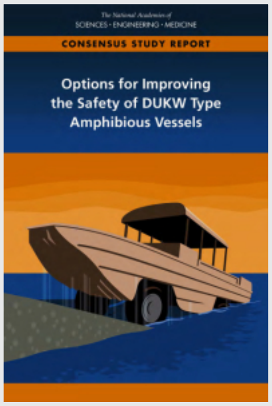

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SPECIAL REPORT 342

Options for Improving the Safety of DUKW Type Amphibious Vessels

Committee on Options for Improving the Safety of Amphibious Vessels (DUKW Boats) When Used in Passenger Service

A Consensus Study Report of
The National Academies of
SCIENCES • ENGINEERING • MEDICINE

TRANSPORTATION RESEARCH BOARD

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COMMITTEE ON OPTIONS FOR IMPROVING THE SAFETY OF AMPHIBIOUS VESSELS (DUKW BOATS) WHEN USED IN PASSENGER SERVICE

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Preface

In September 2020, the United States Coast Guard's (USCG's) Office of Design and Engineering Standards (CG-ENG), Naval Architecture Division (CG-ENG-2) requested that the National Academies of Sciences, Engineering, and Medicine (the National Academies), through the Transportation Research Board's (TRB's) Marine Board, provide guidance to USCG on actions it could take that would increase safety on DUKW boats used for commercial passenger service. To conduct the study, the National Academies appointed a committee of eight experts in the fields of naval architecture, vessel design, and engineering; USCG regulation and inspection activity; safety standards development; vessel safety and operations; and shipbuilding. The committee's full Statement of Task is provided in Chapter 1. The committee's analysis on risk assessment in Chapter 8 was based on its own application of the principles outlined in the guidance notes cited. This report represents the consensus efforts of these eight individuals, who served uncompensated in the public interest. Their biographical information is provided in Appendix A.

ACKNOWLEDGMENTS

The committee met seven times over a 10-month period to gather information relevant to the study, draft sections of its report, and deliberate on the report's content, findings, and recommendations. The committee wishes to thank the individuals participating in the briefings and discussions over the course of the study and making other contributions to the committee's work:

From USCG, CAPT Daniel H. Cost, Chief, Office of Design and Engineering Standards; CAPT Robert C. Compher, former Chief, Office of Design and Engineering Standards; and Jaideep Sirkar, Chief, Naval Architecture Division. The committee especially wishes to thank LCDR Dimitri Wiener and Mr. Andrew J. Lachtman of the Naval Architecture Division who served as the principal contacts between USCG and the committee and coordinated information requests from the committee to offices within the agency.

The committee also wishes to thank the industry representatives who provided valuable information to the committee: Eric Christensen, Director of Regulatory Affairs and Risk Management of the Passenger Vessel Association (PVA); Ms. Cindy Brown, Chief Executive Officer, Boston Duck Tours; and Mr. Tony Cerulle, Chief Engineering Officer, Boston Duck Tours; and Mr. Alex Moyers, former owner of Chattanooga Ducks.

Mark S. Hutchins managed the study and assisted the committee in the preparation of its report under the guidance of Thomas R. Menzies, Jr., Director, Consensus and Advisory Studies. Sarah Jo Peterson supported the writing of the report. Anusha Jayasinghe, Program Officer, provided extensive support to the committee. Karen Febey, Senior Report Review Officer, managed the report review process.

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The committee thanks the following individuals for their review of this report:

MICHAEL DINE, University of California, Santa Cruz
THOMAS H. GILMOUR, United States Coast Guard (retired)
TOM GRUBER, American Bureau of Shipping
KYLE MCAVOY, Robson Forensic, Inc.
T. BLAKE POWELL, JMS Naval Architects
JOHN WATERHOUSE, Elliott Bay Design Group

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft before its release. The review of the report was overseen by **CHRIS T. HENDRICKSON,** Carnegie Mellon University, and **CRAIG PHILIP,** Vanderbilt University. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

Contents

Acronyms and Abbreviations

APV	amphibious passenger vehicle
CFR	Code of Federal Regulations
COI	Certificate of Inspection (issued by USCG to a regulated vessel)
DUKW	collective term for WWII DUKW, Stretch Duck, and/or Truck Duck
MAIB	Marine Accident Investigation Branch (United Kingdom)
MSC	Marine Safety Center (USCG)
MISLE	Marine Information for Safety and Law Enforcement database (USCG)
NOAA	National Oceanic and Atmospheric Administration
NTSB	National Transportation Safety Board
NVIC	Navigation and Vessel Inspection Circular (issued by USCG)
NWS	National Weather Service
OCMI	Officer in Charge, Marine Inspection
PFD	personal flotation device
PVA	Passenger Vessel Association
SMS	safety management system
SST	Simplified Stability Test
USCG	United States Coast Guard
WEA	Weather Emergency Alert
WWII DUKW	DUKW manufactured during World War II

Executive Summary

Safety on DUWKs—amphibious vessels first produced during World War II and long used for sightseeing tours—has been an area of special concern for the United States Coast Guard (USCG) and the National Transportation Safety Board (NTSB).[1] A mass fatality sinking in 1999 led to significant changes in how USCG oversees the DUKWs under its jurisdiction. When another DUKW sank, costing 17 lives, while on a tour in 2018, both government and the tour industry revisited their previous responses and recommendations and looked anew for solutions.

The USCG Assistant Commandant for Prevention Policy (CG-5P), Office of Design and Engineering Standards (CG-ENG) asked the National Academies of Sciences, Engineering, and Medicine (the National Academies) to provide guidance to USCG on actions that will increase safety on DUKWs used for commercial passenger service. USCG specifically requested investigation of changes to vessel design, engineering, and outfitting and also encouraged the exploration of operational and enforcement changes.

DUKWs are essentially military cargo trucks that float. Although tour operations that use the historic vessels from World War II have adapted the DUKWs to meet modern safety standards to the extent possible, some hazards of the original design remain. Modified DUKWs, such as Stretch DUKWs from the 1990s, and Truck Ducks, purpose built in the early 2000s for sightseeing tours, have remedied some of these remaining hazards, but not all. Moreover, because of the many adaptations over time, individual vessels within the DUKW fleet exhibit a significant amount of variability.

DUKWs are at greater risk of sinking—and sinking more quickly—than modern small passenger vessels. They sit low in the water and can be easily swamped by waves. In addition, the requirements for operating on land meant that the historic vessels had numerous locations where water could enter the hull. Maintenance procedures and operating restrictions have long been used to compensate for the vessel's design shortcomings.

NTSB and USCG have identified the presence of canopies as a contributing factor to the loss of life during DUKW fatality events. Tour operators use canopies and, in some cases, clear plastic side curtains, to provide customer comfort during tours. However, if the vessel sinks, these enclosures can prevent passengers from escaping. After the 2018 casualty event, NTSB and USCG both recommended that tour operators remove canopies.

The report examines actions that will improve survivability for the vessel and for persons on board. The report reviews design, engineering, and outfitting options to provide reserve buoyancy and prevent flooding, and it assesses the potential for additional restrictions on operating areas to provide a safer environment for waterborne tours. It also evaluates the advisability of wearing life jackets while on the water and covers methods for improving safety operations.

Recognizing that DUKW tour operators have improved canopy designs since the 1999 sinking, the report reviews the designs for canopies and side curtains currently in use. Still,

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[1] An independent agency, NTSB investigates accidents—often in conjunction with other agencies—but will independently analyze any collected evidence. NTSB will then release an accident report that determines probable cause and issues safety recommendations. While the NTSB recommendations are not mandatory, within 90 days, the designated party (in this case USCG) must respond in writing as to why it agrees or does not agree to the recommendations.

improvements are needed. Canopies should be considered "restrictive canopies" unless demonstrated to be the safety equivalent to no canopy. Any canopy that makes wearing a life jacket inadvisable should also be considered a restrictive canopy.

The risks to passengers on DUKWs vary significantly depending on the DUKW vessel, the operating area, and operator diligence. The committee's recommendations to USCG distinguish between higher risk and lower risk operations and target the most rigorous measures to higher risk operations only. The factors defining higher and lower risk operations are listed in Box ES-1. The risks listed are related to the vessel design, systems, and operating area and are considered physical attributes of the vessel and its environment that are permanent features, unless physically altered. Issues related to operations management, such as lack of proper maintenance and insufficient crew training, could be addressed by improving safety management practices that could apply to any passenger vessels and could be monitored by USCG.

BOX ES-1
Higher Risk and Lower Risk Operations Related to the Vessel Design, Systems, and Operating Area

Factors Leading to Higher Risk Operations

- Fast Sinking Times
- Low Freeboard
- Lack of High-Capacity Bilge Pump
- Multiple Hull Penetrations
- Engine Air Cooling Vents
- Potential Exposure to High Winds and Waves
- High Traffic Areas
- Restrictive Canopies

Lower Risk Operations

- None of the Factors Above
- Reserve Buoyancy, Unless in High Winds and Waves

RECOMMENDATIONS

The committee offers USCG the following recommendations, starting with the use of risk assessment for DUKW operations and then providing specific recommendations to mitigate the hazards discussed in the chapters on flooding, operating areas, canopies, life jackets, and safety operations. All recommendations are specific to WWII DUKWs, Stretch Ducks, and Truck Ducks.

Use of Risk Assessment

Recommendation 1: USCG should base updates to regulations and enforcement practices on the risks to passengers, operators, and the environment posed by each type of DUKW in its intended operating area.

Recommendation 2: USCG should use a consistent risk-assessment methodology, applied at the industry level, to better understand the risks to passenger safety and to allow USCG to focus regulations and requirements on those DUKW operations that present the greatest risk.

Flooding and Survivability

Recommendation 3: USCG should investigate requiring the installation of external inflatable bladders or buoyant floats, alone or in combination with internal flotation foam, to provide reserve buoyancy for DUKWs used in higher risk operations.

Recommendation 4: To reduce the flooding risk from hull penetrations, USCG should investigate requiring DUKW operators to

- **a. Permanently seal all drain plugs and valves that are not necessary for safe operation and maintenance of the vessel.**
- **b. Install carrier bearings.**
- **c. Install reliable bilge pumps of sufficient capacity to respond to flooding through the largest remaining through-hull penetrations, as per NVIC 1-01.**

Recommendation 5: USCG should require vessel operators to demonstrate that adequate engine cooling is available for the expected operating areas and risks found in that area.

Operating Areas

Recommendation 6: USCG should develop uniform guidance to assist Officers in Charge, Marine Inspection (OCMIs) in evaluating the suitability of bodies of water for DUKW operations.

Recommendation 7: USCG should develop requirements for equipment, training, and operations that leverage the National Weather Service's severe weather alert system to reduce the likelihood that a DUKW will encounter wind and waves that exceed its operating capabilities.

Restrictive Canopies

Recommendation 8: USCG should require DUKWs in higher risk operations to remove canopies or to adopt canopy designs that have been demonstrated to provide the equivalent in safety to no canopy.

Life Jackets

Recommendation 9: USCG should consider making the wearing of life jackets mandatory during the waterborne portion of tours run by higher risk operations.

Recommendation 10: USCG should investigate the use of Type III life jackets in place of Type I life jackets.

Safety Operations

Recommendation 11: USCG should require that owners and operators develop an effective company operating and safety manual, as recommended in NVIC 1-01, that incorporates training, maintenance, and operational standards as well as emergency response plans.

Recommendation 12: USCG should require, and the OCMI should confirm, that the operations and safety manual includes procedures for monitoring changing weather conditions and adjusting operations accordingly.

Recommendation 13: USCG should require, and the OCMI should confirm, that the operating and safety manual includes a discussion of the number of personnel and their duties.

1
Introduction

Three DUKWs, amphibious passenger vessels used for commercial tours, have sunk with passengers on board since 1999. In total, across the three major marine casualty events, 32 people have died, including a number of children. The most recent sinking, the *Stretch Duck 7* while touring on Table Rock Lake near Branson, Missouri, in 2018, took 17 lives.

DUKWs in commercial service in the United States currently number about 200 vessels, under the jurisdiction of either the state of Wisconsin or the United States Coast Guard (USCG).[2] USCG's jurisdiction over DUKWs extends only to their water operations and is part of the agency's regulatory oversight of vessels that engage in commercial operations on the navigable waters of the United States. USCG administered regulations aim to ensure that passenger vessels under its jurisdiction operate safely with minimal risk of death or injury to passengers and operating crew.

The original DUKW was designed and manufactured for military use during World War II. After the war, surplus DUKWs were used for tour operations as early as 1946. A surprising number of WWII DUKWs are still in service today, and tour operators often celebrate the vessels' history and ties to the military. In the 1990s and 2000s, two variations of the WWII DUKW came into use. Stretch Ducks and Truck Ducks updated the WWII design for use in the commercial touring industry.

USCG sought recommendations from the National Academies of Sciences, Engineering, and Medicine (the National Academies) on improving the safety on navigable waters of all three types of vessels, collectively referred to as DUKWs. In response to its charge, the National Academies appointed an expert committee to produce this report, which considers and offers recommendations on candidate technologies to prevent flooding and to keep DUKWs afloat and upright, criteria for evaluating the safety of operating areas, design options for improving the safety of canopies, requirements for life jackets, and other means to improve the safe operation of DUKWs. The committee also recommends that USCG use a consistent risk-assessment methodology to evaluate the risks of each type of DUKW.

STUDY ORIGINS, CHARGE, AND APPROACH

In response to the sinking of the *Stretch Duck 7* in 2018 and the long history of discussions regarding DUKW safety, the USCG Assistant Commandant for Prevention Policy (CG-5P), Office of Design and Engineering Standards (CG-ENG) asked the National Academies to provide guidance to USCG on steps that could be taken to improve the safety of DUKW vessels. Specifically, USCG asked that this guidance be based on a review and assessment of investigations of past casualties involving these vessels; technical studies of vessel modifications having the potential to reduce the risk of casualties; and any enforcement and operational changes that may be required to implement the modifications. The full Statement of Task is provided in Box 1-1. In seeking this guidance, it asks for suggestions on places where USCG regulations and policy documents could be modified to implement one or more of the identified options.

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[2] The DUKWs under state jurisdiction in Wisconsin operate on non-navigable waters of the United States.

At the request of USCG, the committee focused only on the DUKW type of amphibious passenger vessels. Other amphibious vessels have different designs, are fewer in number, and have not experienced similar levels of casualties and injuries as the DUKW vessels. The committee only considered in-water operations. Issues related to over-the-road operations were not part of the study.

BOX 1-1
Statement of Task

A study committee appointed by the National Academies of Sciences, Engineering, and Medicine will review the safety record of amphibious vessels (DUKW boats) when used for commercial passenger service and identify options for improving their safety performance through changes in vessel design, engineering, and outfitting. The committee will review findings and recommendations from investigations of casualties involving these vessels by the National Transportation Safety Board, the United States Coast Guard, and other marine safety authorities in the United States and abroad. It will examine the results of technical studies of options for vessel modifications to reduce the risk of a casualty and increase the potential for crew and passenger survival. The committee may also explore other related options that deserve consideration, including any enforcement and operational changes that may be desirable to implement vessel modifications. The committee will summarize the options in terms of the risks they can mitigate and the ways in which the use and operation of DUKW boats could be impacted. Based on its expert appraisal, the committee will identify and suggest places where Coast Guard regulations and policy documents could be modified to implement one or more of the options, such as in the Navigation and Vessel Inspection Circular 1-01 (Inspection of Amphibious Passenger Carrying Vehicles).

The National Academies formed a committee to respond to the USCG Statement of Task and to provide the desired industry and engineering input on how USCG could improve DUKW safety. The members of the committee and their backgrounds are listed in Appendix A of the report.

Public Meetings

The committee began its work in January 2021, and all but one of its meetings were convened virtually because of the COVID-19 pandemic. While the virtual meetings had drawbacks, including constraints on interactive discussion and a spread in time zones, they did allow for a larger number of briefings. The committee was able to use these many opportunities for briefings, as well as requests for more detailed follow-on correspondence, to take a multi-pronged approach to the study.

The committee conducted three meetings open to the public where it received briefings from industry and the sponsoring agency. Meeting dates and presenting organizations are as follows:

January 22, 2021

Representatives from the USCG Commercial Regulations & Standards Directorate, Office of Design & Engineering Standards, Naval Architecture Division, reviewed what they were seeking from the committee, provided background on the topic, and discussed the data they could make available. They also responded to written and verbal questions from the committee.

January 25, 2021

Boston Duck Tours representatives presented an overview of their company, its operations, and the many measures they have taken to improve the safety of the DUKW vessels they operate. They also responded to questions from the committee. Following the meeting, Boston Duck Tours sent further information on the design of their Truck Ducks and the safety measures they have implemented.

March 19, 2021

A representative from the Passenger Vessel Association (PVA) made a presentation describing the DUKW operators who are members of PVA and highlighted the many studies and meetings sponsored by PVA to facilitate communication and understanding between USCG and PVA members and to improve the safety of DUKWs. The presentation provided an overview of pending legislation on DUKW vessels[3] and suggested areas of focus for the committee.

Also, the former owner of the Chattanooga Ducks presented his knowledge and thoughts on DUKW operations, safety concerns, and remedies implemented by his former company. Chattanooga Ducks operates four WWII DUKW vessels on the Tennessee River along the Chattanooga waterfront.

The information presented by industry during the open meetings helped the committee to understand current DUKW operations and the many measures industry has taken to address the safety concerns with these vessels when operating on the water. It also helped the committee understand some of the challenges faced by the operators in implementing additional safety measures.

USCG provided valuable information on the many studies undertaken over the years and provided valuable fleet data and prior studies, USCG recommendations and responses to the prior casualties, and National Transportation Safety Board (NTSB) recommendations from casualty investigations.[4] The committee had access to the NTSB and USCG investigation reports on previous casualties, studies done by USCG on DUKW flotation after flooding, and USCG studies on DUKW intact and damage stability. Because DUKW type vessels are also operated in other countries, the committee had access to the United Kingdom's Marine Accident

[3] S.62 - Duck Boat Safety Enhancement Act of 2021, introduced January 7, 2021, https://www.congress.gov/bill/117th-congress/senate-bill/62/text; and S.1031 - Duck Boat Safety Enhancement Act of 2020, passed by Senate December 10, 2020, https://www.congress.gov/bill/116th-congress/senate-bill/1031.

[4] An independent agency, NTSB investigates accidents—often in conjunction with other agencies—but will independently analyze any collected evidence. NTSB will then release an accident report that determines probable cause and issues safety recommendations. While the NTSB recommendations are not mandatory, within 90 days, the designated party (in this case USCG) must respond in writing as to why it agrees or does not agree to the recommendations.

Investigation Branch investigation reports on DUKW casualties and Canadian government casualty reports.

In addition, the committee reviewed designs for reserve buoyancy and canopies used on DUKWs overseas and in Wisconsin, where DUKWs operate under state jurisdiction, as well as vessels that are purpose built amphibious touring vessels.

REPORT ORGANIZATION

The rest of this report is divided into an overview chapter, five subject-specific chapters, and a final chapter that presents summary findings and recommendations. Each subject-specific chapter reviews major casualty events from the perspective of the chapter's subject, examines regulations, and evaluates potential solutions. Chapter 2 provides an overview of DUKW boats and their regulation and introduces the major casualty events on water that the committee studied, as well as the findings from casualty data. Recommendations from casualty reports from the United States and the United Kingdom are reviewed. The chapter closes with an overview of survivability, including how the concept applies to DUKWs and their operations.

Chapter 3 examines the intact stability of DUKWs, methods to increase reserve buoyancy to keep a DUKW upright and afloat, and solutions to prevent flooding through hull penetrations and engine-cooling air vents. Chapter 4 examines why certain bodies of water pose higher risk for DUKWs and how to make the evaluation of operating areas and operating restrictions more rigorous and objective. Chapter 5 explains why canopies are both an important part of DUKW touring businesses and an impediment to the survivability of persons on board. The chapter then reviews canopy designs currently in use and potential designs that are likely to increase the survivability of persons on board during sinking events. Chapter 6 reviews the data for increasing safety by requiring the wearing of life jackets, the difficulties posed by the requirement that DUKWs carry Type I life jackets, and the potential for Type III life jackets to provide more safety. Chapter 7 looks at the human side of safety on DUKWs, covering the number of personnel, crew training, and passenger responsibilities.

Chapter 8 presents the committee's summary findings on higher risk operations, lists the committee's recommendations, and, in support of the committee's recommendation that USCG use risk assessment to assess DUKW safety, provides examples of risk-assessment methods.

2
DUKW Boats and Safety

Safety experts have known for a long time that DUKWs have had hazards that can increase the risk of loss of life for passengers and crew. Some hazards are connected to obsolete design elements unique to an amphibious vehicle that must travel safely on land and water. Other hazards date back to its original use as a military vehicle intended to be operated and occupied by healthy, fit men in an already high-risk combat environment. Restrictive canopies, however, are a hazard that have been added to the vessels specifically to facilitate their use for sightseeing tours.

The United States Coast Guard (USCG) oversees safety for DUKWs using a mix of regulations and guidance policy documents. DUKWs, as small passenger vessels, are regulated under a structure that requires the Officer in Charge, Marine Inspection (OCMI) to exercise significant independent judgment when determining what is safe for unique vessels such as DUKWs. Part of the challenge of DUKW safety is to create procedures that will support OCMIs in making consistent evaluations of diverse vessels in a variety of operating areas.

This chapter provides of brief history of DUKWs and the major casualty events—accidents or incidents—that led to investigations, studies, and recommendations by government agencies and that also formed the core set of examples for committee study. The chapter presents summary data on fleet size, location, and casualty types and events and provides an overview of the current regulatory structure, key regulations, and the guidance document, "Navigation and Vehicle Inspection Circular No. 1-01 (NVIC 1-01).[5] Recommendations stemming from the major casualty events in the United States and United Kingdom are reviewed. The chapter closes with an overview of the concept of survivability with respect to both the vessel and the persons on board.

BRIEF HISTORY

DUKWs were originally produced for the U.S. military during World War II. The design, funded by the National Defense Research Committee, modified a cargo truck manufactured for the military by General Motors Corporation. Commonly known as "ducks," DUKW is not an acronym but nomenclature for the design: D = 1942, U = utility, K = front-wheel drive, and W = two rear-driving axles. Although intended to meet immediate war needs only, DUKWs went on to serve in the Korean War and were deployed for scientific research, search and rescue operations, and tourism.

Military surplus DUKWs saw use for sightseeing tours as early as 1946. Tour operators acquired them as unique and interesting vehicles for making combined land and water tours, and many of the tour operations celebrate the vessels' historic ties to World War II. Tours are typically advertised as family-friendly and welcome infants and children. To accommodate sightseeing, operators have made numerous modifications to the military DUKWs for passenger safety and comfort and to comply with regulations. Common alterations include adding passenger seating, accommodations to ease boarding, and canopies with and without side curtains.

[5] See https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/5ps/NVIC/2001/n1-01.pdf.

Although many of the DUKWs still in use are from the 1940s, Ride the Ducks International of Branson, Missouri, modified the original DUKW design to develop the Stretch Duck in the 1990s and the Truck Duck in the 2000s for use in sightseeing tour businesses. For Stretch Ducks, they used the original WWII chassis, resulting in a freeboard similar to WWII DUKWs. Truck Ducks are built around a different chassis and the freeboard is higher than for the other DUKW types. For the purposes of this report, the World War II DUKW, Stretch Duck, and Truck Duck are all considered DUKW vessels; their specifications are summarized in Box 2-1.

In recent years, DUKWs have been used for sightseeing tours in Boston, Massachusetts; along the Gulf Coast in Alabama and Galveston, Texas; Hot Springs, Arkansas; Chattanooga, Tennessee; Wisconsin Dells, Wisconsin; and the island of Guam. Tours were also offered by Ride the Ducks International and its franchisees in Baltimore, Maryland; Branson, Missouri; Philadelphia, Pennsylvania; San Francisco, California; Seattle, Washington; and elsewhere until a string of fatalities on water and land ended the businesses. Internationally, World War II DUKWs have been used for amphibious tours in London, Liverpool, and Dublin.

BOX 2-1
DUKW Vessel Types

WWII DUKW Amphibious Truck
- Typical Length and Beam: 31.0’ L × 8.0’ B
- Freeboard: About 12” to 24”

Stretch Duck
- Sold by Ride the Ducks International, Branson, Missouri
- WWII GMC chassis stretched by 15”, new hull, new engine and drive train
- Typical Length and Beam: 33.0’ L × 8.0’ or 8’-6” B
- Freeboard: About 12” to 24”

Truck Duck APV
- Sold by Ride the Ducks International, Branson, Missouri
- Similar design and layout to WWII DUKW, but with different chassis and larger hull
- Purpose built for tours
- Typical Length and Beam: 33.0’ L × 8.0’ or 8’-6” B
- Freeboard: About 24” to 33”

Amphibious passenger vehicles (APVs) must operate safely both on land and on water. The three types of DUKWs are more like a truck that floats, as opposed to a boat that can go on land. The DUKWs’ unique design has presented numerous challenges to safe use on water. Moreover, the DUKWs of the WWII era are now over 75 years old, and the Stretch Ducks and Truck Ducks are no longer being produced and their developer is no longer in business.

MAJOR CASUALTY EVENTS ON WATER

The committee studied eight marine casualty events involving DUKWs that have occurred since 1999 in the United States and the United Kingdom. This overview provides basic information about the casualty events; more detailed descriptions of specific issues will be highlighted in the relevant chapters.

DUKWs proved to be unusually fast sinking during the casualty events in the United States and the United Kingdom that involved progressive flooding. As shown in Appendix B, a 4-inch diameter hole below the waterline could cause a DUKW with a freeboard of 24 inches to sink in 15 minutes. The actual time to sink would likely be less than 15 minutes, depending on winds and waves and the likelihood that the passengers and crew moving around the vessel would increase the rate of flooding. Moreover, WWII DUKWs and Stretch Ducks may have a freeboard as low as 12 inches. During the sinkings with mass fatalities, survivors and witnesses reported that their boat submerged in just a few minutes or even less.

Events with Fatalities

Three incidents led to multiple deaths: the *Miss Majestic* flooding and sinking in 1999 that killed 13; the collision of a barge with *DUKW 34* in 2010, which led to 2 passenger deaths; and the *Stretch Duck 7* flooding and sinking in 2018 that resulted in 17 deaths. All victims drowned.

The *Miss Majestic*, a WWII DUKW, sank in Lake Hamilton, Hot Springs, Arkansas, on May 1, 1999, with 20 passengers and the master on board. Among the 13 fatalities were 3 children ages 3, 4, and 5. The vessel flooded and then sank after a driveshaft boot seal in the hull failed following an improper repair to the seal. The bilge pumps were inadequate to remove the incoming water. Once the DUKW sank low enough to flood over the stern, the boat became completely submerged in about a minute. Passengers attempted, but failed, to don life jackets. Passengers also struggled or failed to escape the vessel because of a canopy with small window openings that impeded exit over the sides and a windshield surrounded by plastic curtains that blocked forward egress.[6]

DUKW 34, a Stretch Duck, sank after a collision with a barge in the Delaware River, Philadelphia, Pennsylvania, on July 7, 2010. Of the 33 passengers and 2 crew on board, 2 passengers—a young adult male and a female teenager—did not survive. The series of events that led to the sinking began when the master of *DUKW 34* executed procedures for a fire emergency that included anchoring the vessel. After anchoring *DUKW 34*, its crew and the crew of the barge's tugboat failed to follow safety procedures intended to prevent collisions. At the time of the collision and rapid sinking, all passengers were still on board the vessel, scrambling to don life jackets.[7]

Stretch Duck 7 sank in a storm on Table Rock Lake, near Branson, Missouri, on July 19, 2018. Of the 31 persons on board, 16 passengers and 1 crew member died. Among the fatalities were 4 children under age 10, 5 adults in their 60s, and 4 adults in their 70s. Although a severe

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[6] National Transportation Safety Board (NTSB), 2002, "Sinking of the Amphibious Passenger Vessel *Miss Majestic*, Lake Hamilton, Hot Springs, AR, May 1, 1999," Marine Accident Report NTSB/MAR-02/01, April 2. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR0201.pdf.

