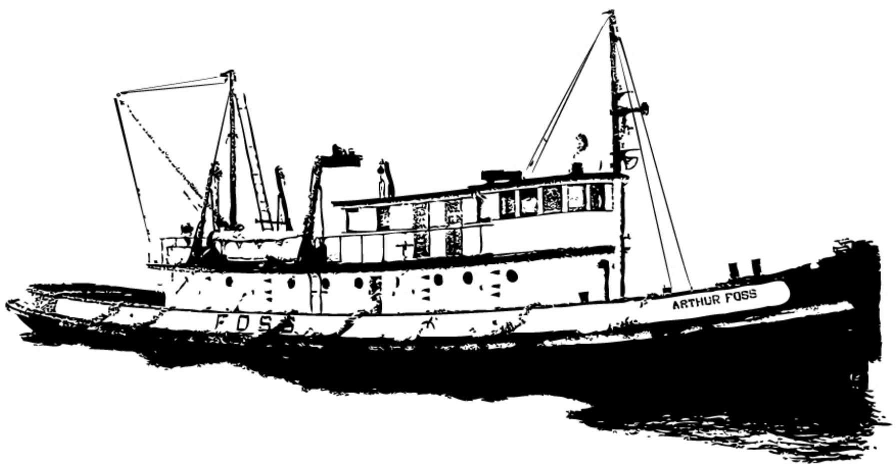

TUGBOATING ON PUGET SOUND

A DOCENT'S GUIDE TO THE ARTHUR FOSS

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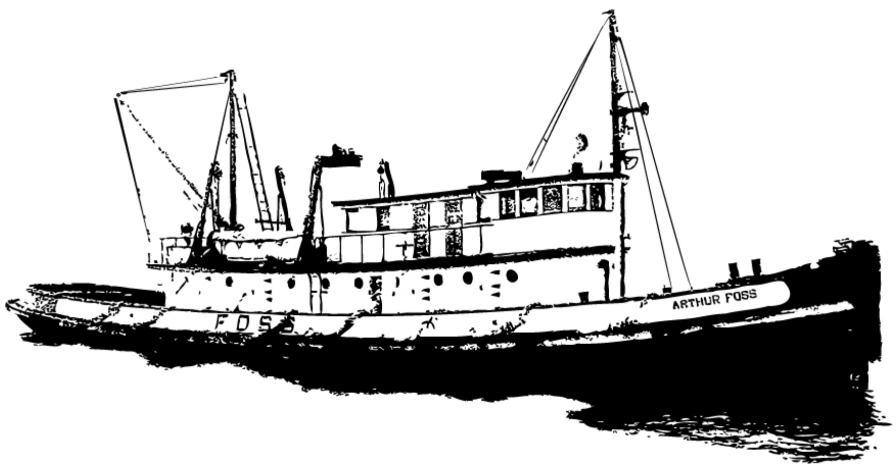

TUGBOATING ON PUGET SOUND

A DOCENT'S GUIDE TO THE ARTHUR FOSS

CULTURE
KING COUNTY LODGING TAX

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INTRODUCTION

Welcome aboard the historic tugboat *Arthur Foss*!

This document is intended as a resource for individuals interested in guiding tours for Northwest Seaport. It contains an overview of the Puget Sound towing industry that tugboats like the *Arthur Foss* participated in and a detailed description of the *Arthur* herself. This document provides background information relevant to the *Arthur Foss* and is not intended as a comprehensive guide to Puget Sound tugboats.

The *Arthur Foss* is an excellent example of Puget Sound tugboats before 1960. In addition to her own unique stories of transporting ships and supplies to Alaska's Klondike Gold Rush and escaping the 1941 Japanese invasion of Wake Island, the vessel exemplifies a generation of working tugboats. As a Foss Company tugboat, she was part of a fleet that expanded from Puget Sound to become one of the largest towing companies in the world. By learning about the *Arthur Foss*, visitors can learn about the towing industry that helped build the Pacific Northwest's maritime economy.

While this document specifically addresses tugboats on Puget Sound from roughly 1920 to 1960, many subjects are still relevant to tugboating today. The technology and cargo may have changed over time, but many essential details have not. Puget Sound tugboats remain small, powerful craft used to pull, push and maneuver barges, log rafts and commercial vessels.

A NOTE ON SOURCES

No definitive book on the history of Puget Sound tugboats has yet been published. While several books, including Michael Skalley's comprehensive *Foss: Ninety Years of Towboating*, Virginia Thorndike's *On Tugboats: Stories of Work and Life Aboard* and Doreen Armitage's *From the Wheelhouse: Tugboaters Tell Their Own Stories* provide valuable information about towing and Pacific Northwest tugboats, a significant portion of the material within this manual was gathered from personal interviews with members of the maritime history and tugboating community.

Karl House, a former Foss Company employee and a volunteer with Puget Sound Maritime Historical Society, provided invaluable answers to many questions about tugboating on Puget Sound. Marine Engineer Adrian Lipp contributed extensive knowledge about antique marine diesel engines, including the *Arthur*'s 1934 engine. Former Northwest Seaport director Mary Kline Rose and former Northwest Seaport volunteer Mike Foley provided stories of the *Arthur Foss*'s time as a heritage vessel in the 1970s and 1980s, and Northwest Seaport trustee Pat Hartle helped scour the archives to provide details about how the *Arthur* came to the organization.

Without these individuals and others like them, historic vessels like the *Arthur Foss* would cease to be relevant – if they survived at all.

TUGBOATS IN PUGET SOUND

Alongside railroads, ocean-going cargo ships, freight trucks, ferryboats and other vehicles, tugboats are an important piece of the regional and national transportation network that moves people, products and raw materials. Tugboats perform a number of tasks, including towing loads, assisting large ships into port and providing support services to the maritime industry.

In the Puget Sound area, water was the primary method of transportation for both industry and people well into the 20th century. Native Americans living on Puget Sound used cedar canoes to travel between settlements and fishing and clamming grounds. The first European-American settlers arrived by water, rather than by land. Many pioneers from the Eastern United States, including Seattle's founding Denny Party, followed the Oregon Trail to Portland and then boarded a schooner or steamer to take them to Puget Sound. Once in Puget Sound, settlers built their towns on the waterfront. Canoes, steamers and ships continued to be the primary means of transportation.

Towns in Puget Sound grew into cities as more settlers arrived to find land and work. Puget Sound's early industry revolved around resource extraction such as logging and mining. Water was the easiest way to move timber and coal to distant markets. The railroads that helped expand American industry in other parts of the country did not come to Puget Sound until relatively late in the 19th century. Even after their arrival, it was often more efficient to transport materials on the water.

Maritime transportation has remained vital to commerce and industry in Puget Sound and tugboats have remained crucial to maritime transportation. Tugboats continue to perform many of the same jobs they have since the mid-19th century, like towing logs and barges. While some traditional tugboat jobs like assisting wind-powered sailing ships through the Strait of Juan de Fuca have disappeared, new jobs, like refueling container ships, keep tugboats busy.

A TYPICAL PUGET SOUND TUGBOAT

Saltwater tugboats, as opposed to the tugs and towboats used on the inland waterways and Great Lakes, share several characteristics. These include a long deckhouse rounded at the bow, tall wheelhouse and bluff bow that drops straight down to the water. Within this general description tugboats can vary widely, especially on Puget Sound.

Until the 1950s and '60s, an onlooker could identify most tugboats on Puget Sound by looking at them. While they shared these general design characteristics and tugs owned by the same company usually had similar paint jobs, each tug was unique. The shape and configuration of the deckhouse and wheelhouse, the position of the railings, the presence or absence of masts and other features made each tug distinctive.

Much of this uniqueness was due to how tugboats were designed and built on Puget Sound. Most builders did not use plans and experimented with minor variations in design from tug to tug. Tugboat companies also commonly purchased an old tugboat with a sound hull and rebuilt them to suit their specifications. This practice further contributed to the uniqueness of Puget Sound tugboats.

There were also variations between tugboats intended for different jobs. Tugs designed to tow heavy loads were long and narrow to minimize water resistance and maximize their momentum. Harbor tugs designed to assist ships were wider to maximize their stability when maneuvering in close proximity to the vessels they assisted. The unique designs of Puget Sound tugboats often made each tug better suited to specific kinds of towing. For example, two tugboats built for general towing might have minor variations that made one more suited for pulling large barges through the Strait of Juan de Fuca, while the other would be more suited for towing logs to a sawmill.

