

**MARITIME PHYSICS: DEVELOPING INTERACTIVE  
TEACHING MATERIALS CONNECTING PHYSICAL  
LAWS AND PRINCIPALS WITH MARITIME  
APPLICATIONS**

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**Abstract** This paper presents preliminary results of an ongoing research project. We present working examples of Physics problems and classroom teaching presentations which are based on real life video clips of maritime activities and/or on routine activities performed by mariners navigating the ship. We discuss interdisciplinary connection between general education Physics and Mathematics courses and maritime subjects taken by maritime students.. We also present here a method of using video documentation of events in a maritime setting, and employing digital analysis of the video using inexpensive commercially available software called VideoPoint to obtain useful data. This data can be then successfully used by Physics instructors at Maritime universities in order to explain students the theoretical basis for motion demonstrated on the video and to produce their own maritime related activities for general Physics classrooms.

**Keywords** general education; physics; maritime applications; software; video analysis; digital

## **0 Introduction**

All Maritime Universities students, including California Maritime Academy (CMA thereafter) cadets, specializing in any kind of Engineering or in Marine Transportation are required to take at least 1 semester of college level Physics during their freshman year . This course is usually included in general education requirements and taught using standard College or Engineering Physics textbooks which rarely show applications of Physics relevant to professional occupations of future mariners. First year cadets have little appreciation of the relevance of mathematics and physics to the maritime profession. Students are exposed to the physics and mathematics concepts (for example vectors) during their first year of maritime education, but are usually not presented with examples of maritime applications of these concepts until at least the second year. Most students are not able to link the skills and knowledge they learn in physics class with professional

courses such as Radar, Navigation, Ship Stability, Static, Dynamics and various technical courses they will take later in their course of study. This lack of understanding of the importance of physical laws and principles to Maritime applications leads on the one hand to students' low interest and motivation in studying Physics and as result to a relatively unsatisfactory learning outcome; on the other hand the faculty members teaching maritime courses (where the level of students' motivation is usually much higher) have to spend time to review and often to teach again the knowledge and skills students are supposed to have after successful completion of their Physics course. The development of computerized teaching materials which use routine operations of ships to illustrate the concepts of general physics would help to establish the missing link between Physics as a general education course and professional maritime studies. These teaching materials can be used in teaching both Physics and various maritime courses.

## 1 Learning physics in context

Researchers in the field of education have been investigating students' difficulties with learning mathematics and physics for many years. Educational researches and successful practitioners have placed great importance on the teaching of these subjects in context by demonstrating their 'real world' applications (see for example, Mazur<sup>[1]</sup>, Lye, et al.<sup>[2]</sup>). Students' understanding of mathematics and physics is enhanced when they see the applicability of what they are learning. Putnum<sup>[3]</sup> wrote that "For them (*students*), an important part of what it means to understand mathematics is knowing how to use various mathematical tools to solve problems encountered in everyday life." The work of Roth and Roychouldhury<sup>[4]</sup> and of Stinner<sup>[5]</sup> showed "that appropriately designed contexts which attract students' interests have been shown to create great motivation to learn science." Wilkinson<sup>[6]</sup> wrote of the necessity "to place physics learning in real life contexts so students could learn that physics wasn't about Abstract concepts that had no place in their out-of-school lives, but that an understanding of physics led to an understanding of the way things work in real life." Hart<sup>[7]</sup> reported that "contexts were an important device for engaging and motivating students, communicating the relevance and purpose of physics, and increasing student enrolments in the subject." Rennie and Parker<sup>[8]</sup> wrote that "...physics needs to be practiced in contexts which enhance understanding through direct relevance to the real world." For our cadets, 'real world' and 'everyday life' is their future maritime environment.

Teaching in context and the descriptive use of real world applications are indispensable instructional tools that enable maritime students to better understand generic math and physics concepts. However, it is unlikely that the instructors of these subjects would have the necessary background to successfully create realistic example problems in math and physics that relate to the maritime field. Therefore, the authors of this paper would like to suggest some ideas and present general education instructors with sample problems with a maritime flavor that could be used in first year college physics courses. Our first example deals with the use of radar plotting to explain the concept of vector subtraction.

