FAN AERODYNAMIC DESIGN

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This chapter describes the aerodynamic design process of a fan. After an overview of fan objectives specificity, the global process is described. Then, we will focus on the main items of this process. First, the impact of technology on the design is described with its evolutions during the last decades. Then, we tackle the core of the design with the aerodynamic analysis. Finally, because the design of a fan is not a pure aerodynamic task and requires a real multi-disciplinary methodology, we give a description of acoustic and mechanical analysis.

1. Objectives and design process

1.1. Design objectives of a modern civil fan

Designing a good fan is a crucial issue for a successful engine. Fan is responsible for 75% of thrust at take-off. Moreover, there is a trade-off of about 0.6% of fuel consumption for 1% of fan efficiency. Finally, fan being the first grid of the engine it must be able to endure harsh inlet conditions with cross wind distortion and sand, ice or birds ingestion. Therefore, the final solution is always a difficult compromise between aerodynamic performances and mechanical constrains with growing acoustics objectives. The main global design objectives are:

- Optimize performances
- Optimize durability
- Ensure engine integrity
- Keep as low as possible the environmental impact (noise)

These objectives can be detailed using the fan map displayed in figure 1. The design focuses on the 4 operation points that are representatives of fan operation: take-off, cruising speed, full speed and landing. Each point has its own particularities that have to be taken into account for a global optimization of the design.

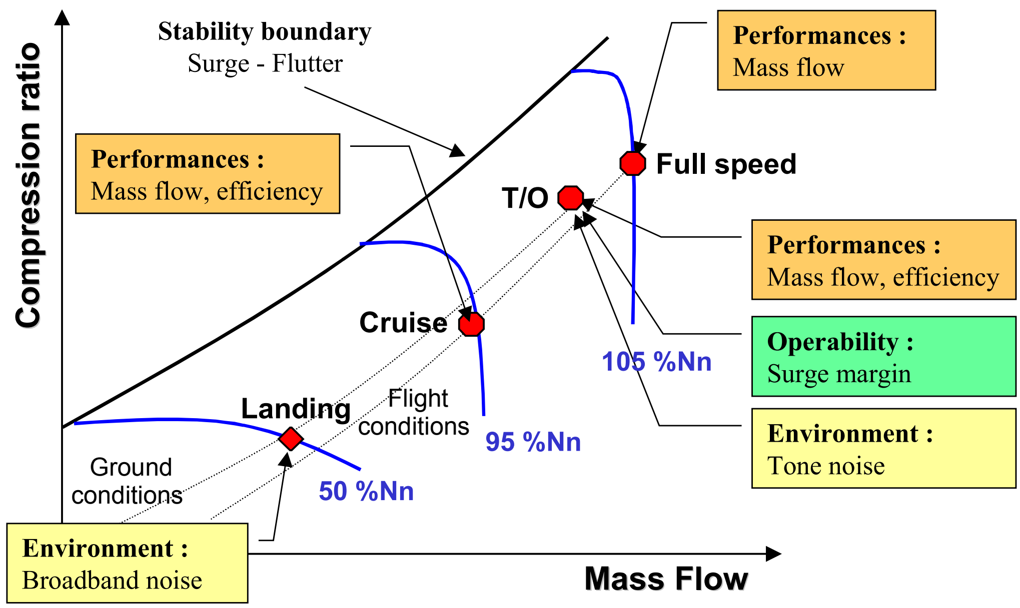

Fig. 1 - Fan operation map

1.1.1. Take-off

The speed at take-off is generally taken as the speed of reference which is also called the *nominal speed* (Nn). This is a crucial point for design because take-off is the moment when the aircraft is the heaviest and when it is the most vulnerable. In deed, any failure of the engine at this point can be disastrous because the proximity of ground does not leave any freedom of maneuver. As a matter of fact, operability and thrust are the main objectives for take-off. Their application to fan design are respectively surge and flutter margin and mass flow.

The other particularity of take-off is noise. In fact, it is more convenient to have airports near the cities but, for that, airplanes must be as quiet as possible. The main source of noise at this speed come from fan shock waves and from the interaction between the fan wake and the outlet grid vanes (OGV). This kind of noise is called *tone noise* and is characterized by specific frequencies related to the fan rotation frequency. The reduction of tone noise requires a very good control of the aerodynamic of the fan to reduce the importance of shock waves and of the fan-OGV interaction.

1.1.2. Cruising speed

The cruising speed vary by some percents around 95% of the take-off speed during the flight because the aircraft becomes lighter as fuel is burnt. As a simplification for the design,