[7] NTSB, 2001, "Collision of Tugboat/Barge *Caribbean Sea/The Resource* with Amphibious Passenger Vessel *DUKW34*, Philadelphia, PA, July 7, 2010," Marine Accident Report NTSB/MAR-11/02, June 21. https://www.ntsb.gov/investigations/Pages/DCA10MM025.aspx.

thunderstorm warning had been issued for the area including Table Rock Lake, the operators "likely believed," according to the National Transportation Safety Board (NTSB), that they "could safely complete the waterborne portion of the tour before the thunderstorm arrived." Instead, the weather suddenly shifted and large waves, which exceeded the vessel's operating limits, led to progressive flooding. The vessel foundered and then capsized. As water surrounded their feet, survivors reported standing up in an attempt to retrieve life jackets, which were stored overhead in the canopy, and suddenly being up to their necks in water. The vessel's canopy, with one of two side curtains still covering the windows, likely slowed or prevented escape.[8]

Other Casualty Events

Additional casualty events, fortunately with no or only minor injuries, provide insights into the safety risks of flooding and fire for DUKWs. These events include several in the United Kingdom.

A Stretch Duck on Lake Union, Seattle, Washington, sank in December 2001 while under tow back to the maintenance facility. The cause of the flooding was a mechanic's failure to replace a 4.5-inch hull drain plug, which was not caught during inspection, after a repair.

Stretch Duck 7, the DUKW that sank in 2018, was involved in an earlier flooding incident in 2015; the master created a large splash when entering the water, and water came in through the engine compartment vents and the vessel lost propulsion.

In the United Kingdom, two WWII DUKWs operating for tours at Salthouse Dock, Liverpool, sank in March 2013 and June 2013 after hull penetrations. Both DUKWs had been modified with buoyancy foam that proved inadequate to prevent sinking. *Wacker Quacker 4* sank from a missing drain plug. The passengers had already disembarked, and the vessel, which had also suffered a steering failure, was under tow at the time of the sinking. *Wacker Quacker 1* sank with its passengers still on board. As the boat began to take on water, the passengers attempted to pass out life jackets and many began jumping out over the sides. Fortunately, the vessel was in shallow waters near the shore, and the stern of the boat did not become fully submerged, allowing all passengers and crew to escape.[9]

The *Cleopatra*, a WWII DUKW operating on the Thames River, London, suffered a fire while on tour in September 2013. Investigators concluded that the fire started when overheated machinery ignited the buoyancy foam, which was tightly packed into the hull and had become contaminated with grease. Upon noticing the fire, the master maneuvered the DUKW close to the shore. As flames engulfed the passenger compartment, passengers escaped over the sides or down the ladders at the stern and into the water.[10]

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[8] NTSB, 2020, "Sinking of Amphibious Passenger Vessel *Stretch Duck 7*, Table Rock Lake, near Branson, MO, July 19, 2018," Marine Accident Report NTSB/MAR/20-01, April 28. https://www.ntsb.gov/news/events/Pages/2020-DCA18MM028-BMG.aspx.

[9] Marine Accident Investigation Branch (MAIB), 2014, Very Serious Marine Casualty Report NO 32/2014, December. https://assets.publishing.service.gov.uk/media/54c1722240f0b6158d00002b/MAIBReport_32-2014.pdf.

[10] MAIB, 2014, Very Serious Marine Casualty Report NO 32/2014, December. https://assets.publishing.service.gov.uk/media/54c1722240f0b6158d00002b/MAIBReport_32-2014.pdf.

Casualty Events on Other Small Passenger Vessels

According to a recent report, 6,097 Subchapter T vessels held a valid Certificate of Inspection (COI) during the 2020 calendar year.[11] Of these 6,097 vessels, only 127 were listed as amphibious vessels, approximately 2 percent of the entire Subchapter T fleet. In comparison, charter fishing vessels numbered 1,005 vessels (16 percent) of the fleet and excursion/tour vessels numbered 2,248 vessels (37 percent) of the fleet. While the number of DUKW vessels in operation has decreased over time, the total number has never been a large percentage of all Subchapter T vessels.

To compare DUKW casualty events to similar events on other Subchapter T vessels, the committee examined casualty incidents for all small passenger vessels from 1995 to present from NTSB's accident reports that resulted in deaths or injuries.[12] The results are summarized in Table 2-1. Of the casualty events between 1995 and 2021, 3 of the 12 events involved amphibious vessels (specifically DUKW boats) and included 39 percent of the total deaths (32) and 38 percent of the total injuries (33), while representing roughly 2 percent of the Subchapter T fleet. Furthermore, all three DUKW casualties involved a flooding or capsizing event while carrying passengers. In comparison, the remaining 98 percent of the Subchapter T fleet suffered 61 percent of the total deaths (51) and 62 percent of the total injuries (53). Three of the remaining nine events on other Subchapter T vessels involved flooding or capsizing, representing 16 deaths and 24 injuries.

TABLE 2-1 Summary of NTSB Subchapter T Small Passenger Vessel Accident Reports from 1995 to 2021

NTSB Report Name and Accident #	Date of Accident	Type of Vessel	Inspection Subchapter	Type of Accident	Deaths	Injuries	Total Number Onboard
P/V Conception (DCA19MM047)	9/2/2019	Overnight	T	Fire in Accommodation Space	34	2	38
P/V Stretch Duck 7 (DCA18MM028)	7/19/2018	Stretch DUKW	T	Flooding by Storm Conditions	17	7	31
P/V Island Lady (DCA18FM010)	1/14/2018	Passenger Shuttle	T	Fire in Engine Room	1	14	53
P/V Tahoe Queen (DCA16FM054)	8/16/2016	Day Excursion	T	Fire, Crew Only Onboard	0	2	4
P/V Adventure Hornblower (DCA16FM035)	3/31/2016	Whale Watching	T	Collided with Dock	0	8	149
P/V DUKW 34 (DCA10MM025)	7/7/2010	Stretch DUKW	T	Flooding, Run Over by Barge	2	26	37
P/V Lady D (DCA04MM015)	3/6/2004	Pontoon Water Taxi	T	Capsized from High Winds	5	16	25
P/V Express Shuttle II (DCA05MM002)	10/17/2004	Passenger Shuttle	T	Engine Room Fire, Crew Only Onboard	0	1	3
P/V Panther (DCA03MM018)	12/30/2002	Small Day Excursion	T	Flooding from Known Leak	0	1	34

[11] See Table 2 of USCG-PVA Quality Partnership Annual Report, 2018-2020, https://www.dco.uscg.mil/Our-Organization/Assistant-Commandant-for-Prevention-Policy-CG-5P/Inspections-Compliance-CG-5PC-/Office-of-Investigations-Casualty-Analysis/Marine-Casualty-Reports.
[12] See https://www.ntsb.gov/investigations/AccidentReports/Pages/Reports.aspx.

P/V Taki-Tooo (DCA03MM035)	6/14/2003	Charter Fishing	T	Capsized Bar Crossing Heavy Seas	11	8	19
P/V Port Imperial Manhattan (DCA01MM008)	11/17/2000	Commuter Ferry	T-L	Fire in Engine Room	0	1	11
P/V Miss Majestic (DCA99MM021)	5/1/1999	WW2 DUKW	T	Flooding, Driveshaft Seal Failure	13	0	21
Total of All Subchapter T Vessels					83	86	425
Total of Subchapter T Vessels (Excluding DUKWs)					51	53	336
Total of DUKWs Only					32	33	89

NOTE: NTSB = National Transportation Safety Board; P/V = passenger vessel.
SOURCE: https://www.ntsb.gov/investigations/AccidentReports/Pages/Reports.aspx.

DUKW FLEET SIZE AND LOCATION

The DUKW fleet in the United States is made up of vessels under two regulatory structures: vessels requiring a COI issued by USCG and vessels subject only to the regulations of their respective states. About 130 to 150 DUKWs are located in Wisconsin and operated under state jurisdiction by two major DUKW tour operators, Original Wisconsin Ducks and Dells Army Ducks.

As of early 2021, 58 DUKWs had an active COI, the majority of which were Truck Ducks. Only 3 Stretch Ducks still have active COIs. Examples of fleets under USCG jurisdiction include Boston Duck Tours, Boston, Massachusetts; Gulf Coast Ducks, Orange Beach, Alabama; National Park Duck Tours, Hot Springs, Arkansas; Chattanooga Ducks, Chattanooga, Tennessee; and Ride the Ducks, Tumon, Guam.[13]

As recently as 2019, the DUKW fleet with COIs numbered 123, and between 2000-2021 197 DUKWs have been active in the USCG-regulated fleet. Although many of these vessels have been taken out of service or scrapped, the potential fleet size under USCG jurisdiction is larger than the current 58 vessels.[14]

The fleets operate in a variety of environments. Table 2-2 describes the numbers of DUKWs under USCG's jurisdiction for years 2019 and 2021 that operate in rivers versus lakes, bays, and sounds and in protected versus partially protected waters.

TABLE 2-2 Number of DUKWs with Active COIs by Type and Route, 2019 and 2021

	WWII		**Stretch Duck**		**Truck Duck**		**Total**	
Water Body of Route	2019	**2021**	2019	**2021**	2019	**2021**	2019	**2021**
Rivers	19	**5**	32	**1**	30	**28**	81	**34**
Lakes, Bays, &Sounds	17	**13**	9	**2**	16	**9**	42	**24**
Total	36	**18**	41	**3**	46	**37**	123	**58**
	WWII		**Stretch Duck**		**Truck Duck**		**Total**	

[13] Boston Duck Tours, https://bostonducktours.com; Gulf Coast Ducks, http://gulfcoastducks.com; National Park Duck Tours, http://rideaduck.com; Ride the Ducks, Guam, https://bestguamtours.com/cruises/ride-the-duck.
[14] Committee review of USCG, Marine Information for Safety and Law Enforcement (MISLE) database, data provided by USCG.

Type of Waters of Route	2019	**2021**	2019	**2021**	2019	**2021**	2019	**2021**
Protected Waters	36	**18**	39	**3**	22	**21**	97	**42**
Partially Protected Waters	0	**0**	2	**0**	24	**16**	26	**16**
Total	36	**18**	41	**3**	46	**37**	123	**58**

SOURCE: USCG, Marine Information for Safety and Law Enforcement (MISLE) database.

Partially protected waters (defined in Box 2-2) are a higher risk environment for DUKWs. Currently, only Truck Ducks, which have a higher freeboard, follow routes in partially protected waters. The safety implications of the route types are discussed more fully in Chapters 3 and 4.

BOX 2-2
Definitions of "Waters" from CFR 46 175.400

Protected waters is a term used in connection with stability criteria and means sheltered waters presenting no special hazards such as most rivers, harbors, and lakes, and that is not determined to be exposed waters or partially protected waters by the cognizant Officer in Charge, Marine Inspection (OCMI).

Partially protected waters is a term used in connection with stability criteria and means:
1. Waters not more than 20 nautical miles from the mouth of a harbor of safe refuge, unless determined by the cognizant OCMI to be exposed waters;
2. Those portions of rivers, estuaries, harbors, lakes, and similar waters that the cognizant OCMI determines not to be protected waters; and
3. Waters of the Great Lakes from April 16 through September 30 of the same year (summer season).

SOURCE: Code of Federal Regulations, https://www.ecfr.gov/current/title-46.

USCG REGULATORY OVERSIGHT

USCG has regulatory oversight over DUKWs that engage in commercial operations on the navigable waters of the United States. As small passenger vessels, safety on DUKWs is regulated under Title 46 of the Code of Federal Regulations (CFR) Chapter I, Subchapter T, Small Passenger Vessels under 100 Gross Tons (hereafter "Subchapter T"). These regulations cover all aspects of the DUKWs, from hull fabrication, machinery and electrical, safety equipment, stability and seaworthiness, and vessel operations. Stability regulations in Subchapter S may also apply. Box 2-3 lists the key applicable regulations in Subchapters S and T. USCG applies the regulations through the process of issuing a COI and, in some cases, stability letters. Vessels with a COI are inspected annually, and the inspections include safety operations.

The OCMI has the discretion under Subchapter T to accept alternatives to Subchapter T's requirements. However, the OCMI must determine that these alternatives provide an equivalent level of safety. DUKWs, because of their unique design, typically cannot meet all of the Subchapter T regulations directly. The USCG's "Navigation and Inspection Circular No. 1-01" (NVIC 1-01) describes methods or configurations that USCG has pre-determined to meet a level of safety equivalent to the intent in Subchapter T. NVIC 1-01 is based on recommendations from the USCG Marine Board of Investigation and NTSB's reports on the sinking of the *Miss*

Majestic. The guidelines are also intended to better educate both USCG inspectors and DUKW operators on recommended safety measures. Owners may employ means or methods other than those in NVIC 1-01, provided that the owner demonstrates they are equivalent to the Subchapter T regulations.

NVIC 1-01 guidelines may recommend more stringent or conservative standards for DUKWs, or the guidelines may, in effect, recommend waiving the Subchapter T standards, allowing lower standards in recognition of the origins of DUKWs as military cargo vehicles and their equally important need to travel safely on land given an equivalent level of safety is provided by other means.

BOX 2-3
Key Regulations: Code of Federal Regulations, Title 46 Shipping, Volume 7, Chapter I Coast Guard

Subchapter S, Subdivision and Stability

- Part 170 Stability requirements for all inspected vessels
  - 170.170 Weather criteria
  - 170.173 Criterion for vessels of unusual proportion and form
- Part 171 Special rules pertaining to vessels carrying passengers
  - 171.050 Passenger heeling requirements

Subchapter T, Small Passenger Vessels (under 100 gross tons)

- Part 175 General provisions
  - 175.400 Definitions of terms used in this subchapter
- Part 176 Inspection and certification
  - 176.110 Routes permitted
- Part 177 Construction and arrangement
  - 177.500 Means of escape
  - 177.820 Seating
- Part 178 Intact stability and seaworthiness
  - 178.310 Intact stability requirements—general
  - 178.330 Simplified stability proof test (SST)
- Part 179 Subdivision, damage stability, and watertight integrity
  - 179.350 Opening in the side of a vessel below the bulkhead or weather deck
  - 179.360 Watertight integrity
- Part 180 Lifesaving equipment and arrangements
  - 180.71 Life jackets
  - 180.72 Personal flotation devices carried in addition to life jackets
- Part 182 Machinery installation
  - 182.520 Bilge pumps
- Part 185 Operations
  - 185.304 Navigation underway
  - 185.506 Passenger safety orientation
  - 185.508 Wearing of life jackets
  - 185.516 Life jacket placards
  - 185.520 Abandon ship and man overboard drills and training

SOURCE: Code of Federal Regulations, https://www.ecfr.gov/current/title-46.

NVIC 1-01 guidelines for bilge pumps are an example of a recommendation that the OCMI apply more stringent standards to DUKWs. Under Subchapter T, small passenger vessels require bilge pump capacity adequate to remove water from normal operations only, because the assumption in Subchapter T is that structural integrity and through hull fittings can be relied on to prevent flooding. NVIC 1-01 instead advises the OCMI to only issue a COI to DUKWs that also have a high-capacity bilge pump "for emergency operations, which can offset uncontrolled flooding of the largest penetration in the hull until the vehicle can be safely beached."[15]

For passenger seating, NVIC 1-01 guidelines allow lower standards, which reflect, in part, that the width of many DUKWs was determined back in 1942. Under NVIC 1-01,

- Seats in rows can be 28 inches apart, seat front to seat front, two inches shorter than under 46 CFR 177.820(d)(3).
- Centerline aisle width can be as narrow as 14 inches, significantly narrower than the minimum 24 inches or 30 inches required, depending on centerline aisle length under 46 CFR 177.820(d)(1) and (2).
- Number of passengers is limited to one passenger per 17 inches width of fixed seating, one inch shorter than under 46 CFR 176.113(b)(3).

USCG justifies standards that allow more cramped conditions in the passenger compartment of DUKWs through another guideline that stipulates the primary means of escape is over the side of the DUKW. Because of this, the narrow aisle width and tighter seating are not considered unacceptable safety hazards by the USCG.

REVIEW OF CASUALTY DATA

Casualty data available from USCG's MISLE database provide insights into the reliability and weaknesses of DUKWs.

The operators of DUKWs under USCG's jurisdiction reported 267 casualty events and 519 casualty types from 1999-2021. For individual vessels, 70 percent had at least one casualty type. (A single casualty event may have more than one casualty type.) Table 2-3 summarizes the

TABLE 2-3 Summary of DUKW Casualty Types and Events, 1999–2021

Number of	WWII DUKW	Stretch Duck	Truck Duck	Total
Boats that had one or more casualty types	33	65	41	139
Casualty types over all events	77	225	217	519
Events	43	121	103	267
Boats active in the fleet, 2000 to 2021	78	70	49	197
% of fleet with at least one casualty type	**42%**	**93%**	**84%**	

NOTE: A single casualty event may have more than one casualty type.
SOURCE: USCG, Marine Information for Safety and Law Enforcement (MISLE) database.

number of casualty types and events. The World War II DUKWs were less prone to incidents than the Stretch Ducks or Truck Ducks. Of the 78 WWII DUKWs active during this time, only 33 of them had at least one casualty type, representing 42 percent of the WWII fleet.

Table 2-4 lists the number of casualties by type and shows that DUKWs have historically had reliability issues, particularly in their propulsion or steering systems. For all DUKW types, the two most frequent casualty types by far were Loss/Reduction of Vessel Propulsion/Steering

[15] USCG, NVIC 1-01, p. 32. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/5ps/NVIC/2001/n1-01.pdf.

(220 total casualties) and Material Failure/Malfunction (210 total casualties). The actual number of times a DUKW had difficulties in the water may be higher than as recorded in Tables 2-3 and 2-4. Statements by operators during the committee's open sessions revealed that not all stoppages are considered reportable to USCG.

TABLE 2-4 Number of Reported Casualty Types, 1999–2021

Casualty Type	WWII DUKW	Stretch Duck	Truck Duck	Total
Abandonment		1		1
Allision		1	2	3
Collision		2		2
Discharge/Release - Pollution	1	1		2
Fire - Initial	2		2	4
Flooding - Initial	3	4	6	13
Flooding - Progressive		1		1
Fouling		2	1	3
Grounding	10	4	5	19
Loss of Electrical Power	2	4	3	9
Loss/Reduction of Vessel Propulsion/Steering	25	105	90	220
Material Failure/Malfunction	17	89	104	210
Set Adrift		4	1	5
Sinking	1	2		3
Vessel Maneuver	3	5	8	16
Total	**64**	**225**	**222**	**511**

SOURCE: USCG, Marine Information for Safety and Law Enforcement (MISLE) database.

RECOMMENDATIONS FROM CASUALTY REPORTS AND SAFETY BULLETINS

After each DUKW marine casualty event with loss of life, NTSB and USCG have carried out investigations, prepared reports analyzing the reasons for the casualty, and made recommendations to enhance safety by design and operational improvements to prevent future casualties. The United Kingdom issues similar reports after significant marine incidents.

Recommendations from key reports relevant to the committee's work are summarized below and discussed in more detail in the relevant chapters. In addition to these reports, the committee also reviewed letters, safety bulletins, and announcements by USCG and NTSB regarding recommendations and measures to improve DUKW safety.

Recommendations After *Miss Majestic* Sinking

The report of USCG's Marine Board of Investigation on the *Miss Majestic* makes multiple recommendations and led to the creation of NVIC 1-01.[16] Key recommendations in this report include:

[16] Marine Board of Investigation, USCG, 1999, "Circumstances Surrounding the Sinking of the M/V *MISS MAJESTIC* on Lake Hamilton, Hot Springs, AR, on May 1, 1999, with Multiple Loss of Life," September 29.

- Listed DUKW documents that should be available to operators and the OCMI,
- Required in-water testing of vessel integrity after repairs to hull or appendages,
- Required testing of bilge pumps with water at every USCG annual inspection,
- Recommended that USCG issue policy on inspecting DUKWs' unique features with emphasis on shaft housings and boot seals (which led to the creation of NVIC 1-01),
- Recommended that USCG establish a working group of operators and industry experts to develop DUKW safety best practices, and
- Recommended considering a requirement for more than one crew member on board when that crew member is acting as a tour guide.

NTSB's Marine Accident Report on the *Miss Majestic* was released in 2002, after USCG had issued NVIC 1-01.[17] The report contains new recommendations and reiterates some existing ones. Most significant to the committee's work, NTSB recommended that USCG require that DUKW passenger vessels have sufficient reserve buoyancy through passive means to remain upright and afloat with full passenger complement in the event of flooding. For DUKWs that lack reserve buoyancy, NTSB recommended that USCG require them to do the following:

- Remove canopies,
- Close all unnecessary access plugs,
- Install independent bilge pumps of sufficient capacity to dewater flooding from the largest remaining penetration,
- Install four independent bilge alarms,
- Inspect the vessel in water each time a through-hull penetration has been removed or uncovered,
- Verify the watertight condition of the vessel at the start of each waterborne departure, and
- Comply with remaining provisions of NVIC 1-01.

Recommendations After *DUKW34* Collision

In its Marine Accident Report on *DUKW34*, NTSB focused its recommendations on cell phone use by safety critical personnel, as this was one of the root causes of the collision. NTSB also recommended that DUKW operators develop improved methods of ensuring safety, including that emergency management procedures be well understood by safety critical employees.[18]

Recommendations After *Wacker Quacker 1* and *Cleopatra*

The United Kingdom's Marine Accident Investigation Branch issued a joint report on *Wacker Quacker 1* and the *Cleopatra.* The report contains multiple recommendations including to

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[17] NTSB, 2002, "Sinking of the Amphibious Passenger Vessel *Miss Majestic*, Lake Hamilton, Hot Springs, AR, May 1, 1999," Marine Accident Report NTSB/MAR-02/01, April 2. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR0201.pdf.
[18] NTSB, 2011, "Collision of Tugboat/Barge *Caribbean Sea/The Resource* with Amphibious Passenger Vessel *DUKW34*, Philadelphia, PA, July 7, 2010," Marine Accident Report NTSB/MAR-11/02, June 21. https://www.ntsb.gov/investigations/Pages/DCA10MM025.aspx.

improve DUKW operations, prevent foam flotation from becoming a fire hazard, improve emergency procedures, reduce the possibility of entrapment from canopies, and improve the availability of life jackets.[19]

Recommendations After *Stretch Duck 7* Sinking

After the sinking of the *Stretch Duck 7* in 2018, NTSB issued a Marine Safety Recommendation Report in 2019 and its Marine Accident Report in 2020. The Marine Safety Recommendation report focused on two of NTSB's *Miss Majestic* recommendations—to either require reserve buoyancy through passive means or remove canopies—and provided additional background information and explanations.[20] The NTSB Marine Accident Report reiterated the recommendations to provide reserve buoyancy or to remove canopies and also included three new recommendations for USCG[21]:

- Require the closure of forward hatches,
- Update NVIC 1-01 to address the issue of severe weather and egress during a rapid sinking event, and
- Examine training and knowledge of operators.

NTSB also made three recommendations for the operator, Ripley Entertainment:

- Revise current operating policy to update guidance on adverse weather operation,
- Modify the spring-loaded forward hatch to enable closure during waterborne operation, and
- Re-evaluate emergency procedures for donning life jackets.

USCG recommended, but stopped short of requiring, that "vessel owners and operators of DUKW passenger vessels remove canopies, side curtains, and associated overhead framing to improve emergency egress for passengers and crew" in its Marine Safety Information Bulletin (MSIB) issued in April 2020. USCG also stated in the bulletin that it would "consider implementation of further safety measures for DUKWs" at the conclusion of its investigation of the *Stretch Duck 7* and "initiate a policy update to NVIC 1-01 with input from public and industry stakeholders."[22]

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[19] MAIB, 2014, Very Serious Marine Casualty Report NO 32/2014, December. https://assets.publishing.service.gov.uk/media/54c1722240f0b6158d00002b/MAIBReport_32-2014.pdf.
[20] NTSB, 2019, "Improving Vessel Survivability and Passenger Emergency Egress of DUKW Amphibious Passenger Vessels," Marine Safety Recommendation Report MSR1901, November 6. https://www.ntsb.gov/investigations/AccidentReports/Reports/MSR1901.pdf.
[21] NTSB, 2020, "Sinking of Amphibious Passenger Vessel *Stretch Duck 7*, Table Rock Lake, near Branson, MO, July 19, 2018," Marine Accident Report NTSB/MAR/20-01, April 28. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.
[22] USCG, 2020, "Recommendation for DUKW Passenger Vessel Canopy Removal," Marine Safety Information Bulletin 15-20, April 22. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/MSIB/2020/MSIB-15-20_Recommendation%20for%20DUKW%20Passenger%20Vessel%20Canopy%20Removal.pdf.

OVERVIEW OF SURVIVABILITY

Survivability formed the organizing principle of the committee's approach to the Statement of Task. The committee considered two types of survivability: of the vessel and of the persons on board. Survival of the vessel should also help the persons on board to survive; however, persons on board should be able to survive even if the vessel does not.

The goal of stability regulations, as discussed in more detail in Chapter 3, is the survivability of the vessel. Chapter 4 exams certain restrictions on operating areas that aim to increase the survivability of the vessel, given conditions in its operating environment. The goal is for the vessel to stay afloat and stable at all times. For intact and damage stability requirements, this includes even after a casualty occurs. However, persons on board may still be injured or killed during a casualty event such as a fire or a collision.

Survivability of all persons on board is the goal of lifesaving regulations. The examination of canopies and escape during emergencies in Chapter 5, the focus on life jackets in Chapter 6, and the review of safety operations, such as training and drills on escaping the vessel, in Chapter 7 are examples of methods to increase the survivability of all persons on board. The waived passenger seating standard, discussed in the section on USCG regulatory oversight, is an example of determining that lowering a standard will not materially affect the survivability of persons on board.

There are trade-offs involved in all methods of increasing the survivability of a vessel or of the persons on board. For DUKWs, which must operate safely on land and on water, evaluating the trade-offs can become even more complex. Chief among the trade-offs is cost versus added survivability. The costs may be direct, such as the cost of retrofitting the vessel, or both direct and indirect, such as removing canopies or wearing life jackets, which may make the vessel and its tours less attractive to potential customers. Ultimately, it is USCG's responsibility to consider the cost and the practicality of implementing any potential changes by performing a formal cost–benefit analyses as part of any future federal rulemaking process. Another trade-off is weighing uncertainty around effectiveness. For example, methods that depend on the ability of the crew and passengers to understand and execute what is required of them, especially in an emergency, may be more vulnerable to human error than techniques that incorporate "passive safety."

Passive safety may be even more crucial for DUKWs than for other small passenger vessels. Because of their design and equipment, DUKWs tend to be far more sensitive to operator mistakes than other classes of Subchapter T boats. DUKWs also rely, to a greater extent, on passengers to be responsible for their own safety and even the safety of others. The higher cost and likelihood of human fallibility puts even more importance on achieving acceptable levels of safety by minimizing the possibility of a casualty event occurring in the first place.

The potential costs and the uncertainty around the effectiveness of various techniques is why the committee considered it critical to consider both types of survivability from all aspects and to examine multiple, complementary risk mitigating actions. Because of the variations among DUKWs and their operating areas, the committee also sought to avoid "one-size-fits-all" approaches to survivability. Instead, the committee divided DUKW operations—the vessels and operating areas—into higher risk and lower risk operations. The factors leading to higher risk operations are listed in Box 2-4, explained more fully in the subject-specific chapters, and summarized in the final chapter on recommendations.

BOX 2-4
Higher Risk and Lower Risk Operations Related to the Vessel Design, Systems, and Operating Area

Factors Leading to Higher Risk Operations

- Fast Sinking Times
- Low Freeboard
- Lack of High-Capacity Bilge Pump
- Multiple Hull Penetrations
- Engine Air Cooling Vents
- Potential Exposure to High Winds and Waves
- High Traffic Areas
- Restrictive Canopies

Lower Risk Operations

- None of the Factors Above
- Reserve Buoyancy, Unless in High Traffic Areas

3
Flooding and Survivability

For DUKWs, the greatest risk to passenger safety is flooding from the failure of through-hull penetrations, hull damage, or overtopping waves. Ideally, DUKW vessels would have the capability to remain afloat and upright even when flooded. This capability has been advocated by the National Transportation Safety Board (NTSB) and in proposed legislation. However, Subchapter T regulations do not require this capability in small passenger vessels the size and passenger complement of DUKWs. In addition, achieving this level of buoyancy on DUKW vessels has proven to be difficult.

