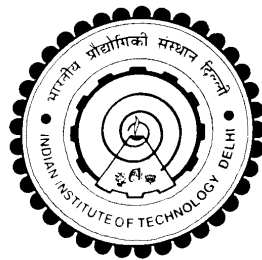


**STUDY OF THE SHIP AIRWAKE- HELODECK FLOW  
FIELD FOR SAFE HELO OPERATIONS.**

**B Praveen**



**DEPARTMENT OF APPLIED MECHANICS  
INDIAN INSTITUTE OF TECHNOLOGY DELHI  
OCTOBER 2018**

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by

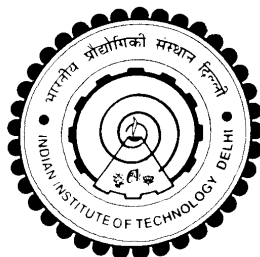
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**DEPARTMENT OF APPLIED MECHANICS**

**SUBMITTED**

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

to the



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**OCTOBER 2018**

**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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## **ACKNOWLEDGEMENTS**

The preparation of this thesis sees the end of a long and tumultuous journey which has seen tremendous contribution from several selfless individuals. This journey would not have been possible without the able guidance of Prof SN Singh and Prof V Seshadri. I have neither the ability nor the intention to separate these two names who, as colleagues, have seen through many a technological challenges over several years together as a team. During the research work, I have been fortunate to witness the very high level of synchronised guidance by both of them, which, at times, ranged from a gentle nudge to explore the endless possibilities to other times where I was made to respect the value of time for reaching the intended targets. The feeling of my gratitude to both of them cannot be expressed in words.

Dr R Vijayakumar has been the leading light and a torch bearer through the difficult phases of this journey. The grit and determination of Dr Vijayakumar in working towards self established targets has been a great source of motivation for me to learn how to break down the big task into smaller achievable targets. I remain deeply indebted to him for his guidance and faith on me.

No words can express my gratitude to Cdr Ishaq Makkar, who, as a colleague and as dear friend, has spent countless days and nights in helping me out with the research work. The free and frank discussions with him over these years form the very basis and the framework for all that could be achieved. I sincerely thank former and present Officer-in-Charges of Naval Construction Wing, Cmde (Dr) PR Kulkarni and Cdr MP Mathew for their continued support and for treating me as part of Team NCW even after my transfer out of the organisation. No words can express my gratitude to my colleagues Lt Cdr Vignesh, Cdr Sunit Mehrotra and Lt Cdr Arun E for giving me those bouts of motivation when I was searching for answers to channelize the findings of the research work and taking care of the many administrative

requirements which arose due to my inability to be physically present in the Institute on many occasions.

Dr Sawan Suman has been a party to many an in-depth discussions during the course of this research work. My gratitude towards him will always remain for the liberty he gave to approach him at any point, despite his busy schedule. I remain indebted to Dr Balaji and Dr Murali Cholemari for their valuable insights in forming of ideas towards solutions to the research problem.

I extend my sincere gratitude to Lt Cdr Bharat Kumar and Lt Cdr S Kaushik who have spent their valuable time and helped me through my experimental works. I thank Mr Tanmay Bankur and his team of entrepreneurs for helping me conduct even those experiments in wind tunnel which I thought were not practical to be undertaken.

I sincerely thank former Experimental Test Pilot of Indian Navy, Cdr KPS Kumar, for taking out valuable time and visiting our premises at multiple occasions to guide us through the work through the eyes of a pilot. Such an insight gave clarity of thought in attempting solutions for the complex problem.

I take this opportunity to thank my fellow students Dr Anubhav Rawat, Mr. Naseeruddin, Mr. Lakhwinder and Mr. Shrish Shukla, with whom I have had meaningful discussions on several occasions during the course of the work. My sincere thanks to the GD Lab technicians Mr Suresh Sharma and Mr Kunj Bihari for helping me with the Lab resources, even when I disturbed them during odd hours and off working days.

