, produced one of the world's first Micro-Turbines, the FD3/67. This engine can produce up to 22 newtons of thrust, and can be built by most mechanically minded people with basic engineering tools, such as a metal lathe.

Microturbines

Also known as:

Turbo alternators

Turbogenerator

Microturbines are becoming widespread in distributed power and combined heat and power applications, and are very promising for powering hybrid electric vehicles. They range from hand held units producing less than a kilowatt, to commercial sized systems that produce tens or hundreds of kilowatts. Basic principles of microturbine are based on micro-combustion.[further explanation needed]

Part of their claimed success is said to be due to advances in electronics, which allows unattended operation and interfacing with the commercial power grid. Electronic power switching technology eliminates the need for the generator to be synchronized with the power grid. This allows the generator to be integrated with the turbine shaft, and to double as the starter motor.

Microturbine systems have many claimed advantages over reciprocating engine generators, such as higher power-to-weight ratio, low emissions and few, or just one, moving part. Advantages are that microturbines may be designed with foil bearings and air-cooling operating without lubricating oil, coolants or other hazardous materials. Nevertheless, reciprocating engines overall are still cheaper when all factors are considered.[original research?]

Microturbines also have a further advantage of having the majority of the waste heat contained in the relatively high temperature exhaust making it simpler to capture, whereas the waste heat of reciprocating engines is split between its exhaust and cooling system.

However, reciprocating engine generators are quicker to respond to changes in output power requirement and are usually slightly more efficient, although the efficiency of microturbines is increasing. Microturbines also lose more efficiency at low power levels than reciprocating engines.

Reciprocating engines typically use simple motor oil (journal) bearings. Full-size gas turbines often use ball bearings. The 1000 °C temperatures and high speeds of microturbines make oil lubrication and ball bearings impractical; they require air bearings or possibly magnetic bearings.

When used in extended range electric vehicles the static efficiency drawback is irrelevant, since the gas turbine can be run at or near maximum power, driving an alternator to produce electricity either for the wheel motors, or for the batteries, as appropriate to speed and battery state. The batteries act as a "buffer" (energy storage) in delivering the required amount of power to the wheel motors, rendering throttle response of the gas turbine completely irrelevant.

There is, moreover, no need for a significant or variable-speed gearbox; turning an alternator at comparatively high speeds allows for a smaller and lighter alternator than would otherwise be the case. The superior power-to-weight ratio of the gas turbine and its fixed speed gearbox, allows for a much lighter prime mover than those in such hybrids as the Toyota Prius (which utilised a 1.8 litre petrol engine) or the Chevrolet Volt (which utilises a 1.4 litre petrol engine). This in turn allows a heavier weight of batteries to be carried, which allows for a longer electric-only range. Alternatively, the vehicle can use heavier types of batteries such as lead acid batteries (which are cheaper to buy) or safer types of batteries such as Lithium-Iron-Phosphate.

In extended-range electric vehicles, like those planned[when?] by Land-Rover/Range-Rover in conjunction with Bladon, or by Jaguar also in partnership with Bladon, the very poor throttling response (their high moment of rotational inertia) does not matter, because the gas turbine, which may be spinning at 100,000 rpm, is not directly, mechanically connected to the wheels. It was this poor throttling response that so bedevilled the 1950 Rover gas turbine-powered prototype motor car, which did not have the advantage of an intermediate electric drive train to provide sudden power spikes when demanded by the driver.[further explanation needed]

Gas turbines accept most commercial fuels, such as petrol, natural gas, propane, diesel, and kerosene as well as renewable fuels such as E85, biodiesel and biogas. However, when running on kerosene or diesel, starting sometimes requires the assistance of a more volatile product such as propane gas - although the new kero-start technology can allow even microturbines fuelled on kerosene to start without propane.

Microturbine designs usually consist of a single stage radial compressor, a single stage radial turbine and a recuperator. Recuperators are difficult to design and manufacture because they operate under high pressure and temperature differentials. Exhaust heat can be used for water heating, space heating, drying processes or absorption chillers, which create cold for air conditioning from heat energy instead of electric energy.

Typical microturbine efficiencies are 25 to 35%. When in a combined heat and power cogeneration system, efficiencies of greater than 80% are commonly achieved.

MIT started its millimeter size turbine engine project in the middle of the 1990s when Professor of Aeronautics and Astronautics Alan H. Epstein considered the possibility of creating a personal turbine which will be able to meet all the demands of a modern person's electrical needs, just as a large turbine can meet the electricity demands of a small city.

Problems have occurred with heat dissipation and high-speed bearings in these new microturbines. Moreover, their expected efficiency is a very low 5-6%. According to Professor Epstein, current commercial Li-ion rechargeable batteries deliver about 120-150 W·h/kg. MIT's millimeter size turbine will deliver 500-700 W·h/kg in the near term, rising to 1200-1500 W∙h/kg in the longer term.

A similar microturbine built in Belgium has a rotor diameter of 20 mm and is expected to produce about 1000 W.

External combustion

Most gas turbines are internal combustion engines but it is also possible to manufacture an external combustion gas turbine which is, effectively, a turbine version of a hot air engine. Those systems are usually indicated as EFGT (Externally Fired Gas Turbine) or IFGT (Indirectly Fired Gas Turbine).

External combustion has been used for the purpose of using pulverized coal or finely ground biomass (such as sawdust) as a fuel. In the indirect system, a heat exchanger is used and only clean air with no combustion products travels through the power turbine. The thermal efficiency is lower in the indirect type of external combustion; however, the turbine blades are not subjected to combustion products and much lower quality (and therefore cheaper) fuels are able to be used.

When external combustion is used, it is possible to use exhaust air from the turbine as the primary combustion air. This effectively reduces global heat losses, although heat losses associated with the combustion exhaust remain inevitable.

Closed-cycle gas turbines based on helium or supercritical carbon dioxide also hold promise for use with future high temperature solar and nuclear power generation.

In surface vehicles

The 1967 STP Oil Treatment Special on display at the Indianapolis Motor Speedway Hall of Fame Museum, with the Pratt & Whitney gas turbine shown

A 1968 Howmet TX, the only turbine-powered race car to have won a race

Gas turbines are often used on ships, locomotives, helicopters, tanks, and to a lesser extent, on cars, buses, and motorcycles.

A key advantage of jets and turboprops for aeroplane propulsion - their superior performance at high altitude compared to piston engines, particularly naturally aspirated ones - is irrelevant in most automobile applications. Their power-to-weight advantage, though less critical than for aircraft, is still important.

Gas turbines offer a high-powered engine in a very small and light package. However, they are not as responsive and efficient as small piston engines over the wide range of RPMs and powers needed in vehicle applications. In series hybrid vehicles, as the driving electric motors are mechanically detached from the electricity generating engine, the responsiveness, poor performance at low speed and low efficiency at low output problems are much less important. The turbine can be run at optimum speed for its power output, and batteries and ultracapacitors can supply power as needed, with the engine cycled on and off to run it only at high efficiency. The emergence of the continuously variable transmission may also alleviate the responsiveness problem.

Turbines have historically been more expensive to produce than piston engines, though this is partly because piston engines have been mass-produced in huge quantities for decades, while small gas turbine engines are rarities; however, turbines are mass-produced in the closely related form of the turbocharger.

The turbocharger is basically a compact and simple free shaft radial gas turbine which is driven by the piston engine's exhaust gas. The centripetal turbine wheel drives a centrifugal compressor wheel through a common rotating shaft. This wheel supercharges the engine air intake to a degree that can be controlled by means of a wastegate or by dynamically modifying the turbine housing's geometry (as in a VGT turbocharger). It mainly serves as a power recovery device which converts a great deal of otherwise wasted thermal and kinetic energy into engine boost.

Turbo-compound engines (actually employed on some trucks) are fitted with blow down turbines which are similar in design and appearance to a turbocharger except for the turbine shaft being mechanically or hydraulically connected to the engine's crankshaft instead of to a centrifugal compressor, thus providing additional power instead of boost. While the turbocharger is a pressure turbine, a power recovery turbine is a velocity one.

