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RESEARCH

Progress in Reducing the Habitat Impact of Trawls and Dredges

by

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MITSG 99-8

MIT Sea Grant College Program

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Submitted as a Final Project Report to NMFS for the F.I.G. project titled:
Development and Demonstration of a Low-Bycatch, Low-Bottom Impact Trawl for Small-Mesh Bottom Trawling

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Report Title: Progress in Reducing the Habitat Impact of Trawls and Dredges

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Project Title: Development and Demonstration of a Low-Bycatch, Low-Bottom Impact Trawl for Small-Mesh Bottom Trawling

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Abstract:

This report describes a project done by the Center for Fisheries Engineering Research (CFER) aimed at reducing the impact of trawls and dredges on the sea bed. Model tests of a variety of flexible devices were performed, exploring the potential of using hydrodynamic forces to control trawl shape and height in the water column. All of the flexible geometries tested offered some potential but additional refinements would be necessary to apply them commercially in reducing the habitat impact of bottom trawls. Utility in midwater and off-bottom fisheries were demonstrated and some devices showed potential in improving trawl selectivity.

A second phase of the project focused on the development of a sea scallop dredge aimed at reducing the habitat disturbance associated with that fishery. Sea trials of a novel dredge design were done to perfect its operation and catch rates. After several modifications, underwater video of the dredge in action indicated proper performance. The project was terminated before catch rates or habitat impacts could be determined in comparison with a conventional dredge.

Executive Summary

The importance of habitat has only recently been recognized as a key element in achieving sustainable fisheries. As a result, most traditional mobile fishing gear embodies little concern for its effects on habitat. Versatility, durability, and consistency of performance are the long-standing measures of merit. The common reliance on underwater weight to keep gear tending results in unnecessary risk to some habitats. This project explored the potential of using hydrodynamic forces rather than weight as a means of keeping mobile gear fishing. Techniques were applied and evaluated on both trawls and dredges.

The trawl evaluations were done at model scale using one-sixth scale Shuman bottom trawls. A program of testing was performed at the Marine Institute flume tank in St. John's, Newfoundland. Fourteen different configurations were evaluated with data or video observations collected over four days of testing. Included in the test series were sweep kites of various widths and lengths, ribbon foil kites attached to netting panels, triangular mesh kites, and parafoil doors. All of the devices were fabricated by Paul Shuman of Rhode Island.

Significant potential was found with some of the configurations examined and several of the designs showing a clear ability to control trawl shape and its position in the water column. Important features of all the devices tested included their light weight and their ability to be rolled onto a net drum.

The concept of using hydrodynamic force rather than weight was also applied to sea scallop dredge design. The conventional New Bedford scallop dredge is known for its massive weight and its ability to endure some of the hardest bottom. It is recognized as being excessively heavy for many traditional scallop beds. By exploiting depressor plates rather than massive weight, comparable fishing performance may be possible while less damage is imposed on the sea bed.

A dredge design was developed that featured pivoting depressor plates and a five-part sweep. The dredge design does not include the normal cutting bar used to level the bottom in preparation for the common single-part chain sweep. Instead, the four pivoting depressors were designed to keep their portion of the chain sweep in good bottom contact while rising independently to clear obstacles.

A prototype of this innovative dredge was fabricated at Dockside Repair, Inc. in New Bedford, Massachusetts. The dredge was tested aboard the F/V Titan, captained by Robert Kohl, out of Fairhaven, Massachusetts. Numerous modifications were required to get the dredge to perform acceptably. Underwater video observations were able to confirm the desired performance of the pivoting depressors and the conformal, five-part chain sweep. Because of regulatory restrictions, a side-by-side evaluation of the dredge was not accomplished, nor was the reduction in bottom impact quantified. The potential of this novel dredge design remains clear and additional testing of the concept is called for.

The use of hydrodynamic forces as a replacement for weight was shown to have merit at both a model scale applied to trawls and at prototype scale applied to scallop dredges. Further refinement of these concepts hold promise for reducing the habitat impacts of mobile gear.

Purpose.

A. Description of Problem.

The issue of groundfish and juvenile finfish bycatch is of great concern to the fishing industry and to the New England Fishery Management Council (NEFMC). The stated goal of this project was to give resource managers a means to allow whiting and other small-mesh species to be harvested without groundfish bycatch. This was viewed as an important goal as current management measures often exclude small mesh vessels from areas closed to groundfishing, partly due to bycatch. Because some of these closed areas are important whiting grounds, these prohibitions significantly impact the small-mesh fleet. The development of gear that reduced or eliminated groundfish bycatch could alleviate the economic hardship.

The project had an additional goal of developing gear that would reduce habitat impacts. The trawl nets used in today's small mesh fisheries evolved from groundfish nets which were designed to hug the bottom. It should surprise no one that groundfish bycatch is a problem with these nets. Neither should it surprise anyone that these nets are altering habitat that may be essential to a sustainable fishery.

The dual goals of reducing groundfish bycatch and reducing habitat impact were to be addressed by developing a trawl net design that did not have significant contact with the seabed. However, because of the trawling practices common aboard small New England draggers, the option of midwater trawling is economically unfeasible. In addition, many of the small-mesh species such as whiting bottom orient, making true midwater gear inappropriate.

The requirements of such a trawl are very different from conventional bottom trawls where the lower perimeter shape is determined by the plane of the seabed. To meet our objectives, a net is needed with a fishing line that does not require the support of the bottom to maintain shape. Contrary to the time-honored goals of bottom fishing, this net would not follow the irregularities of the bottom. It would not encourage ground fish to rise and pass over the fishing line into the net. It would instead use several wide-spread contact points to regulate the overall height of the net. Fish schooling above the bottom would be vulnerable to this gear, bottom-tending groundfish would not. The hundred feet or so of bottom impact seen in a conventional bottom trawl could, in theory, be replaced by subtle paths of contact with a total width of only several feet.

B. Objectives of Project.

The original goals of this project were:

1) Identify promising trawl designs and rigging techniques for minimum groundfish bycatch and habitat impact.
2) Design and construct a trawl incorporating the features identified in task 1.
3) Perform in-situ observations of the trawl during commercial fishing trials.
4) Determine the catch characteristics of the gear.

Following the model test phase of this project, the focus of the project was broadened to explore techniques for reducing the bottom impact of sea scallop harvesting. Two additional goals were added:

5) Design a sea scallop dredge that achieves bottom tending using hydrodynamic forces rather than weight.
6) Evaluate the design using commercial trials to determine catch rates and to quantify seabed impacts.

Approach.

A. Description of work performed.

The low-impact, low-bycatch bottom trawl

The project began with fact finding focused on collaborations with other researchers having experience in similar projects and in identifying relevant material from the scientific literature on bottom trawl selectivity and habitat impacts.

We began a trawl design process aimed at developing a new trawl for use in the whiting fishery. Through consultations with project participants, other experts, and fishery participants, a preliminary trawl design was developed. The design was an evolution of the concept described in the proposal: the low-impact, low bycatch bottom trawl. A net plan was developed and sized appropriately for the F/V Rams, the dragger that was to be used in the fishing trials.

The four-seam trawl would use midwater doors, thereby eliminating the herding of groundfish caused by conventional trawl doors and rigging. Discrete weights at the corners of the sweep would provide the needed weight to hold the net close to the bottom. These features would both reduce groundfish bycatch and bottom impacts. However, the weight needed to keep the net near the bottom would be substantial based on the geometry and resistance of the system. These weights, while having a narrow footprint on the bottom would be massive and capable of severely impacting the seabed. For this reason, construction of this design in model or prototype scale was delayed. A further complication arose, in that the owner of the F/V Rams entered his vessel in the NMFS buy-out program and its continued involvement in the project was in question.

Instead of remaining focused on a specific trawl design, we began exploring options for reducing or eliminating the weight currently needed to keep trawls in a fishing position. Given the novel nature of this approach, we needed to conduct model tests of a variety of devices that might be capable of yielding the required forces. The following concepts were developed:

1) Sweep modifications to achieve bottom tending while using less weight.
    a) Insertion of a narrow fabric depressing panel between the sweep and fishing line of the net.
    b) A wide depressor panel that can have sub-panels added or removed to control the overall hydrodynamic forces.

2) Fabric ring foils to enhance the net opening and thereby reduce or eliminate the need for spread to be provided by conventional trawl doors. Four locations deserve exploration:
   - a) On the side panel adjacent to the front of the square.
   - b) At the fishing circle extending from one side panel lower gore to the other.
   - c) At the mid-belly extending from one side panel lower gore to the other.
   - d) Annular ring foil at the mid-portion of the trawl and behind the tail piece.

A test session was scheduled for the week of September 8-12, 1997 at the Marine Institute flume tank in St. John's Newfoundland. Models of a 2-seam and a 4-seam bottom trawl were used to evaluate the performance of these flexible hydrodynamic devices to control the shape of the trawl and its position with respect to the seabed. The following tests were completed and the results are presented in the Findings section of this report.

Date 9-8-97

Series 1 - 1/6 scale Shuman 2-seam trawl with 14 floats, 4.16 m bridles, 2.64 m ground wire and fitted with a 1" full-width sweep kite. Eleven runs at three speeds, three spreads, on and off bottom, two kite settings.

Series 2 - 1/6 scale Shuman 4-seam trawl with 14 floats, same tow wires as series 1, annular kites in 4 locations. Initial run then second run with headrope kite instead of floats.

Series 3 - 2-seam model with 14 floats, same tow wires as series 1, and fitted with a 2" full-width sweep kite. Ten runs at three speeds, three spreads, on and off bottom.

Date 9-9-97

Series 4 - 2-seam model with 14 floats, same tow wires as series 1, with bare fishing line. Ten runs at three speeds, three spreads, on and off bottom.

Series 5 - 2-seam model with 14 floats, same tow wires as series 1, and fitted a segmented, variable-width sweep kite. Ten runs at three speeds, three spreads, on and off bottom.

Series 6 - 4-seam model with 5 floats, headrope kite, same tow wires as series 1, annular kites in 4 locations. Two runs at two different spreads.

Date 9-10-97

Series 7 - 2-seam model with 14 floats, same tow wires as series 1, after adjustments made to its reduced-size segmented, variable-width sweep kite. Ten runs at three speeds, three spreads, on and off bottom.

Series 8 - 2-seam model with 14 floats, no headrope kite, same tow wires as series 1, after more adjustments were made to its reduced-size segmented, variable-width sweep kite. Three runs at three speeds.

Series 9 - 4-seam model with 2 floats, no headrope kite, same tow wires as series 1, and lift panels added to side panels. Three runs at three speeds.

Date 9-11-97

Series 10 - 4-seam model with 2 floats, no headrope kite, same tow wires as series 1, remove belly annular kite, add top and side annular kite to front of square. Four runs at three speeds and two spreads.

Series 11 - 2-seam model with 14 floats, no headrope kite, same tow wires as series 1, a reduced-size segmented, variable-width sweep kite and an array of triangular lifting panels on upper netting panels. Eleven runs at three speeds, three spreads, on and off bottom.

Series 12 - 4-seam model with 2 floats, no headrope kite, same tow wires as series 1, adjust angle of attack of codend and port annular kites. Four runs at three speeds and two spreads.

Series 13 - 4-seam model with 14 floats and no lifting devices. One run.

Series 14 - 4-seam model with 14 floats and parafoil kites positioned at various locations. Numerous runs with multiple adjustments.

The low-impact sea scallop dredge

As with bottom trawls, mitigating bottom impact by reducing the underwater weight of sea scallop dredges holds promise. The New England sea scallop fishery is noted for its heavy gear and the significant and lingering nature of bottom disturbance left in its wake. Over recent years, typical dredge weight and towing speeds have increased dramatically to 5-6,000 pounds and 4 to 5 knots. This evolution has been in response to the desire to broaden the range of towable bottom and to keep the dredge to bottom while covering more ground per hour of fishing.

With the concurrence of the NMFS project monitor, the scope of the project was expanded to include the development of a low-impact sea scallop dredge. A design was developed aimed at exploiting hydrodynamic force to maintain bottom contact, rather than simply weight.

As shown in Figures 1 and 2, the new design employs the triangular tow frame common locally, but departs radically in the portions of the dredge that contact the bottom. The outer frame sides and their shoes drag along the bottom. The main portion of the dredge, where the cutting bar would normally level the bottom, is fitted with pivoting supports that are held to bottom by hydrodynamic force rather than weight. These supports therefore conform to the bottom yet can rise to clear obstacles. The sweep is supported by longitudinal chains which are connected to the pivoting supports. Therefore, the sweep is lifted clear of obstructions while the remainder is allowed to conform to the bottom.

An 8-foot-wide prototype design is shown in Figure 3 and it was constructed by Dockside Repair of New Bedford, MA. It was fitted with a regulation 3.5-inch chain bag and regulation 5 1/2-inch twine top. It was also adapted for the mounting of underwater cameras to facilitate *in-situ* viewing.

Arrangements were made to test the dredge in comparison with a standard dredge design aboard the F/V Titan, permit No. 330774, of Fairhaven, MA. The charter of the vessel by MIT was to be conducted as a scientific cruise and therefore to be exempt from normal fishing regulations. Letters of authorization were requested from the Massachusetts DMF and the NMFS Regional Administrator. A letter was provided by the Massachusetts Division of Marine Fisheries to facilitate the use of two dredges aboard the F/V Titan in state waters.

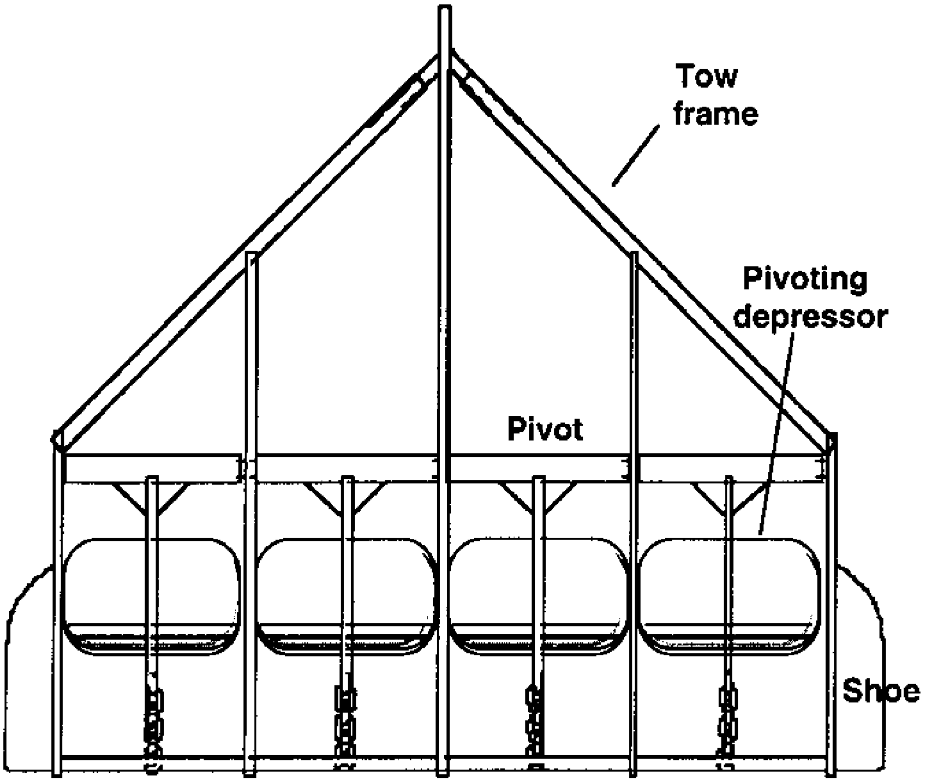

Figure 1. The habitat dredge top view.