Despite these differences, tugboats on Puget Sound and elsewhere shared one common feature: they were *strong*. Tugboats had sturdy hulls and powerful engines, necessary for towing, pushing and hauling. Ship builders and towing companies on Puget Sound and elsewhere took advantage of technological innovations to make each tug as powerful as possible. As these changes in technology made older tugboats obsolete, they were replaced by newer and more powerful tugs. While many tugboats were burned or broken for scrap at the end of their towing careers, others were saved and adapted for modern uses such as private yachting.

The *Arthur Foss* is a typical Puget Sound tugboat from her era. In addition to her physical similarities to other tugboats, she performed a variety of different jobs over her 70-year working career. She was originally built to tow sailing ships across the treacherous Columbia River Bar, then towed ships and barges to Alaska and logs to Puget Sound sawmills. After thirty years towing logs, she was rebuilt into a "modern" diesel tug for coastal routes. During this renovation, she gained a longer deckhouse and a taller wheelhouse while her sturdy hull remained unchanged. After this rebuild, she again towed ships and barges on the Pacific Coast before being out-paced by newer tugs and returned to towing logs. She continued to be used for this purpose until finally being replaced entirely. After her retirement she was again reused, this time as a heritage vessel and museum ship.

THE BUSINESS OF TOWING

Puget Sound industries like logging and mining created a need for the reliable maritime services that tugboats can provide. The way this need expanded allowed individual tugboat operators to grow into large tugboat companies. The Foss Company may be the most famous tugboat company on Puget Sound, but there are many other companies that similarly started small and grew.

LOGGING & SHIPPING

Logging was one of the earliest industries in the Pacific Northwest. The logging industry and the jobs it created drew settlers and workers to the Puget Sound area and created a need to transport the cut timber. While sawmills were initially set up close to forests, the spread of logging soon required the logs be moved the considerable distance to where they would be processed. Puget Sound's rivers and waterways proved an excellent way to transport logs. Cut logs were rolled into the water, corralled into rafts and towed by tugboats to sawmills. Milled logs could then be transported to other markets on the West Coast and beyond in freight-carrying sailing ships.

Schooners and square-rigged sailing ships formed the backbone of the Pacific Coast commercial fleet well into the 1900s. Tugboats assisted these huge, engineless ships into port through the tricky currents and frequently windless passages of Puget Sound. They performed other duties related to industry, commerce and transportation on Puget Sound such as carrying mail and supplying ships at anchor.

As the regional economy grew and changed, so did the role of tugboats. Trade on the Pacific Rim made Seattle, Tacoma and other Puget Sound ports grow as part of a global network of maritime commerce. Water transport remained vital even as roads and railroads provided new ways to move people and goods. Wooden schooners and square-riggers were slowly replaced by powered freighters, removing the need for tugboats to assist these craft on windless days.

However, while freighters could get to Puget Sound ports under their own power, tugboats often delivered the pilots that guided them safely through hazardous waters. Freighters and other large ships made for long-distance ocean travel had difficulty maneuvering into docks or other small spaces and required the assistance of harbor tugs to maneuver them into the docks. Tugboats also serviced freighters and tankers preparing for their outbound journey. As these ships were too huge to dock at any but the industrial docks of major ports, refueling and re-supplying typically took place on the water via tugboats.

COMPETITION & CONTRACTS

Friendly competition was part of the towing business. In the early days of towing, before radio or ship-to-ship communication was common, tugs would wait "on station" at the entrance to the Strait of Juan de Fuca. When an engineless sailing ship was sighted, whichever tug arrived first won the business of towing it into port. Later, tugboats with wireless radios would keep in contact with shipping agents, allowing them to better predict when a ship would be in need of assistance. Sometimes a ship's captain would develop strong loyalties to a particular tugboat and her crew and refuse to be assisted by other vessels.

As maritime commerce changed, so did the nature of this competition. Instead of individual tugboats competing for individual tows, tugboat companies competed for contracts with shipping companies. When radio became common, companies began to use central dispatchers to send their tugboats to towing jobs, increasing the company's efficiency. Tugboats were typically on duty twenty-four hours a day. Even tied up at the dock between jobs, the tug's engines were on and the crew was ready to depart for any job that the company received.

This competitiveness especially showed while maintaining company tugboats. Companies chose distinctive color schemes to make their tugs recognizable from the water. Tugboat captains kept their boats looking sharp, directing their crews to sand, paint, varnish and clean while underway. Many older tugboats resemble old-fashioned yachts, with gleaming wood and shiny metal fittings that showed how well-cared-for the boats were.

THE FOSS STORY

The story of tugboats on Puget Sound would not be complete without mentioning how the Foss Company was founded. While there are numerous other towing companies on Puget Sound, Foss is perhaps the most famous.

The Foss Company began in the 1889 in Tacoma, Washington, a small port and terminus of the Northern Pacific Railroad at the time. Norwegian immigrant Thea Foss started a rowboat rental business from her modest floating home, starting with a rowboat she had purchased from a neighbor. By selling and renting rowboats, Thea made more money than her carpenter husband Andrew made building houses. When Andrew saw how successful Thea's rental business had become, he started building rowboats instead of houses.

The extended Foss family soon expanded their business into motor launches that provided delivery and water-taxi services to ships in Tacoma's harbor. While Andrew applied his carpentry skills to building and refitting launches, Thea incorporated the Foss Launch Company with the help of her nephews. As their boats became more powerful, the Company began to assist ships in docking as well as with harbor services. The Foss family drew upon Tacoma's growing population of Scandinavian immigrants to help run the boats and the business. Thea and Andrew developed reputations as generous, friendly people to work for.

In the early 1900s, the rowboat rental business declined (probably as a result of the popularity of bicycles) and the balance of commerce shifted away from the sailing ships that needed assistance from the Foss harbor launches. At the same time, however, logging on Puget Sound was increasing and tugboats were needed to tow logs to sawmills. The Foss Company decided to expand into log towing and began to build and purchase new tugboats. In 1914, they formally reorganized as Foss Launch & Tug Company, with six tugboats and six launches.

The Foss Company expanded to Seattle in the 1920's by purchasing a tugboat company based in the city. Thea and Andrew's three sons Arthur, Wedell and Henry became president, vice-president and secretary-treasurer of the company respectively, as their aging parents stepped into semi-retirement. Soon, the company was buying tugboats as fast as they could to fill the demand for service, often buying older boats and rebuilding them to suit their needs.

Thea's death in 1927, at the age of sixty-nine, did not slow the business. In the early 1930s, Foss expanded to fill all the niches of tugboating: docking assistance, salvage, rescue and towing barges and log rafts. They also continued to purchase towing companies and tugboats. In 1940, they contracted tugboats to the Navy and civilian companies working in the Pacific. The onset of World War II gave the Foss Company another opportunity for expansion and not a little hardship. The tugboat *Justine Foss* and her crew, including Thea's grandson Drew Foss, were captured by the Japanese in 1941. While Drew was transferred to a different camp due to illness and held as a Prisoner of War, the

rest of the *Justine*'s crew was executed.

Following the war, the Foss Company bought surplus Navy ocean-going tugboats, well-suited for longer tows to Alaska and on the Pacific and continued to expand by purchasing competing companies in Puget Sound, Alaska and California. Wedell Foss passed away in 1955, followed by his brother Arthur in 1964. Henry's subsequent retirement in 1966 left a new generation in charge of the Foss Launch & Tug Company. While only three members of the Foss family remained actively involved in the company's management, the new officers and employees continued to uphold the Foss tradition of quality and reliability. In 1969, the company also became part of maritime stock exchange to ensure its continuing financial stability.

The Foss Company was purchased by Saltchuk Resources Incorporated, a private investment firm focusing on maritime transportation in 1987. Still independently operated and based out of Seattle, this purchase made the Foss Company part of a worldwide network of reliable towing companies. Green-and-white Foss tugboats are still a familiar site on Puget Sound and beyond, upholding Thea Foss's legacy of reliable service.

PUGET SOUND TOWING COMPANIES

In addition to the famous Foss Company, there are numerous other tugboat companies on Puget Sound with their own unique histories.

