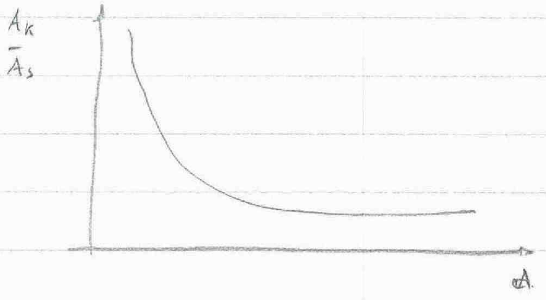
Streamer Dynamics calculations
from 1992 / 1993.

$$T = T_t + \frac{1}{2} \rho U_r^2 \pi d c_t (l - s)$$

$$A_k B_s = T_H \qquad T_H = T_t + \frac{1}{2} \rho U_r^2 \pi d c_t l.$$

$$A_k B_s = T_t + \frac{1}{2} \rho U_r^2 \pi d c_t l$$

$$\frac{A_k}{A_s} = \frac{A_k}{(\pi d^2/4)} = \frac{T_t 4}{\pi d^2 B_s} + \frac{1}{2} \rho \frac{U_r^2 \pi c_t l}{d B_s}$$

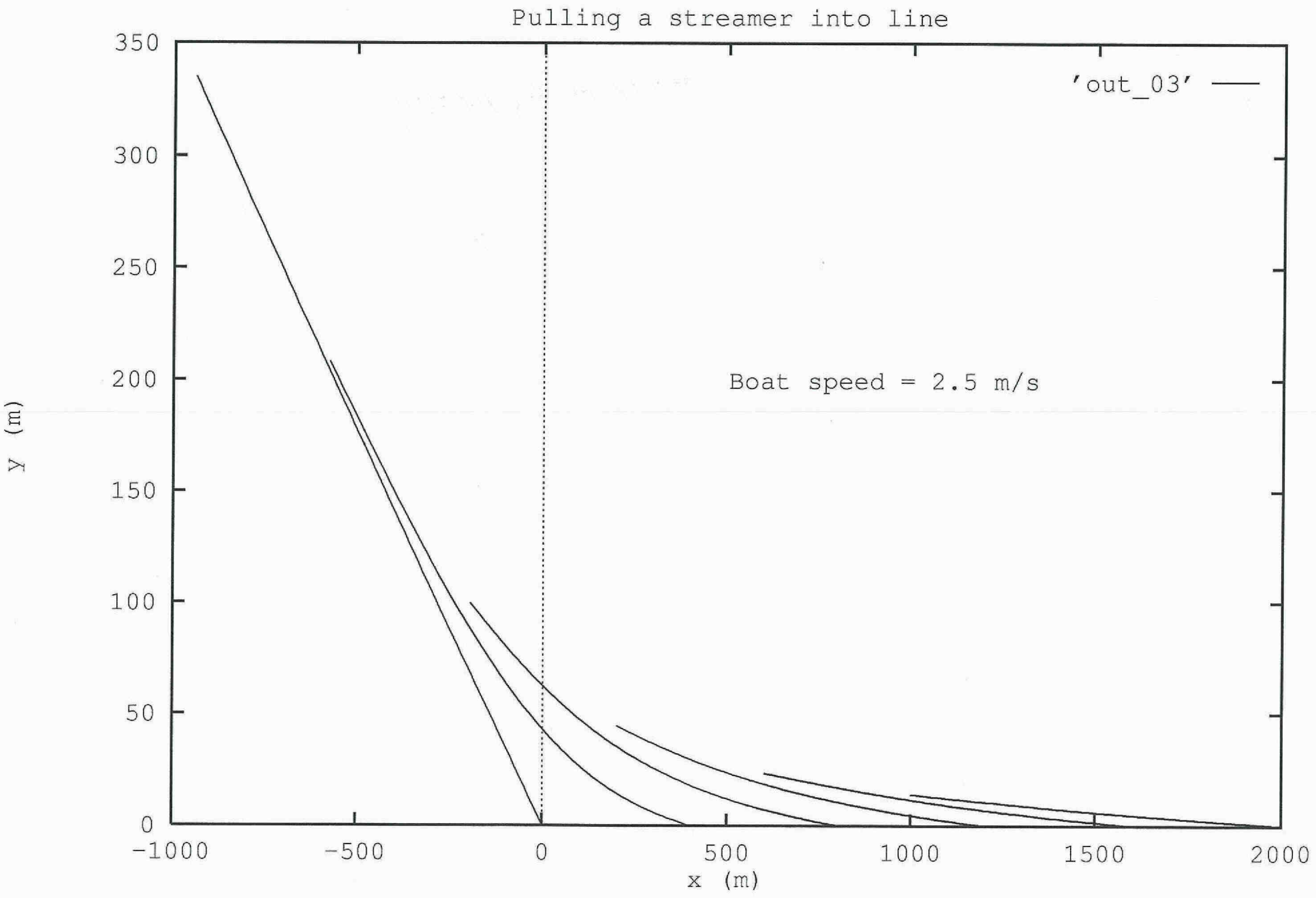


$\rho = 10^3 \quad U_r = 2.5 \quad c_t = 0.004 \quad l = 9 \times 10^3.$

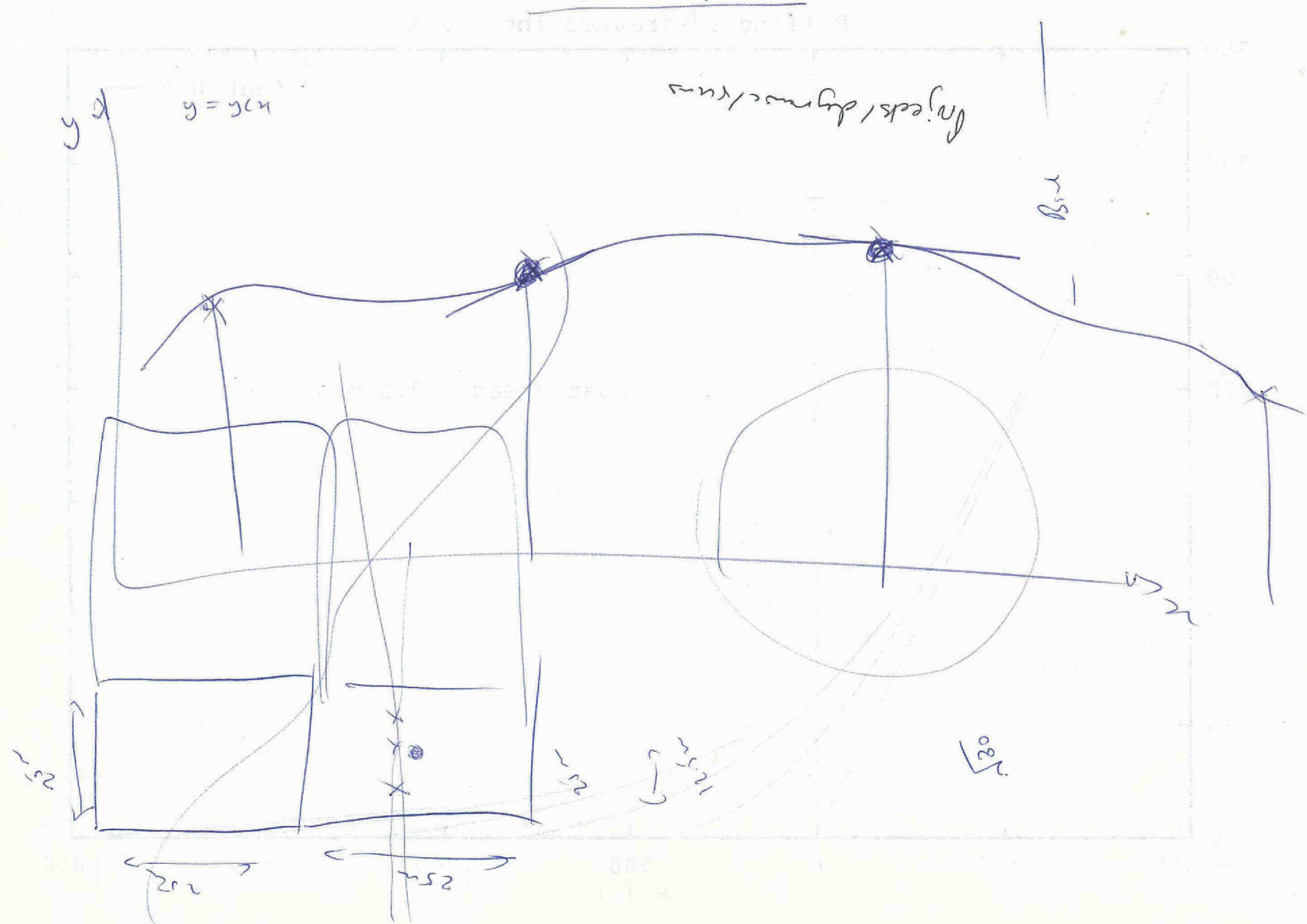
$B_s = 2.7 \times 10^{12}$ Pa.

