Fisheries Research and Development Corporation

Final Report - Project 91/49

Development Of Improved And Environmentally Sensitive Scallop Harvesting Gear

CSIRO Division of Fisheries
Victorian Fishing Industry Federation
Australian Maritime College
Marine Resources Division, Tasmanian Department of Primary Industry and Fisheries

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Development Of Improved And Environmentally Sensitive Scallop Harvesting Gear

Richard McLoughlin
CSIRO Division of Fisheries

Melita Probestl
Victorian Fishing Industry Federation

Dr David Gwyther
Dames and Moore Pty Ltd

Ian Cartwright
Australian Maritime College

David Sterling
Australian Maritime College

William Zacharin
Tasmanian Department of Primary Industry and Fisheries

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Executive Summary

Five different types of scallop dredges, four from overseas and one modified Australian design, were compared for fishing performance against existing designs. The goal of the research was to determine if viable alternatives to gear currently used in the south east Australian scallop fishery could be identified. The objective of the research was to identify gear that did not have the same deleterious catching characteristics of existing dredges used in the fishery. Trials and catch comparisons were undertaken on most of the important fishing grounds within the south east Australian scallop fishery using mainly industry vessels.

Dredges were variously assessed for catch efficiency, handling efficiency, bycatch, incidental mortality characteristics, and engineering performance.

The best performing alternative dredges did not always achieve catch efficiencies as high as that recorded in direct comparison with existing (toothbar) dredge designs, particularly in Bass Strait grounds. Local experience with toothbar dredges compared with alternate designs may have contributed to this result. However, at nearly all sites and times, the alternate dredge designs performed significantly better in relation to bycatch, incidental mortality to scallops and mechanical/engineering aspects.

Results further indicate that improvements in catch efficiency of alternate designs may be achievable with further experimentation and experience by industry. The best performing alternative design, a modified local dredge termed the 'Southern Scallop Harvester', imposes no requirement for significant new changes in fishing practice, vessel deck equipment or investment, and appears to have further development potential.

Results clearly indicate the viability of several alternative dredge designs to the existing toothed mud dredges used in the fishery. These alternate designs have the potential to significantly improve the overall efficiency of scallop fishing in south east Australia if industry is prepared to commit itself to the changes and possible investment costs involved.

Recommendations

- A bioeconomic study needs to be undertaken of the costs of continued use of the existing gear, particularly in relation to losses caused by incidental mortality to target stocks. This will provide the financial information necessary to make better decisions in regard to implementation (or non-implementation) of any alternate technology

- Given the large scale wastage of target scallop stocks in 1986, '89, '92, '93 and '94, fishery managers and the scallop industry needs to immediately review fishing and management practices to minimise incidental mortality and associated environmental problems. This should include both short term and long term solutions, incorporating this study and a bioeconomic study of the costs of not changing current practices.

- Industry must continue to seek to implement and trial improved alternate dredge designs and/or technology, primarily in conjunction with fishing gear engineers at the Australian Maritime College. This should include studies of how best to implement any improved technology on an industry wide basis.

- The New Zealand scallop dredge or similar designs should be introduced into the Port Phillip Bay fishery.

Section 1

Introduction

Introduction

World-wide, scallop fisheries where the principal gear utilised by the commercial fleet is the use of towed dredges, reported problems of environmental impact, resource wastage and poor public perception of fishing practices have been prominent parts of the management debate. However, as is the case for most fisheries (in addition to scallops), quantitative information regarding overall impact and performance of the fishing gear used in commercial operations is generally lacking. Most debates and arguments are subsequently driven by a combination (often) of perception, anecdote, media discussion and occasional qualitative observation. Additionally, where potential exists for resource sharing conflicts to arise, particularly between recreational, conservation and commercial interests, the use by commercial scallop harvesters of gear that looks as if it would have significant impact on the seabed - as scallop gear invariably does - often leads to conflict problems for resource managers, fishery scientists and competing resource user groups.

Historically, developments in fish harvesting technology have focused on improving catch efficiency and productivity of the individual harvester (Smolowitz and Serchuk 1989). Scallop fishing gear has been no exception with regard to research focus, with additional problems of environmental impact, resource wastage, catch inefficiency and the like having been discussed since at least the mid 1950's, and described in at least qualitative detail from Australian, Canadian, US, South American, French and British scallop fisheries (McLoughlin *et al.* 1991; Orensanz *et al.* 1991). Of interest is that only catch efficiency and, to a lesser extent, size selectivity has appeared to receive serious investigation in scallop fisheries, despite the concerns with which the other related problems have been viewed.

In Australia, scallops are fished from three principal genera: *Pecten*, *Chlamys* and *Amusium*. The fishery in south eastern Australia, centred on Bass Strait and taking almost entirely the 'commercial scallop' *Pecten fumatus*, is the only dredge fishery of note in Australian waters. *Pecten* fisheries have historically been the most important scallop fisheries in Australian waters, producing about 4,000 tonnes of meat at the peak of the fishery in 1981/82 (Young and Martin 1989), but this has possibly been eclipsed by a combination of expansion in tropical fisheries for *Amusium* species and by a decline in the *Pecten* fisheries in the second half of the 1980's. The south eastern Australian fishery has traditionally produced a 'roe-on' product for domestic and export markets in Europe.

Fisheries for *Pecten fumatus* started in Tasmanian waters at the turn of the century, using small lip dredges pulled by rowing boats in the D'Entrecasteaux Channel in southern Tasmania (Figure 1). Gradual expansion in the size of vessels and areas worked continued until the 1940's, with a rapid expansion in fishing power and effort after World War II. By 1949, vessels over 15m in length and pulling up to six dredges were operating in the fishery, leading to the imposition of controls on the number of dredges that could be used and areas or times that could be worked (Perrin and Hay 1987; Young and Martin 1989).

As the fishery continued to expand around southern Tasmania, larger and more variable designs of dredges were developed to fish in different areas and bottom types (Young and Martin 1989). This included technical improvements such as runners, toothbars, depressor plates and, in 1957, the first use of the 'Baird Dredge', a recommended design from British fisheries for *Pecten maximus*, a similar species to *Pecten fumatus*. Despite these technical 'improvements' fishermen lobbied at the time, and were successful, for a ban on the use of Baird dredges (locally termed the 'sputnik' dredge) in the D'Entrecasteaux Channel because of fears over environmental impacts and damage to uncaught and juvenile scallops.

The use of sputnik dredges expanded northwards along Tasmanian east coast during the 1950's, with Tasmanian fishermen starting to fish for scallops, using sputnik dredges, in Port Phillip Bay in Victoria 1963. This design rapidly changed to cope with changed seabed conditions and more powerful vessels, quickly evolving into the 'mud' or 'box' dredge (Hughes 1963). With few controls on their use in place in either Tasmania or Victoria, heavy dredges up to 5 metres wide with self-tipping gear were soon operating, although subsequent development has seen dredges stabilise at 3 - 5m in width in line with dredge width restrictions put in place by State fishery managers concerned at reports of over exploitation and wastage of scallops. Mud dredges and self-tipping cradles have remained a feature of the fishery since the late 1960's, and are used by all vessels in the fishery.

Despite its universal use by scallop fishermen in south eastern Australia, there has been much criticism levelled at the mud dredge, both by fishermen and fishery managers (Young and Martin 1989; McLoughlin *et al* 1991, 1994). Typically, this has related to observations of incidental mortality of scallops, environmental impacts, effects on subsequent recruitment, and overfishing. The concern at all levels of industry about dredge impacts, particularly after the collapse of the Bass Strait fishery in the mid 1980's, led to a joint Ministerial statement in December 1990 by the Commonwealth, Tasmanian and Victorian Ministers, announcing that "trials would be conducted with a view to introducing more appropriate and environmentally sensitive harvesting technology". This Ministerial level involvement was further pursued by the two State Ministers in following months in relation to State waters fisheries.

Despite the, at times, considerable level of debate about the impact of scallop dredges in south eastern Australia, there has been little quantitative research on the fishing characteristics of the mud dredge, with the little research that has been done concentrating mainly on catch efficiency and size selectivity characteristics. A study by divers of the number of scallops caught by sputnik dredges in Port Phillip Bay suggested that they caught between 6% and 47% of the scallop estimated to lie in the path of the dredge (Sanders 1966). This variability was thought to be due to the dredge overfilling with epi-benthos (sponges, seaweed, gastropods, etc) in sparse scallop beds, and scallops in areas of higher density. The potential efficiency of the existing mud dredge was inferred from the difference between the size of a scallop population in Port Phillip Bay estimated by divers, and the catch of the same population in the subsequent fishing season - estimates ranged from 37% - 56% (Gwyther and McShane 1985; Gwyther and Burgess 1986).

A quantitative study of mud dredge performance for a commercial fishery in Bass Strait was published by McLoughlin *et al* (1991). That study examined catches from a scallop bed in Banks Strait prior to, during and after intensive fishing in 1986 to determine sources of mortality and yield estimates for the scallop bed. Additionally, catch efficiency and size selectivity were experimentally determined under controlled conditions. Results indicated that catch efficiency generally paralleled that estimated for scallop dredges used elsewhere in the world, averaging about 12%. Size selectivity was also extreme, ranging from 1% for small scallops (57mm shell height) through to 28% for large scallops (87m shell height). Of most concern from this study however was estimates of incidental mortality associated with intense fishing effort applied during the season. A model developed to explain the data obtained during the study predicted that only 12 - 22% of the total available stock of scallops in the scallop bed was removed as catch, with the rest of the available stock killed indirectly from the effects of the gear and enhanced mortality. This result was corroborated by fishermen who participated in the Banks Strait fishery at the time, who themselves were dismayed by the wastage they observed.