The Crowley Maritime Company was started in San Francisco with a single rowboat in 1892 and later incorporated as Crowley Launch and Tugboat Company. Crowley began providing service in Puget Sound in the 1920s, at the same time that Foss Company was expanding into the Seattle area. Since then, Crowley has undergone similar kinds of consolidations and acquisitions and is now also one of the largest towing companies in the world.

Western Towboat Company was started by a Foss Company captain named Bob Shrewsbury. Western Towboat made a niche for itself by towing for lower prices than union companies. They started with logs and expanded into sand and gravel barges. Western Towboat currently has 19 tugboats and offers a variety of towing and ship-assist services in Puget Sound and the West Coast.

In 1987, a tugboat captain named Harley Franco began offering better fueling service on Puget Sound than either Crowley or Foss could provide. Starting as Olympic Tug and Barge with one leased tug and barge, the company has expanded up and down the West Coast. Olympic Tug and Barge now has 15 blue-and-white boats and 14 barges and specializes in fueling services.

TYPICAL TOWS

From the name "tugboat," it is easy to assume that all tugs do is pull barges and other loads from one destination to another. While this is part of what tugboats do, they also push and guide a variety of different kinds of objects to their destinations. If it floats, a tugboat can move it, from barges to docks to bridges. Puget Sound towing can, however, be categorized by the type of cargo and jobs that tugboats perform.

One factor that makes towing in Puget Sound tricky is tides. The narrow passages of the Strait of Juan de Fuca and Puget Sound create strong tidal currents that can seriously hamper the progress of a tug and its tow. Tugboats like the *Arthur Foss* would frequently anchor or moor the log rafts they were towing while the tide was against them.

TYPICAL LOADS

LOGS

Logs began as and remain an important and commonly towed load in Puget Sound. Thousands of logs were assembled into great rafts or *cribs* held together with chains and towed to sawmills. While some rafts were assembled flat, consisting of a single layer of floating logs, others were stacked many layers deep, creating huge loads of logs that would have filled dozens of trucks or railroad cars.

Log rafts were assembled on "booming grounds," an area on the shore where a logging company would send the logs after they had been cut. Using the long, sloping mudflats characteristic of Puget Sound and the Strait of Juan de Fuca, loggers or tugboat crews would stretch huge chains across the mudflats at low tide and then stack logs on top of the chains. Once the first layer was secured, they would wait for the tide to come up and then float the crib to slightly deeper water and pile more logs on, securing them with more chains. They repeated this process until they had a long, floating bundle of logs chained together that could be towed to a saw mill.

SAILING SHIPS

Sailing ships helped create the first great industries in the Pacific Northwest: logging and fishing. Even after the invention of steam engines, sail-powered ships remained an economical way to haul freight from port to port for decades. Schooners and square-riggers carrying lumber, fish and other products could easily sail across oceans or down coasts without engines, but when they reached destinations like the Strait of Juan de Fuca and Puget Sound they required assistance to make it to commercial ports. While they could easily navigate the storms of the open ocean, navigating past rocky shoals through the tricky shifting winds and tides of Puget Sound's waterways without assistance was hazardous and slow. Tugboats would wait "on station" to meet these engineless ships in the straits and assist them into port.

BARGES

Barges – large un-powered vessels that share properties of both rafts and boats – became an economical way to transport cargo and freight as the age of sail waned. While barges were dependent on tugs for power and most steering, they required far fewer crew than sailing ships. Barges could also be left tied up at a dock while being loaded or unloaded, while the tugboat performed other duties. Coal, grain, gravel, petroleum and heavy equipment are just a few of the loads commonly moved on barges.

While barges were once commonly made from the hulls of old ships like schooners or liberty ships, most barges are now built new and configured to suit specific loads.

OTHER JOBS

DOCKING ASSISTANCE

Even ships with engines often needed assistance docking and maneuvering within the tight constraints of a harbor. Many ports required that incoming vessels take on local "pilots", skilled mariners who knew the behavior and hazards of a particular waterway and were tasked with steering ships safely into port. Tugboats frequently transported pilots and assisted ships into tight docks and slips.

Large ships are designed to move forward at open-ocean speeds, not to turn quickly or move sideways as might be required when docking. Two or more tugs, attached to the docking ship with large ropes or hawsers, would provide the fine control needed to maneuver the vessel into a pier. These efforts were frequently coordinated by the pilot, who communicated with tugboat crews via whistles and horns.

SEARCH AND RESCUE

Before modern Coast Guard services in Puget Sound, tugboats often assisted ships in distress. This might involve mooring or even leaving their tow load to help in search and rescue efforts. As more water rescue programs were created on Puget Sound, tugboats were called on less and less to assist in these efforts.

Freighter and Tanker Escort

Most modern freighters and tankers are designed to reach ports without assistance but are required by law to be escorted into port by tugboats as a safety precaution. In Washington State, the Tug Escort Act of 1975 requires oil tankers be escorted by tugboats through the Strait of Juan de Fuca and Puget Sound to help prevent oil spills and other disasters.

Safety Hazards

Working onboard a tugboat had a variety of safety hazards. As on other boats and ships, crew could be swept overboard into chilly water, become tangled in lines or machinery, or be crushed between the boat and another hard object.

Tugboating also has its own unique risks. The huge lines and cables used to tow their loads occasionally snapped from the strain, sending the broken ends whipping through the air at high speed. A crewmember struck by the snapped line could be thrown overboard or suffer lethal wounds from the impact. Tugs pulling a heavy load had to be careful when decelerating, as heavy loads maintained their momentum and could pile up against the tug if not carefully controlled.

Crewmembers on logging tugboats like the *Arthur Foss* faced danger when preparing log rafts for towing. Even while wearing spiked boots called corks, crewmembers climbing over the floating logs to secure the raft with heavy chains could slip off the raft and be trapped or crushed. Routine inspections of the assembled log raft posed the same dangers.

Engine rooms held another set of hazards for a tugboat's crew. Many older engines had exposed belts and shafts in which an unwary engineer could get caught and battery banks could cause burns or shocks. Engineers frequently removed rings or watches while working in the engine room to reduce their risk of electrical burns or other injuries. In addition to these dangers, engine rooms were often noisy enough that an engineer's cries for help might not be heard by other crewmembers.

A TYPICAL CREW

The typical Puget Sound tugboat crew consisted of seven people: a captain, a mate, a chief engineer, an assistant engineer, two deckhands and a cook. These seven-person crews performed most kinds of towing within Puget Sound, such as towing, escort and supply duties.

Tugboats might carry different crews for different kinds of jobs. When towing down the West Coast, tugboats often carried an additional mate and deckhand and sometimes a radio operator, while tugboats towing petroleum also carried tankermen, crewmembers specially trained to handle fuel barges.

Prior to the last quarter of the 20^{th} century, tugboating was an exclusively male profession. While women now serve on tugboats in all positions from cook to captain, the crews described here were all men.

WATCH SCHEDULES

Crews on Puget Sound and elsewhere during the same era typically followed "six on, six off" schedules. Each crewmember spent six hours "on watch," or working, then six hours off. A crew was divided into two separate "watches", with the captain, chief engineer and one deckhand taking the six-to-twelve shifts and the mate, assistant engineer and other deckhand taking the twelve-to-six shifts. The cook worked through the day to prepare meals and run the galley, taking time off between meals.

While the crew followed this six-on, six-off schedule, the half of the crew off duty was ready to help if needed. Tugboats were usually active 24 hours a day and could need extra help within any of those hours.

Most Puget Sound tugboats also followed a two-week-on, two-week-off schedule, in which the crew would work for two weeks, then have two weeks off. This meant that most tugboats had two crews who alternated two-week shifts, keeping the tug in constant service.

DUTIES & TRAINING

Each crewmember onboard a tug had carefully-defined duties that they were expected to perform. While tugboat crews were not as rigidly hierarchal as those of many other vessels, captains were still in charge of the vessel and expected their crews to follow orders.

Up until the middle of the 20th century, training for tugboat crews was relatively informal. Many career tugboaters started as teenage deckhands and learned the job through experience and mentoring. They often worked their way up through the ranks on a boat or in a towing company to become captains. Others decided that the tugboating life was not for them and sought work on other vessels or ashore.

CAPTAIN

As with all vessels, a tugboat's captain is ultimately responsible for the crew, the tugboat and its tow. If anything went wrong, the captain receives a reprimand or punishment for the actions of the crew.

