Aerospace Case study: Cold Duct Fan

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Among the most significant case studies, developed together with our partners, the "Mini Fan" described in this document is one of my favourite one, as we tried to choose the most suitable technology and material to push forward for this project.
We could in fact try to manufacture it with several different technologies, such as CNC machining or through casting with special metal alloys, or even laser sintering of simple PA12 or PA12 glass filled (we cooperate in fact also with some companies in France that have PA12 and have tested it for the mini-fan too), but at the end it has been really clear that <u>WINDFORM® XT was the best choice</u>. Let's see why.

We can think about a little fan, whose engine power is given by an electric device, instead of 2/4 strokes engine. By extrapolation, we could even call it small mono stage compressor even if in this case the static pressure increase is very low (no precise data to be released).

Now, without the classic parameters (due to confidentiality), such as efficiency or level of reaction, which permit to characterize quality of a turboshaft engine, <u>we will try to explain the advantages of this project analyzing the data provided by our partner:</u>

- Engine mass: 270 grams
- Nominal output power: 1000 W (Watts)
- Maxi power: 1200 W
- Current tension for power supply: 24 V
- Theorical Tension: more or less 50 A
- Association of two 12 V lead battery would bring an enormous overall weight and not suitable with a flying equipment: the battery requested for real use could be a Lipo: lithium.
- Specific speed for the project: nominal diameter of 100 mm (98 mm included the play) at 36.000 rpm, given a speed of 184.6 m/s (664.7 km/h) at the extremity of the blade.
- Crossing section measured down to the fan:
    - Nominal diameter 100 mm giving 7854 mm²
    - Hub diameter 48 mm giving 1810 mm²
    - All this give a crossing section of 6044 mm²
- Percentage of resulted thrust in the fan and ducts:
    - without stator and with 9 or 7 blades best result was around 1 kg
    - with stator #1 and 9 blades, result was 1.4 kg
    - with modified stator and 9 blades, result was 2.2 kg
- Profile type for the blades:
    - For the fan blades: unknown but visually quite closed to aircraft wing
    - Chord 21 mm thickness 2 mm

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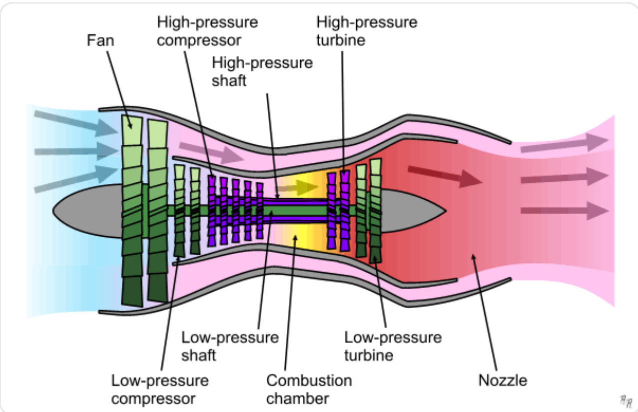
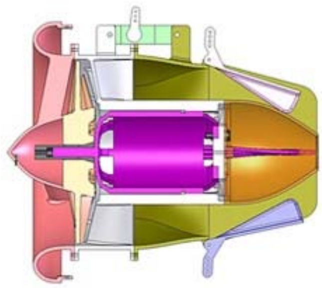
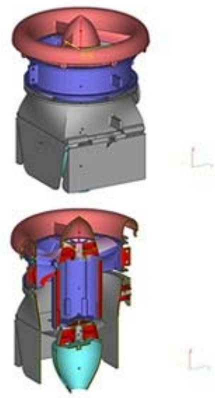
- Angles characteristics for the blades:
    - 9 degrees at the extremity of the blades and same twist ratio to the hub
    - New fan 15 degrees

Project conditions:
Test performed with a temperature of 20 deg Celcius.
The rig for static thrust measurement was made by a ball guide rail and a strain gauge connected to a display.

The mini-fan made by WINDFORM® XT for a fluid dynamic study is composed of a mini axial compressor fitted in a case and characterized by high stiffness values, therefore able to minimize those vibrational problems that affect prototypes made of other materials.



It is therefore called **COLD DUCT FAN**, because it is supplied by a small electric engine which doesn't produce an excessive amount of heat and that stays at almost low thermal regime, it doesn't pollute, it's very easy to use (it doesn't need great open spaces for take off and landing) and can fly for several hours, depending on the technology used for the batteries.
The COLD DUCT FANS can't be visible by IR rays (IR visualize heat over certain temperatures) and if made of non metallic materials can also escape the Radars.
The project realizes a **flying object mostly suitable for short and quick operation such as rapid inspections with photo cameras, illumination** …
In fact it is possible to put 3 or 4 mini fans in series with its own electric rotor connected to the same lithium battery, to allow not only the take off but also the horizontal flight.