This chapter describes the risks to DUKWs that can lead to flooding, the results of that flooding, studies and countermeasures that have been tried in the past, and actions the United States Coast Guard (USCG) can take to reduce the likelihood and consequences of flooding. Specific solutions explored target increasing a vessel's buoyancy and removing the risks posed by driveshaft boot seals and the shortcomings of the Higgins Pump, both original to the WWII design. Mitigations for the risks posed by drain plugs and valves and engine cooling air vents are also discussed. Ultimately, additional actions and regulatory guidance are needed to reduce the likelihood of flooding and, when flooding occurs, to mitigate its effects.

FLOODING AND CASUALTY EVENTS

USCG's MISLE database lists a total of 11 "flooding-initial" events from 1999-2021, and flooding was also the cause of all the DUKWs lost to sinking. For each of the four DUKW sinking accidents, the principal factors contributing to their loss were as follows:

- The *Miss Majestic* had a driveshaft boot seal came loose after an incorrect repair.
- The Seattle Stretch Duck was missing a large drain plug after a repair.
- The *DUKW 34* was run over by a barge and pushed under water.
- The *Stretch Duck 7* (2018) had progressive flooding from large waves swamping the vessel through the bow engine cooling air vents and over the low freeboard on the sides.

Flooding-initial events not leading to sinking include the *Stretch Duck 7* (2015), which experienced partial flooding after a harder than normal entry into the water. The failure of shaft seals on two Truck Ducks operating in Tumon, Guam, allowed water to flood into the "sea chest box," a small watertight compartment, which did not compromise the overall survivability of the vessels. As reported to the committee, five Boston Ducks also experienced flooding-initial events during the span of 1999–2006, although little detail is available about the causes.

The two sinking events in Liverpool, United Kingdom, were also preceded by flooding. *Wacker Quacker 4* sank in January 2013 after suffering a steering failure at the same time a hull drain plug was missing. The Higgins Pump masked the flooding from the missing drain plug until they stopped the engine during passenger evacuation and could not get it restarted. *Wacker*

Quacker 1, which sank in March 2013, suffered hull breaches after its propeller hit a discarded car tire. Its passengers and crew abandoned into the water.[23]

The principal factors that led to these flooding and sinking events are characteristic of many DUKWs. DUKWs are considered "open boats," and as such are more susceptible to catastrophic swamping from boarding seas. In addition, DUKWs do not have a proper "ship shape" bow; rather, they have a flat or "scow" bow and a truck hood. The bow design worsens a DUKW's ability to go through large waves without taking on water. Some DUKWs have large openings on the bow for engine cooling air intake/exhaust vents. The WWII DUKWs and Stretch Ducks have low freeboards, ranging from 12 to 24 inches at their lowest point. Finally, because DUKWs also travel on land and have other unique design features, the vessels have multiple hull penetrations below the waterline. They may have multiple shaft seals and hull drain plugs that are potential large flooding points if damaged, repaired incorrectly, or inadvertently left open.

However, considering the actual casualty events, no DUKW to date has been lost only because of insufficient intact stability. In all cases, the DUKW's initial intact stability had been compromised by progressive flooding of some type before the DUKW was lost. Stability for a boat is the ability to return to an upright position after experiencing a force such as wind, waves, or the forces resulting from the loading and unloading of cargo and passengers. Intact stability, as opposed to damage stability, is the initial stability of the vessel before any incidents that could weaken it.[24]

REGULATIONS AND NVIC 1-01

Regulations and policy documents applicable to DUKW stability and seaworthiness cover intact stability and watertight integrity. Because DUKWs carry fewer than 50 passengers and are less than 65 feet in length, they do not need to meet damage stability standards (46 CFR 179.212). The NVIC 1-01 policy of using bilge pumps during a flooding emergency is also intended to mitigate the risk of flooding.

Intact Stability Standards

Under Subchapter T (46 CFR 178.310), DUKWs may use either the Simplified Stability Test (SST) or the intact stability criteria contained in 46 CFR Subchapter S, Subdivision and Stability. The choice of standard is dependent on several conditions regarding the boat's size, arrangement, and service. DUKWs that only operate on "protected waters," as per NVIC 1-01, can opt to use SST. DUKWs with routes on "partially protected waters," must use the intact stability criteria given in Subchapter S. The owners of DUKWs operating on "protected waters" can also elect to use the stability criteria specified in Subchapter S.

Because DUKWs are considered open boats, they are subject to additional intact stability criteria under both SST and Subchapter S. Under 46 CFR 175.400, the definition of an open boat is "a vessel not protected from entry of water by means of a complete weathertight deck, or by a combination of a partial weathertight deck and superstructure that is structurally suitable for the waters upon which the vessel operates."

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[23] MAIB, 2014, Very Serious Marine Casualty Report NO 32/2014, December. https://assets.publishing.service.gov.uk/media/54c1722240f0b6158d00002b/MAIBReport_32-2014.pdf.

[24] National Academies of Sciences, Engineering, and Medicine (NASEM), 2018, *Review of U.S. Coast Guard Vessel Stability Regulations*, Washington, DC: The National Academies Press, p. 11. https://doi.org/10.17226/25258.

The SST contained in 46 CFR 178.330 is in essence a simple proof test performed on the DUKW at the loading (i.e., operating) condition specified in the regulations. The DUKW is first loaded with fixed weights that represent the weight and location of the maximum number of passengers and crew that will be permitted on board. The lowest freeboard of the DUKW from the waterline to its gunwale is then measured. A portion of the fixed weights is then moved out board to one side to represent the effect of wind and passenger heeling on the DUKW. As an open boat, a DUKW will pass the SST if less than one-quarter of the upright freeboard is subsequently submerged when the weights are moved.

In general, using Subchapter S involves performing an inclining or other suitable means to accurately determine the DUKW's lightship characteristics of weight and vertical and longitudinal center of gravity. With this information a detailed set of stability calculations is performed to show compliance with the three standards.

Subchapter S requires DUKWs to meet stability criteria for vessels of unusual proportion and form (46 CFR 170.173), for weather (46 CFR 170.170), and passenger heeling requirements (46 CFR 171.050). The weather criteria and passenger heeling criteria were developed for mechanically powered vessels of ordinary proportions and form with flush decks (170.170(d)). USCG's Marine Safety Center (MSC) requires additional calculations to be submitted in accordance with 170.170(d) for open boats that lack flush weather decks, including DUKWs, as follows[25]:

- Weather criteria: The regulation, 46 CFR 170.170, limits the maximum heel angle to 14 degrees or one-half of the upright freeboard submerged, whichever is less. The limit used by USCG for DUKWs is 14 degrees or one-quarter of the upright freeboard submerged, whichever is less.
- Passenger heeling criteria: The regulation, 46 CFR 171.050, limits the maximum heel angle to 14 degrees or the angle of heel at which the deck edge is first submerged, whichever is less. The limits used by USCG for DUKWs is 14 degrees or one-half of the upright freeboard submerged, whichever is less.

The additional MSC requirements for weather and passenger heeling criteria for open boats were included in an internal memo as early as November 2007, but not issued as formal USCG guidance until 2018.

Watertight Integrity

DUKWs are subject to two regulations that address watertight integrity. 46 CFR 179.350, covering openings in the side of a vessel below the bulkhead or weather deck, regulates the

[25] These limits, which apply to all inspected open passenger boats—not just DUKWs—were first put forth in an internal November 2007 MSC Memorandum (Serial: H1-0703309), which was confirmed by an internal September 2008 USCG CG-5212 (now CG-ENG-2) Memorandum. No formal guidance, however, was issued by USCG until the 2018 revision of the "MSC Plan Review Guidelines (PRG), Review of Stability for Small Passenger Vessels (T) Procedure Number: H1-01." https://www.dco.uscg.mil/Portals/9/MSC/PRG/PRG.H1-01.2018.04.20.Review_of_Stability_for_Small_Passenger_Vessels_(T).pdf. For a more complete history of the implementation of the stability criteria to DUKWs by USCG and a summary history of the development of small passenger vessel stability regulations in general, refer to Sections 1 and 2.5 of USCG's "MSC Technical Report: Analysis of Open Boat Stability Standard Applied to DUKW Amphibious Vessels," September 3, 2020.

typical thru-hull engine exhausts and overboard discharges from the onboard bilge pumps. It also covers any sea chest seawater connections, but these would not be typical for DUKWs as they do not need to be fitted with a fixed seawater firefighting system. 46 CFR 179.360 regulates watertight integrity and covers any hatches or doors on a Subchapter T passenger vessel. For the typical DUKW this would be the air intake and exhaust vents used for the DUKWs propulsion engine air-cooled radiator.

Flooding/Sinking Events

The committee reviewed the DUKW sinking and flooding casualty events with respect to current regulations and policy.

NVIC 1-01 was created after the *Miss Majestic* sank when a driveshaft boot seal failed after an improper repair to the seal, which had also been previously modified from the original design. NVIC 1-01 addresses shaft boot seals with two recommendations: (1) install restrictor plates in way of the shaft boot seals to slow the rate of uncontrollable flooding from a shaft boot seal failure, or (2) install a carrier bearing in place of the shaft boot seal. This would completely seal the shaft penetration from potential flooding. Neither of these recommendations are mandatory, although the NVIC 1-01 recommends a detailed procedure for inspecting the shaft boot seals, if present, and removing them if their condition appears questionable.[26]

NVIC 1-01 addresses missing drain plugs, the cause of the sinking the Seattle Stretch Duck, only as an inspection item that "should be examined verifying proper fit and function. After the completion of all hull exams for credit these vessels should be operated in the water to ensure watertight integrity."[27]

For watertight integrity, which was compromised by the *Stretch Duck 7*'s large splash event in 2015, the regulations in 46 CFR § 179.360 cover the engine room compartment vents arrangement. Because the *Stretch Duck 7* had been certificated for operation on "protected waters" only, the engine compartment was only required to be able to be made "weathertight," not watertight.

Current stability regulations and policies do not directly address a DUKW's ability to resist boarding seas, which sank the *Stretch Duck 7* in the 2018 storm. Indirectly, the minimum freeboard requirements do tie into potential wind/wave conditions for a given operating route.

Bilge Pumps

Bilge systems on small passenger vessels would not normally be expected to handle emergency flooding events. However, USCG in NVIC 1-01 recommends that DUKW vessels have bilge pumps with the capacity to reliably "offset uncontrolled flooding of the largest penetration in the hull until the vehicle can be safely beached." NVIC 1-01 also raises concerns about the appropriateness of the original WWII high-capacity Higgins Pump for tour operations.[28]

[26] NVIC 1-01, pp. 20, 25. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/5ps/NVIC/2001/n1-01.pdf.
[27] NVIC 1-01, p. 20.
[28] NVIC 1-01, p. 32.

SURVIVABILITY, STABILITY STANDARDS, AND FLOODING

USCG considers it critical to DUKW survivability to mitigate the risk of flooding through means other than relying only on the intact stability requirements in the Subchapter T regulations and their accompanying implementation policy. Although USCG is aware that many DUKWs fail to meet the intact stability standards, as discussed below, the fact that no casualties have been attributed solely to insufficient intact stability has led MSC to conclude that "there is likely a combination of stability standards and operational restrictions that would provide a level of safety equivalent to that intended by the regulation."[29] This conclusion is consistent with the sound application of the concept of survivability, which calls for considering survivability from all aspects, including equipment, outfitting, operational procedures, as well as design. In addition, many DUKW owner/operators have incorporated design changes to improve hull form and vital system survivability inclusive of, and often beyond, Subchapter T regulations.

MSC conducted an in-house intact stability review of DUKWs in 2018. The study re-assessed an in-service DUKW at "intermediate" (i.e., less than the maximum number of passengers permitted) loading conditions using the more stringent "open boat" freeboard limits set forth in USCG's internal 2007/2008 Memorandums. (See section above on "Intact Stability Standards.") The DUKWs included in the study failed to comply with the stability criteria at some of the intermediate loading conditions, which prompted a review of all of the DUKW stability calculations submitted to MSC between 2007 and 2018. This review found that the DUKWs' stability was being assessed using the less stringent flush deck freeboard limits for the weather criteria, 170.170, and the passenger heeling criteria, 171.050, instead of the more stringent open boat freeboard limits given in USCG's internal 2007/2008 Memorandums. A further review found that many of those DUKWs also failed to meet the weather criteria at intermediate loading conditions when using the more stringent open boat freeboard limits.

Despite the DUKWs performance against the stability standards, MSC concluded that "DUKW COIs [Certificates of Inspection] typically list operational restrictions, including limiting route exposure, length of voyage, passenger seating, and acceptable weather and sea states. These restrictions complement the vessels' stability characteristics, further mitigating the risk of flooding and sinking."[30]

The optimum solution to the flooding risk is to prevent flooding events from occurring in the first place. The final sections of this chapter and Chapter 4 on Operating Areas will examine solutions to prevent flooding. The next section explores solutions for preventing sinking after flooding occurs.

REMAINING AFLOAT AND UPRIGHT DURING FLOODING

Providing the means for a DUKW to remain afloat and upright after flooding occurs will significantly mitigate the risks associated with flooding events of any type. Remaining afloat and upright can protect passenger safety in almost any flooding scenario a DUKW may typically encounter. This would include boarding seas over the bow or sides or through the engine cooling air vents and flooding through hull penetrations.

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[29] Marine Safety Center (MSC), USCG, 2020, "MSC Technical Report: Analysis of Open Boat Stability Standard Applied to DUKW Amphibious Vessels," September 3.
[30] MSC, USCG, 2020. "MSC Technical Report: Analysis of Open Boat Stability Standard Applied to DUKW Amphibious Vessels," September 3.

The committee reviewed the fitting of flotation foam internally, the addition of external inflatable bladders or the installation of external floats, and the use of a combination of internal and external buoyancy enhancement. Except for the internal fitting of flotation foam alone, the committee found that all the solutions could potentially work.

Flotation Foam

The committee notes that fitting flotation foam in the hull is not a viable option to keeping a DUKW afloat and upright in case of a swamping or hull breaching incident. Although installing flotation foam has been used in numerous small recreational and small inspected craft to make them "unsinkable" if swamped or capsized, for DUKWs this approach has been studied by both USCG and by the United Kingdom's Marine Accident Investigation Branch (MAIB) and found to be impractical. The space available below the passenger deck is insufficient for the foam volume required. Moreover, installing foam could create potential fire hazards and increase the difficulty of maintaining a DUKW's hull, internal components, and mechanical systems.

After the sinking of the *Stretch Duck 7*, MSC prepared an engineering study on the feasibility of installing foam in this vessel. It calculated that a total of 426.4 cubic feet of foam would have been required to keep the *Stretch Duck 7* afloat. The maximum volume available below the passenger deck was calculated to be 271.6 cubic feet using a permeability factor of 85 percent (machinery spaces). The remaining required foam, 195.5 cubic feet, was calculated to fill approximately 50 percent of the passenger seating space. These volumes are theoretical maximums; the actual space available for flotation foam would be significantly less because clearance is required around equipment, shafts, etc., for inspection, maintenance, and repair. Since MSC determined that installing flotation foam was not feasible, they made no calculations to see if the DUKW would also remain upright in the swamped condition.[31]

Flotation foam has also been tried for DUKWs operating in the United Kingdom, where it has failed to prevent sinking. Instead, the foam became a fire hazard. UK regulations require that DUKWs have 110 percent reserve buoyancy and remain upright and stable in case of a hull breach or swamping.[32] Some UK DUKWs chose to fit internal foam to comply with this reserve buoyancy requirement. Subsequent sinkings revealed the approach inadequate. The sinkings of the *Wacker Quacker 4* in March 2013 and the *Wacker Quacker 1* in June 2013 happened after suffering hull breaches. A fire on another DUKW, the *Cleopatra*, was attributed to the flotation foam coming into contact with rotating machinery and catching fire.[33]

The United Kingdom's MAIB subsequently conducted an investigation that included a series of real-world stability tests and flooding trials on the *Wacker Quacker 1*. When fitting the vessel with the required volume of foam to meet the 110 percent reserve buoyancy requirement, it was found that not all of the foam fit under the passenger deck and distributed the rest in the passenger cabin. After stimulating the actual hull breach by removing pipe caps, the vessel took about 5 minutes to fully flood. It remained afloat and upright with a starboard list. The study did

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[31] MSC, 2020, MSC Memorandum (Serial: H1-2001479), May 13.
[32] UK DUKWs are certified by the Maritime and Coastguard Agency (MCA) and are required to meet the stability criteria given in the Merchant Shipping Notice 1699 M (MSN1699M).
[33] MAIB, Very Serious Marine Casualty Report NO 32/2014, December 2014. https://assets.publishing.service.gov.uk/media/54c1722240f0b6158d00002b/MAIBReport_32-2014.pdf.

not fully evaluate if a swamped DUKW would remain upright when subject to the effects of passengers escaping over the sides.[34]

Inflatable Bladders

Retrofitting DUKWs with inflatable bladders could be a feasible solution to preserve buoyancy when flooding. However, there are disadvantages to this method, chiefly additional costs and labor that also need to be taken into consideration. In addition, the bladders may reduce the vessel's maneuverability in the water.

Inflatable bladders are already in use for amphibious passenger vessels, albeit to provide additional intact stability, not positive flotation during flooding. Companies have developed vessels (USCG inspected) with a flexible bladder on each side of the hull near the waterline. The bladders are deflated for road operations to minimize the vessel's width and are inflated before entering the water. These vessels are purpose built for sightseeing tours and provide combined water and land tours, similar to DUKWs. An example of a bladder deflated for operation on land is found at this website.[35] An example of when the bladder is inflated for operation in the water can be found at the following website.[36]

To explore the feasibility of installing inflatable bladders on DUKWs, the committee calculated the required bladder volume and size to achieve reserve buoyancy, based on USCG's foam reserve buoyancy study for the *Stretch Duck 7*. Assuming the maximum feasible length of a bladder on a DUKW is 26 feet, providing equivalent reserve buoyancy as noted in the USCG study would require two 30.6-inch in diameter by 26-foot long bladders (see Table 3-1).

Although retrofitting a DUKW with bladders is feasible with today's technology, the bladders would be fairly sizable when inflated. The advantages and disadvantages of installing inflatable bladders to provide reserve buoyancy are as follows.

Advantages

- Reserve buoyancy at 100 percent in the event of any flooding incident.
- Minimal likelihood that passengers would need to escape the vessel due to flooding, avoiding hazards including canopies and donning life jackets in cramped spaces while under way.
- Minimal downtime and disruption to operations if retrofit is installed via a prefabricated package.
- No additional permits for operations on roads may be required because bladders can be deflated.
- Air compressors, already installed on some DUKWs to inflate tires, can be used to inflate/deflate the bladders.
- Crew can readily control inflation/deflation.
- No need to reduce passenger capacity to compensate for added weight because the bladders can be made slightly oversized.

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[34] MAIB Accident Report # 32/2014.
[35] Example of a deflated bladder: https://trolleyboats.net/wp-content/uploads/2020/01/100_0384.jpg
[36] Example of an inflated bladder: https://trolleyboats.net/wp-content/uploads/2020/01/duckboat020-1024x766.jpg

Disadvantages

- Acquisition costs of the bladders and supporting equipment.
- Additional costs for the long-term maintenance, storage, and repair of the bladders and supporting equipment.
- Requires the crew's active involvement to inflate/deflate the bladders at the appropriate times.
- Increased resistance of the DUKW making it even slower, less maneuverable, and burn more fuel.
- Added weight may be an issue for over the road operations if maximum vehicle weight limits are exceeded.

TABLE 3-1 Inflatable Bladder Size and Float Size: Estimations for a Stretch Duck

Line	Description	Value	Units	Formula	Notes
1	Stretch Duck 7 Lightship	17,920	lbs		From Stability Letter
2	36 Passengers	6,660	lbs		185 lbs per Passenger
3	2 Crew Members	370	lbs		185 lbs per Crew Member
4	Fuel and Miscellaneous	464	lbs		40 Gallons Fuel and 120 #'s Misc
5	**Total Full Load Displacement**	**25,414**	lbs	= (1) + (2) + (3) + (4)	Before Flooding
6	Buoyancy from Submerged Hull	896	lbs	= 0.05 × (1)	Assumed 95% Permeability
7	Buoyancy from Appendages	2,814	lbs		From USCG Memo H1-2001479
8	Buoyancy from Submerged Passengers	5,868	lbs	= (185 – 22) × (2)	22 lbs per Passenger - PFD Type 1
9	Buoyancy from Submerged Crew Members	326	lbs	= (185 – 22) × (3)	22 lbs per Crew Member - PFD Type 1
10	**Total Submerged Displacement**	**15,510**	lbs	= (5) – (6) + (7) + (8) + (9)	After Flooding
11	Estimated Weight of Bladders and Equipment	1,000	lbs		
12	**Minimum Total Required Buoyant Force**	**16,510**	lbs	= (10) + (11)	
13	Density of Water	62.3	lbs/ft^3		Fresh Water
14	Minimum Total Bladder Volume Required	265.0	ft^3	= (12) / (13)	Combined Volume Both Sides of DUKW
15	Minimum Bladder Volume per Side	132.5	ft^3	= (14) / 2	
16	Maximum Practical Bladder Length	26.0	ft		DUKW Hull = 33 Feet
17	Minimum Required Bladder Cross-Section	5.10	ft^2	= (15) / (16)	
18	**Minimum Required Bladder Diameter**	**2.55**	ft	= 2 × ((17) / 3.14) ^ 0.5	Circular Cross-Section
19	**Minimum Required Bladder Diameter**	**30.6**	inch	= (18) × 12	Circular Cross-Section
20	**Equivalent Buoyant Float Height**	**36.0**	inch		Assumed Value
21	**Equivalent Buoyant Float Width**	**20.4**	inch	= (17) × 144 / (20)	

NOTE: Committee calculations based on specifications found in MSC Memorandum Serial: H1-2001479 (May 13, 2020), data as of August 3, 2021.

Floats

Buoyant floats installed on the sides of a DUKW's hull is similar in concept to inflatable bladders. These floats could be permanently inflated bladders or molded foam-filled units, and they could be permanently mounted or removable, to be installed only for waterborne operations. Removable floats would add labor to a tour and require storage when not in use, but permanently attached floats would increase the width of the DUKW when operating on land unless some type of foldup configuration was used. Both permanently mounted floats and removable floats could be viable options.

Removable, permanently inflated bladders have been used for reserve buoyancy on DUKWs that have operated overseas. Companies have fitted two horizontal clips on the DUKWs, to which floats were installed for waterborne operations. The floats numbered four units on each side and each was fitted with handles on the ends for ease of installation and removal.[37]

Using molded foam-filled floats would allow the floats to have a more compact, rectangular cross section, as opposed to circular cross section of permanently inflated bladders. For example, a circular bladder with a diameter of 30.6 inches—the minimum bladder size according to Table 3-1—is equivalent to a rectangular float with a height of 36 inches and a width of only 20.4 inches. A molded float could also have a streamlined "bow" to reduce waterborne drag. The advantages and disadvantages of non-inflatable buoyancy floats are, in general, similar to those for the inflatable bladder concept with some notable differences as follows.

Advantages

- Reserve buoyancy at 100 percent in the event of any flooding incident.
- Minimal likelihood that passengers would need to escape the vessel due to flooding, avoiding hazards including canopies and donning life jackets in a cramped space while under way.
- Minimal downtime and disruption to operations if retrofit is installed via a prefabricated package.
- If removable, no additional permits for operations on roads.
- No supporting equipment required, such as air pumps.
- No need to reduce passenger capacity to compensate for added weight because the floats can be made slightly oversized.
- Use of closed cell foam would allow the floats to retain their effectiveness in the event of a collision or minor damage.

Disadvantages

- Acquisition costs of floats.
- Recurring maintenance and repair costs.

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[37] Example of removable, permanently inflated bladders or molded foam-filled units: https://www.irishtimes.com/polopoly_fs/1.3572804.1532203638!/image/image.jpg_gen/derivatives/ratio_1x1_w1200/image.jpg.

- If removable, cost and time for the onboard crew or shoreside personnel to install and remove the floats.
- If removable, place to store the floats convenient to the launching ramp. If different ramps are used for entering and exiting the water, the cost, time, and labor to transport floats to the launching ramp.
- Increased resistance making the DUKW even slower, less maneuverable, and burn more fuel.
- Added weight may be an issue for over the road operations if maximum vehicle weight limits are exceeded.

Combining Methods

Because the required external bladders or floats would be fairly large relative to a DUKW's hull size, the committee also explored combining the installation of internal flotation foam with external bladders or floats. For *Stretch Duck 7*, the installation of internal flotation foam to 43 percent of the hull volume, reduces the required external flotation volume by approximately 32 percent (see Table 3-2).

TABLE 3-2 Inflatable Bladder and Float Sizes with Partial Internal Flotation Foam: Estimations for a Stretch Duck

Line	Description	Value	Units	Formula	Notes
1	Stretch Duck 7 Lightship	17,920	lbs		From Stability Letter
2	36 Passengers	6,660	lbs		185 lbs per Passenger
3	2 Crew Members	370	lbs		185 lbs per Crew Member
4	Fuel and Miscellaneous	464	lbs		40 Gallons Fuel and 120 #'s Misc
5	**Total Full Load Displacement**	**25,414**	lbs	= (1) + (2) + (3) + (4)	Before Flooding
6	Buoyancy from Submerged Hull	896	lbs	= 0.05 × (1)	Assumed 95% Permeability
7	Buoyancy from Appendages	2,814	lbs		From USCG Memo H1-2001479
8	Buoyancy from Submerged Passengers	5,868	lbs	= (185 – 22) × (2)	22 lbs per Passenger - PFD Type 1
9	Buoyancy from Submerged Crew Members	326	lbs	= (185 – 22) × (3)	22 lbs per Crew Member - PFD Type 1
10	**Total Submerged Displacement**	**15,510**	lbs	= (5) – (6) + (7) + (8) + (9)	After Flooding
11	Estimated Weight of Bladders and Equipment	1,000	lbs		
12	Estimated Weight of Internal Flotation Foam	200	lbs		From USCG Memo H1-2001479
13	**Minimum Total Required Buoyant Force**	**16,710**	lbs	= (10) + (11) + (12)	
14	Volume of Internal Flotation Foam	100	ft^3		43% of Hull Volume from USCG Memo
15	Buoyancy Provided by Flotation Foam	5,500	lbs	= 55 × (14)	55 lbs/ft^3 per 46 CFR 179.240(b)(8)
16	**Buoyancy Required from Bladders**	**11,210**	lbs	= (13) – (15)	
17	Density of Water	62.3	lbs/ft^3		Fresh Water
18	Minimum Total Bladder Volume Required	179.9	ft^3	= (16) / (17)	Combined Volume Both Sides of DUKW
19	Minimum Bladder Volume per Side	90.0	ft^3	= (18) / 2	
20	Maximum Practical Bladder Length	26.0	ft		DUKW Hull = 33 Feet
21	Minimum Required Bladder Cross-Section	3.46	ft^2	= (19) / (20)	
22	**Minimum Required Bladder Diameter**	**2.10**	ft	= 2 × ((21) / 3.14) ^ 0.5	Circular Cross Section
23	**Minimum Required Bladder Diameter**	**25.2**	inch	= (18) × 12	Circular Cross Section
24	**Equivalent Buoyant Float Height**	**32.0**	inch		Assumed Value
25	**Equivalent Buoyant Float Width**	**15.6**	inch	= (17) × 144 / (20)	

NOTE: Committee calculations based on specifications found in MSC Memorandum Serial: H1-2001479 (May 13, 2020), data as of August 3, 2021.

FLOODING THROUGH HULL PENETRATIONS

DUKWs have multiple hull penetrations below the waterline, including:

- Forward and aft driveshaft penetrations for the road drive axles.
- Maintenance/drain plugs and valves for the hull bilges and drive shaft tubes.
- A propeller shaft stuffing box for the waterborne propulsion system.
- A rudder stock gland for waterborne steering control.

The committee focused only on the driveshaft penetrations and the bilge drain plugs/valves because they are not found on typical Subchapter T boats. The propeller shaft stuffing box and rudder stock gland are typical marine equipment, and they have not been a source of flooding in DUKW accidents. As such, no changes are required of this typical marine equipment.

Higgins Pumps and Bilge Systems

The *Miss Majestic* and the *Wacker Quacker 4* were both dependent on a Higgins pump at the time of their sinking. The combination of a Higgins pump and flooding through a hull penetration creates a higher risk of sinking.

