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THE EFFECTS OF THREE-DIMENSIONAL IMPOSED DISTURBANCES ON  
BLUFF BODY NEAR WAKE FLOWS

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This project has been carried out in collaboration with Professor Peter W. Bearman,  
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## Effects of Three-Dimensional Imposed 3-D Disturbances on Bluff-Body Near Wake Flows

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### PROJECT ABSTRACT

#### Research Goals:

This experimental research effort focuses on the underlying three-dimensional flow structure in the near wake of a bluff body when subjected to imposed geometrical disturbances. We want to understand the effects of three dimensionality that are characterized by vortex splitting and looping and how they are related to other wake parameters such as base pressure shedding frequency, wake width and wake formation length.

#### The long term goals:

1. To gain an improved understanding of the effects of imposed three-dimensional disturbances on the flow structure in the near wake of a nominally two dimensional bluff body.
2. To determine the effects of certain approach flow nonuniformities on the development of the near wake of infinite and finite aspect ratio circular cylinders with and without imposed three-dimensional disturbances (splitter plates) at high Reynolds numbers.

#### Objectives:

1. To obtain a fundamental understanding of the three-dimensional features that arise in the near wake flow region behind nominally two-dimensional bluff bodies subjected to imposed mild three-dimensional disturbances for purpose of flow control. Controlled three-dimensional disturbances will be introduced into the near wake flow of a circular cylinder by a spanwise periodic trailing edge splitter plate and into the near wake of a blunt based section by a sinusoidal-trailing edge.
2. To study the instantaneous occurrence of vortex looping and dislocations which occur in the near wake as result of the imposed three-dimensionality and visualize the various shedding modes.
3. To study the three-dimensional features that arise in the near wake region behind a nominally two-dimensional bluff body due to a linearly varying approaching shear flow.

### Approach:

The approach is experimental and presently utilizes wind tunnel facilities at U. of Notre Dame and water tunnel facilities at Imperial College in cooperation with Professor Peter W. Bearman. Experiments at Imperial College have focused on the flow past sinusoidal-trailing edge blunt based section body (BB) whereas flow past a circular cylinder (CC) with a spanwise periodic trailing edge splitter plate has been studied at Notre Dame. Hot-wire anemometry is used for velocity and velocity fluctuation measurements. Instantaneous pressure measurements and flow visualization via smoke wire are integrated with velocity measurements to reveal the three-dimensional character of the near wake.

### Tasks Completed:

- Velocity and pressure measurements have been completed for a circular cylinder with a two-dimensional splitter plate with varying plate to diameter ratios as well as a circular cylinder with a spanwise periodic trailing edge splitter plate with varying plate to diameter ratios, and varying wave length and amplitude. These experiments were carried out in a Reynolds number range 10,000 to 50,000. Smoke wire and smoke rake flow visualization were used to observe the three-dimensional feature in the flow.
- Flow visualization using electrolytic precipitation was used to observe the flow over these same model in a water channel at Imperial College at a Reynolds number of 5,000.
- We have completed construction of two linear shear screens which provides the capability of operating in two different aspect ratio wind tunnels. The shear screens have a shear gradient,  $du/dz = 8.66$  and  $6.40$  1/sec; a steepness parameter  $\beta = du/dz(D/U_{ref}) = 0.04$  and  $0.03$ ; and shear parameter  $\lambda = \beta H/D = 0.32$  and  $0.36$  respectively.
- We have completed construction of an automated circular cylinder, diameter = 3.5 in with retractable and interchangeable splitter plate capability for use in our 5 ft x 5 ft cross-section wind tunnel. This model provides for splitter plate length to diameter ratios of 0 - 4 with aspect ratio up to 16.

### Scientific Results:

The present work indicates that wakes behind a circular cylinder with a periodic trailing edge splitter plate differs from the wake behind circular cylinder and the wake behind circular cylinder with a two-dimensional splitter plate. The presence of a spanwise periodic splitter plate affects the mean and fluctuating base pressure along the span which in turn modifies the vortex shedding modes. With the introduction of a two-dimensional splitter plate, the shedding frequency decreases to a minimum as the plate length was increased to a plate to diameter ratio of one, and then increased with larger plate lengths. Hence, when the formation length increased with the introduction of splitter plates, the Strouhal number decreases. Due to the longer formation length region, the shear layers elongate resulting in more vorticity diffusion in the shear layers that causes the shedding frequency to decrease.

