Applications de l’automatique au contrôle en boucle fermée d'une couche limite épaisse

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Model in the Wind tunnel

- Smooth contraction (ratio 0.75)
- Articulated flat plate: adverse pressure gradient
- Articulated flap: separation
Actuators: first manual optimization

- **54 configurations** for passive devices:
  - co- or counter- rotating, 3H, 4 $\Delta X_{VG}$, up to 4 $\lambda$ and 2 $L$
- **44 configurations** for active devices:
  - $\beta = 45^\circ$, $\alpha=45^\circ$ or $135^\circ$, co- or counter- rotating, 2$\Phi$, 2 $\Delta X_{VG}$, up to 4 $\lambda$, $L$, 6VRs

On going PhD (C. Cuvier)
Actuators configuration for open and closed loop

22 co-rotating synchronous jets blowing upstream, \( \phi = 6\text{mm}, \lambda/\phi = 13.6 \) and \( \Delta X_{VG}/\phi = 47 \)
Control set-up

\[ u(t) = DC(t) \]

\[ y(t) = x(t) = E(t) - E_0 \]

System diagram:
- Input: \( u(t) \)
- Actuators
- Controlled flow (\( Re, \frac{dCp}{ds} \))
- Sensors
- Output: \( y(t) \)
Control objectif
Open-loop:
First order response to a step function

Actuators ON:

\[\frac{dy}{dt} = -y(t) + \frac{H}{\tau} u(t - t_d)\]
\[y(t) = x(t)\]

State space representation:

Actuators OFF:

Actuators ON: \[x(t) = H(1 - e^{-\frac{t-t_d}{\tau}})\]
Actuators OFF: \[x(t) = H e^{-\frac{t-t_d}{\tau}}\]
Open-loop results: $U_\infty = 5\text{m/s}$

$\tau = 0.5\text{s}$

$t_c = 0.1 \pm 0.1\text{s}$
Open-loop results:  \( U_\infty = 5 - 8 - 10 \text{ m/s} \)

\[ \frac{X_{ss}}{X_{th}} \text{ [Volt]} \]

\[ \text{DC} \]

\[ H/x_{th}=2.09 (\sigma - 0.18) \]

\[ \frac{t_{ca}}{\tau_a} \]

\[ \tau_a=0.8-0.05 \ U_\infty \]
The feedback closed loop:

\[
\frac{du}{dt} = K_p \frac{de}{dt} \quad \text{with} \quad e(t) = r - y(t)
\]

\[
TF = \frac{K_p G(s)}{1 + K_p G(s)} \quad \text{with} \quad K_p = 1
\]
Reactivity:

\[
\int_0^{t_{CL}} Q_{mCL} \, dt = \frac{\int_0^{t_{CL}} DC \, t \, dt}{0.6 t_{OL}} = 0.8
\]

Gain 20%:
Robustness: keep $y(t)=r$ with $r = 1.15 \times \text{th}(5 \text{ m/s})$
Conclusions

- Model:
  **Ramp:** APG-TBL pressure gradient \( (\text{Re}_\theta = 11000, \frac{dCp}{ds}=0.06, \delta = 20\text{cm}) \)
  
  **Flap:** separation (2D over 70%)

- Open-loop tests (SISO):
  - Sensor/Output: hot-film probe/E-Eo
  - Actuators/Input: pulsed jets/DC
  - First order linear system: \( \tau = -0.05 U_\infty + 0.8 \) and \( \frac{H}{x_{th}} = 2 \pm 0.2 \)

- Closed-loop tests:
  - Proportionnal law
  - improvement of reactivity
  - Robustness to be improved