The Future of Civil aviation, a Fan Makers Dream?

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Gas Turbine Engines were the heart of the second revolution in aviation, the first being powered flight by a heavier than air machine. First used for aircraft propulsion in the 1940s, early gas turbines are often called turbojets. Gas turbines are, currently, the dominant source of propulsive power for aircraft. It is very rare, if designing aeroplanes above 10 -15 passengers, to consider any other machine to provide the propulsive power required. From very early it was known that the use of a gas turbine driving a large ducted fan would bring large benefits. This concept is known as the turbofan. In the late 1950s and early 1960s the specific power and underpinning technology was at an adequate level to introduce turbofans in civil aviation. Figures 1 show representations of a turbojet and a turbofan.

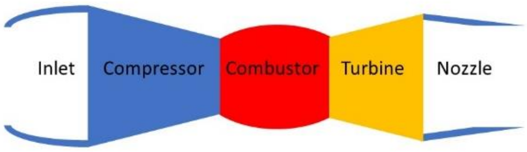

Figure 1a turbojet

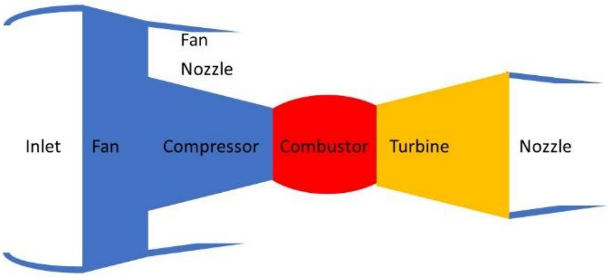

Figure 1b turbofan

In a turbojet air enters the inlet, is compressed in the compressor to a high pressure; more energy is added in the combustor, via hydrocarbon fuels. When the resulting combustion gas expands back to ambient pressure it delivers more energy than is needed in the compressor. The first part of the expansion takes place in the turbine; this delivers the energy needed in the compressor. The second part of the expansion happens in the nozzle, or nozzles, and produces the thrust delivered by the engine. In a turbofan a large compressor (or fan) is added to increase the amount of air compressed. After the fan the air flow splits into two streams, the bypass stream and the core (or high temperature) stream. The bypass stream emerges through the fan nozzle and the hot gas stream emerges through the other nozzle. This arrangement reduces the amount of fuel needed to produce the thrust but needs more and larger compressors and turbines. Figure 2 shows a more detailed layout of a turbofan used in modern airliners.

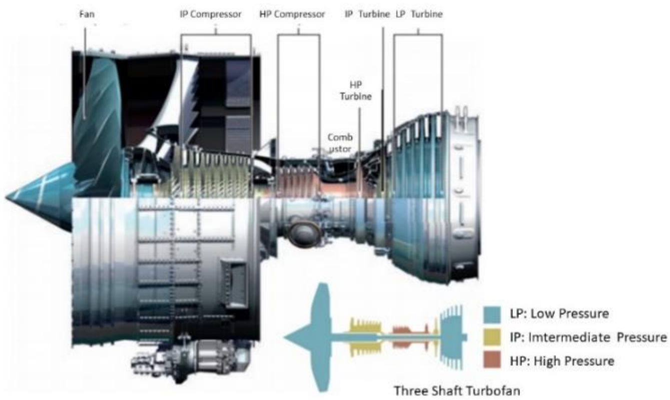

Figure 2 – Layout of a turbofan (courtesy Rolls-Royce)

The fans at the front of these engines are marvels of modern engineering, to make any Fan Maker proud. Vast investments have been made to make them lighter, more efficient, more reliable, quieter and stronger. Figure 3 shows a greatly simplified view of the evolution of large fans over the last 50 years. Great improvements have resulted from the direct application of STEM (Science, Technology, Engineering and Maths) in the conception, design, development, manufacture, certification, operations and maintenance of these works of art. Each one of these fan blades may cost several thousand pounds and will frequently absorb more than 2000 HP for its operation.

Civil aviation produces 2-3 % of anthropogenic carbon dioxide (CO_2) emissions, these arise from the hydrocarbon fuels used in the combustor. Currently great efforts are being made to eliminate these CO_2 emissions to protect the environment. Colossal changes are needed not just for the engine, but for the aircraft, airports, logistics and electricity grids. The change is so large that many label it “the 3rd revolution in aviation”, noting that all these revolutions arise from the propulsion system. A leading contender to replace hydrocarbon fuels is hydrogen This process of replacing hydrocarbon fuels with a fuel that does not contain carbon is often called decarbonisation as there is no CO_2 emitted Hydrogen offers vast benefits, not just the absence of CO_2, sulphur oxides and unburnt hydrocarbon in the exhaust, but also (through very careful combustion system design) dramatically lower nitrogen oxide emissions.