DUKWs during WWII were originally fitted with three bilge pumps to deal with flooding from hull penetrations and modest battle damage. The hand bilge pump had a capacity of approximately 25 GPM (gallons per minute). The transfer case-driven self-priming centrifugal pump had a capacity of approximately 50 GPM through a bilge suction manifold and was operated from the driver's compartment.[38]

The Higgins pump, critical for survivability, is a self-priming pump that is chain-driven by the propeller shaft. The Higgins pump is always "on" whenever the DUKW is traveling afloat, but its capacity depends on the propeller speed. At full propeller speed, the pump has a nominal capacity between 200 to 250 GPM. Slowing the engine significantly decreases the pumping rate, and stopping the engine stops all pumping. The Higgins pump takes suction from the center compartment only.

This wartime design presents several hazards for DUKWs as passenger vessels. To get the full pumping capacity, the DUKW must be operated at maximum rated propeller speed (i.e., full throttle). In addition, the reliability of the chain drive that powers the Higgins pump depends on careful maintenance and frequent adjustments. Finally, the Higgins pump, like any bilge pump, is prone to clogging from the detritus inevitably lurking in every bilge. Clogged bilge pumps were such a concern during World War II that warnings about the importance of keeping bilges clean are found throughout the U.S. Army's DUKW operations manual.[39]

In addition, USCG's requirements for bilge systems under Subchapter T do not intend for bilge systems on small passenger vessels to serve as the primary deterrent to a flooding

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[38] U.S. Army, 1944, "The DUKW: Its Operation and Uses." See https://cgsc.contentdm.oclc.org/digital/collection/p4013coll9/id/397.
[39] U.S. Army, 1944, "The DUKW: Its Operation and Uses." See https://cgsc.contentdm.oclc.org/digital/collection/p4013coll9/id/397.

emergency. The bilge system is to remove water from normal operations. The primary deterrents to prevent flooding are to be the hull's structural integrity and watertight through-hull fittings.[40]

Driveshaft Boot Seals

The committee notes that the original WWII design for driveshaft boot seals, especially in conjunction with a Higgins pump, presents a higher risk of flooding and sinking. DUKWs still using the original design should be modified. The best approach is to replace the boot seals with carrier bearings. In recognition of the high cost of replacement with carrier bearings, the committee offers guidance on actions short of replacement at the end of this section.

All DUKWs have conventional truck axles for land-based operation. These axles are typically powered by conventional cardan-joint driveshafts from a transfer gearbox located in the DUKW's hull. This arrangement necessitates some type of sealing mechanism where the driveshafts penetrate the DUKWs watertight envelope. The original WWII DUKWs used a somewhat complex pivoting driveshaft tube that ran from the axle housing to a pivot joint at the hull. This driveshaft tube was made watertight with large rubber boot seals at each end, as depicted in Figure 3-1.

[40] NVIC 1-01; Subchapter T Part 192.5200.

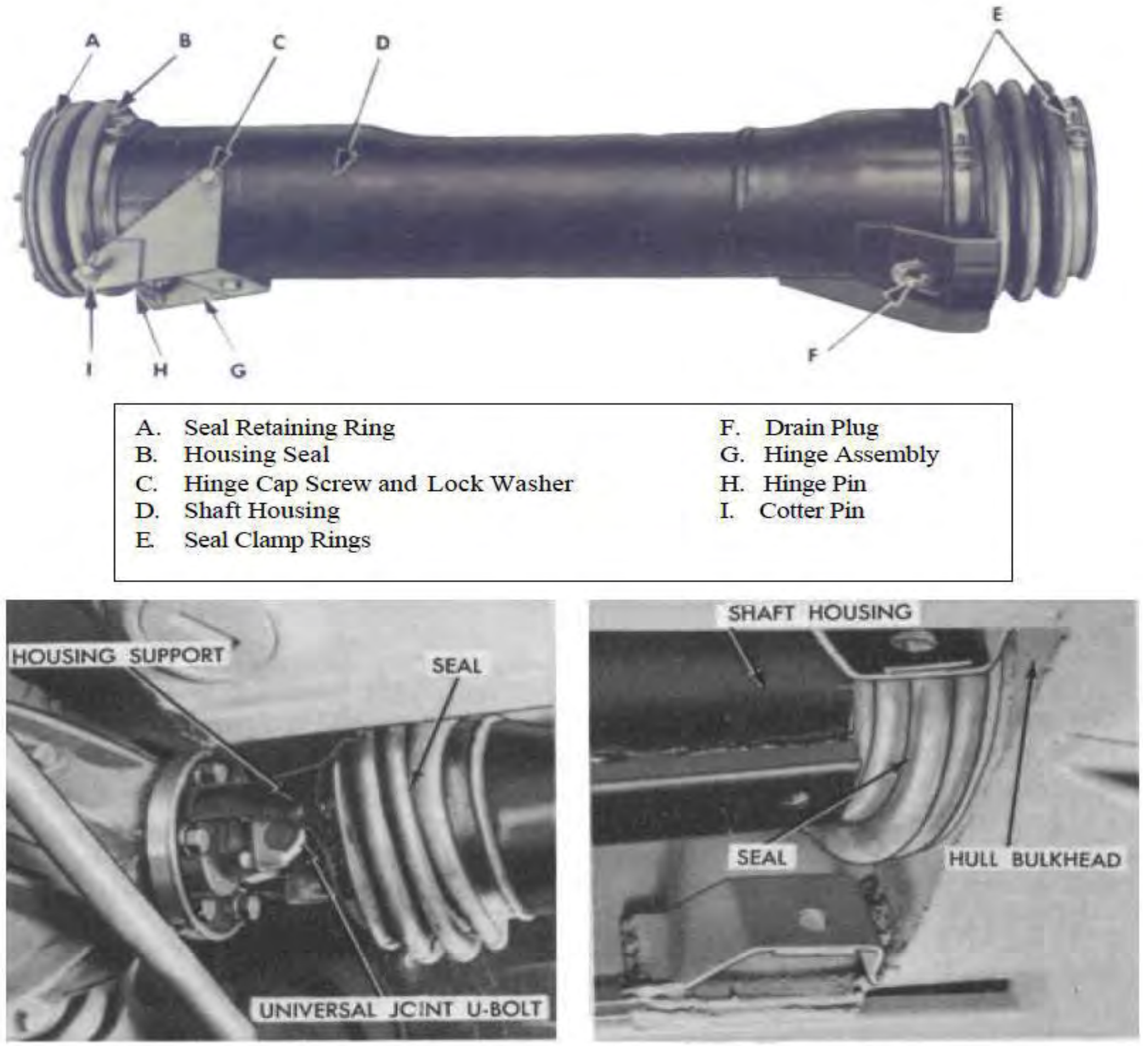

FIGURE 3-1 Example of a boot seal in a WWII DUKW.
SOURCE: USCG, NVIC 1-01, p. 13.

These seals are unlike conventional small craft propeller shaft seals, where there is no lateral or rotational movement of the seal itself. WWII DUKW shaft boot seals must handle both the rotational movement of the driveshaft tubes through the full travel of the road springs, as well as the longitudinal elongation of the driveshaft.

These seals are critical to maintaining the watertight integrity of a WWII DUKW: Their failure essentially results in an approximately 4-inch diameter hole in the hull roughly 26 inches below the DUKWs waterline. According to USCG calculation, this 4-inch diameter hole would let in water at approximately 220 GPM.[41]

For DUWKs still equipped with a Higgins pump, removing flood water from a boot seal failure requires not only that the Higgins pump be operational, but the survival of the DUKW depends on the Higgins pump performing at its full rated capacity. When a boot seal and the

[41] USCG, NVIC 1-01, p. 33.

Higgins pump both fail, sinking can happen in less than 10 minutes. The *Miss Majestic* suffered both when a new, improperly installed boot seal failed (see Figure 3-2) and the Higgins pump

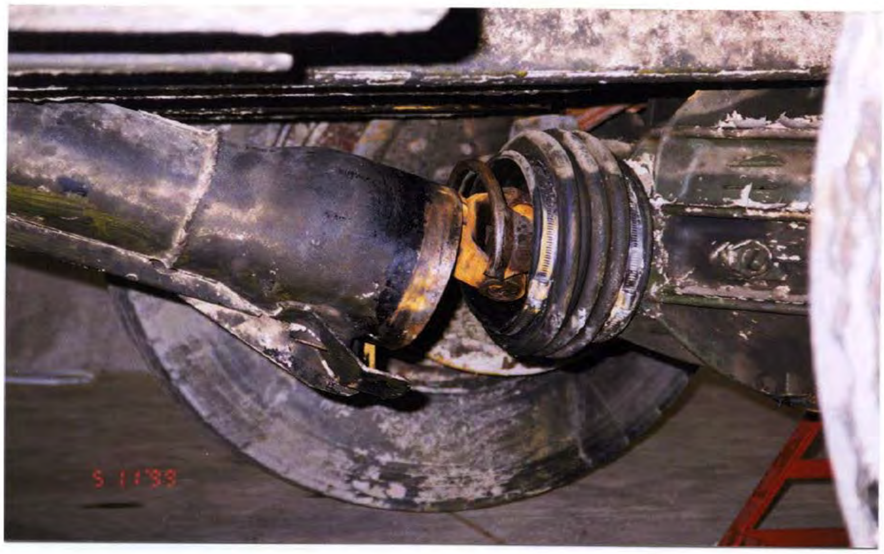

FIGURE 3-2 *Miss Majestic* rear driveshaft boot after sinking accident.
SOURCES: NTSB/MAR-02/01, p. 15. See https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR0201.pdf.

was inoperable because a drive chain sprocket key was missing, there was excessive play in the drive chain, and a portion of one of the impeller blades was broken off. The flooding rate was at least 170 GPM, which would put the stern deck awash within 7 minutes. The DUKW sank 15 to 60 seconds after the passengers and operator realized there was a serious problem and began attempting to escape.[42]

USCG's NVIC 1-01 guidelines, created in response to the *Miss Majestic* sinking, addressed the issue of the driveshaft boot seals in three ways[43]:

1. Heightened inspections of the original-design boot seals during the required annual and drydock inspections;
2. Installation of a restrictor plate in way of the boot seal penetration; and
3. Installation of a carrier bearing in place of the boot seal.

Although USCG's increased inspection requirements are an improvement because they provide specific guidance on how to inspect the boot seal properly, inspections alone are inadequate. Inspections do not remedy the inherent vulnerability of the boot seals and the Higgins pump. Moreover, at this time inspections are only done once per year. The shaft boot seal that failed on the *Miss Majestic* replaced a torn boot seal that was only discovered on an earlier trip when the operator noticed that water was coming out of the Higgins pump overboard discharge. Given their fragile nature, boot seals still in use may warrant more frequent inspections.

[42] NTSB's accident report NTSB/MAR-02/01; DUKW Damage Stability Analysis, December 8, 1999.
[43] USCG, NVIC 10-1, pp. 19–21 and 25.

The installation of restrictor plates reduces the maximum flooding rate in the event of a boot seal failure, decreasing the risk of sinking. The restrictor plate example in NVIC 1-01 reduces the GPM flowing through a failed boot seal from 220 to 30 GPM. Applying the restrictor plate to NTSB's *Miss Majestic* analysis increases the time to swamping from 7 minutes to about 50 minutes.

However, a DUKW with restrictor plates will still depend on its bilge system to prevent flooding, contrary to USCG's requirements.

The installation of carrier bearings in place of the boot seals completely removes the flooding potential from the driveshaft penetrations and is, by far, the safest remedy. This solution also brings the DUKW's bilge system and the DUKW itself in compliance with USCG's intention for Subchapter T passenger boats.

However, given the high cost of installing carrier bearings, the committee recognizes that other actions short of the ideal may be necessary, at least in the near term. These actions, which mitigate at least some of the risk of the WWII driveshaft boot seal arrangement, include:

1. Fit DUKWs that have the original WWII driveshaft boot seal arrangement with at least restrictor plates, as per NVIC 1-01, as soon as possible.
2. Fit DUKWs that utilize restrictor plates with at least two independent bilge pumps (power source, float switch, discharge piping, and operator's visible/audible alarm), each capable of pumping twice the minimum estimated maximum flooding rate possible in the event of a boot seal failure.
3. Institute routine checks and cleaning of the bilges to minimize the clogging of the emergency bilge pumps.
4. Institute routine inspections of the emergency bilge pumps to ensure that they are fully operational.

Drain Plugs and Valves

The sinking of the Seattle Stretch Duck and the *Wacker Quacker 4* were both tied to missing hull drain plugs. On the original WWII DUKWs, plugs and valves were installed for maintaining the transmission, transfer case, and other mechanical systems; draining rainwater when the DUKW was operated on land; and emergency draining a swamped DUKW once on land. (DUKWs have multiple bilge pockets that trap water.)

Numerous accidents during World War II resulted from DUKW crews forgetting to install the plugs before commencing waterborne operations. In response, the U.S. Army specified that DUKWs should be retrofitted with plug racks and stenciled signs in the driver's compartment to remind the crew to reinstall them. The U.S. Army also supplied a modified drain plug wrench to simplify and speed up plug removal and installation. Instructions and warnings on the proper use of drain plugs and valves were also scattered throughout the DUKW operations manual (see Figure 3-3).[44]

[44] U.S. Army, 1944, "The DUKW: Its Operation and Use," p. 11. https://cgsc.contentdm.oclc.org/digital/collection/p4013coll9/id/397.

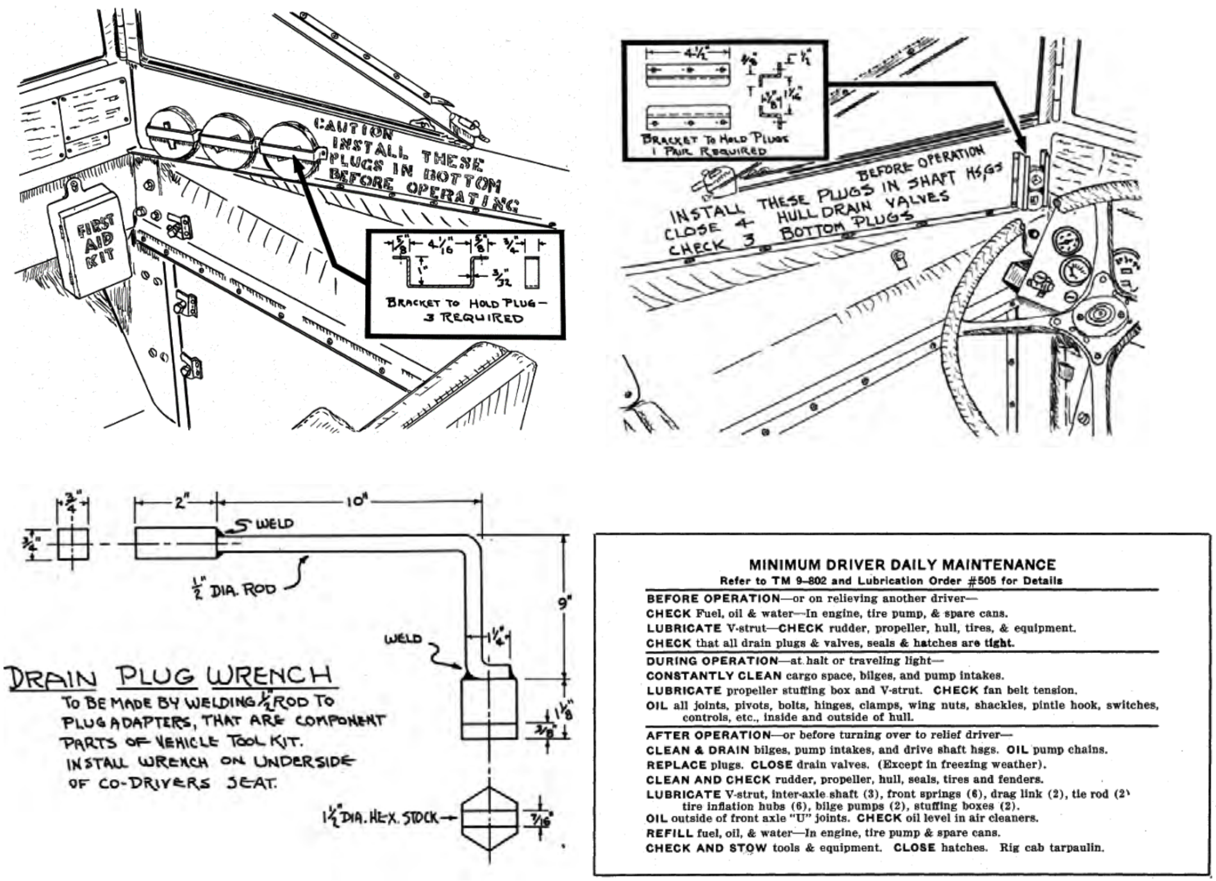

FIGURE 3-3 U.S. Army manual excerpts on drain plugs and valves.
SOURCE: U.S. Army, 1944, "The DUKW: Its Operation and Use."

The problems with drain plugs continued into the 21st century. In 2001, a DUKW sank in Seattle after a large drain plug had not been reinstalled. Fortunately, the master noticed the problem in time to safely disembark the passengers.

USCG Subchapter T regulations require that all areas of the bilge be effectively drained under all practical operating conditions (Subpart E). In addition, most DUKWs are fitted with canopies that minimize rainwater ingress, and the vessels are often stored in a sheltered area when not in use. The benefits of having the hull drain plugs and valves are now far outweighed by the safety hazards they present if not reinstalled after maintenance, repairs, and inspections.

FLOODING THROUGH ENGINE COOLING AIR VENTS

Because the majority of their operations during WWII were intended to be on land, the original DUKWs were fitted with an air-cooled radiator that provided engine cooling for both land and waterborne operations. On water, the required fresh air intake and exhaust vents are sources of flooding from large waves and heavy surf. The committee notes that the air vents required for engine cooling are a significant hazard. Installing keel coolers is one viable remedy, but keel coolers do not eliminate the need to ensure that air vents are securely closed at appropriate times.

The original air-cooled radiator is located in the DUKW's forward engine compartment and utilizes an engine-driven fan to move air through the radiator. Fresh air intake was normally provided through the operator's compartment, with exhaust vents located on the port and starboard sides of the operator's compartment. WWII DUKWs were fitted with closable covers for the air exhaust vents, and "bow surf plates" could be set up as additional protection against flooding. The crew on WWII DUKWS could open a forward hatch in the hood if required for land-based operations. The U.S. Army operations manual requires that this hood be "clamped tightly" for all waterborne operations.

DUKWs modified for commercial passenger use have either a large intake vent on the "hood" or a member of the crew props the forward hatch open to provide adequate cooling, particularly in high ambient temperatures (see Figure 3-4). This modification has contributed to DUKWs experiencing flooding, including the sinking of the *Stretch Duck 7* in 2018. Caught in a

FIGURE 3-4 WWII DUKW with an open hood hatch.
SOURCE: A. Moyers, Chattanooga Ducks.

storm with winds and waves exceeding the DUKW's COI maximum operating limits, the *Stretch Duck 7* began to founder when water came over the vessel's bow and entered through the spring-closed forward air vent. The spring closure mechanism was not strong enough to keep the force of the overtopping waves from intermittently opening the air vent.[45] In 2015, the same DUKW had experienced flooding of the forward compartment after entering the water harder than normal.

Some DUKWs have fitted a keel cooler in line with the existing cooling water loop through the radiator. This minimizes the flooding hazard and allows for the easier fitting of fixed

[45] NTSB, 2020, "Sinking of Amphibious Passenger Vessel *Stretch Duck 7*, Table Rock Lake, near Branson, MO, July 19, 2018," Marine Accident Report NTSB/MAR/20-01, April 28, pp. 50–51. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.

fire suppression systems in the engine compartment, which are required by Subchapter T. A keel cooler augments engine cooling during waterborne operations and still allows for radiator cooling during land operations. With this arrangement, the only action required by the crew is to close or open the forward hatch when entering or leaving the water.

Although keel coolers can significantly improve the safety of DUKWs from flooding, the arrangement still requires the crew to open and *securely* close the forward air vent at the appropriate time. Given its very vulnerable location on the hood of the DUKW, it is critical that this be done correctly every time.

SUMMARY

The committee agrees with USCG that reducing the risk of flooding is critical for DUKWs and that insufficient intact stability has not been the cause of the loss of a DUKW from sinking or capsizing to date. All sinkings or capsizings have been caused by progressive flooding. Given the limitations of the existing DUKW hull design, there is no simple method of effectively enhancing DUKW damage stability by changes to hull internals or adding flotation. Instead of focusing solely on intact stability, the survivability of DUKWs should be considered from all aspects and use multiple, complementary methods.

There are viable methods to retrofitting DUKWs to increase their reserve buoyancy. However, fitting flotation foam in the hull—on its own—will not keep a DUKW afloat and upright during a flooding emergency. There is simply not enough space in the hull. In addition, packing the foam tightly in the hull increases the risk of fire. Installing inflatable bladders or attaching floats to the sides of the DUKW on their own or in combination with flotation foam in the hull are potential solutions.

The original WWII driveshaft boot seals present a higher risk of flooding. Although fitting boot seals with restrictor plates mitigates this risk somewhat, the safest approach is to replace boot seals with carrier bearings.

It is critically important to permanently seal or eliminate wherever practical all drain plugs and valves. For any remaining hull drain and maintenance plugs, all maintenance and repair procedures need to be reviewed to ensure that plugs have been correctly reinstalled before the DUKW is allowed back into service.

Spring-closed engine cooling vents are also a significant flooding hazard. Keel coolers are one solution that allow a DUKW to be safely operated with the forward vents and hatches securely closed while waterborne. If a DUKW's engine cooling system cannot be safely operated with vents and hatches securely closed, the potential for waves high enough to broach the DUKWs bow warrants consideration during the determination of the DUKW's safe operating area.

Because of the higher risks of flooding, the current guideline in NVIC 1-01 that DUKWs have bilge systems capable of offsetting uncontrolled flooding, such as from driveshaft seal failures or missing maintenance plugs, is reasonable and advisable.

4
Operating Areas

One way to improve vessel survivability is to limit the hazards that a vessel is likely to encounter during waterborne operations. Such limitations are already in place to some extent through restrictions that limit WWII DUKWs and Stretch Ducks to protected waters. But these restrictions only work if the definition of "protected waters" indeed excludes all bodies of water capable of experiencing conditions that may threaten a DUKW. Recent major casualty events in the United States indicate that the current definition of "protected waters" may not adequately protect DUKWs.

In addition to reviewing casualty events and regulations, this chapter catalogs the factors an Officer in Charge, Marine Inspection (OCMI) may want to consider in evaluating the risks associated with operating a DUKW on a specific body of water or a specific route on a body of water. The current operating area evaluation method, which depends on the type of body of water, could be improved by considering a consistent set of evaluation criteria. Although blanket prohibitions may be necessary, limiting operating areas by time may present another option to reduce the risks associated with an operating area. As for severe weather, this chapter explains how the National Weather Service's (NWS's) alert system could be leveraged to provide a straightforward and effective way of consistently restricting operating areas and times to reduce the risk that DUKWs are on the water during weather that threatens a vessel's survivability. Setting operating restrictions based on the NWS's alert system would require operators to adopt operating procedures, acquire equipment, and provide training to adequately monitor and respond to severe weather.

OPERATING AREAS AND CASUALTY EVENTS

The operating areas of the *Stretch Duck 7* and *DUKW 34* created the conditions that made the vessels vulnerable to operator errors.

Stretch Duck 7 took passengers on Table Rock Lake, created by a dam on the White River in the Ozark Mountains of southern Missouri. On *Stretch Duck 7'*s route, the bottom of the 43,000-acre lake dropped off quickly from the shore. The boat was eventually recovered from a depth of 85 feet. As a dam-created lake in the mountains, Table Rock Lake has a complex shoreline. Fetch—the straight distance wind can travel over the water—ranges from 1.55 to 3.7 miles for winds out of the north. Fetch affects wave height.[46]

Southern Missouri is in a part of the United States prone to severe thunderstorms during the summer. A derecho, the type of thunderstorm that hit Table Rock Lake on July 19, 2018, is a particularly severe type of thunderstorm, characterized by strong, relatively long-lasting straight-line winds. NWS issued a severe thunderstorm watch 7 hours before and a severe thunderstorm warning 23 minutes before *Stretch Duck 7* entered the water.

Derecho winds hit in advance of the rain line and can appear suddenly. When *Stretch Duck 7* entered the water, the surface of the lake was flat and calm. Five minutes later, the squall

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[46] NTSB, 2020, "Sinking of Amphibious Passenger Vessel *Stretch Duck 7*, Table Rock Lake, near Branson, MO, July 19, 2018," Marine Accident Report NTSB/MAR/20-01, April 28. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.

line hit; within 15 seconds the water surface went from calm to white-capped waves. NWS determined the winds from this squall ranged from 50 to 65 miles per hour (45 to 55 knots) for 30 minutes. Waves were from 2.7 to 3.7 feet, with some estimated as high as 4.2 feet. The wind speeds and wave heights significantly exceeded the maximum operating restrictions in the *Stretch Duck 7's* Certificate of Inspection (COI) of wave heights of 2.0 feet and winds of 35 miles per hour.

DUKW 34's operating area, the Delaware River near Philadelphia, put it at risk of collision with commercial vessels. When *DUKW 34* experienced mechanical trouble, the crew shut down the engine and anchored the boat almost in the center of the navigation channel used by deep draft vessels and commercial barges. At the time of anchoring, the barge's tugboat, the *Caribbean Sea*, was 0.3 nautical miles (1,823 feet) from *DUKW 34*. Human error was ultimately responsible for the collision, but the operating area set the stage for human fallibility to produce deadly results.[47]

REGULATIONS AND NVIC 1-01

Operating areas for DUKWs are currently limited in their stability letters to either "protected waters" or "partially protected waters" (see Box 4-1). Only Truck Ducks, which have a higher freeboard, are allowed to operate in partially protected waters. A DUKW's operating area is further restricted in its COI, as determined by the OCMI. The determination of operating areas and operating restrictions is a subjective process highly dependent on the expertise of the OCMI. OCMIs base their decisions on current and past waterway use, marine casualty information, legal and regulatory standards, and stakeholder input from sources like local Harbor Safety Committees and regional or trade specific Safety Advisory Committees.

Each DUKW's COI has a "Route Permitted and Conditions of Operation" section that details the local restrictions imposed by the OCMI. All COIs include a general route permitted: DUKWs are assigned either "rivers" or "lakes, bays, and sounds." In addition, the OCMI may place additional operating restrictions, such as time limits on the duration of waterborne trips, descriptions of the defined geographical area (e.g., the Tennessee River between Mile Markers 463 and 465),[48] and maximum wind speeds and wave heights.

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[47] NTSB, 2011, "Collision of Tugboat/Barge *Caribbean Sea/The Resource* with Amphibious Passenger Vessel *DUKW34*, Philadelphia, PA, July 7, 2010," Marine Accident Report NTSB/MAR-11/02, June 21. https://www.ntsb.gov/investigations/Pages/DCA10MM025.aspx.

[48] A. Moyers, Chattanooga Ducks, presentation to the committee, March 2021. For example, the COI for Chattanooga Ducks limits operations to daylight on the Tennessee River between only Mile Marker 463 and 465.

BOX 4-1
Subchapter T Regulations Limiting Routes

46 CFR § 176.110 Routes Permitted

a. The area of operation for each vessel and any necessary operational limits are determined by the cognizant OCMI and recorded on the vessel's Certificate of Inspection. Each area of operation, referred to as a route, is described on the Certificate of Inspection under the major headings "Oceans," "Coastwise," "Limited Coastwise," "Great Lakes," "Lakes, Bays, and Sounds," or "Rivers," as applicable. Further limitations imposed or extensions granted are described by reference to bodies of waters, geographical points, distance from geographical points, distances from land, depths of channel, seasonal limitations, and similar factors.
b. Operation of a vessel on a route of lesser severity than those specifically described or designated on the Certificate of Inspection is permitted unless expressly prohibited on the Certificate of Inspection. The general order of severity of routes is: oceans, coastwise, limited coastwise, Great Lakes, lakes, bays, and sounds, and rivers. The cognizant OCMI may prohibit a vessel from operating on a route of lesser severity than the primary route a vessel is authorized to operate on if local conditions necessitate such a restriction.
c. Non-self-propelled vessels are prohibited from operating on an oceans, coastwise, limited coastwise, or Great Lakes route unless the Commandant approves such a route.
d. When designating a permitted route or imposing any operational limits on a vessel, the OCMI may consider:
    1. Requirements of this subchapter for which compliance is based on the route of the vessel;
    2. The performance capabilities of the vessel based on design, scantlings, stability, subdivision, propulsion, speed, operating modes, maneuverability, and other characteristics;
    3. The suitability of the vessel for nighttime operations; and
    4. The suitability of the vessel for all environmental conditions.

