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DTRC-SHD 0540-25 May 1991
Ship Hydromechanics Department
Departmental Report

HYDRODYNAMIC TOWING EVALUATION OF SSN-637 CLASS SHORT-HULL AND LONG-HULL SUBMARINES WITH MODIFIED BOWS

by
Mark S. Fellman
Raymond P. Para

C-SHD 0540-25 HYDRODYNAMIC TOWING EVALUATION OF SSN-637 CLASS SHORT-HULL AND LONG-HULL SUBMARINES WITH MODIFIED BOWS

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An experimental evaluation was conducted to investigate the surface towing characteristics of short-hull and long-hull SSN-637 Class submarines with modified bows. A 1/16.667-scale model was towed in the David Taylor Research Center shallow-water towing basin, varying towpoint location, metacentric height (GM), displacement, trim and sternplane/rudder plate configuration. The short-hull and long-hull SSN-637 Class submarine with modified bow was towed in a stable configuration at speeds up to 10 knots (5.14 m/s) full-scale with the sternplanes set to 25 deg trailing edge up, at a trim of 6 ft (1.83 m) down by the stern, at either displacement, at either GM, with either towpoint, with a lower-rudder plate appendage attached.

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ABSTRACT

An experimental evaluation was conducted to investigate the surface towing characteristics of a short-hull and long-hull version SSN-637 Class submarine with a modified bow. A 1/16.667-scale model was towed in the David Taylor Research Center shallow-water towing basin, varying towpoint location, metacentric height (GM), displacement, trim and sternplane/rudder plate configuration. The short-hull and long-hull SSN-637 Class submarine with modified bow was towed in a stable configuration at speeds up to 10 knots (5.14 m/s) full-scale with the sternplanes set to 25 deg trailing edge up, at a trim of 6 ft (1.83 m) down by the stern, at either displacement, at either GM, with either towpoint, with a lower-rudder plate appendage attached.

ADMINISTRATIVE INFORMATION

This project was sponsored by Naval Sea Systems Command (NAVSEA) PMS 393 under Work Request WX04288 of 5 March 1990 and Purchase Order PX01553 of 27 September 1990 with NAVSEA Code 55W3 as the technical point of contact. This work was performed by the Towed Systems Branch (Code 1541) of the David Taylor Research Center (DTRC) under Work Unit 1-1541-471 and 1-1541-472.

INTRODUCTION

At the request of the Naval Sea Systems Command (NAVSEA), the David Taylor Research Center (DTRC) undertook a program to investigate the surface towing characteristics of a short-hull SSN-637 Class submarine with a modified bow. Following the short-hull evaluation, NAVSEA requested DTRC to investigate the surface towing characteristics of a long-hull version of the SSN-637 Class submarine. The results from both evaluations are included in this report.

Submarines under surface tow often display undesirable tow characteristics such as yawing and extreme kiting to one side. The classic description of a stable tow has the tow positioned ±15 deg directly astern of the tug. As the tow yaws and moves further outboard from a centerline position behind the tug, the towline tension increases, speed must be reduced, and the tow as well as the tug may be in danger. Several basic evaluations have looked at stabilizing methods for a submarine under tow.[1,2]

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[1] *McCauley, S.A.; Para, R.P., "Hydrodynamic Towing Evaluation of the USS Skate (SSN-578)," DTRC Report SHD-1322-01 (Feb 1990).*

This effort was undertaken to determine stable towing configurations for a short-hull and long-hull SSN-637 submarine with a modified bow. The effects of towpoint location, trim, displacement, metacentric height, sternplane aft extensions, and three different lower-rudder plates on towing stability were investigated. This report describes the model, experimental procedure and results. Towline tension and towline angles are presented as a function of speed for all model ballast conditions with various stern configurations.

MODEL DESCRIPTION

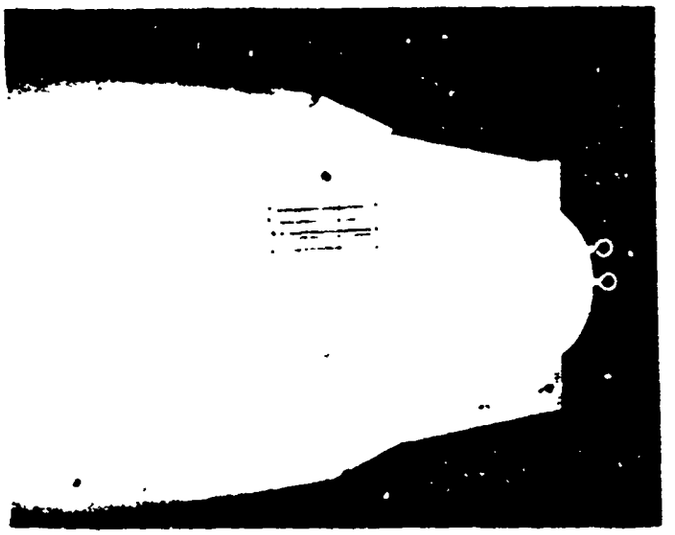
A 17.17 ft (5.23 m) long free-flooding fiberglass model (#5407) of the short-hull SSN-637 was used for the basin evaluation. A 0.496 ft (0.15 m) long section was added at the parallel midbody to represent the long-hull version, which full-scale is approximately 8.26 ft (2.52 m) longer than the short-hull version. The model has a linear scale ratio of 16.667. The bow was modified to represent the submarine with the sonar dome removed and plates welded to cover the sonar sphere and its structure as shown in Fig. 1. The two towpoint locations evaluated are shown in Fig. 1 and listed in Table 1. The model ballast conditions are listed in Table 2.

Table 1. Primary and secondary towpoint locations for SSN-637.

