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Performance Comparisons of Helical Strakes for VIV Suppression of Risers and Tendons

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Abstract

This paper presents experimental results for various helical strake geometries and discusses their performance coefficients and responses. Experimental results from the presence of surface roughness and/or interference (i.e., the presence of upstream tubulars) are also presented. A substantial amount of the experimental data is from experiments performed on flexible cylinders at prototype (critical) Reynolds numbers for actual offshore tubulars.

Introduction

Helical strakes are one of the most popular devices for suppressing vortex-induced vibrations (VIV) of offshore tubulars. The underlying mechanism of vibration reduction with helical strakes is to disrupt the spatial correlation of vortices by gradually changing the flow separation angle in the longitudinal direction. As a result, the intensity of vortices is weakened, and the lift force is reduced.

The general physics of how helical strakes suppress VIV motion is straightforward. However, the performance of strakes and sensitivity of that performance to various geometrical and flow variations are not well understood, especially for marine riser and tendon applications in field conditions. There are primarily three technical issues to be addressed in deepwater project engineering in relation to VIV strakes. One is to determine strake geometry, such as strake height and pitch; a second is to decide on the strake coverage length; and a third is to determine the need for, and suitability of, marine growth retardation coatings or an underwater cleaning/maintenance program.

The strake test data available to designers are usually pertinent to isolated, rigid cylinders in uniform flows. Risers and tendons in field conditions frequently experience sheared flows and respond in elastic structural modes. In addition, offshore tubulars are often in close proximity and interact with flow in a complex manner. Clearly, direct application of rigid cylinder, uniform flow test data to riser and tendon design can lead to erroneous decisions.

Over the past 10 to 15 years, extensive tests have been conducted at Shell to investigate the performance of various strake designs. These tests were performed either in a circulating current tank, on a rotating arm facility, or in a high-speed linear towing channel.

In these tests, geometric parameters were varied, including the height of strakes, the pitch, and the number of starts. The surface roughness of the strakes ranged from smooth, to medium rough, to very rough. The flow profiles included fully or partially uniform and sheared currents. The Reynolds numbers were in subcritical, critical and supercritical range. The test configurations included straked single pipes, and multiple tubulars with strakes in tandem/offset positions. Responses of tubulars with various strake coverage lengths, placed in low and high speed zones, were also evaluated.

One of the test programs, the rotating arm tests, was conducted at the U.S. Navy's test basin in Carderock, Maryland. The 97-ft long test cylinders were made of fiberglass composite, consisted of five joints connected by inner sleeves, and were mounted horizontally beneath a towing bridge. Accelerometers and load cells were used to monitor the accelerations, tension and drag loads. As the bridge rotates, it drives the cylinder in a circular path in still water. The cylinder experiences a sheared flow profile that excites the VIV motion of the cylinders (Figure 1). A more detailed description of the test setup, test procedure, and data acquisition and analysis is provided in Reference [1]. Selected test configurations for pipes with smooth and rough helical strakes are displayed in Figure 2.

Another series of test programs to evaluate strake geometry, surface roughness, coverage length, and interference effects were conducted at Shell's Westhollow circulating current tank. A schematic view of the test setup is displayed in Figure 3. Accelerometers and load cells were used to monitor the accelerations, tension and end loads. A more detailed description of the test setup, test procedure, and data acquisition and analysis is provided in Reference [2]. Selected test configurations for bare pipes and cylinders with smooth and rough helical strakes are displayed in Figure 4. A range of spacings, from 2 to 20D (D is cylinder diameter) in the tandem direction, and from 0 to 1D in the offset direction, was tested (see Figure 5 for general configuration definition).

In each of the following sections, some effects of strake geometry, coverage length, surface roughness, and interference on VIV responses and drag coefficients are demonstrated through test data. This is followed by summary and concluding remarks. This paper will limit its discussions to experimental data of tubulars with strakes in steady-flows. Additional topics, such as transient response behavior of risers with strakes in unsteady flows are not addressed in this publication.

Strake Geometry

The strake geometry can be described by its height, helical pitch, and number of starts. Strake height and pitch are usually expressed in cylinder outside diameter, D. Extensive work on strake performance in wind applications has been performed by Scruton and Walshe [3]. They concluded that 3-start strakes with a height range of 0.02D to 0.2D, and a pitch of 15D could suppress VIV effectively. The optimum strake height was 0.118D. Field experiences have indicated that these designs, such as a strake height of 0.1D, may not be effective in marine applications [4,5]. The performance of helical strakes is most sensitive to the strake height, as evidenced by examples below.

The first example is taken from the rotating arm tests. This was a 97-ft long, 2.5-in. diameter cylinder with strakes in the high-speed zone (the first configuration in Figure 2). Two strake designs were compared:

(1) 3-start, 17.5D pitch, and 0.15D height, and
(2) 3-start, 17.5D pitch, and 0.1D height.