This study can be defined as a double manufacturing: on one side a double flow turbo fan in scale and on the other a protected fan, electrically operated and power supplied by an extra-lightweight set of batteries or by solar panels positioned on a very long wing (in order to have the necessary amperage it would require 1,5 square meters of last generation solar panels).

The heart of both of these realizations is the frontal fan that, experimented in different configurations, also with high revs, almost 36000 rpm, guarantees excellent dynamic performances thanks to the use of WINDFORM® XT.

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Coupling the fan to the mini double flow turbojet, you end up with the above mentioned double flow turbofan, with much higher thrust values (you can reach 6/7 Kg) but, thanks to the compressor performance, it would guarantee extremely low specific consumption values (that's why turbofans are used on commercial aircrafts).

Both in the electric and endothermic cases, the prototyped fan is particularly suitable for the movement of high technology micro aircrafts for military spying or meteorological studies. The choice falls on the electrical engine, for obvious reasons.

In the turbofan case in fact, as the compressor is characterized by such high rpms, it wouldn't even be necessary the insertion of a gear reductor between the turbine and the fan with evident advantages in weight saving for the whole propeller; on the other side it would generate too much heat and would be complicate to manage: both things are to be avoided in this present project.

Two small notes on the turbofan: it is started by an auxiliary unit and once it is at cruising rpms, it can be easily described: entering through the fan, the air is accelerated and compressed: a part of will exit without anymore cycle generating a percentage of thrust (around 35% in general); the remaining mass is introduced, usually after another couple of compression cycle in the combustion chamber. Over here the air is decelerated and undergoes a raise of temperature and pressure. It's then ducted to a turbine (whose blades are highly thermically stressed) which, rotated by the flux, takes part of the pressure energy turning it into mechanic energy, useful to make the fan rotate. The energy left is then turned into thrust in the exhaust's ducts and nozzle. Therefore the high heat would need the use of high performance alloys such as Inconel and would bring great complications for its use, with the consequent impossibility to be used without being seen by Radars and IR.

Thanks to the laser sintering technology and to the newly increased performance allowed by CRP's carbon fibre filled material, different solutions and wing profiles have been experimented to define the better set up.

In this present case, the assembly presented is a system rotor-stator with controlled directional shutters and an electric engine reduced in performance (300 rpm instead of 36 000 rpm) with transformer. The unit has been assembled in a delta structure under real operation and dynamic flight, to complement the static tests.

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Thanks to prototyping, our partner could make several fans with different numbers of blades and various stators, several air ducts, without needing to change angles during operation uses: fan with variable twist ratio would have been a project much more complex and expensive.

We manufactured more than 20 turbines in PA12 and in WINDFORM® XT in order to understand which one was the best: with 3 blades, 5 blades, 7 blades, 9 blades, 11 blades, and so on.
5 axis machining would have been too expensive and too complex and we wanted to have the possibility to test the most suitable number of blades to the engine.

Then the engine has been assembled in the stator and no final adjustment was required, it seemed a perfect assembly of the other parts and very good fitting: no friction or parasitizes vibration while working, both with PA12 and WINDFORM® XT.
The number of revolutions of the engine reached is 36 000 rpm, that is extremely high for this kind of application.
The best vectorial push has been obtained at the first assembly: initially tests have been done only with the turbines (without stator, etc.) in order to find as well as possible the best one; it would seem it's the one with 7 or 9 blades; then second tests were done with the whole assembly (with stator).

- 3 blades: 600 g
- 5 blades: 850 g   1500 g with stator
- 7 blades: 1020 g
- 9 blades: 1050 g
- 11 blades: 980 g   1400 g with stator

Briefly, the parts seemed to be enough defined and rigid, having very positive matching , even with rotors in PA12.

The stator indeed has been manufactured immediately in WINDFORM® XT because it has been immediately clear that the final needed surface quality and rigidity could be obtained only with it, being so able to bear more stress too, without "pulsing" and so allowing a compression factor more reliable, constant and sure. A greater rigidity of the stator is also necessary to make of it a structural part of a delta system wing of a drone.

By the way, after some more tests we understood that also the rotor system had some reliability problems: the blades, at that high speed and compression, were changing their inclination and shape, without being under control, and the performance factor was changing every time, depending on weather, speed, and every other possible variable. It was a dangerous situation that has been solved manufacturing the rotor in WINDFORM® XT too: the blades are now stiffer, don't change their shape and inclination while working. The performance, and so the push, is now fixed and reliable.

Only with laser sintering and carbon fiber filled WINDFORM® XT the project could be developed and tested in such a short time and with a such high performance reached.

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