## 2 Use of navigation and radar topics in teaching relative motion and vector manipulations

Most college level physics and mathematics textbooks devote many pages to the subject of vector addition and multiplication. Both graphical and analytical methods of vector manipulation are usually presented to the student with sufficient numbers of example problems drawn from real-life situations. Typical problems demonstrating vector addition or multiplication deal with simple summation of displacement vectors, finding the resulting force on an object given the magnitude and direction of several independent forces acting on the object simultaneously, finding the torque on a rotating shaft, determining the force on a charge moving through a magnetic field, etc. The understanding of vector addition and multiplication is greatly enhanced by these and other examples of using physics to describe the world around us. For maritime students many ‘real life’ examples of vector manipulations can be found in Radar and Navigation classes. For example Fig. 1 shows vector diagrams used to determine resultant course and speed made good when a vessel is affected by a known current.

In teaching of general physics courses vector subtraction is usually dismissed by converting the problem into vector addition, i.e., simply stating that vector **A** minus vector **B** is the equivalent of vector **A** plus the opposite of vector **B** [ $A - B = A + (-) B$ ]. No attempt is usually made to provide examples of practical applications of the vector subtraction concept and as result students routinely do not understand the idea behind this concept. However, to convey the meaning of relative motion or relative wind in Radar and Navigation classes, students’ understanding of vector subtraction is required. Maritime students can become easily confused and frustrated when they fail to intuitively grasp the meaning behind the math or physics concepts. In his essay “Introducing Vectors” John Roche<sup>[9]</sup>, a physics professor at Linacre College, Oxford, England pointed out what ‘A common complaint about physics is that we do not explain why we are introducing certain concepts: we simply introduce them mathematically, without any justification.’ Unfortunately, the above description is often true when applied to the presentation of the vitally important to a maritime officer concept of relative motion in general physics courses.

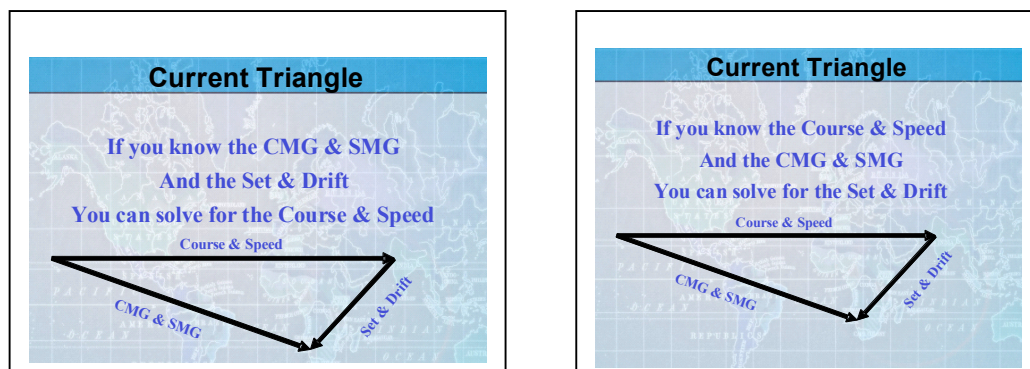


Fig. 1 Vectors addition and subtraction in form of ‘Current Triangle’ from Navigation course.

The proper understanding and analysis of the relative motion between two ships is the foundation of effective collision avoidance. While nearly everyone instinctively uses their sense of relative motion in everyday life to avoid collisions with common objects, other pedestrians, automobiles,

etc., the determination of relative motion between two ships at sea, particularly when observed on a radar screen, is not nearly as intuitive. The somewhat elaborate and cumbersome methods of manual plotting, developed over the last half century by radar schools throughout the world, provide the mariner with effective tools to avoid collisions with other vessels. However, these methods rely on rote memorization of steps to be followed in conducting what is essentially the vector analysis of an encounter by one or more vessels. For students who need to have a more complete understanding of what they are doing before they can do it effectively, the traditional teaching methods of manual plotting may prove to be inadequate. First time failure rates of between 10 - 50% have been observed for radar students at the California Maritime Academy over the last five years. Greater success in the radar course may be obtained by the introduction and more thorough explanation of vector subtraction in a first year physics course.

