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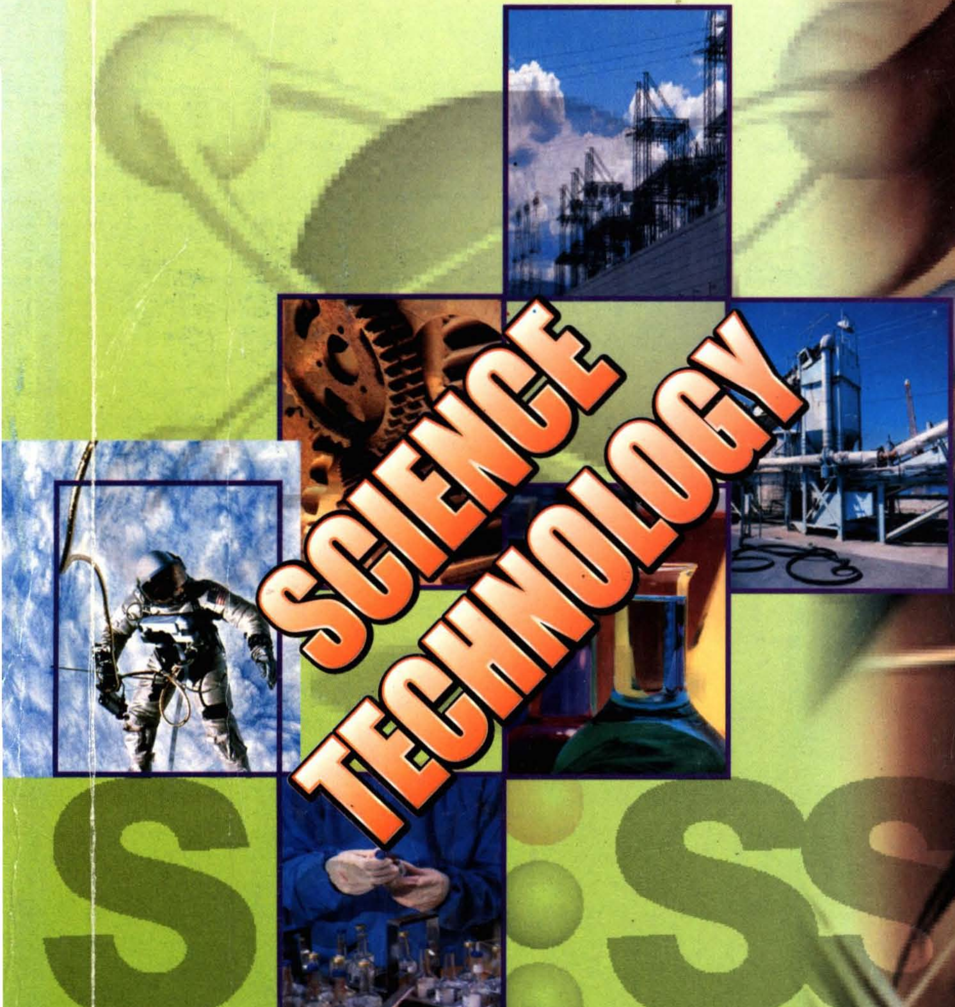

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Aerodynamic Studies on Hovering Probe

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ABSTRACT

The present investigations aim at simulation and analysis of a hovering probe's performance. A modern design method is presented and the simulation of hovering probe is done by Computational Fluid Dynamics. The hovering probe under study consists of four rotors. The central is provided for generating the necessary lift. Two side rotors provide the necessary maneuverability. The fourth rotor is designed to provide the necessary thrust. The entire probe along with the rotors is modeled using Solidworks2004. The probe is designed for a speed of 10 m/s 10 meters height. The pressure and velocity distribution over the hovering probe is studied at various planes and analysed.

Keywords: *Computational fluid dynamics, aerodynamics, Hover probe, laminar and turbulent flow*

Introduction

Since the dawn of human intelligence, the idea of flying in the same realm as birds has possessed human mind. In the middle of the last century, aerospace technology has become a unique, indispensable part of our world. Commercial aviation has made it possible for more people and cargo to travel faster than at any previous time in history. The development of aeronautics in general and aeronautical engineering in particular was exponential after the Wrights' major public demonstrations in 1908 and has continued to be so to present day (Davies 2002).