The strakes were smooth, and the coverage length for both cases was about 18%. One of the acceleration response measurements is displayed in Figure 6. This measurement was made at a distance of 5.5 ft from the outer end. The horizontal axis of the plot is the Reynolds number. The vertical axis is the ratio of the rms accelerations of the pipe with 0.15D strakes over that of the pipe with 0.1D strakes.

On average, as the strake height was increased from 0.1D to 0.15D, the rms acceleration was reduced by more than 40%, or the suppression efficiency (defined as one minus the ratio of rms acceleration with suppression over rms acceleration without suppression) increased by about 50%. Note that the acceleration responses were sensitive to Reynolds numbers.

The next example demonstrates the effect of strake pitch. It is also from the rotating arm tests, for the same cylinder as that in the example above. Two strake designs were compared:

(1) 3-start, 17.5D pitch, and 0.25D height, and
(2) 3-start, 12D pitch, and 0.25D height.

The strakes were smooth, and the coverage length for both cases was about 37%. One of the acceleration response measurements is displayed in Figure 7. The responses were also at a distance of 5.5 ft from the outer end. The horizontal axis of the plot is the Reynolds number. The vertical axis is the ratio of the rms accelerations of the pipe with 17.5D pitch over that of the pipe with 12D pitch.

As most data points indicated, the 17.5D pitch strakes performed better than the 12D pitch strakes. On average, as the strake pitch changed from 12D to 17.5D, the rms acceleration was reduced by about 10%. The strake pitch did not appear to be a very sensitive parameter for the range of values tested.

Coverage Length

In principle, the longer the strake coverage of a cylinder, the more vibration the strakes suppress. Strakes should also be placed in a strong current zone to suppress those lift forces that could excite damaging high structural modes. In design practice, it is often difficult to specify the right amount of strake lengths that both satisfy the suppression needs and the economic constraints. Tests of different strake coverage lengths will reveal the suppression efficiency for each, and the data will be helpful in the decision-making process. Two examples are provided below.

The first example is from the rotating arm tests. This was a 97-ft long, 2.5-in diameter cylinder with 3-start, 0.25D height, and 17.5D pitch strakes. Two coverage lengths were compared: 18% and 37%. The rms acceleration ratios for the two coverage lengths are displayed in Figure 8. The acceleration response was measured at a distance of 5.5 ft from the outer end. The horizontal axis is the Reynolds number. The vertical axis is the ratio of the rms accelerations of the pipe with 37% strake coverage over that with 18% coverage. On average, when the coverage length was doubled, the suppression efficiency increased by about 50%. The test data also indicated that VIV suppression effects could be local, and longer coverage may be needed in order to reduce the vibration to an acceptable level.

The next example is for a 97-ft long, 1.5-in diameter cylinder with strakes in the high-speed zone. The coverage length was approximately 28%.

The rms displacement normalized by the maximum rms displacement (indicated by the vertical axis) among the group of runs (a total of eleven) for the 1.5-in pipe is displayed in Figure 9. The maximum rms displacement in this group occurred at accelerometer #2 in the last run. Accelerometer #2 was at a distance of 4.6 ft from the inner sheave (in the lower speed zone). Accelerometer #4 was at 4.8 ft from the outer sheave (in the higher speed zone where strakes were also located). The horizontal axis is the spatial location.

The results indicated that in lower speed zone where there were no strakes, the response was larger than that in the higher speed zone where there were strakes, on average by a factor of approximately 6.7. Clearly, to reduce VIV response, more strakes are needed at the lower speed zones for this type of current profile (as a matter of fact, tests were conducted for this purpose, and the data have shown significant reduction in responses at lower speed zones).

Surface Roughness

The presence of roughness on the straked surface can reduce its effectiveness. Drag loads on a rough surface are in general larger than those on a smooth surface, regardless of the surface type, bare cylinder, straked pipe, or faired cylinder, as evidenced by the following examples.

The first example is from the rotating arm tests. It was a 97 ft-long, 2.5-in diameter cylinder with strakes in the high-speed zone (the second configuration in Figure 2). The inner three joints (joints 1 through 3) were bare. The outer two joints (joints 4 and 5) had strakes with the following two designs:

(1) 3-start, 17.5D pitch, and 0.25D height (smooth surface)
(2) 3-start, 17.5D pitch, and 0.25D height (rough surface)

The coverage length for both cases was about 37%. The rough strakes were those strakes covered with carpet used to simulate a hard barnicle growth with a soft kelp type growth on top of the barnicles. Both the pipe surface and the helical strakes were covered with the carpet.

Figure 10 presents the rms displacement ratios of smooth strakes over that of rough strakes. The displacement responses were those at a distance of 5.5 ft from the inner end (in the bare joint zone). The efficiency of the rough strakes degraded, on average, by approximately 30% in the tested Reynolds number range.