	Model-scale	Full-scale
Primary	1.44-in. (36.6 mm) above the centerline on the main axis	2.0-ft (0.61 m) above the centerline on the main axis
Secondary	On the centerline on the main axis	On the centerline on the main axis

Stern configurations evaluated for the short-hull SSN-637 include one size of moveable sternplane aft extensions and three sizes of lower-rudder plates. The area of one aft sternplane extension is equal to one half the area of the sternplane moveable flap and is shown in Fig. 2. The full-scale dimensions and

[2] *Fellman, M.S.; Para, R.P., "Hydrodynamic Towing Evaluation of SSN-603 with a Modified Bow," DTRC Report SHD-1328-01 (July 1990).*



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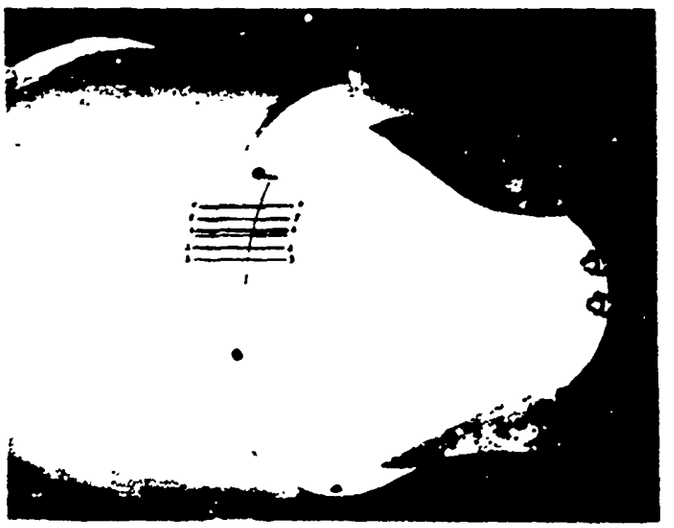

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Fig. 1. Photographs of modified bow and towpoint locations used for SSN-637 evaluation.

Table. 2. Ballast conditions for the short–hull and long–hull SSN–637 submarine.

Ship Characteristic	Full–scale	Model–scale
Short–hull Displacement 1	3,425 long tons (sw) (3,479,961 kg)	1611 pounds (fw) (731 kg)
Mean Draft	21.0 ft ABL (6.40 m)	15.12 in. ABL (0.38 m)
Waterline 1		
Fwd Draft Mark	19.73 ft ABL (6.01 m)	14.21 in. ABL (0.36 m)
Aft Draft Mark	22.27 ft ABL (6.79 m)	16.03 in. ABL (0.41 m)
Trim by the stern	3.0 ft (0.91 m)	2.16 in. (0.05 m)
Waterline 2		
Fwd Draft Mark	19.09 ft ABL (5.82 m)	13.75 in. ABL (0.35 m)
Aft Draft Mark	22.91 ft ABL (6.98 m)	16.50 in. ABL (0.42 m)
Trim by the stern	4.5 ft (1.37 m)	3.24 in. (0.08 m)
Waterline 3		
Fwd Draft Mark	18.46 ft ABL (5.63 m)	13.29 in. ABL (0.34 m)
Aft Draft Mark	23.54 ft ABL (7.17 m)	16.95 in. ABL (0.43 m)
Trim by the stern	6.0 ft (1.83 m)	4.32 in. (0.11 m)
Short–hull Displacement 2	3,712 long tons (sw) (3,771,567 kg)	1,746 pounds (fw) (792 kg)
Mean Draft	22.5 ft ABL (6.86 m)	16.20 in. ABL (0.41 m)
Waterline 4		
Fwd Draft Mark	21.23 ft ABL (6.47 m)	15.29 in. ABL (0.39 m)
Aft Draft Mark	23.77 ft ABL (7.25 m)	17.11 in. ABL (0.43 m)
Trim by the stern	3.0 ft (0.91 m)	2.16 in. (0.05 m)
Waterline 5		
Fwd Draft Mark	20.59 ft ABL (6.28 m)	14.83 in. ABL (0.38 m)
Aft Draft Mark	24.41 ft ABL (7.44 m)	17.58 in. ABL (0.45 m)
Trim by the stern	4.5 ft (1.37 m)	3.24 in. (0.08 m)
Waterline 6		
Fwd Draft Mark	19.96 ft ABL (6.08 m)	14.37 in. ABL (0.36 m)
Aft Draft Mark	25.04 ft ABL (7.63 m)	18.03 in. ABL (0.46 m)
Trim by the stern	6.0 ft (1.83 m)	4.32 in. (0.11 m)
Long–hull Displacement 1	3,555 long tons (sw) (3,611,880 kg)	1673 pounds (fw) (759 kg)
Mean Draft	21.0 ft ABL (6.40 m)	15.12 in. ABL (0.38 m)
Waterline 3		
Fwd Draft Mark	18.46 ft ABL (5.63 m)	13.29 in. ABL (0.34 m)
Aft Draft Mark	23.54 ft ABL (7.17 m)	16.95 in. ABL (0.43 m)
Trim by the stern	6.0 ft (1.83 m)	4.32 in. (0.11 m)
Long–hull Displacement 2	3,850 long tons (sw) (3,911,600 kg)	1,811 pounds (fw) (821 kg)
Mean Draft	22.5 ft ABL (6.86 m)	16.20 in. ABL (0.41 m)
Waterline 6		
Fwd Draft Mark	19.96 ft ABL (6.08 m)	14.37 in. ABL (0.36 m)
Aft Draft Mark	25.04 ft ABL (7.63 m)	18.03 in. ABL (0.46 m)
Trim by the stern	6.0 ft (1.83 m)	4.32 in. (0.11 m)