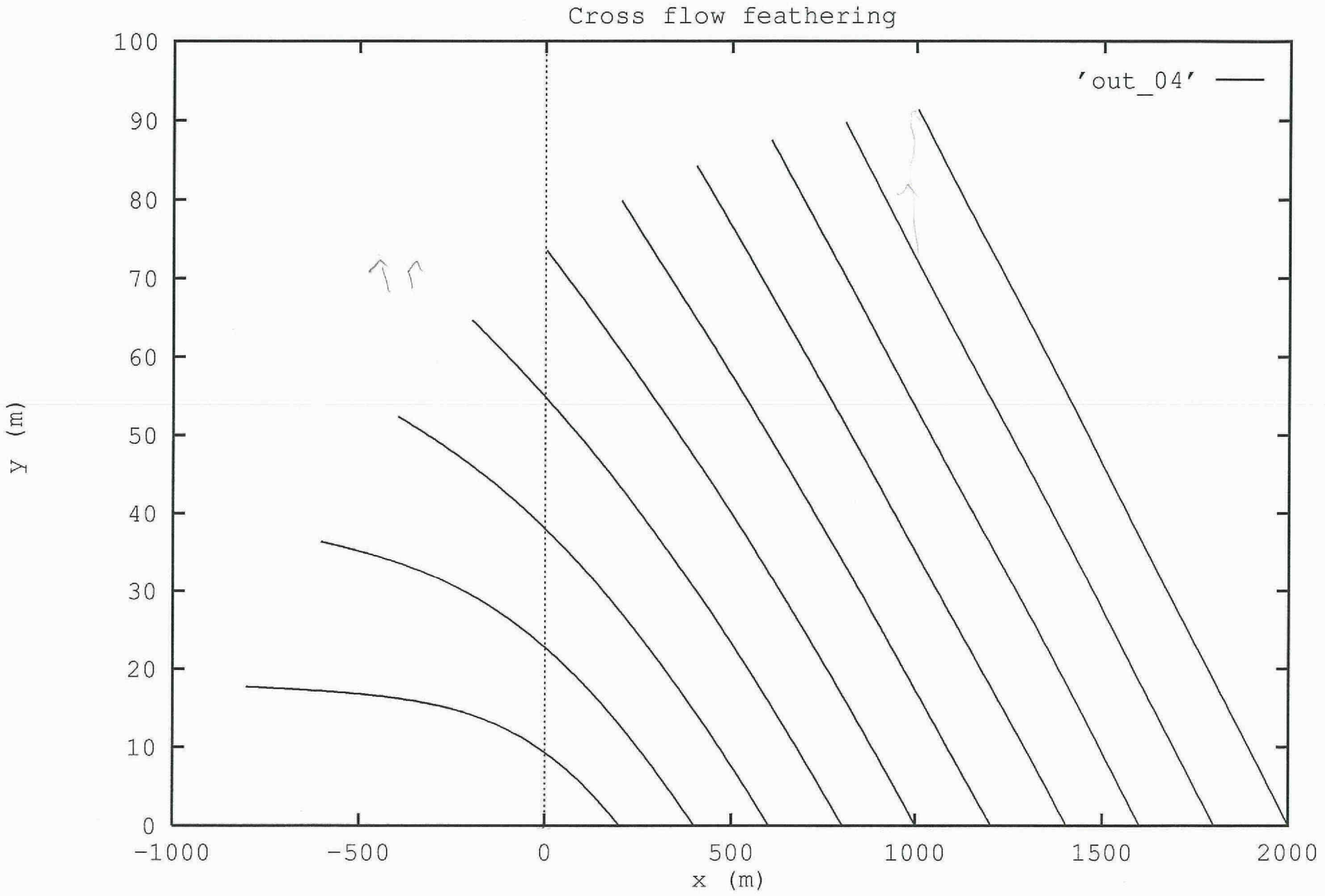
$$\frac{A_k}{A_s} = \frac{~~10^3~~ \; 2.5^2 \; 3. \; 4 \times ~~10^{-3}~~ \; 9 \times 10^3}{2 \; d \; 2.7 \times 10^{12}}$$

$$= \frac{1.39e-8}{d} = 2.3 \times 10^{-7} \; ?$$


Pulling a streamer into line
'out_03'
Boat speed = 2.5 m/s
350
300
250
200
150
100
50
0
y (m)
-1000
-500
0
500
1000
1500
2000
x (m)