So how can we ensure that relative motion concepts are effectively introduced through an enhanced study of vector subtraction in freshman physics? The first step is to make certain that the student completely understands vector addition. Once the student has a grasp of the graphical method of vector addition, it is easier to explain the related concept of vector subtraction. The standard explanation of vector addition follows the **triangle rule** as shown on Fig. 1. The triangle rule is perfectly adequate for explaining vector addition. Problems involving set and drift calculations taken from primary navigation courses in piloting provide students with practical examples of the importance of vector addition to the mariner. However, if we wish to give our maritime students a better understanding of vector subtraction and relative motion, the **parallelogram rule** (Fig. 2) for vector addition is more suitable.

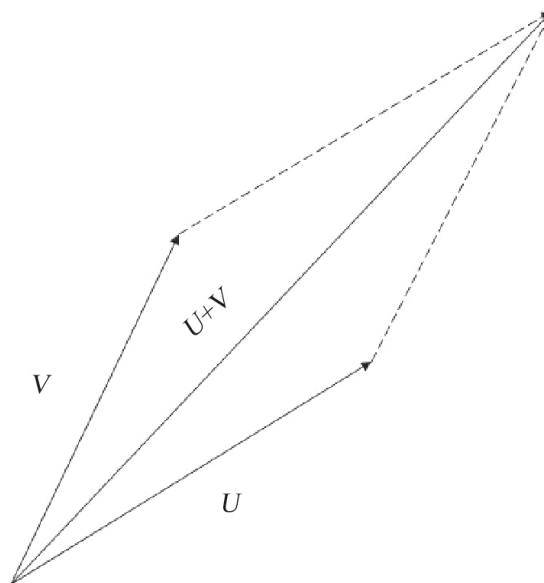


Fig. 2 Parallelogram rule for adding vectors  $U$  and  $V$

With the parallelogram rule, the student can see at a glance the relationship of vector addition to vector subtraction. The large diagonal of the parallelogram represents the addition of the associated vectors forming the sides, and the small diagonal represents the subtraction of the same two vectors (Fig. 3). The direction of the difference vector of course depends on whether we wish to find  $V - U$  or  $U - V$ .

After the student learns how to manipulate vectors confidently, we can then begin the discussion of the phenomena of relative motion between objects and how this is mathematically explained by vector subtraction. It can then be shown that the direction of the difference vector, i.e. the direction of relative motion, depends on which of the original vectors represents the subtrahend and which the minuend. The vector representing the subtrahend also represents the true course and speed vector of own ship in a radar plotting problem. The vector representing the minuend is then the true course and speed vector of the other vessel. In the standard radar plotting problem, the difference vector (relative motion) and the subtrahend vector (own ship true course and speed) are given and the minuend vector (other vessel true course and speed) is the unknown for which to be solved.

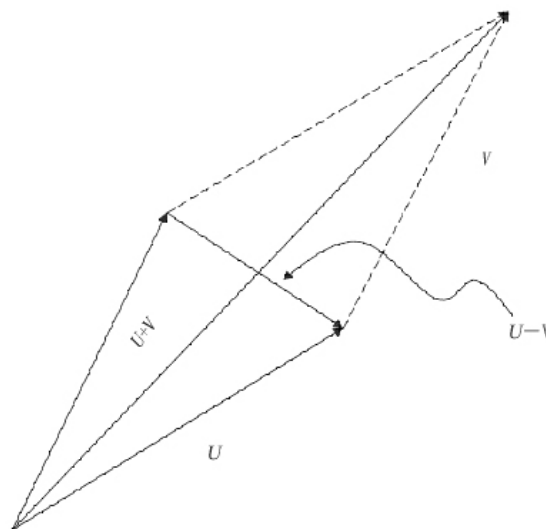


Fig. 3 Parallelogram rule showing the relation of addition and vector subtraction

So what type of motion information is actually presented on a relative motion radar screen? Pseudo-motion that can be described by vector subtraction and represents the difference between the motions of the ship and any other object shown on the screen. And so, the relative motion radar display can be said to provide a graphical, practical, and indeed vital example of the concept of vector subtraction.