Last but never the least, I sincerely thank my family who have stood by me like a rock during these years and have gladly withstood the void of my absence on many an important occasions eagerly waiting for me to complete the research work and looking forward to undertake together, many an unfinished tasks.

## **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 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 कॉन्फिगरेशन 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, हैंगर पर पहचाने गए स्थानों से धूम्र के इंजेक्शन का उपयोग करके हैंगर आकार के विभिन्न आकार पर व्यापक प्रवाह विजुअलाइज़ेशन 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 हैंगर कॉन्फिगरेशन 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।

प्लेटफॉर्म 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।

# CONTENTS

		PAGE NO
<b>CERTIFICATE</b>		i
<b>ACKNOWLEDGEMENTS</b>		iii-iv
<b>ABSTRACT</b>		v-vii
<b>CONTENTS</b>		viii-xvii
<b>LIST OF FIGURES</b>		xviii-xxv
<b>LIST OF TABLES</b>		xxvi
<b>LIST OF ANNEXURES</b>		xxvi
<b>NOMENCLATURE</b>		xxvii-xxx
<b>CHAPTER I</b>	<b>INTRODUCTION</b>	<b>1-26</b>
	1.1 History of Global Naval Aviation - Fighter Planes and Helicopters	1
	1.2 History of Naval Helicopters in India	2
	1.3 Role of helicopter operations on naval ships	2
	1.4 Contemporary Helo Hangar Design on Ships	3
	1.5 Pilot Approach and Landing	5
	1.6 Problems in Configuration of Modern Helo Hangar Design	9
	1.7 Methods Employed Presently to Evaluate Safe Helo Operating Limits	11
	1.7.1 Dynamic Interface Testing	11
	1.7.2 Pilot Workload	12

		<b>PAGE NO</b>
	1.8 Challenges Involved in Dynamic Interface Testing	14
	1.9 Motivation for the Study	15
	1.10 Feasibility of Application of Numerical and Experimental Methods to Study the Effect of Flow Modification Techniques and Evaluation of Safe Operating Envelopes	16
	1.10.1 Ideal Solution for Preparation of Safe Operating Envelopes	16
	1.10.2 Alternative Approach to Ideal Solution	18
	1.10.3 Constraints Pertaining to Ideal Solutions	18
	1.11 Aim of Present Study	18
	1.12 Outline of the thesis layout	19
	Figs 1.1 to 1.10	21-26
<b>CHAPTER II</b>	<b>LITERATURE SURVEY</b>	<b>27-75</b>
	2.1 Introduction	27
	2.2 Flow Over a 2D Backward Facing Step	29
	2.3 Bluff Body Aerodynamics	33
	2.4 Experimental and Numerical Studies Conducted on Analysis of Ship Superstructure Air-wake over Helodeck	35
	2.4.1 The Technical Cooperation Programme (TTCP)	38
	2.5 Experimental and Numerical Studies Conducted at IIT Delhi on Ship Superstructures	41

		<b>PAGE NO</b>
	2.6 Survey of Literature pertaining to Offshore Industry	43
	2.7 Relation between Turbulence Intensity and standard deviation of fluctuating vertical velocity	48
	2.8 Implications of Helodeck Environment on Helicopter Performance and Handling	49
	2.9 Studies Integrating Simulation Results of Ship Air-wake with Piloted Flight Simulations of Helo to Quantify SHOL	60
	2.10 Scaling Laws for Wind Tunnel Experiments on Ship Models	62
	2.11 Conclusions from Literature Survey	63
	2.12 Scope of Present Study	68
	Figs 2.1 to 2.9	72-75
<b>CHAPTER III</b>	<b>EXPERIMENTAL SETUP, PROCEDURE, MEASUREMENTS AND RESULTS - QUANTITATIVE INVESTIGATION USING FIVE-HOLE PROBE</b>	<b>76-129</b>
	3.1 Introduction	76
	3.2 Coordinate System	77
	3.3 Description of the ship model for velocity field measurements	78
	3.4 Choice of Grid for Velocity Measurement	79
	3.5 Experimental Setup	80
	3.5.1 Wind Tunnel	80

