

**EFFECT OF PASSIVE DEVICES AND ISLAND
PARAMETERS ON FLOW CHARACTERISTICS OVER A
GENERIC AIRCRAFT CARRIER**

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by

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C E R T I F I C A T E

This is to certify that the thesis titled "**Effect of Passive Devices and Island parameters on flow characteristics over a Generic Aircraft Carrier**", being submitted by **M P Mathew** 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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A handwritten signature in blue ink, reading "MP Mathew", is written above a single horizontal line.

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(MP Mathew)
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ABSTRACT

The warfighting prowess of any Navy, from the era of the sailing ships, till the dawn of the twentieth century, has been dominated by the gun. However, the development of the aeroplane in the early 1900s, gave a new impetus to naval warfare, with these aircraft being the new weapons of war. These aircraft extended the striking range of maritime forces, limited hitherto by the range of their guns, by an order of magnitude, which was beyond the expectations of any naval ship commander. This led to a paradigm shift in the way naval battles were fought and led to the replacement of the formidable battleships, the capital ships of yore, with a new type of warship, till then unheard and unseen – the aircraft carrier. However, landing an aircraft on an aircraft carrier has always been problematic and challenging for the naval aviation pilots, due to constraints in the runway length and size as compared to land based air fields. Added to these constraints, is the effect of the turbulence generated by the various elements that constitute an aircraft carrier, namely the hull, flight deck configuration and the island shape, aft of the carrier, along the glideslope path of pilot approach, traditionally known as the burble effect.

The naval architects and ship designers, primarily responsible for the design of an aircraft carrier, at present, do not have adequate data for assessing the aerodynamic impact of the flight deck and island configuration on glideslope path and pilot workload. These days, CFD studies may be integral part of the preliminary ship design. However, even with advent of CFD for preliminary ship design studies, there have been no systematic parametric studies conducted on the aerodynamic effect of various constituents of an aircraft carrier like flight deck and island configurations on the burble effect. There are no design guidelines with respect to optimum aircraft carrier flight deck and island configuration. Adverse effect of lack of aerodynamic design guidelines of an aircraft carrier at the Preliminary Design stage are seen only during the trials and testing stage. Any corrective action at this stage, may lead to massive increase in cost and time, and may not be feasible at that stage. The only way for the pilots to cope up with any adverse aerodynamic effects of the aircraft carrier wake would be through increased training to hone their skills.

The motivation for this study is to overcome the lack of design data related to the aerodynamic characteristics of an aircraft carrier, during the preliminary design

stage and come out with design guidelines which could be incorporated during the preliminary design stage of an aircraft carrier design, so as to reduce the burble effect and ease the pilot workload.

As a prelude to the study, the necessity of a benchmark model of a generic aircraft carrier was considered unavoidable, similar to the benchmark model existing in the automobile industry for a generic car, namely the 'Ahmed Body' and for the Frigates and Destroyers in the form of SFS (Simplified Frigate Ship), SFS1 and SFS2, which would be able to simulate the turbulent wake along/behind the carrier similar to a realistic aircraft carrier. An inhouse model of a simplified aircraft carrier in a 1:300 scale, the Generic aircraft carrier (GAC) is developed at IIT Delhi, which is able to simulate the burble effect and turbulence behind similar to a realistic aircraft carrier. Inhouse experiments are conducted using pressure probes to map the pressure field on the flight deck of the GAC with and without the island structure (BGAC configuration) to arrive at the most optimum turbulence model for carrying out CFD studies. The SST k- ω turbulence model was determined to be the most optimum with an error of less than 7% compared to the inhouse experiments for both the GAC and the BGAC variants. To further validate the numerical model, CFD studies are carried out and results compared with the experimental test results of Nimitz and Ford class of island structure published in open source and good qualitative agreement with contours of forward velocity, pitch angle and yaw angles in the transverse plane at a distance of $1/3^{\text{rd}}$ L (L being the length of the aircraft carrier in model scale) behind the aircraft carrier model, is obtained. Good qualitative validation has been obtained using CFD, with the velocity field behind and along the GAC, reported in literature using Particle Image Velocimetry (PIV). The velocity results were made available to me by Mr Vignesh who has completed his PhD thesis (Experimental and computational studies of the flow characteristics over a Generic Aircraft Carrier with and without the island).

Unsteady and Steady RANS computations is carried out using commercial CFD solver Ansys Fluent on GAC and BGAC variants and the validity of using Steady RANS for further parametric studies is established. Mathematical constructs using deficits in the u-velocity, w-velocity and the average Turbulence Kinetic Energy (TKE) has been used to quantitatively ascertain the pilot workload and burble effect along a specified glideslope path using metrics like $U_{Av_Variation}$, $w_{Av_Variation}$ and $TKE_{Average}$. A comparative analysis of the airwake around and behind the GAC and the BGAC variants along

different glideslope path is carried out and a quantitative index for the pilot workload is obtained for both the variants. The individual contribution of the island to the total turbulence along various glideslope paths has been ascertained.