Passenger road vehicles (cars, bikes, and buses)

A number of experiments have been conducted with gas turbine powered automobiles, the largest by Chrysler. More recently, there has been some interest in the use of turbine engines for hybrid electric cars. For instance, a consortium led by micro gas turbine company Bladon Jets has secured investment from the Technology Strategy Board to develop an Ultra Lightweight Range Extender (ULRE) for next generation electric vehicles. The objective of the consortium, which includes luxury car maker Jaguar Land Rover and leading electrical machine company SR Drives, is to produce the world’s first commercially viable - and environmentally friendly - gas turbine generator designed specifically for automotive applications.

The common turbocharger for gasoline or diesel engines is also a turbine derivative.

Concept cars

The 1950 Rover JET1

The first serious investigation of using a gas turbine in cars was in 1946 when two engineers, Robert Kafka and Robert Engerstein of Carney Associates, a New York engineering firm, came up with the concept where a unique compact turbine engine design would provide power for a rear wheel drive car. After an article appeared in Popular Science, there was no further work, beyond the paper stage.

In 1950, designer F.R. Bell and Chief Engineer Maurice Wilks from British car manufacturers Rover unveiled the first car powered with a gas turbine engine. The two-seater JET1 had the engine positioned behind the seats, air intake grilles on either side of the car, and exhaust outlets on the top of the tail. During tests, the car reached top speeds of 140 km/h (87 mph), at a turbine speed of 50,000 rpm. The car ran on petrol, paraffin (kerosene) or diesel oil, but fuel consumption problems proved insurmountable for a production car. It is on display at the London Science Museum.

A French turbine powered car, the Socema-Gregoire, was displayed at the October 1952 Paris Auto Show. It was designed by the French engineer Jean-Albert Grégoire.

GM Firebird I

The first turbine powered car built in the US was the GM Firebird I which began evaluations in 1953. While photos of the Firebird I may suggest that the jet turbine's thrust propelled the car like an aircraft, the turbine in fact drove the rear wheels. The Firebird 1 was never meant as a serious commercial passenger car and was solely built for testing & evaluation as well as public relation purposes.

Engine compartment of a Chrysler 1963 Turbine car

Starting in 1954 with a modified Plymouth. the American car manufacturer Chrysler demonstrated several prototype gas turbine-powered cars from the early 1950s through the early 1980s. Chrysler built fifty Chrysler Turbine Cars in 1963 and conducted the only consumer trial of gas turbine-powered cars. Each of their turbines employed a unique rotating recuperator, referred to as a regenerator that increased efficiency.

In 1954 FIAT unveiled a concept car with a turbine engine, called Fiat Turbina. This vehicle, looking like an aircraft with wheels, used a unique combination of both jet thrust and the engine driving the wheels. Speeds of 282 km/h (175 mph) were claimed.

The original General Motors Firebird was a series of concept cars developed for the 1953, 1956 and 1959 Motorama auto shows, powered by gas turbines.

As a result of the U.S. Clean Air Act Amendments of 1970, research was funded to developing automotive gas turbine technology. Design concepts and vehicles were conducted by Chrysler, General Motors, Ford (in collaboration with AiResearch), and American Motors (in conjunction with Williams Research). Long-term tests were conducted evaluate comparable cost efficiency. Several AMC Hornets were powered by a small Williams regenerative gas turbines weighing 250 lb (113 kg) and producing 80 hp (60 kW; 81 PS) at 4450 rpm.

Toyota demonstrated several gas turbine powered concept cars, such as the Century gas turbine hybrid in 1975, the Sports 800 Gas Turbine Hybrid in 1979 and the GTV in 1985. No production vehicles were made. The GT24 engine was exhibited in 1977 without a vehicle.

In the early 1990s Volvo introduced the Volvo Environmental Concept Car(ECC) which was a gas turbine powered hybrid car.

In 1993 General Motors introduced the first commercial gas turbine powered hybrid vehicle—as a limited production run of the EV-1 series hybrid. A Williams International 40 kW turbine drove an alternator which powered the battery-electric powertrain. The turbine design included a recuperator. Later on in 2006 GM went into the EcoJet concept car project with Jay Leno.

At the 2010 Paris Motor Show Jaguar demonstrated its Jaguar C-X75 concept car. This electrically powered supercar has a top speed of 204 mph (328 km/h) and can go from 0 to 62 mph (0 to 100 km/h) in 3.4 seconds. It uses Lithium-ion batteries to power 4 electric motors which combine to produce some 780 bhp. It will do 68 miles (109 km) on a single charge of the batteries, but in addition it uses a pair of Bladon Micro Gas Turbines to re-charge the batteries extending the range to 560 miles (900 km).

Racing cars

The first race car (in concept only) fitted with a turbine was in 1955 by a US Air Force group as a hobby project with a turbine loaned them by Boeing and a race car owned by Firestone Tire & Rubber company. The first race car fitted with a turbine for the goal of actual racing was by Rover and the BRM Formula One team joined forces to produce the Rover-BRM, a gas turbine powered coupe, which entered the 1963 24 Hours of Le Mans, driven by Graham Hill and Richie Ginther. It averaged 107.8 mph (173.5 km/h) and had a top speed of 142 mph (229 km/h). American Ray Heppenstall joined Howmet Corporation and McKee Engineering together to develop their own gas turbine sports car in 1968, the Howmet TX, which ran several American and European events, including two wins, and also participated in the 1968 24 Hours of Le Mans. The cars used Continental gas turbines, which eventually set six FIA land speed records for turbine-powered cars.

For open wheel racing, 1967's revolutionary STP-Paxton Turbocar fielded by racing and entrepreneurial legend Andy Granatelli and driven by Parnelli Jones nearly won the Indianapolis 500; the Pratt & Whitney ST6B-62 powered turbine car was almost a lap ahead of the second place car when a gearbox bearing failed just three laps from the finish line. The next year the STP Lotus 56 turbine car won the Indianapolis 500 pole position even though new rules restricted the air intake dramatically. In 1971 Lotus principal Colin Chapman introduced the Lotus 56B F1 car, powered by a Pratt & Whitney STN 6/76 gas turbine. Chapman had a reputation of building radical championship-winning cars, but had to abandon the project because there were too many problems with turbo lag.

Buses

The arrival of the Capstone Microturbine has led to several hybrid bus designs, starting with HEV-1 by AVS of Chattanooga, Tennessee in 1999, and closely followed by Ebus and ISE Research in California, and DesignLine Corporation in New Zealand (and later the United States). AVS turbine hybrids were plagued with reliability and quality control problems, resulting in liquidation of AVS in 2003. The most successful design by Designline is now operated in 5 cities in 6 countries, with over 30 buses in operation worldwide, and order for several hundred being delivered to Baltimore, and NYC.

Brescia Italy is using serial hybrid buses powered by microturbines on routes through the historical sections of the city.

Motorcycles

The MTT Turbine Superbike appeared in 2000 (hence the designation of Y2K Superbike by MTT) and is the first production motorcycle powered by a turbine engine - specifically, a Rolls-Royce Allison model 250 turboshaft engine, producing about 283 kW (380 bhp). Speed-tested to 365 km/h or 227 mph (according to some stories, the testing team ran out of road during the test), it holds the Guinness World Record for most powerful production motorcycle and most expensive production motorcycle, with a price tag of US$185,000.

Trains

Main articles: Gas turbine-electric locomotive and Gas turbine train

Several locomotive classes have been powered by gas turbines, the most recent incarnation being Bombardier's JetTrain.