Environmental effects of mud dredges has, in line with scallop fisheries elsewhere, received little attention. Possibly the first environmental impact study of dredges in Australia, a short term study of the effects of scallop dredging in Port Phillip Bay, was completed in 1981 (McShane 1981). Unfortunately, this study has subsequently been found to have had low statistical power, with no basis for assertions of limited impact of scallop gear on the benthos or ecology (Curry and Parry 1994). Later work has confirmed however that statistically rigorous studies do show impacts of scallop dredging on benthic communities in Port Phillip Bay, but that ecological impacts may require a longer time series of data (Curry and Parry 1994). No other published studies of the environmental impacts of scallop dredges in south east Australian fisheries have been made.

Responding to community and political concerns regarding the impact of scallop fishing gear on the environment and resources, the Victorian Fishing Industry Federation (VFIF) applied, in 1991, to the Fisheries Research and Development Corporation for funding to examine possible solutions to these issues. The funding application was successful after the CSIRO Division of Fisheries, the Australian Maritime College and the Department of Primary Industry and Fisheries were included into the study to extend its scope and available expertise.

The FR&DC funded study (copy at end of this report) had three principal goals. These were:

1 To design, develop and test equipment to harvest naturally occurring scallops with minimum disturbance to the seabed and uncaught scallops.

2 To assess improvements in efficiency, selectivity, handling and methods of deployment of improved scallop harvesting gear.

3 To facilitate the phased introduction of new scallop gear over a two year period.

This report provides details of the results of research directed at the first two objectives detailed above. The third objective is a fishery management related responsibility outside of the scope or powers of the authors.

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Section 2

Fishing Efficiency Trials

2.0 Fishing Efficiency Trials

Trials to determine the catching characteristics of the various dredges were conducted in five locations, all of which are areas of previous or existing commercial scallop grounds. These were:

- Great Oyster Bay (Tasmanian east coast)
- Mouth of the Tamara estuary (Bass Strait)
- Ninth Island (Tasmanian north coast, Bass Strait)
- Lakes Entrance (Victorian coastal waters)
- Port Philip Bay (Victoria)

It was acknowledged by project participants that, for logistical and practical reasons, two factors would have to be borne in mind when planning the project. These were (1) that full sets of trials with all dredges would not be possible at all sites and times because of operational constraints on vessels available to do the work and limits on scallop availability, and (2) that the first year of the project would be devoted to trial gears to produce 2 - 3 'best' options, with the second year of the project concentrating on improvements and further development of these designs.

Tasks were apportioned to project participants in the following areas.

2.1 Catch efficiency testing of overseas scallop fishing gear (CSIRO, Tasmanian DPI&F and Australian Maritime College)

Scallop dredges were imported from the United Kingdom and New Zealand, while a Japanese 'Keti-Ami' dredge was loaned from the Fisheries Division of the Tasmanian Department of Primary Industries and Fisheries. An experimental Canadian design was also built in Hobart for inclusion in trials, after discussions with industry participants indicated that it showed promise of being able to be used by the existing winches and self-tipper equipment on the scallop fleet. A local dredge was also built and trialed for use as a control, being modelled on the existing dredges in common usage in Bass Strait.. Thus, the project started with six different scallop dredge designs, of which one was the local mud dredge, one was a modified mud dredge, and four were different designs from overseas fisheries for Pectinid-like scallops.

The Fisheries Division of the Tasmanian Department of Agriculture made available its research vessel FRV 'Challenger' to undertake trials in Tasmanian waters early in February 1992 during which five different types of scallop harvesting gear (4 overseas and 1 local) were tested for differences in catch rates, incidental mortality, catch efficiency and method of operation. These results produced the basis for further testing of dredges in different areas, combined with trials on modified local gear as determined by other elements of the study. Hydrodynamic testing of the imported gear types was completed where possible in the Australian Maritime College flume tank, along with engineering examination.

Further trials were completed in Port Phillip Bay during 1992, again using the FRV 'Challenger' and off Lakes Entrance using commercial vessels. A practical consideration of undertaking gear related trials where a measure of gear success is catch rates is the need for available stocks of scallops with which to undertake trials. Apart from some trials on re-seeded scallops in Great Oyster Bay discussed later, a particular problem of the timing of this study was that during 1991 - 1993, the Bass Strait scallop stock was at a critically low level, particularly around Tasmania. Few beds of scallop were known to exist in the Commonwealth controlled 'central zone' fishery, with scallop stocks available only in Victorian waters in Port Phillip Bay and in limited quantities off Lakes Entrance. These scallop stocks had to be shared with existing commercial operations, producing a problem when attempting to undertake trials under controlled (experimental) conditions.

Mechanical problems on the commercial vessel used at Lakes Entrance eventually caused the cancellation of a full set of trials being completed with the New Zealand, United Kingdom and the Japanese gear. Australian vessels do not have the heavy boom gear capable of deploying these gears over the side of the vessel and towing them off a boom. No other more capable vessels could be organised by the VFIF, and trials with this gear was therefore abandoned.

2.1.1 Results - Port Phillip Bay Trials

Data from this complete set of trials is given below in Table 2.1. Note that the dredges as trialed vary in size, and therefore the area swept by each tow varies accordingly. Catch/m^2 is calculated from the average catch of individual scallop from five separate tows divided by the calculated swept area.

Table 2.1 Results of Catch trials in Port Phillip Bay

Area 1 (Dromana Bay - sandy seabed)

TRIAL 1

DREDGE TYPE	Tow speed	Tow time (mins)	Avg catch	Catch/m^2
United Kingdom	3.0	2.0	199	0.4
New Zealand	3.0	3.0 - 5.0	2112	1.8 - 3.7
Southern scallop har	3.0	5.0	1858	1.2
Japan keti-ami	3.0	2.0	836	1.8
Mud dredge	6.0	2.0	1074	0.9
Modified mud dredge	5.0	2.0	1087	1.15

TRIAL 2

DREDGE TYPE	Tow speed	Tow time (mins)	Avg catch	Catch/m^2
United Kingdom	3.0	2.0	248	0.4
New Zealand	3.0	1.0 - 2.5	1115	3.4 - 4.0
Southern scallop har	3.0	5.0	1377	0.88
Japan keti-ami	3.0	2.0	934	2.0
Mud dredge	6.0	2.0	1448	1.28
Modified mud dredge	5.0	2.0	939	1.0

Ranking	Trial 1	Trial 2
1	New Zealand	New Zealand
2	Japan keti-ami	Japan keti-ami
3	Southern scallop harvester	Mud dredge
4	Modified mud dredge	Modified mud dredge
5	Mud dredge	Southern scallop harvester
6	United Kingdom	United Kingdom

Area 2 (Portarlington - muddy seabed)

TRIAL 1

Dredge type	Tow speed	Tow time (mins)	Avg catch	Catch/m^2
United Kingdom	3.0	1.0	500	1.7
New Zealand	3.0	1.0	1423	5.0
Southern scallop har	3.0	3.0	1421	1.5
Japan keti-ami	3.0	3.0	381	0.5
Mud dredge	6.0	3.0	2512	1.5
Modified mud dredge	6.0	3.0	840	0.5

TRIAL 2

DREDGE TYPE	Tow speed	Tow time (mins)	Avg catch	Catch/m^2
United Kingdom	3.0	1.0	221	0.8
New Zealand	3.0	1.0	987	4.35
Southern scallop har	3.0	3.0	290	0.3
Japan keti-ami	3.0	3.0	574	0.6
Mud dredge	6.0	3.0	671	0.4
Modified mud dredge	6.0	3.0	1754	1.0

Ranking	Trial 1	Trial 2
1	New Zealand	New Zealand
2	Southern scallop har.	Japan keti-ami
3	United Kingdom	Mud dredge
4	Mud dredge	Modified mud dredge
5	Japan keti-ami	Southern scallop harvester
6	Modified mud dredge	United Kingdom

A two-factor analysis of variance on catch per m^2 for these trials where the factors were dredge type and site (Dromana and Portarlington) gave the following Table 2.2.

Table 2.2 Anova of dredge versus site for catch efficiency

Factor	DF	Sum Squares	Mean Square	F	P Value
Dredge type (A)	5	229.07	45.814	67.926	0.0001
Site (B)	1	1.077	1.077	1.597	0.2091
AB	5	10.72	2.144	3.179	0.0102
Error	108	72.843	0.674		

Clearly, dredges were significantly different in mean catch per square metre, but differences between sites were not significant for catch rates between dredges. There was also a possible interaction between dredge catch rate and site. This suggests that a similar level of variation between dredges was observed regardless of site, but that this variation differed in extent between sites.