The next example is also from the rotating arm tests, for the 2.5 in cylinder with the same length as that in the example above. Two test configurations were compared: (1) joints 1 through 3 with smooth strakes, and joints 4 and 5 with rough strakes, and (2) all 5 joints with smooth strakes. Both the smooth and the rough strakes had 3-starts, 0.25D height, and a 17.5D pitch.

Figure 11 presents the drag coefficient ratios of pipes with strakes to those without strakes, as indicated in the vertical axis title. The horizontal axis is the Reynolds number. Compared to the drag coefficients of a bare cylinder, those of a straked pipe increased by 60 to 80%. On average, the rough strakes had a drag coefficient about 10% to 20% larger than that of the smooth strakes.

Interference Effects

If a straked tubular is placed downstream of another tubular, the performance of the strakes will degrade. Therefore, how a straked riser performs downstream is also an important index to gauge its efficiency. The following two examples illustrate some important interference effects.

The first example is taken from the current tank tests (configuration 1 in Figure 4). Both of the pipes had a diameter of 4.5 in, a length of 12 ft, and were fully covered with 3-start, 0.25D height, and 17.5D pitch strakes. Figure 12 presents the rms acceleration ratio of the downstream pipe over that of the upstream pipe. The measurement was made at the center of the pipe (the anti-node of vibration; roughly the point of maximum response). For all spacings, responses of the downstream pipe were much larger than the upstream pipe responses. Note that this was first mode VIV, so there were reduced velocity effects combined with the Reynolds number effects in the x-axis of Figure 12. Even at a spacing of 20D, the interference effects still persisted.

The next example compares the following: (1) two pipes in tandem with conventional strakes (3-start, 0.25D height, and 17.5D pitch), and (2) two pipes in tandem with a “new” strake design. Figure 13 displays the rms acceleration ratio of these two strake configurations. The horizontal axis is the Reynolds number. The vertical axis is the ratio of rms acceleration of the new design over that of the conventional design. The responses were those of the downstream pipe at the pipe center. The new design is significantly more efficient than the conventional strakes, with acceleration (bending stress) ratios as low as 0.5.

Summary and Concluding Remarks

Experimental data have been used to demonstrate the effects of strake geometry, coverage length, surface roughness, and interference on strake performance. It is concluded that

- Strake height has a large impact on suppression efficiency, while strake pitch is not as influential.
- The coverage length has a large effect on suppression efficiency. For certain currents, suppression can have only a local effect, and thus more strakes may be needed to achieve the desired level of suppression along the entire tubular.
- The efficiency of strakes decreases, and the drag loads increase, when the surface is rough.
- The efficiency of strakes decreases, and the drag loads increase, when an upstream tubular is present.

Helical strake design must adequately model the effects of strake geometry, surface roughness, drag, and the presence of adjacent tubulars to be accurate or conservative. It is hoped that the insights expressed herein will indeed facilitate safer designs.

Acknowledgments

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SI Metric Conversion Factors

