STUDY OF THE SHIP AIRWAKE- HELODECK FLOW FIELD FOR SAFE HELO OPERATIONS.

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by

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DEPARTMENT OF APPLIED MECHANICS

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in fulfillment of the requirements of the degree of **DOCTOR OF PHILOSOPHY**

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Dedicated to

My sons Sasmit and Sanchit

C E R T I F I C A T E

This is to certify that the thesis titled "**Study of the Ship Airwake - Helodeck Flow Field for Safe Helo Operations**", being submitted by **B Praveen** is report of bonafide research work carried out by him under our supervision. This thesis has been prepared in conformity with the rules and regulations of Indian Institute of Technology, New Delhi, India. We further certify that the thesis has attained a standard required for a Ph. D. degree of the Institute. The research reported and results presented in the thesis have not been submitted, in part or full to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Amongst the roles undertaken by rotor craft pilots across a wide spectrum of industry operations, undertaking helicopter flight operations over helodeck of warships (other than ships designed exclusively for flight operations) is considered to be one of the high risk tasks. The surging platform with a helodeck aft of the superstructure presents a challenging environment to the pilots for helo operations owing to a string of reasons. The sea-keeping motions encountered by a warship in high seas provide the pilots with a non-stationary oscillating platform and the visual cues reduce drastically due to sea spray. The air flow conditions on the helodeck are characterised by the presence of a complex air-wake, created due to the presence of a bluff body in the form of a superstructure in front and its interaction with the helo downwash. Notwithstanding the challenges mentioned above, the range of responsibilities conferred on helo operations on warships render them unavoidable even in high seas. A good design of helodeck on such warships is hence a necessity to realise the full envisaged potential of helo operations.

The study is thus aimed at utilising the available experimental and numerical resources to understand the airwake component on helodeck contributing to the Pilot workload, and explore solutions for an improved design of helodeck-hangar configuration on modern ships for safe helo operations. The motivation of the study originates from the near total absence of design considerations for helo operations from contemporary naval platforms, which, over time, have evolved to cater for stealth requirements as the main design driver and, as a consequence, have resulted in increased Pilot workload for helo operations.

Investigations have been undertaken on Internationally accepted Simplified Frigate Ship (SFS), which represents the typical form of a frontline Frigate/ Destroyer and is currently being used for research purposes by many advanced countries. The airwake on the helodeck for the ship model is experimentally mapped through a grid of over 1500 points in wind tunnel, over seven planes, by using a five-hole pitot probe. The results in terms of contour, vector and wire mesh plots have been analysed in line with the findings of the literature survey. Also, extensive flow visualisation studies have been undertaken on varying geometries of hangar shapes using injection of smoke from identified locations on the hangar to understand and qualitatively appreciate the flow structure on the helodeck. A viable practical solution for tailoring the airwake for reduction of the Pilot workload should result from use of understanding gained from the studies and conducting further optimisation studies on the geometries being explored.

On the numerical front, the environment of the experiments has been modeled in ANSYS FLUENT for the SFS model and a validation study is undertaken through use of a large databank generated through the quantitative and qualitative experiments mentioned above. The validated numerical model has then been used to numerically explore the feasibility of modifying the airwake by undertaking a parametric investigation through introduction of passive and active geometry changes to the hangar configuration. The results have been analysed on relevant planes through vector and contour plots of significant flow parameters which have been identified to contribute towards the Pilot workload. The results qualitatively ascertain the effect of change in a particular geometrical parameter to the changes in the flow domain over the helodeck.

In order to create a platform where geometries can be numerically assessed for their contribution towards Pilot workload, a criteria set has been evolved, consisting of significant flow parameters affecting the Pilot workload, which can be used to comparatively appreciate various geometric configurations for their effectiveness in improving the helodeck environment. Further, in order to be able to quantitatively evaluate these significant flow parameters, a Statistical Value based approach has been developed, which can be deterministically compared across various geometries for their contribution towards pilot workload.

Proposals for further research studies have been laid out which are expected to aid in the endeavor towards a complete numerical assessment of the ship helo interaction problem in future and creation of ship helo operating envelopes (presently created through rigorous flight testing by Test Pilots) within the realms of a laboratory.