Overall ranking of catch rates from both trials combined:

1 New Zealand
2 Japanese keti-ami
3 Southern scallop harvester
4 Mud dredge
5 Modified mud dredge (mouth organ)
6 United Kingdom

2.2.1 Size selectivity

A complicating factor in any catch efficiency study is the different sizes of the scallops available to be caught at different sites, and the difficulty in getting samples of the 'true' population size distribution. Size selectivity has been shown in many studies of scallop dredges to be an important factor in retention rates of scallops (eg. McLoughlin *et al* 1991). For these trials the United Kingdom, keti-ami and New Zealand dredges in particular had ring meshes of different sizes, so could be expected to differ in retention rates of different sized scallops. The box dredges had the same size rigid square mesh and could be assumed to have the same size selectivity through the mesh, except for the southern scallop harvester which has a combination of both rigid square meshes and chain mesh rings. The rigid square meshes of the mud dredges was rectangular in shape and measured 50 x 70mm, while the ring mesh had an inside diameter of 70mm.

Results showed that the New Zealand dredge was clearly superior with respect to catching efficiency in Port Phillip Bay, although size selectivity was found to be poor. The Japanese keti-ami dredge showed good catch efficiency, but was difficult and dangerous to work in any conditions except calm weather, due to the long (50cm) teeth on these dredges and the need to swing them high overhead to get them on board - Victorian scallop fishermen who observed the trials with the keti-ami dredge were concerned about the safety of these dredges in areas like Bass Strait which frequently experiences rough conditions. The United Kingdom dredges were overall relatively poor performers on both soft and moderately hard bottoms.

At both sites (Dromana and Portarlington), divers collected every scallop they swam over during a random 15 minute dive in the experimental area. The goal here was to use the size frequency of scallops selected by diving as a best estimate of 'true' population size frequency and compare this against that recorded for the different dredges.

Table 2.3 Mean size of scallops caught in two areas of Port Phillip Bay by six different dredge types for combined trials, and by random sampling from divers. N>150 scallops for each sample

DREDGE TYPE	Area 2 (Portarlington)	Area 1 (Dromana)
	Mean size (mm)	
United Kingdom	66.9	59.5
New Zealand	65.9	61.4
Southern scallop har	68.6	62.4
Japan keti-ami	65.4	62.0
Mud dredge	65.2	60.9
Modified mud dredge	67.1	60.2
Dive survey	67.3	59.9

A t test for comparison of means was used to test for differences between the mean size of scallops caught by divers (the 'population' mean) and that recorded for each dredge.

Table 2.4 T test results for size frequency for each dredge type at each site for each trial in Port Phillip Bay compared with diver collected scallops. Population mean: Dromana = 67.33mm, Portarlington = 59.91mm. Probability: * = <0.05, * * = <0.01, ns = not significant

DREDGE	Area	Trial No	Sample Mean	T value	Prob (2 tail)
United Kingdom	Dromana	1	66.95	-0.996	ns
United Kingdom	"	2	66.16	-3.234	* *
New Zealand	"	1	67.63	0.852	ns
New Zealand	"	2	64.36	-7.894	* *
Southern scallop harvester	"	1	68.61	3.550	* *
Southern scallop harvester	"	2	65.77	-3.341	* *
Keti-ami	"	1	65.83	-4.051	* *

Keti-ami	"	2	65.13	-5.684	* *
Mud dredge	"	1	65.31	-4.979	* *
Mud dredge	"	2	65.16	-5.122	* *
Modified mud dredge	"	1	65.95	-3.583	* *
Modified mud dredge	"	2	68.38	2.835	* *
United Kingdom	Portarlington	1	59.61	-0.758	ns
United Kingdom	"	2	61.28	2.841	*
New Zealand	"	1	not done		
New Zealand	"	2	61.44	2.509	*
Southern scallop harvester	"	1	62.84	7.812	* *
Southern scallop harvester	"	2	not done		
Keti-ami	"	1	59.61	-0.613	ns
Keti-ami	"	2	64.59	8.324	* *
Mud dredge	"	1	59.83	-0.200	ns
Mud dredge	"	2	62.01	3.545	* *
Modified mud dredge	"	1	59.55	-1.003	ns
Modified mud dredge	"	2	60.20	0.527	ns

It can be seen from Table 2.4 that, in most instances, scallops caught by the dredges differed statistically significantly in size (on average) from those available to be caught, as indicated by diver collected scallops. Of interest is that most of the differences between the size of scallops caught and those in the fishable population were negative, except for the southern scallop harvester. That is, most dredges selected scallops that were smaller on average available from the population. This result needs more investigation in relation to (1) assumptions used in the analysis, and (2) the efficacy of divers selecting a representative sample of the available population, as it is well known that small scallops are quite cryptic.

2.1.3 Fishing efficiency

A further test of catching efficiency in Port Phillip Bay was undertaken by attempting to estimate absolute efficiency of dredges at one site (Dromana) which had conditions suitable for divers to undertake surveys of scallop numbers with some precision. Here, three randomly placed transects of 100m each were placed in the study area prior to the dredge trials by laying out a 100m long rope, buoyed at each end. Two divers then swam along the rope, counting every scallop that lay within an estimated one metre of either side of the rope for its entire length, giving an estimated density of scallops per $200m^2$. Counts were pooled from the three separate counts and converted to scallops/m^2 in the study area. This density estimate was assumed to represent the scallop density available on the bottom for each of the dredges. The difference between this estimate of density, which was surprisingly high (5.27m^2), and those recorded for the dredges gives an estimate of absolute efficiency, as shown in Table 2.5.

Absolute efficiency is a function of a number of variables including size selectivity and sustrate effects on the dredges. It can be seen that the New Zealand dredge performed exceptionally well compared to all other dredges, recording an absolute catch efficiency of over 60%, followed by the Japanese keti-ami dredge with 36%. Both of these dredges are flexible mesh bag type dredges. The southern scallop harvester and the two other box type dredges performed within the expected range of 10 - 25%.

Table 2.5 Catch efficiency of scallop dredges at Dromana, Port Phillip Bay

DREDGE TYPE	Mean Catch Rate (scallops/m^2)	Mean scallop density (scallops/m^2)	Catch efficiency (%)
New Zealand	3.22	5.27	61.0
Keti-ami	1.90	"	36.0
Mud dredge	1.10	"	20.8
Modified mud dredge	1.10	"	20.8
Southern scallop har	1.04	"	19.7
United Kingdom	0.40	"	7.6

2.1.4 Damage rates to scallops in the catch

The numbers of damaged scallops in each catch were recorded for comparison of incidental mortality to scallops in catches at Dromana, one of the main sandy bottom sites in Port Phillip Bay. This trial was conducted in a previously undredged area of the scallop bed so as to avoid any previouly damaged scallops from other work, with short (5 minutes at 3 knots) tows. Of primary interest here was a comparison of the mud dredge, the mouth organ (modified mud dredge) and the southern scallop harvester, being the three with the most acceptability by industry for a change of practice.

For both sets of trials at Dromana, all scallops were counted, but with the numbers of scallops in a damaged state recorded separately. For this data, damaged means a scallop in a condition such that it would almost certainly die if released back to the sea. These scallops are characterised by large sections of the shell missing, both valves crushed, or the hinge broken, twisted and/or missing. The data was transformed by natural logarithms to maintain assumptions of normality for the analysis of variance detailed below in Tables 2.7 and 2.8. Results for summary data are shown in Table 2.6 below.

Table 2.6 Summary results for damage rates of scallops. Numbers in brackets in second column refer to percentage of damaged scallops compared to undamaged scallops.

DREDGE TYPE	Mean catch undamaged	Mean catch damaged
Mud dredge	1029.6	86.4 (8.39)
Modified mud dredge	1147.1	150.3 (13.1)
Southern scallop harvester	494.3	15.9 (3.2)

Analysis of variance on the transformed data show that, both for catches of damaged and undamaged scallops, dredges were significantly different in catch characteristics and number damaged, but no difference was recorded between replicates and there was no significant interaction between site, replicate or dredge (Tables 7, 8). That is, dredges were significantly different with respect to the number of scallops damaged in each drag, and this was consistent between sites and times.

Table 2.7 Anova table for a 2-factor Analysis of Variance on ln(number of scallops caught by each dredge type)

Factor	DF	Sum Squares	Mean Square	F	P value
Dredge type (A)	2	5.04	2.52	5.991	0.0065
Site (B)	1	0.002	0.002	0.004	0.9520
AB	2	1.219	0.609	1.449	0.2508
Error	30	12.62	0.421		

Table 2.8 Anova table for a 2-factor Analysis of Variance on ln(number of scallops caught by each dredge type that were damaged)

Factor	DF	Sum Squares	Mean Square	F	P value
Dredge type (A)	2	32.734	16.367	29.537	0.0001
Site (B)	1	0.006	0.006	0.011	0.9177
AB	2	0.867	0.434	0.782	0.4664
Error	30	16.623	0.554		

These results confirm that, in comparison with the mud dredge and the modified mud dredge (mouth organ), the southern scallop harvester damaged significantly fewer scallops at the Dromana site.

2.1.5 Lakes Entrance Trials

Two weeks of trials were undertaken in February 1993 with the dredges from the 1992 work that showed most potential for further improvement and acceptance by industry. These were the southern scallop harvester, mouth organ (modified mud dredge) and the New Zealand mesh dredge. Although performing relatively well in Port Phillip Bay, the Japanese keti-ami dredge was not included because of strong industry resistance to the use of dredges with the safety and handling problems expected (and experienced) with the keti-ami dredge.