Cubic Splines

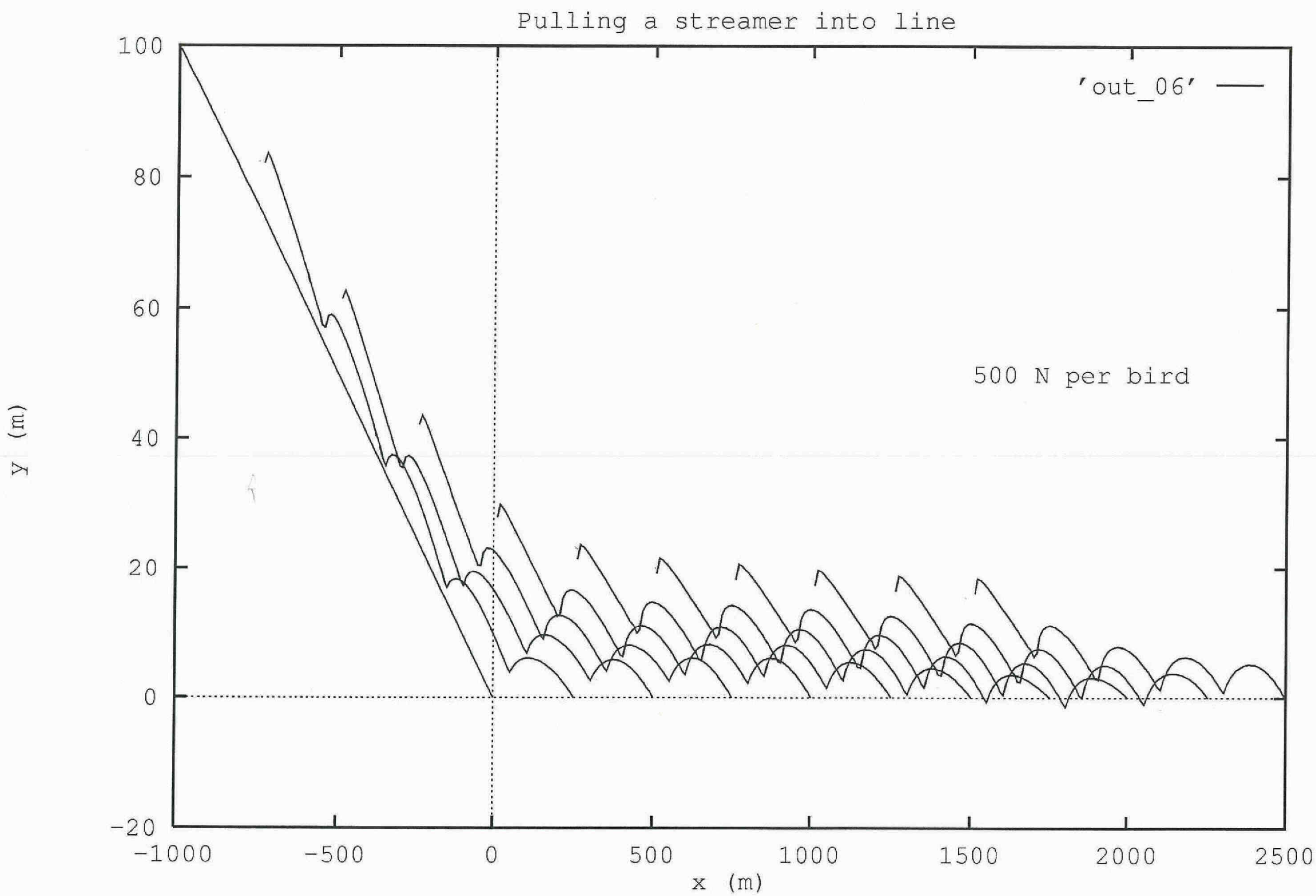


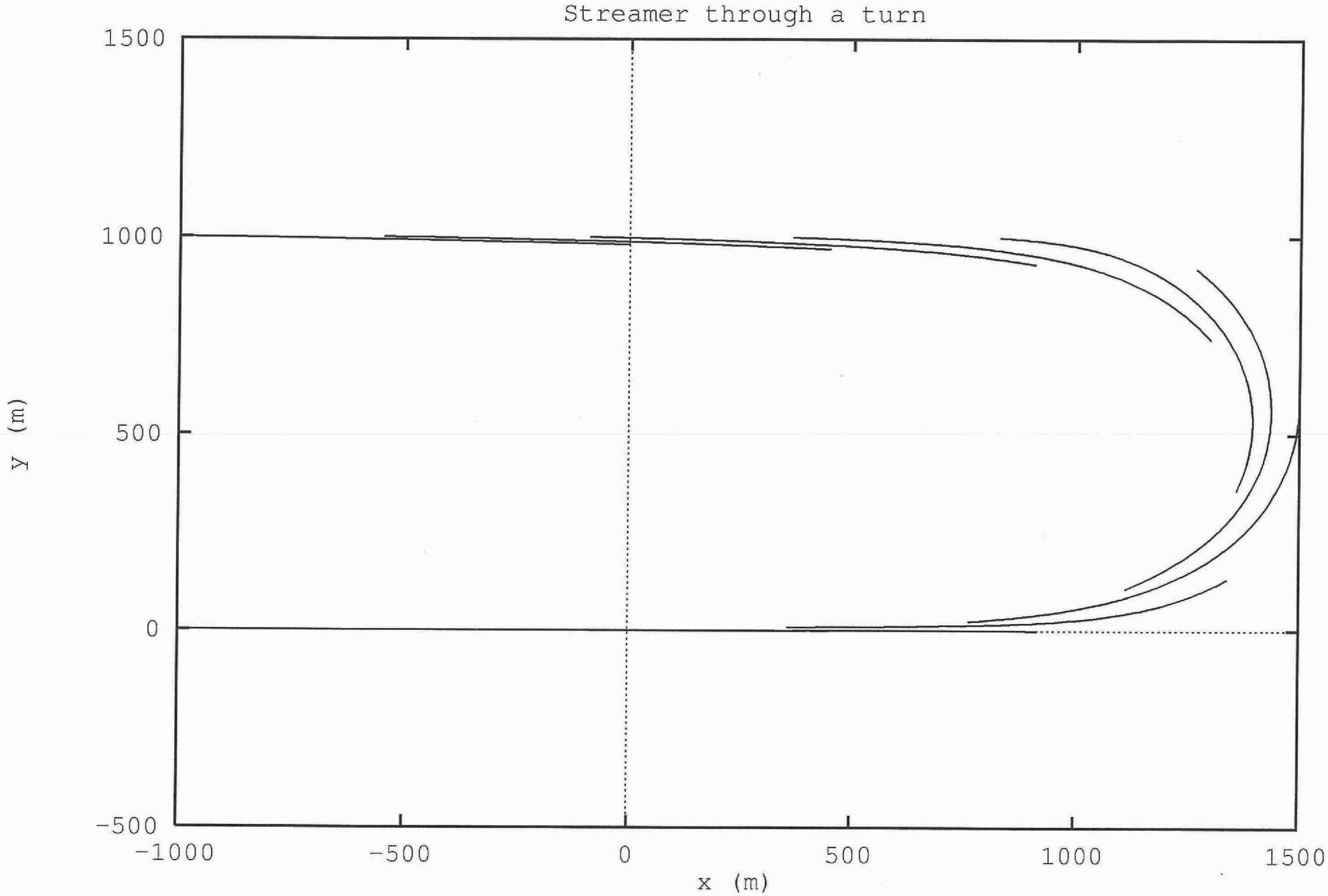

Cross flow feathering
'out_04'
100
90
80
70
60
50
40
30
20
10
0
y (m)
-1000
-500
0
500
1000
1500
2000
x (m)