During watches, captains steer and navigate the tugboat, monitor the load being towed, work with the deckhand on duty to maneuver or dock and supervise the bridge and decks.

MATE

Mates are the second in command of the bridge and perform most of the same duties as the captain. During watches, they steer, navigate and supervise the bridge and decks.

CHIEF ENGINEER

Chief engineers run the engine room. They have responsibility for the engine and much of the tug's machinery and equipment, performing repairs and maintenance as needed and supervising any engineers under them. On a "bell boat" like the *Arthur Foss*, the chief engineer operates the engine in response to signals from the bridge. These duties often keep engineers out of touch with the rest of the boat.

ASSISTANT ENGINEER

The assistant engineer monitored and operated the engine while the chief engineer was off duty. While they were often able to perform minor repairs and maintenance, major tasks were the chief engineer's responsibility.

DECKHANDS

The two deckhands aboard a tugboat split the deck responsibilities, handling lines and serving as the captain's "hands." Deckhands were responsible for making and maintaining the connection between a tugboat and its load. While many deckhands started out with no knowledge of boats or towing, they learned quickly to throw and secure lines and maneuver barges, log tows and other loads. On a logging tug, experienced deckhands also secured and inspected the log rafts, walking from log to log to look at chains and fastenings.

COOK

Cooks on Puget Sound tugboats served up to four meals a day to accommodate the two different watches. Meals were typically served as one crew came off of watch and the other went on, at midnight, six AM, noon and six PM. Crewmembers going on watch would eat before relieving the other watch, who would then come to the galley for their meal.

Cooks had to be able to prepare food while the tugboat moved with the waves and often had to master the art of cooking on a diesel stove. Good cooks were able to work around these challenging conditions and prepare good meals, frying, grilling and even baking. Bad cooks typically did not last more than one or two assignments onboard a tugboat.

COMING ABOARD

Most tugboat companies supplied their crews with bed linens, towels and food for the duration of their trip. The crews in turn would bring their clothing, foul weather gear and any other gear they personally needed. Most crewmembers brought their own flashlights and knives (usually a folding pocket knife). Crewmembers on a logging tugboat often brought their own corks – spiked boots worn by loggers that made it easier to keep their footing while walking on a slippery log raft.

While Puget Sound tugboaters were usually able to bring along enough clothing to last them through their entire two-week shift, they sometimes needed to wash clothing onboard the tug. Crewmembers would rig contraptions of plungers and buckets to agitate the laundry with hot water from the galley, then dried their clothes on the deck rails during fair weather.

OFF DUTY

When not standing watch, crewmembers mostly slept. The six-on, six-off schedule kept on tugs made staying well-rested difficult. When not sleeping, crewmembers often read or played cards. According to some accounts, tugboaters could also be inventive practical jokers, playing tricks on one another during long, slow tows. Doreen Armitage's *From the Wheelhouse* relates a story of deckhands catching seagulls and pushing them through a porthole into the head. The birds reportedly stayed calm and quiet—until the unsuspecting captain opened the door and they all tried to fly out at once.

ONBOARD THE *ARTHUR FOSS*

An important part of the *Arthur Foss*'s significance is her physical form. This section provides an overview of the tug's spaces and equipment, both typical of Puget Sound tugboats and unique to the *Arthur*.

HULL & HOUSES

The *Arthur Foss's* hull and houses are typical of early 20th-century saltwater tugboats. She has a long deckhouse roughly two-thirds the length of the hull, which is rounded on the bow end and square on the aft end.

HULL

The *Arthur Foss* is 112 feet long, 24 feet wide and draws 15 feet (meaning that her hull extends 15 feet below the surface of the water). Her propeller is eight feet in diameter. The tug has the long, deep, narrow hull typical of a tugboat designed for towing heavy loads over long distances. The propeller is placed deep to give the tug leverage when pulling. The long hull makes the *Arthur* relatively fast for a tugboat. However, these same characteristics make her hard to maneuver, especially in restricted areas. While this makes her unsuitable for ship assistance duties, it makes her an excellent logging tug.

The *Arthur Foss* is constructed primarily from Douglas fir with strips of a tough wood called ironbark nailed over her hull. This ironbark sheathing helped protect the tug from damage during common, minor accidents such as collisions with floating logs.

DECKHOUSE

The first floor of a tugboat is called the deckhouse. The *Arthur Foss*'s deckhouse contains the crew cabins, galley, mess, engine room, first head and steering room. It has several exterior doors leading to these rooms, which have distinctive high stoops and double-doors. This style of doors helped keep water on the deck from running into the interior, while still allowing the doors to be kept open for ventilation. The galley's stove and the engine could produce a great deal of heat. Tug crews unlucky enough to serve on a boat without this feature might be forced to keep their doors shut despite high temperatures inside.

PILOTHOUSE

The second floor of a tugboat is called the pilothouse. The *Arthur Foss*'s pilothouse contains the officers' cabins, second head and bridge. It is accessible via the ladders on either side of the boat deck or the interior ladder in the engine room.

DECKS

Decks are the exterior flat spaces onboard a ship. The *Arthur Foss* has three main decks: the Stern Deck, Bow Deck and Boat Deck.

Crewmembers performed a variety of tasks on the tugboat's different decks, including securing and releasing tow lines; managing the tow load; and of course sanding, painting, varnishing and cleaning.

LINES, CABLES, & CHAINS

Lines (ropes) are essential to tugboats, as they are used for towing loads, tying up to docks, guiding other vessels and countless other jobs. Lines have been made from a variety of materials, from hemp and other natural fibers to modern synthetics. As loads have gotten heavier and more complicated, chains and steel cables have replaced some of the traditional braided or "laid" line.

The *Arthur Foss* used a long steel cable to tow log rafts and other loads. It is still stored on the towing winch on the stern deck. This type of cable replaced the twisted fiber *hawsers* that were traditionally used to tow sailing ships and other large loads, as cable is stronger and stretches less than fiber.

TOWING WINCH

The towing winch is the large piece of machinery on the Stern Deck, just aft of the deckhouse. The steel tow cable is wound around the winch's cylindrical drum.

FORWARD WINDLASS

The windlass on the bow deck is two winches mounted together. The starboard winch is used to raise and lower the *Arthur Foss*'s anchor. The port side winch is used to tighten lines, often when towing barges alongside the tugboat. These two winches function independently of each other.

BITTS

Bitts are large metal fittings with protruding bars, used to secure large, heavily loaded lines. Deckhands looped lines around the bars on the bitt so that pulling would tighten the loops, "making them fast" without tying them. Towing lines were never knotted, as loaded lines could pull knots so tightly that they would be impossible to untie.

The *Arthur Foss* has four bitts on her Stern Deck, two on either side.

CLEATS

Cleats are similar to bitts but are intended to secure smaller lines carrying less of a load. Cleats can be found on nearly any boat.

Masts

Many older tugs, including the *Arthur Foss*, were built with masts and booms. While they look similar to the masts and booms on sailing vessels, most tugboats never used sails. Instead, these booms and masts were used as cranes to handle the heavy chains used for securing log rafts and to bring supplies aboard.

Living Spaces

When rebuilt in 1934, the *Arthur Foss* was outfitted for coastal towing, which required more crew than the typical seven onboard Puget Sound tugs. As a result, her living spaces are larger than were common to accommodate these extra crewmembers.

As outfitted now, she can sleep six crewmembers in the forward cabins and three officers in the upper cabins. Additionally, what is now the steering room aft of the engine room was originally a cabin that slept an additional two crewmembers, bringing the total she could accommodate as a working tug up to eleven.

Heads

In the days of square-rigged sailing ships that crossed the ocean via trade winds, the toilets were placed in the bow, or head, of the vessel, so that odors would be carried ahead and away from the boat. Even though engines and plumbing made placement in the bow unnecessary, ships' bathrooms are still called heads.

The *Arthur Foss* has two small heads: one on the aft side of the pilothouse, opening onto the boat deck at the top of the stairs from the engine room and one on the aft port side of the deckhouse, opposite the steering room. Both heads have a sink and a plumbed toilet that flushes either into the tug's sewage tanks or over the side. There is a shower in the deckhouse head.

