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ROLL, HEAVE AND VERTICAL ICHTHYOPLANKTON TOWS

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ABSTRACT

A simple model of ship's motion is described and used in the design of vertical ichthyoplanktons tows. The velocity of the net, as it is affected by roll, heave and retrieval rate, is plotted for the duration of the tow. After simulating various conditions the retrieval rate may be specified that minimizes extrusion of soft bodied organisms and is still sufficient to prevent stalling and back flushing of the net; the model may also be used to specify the sea state at which field operations should be suspended.

INTRODUCTION

The CalCOFI (California Cooperative Oceanic Fisheries Investigation) Vertical Egg Tow (CalVET) was designed to collect pelagic fish eggs occurring from 70 m depth to the surface. Design specifications included a 0.05 m^2 net aperture, 0.87 m^2 filtering surface and .333 mm nylon mesh net. Operational specifications dictated that the net be deployed at 70 m/min, allowed to rest at depth for 10 sec, and retrieved vertically at 70 m/min. (Figure 1).

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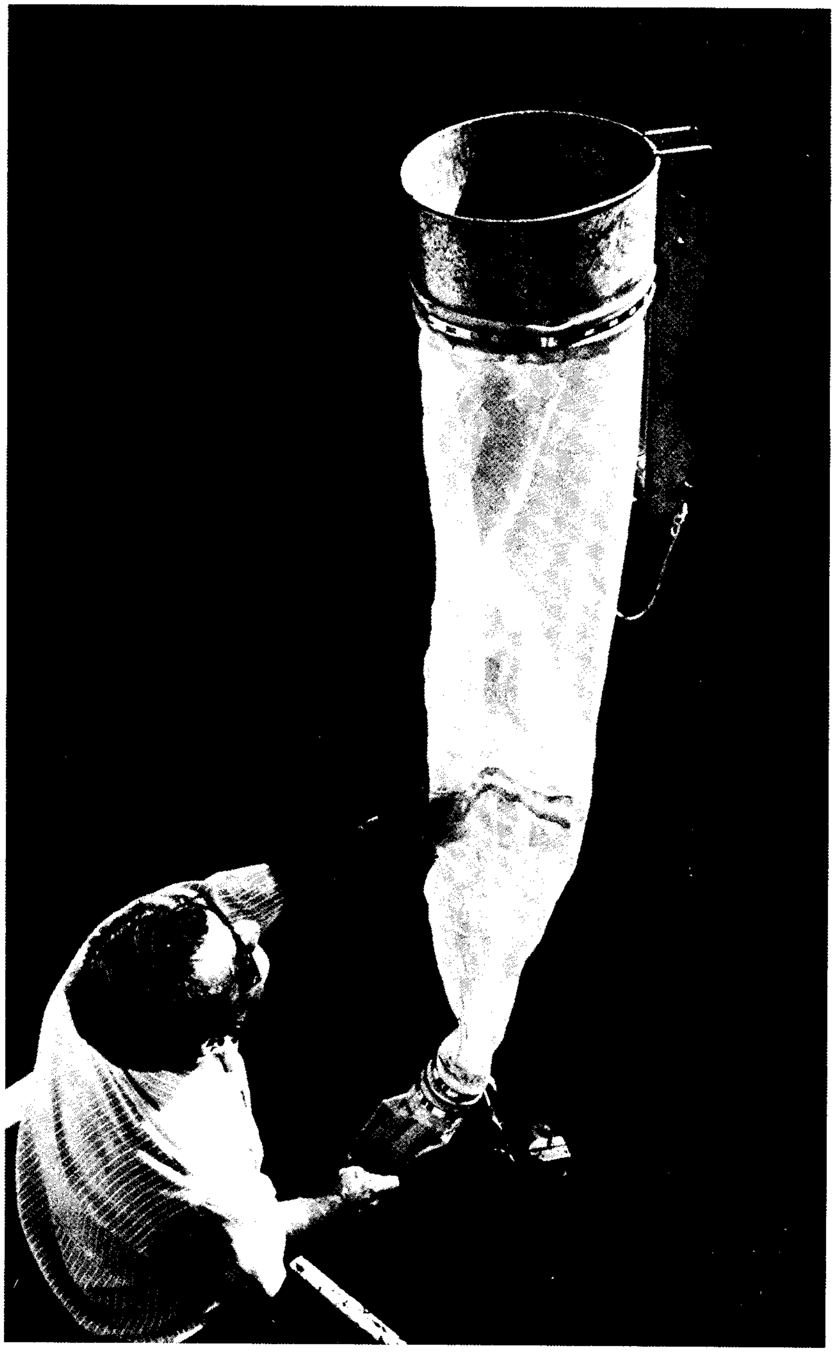


