Control of Two- and Three-Dimensional Wake Instabilities from Bluff-Bodies

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PROJECT ABSTRACT

Research Goals:

The long-range goals of this investigation are to:

1. Determine the effects of various active and passive control techniques on the instantaneous and time-averaged structure of the three-dimensional wake of a cylinder at low and high Reynolds number.

2. Characterize the unsteady loading on the cylinder, including the phase shifts between the cylinder motion, the forces acting on the cylinder, and the three-dimensional structure of the near-wake.

3. Develop new types of experimental techniques, focusing on high-image-density particle image velocimetry (PIV), image processing and pattern recognition, and methods of instantaneous force measurement.

Objectives:

The immediate objectives are to:

1. Determine the effect of active (open-loop) control of the cylinder motion, in the form of sinusoidal, amplitude-modulated and frequency-modulated excitation, on the quasi-two-dimensional and three-dimensional flow structure.

2. Investigate the effect of imposed three-dimensionality in the form of surface nonuniformities or, equivalently, localized suction/blowing on the flow structure.

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3. Develop integrated PIV-force measurement systems, including PIV cinematography, high-speed digital processing of images, and multicomponent force transducers.

Approach:

An integrated, active (open loop) control–quantitative flow visualization system has been implemented. It involves digital computer control of the cylinder motion, the localized fluid injection, and the phase angle between them. Moreover, this integrated system allows simultaneous firing/scanning of lasers, image shifting systems, camera systems and other related instrumentation. Use of a high-image-density PIV approach allows characterization of the instantaneous streamline pattern and vorticity field over an arbitrary plane in a highly three-dimensional flow at high values of Reynolds number. Concepts of flow topology based on critical point theory are employed to identify crucial features of the instantaneous flow structure. These approaches will be integrated with techniques of instantaneous force measurement, in order to provide direct, wholefield correlations of the near-wake and the loading on the cylinder.

Tasks Completed:

The quasi-two-dimensional wake structure has been addressed, with emphasis on the phase shift between the cylinder motion and the large-scale vortices, as well as the rapid destabilization and restabilization of the vortices for sinusoidal, amplitude- and frequency-modulated excitation. The three-dimensional structure of the near-wake, in the presence of localized disturbances, has been characterized quantitatively in terms of projections of the three-dimensional streamline patterns and vorticity distributions.

Results:

The quasi-two-dimensional flow structure from a uniform cylinder subjected to sinusoidal excitation shows the well-known phenomenon of locked-in vortex formation. For amplitude-modulated and frequency-modulated excitation, new types of locked-in response have been revealed. Moreover, away from the locked-in region, it is possible to attain rapid destabilization of the large-scale vortex formation or, in certain cases, to restabilize the vortex formation to a periodic state. All of these features require consideration of AM and FM parameters such as modulation frequency and frequency deviation. Even in the presence of purely sinusoidal excitation, higher Reynolds number flows that are usually assumed to be in a locked-in state actually exhibit large instantaneous excursions of the flow pattern from one cycle to the next. These excursions can be viewed as amplitude- and frequency-modulated phenomena occurring in a system subjected to pure sinusoidal excitation; they are not revealed by classical ensemble-averaged
representations of the flow structure.

The three-dimensional flow structure from a uniform cylinder at higher values of Reynolds number (5,000 to 10,000) involves pronounced three-dimensional vorticity concentrations \( \omega_x \) and \( \omega_y \), relative to the classical Kármán vortices having only \( \omega_z \) vorticity. The circulation \( \Gamma_x \) and \( \Gamma_y \) of vortices can be of the same order as the Kármán vortices \( \Gamma_z \).

At low values of Reynolds number, the three-dimensional structure from an oscillating cylinder having a geometrical nonuniformity shows not simply distorted patterns of quasi-two-dimensional vortex formation having nominal vorticity \( \omega_z \), but very pronounced clusters of vorticity concentrations \( \omega_y \). It is possible to generate values of circulation \( \Gamma_y \) of the same order as the dimensionless circulation \( \Gamma_z \) of the Kármán vortices. These patterned clusters of vorticity, arising from the localized nonuniformity of the cylinder, provide the basis for similar studies at higher values of Reynolds number. In a related study focusing on the three-dimensional structure at low Reynolds number from a uniform cylinder with localized suction/blowing, patterns of vorticity clusters \( \omega_y \) are analogous to those attained for the geometrical nonuniformity. Moreover, \( \omega_y \) concentrations at the end of the cylinder can be drastically attenuated by localized blowing.

Recent developments in high-image-density particle image velocimetry have focused on techniques for characterizing the instantaneous structure in the near-wake at high-Reynolds number. Techniques of correlation of instantaneous vorticity over an entire plane provide a basis for linking the flow structure to the instantaneous surface loading on the cylinder. Moreover, new approaches to high speed image acquisition in the form of PIV cinematography have been initiated. Complete time histories of the flow will be obtained using this approach.

Accomplishments:

1. Patterns of three-dimensional vorticity concentrations have been defined in the near-wake at low and high Reynolds number; these vortices can have strengths of the same order as the classical Kármán vortices.

2. Quantitative techniques for characterizing the instantaneous structure of the near-wake at high Reynolds number have been developed; they provide new types of velocity and vorticity correlations that can link the flow patterns to the loading on the cylinder.
Contours of constant streamwise vorticity (top image) and superposition of sectional streamlines and vorticity contours (bottom image) on a plane cutting across turbulent wake ($Re = 5000$). Plane is perpendicular to the freestream and located one diameter downstream of the base of the cylinder. Images are obtained via high-image-density particle image velocimetry.


92-R Several progress and final reports to ONR; essential advances are described in the foregoing journal articles.


(Unable to accept a substantial number of invited seminars and lectures at various universities and technical meetings due to research commitments.)
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a. Number of Papers Submitted to Refereed Journal not yet Published: 1
b. Number of Papers Published in Refereed Journals: 10
   (List Attached):
c. Number of Books or Chapters Submitted but not yet Published: 1
d. Number of Books or Chapters Published (List Attached): --
e. Number of Printed Technical Reports and Non-Refereed Papers (List Attached): --
f. Number of Patents Filed: --
g. Number of Patents Granted (List Attached): --
h. Number of Invited Presentations at Workshops or Professional Society Meetings (List Attached): 2
i. Number of Presentations at Workshops or Professional Society Meetings (List Attached): 3
j. Honors/Awards/Prizes for Contract/Grant Employees: (List Attached, this might include Scientific Soc. Awards/Offices, Promotions/Faculty Awards/Offices, etc.) 2

k. Total Number of Graduate Students and Post-Docs Supported at Least 25% This Year on This Contract/Grant
   Grad Students 3 and Post-Docs 2 including
   Grad Student Female -- and Post-Doc Female --
   Grad Student Minority -- and Post-Doc Minority --

Minorities include Blacks, Aleuts, AmIndians, Hispanics, etc.
NB: Asians are not considered an under-represented or minority group in science and engineering.

Enclosure (3)