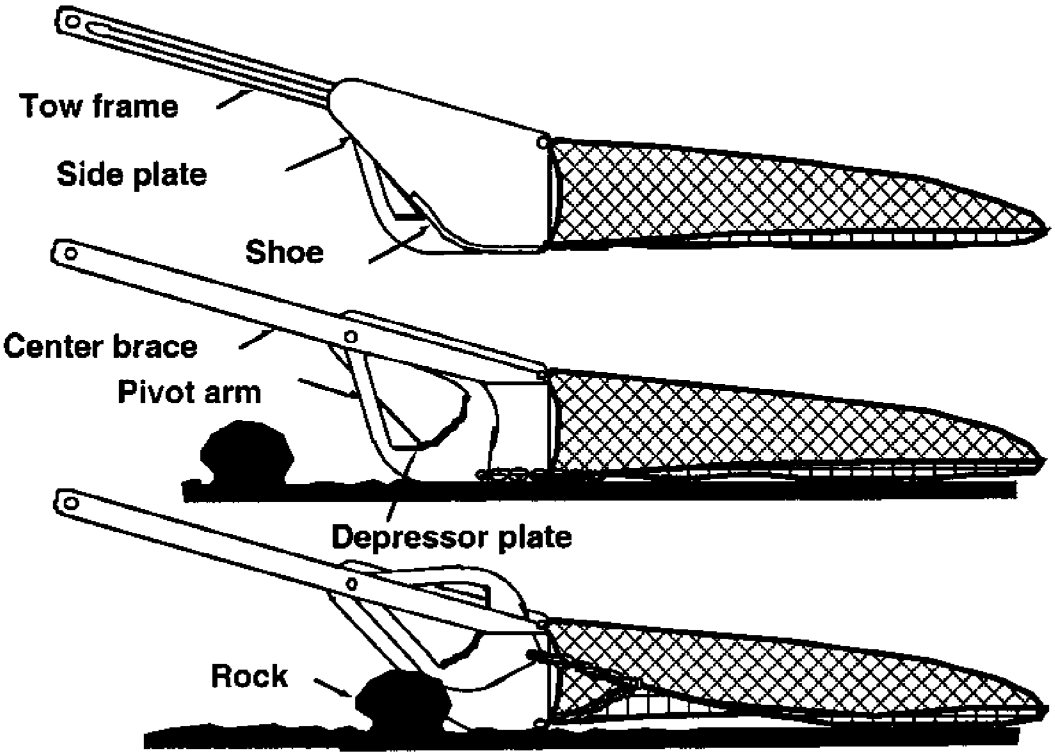

Figure 2. The habitat dredge, side view.

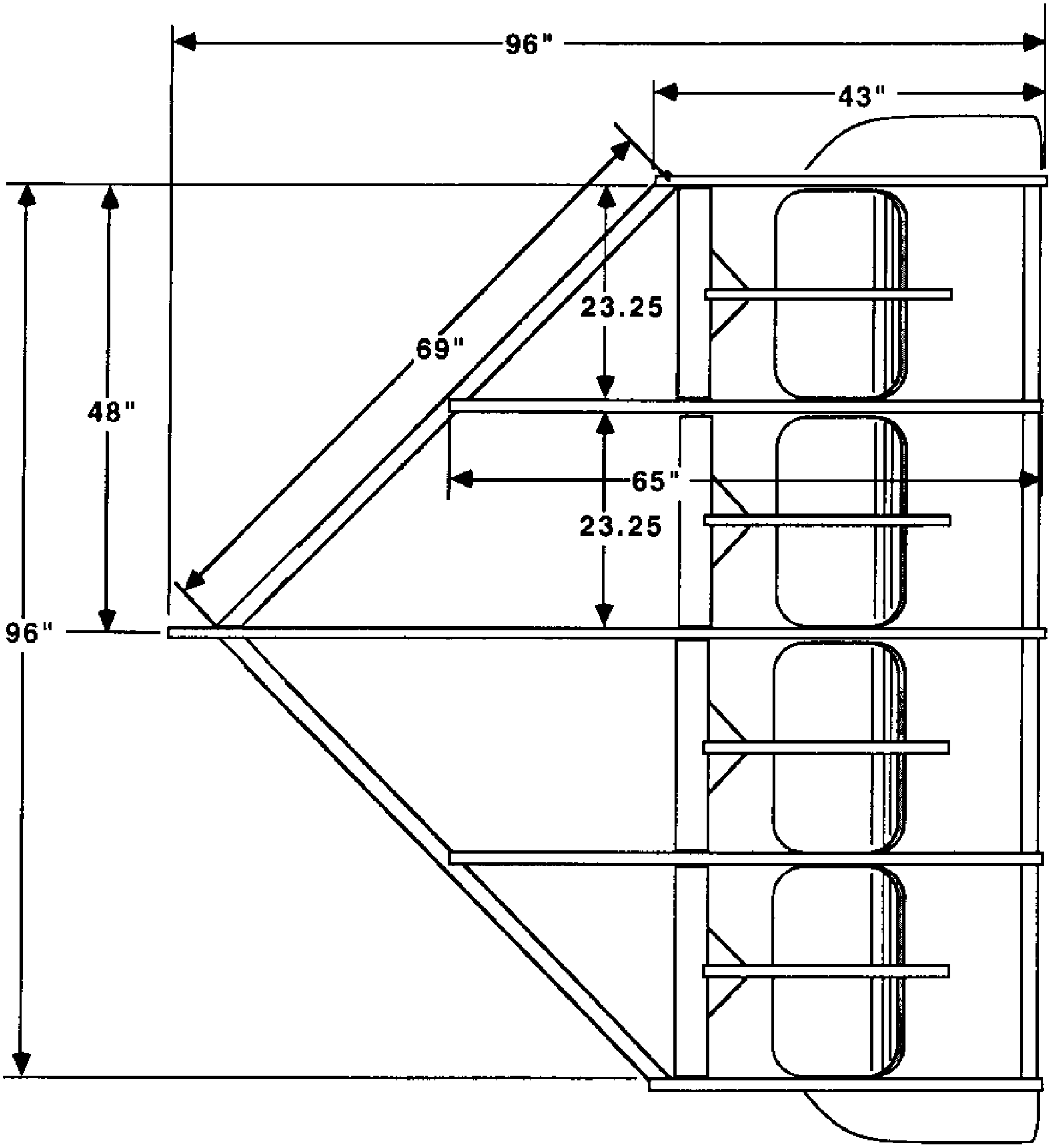

Figure 3. Eight-foot-wide prototype habitat dredge.

Sea trials of the habitat dredge began on June 15, 1998 and continued intermittently through 6 August. A total of six at sea days were used as well as four in-port days when on-deck modifications were done to the dredge. On two occasions the dredge was transported to Globe Iron Works, in Somerville, for major modifications.

Initial efforts focused on getting the new dredge to set properly since its weight distribution and hydrodynamics differed greatly form the standard dredge. The task was important because without a consistent setting process, camera gear could not be risked. Ultimately, an awkward technique was used to set the dredge upright on the bottom while hove-to, and then the vessel could steam away. Some footage was obtained this way on the first trip.

Shop modifications involving altering the shape of the dredge side plate, the angle of the depressor plates, and the removal of steel from the side plates to lighten the dredge. These changes did nothing to improve the setting of the dredge. A final modification where part of the frame was covered with plating provided consistent setting. Observations of the dredge were made with cameras facing forward and towards the sweep chain. Good tending was observed as the depressor surfaces forced the pivoting arms to the seabed while accommodating topography and rocks.

The following work was done aboard the F/V Titan under this plan:

Date	Description
June 11	Dredge gear rigging, Fairhaven
June 15-16	Cape Cod Bay dredge trials
July 14	Dredge modifications & repairs, Somerville
Jul. 15-16	Cape Cod Bay dredge trials
July 17	Dredge repairs & de-rigging, Fairhaven
4 Aug.	Dredge modifications, Somerville
5 Aug.	Buzzards Bay setting tests
6 Aug.	Stellwagen Bank tests (new dredge only)

Table 1. Schedule of habitat dredge vessel operations.

We now needed to compare the performance of the two dredges on productive scalloping grounds. Testing and adjustments of the dredge were needed to achieve catch rates comparable to the conventional design. This required side-by-side towing of the new and the conventional dredges on grounds that have sufficient scallops. Once parity was achieved, additional tests would compare the disturbance to the seabed associated with the passage of each dredge. Again, side-by-side towing would facilitate this process, followed by cross-path observations from a camera sled.

The hypothesis to be tested was that a dredge that utilizes hydrodynamic force rather than dead weight and a conformal sweep chain rather than a cutting bar would cause less physical alteration to the seabed compared to a conventional dredge. However, the project was denied a letter of authorization by the NMFS Regional Director for conducting the experiments in federal waters.

B. Project Management.

This project was be managed by Clifford A. Goudey, project director for the MIT Sea Grant Center for Fisheries Engineering Research. He was responsible for the overall project management, the design of innovative harvesting gear, the conducting of model tests and sea trials, data analysis, and project reporting.

Assisting in the initial trawl gear design process was Gary Loverich of Nor'Eastern Trawl Systems of Bainbridge Island, WA. Model construction was done by Paul Shuman of R.I. Paul also assisted in the conduct of the model tests at the Marine Institute in St. John's, Newfoundland.

The commercial trials of the sea scallop dredge were done aboard the F/V Titan, captained by Robert Kohl. Captain Bob's assistance in the dredge evaluation and modifications were critical to this aspect of the project.

Findings.

A. Accomplishments and Findings.

Previous and current work on improving the species selectivity of bottom trawls has focused on modifications to trawls that were originally designed to catch groundfish. Many gear selectivity improvements have sought to reduce the inherent effectiveness of these fishing systems in several ways:

1) Facilitate the downward escapement of some fish by reducing the extent and intensity of bottom contact of the sweep and fishing line (cut-away lower wings, lighter sweeps, longer dropper chains, sweep/fishing line adjustments).
2) Improve the escapement of some fish by increasing the mesh size in parts of the trawl (large-mesh lower wings, belly escapement panels).
3) Improve the escapement of all fish by increasing mesh opening (square-mesh codends and extensions, tight rib lines, hoops).
4) Improve the escapement of some fish by introducing devices and apertures (bycatch reduction devices, holes).
5) Improve the escapement of some fish by introducing sorting devices to eject or separate animals by size and shape (Nordmore grate, TEDs, trawl curtains).

Some of these approaches have yielded improvements, especially when there is a significant difference between the target species and the bycatch species. For example, TEDs and Nordmore grates have exploited the size and behavioral differences between shrimp and sea turtles, and shrimp and fish, respectively. However, other efforts have resulted in minor or no improvements or have called for overly-complicated modifications and devices that lack practicality in a commercial setting.

The lingering difficulty in the task of reducing groundfish bycatch in a trawl fishery is that traditional trawl designs are, by design and optimization, excellent at catching groundfish. A relevant analogy is the current interest in making hand guns safer.

The significant reduction of groundfish bycatch in demersal fisheries may require the adoption of gear other than the groundfish trawl. This does not mean the abandonment of trawling and the obsolescence of a fleet. Instead it can mean an approach to trawling which does not begin with the typical bottom trawl.

Through continued liaison with other project participants and with external experts, a concern surfaced that impacted the project. It was suggested by several knowledgeable persons that because of the days-at-sea limitations imposed by Amendment 5 and Amendment 7, many vessels are entering the exempted small-mesh fisheries with the intention of continuing to land groundfish. Inadequate enforcement of landings and at-sea transfers makes this possible.

This realization added complication to the project: that the gear needed to be tamper-resistant. In other words, achieving a net design that would meet bycatch limits imposed by NEFMC or DMF would be meaningless if fishermen could alter this gear to target groundfish.

The bottom trawl has evolved considerably over its many decades of use. However, the introduction of lightweight synthetic twine, more effective doors, more vertical opening, four and six seam designs, and more adventurous roller gear has not altered its fundamental operating principals. They are:

1) Get the gear to the bottom using the weight of the doors and the sweep.
2) Achieve horizontal width using trawl doors.
3) Herd fish from between the doors into the path of the net using ground wires and a mud cloud.
4) Prevent upward escapement using the overhang of the top square.
5) Prevent sideways escapement using wings and jibs.
6) Prevent escapement under the trawl by maintaining consistent contact with the bottom along the bottom perimeter of the mouth opening.
7) Overtake the fish and as they tire and, as they fall back towards the rear portions of the net, prevent the escapement of marketable fish.

These principles combine to frustrate most attempts to reduce groundfish bycatch which typically offer escapement opportunities well after groundfish have been caught. By revisiting these principles and using those that are essential to the target species, a trawl can be designed to be commercially viable yet ineffective on groundfish.

Bottom impacts of trawl nets are associated with principles 1, 2, 3 and 6. It is likely that an approach to bycatch reduction that does not depend on these principles would have little or no physical impact on the seabed.

Instead of weight to keep a trawl to bottom, the use of a flexible depressor to generate hydrodynamic force was considered. The precedent for this approach is the success seen in some fisheries where the buoyancy of headrope floats have been replaced with headrope kites. This idea was first perfected by CFER during the S-K sponsored trawl net training courses in 1985 (Goudey, 1985). It was further exploited by CFER in an S-K sponsored project which developed a semi-pelagic squid/butterfish trawl in 1987 (Goudey, 1987). Today these rectangular panels of fabric are common on high-opening and midwater nets up and down the U.S. east coast.

A similar approach could be used for the bottom of the net and if it is successful, several useful features could result.

1) Trawl performance would be less dependent on vessel speed. As with the headrope kites, the hydrodynamic lift of these depressor panels would vary closely with hydrodynamic drag. Trawl geometry would be relatively stable, regardless of towing speed and tidal currents.

2) The trawl net would be much lighter that conventional rigs because there would be less dependency on weight to keep the net at the bottom. The

hauling and handling of the net on deck would be much easier and the impact on the seabed would be greatly reduced.

3) The awkward sweep and rollers associated with conventional nets would be eliminated, easing the bulk and the safety hazards associated with rolling this gear on a net drum.

Model Test Results

Model tests were performed and comprehensive data was recorded on all the test series including the heights and widths at all critical locations on the model. These data are presented in Appendix I.

The procedure for most of the tests was to deploy the model trawl with the flexible lift devices installed. If the devices were adjustable, they were set at an initial arbitrary setting. The performance of the device would be quickly assessed and adjustment were made as needed to obtain meaningful performance.

For example, it took several adjustments of the leading edge cable to get the sweep kites to assume a useful angle of attack. Data was collected once the performance was judged to meet the intended purpose. Data was generally not taken on configurations that seemed dysfunctional.