For the periodic splittter plates the values of the shedding frequency at the peak and valley fell between values for the two equivalent two-dimensional splitter plates respectively. However, a spanwise variation in the shedding frequency is observed i.e., as a probe is

traversed from valley to peak, a second frequency appears in the spectra and is as dominant as the shedding frequency when the peak is approached whereas it is virtually nonexistent at the valley. This presence of a second shedding frequency leads to vortex dislocation and is manifested by the spanwise periodicity introduced by the periodic splitter plate.

Instantaneous base pressure measurements on the cylinder with spanwise periodic trailing edge splitter plate disturbances indicate a direct coupling to the shedding frequency. A strong correlation existed between the stagnation-line and base pressure signals. A low frequency component in the base pressure power spectra was found and was directly related to an irregular shedding mode observed in the wake. This observed low frequency corresponds to the dislocation frequency observed in the spectra obtained from hot-wire traverses.

Flow visualization experiments carried out in water channel at Imperial College for the CC body in a using the electrolytic precipitation method have clearly indicated several modes of shedding and strong three dimensionality that include vortex looping, vortex splitting and vortex dislocations. It was found that for certain splitter plate length to diameter ratios, for those below the minimum drag condition, the shedding pattern became very regular and two-dimensional in spite of the geometrically imposed three dimensionality in the near wake. Frame by frame analysis of the flow visualization video shows an instantaneous mode selection of twice the frequency of the input spanwise periodic splitter plate, see Figure 1,  $t=1.00$  and  $t=1.667$  sec. As one progresses in time,  $t=1.167 - 1.500$  sec. these shed vortices tend to straighten out and get convected downstream before the pattern repeats itself again. Hence, flow visualization results appear to indicate that there exists some feedback mechanism of the spanwise periodic trailing edge structure to the vorticity shed at the separation line. The effects of the input wavelength and amplitude have yet to be determined and additional experiments are planned to obtain a better understanding of these flow input features and how they relate to the fundamental features of vortex dislocations.

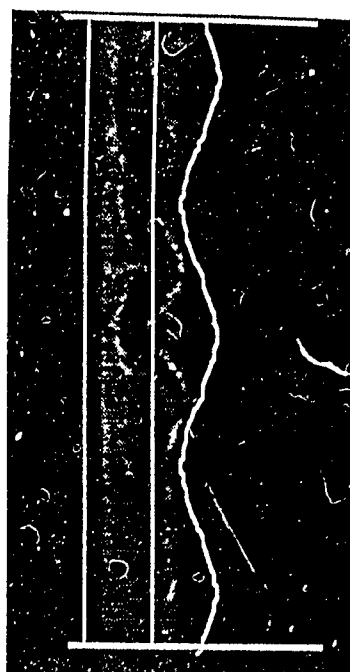
#### Approach Flow Nonuniformity

Only the following preliminary results are available for linear incoming shear flow.

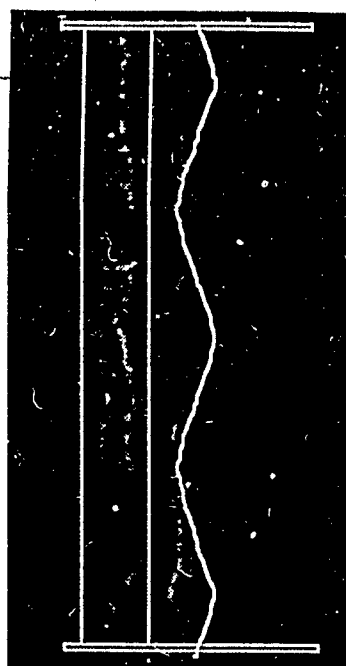
- For a plain cylinder two well defined spanwise cells of constant shedding frequency are observed. In the power spectra we observe a sharper peak for the high frequency cell than for the low frequency cell indicating a more well defined shedding structure.
- Addition of a splitter plate results in a modification of the shedding characteristics and has a strong dependence on the splitter plate length to diameter ratio.
- Distinct differences in the power spectra are observed between the low and high velocity shear regions. The dominant mode in the low velocity shear region is higher than the mode in the low velocity cell for all splitter plates