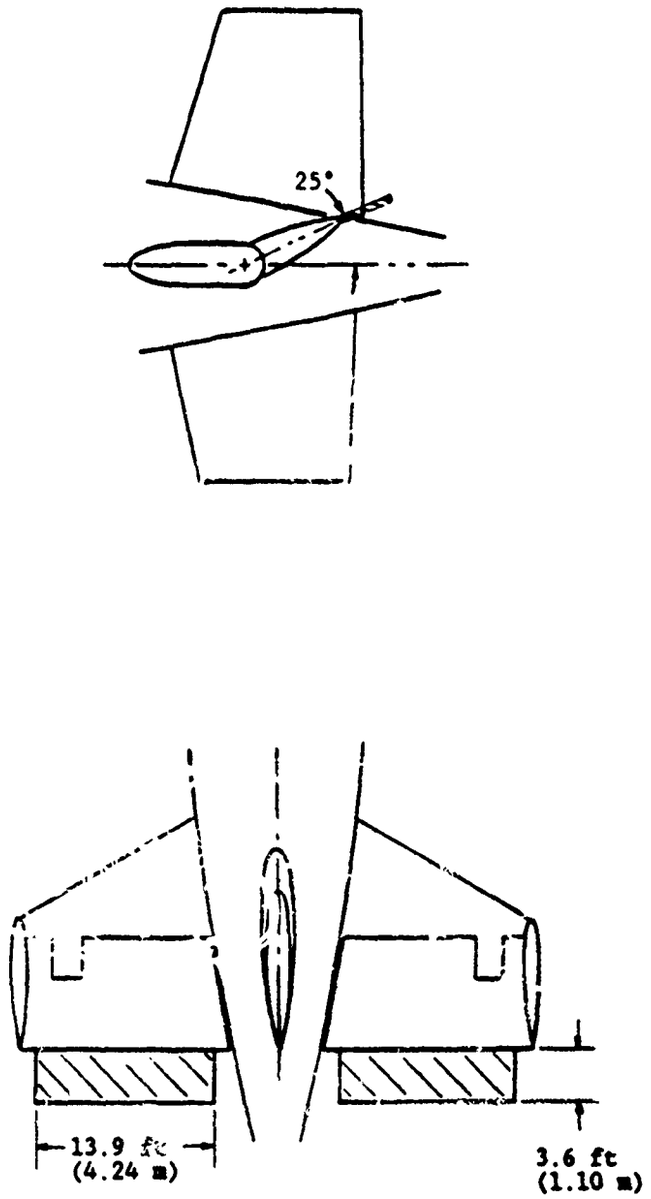

Fig. 2. Beam view and bottom view of sternplane aft extensions for SSN 637.

location of the three lower-rudder plates evaluated are included in Fig. 3. Rudder Plate A has an area equal to 50 percent of the area of the moveable sternplane flap on each side of the rudder. Rudder Plate B has an area equal to 41 percent of the area of the moveable sternplane flap on each side of the rudder. Rudder Plate C has the same surface area as Rudder Plate A. However, the chord has been extended to 14.6 ft (4.45 m) and the span reduced to 8.0 ft (2.44 m) full-scale. The long-hull SSN-637 was evaluated only with Rudder Plate A.

PROCEDURE

The short-hull SSN-637 model was statically trimmed for surface towing by ballasting to displacements of 3425 and 3712 long tons sea water (LTSW) (3,478,000 and 3,771,500 kg). These displacements represent mean drafts of 21.0 and 22.5 ft (6.40 and 6.86 m) above the base line (ABL), respectively. Each displacement was ballasted for trims of 3.0, 4.5 and 6.0 ft (0.91, 1.37 and 1.83 m) down by the stern, for a total of six waterlines. Roll incline tests were then conducted to obtain the required metacentric heights (GM) of 9.60 and 18.63 in. (0.24 and 0.47 m) at each waterline.

The long-hull SSN-637 model was statically trimmed for surface towing by ballasting to displacements of 3555 and 3850 LTSW which represent mean drafts of 21.0 and 22.5 ft (6.40 and 6.86 m) ABL, respectively. The long-hull SSN-637 model was ballasted for a trim of 6.0 ft (1.83 m) down by the stern at GMs of 9.60 and 18.63 in. (0.24 and 0.47 m) at both displacements.

The tow tests were conducted in the shallow water basin at DTRC. The basin is 52 ft (15.8 m) wide, and has an approximate run length of 800 ft (243.8 m). The model was towed at equivalent full-scale speeds of 4, 7 and 10 kn (2.06, 3.60 and 5.14 m/s). The model towline was a 14-foot (4.27 m) length of 3/16-inch (4.8 mm) diameter nylon rope. Only one towline length was used since earlier basin tests have shown that various towline lengths do not affect the towing behavior of the model.[3]

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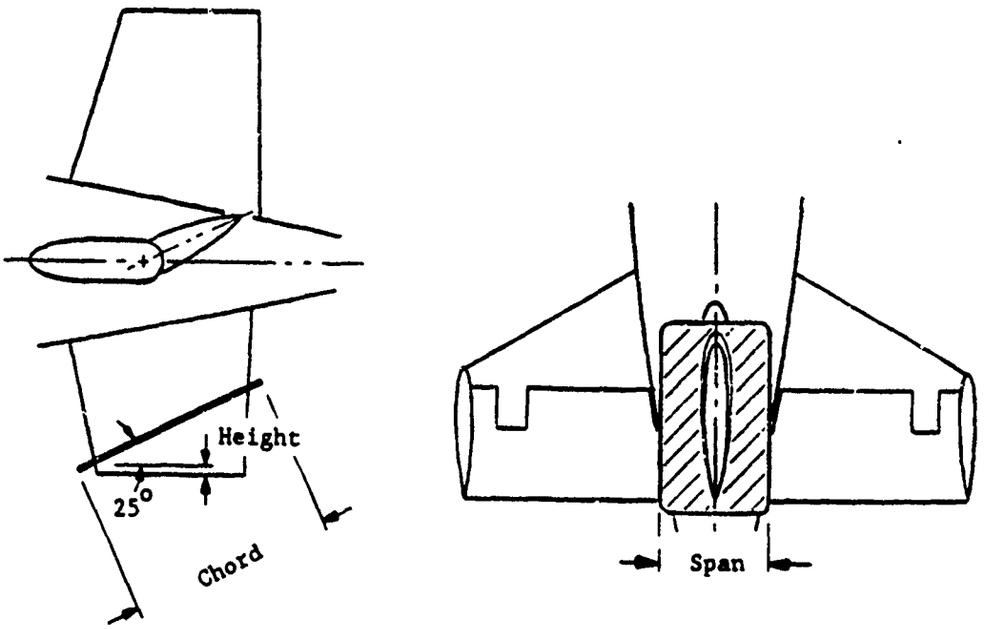
[3] *Mirabella, J.V. "Investigation of Techniques for Submarine Towing," DTNSRDC Report 432-H-01 (Jun 1971).*



