JOURNAL OF AIRCRAFT
Vol. 45, No. 5, September–October 2008

Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes should not exceed 2500 words (where a figure or table counts as 200 words). Following informal review by the Editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Aerodynamics of a Generic Optical Turret

Robin Sluder,* Laurie Gris,* and Joseph Katz†
San Diego State University, San Diego, California 92182

DOI: 10.2514/1.36804

Introduction

THE operational requirements for many airborne sensors favor their mounting outside the airframe, mainly to ensure a larger field of view. Most of these sensors are sensitive to the external environment and aerodynamic shielding is frequently used. Optical sensors, in particular, are positioned in unobscured regions to ensure the largest possible field of view. For example, if located at the nose, only forward viewing is possible, but a vertical mounting of an optical turret, either above or under an airplane's fuselage allows a 360 deg horizontal viewing range. A possible problem associated with this approach, however, is that unsteady flow separation behind the turret may increase optical scattering for incoming or exiting beams. This may even be more severe for outgoing beams where long-range accuracy is important. Therefore, the aerodynamic study of such configurations must provide information, in addition to the aerodynamic loads, on regions of flow separation and on the unsteady flow and air density variations around the turret.

Recent studies of similar configurations by Snyder and Franke [1] focused on measuring the incremental drag coefficient due to such a turret. The geometry tested in [1] consisted of a sphere mounted on a smaller diameter cylinder, and the study was aimed at drag reduction. Snyder and Franke also tried splitter plates and fairings, which were found to be effective in reducing the drag. Schwabacher et al. [2] continued this study and used computational fluid dynamics (CFD) to model the turret model used in [1]. He used a fully turbulent CFD model, with time-accurate solution, but the drag numbers and fine details of the flow were not sufficiently accurate.

The objective of the present study is to document the aerodynamic loads, including lift, which were not reported before. At the same time, we aim to identify which areas of the turret are dominated by unsteady separated flows and measure surface pressure distribution for future CFD validations.

Aerodynamic Load and Surface Pressure Measurements

The generic optical turret model studied here had a cylindrical base of diameter $D = 10$ in. (0.254 m) and a hemispherical top, as shown in the insert of Fig. 1. The model was tested in a low-speed wind tunnel having a 3-ft-high and 4-ft-wide test section (0.91×1.22 m). Based on the turret diameter D, the Reynolds number for this test varied within the range of 0.5 to 1.0×10^6, which is representative of the expected operation range. Surface pressures were measured by a 48 port internal transducer. Accuracy of the six-component balance was about ± 0.004 for C_L and ± 0.002 for C_D, and freestream turbulence levels were below 2%. The turret model could move up and down relative to the ground plane, and h measured the height of the junction between the hemisphere and the cylinder, relative to the ground plane. Thus, $h = 0$ represents a condition when only the hemisphere is visible. The results for drag and lift are presented in Fig. 1 and the coefficients are based on the (top view) circle's area, $\pi D^2/4$. The loads for both drag and lift increase as the turret extends above the ground. The drag coefficient of about 0.6 (at $h = 0.5$) compares well with the results obtained for a similar configuration in [1,2]. The height of most optical turrets is near the h/D range of 0.5 because of the need to shield a circular antenna. However, it is clear that, for much larger values of h/D, the drag will increase following a similar slope, whereas the lift will plateau slightly above the maximum value shown in Fig. 1. These data were replotted in [3], using the frontal area (instead of $\pi D^2/4$) to calculate the lift and drag coefficients. As expected, the drag coefficient variations were small (slightly below $C_D = 0.5$), and the lift coefficient was dropping rapidly with increasing h/D.

During the wind-tunnel tests, flow visualization was conducted using surface oil and tufts. These limited tests identified the complex nature of the separated flow behind the turret. In general, a large unsteady vortex structure per side was visible, whereas, near the base, a typical horseshoe-shaped vortex formed. The size of the separation, in general, is about 15 deg behind the half circle (and optical quality is reduced in this area). Surface pressure measurements were also conducted, mainly to verify these observations and also to provide information for future numerical modeling.

The surface pressure data are reported in [3] and the major findings are summarized in the following two figures. The centerline pressure coefficients for three turret heights are plotted in Fig. 2. The first case ($h/D = 0$) is basically a hemisphere, whereas the other two are the semi-exposed ($h/D = 0.5$) and the fully exposed turrets ($h/D = 1.0$). The distance along the centerline is shown on the abscissa, in terms of the diameter D. Therefore, zero represents the base of the cylinder (at $h/D = 1.0$), D represents the forward junction between the cylinder and the hemisphere, and the top of the turret is at $(1 + \pi/4)D$. The measured pressures represent a time average of about 1000 samples taken within 1 s. Because of the separated flow behind the turret, the pressure there is highly unsteady and momentarily not symmetric. The time-averaging process, however, will smooth out the left/right asymmetry.

The measured data in Fig. 2 indicate that, as the height of the turret is increased, the velocity at the top increases (lower Cp), which is consistent with the trend of lift shown in Fig. 1. Also, at the front, slightly above the ground horseshoe vortex (for $h/D = 0.5$ and $h/D = 1.0$), a true stagnation line exists (with $Cp = 1.0$). This ground plane vortex forces a velocity higher than zero near the cylinder base, so that, for all three cases, the pressure there does not recover to the $Cp = 1.0$ level. Behind the turret, over the top, the flow separates and the pressures are slightly below static (this, of course, is the source for the pressure drag). The shape of the pressure

Presented as Paper 0429 at the 46th AIAA Aerospace Sciences Meeting, Reno, NV, 7–10 January 2008; received 23 January 2008; revision received 29 April 2008; accepted for publication 30 April 2008.