Ft X 0.3048 = m,
Inches X 0.0254 = m,
Ft/s X 0.3048 = m/s,
Lbf X 4.448 = N

Figure 1. Long Pipe in Circular Tow

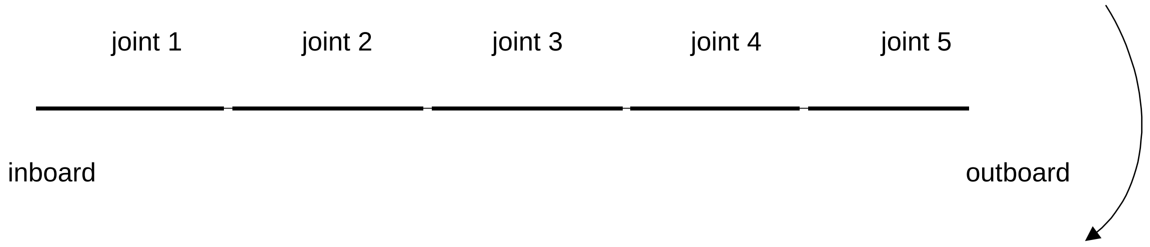

Figure 2. Selected Test Configurations I

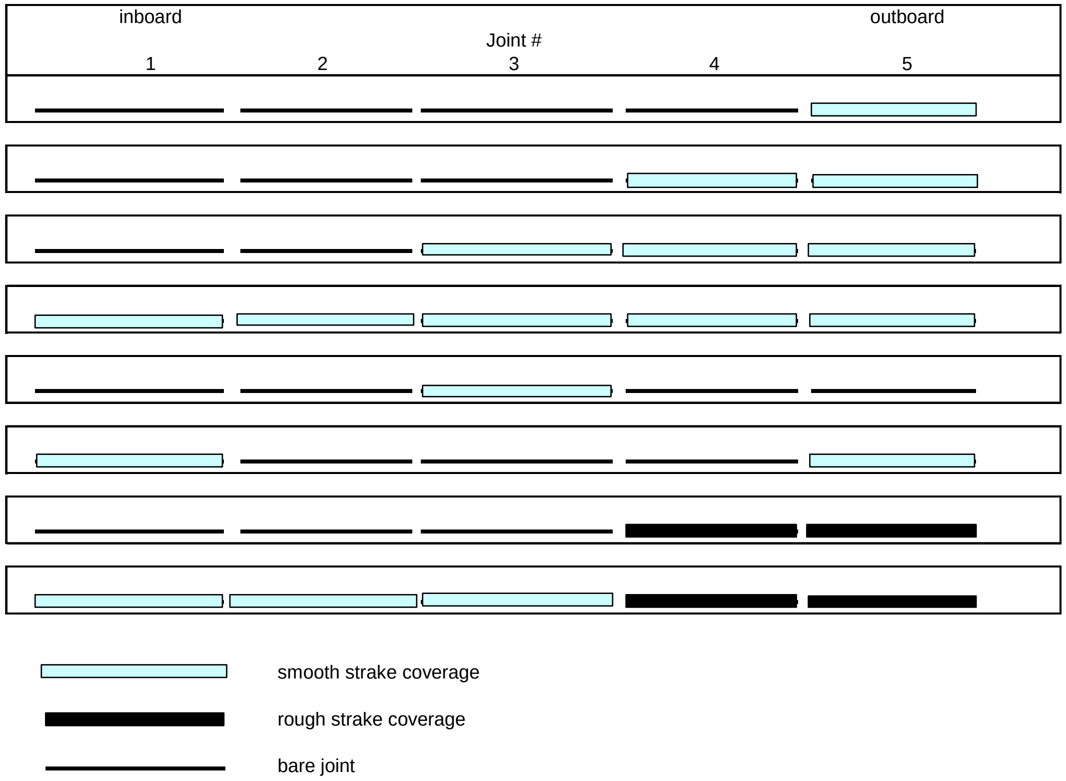

Figure 3. Current Tank Test

