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Flow Structure Generated by Perpendicular Blade Vortex Interaction and Implications for Helicopter Noise Predictions

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Flow Structure Generated by Perpendicular Blade Vortex Interaction and Implications for Helicopter Noise Predictions

This semi-annual report summarizes accomplishments and progress on the above project since October 1993. The project work statement (attached) outlines both experimental and theoretical tasks. We have made substantial progress in both areas, as detailed below.

1. Construction of 8"-chord NACA 0012 full-span blade

Item 1 of the work statement proposes construction of an extension to our existing NACA 0012 blade. The composite blade would completely span the wind tunnel, enabling us to examine perpendicular blade vortex interactions in the absence of blade-tip effects. On examining the technical difficulties involved in the construction we decided it would be simpler to build a completely new full-span blade. Furthermore, such a blade could be made hollow, allowing for instumentation to be placed inside it.

Construction of this new blade is now almost complete. The blade consists of eight 2' span half sections (split down the chord line), machined individually to a tolerance of about 0.001" on a numerically controlled milling machine. By making the sections in halves we have been able to hollow out the inside of the blade. Initially we are using the hollow space to run tubing for pressure taps installed in the blade surface to help with alignment In the future we could add rows of surface microphones or other instrumentation.

Bolted together the half sections make a single 8"chord NACA 0012 blade of total span 8 feet. This is two feet wider than the wind tunnel allowing for some spanwise movement without changing the configuration in the flow. This may be desirable if instrumentation is installed in the blade surface.

Construction of the mount for this blade is also nearing completion.

2. Additional full span blades

We have been able to procure a gift of two large blade models from Sandia National Labs. They have donated two rectangular blades both of 2-foot chord and 8-foot span. One has a NACA 0016 section and the other a SAND 1850 section (a natural laminar-flow section). We are currently preparing these blades and building mounts for them. In combination with our existing 8" chord blades they offer us the opportunity of studying the effects of core-radius to blade chord ratio and of blade section shape on perpendicular BVI.

These blades can be mounted either as half-span vortex generators (allowing us to produce very large vortex cores) or full-span interaction blades.

3. Preparation for hot-wire measurements

Velocity measurements to reveal the effects of blade vortex separation on the effects of perpendicular BVI (item 4a, work statement) are proposed for this year. These will be completed during a tunnel entry scheduled for August 1, 1994. We shall be using miniature four-sesnor hot-wire probes directly calibrated for flow angle to make measurements of all mean velocities, Reynolds stresses and spectra. Preparations for that test are well underway. We have developed a repair facility for the four-sensor hot-wire probes, we have updated our data analysis procedures used with them and we have improved the traverse gear they are mounted to, eliminating a vibration problem that used to appear at higher speeds. This will allow us to at least double the Reynolds number at which we make our measurements (we expect to be making measurements at Re_c of 530000 or greater).

4. Related work on a modified Betz's theory

One of the most important conclusions from previous work was that blade vortex interaction substantially changes the circulation distribution associated with the vortex. Specifically, vorticity shed from the blade becomes rolled into the vortex so that the circulation distribution in the vortex no longer agrees with that one would predict from Betz's theory. We have begun development of a theoretical approach for predicting the ultimate circulation distribution of the vortex taking into account the effects of the blade. In brief, lifting line theory is used to determine the circulation distribution shed from the blade in the non-uniform approach flow produced by the vortex. Betz's theory is then used to combine this circulation distribution with that of the original vortex. An early result of this work is that the ultimate circulation distribution of the vortex should be independent of the angle of attack of the blade. Measurements planned for next year should confirm whether or not this is so.

5. Publications

We have produced the following publications on results from the last set of experiments;

Kenneth S. Wittmer, William J. Devenport and Stewart A. L. Glegg, 1994, "Perpendicular Blade Vortex Interaction", AIAA 32nd Aerospace Sciences Meeting, January 10-13, Reno, NV. Submitted to *AIAA Journal.*

Michael C. Rife and William J. Devenport, 1994," Flow Visualizations of Perpendicular Blade Vortex Interaction", to be submitted to *Journal of Aircraft*, 6/1994.

6. Work Related to Helicopter Noise Prediction

The objective of this part of the study has been to incorporate the output from helicopter wake codes into the BWI noise prediction scheme developed over the past few years at FAU. The approach is to make use of CAMRAD calculations of the blade wakes as an input to the code. These calculations are being carried out at NASA Langley and, in the near future, the data files containing the results will be transferred to FAU. Sample files have been sent to FAU and these have been checked for compatibility with the systems which are available.

APPENDIX 1: WORK STATEMENT

1. Design and construction of the blade extension. The extension will have a span of at least 2 feet, a NACA0012 section, and will be instrumented with pressure taps so that the blade can be easily placed at zero angle of attack. It will be cut from a solid aluminum block using a numerically controlled milling machine. We have substantial experience building wing models in this fashion.

2. Re-design of mount to enable blade to be supported from both sides of the test section.

3. Helium bubble flow visualizations to find z location of blade where vortex impinges on its leading edge (i.e. the location where $z_s = 0$).

4. Velocity measurements to examine the effects of perpendicular blade interaction on the structure of the trailing vortex. Our four-sensor hot wire probe system, already developed and tested, will be used. Measurements will be made at the conditions listed below, defined by the blade vortex separation z_v, streamwise distance downstream of the second blade X, vortex generator angle of attack α_1, and blade angle of attack α_2. At all conditions three-component profiles of mean-velocity, turbulence stresses and spectra will be measured through the vortex. At selected conditions velocity measurements will also be made in grids to reveal the entire wake structure. All velocity measurements will be performed at the highest practicable Reynolds number. Both vortex generator and blade boundary layers will be tripped.

(a) To determine the effects of z_s at fixed X and α_t .

The flow resulting from the blade vortex interaction will be studied for a range of blade-vortex separations z_s. All measurements will be made 15 chordlengths downstream of the blade and α_1, and α_2 will be fixed at 5° to reflect typical helicopter rotor conditions. Sufficient z_s separations will be considered to clearly define the functional variation of parameters such as core diameter and strength with z_s. z_s will be varied from zero (vortex impinging on leading edge) to positive and negative values where the blade-vortex interaction is insignificant.

(b) To determine the effects of X with at fixed z_s and α_t.

The streamwise development of the vortex after its interaction with the blade will be documented for at least three representative z_s values. Again α_1, and α_2 will be fixed at 5°. Measurements will be made to sufficient X locations to clearly define the functional variation of the vortex parameters.

(c) To determine the effects of α_t and α_2 at fixed z_s and X.

The flow resulting from the blade vortex interaction will be studied as a function of vortex strength and blade angle of attack for at least three z_s values. All measurements will be made 15 chordlengths downstream of the blade. The angles of attack α_t and α_2 will be varied together in sufficiently small steps to fully resolve the dependence of the flow structure upon these parameters. If time permits further measurements will also be made with combinations of different angles of attack.

All the above measurements will be fully analyzed and discussed. Their implications for helicopter noise prediction will be carefully assessed.