Thermodynamics on the S.S. John W. Brown

Aaliyah St. Jules, Jasmine Patel, Sean Beahn and Daniel Roland

Towson University, Towson, Maryland

Fig. 1: Sean, Daniel, Aaliyah and Dr. Overduin in front of the S.S. John W. Brown at Pier 13 in Baltimore Harbor

Introduction

The S.S. John W. Brown is one of the last two Liberty Ships remaining from World War II. Her 20 foot-high reciprocating steam engine still operates and is used today mostly for educational purposes. (Her twin sister, the S.S. Jeremiah O'Brien in San Francisco, was used to film the engine room scenes in the 1997 Hollywood movie *Titanic*). We partnered with three of the ship's engineers, Greg Mucci, Paul Cervenka and Dave Algert, to study several engines on the ship. We learned how old-time engineers assessed the health of their ships' engines using steam indicators, and we reproduced those results using modern equipment.

Method

The basic tool is a Pressure-Volume (PV) diagram which plots pressure versus volume inside the engine cylinder. As the piston moves through a complete cycle, it traces out a closed contour on this diagram, and the area inside this shape (which we would today call the integral of the curve) gives the work done by the piston. Dividing by the time per cycle gives the engine's power. Mathematically, taking units into account, these details are captured in a formula known as "PLAN," in which P is pressure, L is the length (or stroke) of the piston, A is its area (equal to $\pi b^2/4$ where b is the piston diameter or bore), and N is the number of strokes per cycle. Taking units into account, the formula reads

$$\text{Power (hp)} = \frac{P\left(\frac{\text{lbs}}{\text{in}^2}\right) \times L(\text{ft}) \times A(\text{in}^2) \times N\left(\frac{\text{strokes}}{\text{min}}\right)}{33{,}000\ (\text{ft}\cdot\text{lbs/min})/\text{hp}}$$

Fig. 2 shows a PV diagram for all three cylinders of the triple-expansion engine that powers the S.S. John W. Brown, together producing 2500 hp at 76 rpm.

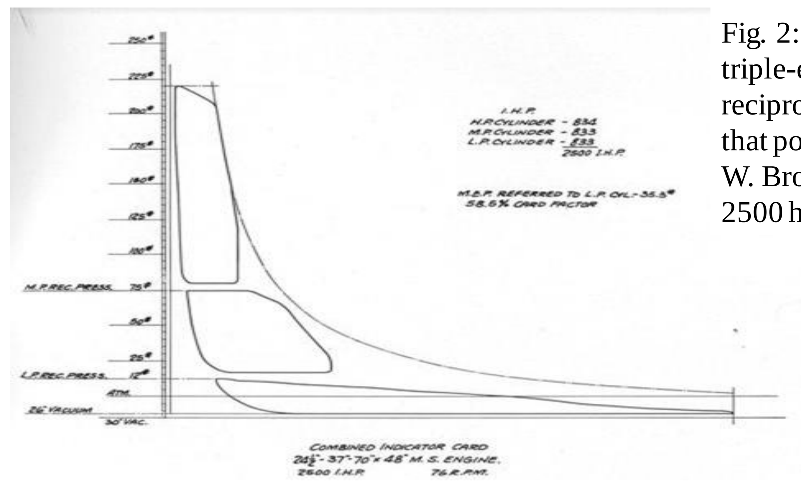


Fig. 2: PV diagram for the triple-expansion reciprocating steam engine that powers the S.S. John W. Brown and produces 2500 hp at 76 rpm