We used two trawl models for our test program; a two-seam Shuman bottom trawl and a four-seam Shuman bottom trawl. Both models had similar fishing circles and were built to one-sixth scale. In previous tests, these models showed very similar performances with respect to gross geometry (Goudey, 1985).

To make the best use of test-tank time, we alternated from one model to the other, testing one while the other was undergoing device changes. The final test on each trawl was to measure its performance bare, with only its normal flotation.

Summary of configurations tested:

1) Sweep kites.

The sweep kites were tested on the two-seam model. This trawl is pictured in Figure 4 with its standard arrangement of 14 floats. In this figure, the sweep and lower leg of the trawl are horizontal, streaming directly behind the towing points.

In Figure 5, the net has been fitted with a uniform one-inch-wide sweep kite extending along the full length of the fishing line. This installation is detailed in Figure 6 where its attachment to the fishing line can be seen in the vicinity of the starboard bosom. The adjustment cable runs through its leading edge and terminates at the wingend. A triangular plate and a length of adjusting chain allows the tightness of the kite and its angle of attach to be optimized. As seen in Figure 5, this arrangement provided a much larger vertical opening to the trawl and it pulled the center of the sweep well below the level of the tow points.

In Figure 7, we see a detail of three-inch-wide discrete kite panels. This view is the center section of a variable-width sweep kite that showed exceptional performance as shown in Figure 8. As detailed in Figure 9, this combination of 3", 2" and 1" widths covered only the central portion of the sweep and provided the greatest depressing force of all configurations tested.

All configurations tested would pull the trawl to the bottom if the tow points were lowered sufficiently. The leading edge of the kite would be the first to contact the seabed. Upon further lowering of the tow points, the kite would flatten and begin to flog about, in some cases reversing its orientation and lifting the sweep.

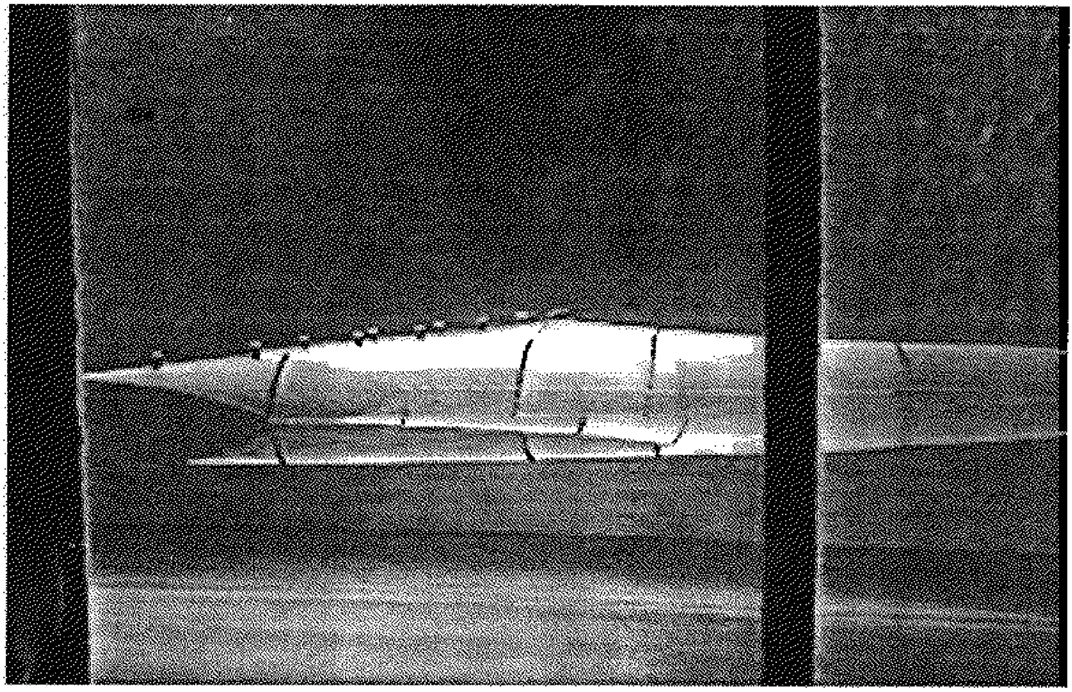

Figure 4. Two-seam Shuman bottom trawl with no sweep.

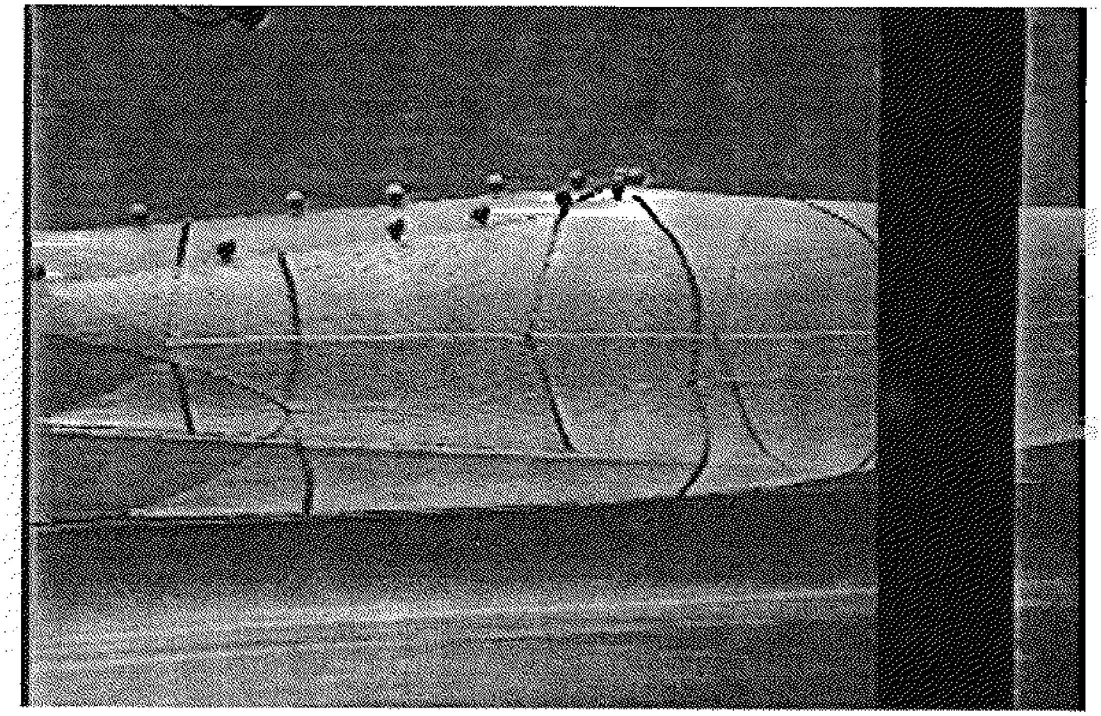

Figure 5. Uniform 1" wide sweep kite along entire fishing line.

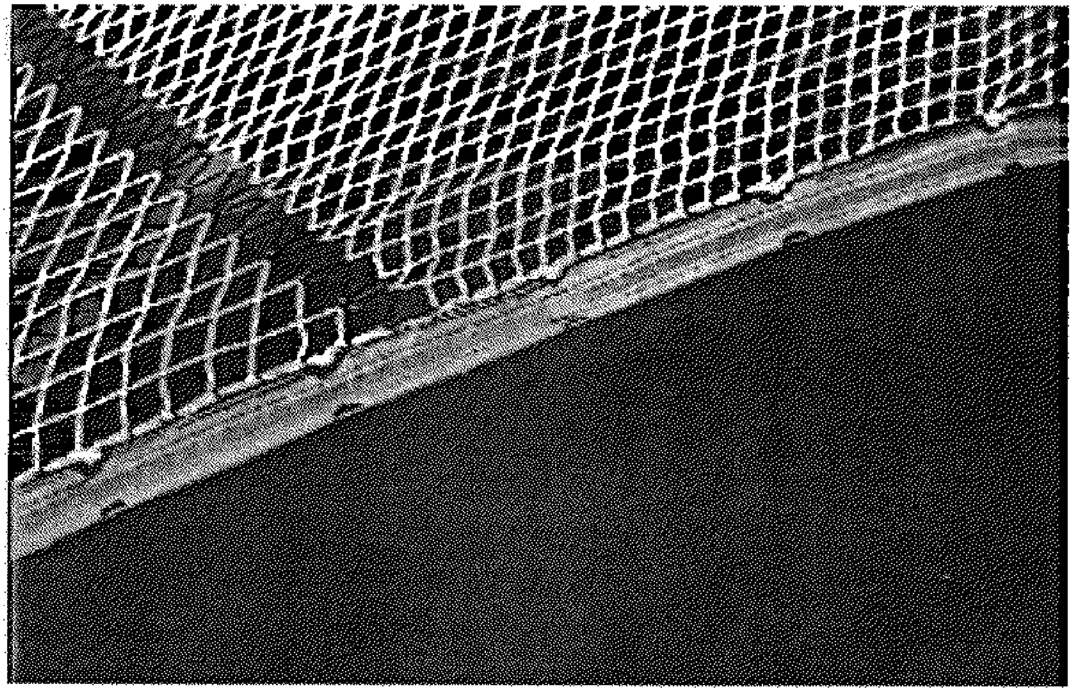

Figure 6. Detail of 1" sweep kite along starboard bosom and wing.

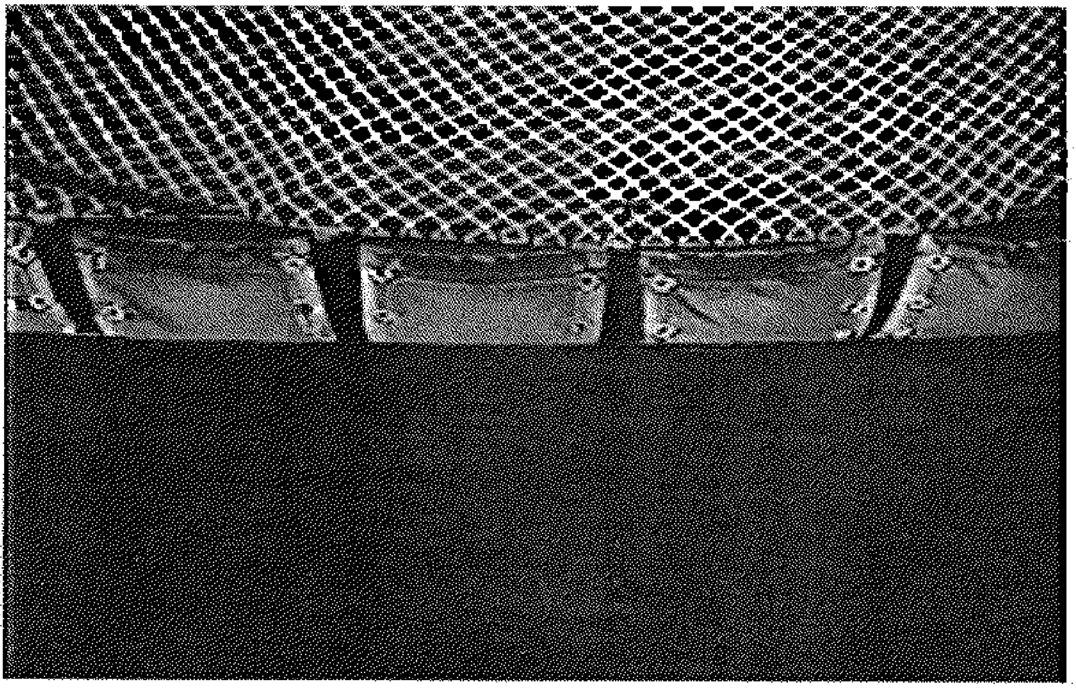

Figure 7. Detail of center portion of 3" wide sweep kite.

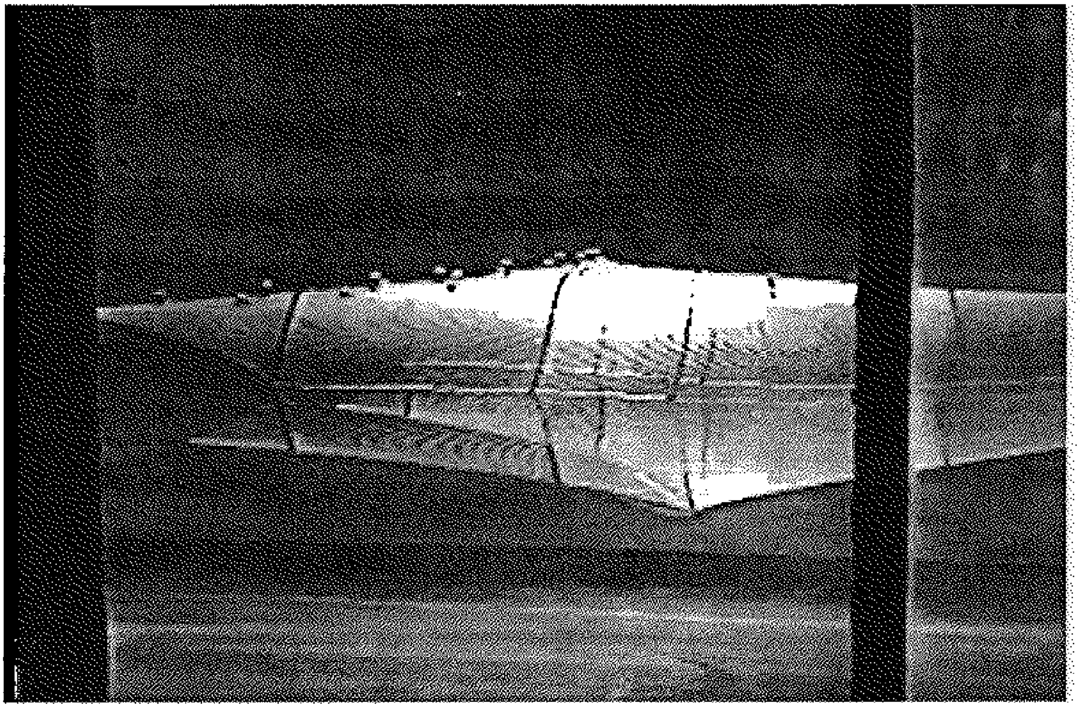

Figure 8. Tapered sweep kite.