सार

संचालन के विस्तृत स्पेक्ट्रम में पायलटों द्वारा की गई भूमिकाओं में से, युद्धपोतों पर हेलीकॉप्टर उड़ान संचालन उपक्रम को उच्च जोखिम कार्यों में से एक माना जाता है। जहाज के एक हेलो डेक के साथ चलने वाला प्लेटफार्म पायलटों को हेलो ऑपरेशंस के लिए चुनौतीपूर्ण वातावरण प्रस्तुत करता है। युद्धपोत की गति पायलटों को एक उत्तेजक प्लेटफार्म प्रदान करती है और समुद्री स्प्रे के कारण दृश्य संकेतों में भारी कमी आती है। हेलो डेक पर एक जटिल वायु प्रवाह की स्थिति है, जो सामने एक ब्लफ बॉडी की उपस्थिति और हेलो डाउनवॉश के के कारण बनाई गई है। ऊपर वर्णित चुनौतियों के बावजूद, युद्धपोतों पर हेलो संचालन पर प्रदान की गई जिम्मेदारियों की सीमा उन्हें अपरिहार्य प्रदान करती है। ऐसे युद्धपोतों पर हेलो डेक का एक अच्छा डिजाइन, हेलो ऑपरेशन की पूरी क्षमता को समझने के लिये आवश्यक है।

अध्ययन का उद्देश्य पायलट वर्कलोड में योगदान देने वाले हेलो डेक पर एयरवेक घटक को समझने के लिए उपलब्ध प्रयोगात्मक और संख्यात्मक संसाधनों का उपयोग करना है, और सुरक्षित हेलो संचालन सुनिश्चित करने के लिए आधुनिक जहाजों पर हेलो डेक -हैंगर कॉन्फ़िगरेशन के बेहतर डिजाइन के लिए समाधानों का पता लगाने का लक्ष्य है। अध्ययन की प्रेरणा आधुनिक नौसेना के प्लेटफार्मों से हेलो संचालन के लिए डिजाइन विचारों की कुल अनुपस्थिति से उत्पन्न होती है।

अंतरराष्ट्रीय स्तर पर स्वीकृत सरलीकृत फ्रिगेट शिप (एसएफएस) पर जांच की गई है, जो फ्रंटलाइन फ्रिगेट / डिस्ट्रॉयर के विशिष्ट रूप का प्रतिनिधित्व करती है और वर्तमान में कई उन्नत देशों द्वारा शोध उद्देश्यों के लिए उपयोग की जा रही है। जहाज मॉडल के लिए हेलो डेक पर एयरवेक को पांच छेद पिटोट जांच का उपयोग करके, पवन सुरंग में 1500 से अधिक अंकों के ग्रिड के माध्यम से प्रयोग किया गया है। समोच्च, वेक्टर और तार जाल भूखंडों के परिणामस्वरूप साहित्य सर्वेक्षण के निष्कर्षों के अनुरूप विश्लेषण किया गया है। इसके अलावा, हैगर पर पहचाने गए स्थानों से धूम्र के इंजेक्शन का उपयोग करके हैंगर आकार के विभिन्न आकार पर व्यापक प्रवाह विज़ुअलाइज़ेशन अध्ययन किए गए हैं और हेलोडेक पर प्रवाह संरचना की गुणात्मक रूप से सराहना किया गया है ।

संख्यात्मक मोर्चे पर, प्रयोगों के पर्यावरण के मॉडल के लिए ANSYS FLUENT का उपयोग किया गया है और ऊपर वर्णित मात्रात्मक और गुणात्मक प्रयोगों के माध्यम से उत्पन्न एक बड़े डाटाबेस के उपयोग के माध्यम से एक सत्यापन अध्ययन किया गया है। मान्य संख्यात्मक मॉडल का उपयोग हैगर कॉन्फ़िगरेशन में निष्क्रिय और सक्रिय आकार परिवर्तनों के परिचय के माध्यम से एक पैरामीट्रिक जांच करके एयरवेक को संशोधित करने की व्यवहार्यता को अंकीय रूप से एक्सप्लोर करने के लिए किया गया है।

प्लेटफ़ॉर्म बनाने के लिए जहां पायलट वर्कलोड के प्रति उनके योगदान के लिए आकार का आकलन किया जा सकता है, एक मानदंड सेट विकसित किया गया है। इसका उपयोग हेलो डेक पर्यावरण में सुधार करने के लिए उनकी प्रभावशीलता के लिए विभिन्न विन्यासों की तुलनात्मक रूप से सराहना करने के लिए किया जा सकता है। इसके अलावा, इन महत्वपूर्ण प्रवाह मानकों का मात्रात्मक मूल्यांकन करने में सक्षम होने के लिए, एक सांख्यिकीय मूल्य आधारित दृष्टिकोण विकसित किया गया है, जिसे पायलट वर्कलोड के प्रति उनके योगदान के लिए विभिन्न आकार में निश्चित रूप से तुलना की जा सकती है।

आगे के शोध अध्ययनों के प्रस्तावों को भविष्य में जहाज में हेलो इंटरैक्शन समस्या के पूर्ण संख्यात्मक मूल्यांकन और प्रयोगशाला के क्षेत्र में जहाज हेलो ऑपरेटिंग नक्शा के निर्माण के प्रयास में मदद करने की उम्मीद है।