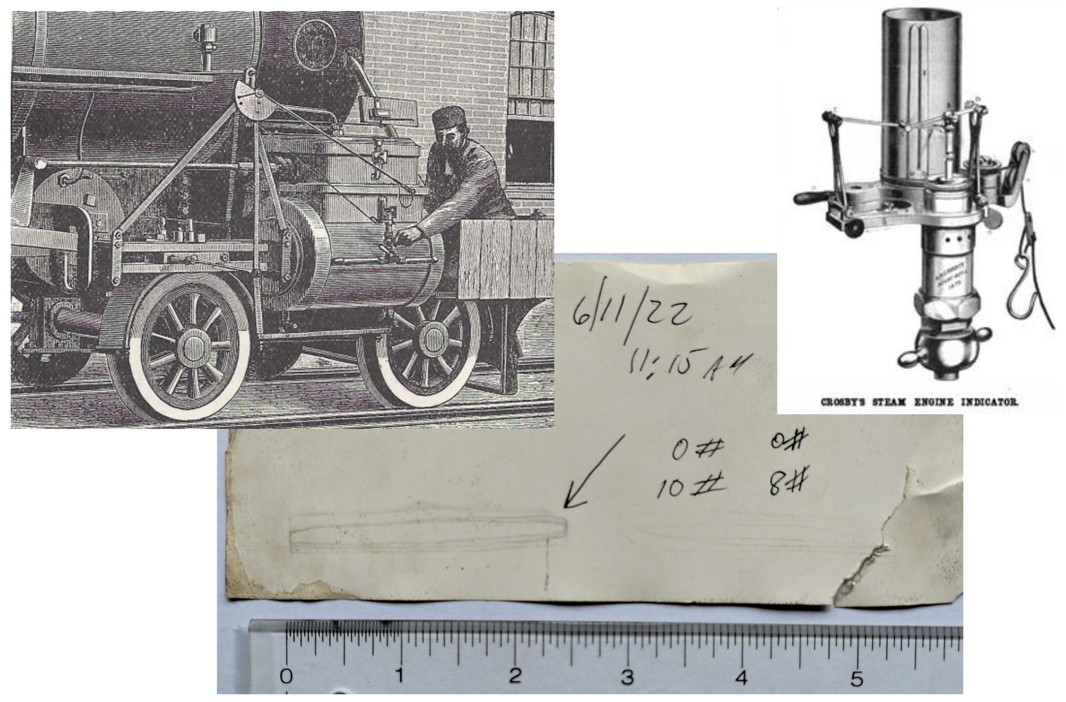


Fig. 3: A railway engineer (top left) measuring pressure and piston displacement simultaneously using a steam engine indicator (top right), an analog device with a stylus that mechanically traces out a PV diagram (or "indicator card"). We used one of these devices to produce the indicator card shown for the Deane water pump aboard the ship.

Historical Steam Indicator

Pressure P can be measured by fitting a pressure gauge to the cylinder (in old days, this would raise a weight, enabling engineers to "weigh" the pressure). A is a known quantity, and N can be measured by plotting pressure vs. time and counting the strokes. The hard part is to measure displacement L. This typically involves attaching a string to some arm or shaft that tracks the moving piston and measuring the motion of the string back and forth.

We used an old-fashioned analog device known as a steam engine indicator to do this for a small engine (Deane water pump) aboard the ship, producing the PV diagram (or "indicator card") shown in Fig. 3. We measured $P = 8$ lbs/in^2 and counted14.5 back-and-forths in 11 s, so $N = 158$ strokes/min (since work is done both ways). With a stroke $L = 4$ in and bore $b = 4.5$ in, the PLAN formula gave the power of this pump as 0.20 hp.

Modern Equipment

We next learned how to replicate these results using modern laboratory sensors with a laptop and PASCO interface. Our pressure sensor reads out in volts, so we had to calibrate it using weights with known pressures, producing the plot in Fig. 4. From this data we determined a scale factor of 29.8 lbs/in^2 per volt.

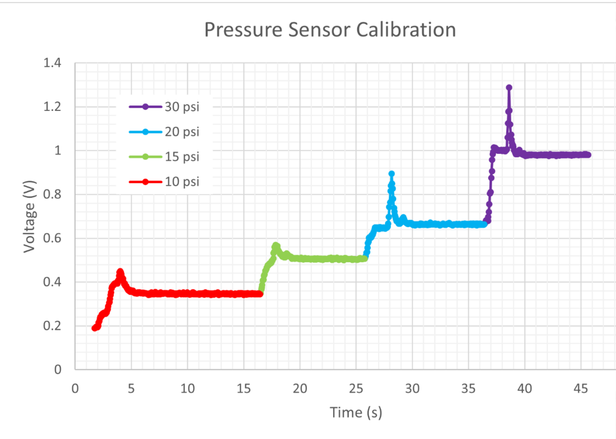


Fig. 4: Aaliyah and Sean (right) producing the calibration plot at left. The circular disks at far right are weights that apply a known pressure to the sensor, which then reads out in volts.

Fig. 5: Jasmine, Aaliyah and Sean using the rotary motion sensor to measure piston displacement in the Deane water pump (schematic at right). A string passes from the pump around the sensor flywheel and is then anchored to the floor using one of Aaliyah's hairbands.

