Conceptual Guide to Torpedo System Design and Development

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Defence Research & Development Organisation
Ministry of Defence, New Delhi - 110 011

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2024

DRDO MONOGRAPHS/SPECIAL PUBLICATIONS SERIES

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Cataloguing-in-Publication

Subrahmanyam, RVS and Rao, Y Sreenivas

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DRDO Monographs/Special Publications Series

1. Naval Warfare	2. Weapon System	3. Torpedo System
4. Design & Development	5. Naval Engineering	
I. Title	II. Series	

623.946:62

ISBN 978-93-94166-87-5

Cover Design	*Printing*	*Marketing*
Rajesh Kumar	Rajesh Kumar Singh	Dipti Arora

Published by Director, DESIDOC, Metcalfe House, Delhi – 110 054.

Dedicated
To
Our Beloved Families

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सचिव, रक्षा अनुसंधान तथा विकास विभाग
एवं
अध्यक्ष, डीआरडीओ
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FOREWORD

In the ever-evolving landscape of naval engineering, particularly within the specialized domain of underwater systems, the need for a reliable and comprehensive resource has never been more critical. *The Conceptual Guide to Torpedo System Design and Development* stands out as a crucial work, providing a meticulously organized roadmap through the intricate processes of torpedo design, development, and deployment. More than just a collection of technical information, it is a thoughtfully structured resource that serves as both an educational foundation for newcomers and a practical reference for seasoned professionals.

The authors' profound understanding of the subject, coupled with their extensive hands-on experience, shines through in every chapter. Each section is crafted with care to ensure that even the most advanced topics are presented with clarity, making the content accessible to a wide audience. The guide's ability to seamlessly bridge the gap between theoretical concepts and practical applications underscores its value as an indispensable resource for anyone involved in torpedo design and development.

As *The Conceptual Guide to Torpedo System Design and Development* positions itself to become a cornerstone in the field of underwater weaponry, its comprehensive coverage of essential topics, paired with a strong focus on practical application, solidifies its status as a must-read in this specialized area. I am pleased to see such a significant guide come to fruition and recognize the dedication and expertise that the authors have poured into this work. This text is set to be an invaluable tool for readers and all stakeholders associated with weapon systems, and I commend the authors for their outstanding contribution to the field of naval engineering.

In particular, I must express appreciation for DESIDOC, whose unwavering support and encouragement drive authors to produce such valuable monographs. Their dedication to advancing knowledge through research, collaboration, and resource development ensures that future generations of engineers, researchers, scientists, and defence personnel are equipped with the tools and insights necessary to excel in their respective fields.

(Dr. Samir V. Kamat)

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Preface

The rapid evolution of maritime warfare technology necessitates constant innovation and enhancement of underwater weaponry. This book, titled Conceptual Guide to Torpedo System Design and Development, has been crafted to provide a comprehensive overview of the standard procedures and systematic work flows essential for designing and developing state-of-the-art torpedoes. The primary objective of this guide is to bridge the gap between technical data and practical application, aligning the content with the structured processes followed during torpedo design and development.

This guide serves as a valuable resource that connects theoretical knowledge with real-world practices, offering readers a broad repository of technical information essential for contributing to the field of torpedo technology. The intended audience for this guide is diverse, including students, engineers, defence personnel, researchers, and scientists. Regardless of their specific disciplines, readers may find value in the cross-field concepts that this book presents, providing a broad understanding that enhances their ability to contribute to this specialised field.

The content of this book spans a wide range of topics central to torpedo design and development. It begins with the configuration of the torpedo, based on hydrodynamic design, necessary to achieve the optimal shape and size of the torpedo. The guide then progresses through critical areas such as sensor design,power requirements, stability, and control. Key sections explore the torpedo's capacity to withstand various operational and environmental conditions, focusing on mechanical shell design, material selection, and the integration of miniaturised subsystems. Additionally, the book delves into onboard computing systems, monitoring and safety systems, and comprehensive design considerations for both exercise and warshot iterations. The aerial deployment of torpedoes from helicopters and

fixed-wing aircraft is also covered, including the certification procedures that ensure the safety of both the platform and the weapon. Furthermore, related systems crucial for deployment, such as launchers, fire control computers, and testing protocols, are thoroughly examined.

Torpedo technology plays a pivotal role in modern naval warfare, where maintaining maritime dominance and security is of utmost importance. Advancements in torpedo design and technology have significantly influenced military strategies and underwater operations, making this a critical area of study and development. By following a well-defined workflow, this guide ensures that each aspect of torpedo design is meticulously addressed, providing valuable insight for designers, operating teams, and manufacturers.