Galley

The *Arthur Foss's* galley is located amidships, forward of the engine room and aft of the crew cabins and mess. It has two double doors leading to both side decks and a long counter with a bench on the forward wall. Underneath this bench is storage space for food and supplies. The aft wall has a refrigerator and freezer, a diesel stove and a counter with a sink.

The diesel stove is similar to those found on many other ships and boats and draws diesel fuel from the same tanks as the engine. The stove takes several hours to heat up, so it was usually left running 24 hours a day. This kept the galley warm during cold weather but could make it unbearably hot during the summer even with the ventilation from the split doors. The stove is still fully functional. Northwest Seaport uses it to cook food during classes and volunteer events and to heat the interior of the tug on cold days.

MESS

The *Arthur Foss's* mess (dining room) is located on the port side, forward of the galley. It has a large table with padded benches on two sides (containing more storage for food and supplies) and a split door leading to the side deck. Trophies and plaques from tugboat races and other events adorn the walls alongside framed photographs and documents.

All the members of a watch ate here together, which illustrates the relatively relaxed relationship between officers and crew.

CREW CABINS

The *Arthur Foss* has three crew cabins located forward of the galley—two on the starboard side and one on the port side, forward of the mess. These cabins are very similar: each contains two stacked bunks, two closets, a sink and a split door leading to the side deck.

OFFICER CABINS

The *Arthur Foss* has three officer's cabins upstairs aft of the pilothouse. Each has a bunk, a desk, a sink and a closet.

The chief engineer's cabin is just off the top of the stairs leading up from the engine room. This close proximity to the engine room allowed the chief engineer to monitor the engine when off-duty.

The mate's cabin is forward of the chief engineer's cabin, on the starboard side of the tug.

The captain's cabin is only separated from the bridge by a curtain, allowing the captain to monitor the bridge when off-duty. The captain's cabin on the *Arthur Foss* has a fold-down chart table over the bed as well as a reading lamp. The modern VHS radios used for ship-to-ship communication are mounted inside the captain's cabin, as are the electronics for the radar. While these are relatively modern installations, they emphasize the importance of keeping the captain connected with the bridge.

BRIDGE

The bridge contains most of the steering, navigation and communication equipment and serves as the command center of any boat. The captain and mate stand their watches on the bridge, monitoring activity on the rest of the tug.

WHEELS

There are two wheels on the *Arthur Foss*'s bridge. The large wooden wheel controls the tug's manual steering. It is attached to the rudder by a system of cables that are visible from the engine room and the tug's stern deck. When the wheel is turned to one side, these cables pull the stern end of the rudder to the side, turning the tug in that direction. The *Arthur Foss*'s rudder is very large and heavy, making it difficult to move quickly by hand.

The small metal wheel controls the tug's power steering. It governs a system that uses pneumatics to turn the rudder much faster than it can be turned with the manual cable system. This system is used when the tug is docking or otherwise maneuvering in tight spaces. There is a similar wheel connected to the power steering system on the boat deck that the captain or mate can use if they need to see behind the tug while maneuvering.

TELEGRAPH

The brass and glass dial marked with speeds and directions on the starboard side of the bridge is called a telegraph. The bridge telegraph allows the bridge to reliably send specific signals to the engine room. It is connected to a similar telegraph in the engine room via a system of cables and pulleys.

When the captain or mate moved the bridge telegraph's handle, it moved the dial in the engine room and sounded an audible indicator, signaling the engineer to adjust the engine's speed or direction. After adjusting the engine, the engineer moved the handle on the engine room telegraph to move the dial on the bridge telegraph in response to the original order.

SPEAKING TUBE & HANDSET

The speaking tube on the starboard side of the bridge is connected to a similar tube in the engine room and was used to communicate when more information was needed than the telegraph could convey. The handset performs the same function but was installed later in the *Arthur Foss*'s working career.

COMPASS

The compass, forward of the wheels on the starboard side of the bridge, is one of the most critical pieces of navigation equipment onboard any older vessel. It points to magnetic north and can be used with charts and other navigational aids to determine the ship's position and heading.

The large metal spheres on either side of the compass are used to calibrate the compass, minimizing errors that the metal and electronics in the tug cause. While the *Arthur Foss* is made almost entirely from wood, even a minor error in heading on a trans-oceanic tow can result in missing the destination by tens or hundreds of miles.

Radar

The radar console is mounted on the port side of the bridge, with a cone-shaped black light-shield. Radar is a comparatively modern navigational aid, becoming common on ships and boats in the 1950s and '60s. It broadcasts radio waves and uses their echoes to create a two-dimensional image of solid objects nearby, showing the bridge crew nearby land and other vessels.

Radios

The radios are mounted in the captain's cabin, just aft of the bridge. Like most vessels these days, the *Arthur Foss* carries a VHF, or "Very High Frequency," radio. The bridge crew used these radios to communicate with other ships, the tugboat company dispatchers and the Coast Guard.

Engine Room

As with most tugboats, the engine and the equipment needed to run it occupy most of the space within the *Arthur Foss*'s hull. The engine room is located in the middle of the tug and has two levels: the main level in the deckhouse and a lower level typically just called "below." The engine is so large that while it is mounted in the very bottom of the tug, it extends all the way up to the main level. The lower level is accessed by a steep set of stairs on the starboard side of the engine room and a ladder on the port side (currently blocked off).

Engineer's Station

The engineer's station is located in the aft starboard corner on the lower level and is from where the engineer on duty controls the engine. It is visible through the metal grating of the main deck and contains the telegraph and handset connected to the bridge and the engine controls.

Generator

The *Arthur Foss* has a modern generator that uses diesel fuel to produce electricity that powers the air compressor and other equipment. The generator is located astern of the engine.

AIR COMPRESSOR & AIR TANKS

The air compressor is located astern of the engine on the starboard side of the engine room. It is a piece of machinery around knee-height that forces pressurized air into the tanks. The air tanks are located along both sides of the engine room; they are the large white tanks on either side of the engine.

Compressed air is required to start and shift the *Arthur Foss*'s engine.

FUEL STORAGE TANKS

The *Arthur Foss* has a total of five fuel storage tanks; two large ones in the bow and three smaller ones in the stern. Combined, these tanks could hold approximately 25,000 gallons of diesel fuel—enough for long hauls up and down the West Coast or across the ocean.

The after-most stern tank is currently used for bilge water and other waste, rather than fuel. The bow tanks are no longer used.

Fuel is pumped from the fuel storage tanks into the "day tank" – a small fuel tank that feeds the engine. Using the day tank rather than the large storage tanks avoids some of the difficulties of trying to feed fuel from a large container. The day tank is located in the aft starboard corner of the engine room.

STEERING ROOM

The steering room is a small room in the aft starboard corner of the engine room. It contains the pneumatic machinery that makes up the tugboat's power steering system and also serves as storage for engine room equipment and supplies.

The steering room once functioned as a crew cabin when the *Arthur Foss* was outfitted for coastal towing.

ENGINE

The *Arthur Foss* uses a 700 horsepower direct-reversing diesel engine. It was built by Washington Iron Works (an industrial manufacturing company in Seattle, Washington) in 1934 and installed later the same year during a refit of the tugboat. It replaced the coal-oil steam engine that had been installed in 1901.

The engine has six cylinders with 18" bores and a 24" stroke. This means that the inside compartment of the cylinders are 18" in diameter and the pistons inside the cylinders move up and down 24" while the engine is operating. It has a common rail fuel system, which means that the same fuel pump feeds all six fuel injectors in the engine. It uses a 4-stroke cycle to produce power and operates at up to 200 RMP (revolutions per minute).

This engine could drive the *Arthur Foss* up to 12 knots when not pulling a tow, relatively fast for a tugboat. While towing, she usually kept to two or three knots in order to control the load.

The *Arthur Foss*'s antique diesel engine is explained in more detail in the final section of this document, *A Brief Introduction to Diesel Engines*.

THE *ARTHUR FOSS'S* HISTORY

The *Arthur Foss* has enjoyed an unusually long career, both as a working tugboat and now as a heritage vessel. This is in part due to a 1934 rebuild, where the Foss Company rebuilt the tugboat into a new vessel, reusing only her sturdy hull. With continued maintenance, repairs and attention, the *Arthur Foss* will continue to exist for more years to come.