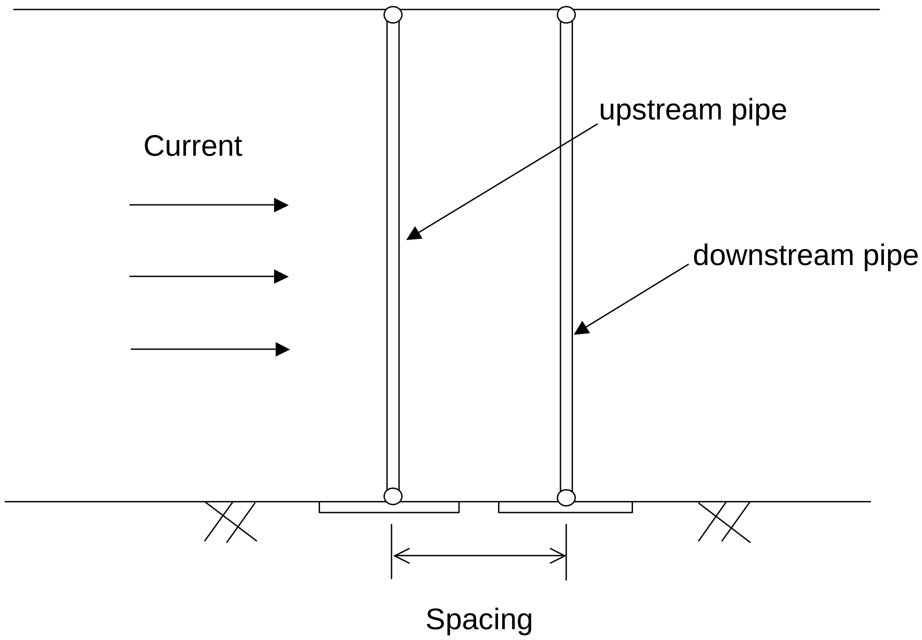

Figure 4. Selected Test Configurations II

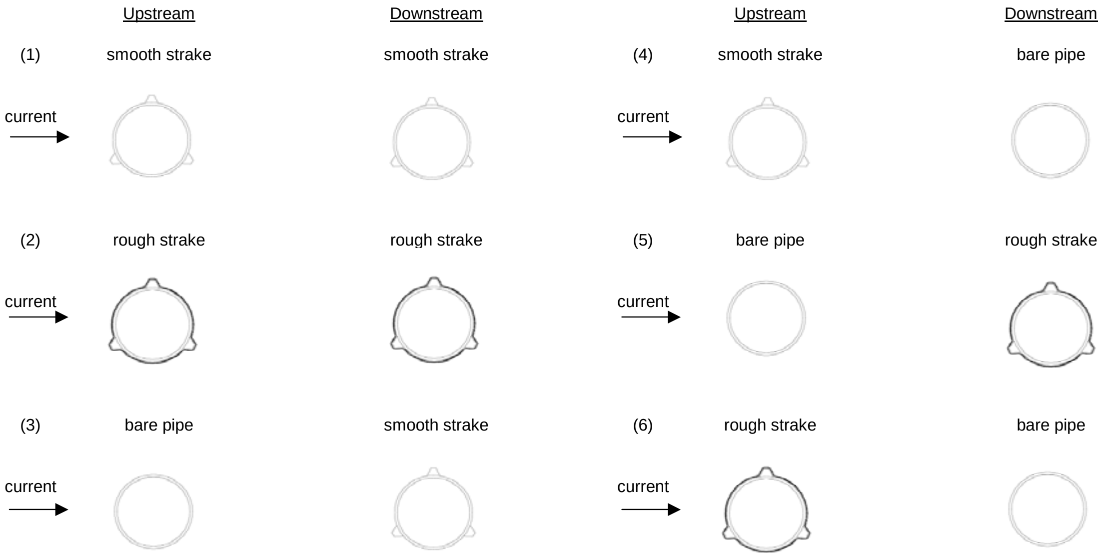

Figure 5. General Configuration Definition

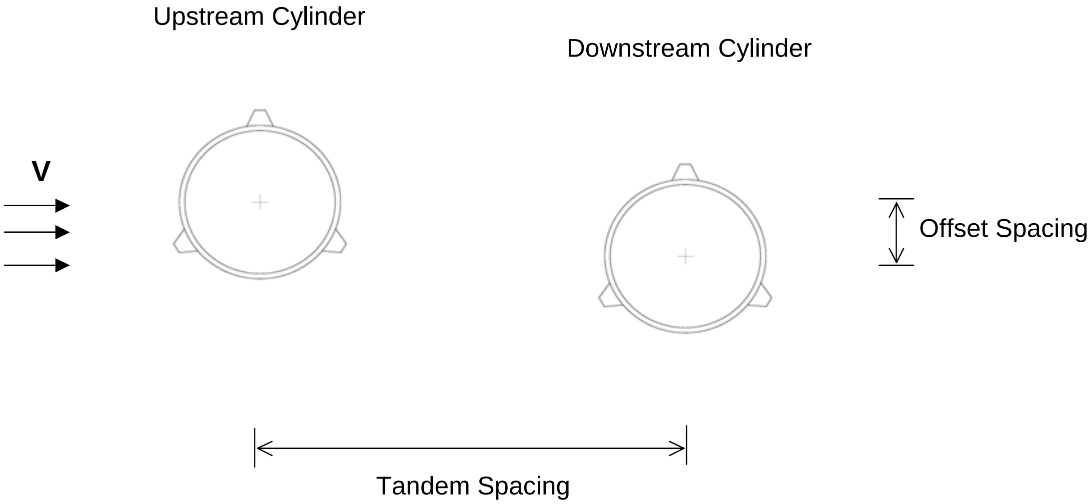