Trials were conducted off industry vessels, the FV 'Alex Vanessa' and the FV 'Southern Cross Star', skippered by experienced Lakes Entrance scallop fishermen Brian and Darren Fearnley. Trials were undertaken on three grounds approximately 20 km from Lakes entrance, on day trips from the port. Bad weather limited the number of trials that could be undertaken, with the use of divers to assess scallop density and other variables not possible because of depth and distance to decompression facilities. Trials undertaken thus were essentially comparison trials, with work aimed at improving the catch rate of alternative gears, as well as assessing damage rates and engineering aspects. Two weeks were assigned to the trials, with week one spent configuring the gear, determining bycatch and undertaking size measurements on scallops from the beds. Week two was spent undertaking catch rate trials with three gear types - the standard mud dredge, southern scallop harvester and the modified mud dredge termed the 'mouth organ' dredge.

Almost immediately in the first week, it was apparent that reliable trials with the New Zealand dredge were not going to be possible with the deck configuration of vessels available . New Zealand dredges are deployed over the stern from 'A' frames in the New Zealand fishery. In south eastern Australia, all scallop boats are equipped with dredge tippers, in which the mesh New Zealand dredges collapse when tipped. A vessel with a boom strong enough to safely tow the New Zealand dredge from a boom swung out over the side was not available at Lakes Entrance, and a jury-rigged system off one vessel failed after four drags. No further work with the New Zealand dredge was possible, and work thus concentrated on the three box dredge designs that could be deployed safely from the existing tipper gear.

After two full days configuring the southern scallop harvester for a single tickler chain, and after completing major repairs to the southern scallop harvester after the prototype was damaged during one drag, a series of trials on three separate scallop beds was completed, using as a 'standard' the toothbar dredge deployed from the 'Southern Cross Star' skippered by Mr Brian Fearnley. Mr Fearnley is well regarded as one of the most experienced and best scallop fishermen operating from Lakes Entrance, providing a rigorous test of the performance of alternative designs.

Results of these trials are shown in the table below.

Table 2.9 Catch trials of southern scallop harvester, mud dredge and 'mouth organ' harvester at Lakes Entrance, February 1993. Note that numbers of scallops have been adjusted for swept area for the different sized dredges used in the trials. All drags were exactly 0.5mm in length. The toothbar dredge was fitted with a 1" (25mm) toothbar for all trials. Typically, much longer toothbars of 75-100mm length are fitted to the dredges in Bass Strait, however, Mr Fearnley advised that the shorter toothbar was suitable for the area under study, despite the fact that longer toothbars would normally be used in the area by the majority of the fleet.

TRIAL 1 (INSHORE)

Drag No	Mud dredge		Southern scallop harvester		Mouth organ	
	Number of scallops	Number damaged	Number scallops	Number damaged	Number scallops	Number damaged
1	539	5	421	2	186	12
2	602	13	236	0	188	11
3	543	9	129	3	343	26
4	531	6	162	4	278	15
5	431	5	156	2	411	10
6	635	9	140	1	321	12
7	793	8	266	3	606	14
8	599	5	145	1	234	13
9	602	7	160	2	271	4
10	556	14	150	4	368	12
Total	5831	81	1856	22	3206	118
Mean	583	8	186	2	320	12
% toothbar dredge	-	-	32	25	54	150

TRIAL 2 (OFFSHORE)

Drag No	Mud dredge		Southern scallop harvester		Mouth organ	
	Number scallops	Number damaged	Number scallops	Number damaged	Number scallops	Number damaged
1	646	19	301	2	152	8
2	661	25	408	4	226	7
3	689	30	392	2	130	5
4	804	26	412	5	195	5
5	808	28	660	4	179	13
6	894	36	396	0	209	11
7	871	22	503	2	232	15
8	598	35	740	4	237	6
9	851	21	756	6	197	12
10	846	31	494	5	438	7
Total	7668	273	5062	34	2195	89
Mean	767	27	506	3	220	9
% toothbar dredge	-	-	66	11	28.6	33

TRIAL 3 (OFFSHORE SITE 2 - ABORTED DUE TO BAD WEATHER AFTER 4 DRAGS)

Drag No	Mud dredge		Southern scallop harvester		Mouth organ	
	Number of scallops	Number damaged	Number of scallops	Number damaged	Number of scallops	Number damaged
1	442	17	294	3	152	8
2	549	24	332	2	226	7
3	564	39	395	4	130	5
4	425	29	192	2	195	5
Total	1980	109	1213	11	703	25
Mean	495	27	303	3	178	7
% toothbar dredge	-	-	61	11	36	26

Results indicate that the existing toothed mud dredge has the highest catch rate of the three dredges in the grounds off Lakes Entrance, but accentuated the difference that sea bottom conditions play in gear performance. The results held for these different seabed conditions of offshore and inshore, with the offshore site characterised by a considerably 'harder' bottom compared to the inshore site. At the inshore 'soft' bottom site, catch rates with the southern scallop harvester were, on average, only 30% of the toothbar catch rates, while the mouth organ dredge catching 54%. This result however was different at the harder bottom site, with the southern scallop harvester landing 66% of the catch of the mud dredge on average, while the mouth organ catch rate dropped considerably to less than 30%. The offshore site was regarded by Mr Fearnley as more typical of most Bass Strait scallop beds compared to the inshore site. Results therefore for the offshore sites (Trials 2 and 3) may be typical of relative performance of the dredges in most areas of the fishery.

Damage rates of scallops did not reflect catch rates however, with both the southern scallop harvester and the mouth organ dredge damaging significantly fewer scallops than the toothed mud dredge on average, on both hard and soft grounds. For the harder offshore grounds where damage rates could be expected to be higher, the southern harvester damaged only 11% of the number that were damaged in the toothed mud dredge, with the mouth organ damaging about 30% on average for two trials. Analysis of variance of this data confirmed that these results represented highly significant differences in damage rates between the dredges.

2.1.6 Size Selectivity

Tows with four dredge types were first undertaken at an inshore scallop bed, where a random sample of scallops was collected for size frequency comparison of the catches. The dredges included the New Zealand, toothbar mud, southern scallop harvester and mouth organ and were towed parallel across the scallop bed, but not over the same ground. That is, the dredges were towed in the same direction across the centre of a scallop bed of known extent, but care was taken to ensure that no tow was over or along the track of any previous dredge used. As far as is known, the scallop bed had not previously been fished and so represented a population of unknown, but unfished, size frequency distribution and was located on a 'soft' bottom. Unfortunately, the depth of the scallop bed precluded the use of divers to assess population size frequency as was done in the Port Philip Bay trials. Results of the analysis are shown in Table 2.10.

Table 2.10 Mean size of scallops from Lakes Entrance dredge trials

DREDGE TYPE	Mean shell size	Std dev	Std error	N
Mud dredge	78.7	8.1	0.55	219
New Zealand	78.5	8.5	0.58	214
Southern scallop har	77.2	9.8	0.80	150
Mouth organ	77.3	8.7	0.60	219

A one way analysis of variance was performed on the data from Table 2.10 with initially untransformed size data. Transformation using square roots decreased one estimate of between component variance, but did not change the results of the analysis which show the use of untransformed data (Table 2.11).

Table 2.11 Anova table for a 2-factor Analysis of Variance on size of scallops caught by four scallop dredges

Factor	DF	Sum Squares	Mean Square	F	P value
Between groups	3	4056.38	1352.13	17.689	0.0001
Within groups	798	60996.56	76.437		
Total	801	65052.949			

Results indicate that there is a significant difference between dredges for mean size. Of interest was that the southern scallop harvester selected slightly smaller scallops on average than either the New Zealand or the toothed mud dredge, but was no different to the mouth organ dredge. This result differed from that obtained later in the trials when the size frequency of scallops measured during the trials detailed in Table 2.9 (Trial 2 - Offshore) gave the following result:

Table 2.12 Size frequency distribution of scallops caught in the offshore trials of the toothed mud dredge and the southern scallop harvester

DREDGE TYPE	Mean shell size	Std dev	N
Mud dredge	72.9	8.1	138
Southern scallop harvester	75.3	8.5	144

A t test for differences between means indicated a statistically significant result for these trials, with the southern harvester landing larger scallops on average (T = -0.231, df = 280, P= 0.02). This result also highlights the difference that different substrate types, scallop density and bycatch factors has on size selectivity and catch efficiency.

2.2 Modifications to existing dredge design (VFIF and Dames and Moore)

Three dredges were built for the purposes of this study. Two were of a standard design which was modelled from the 'Peninsula' type dredge commonly used in Port Phillip Bay, with one of these transferred to CSIRO in Hobart for use as the control dredge (mud dredge) in trials with imported gear types (see above). The third dredge was an experimental model which includes several modifications to the standard design. Initially, these modifications included

- increasing the height of the skids to lift the dredge 100mm of the bottom
- replacing the cutter bar with a row of forward-pointing tines (toothbar),
- moving the row of tines 200mm forward.

The standard and modified dredge design were deployed in Port Phillip Bay for preliminary assessment under commercial scallop fishing conditions by two separate vessels over a period of five days. The purpose of this preliminary work was to assess the fishing capacity of both dredges and to remedy any immediately obvious design faults before commencing the comparative trials. It also gave the vessel operators time to become acquainted with their new dredges, making the necessary adjustments to optimise performance.