The motivation behind writing this book stems from the authors' intention to provide comprehensive knowledge to a varied cross-section of readers engaged in the design and development of torpedoes. The authors' experience and expertise, coupled with a passion for naval engineering, have driven the creation of a structured, practical resource that aligns technical knowledge with real-world applications.

This work owes much to the contributions of colleagues who shared their expertise on specific workflows within their respective fields. We are deeply thankful to the researchers and officers who offered essential input and feedback during the development of this guide. We also extend our profound thanks to the Director, NSTL, and the entire fraternity for their unwavering support throughout this endeavour.

The book is structured to reflect the natural progression of the torpedo development process, beginning with conceptual design and culminating in final validation. Each chapter builds on the previous one, ensuring a logical flow that facilitates understanding and keeps readers engaged. The intent is to provide a cohesive narrative that not only educates but also captivates the reader, leading to a thorough grasp of the torpedo development process.

This guide is expected to be an invaluable resource, equipping readers with the knowledge and techniques necessary to advance their work and make significant contributions to the field of underwater weaponry.

Acknowledgements

With decades of combined experience in the design, development, and testing of advanced defence technologies and systems, we have been fortunate to accumulate a deep reservoir of knowledge. Reflecting on this journey, we were inspired to transform our practical understanding into this book, with the hope of offering clear and valuable insights into the intricacies of torpedo systems. It has been our collective motivation to share this knowledge, ensuring its relevance for current and future generations of engineers, researchers, and defence professionals.

This book is the culmination of dedicated efforts and the invaluable contributions of many passionate colleagues. Shaped by a structured workflow process, it has been meticulously crafted to reflect both expertise and practicality, serving as a practical and comprehensive resource for our readers. We are deeply grateful for the collective wisdom and constructive feedback shared throughout this journey, which have significantly enriched the content and nurtured a spirit of teamwork and learning. Our heartfelt appreciation goes to Dr Abraham Varughese, Director, NSTL and his team for their unwavering support, insightful discussions, and expertise. We hope the knowledge presented here serves as a comprehensive guide and contributes to the advancement of underwater systems and related technologies.

Additionally, we extend our heartfelt gratitude to the team of office of DG(NS&M) for their invaluable support.

We sincerely acknowledge the invaluable support of Dr K Nageswara Rao, Director, DESIDOC, Ms Alka Bansal and the editorial team for their technical expertise and dedication, which greatly contributed to the preparation of this monograph.

We sincerely thank Dr Samir V Kamat, Chairman, DRDO and Secretary, DDR&D for the exceptional motivation and unwavering encouragement, which has been a source of inspiration throughout the creation of this document. The guidance and support provided have been instrumental in bringing this work to fruition.

Finally, we extend our heartfelt gratitude to our spouses, Smt R Visala Subrahmanyam and Smt Y Lakshmi Sreenivas Rao, for their unwavering patience, understanding, and support throughout the many months of our dedication to crafting this monograph. Their encouragement has been our pillar of strength.

Visakhapatnam

Dr RVS Subrahmanyam
Dr Y Sreenivas Rao

List of Acronyms

ADC	Analog-to-Digital Converter
AHRS	Attitude and Heading Reference Systems
AI	Artificial Intelligence
AR	Augmented Reality
AUVs	Autonomous Underwater Vehicles
BAR	Blade Area Ratio
BEM	Boundary Element Methods
BLDC	Brushless DC
BMS	Battery Management Systems
BW	Bandwidth
CAD	Computer-Aided Design
CATH	Combined Altitude Temperature and Humidity
CCO	Ceiling Cut Off
CFD	Computational Fluid Dynamics
CFRP	Carbon Fiber Reinforced Polymer
CMM	Coordinate Measuring Machines
CNC	Computer Numerical Control
CNT	Carbon Nanotube
CONOPS	Concept of Operations
CPU	Central Processing Unit
CRAW	Compact Rapid Attack Weapon
CRC	Cyclic Redundancy Check
DAC	Digital-to-Analog Converter
DCO	Depth Cut Off