*Graduate Student, Department of Aerospace Engineering and Engineering Mechanics. Member AIAA.

†Professor and Department Chairperson, Department of Aerospace Engineering and Engineering Mechanics. Associate Fellow AIAA.

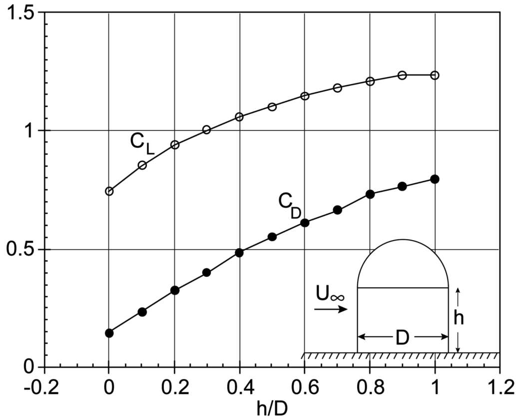

Fig. 1 Aerodynamic lift and drag vs turret height ($Re_D = 0.95 \times 10^6$).

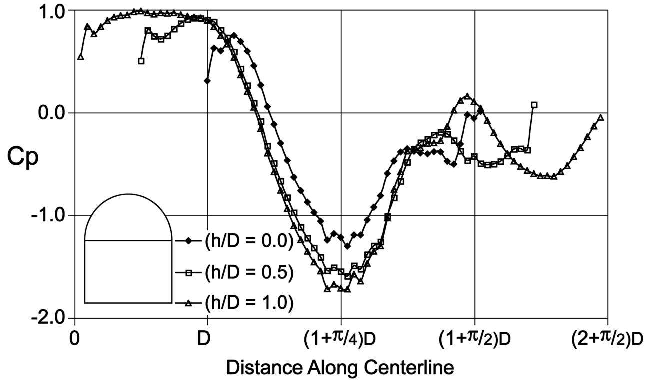

Fig. 2 Comparison of the measured *Cp* along the centerline of the optical turret at three h/D levels ($Re_D = 0.55 \times 10^6$).

variation inside this separation zone is more complex, due to the aforementioned unsteady vortex structure.

Additional insight into the pressure distribution around the optical turret is presented by plotting the data for various horizontal cuts (e.g., radial plots). Such peripheral pressure distributions on the turret surface are presented in Fig. 3 for the case of $h/D = 1.0$. The three curves in this figure show the pressures at three heights: $z/D = 0$ is at the base, $z/D = 0.5$ is at the center of the cylinder, and $z/D = 1.0$ is at the junction between the cylinder top and the hemisphere. Note that the front of the cylinder is at the 180 deg position, whereas the back is at 0 deg. As expected, the pressure is higher at the front and lower at the aft section due to flow separation. Of course, the lowest pressure is at the highest velocity region, on both sides. These observations apply to all three cases, however, the pressure does not rise to $Cp = 1.0$ at the base ($z/D = 0$) because of the aforementioned ground plane vortex. The effect of the floor boundary layer and this vortex is to slow down the flow on the sides

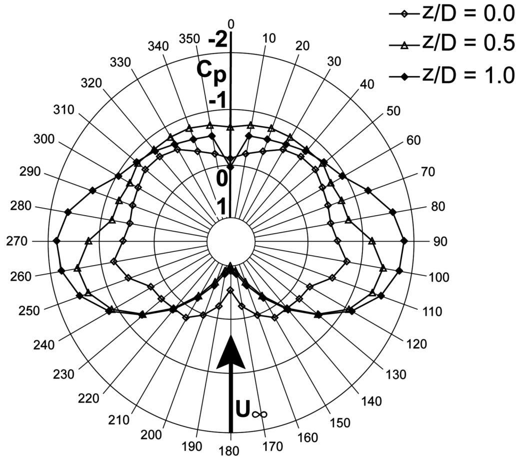

Fig. 3 Radial pressure coefficient variations around the cylindrical part of the turret ($h/D = 1.0$, $Re_D = 0.55 \times 10^6$).

as well (compared with the plots at $z/d = 0.5$ and 1.0). The highest velocity is near the junction between the hemisphere and the cylinder and the flow seems to be attached there beyond the maximum width point of the cylinder. This is not the case for $z/D = 0.5$ and the flow seems to separate earlier. Surface flow visualizations showed a large vortex cell with smaller vortical structures there, suggesting further investigations are required (to understand the flow).

Conclusions

The flowfield ahead of the optical turret geometry tested here is mainly steady, and optical distortions due to air density changes are predictable. Behind the turret, however, the flow is unsteady and dominated by separated vortex flow. The measured lift force was found to be larger than the drag, and this must be taken into account when placing the turret on an existing airplane. The complex flowfield behind the turret warrants further investigation and CFD validations.

Acknowledgment

This work was partially supported by Advanced Capabilities Development, Integrated Systems, Western Region, Northrop Grumman Corporation.

References

[1] Snyder, C. H., and Franke, M. E., "Wind Tunnel Tests of an Aircraft Turret Model," *37th Aerospace Sciences Meeting*, AIAA Paper 99-0939, Jan. 1999.

[2] Schwabacher, G., Bons, J., and Franke, M, E.,"CFD Simulation of an Aircraft Turret Model with Fairings," *39th Aerospace Sciences Meeting*, AIAA Paper 2001-0889, Jan. 2001.

[3] Sluther, R., Gris, L., and Katz, J., "Optical Turret Aerodynamics: A Preliminary Study," AIAA Paper 2008-0429, Jan. 2008.