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NOMENCLATURE

ALH	Advanced Light Helicopter
BFS	Backward Facing Step
CAA	Civil Aviation Authority, UK
DERA	Defence Evaluation and Research Agency, UK
DES	Detached Eddy Simulation
DI	Dynamic Interface
DIPES	Deck Interface Pilot Effort Scale
DNS	Direct Numerical Simulation
DSTO	Defence Science and Technology Organisation, Australia
fps	Frames per second
Helo	Helicopter
LDV	Laser Doppler Velocimetry
LES	Large Eddy Simulation
LHA	Landing Helicopter Assault Ship
LPD	Landing Platform Dock Ship
MATCH	Medium Altitude Torpedo Carrying Helicopter
NATO	North Atlantic Treaty Organisation
NAWC	Naval Air Warfare Centre, USA
NLR	National Aerospace Laboratory, Netherlands
NPS	Naval Postgraduate School, USA
NRC-IAR	National Research Council-Institute for Aerospace Research, Canada
PIV	Particle Image Velocimetry
RANS	Reynold's Averaged Navier Stokes Equations
RAS	Replenishment at Sea
RCS	Radar Cross Section
RPM	Rotations per minute
RSM	Reynold's Stress Model

RTO	Research and Technology Organisation, NATO
S&R	Search and Rescue
SFS	Simplified Frigate Ship
SGS	Sub Grid Scale
SHOL	Ship Helicopter Operating Limits
TTCP	The Technical Cooperation Program
VERTREP	Vertical Replenishment
b	Half-breadth of hangar on model
Calibration Function Q_p	$\frac{P_5 - P_m}{\frac{1}{2}\rho V^2}$
Calibration Function S_p	$\frac{H - P_5}{P_5 - P_m}$
Calibration function $f(\theta)$	$\frac{P_3 - P_1}{P_5 - P_m}$
Calibration function $f(\psi)$	$\frac{P_2 - P_4}{P_5 - P_m}$
D	Diameter of the cylinder on model
D/h	Normalised diameter of cylinder
D_R	Indicative diameter of Helo rotor
D_R/ H_L	Normalised indicative diameter of Helo rotor
G	Gap between Inclined plate and the hangar at the edge of hangar top
G', G/h	Normalised gap of inclined plate
h	Height of hangar on model
H	Total Pressure
H_{BFS}	Height of Step in BFS
H_L	Length of Helodeck
I	Turbulence Intensity
K	Ratio of Exhaust smoke velocity to the relative wind over deck velocity
L_N	Length of Notch in Hangar shapes

L_R	Ratio of the length of recirculation to the height of the hangar
L_S	Length of Superstructure
P, P_{stat}	Static Pressure
P_1, P_2, P_3, P_4, P_5	Pressures sensed by 5-hole probe
P_m	$\frac{P_1 + P_2 + P_3 + P_4}{4}$
S_w	Standard deviation of vertical velocity component
U_{ref}	Reference Velocity in BFS
V	Total velocity vector at a point
V'	Normalised total velocity vector at a point
V_{ship}	Velocity vector of ship motion
V_w	l V_{wod} l, Free stream velocity in wind tunnel
V_{wind}	Velocity vector of Wind
V_{wod} , WOD	Velocity vector of Wind Over Deck
V_x'	Normalised velocity component in x direction
V_x, u	Velocity component in x direction
$\overline{V_x}$	Mean of normalised x component of velocity
V_{xy}	Tangential velocity vector on x-y plane, $\sqrt{(V_x)^2 + (V_y)^2}$
V_{xy}'	Normalised tangential velocity vector on x-y plane
V_{xz}	Tangential velocity vector on x-z plane, $\sqrt{(V_x)^2 + (V_z)^2}$
V_{xz}'	Normalised tangential velocity vector on x-z plane
V_y'	Normalised velocity component in y direction
V_y, v	Velocity component in y direction
V_{yz}	Tangential velocity vector on y-z plane, $\sqrt{(V_y)^2 + (V_z)^2}$
V_{yz}'	Normalised tangential velocity vector on y-z plane
V_z'	Normalised vertical component of velocity (in z direction)
V_z, w	Vertical Component of velocity (in z direction)
$\overline{V_z}$	Mean of normalised vertical component of velocity

$\overline{u'u'}$, $\overline{v'v'}$, $\overline{w'w'}$	Diagonal components of Reynold's stresses in terms of velocity fluctuations in x, y and z directions respectively
W	Width of Inclined Plate on top of hangar
W', W/h	Normalised width of Inclined Plate
X direction	Longitudinal direction along length of ship
x', x/H_L	Normalised x coordinate
Y direction	Transverse / Athwartship direction
y', y/b	Normalised y coordinate
Z direction	Vertical Direction
z', z/h	Normalised z coordinate
α	Angle of inclination of deflector plate
β	Ratio of the tangential velocity of the cylinder circumference to the free stream velocity
ε	Turbulent dissipation rate
$\bar{k}$, k	Turbulent Kinetic Energy
μ_t	Turbulent viscosity
ρ	Density of air
Θ	Pitch Angle of wind over deck at a given point
Ψ	Yaw Angle of the wind over deck at a point
ω	Specific dissipation rate