STEAM TUG

1889-1898: ON THE COLUMBIA BAR

The tugboat now known as the *Arthur Foss* was built in 1889 by the Edward Cashen Boatyard in Portland, Oregon. Designed by David Stephenson, a marine architect in Portland, the tugboat *Wallowa* was later considered his finest work. The Oregon Railway and Navigation Company used her to assist sailing vessels into the Columbia River and upstream to Astoria.

1898-1900: TO THE KLONDIKE GOLD RUSH

In 1898, a Seattle captain named E. Caine bought the *Wallowa* to tow barges between Seattle and Skagway during the Klondike Gold Rush. Captain Caine owned two other tugs, three sailing ships and several barges, which he operated as the Pacific Clipper Line. The *Wallowa* towed barges and sailing ships for two years under Captain Caine, before being sold to Puget Sound Sawmills.

1900-1929: LOGGING ON THE STRAIT OF JUAN DE FUCA

In 1900, Puget Sound Sawmills purchased the *Wallowa* to tow logs from forests on the Olympic Peninsula to sawmills in Bellingham. In 1901, the company installed a modern steam engine in the tug, increasing her efficiency. Later, Puget Sound Sawmills sold her to the Merrill & Ring logging company, which continued using her to tow logs to sawmills.

FOSS DIESEL TUG

1929-1933: LOGGING WITH THE FOSS COMPANY

In 1929, Foss Launch and Tug Company bought the tug. At the time, the Foss Company could barely purchase tugboats fast enough to keep up with their growing contracts. A shortage of seasoned wood suitable for ship-building following World War One made even old tugboats like the *Wallowa* worth using. While the tug had seen 40 years of nearly constant use, her hull was sound. The *Wallowa* was one of many older tugboats that Foss purchased in the 1920s. The company used her for towing logs until 1933.

1933-1934: A STARRING ROLE

In 1933, the *Wallowa* became a movie star. Norman Reilly Raine, a writer with the Saturday Evening Post, popularized Puget Sound tugboating with his "Tugboat Annie" short stories. When MGM made the stories into the 1934 movie "Tugboat Annie," they leased the *Wallowa* to play Tugboat Annie Brennan's old steam tug *Narcissus*.

1934-1941: ON COASTWISE ROUTES

Shortly after filming "Tugboat Annie," the Foss Company rebuilt the *Wallowa* into a modern diesel tug. With new deck cabins, pilothouse and a 700 horsepower diesel engine, the tug was renamed *Arthur Foss* in honor of the company's president. Rebuilt as a coastwise tug for towing loads up and down the Pacific Coast, the *Arthur Foss* made several record-setting tows from Seattle to Los Angeles with her powerful new engine. She also helped establish two of the Pacific Northwest's famous landmarks, towing barges used to construct the first Tacoma Narrows Bridge and making waves to test prototypes for the Lake Washington Floating Bridge.

1941-1948: CONTRACTED BY THE NAVY

In 1941, the *Arthur* and several other Foss tugs were chartered to the Pacific Naval Airbase Contractors group. The *Arthur Foss* then towed barges full of construction material on a regular route between Honolulu and Wake Island. When the tug left Wake Island in late December of 1941, she became the last vessel to leave before the island fell to the invading Japanese Navy. Her sister ship the *Justine Foss* was not so lucky, as the *Justine* and her crew were captured by the Japanese. The tug was eventually sunk and most of her crew executed when food supplies for prisoner camps ran low.

After escaping Wake Island, the *Arthur* continued to tow for the Pacific Naval Airbase Contractors, helping construct air strips in the war effort. She finished the end of the war tied up in Honolulu, probably for want of a diesel mechanic qualified to fix her engine. While the Navy released the tug from service at the end of the war, she was transported back to Puget Sound in a sea-going dry dock. During the voyage, rough weather knocked the *Arthur Foss* out of her cradles within the floating dry dock. The fall badly damaged the side of her hull, but fortunately did not dislodge the heavy engine. Once back in Tacoma, the tug underwent extensive repairs that lasted nearly a year. She re-entered service as a Foss tug in August 1948.

1948-1968: LOGGING FROM PORT ANGELES

With the advances in technology made since her 1934 refit, the *Arthur Foss* was no longer a powerful, modern tug suited for coastwise towing. The Foss Company and other Puget Sound tugboat companies bought up surplus Navy tugboats and refitted them for the coastal routes, relegating their older tugboats to other jobs. The *Arthur* was, however, ideally suited for log towing. With her deep, narrow hull and slow, powerful engine, the tug towed logs from the western Olympic Peninsula to saw mills in Port Angeles and Puget Sound. In 1964, she was renamed the *Theodore Foss*, after Arthur's uncle. The name *Arthur Foss* went to a powerful new Foss tug built especially for ocean towing.

Finally, despite her suitability for log tows, the old *Theodore* was replaced by newer tugboats. She made her last tow on July 26, 1968 and was laid up in Tacoma for two years.

HERITAGE VESSEL

1970-1981: THE PRESERVATION MOVEMENT

In June of 1970, the Foss Company donated the *Theodore Foss* to a non-profit preservation group called Save Our Ships. S.O.S. renamed the tug *Arthur Foss* to recognize her significant career as a Foss tug. She joined S.O.S.'s two other historic ships, the lumber and fishing schooner *Wawona* and the lightship #83 Relief, in displaying the maritime history of Puget Sound and the Pacific Northwest.

However, during much of her first decade as a museum ship, the *Arthur Foss* lacked both formal interpretation and a dedicated volunteer force to keep her active. As S.O.S., renamed Northwest Seaport in 1972, worked to secure a permanent home for its historic fleet, the tugboat mostly sat inactive on Seattle's downtown waterfront.

This changed in the late 1970s when Northwest Seaport successfully moved the *Arthur Foss* and its other vessels to the town of Kirkland on Lake Washington. On Kirkland's waterfront, the tugboat became accessible to a group of young volunteers who became involved with the tug. Under the supervision of volunteers from the Foss Company, this group eventually returned the tug to operating condition.

1981-1996: A MOBILE MUSEUM

Once operating again, the *Arthur Foss* became a regular on Puget Sound's maritime heritage circuit. With a volunteer crew, she participated in the Olympia Harbor Days festival and other events, especially the tugboat races held in different Washington ports.

In 1985, the tug added ambassadorship to her activities, first voyaging up the Inside Passage to Juneau in celebration of Alaska's 25th anniversary of statehood, then representing the State of Washington at Vancouver's Expo '86.

Also in the 1980s, the *Arthur Foss* moved from Kirkland to the south end of Seattle's Lake Union, joining several other historic ships and maritime heritage attractions. The tug was opened to the public on weekends and select weekdays for tours and events. In 1989, her 100th birthday coincided with the 100th anniversary of both Washington State and the Foss Company. In the same year, the National Park Service declared the tugboat a National Historic Landmark in recognition of her historic importance.

The *Arthur Foss* continued participating in regional maritime heritage events and receiving ongoing maintenance until 1999, when volunteer burnout ultimately led to the tug falling idle at the dock.

2000-Present: Classroom and Museum

By 1999, the *Arthur Foss*'s thirty years as a museum ship had taken their toll. While her volunteer crews had kept the tug operational, she was in need of major repairs that in turn needed major funding and professional assistance.

At the same time, many maritime heritage groups in Puget Sound were increasingly focusing on preserving the skills associated with traditional ship building. Shipwrights find large wooden vessels like the *Arthur Foss* excellent classrooms to teach students about traditional construction and restoration techniques. In this spirit, the *Arthur Foss* was sent to the Bates Technical College in Tacoma as part of a restoration workshop. Under the supervision of professional shipwrights, students used traditional methods and materials to repair the bulwarks (walls beneath the railings on either side of the main deck). The tugboat also received a major Save America's Treasures grant to replace sections of her aft deck.

Since the successful Bates restoration class, the *Arthur Foss* has increasingly become a platform for hands-on workshops and classes aimed at preserving maritime skills and historic ships. In 2005, a series of classes began that focus on maintaining and restoring her antique diesel engine. These classes invite members of the public to take apart, clean, repair and reassemble the engine as part of a 10-year restoration plan. Following the success of these courses, several more hands-on workshops are planned in the coming years, including a hull survey class.

At the same time, the long plans for a Maritime Heritage Center at Seattle's Lake Union Park are finally coming to fruition. The *Arthur Foss* is one of several large, historic vessels that have found a permanent home at the Heritage Wharf. As public interest in Puget Sound maritime history grows, these vessels function increasingly as both museum ships and classrooms. The *Arthur* is now being used in a variety of public and educational programs designed to share her unique history with visitors.