		<b>PAGE NO</b>
	3.5.2 Velocity Control in Wind Tunnel	81
	3.5.3 Probe Traversing Mechanism	81
	3.5.4 Measurement of the free stream velocity	84
	3.5.5 Positioning of the Model in Wind Tunnel	84
	3.6 Instrumentation	85
	3.6.1 Manometers	85
	3.6.2 Five Hole Pressure Probe	85
	3.7 Similarity during Model Tests	87
	3.8 Range of parameters	88
	3.8.1 Sources of Experimental Errors and their Mitigation	90
	3.9 Mapping of Flow Measurements and Analysis	93
	3.9.1 Flow structure downstream of the hangar at Plane A	94
	3.9.2 Flow structure downstream of the hangar at Plane B	96
	3.9.3 Flow structure downstream of the hangar at Plane C	98
	3.9.4 Flow structure downstream of the hangar at Plane D	99
	3.9.5 Flow structure at Helo Rotor Plane K	100
	3.9.6 Flow structure at Helo Rotor Plane L	102

		<b>PAGE NO</b>
	3.9.7 Flow structure at Helo Rotor Plane M	103
	3.10 Concluding Remarks	104
	Table 3.1	106
	Figs 3.1 to 3.22	106-129
<b>CHAPTER IV</b>	<b>EXPERIMENTAL SETUP, PROCEDURE AND RESULTS - QUALITATIVE INVESTIGATION USING FLOW VISUALISATION STUDIES</b>	<b>130-168</b>
	4.1 Introduction	130
	4.2 Models for Flow Visualisation Studies	131
	4.3 Experimental Setup for Flow Visualisation	132
	4.3.1 Design of Hangar Sections	132
	4.3.2 Modelling of Cylinder Rotation	133
	4.3.3 Set up of Smoke/Fog Generators and Pipe Leading to Wind Tunnel Bottom	134
	4.3.4 Wind Tunnel Lighting and Markings	134
	4.3.5 Set Up of Cameras	135
	4.4 Wind Tunnel Speeds for Flow Visualisation	136
	4.5 Setting up of Cases for Flow Visualisation Studies	137
	4.6 Analysis of Flow Visualisation Recordings of Hangar Shape Variations	138
	4.6.1 The Length of Recirculation Zone on Helodeck	138

		<b>PAGE NO</b>
	4.6.2 The Extent of Low Momentum Flow on Rotor Planes	143
	4.6.3 Observations on the Levels of Turbulence	145
	4.7 Analysis of Flow Visualisation Recordings of Rotating Cylinder on Hangar	146
	4.8 Concluding remarks	149
	Tables 4.1 to 4.4	151-153
	Figs 4.1 to 4.15	154-168
<b>CHAPTER V</b>	<b>MATHEMATICAL FORMULATION AND VALIDATION</b>	<b>169-235</b>
	5.1 Introduction	169
	5.2 Computational Fluid Dynamics (CFD)	170
	5.3 Overview of Turbulent Flow	171
	5.4 Mathematical Formulation for the Present Study	172
	5.4.1 Continuity Equation	173
	5.4.2 Momentum Equation	173
	5.4.3 The Energy Equation	174
	5.4.4 Turbulence Modelling	176
	5.5 Overview of Commercial CFD Code ANSYS FLUENT	179
	5.5.1 Final form of Equations in FLUENT	181

