

Diesel Engine Theory Workshop Series Cylinder #4 Final Report

September 2009

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Crystal measures the piston ring gap in the crankpit

Introduction

Northwest Seaport's National Historic Landmark vessel *Arthur Foss* is powered by a heavy-duty diesel engine manufactured in 1934 by the Washington Iron Works of Seattle, Washington. This engine is a significant artifact in and of itself, which has led NWS to create both public program and restoration strategies for the engine, in addition to the vessel itself.

A 2004 condition survey provided information that, combined with the increasing interest in hands-on heritage programming opportunities, resulted in the development of a long-term plan for restoring the engine. This Diesel Engine Theory Workshop series invites members of the public to rehabilitate a different component of the engine each year. The full ten-year restoration plan and process is outlined in the report *Restoration Plan for the Tugboat Arthur Foss's 1934 Washington Iron Works Diesel Engine and Proposal for a Restoration Workshop Series*, available from Northwest Seaport's main office or on its website.

The 2009 Diesel Engine Theory Workshop session was the fourth in this planned ten-year process. In 2005, the workshop serviced and repaired the valves and valve cages; in 2006, the fuel injectors, and in 2007, the engine's bearings. The 2009 workshop focused on the engine's Cylinder #4, inspecting, servicing, and repairing its component systems.

Planning & Preparation

To finalize plans for the 2009 Diesel Engine Theory Workshop, NWS reviewed its *Restoration Plan For the Tugboat Arthur Foss's 1934 Washington Iron Works Diesel Engine and Proposal for a Restoration Workshop Series to Implement the Restoration Plan*, especially the plan for Cylinder #4 activities.

A 2004 condition survey found evidence of past damage and repairs to Cylinder #4. There are several metal patches on the exterior, made from lead and attached with small screws. There is also a thick steel band tightened and bolted around where the head meets the cylinder, and a crack in the forward side of the cylinder head. Finally, the water jacket between the cylinder wall and the liner is leaking, indicating a crack inside the cylinder as well.

The 10-year plan identified the following issues to address during the session concentrating on Cylinder #4:

- remove the rocker assemblies, intake, exhaust, and air start valve sets, fuel injector and push rods; all previously serviced by the Diesel Engine Theory Workshop series
- inspect and remove, then clean and service the cylinder head
- remove the piston and connecting rod, then disassembling, inspecting, and cleaning each
- remove and inspect the cylinder liner, honing out ridges if necessary
- replace the piston rings and cylinder gaskets
- document, inspect, and repair the existing patches and repairs made to the cylinder in previous years
- reassemble and reinstall these component parts, in reverse order of removal



Diesel repair expert Dan Grinstead gives an introductory lecture

Project Design

NWS began planning the 2009 workshop in 2008. A brief survey of Cylinder #4 showed that its condition had not changed significantly from the 2004 survey, and NWS determined that the planned activities were both desirable and feasible to perform as planned.

As with past Diesel Engine Theory Workshop, NWS contracted with local marine repair company Old Tacoma Marine Inc to provide both repair services and workshop instruction.

Publicity & Recruiting

NWS identified a broad audience as potential workshop participants, from maritime heritage enthusiasts to individuals interested in maritime careers. To recruit workshop participants, NWS representatives met with leaders of organizations like The Anchor Program, Seattle Central College, the Youth Maritime Training Association, and the Ballard Maritime High School. The Diesel Engine Theory Workshop was published in the Center for Wooden Boats' print course catalog, and NWS also called past program participants to notify them of the opportunity.

In addition to these targeted efforts, NWS also distributed posters and fliers (bearing the 4Culture logo) in several locations and posted information about the workshop on the organization's website.



