Laminar wings on future aircrafts

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SUPERTRAC (S)

SUPERTRAC stands for SUPERsonic TRAnsition Control. Flying at supersonic speeds involves problems like for example noise and high fuel consumption. A reduction of the skin friction coefficient to reduce drag would improve on these problems. The objective for the SUPERTRAC project is to investigate various methods to delay transition from laminar to turbulent flow over the wings at supersonic speeds. These methods have been tested at subsonic speeds but little is known of their efficiency at supersonic speeds. Both Airbus and Dassault have an interest to apply the techniques to improve on future supersonic passenger aircrafts.

TELFONA (T)

One of the future challenges for the aircraft industry is to develop more environmentally friendly aircrafts. By optimizing the shape of the wing profile, the flow can remain laminar over a larger proportion of the chord. This Natural Laminar Flow (NLF) technology can reduce the drag by 20% and thus reduces the fuel consumption and emissions. TELFONA (TEsting for Laminar Flow On New Aircraft) will develop experimental and computational methods that will enable the design and performance prediction of NLF wings.

TELFONA and SUPERTRAC are EU projects which together gather 14 organizations from 8 different countries:

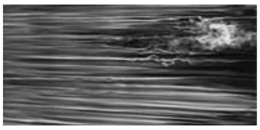
- Research centers: ONERA, CIRA, DLR, FOI, VZLU
- Industries: Airbus, Dassault, Piaggio
- Consultants: IBK
- Universities: KTH, IST, IC, TUB
- Windtunnel facilities: ETW, MTL (KTH)

Receptivity

The transition from laminar to turbulent flow is always initiated by a receptivity process in which a disturbance entrains the laminar boundary layer. The unstable disturbance grows until it reaches a critical amplitude and breaks down to turbulence. The goal of Receptivity theory is to estimate the receptivity coefficient, i.e. the relationship between the disturbance environment and the initial disturbance that is triggered in the boundary layer.

Transition can be caused by a range of disturbances, the character of the transition process is decided by which type of disturbance the boundary layer is subjected to:

- Acoustic disturbances in a 2D boundary layer trigger exponentially growing TS-waves. The long wavelength of the acoustic disturbance must be reduced to the short wavelength of the TS-waves, this can happen at the leading edge or at surface roughness where the flow experience a sharp gradient in the streamwise direction.
- Free-stream turbulence or roughness in a 2D boundary layer gives rise to streamwise streaks of alternating low and high velocity. Due to the sharp wall-normal gradient of the boundary layer, a small disturbance in the wall-normal velocity can cause a large disturbance in the streamwise velocity, this is known as the lift-up effect.

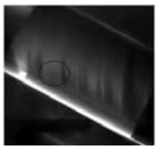


Alfredsson & Matsubara, 2000

- Free-stream turbulence or roughness in a 3D boundary layer triggers cross-flow waves.

CF and TS waves

The disturbances in the boundary layer on a wing can be divided into two families, TS-waves and Cross-flow waves (CF). The wave vector of TS-waves are approximately oriented parallel and the wave vector of cross-flow waves perpendicular to the flow direction. These two types of disturbance grow under different conditions. The CF-waves grow stronger in flows with a negative pressure gradient that is in accelerated flows for example close to the leading edge. TS-waves grow faster in a flow with positive pressure gradient as on the back of the wing. Below is an experiment at ONERA showing stationary CF-waves on a wing.



The NLF HARLS Wing (T)

TELFONA will use a wing concept called High Aspect Ratio Low Sweep (HARLS), with the following advantages and disadvantages:

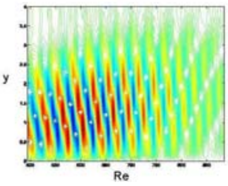
- Lower drag → Lower emission levels
- Higher lift/drag ratio → Less noise in airport areas
- Low sweep angle → Lower cruise speed

Transition on aircraft wings is generally caused by either TS-waves or CF-waves. A favorable pressure gradient will prohibit the TS-waves from growing, but may enhance the growth of CF-waves. The low sweep angle of the HARLS wing reduces the risk of CF-waves, the shape of the wing profile can then be optimized to extend the favorable pressure gradient and thereby the laminar flow. It has been predicted that a NLF HARLS wing may reduce the drag by 20% compared to conventional turbulent wings.

Performance prediction (T)

The most critical factor when predicting the performance of a NLF wing is the location of transition. TELFONA will develop new experimental and computational transition prediction tools for NLF wings. These methods will then be put to the test in the design of a wing profile optimized for NLF.

- Experimental methods
  The high Reynolds number (Re) and low disturbance levels at free flight are very hard to achieve in wind tunnel experiments. TELFONA will use the cryogenic European Transonic Wind tunnel (ETW) to achieve flight Re. The low disturbance level of the Minimum Turbulence Level (MTL) windtunnel at KTH will be utilized to determine the influence of free-stream disturbances and surface roughness on the transition process. The objective is to find a correlation so that data from wind tunnels with high disturbance levels can be used to determine the transition location at free flight conditions.
- Computational methods
  TELFONA will develop computational transition prediction methods that incorporate receptivity models so that the relationship between the disturbance level and the transition location can be calculated. KTH/FOI will use sensitivity analysis based on adjoint methods to calculate the receptivity coefficient for free-stream disturbances and surface roughness. The figure below shows the sensitivity (real part) of a TS-wave to momentum forcing.



Flow control methods (S)

- *NFL: Natural laminar flow:* This is the easiest method to apply to an aircraft. What it means is that you tailor the airfoil shape to inhibit disturbances. This could for example include a very short pressure recovery zone on the back of the airfoil to prevent growth of TS-waves.
- *LFC: Laminar flow control:*The idea is to prevent the boundary layer from developing and thereby also preventing disturbances to grow. This is accomplished by using a perforated surface with a suction system. Below is an image of a NASA flight test with a suction wing.

- *HFLC: Hybrid laminar flow control, NFL and LFC:* This is a combination of the two above-mentioned techniques. For example using suction close to the leading edge to inhibit CF-waves and tailoring the aft part of the profile to control TS-waves.
- *Micron-sized roughness:* Transition is caused by growth and break down of disturbances. Disturbances with different wave numbers grow at different rates. The idea is to generate disturbances with a certain wavelength (killer) to modify the boundary layer in order to damp the most dangerous disturbances (target). The killer disturbance is generated by micron-sized roughness elements close to the leading edge.
- *Gaster bump:* As the boundary layer develops along the fuselage it becomes turbulent. The turbulent boundary layer spread from the fuselage along the leading edge and contaminates the boundary layer on the wing. The Gaster bump is a bracelet or a bump that is put on the leading edge of the wing quite close to the fuselage. If designed properly it can stop the turbulent boundary layer from the fuselage to develop on to the wing.

Micron-sized roughness (S)

The problem consists of finding the right wavelength of the disturbance (killer) to modify the flow such that the dangerous wavelength that is the most likely candidate to cause transition (target) will de damped. In the experiments the killer wave will be created by tiny bumps on the surface of the wing. The distance between the bumps decides the wavelength of the killer. The difficulty is to find a killer that only reduces the target. The killer affects different wavelengths and there is a risk that energy is put into another mode that causes early transition. The left image shows growth of the target wave and choice of the killer one. It is important to choose a killer wave that grows rapidly in the beginning and decays further back on the wing. Otherwise it could cause transition on its own. The right image shows the effect of different amplitudes for the killer wave on the target wave. As we can see the target wave grows slower when the killer wave start amplitude is increased. The start amplitudes represent the height of the roughness elements.