Time Scales

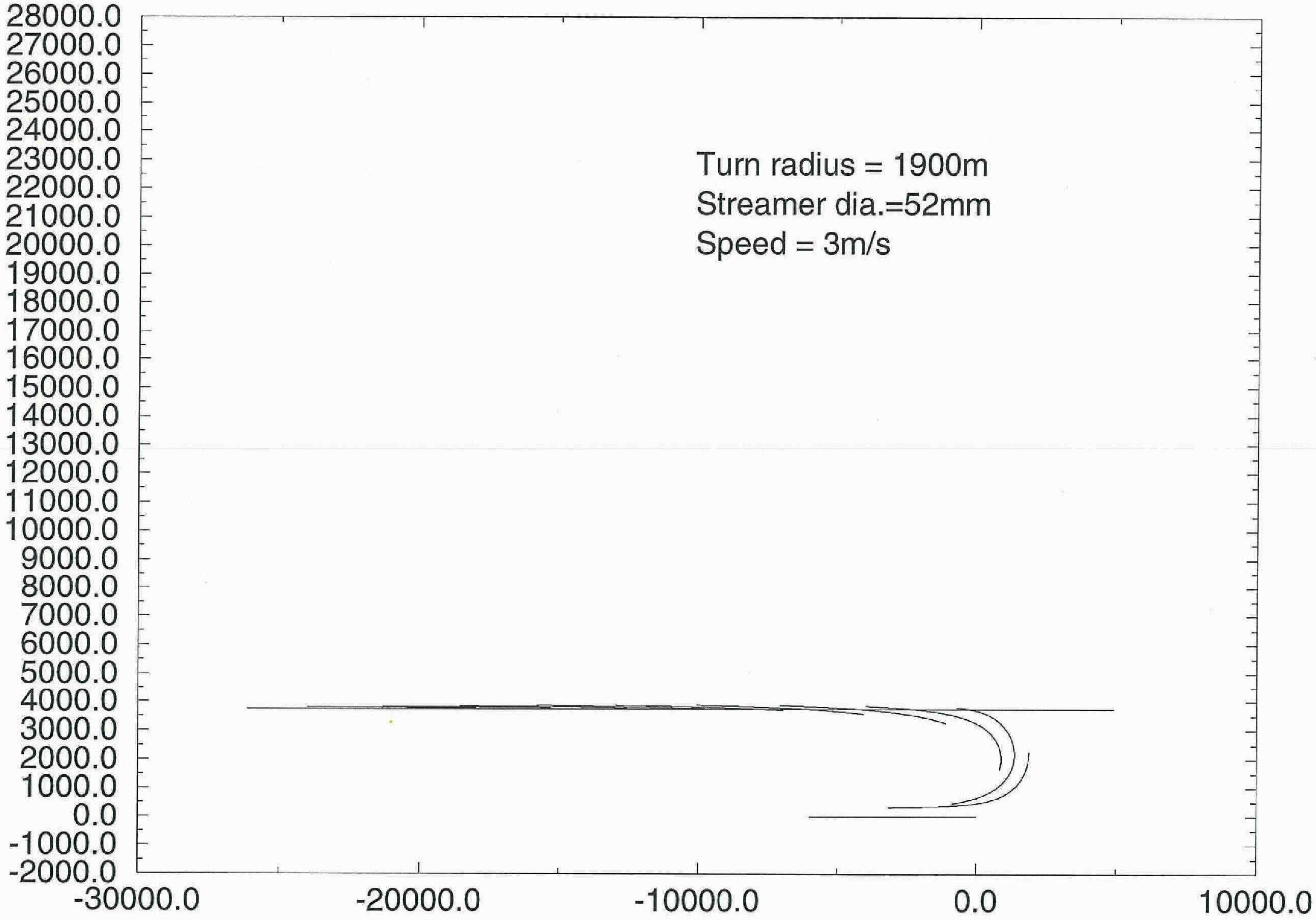
1) Depth control – time scale – from current data
2) Rotational time scale
3) Horizontal Steering
4) Wave action
5) cross-flow

±1m

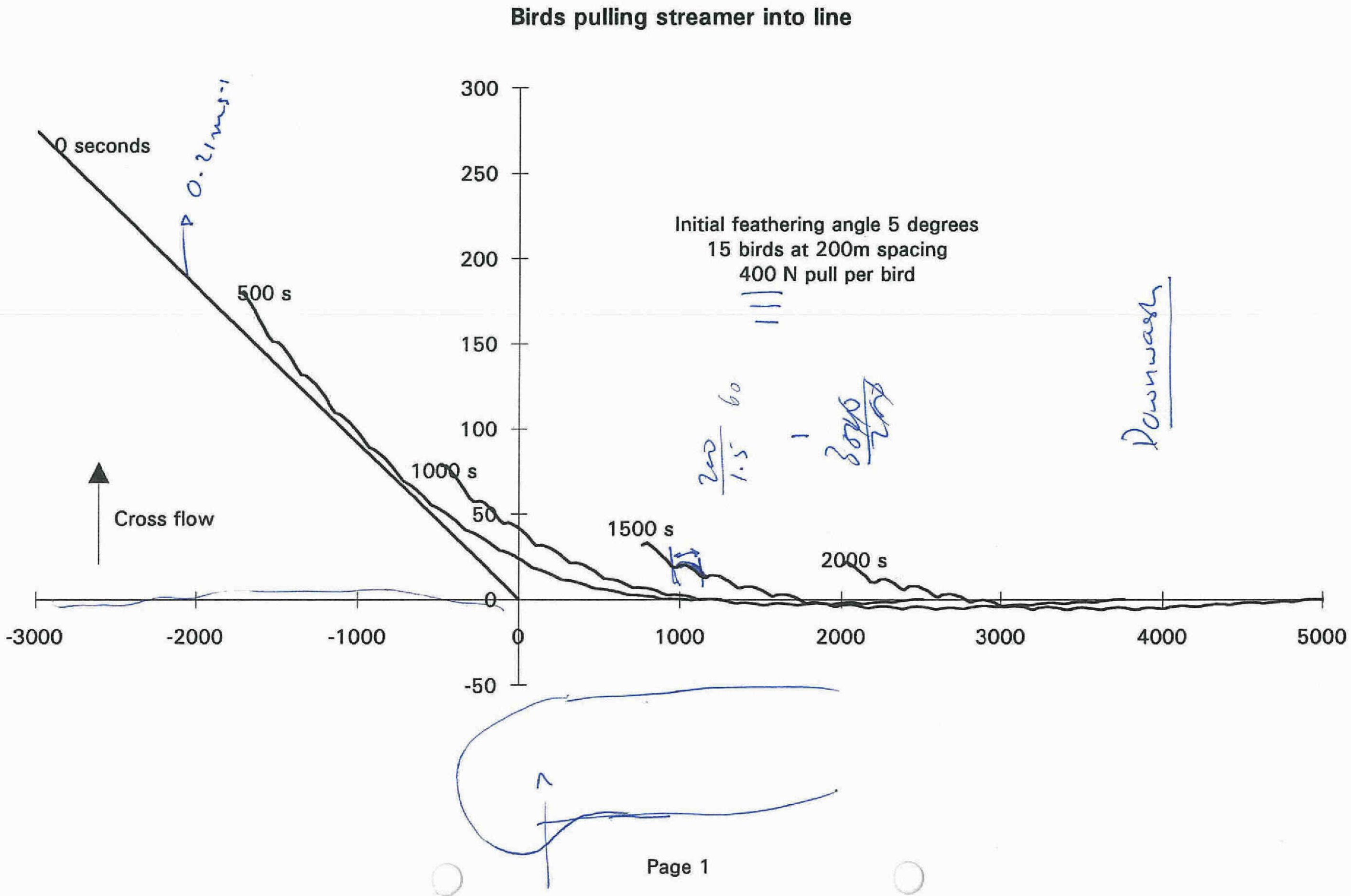

Pulling a streamer into line
'out_06'
500 N per bird
y (m)
100
80
60
40
20
0
-20
-1000
-500
0
500
1000
1500
2000
2500
x (m)