DEMAG	Demagnetisation
DoD	Depth of Discharge
DSP	Digital Signal Processing
DSPs	Digital Signal Processors
DTC	Direct Torque Control
EEZs	Exclusive Economic Zones
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMF	Electromotive Force
EMI	Electromagnetic Interference
EMRU	Electro-Mechanical Release Unit
ESD	Electrostatic Discharge
ETs	Environmental Tests
FCS	Fire Control System
FEA	Finite Element Analysis
FEM	Finite Element Method
FIAM	Flight in Air Materials
FOC	Field-Oriented Control
FOG	Fiber Optic Gyroscopes
FoS	Factor of Safety
GCPs	Ground Control Points
GFRP	Glass Fiber Reinforced Polymer
GM	Gain Margin
GPS	Global Positioning System
GPU	Graphics Processing Units
HB	High Bandwidth
HB Array	Halbach Array
HILS	Hardware-in-the-Loop Simulation
HMI	Human-Machine Interface
HRG	Hemispherical Resonating Gyroscopes
HWT	Heavyweight Torpedo
ICDs	Interface Control Documents

ICZM	Integrated Coastal Zone Management
IGBTs	Insulated Gate Bipolar Transistors
IM	Insensitive Munitions
INS	Inertial Navigation System
IPM	Interior Permanent Magnet
IRS	Instrumentation and Recording System
ISD	Initial Straight Depth
ISR	Initial Straight Run
ITA	Initial Turn Angle
LCB	Longitudinal Centre of Buoyancy
LCG	Longitudinal Centre of Gravity
LDV	Laser Doppler Velocimetry
LWT	Lightweight Torpedoes
MASD	Multi-Static Active Sonar
MEMS	Microelectromechanical Systems
ML	Machine Learning
MPA	Maritime Patrol Aircraft
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NATO	North Atlantic Treaty Organisation
NDT	Non-Destructive Testing
OBC	Onboard Computer
PCMs	Phase Change Materials
PDMT	Programmable Deep Mobile Target
PEDs	Power Electronic Devices
PEMFCs	Proton Exchange Membrane Fuel Cells
PID	Proportional-Integral-Derivative
PIV	Particle Image Velocimetry
PJP	Pump Jet Propellers
PM	Phase Margin
PMSMs	Permanent Magnet Synchronous Motors
PN	Proportional Navigation

PPUs	Peripheral Processing Units
PRI	Pulse Repetition Interval
PSU	Power Supply Unit
PWM	Pulse Width Modulation
REEs	Rare Earth Elements
RLG	Ring Laser Gyroscopes
ROVs	Remotely Operated Vehicles
RTDs	Resistance Temperature Detectors
RTOS	Real-time operating system
SAR	Synthetic Aperture Radar
SEMA	Switched Reluctance Motors
SIL	Software-In-the-Loop
SL	Source Level
SLBMs	Submarine-Launched Ballistic Missiles
SNR	Signal-to-Noise Ratio
SOA	Service-Oriented Architecture
SOC	State of Charge
SoC	System on Chip
SoH	State of Health
SoM	System on Module
SSD	Solid-State Drive
TR	Transmit Receiver
TRM	Torpedo Release Mechanism
TVR	Transmitting Voltage Response
USVs	Unmanned Surface Vessels
UUVs	Unmanned Underwater Vehicles
UV	Ultraviolet
VCB	Vertical Centre of Buoyancy
VCG	Vertical Centre of Gravity
VLM	Vortex Lattice Methods
VLWT	Very Lightweight Torpedoes
VR	Virtual Reality
WFCS	Weapon Fire Control Systems

CHAPTER 1

Introduction

Coastlines around the world extend for thousands of kilometres, encompassing diverse and strategically vital geographical features such as sandy beaches, rocky shores, river deltas, estuaries, and coral reefs. These coastal regions are crucial for economic activities like fishing, tourism, and trade, and they hold significant reserves of minerals, oil, and natural gas.

1.1 COASTAL ECONOMIC ZONES AND STRATEGIC RESOURCES

Exclusive Economic Zones (EEZs) extend up to 200 nautical miles from the coastlines, granting countries sovereign rights for the exploration, exploitation, conservation, and management of natural resources within this zone. These EEZs are rich in marine biodiversity and significant mineral resources, including polymetallic nodules valuable for their manganese, nickel, cobalt, and copper content. Additionally, many EEZs include substantial offshore oil and natural gas reserves, crucial for energy security.

Legal Frameworks and Enforcement within EEZs are established by national laws and international agreements, ensuring that countries' rights are protected against unauthorised activities by foreign entities. Enforcement within EEZs is carried out by national navies and coast guards through regular patrols and surveillance missions, supported by advanced radar and satellite systems that monitor and deter illegal activities such as unauthorised fishing, smuggling, and incursions by foreign vessels. Sustainable management of EEZs also involves the regulation of fishing practices to maintain fish stocks and marine biodiversity, supported by policies implemented by relevant governmental bodies.