### 3 Physics in ship stability course

The previous section described in detail one topic where Physics and Radar course are closely overlap. This interdisciplinary overlap can and must be used in teaching of general Physics courses at Maritime Universities and Academies. In this section we present in Table 1 a preliminary list of Physics and Ship Stability courses topics which are closely related. The marine applications are taken from the Stability and Trim for the Ship's Officer<sup>[10]</sup> textbook used in teaching of NAU 205 Ship Stability course at CMA.

Table 1 Overlapping topics in General Physics and Ship Stability courses.

Physics Topics	Ship Stability Topics
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Vectors, relative motion:	
a. vector addition graphically	effect to the center of gravity of the vessel by cargo movements (load, discharge, shift)
b. vector addition by component vectors	indirect determination of the Righting Moment: $GZ = GM \times \sin$ (Angle of Inclination)
c. vector addition for relative motion	value of the righting arm (GZ) at large angles of inclination
1 and 2 dimensional kinematics:	
a. velocity vectors b. acceleration vectors c. displacement vectors	moment to trim 1 inch of a vessel at a given waterplane
Newton's laws of motion:	
a. static forces	bending moments and shearing
b. conservative forces c. non-conservative forces d. friction	the position of the center of buoyancy at various small angles of inclination
e. normal force f. tension	hull strength (hog and stress numerals), strength of materials
Equilibrium, Energy, conservative and non-conservative forces	vessel equilibrium (positive, negative, neutral)
Rotational Kinematics	angular acceleration due to rolling and resultant racking stresses
Rotational Dynamics:	
a. Torque b. levers c. angular momentum d. moment of inertia	transverse and longitudinal stability about the longitudinal axis, transverse axis, vertical axis; free surface effects
Archimedes Principle	displacement of the vessel in salt/fresh water; specific gravity effects, change of salinity

## 4 Digital video analysis in teaching maritime physics

### 4.1 Software and limitations

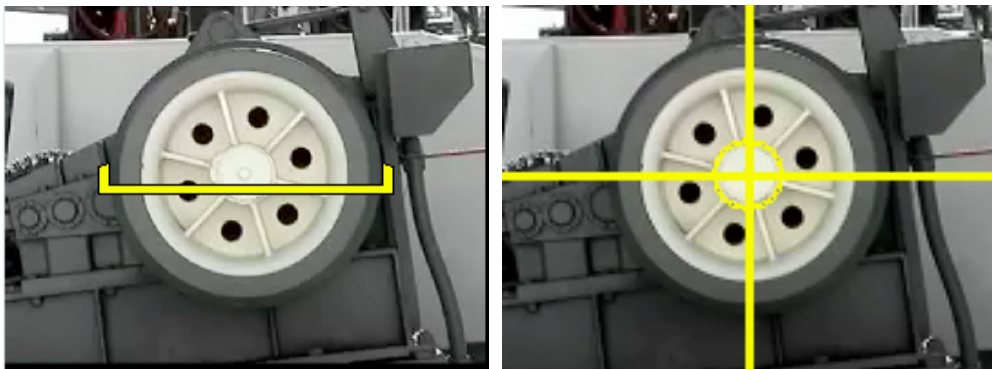
After extensive research and comparison, we found and purchased an inexpensive commercially available video analysis software package called **VideoPoint** Physics Fundamentals, Version 1.0.0 Copyright 2005 Lenox Softworks, Inc. designed to teach the fundamental laws of physics using video analysis. The software uses a video analysis process in which position and time data are collected from digital videos. The practical use of this way of video analysis involves some limitations. The time base for video documentation is determined by the video camera frame rate. This time base is either 20 frames per second, when using inexpensive digital cameras, or 30 frames per second, when using more expensive equipment. This is adequate for many applications but is inadequate for applications such as electric motors running at 3600 rpm. Such a speed would yield 60 revolutions per second. Even at shutter speeds of 30 frames per second, there would be 2 revolutions during each frame.