Streamer through a turn
1500
1000
500
0
-500
y (m)
-1000
-500
0
500
1000
1500
x (m)

TURN WITH 6KM STREAMER (WITHOUT BIRDS)



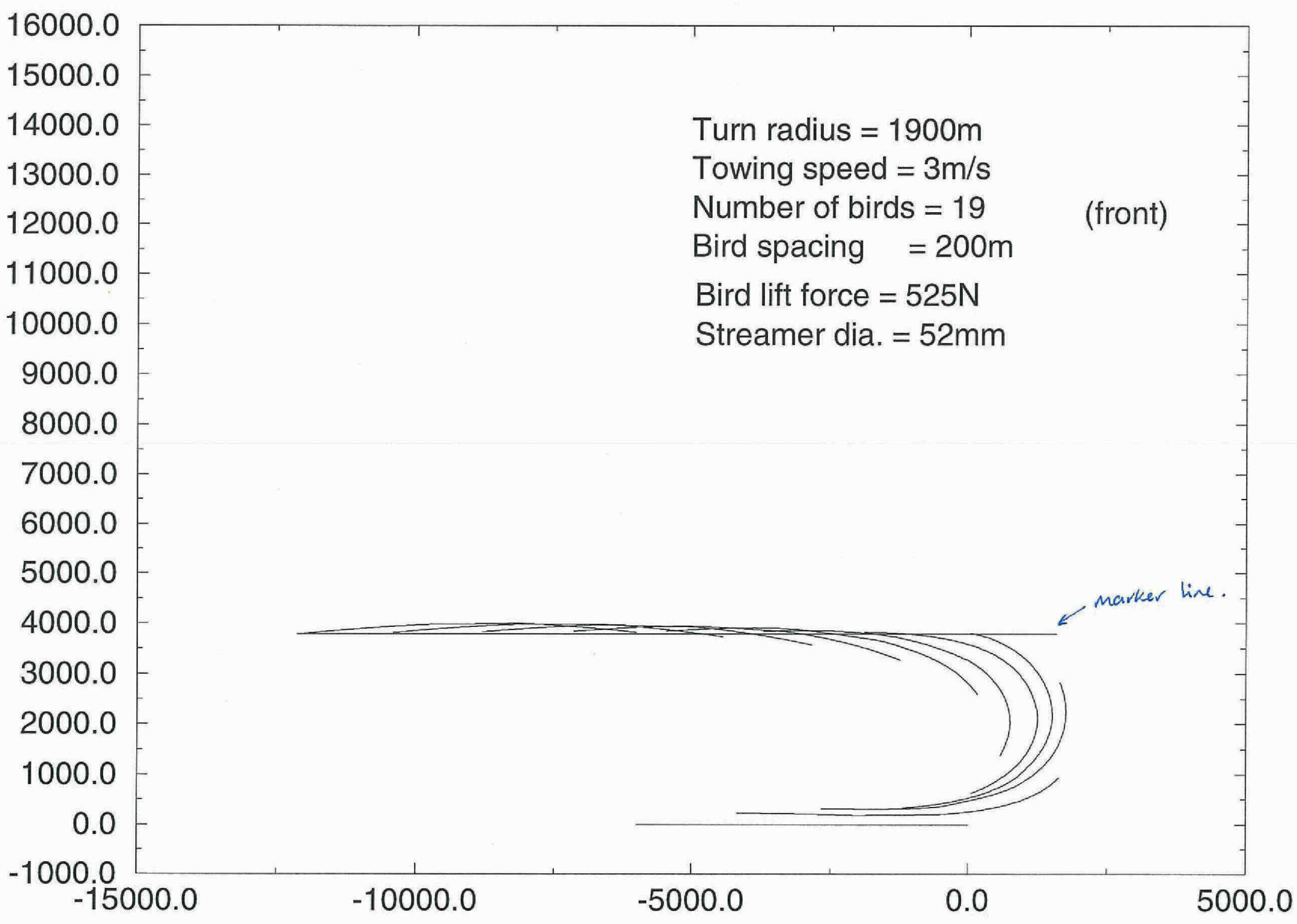
TEST12.TXT Chart 1

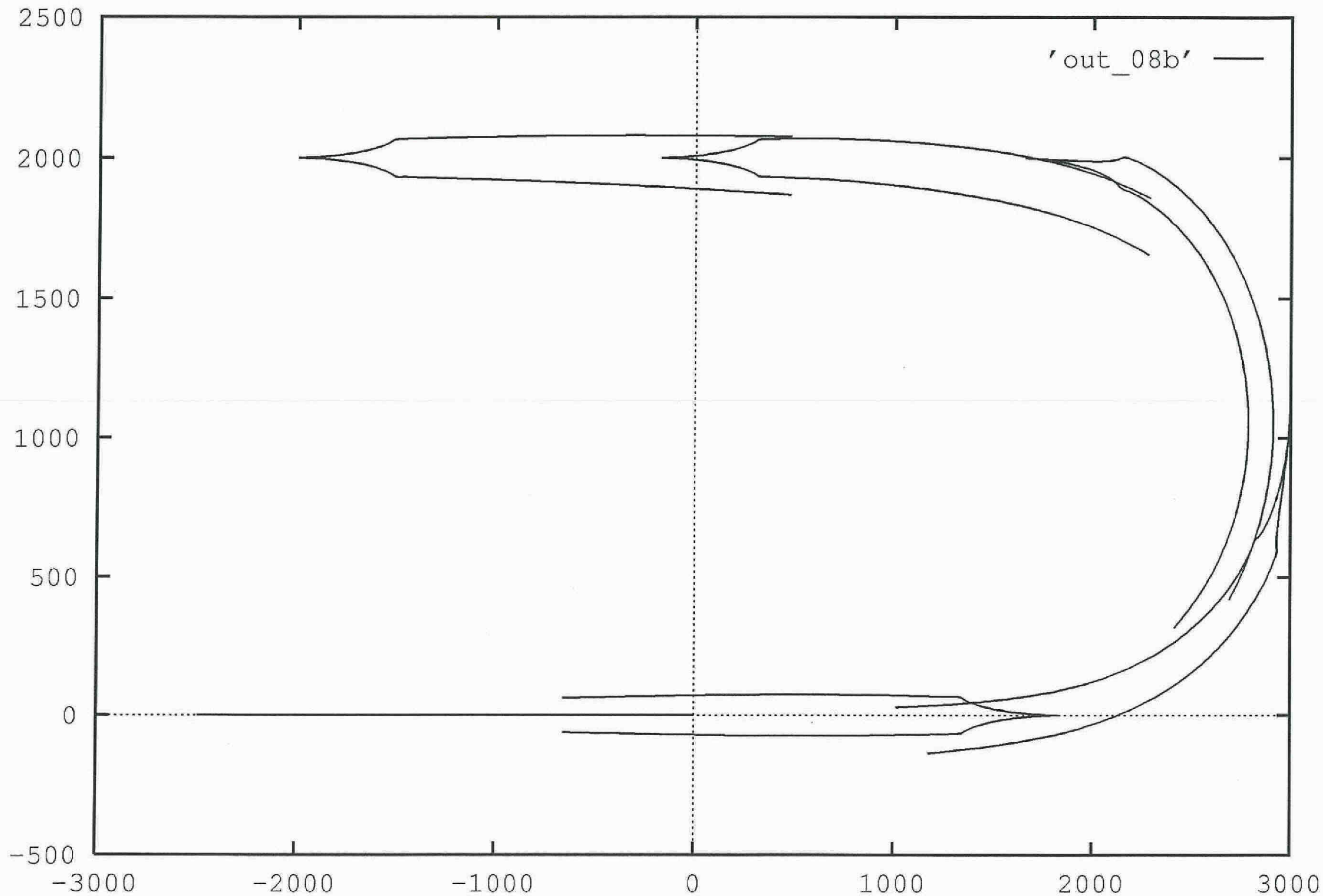


Page 1

Birds on first 2/3 of streamer.