		<b>PAGE NO</b>
	5.5.2 Discretization	181
	5.5.3 Linearised Form of the Discrete Equation	183
	5.5.4 Discretization of the Momentum Equation	184
	5.5.5 Discretization of the Continuity Equation	184
	5.6 Identification of Turbulence Model	185
	5.6.1 The Transition SST turbulence model	186
	5.7 Numerical Solution for Present Study	195
	5.7.1 Geometry and Boundary Condition	197
	5.7.2 Computational Mesh	198
	5.7.3 Grid Adaptation and Grid Independence	199
	5.8 Quantitative Comparison between the Velocity Flow Field obtained from Wind Tunnel Studies and CFD Simulations	200
	5.8.1 Results of Comparisons between Experimental and CFD Simulations	201
	5.9 Qualitative Comparison between Flow Visualisation through CFD simulations and wind tunnel studies	209
	5.9.1 Comparison of Flow Visualisation results conducted on hangar shape variations with CFD predictions	210
	5.9.2 Comparison of Flow Visualisation results conducted on cylinder rotation speed variations with CFD predictions	213
	5.10 Concluding remarks	214

		<b>PAGE NO</b>
	Figs 5.1 to 5.18	217-235
<b>CHAPTER VI</b>	<b>PARAMETRIC INVESTIGATION USING NUMERICAL TECHNIQUE - INTRODUCTION OF FLOW CONTROL METHODS</b>	<b>236-305</b>
	6.1 Introduction	236
	6.2 Setting up of cases for Parametric Analysis using Passive Flow Modification Methods	237
	6.3 Computational Mesh and Boundary Conditions for Hangar Shape Variation Study	237
	6.4 Analysis of the Flow over Hangar Shape Variations using Vector Plots and Contour Plots from CFD	238
	6.4.1 Establishing the Extents of Rotor Plane for Analysis	242
	6.4.2 Analysis of vector plots of velocity vector $V_{xy}'$ for all variants	242
	6.4.3 Analysis of vector plots of velocity vector $V_{xz}'$ for all hangar variants.	246
	6.4.4 Analysis of contour plots of turbulence intensity, Velocity Components $V_x'$ and $V_z'$ for hangar variants.	250
	6.4.5 Summary of Results with Change of Hangar Shapes.	251
	6.5 Setting up of cases for Parametric Analysis using Active Flow Modification Methods	253
	6.6 Computational Mesh and Boundary Conditions for Active Flow Modification Devices	255
	6.7 Analysis of the Flow with Active Flow Modification Devices using Vector Plots and Contour Plots from CFD	256
	6.7.1 Analysis of vector plots of vector $V_{xy}'$ for Deflector Plate Variants	256

		<b>PAGE NO</b>
	6.7.2 Analysis of vector plots of vector $V_{xz}'$ for Deflector Plate Variants	257
	6.7.3 Analysis of contour plots of turbulence intensity, relative velocity and the downdraft	259
	6.7.4 Summary of Results for Inclined Plate Configurations	261
	6.7.5 Analysis of vector plots of velocity vector $V_{xy}'$ for Rotating Cylinder Variants	262
	6.7.6 Analysis of vector plots of velocity vector $V_{xz}'$ for Rotating Cylinder Variants	264
	6.7.7 Analysis of contour plots of turbulence intensity, relative velocity and the downdraft for rotating cylinder variants	267
	6.7.8 Summary of Results for Rotating Cylinder Configurations	270
	6.8 Concluding remarks on the Parametric Investigations	271
	Tables 6.1 to 6.4	273-274
	Figs 6.1 to 6.38	275-305
<b>CHAPTER VII</b>	<b>DEVELOPMENT OF MODEL CRITERIA SET AND STATISTICAL FLOW PARAMETERS BASED APPROACH</b>	<b>306-340</b>
	7.1 Introduction	306
	7.2 Establishing the Extents of Rotor Plane for Quantitative Analysis	307
	7.3 Approach Adopted for Quantitative Relative Assessment of Helo Hangar Configurations for Pilot Workload using CFD	308