Full-scale dimensions			
Rudder plate	Chord ft (m)	Span ft (m)	Height ft (m)
A	12.6 (3.84)	9.0 (2.74)	0.5 (0.15)
B	12.6 (3.84)	8.0 (2.44)	0.5 (0.15)
C	14.6 (4.45)	8.0 (2.44)	1.0 (0.30)

Fig. 3. Beam view and bottom view of lower-rudder plates for SSN 637.

Once the towing carriage reached the desired speed, the model was displaced to one side of the tow carriage's centerline and then allowed to seek its equilibrium position. The towing stability for the short-hull SSN-637 was evaluated for stern configurations with no extensions, aft extensions, Rudder Plate A, Rudder Plate B and Rudder Plate C. Based on the results from the short-hull evaluation, the long-hull SSN-637 was evaluated only with Rudder Plate A. The moveable sternplane flaps were set to 25 deg trailing edge up (TEU) for all but one set of runs as noted.

INSTRUMENTATION

The instrumentation located at the gimbal towpoint consisted of:

1. An angle potentiometer to measure the horizontal towline angle, defined as the towline angle relative to the direction of tow. The potentiometer has a range of 60 deg port and starboard with a system accuracy of ± 0.5 deg.

2. A 100-pound (444 N) capacity load cell to provide measurements of towing tension with a system accuracy of ± 0.5 lb (2 N). The full scale accuracy would be equivalent to ± 2380 lb (10600 N).

Additional instrumentation consisted of a magnetic pickup on the towing carriage to provide measurements of speed with a model accuracy of ± 0.01 kn and a full-scale accuracy of ± 0.04 kn. For all measurements, data was collected on an eight-channel stripchart recorder and an HP9836 computer.

RESULTS AND DISCUSSION

The test results are presented as full-scale values. Towline tension was scaled by:

$$\frac{\rho_{sea}}{\rho_{fresh}} \cdot \lambda^3$$

where,

ρ_{sea} is the density of sea water at 59 deg F.
ρ_{fresh} is the density of fresh water at 68 deg F., and
λ is the linear scale ratio.

The short-hull SSN 637 horizontal towline angles measured after the model had reached an equilibrium condition are presented in Tables 3 through 11 for

Table 3. Horizontal towline angles for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 3.0 ft (0.91 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)	31.0 S	35.0 S	33.0 S	27.0 S		
7 (3.60)	34.0 S			25.0 S		
10 (5.14)	40+ S	28.0 S	20.5 S	12.5 S		

P – Port S – Starboard

Table 4. Horizontal towline angles for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 4.5 ft (1.37 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		27.0 S	25.5 S	16.5 S		21.0 S
7 (3.60)		30.0 S		21.0 S		22.0 S
10 (5.14)		22.0 S	19.0 S	13.0 S		14.5 S

P – Port S – Starboard

Table 5. Horizontal towline angles for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 4.5 ft (1.37 m) trim down by the stern, at a GM of 9.60 in. (0.24 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		31.0 S		21.0S		
7 (3.60)		32.0 S		20.0 S		
10 (5.14)		10–25 S		10.0 S		

P – Port S – Starboard

Table 6. Horizontal towline angles for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		20.5 S	19.5 S	12.0 S	14.0 S	16.0 S
7 (3.60)		22.0 S	15–20 S	5.0 S	8.0 S	12.0 S
10 (5.14)		8–22 S	15.0 S	11.0 S	13.0 S	8.0 S

P – Port S – Starboard

Table 7. Horizontal towline angles for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 9.60 in. (0.24 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions 25 TEU	Rudder Plate A 25 TEU	Rudder Plate B 25 TEU	Rudder Plate C 25 TEU
	0	25 TEU				
4 (2.06)		20.0 S		13.0 S	15.5 S	17.0 S
7 (3.60)		24.0 S		9.0 S	12.0 S	17.0 S
10 (5.14)		15–20 S		10.0 S	12.0 S	12.5 S

P – Port S – Starboard

Table 8. Horizontal towline angles for a short–hull SSN–637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 3.0 ft (0.91 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions 25 TEU	Rudder Plate A 25 TEU	Rudder Plate B 25 TEU	Rudder Plate C 25 TEU
	0	25 TEU				
4 (2.06)		32.0 S		27.0 S		
7 (3.60)		28.0 S		17.0 S		
10 (5.14)		15–20 S		12.0 S		

P – Port S – Starboard

Table 9. Horizontal towline angles for a short–hull SSN–637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 4.5 ft (1.37 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions 25 TEU	Rudder Plate A 25 TEU	Rudder Plate B 25 TEU	Rudder Plate C 25 TEU
	0	25 TEU				
4 (2.06)		23.0 S		16.0 S		19.0 S
7 (3.60)		14–26 S		15–20 S		17 S
10 (5.14)		22.0 S		13.0 S		14.0 S

P – Port S – Starboard

Table 10. Horizontal towline angles for a short–hull SSN–637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions 25 TEU	Rudder Plate A 25 TEU	Rudder Plate B 25 TEU	Rudder Plate C 25 TEU
	0	25 TEU				
4 (2.06)		19.0 S	17.0 S	10.0 S	13.0 S	13.0 S
7 (3.60)		16.0 S	15–20 S	12.0 S	11.0 S	15.0 s
10 (5.14)		18.0 S	17.0 S	10.0 S	13.0 S	14.0 S

P – Port S – Starboard

Table 11. Horizontal towline angles for a short–hull SSN–637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 9.60 in. (0.24 m).