Tanks

Marines from 1st Tank Battalion load a Honeywell AGT1500 multi-fuel turbine back into an M1 Abrams tank at Camp Coyote, Kuwait, February 2003

The Third Reich Wehrmacht Heer's development division, the Heereswaffenamt (Army Ordnance Board), studied a number of gas turbine engine designs for use in tanks starting in mid-1944. The first gas turbine engine design intended for use in armoured fighting vehicle propulsion, the BMW 003-based GT 101, was meant for installation in the Panther tank. The second use of a gas turbine in an armoured fighting vehicle was in 1954 when a unit, PU2979, specifically developed for tanks by C. A. Parsons & Co., was installed and trialled in a British Conqueror tank. The Stridsvagn 103 was developed in the 1950s and was the first mass-produced main battle tank to use a turbine engine. Since then, gas turbine engines have been used as APUs in some tanks and as main powerplants in Soviet/Russian T-80s and U.S. M1 Abrams tanks, among others. They are lighter and smaller than diesels at the same sustained power output but the models installed to date are less fuel efficient than the equivalent diesel, especially at idle, requiring more fuel to achieve the same combat range. Successive models of M1 have addressed this problem with battery packs or secondary generators to power the tank's systems while stationary, saving fuel by reducing the need to idle the main turbine. T-80s can mount three large external fuel drums to extend their range. Russia has stopped production of the T-80 in favour of the diesel-powered T-90 (based on the T-72), while Ukraine has developed the diesel-powered T-80UD and T-84 with nearly the power of the gas-turbine tank. The French Leclerc MBT's diesel powerplant features the "Hyperbar" hybrid supercharging system, where the engine's turbocharger is completely replaced with a small gas turbine which also works as an assisted diesel exhaust turbocharger, enabling engine RPM-independent boost level control and a higher peak boost pressure to be reached (than with ordinary turbochargers). This system allows a smaller displacement and lighter engine to be used as the tank's powerplant and effectively removes turbo lag. This special gas turbine/turbocharger can also work independently from the main engine as an ordinary APU.

A turbine is theoretically more reliable and easier to maintain than a piston engine, since it has a simpler construction with fewer moving parts but in practice turbine parts experience a higher wear rate due to their higher working speeds. The turbine blades are highly sensitive to dust and fine sand, so that in desert operations air filters have to be fitted and changed several times daily. An improperly fitted filter, or a bullet or shell fragment that punctures the filter, can damage the engine. Piston engines (especially if turbocharged) also need well-maintained filters, but they are more resilient if the filter does fail.

Like most modern diesel engines used in tanks, gas turbines are usually multi-fuel engines.

Marine applications

Main article: Marine propulsion

Naval

The Gas turbine from MGB 2009

Gas turbines are used in many naval vessels, where they are valued for their high power-to-weight ratio and their ships' resulting acceleration and ability to get underway quickly.

The first gas-turbine-powered naval vessel was the Royal Navy's Motor Gun Boat MGB 2009 (formerly MGB 509) converted in 1947. Metropolitan-Vickers fitted their F2/3 jet engine with a power turbine. The Steam Gun Boat Grey Goose was converted to Rolls-Royce gas turbines in 1952 and operated as such from 1953. The Bold class Fast Patrol Boats Bold Pioneer and Bold Pathfinder built in 1953 were the first ships created specifically for gas turbine propulsion.

The first large scale, partially gas-turbine powered ships were the Royal Navy's Type 81 (Tribal class) frigates with combined steam and gas powerplants. The first, HMS Ashanti was commissioned in 1961.

The German Navy launched the first Köln-class frigate in 1961 with 2 Brown, Boveri & Cie gas turbines in the world's first combined diesel and gas propulsion system.

The Danish Navy had 6 Søløven-class torpedo boats (the export version of the British Brave class fast patrol boat) in service from 1965 to 1990, which had 3 Bristol Proteus (later RR Proteus) Marine Gas Turbines rated at 9,510 kW (12,750 shp) combined, plus two General Motors Diesel engines, rated at 340 kW (460 shp), for better fuel economy at slower speeds. And they also produced 10 Willemoes Class Torpedo / Guided Missile boats (in service from 1974 to 2000) which had 3 Rolls Royce Marine Proteus Gas Turbines also rated at 9,510 kW (12,750 shp), same as the Søløven-class boats, and 2 General Motors Diesel Engines, rated at 600 kW (800 shp), also for improved fuel economy at slow speeds.

The Swedish Navy produced 6 Spica-class torpedo boats between 1966 and 1967 powered by 3 Bristol Siddeley Proteus 1282 turbines, each delivering 3,210 kW (4,300 shp). They were later joined by 12 upgraded Norrköping class ships, still with the same engines. With their aft torpedo tubes replaced by antishipping missiles they served as missile boats until the last was retired in 2005.

The Finnish Navy commissioned two Turunmaa-class corvettes, Turunmaa and Karjala, in 1968. They were equipped with one 16,410 kW (22,000 shp) Rolls-Royce Olympus TM1 gas turbine and three Wärtsilä marine diesels for slower speeds. They were the fastest vessels in the Finnish Navy; they regularly achieved speeds of 35 knots, and 37.3 knots during sea trials. The Turunmaas were paid off in 2002. Karjala is today a museum ship in Turku, and Turunmaa serves as a floating machine shop and training ship for Satakunta Polytechnical College.

The next series of major naval vessels were the four Canadian Iroquois-class helicopter carrying destroyers first commissioned in 1972. They used 2 ft-4 main propulsion engines, 2 ft-12 cruise engines and 3 Solar Saturn 750 kW generators.

An LM2500 gas turbine on USS Ford

The first U.S. gas-turbine powered ship was the U.S. Coast Guard's Point Thatcher, a cutter commissioned in 1961 that was powered by two 750 kW (1,000 shp) turbines utilizing controllable-pitch propellers. The larger Hamilton-class High Endurance Cutters, was the first class of larger cutters to utilize gas turbines, the first of which (USCGC Hamilton) was commissioned in 1967. Since then, they have powered the U.S. Navy's Oliver Hazard Perry-class frigates, Spruance and Arleigh Burke-class destroyers, and Ticonderoga-class guided missile cruisers. USS Makin Island, a modified Wasp-class amphibious assault ship, is to be the Navy's first amphibious assault ship powered by gas turbines. The marine gas turbine operates in a more corrosive atmosphere due to presence of sea salt in air and fuel and use of cheaper fuels.

Civilian maritime

Up to the late 1940s much of the progress on marine gas turbines all over the world took place in design offices and engine builder's workshops and development work was led by the British Royal Navy and other Navies. While interest in the gas turbine for marine purposes, both naval and mercantile, continued to increase, the lack of availability of the results of operating experience on early gas turbine projects limited the number of new ventures on seagoing commercial vessels being embarked upon. In 1951, the Diesel-electric oil tanker Auris, 12,290 Deadweight tonnage (DWT) was used to obtain operating experience with a main propulsion gas turbine under service conditions at sea and so became the first ocean-going merchant ship to be powered by a gas turbine. Built by Hawthorn Leslie at Hebburn-on-Tyne, UK, in accordance with plans and specifications drawn up by the Anglo-Saxon Petroleum Company and launched on the UK's Princess Elizabeth's 21st birthday in 1947, the ship was designed with an engine room layout that would allow for the experimental use of heavy fuel in one of its high-speed engines, as well as the future substitution of one of its diesel engines by a gas turbine. The Auris operated commercially as a tanker for three-and-a-half years with a diesel-electric propulsion unit as originally commissioned, but in 1951 one of its four 824 kW (1,105 bhp) diesel engines – which were known as "Faith", "Hope", "Charity" and "Prudence" - was replaced by the world’s first marine gas turbine engine, a 890 kW (1,200 bhp) open-cycle gas turbo-alternator built by British Thompson-Houston Company in Rugby. Following successful sea trials off the Northumbrian coast, the Auris set sail from Hebburn-on-Tyne in October 1951 bound for Port Arthur in the US and then Curacao in the southern Caribbean returning to Avonmouth after 44 days at sea, successfully completing her historic trans-Atlantic crossing. During this time at sea the gas turbine burnt diesel fuel and operated without an involuntary stop or mechanical difficulty of any kind. She subsequently visited Swansea, Hull, Rotterdam, Oslo and Southampton covering a total of 13,211 nautical miles. The Auris then had all of its power plants replaced with a 3,910 kW (5,250 shp) directly coupled gas turbine to become the first civilian ship to operate solely on gas turbine power.