Sterling and Chris oil the Arthur Foss's engine prior to a test start-up

Preservation Standards

As the *Arthur Foss* is both owned by an organization dedicated to historic preservation and recognized as a National Historic Landmark, Northwest Seaport must adhere to certain standards of preservation and documentation to ensure that the vessel's significance and authenticity is not compromised. The government publication *the Secretary of the Interior's Standards for Historic Vessel Preservation Projects* provides general guidelines for preservation and restoration activities, including recommendations specific to machinery and equipment. These include:

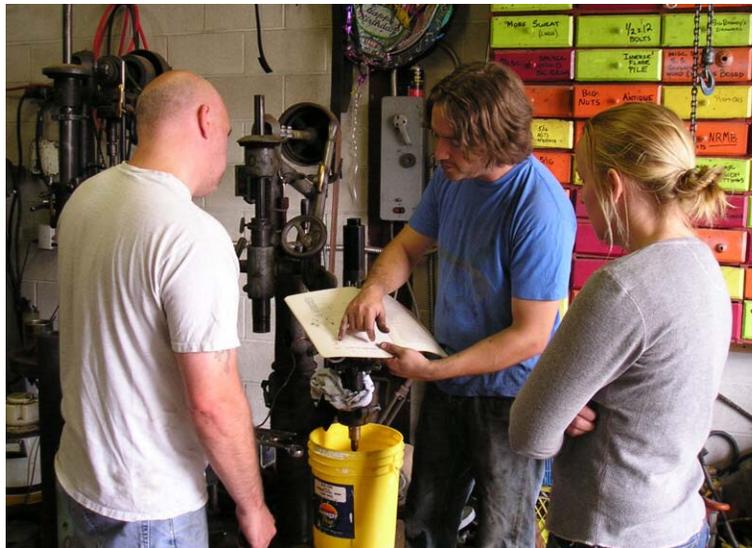
- Lubricating bearings, etc, of motors and generators. Rotating, if possible
- Repairing rather than replacing deteriorated material whenever possible
- Cleaning dirt, loose paint, corrosion, etc from machinery using the least caustic/abrasive effective means
- Disassembling and thoroughly cleaning interiors and moving parts of machinery, lubricating parts with clean lubricant.
- Ensuring that operable machinery is not permitted to deteriorate through lack of maintenance or protection
- Establishing and adhering to a regular schedule of inspection, lubrication, and rotation of operable machinery

- Retaining and preserving existing machinery that are important in determining the overall historic character of the vessel

The *Standards* also include recommendations for documentation of historic preservation projects, including:

- Thoroughly recording all work performed on the vessel in the course of treatment, with notations of method and materials used in the work, original fabric affected by the work, and the reasoning or justification for the work.
- Keeping records of regular maintenance and cleaning of the vessel
- Thoroughly recording damage to the vessel from external causes, as well as changes over time in the form or condition of the vessel

In addition to the *Standards*, there is another important resource available to guide the restoration of the *Arthur Foss's* engine without compromising its authenticity: the original Washington Iron Works diesel engine operation and repair manuals. NWS uses these publications to determine optimal engine settings and other adjustments.



The Diesel Engine Theory Workshop uses an original Washington Iron Works engine manual to set the injector spring tension

As with other Diesel Engine Theory Workshop sessions, the 2009 session used the following guidelines to ensure the long-term preservation of the *Arthur Foss's* diesel engine:

- Adherence to the guidelines given by the Secretary of the Interior's Standards for Historic Vessel Preservation Projects
- Use of the original factory settings and recommendations given by Washington Iron Works in its original manuals
- Documentation through photography, recording specific restoration and maintenance activities, and noting the cleaners, solvents, paints, and other products used on it. This information should be presented in reports to be kept in Northwest Seaport's *Arthur Foss* archives and to be distributed as requested to stakeholders and community members

Public Programs

The 2009 Diesel Engine Theory Workshop had three main public programming opportunities. First, the workshop itself, open to paying participants and spanning five days. Second, the Galley Program, in which marine cooks use the Arthur Foss's behemoth 1934 diesel stove to prepare meals for course participants and other occasions. Third, the workshop provides numerous opportunities for public demonstrations of the engine and other systems aboard the tug.

Diesel Engine Theory Workshop

The Diesel Engine Theory Workshop spanned five sessions, taking place over five consecutive Saturdays in 2009. A schedule is provided in the Appendix of this report.

NWS ultimately filled all eight available spaces in the Diesel Engine Theory Workshop. Two were youth interested in learning more about maritime careers who registered for the class through the Center for Wooden Boats. One was a prior course participant who has since embarked on a career in marine repair and one was a NWS volunteer interested in historic ships in general and the *Arthur Foss* in particular.

