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Unsteady Separated Flows and their Control

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Flow separation is often associated with the formation of large wakes, and hence the generation of undesirable, large drag forces. Passive and active control measures have been studied and employed to reduce such separation effects particularly behind bluff bodies. In unsteady flows, in particular, the vortices which form from unsteady separation can be actively controlled to achieve drastic reduction of adverse pressure gradients, or even generate propulsive forces. Self-propelled bodies that employ significant body-flexing and fins to control the flow are prime examples of unsteady flow separation and control.

We consider examples from two basic problems in fluid mechanics:

- Unsteady separation in bluff bodies undergoing vortex-induced vibrations and the passive and active control measures to reduce them.
- The flow mechanisms employed in actively controlled, fish-like bodies to optimize their locomotion and maneuvering performance.

In the case of unsteady separation in bluff bodies, there are two principal control mechanisms guiding the passive or active control mechanisms, viz. either the reduction or even elimination of the absolute-instability region behind the bluff body, or a reduction in the spatial coherence of the shed vorticity. In the first case, of controlling the area of absolute instability, we report on the effect of:

a) small vibrating rods,
b) active and passive ventilation methods, and
c) rotational control.

In the case of de-correlating the vortex shedding process, we report on:

a) the effect of step changes in the bluff body diameter,
b) tabs and spoilers to control correlation,
c) periodic flow forcing (suction and blowing),
d) using wavy separation edges,
e) strakes, which are extensively used in the offshore industry,
f) internal strakes
g) shrouds, and
h) flaps and fins.

Several applications of vortex-induced cancellation devices will be considered in detail, including the helical strakes used in long tethers; the natural loss of spatial correlation at critical Reynolds number; the flow injection or suction behind bluff bodies; fins and protrusions to de-correlate the flow. In all cases the principal parameters controlling the elimination of unsteady vertical wakes are outlined. Recent results from an experimental project supported by BP will be presented.

In the case of fish-like bodies we present results from coordinated body flow separation and tail manipulation, to achieve optimal propulsion and maneuvering. Fish-like propulsion provides an integrated example of separation control, since a combined effort to control the boundary layer on the body, and coordinate body-shed vortices and tail-shed vortices is essential to optimal locomotion and maneuvering. Recently developed theories of the detailed flow structure around a steadily moving fish, producing a momentum-less wake, are reviewed; as well as theories of fast-starting and rapidly-turning fish, achieving super-maneuverability through vorticity control.

In steadily moving fish, vortices form upstream which can be used through suction effect to develop thrust, while repositioning them by the tail, together with shedding of additional vorticity, completes the propulsion scheme; hence unsteady separation can be exploited to advantage by fish-like mechanisms. In fast-starting or rapidly-turning fish the large forces required to implement the maneuvers are generated through fast but controlled shedding of large vortical structures, a prime example of effective use of unsteady separation to generate forces.

In both cases, of steady and unsteady locomotion, fundamental scaling laws control the process, which are derived based on principles of vorticity control.