Nowadays, we are reaching the capacity limit of the airspace system, while transportation demand of both passengers and freight is expected to increase in the long term. In space, our assets have improved weather prediction, provided global communication and navigation facilities to link people and businesses more effectively, and enabled spectral imaging of earth to enhance our environmental stewardship and land used. Note that, flying vehicle play an important rules in 20th millennium century and next future. Across the entire flying vehicles, such as aircraft and helicopter, intelligent systems composed of sensors, actuators, microprocessors, and adaptive controls will provide a full system, distributed knowledge network - a central nervous system to affect an adaptive physical response. This type of flying vehicles will be able to monitor their own performance, their environment and even their operators.

More recently, automobile designers are turning to aerodynamic streamlining and wind tunnel testing to reduce drag, hence increase fuel economy. Thus, the parallel development of the airplane and automobile over the past 100 years has been mutually beneficial. Therefore, the philosophy of *faster and higher* that has driven aeronautics throughout most of the 20th century is now being mitigated by practical constrains (Anderson 2000). So to this we must add safer, cheaper more reliable and more environmentally clean technologies. Other technologies to improve and situation awareness may use advance sensors, digital terrain databases, accurate geopositioning, and digital processing to improve three dimensional moving displays showing aircraft, landing and approach patterns, runaway surfaces, fixed and moving objects on the ground.

The goal of computational fluid dynamics (CFD) is to approximate the physical flows that we encounter in nature, as accurately as possible using numerical techniques. However, the cost of accuracy of any CFD procedure has to be matched by enough computer power and storage. Practical problems usually are the most complex. The flow-field around a complete aircraft, the internal flow structure of a turbojet engine with several stages and hundreds of blades and passages, the detailed effects of a wake and vortex flow generated by a helicopter rotor system on rotorcraft aerodynamics, aeroacoustic and aeroelasticity problems are some important examples that aeronautical engineers have to solve today and in the future. These large-scale problems require huge amounts of computer power and storage. Despite the steady growth in computer speed and power, the complexity of modern problems still requires the application of the most effective solution procedures. Accurate prediction of rotorcraft aerodynamics using existing CFD tools is still a challenge. This is because a rotorcraft often operates in more severe flow conditions than a fixed-wing aircraft.

The real world of fluid dynamics machines such as compressors, turbine, flow ducts, airplane etc, is mainly a three dimension world. Though three dimensional flow field solution are abundant they may not be routine in the sense that great deal of human and computer resources are still frequently needed to successfully carry out such three dimensional solutions for application like the flow over a complete airplane configuration (Cohen & Miloh 2001). In short, CFD is playing a strong role as a design tool. Along with its role CFD has become a powerful influence on the way fluid dynamics and aerodynamics do business (Anderson 1995).

Initially, several turbulence models have been used in three-dimensional (3-D) CFD analysis to find a suitable model for this kind of slow speed unconventional hovering device. Today CFD is principle aerodynamics technology along with wind tunnel testing with flight testing being used for final validation (Bertin 2002). Experiments have been conducted to validate the CFD results and also to analyze the aerodynamics at various stations of the hovering device such as hovercraft, hovercraft and hovering vehicle (Savino et al. 2005).

However, the structure, mechanisms and the control system of the aircraft and helicopter is too complicated. Hence, the idea of modeling and prototyping hovering probe is a main interest and objective of this project. This may due to the fact that hovering probe is a smaller flying vehicle that has more flexibility, simple mechanisms and control system compared to the aircraft and helicopter. The main application of this development is to provide surveillance services in building, bridges. In addition, it can also do search and rescuer functions for the probe carrying surveillance CCTV camera and other mechanisms for diagnosis and responses.

CFD Modelling

Simulation is an iteration process and sequential work accomplished work for the simulation of the hovering probe is as follow:

CAD Modeling

The 3-D model shape profile of the probe is developed by using CAD design software SolidWorks 2004. This design model is built by using extrude, cut-extrude, reference geometry, circular pattern, linear pattern, chamfer, mirror, fillet tool in SolidWorks design software. The completed design model of hovering probe is shown in figure 1. After CAD model is finished, the next step is to use the COSMOSFloWorks 2004 CFD analysis software to simulate and analyse the flow behaviour, pressure profiles and velocity profiles at various planes of the hovering probe.