Other limitations include a stationary frame of reference. At sea, the motion of the vessel is continually changing, and the movement of the activity that is being observed, such as use of a block and tackle, would be affected by the motion of the reference frame. However, if the video is

of short duration, these affects can be minimized.

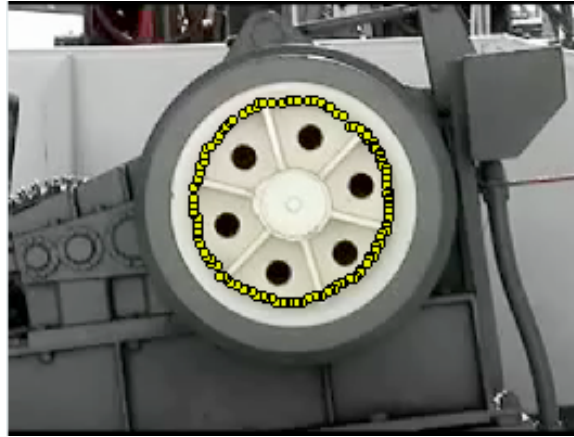
#### 4.2 Digital analysis procedure and example of rotating winch on the ship

- (1) Several seconds or minutes of an action are filmed with the camera mounted on a tripod. The tripod is necessary to maintain a stationary frame of reference. The action that is being filmed must fit within the frame of view because the camera should not be moved during the action.
- (2) The video camera is then connected to a computer. S-video connection is preferred. If the computer does not have connections, an interface may be required. We used a SIIG AVTuner-PVR to connect the S-video port of the camera to a USB port on the computer.
- (3) Different manufacturers use various codes for the digital video signal. VideoPoint Physics Fundamentals requires videos to be in the Sony QuickTime format (files with extensions .mov). Some conversion programs such as the AVTuner that we used, employs the mpeg format.
- (4) A program to convert the mpeg or wmv to mov is often required.
- (5) We used ConvertMovie 4.1 by Movavi to convert between file types.
- (6) Analysis software required video in the Quicktime movie format (mov)
- (7) Once the camera is connected to the computer, the program VideoPoint Capture by Lenox Software Inc. is used to review the video and capture the segment of the video that is going to be used for analysis. Video files are quite large and it is useful to keep the segment of film for analysis very brief. Typically a five-second video is sufficient. This length will provide 150 frames. This will yield 150 data pairs in 2-dimensional analysis
- (8) Once the video segment is captured ( in Quicktime format) it is opened in the VIdoPoint analysis software. The steps for analysis are;
  - a. preview
  - b. Calibrate-This is where the frame of reference is established. For example an x,y coordinate system centered at a particular point on the frame.



- c. Set up for analysis- reference frame can be rotating, time base can be set to zero.
- d. Analysis- a point is traced as it moves through 2-dimensional space.



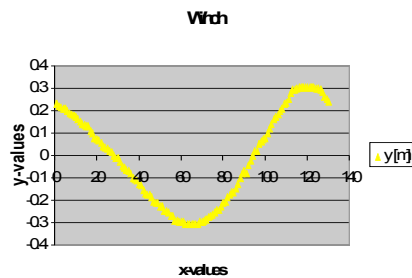


e. Data collection- at this point the data from the 2-dimensional analysis can be saved, analyzed with the software in VideoPoint Physics, or exported to an Excel file for analysis.

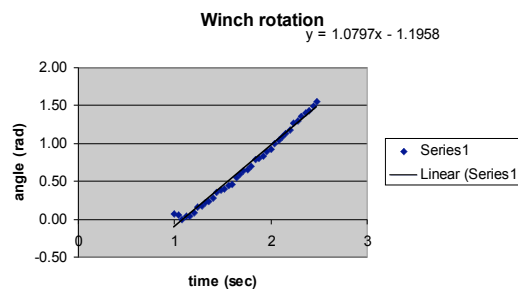
From the data set given we can do a large amount of analysis. First, we may look at the raw data plot of x,y. We know that a plot of a point on a rotating circle will provide a sine wave. Here we see such a plot and the resulting sine wave.