FIG. 1. The CalVET net is retrieved vertically from 70 m depth and is designed to sample pelagic marine fish eggs. Fish abundance is determined by relating egg production to adult fecundity.

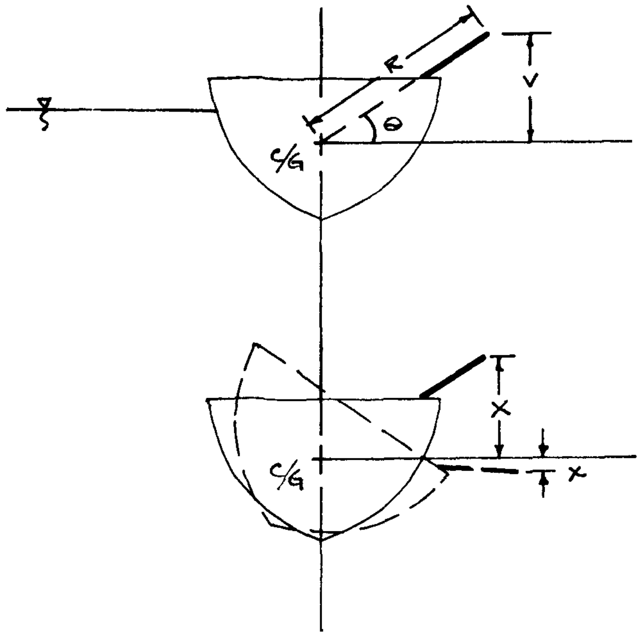
The retrieval rate specified was a compromise between the desire to minimize extrusion of soft bodied organisms through the meshes of the net and the necessity to overcome the downward velocity caused by the ships roll. As the ship rolls, in response to surface waves, the end of the winch boom traverses a vertical arc. If the downward velocity of the boom exceeds the upward velocity of the net frame then the net will collapse and its contents will be "pumped" out. The upward velocity of the end of the winch boom adds to the retrieval velocity and thus aggrevates the extrusion problem. To minimize losses caused by extrusion and pumping the retrieval rate should be just great enough to overcome stalling caused by the ship's roll.

The specified retrieval rate of 70 m/min was an initial estimate of the optimum rate. The present study refines the estimate of optimum retrieval rate by using an analytical description of ship's motion. Given the ships design characteristics and the sea state, the optimum retrieval rate is specified; a rate which will minimize the loss of material caused by extrusion and pumping.

MODEL

Roll

Ship's roll is a function of the design characteristics of the vessel, sea state and to a lesser extent the wave period. The roll period of the ship is a characteristic response to most surface waves and the half angle of the roll is an indicator of sea state. Ship's roll motion may be translated into vertical motion of the net by knowing the relationship of the end of the winch boom to the ship's center of gravity. These terms are related in the figure below:



where R = radial distance from center of gravity (C/G) to the end of the winch boom,

V = vertical distance from C/G to end of boom at its resting position,

θ = angle from the horizontal, C/G to end of boom,

X = variable = vertical position of the end of the boom where up is positive and down is negative.

The motion of the ship may be described by letting

A = half angle of ship's roll,

P = period of ship's roll,

t = variable = time.