		<b>PAGE NO</b>
	7.4 Setting up of Criteria for Flow Assessment and Comparison	310
	7.5 Comparative Analysis of results for Parametric Investigation on Hangar Shape Variants using the Quantitative Relative Assessment Approach	315
	7.6 Summary of comparative analysis of variation in hangar shapes	320
	7.7 Approach Adopted for Quantitative Relative Assessment of Plate and Cylinder Configurations for Pilot Workload using CFD	322
	7.8 Comparative Analysis of results for Parametric Investigation on Inclined Plate configurations using the Statistical Value based method	323
	7.9 Summary on comparative analysis of variation for Deflector Plate Configurations	326
	7.10 Comparative Analysis of results for Parametric Investigation on Rotating Cylinder configurations using the Statistical Value based method	327
	7.11 Summary on comparative analysis of variation for rotating cylinder Configurations	329
	7.12 Concluding Remarks for Parametric Investigation Study using Quantitative Statistical Method	330
	Figs 7.1 to 7.15	332-340
<b>CHAPTER VIII</b>	<b>CONCLUDING REMARKS</b>	<b>341-349</b>
	8.1 Summary of the Research Study	341
	8.2 Major Conclusions	344
	8.3 Suggestions for Future Work	346
<b>REFERENCES</b>		<b>350-360</b>
<b>BIO-DATA OF THE AUTHOR</b>		<b>361</b>

## LIST OF FIGURES

Fig No	Title Of The Figure	Page No
1.1	Types of Helicopters in Indian Navy	21
1.2	Vertical Replenishment by a Naval Helicopter	23
1.3	Older configurations of hangar	23
1.4	Kashin-II class destroyer with submerged hangar	24
1.5	Helicopter Deck and Hangar forming a Backward Facing Step in state of the art frigates/ destroyers	24
1.6	Fore/Aft Take off and Landing	25
1.7	Relative Wind Take off and Landing	25
1.8	Relative Wind Take off and Landing	25
1.9	Deck Interface Pilot Efforts Scale (DIPES)	26
1.10	A representative Ship Helo Operating Limit (SHOL)	26
2.1	Idealized flow over a backward facing step	72
2.2	Flow structure behind a bluff body	72
2.3	Flow structure behind a Helodeck	72
2.4	Flow structure over helodeck of Patrol frigate	73
2.5	The generic simple frigate ship configurations developed by TTCP	73
2.6	Modelling and Simulation work linking turbulence with pilot workload and flight safety	74

<b>Fig No</b>	<b>Title Of The Figure</b>	<b>Page No</b>
2.7	Set-up of helicopter/ ship qualification procedure at NLR, Netherlands	74
2.8	Detailed results from land based hover tests	75
2.9	Contour plots of vertical wind component on Type 23 Frigate for 30 knots WOD from 30 <sup>0</sup> starboard	75
3.1	Coordinate System for present study	106
3.2	Simplified Frigate Ship Model (SFS2) used in TTCP	107
3.3 (a)	1:100 Scale Base Model used for Wind Tunnel Experiments	107
(b)	Dimensional Details of the Base Model	107
3.4	Planes for Experimental Velocity Measurements	108
3.5	Grid Points for Measurement in Wind Tunnel (Planes A, B, C, D)	110
3.6	Grid Points for Measurement in Wind Tunnel (Planes K, L, M)	110
3.7	Model set up in the wind tunnel	111
3.8	Schematic of 3D traversing mechanism	111
3.9	Probe Holder setup on Traversing System	111
3.10	Velocities and Directions of Ship and Wind	112
3.11	Model setup inside wind tunnel	112
3.12	Nomenclature of a 5-hole probe	113
3.13	Flow Pitch and Yaw Angles at the point of Measurement	113
3.14	Setup for Calibration	113

