About the Wright Cyclone the Napier Nomad and the misconceptions of aeronautical turbocompound engines

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to Garrison and Self

I have read a lot about turbocompound engines and I have been dismayed by the amount of misunderstanding about them and the fact that they are considered a failure; when what failed was a poor implementation of the same, mixed with the absolute monopoly of GE on the recovery turbines and their materials and the change of goals from the aeronautical industry to the turbojets. Because of these poor implementations and this policy in the jet era, people still think that such engines were a fiasco, when today they try to rerun, with more difficulty, their same thermodynamic cycle in gas turbines. The gas turbine of constant volume; that for technological reasons, it will never reach the possible efficiency of a good turbocompound.

Basic thermodynamic and mechanical concept.

It consists of implementing the so-called Humprey cycle, with some modifications. (Figure 1). The air is compressed first by a turbocharger and sent to an intercooler, whose function is to increase the mass of air entering the cylinders while allowing a high compression ratio without danger of detonation. From there, it enters the engine as a carbureted mixture and is compressed by the pistons to the end of the stroke, ignited and burned at a constant volume. From there it expands, first inside the cylinder and then through two enthalpy recovery turbines. A turbine connected to the motor shaft and one that moves the turbocharger. Otherwise, in a supercharged and not recovered engine the exhaust would be in point 6 and there would be a Joule-Tompson expansion to the outside pressure, with no gain of useful work and infernal exhaust temperature. The lower average temperature of the cycle will have increased and there we can count our efficiency losses.
So a turbocompound does not mean a turbocharged engine. The turbocharger may or may not exist and we could perfectly have a naturally aspirated engine with an enthalpy recovery turbine for high regimes. Having turbochargers separated from the recovery turbine thus allows modulating the power of the engine with great flexibility, maintaining maximum operating efficiency and the coldest exhaust at each point and altitude.
An especially interesting point of these motors is their high specific power, product of working with a high pressure in the intake manifold and leaving part of the energy extraction work to a turbine, which is a device of greater specific power than a machine of positive displacement. In short, the turbomachine reduces the total weight of the engine.
This is what a turbocompound should have been, however, things did not turn out that way. The incomprehension of the cycle, the technology of the time, the costs of developing an engine from scratch, with its production lines included and commercial policy in the nascent era of the Jet made the turbocompound fail before it was even born; giving the impression to the layman that it was a wrong concept.[1]

History. Implementation, policy and lucky coincidences.

Historically, the only real references of turbocompound-type engines applicable to aircraft were the Napiers Nomad I and II and the Wright R-3350 Duplex-Cyclone. Of which only the R-3350 came to be used in practice. Taking this engine as a reference of the possibilities and advantages offered by turbocompound engines as well as their cost, weight and complexity is one of the main reasons why the turbocompound engine applied to aircraft is considered a

[1] At the end of the article the reader can see a short thermodynamic description of the cycle.

failure. We could remember that the W-C was the reason why Lockheed Constellation was called the best trimotor in history.
It is however incorrect to assume that the faults of this engine are inevitably transferred to any other turbcompound engine.
The root of the problem is that R-3350 was not conceived from its origin as a turbocompound engine and ended as a collection of aggregates. This leads to an inadequate and complex mechanical and thermodynamic design. The engine has absurd conceptual, mechanical and thermodynamic errors. The turbines are mechanically connected through speed reduction boxes and complex couplings to the main motor shaft from which the mechanical power is extracted to move the compressor through an embragement!. This inevitably leads to a considerable increase in weight, a marked decrease in efficiency, and the need to have a large number of complex and expensive parts.
It is a gasoline engine and yet has no intercooler! By having a compressor with an inherently low thermodynamic efficiency and lack of intercooler the positive displacement machine is forced to a very low compression ratio and this is the reason why the engine had excessively high exhaust temperatures, so much that it was necessary develop new alloys for exhaust ducts and turbines. Alloys that were later used in the first turbojets and turboprops.
The high exhaust temperatures at the time of the opening of the exhaust valve lead to high heat losses in the ducts, heat losses that are reflected in a lower extraction of work by the enthalpy recovery turbines.