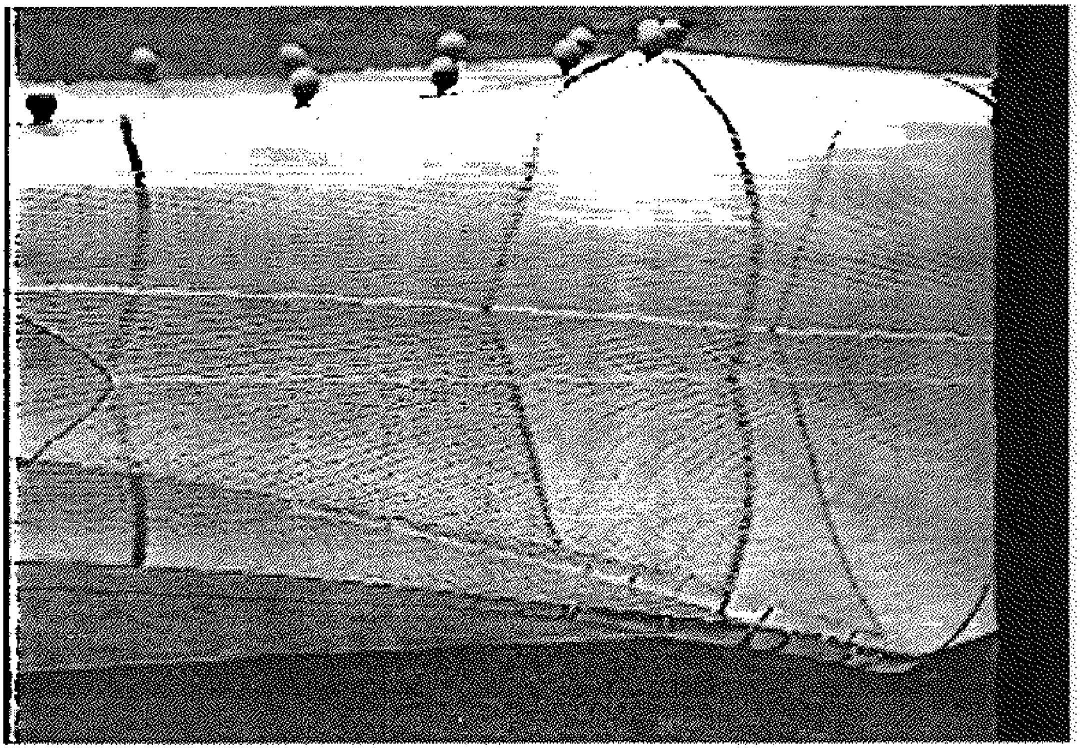

Figure 9. Detail of 3", 2", and 1" kite placement.

2) Ribbon-foil kites.

The ribbon-foil kites were designed to provide lift that would open the trawl in a direction normal to the plane of the netting panel on which they were installed. They are made of fabric panels that are scalloped into a configuration that allows the fabric to billow back to intercept the water flow. They can be attached to netting and therefore can be mounted anywhere additional opening is desired.

Our first tests on these devices included an array of installations starting with short length at the front of each side panel above the bosom. These were followed by a continuous band at the front of the first belly that encompassed both side panels and the top panel. These two installations are shown in Figure 10. A noticeable increase in vertical opening at the fishing circle can be seen, attributable to the devices.

Figure 11 shows a subsequent arrangement where the continuous ribbon kite has been moved forward to the front of the square and additional side-panel units have been added to the wings. Note that the vertical opening of the trawl is achieved by the ribbon kites as all but two floats have been removed.

The installation of these devices further back in the net seemed to provide greater effects. Figure 12 shows a circular ribbon foil kite installed at the intersection of the first and second bellies. This device provided a generous increase in crossectional area compared to the normal shape. Because of the natural tapering of the net in that location, the ribbon foil assumed an aggressive angle of attack giving the model the appearance of having a rigid hoop holding it open.

Equally interesting results were seen with a small ribbon kite installed between the extension and the codend. A dramatic opening of the meshes occurred, increasing the crossectional area to approximately double is normal size.

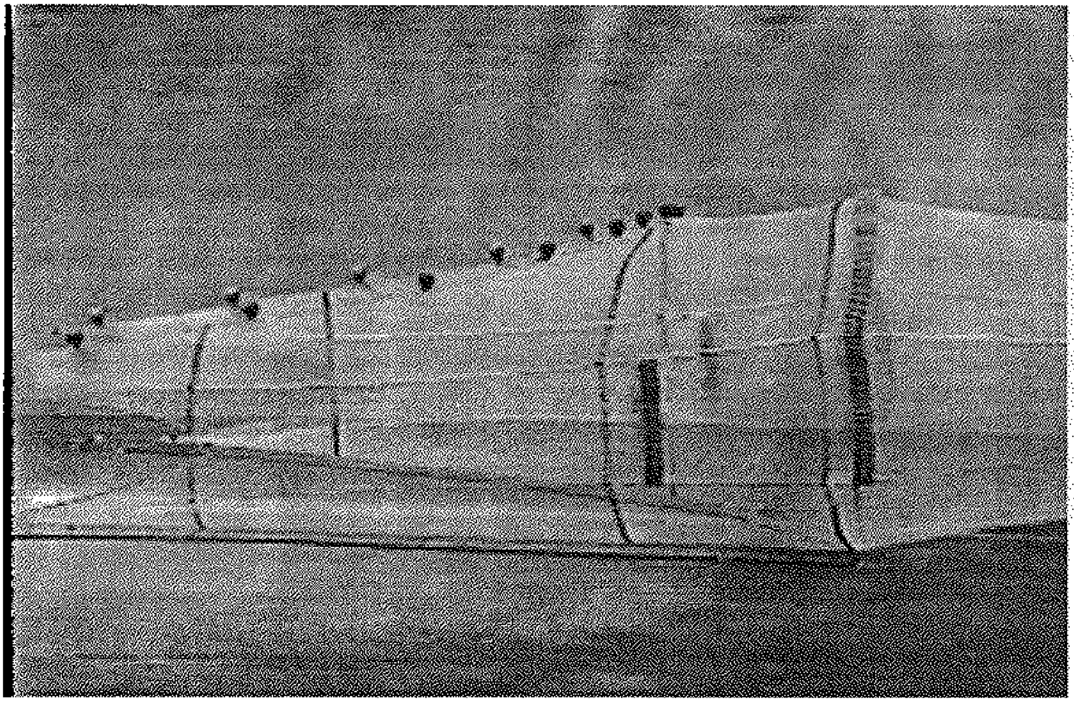

Figure 10. Four-seam Shuman trawl with "ribbon-foil" kites installed.

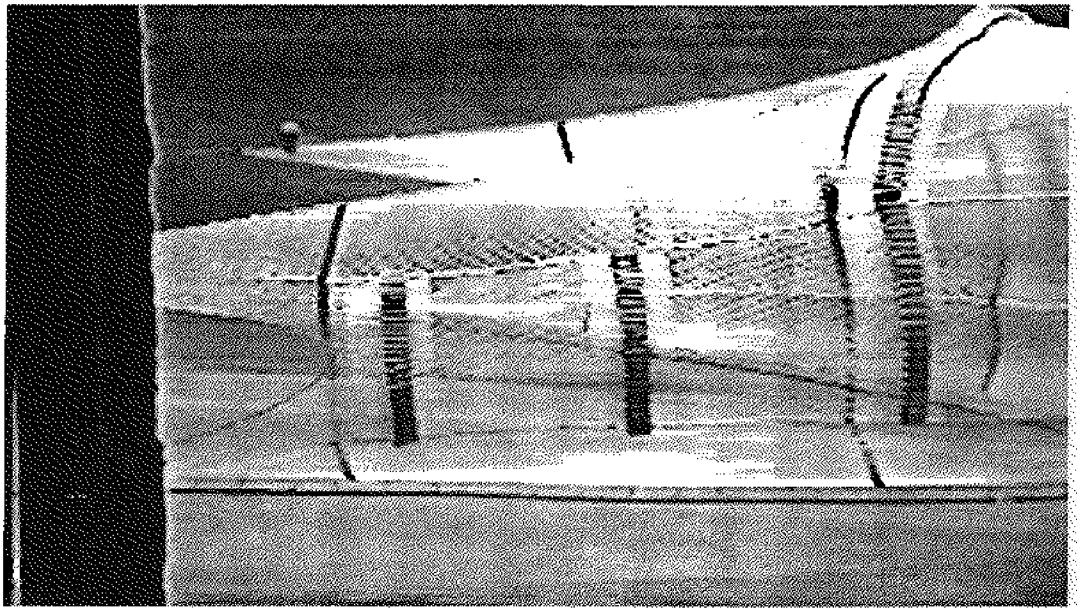

Figure 11. Ribbon foil kites moved forward and one side-panel unit added.

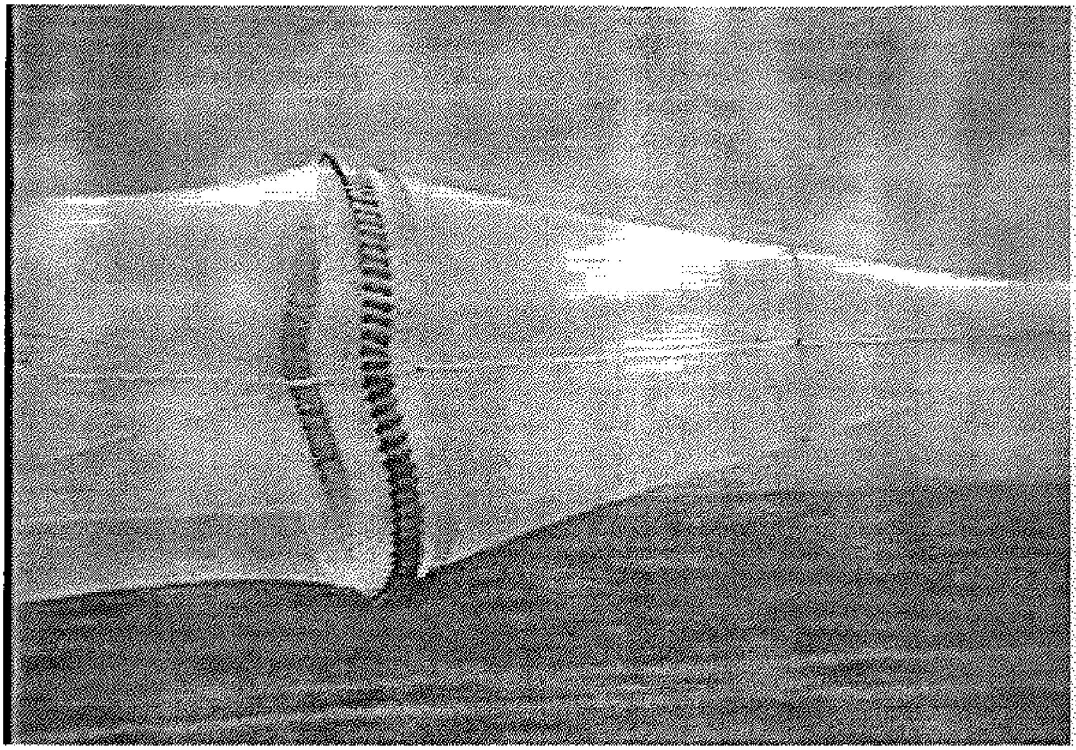

Figure 12. Circular ribbon foil kite at intersection of first and second bellies.

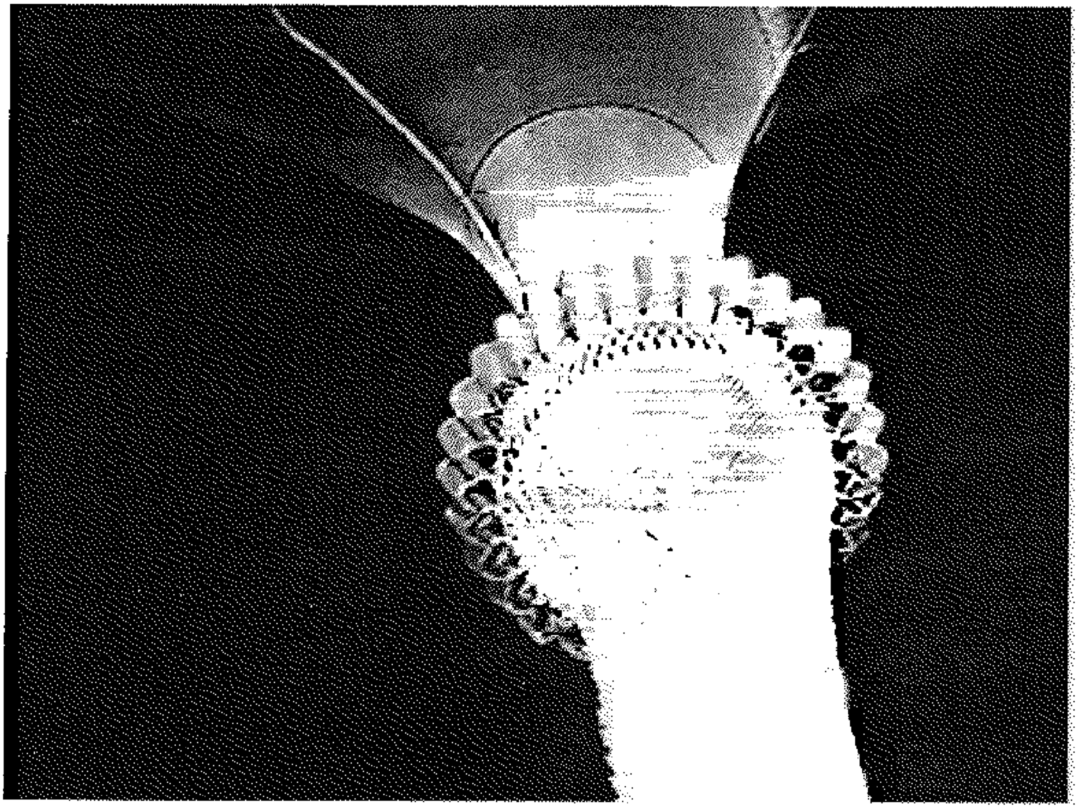

Figure 13. Tail piece ring foil viewed from behind.

3) Triangular mesh kites.

These devices are simple triangular pieces of fabric that are attached to netting along a bar edge. The angle of attack of the units can be controlled by the angle specified between the two sides of the fabric. The units tested were cut at either 90° or 60°, and both scooped out acceptably, providing lift. Figure 14 shows a single unit placed along the top edge of the port wing. This unit was cut at 90° and sets well at the bar angles seen in this portion of the trawl.

Figure 15 shows an array of 60° mesh kites places along the middle of the square. These devices are small and their effects are subtle. Significant numbers of them would be needed to make substantive changes in the trawl's geometry. However, their potential and their fool-proof performance were demonstrated.