<b>Fig No</b>	<b>Title Of The Figure</b>	<b>Page No</b>
3.15 (a)	Calibration Chart $F(\theta)$ Vs $F(\psi)$	114
(b)	Calibration data. Contours of $Q_P$	115
(c)	Calibration data. Contours of $S_P$	115
3.16 (a)	Plane A, Contour Plot of Normalised Total Velocity $V'$	116
(b)	Plane A - Velocity Vector plot of $V_{yz}'$	117
(c)	Plane A - Wiremesh plot of Normalised x-velocity $V_x'$	117
3.17 (a)	Plane B, Contour Plot of Normalised Total Velocity $V'$	118
(b)	Plane B - Velocity Vector plot of $V_{yz}'$	119
(c)	Plane B - Wiremesh plot of Normalised x-velocity $V_x'$	119
3.18 (a)	Plane C, Contour Plot of Normalised Total Velocity $V'$	120
(b)	Plane C - Velocity Vector plot of $V_{yz}'$	121
(c)	Plane C - Wiremesh plot of Normalised x-velocity $V_x'$	121
3.19 (a)	Plane D, Contour Plot of Normalised Total Velocity $V'$	122
(b)	Plane D - Velocity Vector plot of $V_{yz}'$	123
(c)	Plane D - Wiremesh plot of Normalised x-velocity $V_x'$	123
3.20 (a)	Plane K, Contour Plot of Normalised Total Velocity $V'$	124
(b)	Plane K - Wiremesh plot of Normalised z-velocity $V_z'$	125
3.21 (a)	Plane L, Contour Plot of Normalised Total Velocity $V'$	126

<b>Fig No</b>	<b>Title Of The Figure</b>	<b>Page No</b>
(b)	Plane L - Wiremesh plot of Normalised z-velocity $V_z'$	127
3.22 (a)	Plane M, Contour Plot of Normalised Total Velocity $V'$	128
(b)	Plane M - Wiremesh plot of Normalised z-velocity $V_z'$	129
4.1	Dimensional Details of Hangar Configurations	154
4.2	Hangar Configurations used for Flow Visualisation	155
4.3	Photograph of cylinder on model	155
4.4	Schematic of experimental setup of smoke generators	155
4.5	Photograph showing arrangement of plastic cone for introduction of smoke into helo hangar	156
4.6	LED Lighting arrangement with black stickered background for enhancing flow visualisation	156
4.7	Schematic of experimental setup with cameras	156
4.8	Details of the Cameras for Various views	157
4.9	Reynolds number independence study	158
4.10	Illustrative Frame of Recordings for the Four Cameras	159
4.11	Smoke Visualisation Flow frames - Rectangular Hangar Shapes (Base Model & Variant 5)	160
4.12	Smoke Visualisation Flow frames - Trapezoidal Hangar Shapes (Base Model & Variant 6)	162
4.13	Smoke Visualisation Flow frames - Top View of all Hangar Shapes (Smoke from Slits on Hangar and Middle)	164
4.14	Smoke Visualisation Flow frames - Rotating Cylinder - Smoke from Top of hangar	165

<b>Fig No</b>	<b>Title Of The Figure</b>	<b>Page No</b>
4.15	Smoke Visualisation Flow frames - Rotating Cylinder - Smoke from hangar	167
5.1	Flow Chart of Solution Procedure in FLUENT	217
5.2	Representative half planes on view from aft of ship on helodeck for plot of velocity contours	218
5.3	The symmetry half domain and boundary conditions for model for validation	218
5.4	The grids used for Grid Independence Study	219
5.5	Percentage Errors on Validation Planes	220
5.6	Plane A Validation Contours of Total Normalised Velocity vector $V'$	221
5.7	Plane B Validation Contours of Total Normalised Velocity vector $V'$	222
5.8	Plane C Validation Contours of Total Normalised Velocity vector $V'$	223
5.9	Plane D Validation Contours of Total Normalised Velocity vector $V'$	224
5.10	Plane K Validation Contours of Total Normalised Velocity vector $V'$	225
5.11	Plane L Validation Contours of Total Normalised Velocity vector $V'$	226
5.12	Plane M Validation Contours of Total Normalised Velocity vector $V'$	227
5.13	Representative Figure showing relative position of helo on helodeck while hovering before landing	228
5.14	Comparison of CFD simulation results against flow visualisation frames - Variation in hangar shapes (Front View- Cam 4)	229
5.15	Analysis of Variant 5 flow in recirculation region	231
5.16	Comparison of CFD simulation results against flow visualisation frames - Variation in hangar shapes (Top View - Cam 2)	232