Speed kn (m/s)	Horizontal Towline Angle, deg					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		20–25 S	16.0 S	9.0 S	12.0 S	10.0 S
7 (3.60)		14–20 S	16.0 S	11.0 S	14.0 S	11.0 S
10 (5.14)		16–22 S	10.0 S	8.0 S	12.0 S	12.0 S

P – Port S – Starboard

Table 12. Horizontal towline angles for a long–hull SSN–637 class submarine with a trim of 6 ft (1.83 m) down by the stern with Rudder Plate A and the moveable sternplanes at 25 deg trailing edge up.

Speed kn (m/s)	Horizontal Towline Angle, deg			
	Mean = 21.0 ft Draft (6.40 m) GM = 9.6 in. (0.24 m)	Mean = 21.0 ft Draft (6.40 m) GM = 18.63 in. (0.47 m)	Mean = 22.5 ft Draft (6.86 m) GM = 9.6 in. (0.24 m)	Mean = 22.5 ft Draft (6.86 m) GM = 18.63 in. (0.47 m)
4 (2.06)	13.4 S	13.1 S	12.2 S	12.0 S
7 (3.60)	10.9 S	12.1 S	5.2 S	6.0 S
10 (5.14)	9.7 S	9.1 S	8.7 S	5.4 S

P – Port S – Starboard

various speeds, stern configurations and ballast conditions. Only nine of the twelve ballast conditions were tested because unstable model configurations were not repeated at both GMs. For all conditions, when the model was deflected to port or starboard, the model always had an equilibrium towline angle to the starboard side of the centerline. Based on runs with the model rudder adjusted 1 deg starboard, it was concluded that the tendency of the model to tow to starboard was caused by asymmetries in the model rather than instability of the model.

The short-hull SSN-637 model without aft extensions or a rudder plate exhibited undesirable large horizontal towline angles at speeds of 4, 7 and 10 kn (2.06, 3.60 and 5.14 m/s) at all trim, displacement and GM combinations evaluated. Moving the moveable sternplane flaps from 0 to 25 deg TEU reduced the horizontal towline angle slightly. The sternplanes were set at 25 deg TEU for the remainder of the evaluation; alone, and in combination with aft extensions or a rudder plate.

With a full-scale displacement of 3425 LTSW (3,480,000 kg), the short-hull SSN-637 model was unstable for trims of 3.0 ft (0.91 m) and 4.5 ft (1.37 m) down by the stern, at both GMs, with any stern configuration. At a trim of 6.0 ft (1.83 m) down by the stern, the model achieved a stable tow with Rudder Plate A or Rudder Plate B at both GMs evaluated. The horizontal towline angles for Rudder Plate B were approximately 2 deg larger than with Rudder Plate A at each speed. The aft extensions were not effective in reducing the horizontal towline angle, and also added some instability to the equilibrium angle.

When the full-scale displacement for the short-hull SSN-637 was increased from 3425 LTSW (3,480,000 kg) to 3712 LTSW (3,771,500 kg), the resulting horizontal towline angles were similar at each trim. Again, the model was unstable at trims of 3.0 ft (0.91 m) and 4.5 ft (1.37 m) down by the stern, at both GMs, with any stern configuration. At a trim of 6.0 ft (1.83 m) down by the stern, the model achieved a stable tow with Rudder Plate A or Rudder Plate B or Rudder Plate C at both GMs evaluated. At all speeds, Rudder Plate A provided the smaller horizontal towline angles compared with Rudder Plates B or C. Aft extensions were not effective at any trim. The horizontal towline angles at the

3712 LTSW (3,771,500 kg) displacement were generally 2 to 3 deg smaller than the corresponding stern configurations at the 3425 LTSW (3,480,000 kg) displacement. Identical runs with primary and secondary towpoint locations resulted in horizontal towline angles within 1 deg of each other at 4, 7 and 10 kn (2.06, 3.60 and 5.14 m/s).

For the short-hull SSN-637, the effect of GM on horizontal towline angle is shown as a function of elapsed time in Figs. 4 and 5. The effect of trim down by the stern on horizontal towline angle is shown as a function of elapsed time in Figs. 6 and 7. Horizontal towline angle as a function of elapsed time for a sternplane angle of 25 deg TEU, for all stern configurations, is presented in Figs. 8 and 9.

The long-hull SSN 637 horizontal towline angles measured after the model had reached an equilibrium condition are presented in Table 12 for various speeds and ballast conditions. Based on the results from the short-hull evaluation, the long hull was only towed at a trim of 6 ft (1.83 m) down by the stern with Rudder Plate A to confirm that the small extension of the parallel mid-body would not degrade the stable towing configuration achieved with the short-hull model. The horizontal towline angles for the long-hull at both GMs and both displacements were all less than ±15 deg and were within ±5 deg to the horizontal towline angles of the short-hull version in the same configuration.

Full-scale towline tension measurements for the short-hull SSN-637 are presented as a function of speed and stern configuration in Tables 13 through 21 for various ballast conditions. At 4 knots (2.06 m/s), the towline tension did not vary with change of trim or displacement for each stern configuration. At 7 and 10 knots (3.60 and 5.14 m/s), towline tension was generally 5 percent higher for the larger displacement at the same trim by the stern for each stern configuration. With any rudder plate, towline tension at 10 knots (5.14 m/s) was generally 10 percent higher than without a rudder plate. Towline tension with primary and secondary towpoint locations were the same within the accuracy of the measurement.