Further studies on the BGAC configuration have been carried out by varying various parameters of the flight deck, namely, filleting the notches, rounding/ angled sloping of the flight deck edges and fitment of passive devices on the flight deck. Substantial improvements to the flow field is seen by all the passive modifications to the flight deck configurations. Thereafter studies on the GAC variant is undertaken by varying the geometrical shape of the island structure. The effects of the geometrical features of the island (varying the aspect ratio, length and the geometrical profile shape of the island) and its effect on the turbulence generated behind the aircraft carrier are studied and a set of design guidelines which could aid the naval ship design during the preliminary design stage has been arrived at.

The comprehensive studies undertaken on the various variants of GAC and BGAC models are a first of its type undertaken anywhere and would go a long way in providing design stage inputs to an aircraft carrier designer, for obviating the detrimental effects of flight deck and island configurations on the aerodynamic wake behind the carrier and thus reducing the pilot workload.

सार

नौकायन जहाजों के युग से लेकर बीसवीं सदी की सुबह तक, किसी भी नौसेना के युद्ध लड़ने की प्रभावशीलता बंदूक पर हावी थी। 1900 के दशक की शुरुआत में, हालांकि, हवाई जहाज के विकास ने एक नाटकीय नए सैन्य लाभ की शुरुआत की - बेड़े के ऊपर उड़ान भरने और क्षितिज पर देखने की क्षमता। नौसेना के बंदूकों की पहुंच से दूर समुद्री बलों की हड़ताली रेंज का विस्तार करते हुए विमान बेड़े की आंखें और कान बन गए। नौसेना विमानन की कट्टरपंथी और परिवर्तनशील क्षमता ने भी युद्धपोत को पूरी तरह से नए प्रकार के युद्धपोत - विमान वाहक - सबसे शक्तिशाली पूंजी जहाज के रूप में युद्धपोत के प्रतिस्थापन के लिए प्रेरित किया। हालांकि, रनवे की लंबाई और आकार में भूमि आधारित वायु क्षेत्रों की तुलना में बाधाओं के कारण, एयरक्राफ्ट कैरियर पर एक विमान को उतारना नौसेना के पायलटों के लिए हमेशा समस्याग्रस्त और चुनौतीपूर्ण रहा है। इन बाधाओं में जोड़ा गया, विभिन्न तत्वों द्वारा उत्पन्न अशांति का प्रभाव है जो विमान वाहक, अर्थात् पतवार, उड़ान डेक विन्यास और द्वीप के आकार, वाहक के पीछे, पायलट दृष्टिकोण के ग्लाइडलोप पथ के साथ पारंपरिक रूप से जाना जाता है। 'बरबल इफ़ेक्ट'

नौसेना के आर्किटेक्ट्स और शिप डिजाइनर, मुख्य रूप से एक एयरक्राफ्ट कैरियर के डिजाइन के लिए जिम्मेदार हैं, वर्तमान में, एयरक्राफ्ट कैरियर के एरोडायनामिक्स और दृष्टिकोण ग्लाइडलोप पथ पर इसका प्रभाव नहीं है, विशेष रूप से डिजाइन सर्पिल के पारंपरिक लूप में। डिजाइन के प्रारंभिक चरण। डिजाइन की प्रक्रिया में यह स्पष्ट रूप से स्पष्ट रूप से विभिन्न वायुगतिकीय घटकों के बारे में नौसेना पोत डिजाइनर के दिशानिर्देशों की कमी के कारण है जो मुख्य रूप से प्रभाव को जन्म देते हैं, खासकर उड़ान डेक विन्यास और द्वीप के लिए एक विमान वाहक के ज्यामितीय मापदंडों के संबंध में। आकार। प्रारंभिक डिजाइन चरण में एक एयरक्राफ्ट कैरियर के एरोडायनामिक्स / एयरवेक को शामिल करने के लिए यह अवहेलना, विमान वाहक विन्यास के प्रतिकूल वायुगतिकीय प्रभावों का पता लगाने की ओर जाता है, केवल परीक्षण और परीक्षण चरण के दौरान, जिस बिंदु पर कोई सुधारात्मक कार्रवाई बड़े पैमाने पर होगी। परिणामी समय अंतराल के साथ लागत में वृद्धि, जो परिदृश्यों के बहुमत में अप्रभावी मानी जाएगी। विमान वाहक वेक के किसी भी प्रतिकूल वायुगतिकीय प्रभावों से निपटने के लिए पायलटों के लिए एकमात्र तरीका उनके प्रशिक्षण को बढ़ाने के लिए प्रशिक्षण के माध्यम से होगा।