Figure 6. RMS Acceleration Ratio: Effects of Strake Height

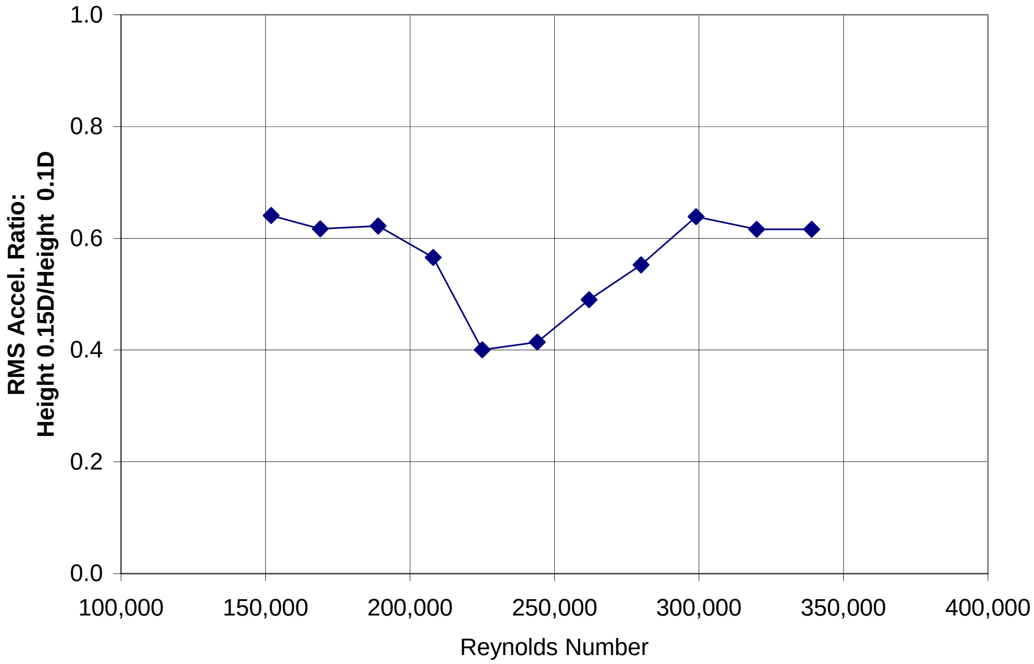

Figure 7. RMS Acceleration Ratio: Effects of Strake Pitch

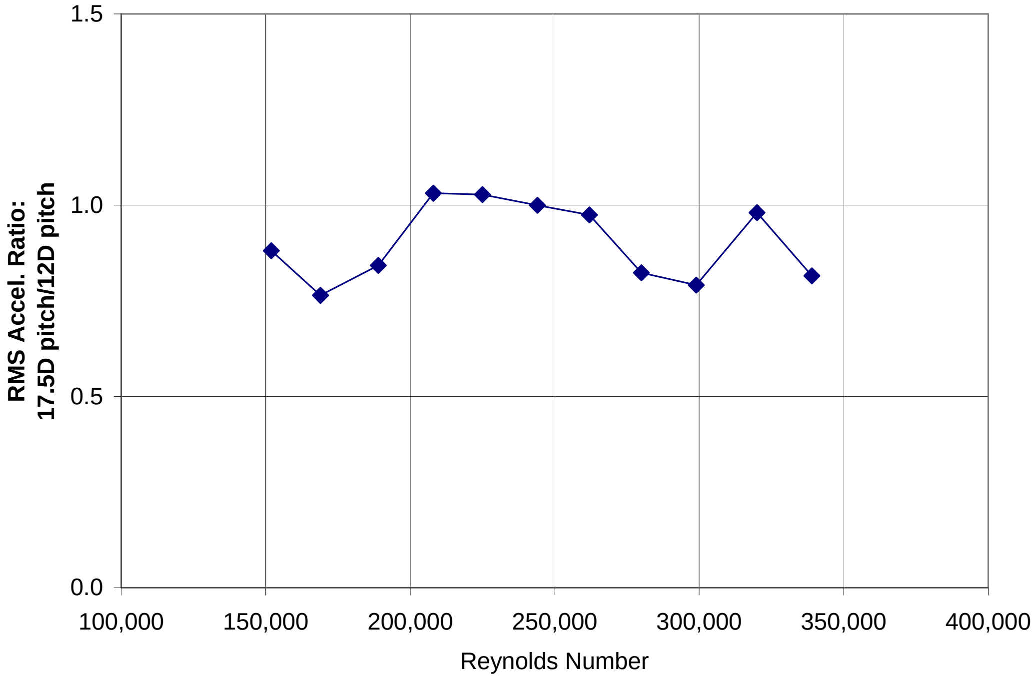

Figure 8. RMS Acceleration Ratio: Effects of Coverage Length