Table 2 Raw data collected from digital analysis of rotating winch

Frame	Time (s)	x (m)	y (m)	Frame	Time (s)	x (m)	y (m)
1	0	0.202	0.2323	26	1	0.303	0.0202
2	0.04	0.207	0.2222	27	1.04	0.303	0.0151
3	0.08	0.2121	0.2171	28	1.08	0.303	0
4	0.12	0.2222	0.2121	29	1.12	0.308	-0.0101
5	0.16	0.2272	0.2121	30	1.16	0.303	-0.0101
6	0.2	0.2272	0.202	31	1.2	0.303	-0.0252
7	0.24	0.2424	0.1919	32	1.24	0.2929	-0.0454
8	0.28	0.2474	0.1818	33	1.28	0.2929	-0.0505
9	0.32	0.2525	0.1767	34	1.32	0.2878	-0.0656
10	0.36	0.2525	0.1717	35	1.36	0.2878	-0.0707
11	0.4	0.2525	0.1616	36	1.4	0.2828	-0.0808
12	0.44	0.2626	0.1515	37	1.44	0.2727	-0.101
13	0.48	0.2676	0.1414	38	1.48	0.2676	-0.106
14	0.52	0.2676	0.1363	39	1.52	0.2676	-0.1111
15	0.56	0.2727	0.1313	40	1.56	0.2626	-0.1262
16	0.6	0.2727	0.1313	41	1.6	0.2626	-0.1313
17	0.64	0.2828	0.1111	42	1.64	0.2525	-0.1515
18	0.68	0.2878	0.101	43	1.68	0.2474	-0.1666
19	0.72	0.2929	0.0808	44	1.72	0.2323	-0.1717
20	0.76	0.2929	0.0757	45	1.76	0.2272	-0.1717
21	0.8	0.2929	0.0707	46	1.8	0.2222	-0.1868
22	0.84	0.303	0.0555	47	1.84	0.207	-0.207
23	0.88	0.303	0.0404	48	1.88	0.202	-0.2121
24	0.92	0.303	0.0353	49	1.92	0.1919	-0.2121



A plot of the position of a point on the winch vs time



A plot of the angle of the winch vs time. The slope of the curve is the velocity which is 1.08 rad/s.

Other analyses that have been done include, angular rotation of small craft about long axis, the trajectory of a heaving line, and the use of a block and tackle.

### 4.3 Student problems based upon rotational dynamics

After the students have observed the video clip and the analysis including data capture, a number of similar questions can be posed for the student to answer based on the scenario.

As you see in the video, Peter started the winch. We observed that after 4.0 seconds, the winch was moving with an angular velocity of 2.0 rotations/s.

(a) Find the angular velocity in radius/s.

$$2 \text{ rotations/s} = 2 \cdot 2 \pi \text{ rad/s} = 4 \pi \text{ rad/s} = 12.56 \text{ rad/s}$$

(b) Find the angular acceleration (i) in radian/s<sup>2</sup> (ii) rotations/s<sup>2</sup>

$$(i) a = \frac{w-w_0}{t} = \frac{12.56 \text{ rad/s}}{4.0 \text{ s}} = 3.14 \text{ rad/s}^2$$

$$(ii) (3.14 \text{ rad/s}^2) (1 \text{ rot}/2 \pi \text{ rad/s}) = 0.5 \text{ rot/s}^2$$

(c) The winch needs to be stopped. It took 2.0s for the winch to come to rest from the velocity of 12.56 rad/s or 2 rev/s. Find the deceleration presuming the winch was decelerating uniformly.

$$a = \frac{0 - 12.56 \text{ rad/s}}{2.0 \text{ s}} = -6.28 \text{ rad/s}^2, \text{ or } = \frac{-1 \text{ rot}}{\text{s}^2}$$

(d) If the moment of inertia of the winch was 100 kg • m<sup>2</sup>. Find the (i) accelerating torque (ii) decelerating torque.