#### **Accomplishments:**

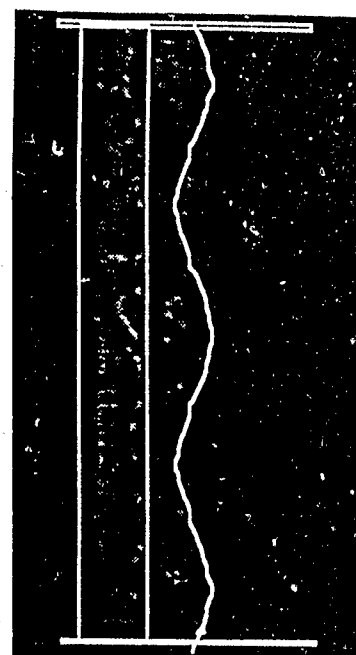
1. Demonstration of several shedding modes in the flow behind a bluff body with geometrically imposed three-dimensionality.
2. We have found that the introduction of mild geometric three-dimensionality through spanwise periodic splitter plates can control the positions of vortex dislocations.



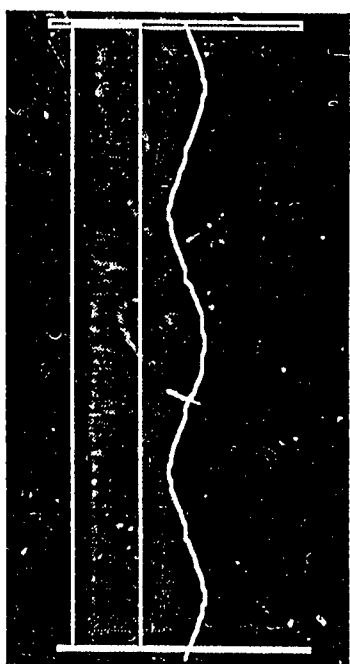
$t = 1.00$



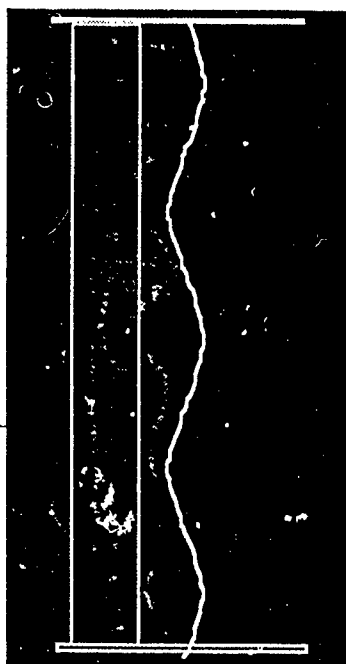
$t = 1.167$



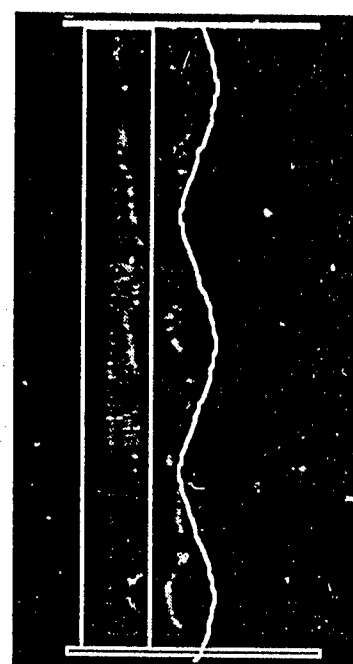
$t = 1.333$



$t = 1.500$



$t = 1.667$



$t = 1.833$

Figure 1. Flow visualization time sequence ( $t = \text{sec}$ ) of shed vortices from a circular cylinder with a spanwise periodic splitter plate with  $\ell/D = 1.0$ ,  $\lambda/D = 3.0$ , and  $a/D = 0.5$ .