Full-scale towline tension measurements for the long-hull SSN-637 are presented in Table 22 for various speeds and ballast conditions. The long-hull

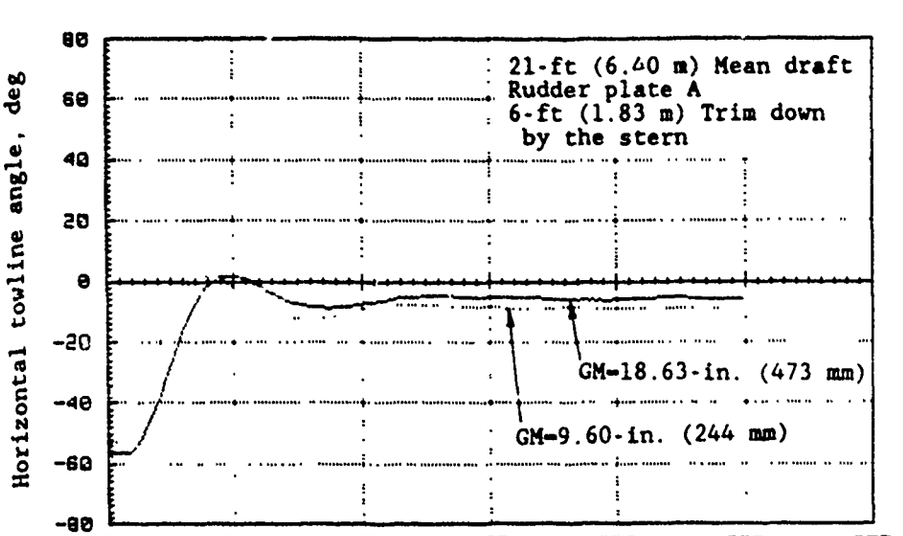


Fig. 4. Effect of GM on horizontal towline angle as a function of elapsed time at a speed of 7 kn (3.60 m/s).

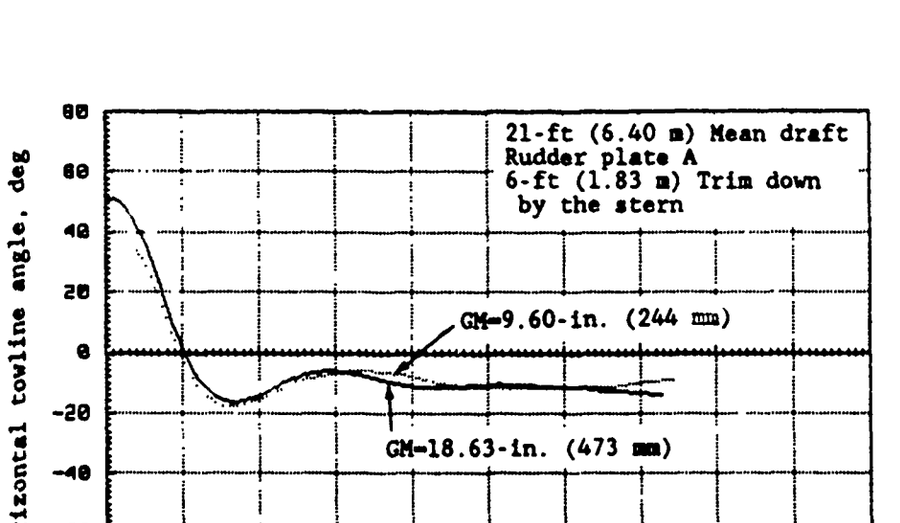


Fig. 5. Effect of GM on horizontal towline angle as a function of elapsed time at a speed of 10 kn (5.14 m/s).

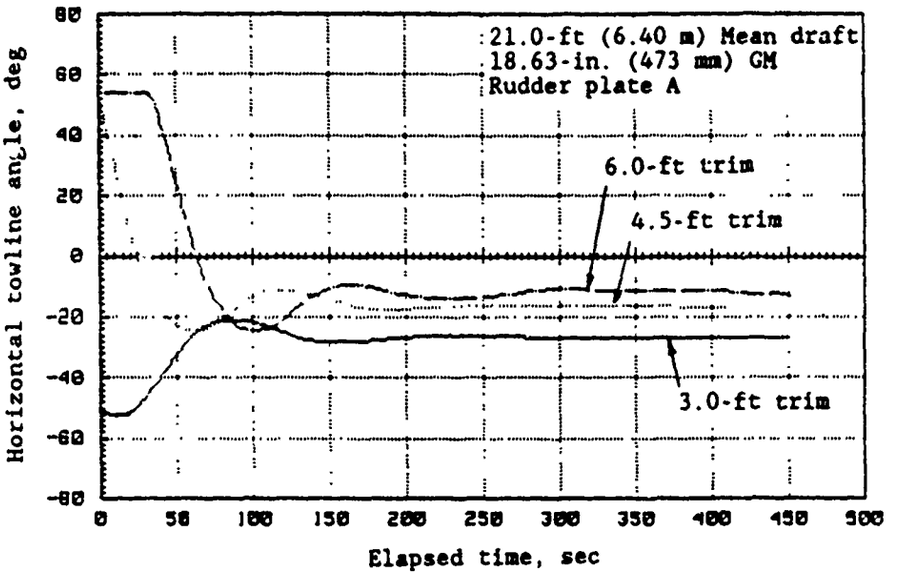


Fig. 6. Effect of trim on horizontal towline angle as a function of elapsed time at a speed of 4 kn (2.06 m/s).