Torque = (Moment of Inertia) (Angular acceleration)

$$(i) \text{ Torque (accelerating)} = (100 \text{ kg} \cdot \text{m}^2) (3.14 \text{ rad/s}^2) = 314 \text{ N} \cdot \text{m}$$

$$(ii) \text{ Torque (decelerating)} = (100 \text{ kg} \cdot \text{m}^2) (-6.28 \text{ rad/s}^2) = -628 \text{ N} \cdot \text{m}$$

(e) Suppose you wanted to stop this winch from the angular velocity of 20 rad/s in 0.5 seconds. What should be the magnitude of the decelerating torque?

$$T = (\text{Moment of Inertia}) (\text{deceleration})$$

But deceleration in this case =  $\frac{0 - 20 \text{ rad/s}}{0 - 5} = -40 \text{ rad/s}^2$

$$\text{Torque} = (-40 \text{ rad/s}^2) (100 \text{ kg} \cdot \text{m}^2) = -4,000 \text{ N} \cdot \text{m}.$$

(f) The winch is 2.0m in diameter. What tangential force is going to produce this 4,000 N • m. torque?

$$\text{Torque} = (\text{Radius}) (\text{Tangential force which is perpendicular to the radius})$$

$$4,000 \text{ N} \cdot \text{m} = (1 \text{ m}) (\text{Force})$$

$$\text{Force} = 4000 \text{ N}$$

(g) For simplicity, presume that the winch is a solid cylinder rotating about its axis and has mass of (100kg) and radius of 2.0m. Find the moment of inertia.

Moment of Inertia of a solid cylinder about its axis

$$\begin{aligned} &= \frac{1}{2} MR^2 = \frac{1}{2} (100 \text{ kg}) (2 \text{ m})^2 \\ &= 200 \text{ kg} \cdot \text{m}^2 \end{aligned}$$

(h) If the torque of 4000N • m. is acting for 1.5 seconds, how much angular displacement is produced during these 1.5 seconds.

$$\text{Angular acceleration} = \frac{\text{Torque}}{\text{Moment of Inertia}}$$

Moment of Inertia

$$a = \frac{4000 \text{ N} \cdot \text{m}}{200 \text{ kg} \cdot \text{m}^2} = 20 \text{ rad/s}^2$$

$$\theta = \text{Angular displacement} = \omega_0 t + \frac{1}{2} a \cdot t^2$$

where  $\omega_0$  is initial angular velocity and “a” is angular acceleration.

$$\begin{aligned} \theta &= \frac{1}{2} (20 \text{ rad/s}^2) (1.5 \text{ s})^2 \\ &= 22.5 \text{ rad.} \end{aligned}$$

(i) What is the final angular velocity ( $\omega$ ) in rad/s?

$$\omega = \omega_0 + a t$$

$$\omega = 0 + (20 \text{ rad/s}^2) (1.5 \text{ s}) = 30 \text{ rad/s}$$

(j) Why flywheel and winches are heavy at the rims.

Because moment of inertia (I) depends on the distribution of mass around the axis of rotation =  $I =$

$$\int r^2 \cdot dm$$

Heavier is the object around the rim, more will be the moment of inertia. (Cheaper to have more mass around the rim)

(k) What is the kinetic energy of the winch when it is moving with 30 rad/s?

$$k \cdot E = 1/2 I\omega^2 = (1/2) (200 \text{ kg} \cdot \text{m}^2) (30 \text{ rad/s})^2 \\ = 90000 \text{ J}$$

(l) What is the source of this increase in kinetic energy?

Work done by the torque increases the kinetic energy.

$$\text{Work done} = (\text{Torque}) (\text{Angular displacement}) \\ = \text{Change in } K \cdot E \\ (4000 \text{ N/m}) (22.5 \text{ rad}) = 90000 \text{ J}$$

Another scenario that we filmed was the use of a block and tackle.