NAMING & RE-NAMING

Tugboats throughout the United States typically had several names throughout their working lives. As tugboats were built, sold and transferred between companies, their names were frequently changed to reflect the changes in ownership. Tugboat names were also frequently "recycled." The *name Arthur Fos*s has been assigned to three different tugboats: the 1889 wooden tugboat; a former World War II Army tug purchased and refitted by the Foss Company in the 1960s; and a modern "tractor tug" built for Foss in 1982.

The historic 1889 tugboat *Arthur Foss* has had four names in her career:

WALLOWA

The tugboat was built in 1889 as the *Wallowa*, a word that is likely an adaptation of a Nez Perce word for either "fishing weir" or "winding water." Lewis and Clark formally gave the name "Wil-le-wah" to a river in northeast Oregon, which became the Wallowa River on American maps. Part of the immense Columbia River watershed, it flows into the Grande Ronde River, which flows in turn to the Snake River, which flows to the Columbia. The name Wallowa is also given to a county, a city and a mountain range in the river's drainage. Whichever of these sources the tug *Wallowa* was named after is fitting, as she was built to pull ships across the mighty Columbia River mouth.

NARCISSUS

Purchased by the Foss Company in 1929, Foss later leased the *Wallowa* to MGM studios for the 1934 film "Tugboat Annie." While the tugboat's name wasn't formally changed during filming, she became famous as the old tug *Narcissus* under the command of Captain Annie Brennan.

ARTHUR FOSS

In 1934, the Foss Company extensively renovated the *Wallowa*. To commemorate her re-launch as one of the most modern and powerful tugboats on the West Coast, she was renamed *Arthur Foss* in honor of the Foss Company's president. Oldest son of Thea and Andrew Foss, who founded the company in the 1800s, Arthur grew up helping the family business as it changed from rowboat rental to one of the premier towing companies in Washington State.

Theodore Foss

In 1964, the tug was renamed *Theodore Foss* after Arthur's uncle. The name *Arthur Foss* went to one of the Foss Company's new ocean-going tugs and later to a new tractor tug in 1982. When the Foss Company donated the historic tugboat to Northwest Seaport (then called Save Our Ships), the organization renamed her *Arthur Foss* to honor her long career as a working tug.

A Brief Introduction to Diesel Engines

A major part of the *Arthur Foss*'s significance as both a historic vessel and as a platform for educational programs comes from her antique engine. By learning about the *Arthur Foss*'s engine it is possible to gain insight into the importance of diesel engines to the towing industry. This guide contains an introduction to how diesel engines work, using the *Arthur*'s 1934 engine as an example.

Characteristics of Diesel Engines

Diesel engines, invented by Rudolph Diesel in the 1890s, are designed to use diesel fuel in the four-stroke cycle described in the next section. Diesel is a type of fuel that can be refined from petroleum or vegetable oils. It differs from gasoline in several ways.

First, diesel fuel is not as volatile as gasoline, reducing the potential risk of explosive fuel vapors collecting in the closed spaces onboard ships and boats. Second, diesel fuel is more efficient than gasoline, containing more potential energy than a similar volume of gasoline.

Third, diesel fuel – even petroleum-based diesel – produces fewer carbon emissions than gasoline, although diesel can contain higher amounts of sulfur if not properly refined. Using biodiesel based on vegetable oils rather than petroleum, further reduces the carbon emissions and environmental pollution from diesel engines. Northwest Seaport currently operates the *Arthur Foss*'s antique engine using biodiesel.

Ignition via Compression

Gasoline engines ignite fuel with an electrical spark. In contrast, diesel engines use mechanical compression to raise the temperature inside the engine above the temperature required to ignite fuel. This causes the fuel to spontaneously ignite without needing a spark.

Understanding this process begins by understanding that the volume, pressure and temperature of a gas are related. Decreasing the volume of a container increases the pressure and temperature of the gas within. In a diesel engine, the cylinder is filled with air and the piston is driven up into the cylinder. This action reduces the volume and increases the temperature and pressure of the air inside the cylinder. When compressed, the air is hot enough that when vaporized diesel fuel is injected into the cylinder, it will instantly ignite and burn. This makes the air inside the cylinder expand and force the piston down. The conversion of this motion into mechanical energy is explained in a later section, *The Four-Stroke Cycle*.

Using compression to ignite the fuel gives diesel engines common characteristics. Diesel engines must have thick walls and heavy parts to withstand the pressure created within the cylinders. This traditionally made diesel engines more suited to heavy-duty applications such as ships and construction equipment, but improvements in technology have made them small and light enough to be used in trucks and cars.

Burning diesel using compression creates a smoother and more consistent source of energy than gasoline. This gives diesel engines more constant *torque*, or rotating power, especially at low speeds.

ADVANTAGES OVER STEAM ENGINES

The first type of engines commonly used in ships and boats were powered by steam. While steam engines revolutionized maritime industries during the 19th century, they have been almost entirely replaced by diesel engines. Most commercial vessels now use diesel engines for propulsion and power, with steam engines still in service in only a handful of older vessels. This change was driven by the multiple advantages diesel engines have over steam engines.

First, diesel engines are more energy-efficient. Steam engines function in a way that produces a great deal of waste heat (energy) during each cycle. Diesel engines are able to use more of the heat (energy) they produce. While diesel engines still waste some of the power they create in the form of heat, they are much more efficient than steam engines.

Second, diesel engines use less space within a ship. Steam engines require large boilers (tanks of heated water that produce the steam that powers the engine) in addition to the power-plant that creates the mechanical energy. This leaves less space in a vessel to carry fuel and other supplies.

Third, diesel engines are easier to maintain and operate than steam engines. Boilers and the equipment that connects them to the steam power plant must be cleaned and serviced much more than a diesel engine. Steam engines require a large crew to maintain fire in the furnace and keep the machinery running, while diesel engines can be operated with one or two engineers. Vessels powered by diesel engines were also subject to far fewer government regulations than steam vessels, an attractive advantage to many towing companies when choosing an engine.

Finally, diesel engines were generally safer than steam engines. The boilers used to make steam were under constant pressure when operating and could explode if not properly constructed or maintained. Even minor steam leaks could be dangerous to engine room crew.

In the 1920s and '30s, as these advantages of diesel became clear and the price of petroleum diesel remained a fraction of the cost of coal, gasoline, or other fuels, many tugboat and shipping companies began replacing their steam engines with diesels. The *Arthur Foss* was one of many vessels affected by this change in technology when her steam engine was replaced with a diesel in 1934.

HOW THE *ARTHUR FOSS*'S DIESEL ENGINE WORKS

Burning fuel in a compressed cylinder as explained in the *Ignition via Compression* section above forcefully drives the piston out of the cylinder. This outward movement rotates the crankshaft, which drives the piston back into the cylinder and continues the cycle. The rotation of the crankshaft is also used to drive machinery attached to the engine; it can turn wheels or propellers or other machinery. The *Arthur Foss*'s engine uses the four-stroke cycle to convert the potential energy in diesel fuel into mechanical energy.

THE FOUR-STROKE CYCLE

The four-stroke cycle is a set of motions that internal combustion engines use to create power. While some engines use a two-stroke cycle in which both combustion and exhaust occur each time the piston cycles, the *Arthur Foss* and uses the four-stroke cycle.

The four stages in the cycle are the *intake* stroke (one), the *compression* stroke (two), the *power* stroke (three) and the *exhaust* stroke (four). A *stroke* is the movement of the piston up or down inside the cylinder; in the four-stroke cycle, the piston moves down (one), then up (two), then down (three), then up (four) to complete a cycle.

The intake stroke begins with the intake valves opening as the piston moves down, sucking fresh air into the cylinder. When the piston reaches the bottom of the intake stroke, the valves close and seal the fresh air inside the cylinder.

In the compression stroke, the piston moves up, compressing the air drawn in during the intake stroke. This compression raises the temperature in the cylinder to about 1000°F, hot enough for diesel fuel to spontaneously ignite.

The power stroke begins when vaporized diesel fuel is sprayed into the compressed cylinder. The high temperature in the cylinder causes the diesel to ignite and burn, creating heat, expanding the compressed air and pushing the piston down. This downward thrust drives the rotation of the crankshaft.