Despite the success of this early experimental voyage the gas turbine was not to replace the diesel engine as the propulsion plant for large merchant ships. At constant cruising speeds the diesel engine simply had no peer in the vital area of fuel economy. The gas turbine did have more success in Royal Navy ships and the other naval fleets of the world where sudden and rapid changes of speed are required by warships in action.

The United States Maritime Commission were looking for options to update WWII Liberty ships, and heavy-duty gas turbines were one of those selected. In 1956 the John Sergeant was lengthened and equipped with a General Electric 4,900 kW (6,600 shp) HD gas turbine with exhaust-gas regeneration, reduction gearing and a variable-pitch propeller. It operated for 9,700 hours using residual fuel (Bunker C) for 7,000 hours. Fuel efficiency was on a par with steam propulsion at 0.318 kg/kW (0.523 lb/hp) per hour, and power output was higher than expected at 5,603 kW (7,514 shp) due to the ambient temperature of the North Sea route being lower than the design temperature of the gas turbine. This gave the ship a speed capability of 18 knots, up from 11 knots with the original power plant, and well in excess of the 15 knot targeted. The ship made its first transatlantic crossing with an average speed of 16.8 knots, in spite of some rough weather along the way. Suitable Bunker C fuel was only available at limited ports because the quality of the fuel was of a critical nature. The fuel oil also had to be treated on board to reduce contaminants and this was a labor-intensive process that was not suitable for automation at the time. Ultimately, the variable-pitch propeller, which was of a new and untested design, ended the trial, as three consecutive annual inspections revealed stress-cracking. This did not reflect poorly on the marine-propulsion gas-turbine concept though, and the trial was a success overall. The success of this trial opened the way for more development by GE on the use of HD gas turbines for marine use with heavy fuels. The John Sergeant was scrapped in 1972 at Portsmouth PA.

Boeing Jetfoil 929-100-007 Urzela of TurboJET

Boeing launched its first passenger-carrying water jet-propelled hydrofoil Boeing 929, in April 1974. Those ships were powered by two Allison 501-KF gas turbines.

Between 1971 and 1981, Seatrain Lines operated a scheduled container service between ports on the eastern seaboard of the United States and ports in northwest Europe across the North Atlantic with four container ships of 26,000 tones DWT. Those ships were powered by twin Pratt & Whitney gas turbines of the FT 4 series. The four ships in the class were named Euroliner, Eurofreighter, Asialiner and Asiafreighter. Following the dramatic Organization of the Petroleum Exporting Countries (OPEC) price increases of the mid-1970s, operations were constrained by rising fuel costs. Some modification of the engine systems on those ships was undertaken to permit the burning of a lower grade of fuel (i.e., marine diesel). Reduction of fuel costs was successful using a different untested fuel in a marine gas turbine but maintenance costs increased with the fuel change. After 1981 the ships were sold and refitted with, what at the time, was more economical diesel-fueled engines but the increased engine size reduced cargo space.

The first passenger ferry to use a gas turbine was the GTS Finnjet, built in 1977 and powered by two Pratt & Whitney FT 4C-1 DLF turbines, generating 55,000 kW (74,000 shp) and propelling the ship to a speed of 31 knots. However, the Finnjet also illustrated the shortcomings of gas turbine propulsion in commercial craft, as high fuel prices made operating her unprofitable. After four years of service additional diesel engines were installed on the ship to reduce running costs during the off-season. The Finnjet was also the first ship with a Combined diesel-electric and gas propulsion. Another example of commercial usage of gas turbines in a passenger ship is Stena Line's HSS class fastcraft ferries. HSS 1500-class Stena Explorer, Stena Voyager and Stena Discovery vessels use combined gas and gas setups of twin GE LM2500 plus GE LM1600 power for a total of 68,000 kW (91,000 shp). The slightly smaller HSS 900-class Stena Carisma, uses twin ABB–STAL (sv) GT35 turbines rated at 34,000 kW (46,000 shp) gross. The Stena Discovery was withdrawn from service in 2007, another victim of too high fuel costs.

In July 2000 the Millennium became the first cruise ship to be propelled by gas turbines, in a Combined Gas and Steam Turbine configuration. The liner RMS Queen Mary 2 uses a Combined Diesel and Gas Turbine configuration.

In marine racing applications the 2010 C5000 Mystic catamaran Miss GEICO uses two Lycoming T-55 turbines for its power system.

Advances in technology

Gas turbine technology has steadily advanced since its inception and continues to evolve. Development is actively producing both smaller gas turbines and more powerful and efficient engines. Aiding in these advances are computer based design (specifically CFD and finite element analysis) and the development of advanced materials: Base materials with superior high temperature strength (e.g., single-crystal superalloys that exhibit yield strength anomaly) or thermal barrier coatings that protect the structural material from ever-higher temperatures. These advances allow higher compression ratios and turbine inlet temperatures, more efficient combustion and better cooling of engine parts.

Computational Fluid Dynamics (CFD) has contributed to substantial improvements in the performance and efficiency of Gas Turbine engine components through enhanced understanding of the complex viscous flow and heat transfer phenomena involved. For this reason, CFD is one of the key computational tool used in Design & development of gas turbine engines.

The simple-cycle efficiencies of early gas turbines were practically doubled by incorporating inter-cooling, regeneration (or recuperation), and reheating. These improvements, of course, come at the expense of increased initial and operation costs, and they cannot be justified unless the decrease in fuel costs offsets the increase in other costs. The relatively low fuel prices, the general desire in the industry to minimize installation costs, and the tremendous increase in the simple-cycle efficiency to about 40 percent left little desire for opting for these modifications.

On the emissions side, the challenge is to increase turbine inlet temperatures while at the same time reducing peak flame temperature in order to achieve lower NOx emissions and meet the latest emission regulations. In May 2011, Mitsubishi Heavy Industries achieved a turbine inlet temperature of 1,600 °C on a 320 megawatt gas turbine, and 460 MW in gas turbine combined-cycle power generation applications in which gross thermal efficiency exceeds 60%.

Compliant foil bearings were commercially introduced to gas turbines in the 1990s. These can withstand over a hundred thousand start/stop cycles and have eliminated the need for an oil system. The application of microelectronics and power switching technology have enabled the development of commercially viable electricity generation by micro turbines for distribution and vehicle propulsion.

Advantages and disadvantages

The following are advantages and disadvantages of gas-turbine engines:

Advantages

Very high power-to-weight ratio compared to reciprocating engines.

Smaller than most reciprocating engines of the same power rating.

Smooth rotation of the main shaft produces far less vibration than a reciprocating engine.

Fewer moving parts than reciprocating engines results in lower maintenance cost and higher reliability/availability over its service life.

Greater reliability, particularly in applications where sustained high power output is required.

Waste heat is dissipated almost entirely in the exhaust. This results in a high-temperature exhaust stream that is very usable for boiling water in a combined cycle, or for cogeneration.

Lower peak combustion pressures than reciprocating engines in general.

High shaft speeds in smaller "free turbine units", although larger gas turbines employed in power generation operate at synchronous speeds.

Low lubricating oil cost and consumption.

Can run on a wide variety of fuels.

Very low toxic emissions of CO and HC due to excess air, complete combustion and no "quench" of the flame on cold surfaces.

**Disadvantages**

Core engine costs can be high due to use of exotic materials.

Less efficient than reciprocating engines at idle speed.

Longer startup than reciprocating engines.

Less responsive to changes in power demand compared with reciprocating engines.

Characteristic whine can be hard to suppress.

Testing

British, German, other national and international test codes are used to standardize the procedures and definitions used to test gas turbines. Selection of the test code to be used is an agreement between the purchaser and the manufacturer, and has some significance to the design of the turbine and associated systems. In the United States, ASME has produced several performance test codes on gas turbines. This includes ASME PTC 22-2014. These ASME performance test codes have gained international recognition and acceptance for testing gas turbines. The single most important and differentiating characteristic of ASME performance test codes, including PTC 22, is that the test uncertainty of the measurement indicates the quality of the test and is not to be used as a commercial tolerance.