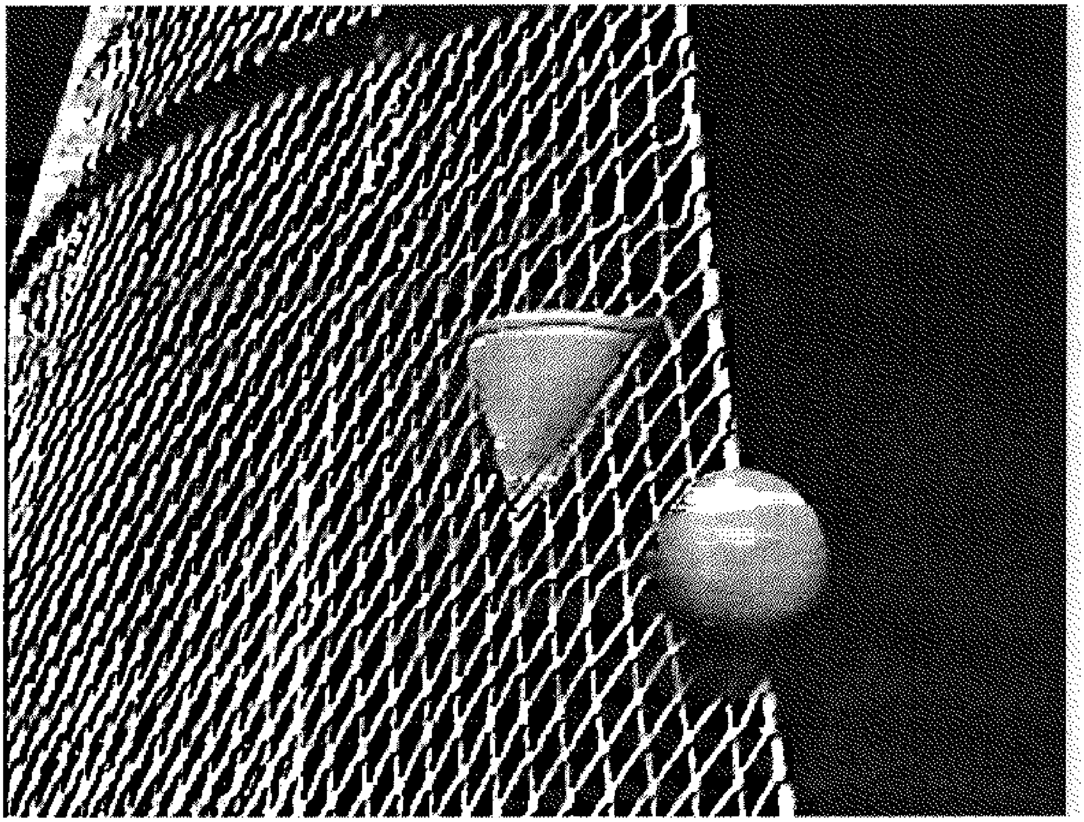

Figure 14. Triangular mesh kite installed in top port wing.

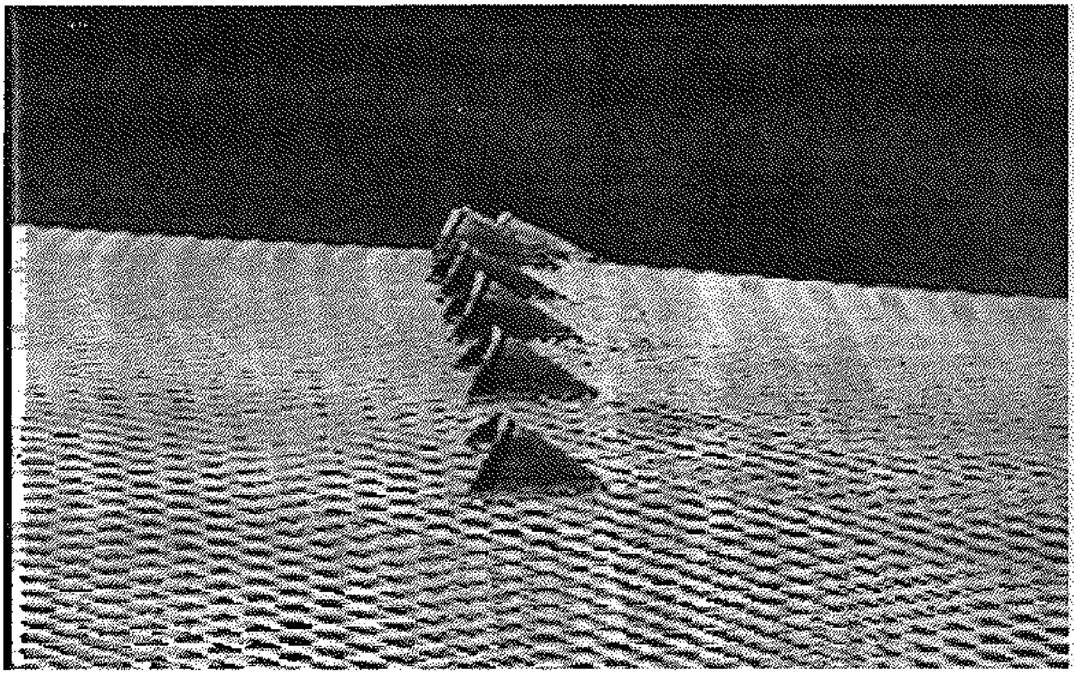

Figure 15. An array of mesh kites at rear of top square.

4) Parafoil trawl doors.

The conventional trawl door is an obvious candidate for possible replacement with a flexible fabric lifting device. To evaluate the concept, we adapted parafoil kite technology common in sport kites and parachutes. Our design is a cellular fabrication of fabric that has an open leading edge that inflates the device to a specified thickness and camber.

We tested the units by first mounting them at the trawl's wingend. Figure 16 views an installation on the port wing from the inside the trawl's mouth. Here, the 10" x 8" parafoil door has been attached to the Vee framing line. A substantial spread increase was noted. Figure 17 is a top view of the same installation.

These devices can be flown from a single attachment point as shown in Figures 18 and 19. The angle of attack in such installations is controlled by the relative lengths of the multiple bridles that converge to the attachment line. In Figure 19, two small floats were inserted into the side chamber of the kite, resulting in an outward bias to the two units. In this way, both spread and lift were applied to the top wing tips.

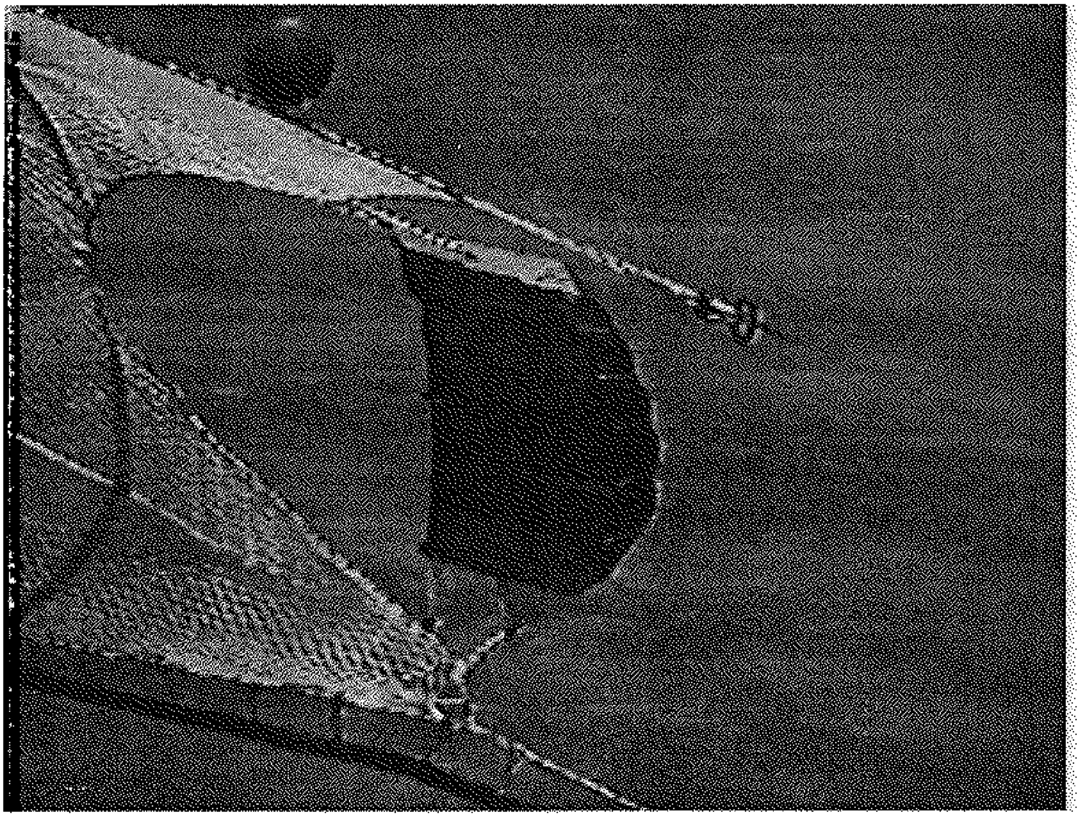

Figure 16. Parafoil door installed on port wing of four-seam Shuman trawl.

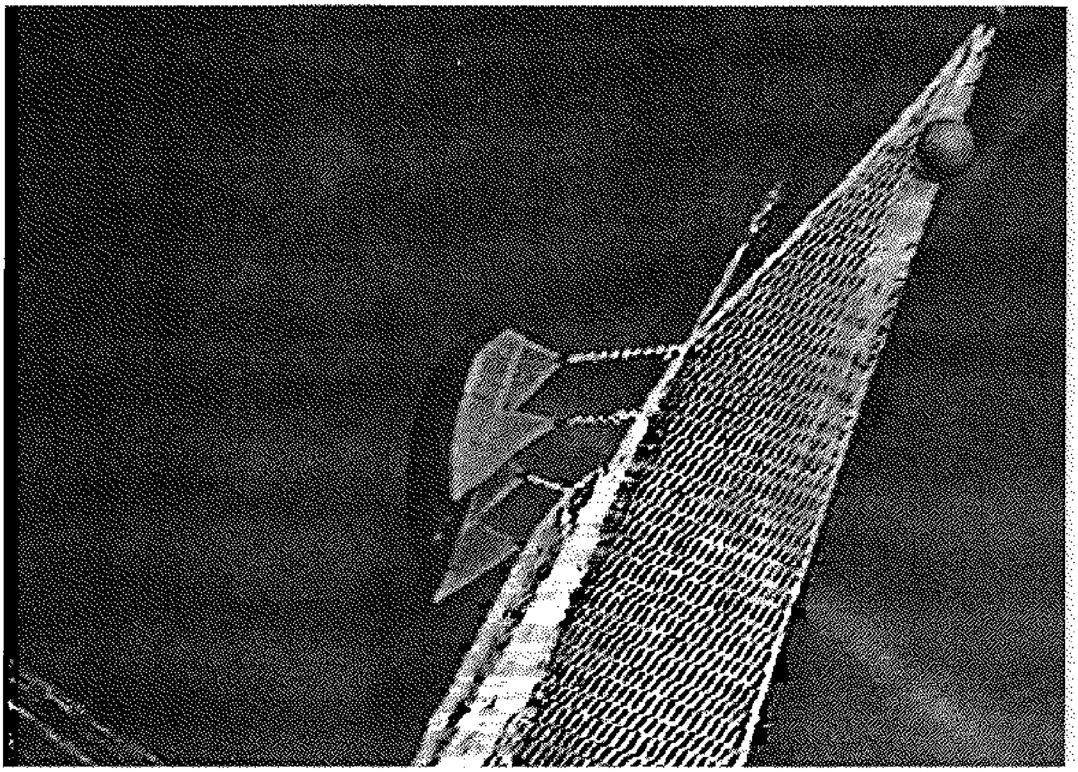

Figure 17. Top view of parafoil door.

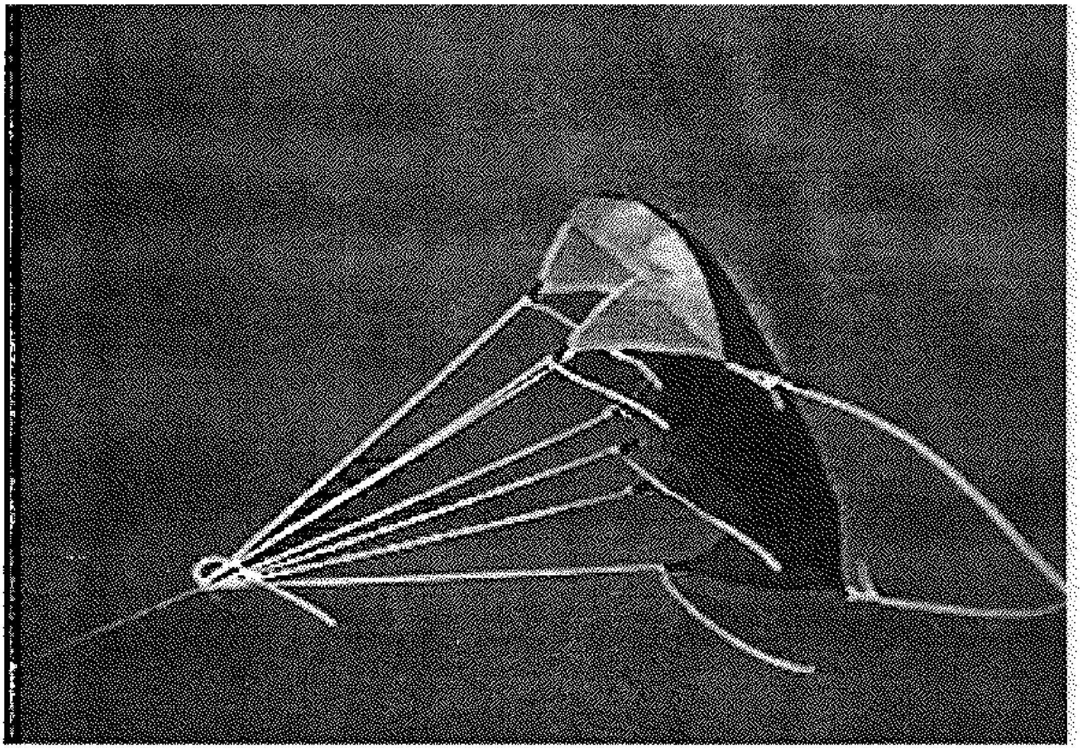

Figure 18. Parafoil door operating on a single attachment line.

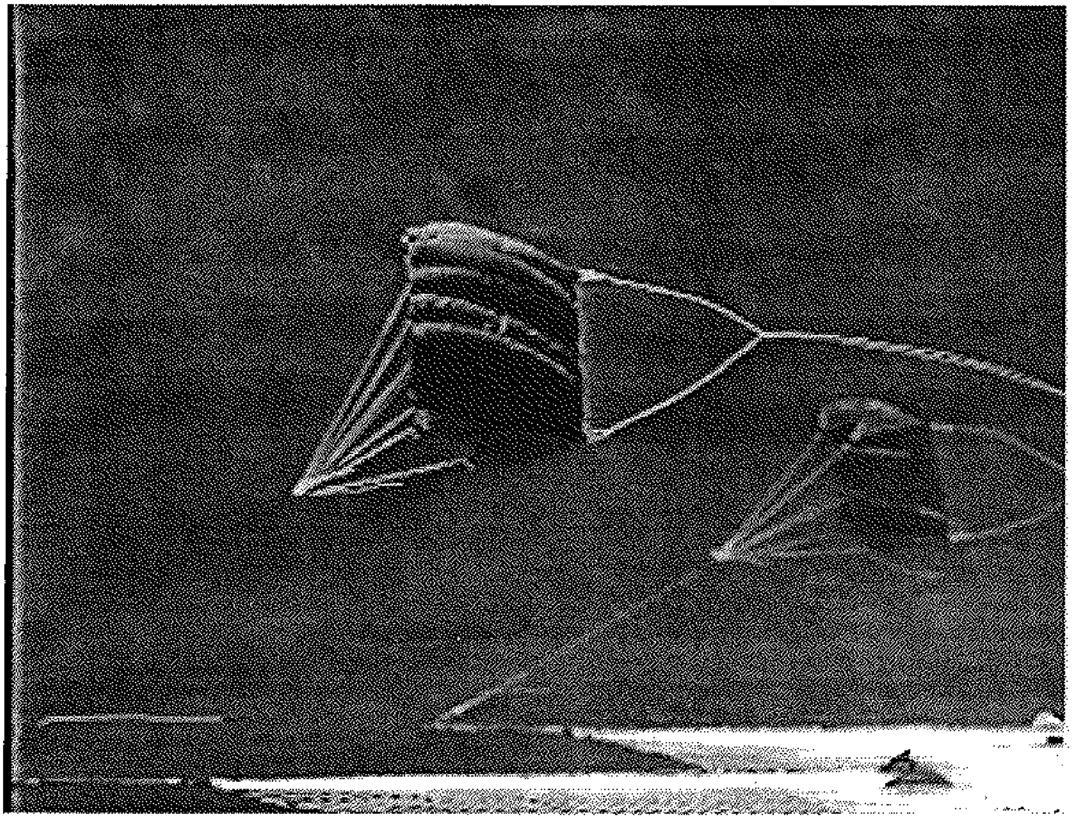

Figure 19. A pair of parafoil doors rigged to provide both lift and spread.