A time dependent description of the ship's angular motion (y) is thus:

$$y = A \, \mathrm{Sin} \left(\frac{2\pi t}{P}\right).$$

So that the vertical position of the end of the boom (X) relative to C/G is:

$$X = R \, \mathrm{Sin} \, (\theta + y)$$

$$X = R \, \mathrm{Sin} \, \left(\mathrm{Arcsin} \, (V/R) + A \, \mathrm{Sin} \left(\frac{2\pi t}{P}\right)\right).$$

and the velocity of the end of the boom is:

$$\frac{dX}{dt} = R(A)\left(\frac{2\pi}{P}\right)\mathrm{Cos}\left(\frac{2\pi t}{P}\right)\mathrm{Cos} \, \left(\mathrm{Arcsin} \, (V/R) + A \, \mathrm{Sin}\left(\frac{2\pi t}{P}\right)\right).$$

Heave

Heave of the ship is defined as the vertical motion experienced by a vessel as a wave passes under the hull. Ocean swell may be represented simply as a Sin wave:

$$X_w = \frac{H}{2} \, \mathrm{Sin} \left(\frac{2\pi t}{P_w}\right)$$

where

X_w = vertical displacement (heave) of the ship,

H = height of the swell (trough to peak),

P_w = period of the swell (peak to peak).

Vertical velocity due to heave is:

$$\frac{dX_w}{dt} = \frac{H\pi}{P_w} \; \mathrm{Cos} \left(\frac{2\pi t}{P_w}\right)$$