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Solar T-62T-32

(or one most enjoyable week on Cyprus)

**News - stories from another trip to Cyprus**

Well all this started just short of two years ago when I decided to design an electronic governing device for my TS-21 and Andreas’s Monocopter engine. It must have been just about that time that Platon found my web site in search for turbine engines that might possibly suit his “Ultrasport 496” two-seat micro helicopter. I told him the only engine I could think of that is in the required power range and is readily available and affordable would be the Solar T-62T-32, originally being used in the EMU-30/E 60kVA gensets. Of course I explained to him the shortcomings of this engine, especially the necessity of an electronic governor since it isn’t equipped with a hydromechanical one. I also gave Platon the link to an individual in the Netherlands (sorry, forgot his name) who offered such an engine on Barnstormers at a considerable price.

Platon mailed me back and asked if I would be able to design a suitable governor. I had a quick glance at my very preliminary design of the governor for the Monocopter and TS-21 engines and decided that it wouldn’t make much difficulty to actually adapt it to any other small turbine engine in that power range. Shortly after this, Platon bought the engine from the guy in the Netherlands, while I continued hardware design of the governor.

I thought about which way to go with the design and since the possibility of field adjustments to the parameters of the governor were one of my major requirements, I decided for a combined digital/analog solution. Hence the governor would consist of two modules, the “Turbine Engine Control Module” (TECM) which is an analog “calculator” resembling all the control functions of a small turbine engine’s hydromechanical fuel control unit (FCU), only doing it electronically:

As can easily be seen, this unit offers a lot of adjustment pots. In detail they are

- frequency/voltage converter gain

- error gain (proportional)

- derivative gain

- derivative time

- minimum fuel flow

- acceleration limiter gain

- EGT limiter setpoint

- EGT limiter droop (gain)

One of the design features I’m most proud of is the “instantaneous” frequency/voltage converter. Since input to the TECM is a frequency signal from some kind of (electromagnetic) RPM pickup device on the engine, it is necessary to convert this into a voltage signal in order to do the analog “calculations”. Actually I did some experiments on a breadboard with a PLL circuitry but loop stability wasn’t satisfactorily, especially when regarding the adjustment requirements of a turbine engine. Once this TECM unit worked fine on my breadboard, I designed a nice and small PCB for it and had it made by my favorite PCB manufacturer (Ingenieurbüro Ringler, http://www.ibr-ringler.de).

The next tests with the first assembled TECM unit turned out to be very promising and only minor tweaking was required. Now the next question arose - namely the implementation of safety mechanisms that are most important on turbine engines. If for instance the RPM pickup on the engine should go bad or a component in the RPM signal path on the TECM fails, the engine speed will be increased infinitely (actually the acceleration control will to some degree take care of this), but since a startup sequencer was required anyway, I decided to go with a microcontroller which controls all the protection, sequencing and safety functions and as well allows for some debugging. Consequently, the “Gas Turbine Engine Sequencer” which also houses the “TECM”, was designed:

It contains all the power circuitry to operate from a voltage range of 8-30V (important when the power supply voltage is being “pulled down” by the high current drain of the starter motor), provide four high-current relay outputs, two indicator outputs for LEDs/Lamps, two opto-isolated inputs and a special starter switch input that enables the starter/ignitor fuctions by direct hardware link (though they are still to be enabled by the sequencer controller - it only prevents their activation in case of a failure of the microcontroller). The most important output is probably the PWM-controlled throttle actuator driver. All of this system is designed to provide the best safety possible for both the turbine engine and the operator.

The current software version performs a shutdown in any case of malfunction, though the special version for Platon’s engine will only initiate a shutdown in case of a severe engine overspeed. Any other exceeded engine condition like high EGT, low oilpressure, slight overspeed... will only make a warning light come on but won’t stop the engine. That’s since the engine can be expected to keep on running for a certain time even if there is a malfunction and will possibly allow the pilot to emergency land his helicopter under power. The reason that a severe overspeed condition is actually an indication for a shutdown is that in this case an engine rotor burst is to be expected, and an uncontained engine failure may cause such bad damage to the helicopter that an autorotation landing wouldn’t be possible anymore.

A future version of the governor will also contain some clutch engagement functions as to automatically bring the (helicopter) rotor up to speed.

Late during the last year Platon came to Germany to visit a few gearbox manufacturers since he needed a special one to match the turbine shaft to his helicopter main gearbox input shaft.

At this time we personally met for the first time and I showed him the governor hardware which was already finished for some months while I had not started the work on the software yet. We had some very enjoyable discussions about gearboxes, helicopters in general and a lot of turbine-related stuff. I also had the chance to show him a few of my engines.

At that time the control panel was already more or less finished:

This photo has been taken during a “dry test” of the control panel and doesn’t represent an actual engine condition.

The panel mainly consists of two off-the-shelf LED panel meters for indicating RPM and EGT, a LED indicator for engine status, an RPM preset pot, a fuse (socket) to prevent fire in case of a short on the governor board, a toggle switch to activate main power to the engine systems and momentary switch to initiate the startup cycle. After this photo was taken, I machined another very simple PCB to provide a means to attach the control panel umbilical without having to directly solder to the components on the control panel. This allows for easier removal of the control panel and adjustment of the length of the umbilical.

Well, and then came early march this year when Platon invited me to come to Cyprus for late May / early June. Actually I still had not done a thing regarding the sequencer firmware (somehow I don’t like this programming stuff, though once started, it’s quite fun to do it). Anyway, that’s exactly the way that I get things done. One has to put just slight pressure on me and I’ll actually do my job :-). So late April I finished the sequencer/protection software which turned out to be much less work than expected.

I decided to send most of the bulky and somehow “airport-security-critical” stuff in a parcel to Cyprus about three weeks before I would actually go there myself. This should leave me enough time to have another one of the governors ready in case the parcel wouldn’t make it in time. Anyway, we were lucky and the parcel made it one week before I was supposed to arrive.

And then came that certain May 28th (Friday) when I stepped on the plane to Cyprus with hand luggage heavy as lead, containing a notebook computer, multimeter, clamp-on current probe, hand-held oscilloscope and programming equipment for Microchip PIC MCUs along with my digital camera and a camcorder. After a nice, calm flight I put my foot on Cyprus just before sunset and was welcomed very warmly by Platon and his lovely family.

This night we went out to the beach promenade of Larnaca where some kind of fairground-like festivity took place with a lot of music and folkloristic dances (I hope that’s the right word... ;-). I also had the chance to have a look at the church where holy Lazarus has his grave. I can tell you Cyprus is a place where history of human culture meets the present. There are archeological sites on this island with artefacts dating back more than 9000 years. Really amazing!

Saturday: The next morning we picked up Platon’s friend Anthony and went to the hangar where Platon’s Ultrasport 496 and Anthony’s Mini 500 helicopters are placed along with a decent amount of machining and tooling equipment. It is situated next to a beautiful small village called TOCHNI. It is told that this name has got its origin in the ancient Greek word “Techni” which is supposed to tell about the technical and artistic skills of the domestic stonemasons. It’s quite a coincidence that Platon of course brings a huge amount of technical skills with him to this place!

That’s the view from the road (well...sort of...) to the hangar. It’s the white building just below the little mountain. The road is supposed to have tarmac put on early next year, so travelling there will become more comfortable then. Anyway, it’s a most lovely place where the hangar is located. It’s very quiet so one can really concentrate on his work while he can make as much noise as he wants as well without disturbing anybody.

Directly in front of Platon’s hangar. Since the Hangar has got a large door in front and at the rear, the quite strong wind blows right through it and it’s very comfortable inside even if the temperatures may be quite high. At the left, there’s a small kitchen and a lavatory so Platon’s got everything to stay there the whole day if he wants to. The self-tilting solar panel at the right (very clever construction...) supplies sufficient electricity to the facility so Platon actually hasn’t got to start his diesel generator (placed behind the hangar) at all except for watering his plants.