इस अध्ययन के लिए प्रेरणा एक विमान वाहक की वायुगतिकीय विशेषताओं से संबंधित डिजाइन संबंधी आंकड़ों की कमी को दूर करना है, प्रारंभिक डिजाइन चरण के दौरान और डिजाइन दिशानिर्देशों के साथ बाहर आना जो एक विमान वाहक डिजाइन के प्रारंभिक डिजाइन चरण के दौरान शामिल किया जा सकता है, ताकि 'बरबल इफ़ेक्ट' को कम किया जा सके और पायलट कार्यभार को कम किया जा सके।

अध्ययन के अनुसार, जेनेरिक एयरक्राफ्ट कैरियर के बेंचमार्क मॉडल की आवश्यकता को अपरिहार्य माना गया था, जेनेरिक कार के लिए ऑटोमोबाइल उद्योग में मौजूद बेंचमार्क मॉडल के समान, 'अहमद बाँडी' और फ़्रिगेट और डेस्ट्रॉयर्स के लिए। एसएफएस (सरलीकृत फ़्रिगेट शिप), एसएफएस 1 और एसएफएस 2 के रूप में, जो एक यथार्थवादी एयरक्राफ्ट कैरियर के समान वाहक के साथ अशांत वेक को अनुकरण करने में सक्षम होगा। 1: 300 स्केल में एक सरलीकृत विमान वाहक का एक इनडोर मॉडल, जेआईटी दिल्ली में जेनेरिक एयरक्राफ्ट कैरियर (जीएसी) विकसित किया गया था, जो एक यथार्थवादी विमान वाहक के समान बर्बल

इफेक्ट ' और अशांति का अनुकरण करने में सक्षम था। सीएफडी अध्ययन करने के लिए सबसे इष्टतम अशांति मॉडल पर पहुंचने के लिए द्वीप संरचना (बीजीएसी कॉन्फिगरेशन) के साथ और बिना जीएसी के फ्लाइट डेक पर दबाव क्षेत्र का नक्शा बनाने के लिए दबाव जांच का उपयोग करके इनहाउस प्रयोग किए गए थे। SST $k-\omega$ टर्बुलेंस मॉडल को GAC और BGAC दोनों वेरिएंट के लिए इनडोर प्रयोगों की तुलना में 7% से कम की त्रुटि के साथ सबसे इष्टतम निर्धारित किया गया था। संख्यात्मक मॉडल को और अधिक मान्य करने के लिए, सीएफडी अध्ययन किए गए थे और परिणाम के प्रायोगिक परीक्षण के परिणाम की तुलना में निमिट्ज़ और द्वीप के फोर्ड संस्करण के खुले स्रोत में प्रकाशित किया गया था और अनुप्रस्थ वेग, पिच कोण और अनुप्रस्थ कोण के कोणों के साथ अच्छा गुणात्मक समझौता किया गया था। विमान वाहक मॉडल के पीछे 1 / 3rd L (L मॉडल में एयरक्राफ्ट कैरियर की लंबाई लंबाई) की दूरी पर विमान प्राप्त किया गया था। इसके अलावा, आईआईटी दिल्ली में किए गए एक अलग शोध के हिस्से के रूप में, जीएसी के साथ और पीछे के क्षेत्र को कण छवि वेलोसिमिटी (पीआईवी) प्रयोगों का उपयोग करके मैप किया गया था और सीएफडी परिणामों के साथ अच्छी मात्रात्मक मान्यता प्राप्त की गई थी।

Unsteady और Steady RANS अभिकलन GAC और BGAC वेरिएंट पर वाणिज्यिक CFD सॉल्वर Ansys Fluent का उपयोग करके किया जाता है और आगे पैरामीट्रिक अध्ययन के लिए Steady RANS का उपयोग करने की वैधता स्थापित की जाती है। यू-वेलोसिटी, डब्ल्यू-वेलोसिटी और औसत टर्बुलेंस काइनेटिक एनर्जी में घाटे का उपयोग करते हुए गणितीय निर्माणों का उपयोग मात्रात्मक रूप से पायलट वर्कलोड का पता लगाने के लिए किया गया है और एक निर्दिष्ट ग्लाइडस्लो मार्ग के साथ प्रभाव। जीएसी और बीजीएसी वेरिएंट के आसपास और पीछे अलग-अलग ग्लाइडस्लोप पथ के साथ एयरवेक का तुलनात्मक विश्लेषण किया जाता है और दोनों वेरिएंट के लिए पायलट वर्कलोड के लिए एक मात्रात्मक सूचकांक प्राप्त किया जाता है। विभिन्न गलियारों के रास्तों पर कुल अशांति के लिए द्वीप के व्यक्तिगत योगदान का पता लगाया गया है।