How is it then that this engine turned out to be so efficient? Just a lucky coincidence.
The main reason behind the high deficiency of the R-3350 are the operating conditions rather than the design of the engine. Being a strongly compressed turbo engine designed to operate at cruising altitudes above 7000 meters, it was these conditions of low pressure and low temperature that allowed operating the engine with high total compression ratios, and a very low cold source temperature in the thermodynamic cycle.
The high compression ratio as far as the entry temperature in the intake manifold allowed, guaranteed a comparatively high gas power density with respect to the power of the mechanical losses.
The comparatively high efficiency achieved by these engines is nothing more than a clear demonstration of how much can be achieved by raising the altitude of the cruise flight and thereby reducing the minimum temperature of the cycle.

The story would have been completely different if these engines had been conceived from the beginning as authentic turbocompound. In this case the engines would have had turbochargers with intercooling, a mechanical scheme and a thermodynamic cycle designed to keep the temperature in the intake manifold low and thereby increase the compression ratio, not excessively, but to be able to reduce the temperature enough at the time of opening the valves.
Having intercooling would have allowed these engines to operate with a higher net compression ratio and therefore with a higher expansion ratio while reducing thermal losses in the exhaust manifold ducts. All done without getting to excessively increase the weight of the positive displacement machine.

Only the final exhaust enthalpy turbine would have been mechanically coupled to the motor shaft, at its front end, without the need for another embrage except the unidirectional one.

Such a construction scheme would have given this engine enormous operational flexibility, which the original W.C did not have, and a substantial reduction in both weight, construction and maintenance costs.
The engine would have been much more compact, with a higher specific power, much colder, would have needed less quantity of special alloys and things like valves cooled with sodium and would have had a much longer life between maintenance disarms. On the other hand, being a much more modular construction, with components not mechanically linked, the maintenance of the engine would have been much less expensive.
Likewise, an engine with less mechanical linkage of components makes the design

simpler and more flexible to adapt to different aircraft.

Intrinsic flaws in the design of the Wright Cyclone R-3350:

- General mechanical complexity
- Low volumetric compression ratio and very high temperature and excape pressure.
- High exhaust temperature and hot valves cooled with sodium.
- Did not use intercooler after the compressor. So it was at most an engine of "constant intake temperature in height"
- Mecanical drived compressor instead Turbocharger. This precludes the use of turbomodulation of the power by varying the admitted mixture mass without using a thro

The Nomad II and the aircraft turbo-Diesel engine.

The Napier Nomad, an engine in which much was invested during the 50s and that did not reach mass production, was considered for a long time the most efficient thermodynamic internal combustion engine ever built. This, again and mainly, was due to the low minimum temperature of the cycle and the very high total compression ratio that allowed, without intercooler, the use of a two-stroke Diesel core.
However, this engine, which was an authentic Jewel of mechanics, had been poorly designed from the thermodynamic point of view. If the engineers who designed and developed the Napier Nomad had done before starting a qualitative parametric study of the thermodynamic cycles in the TS plane they would have discovered that the motor core, a 10-cylinder 2-stroke with loop scavenging, was an important generator of entropy.

Without resorting to intercooling and changing this motor with loop scavenging and a very low compression ratio, which was only 5:1, by a motor also two-stroke but with unidirectional scavenging or a 4-stroke engine with little compression ratio but greater than 5:1, the result would have been an unprecedented thermodynamic efficiency, only matched by the large naval Diesel engines, which ultimately operate in very similar cycles and conditions, with a high degree of over expansion in what happens to constitute a hybrid between the Humprey cycle and the Brayton cycle with a high compression ratio.