Over the five days, the standard dredge was found to catch as well as could be expected from any currently-used dredge. However, several adjustments needed to be made to the experimental dredge before it would catch commercial quantities of scallops. The major modification involved the welding of a continuous bar across the ends of the forward pointing tines, so forming the 'mouth-organ' design. The forwardly pointing tines could not be made to lift scallops into the cage, but instead became clogged and contributed to drag and the tendency to dig into the seabed. Thus the major difference between the two harvesters became the hollow 'mouth-organ' type arrangement compared to the solid cutter bar of the conventional gear. At this stage it was considered that both dredges were capable of performing to commercial standards, so a series of six comparative trials were undertaken. For each trial the boats were permitted to catch the commercial quota of scallops for Port Phillip Bay. Weather permitting, the boats were then tied side-by-side so that results were directly comparable and a sample from each vessels tow could be taken from both dredges simultaneously. This also kept cable length, tow duration, speed and fishing area the same for each trial, with the number of adult and juvenile scallops, damaged scallops and amount and size of by-catch noted for each set of tows.

2.2.1 Results

Results suggest that both adult and juvenile catch rates were generally the same for both dredges on any particular trial day. The experimental dredge showed a tendency to catch slightly more scallops in total, however the proportion of juveniles to adults caught was similar for both dredges. The one occasion when the experimental dredge caught significantly more scallops than the standard dredge was on the fourth trial in an area which had been heavily fished. Analysis of length frequency distributions show that there is little or no difference between the two dredge designs in terms of adult size selectivity. However, the experimental dredge is inclined to reduce the proportion of smaller-sized juveniles in the catch according to the juvenile length frequency results.

From these trials was developed the highly modified toothbar arrangement which is, in practice, a modified scraper bar. This variant was termed the 'mouth organ' due to its grate-like arrangement of teeth and supporting bars.

Section 3

Bycatch characteristics of scallop gear

3.0 Bycatch characteristics of scallop gears

During many of the trials of the different types of scallop harvesting gear, bycatch was retained and counts were made of the numbers of principal components, both live, dead and inanimate. These included fish, benthic and epi-benthic invertebrates, seaweed, dead scallop and oyster shells. Where possible, numbers of individuals were counted. Items such as seaweed were counted as individual clumps, and thus this measure is semi-quantitative at best. The data was gathered during the following periods.

- September and October during the 1991 fishing season in Port Phillip Bay. The experimental 'mouth organ' harvester was compared with the traditional Peninsula type dredge commonly used in Port Phillip Bay. These trials were conducted using two commercial vessels tied together so that fishing with the two gears was carried out simultaneously and under the same conditions of speed and warp length. Trials were conducted off Mornington because of commercial fishing in that region at the time; otherwise all trials were conducted off Dromana. The bycatch results are shown in Table 3.2 and represent the average of five hauls, standardised to catch per 2 minute haul.

- Trials of a range of harvesters off Lakes Entrance during February 1993. These trials included the use of standard, mouth organ and prototype southern scallop harvesters. Trials with the Scottish and keti-ami harvesters were generally unsuccessful and not completed. The bycatch information is shown in Table 3.3 These figures represent the average number of bycatch organisms taken from ten hauls over 5 minutes at a towing speed of 3 knots. Although not reported here, bycatch information was also noted for most trials where other tasks, such as load trials, etc were being conducted.

- During the 1993 season in Port Phillip Bay, between April and August, and under normal fishing conditions, comparing a number of different gear designs. In August, direct comparisons between the southern scallop harvester, mouth organ and bay dredge were undertaken. These results are given in Table 3.4 and represent the average of five, 2 minute hauls at 6 knots. The 2 minute sample hauls were interspersed among the normal fishing day. However, during the trials in Port Phillip Bay on 27 August 1993, the fishing was conducted under controlled conditions and results represent the average catch from four 2 minute hauls at 6 knots. These results are given in Table 3.5 Prior to this experimental fishing day, some time had been spent on the previous two days carrying out practice trials with the different harvesters.

The studies of bycatch represent a range of gear designs and operating conditions including both experimental and commercial. One difficulty in conducting studies of this nature is that there is no configuration of fishing (warp, speed, etc.) which typically represents commercial fishing for any given location, weather conditions or scallop density. Thus the results reflect the general bycatch retention characteristics under experimental trials and a range of commercial conditions.

3.1 Results And Discussion

In general, the amount of bycatch of marine fauna and flora (fish, benthos and seaweed) in scallop harvesters of any design is low. The bycatch composition is predominantly dead shells of scallops and oysters. Epibenthic species are generally more abundant than benthic ones. Partly this may be a factor of size, as small bivalves, crustaceans and polychaetes would mostly pass through the dredge meshes, while the larger epibenthic species are more likely to be retained. On certain occasions, large numbers of oysters were also retained by the gear, and there are occasions when significantly large numbers of tunicates, (also known as cunjevoi, or *Pyura stolonifera*) and spider and swimmer crabs were also caught. The tunicates in particular often form dense clumps and help to stabilise the sea bed and probably form an important part of the sea bed ecology and fish feeding areas. There is also the probability of a negative correlation between large numbers of filter feeding and scavenging epibenthic animals and large numbers of scallops, in addition to the reluctance of scallop fishermen to fish in areas of a high density of epibenthic organisms – catch rates are generally poor in these areas. These factors were not examined here.

Results of the initial comparisons of the mouth organ and standard harvester (Table 3.1) did not indicate any evident differences in the abundance and species of the bycatch. Under conditions as controlled as possible, with two boats fishing while tied together, the bycatch composition was similar between each paired trial. On the occasions where epi-benthic organisms were abundant, they were retained equally by the two gears. The main differences were a lower proportion of juvenile scallops retained and lower incidence of shell breakage by the mouth organ harvester.

Results of the sampling at Lakes Entrance during February 1993 are shown in Table 3.4

Results of trials carried out in Port Phillip Bay during 1993 (Table 3.5) also indicate the generally low bycatch characteristics of the different harvesters. While not directly comparable between the different harvester designs, the results are indicative of the general bycatch composition retained during commercial operations. With the exception of dead scallop and oyster shells, oysters and tunicates (*Pyura*) were the most common components of the bycatch. While it is inevitable that a certain number of oysters will be retained since they have a similar mode of existence as scallops on the seabed, there is no need to disturb beds of *Pyura* while catching scallops. Consequently, harvesters which can effectively catch scallops without disturbing *Pyura* beds would have considerable environmental benefit.

The standard Peninsula gear (or mud-dredge) appeared to catch the highest number of *Pyura* (> 300 per 2 minute drag in some instances) while the mouth organ and southern scallop harvester did not retain such numbers in any of the trials. While these particular trials were not directly comparable, they indicate some difference in retention characteristics and a lesser disturbance of tunicates by the modified harvester designs.

During the trials in Port Phillip Bay in August 1993, the performances of the dredges can be directly compared, as the fishing was conducted under controlled conditions and results represent the average catch from four 2 minute hauls at 7 knots. The results are summarised in Table 3.1.

Table 3.1 Ranges of bycatch organisms (numbers per 2 - minute drag) taken by different gear during trials in Port Phillip Bay during August 1993

Harvester type	Fish (F)	Oysters (O)	*Pyura* (P)	Rank		
				F	O	P
Mouth Organ	1 - 7	5 - 14	44 - 105	-	1	5
Bay Dredge	1 - 5	270	14 - 58	-	5	1
SSH (1)	1 - 9	260	40 - 73	-	4	2
SSH (2)	1 - 6	7 - 23	39 - 67	-	2	2
SSH (3)	1 - 7	7 - 36	49 - 74	-	3	2

The numbers in brackets refer to the numbers of chains attached to SSH gear.

The different gears have been ranked according to the numbers of bycatch organisms retained, with the ranking representing least bycatch. The southern scallop harvester performed better when fitted with 2 or 3 chains. There was little difference between the southern scallop harvester and bay dredge in numbers of tunicates but the mouth organ retained more. The bay dredge and SSH (1) caught high numbers of oysters. On the basis of the numbers of oysters and tunicates, the SSH (2) received the highest overall ranking.

Results of trials undertaken in Port Phillip Bay in November 1993 are shown in Table 3.5

3.2 Discussion and Conclusions

The observations on bycatch retention characteristics provide some semi-quantitative comparisons of the different gear types. Some observations were made under experimental conditions, others during commercial operations.

In general the amount of bycatch of fish and benthic (infaunal) organisms is low to moderate. More epi-benthic than benthic organisms are retained, of which oysters and tunicates, (mostly *Pyura stolonifera*) are sometimes abundant. There was no major difference in the amounts of seaweed, most of which was probably drift weed moving in the tide.

The retention of *Pyura* in the catches is an undesirable environmental feature of certain scallop harvesters. This species may be regarded as a useful indicator of when a scallop harvester is penetrating the sediment more than necessary to catch scallops. On the basis of the numbers of tunicates (*Pyura*) retained as an indicator of environmental disturbance, the southern scallop harvester (with 2 chains) and the bay dredge performed better than the peninsula and mouth organ as they seldom caught high numbers.