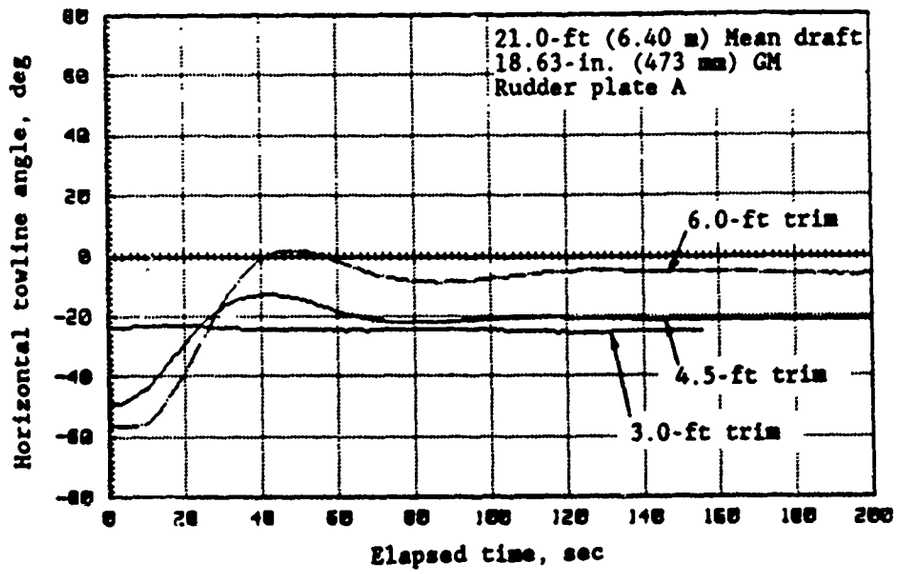


Fig. 7. Effect of trim on horizontal towline angle as a function of elapsed time at a speed of 7 kn (3.60 m/s).

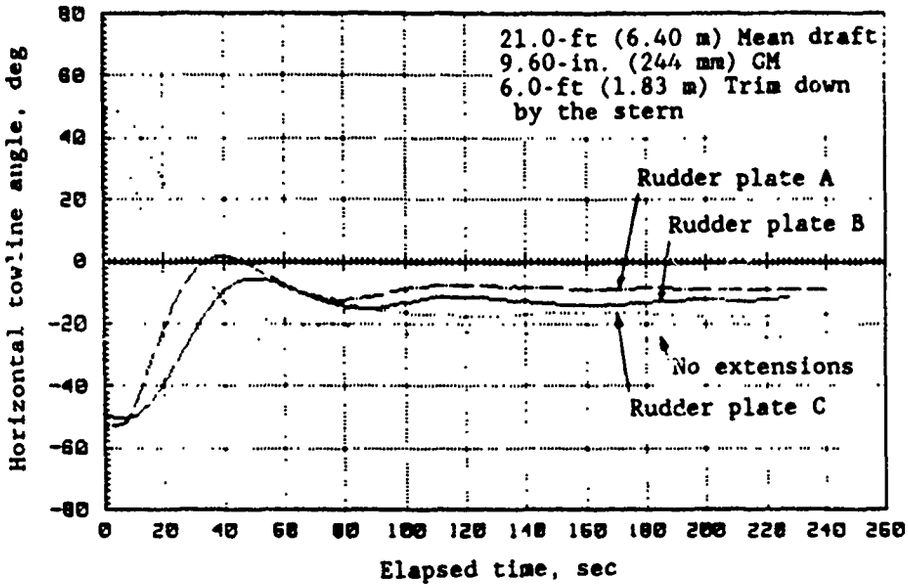


Fig. 8. Effect of stern appendages on horizontal towline angle as a function of elapsed time at a speed of 7 kn (3.60 m/s).

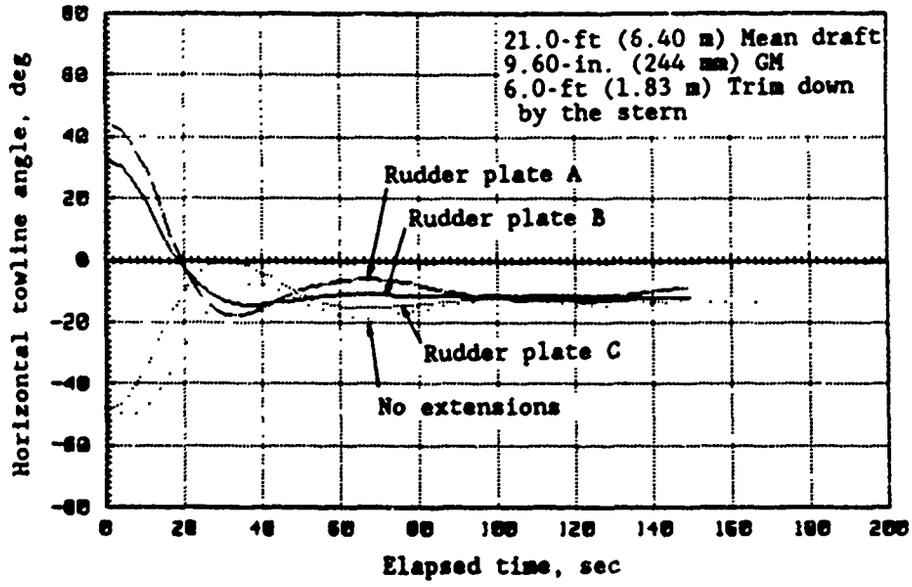


Fig. 9. Effect of stern appendages on horizontal towline angle as a function of elapsed time at a speed of 10 kn (5.14 m/s)

Table 13. Towline tension for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 3.0 ft (0.91 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)	6,200 (27,500)	7,600 (33,900)	7,600 (33,900)	7,600 (33,900)		
7 (3.60)	17,600 (78,400)			21,700 (96,400)		
10 (5.14)	44,300 (197,000)	39,000 (173,700)	40,500 (180,000)	42,600 (189,600)		