Three were from The Anchor Program, a non-profit organization that provides entry-level job training to at-risk and inner-city youth and adults, and regularly partners with NWS in that mission. A community partner, the Youth Maritime Training Association, sponsored two of these students and NWS and the Center for Wooden Boats combined to sponsor the third.

One heard of the Diesel Engine Theory Workshop through The Anchor Program while not participating in its programs.



George starts the *Arthur Foss's* 1934 engine

On the first day of the workshop, lead instructor Adrian Lipp of OTM Inc led introductions and gave a short safety orientation, then led participants on an in-depth tour of the vessel, concentrating on the propulsion system and its components. Participants ran the main engine and both auxiliary generators, inspected and greased the steering system, and switched the vessel from shore power to onboard power. After lunch,



Participants clean the #4 piston with sandpaper

regional diesel expert Dan Grinstead of Ace Tugboat Co gave the Diesel Engine Theory lecture, a short introduction to the theory and practice of diesel propulsion. The lecture was accompanied by spare parts to illustrate topics.

Following the Diesel Engine Theory lecture, participants disassembled the external components under the supervision of Lipp, using basic tools such as wrenches and vice grips. The focus was split between the cylinder head and the crankpit, and gave participants their first chance to get their hands dirty. By the end of the session, participants had removed all of the components on the cylinder head and had readied the rod bearing, deep in the crankshaft, to be removed during the following week.

The second session met at OTM Inc's specialized machine shop, where participants spent the day cleaning, servicing, inspecting, and repairing components removed the previous week. The third session started the same way, then returned to the vessel for lunch. The afternoon was spent cleaning the piston and measuring new piston rings.

The fourth session met at the *Arthur Foss*, where participants helped prepare the components to be reinstalled in the engine. These activities included more painting, cutting and installing gaskets, and continuing to clean the cylinder and head. Participants also helped re-install the rod-bearing on the crankshaft, an exacting process that required extensive teamwork and coordination.

The fifth session met at the *Arthur Foss* and focused on reassembling the remaining components of Cylinder #4 and the air manifolds. This process was completed in the early afternoon, during the Lake Union Wooden Boat Festival. Participants helped run the engine for a few minutes, long enough to determine that the components worked.

Galley Program

Started in 2007, the Galley Program is an effort by NWS to both provide meals for workshop participants and to exercise the *Arthur Foss's* 1934 galley equipment. In its past sessions, the Galley Program has achieved the desired results: to provide a convenient, engaging setting for workshop participants to informally discuss course topics; to provide the authentic experience of an old-time tugboat, which employed full-time cooks as part of the crew; and to use the diesel stove.



Fresh bread and French onion soup, made in the *Arthur Foss's* galley

The 2009 Diesel Engine Theory Workshop pushed the boundaries of the Galley Program when Chef Kim baked fresh bread in the diesel oven, gauging the temperature by putting her hand within it for a few moments. Chef Kim and Chef Lia also prepared tacos, hamburgers, French onion soup, grilled cheese sandwiches, brownies, cookies, and a variety of side dishes, to rave reviews from workshop participants.

Public Demonstrations

As a National Historic Landmark vessel, the *Arthur Foss* is often open to the public for self-guided tours and other interpretive activities. The Diesel Engine Theory workshop provided a variety of opportunities for members of the public to observe the restoration in process.

The last workshop session was held on the first day of the Lake Union Wooden Boat Festival, an annual event held at Lake Union Park by the Center for Wooden Boats. On this day, almost 1,000 visitors came aboard the vessel, many of whom stopped in the engine room or in the galley, where samples of fresh hot bread baked in the diesel stove were available for as long as they lasted. Visitors also interacted with participants in the Diesel Engine Theory Workshop, who were able to help interpret components of the vessel and especially the engine room from their first-hand perspective.