SOURCE: https://www.ecfr.gov/current/title-46/chapter-I/subchapter-T/part-176

For the classification of the body of water, the local OCMI makes this determination mostly based on local knowledge and the availability of "harbors of safe refuge." 46 CFR § 175.400 defines a "harbor of safe refuge" as "a port, inlet, or other body of water normally sheltered from heavy seas by land and in which a vessel can navigate and safely moor." The OCMI determines whether a location can function as a harbor of safe refuge for a specific vessel, based on the vessel's size, maneuverability, and mooring gear. There are no written guidelines or policies that provide definitive and uniform methods on which OCMIs can base their determination. Furthermore, the definitions provided in Subchapter T (46 CFR § 175.400) for the various route designations are open to interpretation. For example, "rivers" could mean a route on any of the following waters:

1. A river,
2. A canal, or

3. Such other similar waters as may be designated by a Coast Guard District Commander.

"Lakes, bays, and sounds" means a route on any of the following waters:

1. A lake other than the Great Lakes,
2. A bay,
3. A sound, or
4. Such other similar waters as may be designated by a Coast Guard District Commander.

The designation as a river or a lake, bay, or sound may not capture what makes an operating area higher or lower risk for DUKW operations. Many lakes, bays, and sounds are benign bodies of water that are generally calm and protected from large waves and strong winds. However, some lakes are known for high winds that appear daily, such as Flathead Lake, Montana, and Lake Tahoe in Nevada and California. Table Rock Lake was classified as protected waters, even though portions of the lake have fetches of 1 to 4 miles. Many mid-continent reservoirs and pools created by flood control or navigation dams may have similar fetches.

Similarly, a river can be anything from a languid stream meandering through pastures to a swift-flowing torrent between high banks to a broad expanse of pool water, exposed to sudden and unpredictable winds, including tornadoes and thunderstorms. Rivers can be as innocuous as the upper reaches of the Potomac River and countless other rivers throughout the 50 states. In contrast, the Columbia River Gorge, near Hood River, Oregon, is renowned as the windsurfing capital of the world, and the Salmon River in Idaho is notorious as the "river of no return." A river designation includes the Fox River in northern Illinois, which is barely 100 feet across in most places, as well as the Mississippi and Missouri rivers, which in places are a mile wide.

Compliance with the operating restrictions in the COI is the responsibility of the crew and land-based support personnel. For maximum wind speeds and wave heights operating restrictions, the operator must obtain up-to-date weather information far enough in advance to make the decision to cancel the waterborne portion of a tour or to cut short a tour and safely leave the water. Wave heights in excess of limitations can also be created by the wakes of large high-speed recreational or commercial vessels, a situation where a DUKW's crew would have little control over once on the water.

FACTORS FOR EVALUATING OPERATING AREAS

The evaluation of a DUKW's operating area requires knowledge of the capabilities of the vessel and the range of operating conditions likely to be found on the body of water. The wide variability within types of water bodies and types of DUKWs complicates efforts to create a definitive guide for designating operating areas. Still, developing a consistent set of evaluation standards is likely a feasible endeavor.

Vessel Weaknesses

Relative to other small passenger excursion vessels, DUKWs have several known design weaknesses that compromise their ability to deal with wind, waves, and other boat traffic. Forward speeds are slow, typically six knots or less and speeds in reverse are only two knots, according to the U.S. Army's DUKW Operations Manual. Steering is also poor, particularly if there are any significant crosswinds or currents. In addition, DUKWs do not have a traditional bow; they have a scow bow and modified truck hood that, when the bow is turned into a wave, acts more as a scoop. The bow design and low freeboard add to flooding risk.

DUWKs also have reliability issues, as reviewed previously in Tables 2-2 and 2-3. Stretch Ducks and Truck Ducks are not more reliable than WWII DUKWs. DUKWs are particularly vulnerable to a loss or reduction of vessel propulsion and steering.

High-Traffic Areas

Because of the DUKW's inherent maneuverability limitations, the presence of large commercial ships is a major safety concern. These much larger vessels are likely to be moving at higher speeds than a DUKW. These ships may also be operating in a defined channel, limiting their ability to go around a DUKW in distress. The small silhouette of a DUKW may not be easily visible from the pilothouse of a commercial tug and barge combination, particularly when the tug is pushing or working alongside the barge.

The presence of large numbers of recreational craft also presents a safety risk to DUKWs. Some recreational craft are capable of higher speeds and may be operated unpredictably by mariners with a range of skill levels. Operating a DUKW in or near a busy marina or waterway will increase the risk of collisions, especially given the difficulty a typical DUKW will have getting out of harm's way even if the other vessel legally has the right of way.

Large wakes, from commercial ships or reckless recreational craft, may be dangerous for DUKWs because of the bow design and limited maneuverability. Although the presence of other commercial or recreational craft may—and has—provided benefits as "Good Samaritan" rescue craft, this benefit should be weighed against their potential dangers.

Wind and Waves

A DUKW's operational weaknesses limit its ability to survive when caught in a storm. DUKWs have such poor maneuverability that high winds greatly increase the likelihood that a DUKW will lose control and hit things, run aground, or be unable to avoid collisions. Even if just 10 feet from a dock, the wind and waves could prevent a DUKW from landing safely. If docked, large waves pounding the boat may make it unsafe for passengers to disembark. Anchoring a DUKW to wait out a storm is also not a safe solution. In addition to the DUKW's bow being prone to shipping water (or taking on water), the anchor would restrain the DUKW from rising to the waves, increasing the likelihood of water coming over the bow. Safely beaching a DUKW during an emergency will depend on the water bottom's type and contour, the wind direction and speed, and the available space ashore to park the DUKW or unload passengers.

It may be possible for a DUKW caught in a storm to escape to land via "safe refuge locations" (see Box 4-2). These are places such as docks or boat ramps where a DUKW could safely disembark passengers or escape onto land before a storm struck. These docks or boat ramps would be in addition to ramps or docks normally used to enter and exit during a tour.

BOX 4-2
Safe Refuge Locations for Escape onto Land

The committee considers "safe refuge locations" to be places such as docks or boat ramps where a DUKW could safely disembark passengers or escape onto land in an emergency.

The close proximity of safe refuge locations may be a factor the Coast Guard considers in evaluating an operating area or operating restrictions. To determine whether safe refuge locations are available, the following factors could be considered:

- The distance from the vessel's normal track line/tour path
- Expected warning time for severe weather.
- For docks:
  - Are mooring lines and cleats available?
  - Is the DUKW set up for passengers to egress onto a dock?
  - Is the crew trained in the debarkation procedure?
  - Are the docks physically suitable for a DUKW to safely moor up to?
  - Is shelter available on or near the dock?

An ideal safe refuge location would allow all passengers to be safely evacuated from the DUKW to a secure shelter before a storm hits. Close proximity of a shoreline or beach should not be considered a safe refuge location in a storm event unless the shoreline is such that the DUKW can exit the water and drive to a safe location.

OPERATING RESTRICTIONS DURING SEVERE WEATHER

The committee considered two approaches that the United States Coast Guard (USCG) could use to evaluate weather risks and apply appropriate safeguards to enhance weather-related safety. One approach evaluates each proposed route individually and develops a probability assessment of weather hazards based on historic weather data, vessel particulars, and waterway characteristics. The second approach leverages NWS's integrated severe weather alert system. The committee concluded that tying operating restrictions to the severe weather alert system was more feasible than the individual assessments of routes.

Although an individual assessment of weather hazards for each proposed operating area would provide a tailored picture of risks, the process would be labor intensive, rely heavily on the availability of weather data, and likely involve the extrapolation of weather information from large geographic areas down to a very small DUKW operating area. In addition, because of the extensive effort needed to carry out an individualized weather risk assessment, the committee is concerned that OCMIs would rarely reconsider a completed evaluation unless some type of event, such as a major marine casualty, prompted re-evaluation.

Setting operating restrictions according to the severe weather information produced by NWS would take advantage of NWS's real-time, mature, dynamic, and continually improving tools. NWS has developed an integrated severe weather alert system with the intent "to minimize injury, death, and property damage due to hazards such as severe weather and flooding. In other words, the goal of a warning is to provide sufficient time for people to get out of harm's way." NWS issues watches, warnings, and advisories through evaluating data from remote sensing devices, such as radar and satellites; on-site observing devices, such as river and rain gauges and automated flood warning systems; and eyewitness reports. NWS coordinates with all levels of government and the private sector to disseminate alerts of a hazard on multiple platforms. NWS is also committed to leading or coordinating outreach and educational initiatives designed to increase the public's awareness of safe responses to weather emergencies.[49]

With respect to the *Stretch Duck 7* sinking, the weather alert system provided the necessary and timely information for operators to have made the decision to cancel the upcoming tour. NWS issued a severe thunderstorm watch for the area 7 hours prior to the accident, followed by a severe thunderstorm warning 1 minute before the vessel departed from the passenger boarding facility and 23 minutes before it entered the water. Had the vessel been restricted from conducting waterborne operations during a severe weather warning through either regulation or an operating restriction, the casualty could have been prevented.

Leveraging NWS's expertise and the agency's alert system will provide a consistent and simpler method for addressing weather-related risks. As compared to relying on the maximum wind and wave criteria listed in the COI, it will also provide a more objective standard for when it is safe to operate a DUKW. Predicting whether a forecasted severe weather event will create conditions that exceed the COI's permitted values is a difficult task, particularly for DUKW operating personnel who are not weather experts. NWS has recently augmented its severe thunderstorm warnings to indicate the severity of a storm, providing additional information applicable to safe DUKW operations. The three damage threat levels—base, considerable, and destructive—vary by increasing size of hail and/or speed of wind. The definitions of the new damage threat levels are found in Box 4-3.[50]

BOX 4-3
National Weather Service's Definitions of Types of Severe Thunderstorm Warnings

Destructive damage threat is at least 2.75-inch diameter (baseball-sized) hail and/or 80 mph thunderstorm winds. Warnings will automatically activate a Wireless Emergency Alert (WEA) on smartphones within the warned area.

Considerable damage threat is at least 1.75-inch diameter (golf ball-sized) hail and/or 70 mph thunderstorm winds. Warnings will not activate a WEA.

Baseline or "base" severe thunderstorm warning is 1.00-inch (quarter-sized) hail and/or 58 mph thunderstorm winds. Warnings will not activate a WEA.

SOURCE: https://www.weather.gov/news/072221-svr-wea.

Using the NWS alert system would allow USCG to restrict DUKWs from conducting waterborne operations during relevant warnings and advisories, such as a severe thunderstorm

[49] National Weather Service (NWS), 2018, "Warning Coordination and Hazard Awareness," NWS Instruction 10-1801, April 18. https://www.nws.noaa.gov/directives/sym/pd01018001curr.pdf.
[50] NWS, 2021, "New 'Destructive' Severe Thunderstorm Warning Category to Trigger Wireless Emergency Alerts on Mobile Phones," July 22. https://www.weather.gov/news/072221-svr-wea.

warning, tornado warning, high wind warning, small craft advisory, dense fog advisory, or other appropriate alert. For DUKWs already on the water, the alert system would allow USCG to require DUKWs to immediately proceed to a safe refuge location during specified warnings. To be effective, both the vessel's crew and land-based personnel would need to have access to the equipment necessary to be informed of severe weather alerts. Land-based personnel would also need to monitor the alert system as part of their routine activities and communicate necessary information to the vessels. All activities designed to ensure safety during severe weather, including using the alert system, should be documented in operating manuals and be incorporated into personnel training.

The NWS alert system also issues watches, which provide "advance notice that conditions are favorable for dangerous weather."[51] USCG could take advantage of the alert system's watches to require DUKW operators to modify their routes in anticipation of severe weather. For example, during a severe thunderstorm watch, operating restrictions could instruct a DUKW to follow a water route that allows it to navigate to a safe refuge location within a specified amount of time. The amount of time would depend on the prevailing weather patterns in the vessel's operating area, such that an area that experiences frequent popup thunderstorms with little advance notice would have a shorter specified amount of time to reach a safe refuge location than an area with more reliably predictable weather patterns.

For DUKWs operating on very sheltered or benign waterways that are not significantly impacted by severe weather, it may be appropriate to reduce some or all of these severe weather requirements.

In addition to its commitment to education and outreach, NWS has worked with USCG in some areas of the country to provide decision support tools to help mariners and USCG officials make risk-based decisions regarding maritime operations. There is an opportunity for OCMIs who oversee DUKW operations to consult with their local NWS office on developing operating restrictions and decision support guides.

SUMMARY

Under Subchapter T, OCMIs must exercise their professional judgment when defining the bodies of water and setting operating restrictions. Although there is a great deal of variability between waterways under USCG jurisdiction, the committee believes that it is feasible to develop a consistent set of standards for evaluating which bodies of water or portions thereof are suitable for the safe operation of a particular type of DUKW. Developing this consisted set of evaluation standards would require considering the following factors:

- Vessel traffic, including commercial, pleasure, or government vessels
- Physical dimensions of the waterway, e.g., fetch
- Depth of the water (i.e., is the water deep enough to fully submerge the DUKW?)
- Constraints on the waterway such as speed limits or horsepower limitations
- Waterway entry to and exit points for the DUKW
- Proximity to available rescue craft
- Availability of safe refuge locations (see Box 4-2 above)

[51] NOAA Weather Partners, 2021, "FAQ: What Is a Watch," March 6. https://www.youtube.com/watch?v=x3V3HZBs1Y4.

For severe weather, incorporating the alert system run by NWS into DUKW operating restrictions is a means to reduce the risk that DUKW operators will misjudge the severity of the weather or capabilities of their craft. Such an effort would likely require USCG to consult with local NWS offices.

5
Canopies and Escape During Emergencies

INTRODUCTION

DUWK tour operators typically outfit their boats with canopies to provide passenger comfort against the sun, rain, and wind. Tour operators briefing the committee stressed the importance of canopies for their tour businesses. However, canopies can be a major impediment to safe escape during an emergency.

For small passenger vessels, a canopy covering the open seating area creates an enclosed passenger area and can slow or prevent escape, increasing the risk of injury and death. Because DUKWs have a greater risk of sinking rapidly, the risk that a DUKW's canopy will interfere with escape is even more significant. Moreover, canopies can complicate the decision to don a life jacket during an emergency to such an extent that it is not even clear whether it is advisable for passengers to wear or don life jackets before escaping the boat.

The National Transportation Safety Board (NTSB) and the United States Coast Guard (USCG) have both recommended that DUKW operators remove canopies until a design can be approved that does not restrict the escape of passengers and crew. This chapter explains the history of these recommendations and the conclusions of other studies on the risks posed by canopies. It then reviews some of the alternative types of canopies developed in recent years, which attempt to mitigate the risks in different ways. The chapter then proposes additional canopy designs for further exploration. The committee considers a "restrictive canopy" to be any canopy design that has not been demonstrated in a practical test to provide the equivalent in safety to no canopy. Restrictive canopies include any canopy that makes it inadvisable to wear a life jacket during the waterborne part of a tour.

CANOPIES, LIFE JACKETS, AND LOSS OF LIFE

Canopies have been found to be a contributing factor to the loss of life in the *Miss Majestic* and *Stretch Duck 7* sinkings. Survivors reported fighting their way through or past the canopies, and, in both tragedies, victims were recovered still in the vessels. This section reviews the presence of canopies and the donning of life jackets for the three casualty events in the United States with fatalities.

In these three casualty events, life jackets were stored in the canopies directly above the passengers, yet only a few passengers managed to don a life jacket even partially before being submerged. There has not been a fatality event on a DUKW in the United States where passengers were wearing life jackets at the time the vessel began sinking. Counter-intuitively, this has probably been a benefit for the survivability of some passengers when not wearing a lifejacket expedited their escape from the restrictive canopy.

If a small passenger vessel without a canopy sinks, passengers wearing life jackets will stay floating on the surface as the boat sinks beneath them. If a small passenger vessel with a canopy sinks, the buoyancy of the life jacket may force the wearer up against the inside of the canopy. To escape, they must swim down against the force of the life jacket and out a canopy window. The presence of a canopy creates a situation where it is not necessarily safer to be wearing a life jacket.

The *Miss Majestic* began sinking with all 20 passengers and the master still on board. Of the 13 dead, 7 were found still in the boat. The 8 survivors managed to swim out the side windows to safety. The canopy's supports defined the side windows, with a height of 28 inches. However, when the canopy's side curtains were in the rolled-up position, as they were at time of sinking, the window height was reduced to 21 inches. The life jackets were stored in the canopy, and the master and a passenger reported difficulty trying to remove them. None of the passengers succeeded in donning a life jacket themselves or putting one on a child.[52]

The NTSB found that the *Miss Majestic*'s canopy was a "major impediment" to passenger survival and that wearing life jackets for the waterborne part of a tour would "enhance the safety of passengers on board DUKWs without adequate reserve buoyancy where canopies have been removed."[53] The USCG investigation also concluded "that the donning of life jackets would have prevented escape from under the canopy and led to additional deaths."[54]

After the *Stretch Duck 7* sinking, the NTSB again concluded that the canopy and side curtains likely contributed to the loss of life and that if the passengers had donned life jackets, the life jackets "would have created an impediment to escape" that "could have resulted in additional fatalities." Of the 17 deceased, 9 bodies were recovered under water, including 1 still in the boat.[55]

As the storm began to hit Table Rock Lake, *Stretch Duck 7*'s master lowered the side curtains to protect the passengers from the wind and rain. The master did not order the passengers to don life jackets when he cut short the tour and headed for shore. As the vessel began quickly sinking, the master only managed to release one of the canopy's side curtains before the incoming water swept him out of the boat. Fortunately for the passengers who reported floating up to the underside of the canopy, the canvas became partially dislodged, and some managed to escape through the opening. On the recovered vessel, 41 of 56 life jackets were still connected to *Stretch Duck 7*'s canopy.[56]

For the *DUKW 34* collision, although the canopy was not considered a contributing factor to the loss of life, it was damaged in the collision. The canopy supports on the port side were bent, two of them by about 45 degrees, toward the interior of the passenger compartment. The port-side roller curtain was also damaged so that it hung from one of its mountings.[57]

Of the 37 people on board *DUKW 34*, only 1 evacuated in advance of the collision. The DUKW's master had not ordered the passengers to don life jackets when he anchored the vessel.

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[52] NTSB, 2002, "Sinking of the Amphibious Passenger Vessel *Miss Majestic*, Lake Hamilton, Hot Springs, AR, May 1, 1999," Marine Accident Report NTSB/MAR-02/01, April 2. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR0201.pdf.
[53] NTSB, 2002, "Sinking of the Amphibious Passenger Vessel *Miss Majestic*, Lake Hamilton, Hot Springs, AR, May 1, 1999," Marine Accident Report NTSB/MAR-02/01, April 2, 2002.
[54] USCG, 1999, "Investigation into the Circumstances Surrounding the Sinking of the M/V Miss Majestic…," September 29. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/INV/docs/boards/dukw.pdf.
[55] NTSB, 2020, "Sinking of Amphibious Passenger Vessel *Stretch Duck 7*, Table Rock Lake, near Branson, MO, July 19, 2018," Marine Accident Report NTSB/MAR/20-01, April 28. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.
[56] NTSB, 2020, "Sinking of Amphibious Passenger Vessel *Stretch Duck 7*, Table Rock Lake, near Branson, MO, July 19, 2018," Marine Accident Report NTSB/MAR/20-01, April 28.
[57] NTSB, 2011, "Collision of Tugboat/Barge *Caribbean Sea/The Resource* with Amphibious Passenger Vessel *DUKW34*, Philadelphia, PA, July 7, 2010," Marine Accident Report NTSB/MAR-11/02, June 21. https://www.ntsb.gov/investigations/Pages/DCA10MM025.aspx.

In the minute before the collision, passengers started to scramble for life jackets, but only a few managed to get them over their heads, and no one donned and fully fastened a life jacket before being hit by the barge. Fortunately, the canopy's side curtains were rolled up at the time of the collision because it was a nice day. Those with life jackets in hand at the time of the collision reported losing grasp of them during the sinking. Some survivors were able to grab hold of floating life jackets once they reached the surface of the water.[58]

REGULATIONS AND NVIC 1-01

Regulations and guidance for canopies aim to prevent canopies from interfering with escape during an emergency. Navigation and Vessel Inspection Circular 1-01 (NVIC 1-01) was created to implement the recommendations, including for canopies, after the sinking of the *Miss Majestic*. Among its recommendations, NIVC 1-01's guidance remedies the small effective height of the windows that helped trap *Miss Majestic*'s passengers by recommending a vertical distance of 32 inches.

Because of a DUKW's small size, Subchapter T, 177.500, Means of Escape, requires only one means of escape, and NVIC 1-01 stipulates that the primary means of escape is over the side. If a canopy is present, the primary means of escape becomes through the canopy "windows" as delineated by the supports holding up the canopy. NVIC 1-01[59] directly addresses canopies by outlining design specifications allowing safe egress over the side:

> Canopy supports should be positioned to allow the majority of passengers unobstructed egress. If a canopy support is located directly adjacent to a passenger's seat it should be shown, through a practical test, that the passenger can adequately egress the vehicle. The window framing vertical distance should be sufficient for a passenger to exit while wearing a life jacket. A vertical distance of 32 inches from gunwale to canopy appears sufficient for most installations. Overhead storage of life jackets should not impede the egress of passengers.

In addition, NVIC 1-01 advises that side curtains "should be able to be opened with minimal force, generally by a simple action by one person." NVIC 1-01 does not anticipate escape through the "roof" of the canopy itself.[60] Because the primary means of escape is over the side, NVIC 1-01 also allows more cramped conditions in the passenger compartment, putting even more importance on easily retrieving life jackets and exiting over the sides.

Despite the stipulation that passengers should escape over the side, USCG also recognizes that "this goes against human nature, which is to exit in the same manner one enters." For most DUKWs, passengers enter over the stern and will assume that the exit is also at the stern. Because of the discrepancy between ingress and safe egress locations, NVIC 1-01 stresses that "the master should give specific instructions to the passengers during the safety orientation concerning the method of escape from the vehicle."[61]

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[58] NTSB, 2011, "Collision of Tugboat/Barge *Caribbean Sea/The Resource* with Amphibious Passenger Vessel *DUKW34*, Philadelphia, PA, July 7, 2010," Marine Accident Report NTSB/MAR-11/02, June 21.
[59] NVIC 1-01, p. 23. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/5ps/NVIC/2001/n1-01.pdf.
[60] NVIC 1-01, p. 23.
[61] NVIC 1-01, p. 23.

RECOMMENDATIONS FROM STUDIES AND INVESTIGATIONS

The hazard canopies pose to safe escape applies to all small passenger vessels, not just DUKWs. Investigations and studies conducted by NTSB, USCG, and the Worcester Polytechnic Institute over the past 20 years all agree that canopies are a significant safety hazard on small passenger vessels if not constructed for easy egress.

After the sinking of the *Miss Majestic*, NTSB issued Safety Recommendation M-02-2 directed to the attention of USCG and the states of New York and Wisconsin. The recommendation highlighted the relationship between reserve buoyancy (Chapter 3) and canopies:

> Until such time that owners provide sufficient reserve buoyancy in their amphibious passenger vessels so that they will remain upright and afloat in a fully flooded condition (by M-02-1), require the following: (1) removal of canopies for waterborne operations or installation of a Coast Guard-approved canopy that does not restrict either horizontal or vertical escape by passengers in the event of sinking."[62]

USCG concurred with the intent of the recommendation and developed the canopy guidelines in NVIC 1-01 described in the previous section. In 2003, NTSB expressed its dissatisfaction with USCG's approach, noting that NTSB's recommendation was that USCG either require the removal of canopies or create additional design requirements, not advisory guidelines.

At the request of USCG, students at the Worcester Polytechnic Institute produced "Standards for Enclosed Canopies on Small Passenger Vessels" in 2009,[63] which provides a full review and analysis of the types of canopies, applicable regulations, their role in casualties, and impacts on passenger behavior. The committee highlights four of their findings and recommendations to improve canopies:

- Donning of bulky Type 1 life jackets while inside a canopy with escape routes of insufficient size can lead to entrapment during a flooding event, as the life jacket will hold the passenger up against the canopy and prevent them from diving out through an opening.
- Side windows can be a major impediment to escape and, if fitted, should have an emergency release mechanism that is easily operable.
- Darkness inside the canopy while flooding can lead to confusion and disorientation. Underwater LED lights should be installed that would be activated automatically in an emergency.
- Passenger education on how to act in an emergency is critical before an emergency situation occurs. Crew training and signage are also important to provide direction to passengers in an emergency.

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[62] NTSB, 2019, Recommendation M-02-2 as reprinted in NTSB, "Improving Vessel Survivability and Passenger Emergency Egress of DUKW Amphibious Passenger Vessels," Marine Safety Recommendation Report MSR-19-01, November 6.

[63] See https://web.wpi.edu/Pubs/E-project/Available/E-project-121609-190318/unrestricted/USCG_Final_IQP.pdf?_ga=2.149754993.67315947.1634477406-1311220223.1634477406.

After the sinking of *Stretch Duck 7*, NTSB adopted Safety Recommendation M-19-16 in 2019. The agency again recommended that USCG require the removal of canopies, but this time without presenting the option that perhaps the design of canopies could be improved:

> For DUKW amphibious passenger vessels without sufficient reserve buoyancy (commonly referred to as original and/or "stretch" DUKWs), require the removal of canopies, side curtains, and their associated framing during waterborne operations to improve emergency egress in the event of sinking.[64]

USCG issued a similar recommendation in Marine Safety Information Bulletin 15-20, issued April 22, 2020, which stated "that vessel owners and operators of DUKW passenger vessels remove canopies, side curtains, and associated overhead framing to improve emergency egress for passengers and crew."[65] However, USCG made canopy removal a recommendation, not a mandate, so operators could still retain canopies if desired.

TYPES OF CANOPIES IN USE

DUKWs currently use a range of canopy designs, and many of the designs consider the decades of concerns that canopies pose a hazard to passengers in an emergency. Canopies generally consist of canvas or plastic material stretched across metal framing and supported by multiple vertical supports. Some DUKWs also use side curtains made of clear plastic. This section reviews the types of canopies and side curtains in use on DUKWs currently or in the recent past to examine how canopies create impediments to escape and how design modifications aim to mitigate these hazards.

Some DUKW operators forego side curtains, which allows easier escape over the side of the vessel. However, close spacing of the vertical canopy supports may still interfere with escape, particularly if passengers are wearing bulky life jackets. For DUKW operators that continue to use side curtains, there are designs that allow each window to be opened individually by a person sitting or standing adjacent to the window, instead of using a single mechanism to drop the entire side curtain at once.

The area under the canopy roof is often used to store life jackets, as shown in Figure 5-1. This arrangement puts a life jacket above each passenger, within reach if they stand. However, disabled passengers or children unable to reach the overhead life jackets would need to be assisted by others. For operators, storing life jackets in the canopy makes it easier to use the limited amount of deck area for passenger seating.

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[64] NTSB, 2019, "Improving Vessel Survivability and Passenger Emergency Egress of DUKW Amphibious Passenger Vessels," Marine Safety Recommendation Report MSR-19-01, November 6.
[65] USCG, 2020, "Recommendation for DUKW Passenger Vessel Canopy Removal," Marine Safety Information Bulletin 15-20, April 22. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/MSIB/2020/MSIB-15-20_Recommendation%20for%20DUKW%20Passenger%20Vessel%20Canopy%20Removal.pdf.

FIGURE 5-1 Stowage of life jackets under the canopy from *Stretch Duck 7*.
SOURCE: https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.