The most attractive part of the Turbo-Diesel engines is that they can achieve a high thermodynamic efficiency without the need of an intercooler thanks to the high temperature that they tolerate in the intake manifold

While placing one or two intercooler stages in a turbocharged and turbocompound Otto cycle engine leads both to an increase in specific power and to thermodynamic efficiency, placing intercooler stages in an engine with a Diesel core leads to an increase in the specific power but not necessarily nor allways an increase in thermodynamic efficiency.

Perhaps the greatest attraction of the turbocompound Diesel engine is the comparative simplicity of the design and the ease during the global optimization process in relation to an Otto cycle engine and, although the gains in efficiency are not as marked, both engines can have , finally and applying the meredit effect in the intercoolers, a similar installed efficiency, represented by very low exhaust temperatures after the last expander.

Surprising as it may seem, these simple thermodynamic cycles are particularly flexible, not very susceptible to the high and hot conditions that condemn turboprops and, because they are configured to operate above 7000 and 8000 meters of altitude, capable of achieving thermodynamic efficiencies without precedents.

The Otto turbocompound and its real possibilities.

The operation with an atmospheric pressure of a quarter of the pressure at sea level and an intake air temperature below -20C ° allows an Otto Turbo compound engine to achieve thermodynamic efficiencies of the order of 60%

Having two stages of modular turbocharging and one or two stages of intercooling, in addition to an exhaust gas recovery turbine mechanically coupled to the shaft, allows to modulate the power and torque of these engines at different heights in a huge range, with very small sacrifice in instantaneous efficiency. Having an intercooler stage allows a heavily turbocharged Otto engine to operate with air inlet temperatures of -50 ° C while retaining its rated power at the cost of a tolerable reduction in thermodynamic efficiency. Something that a turboshaft can not get.

The Otto cycle reciprocating engines that make up the core should be designed to operate with a pressure in the intake manifold slightly higher than 2 atmospheres and an inlet manifold intake temperature of around 100 degrees centigrade.

This leads to moderate compression ratios with the disadvantage of a high temperature at the time of the opening of the exhaust valve. Conditions that must be taken into account. Increasing above this figure the pressure in the intake manifold leads to a machine necessarily more robust and also heavier, which will therefore lead to an engine with lower specific power and lower net efficiency by increasing the mechanical losses. The optimal point will vary strongly for each particular case and for each design operational condition.

What failure? The future of turbocompound engines.

Aeronautical turbocompound engines never failed, they simply never existed. And the reason they never existed was the reason that led to the termination of the Napier Nomad, the rise of the turbojets and the turboprops.

The new technologies and design tools of internal combustion engines and the possibility of developing these tools for very specific in-house cases currently allow to revive the concept of turbocompound for very small aircraft, thanks to the substantial reduction in time and the design costs, the possibility of producing the engines with standard and modular components and the existence of micro-turbines, minimizing the total number of parts and assemblies.

An important aspect is the possibility of having modern microturbomachines, used for different engines both aeronautical and terrestrial, and the possibility of varying only the materials and manufacturing issues of these, such that these allow achieving aeronautical homologation of the power plant without having to intervene in the design of the positive displacement machine.

The market that these engines would cover in an era where fuels are increasingly expensive is that of small-sized and long-range aircraft, where electric planes simply can not fulfill the mission.
This applies to small private aircraft for countries with a large geographical area, coastal surveillance aircraft, agricultural control and some cases of flight enthusiasts who enjoy traveling the planet in their small planes, without the need to make short stops and be restricted in the journeys by the minimum oceanic jump lengths, a market that may be worth exploring and that will not exist until these new engines exist.

On long-haul flights using small airplanes of 6 to 10 seats these turbocompound engines will obviously be competitive against turboprops in terms of increasing fuel costs. In addition, they are advantageous in terms of the total take-off weight of the aircraft for a given mission, since this type of engine weighs just over twice as much as the turboprop they replace and have a fuel consumption that is less than of conventional engines.