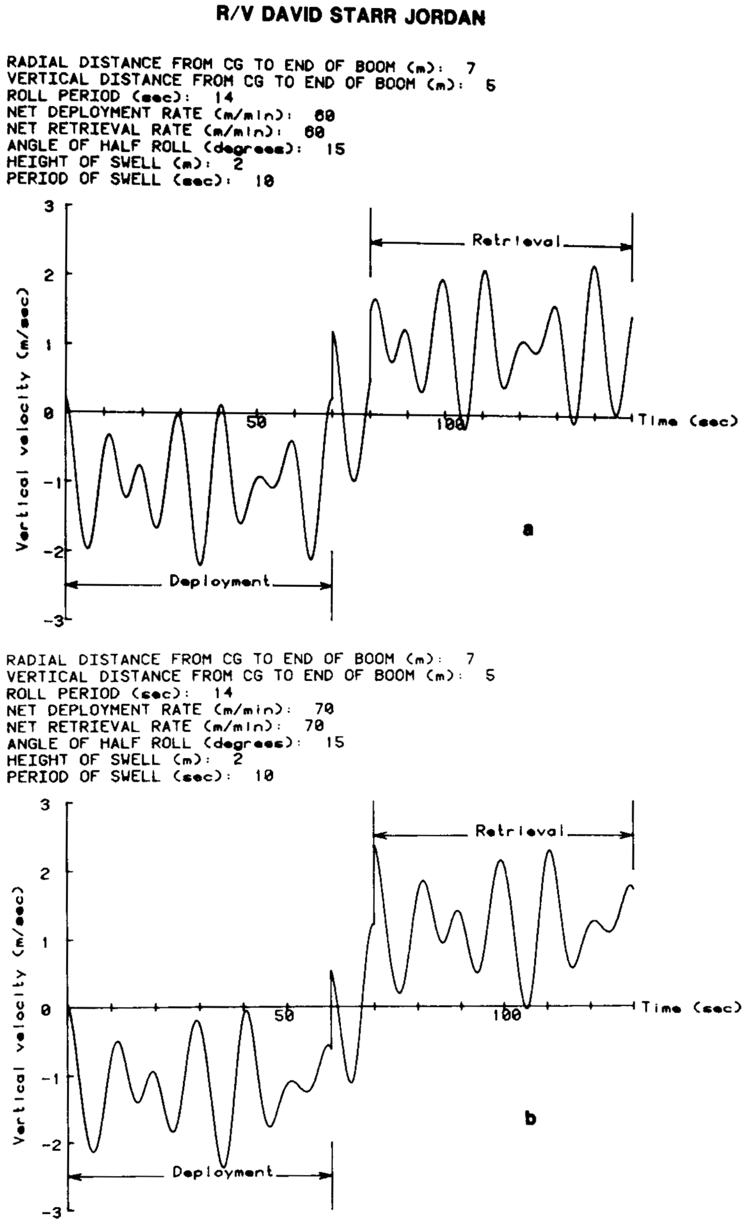


FIG. 2. The effect of net retrieval rate on the vertical velocity of the net. Simulations were conducted fore the R/V _David Starr Jordan_ and a "worst case" sea state.

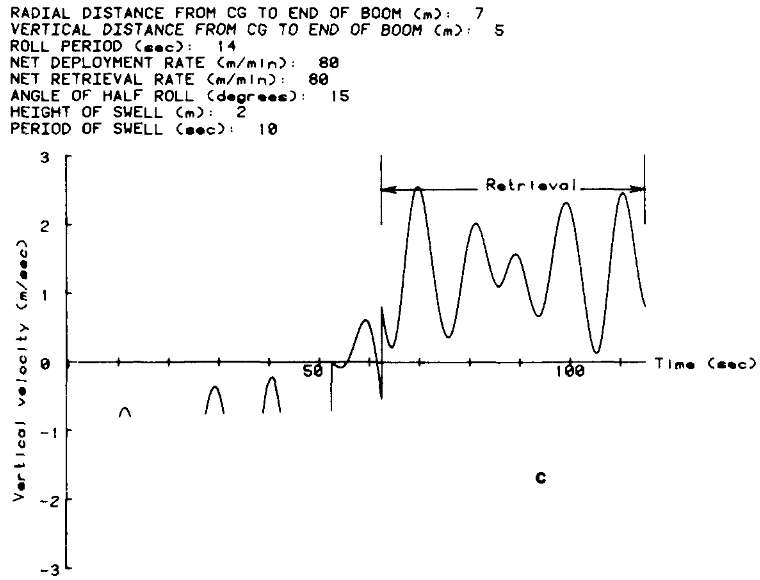


FIG. 2 (continued)

Movement of the Net

The vertical velocity of the net (S) is estimated as the sum of the vertical motions of roll, heave and net retrieval (N):

$$S = N + \frac{dx}{dt} + \frac{dx_w}{dt}$$

EXAMPLE

Velocity of the net during retrieval is the critical variable: it should always be greater than zero to prevent loss of sample by pumping and should not exceed 2 m/sec to prevent loss of sample by extrusion. The ship's design