Calvin talks with a visitor at the Lake Union Wooden Boat Festival

Preservation & Rehabilitation

The 2009 Diesel Engine Theory Workshop performed the following activities to preserve, repair, and rehabilitate the *Arthur Foss's* 1934 Washington Iron Works diesel engine:

- ran the engine and systems at the beginning of the course to exercise the equipment and provide workshop participants with a demonstration
- removed the external components on cylinder #4, including the rockers, push rods, valve cages, valve clamps, and fuel injector, all of which had been removed for service or repair in previous Diesel Engine Theory Workshop. The 2009 workshop also removed the rocker studs, water cooling system pipes, exhaust manifold coupling, and intake manifold coupling
- cleaned, stripped, and painted or oiled these external components, using methods such as sand-blasting, soaking in hot solvent, and manual scraping or grinding
- serviced and tested the fuel injector, re-setting the spring pressure to the original factory specifications during a workshop demonstration
- disassembled the valve cages, cleaned them, and lapped the valves
- cleaned the water passages in the exhaust valve cage by removing the lower plug, reaming the passage, and inserting a new plug. Not all corrosion was removed within the available time for this service; future workshop sessions should further clean the water passages
- removed cylinder head nuts in preparation for removing the cylinder head using heat, paraffin, lubricant, and a slugging wrench.
- manually cleaned the head nut stud threads with valve-lapping compound
- removed the cylinder head; the leak observed during the 2004 survey resulted in extensive corrosion between the cylinder and the cylinder head. Mechanics removed



Grant removes a valve cage using vice grips

this built-up rust with sawzall blades and then pried the cylinder head loose with metal wedges driven into the seam

- cleaned the cylinder head both inside and out, using scrapers, sandpaper, and solvent to remove corrosion, paint, and other detritus
- cleaned the exposed upper surface of the cylinder head and the water passages between the cylinder and the liner, using scrapers and shop vacuums to remove built up corrosion
- removed the air-start valve in cylinder head using a specialized tool and significant force. Once removed, mechanics disassembled the valve and cleaned the components, then lapped valve into the seat and reassembled it with a new o-ring
- removed the piston, then the old piston rings, and cleaned the piston using sandpaper and scrapers to remove built-up carbon from all surfaces, especially the ring grooves
- installed new piston rings, which were measured and staggered for a precise fit
- removed and inspected the rod bearing; the inspection found cracks on the low-friction babbitted surface, but mechanics determined the bearing to be usable during anticipated operation
- inspected and honed the cylinder liner, using a ball hone and making the necessary crosswise pattern to hold oil



Sterling and Chris clean components removed from Cylinder #4 on the aft deck

- cut and installed new gaskets for the exhaust flange, using a compressed graphite material to replace the original asbestos gaskets
- cut and installed new gaskets for the water jumper flanges, using a black rubber material, and replaced water system hoses with new material

- installed new cylinder head gasket, using a pure copper ring to replace the original copper and asbestos gasket
- cleaned and repainted components of the exhaust and intake manifolds; the exhaust manifold was painted with a specialized high-temperature paint. Bronze portions of the intake manifolds were left unpainted, as was often common on engines of this type and era
- reassembled the cylinder and air manifolds,



Feeler gauges, used to take precise measurements



Participants in the 2009 Diesel Engine Theory Workshop disassemble components of the cylinder head and air manifolds, using wrenches, sockets, vice grips, and other standard tools

and test-ran the engine for a few minutes on the last day of the workshop

Results

The 2009 Diesel Engine Theory Workshop successfully completed all of its defined objectives, focusing on Cylinder #4. By the end of the workshop, the engine was fully reassembled.

However, following reassembly, it was discovered that the new copper head gasket failed to "seat," or create an effective seal. This resulted in an air leak between the cylinder and cylinder head, which created a loud whooshing noise during operation. This is a result of using a pure copper gasket, rather than the original copper-and-asbestos gasket. Future replacement head gaskets will be fabricated from copper and pressed graphite, which creates a gasket very similar to the old-style copper-and-asbestos gaskets. This issue will be corrected "post-workshop" by professional engineers who specialize in heavy-duty diesel engines.

Participant Evaluations

In addition to numerous positive comments throughout the workshop, NWS asked participants to fill out a short evaluation of the 2009 Diesel Engine Theory Workshop. A selection of comments from these evaluations follows:

- "I think the program was cool. I really liked it and learned a lot. It would be better if we had a couple of days in the week instead of one."
- "I enjoyed all aspects of the engineer class. I only wish there were more classes during the week. I hope you keep the cook."
- "I think the students should be here for more important things like pulling the head and all the fun stuff like that."
- "Overall it was quite enjoyable. I loved being able to really understand something that at the start seemed so complex. As for suggestions, a longer time period would have been nice."
- "I enjoyed most of the class. The use of all the tools and seeing the process of taking apart and rebuilding the engine was the best part. It was fun to see the moving parts and how simple diesel engines actually are. I don't have any negative points except kerplunking the valves. If I could change anything, I would increase the length of the program. That way we would not have to rush putting it back together."