Canopy with Rolldown Side Curtains

The canopy on the *Stretch Duck 7*, shown in Figure 5-2, included two side curtains, each made out of a single sheet of clear plastic that could be rolled down and up as needed. Figure 5-3 shows the plastic side curtains in the down or deployed condition. In emergencies, each curtain is released by its corresponding lever located on each side of the vessel. The release mechanism does not roll up the curtain; instead, the release mechanism causes the curtain to disengage at the top and fall away. On the *Stretch Duck 7*, one release lever was located on the port side above

FIGURE 5-2 Canopy on *Stretch Duck 7* after casualty.
SOURCE: https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.

the driver's seat and one in the corresponding location on the starboard side. The driver's seat is located directly behind the captain's seat. The starboard release mechanism was not within easy reach of either the captain's or driver's seat. Figure 5-4 shows the successful test, post casualty, of the *Stretch Duck 7*'s starboard window release mechanism.

FIGURE 5-3 Side curtain rolled down to protect passengers.
SOURCE: https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.

FIGURE 5-4 Side curtain released for emergency exit.
SOURCE: https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR2001.pdf.

Shortened Canopy, No Side Curtains

Some DUKW operators use shortened canopies, typically with no side curtains. Figure 5-5, a WWII DUKW operated by Chattanooga Ducks, has a shortened canopy so that the aft, raised

FIGURE 5-5 Chattanooga WWII DUKW with shortened canopy.
SOURCE: A. Moyers, Chattanooga Ducks.

seating area is not covered. The canopy only uses four vertical supports on each side, spaced well apart. A person could also escape through the front, going around or over the windshield. Figure 5-6 shows an Original Wisconsin Ducks DUKW with another version of a shortened canopy, with no side curtains and open at the front and back. This configuration still has relatively closely spaced vertical supports that can impede escape over the side.

Shortened canopies with no side curtains may be a challenge for businesses operating in areas that frequently experience cold, breezy, or rainy weather during their operations.

FIGURE 5-6 Original Wisconsin Ducks DUKW with open, reduced-size canopy.
SOURCE: T. Graul, committee member.

Escape Hatch in Canopy

An escape hatch in the canopy allows at least some of the passengers to swim or float to the surface without having to leave the vessel over the sides. Designs for escape hatches vary in their length and the means of opening.

Boston Ducks, which has a fleet of Truck Ducks, uses a sliding hatch in its canopies. The canopies are constructed of a lightweight reinforced vinyl that is easy to cut. The hatch panel is 7 feet square, located in the stern area, and slides forward (see Figure 5-7).

FIGURE 5-7 Stern area slide roof on Boston Duck Tours.
SOURCE: T. Cerulle, Boston Duck Tours.

The hatch is normally closed and has a handle with instructions to slide open in case of an emergency (see Figure 5-8).

FIGURE 5-8 Emergency handle with manual pull for sliding roof, Boston Duck Tours.
SOURCE: T. Cerulle, Boston Duck Tours.

The hatch is mentioned in the pre-trip safety orientation. Although this hatch provides a means of escaping upward and through the roof during a casualty, it only extends for a limited length of canopy. This escape route is only available to persons who can reach the hatch in time and swim up through it as the vessel is sinking.

Boston Ducks has also developed another design, yet to be approved by USCG, that includes two hatches, the hatch in the stern area and a centerline hatch. The hatch at the stern slides aft. The centerline hatch is 11 feet by 4 feet and slides forward (see Figure 5-9).

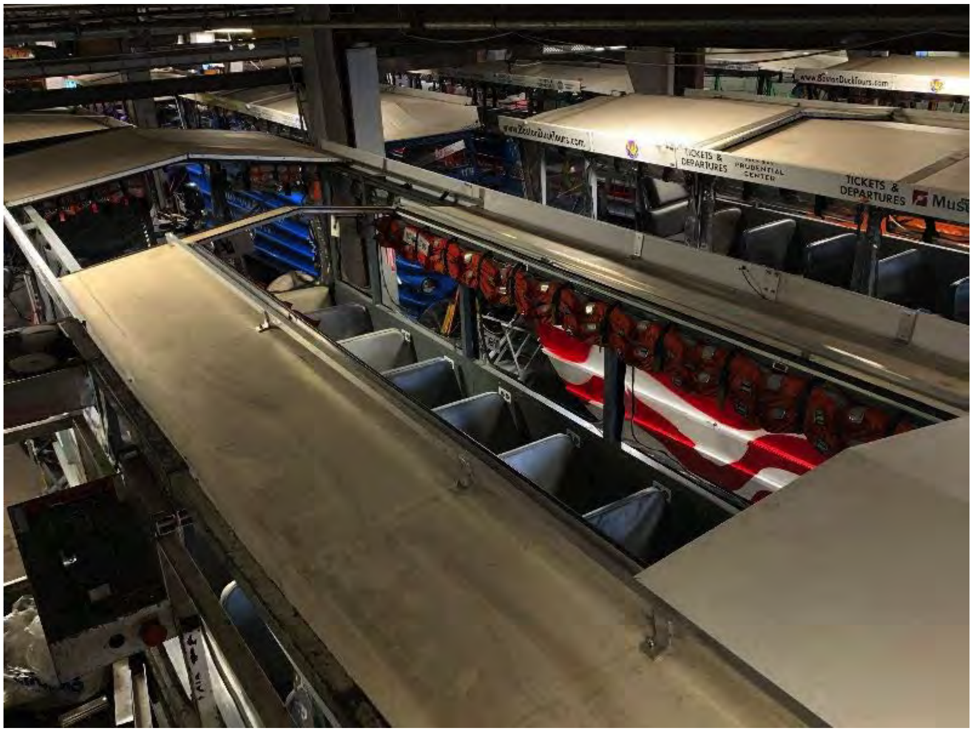

FIGURE 5-9 Slide roof panels with centerline hatch, Boston Duck Tours.
SOURCE: T. Cerulle, Boston Duck Tours.

The Original Wisconsin Ducks has developed a removable center section that extends the full length of the canopy. It is opened in an emergency by pulling downward (see Figures 5-10 and 5-11).

FIGURE 5-10 Pull open canopy section, Original Wisconsin Dells.
SOURCE: T. Graul, committee member.

FIGURE 5-11 Pull down canopy section on length of centerline, Original Wisconsin Dells.
SOURCE: T. Graul, committee member.

Passenger-Opened Side Windows

All Boston Ducks are fitted with side curtains made of a piece of clear plastic for each window frame defined by the vertical supports. The canopy frame and supports are constructed of aluminum, and the supports provide an opening that is 4 feet 6 inches wide and 2 feet 10 inches high. The plastic windows are attached to the canopy frame using hook-and-loop (Velcro) fasteners and are easily removed or released for over-the-side egress. Figures 5-12 and 5-13 show a Boston Duck side curtain pushed open, like for an escape, and one stowed in rolled up position.

FIGURE 5-12 Side curtains affixed with Velcro tabs, Boston Duck Tours.
SOURCE: R. Cook, committee member.

FIGURE 5-13 Side curtain in rolled up position, Boston Duck Tours.
SOURCE: R. Cook, committee member.

No Canopy During Water Operations

In Ireland, regulations for amphibious passenger vehicle (APV) operations require operators to remove canopies and passengers to don life jackets for the duration of on-water operations.

According to the United Kingdom's Marine Accident Investigation Branch (MAIB), passengers were willing to wear life jackets as part of the tour.[66]

The lack of a canopy during water operations may make operating a business in colder, rainy climates more difficult.

OTHER CANOPY SOLUTIONS

The committee investigated potential solutions that would retain the canopy and side curtains, but still improve the ease of escape. Breakaway or float-away canopies could work in theory, but present difficulties in safe execution. More promising are easy open canopies and easy open side curtains. The committee learned that DUKW tour operators are considering some of these solutions with the goal of making canopies less of an impediment to escape.

Float-Away Canopy

A float-away or breakaway canopy could remove the canopy from blocking escape upward as the vessel is sinking; however, to be effective, such a canopy would need to be released and shifted away well before the DUKW was fully immersed. In addition, any float-away mechanism would need to be below the canopy itself. If the canopy were the floating part, it would not lift off the vessel until the canopy was immersed, and such a canopy could still potentially trap passengers under water, especially if they are wearing life jackets. The design for such a float-away or breakaway canopy would also need to be able to prevent the canopy from being blown off while driving on land or in squalls on the water. The many difficulties with this concept have prevented it from widespread implementation.

Easy-Open Canopy

During the sinking of the *Stretch Duck 7,* some passengers escaped through an opening made when part of the canopy dislodged. Installing rip-away soft canopies, or clamshell hard canopies that open upward during a casualty, would provide a ready means of escape as the vessel sinks. Such a canopy would allow operators to direct passengers to wear life jackets for all waterborne operations or to don them during early phases of an incident. Designs for easy-open canopies should include activation mechanisms that do not require operator actions to open the canopy.

Easy-Open Side Curtains

Side curtains, if any, need to be opened quickly and fully to facilitate the escape of persons wearing bulky life jackets. As the *Stretch Duck 7* revealed, even having just two release mechanisms, one for each side curtain, proved too much for the crew to execute during the emergency. If the crew member is injured during a casualty, then it is even more likely the side curtains will not be released, trapping the passengers. Passengers should be able to assist or lead with opening side curtains to expedite their escape. Having passengers open any side windows

[66] MAIB, 2014, Very Serious Marine Casualty Report 32/2014, December. https://assets.publishing.service.gov.uk/media/54c1722240f0b6158d00002b/MAIBReport_32-2014.pdf. The committee attempted to contact the operator to gather more information about this operation; however, the operating company is in liquidation.

themselves is also consistent with the NVIC 1-01 stipulation that the primary means of escape is over the side and that any impediments to passenger escape should be minimized.[67]

On the Boston Ducks, the window coverings attached via hook-and-loop (Velcro) can be pushed outward and almost completely removed from the frame during emergencies (see Figure 5-12). Individual window coverings save the person removing a curtain from having to struggle with a long length of side curtain. However, individual window coverings do require multiple passengers—likely two for every row of seats—to have the height and strength to remove the window curtain. If window coverings are just pushed open on the bottom or side, and not removed, the hook-and-loop could reseal itself after an individual escape. The possibility of resealing implies that all passengers would need to be capable of opening a window curtain. In addition, hook-and-loop window attachments must be weak enough for passengers to detach, but strong enough to not blow free when traveling down the road.

Easy open side curtains should be designed so that passengers of a reasonable range of weight, height, and strength can open or remove the window covering nearest them by pushing on the center of the window and easily exit the vessel over the side. Clear visual instructions should be posted on the curtains instructing passengers where and how to open the curtains, if required.

SUMMARY

The committee agrees with NTSB and USCG that canopies pose a significant risk to passenger safety when escape during an emergency is necessary. Canopies can be particularly deadly when a DUKW sinks because of flooding. Rigorous requirements are appropriate for higher risk operations, as defined in Chapter 8. These requirements would include removing canopies or mandating canopy designs that have been demonstrated to minimize risk while wearing life jackets to the equivalent of no canopy. Canopies on DUKWs that are part of lower risk operations pose less of a risk to passenger safety, but implementing improved designs is still likely to be an advisable safety improvement. Any side curtains should not require crew actions to activate and should be easily openable by a range of passengers, intuitive to use, and labeled with instructions on how to use.

[67] Enclosure 1 to NVIC 1-01, section regarding 177.500 - Means of Escape

6
Wearing Life Jackets

Life jackets are the primary means to keep persons afloat after they have entered the water, particularly for persons unable to swim. All small passenger vessels operated under United States Coast Guard (USCG) jurisdiction are required to have USCG-approved Type I life jackets equal to the number and types of persons, adults and children, expected on board. Life jackets are a key tool to increasing the survivability of persons on board, but only if they are actually worn or successfully donned during an emergency.

The difficulties passengers have accessing and donning life jackets and then escaping a DUKW with a canopy are discussed in Chapter 5. The analysis in this chapter assumes that canopies have either been removed or that the hazard they pose has been successfully mitigated. This chapter examines whether passengers should be required to wear life jackets during the waterborne portion of trips. The chapter also addresses which types of life jackets, Type I, Type II, or Type III, are most appropriate for DUKWs.

LIFE JACKETS AND CASUALTY EVENTS

As described in Chapter 5, the life jackets on DUKWs have not been very effective at increasing the survivability of DUKW passengers and crew. A few survivors have been able to grab a floating life jacket once already in the water, but for the most part, survivors depended on their own ability to swim or on flotation devices thrown from other boats. In the sinkings of the *Miss Majestic* and *Stretch Duck 7*, a number of young children were on board. The adults responsible for them had great difficulty getting life jackets on the children, let alone themselves, before ending up in the water.

In the sinking of the *Wacker Quacker 1*, the reserve buoyancy gave passengers a little more time to escape the vessel. Most still ended up in the water without having donned life jackets. In the panic to escape the fire on the *Cleopatra*, a majority of the passengers left the boat with a buoyancy aid, but few had donned them properly. A child, age 4, was among those who ended up in the water without a buoyancy aid. The United Kingdom's Marine Accident Investigation Branch (MAIB) noted that if the crew of the *Cleopatra* had taken the time to help disperse the life jackets and assist passengers in donning them, many passengers may not have escaped the vessel in time.[68]

REGULATIONS AND NVIC 1-01

Subchapter T specifies the number and types of life jackets that must be on board small passenger vessels. As per 46 CFR Part 180, one adult life jacket must be provided for each person on the vessel. The number of child-sized life jackets must equal either 10 percent of the total number of persons on board or the number of children on board, whichever is greater. Life jackets must be stowed in convenient places distributed throughout the passenger space and be readily available. If practicable, the method of stowing should allow the life jackets to float free if submerged.

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[68] MAIB, 2014, Very Serious Marine Casualty Report NO 32/2014, December.

For the type of life jacket, Subchapter T regulations are a "one-size-fits-all" mandate for all boats and all areas of commercial operation. In accordance with 46 CFR § 180.72(a), only Type I life jackets meet regulatory requirements for use in an emergency on any commercial vessel, including DUKWs. Box 6-1 covers the USCG definitions of Types I, II, and III life jackets. Currently, Types II and III are only approved for recreational use and general boating activities.

BOX 6-1
Types of Life Jackets as Defined by USCG

TYPE I PFDS/OFF-SHORE LIFE JACKETS:
Best for all waters, open ocean, rough seas, or remote water, where rescue may be slow coming. Abandon-ship life jacket for commercial vessels and all vessels carrying passengers for hire:

- Inherently Buoyant Type I PFDs (personal flotation device) - SOLAS Service
- Inherently Buoyant Type I PFDs - U.S. Service
- Inflatable Type I PFDs - SOLAS and Domestic
- Hybrid Type I PFDs - U.S. Service

TYPE II PFDS/NEAR-SHORE BUOYANT VESTS:
For general boating activities. Good for calm, inland waters, or where there is a good chance for fast rescue.

- Inherently Buoyant Type II PFDs
- Inflatable Type II PFDs
- Hybrid Type II PFDs

TYPE III PFDS/FLOTATION AIDS:
For general boating or the specialized activity that is marked on the device such as water skiing, hunting, fishing, canoeing, kayaking, and others. Good for calm, inland waters, or where there is a good chance for fast rescue. Designed so that wearing it will complement your boating activities:

- Inherently Buoyant Type III PFDs
- Inflatable Type III PFDs
- Hybrid Type III PFDs

NOTE: USCG's PFD website includes the following: "The Coast Guard is working with the PFD community to revise the classification and labeling of PFDs."
SOURCE: USCG, "PFD Selection, Use, Wear, and Care: Recreational Boating PFD Selection." https://www.dco.uscg.mil/CG-ENG-4/PFDSel.

Type I life jackets are bulky and uncomfortable, but they will turn most unconscious wearers face up in the water. Type II life jackets will turn some unconscious persons face up, and they have less buoyancy than Type I life jackets. Type III life jackets are designed to be comfortable to wear while in a boat but will not keep an unconscious person face up in the water.

The regulations on means of escape also affect accessing and donning life jackets. As described in Chapter 2, because the primary means of escape is over the side, Navigation and Vessel Inspection Circular 1-01 (NVIC 1-01) guidelines on aisle width and passenger seating allow more cramped conditions. In addition to the small space, the number of personnel and their responsibilities, as described in Chapter 7, also affect the availability of crew members to assist passengers with life jackets.

During the passenger safety orientation (46 CFR 185.506), the master should include the following information about life jackets: their location, the proper method of donning and adjusting via a demonstration, the location of instruction placards, and the times when all passengers will be required to don life jackets because of hazardous conditions or as directed by the master. Training for abandoning ship and man overboard is also to cover the donning of life jackets (46 CFR 185.520–524). The drills are to be conducted as if the emergency actually existed.

Committee interviews with DUKW owners and operators identified no violations to Subchapter T regulations or the NVIC 1-01 guidelines. The number and type of life jackets aboard may differ by tour operator (i.e., numbers of child versus adult life jackets), but they meet the requirements of the current regulations. In all cases, the life jackets were locally available and distributed throughout the accommodation space for ease of access for all passengers. All owners and operators interviewed identified that they stored life jackets in one of two places: under the seats or directly above the seats. Passengers receive instructions on the location and donning of jackets in emergency situations.

INVESTIGATIONS AND STUDIES

According to USCG's Recreational Boating Statistics for 2019, where the cause of death was known, 79 percent of fatal boating accident victims drowned. Of those drowning victims, 86 percent were not wearing a life jacket.[69] Although DUKWs are not recreational boats, passengers on these small touring vessels have an experience, including the purpose of the trip, similar to what they would have on recreational boats. Studies and their recommendations for life jackets on both recreational boats and small passenger vessels are likely to be applicable to DUKWs.

In addition to the regulations in Ireland requiring that DUKW passengers wear life jackets during the waterborne parts of trips, recommendations coming out of the United Kingdom also favor wearing life jackets. Following the fire on the *Cleopatra*, the Thames Passenger Boat Investigation Committee (London Assembly) issued a recommendation that London Duck Tours "should consider whether there is a case for passengers to wear life jackets as a matter of course on the water part of the tour." The MAIB, in its report on the *Cleopatra* and *Wacker Quacker 1*, also recommended that "consideration [be] given to requiring all passengers to wear PFDs whenever DUKWs are waterborne."[70]

There is recognition in Canada and the United States that wearing life jackets significantly mitigates risks during recreational boating. In 2011, the National Boating Safety Advisory Council recommended that USCG initiate a future regulatory project to pursue

[69] USCG, 2020, "2019 Recreational Boating Statistics," June 4. https://www.uscgboating.org/library/accident-statistics/Recreational-Boating-Statistics-2019.pdf.
[70] MAIB, 2014, Very Serious Marine Casualty Report NO 32/2014, December. https://assets.publishing.service.gov.uk/media/54c1722240f0b6158d00002b/MAIBReport_32-2014.pdf.

requirements that recreational boaters wear life jackets.[71] Transport Canada's public information for recreational boating also strongly encourages the wearing of life jackets, noting, "It won't work, if you don't wear it!" and "Never underestimate how much protection a flotation device can give you. It is called lifesaving equipment for a reason."[72]

Research on life jackets makes it clear that donning life jackets during an emergency is a recipe for chaos, but getting passengers to wear life jackets during a pleasure tour requires mandatory regulations. An exercise in Rhode Island that challenged boaters to locate and don their life jackets in under 30 seconds was described as "almost comical as people scrambled around looking for their life jackets. In many instances, the test ended with adults trying to put on children's life jackets or finding no life jackets at all."[73] Research on life jacket use among adult recreational boaters found that "participants repeatedly emphasized that making life jacket use mandatory through legislation and enforcement would be the only way to get more people to use them." The study did find, however, that boaters were open to life jacket options deemed more comfortable for longer-term wear.[74]

The committee identified a similar concern about mandatory life jacket wearing in its conversations with DUKW owners and operators. They are reluctant to require the wearing of life jackets for the waterborne parts of their trips unless backed up by an official regulatory body such as USCG. Owners and operators anticipate coming into conflict with their customers over comfort or bias against life jackets. They also are concerned that wearing life jackets would lead customers to assume that riding DUKWs is unsafe. A regulation requiring the wearing of life jackets, however, would be similar to regulations requiring seat belts in motor vehicles or helmets for motorcycles.

WEARING LIFE JACKETS WHEN WATERBORNE

Wearing life jackets during the waterborne parts of a DUKW tour will increase the survivability of passengers during casualty events, assuming that the problems with egress through a canopy and its side windows can be satisfactorily resolved. Wearing a life jacket mitigates risk of fatalities in a sudden event such as a capsizing, swamping, or collision.

USCG's current approach, which leaves it to passengers to locate and don life jackets after an incident, is based on two assumptions that may not be applicable to DUKW passengers. The first assumption is that there will be enough time during an emergency for all passengers to locate and don life jackets. For certain types of DUKWs, the time to safely escape during a fire or flood may be only a few minutes or even less. Because DUKWs are family-oriented tourist activities, passengers often include children and others who may need assistance retrieving and donning a life jacket. Moreover, the reality is that some of the passengers and crew will likely be

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[71] National Boating Safety Advisory Council, April 1–2, 2011, Arlington, Virginia, Resolution Number 2011-87-01 Appropriate Regulations for Life Jacket Wear by Recreational Boaters. https://homeport.uscg.mil/Lists/Content/Attachments/459/NBSAC%202011-87-01%20-%20Signed_2.pdf.

[72] See https://tc.canada.ca/en/marine-transportation/getting-started-safe-boating/choosing-lifejackets-personal-flotation-devices-pfds.

[73] Groff, P., and J. Ghadiali, 2003, "Will It Float? Mandatory PFD Wear Legislation: A Background Research Paper prepared for the Canadian Safe Boating Council," SMARTRISK Toronto, Ontario, Canada. https://www.seattlechildrens.org/pdf/will-it-float-mandatory-PFD-wear-legislation-in-canada.pdf.

[74] Quistberg, D. A., E. Bennett, L. Quan, and B. E. Ebel, 2014b, Low life jacket use among adult recreational boaters: A qualitative study of risk perception and behavior factors. *Accident Analysis and Prevention* 62:276–284. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3919505.

operating in a state of shock—"fog" or "confusion"—when an event occurs. The time it takes for the diverse types of passengers to locate and don life jackets and escape safely will vary widely.

The second faulty assumption is that people are capable of properly donning a life jacket once in the water; that persons will escape the vessel with life jackets in hand, instead of properly donned; or that they will be pulled under the water and will locate a floating life jacket once they swim to the surface. Instead of assuming success, experience has shown that donning life jackets once overboard is nearly impossible. Wind, waves, weather, and temperature conditions will all make it extremely difficult for someone to maneuver themselves into an unfamiliar life jacket while also needing to swim or tread water.

Wearing life jackets would also allow the crew to assist passengers, ensuring that the life jackets have been properly donned before embarking on the waterborne part of the trip. Because of the narrow aisle widths, it is often not practical for the master or a crew member to assist passengers with life jackets once the vessel is under way. As discussed in Chapter 7, DUWKs are often operated by a one-person crew who has many responsibilities during an emergency. In all the casualties reviewed, passengers have had to assist (or attempt to assist) other passengers with life jackets.

TYPE III LIFE JACKETS

Allowing the use Type III life jackets instead of Type I life jackets on DUKWS holds promise as a means to encourage the wearing and ease the donning of life jackets.

Exclusively relying on Type I life jackets on DUKWs has disadvantages. They are bulky, making them uncomfortable to wear, and donning them is not intuitive, especially for those who rarely travel on a commercial vessel. When stowed on board, their bulk takes up space in an already cramped passenger compartment. Their bulk also complicates attempts by the crew or other passengers to walk the narrow aisle of a typical DUKW to assist with their distribution and donning.

Although Type III life jackets do not keep an unconscious person face up, the operating areas for DUKWs are normally close to shore. Rescue by other boats or those on shore typically happens quickly for those who reach the water's surface. Type III life jackets are also more likely to be familiar to passengers who are recreational boaters. Offering DUKW operators the flexibility of using Type I or Type III life jackets would allow them to choose the life jacket type that best fits their circumstances and may encourage passengers to wear them during the tour.

SUMMARY

Meeting Subchapter T regulations for the number and placement of Type I life jackets was not found to be an issue on DUKWs. However, the committee believes that the current policy allowing life jackets to be donned only in an emergency is based on faulty assumptions about the likelihood of successfully donning life jackets either on the boat or once in the water.

Especially for higher risk operations, the best way to ensure the survivability of passengers, once the canopy issue has been successfully resolved, is to require the wearing of life jackets. Given the typical operating area of DUKWs, Type III life jackets may be an appropriate substitute for Type I life jackets, if future investigations show that persons are more likely to wear them.

7
Operations and Safety

The DUKW's operating personnel on board—the crew—are the key persons who control its safe operation. They take the lead in assuring passenger safety during both normal operations and in emergencies. Although the United States Coast Guard (USCG) licensing requirements, required drills, and inspections help to set minimum standards for crew knowledge and capability, they are not enough on their own. Safe operations require significant crew training and investment by the operator in a well-planned safety system to ensure that passengers will have a safe ride at all times.

Even more than for other small passenger vessels, DUKWs require their passengers to take responsibility for their own safety and even the safety of others during an emergency. With only one or two crew members on board and the crowded conditions in the passenger compartment, the crew is unlikely to be able to assist most passengers. In addition, preceding or during all three major casualty events with loss of life, members of the crew or the support staff on land failed to execute some of the actions prescribed to maintain safety.

This chapter examines policies for the number of personnel on board, tour preparations, such as safety checks and training, and the responsibilities of passengers during an emergency. Although there are ways to increase the likelihood that people will follow sound procedures and respond appropriately during emergencies, depending solely on human behavior to attain adequate safety is less than ideal.

REGULATIONS AND NVIC 1-01

The committee identified regulations covering the number of personnel required on board (46 CFR 185 Subpart D Crew Requirements), the passenger safety orientation (46 CFR 185.506), and the operator's procedures for crew training (46 CFR 1985.520–524) as the most significant for safe operations, given the major casualty events. USCG has developed Navigation and Vessel Inspection Circular 1-01 (NVIC 1-01) guidance for all three of these topics, which is discussed in more detail in the sections below.

Regulations and NVIC 1-01 guidance on means of escape and design requirements for the passenger compartment, discussed in more detail in Chapter 2, also impact how the crew will likely act during an emergency.

NUMBER OF PERSONNEL ON BOARD

The operators of DUKWs are responsible for movement over land as commercial vehicle operators and through the water as vessel masters. DUKWs generally operate with either a single master or with one master plus one deckhand, as stipulated in the vessel's Certificate of Inspection (COI). Manning requirements for DUKWs are set by the Officer in Charge, Marine Inspection (OCMI) in accordance with 46 CFR §185, with additional guidance in NVIC 1-01.

NVIC 1-01 sets the conditions to be met for operation by a master with no deck hand. A single master may be allowed if the operator can demonstrate control of the vessel while conducting normal operations and during emergencies. The OCMI is to consider numerous factors when stipulating required personnel, such as the vessel itself, tour route, maneuvering requirements, and number of passengers who are children. The OCMI will also likely witness emergency drills that are conducted annually.

DUKW tour businesses deploy personnel in a variety of ways. In some cases, when a vessel is required to have a deckhand on board, the DUKW will operate on land with a single driver and then pick up a deckhand before entering the water. Some operations choose to have a single person with a commercial driver's license (as required by the state) and a USCG master's license serve as both the on-land and on-water operator. Other businesses opt to change operators when the vessel enters the water.

In general, vessels that operate on protected waters with very little water traffic often operate with only a master. For vessels operating on partially protected waters and areas with additional water traffic (such as rivers on which other commercial traffic operates), OCMIs typically require a master and a deckhand. Additionally, COIs often require a deckhand for night operations.

For the DUKW casualty events with loss of life, the required number of personnel varied. The *Miss Majestic* carried only a master, who was also the driver for the land portion of the trip. For *DUKW 34*, USCG required a master and a deckhand. The master narrated the tour. The deckhand's use of a personal cell phone during the incident leading to the collision contributed to the casualty event. The deckhand was also the only boat occupant to evacuate the DUKW before the collision. The *Stretch Duck 7* required only a master for the water portion of the tour, who also narrated the tour. However, the driver for the land portion of the tour was on board and assisted the master as directed. The driver for the land portion was among the fatalities.

TOUR PREPARATIONS

There are demonstrated risks in depending on the actions of humans to achieve safety. This is particularly true for DUKW tour businesses, which are often seasonal and may have high crew turnover. Preparing for fast-changing weather is a specific concern.