In the first controlled trials, there was little difference in terms of bycatch retention characteristics between the mouth organ and standard peninsula gear. However, in subsequent experimental trials, the southern scallop harvester (2) ranked better than the others.

Under commercial conditions, particularly during the early part of the season in Port Phillip Bay (April and May 1993), the peninsula gear tended to catch high numbers of tunicates. To some extent this may reflect the method of deployment of the gear; for example letting out longer warp when operators are searching for patches of scallops which are in good marketable condition but may be less densely distributed. Clearly the bycatch retention characteristics and environmental impact depend both on the gear's inherent characteristics and also on the method of deployment. The design of the southern scallop harvester should prevent excessive catches of epi benthic animals and on the basis of the tunicate index, there is some evidence that this harvester does not catch as much epi-benthic material as the other harvesters.

Table 3.2 Bycatch (frequency of individuals) from standard and mouth organ harvesters operated simultaneously in Port Phillip Bay, September and October 1991 (Average per 2 minute drag at 6 knots).

Harvester	Exp	Std	Exp a	Exp b	Std	Exp	Std	Exp	Std	Exp	Std	Exp	Std
Date	04/9	04/9	09/9	09/9	09/9	11/9	11/9	16/9	16/9	18/9	18/9	02/10	02/10
Fish	15	5	8	15	0	2	2	2	0	2	1	15	18
Oysters	250	250	40	40	0	60	50	100	50	30	0	150	150
Tunicates	<5	<5	<5	5	0	30	0	1	10	2	0	20	15
Crabs	0	0	10	9	0	0	0	1	6	0	0	3	9
Starfish	0	0	0	0	0	1	0	0	0	0	0	0	2
Sponges	0	0	0	0	0	0	2	0	0	1	1	0	0
Bivalves	0	0	0	0	0	0	0	0	0	0	0	0	10
Seaweed	0	0	3	3	0	5	0	0	1	1	0	20	20

Exp = Experimental "Mouth organ" harvester; (a) with all tines present and (b) with alternate tines removed

Std = Standard Peninsula dredge

Table 3.3 Comparison of bycatch under experimental conditions off Lakes Entrance, February 1993 (Average of 10, five minute drags at 6 knots)

Date	18/2/93	18/2/93	17/2/93
Harvester	Mouth organ	1" toothbar	Sthn harvester
Width (m)	3.35	3.7	3.35
Vessel	Alex Vanessa	Sthn Cross Star	Alex Vanessa
Location	Lakes Entrance	Lakes Entrance	Lakes Entrance
BYCATCH			
Fish	0.2	0	0.7
Rays	0.7	0	0.4
Crabs	1.1	4.3	3.9
Ascidians	3.9	1.5	1
Gastropods	7.4	5.5	3.1
Rocks	1.8	many small	0
Sponge	4.7	7.5	1.9
Bryozoans	0.2	0.3	0.2
Octopus	0.2	1.2	1
Other	anemones, bugs	anemones, bugs	1 bug

Table 3.4 Bycatch of a range of harvesters under commercial conditions (Average 2 minute drag at 6 knots)

Date	13/4/93	27/4/93	3/5/93	4/5/93a	4/5/93b	11/5/93	17/5/93
Harvester	Peninsula	Peninsula	Peninsula	Peninsula	Peninsula	Bay	Bay
Harvester Width (ft)	10	10	10	10	10	8	8
Vessel	Saint	Saint	Fairwind	Fairwind	Fairwind	George F	Maureen
Location	Dromana	Dromana	Mornington	Mornington	Dromana	Dromana	Mornington
BYCATCH							
Fish	0.9	0	1.0	1.0	2.8	1.6	0.8
Rays	0.8	0	0.6	0.5	0.9	0	0
Crabs	1.5	0.9	1.3	4.0	1.7	0.8	12.8
Starfish	0	0	0	0	2.5	0	0
Other Bivalves	26.6	0	11.5	27.2	8.7	97.2	40.8
Gastropods	0.8	1.8	0.3	1.0	2.0	2.4	21.6
Seaweed	3.0	0.6	15.4	16.5	8.9	0.8	16.0
Sponge	0.2	0	1.6	7.0	1.4	0	10.4
Tunicates	18.4	200	131.2	343.5	322.7	26.0	219.2
Cephalopods	0.1	0	0	1.0	0.7	1.2	1.6
Polychaetes	0	0	0.6	2.0	0	0	0.8
Dead Scallop Shell*	NR	300	200%	100%	100%	20-100%	25%
Dead Oyster Shell *	NR	NR	NR	NR	NR	NR	NR
Other	0	1 urchin	0	0	0	0	6 isopods

Table 3.4 (Continued)

(Average 2 minute drag at 6 knots)

Date	14/6/93	21/6/93	7/7/93	15/7/93	22/7/93	27/7/93	19/8/93
Harvester	Peninsula	Mth organ	Peninsula	Peninsula	SSH	Bay	SSH
Harvester Width	10	9	10	10	10	9	10
Vessel	Tiki	Mildred J	Fairwind	Leigh	Lisa Jean	Ajax	Lisa Jean
Location	Portarln	Portarln	Dromana	Ann Dromana	Dromana	Dromana	Capel S.
Bycatch							
Fish	3.6	2.0	0	0	2.8	0.4	2.0
Rays	0	0.4	0	0.8	0.8	0	0
Crabs	0.8	0.4	0.8	4.4	4.8	2.8	0.4
Starfish	0	0	0	0.4	0.4	0	0.4
Other Bivalves	248.4	64.8	56.0	95.2	118.8	65.6	12.0
Gastropods	0	0	1.2	0.4	0.8	0.4	0.4
Seaweed	0.7 bin	3 bins	5.6	1.6	2.0	0.4	0.4 bin
Sponge	0	0	3.2	0.4	4.8	1.6	0.4
Tunicates	31.2	86.4	20.4	32.4	61.6	52.0	95.6
Cephalopods	0	0.8	0	0.4	0	0	0.4
Polychaetes	204.8	124.5	0	0.4	0	0	1.5
Dead Scallop Shell*	20%	10%	50%	200%	20%	33%	10%
Dead Oyster Shell *	5%	0%	25%	200%	20%	20%	5%
Other	6 urchins	2.8 urchins	0	0	3.6 anemones	0	8.8 urchins

Table 3.5 Comparison of bycatch of a range of harvesters under experimental trials (Average 2 minute drag at 6 knots)

Date	27/8/93	27/8/93	27/8/93	27/8/93	27/8/93
Harvester	SSH1	SSH2	SSH3	Mouth organ	Bay Dredge
Harvester Width	10	10	10	10	9
Vessel	Lisa Jean	Lisa Jean	Lisa Jean	Saint	Ajax
Location	Portarlington	Portarlington	Portarlington	Portarlington	Portarlington
BYCATCH					
Fish	5.3	3.8	3.8	3.8	3
Rays	0.8	1.3	1.3	0.5	0.8
Crabs	0.3	0.8	0.5	0	0.8
Starfish	4.5	3.8	3.8	3.3	5.8
Other Bivalves	268	12.3	18.5	8.5	279
Gastropods	1.3	0.5	0.8	1	2
Seaweed	1.3	0.5	0	0	3.8
Sponge	2.3	0.5	0.5	0.3	2.8
Tunicates	57.3	50	59.5	67.5	33.8
Cephalopods	0.3	0.5	0	0.8	0.5
Polychaetes	11.8	12.5	11.5	3.5	36
Dead Scallop Shell*	200%	-	-	-	-
Dead Oyster Shell *	150%	-	-	-	-
Other	1.3 Holothurian 0.3 Urchins	1.3 Green Seaweed	2.3 Green Seaweed 0.3 Holothurians	0.3 Green Seaweed	1 Holothurian 1.3 Urchins

Section 4

Engineering Appraisal of Scallop Dredges

4.0 Engineering Appraisal of Scallop Dredges

An appraisal of the dredges used in the south eastern Australian scallop fishery was undertaken and a comparison made with a selection of scallop harvesting gear used elsewhere in the world.

Variations of the toothed mud dredge with respect to skid, box and depressor plate details were surveyed and described. The vertical forces acting on the toothed mud dredge consisting of downward directed hydrodynamic lift, weight, and the upward component of the tow cable tension were analysed in a manner which shows how the resultant seabed contact pressure changed with tow speed. AMC flume tank and sea trial measurements were used to produce a mathematical model of the horizontal forces acting on a typical mud dredge (hydrodynamic drag, ground friction and ploughing). The turning moments and dynamics occurring during dredging operation were also studied.

The toothed mud dredge was compared with the New Zealand dredge, the Japanese keti-ami, and the Scottish mini dredge in terms of downward contact pressures and drag forces per meter of swept width. It was found that the toothed mud dredge, ket-ami, and Scottish mini dredges exert very high downward contact pressures with point loading. The toothed mud dredge had the highest drag while the New Zealand dredge had the lowest drag especially at the lower tow speeds typical for this dredge.

Flat foils at a high angle of attack to a flow and in close proximity to a boundary were investigated in terms of the resulting pressure disturbance and flow patterns. Behind such foils it was found that there existed an extensive region of low pressure fluid that remained relatively stationary with respect to the foil, providing potential as a scallop catching mechanism.

The details of modifications made to a standard New Zealand dredge and south east Australian tipper to allow compatible operation are given.