PUBLICATIONS FROM ONR SPONSORED WORK - FY92/FY93

Professor Albin A. Szewczyk

Professor Peter W. Bearman

September 1993

- 92 - C Szewczyk, A. A. and Anderson, E., Some 3-D vs. 2-D Effects of a Splitter Plate on the Near Wake Flow of a Circular Cylinder. Amer. Phys. Soc. Bull. Vol. 37, No. 8, p.1747, November 1992.
- 92 - P Pearson, L. and Szewczyk, A. A., The Near-Wake of a Circular Cylinder with a Spanwise Periodic Trailing Edge Splitter Plate. FED-Vol. 138/PVP-Vol. 245, ASME Proc. Inter. Symp. Flow-Induced Vibration and Noise, Vol. 6, pp 75-86, November 1992.
- 92 - C Bearman, P. W. and Tombazis, N., The Effects of Three-Dimensional Imposed Disturbances on Bluff Body Near Wake Flows. Second International Colloquium on Bluff Body Aerodynamics and Applications, Melbourne, December 1992.
- 93- R Tombazis, N., *Effects of Three-Dimensional Disturbances on Bluff Body Near Wakes*. Ph. D. Thesis, University of London, March 1993.
- 93 - PC Bearman, P. W., Challenging Problems in Bluff-Body Wakes. " Bluff-Body Wakes, Dynamics and Instabilities, " Eds.H. Eckelmann, J.M.R. Graham, P. Huerre, P.A. Monkewitz, pp 39-43, Springer-Verlag, 1993
- 93 - PC Borg, J. and Szewczyk, A. A., Unsteady Base Pressure Measurements in the Near Wake of a Cylinder with Imposed Three-Dimensional Disturbances. " Bluff-Body Wakes, Dynamics and Instabilities, " Eds.H. Eckelmann, J.M.R. Graham, P. Huerre, P.A. Monkewitz, pp 39-43, Springer-Verlag, 1993
- 93-PI Tombazis, N. and Bearman, P.W. , Effects of Three-Dimensional Disturbances on Bluff Body Near Wakes. To be submitted to the Journal of Fluid Mechanics.
- 93-PI Pearson, L.F., Borg, J.P., and Szewczyk, A.A., Effects of Three-Dimensional Disturbances on the Near Wake of a Circular Cylinder. To be submitted Experiments in Fluids.
- 93-PI Anderson, E., Effects of a Nonuniform Approach Flow on the Near Wake of a Circular Cylinder with Splitter Plate. Ph. D. Thesis in progress. U. of Notre Dame.

Enclosure (2)

OFFICE OF NAVAL RESEARCH  
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT\*  
1 Oct 92 through 30 Sep 93

R&T Number: 421g012---01

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Contract/Grant Title: The Effect of Three-Dimensional Imposed Disturbances on Bluff  
Body Near Wake Flows

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- a. Number of Papers Submitted to Referred Journal but not yet published: 3
- b. Number of Papers Published in Refereed Journals: 1  
(list attached)
- c. Number of Books or Chapters Submitted but not yet Published: 0
- d. Number of Books or Chapters Published: 2 (list attached)
- e. Number of Printed Technical Reports and Non-Refereed Papers: 2  
(list attached)
- f. Number of Patents Filed: 0
- g. Number of Patents Granted: 0 (list attached)
- h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 1
- i. Number of Presentations at Workshops or Prof. Society Meetings: 3
- j. Honors/Awards/Prizes for Contracts/Grant Employees: 0  
(list attached, this might include Scientific Soc. Awards/  
Offices, Promotions/Faculty Awards/Offices, etc.)
- k. Total Number of Graduate Students and Post-Docs Supported at  
least 25% this year on this contract/grant:

Grad Students 2 and Post-Docs 0 including  
Grad Student Female 0 and Post-Docs Female 0.  
Grad Student Minority 0 and Post-Doc Minority 0.

\*The above relates to work carried out at Imperial College and U of Notre Dame.

Enclosure (3)