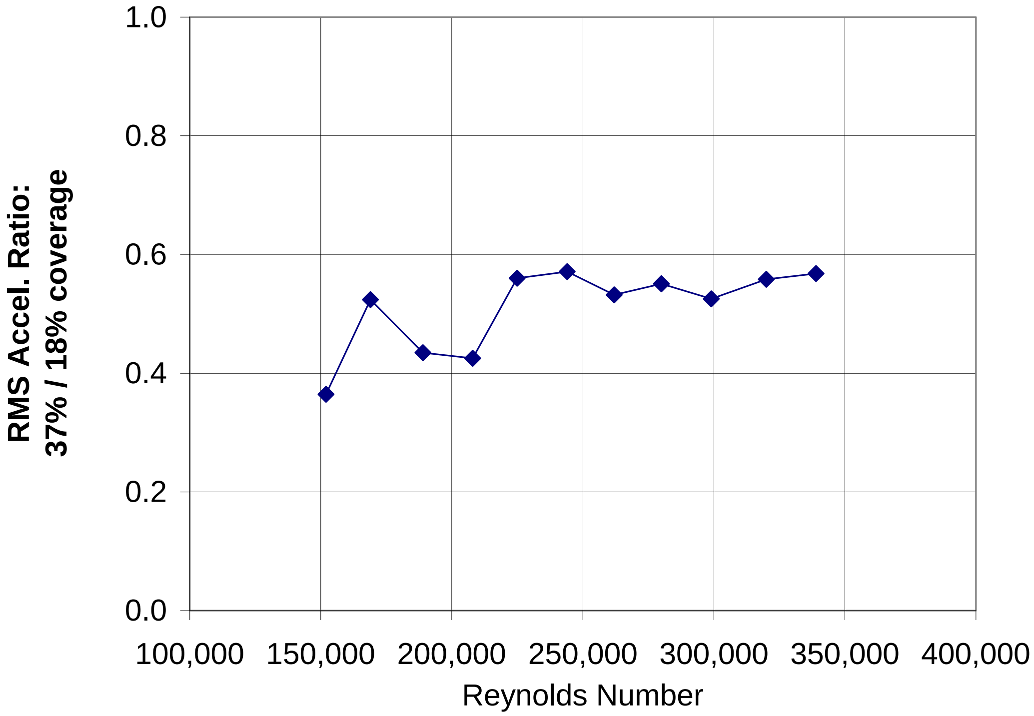

Figure 9. RMS Displacement vs. Spatial Location

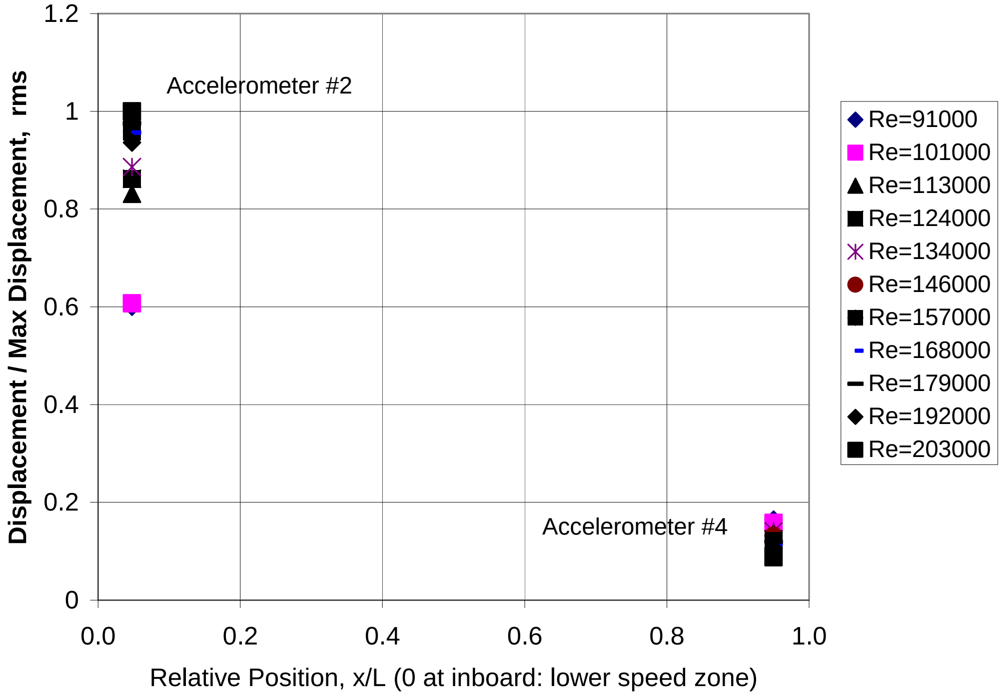

Figure 10. RMS Acceleration Ratio: Effects of Roughness

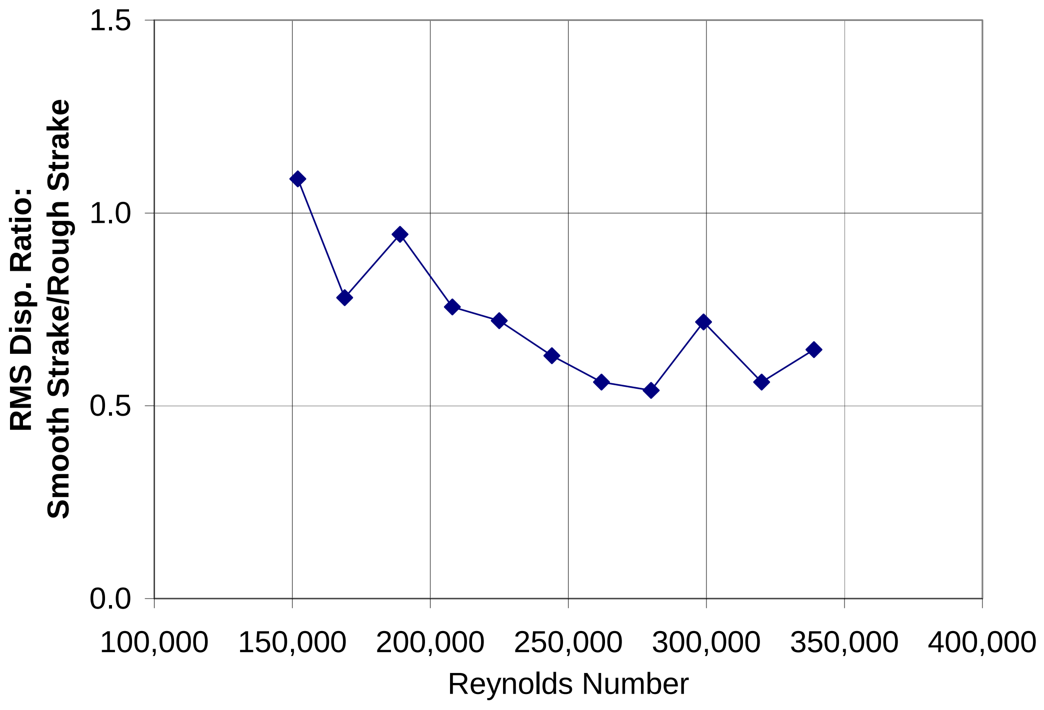

Figure 11. Drag Coefficient Ratio: Effect of Strakes and Roughness