4.1 Introduction

In Australia, fishers of the Tasmanian, Victorian and Bass Strait scallop (*Pecten fumatus*) grounds have experienced an extensive period of diminished returns and closures. For example the D'Entrecasteaux Channel was closed from 1970 to 1981 and closed again in 1986 (Perrin, 1986), and the Bass Strait Tasmanian zone was closed in 1987 (Zacharin, 1991). This south eastern Australian scallop fishery is experiencing low catch rates because of low stock levels and poor recruitment. This has lead to the voluntary withdrawal of boats and licences from the fishery (DPI&F data). The poor state of the scallop fishery has been attributed in part to the inefficiency and destructive fishing methods used (McLoughlin et al, 1991).

The catching efficiency of the Australian scallop 'mud' dredge was found to be low (on average only 11.6%) and incidental damage is high (McLoughlin et al, 1991). This high incidental damage may be detrimental to the long term viability of the fisheries in which it is used (Zacharin, 1988).

Scallop fishing gear used world wide include box type dredges, the ring mesh bag type dredge, small multiple units and trawl gear. This gear has evolved to suit the local conditions including scallop species, bottom terrain, and local technology. In view of the poor state of the SE. Australian scallop stocks, there is a need to investigate scallop harvesting gear both in terms of efficiency (catching and engineering) and environmental impact.

To date there have been few studies of scallop dredges from an engineering viewpoint. Past research includes work on: Teeth and depressors (Baird, 1959), drag measurements (Hughes, 1973) and the pressure drop behind a stalled foil (Vaccaro & Blott, 1987). Baird (1959) found that teeth improved catching efficiency, while bottom contact was improved by the use of a depressor (or diving) plate. Hughes (1973) measured typical bollard pulls and warp cable tensions for box dredges in Port Phillip Bay. Vaccaro and Blott (1987) suggest that a simple flat depressor plate at an angle of 60 to 75 degrees with a gap to chord length ratio of 0.27 could be used to improve the efficiency of scallop harvesting gear.

This section of this report outlines the work conducted by the Australian Maritime College (AMC) in co-operation with CSIRO Division of Fisheries and the Tasmanian Fisheries Department towards developing better scallop harvesting gear for use in Australia. The AMC's role was to investigate the engineering aspects of the gear.

The work conducted by the AMC was based on six objectives:

- Review world-wide literature in relation to scallop harvesting gear and engineering performance.
- Survey current box dredge designs used in the scallop fishery of south eastern Australia.
- Assess the engineering performance of the toothed mud dredge.
- Compare engineering aspects of the toothed mud dredge to designs used elsewhere in the world.
- Assess the potential of hydrodynamic catching systems.
- Develop a modified New Zealand dredge and compatible tipper arrangement.

4.2 Review of literature

4.2.1 Scallop Fisheries

A wide variety of scallop species are taken commercially by dredges and trawls. These species occur world-wide within definable geographic areas (see Table 4.1).

Countries having significant scallop fisheries include: Canada, Australia, Japan, the United Kingdom, Iceland, Peru, Norway, France, New Zealand, the United States, Faeroe Islands, China, Denmark, and Ireland (FAO, 1989)

Table 4.1 Common names and geographical regions for commercially important scallop species. (Brand 1991)

Species	Common names	Geographical region
Amusium balloti	Southern saucer scallop	Indo-Pacific
Amusium pleuronectes	Moon scallop	Indo-Pacific
Argopecten gibbus	Calico scallop	Gulf of Mexico, NW Atlantic
Argopecten irradians	Bay scallop	NW Atlantic, East coast USA
Argopecten purpuratus	Ostion	SE Pacific
Chlamys asperimus	Doughboy scallop	Southern Australia
Chlamys bifrons	Queen scallop	Southern Australia
Chlamys islandica	Iceland scallop	Sub-Arctic
Chlamys opercularis	Queen scallop, Queenie	NE Atlantic
Chlamys varia	Black, variegated scallop	NE Atlantic
Patinopecten caurinus	Weathervane scallop	NE Pacific
Patinopecten yessoensis	Yezo scallop, hotategai	NW Pacific
Pecten fumatus	Commercial scallop	Southern Australia
Pecten jacobaeus	Pilgrim scallop	Mediterranean
Pecten maximus	Giant scallop, escallop, coquille St Jacques	NE Atlantic
Pecten novozelandiae	New Zealand scallop	New Zealand
Placopecten magellanicus	Sea scallop, giant scallop	NW Atlantic

4.2.2 Scallop Fishing Methods

4.2.2.1 Classification of Scallop Harvesting Gear

Table 4.2 Scallop Harvesting Gear Classification

Method	Type	Example and catch mechanism	Fishery	Scallop Type
Dredge	Box	Toothed mud dredge	Tasmania and New	*Pecten fumatus*
		Mesh dredge	Zealand	*Pecten Novaezelandiae*
		Peninsula dredge	Port Phillip Bay	*Pecten fumatus*
		Bay dredge	Port Phillip Bay	*Pecten fumatus*
	Hybrid		US/Canadian	Experimental
		Southern Scallop Harvester	Experimental	*Pecten fumatus*
	Flexible		New Zealand	*Pecten novaezelandiae*
		Keti-ami	Japan	*Patinopecten yessoensis*
		New Bedford	Atlantic	*Placopecten magellanicus*
		St Brieuc	France (off-shore)	*Pecten maximus*
		Tumbler	USA	*Argopecten gibbus*
		Multi Unit	Scottish	*Pecten maximus*
		Digby (frame only)	US & Canada	*Argopecten irradians*
Hydraulic		Magnus (rotors)		
		Quahog (pump)		
Trawl		Modified prawn trawl	southern USA	*Argopecten gibbus*
		mid Atlantic Australia		
				Placopecten magellanicus
				Amusium balloti

Scallop dredge types are the result of design and evolution toward greater catching efficiency and selectivity in accordance with local bottom terrain and scallop behavioural characteristics. There is significant variation in terms of catching efficiency and methods of handling. Table 4.2 contains a classification system for scallop harvesting gear used throughout the world.

4.2.2.2 Box Type Dredges

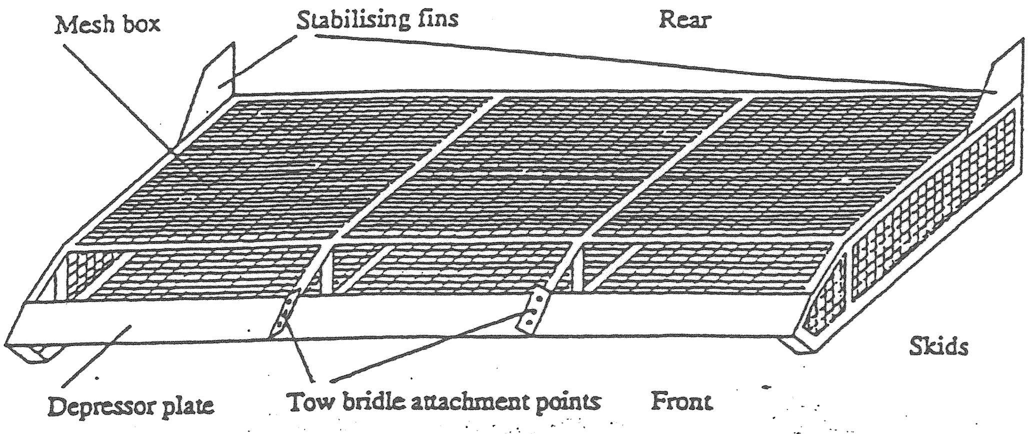
Box dredges are completely rigid structures, generally consisting of a steel prismatic frame supporting wire mesh walls. The major feature of the box dredge is its longitudinal rigidity which allows the device to be used in conjunction with a tipper. The benefits of this handling technique is that the dredge becomes very easy to operate, even in very adverse conditions.

The Toothed Mud Dredge

The scallop fishery in south eastern Australia began in the early 1900s at which time a rowing or sailing boat was used to tow a dredge which was then hand hauled aboard for sorting the catch (Harrison 1965 in Perrin 1986). The early type of dredge used was the 'Lip dredge', which was superseded by the 'Sputnik' or modified Baird sledge and in turn was replaced by the currently used toothed mud dredge. In the New Zealand scallop fishery of the North Island where the scallop beds generally coincide with sandy substrates, a single box dredge with rigid tooth bar is also used (Bull 1988).

The toothed mud dredge generally has the rigid steel mesh box on two longitudinal skids. Also incorporated is a bottom contacting tooth or cutter bar and a forward mounted hydrodynamic pressure plate containing the tow point attachments (see Figure 1).

Figure 1 The Toothed Mud Dredge.



Scallop fishermen prefer the use of the box dredge in conjunction with a tipper due to its ease of operation. Dredge teeth play an important part in the capture of scallops in some areas, since the scallops tend to lie in the bottoms of sand mega-ripples or partially submerged in recesses on flat ground. Teeth ensure a level of bottom contact and penetrate sufficiently to 'flick' the scallops upward into the mesh box.

According to Baird (1965), the presence of teeth in the box dredge increases the catching efficiency. Baird and Gibson (1956) state that the teeth have a selectivity role and serve to reduce trash picked up by the dredge.