The results can be summarized as follows:

1) All of sweep modifications that were tested proved effective at providing the downward force required to depress the nets and achieve vertical opening. The portions located in the center of the sweep proved to be most effective as panels located toward the wing ends tended to stay vertical, yielding little useful force.
2) Of the variations tried, the abbreviated tapered segmented configuration seemed most effective (Figure 6).
3) Due to the likelihood of experiencing damage, the weight-reducing potential of these devices seem applicable to mid-water or other off-bottom applications.
4) The sweep kites would loose their lift when they contacted the bottom but methods need to be devised to protect the kites before their value can be explored in a commercial setting.
5) The ribbon foil kites showed variable performance depending on their location. They were particularly effective at increasing the crossectional area of the trawl at the bellies and further back towards the codend.
6) The ribbon foil kite would provide an effective and practical way to provide open meshes that could allow for the escapement of undersized fish. When in use, they act like hoops, substantially increasing the diameter of the trawl yet they are completely flexible for handling and hauling purposes.

7) The triangular mesh kites proved simple to construct and performed reliably. Because of their small size, their effects are subtle and many units would be needed to generate significant changes in trawl geometry.

8) The flexible parafoil kites provided lift both when tethered from a single point and when stretched between the top and bottom jibs. The size of the kites tested proved inadequate for spreading the net significantly. However, their operational potential was demonstrated.

Scallop dredges:

The prototype dredge design shown in Figure 3 is a radical departure from the conventional New Bedford type dredge. The significance of this difference became apparent immediately upon use. It would not set correctly. The dredge would consistently set on its back and all attempts to correct this behavior proved futile.

The dredge is pictured in Figure 20 aboard the chartered F/V Titan. The tow frame is kept well off the bottom by the sizable side panels and shoes. The chain bag installed on the dredge is shown in Figure 21. It is of conventional construction, using 3.5" steel rings and double split links. The five-part chain sweep can be seen at the top of this image. Each chain catenary is connected to a supporting pivoting depressor or the side panels.

Figure 20. Original configuration tested aboard the F/V Titan.

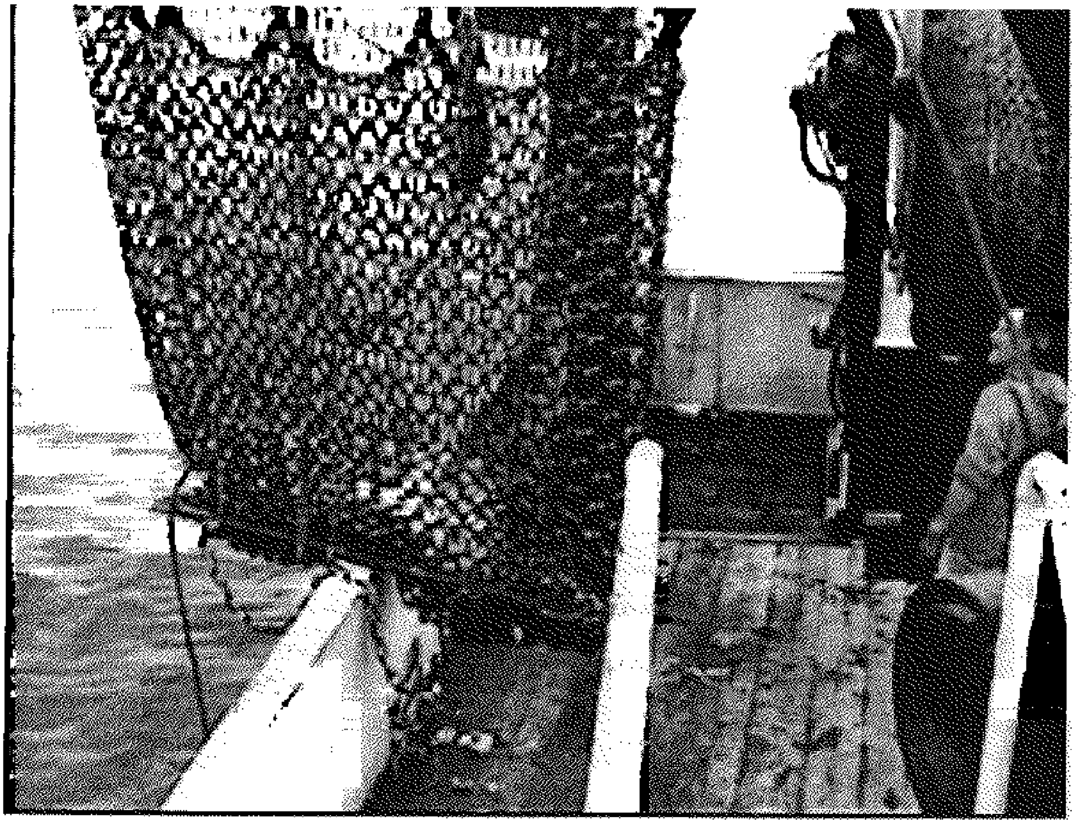

Figure 21. Chain bag of 3.5" rings.

Underwater video footage of that first configuration was obtained by providing a three-point bridle and lowering the dredge horizontally using a line. Once on the seabed, the rope was released and the Titan would carefully steam away from the stationary dredge, paying out towing warp. When the proper scope was attained, the tow would start and the dredge would remain properly oriented.

During this first day of testing we observed that the pivot arms were trailing back and that there was a lot of turbulence behind them. We concluded that the entire dredge was too high and that the depressor plates were set at too high an angle of attack, yielding excessive drag and insufficient downward lift.

The dredge was returned to the pier and transported to Globe Iron Works in Somerville, Massachusetts. There, side plates were re-configured as shown in Figure 22 and the angle of attack of the depressor plates was reduced as shown in Figure 23.

Subsequent testing aboard the Titan indicated that the setting problems still remained but the depressors were now functioning properly. We concluded that the side panels were contributing to the instability at the surface. The dredge was returned to the shop and much of the steel plate in the dredge's side panel was cut away.

Once again aboard the Titan we found the setting to be improved but still too inconsistent for normal operations. In an attempt to improve the setting characteristics, a triangular panel of heavy PVC-coated fabric was lashed to the underside of the towing frame. Setting became consistent with this addition.

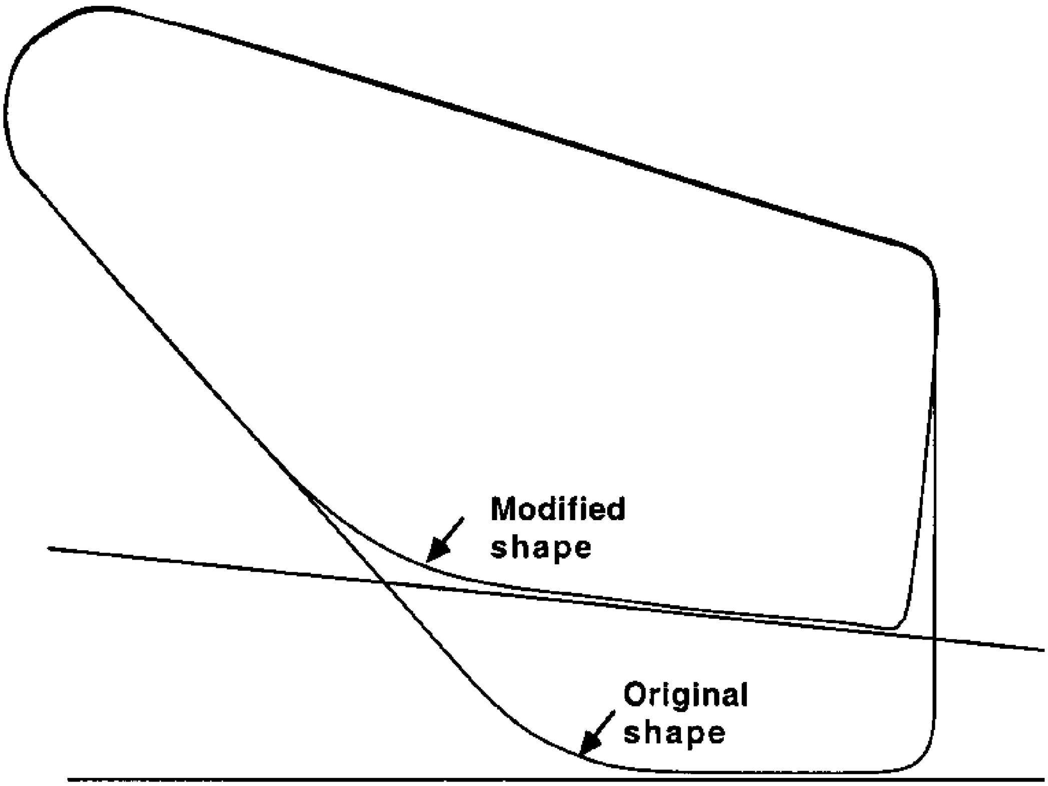

Figure 22. Modifications to the dredge side panel.

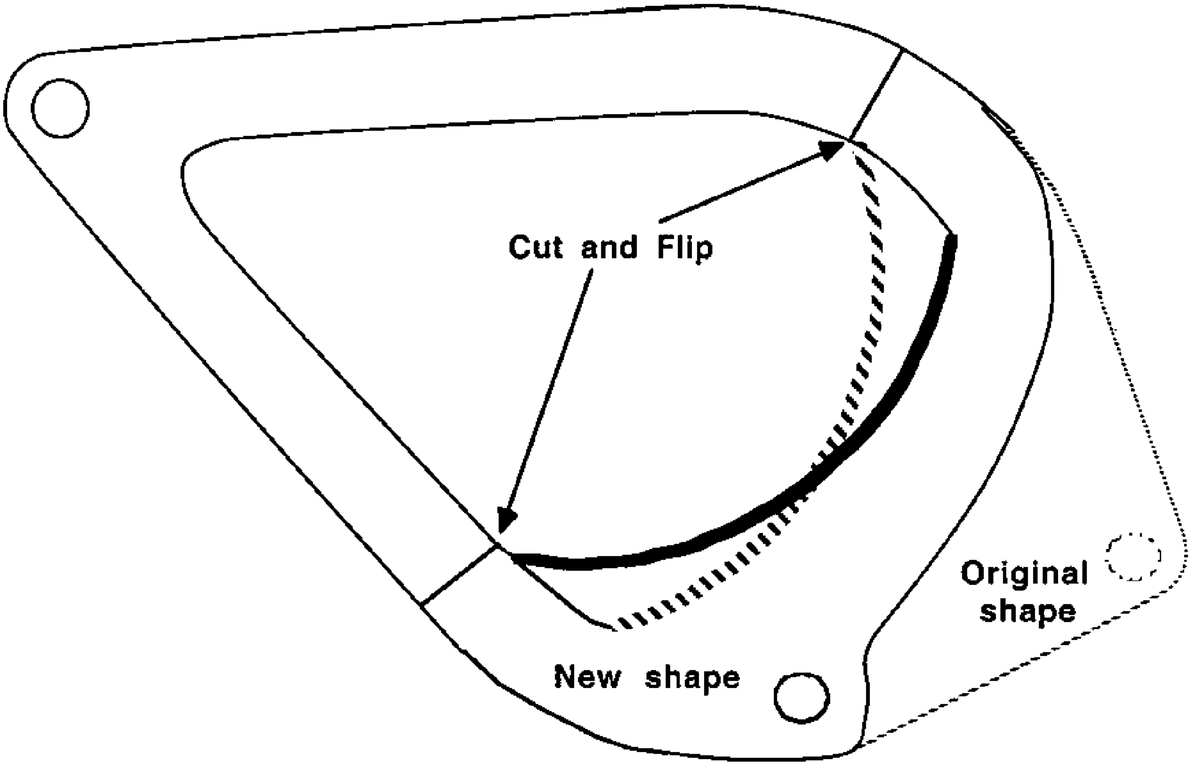

Figure 23. Modifications to the pivot arms to reduce the angle of the depressor plate.

Before the next trip, the fabric was replaced with 1/8" steel diamond patterned plate. The four panels were cut and welded into the spaces between the bar frame and the flat-bar longitudinals. This delta-wing configuration is shown in Figure 24 and with it, the dredge could be set with the normal anti-back-job precautions associated with conventional dredges. Figure 25 reveals a desirable shine to the full length of the shoes and the entire length of the five-part sweep chain, indicating a proper fishing attitude and good bottom tending. An image of the four pivot arms and their depressor plates is shown in figure 26.

Once consistent mechanical performance of the dredge was attained, we concentrated on observing the underwater performance of the dredge. Figure 27 is an image from a front-mounted camera looking aft. The image shows two of the depressor plates and one pivot arm. The pivot arm was just barely touching the seabed and between the plates a small area of turbidity is seen where the chain sweep contacts the seabed. Not evident in this still image is the movement of shells and other objects in front of the sweep chain due to the high flow velocities and resulting suction caused by the cambered depressors.

Throughout the sequence of testing, the Titan's own 10' dredge was used to compare catching performance. The prototype dredge was able to catch scallops, though very inconsistent at first. Testing was done in areas of very low scallop abundance and we were unable to get the new dredge to catch as well as the conventional design. In a final trip to Stellwagen Bank, catch results were inconclusive because only the prototype dredge was allowed on board when the vessel fished in federal waters.