In the sinking of the *Miss Majestic*, the National Transportation Safety Board (NTSB) noted that there were no written procedures for maintenance inspections or other safety checks. The owner, who had been in business for 40 years, relied on assigning a specific DUKW to an operator who would get to know their vessel's sounds and handling norms. The safety procedures outlined in NVIC 1-01 are an attempt to provide guidance in response to this owner's informal procedures.[75]

For the *DUKW 34* collision, the NTSB found that the master did not follow all the safety procedures in the company's manual during the emergency, and, as mentioned earlier, the deckhand was texting on a personal cell phone.[76] In the *Stretch Duck 7* sinking, NTSB found that the tour business and the master lacked the specific guidance and training needed to effectively use information on impending weather conditions.[77]

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[75] NTSB, 2002, "Sinking of the Amphibious Passenger Vessel *Miss Majestic*, Lake Hamilton, Hot Springs, AR, May 1, 1999," Marine Accident Report NTSB/MAR-02/01, April 2. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR0201.pdf.

[76] NTSB, 2011, "Collision of Tugboat/Barge *Caribbean Sea/The Resource* with Amphibious Passenger Vessel *DUKW34*, Philadelphia, PA, July 7, 2010," Marine Accident Report NTSB/MAR-11/02, June 21. https://www.ntsb.gov/investigations/Pages/DCA10MM025.aspx.

[77] NTSB, 2020, "Sinking of Amphibious Passenger Vessel *Stretch Duck 7*, Table Rock Lake, near Branson, MO, July 19, 2018," Marine Accident Report NTSB/MAR/20-01, April 28.

Safety Checks, Drills, and Manuals

NVIC 1-01 states that the operator should perform safety checks on the vessel before leaving for a tour. Operators generally have a checklist of items that must be run through at the start of the day; some conduct safety checks before each tour.

Masters are responsible for conducting various emergency drills and for ensuring that all crew members are familiar with their duties during emergencies. While drills are conducted annually as part of the OCMI's inspection for a COI, it is desirable for operators to perform drills quarterly or even monthly. High-quality drills are as realistic as practical, with limited time to react to an emergency and multiple persons donning life jackets in the confined space, replicating what would occur in a real emergency.

NVIC 1-01 also strongly encourages tour businesses to develop operating manuals with training, maintenance, operational, and emergency requirements. Because these manuals are not required, those that do exist vary significantly from operator to operator in both content and quality.

Weather

Weather preparation and monitoring are some of the most important active measures of safety an operator can take and are generally required by current regulations. Because OCMIs may place operating restrictions based on winds and wave height, weather preparations play a significant role in many companies' operations. Weather forecasts are expected to be watched by both shoreside staff and the masters of the vessels. Operators need to be able to cut short or cancel on-water tours if inclement weather threatens.

Training

A DUKW master is to receive training through the USCG licensing process and through the company's training program. The reality is that the level of training received by these masters varies greatly, as described in the accident reports and testimony of operators. Some companies hire masters with licenses for suitable routes and tonnage (traditionally a 100-ton license for Subchapter T vessels). In contrast, because operating environments vary by region, some companies request and receive approval for the use of limited licenses. An operator with a traditional master's license may not necessarily have situational awareness or local knowledge of weather trends and safe refuge locations. Typical certification courses do not teach recognizing weather trends and what to do about sudden changes in weather. There is no test to prove competency in real emergencies.

Under current regulations, the owner and operator are responsible for the content of and emphasis on crew training. Best practices would require developing a thorough training program as part of their operations manual, constantly emphasizing training and drills, and maintaining complete training records. The importance of training and drills cannot be overemphasized, and a standardized DUKW training program would be a valuable addition to the industry.

PASSENGER ACTIONS DURING EMERGENCIES

DUKWs and other similar small "open" passenger vessels, such as water taxis, small excursion boats, and launches, require passengers to take responsibility for much of their own safety during an emergency. This reliance on passenger responsibility is just one more reason why it is critical to minimize the possibility of a casualty occurring on a DUKW in the first place. While it is the committee's judgment that safety orientations can be improved, relying on the assistance of passengers with diverse physical abilities and widely varying familiarity with safety on boats is still fraught with risk.

Because of the DUKW's unique design and lack of an open deck area, NVIC 1-01 allows narrower aisles and tighter passenger seating (see Chapter 2), with the stipulation that the primary means of egress is directly over the side. To escape in an emergency such as flooding, capsizing, or fire, passengers are to move from where they are seated, over the side, and into the water. The cramped conditions make it difficult to impossible for a crew member to assist passengers with tasks such as

1. Retrieving the appropriate (adult versus child) life jacket from overhead storage in a canopy.
2. Donning the life jacket.
3. Opening the side curtain on the window nearest them.
4. Exiting through side curtain opening.

A safe escape requires passengers to make multiple decisions and take unfamiliar actions. Not only are passengers expected to be almost entirely self-reliant during an emergency escape, they may also feel an obligation to help others. Some of the challenges and tasks passengers face in an emergency are listed below.

1. The crew is located at the forward end of the passenger space and, during an emergency, will be occupied with many responsibilities and tasks. The crew will not be able to move about to assist passengers with finding and donning life jackets, to show them how or where to escape, or to assist them with escaping through side curtains.
2. To egress out a side opening over seats and gunwales without assistance, particularly when the vessel may be heeling to one side or in heavy seas, will require a passenger to be reasonably fit. Small children, the elderly, and those with mobility issues may be unable to perform these actions without aid from other passengers.
3. Emergencies can happen very quickly, particularly in a capsizing or flooding event. There may be no time for the crew to give necessary instructions on how to escape once an emergency has started, especially in the case of a one-person crew.
4. If side curtains are in use, the need to open or release them may add to passenger and crew responsibilities to escape quickly in an emergency on the water.
5. If a one-person crew is allowed, the master may not be able to assist passengers who need assistance escaping the vessel. An able-bodied passenger may be asked to stay behind until all passengers are safely evacuated.

Emphasizing passenger responsibility during the required safety orientation, mandated by 46 CFR § 185.506, is one way to partially address these issues. During the safety orientation, passenger responsibility should be emphasized in the instructions for embarking/disembarking during normal operations and emergencies; locating instruction placards for life jackets; locating, donning, and adjusting life jackets; locating ring buoys, fire extinguishers, and emergency exits; and removing any obstructions to exits. However, too many safety instructions may overload a passenger and result in their being unwilling to participate in the tour or assist in the egress of others once under way. Although detailed safety instructions can be provided for passengers before getting under way, the number of safety instructions required and the difficulty of doing them while an emergency is occurring underscores the need for passive safety on DUKW boats.

SUMMARY

Safe operations depend on well-trained personnel—on the boat and on the ground in a support capacity—who act with confidence while following established, proven procedures. NVIC 1-01 emphasizes the importance of operations and safety manuals. These manuals should incorporate training, maintenance, and operations standards, as well as emergency response plans. Procedures to monitor and act in response to impending weather conditions also need to be included.

The reality on board a DUKW during a tour is that the master and crew—even if well trained—are not likely to have the capacity to assist all passengers during an emergency. Safety and emergency procedures need to be developed that convey the importance of passengers taking responsibility for themselves and others.

8
Risk Assessment and Recommendations

Evaluating and ranking risks is a well-established method to address dangers and hazards that can arise from industrial and commercial activities, including transportation. Risk assessment is also a useful method for evaluating and choosing the appropriate response to situations that are unique, or at least variations on a theme. For DUKWs, risk assessment avoids the likelihood that a "one-size-fits-all" approach will unnecessarily increase costs for some DUKW operators, while leaving other hazards unmitigated. Having information on the relative significance of risks from various hazards will provide the United States Coast Guard (USCG) an opportunity to focus its regulatory efforts. In addition, USCG already utilizes risk assessment when determining the level of inspection intensity for various small passenger vessels.[78]

For all these reasons, the committee considers risk assessment as the central strategy to identity and mitigate safety hazards associated with DUKWs and their operations.

Before listing the recommendations, this chapter presents the committee's summary findings on which factors make for higher risk operations. These findings then inform the recommendations targeting the use of risk assessment and the mitigation of hazards presented in each of the safety categories—flooding, operating areas, restrictive canopies, life jackets, and safety operations.

The chapter concludes with an overview of risk-assessment tools that the committee has identified as especially appropriate for USCG use. The results of the committee's initial application of one of the tools, a sample output (HAZID Register) of the Hazard Identification (HAZID) method, is contained in Appendix C.

SUMMARY FINDINGS ON HIGHER RISK OPERATIONS

As presented throughout this report, the risks to passengers on DUKWs vary significantly depending on the type of DUKW vessel, the operating area, and operator diligence. In order to identify appropriate areas for USCG regulatory and policy changes, the committee divided DUKW operations into two categories: higher risk and lower risk. The committee finds that the following characteristics of a DUKW vessel and its operation could result in a higher risk to passengers and higher likelihood of a major marine casualty event, even when the regulations in Subchapter T and the guidelines in Navigation and Vessel Inspection Circular 1-01 (NVIC 1-01) are followed. Some of the committee's recommendations, below, distinguish recommendations for higher risk versus lower risk operations.

Fast Sinking Times

Sinking times of 15 minutes or less are fast sinking and create greater risk of passenger injury and death. The risks inherent in low freeboard, the lack of a high-capacity bilge pump, multiple

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[78] USCG Work Instruction CVC-WI-028(1), 2021, Small Passenger Vessel Risk Based Inspection Program, issued June 14. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/CG-CVC/CVC_MMS/CVC-WI-028(1)a.pdf.

hull penetrations, engine air cooling vents, and operating areas exposed to high winds, waves, and traffic can easily combine to sink certain DUKWs in less than 15 minutes.

Low Freeboard

DUKWs having less than approximately 24 inches freeboard are at greater risk of rapid sinking, as compared to other open small passenger vessels of a similar size. WWII DUKWs and some Stretch Ducks have less than 24 inches of freeboard, but Truck Ducks generally have higher freeboard.

Lack of High-Capacity Bilge Pump

DUWKs that do not have a reliable, high-capacity bilge pump that can dewater at the maximum anticipated flow rate of a hull penetration can be quickly flooded. The Higgins Pump, part of the original design of the WWII DUKW, is not a reliable method of emergency dewatering.

Multiple Hull Penetrations

DUKWs that have shaft boot seals with or without restrictor plates, multiple shaft penetrations, and multiple drain plugs have a higher risk of flooding.

Engine Air Cooling Vents

DUKWs that have air vent covers on the engine hood that lack a positive latching mechanism are susceptible to downflooding through these openings when encountering large waves. Vents that must be closed by the crew also present risks for downflooding.

Potential for Exposure to High Winds and Waves

DUKWs that operate on waters where high winds and high waves can occur, particularly high waves from rapidly developing squalls and storms, may be exposed to conditions that exceed those allowed by their Certificate of Inspection (COI). Given DUKWs' maneuverability limitations, high winds can also make it difficult for a DUKW to safely escape severe weather. The current definition of "partially protected waters" may not cover all higher risk operating areas. Even waters considered "protected waters" may produce high winds and high waves during rapidly developing storms if they have a long fetch in one direction.

High Traffic Areas

DUKW operation in areas with high levels of marine traffic or in proximity to shipping channels for larger commercial vessels can create greater risk of collision.

Restrictive Canopies

Canopies augment the risks arising from a vessel's characteristics and operating areas. Canopies that have restrictive side curtains or closely spaced vertical canopy supports and that cover most or all of the passenger seats make emergency escape difficult and slow, creating greater risk. Such canopies also interfere with the wearing of life jackets during the tour or the donning of life jackets in an emergency. A canopy is considered to be a restrictive canopy unless its design has been demonstrated to provide the equivalent in safety to no canopy.

LOWER RISK OPERATIONS AND RESERVE BUOYANCY

DUKW operations that do not have any of the above higher risk factors can be considered lower risk operations. In addition, DUKWs fitted with reserve buoyancy such that they will remain afloat and upright in case of flooding can be considered lower risk operations unless they operate on partially protected waters or high traffic areas. Ultimately, whether the risks faced by lower risk operations are acceptable must be determined by more detailed review, but in recent years DUKW commercial operations that meet these criteria for lower risk operations have not experienced marine casualties with loss of life.

COMMITTEE RECOMMENDATIONS

The committee offers USCG the following recommendations, starting with the use of risk assessment for DUKW operations and then providing specific recommendations to mitigate the hazards discussed in the chapters on flooding, operating areas, canopies, life jackets, and safety operations. All recommendations are specific only to WWII DUKWs, Stretch Ducks, and Truck Ducks. The recommendations should not be construed to apply to other amphibious passenger vessels or small passenger vessels.

Use of Risk Assessment

Recommendation 1: USCG should base updates to regulations and enforcement practices on the risks to passengers, operators, and the environment posed by each type of DUKW in its intended operating area.

Because of the uniqueness of the DUKW design, the standard risk-abatement methods—regulations and policies—applied to other small passenger vessels may not be adequate for the DUKW fleet. There are also significant variations in design between DUKW vessels, so a "one-size-fits-all" approach to the DUKW fleet under USCG supervision may be both inadequate for some DUKWs and overly conservative for other DUKWs. Assessing risk for each type of DUKW in its intended operating area also allows for the use of multiple, complementary methods to increase the survivability of the vessel and the persons on board.

Recommendation 2: USCG should use a consistent risk-assessment methodology, applied at the industry level, to better understand the risks to passenger safety and to allow USCG to focus regulations and requirements on those DUKW operations that present the greatest risk.

Risk analysis methodologies will help USCG better understand the greatest risks to passenger safety on DUKW vessels. There are standard risk-assessment processes used by industry to improve safety of higher risk operations. A method commonly used in the marine industry, the

HAZID method, is described in more detail after the recommendations. The results of the committee's initial run of HAZID is found in Appendix C.

Flooding and Survivability

Recommendation 3: USCG should investigate requiring the installation of external inflatable bladders or buoyant floats, alone or in combination with internal flotation foam, to provide reserve buoyancy for DUKWs used in higher risk operations.

These are likely to be the most viable options for keeping a DUKW afloat and upright in a fully flooded condition. Internal flotation foam alone, however, is not a viable solution. USCG should consider, during its investigation, the costs and required operational changes as well as the improvement to safety.

Recommendation 4: To reduce the flooding risk from hull penetrations, USCG should investigate requiring DUKW operators to

- **a. Permanently seal all drain plugs and valves that are not necessary for safe operation and maintenance of the vessel.**
- **b. Install carrier bearings.**
- **c. Install reliable bilge pumps of sufficient capacity to respond to flooding through the largest remaining through-hull penetrations, as per NVIC 1-01.**

Hull drain plugs and valves are a significant risk factor for flooding. Similarly, original drive shaft boot seals if not fitted with restrictor plates or modified with carrier bearings as detailed in NVIC 1-01 are another risk factor. As stated in the findings above, the Higgins Pump is not a reliable bilge pump.

Recommendation 5: USCG should require vessel operators to demonstrate that adequate engine cooling is available for the expected operating areas and risks found in that area.

Engine cooling hatches can be a source of downflooding into the engine compartment. To address this, some DUKWs have been fitted with keel coolers or alternate means to allow engine cooling with all hatches below the freeboard line closed while in the water. Vessels must be able to operate with cooling hatches closed if there is a risk of experiencing sea conditions that could cause flooding through these hatches.

Operating Areas

Recommendation 6: USCG should develop uniform guidance to assist Officers in Charge, Marine Inspection (OCMIs) in evaluating the suitability of bodies of water for DUKW operations.

This guidance should consider the physical characteristics of the body of water, the presence of commercial and recreational traffic, the proximity of rescue craft, and access to "safe refuge locations" (see Box 4-2) in the event of an emergency.

Recommendation 7: USCG should develop requirements for equipment, training, and operations that leverage the National Weather Service's (NWS's) severe weather alert system to reduce the likelihood that a DUKW will encounter wind and waves that exceed its operating capabilities.

For the duration of relevant NWS-issued warnings and advisories, the requirements should restrict DUKWs from conducting waterborne operations and mandate that already waterborne DUKWs proceed immediately to a safe refuge location. For the duration of NWS-issued watches, DUKWs should be required to follow a water route that allows them to navigate to a safe refuge location within a specified amount of time that incorporates the likely amount of time between a warning being issued and severe weather occurring along the route. Vessels should be required to carry equipment that alerts the crew to severe weather watches, advisories, and warnings, and land-based operation centers should be required to monitor weather conditions and communicate weather information to their vessels. Operating manuals and personnel training should address procedures for severe weather. On very sheltered or benign waters that are not likely to be impacted by severe weather, it may be appropriate for the OCMI to exercise discretion on these requirements. USCG should consult with NWS when developing these requirements and any decision-support tools to be used by OCMIs.

Restrictive Canopies

Recommendation 8: USCG should require DUKWs in higher risk operations to remove canopies or to adopt canopy designs that have been demonstrated to provide the equivalent in safety to no canopy.

Considering the existing National Transportation Safety Board (NTSB) recommendations to remove canopies that impede passenger escape, the committee recommends that DUKWs in higher risk operations should either have no canopy or an easy-open, breakaway, shortened, or other canopy design that has been demonstrated to provide the equivalent in safety to no canopy. Designs for any canopy side curtains should also be demonstrated to provide the equivalent in safety to no side curtains. Side curtains that must be released by the crew do not provide the equivalent in safety to no side curtains. Side curtains designed to be opened by passengers should be demonstrated to provide the equivalent in safety to no side curtains before adoption. Signage and passenger orientation should include explicit instructions on how to escape the vessel through any canopy or side curtain.

For DUKWs in lower risk operations or that have means of supplemental flotation, more complete canopies with easy-open side curtains may be suitable.

Life Jackets

Recommendation 9: USCG should consider making the wearing of life jackets mandatory during the waterborne portion of tours run by higher risk operations.

Wearing life jackets will save lives, assuming the DUKW in crisis no longer has a restrictive canopy. Given the cramped conditions of the passenger compartment and that crew on board will likely number no more than two, the assumption that passengers will successfully don life jackets during an emergency is highly suspect. In addition, any policy that expects passengers to don life jackets once they are already in the water is strongly inadvisable.

Recommendation 10: USCG should investigate the use of Type III life jackets in place of Type I life jackets.

Type I life jackets, required on all commercial passenger vessels, are bulky and can be uncomfortable to wear. They can also restrict escape through a canopy not meeting the recommended standard in Recommendation 7. Type III life jackets are easier to don and wear for extended periods on a boat. The permitted routes for DUKWs are normally close to shore, so persons can be quickly rescued. The capabilities of Type I life jackets may not be needed.

Safety Operations

Recommendation 11: USCG should require that owners and operators develop an effective company operating and safety manual, as recommended in NVIC 1-01, that incorporates training, maintenance, and operational standards as well as emergency response plans.

The safety related parts of the manual could be incorporated into a company safety management system (SMS) if USCG eventually requires SMS for all passenger vessels.

Recommendation 12: USCG should require, and the OCMI should confirm, that the operating and safety manuals include procedures for monitoring changing weather conditions and adjusting operations accordingly.

Recommendation 13: USCG should require, and the OCMI should confirm, that the operating and safety manual includes a discussion of the number of personnel and their duties.

Regular crew drills are an important part of demonstrating crew knowledge of the operating and safety procedures included in the manual, or an SMS if eventually required. If only one crew member is allowed, this discussion should justify how all safety functions are to be performed. Crew members—even if well trained—do not have the capability to assist all passengers in an emergency because they will be performing multiple roles.

RISK-ASSESSMENT MATRIX

Methodologies to identify hazards, evaluate their likelihoods and consequences, and develop ways to mitigate their risks are frequently used to assess and mitigate risks like those occurring in DUKW operations. The committee employs one such methodology that uses risk assessment to manage hazards in the marine industry. The following analysis by the committee draws on its contents.[79]

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[79] American Shipping Bureau (ABS), 2020, "Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries," May. https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/97_riskassessapplmarineandoffshoreoandg/risk-assessment-gn-may20.pdf.

In the marine context, a hazard is a condition that may lead to an undesirable event. Typical hazards for DUKWs include external factors like storms or other boat traffic and internal factors such as the equipment and its known weaknesses, the number of personnel, the lack of safety equipment or training, or the maneuverability of the boat. Hazard events include flooding, but also stopping/stranding, collision, capsizing, or fire.

Risk is the product of consequences and likelihood. Consequences flow from the hazard event and are typically measured in injury and loss of life, property damage, environmental damage, and operability downtime. Likelihood is the chance or probability that a hazard will lead to an event, and it is typically expressed as a function of time, such as over a vessel's operating life: for example, the likelihood of a propulsion failure leading to the vessel being towed once or repeatedly over its lifetime. Events may be produced by multiple hazards interacting, such as failed bilge pump coinciding with boat traffic producing waves. Multiple events may occur simultaneously or in quick succession, such as a propulsion failure stranding the boat followed by a storm.

The risk guide defines "controls" as "the measures taken to prevent hazards from causing undesirable events." These can include physical changes to the boat and operational changes. In other contexts, "controls" are sometimes called "mitigation" or "safeguards."

Table 8-1 is an example of a typical risk-assessment matrix that defines likelihood, consequences in terms of their severity, and lower to higher risk. High-risk hazards are those that have the highest likelihood and highest consequences. The matrix indicates that these hazards must be mitigated to lower the risk to medium or low. Medium-risk hazards are acceptable with controls, which the responsible parties should verify. Low-risk hazards are acceptable: no mitigation is required.

The matrix provides example definitions of consequences for passengers and the crew, environment, property damage, and operability downtime. "Insignificant" and "low" consequence events would include those incidents that are not reportable to USCG because they do not involve first-aid injury and any damage is less than $10,000. "Medium" consequence events would include those that require reporting to USCG because they involve a minor injury that requires professional treatment beyond first aid, damage greater than $10,000 but less than $100,000, and possibly notification to the National Response Center. "High" consequence events would include those with one fatality or major injury, damage above $100,000 but less than $1 million, and possibly require specialist cleanup. "Very high" consequence events would include those that involve multiple deaths or major injuries, large-scale property damage greater than $1 million, and/or other special outcomes such as an oil spill requiring third-party cleanup and long-term remediation.

Once a risk assessment is completed, the results can be implemented with decision-support tools. For example, for the matrix in Table 8-1, OCMIs would still need a practical method for evaluating risk and risk mitigation for the DUKW operations under their jurisdiction. Checklists and other tools such as decision trees would still need to be developed.

TABLE 8-1 Example of a Risk Matrix

Likelihood	Consequences of Increasing Severity: 1	2	3	4	5
A	L	L	L	M	M
B	L	L	M	M	H
C	L	M	M	M	H
D	M	M	M	H	H
E	M	H	H	H	H

Definitions of Risk:
H = High Risk: Must be mitigated with engineering and/or administrative controls to a hazard category of L or M and incorporated into the design and operation.
M = Acceptable Risk with Controls: Should be verified that procedures or controls are in place.
L = Acceptable: No mitigation required.

Definitions of Likelihood Over the Life of the Vessel:
A = Very Low: Conceivable, but extremely unlikely
B = Low: Credible, but unlikely in the inspected DUKW fleet
C = Medium: Likely to occur in the inspected DUKW fleet
D = High: May occur about once on each vessel
E = Very High: Event or similar may occur repeatedly on each vessel

Definitions of Consequences of Increasing Severity:

Level	Passenger and Crew	Environment	Property Damage	Operability Downtime
1 = None/Insignificant	No observable effects	No observable effects	< $1k	Minimal
2 = Low	First aid needed	Non-reportable spill or release	< $10k	< 0.5 day
3 = Medium	Lost time injury	Reportable spill or release with company cleanup	< $100k	< 2 days
4 = High	Single fatality or permanent major injury	Reportable spill or release with specialist cleanup	< $1M	< 10 days
5 = Very High	Multiple fatalities	Requires long-term remediation	> $1M	> 10 days

SAMPLE HAZARD REGISTER

The HAZID technique is an example of a risk-assessment methodology that could be used to provide insights on which risks present the greatest dangers to DUKW passengers. Although it is not practical for USCG to carry out a HAZID for each DUKW operation under its purview, a general HAZID for typical risks, including those described in this report, across all DUKW operations, is feasible. Information on relative risk would provide USCG the opportunity to focus its regulatory efforts on the higher risks and continue with existing regulations for risks considered acceptable.

The committee conducted a preliminary or sample HAZID analysis of DUKW vessels and the product, a Hazard Register, is found in Appendix C. Conducting a full risk evaluation using the HAZID technique typically requires holding a workshop attended by subject experts and knowledgeable persons. Although the committee's work is not a substitute for a fully executed HAZID workshop, its results are useful for illustrative purposes.

For its HAZID analysis, the committee examined hazards pertaining to vessels, weather, geography, waterway navigation, and personnel. The committee identified 17 high-risk hazards, according to the definitions in Table 8-1. The committee also conducted preliminary evaluations on whether high-risk hazards could be lowered to medium or low risk using controls or safeguards. For four of these high-risk hazards, the most typical mitigation actions, if used alone, were inadequate to lower their risk. Multiple safeguards were required to lower these four high-risk hazards to at least medium risk.

Appendix A
Study Committee Biographical Information

Eugene A. van Rynbach, *Chair*, is the Chairman of Herbert Engineering Corp. (HEC). He joined HEC in 2005 after an extensive background in the ship operation and engineering fields. At HEC he has worked on major ship design and conversion projects, including designing new training ships for the U.S. State Maritime Academies for the U.S. Maritime Administration (MARAD); working on a major conversion and upgrade of the FPSO EnQuest Producer; overseeing the design of a suite of ro-ro vessel designs for MARAD and other organizations for American Marine Highways; acting as the owner's technical advisor and carrying out plan approval for multiple new construction projects; and designing many modifications, updating stability documentation, and advising on major repairs for commercial ships. Prior to joining HEC, he worked for 15 years as the Manager of Technical Services for the container ship operator Sea-Land Service and its offshoot U.S. Ship Management. His areas of responsibility included vessel new construction, conversions, major modifications, and technical engineering, including stability documentation. Earlier work included time with the American Bureau of Shipping (ABS) doing plan review for mobile offshore drilling units and several years of seagoing experience as a United States Coast Guard (USCG)-licensed marine engineer. He is a member of ABS and the Society of Naval Architects and Marine Engineers (SNAME). He received the Linnard Prize from SNAME for presenting the best paper at the 1995 SNAME annual meeting. Over the past 5 years, he has served on three Transportation Research Board committees for USCG: the Committee to Revise and Update U.S. Coast Guard Ship Stability Regulations (as chair); the Committee on Polar Icebreaker Cost Assessment (as a member); and the Committee on Impact of U.S. Coast Guard Regulations on U.S. Flag Registry (as a member). He received a B.S. in mechanical engineering with a specialization in naval architecture from the University of California, Berkeley, and an M.S. in transportation management from the State University of New York Maritime College.

CAPT Scott Anderson, United States Coast Guard (USCG) (retired), is currently a financial advisor for First Command Financial Services. He retired from USCG in 2020 as the Sector Commander and Captain of the Port of the USCG Fifth District Sector Delaware Bay. In serving as Captain of the Port for 3 years, he directed operational units conducting all USCG missions in the sector. He served as the Deputy Sector Commander for the 2 years prior. While in the USCG Ninth District between 2011 and 2015, he served as the Chief of Inspections and Investigations providing oversight and support for regulatory inspections and casualty investigations. He also served as the Acting Chief of Prevention for 8 months. In Sector Lower Mississippi River, he served as the Deputy Sector Commander and the Prevention Department Head between 2008 and 2011. In Sector New Orleans, he served as the Assistant Chief, Inspection Division between 2005 and 2008. He holds an M.S. in naval architecture and marine engineering from the University of Michigan and a B.S. in naval architecture and marine engineering from the USCG Academy.