REDUCTION OF RUN-IN FOR 6KM STREAMER





'out_08b'
2500
2000
1500
1000
500
0
-500
-3000
-2000
-1000
0
1000
2000
3000

ton = 1000 kg   N = 1 kg m / s²

$$T = T_t + \frac{1}{2} \rho U_r^2 \pi d C_t l.$$

60 mm $l = 9 \times 10^3$ $U_r = 2.5$ $\rho = 10^3$ $T_t = 10^3$

$T_H = 2.2e4$ N.

$B_s = 2.7e9$ Pa.

$A_k B_s = T_H.$

$$A_k = \frac{2.2e4}{2.7e9} = 8.12 \times 10^{-6}.$$

$3 \pi a^2 = 8.12 \times 10^{-6} \Rightarrow 9.28e-4$ m

$d = 1.9$ mm.

$$\frac{A_k}{A_s} = \frac{3\pi a^2}{\frac{\pi d^2}{4}} = \frac{8.12 \times 10^{-6}}{3.1 \times (60 \times 10^{-3})^2} \cdot 4 = 2.9e-3.$$

0.3% of the cross rectional area

<u>2.2 TON</u>

5 knots 8000m => 2.05 tons => 9

$$P = \frac{F}{\frac{\omega^2}{v^2}\left(\frac{kv}{\omega} + 1\right)^2 + \frac{\omega^2\alpha^2}{v_c^2}}$$

$$P\left(-\frac{\omega}{v}, \omega\right) = \frac{F}{\left(-\frac{\omega}{c} + \frac{\omega}{v}\right)^2 + \frac{\alpha^2\omega^2}{v_c^2}}$$

$$\frac{P(k\,\omega)}{P\left(\frac{-\omega}{v}, \omega\right)} = \frac{\frac{\alpha^2\omega^2}{v_c^2}}{\frac{\omega^2}{v^2}\left(\frac{kv}{\omega} + 1\right)^2 + \alpha^2\frac{\omega^2}{v^2}}$$

$$= \frac{1}{1 + \frac{\left(\frac{kv}{\omega} + 1\right)^2}{\alpha^2}}$$

PRECISE STREAMER LENGTH

How this can be determined and applied in the computation of receiver coordinates.

By Jon Falkenberg, RENAV

There is never time to do it right, but
there's always time to do it over.
(Murphy)

Introduction

The requirements for higher accuracy in the final source and receiver positions have made it necessary to look a bit closer at the length of a streamer section when it is being used, as this can differ significantly from the nominal length. An example illustrates the order of magnitude, on a recent job the tailbuoy positions revealed that the "3000m" streamer actually was 10 meters shorter.

Some physical facts

When the streamer is pulled through the water, there will be induced drag forces. The drag will:

- Depend on the material in the streamer skin
- Be proportional to the circumference of the streamer (then also proportional to the diameter) d
- Be proportional to the length of the streamer L
- Increase with the squared water-speed V^2
- Increase with the number of birds attached
- The drag from the tailbuoy will be added

As the steel wires taking the stress in the sections are elastic, they will be stretched.Since the drag is proportional to the streamer length it means that the first section will take the full force, while the last one only transfers the pull from the tailbuoy.Accordingly, the length increase as a function of the drag will diminish linearly down the streamer.However, since the wires are connected to the skin only at the start and end of each section there will not be a perfect linearity, it will be a "stair" function, with a step at each joint. The skin is not designed to take any in-line pressure, therefore the drag from a section will be transferred to the front. If there had been no tailbuoy, the last section would not get any stretch.

A steel wire will also change its length as a function of the **temperature**. The expansion coefficient for solid steel is 0.0000115 pr degree Celsius. For a wire it will be less, but it is difficult to find the exact value, as this will depend on the stress in the wire. If the coefficient stated is used it means that a 6000m streamer deployed in waters with a temperature 10^0 different from the conditions where it was manufactured will shrink (or expand) 0.69 meters. As the change for a wire will be much less, this correction can be regarded as insignificant for our purpose.

How to include the stretch in the computations

The additional length of a section caused by the stress can be expressed as:

$dL = L \times P / (E \times C)$

L = The relaxed length

P = Stress

E = Elasticity module for steel wire

C = Cross-section of the wires

The elasticity module for a steel wire is dependent on the type of wire and if and how it might have been pretensioned. It is not a constant, it varies slightly with the tension.For low tension the value is small (meaning large elongation), but it increases towards the value for solid steel with stress near the breaking point.For our purpose it is found most convenient to use an average figure based on actual tests. It is no secret that the opinion about what is the best value has changed over the years, and might change again as we learn more.

*While all our sections so far have three steel wires to take the stress, there will be a change in the not too distant future to **kevlar** or similar materials. While this will give increased strength, the elongation will be larger.*

Combining E and C into one constant we get 0.4×10^6 **kg**

The formula can then be written

$dL = L \times P / 0.4 \times 10^6$

or, more convenient

$\mathbf{dL = L \times P \times 2.5 \times 10^{-6}}$

The true length, D, will then be:

$D = L \times (1 + P \times 2.5 \times 10^{-6})$

and the major challenge is to find P. The task can be split in two, to establish P for the first section, then to derive the changes going down the streamer.

The total drag in the front might be taken from tables/diagrams with streamer length and water-speed as variables, however, nothing is like a real observation. Most vessels now have tension meters installed between the last stretch and the first active section, with readout and graphical recording in the instrument room In the future this device will be interfaced to the navigation computers. Until then it will be sufficient to have a representative figure for every line, or might be group of lines. In areas with currents it has to be checked more often, as the water speed of the streamer will change with the line heading.

If P is the stress in front of the active section, then the stress acting on section no. n will be:

$$P_n = P_{tail} + (P - P_{tail})(N - n)/ N$$

$$= P_F \cdot (1-\frac{n}{N}) + P_T \cdot \frac{n}{N}$$

Ligning for 1. grads linje hvor $P_n = P_F$ for $n = 0$ og $P_n = P_T$ for $n = N$.

n = Section number

N = Total number of sections

P_{tail} = Drag from the tailbuoy

Sjekk grensebetingelser

Er det riktig med n/N og

The actual value for the tailbuoy drag is normally not measured. Based on a combination of theoretical computations and experience, a value of 150 kg is recommended, *if the water-speed is around 5 knots*. For significant speed differences it should be adjusted.