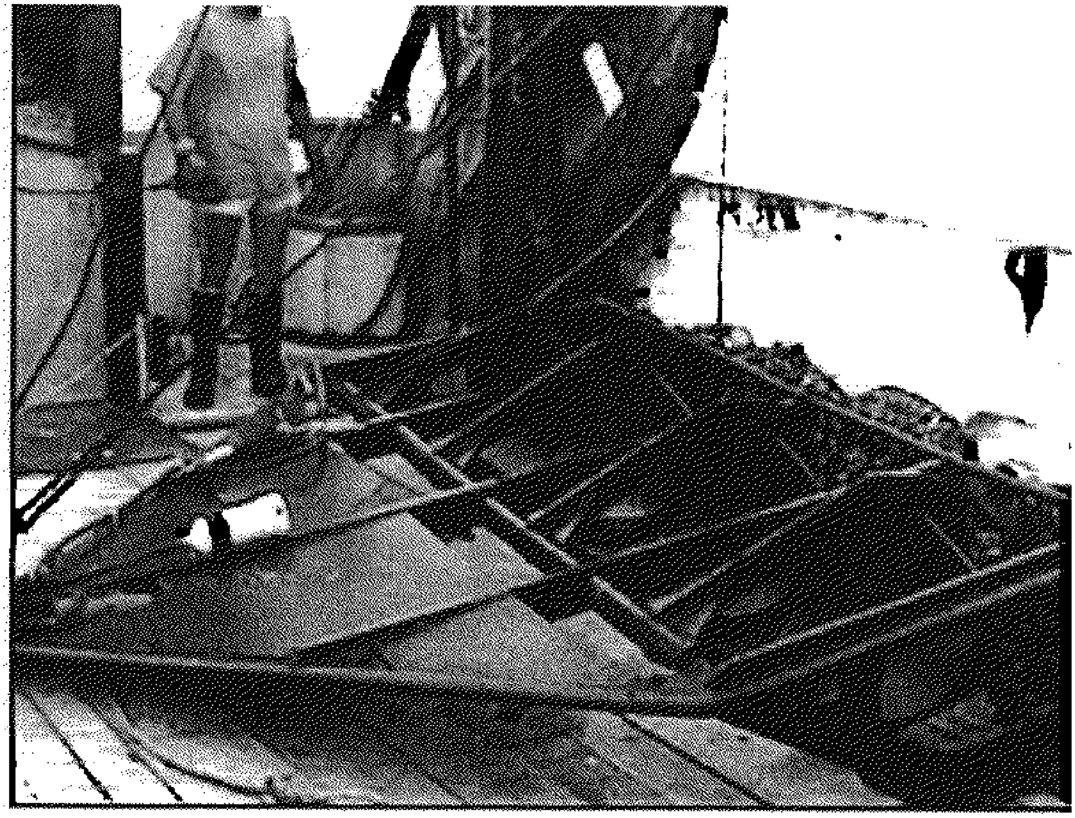

Figure 24. Delta-wing plating added to facilitate proper setting.

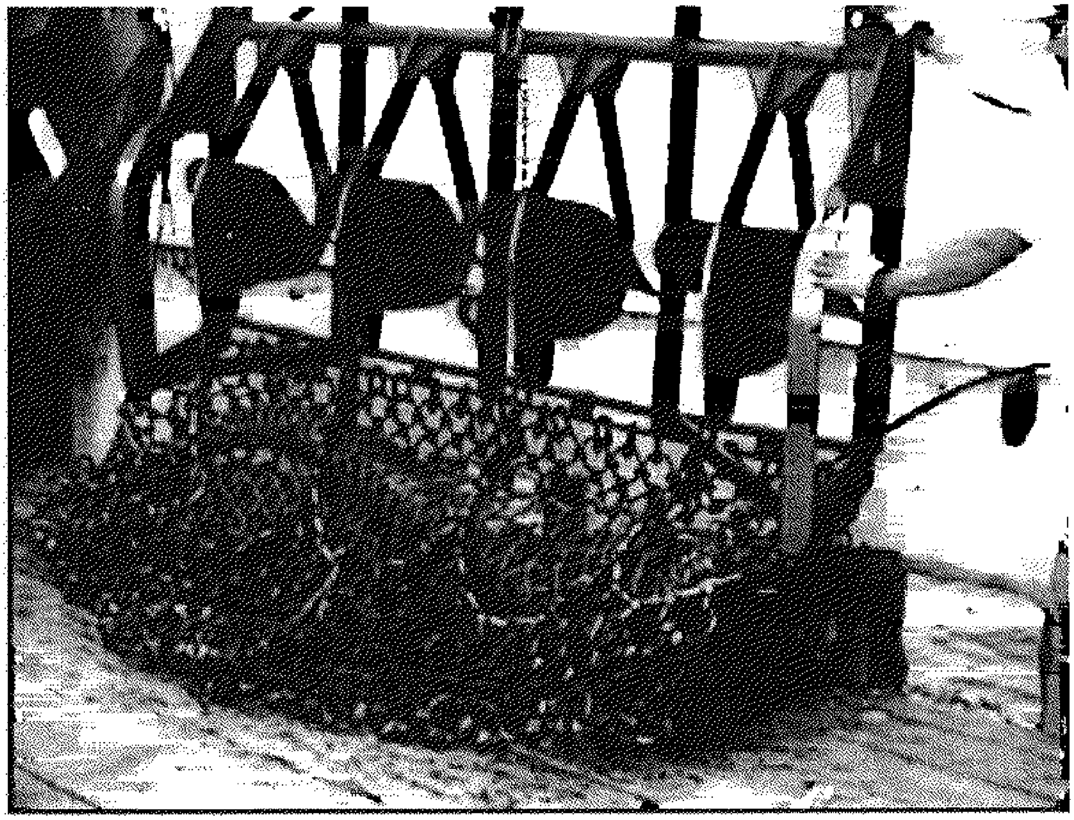

Figure 25. Underside of dredge showing shoes and modified pivot arms.

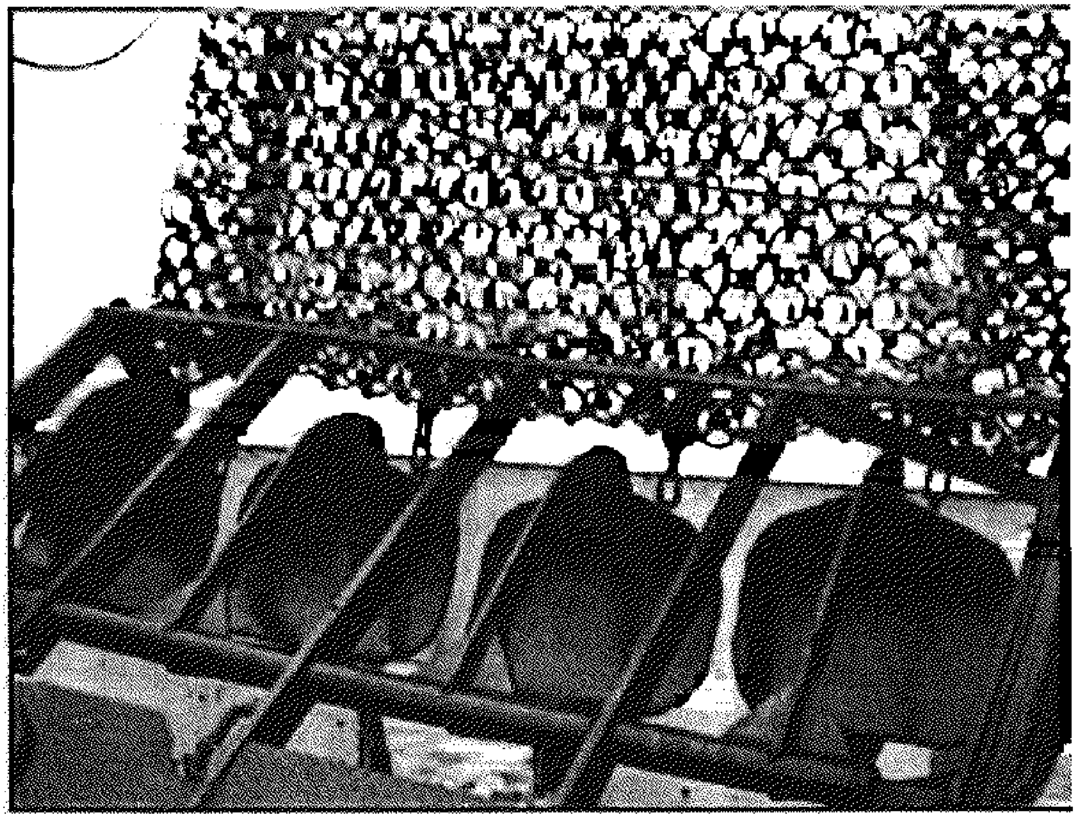

Figure 26. Detail of pivoting depressors.

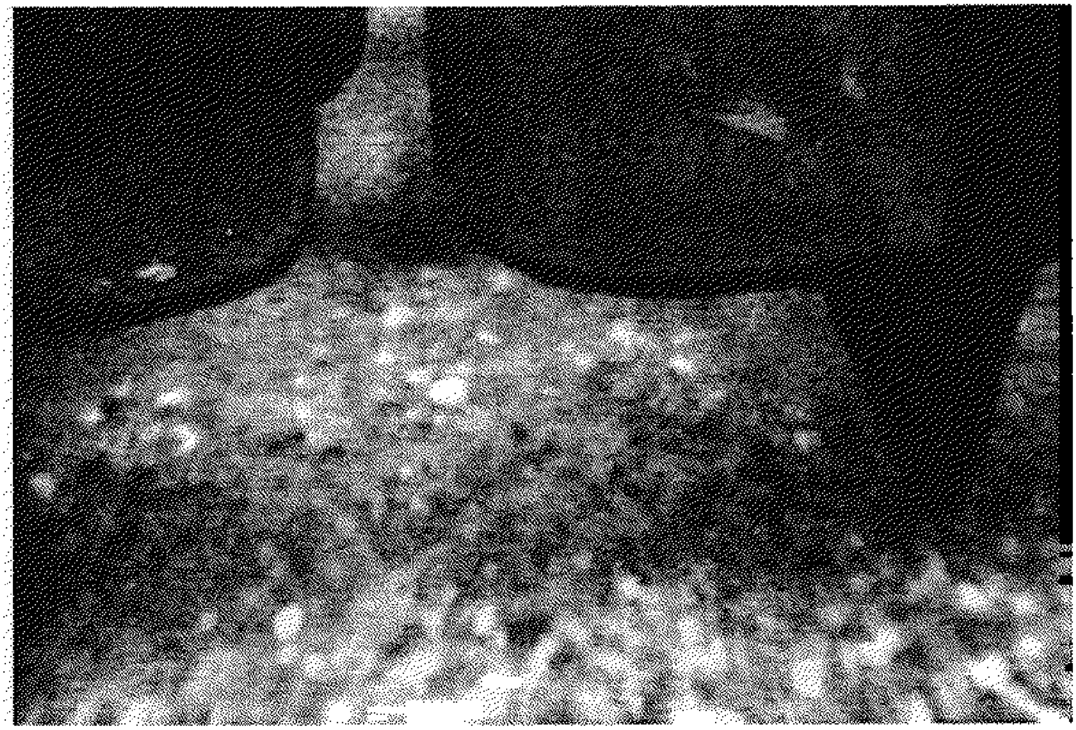

Figure 27. Underwater view of pivot arms contacting sea bed.

B. Problems Encountered.

Early in the project, the apparent success of DMF's off-bottom whiting trawl project diminished the need for our original goals in that area. In addition, discussions with some fishermen have brought into question the real impact of a low-bycatch whiting trawl. Because of the days-at-sea advantages associated with operating in an exempted fishery, there is concern that some fishermen would adopt such gear to illegally exploit and land groundfish.

The original project plan specified model testing at the Navy's David Taylor Model Basin (DTMB) in Bethesda Maryland. For reasons of economy and convenience, we decided to do the tests at the Marine Institute in St. John's, Newfoundland. This facility has better video observation capabilities and does not require the two days of pre-test rigging required to get the DTMB circulating water channel set up for trawl model testing.

The broadening of the goals of the project to include research on scallop dredges was a significant change to the scope of our efforts. Our approach to developing a radically-new dredge design proved challenging. We might have been wiser to include a modeling phase in the development process and the many frustrating days experimenting with an unstable dredge could have been avoided. In addition, our move to begin at commercial scale forced us into to deal with the realities of current regulations. For example, it precluded some interesting options with mesh bags that are prevented by the ring-size regulations in the current Sea Scallop Fisheries Management Plan.

The F/V Titan scallops under a multi-species permit and is allowed a total of 10 feet of dredge width on board. We requested and obtained permission from the

Massachusetts DMF to have aboard and use both dredges while in state waters. However, because of bottom conditions and unprecedented amounts of fixed gear, we were unable to do meaningful catch comparison trials near shore.

In compliance with the Magnuson-Stevens Act, we requested a scientific research exemption for our chartered trips aboard the F/V Titan. However, the Northeast Regional Administrator denied our request suggesting that we instead apply for an experimental fishery permit. The R.A. further suggested that the permission we obtained from Mass. DMF was invalid.

In spite of the importance of the remaining work, we elected to forego continued at-sea testing of the dredge that was planned for the fall of 1998 as experimental permits have been difficult to obtain and even if approved, the review process would have pushed the testing into the winter months.

In the spring of 1999, Capt. Robert Kohl of the F/V Titan reported that the vessel was being sold and that he had no alternative vessel with which to pursue the project. At this point we elected to terminate the project.

C. Need for Additional Work.

The heightened importance of habitat within the current fisheries management structure brings a compelling need for information of the role habitat plays in sustainable fisheries and in finding ways to protect habitat deemed essential. However, since the principal justification for protecting such habitat is the preservation of the fisheries, eliminating fishing effects is an illogical approach. Instead, fishing practices that are inappropriately destructive should be restricted and gear and methods should be developed to allow the responsible harvesting of managed species.

This project has demonstrated an approach to reducing the habitat impact of two common forms of mobile gear; the bottom trawl and the scallop dredge. In both cases, the findings of this project show promise and continued work is called for. The following specific tasks should be pursued to further refine, demonstrate and commercialize the novel designs and concepts introduced by this CFER project:

1) Ways to prevent sweep kites from hitting the bottom need to be developed. Some mechanism is needed that reduces or spoils the downward lift of the devices so a position above the seabed can be maintained.

2) Sweep kites can be directly applied to midwater and off-bottom trawls. Possible advantages over current techniques would be shape and depth stability regardless of speed and an elimination of the massive clump weight currently in use. Specific candidate nets and sweep kites need to be tested at model scale followed by prototype commercial trials.

3) Ring-foil kites show direct applicability to trawls with large-mesh front ends. The introduction of small mesh in the after bellies can be delayed by maintaining a generous crossectional area at the transition point. More selective and energy efficient trawls could result. Again, specific candidate nets and ring-foils need to be tested at model scale followed by prototype commercial trials.

4) Ring-foil kites have obvious applicability in promoting codend size selectivity. By maintaining open meshes, the advantages of square mesh could be realized without its structural complexities. This concept is simple to implement and prototype trials could be conducted.

5) Triangular mesh kites seem to be fool proof and simple to fabricate and install. They have immediate applicability in trawls needing added height or width. Specific candidate nets and mesh kites need to be tested at model scale followed by prototype commercial trials.

6) Parafoil doors showed significant potential as a spreading device for bottom trawls. These devices are also candidates for the direct replacement of clump weight in midwater trawling. Tests of the current devices in with more appropriately-sized trawls are called for.