Figure 3 – Evolution of fans for jet engines resulting from the continuous application of STEM knowledge (Images courtesy of Rolls-Royce, a large UK jet engine manufacturer). The earlier blades (to the left) were straight and had a supporting element one third of the distance from the tip. In the second image these structures are removed through wider, hollow blade designs. In the middle image the degree of hollowness increases and so does the curvature of the blade. In the fourth the curvature increases and in the final one, to the right, the material (titanium in the first four) of the blade is replaced by composite blades with a titanium leading edge. Thanks to aerodynamic, structural and manufacturing advances, over 50+ years, stronger, lighter and more efficient fan blades are being produced.

The author expects these hydrogen fuelled aircraft to enter service in innovation waves. These waves will permit a swifter new aircraft introduction to accrue environmental benefits earlier. In the first innovation wave the objective will be the early (to start decarbonising quickly) delivery of aircraft as safe to fly as those that we have today. This will require a focus on aircraft development in parallel with the adaptation of certification rules ensuring the safety levels we see today. In the second innovation wave the objective will be technology refinements to improve the effectiveness and economy of new airliners. Figures 4 show aircraft design possibilities of the first and second innovation waves. It can be noted that, apart from a concession for the great volume hydrogen requires, the aircraft, externally, look similar to those in use today. The great changes are inside. The engines continue to be turbofans albeit with the large changes needed to burn hydrogen.

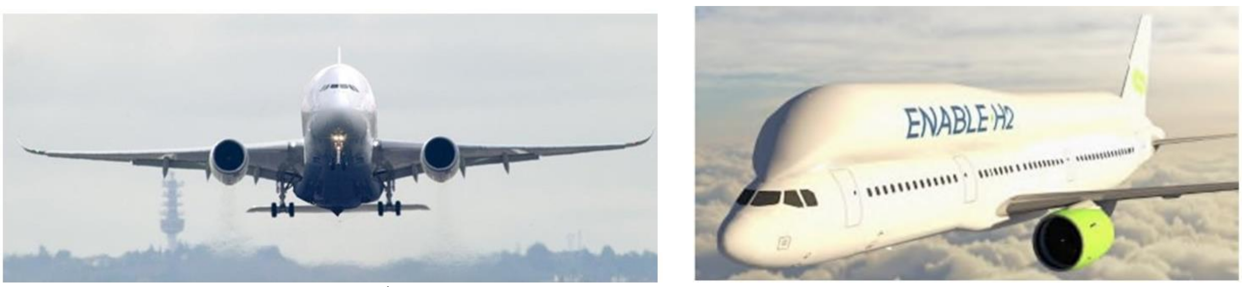

Figure 4 aircraft of the 1st and 2nd Hydrogen Innovation waves (Courtesy Airbus-modified by the author and EU Horizon 2020 ENABLEH2 project)

The third innovation wave, maybe 30-40 years from now, could exploit the very low temperature needed to store liquid hydrogen (minus 250C) to enable superconducting electrical circuits. These could give rise to installations using two gas turbine engines producing large amounts of electricity and some thrust. This electricity would be used, via very cold superconducting electrical transmissions, to drive 10-20 electrically driven fans located at the rear of an aeroplane of a radical design; a blended wing body aircraft. This installation offers a promise of greatly improved efficiency and economics. An example is shown in figure 5.

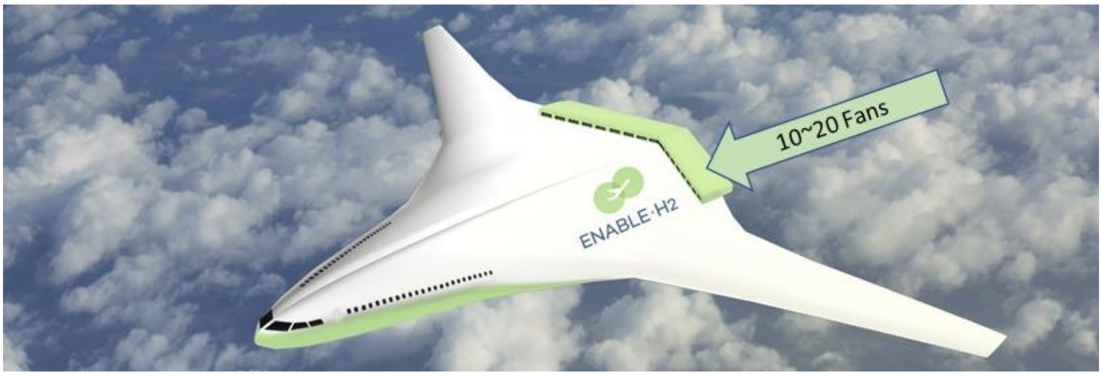

Figure 5 *aircraft of the 3rd Hydrogen Innovation wave (Courtesy EU Horizon 2020 ENABLEH2 project)*

In the long term the economics of these hydrogen aircraft, that emit just water, are confidently expected to be better than those of today. The key issue is to find the large investments needed to cover the transition costs to realise aircraft that will keep thousands of Fan Makers gainfully occupied for generations.