A very real white unicorn

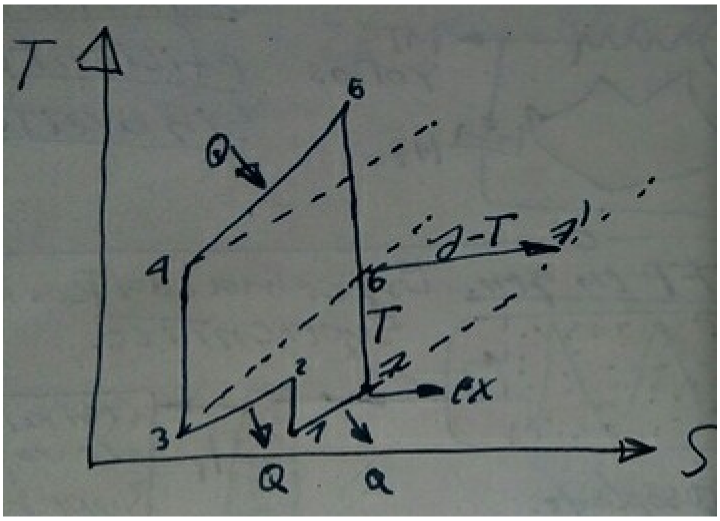
Contrary to what can be supposed this white unicorn of the aeronautical engines would not have construction development costs much higher than the costs of current engines and much of the problem, which constitutes the control of these engines, especially in the case of 2-stroke engines with uni-flow sweeping, is now at the hands of a very economical electronics, which in any case, is now of standard use in any street car. The turbocompound engine does not have many more components than a turbocharged normal reciprocating engine. It simply has these components linked differently.

Wankel engines after the Renesis 8 and the Wankel turbocompound.

These engines, whose gasodynamics are substantially different from the previous models, present very attractive characteristics to be transformed into compressed turbocompounds and naturally aspirated turbocompounds.
• Low weight.
• High mechanical reliability.
• High natural thermodynamic efficiency
• Compact. Low aerodynamic drag by volume.
• Refrigerated by liquid, which allows an improved design of the cooling system according to the Meredith effect. (*)
• they do not have crossing ports, so the exhaust pressure can be higher than the intake pressure. This should be done a little to avoid a great overpressure at the moment of opening the admission, applying a small Cadenaci effect in the exhaust or a delay in the opening of the intake port.
• A turbocharged version of it already exists. So just put the exhaust gas recovery turbine in the exhaust and adjust the operating parameters of the turbocompresor turbine, larger than the current because density behind the recovery turbine had fallen.

A technical note: The right gasoline turbocompound engine and its cycle...

It is an engine where the crossing of valves is non-existent, the volumetric compression ratio is that allowed by the temperature of the intake mixture, before reaching the detonation. The intake temperature of the mixture at the intake manifold (3) is kept low thanks to an intercooler after the last compressor(2-3). The compressors are moved in their entirety by turbines. The opening pressure of the exhaust valve (6) is coincident with the pressure in the exhaust manifold and the opening moment of the intake valve (3) occurs when the pressures of the intake manifold and the cylinder are equated, with the possibility of resonant effect designed for cruise operation. After the last turbine (6’), which can be the recovery or the turbocharger, if this is active, the gases expand until the final enthalpy jump in the exhaust pipe (6’-7) allows an ejection at 30-50% more speed than the flight and equal static pressure than the outside. This remaining speed is optimizing the system for propulsive purposes in aircraft and it will be practically zero in a helicopter.
In the ideal turbocompound the exhaust enthalpy recovery turbine is running all the time, while the turbocharger is a power modulation element. The thermodynamic cycle thus established is a Humprey cycle with precompression and intercooling.



Thermodynamic diagram of the turbocompound cycle and Superchargued cycle in the T-S plane

Best regards. Lisandro Antonio Rodriguez.