1.2 COASTAL PROTECTION AND SECURITY MEASURES

Multi-layered Protection Strategies involve integrating military, technological, environmental, and community-based approaches. Navies and coast guards are at the forefront of maritime security, conducting regular patrols and surveillance missions to deter illegal activities such as smuggling, piracy, and unauthorised intrusions. Advanced coastal radar networks, satellite surveillance, Maritime domain awareness, and automated identification systems provide comprehensive monitoring of maritime activities, ensuring real-time data for quick response to potential threats. Major naval bases and coast guard stations are strategically located along coasts, enhancing countries' defensive capabilities.

Environmental conservation efforts are another critical aspect of coastal security. Conservation efforts are directed towards preserving fragile ecosystems like mangroves, coral reefs, and estuaries, which act as natural barriers against coastal erosion and storm surges. Sustainable fishing practices and stringent regulations help maintain marine biodiversity and prevent overexploitation of resources. Coastal communities are actively involved in these conservation efforts, receiving training and support to adopt sustainable livelihoods that do not harm the environment.

1.3 INFRASTRUCTURE DEVELOPMENT AND INTEGRATED COASTAL ZONE MANAGEMENT

Modernisation of ports and coastal infrastructure plays a vital role in enhancing economic security and resilience against natural disasters. Integrated Coastal Zone Management (ICZM) plans are implemented to balance development with environmental sustainability, ensuring that coastlines can support both economic growth and ecological health.

1.4 HYDROGRAPHIC SURVEYS AND NAUTICAL CHARTING

Hydrographic surveys and nautical charting are periodically conducted by national hydrographic offices under their respective authorities. These surveys are essential for updating nautical charts, ensuring safe navigation, and supporting various maritime activities. The primary purposes include identifying underwater hazards, determining water depths, and monitoring coastal and marine environments to aid in conservation efforts and pollution control. The survey process involves meticulous planning based on maritime stakeholder requirements, environmental changes, and

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About the Monograph

This guide comprehensively explores workflows for modern torpedo design, bridging theoretical principles with practical application. It offers a structured approach integrating engineering practices with technical data, making it highly useful for professionals, researchers and students.

Key topics include hydrodynamic configuration, sensor design, power requirements, stability, and control mechanisms. The book covers critical aspects such as shell design, material selection, onboard computing, monitoring, safety measures, and considerations for both exercise and combat torpedoes. Deployment strategies for aerial launches from helicopters and fixed-wing aircraft are discussed, emphasizing safety and compatibility certification.

The guide also examines launchers, fire control computers, and rigorous testing protocols to ensure reliability and operational readiness. It reflects the development cycle, from conceptual design to validation, adhering to a systematic engineering process.

Designed with a systems engineering perspective, it offers cross-disciplinary insights, building foundational expertise for designing and developing underwater weapon systems. It serves students, engineers, defence personnel, researchers, and scientists, equipping readers to contribute meaningfully to underwater weaponry.

About the Authors

Dr Rallabhandi Venkata Surya Subrahmanyam, retired Scientist 'G' from Naval Science and Technological Laboratory (NSTL), has nearly four decades of expertise in torpedo systems and underwater technologies. A Mechanical Engineering graduate from Sri Venkateswara University, with Masters from IIT Kanpur and a PhD from Andhra University, he established key facilities like the Cavitation Tunnel, CNC Manufacturing Centre, and Weapon Integration Centre. He spearheaded the critical technologies project and, as Head of the Mechanical Engineering Directorate, led projects on torpedoes, decoys, weapon fire control systems for submarines, and aerial delivery systems, advancing NSTL's defence innovations.

Dr Y Sreenivas Rao, retired Distinguished Scientist and former Director General (Naval Systems & Materials), has extensive experience in missile and product development. A Mechanical Engineering graduate from JNTU, Hyderabad, with a PhD from Osmania University, he began his career at BHEL in gas turbine manufacturing. Joining DRDO in 2000, he worked on Prithvi warheads, contributed to missile defence, and led Mission Shakti as Project Director for the Exo Interceptor Missile. As NSTL Director and later Director General (NS&M), he advanced underwater weapons and oversaw six laboratories.

978-93-94166-87-5

Price: ₹ 2500
US $ 50
UK £ 40

Defence Scientific Information & Documentation Centre
Defence Research & Development Organisation
Ministry of Defence, Metcalfe House, Delhi - 110 054