In the exhaust stroke, the exhaust valves open as the piston rises, forcing the expended air and fuel out of the cylinder. At the end of the stroke, the exhaust valves close and the intake valves open in preparation for the intake stroke.

The power stroke is the only stage of the four-stroke cycle that actually produces mechanical energy. Engines with multiple cylinders are set with each cylinder at a different stage of the cycle simultaneously, so that some cylinders are driving the crankshaft while it works to compress the others. The six cylinders in the *Arthur Foss*'s engine are set in pairs. When cylinders one and six are at the beginning of stroke one, cylinders two and five are part way through stroke two and cylinders three and four are finishing stroke three. This ensures that while some of the cylinders are in their intake, exhaust and compression strokes (which do not produce power), other cylinders are completing the power stroke to keep the engine moving. The crankshaft receives the energy of two power strokes every two-thirds of a revolution, rather than all six power strokes simultaneously every two revolutions.

AIR-STARTED

The *Arthur Foss'*s engine is started with compressed air. By pulling a lever located with the other controls on the aft starboard side of the engine, engineers flood the cylinders with compressed air in sequence, causing them to begin moving. This starts the mechanical cycle of compression and combustion that powers the engine.

The compressed air supply comes from an air compressor driven by the auxiliary generator. When full, the air tanks along the engine room are pressurized at about 250 pounds per square inch (psi) of compressed air. Without sufficient pressure in the tanks, the engine cannot be started.

DIRECT-REVERSING

The *Arthur Foss* has a direct-reversing engine, meaning that it has no reverse gear. To back up the tug, the *engine* must be run in reverse to turn the crankshaft and propeller in the opposite direction. Engines that are not direct-reversing use gears to reverse the direction of mechanical rotation.

In order to switch into reverse, the engine must be stopped and the camshaft shifted. The shift in position changes the sequence of lobes on the camshaft and changes the timing of the fuel injectors and valves so that the engine can run in the opposite direction. The compressed air supply that used to start the engine is also used to shift the camshaft.

MAJOR ENGINE PARTS

The *Arthur Foss*'s engine is an excellent reference for demonstrating how engines work, since the parts are very large and mostly on the exterior of the metal casing. Several spare parts, such as a piston, are also available to use in demonstrations.

The main parts of the engine work together in a cyclical pattern that transfers mechanical energy from one part to another to continue the cycle that creates usable energy. To choose an arbitrary starting point, the *cylinder* contains the *piston*, which drives the *connecting rod*, which rotates the *crankshaft,* which turns the *camshaft*, which moves the *push rods*, which are connected to the *rockers*, which open and close the *fuel injectors* and the *valves*, which are connected to the *cylinder*.

CYLINDER

The cylinders are the engine's combustion chambers. The tall, round units seen from above and the side of the engine each contain a cylinder, with thick walls to contain the pressure from combustion.

The four-stroke cycle previously described occurs within the cylinders, where fuel is burned to produce mechanical power. Each cylinder is surrounded by a water jacket – a compartment in the cylinder wall flushed with water that keeps the cylinder cool. The *Arthur Foss*'s engine has six cylinders.

PISTON

The pistons are round metal parts located within the cylinders. The pistons act like moving plugs inside the cylinder; they slide inside with such a tight fit that they can compress the air within the cylinder without letting any escape. The pistons move up and down inside the cylinder with the four-stroke cycle. The pistons use diesel fuel to lubricate the inside of the cylinder.

CONNECTING ROD

The connecting rods are metal bars attached to the underside of the pistons that extend down to the crankshaft. They are attached to the pistons with *wrist pins*, which allow the joints to pivot. The connecting rods move up and down with the pistons, transferring the explosive downward force of the power stroke to the crankshaft. There are six connecting rods, one on each cylinder.

CRANKSHAFT

The crankshaft is a long, thick metal rod that runs through the length of the engine and attaches to the propeller. Rather than being a straight cylindrical bar, the crankshaft has deep u-shaped notches to which the connecting rods are attached. Rotating the crankshaft rotates the propeller when the engine is engaged.

CAMSHAFT

The camshaft is a long metal rod about six inches in diameter that runs the length of the engine on its starboard side, above the crankshaft. It has protruding *lobes* that function like the bumps on a music box reel. These lobes rotate around the spinning camshaft, forcing the *pushrods* up when they come into contact and triggering the fuel injectors and valves.

There are three sets of lobes on the camshaft. One set controls the engine when it runs forward, one set controls the engine when it runs backwards and one set controls the engine when it is started. These different sets of lobes are shifted into the right position by using compressed air to slide the camshaft back and forth within the engine.

The camshaft is connected to the crankshaft by a series of gears. This allows the camshaft to use the energy of the crankshaft to drive the pushrods.

The doors on the starboard side of the *Arthur Foss*'s engine open to reveal the camshaft; the crankshaft is dimly visible far below it.

PUSH RODS

The push rods are long metal tubes that run between the camshaft and the rockers. They transfer the mechanical energy from the rotating lobes on the camshaft to the rockers on the top of the cylinders. There are eighteen push rods, three on each cylinder.

ROCKERS

The rockers are metal arms on the top of the cylinder that rock back and forth to operate the fuel injectors and intake/exhaust valves as part of the four-stroke cycle. One end of each rocker sits above a push rod, while the other end is connected to the valve or fuel injector it controls. The central rocker is attached to a valve on the fuel injector, while the outer rockers are connected to the intake and exhaust valves.

When the lobes on the camshaft lift the push rods, they move the rockers and trigger the valves or the fuel injectors. There are eighteen rockers; three for each cylinder.

VALVES

The valves are disc-shaped metal parts that sit in the air intake and exhaust tubes at the top of the cylinder. Through most of the four-stroke cycle, the valves are closed, pulled up against the top of the cylinder and blocking air from entering or leaving the cylinder through the tube. During the intake stroke, the intake valves open to allow fresh air to enter the cylinder and close for the compression stroke; during the exhaust stroke, the exhaust valves open to allow the exhausted gas to be forced out of the cylinder. When it is open, a valve extends a short distance into the cylinder.

The valves are attached to the outer rockers on top of the cylinder. The rockers move in response to the camshaft and push rods, opening and closing the valves during the appropriate part of the four-stroke cycle. There are twelve valves, with one intake valve and one exhaust valve in each cylinder.

The *Arthur Foss*'s valves were serviced in 2005 during a Diesel Engine Theory course.

FUEL INJECTORS

The fuel injectors are devices installed in the top of each cylinder, behind the rockers. One set of lobes on the camshaft move the middle rocker to open the fuel injector's valve, injecting a precise amount of vaporized diesel fuel into the cylinder. The fuel injectors on the *Arthur Foss* are the size of an adult's arm and are bolted to the top of the cylinders. The *Arthur Foss*'s fuel injectors were serviced in 2006 during a Diesel Engine Theory course.

GOVERNOR

The governor is a device at the bottom of the push rods that determines the amount of fuel injected into the cylinder, which in turn determines how fast the engine runs. In addition to making automatic adjustments to the automatic fuel in reaction to the speed of the engine, the governor can be controlled by the engineer to speed or slow the engine. It has wedge-shaped components that slide underneath the push rods, changing how high each push rod moves when its corresponding lobe cycles by.

GLOSSARY

aft – in the direction of the stern, or back, of a ship or boat

bow – the front end of a ship or boat, usually pointed

bulkhead – the walls of a ship or boat

forward – in the direction of the bow, or front, of a ship or boat

lines – a rope used onboard a ship or boat

pilot – an individual trained to assist ocean-going ships into a particular harbor, usually dropped off on the incoming ship by a pilot boat or tugboat

port – in the direction of the left-hand side of a ship or boat

schooner – a sailing ship with fore-and-aft sails (not square-rigged) and at least two masts, used to transport for passengers and freight until the 20th century

starboard – in the direction of the right-hand side of a ship or boat

tugboat – a small boat (compared to its load) used to move other vessels by pushing, pulling, or providing them other powered assistance

towboat – in coastal and salt water regions, the term "towboat" is used interchangeably with "tugboat." However, on rivers and inland waterways, "towboat" denotes a large vessel that moves barges and ships, while "tugboat" denotes smaller boats that assist less maneuverable vessels.

watches – formally structured duty shifts onboard a ship or boat

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