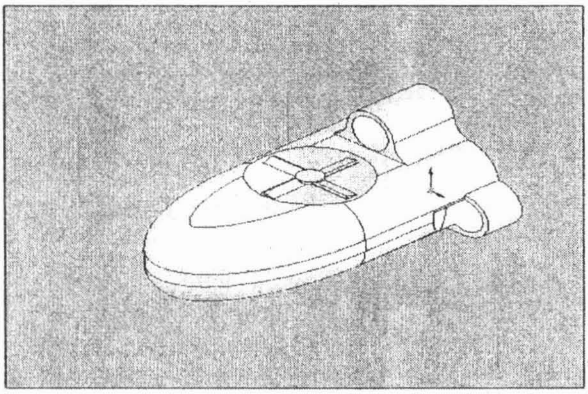

Fig. 1: Design Model for CFD Analysis

CFD Analysis

COSMOSFloWorks 2004 CFD analysis software is applied. COSMOSFloWorks can analyze either incompressible liquids or compressible gases, but not both in the same run. The turbulent equations can be removed if the flow is entirely laminar. Finally, COSMOSFloWorks can handle low and high Mach number compressible flows for gases. As the speed of the probe is low and hovers in the air, the flow is treated as incompressible. The flow is considered as viscous. The default wall condition is set to adiabatic wall as there is no heat flow between the fluid and solid.

The design model is refined so that it takes the shape and intricate features of the actual model. The boundary condition of the computational domain is reset for x, y, and z direction for suitable distance and the refining cell number of the local initial mesh is set to adequate level to obtain the smooth flow trajectory profile of velocity and pressure of the hovering probe. Grid independence study was conducted.

Results and Discussion

The analysis of design model by CFD with regards to the shape profile consists of two main trajectory behaviours, namely, velocity and pressure profile trajectories on the front, top and side surfaces of the hovering probe. The shape profile was subjected to the flow conditions similar to that exist at take-off and forward flight where the air flow is assumed to be coming from the top flowing downward and coming from the front flowing towards the back of the probe respectively.

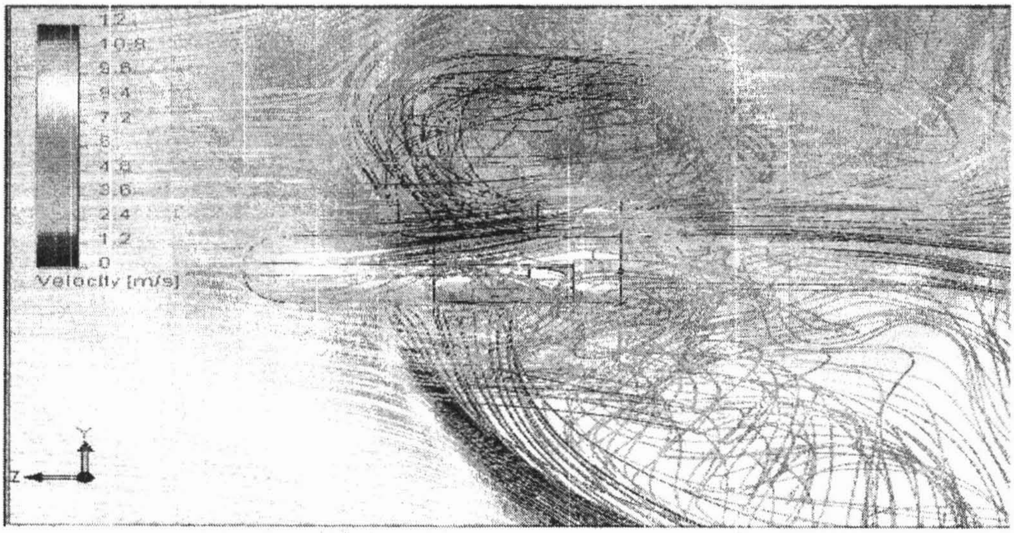

Fig. 2: Velocity Profile with Flow Trajectory (from z-direction)

In figures 2 and 3 the region with the red colour indicates a high velocity and the blue colour of the trajectory indicates the low velocity of air flow. For figure 2, the air flow is high at the top and bottom of the main and tail propellers. From the stagnation zone, the flow accelerates as it follows the curvature of the front end.

In figures 4 and 5 the region with the blue colour of the trajectory indicates the low pressure. The pressure at the front end of the craft indicates a low pressure zone created due to the acceleration of the fluid over the curvature. The pressure in the other parts of the craft remains slightly below the atmospheric value due the dynamic pressure of the air over the hovercraft body. The pressure gets modified locally due the presence of various rotors. It must be borne in mind that the craft essentially travels atmospheric air. The necessary lift and propulsion forces are imparted by the appropriate rotors. Hence, the pressure values do not change appreciably over the craft body. The pressure of the air away from the surfaces of profile is basically atmospheric.

