ESTIMATING THE BURN RATE FROM THE BOOM CONFIGURATION

Kaufui Vincent Wong, Ph.D. and Rajnish Kashyap
Mechanical Engineering
University of Miami, Coral Gables, FL 33124.

Abstract

The burn rate of the oil is an important parameter in the Newfoundland Offshore Burn Experiment of August 12, 1993. The objective of the present work is to provide a physical basis for the method used in estimating this quantity. In the fluid mechanical analysis used in the present work, a curve was obtained that described the curved shape of the fire boom under tow. The areas covered by oil when it contacted different sections of the boom were calculated. It was seen that the fluid mechanical method developed here led to results that were within an acceptable range of error when compared to the results obtained by the basic planimetric method.

Nomenclature

a	Semi major axis
b	Semi minor axis
c-m	Coefficients
F	Force
s	Arc coordinate
T	Boom tension
x	Horizontal coordinate
y	Vertical coordinate
λ	dy/dx

Introduction

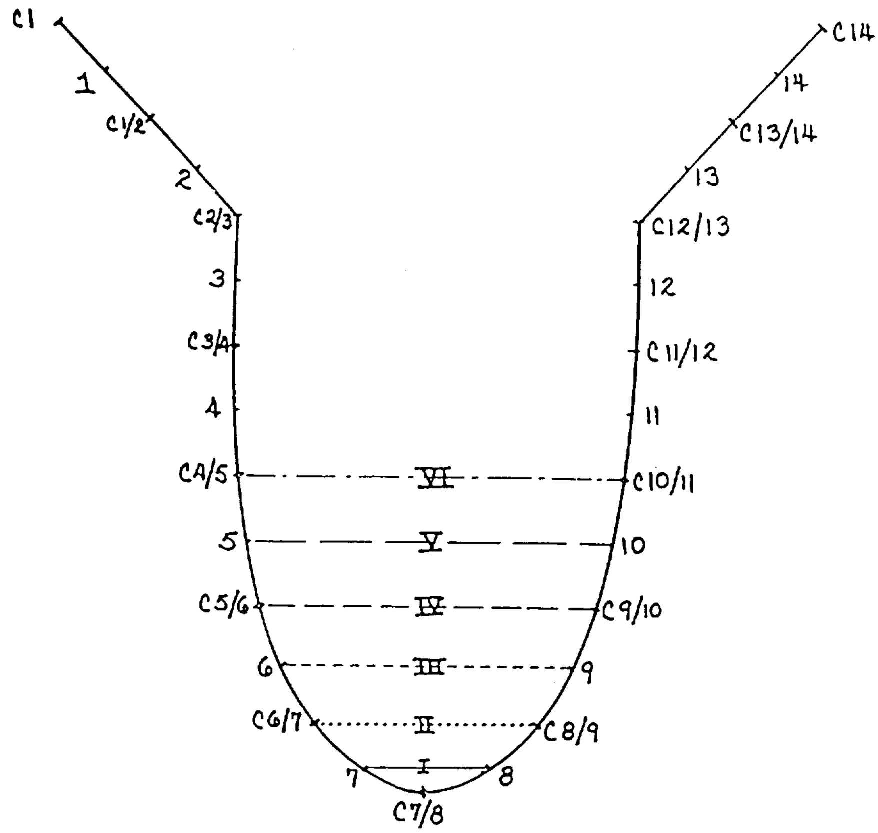
The Newfoundland Offshore Burn Experiment (NOBE) is an oil spill combustion test that took place on the Grand Banks at a location about 42 km (25 nmi) east of St. John's, Newfoundland. The place was chosen to minimize ecological damage and impact on the fishery industry. The first attempt to perform the NOBE was taken on August 7, 1993, but was scrapped at sea because fog rolled in after everything was set up. The NOBE was successfully carried out on August 12, 1993. Favorable weather was present that day.

Objective

The burn rate of the oil is an important parameter in the experiment. The aim of the present work is to provide the physical basis for the method used in estimating this quantity.

Environment Canada. Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, 17th Proceedings. Volume 2. June 8-10, 1994, Vancouver, British Columbia, Environment Canada, Ottawa, Ontario, 1313-1318 pp, 1994.

FIGURE 1. LAYOUT OF THE FIRE BOOM



Method

The method consisted of taking aerial photographs of the fire boom under tow when calm sea conditions prevailed. The shape of the fire boom was then determined, Figure 1, Allen (1993). The quantity of oil can be estimated by the sections of boom contacted. The burn rate is estimated by the rate of decrease in the number of boom sections contacted by the oil.

After the boom shape has been photographed (Allen, 1993), the area enclosed by different sections have to be calculated. The first and most obvious way is to find the area enclosed using planimetric methods. A second method is to fit a polynomial curve to the shape of the boom, and to calculate the area using integral calculus. A third method is to look at the physics of the flow around the boom, and to arrive at an equation describing the shape of the boom.

In the third method, one looks at the flow around the boom sections as they float on top of the water. The resultant current (induced or otherwise) is parallel to the straight portions of the boom. It is assumed that the component of the resultant force parallel to the current is uniform per unit length normal to the current. It is also assumed that the component of resultant force normal to the current is uniform per unit length parallel to the current. Under these conditions, it is shown in the present work that the shape of the boom is an ellipse.