CAPT Robert K. Cook retired from Military Sealift Command (MSC) Atlantic after serving on Underway Replenishment Ships as the Department Head, where he oversaw dry-dock operations and ship repair work both in domestic and foreign shipyards. He also served on an MSC Hydrographic Surveillance ship and the USNS *Harkness*, after which he received the Navy Humanitarian Service award for work done in the Gulf of Suez and the Red Sea during Operation Intense Look. In 1993, he became one of the first African American U.S. Marine pilots, in modern times, when he became a partner in the Pilot's Association for the Bay and River Delaware. In 1994, he and five other African American SUNY Maritime College graduates formed the Organization of Black Maritime Graduates (OBMG). He has served as the president of OBMG since its inception, where he provides opportunities for African Americans and other minorities in such areas as recruitment for the maritime industry, educational partnerships, scholarships, mentoring, and networking for students and graduates. In 2014, he was inducted into SUNY Maritime College's Heritage Hall. He is a Trustee on the Board of Directors of the Maritime Academy Charter School in Philadelphia, a Port of Philadelphia Marine Society Board member, as well as an active supporter of the United States Coast Guard (USCG) Foundation. He is also a member of the Transportation Research Board's Marine Board. He graduated from the State University of New York (SUNY) Maritime College with a B.S. in physical oceanography and meteorology. He also graduated with an Unlimited USCG 3rd Officer's license.

Timothy A. Graul retired as the Principal of Timothy Graul Marine Design (TGMD) after a 50-year career in naval architecture and marine engineering. While at TGMD, Mr. Graul designed many ferries, small passenger vessels, crewboats, fast supply boats, workboats, and research boats. He specialized in issues of lengthening, repowering, tonnage, and stability. In 1991, TGMD was chosen to design the three-masted schooner *S/V Denis Sullivan*, the official flagship of Wisconsin, which was completed in 2000. Before establishing his own firm in 1981, he managed commercial and workboat programs for Peterson Builders, Inc., in Sturgeon Bay, Wisconsin, a builder of ships and boats in steel, wood, aluminum, and fiberglass. Prior to that, he was the Vice President of Engineering and Sales at Grafton Boat Company, Inc., in Grafton, Illinois, where he was responsible for the design of more than 200 small military and service craft. As an associate member of the Passenger Vessel Association (PVA), he was active in several ad-hoc committees and task forces that addressed stability, handicap access, and passenger weight issues. He has authored and presented papers for various outlets, including the Society of Naval Architects and Marine Engineers (SNAME), Marine Technology, Workboat Show seminars, IBEX technical sessions, and PVA annual meetings. Mr. Graul has performed nonexclusive tonnage admeasurement for Det Norske Veritas and Germanischer Lloyd. Throughout his career, he has served as a mentor and a judge of design projects at the U.S. Naval Academy, Webb Institute, and the SNAME Lisnyk Student Ship Design Competition. He received his B.S. in naval architecture and marine engineering from the University of Michigan.

Jennifer Kollmer is currently the Chief of Lifecycle Engineering at Rolls-Royce Marine North America where, as a member of the Engineering Leadership team, she is responsible for integrating all operational aspects and considerations for products at all phases of the lifecycle on behalf of the Chief Engineer for the U.S. Navy and United States Coast Guard programs. Her roles have involved in-service engineering efforts, and her current work with the Rolls-Royce Defense group involves functional management of the North America Naval Engineering for Services team. She started her career as a naval architect with Seaworthy Systems, Inc., in 1991 where she was involved with the new design and construction management of ships and small passenger vessels (Subchapter K and T) for clients such as New York City's Department of Environmental Protection, Casco Bay Lines, Maine State Ferry Service, California Department of Transportation, and Cape May Lewes Ferry. Her other engineering program efforts with Seaworthy supported the company's National Oceanic and Atmospheric Administration (NOAA) and Military Sealift Command naval architecture and marine engineering support contracts and the Long Island Sound Waterborne Transportation Plan, which was developed between 2003–2005 for several tri-state transportation organizations. Rolls-Royce purchased Seaworthy Systems in 2007. She is active with the Society of Naval Architects and Marine Engineers (SNAME), serving as New England Section Chairman, and on the Papers Committee for the International Conference on Marine Engineering Systems (ICMES). She holds a B.S. in naval architecture and marine engineering from the Webb Institute of Naval Architecture.

Maggie Nate is the Department Manager for Survivability at Gibbs & Cox, where she leads a team of engineers that focuses on specialty engineering, including areas such as shock, vibration, electromagnetic interference, susceptibility, vulnerability, and recoverability. Prior to joining Gibbs & Cox, she worked at Alion Science and Technology as a Senior Test Engineer where she reviewed marine system designs to assess for survivability and safety. She serves on the editorial boards for *Marine Technology Magazine* (MT) and the *Journal of Ship Production and Design* and as the Chair for the Chesapeake Section of the Society of Naval Architects and Marine Engineers. She holds a B.S. in aerospace engineering and marine engineering from Virginia Polytechnic Institute and State University.

RADM Joel R. Whitehead, United States Coast Guard (USCG) (retired), is the President of J. Whitehead & Associates, Inc., a transportation-related consulting firm based in New Orleans. His focus is on international and U.S. maritime regulatory compliance, support to admiralty law firms through expert witness reporting and trial testimony, hazardous materials issues, port development (LNG, traditional, and recreational) and governmental relations. In his last military assignment from 2006 to 2009, he served as the Commander of the Eighth Coast Guard District in New Orleans, where he was responsible for operations and oversight of the maritime and offshore oil industry in 26 states and the entire Gulf of Mexico. After retiring in 2009 as a Rear Admiral from USCG with 38 years of service, he served until 2011 as the Vice President, National Security Sector of SRA International, Inc. His operational career was primarily as a marine safety specialist. Trained as a marine inspector and a casualty investigator at the Marine Inspection Office, New York, he conducted hundreds of inspections and investigations worldwide for more than 10 years on commercial vessels, passenger vessels, barges, offshore supply vessels, and oilrigs. In Washington, D.C., he drafted USCG regulations implementing the International Convention for the Prevention of Pollution from Ships (MARPOL) and participated in international negotiations relating to MARPOL at the International Maritime Organization in London. He also served as the Commanding Officer of the Marine Safety Office and Captain of the Port of Boston from 1999–2001 where he had oversight of the largest LNG import facility in the United States. He is the Immediate Past President of the International Propeller Club of the United States, and a member of the Board of Directors of the New Orleans Propeller Club. From 1996–1997, he was a National Security Fellow at the John F. Kennedy School of Government at Harvard University in Cambridge, Massachusetts. He holds merchant marine licenses as Master of Vessels of less than 1,600 Gross Tons upon Oceans and as 2nd Mate of Unlimited Tons upon Oceans. He holds a B.S. in history and government from the USCG Academy and an M.P.A.in public administration from the Rockefeller College of Public Affairs & Policy at the State University of New York at Albany.

John Womack has practiced in the small commercial vessel field for 34 years, principally in the area of small passenger vessels. During this time, he has worked in all aspects of small commercial vessel design, construction, and repair from the conceptual design, through construction, to final inspections and sea trials. Design responsibilities include all areas of a vessel's stability, structures, machinery and piping systems, electrical systems, joinery, and outfitting. Projects include the design of more than 30 vessels, including dinner vessels, overnight cruise ships, car ferries, and small oil and work barges. Current projects are the design of the latest generation of Western Rivers and small coastal overnight cruise ships. He also has worked in many aspects of commercial fisheries, including vessel, plant, and equipment design and operations; fishing vessel stability analysis; stock assessments; habitat issues; and crew safety training. He is an active member of the Society of Naval Architects and Marine Engineers and has served as the Co-Chair of the Small Working Vessel Technical and Research Panel. Previously, he served as the naval architect representative on the United States Coast Guard's (USCG's) voluntary Commercial Fishing Industry Safety Advisory Committee, working to assist USCG in developing new regulations, inspection programs, and voluntary safety. He holds a B.S. and an M.S. in naval architecture and marine engineering from the University of Michigan.

Appendix B
Time to Sink Analysis

The committee identified low freeboard as one of the factors that define if a DUKW is a higher risk DUKW. To explore the effect of freeboard on DUKWs, the committee undertook a time to sink study. This study used a WWII DUKW hull as the model and calculated the theoretical maximum time before sinking over a range of freeboards. The methodology used was a time step approach as follows:

1. A starting draft was set to give the desired initial starting freeboard for the study.
2. An initial flooding rate was then calculated based on the study's damage hole size and starting depth below the initial waterline.
3. Based on the calculated flooding rate, the volume of water flooding for the time step interval was calculated.
4. From the cumulative total volume of water flooded, a new draft and freeboard were calculated along with the new cumulative level of the water inside the DUKW's hull.
5. Using the new draft and internal water level, a new flooding rate was calculated based on the new static head below the waterline for the damage hole.
6. The calculations are repeated in steps 2 to 5 until the freeboard is zero.

The hull model used was based on the WWII DUKW and was simplified, as shown in Figure B-1, to be utilized in a basic spreadsheet. This allowed for the change in the hull displacement to be accounted for as the draft increases and the change in the hull's internal volume as the flooding water levels increase. The following assumptions were used in the time to sink study:

A. The internal hull volume permeability was set at 85 percent to account for the DUKW's engine and drive train, fuel tanks, and other internal outfitting when calculating the internal flooded water depth.
B. The flooding rate was calculated using the methodology in the United States Coast Guard's (USCG's) Navigation and Vessel Inspection Circular 1-01 (NVIC 1-01) using a 4-inch diameter hole, which is equivalent to the failure of a WW2 DUKW driveshaft boot seal.
C. The DUKW was assumed to sink with an even keel and trim.
D. No dynamic effects of wind or waves were considered.
E. No effects of the passengers moving to don life jackets or escape was factored in.

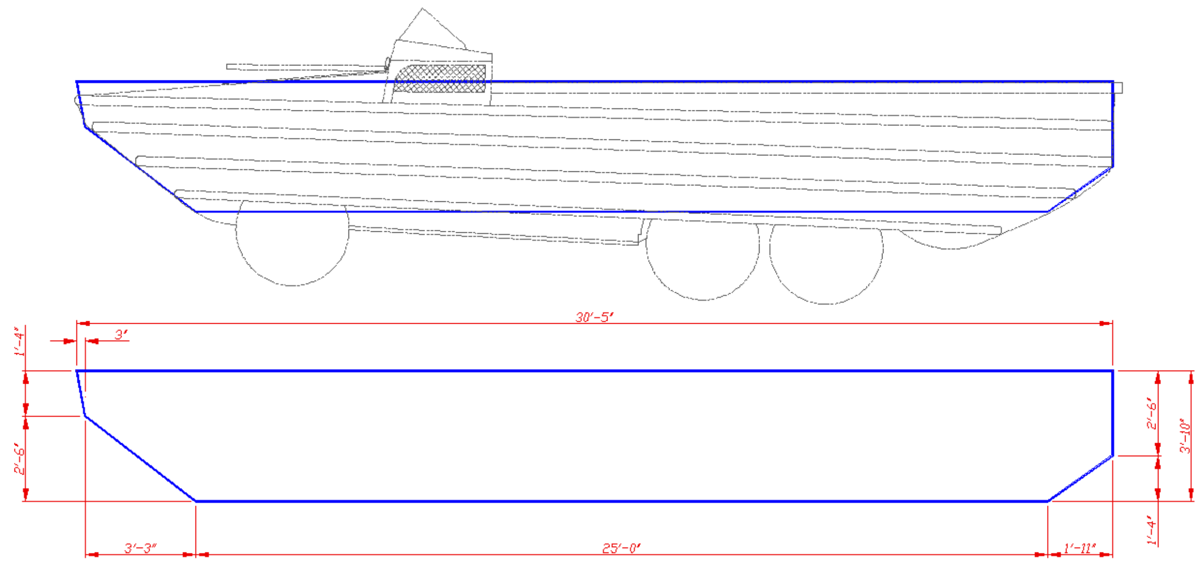

FIGURE B-1 WWII DUKW hull used in the model.

With the last three assumptions the time to sink study is a theoretical maximum time before sinking. The actual real-world time to sink will be less than the time calculated in this study as the location of the downflooding point will be affected by these factors. The effects of changes in trim could have been accounted for in the calculations by utilizing a hydrostatics program such as GHS coupled with a custom programming macro or a complex spreadsheet with detailed hull hydrostatics and internal hull (tank) lookup tables. The committee chose to use the even keel sinkage assumption based on available resources and that the effect of changes in trim would be small compared to the potential effects of wind, waves, or the movement of the passengers on the actual downflooding point. For example, 30 passengers and crew at 185 pounds each, 5,500 pounds total, is approximately 30 percent of the typical Stretch DUKW's lightship of 18,000 to 19,500 pounds. Based on this, the assumptions used are acceptable for the intent of this study as the committee is looking at the relative effects over a range of freeboards.

Figure B-2 shows the results of the study. The black line labeled "To 0" Freeboard" is the theoretical maximum time for the DUKW to sink to the gunwale versus the starting freeboard.

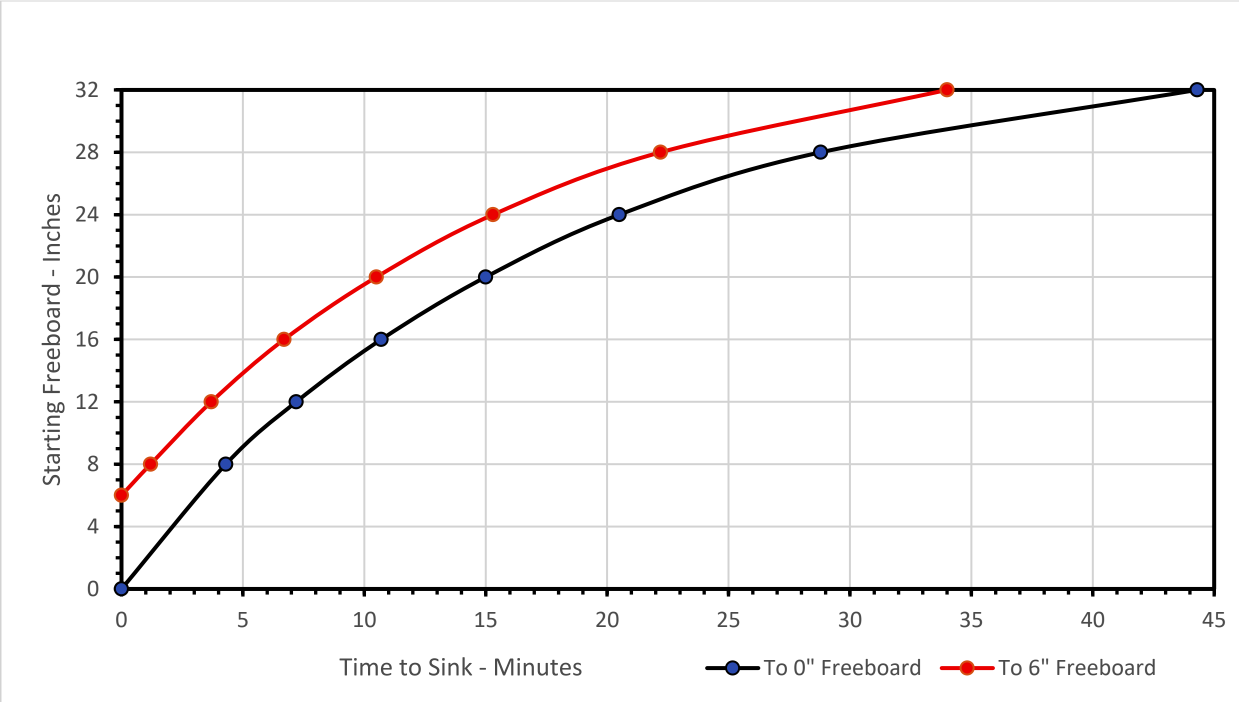

FIGURE B-2 Results of DUKW boat time to sink analysis.

The theoretical maximum time sink ranged from approximately 7 minutes at 12 inches starting freeboard, the low end of minimum permitted freeboards, to 30 to 35 minutes at the high end of the minimum permitted freeboards. At the mid range of permitted minimum freeboards, 20 to 24 inches, the calculated maximum time to sink was approximately 15 to 20 minutes.

While 15 to 20 minutes may seem at first review sufficient time to organize a safe evacuation of a DUKW, it must be remembered that this is the maximum theoretical time to sink. As previously discussed, the actual time to sink will be significantly less particularly when the effects of wind and waves and the movement of passengers donning life jackets and escaping the DUKW (likely in panic) are factored in. To estimate the effect of waves, the committee also calculated the time to sink to a nominal 6-inch freeboard (red line on Figure B-2). This was intended to approximate the static effect a 1-foot wave would have on the potential downflooding point and the resulting time to sink. At the mid range of permitted minimum freeboards, 20 to 24 inches, the calculated time to sink is now approximately 10 to 15 minutes.

The actual effective evacuation time will be significantly less than the calculated 10- to 15-minute time to sink when the movement of the passengers is taken into account and the inherent delay in the start of any evacuation from the start of the flooding emergency. The committee estimated that 3 to 5 minutes would be lost from the time the crew is first alerted to the problem, investigates and evaluates the severity of the flooding, and initiates the emergency evacuation procedures. Coupled with the reduction in the calculated time to sink from the movement of the passengers during the evacuation and the realistic evacuation time is estimated to be on the order of 5 minutes. The committee believes this is the minimum evacuation time that will provide for the safe evacuation of a DUKW when fitted with a canopy in the event of a flooding emergency.

Appendix C
Simplified HAZID Register for Water Segment of the Tour

The table below is a simplified HAZID Register created by the committee for some of the key hazards that a DUKW in commercial tour service may encounter during the water segment of the tour. It is focused on commonly encountered hazards that could cause significant damage to the vessel or injury to passengers. The risk evaluations and impacts of mitigation actions were made by the committee and are the subjective opinion of the committee. Normally, a HAZID Register is prepared by a workshop of knowledgeable experts whose evaluation of risks and impacts of mitigation actions is also subjective, but informed by the expert's knowledge of the subject and related experience. While the committee members have knowledge and experience in the marine industry, its members do not claim to have the full range of experience and knowledge desired for a formal HAZID workshop.

System	Hazard Category	Hazard	Cause	DUKW Type	Consequence	Initial Risk Evaluation			Safeguards	Residual Risk Evaluation			Actions	Remark
						Likelihood	Severity Level	Risk		Likelihood	Severity Level	Risk		
1. Vessel Hazards	**1.1 Vessel Related Hazards**	**Loss of propulsion**	**Mechanical or electrical failure**	**WWII & Stretch DUKW with gas engine**	**vessel adrift**	**E**	**2**	**H**	**back up vessels, nearby vessels or rescue boats**	**E**	**1**	**M**		
				Diesel powered	**vessel adrift**	**D**	**2**	**M**	**back up vessels, nearby vessels or rescue boats**	**D**	**1**	**M**		
		Loss of steering	**multiple**		**vessel loses directional control, adrift**	**D**	**2**	**M**	**back up vessels, nearby vessels or rescue boats**	**D**	**1**	**M**		
		PA system failure	**Electrical**		**lose capability to communicate easily with passengers**	**D**	**1**	**M**	**operators speak loudly to be heard**					

		Loss of communications	**Electrical**		**cannot monitor weather conditions or communicate with shore**	**D**	**2**	**M**	**redundancy, if available**	**C**	**1**	**L**	**short trip, repair when return to shop**	
		Hull limitations	**original design function was different**	**WWII & Stretch DUKW without flotation**	**low freeboard, poor hull shape**	**C**	**5**	**H**	**monitor weather forecasts, limited operating areas, vessel modifications**	**B**	**4**	**M**		**WWII and Stretch DUKW with 2 ft or less freeboard are high susceptible to rapid flooding and sinking from water ingress**
									Install flotation	**C**	**2**	**M**		
				Truck Duck	**medium freeboard, hull shape**	**C**	**3**	**M**	**monitor weather forecasts, limited operating areas, vessel modifications**	**B**	**3**	**M**		
		Shaft Penetration Leakage	**leaking seal,**	**WWII & Stretch DUKW with original boot seal**	**flooding**	**D**	**5**	**H**	**add restrictor plate, in water inspection after repair, frequent inspections, bilge alarms, bilge pumps**	**C**	**3**	**M**		**WWII and Stretch DUKW with 2 ft or less freeboard are high susceptible to rapid flooding and sinking from water ingress**
						D	**5**	**H**	**add carrier bearing, in water inspection after repair, frequent inspections, bilge alarms, bilge pumps**	**C**	**1**	**L**		

			leaking seal, broken fitting	Truck Duck with sea chest	flooding	C	1	L						
		Drain or Plug Leakage	Leaking or missing plug	All	flooding	D	4	H	remove or seal plugs, in water inspection after repair, bilge alarms, bilge pumps	B	1	L		
		Hull Leakage	wastage, fracture or damage		flooding	D	4	H	frequent inspections, bilge alarms, bilge pumps	C	3	M		WWII and Stretch DUKW with 2 ft or less freeboard are high susceptible to rapid flooding and sinking from water ingress
		Bilge Alarm Failure	electrical or damage		delayed notification of water intake & flooding	D	2	M						
		Bilge Pump Failure	electrical or mechanical		Inability to pump out incoming water, vessel sinking	D	5	H	multiple bilge pumps	C	3	M		WWII and Stretch DUKW with 2 ft or less freeboard are high susceptible to rapid flooding from waves.
		Fire in engine compartment	fuel leakage or exhaust temperature high		loss of propulsion, fire engulfing the vessel	C	4	M	fixed/automatic co2 & dry chemical system; fire alarm	C	2	M		
		Fire in passenger compartment	smoking, electrical issue, intentional		fire injury to passengers	B	4	M	careful observation	B	2	L		

		Gasoline vapor explosion	**fuel leakage and spark**		**explosion damage, loss of propulsion, injury to passengers**	**C**	**4**	**M**	**inspection; fuel "sniffer" alarm**	**B**	**3**	**M**		
		Narrow Aisles and Unclear Escape path	**design constraints**		**difficulty or failure to evacuate in an emergency leading to drowning or injury**	**C**	**5**	**H**	**signage and safety briefing**	**B**	**5**	**H**		**Signage and safety briefing without other mitigation actions is inadequate to reduce risks to acceptable level.**
2. Underwa y Hazards	**2.1 Weather hazards**	**Extreme Winds from Storms**	**storms (large area wide storms)**		**capsizing, high waves causing vessel flooding, loss of control**	**D**	**5**	**H**	**monitor weather forecasts, most major storms have adequate warning time to avoid water operation during the storm period.**	**B**	**3**	**M**		**WWII and Stretch DUKW with 2 ft or less freeboard are high susceptible to rapid flooding from waves.**
		Thunderstor ms	**seasonal conditions**		**very strong gusts which can cause capsizing, high winds and loss of control**	**D**	**5**	**H**	**monitor weather, no water segments during thunderstorm warning period. Thunderstorm s likely have distant thunder as they are approaching so some warning is available, sensitivity to regional variation in likelihood**	**C**	**3**	**M**		**WWII and Stretch DUKW with 2 ft or less freeboard are susceptible to rapid flooding from waves. However, for certain types of storms that are more predictable this risk can be reduced to acceptable level by**

									avoid bodies of water with large fetch or partially protected waters					**avoiding in water tours when thunderstorms are approaching.**
		Squalls	**seasonal conditions**		**very strong sustained winds and gusts with similar consequence as extreme winds**	**D**	**5**	**H**	**monitor weather forecasts, sensitivity to regional variation in likelihood, avoid bodies of water with large fetch or partially protected waters**	**B**	**5**	**H**	**Squalls not related to thunderstorms may have little or no warning, so need to rely on weather forecasts**	**WWII and Stretch DUKW with 2 ft or less freeboard are high susceptible to rapid flooding from waves. Monitoring of weather alone without other mitigation actions, such as stopping water segments during weather warnings, has been found to be inadequate to reduce risks to acceptable levels in areas with large enough**
									install effective weather monitoring equipment and policy of no water segments during severe weather warnings.	**B**	**3**	**M**		

														fetch to form waves that can overtop a low freeboard DUKW (see 'Stretch Duck 7' casualty)
		Tornadoes	**seasonal conditions**		**temporary extreme winds with overturning and destruction of the vessel**	**C**	**5**	**H**	**monitor weather forecasts, no water segments during tornado warning period**	**B**	**4**	**M**		**WWII and Stretch DUKW with 2 ft or less freeboard are high susceptible to rapid flooding from waves.**
		Lightning	**seasonal conditions**		**lighting strike can cause passenger injury, fire and electrical failure**	**B**	**4**	**M**	**avoid operation during thunderstorms**	**A**	**4**	**M**		
		Poor visibility	**fog**		**collision, grounding, inability to find safe area for landing the vessel**	**C**	**3**	**M**	**reduce speed, head for nearest safe shore**	**D**	**2**	**M**		
		Other as identified by HAZID team												
	2.2 Geographic/ Natural hazards	**Sandbars**	**terrain**		**stranding of the vessel**									

		Strong Currents	**seasonal conditions**		**loss of control of the vessel, inability to return to water exit ramp**	**C**	**1**	**L**						
		Large Fetch	**natural occurrence**		**collision and leakage**	**B**	**1**	**L**						
		Other as identified by HAZID team												
	2.4 Waterway Navigation	**Other vessels sharing the same waterway**	**busy waterway**		**collision and wakes**	**D**	**4**	**H**	**stay out of channel, away from other traffic**	**D**	**3**	**M**		
		Shallow water or underwater objects (e.g. wrecks)	**natural occurrence**		**damage and flooding**	**B**	**2**	**L**	**because of wheels DUKW can ride over shallow water areas**					
		Man-made obstacles (e.g. bridges, navigation buoys, piers, offshore structures)	**man-made occurrence**		**damage and flooding**	**D**	**2**	**M**						

		Floating natural obstacles (logs or other debris)	**natural and man-made**		**damage and flooding**	**D**	**3**	**M**						
		Pilotage error	**human error**		**collision, failure to return to exit ramp, operate in unsafe conditions**	**C**	**4**	**M**						
		Other as identified by HAZID team												
3. Personnel Hazards	**3.1 Personnel Hazards**	**Canopy entrapment**	**enclosed canopy**	**without flotation**	**difficulty or failure to evacuate in an emergency leading to drowning or injury**	**C**	**5**	**H**	**easy open windows, sliding hatches in canopy roof, large enough gap between pillars**	**C**	**3**	**M**		**WWII and Stretch DUKW with 2 ft or less freeboard are highly susceptible to rapid flooding and so escape from under canopy may be required in seconds, not minutes. Disabled or untrained persons may not be able to manage this. Escape route may be blocked or difficult for disabled or overweight persons, for**

														elderly or for children
				with flotation	**need to evacuate is reduced**	**C**	**2**	**M**						
			no canopy			**C**	**2**	**M**						
		Narrow Aisles and Unclear Escape path	**design constraints**		**difficulty or failure to evacuate in an emergency leading to drowning or injury**	**C**	**5**	**H**	**easy open windows, sliding hatches in canopy roof, large enough gap between pillars**	**C**	**3**	**M**		
									installed flotation	**B**	**2**	**L**		

		Difficulty to put on lifejacket and minimal briefing	**Life jackets in overhead or under seat**	**WWII, Stretch DUKW with canopy**	**passenger injury or drowning**	**C**	**5**	**H**	**improved instruction on how to put on life jacket at beginning of tour and well placed instruction signs**	**C**	**5**	**H**		**Life jackets are hard to put on by persons not experienced in doing it and can trap the person under the canopy. May not be the right size for children or overweight persons. Wearing life jackets without other mitigation actions is insufficient to achieve acceptable risk as demonstrated by the DUKW multiple fatality sinkings.**
									mandatory wearing and no canopy	**C**	**3**	**M**		**Removal of canopies is an example of a mitigation action that together with wearing of life jackets can create an acceptable level of risk.**

				WWII & Stretch DUKW without canopy or Truck Duck even with canopy	**passenger injury or drowning**	**C**	**4**	**M**	**improved instruction on how to put on life jacket at beginning of tour and well placed instruction signs**	**C**	**3**	**M**		
									add second crew member	**C**	**3**	**M**		
		Slipping and tripping hazards	**slippery surface**		**passenger injury**	**E**	**3**	**H**	**non-skid; steps; grab rails**	**D**	**2**	**M**		
		Falls	**tripping or slippery surface**		**passenger injury**	**E**	**3**	**H**	**non-skid; steps; grab rails**	**D**	**2**	**M**		
		Drugs and alcohol	**poor managemen t of personnel**		**operator error, lack of safe operation, passenger injury, damage to the vessel**	**C**	**3**	**M**	**pass. screening before boarding**	**C**	**2**	**M**		
		Fatigue	**poor managemen t of personnel**		**operator error, lack of safe operation, passenger injury, damage to the vessel**	**C**	**3**	**M**	**follow the safety rules**	**C**	**2**	**M**		