Isn’t this a beutiful view from the porch in front of the hangar towards the Mediterranean?

Inside the hangar, the two ultralight helicopters are placed on one side. The one in front is Anthony’s Mini 500, a very cute looking craft. The one behind is Platon’s Ultrasport 496, maybe not as cute (sorry Platon ;-) as the Mini but much more versatile since it has got two seats and is probably mechanically a better design (don’t know exactly since I’m no helicopter expert, but with my limited mechanical experience it appeared to me like this - sorry Anthony ;-). Anyway, they both had been built with outstanding craftsmanship by Anthony who actually is an aircraft constructor by profession.

That’s a view from the other gate of the hangar. Actually work on the engine had already commenced when this photo was taken. But you can get an idea of how well equipped Platon’s “hangar worshop” is. He has got a small combined mill / lathe (but that’s not supposed to be used in future anymore), a seven (!) axis tool grinding machine, a large lathe and a nice, big milling machine with digital measures attached. Moreover, he has got a very complete equipment of hand tools of only the highest quality. I was really impressed I have to admit.

This day, we started with external inspection of the Solar T-62T-32 engine.

Since the unit appeared to be in a somewhat questionable condition with traces of storage under free sky or at least not in a completely moisture-fee environment, I suggested to have at least the hot section stripped down to make sure everything’s fine there and we won’t have to expect a really dangerous experience. Since there was some minor corrosion on the external parts of the engine, I would have also liked to inspect the compressor wheel more closely, but on engines with cantilevered rotor arrangements like the Garrett GTP30 or this Solar, this usually requires disassembly of the rotor shaft unit which is not without its problems since special tooling is required to do so. Hence we just left it with a visible inspection of the compressor rotating inlet guide vane section that’s visible from the outside.

Platon (rear) and Anthony (front) are working at the engine. The combustor is already removed and they are about to unmount the NGV assembly.

Some stains of moisture or even water appear to be present on the NGV and the rear parts of the compressor housing. Yet, apart from this, the hot section seems to be in a reasonably good condition.

Finally the NGV is out. There’s some very minor surface corrosion on the rear compressor housing that can be wiped away with a damp cloth quite easily (already done at the lower half). The colour of the turbine wheel shows it has already run for some time but yet it’s still in perfect mechanical condition. There are no signs of heat damage as can be found on some of the T-62T-32 where the original electronic governor went bad.

One quite interesting design detail of the T-62 is its combustor. Fuel is introduced through six airblast type fuel nozzles which probably also have some vaporizing capabilities. With this arrangement, the fuel injection pressure can be kept lower than it would be required in case of atomizing burners. Dilution air is applied only through a single row of holes in the outer combustor liner while both liners are cooled by a layer of cooling air, supplied by a row of small holes and an air deflection baffle on each side (inner and outer). As it seems, most of the primary combustion air is introduced through the airblast nozzles and a single row of small holes in the rear wall of the liner. This system only works correctly, if there is sufficient pressure differential across the combustor liner in order to atomize the fuel.

Here the combustor is shown from the rear. The hole in the 2 o’clock position accepts the ignitor (spark plug) while the stub just visible at the outer liner allows the start fuel atomizing nozzle to project radially into the liner.

This photo is actually a magnification from the above one, showing the arrangement of the airblast nozzle more clearly. The six fuel feed pipes project radially from the rear of the combustor casing and are inserted into the bores of the transition pieces to be seen at the left. The fuel is guided by the transition piece into the U-bent tube which finally discharges it into the entry of the venturi duct. So these nozzle’s operating principle is not much different from small but high fuel-flow carburettors. Yet I think, the radiated heat from the flame inside the combustor contributes to at least partial vaporisation of the fuel. Anyway that’s quite an interesting design detail I’ve never seen on a turbine engine before.

The NGV assembly was discoloured but otherwise in very good condition. No cracks or traces of erosion were found so this part could be put back into the engine without any concerns.

While Anthony and Platon were cleaning the engine components, I started to figure out the electrical connection arrangement of the engine’s main umbilical connector. Since Platon had got both the socket (on some kind of “control panel”) and the plug (on the engine) together with the engine, I decided to use them to allow for a more comfortable way of attaching the governor to the engine.

We also found out that the thread that holds the compressor delivery probe fitting in place at the periphery of the compressor housing, was stripped. We discussed the options of holding the probe fitting in place with high strength putty or cement but we finally decided that only a metal reduction bushing would be up to the task permanently. So for the next day, machining of such a bushing was scheduled. Fortunately the hub that this fitting is supposed to be screwed in, provides enough “meat” to cut a larger thread as for the reduction bushing to be screwed in. I planned to finish the wiring of the engine the next day.

Sunday: This morning, Platon and me went alone to the hangar since Anthony had other duties. While Platon started machining the fitting as we discussed the previous day, I prepared a lot of wires to connect the umbilical socket to the plug that goes onto the governor unit. Since a lot of connections had to be made, the job took me almost the whole morning. At some time around noon Platon asked me to help him figuring out the right gear combination to be able to cut the external thread of the reduction bushing (we opted for a M14 x 1.5 since he had got the corresponding tap to cut the thread in the compressor housing). After some tampering, we finally sorted out the gears and Platon continued machining while I did some more electrical stuff on the engine (installing compensation wire for the type K thermocouple into the engine’s wiring harness).

Platon and me finished our work approximately at the same time and Platon proudly showed me his “artwork”. Actually, considering that it was the first time that Platon used a lathe to cut a thread, the result was not bad, but I tried to signal him as diplomatically as possible that the surface quality of the thread would probably not represent the craftsmanship usually to be found on a turbine engine. At least I wouldnt have used this reduction bushing if it was my turbine enigne... Of course it was a very nasty material to work with (hardened stainless), and maybe I should have told Platon a few tricks how a lathe-cut thread will turn out better. Since he cut the thread towards the chuck, he had to run the lathe quite slowly so he would be able to stop it soon enough before running into the chuck. Also, the cutting tool wasn’t too sharp anymore. Since we still had a reasonable length of the base material left to have a second attempt, I re-ground the tool to shape and mounted it with the edge facing down so we could run the spindle of the lathe the other way round. This would allow us to cut the thread away from the chuck and we won’t run into collision problems and could even run a higher cutting speed. Anyway, this collective effort was in the end rewarded with a reduction bushing that suited the application perfectly well.

After boring and tapping the hole in the compressor housing where the newly made part was supposed to go, we screwed it home with high-strength thread locking compound applied. This way it would never come out again and the mechanical arrangement would be better than new.

The last thing we did this afternoon was reassembling the engine’s hot section and putting the combustor housing back on using RTV sealant to get the system air-tight.

Monday: This day was the day we were supposed to start the engine for the first time. I wired everything up and wanted to do some “dry tests”, i.e. with a frequency generator instead of the RPM pickup and the engine actually spinning. Yet, it turned out the RPM and EGT signal readings at the control panel were quite unstable. After some tests with the oscilloscope it became very quickly clear that we had problems with switching noise superimposed to the floating supply voltage for the panelmeters. This was probably a result of the high supply voltage (27V) to the governor. Anyway, after some tweaking I got this problem sorted with four small capacitors placed at the inputs of the panelmeters and from their (floating) supply voltage terminals to ground.

Now that everything seemed to work just great, we decided to have an actual “dry run” on the starter motor. So all the required wiring was hooked up, the system one final time tested for a short, the power supply (four 12V lead-acid batteries of 200Ah each, wired in series/parallel which are Platon’s buffer of the solar panel electrical supply of the hangar) and I gave the “Start” button a firm push - chunk - and nothing else happened. So it appeared that the starter bendix engaged but the starter motor wouldn’t run. Since Platon and Anthony stated that they ran it before with the power connected to the motor’s terminals directly, I assumed the problem could only be a bad starter contactor. Consequently we opened it and sure enough found what we expected.