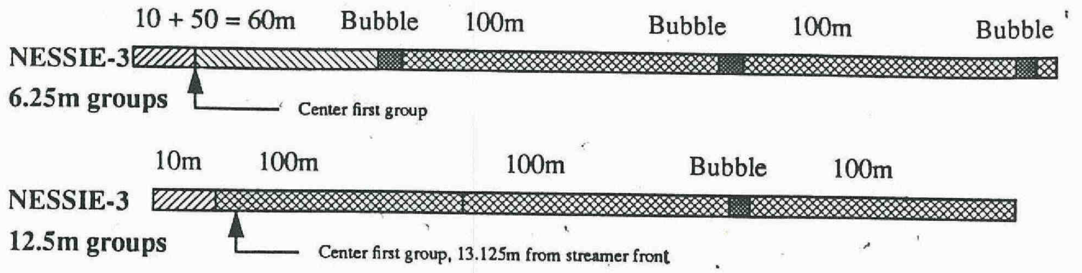
In our programs for receiver positions a set of coordinates for one receiver is computed based on the position of the previous receiver, an azimuth (from the streamer shape model), and the group length. To do this accurately, we have to use the relaxed group length corrected with the stretch.

The correction for a certain receiver group will depend on in which section it is located. Since the wires, as earlier mentioned, is connected to the skin only at the front and end of a section, it is not acceptable to use receiver group numbers instead of section numbers in the formula above.

Other factors influencing total length

There might still be some conservative clients around that out of old habit insists on having some water-breaks in the streamer. The length of these should be added. (1 meter for each) Some acoustic systems also require insertion of special units.

The electronic units (bubbles) in our digital streamers require additional consideration. In order to have the bubble in the center of a receiver group, there is a special section used at the front of every streamer. For NESSIE-2 this is 6 meters, and center of the first group will be the bubble between this and the first 100m section. NESSIE-3 have one 10 meters long. This is used alone for 12.5 m group length, for 6.25 m groups it is followed by a 50 m section. For this purpose the two special sections are built together to a 60m section.



For 6.25 m group length, one bubble is required for each section. For 12.5 m groups, only every second section will need one. For NESSIE-2, there will be an adapter (dummy) instead, with the same length as a bubble. **In NESSIE-3, however, there are no adapters**, and 0.48 meters has to be deducted from the given length for every second section.

Facts about GECO streamers

To have a nearly correct streamer length under average conditions, sections manufactured at Fjord Instruments traditionally was made a bit shorter than nominal length. At our US Marine Cable Facility in LaMarque, Texas, the nominal length has always been used, and in order to have the same, Fjord Instruments have now changed to using nominal length for analog sections. The difference in length between NESSIE-2 and 3 reflects the experience gained with respect to stretch.

The length of relaxed sections are:

ANALOG, produced at LAMARQUE	**74.94 meters**
ANALOG, produced at FJORD before February 1989	**74.70 meters**
ANALOG, produced at FJORD after February 1989 serial no. L 311 and onwards	**74.94 meters**

NESSIE-2	**99.50 meters (Including bubble)**
NESSIE-3	**99.83 meters (Including bubble)**

Most vessels shooting with analog streamers have a mixture of sections from LaMarque and old and new ones from Fjord. It is an unrealistic demand to keep track of, and use in the computation, different relaxed lengths. The best approximation will be to count the number of each type of sections, and then apply the average length. Replacement of a few sections with shorter or longer ones should not give any significant errors.

Examples

The total length of a streamer, T, will be:

$$T = L \times N + \Sigma L \times 2.5 \times 10^{-6} (P_{tail} + (P - P_{tail}) (N - n) / N)$$

$$T = L \times N (1 + P_{tail} \times 2.5 \times 10^{-6}) + L(P - P_{tail}) \times 2.5 \times 10^{-6} \Sigma (N - n) / N$$

With summing from n = 1 to n = N this can be written:

$$T = L \times N (1 + P_{tail} \times 2.5 \times 10^{-6}) + (L (P - P_{tail}) \times 2.5 \times 10^{-6}) (N - 1) \times 0.5$$

The effect of the stress can now be shown for some configurations. The purpose is just to illustrate elongation/shortening relative to the nominal length, and the given figures will not equal the distance from the first to the last receiver.

3000m Analog sections from Fjord, manufactured before February 1989

Total stress measured at front of streamer:	1000kg	
Assumed caused by the tailbuoy:	150kg	
Water speed was around 5 knots.		
T = 2988.00 + 1.12 + 3.11 = 2992.23	**2992 m**	**i.e. 8 m "short"**

3000m Analog sections from LaMarque

Total stress measured at front of streamer:	1000kg	
Assumed caused by the tailbuoy:	150kg	
Water speed was around 5 knots.		
T = 2997.60 + 1.12 + 3.11 = 3001.83	**3002 m**	**i.e. 2 m "long"**

3000m NESSIE-2

Start section not included.

Total stress measured at front of streamer:	750 kg	
Assumed caused by the tailbuoy:	100 kg	
Water speed was around 4 knots.		
T = 2985.00 + 0.75 + 2.36 = 2988.11	**2988 m**	**i.e. 12 m "short"**

6000m NESSIE-3, 12.5m groups

Start section not included.

Total stress expected at front of streamer(5 knots)	2050kg
Assumed caused by the tailbuoy:	150 kg

T = 5989.80 + 2.25 + 13.99 = 6006.04

"Missing" bubbles: 30 x 0.48 m = 14.40 m **Total 5992 m** **i.e. 8 m "short"-**

UTM scale factor

All our 3D grids are defined in the UTM plane projection, and the coordinate computations are normally performed in this projection. It is then necessary to scale the length input to the program routines.

For our purpose the scale factor for a line in UTM can be expressed as:

$$S = 0.9996 + (1/2R^2) \times (E - 500)^2$$

R = The earth radius, ~ 6390 km

E = Easting coordinate for the middle of the line, in km

The formula will then be:

$$S = 0.9996 + 1.225 \times 10^{-8} \times (E - 500)^2$$

Since E is defined as 500 km in the central meridian it means that the scale here will be 0.9996, i.e a correction of 40 cm for 1 km, or 2.4 m for a 6 km streamer.

If the line in question is 180 km from the central meridian, E = 680 km, then the scale will be 1.0 Further away it will be bigger than 1.0, meaning that the correction will make the line longer. The worst case will be found at equator, where the correction might be up to 1.0 meters pr km.

When computing in the UTM plane, any length should be multiplied with the scale factor.

The difference between actual curved streamer length and the chord is negligible for the group lengths in question. Assuming the streamer along a circle segment with radius 1000m (this might be the case in circular shooting), the difference over 25 metres will be 0.6 millimeter.

TM - RSQ

Conclusion

The elongation of the streamers, caused by drag, has to be included in the computation of receiver positions

Since the elongation for a section will vary, depending on the conditions and the location along the streamer, it is not practical to make sections that will be "correct". The only advice to the streamer designers and manufacturers are to try to standardize as much as possible.

18. Streamer elongation

A result from the induced drag forces on a towed streamer is that the nominal length will increase.
Since the drag is proportional to the streamer length it means that the first section will take the full force, while the last one only transfers the pull from the tailbuoy.
Accordingly, the length increase as a function of the drag will diminish linearly down the streamer.