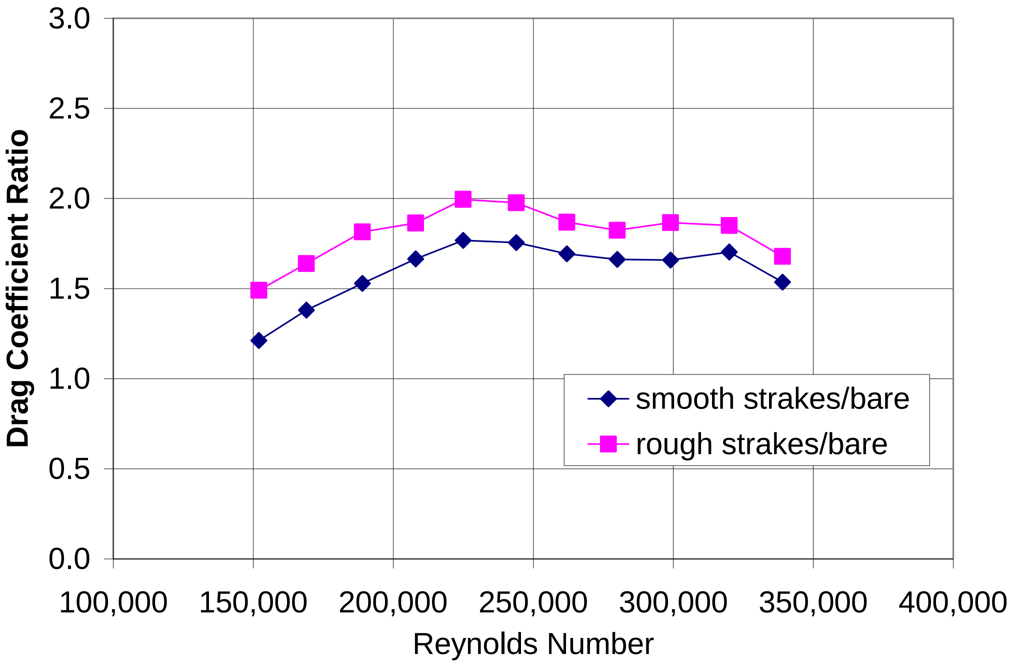

Figure 12. RMS Acceleration Ratio: Interference Effects (Smooth Strakes)

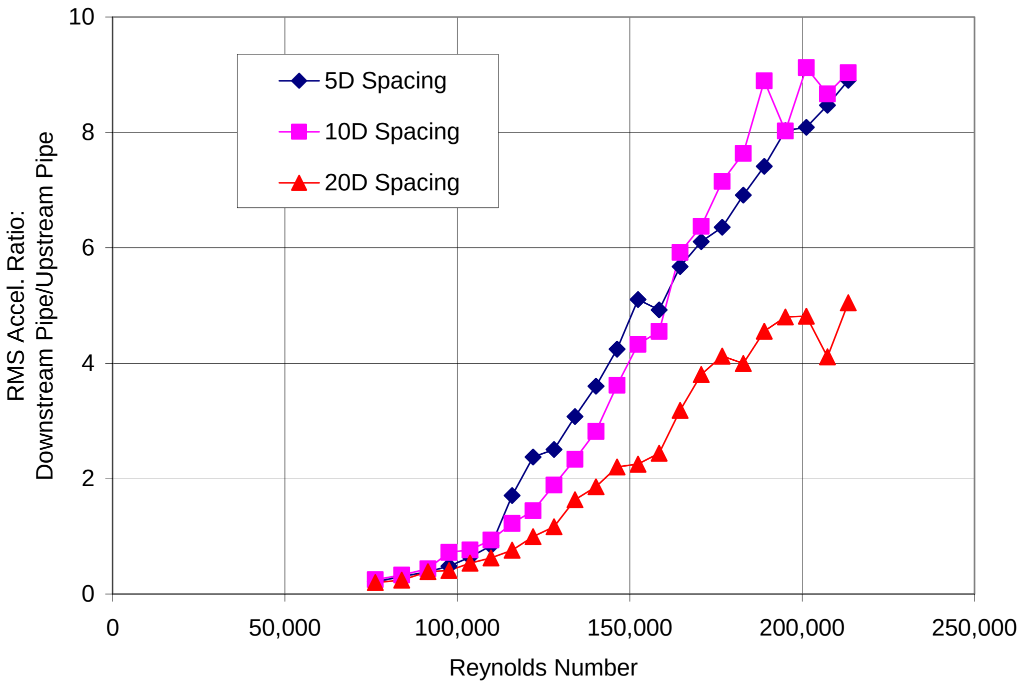

Figure 13. RMS Acceleration Ratio: New Design vs. Conventional Design