Table 14. Towline tension for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 4.5 ft (1.37 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		6,700 (29,700)	6,900 (30,700)	7,100 (31,800)		7,100 (31,800)
7 (3.60)		19,800 (67,900)		20,700 (92,100)		21,000 (93,200)
10 (5.14)		37,100 (165,200)	39,300 (174,700)	41,400 (184,300)		41,900 (186,400)

Table 15. Towline tension for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 4.5 ft (1.37 m) trim down by the stern, at a GM of 9.60 in. (0.24 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		7,100 (31,700)		7,900 (34,900)		
7 (3.60)		20,000 (89,000)		21,200 (94,200)		
10 (5.14)		37,600 (167,300)		41,900 (186,400)		

Table 16. Towline tension for a short–hull SSN–637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		6,400 (28,600)	6,900 (30,700)	7,600 (33,900)	7,100 (31,800)	7,400 (32,800)
7 (3.60)		17,900 (79,400)	18,600 (82,600)	19,300 (85,800)	18,800 (83,700)	19,800 (87,900)
10 (5.14)		36,700 (163,100)	38,600 (171,600)	41,900 (186,400)	40,900 (182,100)	40,000 (177,900)

Table 17. Towline tension for a short-hull SSN-637 class submarine with a 21.0 ft (6.40 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 9.60 in. (0.24 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		6,700 (29,700)		7,100 (31,800)	6,900 (30,700)	7,100 (31,800)
7 (3.60)		18,300 (81,500)		19,800 (87,900)	19,000 (84,700)	20,000 (89,000)
10 (5.14)		36,200 (161,000)		41,900 (186,400)	40,500 (180,000)	41,400 (184,300)

Table 18. Towline tension for a short-hull SSN-637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 3.0 ft (0.91 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		7,100 (31,800)		8,100 (36,000)		
7 (3.60)		19,000 (84,700)		21,000 (93,200)		
10 (5.14)		42,900 (190,600)		47,400 (210,700)		

Table 19. Towline tension for a short–hull SSN–637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 4.5 ft (1.37 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		6,700 (29,700)		7,600 (33,900)		7,600 (33,900)
7 (3.60)		18,600 (82,600)		21,000 (93,200)		20,500 (91,100)
10 (5.14)		41,200 (183,200)		44,000 (195,900)		44,000 (195,900)

Table 20. Towline tension for a short–hull SSN–637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 18.63 in. (0.47 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		6,700 (29,700)	6,900 (30,700)	7,400 (32,800)	7,100 (31,800)	7,100 (31,800)
7 (3.60)		17,600 (78,400)	19,300 (85,800)	20,200 (90,000)	20,000 (89,000)	20,200 (90,000)
10 (5.14)		38,800 (172,600)	40,000 (177,900)	43,300 (192,700)	43,100 (191,700)	42,900 (190,600)

Table 21. Towline tension for a short–hull SSN–637 class submarine with a 22.5 ft (6.86 m) mean draft, with a 6.0 ft (1.83 m) trim down by the stern, at a GM of 9.60 in. (0.24 m).

Speed kn (m/s)	Towline Tension, lb (N)					
	Stern Configuration with Sternplane Angle, deg					
	No extensions		Aft Extensions	Rudder Plate A	Rudder Plate B	Rudder Plate C
	0	25 TEU	25 TEU	25 TEU	25 TEU	25 TEU
4 (2.06)		6,700 (29,700)	6,900 (30,700)	7,400 (32,800)	7,400 (32,800)	6,900 (30,700)
7 (3.60)		17,600 (78,400)	19,000 (84,700)	20,200 (90,000)	20,200 (90,000)	20,200 (90,000)
10 (5.14)		39,000 (173,700)	40,000 (177,900)	43,600 (193,800)	42,600 (189,600)	42,900 (190,600)

Table 22. Towline tension for a long–hull SSN–637 class submarine with a trim of 6 ft (1.83 m) down by the stern with Rudder Plate A and the moveable sternplanes at 25 deg trailing edge up.

Speed kn (m/s)	Towline Tension, lb (N)			
	Mean = 21.0 ft Draft (6.40 m) GM = 9.6 in. (0.24 m)	Mean = 21.0 ft Draft (6.40 m) GM = 18.63 in. (0.47 m)	Mean = 22.5 ft Draft (6.86 m) GM = 9.6 in. (0.24 m)	Mean = 22.5 ft Draft (6.86 m) GM = 18.63 in. (0.47 m)
4 (2.06)	7,200 (32,000)	7,200 (32,000)	7,600 (33,800)	7,600 (33,800)
7 (3.60)	19,400 (86,400)	19,300 (85,900)	19,600 (87,300)	19,300 (85,900)
10 (5.14)	41,200 (183,400)	41,300 (183,600)	43,900 (195,500)	44,000 (195,900)

towline tensions were similar to the short-hull version at the same mean draft, trim and GM to within the accuracy of the measurements.

CONCLUSIONS

The following conclusions are made based on the results of this evaluation:

1. The short-hull and long-hull SSN 637 class submarine with modified bow should be ballasted to a trim of 6.0 ft (1.83 m) down by the stern, with a full-scale GM between 0.80 and 1.55 ft (0.24 and 0.47 m). The mean draft should be between 21.0 and 22.5 ft (6.40 and 6.86 m).
2. To produce a stable towing configuration, a plate 9 ft (2.74 m) wide should be attached to the lower rudder at an angle of 25 deg trailing edge up. The plate area on each side of the rudder is approximately equal to 50 percent of the area of one moveable sternplane. The moveable sternplanes should be set to an angle of 25 deg trailing edge up.
3. Towing stability was not effected by moving the towpoint from the primary to the secondary location.

SUPPLEMENTARY

INFORMATION

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