बीजीएसी कॉन्फिगरेशन पर आगे के अध्ययन उड़ान डेक के विभिन्न मापदंडों को अलग-अलग करके किया गया है, अर्थात्, फ्लाइट डेक किनारों को बंद करने, राउंडिंग / एंगल्ड ढलान को हटाने और फ्लाइट डेक पर निष्क्रिय उपकरणों के फिट होने से। फ्लाइट डेक कॉन्फिगरेशन के सभी निष्क्रिय संशोधनों द्वारा प्रवाह क्षेत्र में पर्याप्त सुधार देखा जाता है। इसके बाद जीएसी संस्करण पर अध्ययन द्वीप संरचना के ज्यामितीय आकार को अलग-अलग करके किया जाता है। द्वीप की ज्यामितीय विशेषताओं के प्रभाव (पहलू अनुपात, लंबाई और द्वीप के ज्यामितीय प्रोफ़ाइल आकार) और विमान वाहक के पीछे उत्पन्न अशांति पर इसके प्रभाव का अध्ययन किया गया है और डिजाइन दिशानिर्देशों का एक सेट है जो नौसेना की सहायता कर सकते हैं प्रारंभिक डिजाइन चरण के दौरान जहाज डिजाइन पर आ गया है।

जीएसी और बीजीएसी मॉडल के विभिन्न प्रकारों पर किए गए व्यापक अध्ययन कहीं भी किए गए अपने प्रकार के पहले हैं और फ्लाइट डेक और द्वीप विन्यास के हानिकारक प्रभावों को कम करने के लिए एक एयरक्राफ्ट कैरियर डिज़ाइनर को डिज़ाइन चरण इनपुट प्रदान करने में एक लंबा रास्ता तय करेंगे। वाहक के पीछे एरोडायनामिक जगा और इस तरह पायलट कार्यभार को कम करता है।

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NOMENCLATURE

Notation

l	Length of Island, mm.
u	Wind velocity in X-direction (Forward Velocity), m/s.
$u_{Av_Variation}$	Variation in u-velocity from farstream, m/s.
v	Wind velocity in Y-direction, m/s.
w	Wind velocity in Z-direction, m/s.
$w_{Av_Variation}$	Average downwash, m/s
ρ	Density of Air, Kg/m ³
k , TKE	Turbulence Kinetic Energy, J/Kg
μ_t	Turbulent viscosity, Kg/m-s.
ε	Turbulent dissipation rate, m ² /s ³ .
ω	Specific dissipation rate, /s
B	Breadth of GAC Model (Maximum at Flight Deck), m.
D	Depth of Aircraft Carrier, m.
L	Length of GAC Model (Maximum at Flight Deck), m
T	Draught of Aircraft carrier, m.
TI	Turbulence Intensity
$TKE_{Average}$	Average Turbulent Kinetic Energy along glideslope, J/kg.
V_∞	Free stream velocity at inlet of wind tunnel, m/s
W	Width of Island, mm.
X	Distance along longitudinal direction from Origin, m.
Y	Distance along transverse direction from Origin, m.
Z	Distance along vertical direction from Origin, m.

Acronyms

ABL	Atmospheric Boundary Layer
ADV	Acoustic Doppler Velocimeter
AFD	Angled Flight Deck Edge
BFS	Back Facing Step
BGAC	Baseline Generic Aircraft Carrier (GAC without island)
CFD	Computational Fluid Dynamics

CVG	Columnar Vortex Generator
CVN	Aircraft Carrier (Nuclear Propulsion)
CVA	Attack Aircraft Carrier
DTMB	David Taylor Model Basin
DES	Detached Eddy Simulation
DDES	Delayed Detached Eddy Simulation
FLOLS	Fresnel Lens Optical Landing System
FLTDKH	Flight Deck with Half Rounded Edges
FLTDKF	Flight Deck with Full Rounded Edges
FLT	First Layer Thickness
GAC	Generic Aircraft Carrier
Helo Deck	Helicopter Deck
LES	Large Eddy Simulation
LHA	Landing Helicopter Assault
LPD	Landing Platform Dock Ship
LSO	Landing Signals Officer
MILSPEC	Military Specification
MILES	Monotone Integrated Large Eddy Simulation
NATC	Naval Air Test Center
PIV	Particle Image Velocimetry
QEC	Queen Elizabeth Class
RANS	Reynolds Averaged Navier Stokes
Re	Reynolds Number
SFS	Simplified Frigate Ship
TTCP	The Technical Cooperation Program
USN	United States Navy
WOD, V_{wod}	Wind Over Deck