Dirty hands after a hard day's work

- "I thoroughly enjoyed the Diesel Engine Theory class. I learned much more than I imagined I would."

Acknowledgements

Northwest Seaport wishes to thank the following sponsors and partners for their generous support of the 2007 Diesel Engine Theory Workshop:

King County 4Culture Heritage Special Projects Program

Foss Maritime Company

The Goodfellow Fund at the Seattle Foundation

Coastal Transportation Inc

The Youth Maritime Training Association

The Center for Wooden Boats

The Anchor Program

Old Tacoma Marine Inc

Ace Tugboat Company

Buca di Beppo Seattle

Members of Northwest Seaport

Appendices

Budget

Expenditures

<i>Item</i>	<i>actual</i>	<i>estimated</i>
project preparation	\$ 2,000	\$ 2,000
workshop instruction	\$ 2,165	\$ 2,000
labor	\$ 6,900	\$ 5,000
course materials	\$ 172	\$ 200
course meals	\$ 890	\$ 800
parts	\$ 4,425	\$ 2,500
tools	\$ 1,578	\$ 1,000
supplies	\$ 672	\$ 500
fuel & oil	\$ 161	\$ 7,000 ¹
photography & documentation	\$ 600	\$ 1,000
board supervision & direction	\$ 500	\$ 500
public demonstrations & displays	\$ 500	\$ 500
final report & distribution	\$ 1,000	\$ 2,000
<i>totals</i>	\$ 21,563	\$ 25,000

Income

<i>item</i>	<i>actual</i>	<i>estimated</i>
4Culture Heritage Special Projects Support	\$ 7,000	\$ 10,000
Foundation Support	\$ 5,000	\$ 5,000
Corporate Support	\$ 5,500	\$ 7,800
NWS staff time	\$ 1,863	\$ -
Course Tuition	\$ 800	\$ 1,600
Tuition Support (in-kind donation)	\$ 800	\$ -
Board supervision (in-kind donation)	\$ 500	\$ 500
Final Banquet (in-kind donation)	\$ 100	\$ 100
<i>totals</i>	\$ 21,563	\$ 25,000

surplus/deficit \$ - \$ -

¹ NWS did not make a substantial fuel purchase as part of the 2009 Diesel Engine Theory Workshop as the *Arthur Foss's* fuel tanks need additional preparation work before we can take delivery. Preparation of fuel tanks was not included in this program.

Schedule

Session 1

Meet on the *Arthur Foss* at Lake Union Park

0830	Coffee pot on
0900	Introductions, tour of the <i>Arthur Foss</i>
1000	Run engine
1200	Lunch
1300	Diesel Engine Theory lecture by Dan Grinstead
1400	Disassemble cylinder #4
1645	Clean-up and debrief
1700	Class ends

Session 2

Meet at OTM Inc shop in Ballard

0830	Carpools to Ballard leave the <i>Arthur Foss</i>
0900	Clean, paint, and inspect disassembled engine parts
1130	Carpool back to <i>Arthur Foss</i>
1200	Lunch
1300	Continue cleaning, painting, and inspecting engine parts aboard the <i>Arthur</i>
1645	Clean-up and debrief
1700	Class ends

Session 3

Meet on the *Arthur Foss* at Lake Union Park

0830	Coffee pot on
0900	Inspect parts, begin fitting into engine
1200	Lunch
1300	Reinstall parts on engine, set up bearings
1645	Clean-up and debrief
1700	Class ends

Session 4

Meet on the *Arthur Foss* at Lake Union Park

0830	Coffee pot on
0900	Finish reassembling engine, lead piston, shim rods, check bearing clearance
1200	Lunch
1300	Install and begin timing valves
1645	Clean-up and debrief
1700	Session ends

Session 5

Meet on the *Arthur Foss* at Lake Union Park

0830	Coffee pot on
0900	Finish timing engine
1100	Snack
1130	Operate engine
1430	Clean-up and debrief
1500	Celebratory banquet
1700	Session ends