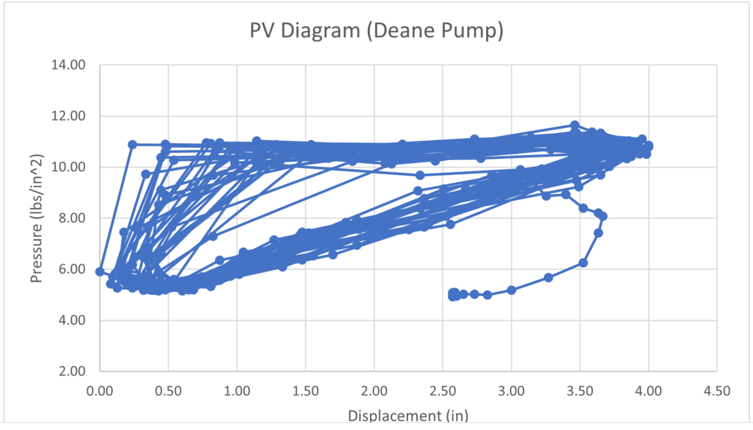
We measured displacement using a rotary motion sensor (Fig. 5). It required some ingenuity to figure out how to tie one end of a string to a shaft connected to the piston, pass the string around the sensor wheel, and then anchor it. To convert from sensor readout (in rad) to linear position (inches) we noted the maximum and minimum angles reached by the sensor wheel and equated the difference between them to the stroke.

Deane Pump

In this way, we were able to measure voltage and angle for the Deane pump using PASCO Capstone software, export the data to Excel, and convert to pressure and displacement in Excel using our scale factors. This resulted in the PV diagram shown in Fig. 6 (top), with $P = 8.02$ lbs/in^2. We plotted pressure versus time to determine the frequency, finding $N = 129$ strokes/min (Fig. 6, bottom). With L and A the same as before, the PLAN formula then gave us a power of 0.166 hp, in good agreement with the indicator card.

Yacht Tender

Finally, we applied what we had learned to a yacht tender, a compound steam engine in which steam first drives a small high-pressure (HP) cylinder and then a larger low-pressure (LP) cylinder (Fig. 7). Again we used our calibrated pressure



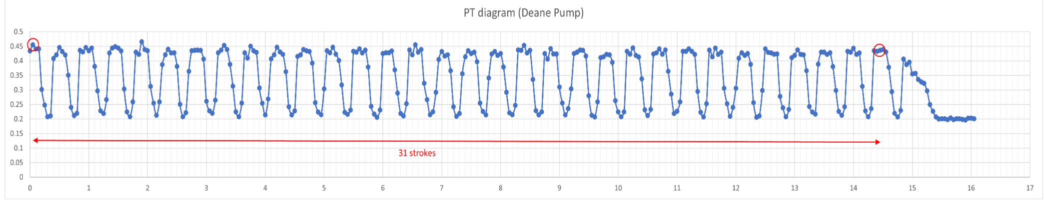


Fig. 6: PV diagram for the Deane pump (top) with P vs time plotted (bottom) in order to find N, the number of strokes per minute