The video was calibrated (Fig. 4), axes were established (Fig. 5), and digital analysis of the hand and the weight were performed (Fig. 6). These are summarized in the following images and tables.

Table 2 Raw Data from Block and Tackle

Frame	Time (s)	X (m)	Y (m)	Y (m)
1	0	0.1935	-1.3064	-0.3709
2	0.04	0.2016	-1.2822	-0.379
3	0.08	0.2096	-1.2741	-0.387
4	0.12	0.2096	-1.25	-0.387
5	0.16	0.2096	-1.2419	-0.387
6	0.2	0.2258	-1.2177	-0.4032
7	0.24	0.2258	-1.2096	-0.4032
8	0.28	0.2258	-1.1854	-0.4112
9	0.32	0.2258	-1.1854	-0.4112
10	0.36	0.2258	-1.1854	-0.4193
11	0.4	0.2338	-1.1854	-0.4193
12	0.44	0.2338	-1.1774	-0.4193
13	0.48	0.2419	-1.1612	-0.4354
14	0.52	0.2419	-1.1532	-0.4354
15	0.56	0.2419	-1.1451	-0.4435
16	0.6	0.2419	-1.1209	-0.4435
17	0.64	0.2419	-1.1209	-0.4516
18	0.68	0.258	-1.0967	-0.4516
19	0.72	0.2741	-1.0322	-0.4516
20	0.76	0.2903	-1	-0.4758
21	0.8	0.2983	-0.9919	-0.4758
22	0.84	0.2983	-0.9677	-0.4758
23	0.88	0.3064	-0.9516	-0.4838
24	0.92	0.3064	-0.9354	-0.4838
25	0.96	0.3225	-0.9193	-0.4838
26	1	0.3225	-0.9032	-0.4838

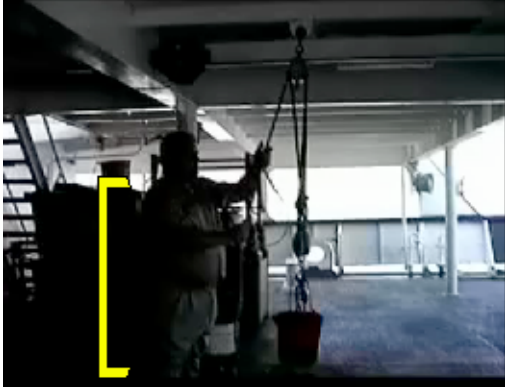


Fig. 4

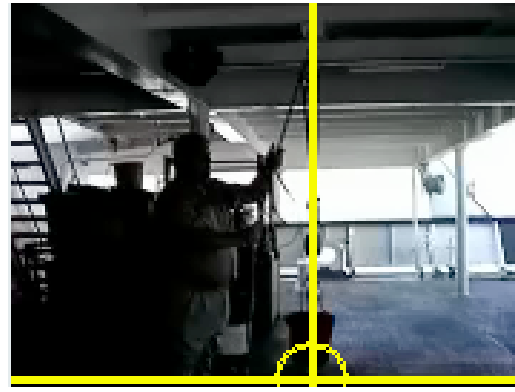


Fig. 5

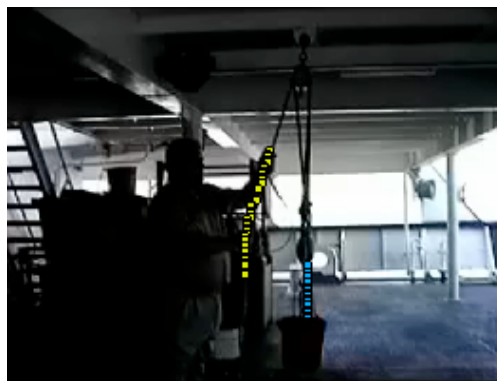


Fig. 6

## 5 Conclusion

We foresee developing a library of video clips of many maritime operations that can be analyzed with this software. The video clips and the raw data obtained from them would then serve as the basis for a set of student activities and questions. In this way, many of the concepts of first semester physics can be demonstrated to students with maritime examples.

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