<b>Fig No</b>	<b>Title Of The Figure</b>	<b>Page No</b>
5.17	Comparison of CFD simulation results against flow visualisation frames - Variation in Cylinder rotation (Front View - Cam 4- Smoke from top)	234
5.18	Comparison of CFD simulation results against flow visualisation frames - Variation in Cylinder rotation (Front View - Cam 4- Smoke from hangar)	235
6.1	Details of Analysis Planes for Vector Plots and Contour Plots	275
6.2	Details of extents of Rotor Planes considered for analysis	275
6.3	Representative close up view of vectors $V_{xy}'$ and $V_{xz}'$ on Base Model	276
6.4	Vector plot of $V_{xy}'$ on Rotor Planes for Base Model	277
6.5	Vector plot of $V_{xy}'$ on Rotor Planes for Variant 6	278
6.6	Vector plot of $V_{xy}'$ on Rotor Planes for Variant 5	279
6.7	Vector plot of $V_{xy}'$ on Rotor Planes for Variant 4	280
6.8	Vector plot of $V_{xy}'$ on Rotor Planes for Variant 3	281
6.9	Vector plot of $V_{xy}'$ on Rotor Planes for Variant 2	282
6.10	Vector plot of $V_{xy}'$ on Rotor Planes for Variant 1	283
6.11	Vector plot of $V_{xz}'$ on x-z planes for Base Model	284
6.12	Vector plot of $V_{xz}'$ on x-z planes for Variant 6	285
6.13	Vector plot of $V_{xz}'$ on x-z planes for Variant 5	286
6.14	Vector plot of $V_{xz}'$ on x-z planes for Variant 4	287
6.15	Vector plot of $V_{xz}'$ on x-z planes for Variant 3	288

<b>Fig No</b>	<b>Title Of The Figure</b>	<b>Page No</b>
6.16	Vector plot of $V_{xz}'$ on x-z planes for Variant 2	289
6.17	Vector plot of $V_{xz}'$ on x-z planes for Variant 1	290
6.18	Variation of Significant Flow Parameters on Rotor Planes - Base Model (Variant 7)	291
6.19	Variation of Significant Flow Parameters on Rotor Planes - Variant 6	291
6.20	Variation of Significant Flow Parameters on Rotor Planes - Variant 5	292
6.21	Variation of Significant Flow Parameters on Rotor Planes - Variant 4	292
6.22	Variation of Significant Flow Parameters on Rotor Planes - Variant 3	293
6.23	Variation of Significant Flow Parameters on Rotor Planes - Variant 2	293
6.24	Variation of Significant Flow Parameters on Rotor Planes - Variant 1	294
6.25	Configuration used for parametric investigation using inclined plate	295
6.26	Configuration used for parametric investigation using rotating cylinder	295
6.27	Vector plot of $V_{xy}'$ on Rotor Planes for Plate $G/h=0.24$ , $W/h=0.32$ , $\alpha=6\text{deg}$	296
6.28	Vector plot of $V_{xy}'$ on Rotor Planes for Plate $G/h=0.143$ , $W/h=0.48$ , $\alpha=9\text{deg}$	297
6.29	Vector plot of $V_{xz}'$ on x-z planes for Plate $G/h=0.24$ , $W/h=0.32$ , $\alpha=6\text{deg}$	298
6.30	Vector plot of $V_{xz}'$ on x-z planes for Plate $G/h=0.143$ , $W/h=0.48$ , $\alpha=9\text{deg}$	299
6.31	Significant Flow Parameters on Rotor Planes - Plate $G/h=0.24$ , $W/h=0.32$ , $\alpha=6\text{deg}$	300
6.32	Significant Flow Parameters on Rotor Planes-Plate $G/h=0.143$ , $W/h=0.48$ , $\alpha=9\text{deg}$	300
6.33	Vector plot of $V_{xy}'$ on Rotor Planes for Cylinder $D/h=0.08$ , $\beta=1.1$	301