R/V SCORPIUS

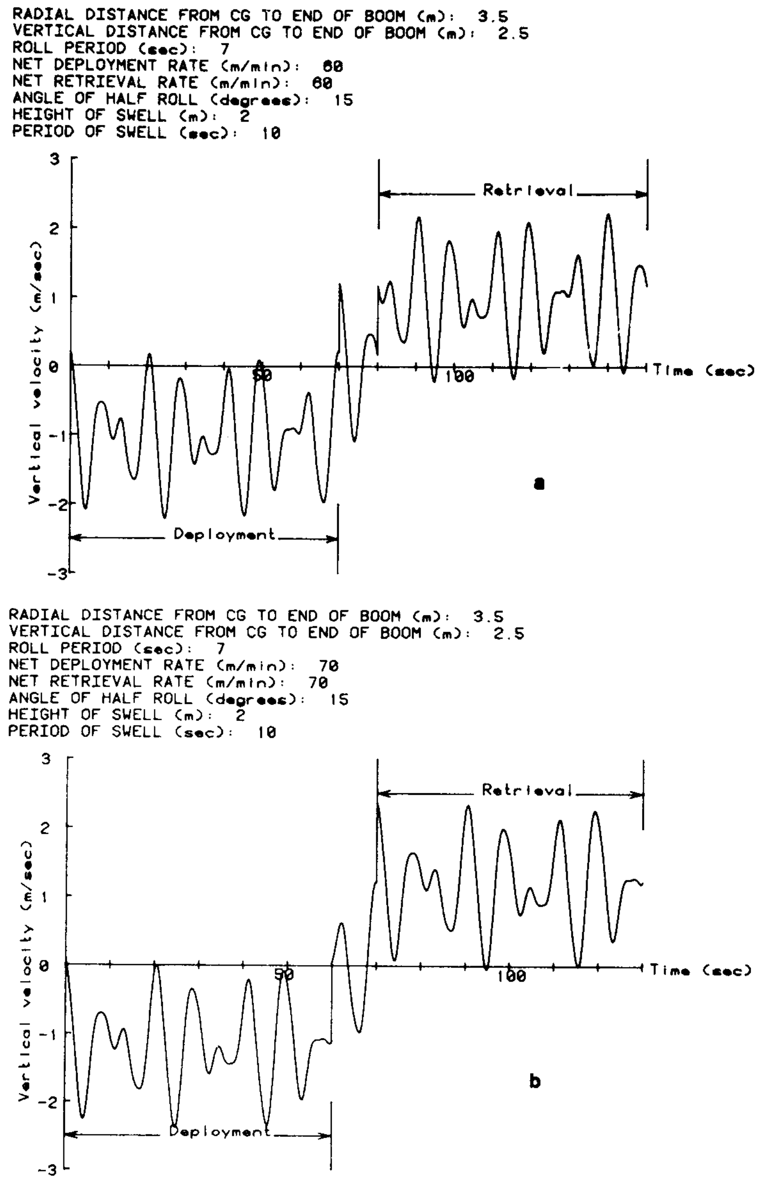


FIG. 3. The effect of net retrieval rate on the vertical velocity of the net. Simulations were conducted for the R/V Scorpius and a "worst case" sea state.

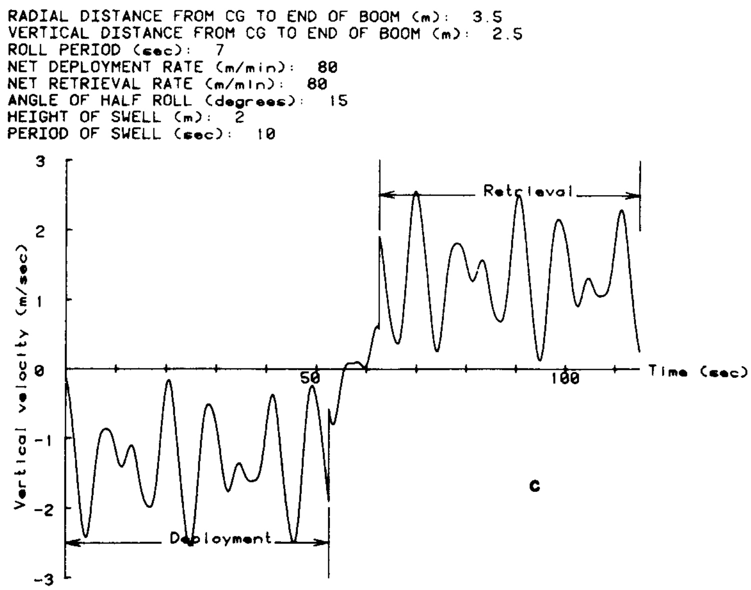


FIG. 3 (continued)

characteristics and sea state are specified and the time course of net velocity can be plotted; the existence and extent of critical velocities may be determined from visual inspection of the plots.

I assumed ship design characteristics similar to the R/V David Starr Jordan and also to a vessel one-half her size, similar to the R/V Scorpius. I assumed the ship's half-roll angle to be 15°; i.e., CalVET sampling would be suspended during sea states which caused ship's roll to exceed 15° from the vertical. I further imposed a 2 m swell with a 10 sec period. The circumstances are thus "worst case" and the simulations were made at different retrieval rates in a search for the minimal rate which will prevent pumping (Figures 2 and 3). The simulation may also be run (Figure 4),at different sea states and ship designs, as a sensitivity study. Criteria may be specified for suspension of operations due to weather for specific vessels.

