Active aerodynamic control of a bluff body based on machine learning control

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1. Background


Drag force $F_d$ - 17%

Averaged $F_s$ value is 0 N 

Side force $F_{s,rms}$ + 32%

Fig. 1. Main sources of aerodynamic drag for a truck (a). The A-pillar separation and the effect of the actuation (b).
1. Background

(a) Wind tunnel wall

(b) W = 400, 24 slits

(c) Averaged velocity profile

1. Objective function

2. Control parameters $A, f$ and $\phi$
2. Machine learning control (MLC)

Bluff body system

Control law

MLC learning loop

Cost function

LabVIEW platform

Actuation

Control loop

$b$

$k_\alpha b$

$b$

$S_1: b_1 = \sin(f_1 t) \times |A_1 \sin(f_2 t)|$

$S_2: b_2 = \sin(f_1 t) \times |A_1 \sin(f_2 t + \varphi)|$


$f_1, f_2, A_1, \varphi$

$\delta_{C_s,\text{rms}}$
2. Machine learning control (MLC)

Population creation \rightarrow Population evaluation

Control law \( b \)

Is termination criterion \( J \) reached?

Yes \rightarrow Stop

No

\( f_1, f_2, A_1, \varphi \)

\( n \) th Individual: \( N = 60 \)

\( (n+1) \) th Individual

Elitism

Evolution

Tournament \( \rightarrow \) Crossover (0.8) \( \rightarrow \) Mutation (0.025)

Generation: \( n > 30 \)
3. Control Results

Maximum side force $F_{s,rms}$ - 40%
3. Control Results

Best individual $f_1, f_2, A_1, \varphi$

$f_1^* = 3.1$
$f_2^* = 0.08$
$A_1^* = 0.67\, V$
$\varphi = 1.81$
3. Control Results

(a) $S_2$

- $b_2$
- $f_1^* = 3.16$, $\sin(f_1 t)$
- $f_2^* = 0.08$, $|A_1 \sin(f_2 t + 104^\circ)| \leq 0.4V$

(b) $S_1$

- $b_1$
- $f_1^* = 3.16$, $\sin(f_1 t)$
- $f_2^* = 0.08$, $|A_1 \sin(f_2 t)| \leq 0.4V$

Input energy reduced by 45%
4. Physical aspect

Forced vibration

Shear layer frequency
Minelli et al. (2017)

Collision for $U_{\text{inf}} = 0$ m/s
No control for $U_{\text{inf}} = 10$ m/s
No control for $U_{\text{inf}} = 19$ m/s
No control for $U_{\text{inf}} = 29$ m/s
Best individual for $U_{\text{inf}} = 19$ m/s

$E$ of $C_{s,\text{rms}}$ and $F_s$
4. Physical aspect

1. Multi-frequencies control

- Drag force $F_d$:
  - $f_1^* = 3.1$
  - $f_2^* = 0.08$
  - $-30\%$
  - $-11\%$

2. Single frequency control

- $f_1^* = 3.1$
- $f_2^* = 0.08$
- $-26\%$ and $-3\%$

3. Phase control

- $\varphi = 1.81$
- $-6\%$

No control

- $f_1^* = 2.11$, $A_1 = 0.4V$
- $f_1^* = 3.14$, $f_2^* = 0.08$, $A_1 = 0.67V$, $\varphi = 1.81$
- $f_1^* = 3.14$, $f_2^* = 0.08$, $A_1 = 0.67V$, $\varphi = 0$
- $f_1^* = 3.14$, $A_1 = 0.4V$
- $f_2^* = 0.08$, $A_1 = 0.4V$

$F_{s,rms}$

$\delta c_{s,rms}$ (%)

$k$

$U_\infty$

$S_1$

$S_2$

$O$

$x$

$y$

$z$

$S_1$

$S_2$

Drag force $F_d$
4. Physical aspect

Vortex shedding Strouhal number $f^* = 0.15 - 0.2$ in the wake (Bai & Alam 2018 Phys. Fluid; Zhang et al. 2015 JFM)
4. Physical aspect

Spectral energies of the vortex shedding in the wake

No control

Optimal control
Conclusion

1 The MLC figure the optimal control parameters out for reducing $F_{s,rms}$ as $f_1^* = 3.1$, $f_2^* = 0.08$, $A_1 = 0.67V$ and $\phi = 1.81$ or $104^\circ$. The maximum reduction achieved is 30%, larger than 26% attained from the reference single frequency control. Furthermore, the corresponding input energy are reduced by 45%.

2 The power spectra of the force balance indicate unequivocally that the MLC controller has exactly found one natural frequency of the mechanic system and one frequency of the shear layer, thus greatly suppressing the lateral vibration.

3 Under the optimal control, the vortex shedding has been shrunk substantially and reduced in its strength in the wake.
Thank you for paying the attention!