The total length of a streamer can be calculated using the following formula:

$$T = LxN(1+Ptail x2,5x10^{-6})+(L(P-Ptail)x2,5x10^{-6})(N-1)x0,5$$

L is the relaxed length of a section, P is the total stress measured at the front of the streamer and N is the total number of sections.

We can assume that the stress caused by the tail buoy is 150 kg and the stress measured at the front end is 1500 kg (at approx. 4 knots speed). The streamer consist of 60 sections.

A relaxed Nessie 3 section is 99,83 m including bubble.

T = 5989,80 + 2,25 + 9,94 = 6001,70 m for 6,25 m grouplength.

For 12,5 m grouplength we must subtract 30 x 0,48 m for the bubbles "missing" which gives us a total streamerlength of 5987,3 m.

It is recommended to record the average tension of the streamer front in the line log. This should be done for each line.

19. Tailbuoy Tow Cable (TTC)

The purpose of the TTC is to replace the previous tailbuoy rope and the cable used to communicate with the buoy. It shall reduce the tugging noise from the buoy to a minimum and also be the electrical link handling both power and navigational signals.

Connected with a power bubble the TTC will supply 60 VDC to the TBVR (Tail Buoy Voltage Regulator) onboard the tailbuoy.

Note that the TTC cable will shortcircuit the streamer if connected without a power bubble.

The TTC layout drawing FI 103-88 also shows the wiring of the cable. The front coupler can be patched if you want to change aux. functions or to use the spare lines. In that case the insert plate has to be opened and pulled out and the pin-contacts moved.

In the tailbuoy end of the cable the pigtails can be easily changed out by opening the tail termination chamber. The pigtails in use are identical to standard pigtails used on the air-gun termination.

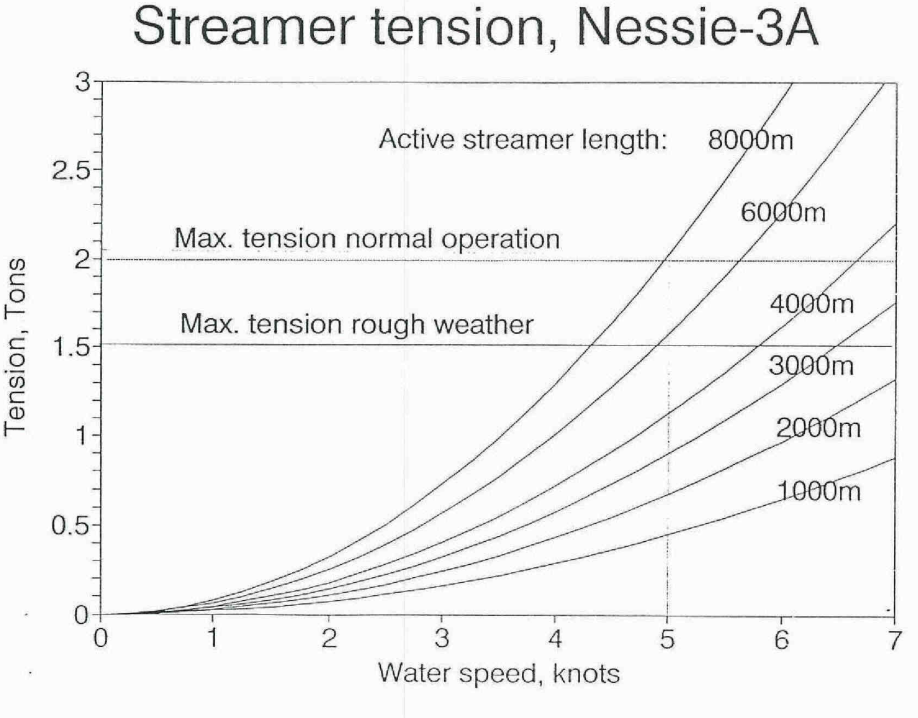
The Miniwing is attached to the streamer via an aluminium tube some distance behind the Monowing and pulls the cable sideways and out of the Monowing wake.
The Miniwing is free to rotate around its center axis but will stay vertical in the water due to a "bulb weight" and a"bulb float" installed at the lower and upper tip of the foil respectively.
The sideways pull is depending of the foil angle and can be changed by changing the center "boss".
The Miniwing is made of glass fiber and is ballanced to be neutral buoyant. This is assured by adjusting the led weights in the "bulb weight" according to the salinity in the prospected area.

17. Streamer tension

The tension on the streamer will vary with a number of factors like streamer skin material, diameter and length of streamer and the speed through the water. The drag from the tailbuoy will also be added.

The curves below are valid for straight on course of the ship at moderate sea state and with a cable diameter of 71 mm.
For a 3000 m long streamer the tension measured at the front end will typically be 1000 kg at 5 knots speed.

In rough sea the tow force will not be uniform but increase and decrease at the same speed. In any case the peaks should not exceed 20 kN.
The tow force may also vary with number of birds.
Always slow down the speed when retrieving the streamer but keep control with the front-end depth until the lead-in is onboard.
The heavy lead-in will bring the streamer front further down immediately when the speed slows down.



RECOMMENDATIONS

Onboard

- The forms for streamer configuration should also include information about the relaxed length of the sections. (In case there is a mixture, an average should be worked out.)

- The line logs should have a place for recording of the tension at the front of the streamers. An average figure for each line will be enough under normal conditions.

Navigation processing centers

- Use correct relaxed length of the sections when inputting group interval to the existing programs.

- Modify the software for receiver coordinate computations so that the elongation caused by the drag is correctly compensated for. Input should be the tension observed at the front of the active streamer, and an estimated figure for the drag from the tailbuoy.

- Modify the source and receiver position program to apply the projection scale factor to all lengths.

RENAV

- In the software for The SUN 3D QC system implement the algorithms to account for length variations caused by stress in the streamer and projection scale factors.

⇐ ℵℵℵℵℵℵℵℵℵℵℵℵℵℵ⇒

Sandvika, April 30, 1991

9000m

Axial Tension and Elongation

Here I will briefly discuss the problem of tension in the Nessie 4 streamer and elongation of the streamer. When the streamer is being towed at a steady speed with a cross flow U_{cross} in a straight line the solution of the dynamical equations is simple. The tension in the streamer is

$$T = T_{tail} + \underbrace{\frac{1}{2}\rho(U^2 + U_{cross}^2)^{1/2}\pi d c_t}_{\alpha}(l - s)$$

where s is the distance measured from the head of the streamer. When the streamer is put into a turn the tension is reduced. Thus the above equation gives a reasonable estimate of the maximum tension in the streamer during normal towing. Now the length of the streamer under tension l, is related to its length when there is no tension by

$$l = l_0\left\{1 + \frac{1}{2AE}(T_h + T_t)\right\}$$

$$T = T_t + \left(l_0\{1 + \beta(T_h - T_t)\} - s\right)\alpha$$

when $s = 0$ $T = T_h$.

$$T_h = T_t + l_0\{1 + \beta(T_h - T_t)\}\alpha$$

$$T_h\{1 - \alpha\beta l_0\} = T_t\{1 - \alpha\beta l_0\} + l_0\alpha$$

$$T_h = T_t + \frac{l_0\alpha}{1 - \alpha\beta l_0} \simeq T_t + \alpha l_0$$