7) The prototype dredge has yet to be conclusively evaluated. This work should continue. The catch rates of the new design need to be compared to the conventional New Bedford dredge in commercial trials on productive scallop beds. The habitat impact of the design needs to be evaluated in side-by-side testing.

8) This project has revealed the potential of using hydrodynamic force rather than weight in scallop dredges. The concept needs to be explored further and the abandonment to other current practices examined as well. For example, the weight of the traditional chain bag is a major factor in the dynamics of a dredge and is clearly second only to the present cutting bar in its impact on the seabed. The use of mesh bags and their support by "runners" needs to be explored. It is recommended that future dredge developments that depart significantly from conventional designs include tests at model scale or allow ample time for tinkering before fishing trials commence.

Evaluation.

The evaluation of this project with respect to the objectives stated in the proposal reveal only partial success. The planned developments applicable to bottom trawling were taken to the model testing phase and no further. However, the project, when re-focused on scallop dredges, did include commercial trials. In general, important progress was made in direct pursuit of the project's overall goals.

In a way, we were able to extract this success by adapting our plans in response to changing situations and new opportunities. The understanding and support of the project monitor and others at NMFS's Industry Services Division in Gloucester was critical to this responsiveness.

There were many avoidable and unavoidable delays associated with the conduct of this project. For the former, I apologize, though my punishment has already been a variety of unsavory paperwork tasks linked to the repeated extending of a project that was supposed to be completed in 12 months.

There is much more to do to make trawls and dredges habitat-friendly. Given the importance of that task, this project has made important early progress.

Acknowledgments

This project was funded by NOAA Grant number NA66FK0072, awarded under the Fishing Industry Grants Program. Project administration and monitoring was done by the Industry Services Division, NMFS Northeast Region in Gloucester.

Partial support was also provided by the MIT Sea Grant College Program under federal grant number NA86RG0074 from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

This project was a collaborative undertaking by CFER and numerous experts from the fishing industry. That collaborative process began with Captain Robert Kohl's assistance in the development of the proposal and our exploration of ideas for alternative approaches to whiting fishing. His expertise was particularly critical in our sea trials of the new dredge design.

Gary Loverich of Nor-Eastern Trawl Systems assisted in the development trawl configurations explored early in the project. Paul Shuman, a Rhode Island net designer, assisted in the design and execution of the model tests. In addition to fabricating the devices tested, he participated in the testing process and effected all device installations and adjustments.

The important role played by the staff of the Marine Institute flume tank, lead by John Foster, is acknowledged. In particular, the efforts of Harold DeLouche, tank operator, were appreciated.

More locally, the advice of Ron Smolowitz of North Falmouth and Richard Taylor of Gloucester was important in refining ideas applicable to the scallop industry. The advice of Roy Enoksen, Nordic Fishery Corp. is also acknowledged. The expertise and craftsmanship of Peter Anthony of Dockside Repairs in fabricating the prototype dredge is appreciated. Jack Schmelzer of Globe Iron Works, Inc. helped significantly in his execution of the dredge modifications. The patient and energetic crew of the F/V Titan, Peter Loane and Steve McNalley, contributed to the value of our at-sea testing program.

The cooperation of Jim Fair of the Massachusetts Division of Marine Fisheries in providing a Letter of Authorization for our dredge testing in state waters was critical to the progress we made in evaluating the dredge. The assistance of CFER's Ken Ekstrom and Liz Sylvan of MIT Sea Grant Communications is acknowledged in acquiring and processing some of the images included in this report.

References

Goudey, C.A. 1985. "Test Results from the New England Trawl Net Training Courses. Reprinted from Commercial Fisheries News". Center for Fisheries Engineering Research Report No. 11, MITSG 85-33.

Goudey, C.A. 1987. "The Development of a Semi-Pelagic Trawl for Squid and Butterfish". Ocean '87, Halifax, Sept.

Appendix I

Tables 2-6: Speeds are in full-scale knots, dimensions are in model meters, strut separation and wing spread are horizontal measurements, all others are vertical.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	1	6	1.33	1.64	0.85	0.73	2.56	2.75
2	2.5	1	7.8	1.2	1.44	0.69	0.58	3.03	3.3
3	2.5	1	4.2	1.39	1.84	0.95	0.76	2.01	2.16
4	3.25	1	4.2	1.29	1.66	0.89	0.67	2.04	2.17
5	3.25	1	6	1.16	1.38	0.72	0.53	2.56	2.74
6	3.25	1	7.8	1.01	1.14	0.55	0.34	3.04	3.29
7	4	1	7.8	0.88	0.95	0.45	0.19	3.06	3.3
8	4	1	6	0.99	1.13	0.6	0.32	2.58	2.74
9	4	1	4.2	1.17	1.44	0.82	0.53	2.07	2.17
10	3.25	0.15	6	0.5	0.79	0.1	0	2.56	2.76

Table 2. Series 1 - Shuman 2-seam, 14 floats, 1" full-width sweep kite, 4.16m bridles, 2.64m ground wires, sweep adjustment 3 links hanging.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	3.25	1	6	1.15	1.36	0.72	0.59	2.6	2.75

Table 3. Series 1 -Shuman 2-seam, 14 floats, 1" full-width sweep kite, 4.16m bridles, 2.64m ground wires, sweep adjustment 5 links hanging.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	3.25	0.15	6	0.59	0.92	0.22	0.14	2.51	2.69

Table 4. Series 2 - Shuman 4-seam, 14 floats, 1st ribbon foil rig, 4.16m bridles, 2.64m ground wires.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	3.25	0.15	6	0.53	1	0.16	0.08	2.45	2.67

Table 5. Series 2 - Shuman 4-seam, 5 floats, headrope kite, 1st ribbon foil rig, 4.16m bridles, 2.64m ground wires.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	1	6	1.13	1.38	0.59	0.3	2.58	2.83
2	2.5	1	7.8	0.92	1.08	0.34	0	3.08	3.42
3	2.5	1	4.2	1.29	1.69	0.75	0.48	2.04	2.2
4	3.25	1	4.2	1.14	1.46	0.68	0.3	2.08	2.18
5	3.25	1	6	0.9	1.1	0.41	0	2.6	2.79
6	3.25	1	7.8	0.82	0.93	0.3	0	3.09	3.39
7	4	1	7.8	0.79	0.84	0.29	0	3.1	3.39
8	4	1	6	0.84	0.96	0.38	0	2.62	2.83
9	4	1	4.2	1.01	1.25	0.6	0.18	2.18	2.08
10	3.25	0.15	6	0.5	0.8	0.1	0	2.58	2.88

Table 6. Series 3 - Shuman 2-seam, 14 floats, 2" full-width sweep kite, 4.16m bridles, 2.64m ground wires, sweep adjustment 3 links hanging.

Tables 7-9: Speeds are in full-scale knots, dimensions are in model meters, strut separation and wing spread are horizontal measurements, all others are vertical.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	1	6	1.44	1.77	0.99	1.02	2.55	2.7
2	2.5	1	7.8	1.38	1.6	0.92	0.96	3.02	3.22
3	2.5	1	4.2	1.48	1.95	1.06	1.02	2.02	2.15
4	3.25	1	4.2	1.39	1.75	1.04	0.99	2.04	2.15
5	3.25	1	6	1.31	1.56	0.95	0.95	2.56	2.7
6	3.25	1	7.8	1.25	1.41	0.87	0.88	3.04	3.19
7	4	1	7.8	1.13	1.26	0.86	0.81	3.01	3.19
8	4	1	6	1.22	1.41	0.92	0.9	2.57	2.7
9	4	1	4.2	1.3	1.62	1.01	0.96	2.06	2.17
10	3.25	0.15	6	0.5	0.8	0.1	0	2.58	2.88

Table 7. Series 4 - Shuman 2-seam, 14 floats, no sweep kite, 4.16m bridles, 2.64m ground wires.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	1.5	4.2	1.62	1.98	1.11	0.69	2.01	2.06
2	2.5	1.5	6	1.55	1.79	1.02	0.62	2.54	2.65
3	2.5	1.5	7.8	1.43	1.56	0.87	0.48	3.02	3.19
4	3.25	1.5	7.8	1.29	0.32	0.78	0.99	3.03	3.18
5	3.25	1.5	6	1.41	1.55	0.92	0.48	2.57	2.64
6	3.25	1.5	4.2	1.53	1.81	1.06	0.6	2.02	2.06
7	4	1.5	4.2	1.45	1.66	1.02	0.52	2.04	2.05
8	4	1.5	6	1.3	1.38	0.85	0.37	2.56	2.62
9	4	1.5	7.8	1.16	1.18	0.68	0.19	3.03	3.18
10	3.25	0.15	6	0.49	0.79	0.08	0	2.56	2.71

Table 8. Series 5 - Shuman 2-seam, 14 floats, full width 1"- 3" tapered sweep kite, 4.16m bridles, 2.64m ground wires, sweep adjustment 3 links hanging.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	1.5	4.2	1.67	2.06	1.16	0.78	1.99	2.02
2	2.5	1.5	6	1.63	1.88	1.11	0.76	2.54	2.61
3	2.5	1.5	7.8	1.58	1.74	1.05	0.73	3.02	3.14
4	3.25	1.5	7.8	1.43	1.54	0.98	0.62	3.02	3.14
5	3.25	1.5	6	1.53	1.7	1.06	0.67	2.55	2.6
6	3.25	1.5	4.2	1.58	1.91	1.14	0.7	2.01	2.02
7	4	1.5	4.2	1.52	1.78	0.111	0.66	2.02	2.01
8	4	1.5	6	1.42	1.53	1	0.58	2.55	2.58
9	4	1.5	7.8	1.32	1.37	0.89	0.48	3.03	3.14
10	3.25	0.15	6	0.5	0.81	0.1	0.02	2.56	2.67

Table 9. Series 7 - Shuman 2-seam, 14 floats, abbreviated 1"- 3" tapered sweep kite, 4.16m bridles, 2.64m ground wires, sweep adjustment 3 links hanging.

Tables 10-14: Speeds are in full-scale knots, dimensions are in model meters, strut separation and wing spread are horizontal measurements, all others are vertical.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	1.5	7.8	1.65	1.84	1.09	0.8	3.01	3.14
2	2.5	1.5	6	1.69	1.95	1.14	0.8	2.54	2.58
3	2.5	1.5	4.2	1.7	2.11	1.18	0.78	1.98	2.01
4	3.25	1.5	0.42	1.63	1.96	1.16	0.75	2.01	2.01
5	3.25	1.5	6	1.6	1.81	1.11	0.74	2.53	2.58
6	3.25	1.5	7.8	1.57	1.7	1.06	0.71	3.01	3.12
7	4	1.5	7.8	1.5	1.59	1.02	0.66	3.02	3.12
8	4	1.5	6	1.54	1.71	1.09	0.68	2.55	2.58
9	4	1.5	4.2	1.58	1.88	1.15	0.71	2.01	2
10	3.25	0.15	6	0.55	0.88	0.11	0.02	2.55	2.64

Table 10. Series 8 - Shuman 2-seam, 14 floats, abbreviated 1"- 3" tapered sweep kite, 4.16m bridles, 2.64m ground wires, sweep adjustment 5 links hanging.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	3.25	0.15	6	0.71	1.21	0.33	0.29	2.47	2.69
2	3.25	0.15	0.72	0.7	1.52	0.34	0.08	0.64	0.68
3	3.25	0.15	6	0.38	0.62	0.08	0.04	2.52	2.71

Table 11. Series 6 - Shuman 4-seam, 5 floats, headrope kite, 2nd ribbon foil rig, 4.16m bridles, 2.64m ground wires.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen
1	4	1.5	6	1.3	1.38	0.9	0.46
2	3.25	1.5	6	1.22	1.28	0.82	0.35
3	2.5	1.5	6	0.99	1.06	0.6	0.13

Table 12. Series 8 - Shuman 2-seam, 14 floats, abbreviated 1"- 3" tapered sweep kite, 4.16m bridles, 2.64m ground wires, sweep adjustment 5 links hanging.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	0.15	6	0.48	0.91	0.08	0.04	2.52	2.96
2	3.25	0.15	6	0.56	0.99	0.19	0.09	2.52	2.7
3	4	0.15	6	0.64	1.07	0.28	0.22	2.52	2.7

Table 13. Series 9 - Shuman 4-seam, 2 floats, no headrope kite, 3rd ribbon foil rig, 4.16m bridles, 2.64m ground wires.

	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	0.15	6	0.49	0.89	0.11	0.05	2.66	2.89
2	3.25	0.15	6	0.57	0.99	0.23	0.13	2.66	2.9
3	4	0.15	6	0.66	1.06	0.34	0.26	2.67	2.9
4	3.25	0.15	0.72	0.66	1.06	0.34	0.26	2.67	2.9

Table 14. Series 10 - Shuman 4-seam, 2 floats, no headrope kite, 4th ribbon foil rig(no annular foils), 4.16m bridles, 2.64m ground wires.

Tables 14-17: Speeds are in full-scale knots, dimensions are in model meters, strut separation and wing spread are horizontal measurements, all others are vertical.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	2.5	1.5	7.8	1.69	1.82	1.05	0.8	3.33	3.19
2	2.5	1.5	6	1.72	1.89	1.1	0.8	2.89	2.67
3	2.5	1.5	4.2	1.71	1.99	1.14	0.77	2.4	2.11
4	3.25	1.5	0.42	1.77	2.07	1.25	0.84	2.38	2.09
5	3.25	1.5	6	1.78	1.94	1.2	0.85	2.89	2.66
6	3.25	1.5	7.8	1.79	1.9	1.18	0.84	3.35	3.18
7	4	1.5	7.8	1.87	1.93	1.24	0.9	3.33	3.19
8	4	1.5	6	1.91	2.01	1.29	0.91	2.92	2.66
9	4	1.5	4.2	1.92	2.15	1.35	0.91	2.4	2.09
10	3.25	0.15	6	0.78	1.06	0.22	0.04	2.92	2.67
11	3.25	0.15	0.72	1.02	1.65	0.52	0.24	1.21	0.88

Table 15. Series 11 - Shuman 2-seam, 14 floats, abbreviated 1"- 3" tapered sweep kite, arrays of triangular mesh kites added, 4.16m bridles, 2.64m ground wires, sweep adjustment 5 links hanging.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	3.25	0.15	6	0.56	0.98	0.22	0.16	2.66	2.89
2	3.25	0.15	6	0.57	0.99	0.23	0.13	2.66	2.9
3	4	0.15	6	0.66	1.06	0.34	0.26	2.67	2.9
3	3.25	0.15	0.72	0.66	1.06	0.34	0.26	2.67	2.9

Table 16. Series 12 - Shuman 4-seam, 2 floats, no headrope kite, adjusted angle of codend and port ribbon foils, 4.16m bridles, 2.64m ground wires.

run	speed	tow pt ht	strut wdt	top tip	top cen	bot tip	bot cen	top wing	bot wing
1	3.25	0.15	6	0.45	0.8	0.09	0.05	2.53	2.71

Table 17. Series 13 - Shuman 4-seam, 14 floats, no lifting devices, 4.16m bridles, 2.64m ground wires.