<b>Fig No</b>	<b>Title Of The Figure</b>	<b>Page No</b>
6.34	Vector plot of $V_{xy}'$ on Rotor Planes for Cylinder $D/h=0.24$ , $\beta=2.76$	302
6.35	Vector plot of $V_{xz}'$ on x-z planes for Cylinder $D/h=0.08$ , $\beta=1.1$	303
6.36	Vector plot of $V_{xz}'$ on x-z planes for Cylinder $D/h=0.24$ , $\beta=2.76$	304
6.37	Significant Flow Parameters on Rotor Planes - Cylinder $D/h=0.08$ , $\beta=1.1$	305
6.38	Significant Flow Parameters on Rotor Planes - Cylinder $D/h=0.24$ , $\beta=2.76$	305
7.1	Grid points used for flow parameter data collection on a rotor plane	332
7.2	Variation of Normalised Length of Recirculation Zone - Hangar Shape Variations	332
7.3	Variation of Significant Flow Parameters - Hangar Shape Variations	333
7.4	Close-up view of Vector $V_{xz}'$ for Base Model and Variant 6	334
7.5	Variation of Turbulence Intensity - Inclined Plate Configurations	335
7.6	Variation of Downdraft - Inclined Plate Configurations	336
7.7	Variation of Relative Velocity - Inclined Plate Configurations	337
7.8	Variation of Standard Deviation of Relative Velocity $V_x'$ - Inclined Plate Configurations	338
7.9	Variation of Normalised Length of Recirculation Zone - Inclined Plate Configurations	338
7.10	Effect of forward step (Bridge) on Helodeck Environment	339
7.11	Variation of Flow Parameters - Cylinder Rotation	339
7.12	Variation of Normalised Length of Recirculation Zone - Rotating Cylinder	340

## LIST OF TABLES

Table No	Name Of The Table	Page No
3.1	Estimated uncertainties in the measured quantities	106
4.1	Specifications of motor used for cylinder on model	151
4.2 (a)	The Details of Case numbers for Smoke Flow Visualisation - Hangar Shape Variations	151
(b)	The Details of Case numbers for Smoke Flow Visualisation - Cylinder Rotation	152
4.3	Grading of Hangar Variants with respect to the Length of Recirculation Zone	153
4.4	Grading of Hangar Variants with respect to the Extent of Low Momentum Flow	153
6.1	Normalised Area Fraction of Low Momentum Region on Rotor Planes for Hangar Variants (Area normalised with rotor plane area)	273
6.2	Normalised Area Fraction of Low Momentum Region behind hangar on Plane L and K for Hangar Variants (area normalised with helodeck area)	273
6.3	Range of parameters investigated in for Inclined Plate in CFD	273
6.4	Range of parameters investigated in for Cylinder in CFD	274

## LIST OF ANNEXURES

Annex No	Name Of The Annexure
1	DVD containing Flow Visualisation Videos

# 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 <sub>R</sub>	Indicative diameter of Helo rotor
D <sub>R</sub> / H <sub>L</sub>	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 <sub>BFS</sub>	Height of Step in BFS
H <sub>L</sub>	Length of Helodeck
I	Turbulence Intensity
K	Ratio of Exhaust smoke velocity to the relative wind over deck velocity
L <sub>N</sub>	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
$V_w$	$ V_{wod} $ , 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
$\bar{V}_x$	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)
$\bar{V}_z$	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/HL	Normalised x coordinate
Y direction	Transverse / Athwartship direction
y', y/b	Normalised y coordinate
Z direction	Vertical Direction
z', z/h	Normalised z coordinate
$\alpha$	Angle of inclination of deflector plate
$\beta$	Ratio of the tangential velocity of the cylinder circumference to the free stream velocity
$\epsilon$	Turbulent dissipation rate
$\bar{k}, k$	Turbulent Kinetic Energy
$\mu_t$	Turbulent viscosity
$\rho$	Density of air
$\Theta$	Pitch Angle of wind over deck at a given point
$\Psi$	Yaw Angle of the wind over deck at a point
$\omega$	Specific dissipation rate