The above assumptions are consistent with the flow mechanics. At the apex, the area over which drag acts is proportional to half the circumference, assuming that the boom is half submerged and neglecting the skirt. Going away from the apex, this area over which drag acts increases.

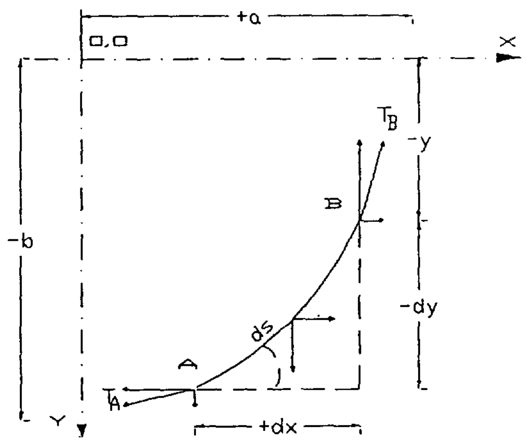


Figure 2 Forces acting on Boom Element

As stated above, the horizontal and vertical components of the resultant of external forces per unit area acting o<xthe boom are constant. Further the value of constant for the X-direction component is assumed to be a^2 and for Y-direction component to be b^2. With reference to Figure 2, the different boundary conditions are
for $x=0$,

$$y=-b,\ dx/ds=1,\ \text{and}\ dy/dx=dy/ds=0$$

and for $y=0$

$$x=+a,\ -dy/ds=1,\ \text{and}\ -dx/dy=dx/ds=0.$$

Now the equilibrium of forces in X-direction require that the sum of all forces acting on elemental length ds in X-direction be zero, that is:

$$\sum F_x = 0$$

which gives

$$d\left(T\frac{dx}{ds}\right) = a^2 dy \tag{1}$$

integrating the differential balance equation, we get

$$T\frac{dx}{ds} = a^2 y \tag{2}$$

Similarly for

$$\sum F_y = 0$$

we get

$$\frac{d}{dx}\left(T\frac{dy}{ds}\right) = -b^2 \tag{3}$$

which can be written as

$$\frac{d}{dx}\left(a^2 y\,\frac{dy}{dx}\right) = -b^2 \tag{4}$$

which on expanding gives

$$y\frac{d^2y}{dx^2} + \left(\frac{dy}{dx}\right)^2 + \frac{b^2}{a^2} = 0 \tag{5}$$

The above nonlinear differential equation is the basic governing equation for the shape of the boom under the aforementioned assumptions. This can be solved by assuming

$$dy/dx=\lambda$$

which reduces the above nonlinear equation to simple first order linear differential equation which can be readily solved as

$$y\lambda \frac{d\lambda}{dy} + \lambda^2 + \frac{b^2}{a^2} = 0 \tag{6}$$

$$\frac{dy}{dx} = \frac{b}{a}\left[\frac{\sqrt{(b^2 - y^2)}}{y}\right] \tag{7}$$

by substituting y=b.sinθ into the above equation we get

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{8}$$

which is an equation for ellipse. Hence we can say that with the aforementioned assumptions the boom will take the form of an ellipse, described by an ellipse with a=4 and b=8.

Table 1. Comparison of Areas by the 3 Different Methods

ZONE/ BOOM SECTION	AREA (FT^2) PLANIMETRIC	POLYNOMIAL	FLUID MECHANICAL
I	325	320	329
II	1,325	1,405	1,355
III	3,450	3,580	3,450
IV	6,200	6,097	5,858
V	9,450	9,304	8,918
VI	12,950	12,702	12,242

Results

The layout of the fire boom under tow is shown in Figure 1. This was obtained from Allen (1993). A polynomial curve fit was performed on this layout. The origin was chosen to be the apex, the x-axis as tangent to the apex, and the y-axis parallel to the straight parallel sections of the boom. With a ten degree polynomial fit, starting with x^0, the coefficients obtained were as follows:- c=-0.00133061, d=-0.0393106, e=0.391279, f=0.0205577, g=-0.0927551, h=-0.00402745, i=0.0212513, j=0.000261256, k=-0.00186054, l=-8.12660 x 10^{-6}, m=5.93165 x 10^{-5}. The sensitivity analysis showed that the change in fit ranged from an average of 1% to 9% in the coefficients c to m for a 1% change in x's and y's.

The results of the planimetric method, the polynomial curve-fit method, and the fluid mechanical method are presented in the table. These areas are computed so that the amount of oil can be estimated if the oil is occupying zones I, II, III of the boom and so on. The areas computed by the planimetric method is by Allen (1993), and verified for section IV, Allen(1993). The areas computed by the other two methods are results of the present work.

Discussion and Conclusion

The fluid mechanical method gives a basis for obtaining the shape of a boom in tow. Flow considerations on the boom gives a shape to the boom that ultimately provided an acceptable estimate of the area enclosed by different sections of the boom. This method of arriving at the shape of the boom under tow may be used to assist in estimating the burn rate of the oil.

References

Allen, A., "Personal Communications", 1993.