A little touching up with fine sand paper made the contacts shiny again and after reassembly we were ready for the next attempt. Now, after pressing the start button, the engine picked up speed quickly and everything seemed to work about right. Since there was no oil in the engine yet, I immediately released the start button again as not to stress the engine’s bearings and gears more than necessary. So we filled in oil (five quarts) and were ready to go.

We placed the engine on the porch in front of the hangar, wired up the electrical low pressure fuel feed pump, added the fuel and finally were ready for the first “real” test. I must admit this was the first time I was quite excited and also a little afraid that something might go wrong.

And here’s a video clip (1.6MB) of what that certain “run” was like. Actually, we had about everything of a real jet engine except ignition ;-). I cranked it for quite a while, yet only unburnt fuel mist was blown from the exhaust. After shutdown, the combustor housing drain valve opened and quite some fuel puddled beneath the engine. I was sure to hear the ignitor snapping but the others didn’t, so we consequently removed it to check the presence of the spark visually. Fortunately, we had a spark and didn’t have to bother about this. After a little reasoning why the engine might not have lit off, we agreed that it might have been due to the fact that the engine had been sitting for a long time and probably the fuel system was completely dry. So start burner fuel probably wasn’t present soon enough to light, and later the airflow through the combustor might have been already too high to permit an ignition.

So we just gave it another try, shown here (1.4MB). This time we got ignition! When the engine accelerated happily, I had a look at the gauges and found we had an EGT reading of 0°C. Of course immediately I shut down the engine just short of 30% rpm to research this. Well, for sure it was my fault, I just placed the thermocouple compensation wires at the governor connector in reverse. So this problem was resolved within five minutes.

Now that we had got correct EGT readings, we had another start attempt. Actually we did two in sequence, and here’s the clip (3.3MB). During both runs, the engine accelerated just up to 30% rpm and then flamed out. Since I pressed the main power switch too soon, I did not have the chance to check the reason for this behavior (i.e. condition of the status light on the control panel). Anthony suggested that we might have an oil pressure problem since the gauge just indicated zero after it came up during initial cranking for a split second. So we had the second start to find the same problem and sure enough, I got the “error flashing” from the status light. So probably the oil pressure switch didn’t close the circuit and the security systems in my governor shut down the engine at 30% rpm after no oil pressure was sensed. As it later turned out, this function saved the engine (and possibly even more...).

We did a lot of testing this evening, trying to figure out the problem we had with the oil pressure. The pump would actually deliver a good flow of oil but with even the lowest flow resistance present, it would stop flowing. Platon was quite disappointed because we all expected to get the engine running this day. But since it was getting late already, we decided to separate the power section from the gearbox the next morning to check out what’s wrong.

Tuesday: Once again we had nice warm weather (who would expect something different on Cyprus anyway?) and our mood was quite good again after the disappointing experiences of the last day. Immediately we started undoing all the wiring and plumbing to the power section of the engine and drained (most of) the oil from the gearbox. From the engine’s manual, we had a good understanding of how the lubrication system was supposed to work, and we suspected the pressure regulating valve being stuck open. Since this valve was located on the spider that holds the planetary gears, the power section had to be removed to gain access to it.

When we removed the power section, we found the pressure regulating valve to be located approximately at the 2 o’clock position of the spider while it actually had to be exactly at the opposite place. Platon got a “guilty smile” on his face and we all started laughing. Platon and Anthony had to remove the power takeoff shaft when they were about to order the bevel gearbox and make it available to the gearbox manufacturing company so they could match the spline. Upon reassembly, Platon simply got the spider the wrong way in.

This photo shows the correct orientation of the gearbox spider with the oil pressure regulating valve located at the 8 o’clock position. The hollow strut just lines with an orifice in the gearbox housing where the oil pump supplies its flow through the oil filter. If the spider is oriented the wrong way, this orifice is covered only about half-way so the oil just flows back to the sump. The bad thing about this is that there’s no lubrication to the high-speed gears and bearings of the engine rotor. Yet, since we only had the engine up to 30% tree times in this condition, I’m pretty sure no damage was done. At least the gears and bearings still had a thin film of oil on them.

Here the spider is shown removed from the gearbox. The three small tubes running through the spaces between the planetary gears at about the centre of the spider supply oil to the intermeshing areas of the sun and planetary gears as well as via a small injection nozzle, to the high speed rotor bearings in the form of oil mist. This mist travels through a bore in the power section drive shaft, then turns around and goes through the rear bearing located inside the compressur hub. After that it continues through the shaft tunnel and the gearbox end (front) bearing of the rotor where it is being “sucked out” by an oil/air slinger. This way, a pressure differential is maintained all the time from the oil mist injection port to the front face of the gearbox end bearing of the high-speed shaft. Quite a clever design!

That’s the spider viewed from the side. The holes in the side of the ring gear line up with the magnetic RPM pickup that works on the principle of magnetic reluctance. The gear just next to the bearing drives the accessories and is being driven by the starter motor upon startup.

Here we’ve got another shot of the gearbox, this time with the spider removed. The lower gear drives the oil pump while the upper is a member of the auxiliary drivetrain.

Here we’ve got the power section - well basically it’s mounting flange. The serrated part at the front actually isn’t just a splined coupling but the sun gear of the planetary reduction gear system. It just centers all by itself between the three planetary gears. Just behind this gear, the oil/air slinger is located. The center bore in the gear/shaft assembly runs right into the hollow compressor hub to supply oil mist to the roller bearing loacted there.

Well, now that this problem was sorted and rectified, we were ready for more testing. Fortunately separating the main engine components can be done quite quickly and it took us a total of less than two hours to get everthing done. Now things started to get really exciting, and after a quick “cold start” to make sure we got oil pressure, we started it once more (1.6MB) with fuel and ignition on. This time, we quickly passed the 30% and the engine happily accelerated towards the 60% governor setting. At exactly that speed, the engine flamed out and gave a huge puff of smoke from the exhaust. I suspected the governor to close the fuel valve too quickly and consequently reduced the proportional gain a little bit (actually, derivative gain was adjusted to minimum during these first start attempts). So we were ready to have one more try and this time (success, success!!!) we got it governed for the first time (2.3MB). It just stayed rock-solid at 60% rpm. Anthony couldn’t help but cry out in joy! Yet, we got some smoke from the exhaust so I assume that combustion isn’t too good at this speed. This proved to be true when I started increasing the RPM preset a little bit and upon reducing the speed, we got another flameout. Later we actually found out, that with the start fuel nozzle activated and the restrictor in-line with the main burners, the Solar T-62T-32 is very likely to flame out if RPM is not reduced VERY carefully.

To further figure out the behavior of the engine / governor system, I still reduced the proportional gain and we started the unit again (1.7MB). This time I probably went too low with the gain and we actually got a runaway condition. As the engine headed for 80%, I quickly shut it down manually. The adjustment range of the pots on the TECM proved to be too large so I decided to replace them with others of smaller resistance to have a better control. Then I sat down for half an hour to do some calculations and a few “educated guesses” to do at least a preliminary adjustment of proportional and derivative settings as well as of the acceleration control and EGT limiting circuitry. Since the Solar is equipped with mechanical systems to adjust minimum and maximum flow (setscrews), I left my minimum flow pot at the lowest possible position.

During the next test runs, we had some hunting at governed speed so I did some further adjustments until we found quite a nice configuration. This time we already went up to 80% rpm (3.1MB) in small increments.

Now that we knew the engine was performing well with the governor (at least so far), Platon phoned his family and they came over to the hangar quite quickly.

With them present, we had another run up to 80% (actually I felt a little uncomfortable since running a turbine engine of more or less unknown history isn’t the safest occupation one can imagine). Anyway, everything worked just well and Platon wanted his dad (just right behing the engine in this clip, 4.3MB) to start the turbine - and he finally did it, making Platon very happy.