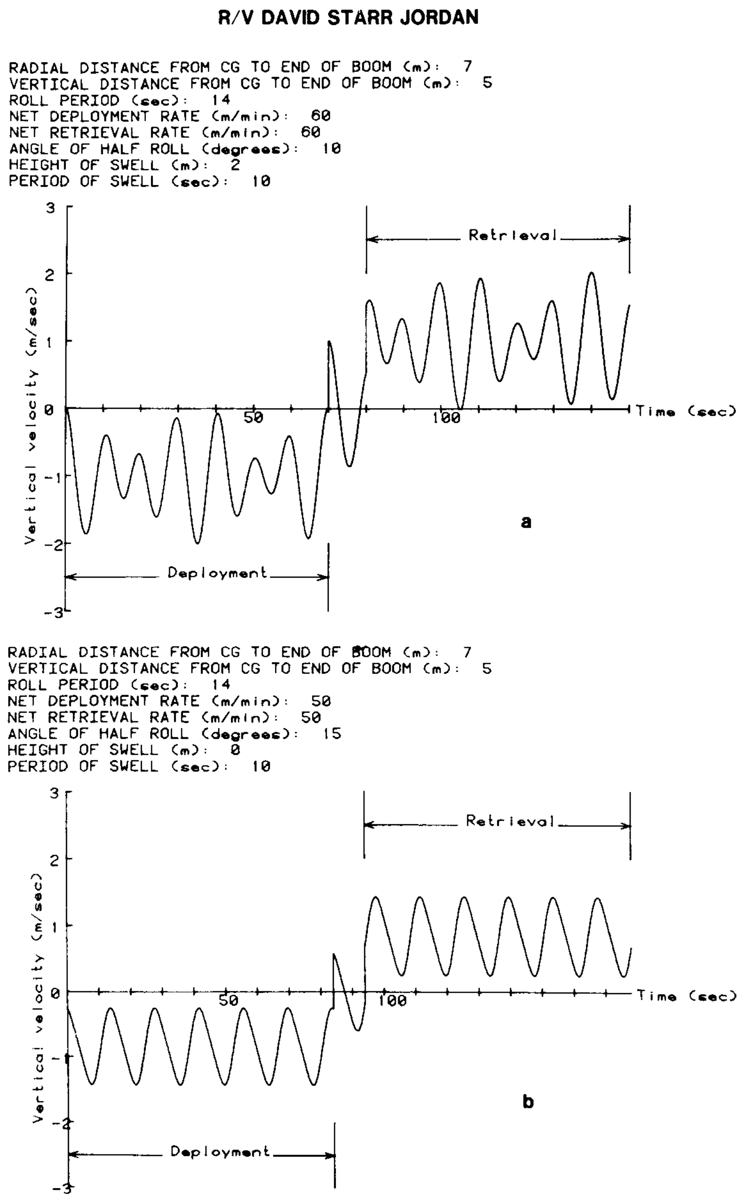


FIG. 4. The effect of sea state on the minimum net retrieval rate. Simulations were conducted for the R/V *David Starr Jordan*.

RECOMMENDATION

If field operations continue under conditions in which the ship's half-roll angle does not exceed 15° and if the ground swell does not exceed 2 m (trough to peak), then the optimal net retrieval rate is 70 m/sec on both the R/V *David Starr Jordan* (Figure 2) and the R/V *Scorpius* (Figure 3). At 60 m/sec "pumping" is evident (Figures 2a and 3a); at 80 m/sec the velocity of the net exceeds 2 m/sec for a considerable amount of time (Figures 2c and 3c).

The ship's heave due to ground swell generates more sampling problems than the ship's roll. The R/V *Jordan* could retrieve the net at 60 m/sec if operations were suspended when the ship's half-roll angle exceeded 10° (Figure 4a). However the retrieval rate could be lowered to 50 m/sec if there were negligible motion due to heave (Figure 4b).