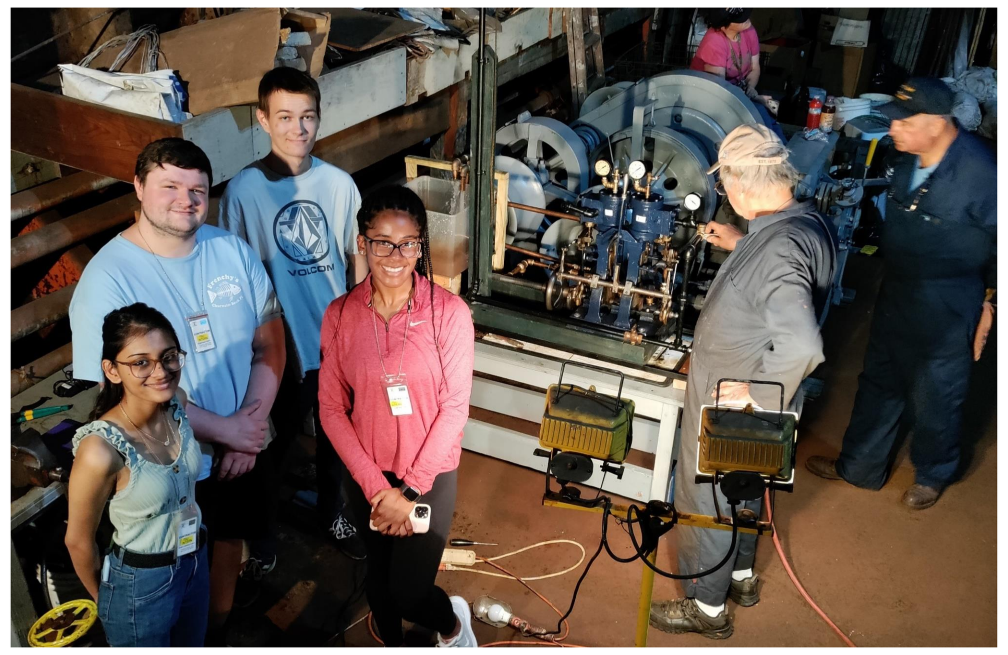


Fig. 7: Jasmine, Sean, Daniel and Aaliyah(left) in front of the yacht tender, a steam-powered ship engine with a propeller driven by two cylinders, both of which we measured using our PASCO equipment.

sensor to find P and the rotary motion sensor to measure displacement, this time running the string over a pulley suspended from a beam held above the engine by a pair of ladders. Our resulting PV diagrams are shown in Fig. 8.

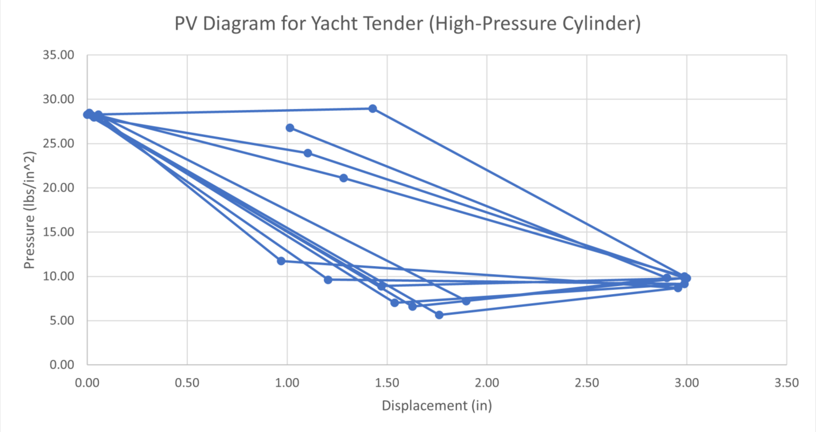
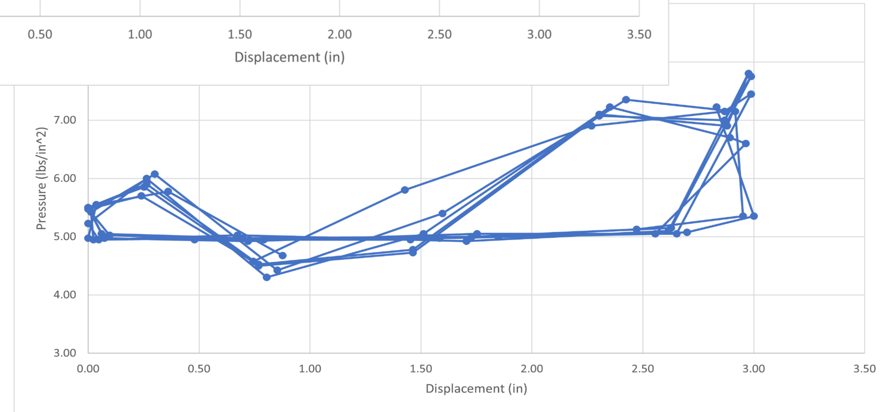


Fig. 8: PV diagrams for the HP (top left) and LP (bottom right) cylinders of the yacht tender



For the HP cylinder, we found $P = 27.8$ lbs/in^2, $L = 0.25$ ft, $A = 1.77$ in^2, $N = 313$ strokes/min, so power = 0.12 hp. For the LP cylinder, L was the same but $P = 4.17$ lbs/in^2, $A = 7.07$ in^2, and $N = 131$ strokes/min, so power = 0.03 hp.

Discussion

Beyond the numbers, we learned how these diagrams help engineers assess the health of their engines, much as an X-ray allows a doctor to diagnose a patient. The PV diagram for the LP cylinder in Fig. 8 is seriously "ill," with pressure diving precipitously in the middle of the cycle, perhaps due to a stuck valve. This would not have been apparent from looking at the engine itself.

Acknowledgments

We thank Greg Mucci, Paul Cervenka, Dave Algert and all the other engineers and volunteers on the S.S. John W. Brown for generously sharing their time and knowledge with us. This work was supported by the Fisher College of Science and Mathematics and BTU programs at Towson University and the Maryland Space Grant Consortium.