I didn’t push the speed of the engine any further up while Platon’s family was present due to safety reasons. To be honest, I was quite scared to go beyond the 96% point when the start fuel valve will cut out and bypass the restriction to the main fuel nozzles. Anyway, it had to be done and finally I got a heart and just did it. Once again we got a little hunting but it stabilised all by itself. What a blast I can tell you! To check combustion stability, I gave the engine quick acceleration/deceleration adjustments in the range of 95-100%. No combustion problems were observed and the engine had very fast throttle response. This certain run (4.4MB) was actually the first one that wasn’t terminated by a flamout or another problem but by me pressing the shutdown switch.

We did quite some more testing and also a few more adjustments in order to do away with the short, minor hunting at 100% rpm and also found out that throttling from 100% down to 60% in one quick flip of the RPM preset was possible without flamout since once the start fuel valve is disengaged, it stays this way and leaves the restrictor to the main fuel nozzles bypassed. Anyway, at 60% we’ve got some smoke from the engine as well as during startup and after shutdown. I partly blame this to the fuel we used - low sulphur diesel and not kerosene. But what the heck, the engine works just great at around 100% and I think a load will rather stabilise its operation since its reaction will become slower. But that’s one thing that has to be found out later.

On Wednesday and Thursday I did some tweaking of the safety features in the governor’s microcode to meet the requirements of an application in a helicopter (first save the pilot’s life, then the engine’s ;-). I also helped Platon with some electrical stuff in his workshop and then we went off and Platon showed me some nice places of the island during the other half of these days.

For instance, that’s the place where - as told by ancient Greek mythology - Aphrodite, the Godess of Love, was born. Actually this photo doesn’t do justice to the real place - it was so amazing to see the huge cliffs sloping steeply down to the Mediterranean. A strong, warm wind was blowing towards the shore and color of the water probably cannot be reproduced in any photo. I was really sad I had to leave Cyprus the next day but anyway, I’m sure I’ll come back again one day in future.

Now that Platon has got a running turbine engine, I guess the real work is just about to begin. It will still take a lot of effort to actually put it into the helicopter and get everything rigged up.

I really want to thank Platon and his wife Maria for giving me such an amazing time on Cyprus, and of course for the great meals Maria prepared for us. Thank you so much!

Btw, currently I’m considering to offer my governor/sequencer units for sale especially for use with the Solar T-62T-32 engines. Production will still take some time since many different suppliers of componets will be involved, and as yet I haven’t even decided for a price of this unit. But if anyone is interested in one of these devices, please just drop me a line. Contact. And if anyone has got a spare T-62T-32 engine he or she won’t need anymore, I would be very much interested in a deal or partial trade if it is available at reasonable expense. It wouldn’t need to be in mint condition but it should be mechanically sound and in (more or less) operational shape.

Meanwhile more than two years have passed and both Platon and me had been quite busy. We met four times since, twice he came to Germany and I’ve been to Cyprus two more times as well. Unfortunately my visit in march this year wasn’t that successful - I intended to adapt a nice brushless starter generator to Platon’s engine that I designed specifically for this application. It was of the brushless, sensorless outrunner design (LRK). It would have meen more than powerful enough to crank the engine. Yet the inertia of the turbine rotor driven by the gearbox during startup, combined with the considerable friction caused by the fuel and oil pump systems made it impossible to get the transition from forced motion to back-EMF feedback motion in the electronic motor controller right. This means, it was impossible to make the motor running continuously and accelerating smoothly. It might have been possible but I’m not the real software guru even I get along fine usualyl with my programming jobs. Anyway, I guess a brushless motor with position sensors would have been the way to go. That’s what our system looked like:

This last photo show my really sophisticated brushless sensorless motor controller that should be capable of approx. 400 Amps. Well, I never really tested it...call me a coward ;-)

Anyway, Platon got the starting problem sorted by himself. Firstly he used a Plettenberg “Dino” which worked fine until he attempted a startup cycle with the clutch (and consequently main rotor) engaged... This caused the motor to release its “magic smoke”. After that he found a “Magmotor” that produces truely amazing power and doesn’t even seem to get warm during startup of the engine. Now the engine reaches 40% idle in less then ten seconds after pressing the start engine button.

With this system and a complete installation of the engine, Platon actually did several hover flights with his Turbine Ultrasport 496 (a total of about 16 hours if I remember correctly), assisted by our friend Keith “KGB” Baker from Australia. Yet, he found several small annoyances and he had a few “almosts” although since he never flew any higher than perhaps two meters, a real problem wouldn’t have damaged anything other than his helicopter and probably his pride.

Yet, these small difficulties caused Platon to ask me for some assistance again. Since he isn’t able to reach the panel once he’s got his seatbelts on, he definitely needed a means to trim engine RPM as well as initiate an emergency shutdown. Moreover, it would be very convenient to have a system that automatically engages the clutch after the engine has reached approx. 65% RPM and produces enough power to crank up the rotor. Also, the RPM preset pot I put on the original engine control panel was way too coarse (just a 270° type). So I desigend and constructed a tiny motor pot since something like this isn’t commercially available yet. It’s a ten turn (3600°) wire-wound precision pot equipped with a truely tiny stepper motor:

This pot is controlled by a small electronic board that drives the stepper motor and converts the trim switch input to the appropriate movement. After long reasoning, we decided to include a wind-down after switching on the whole system. This means, the pilot cannot forget to reduce preset RPM to idle. I was a little afraid of what might happen if there’s a momentary loss of electrical power. But this would stop the engine anyway since the governor is also affected. The switch input pwemits a motion of one turn at a time. This means, to go from idle to full power, you have to push the RPM trim switch at least ten times up. I arranged the control this way because this would cause the RPM to change at maximum by 6% if there’s a short in the wiring somewhere. Yet, by pressing the trim switch for shorter times than what’s required for a full turn, the RPM can be adjusted by arbitrary amounts. Platon was very happy with this arrangement even though mounting the pot directly at the cyclic stick might have done the trick as well...

I also did some re-programming of the engine sequencer device to do away with the automatic shutdown in case of a serious engine problem. This includes high EGT, low oil pressure and slight overspeed. These would have caused a shutdown of the engine before. Now we placed a “devil’s eye” warning light on the panel (the red one above the yellow light) that signals the serious problem to the pilot. Since it is well possible that there’s a fault in a pressure switch or another place of the system, and the engine might even continue to work for considerable time with low oil pressure or too high EGT, shutting down the engine is up to the pilot so he’s got at least a little more time on power to land the helicopter. Yet, a serious overspeed is always a reason for a shutdown because the result of such a situation will be more critical than a forced autorotation.

We also implemented a “kill switch” that’s located at the collective stick. The switch itself ist equipped with a mechanical lock so it cannot be pressed accidentially. I also implemented an electronic safety system that requires the switch to be pressed at least for half a second to shut down the engine. This eliminates the effect of electrical interference. The kill switch doubles as a cold crank initiator. If it is pressed directly after switching on the engine systems, it will cause a cold crank cycle when the engine start button is pressed. This is also signaled to the pilot by the engine status light.

Next combined effort will be designing a new panel with displays that are more easily readable in bright light as well as constructing a new, less chaotic wiring loom. Since several other Ultrasport 496 are supposed to be converted to turbine, this will be mandatory for future installations. I’ll contribute to the panel design. Moreover, I decided to make a new PCB for the engine control system. I simply want to have the connections for the engine, panel and other system components located on separate connectors so wiring everything up will become a lot easier. Moreover, the new system will be a single PCB design (no piggyback as the current one) that’s protected in a layer of polyurethane resin. This will also permit operation of the sytem in the rain. The current configuration can still be considered a prototype with the corresponding shortcomings. I might also include an H-bridge output stage to control the toque motor that controls fuel flow to the engine. This would cause the system to become independent of the return spring at the torque motor lever. Anyway, this would mean a lot of testing on an engine will be required. Yet, this wouldn’t be a problem anymore since Platon and me bought three T-62T-32 engines of which two will need substantial repair work.