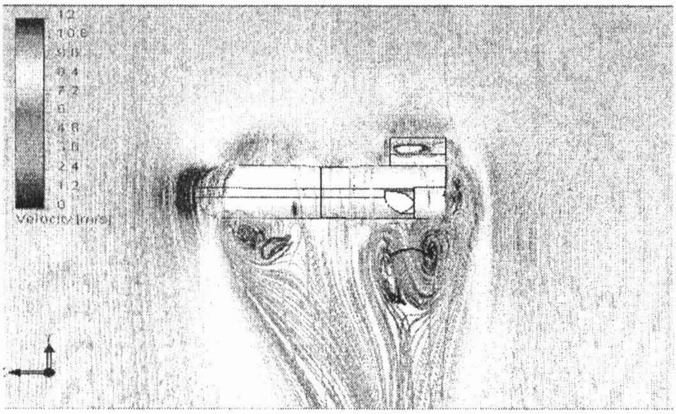

Fig.3: Velocity Profile with Flow Trajectory (from y-direction)

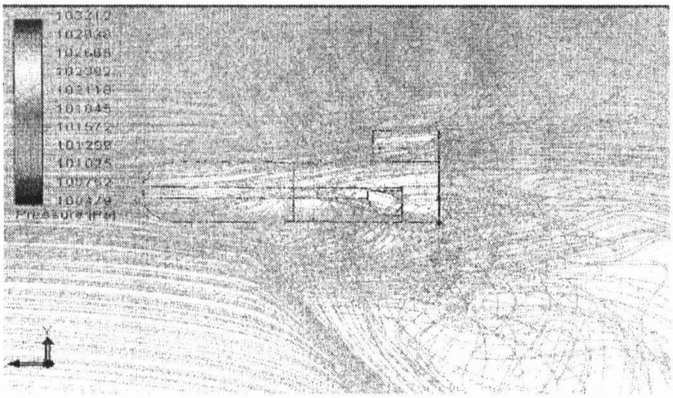

Fig. 4: Pressure Profile with Flow Trajectory (from z-direction)

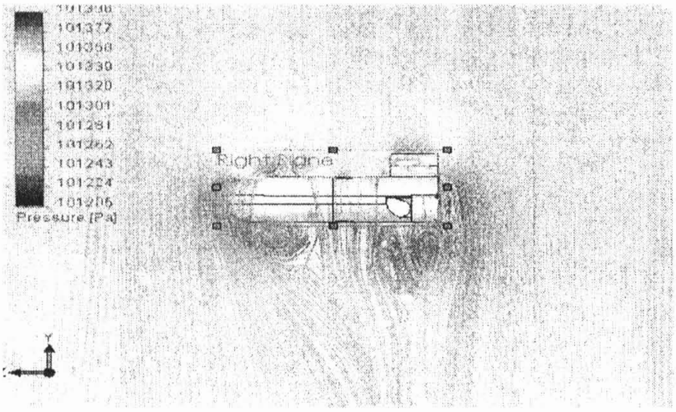

Fig. 5: Pressure Profile with Flow Trajectory (from y-direction)

The main consideration in this project is the point of transition whereby air flow at the boundary layer transits from the laminar to the turbulence flow. However, it is found that the transition of the laminar flow to turbulent flow would not create much problem in the design model profile of the hovering probe. This is due to the thrust rotor mounted at the center of the hovering probe. The thrust rotor would suck the air from the top and would eventually delay or totally eliminate the flow transition to turbulent. Therefore, the air flow streams would be maintained at the laminar flow throughout the upper surface profile.

The ducted propeller was incorporated in the design in order to maintain the stability of the probe. If the main propeller area were not ducted, the air flowing between the blades would flow into the internal structure of the probe, which may create turbulent at those particular areas Thus, stability of the probe would be affected and also the internal structure may sustain a heavier load than it should due to the turbulent flow. Hence, a ducted system would also help in supplying a more consistent and proper air flow stream for the propeller. Rotors of the hovering device are importance in order to lift the device to the certain height, maintain the device at the certain position, to move the craft and for controlling purposes.

Conclusion

From the understanding of the hovering theory aerodynamics and computational fluid dynamics, the shape profile suitable for the hovering probe design was evolved. Through the CFD analysis the variation of velocity and pressure have been determined and analysed.

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