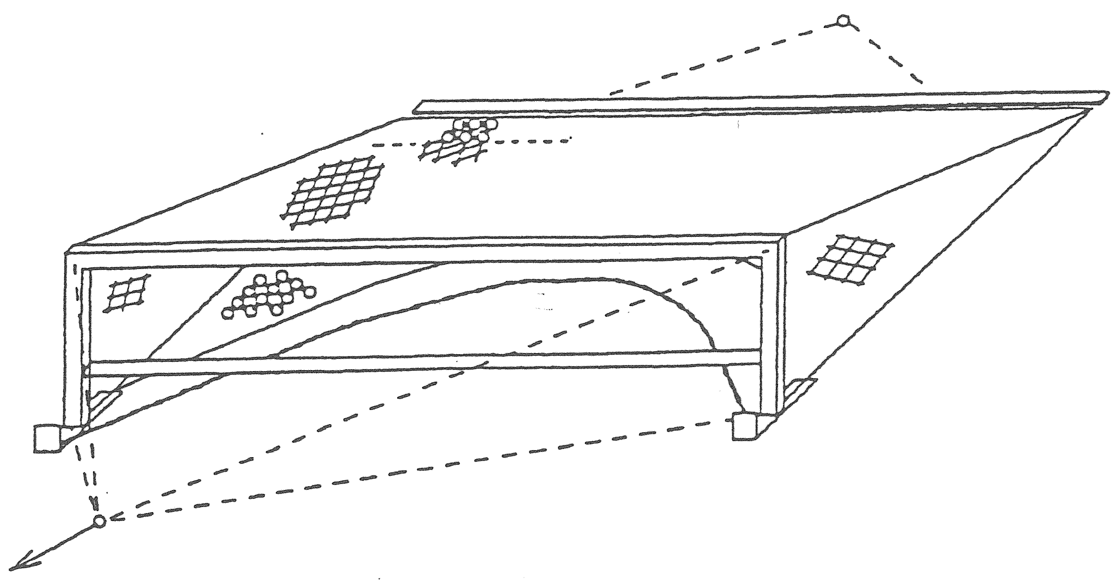
4.2.2.3 Flexible Mesh Bag Dredges

The New Zealand Scallop Dredge

In the southern New Zealand scallop fishery (*Pecten novaezelandiae*) where soft muddy substrate predominates and scallop densities are often quite low (< 1 per $5m^2$) most vessels use a pair of ring bag dredges each up to 2.5m in width and fitted with heavy tickler chains.

The New Zealand dredge, overall, is a relatively light weight unit consisting of a head frame, tickler chains, flexible ring mesh floor, nylon mesh top and a tipping bar (Figure 2). This design is the result of evolution from traditional English beam trawl designs, including the Blake dredge.

Figure 2 **The New Zealand Dredge**



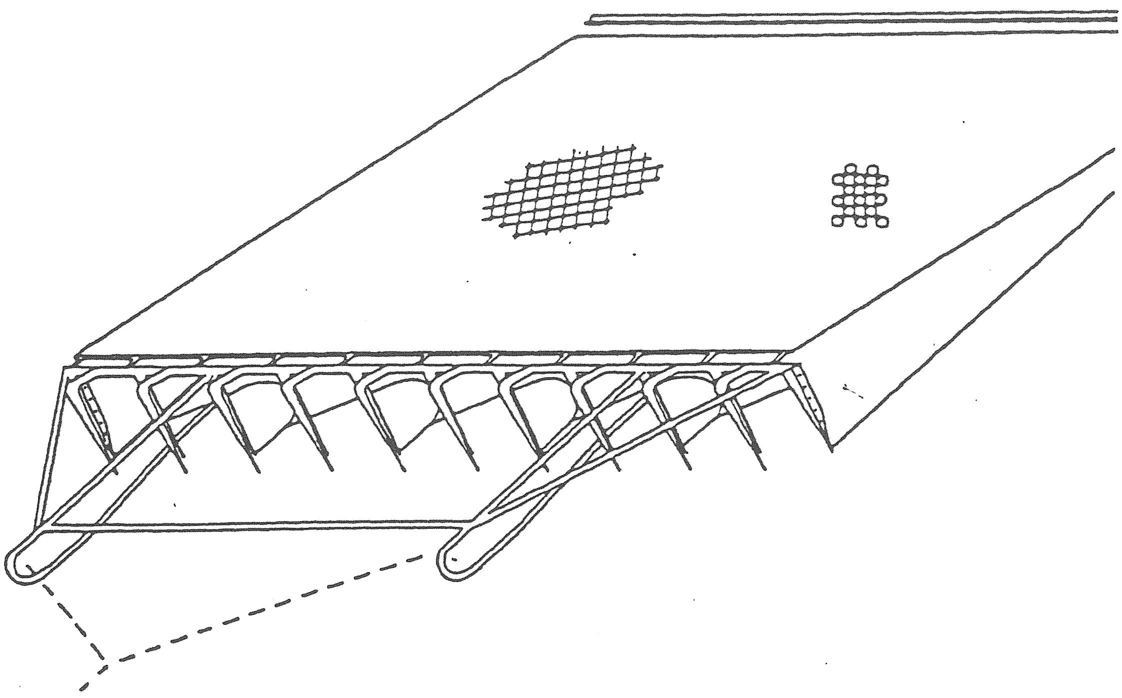
Flexible ring mesh bag dredges similar to the New Zealand dredge are also used elsewhere. Strange (1977) describes the Queen dredge used by the Scottish fishery. It consists of a low profile steel box frame with runners incorporated at each end. A chain bag is attached behind the frame. It has no tooth bar and incorporates four towing chains'.

The Japanese Keti-ami Dredge

The scallop commonly cultivated in Japan (*Patinopecten yessoensis*) is also harvested from a natural resource by the keti-ami dredge.

The keti-ami dredge (Figure 3) consists of an elaborate tow frame with very large teeth or tines projecting downward from the top rear of the frame. There is also a tickler chain, rock chains, a catch bag made of flexible ring mesh floor and nylon mesh top, and a tipping bar at the rear. There are many variants of the keti-ami dredge used in different parts of Japan.

Figure 3 The Keti-ami Dredge

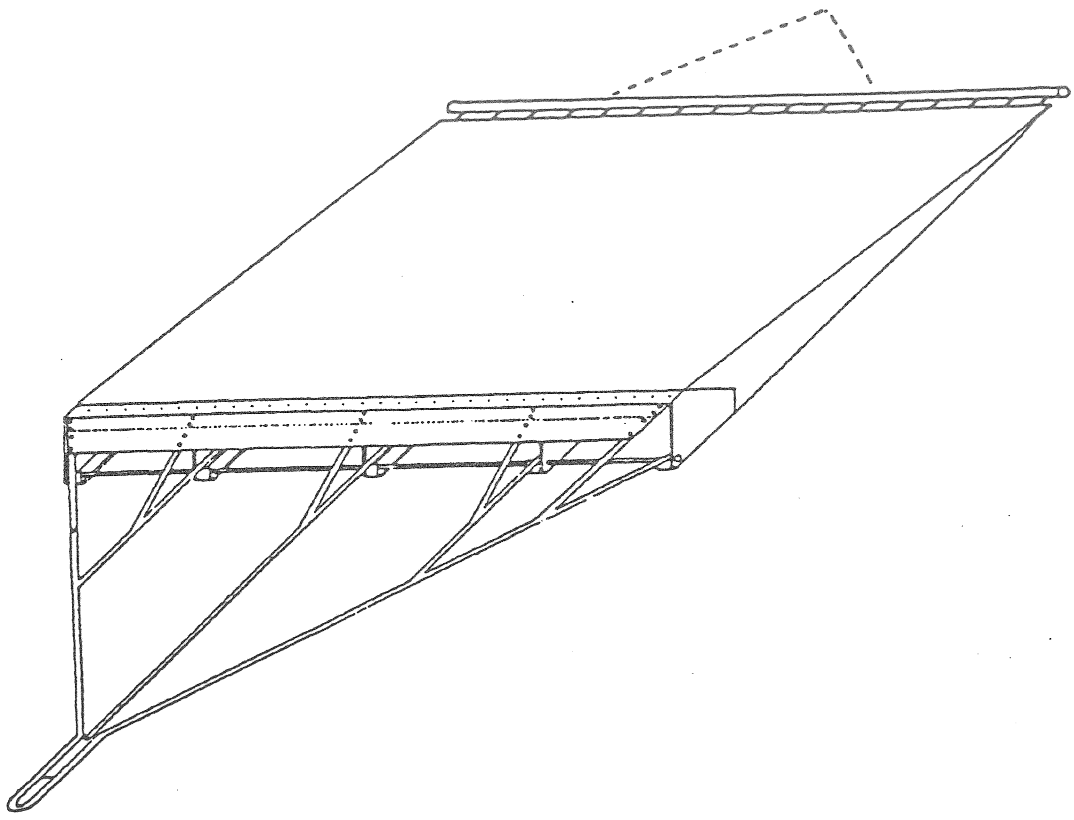


Two specific keti-ami designs were investigated in Tasmania by the Department of Sea Fisheries (Zacharin 1988). Comparative trials between the keti-ami and a 2.5m toothed mud dredge showed that the Keti-ami dredges took more than five times the catch of a toothed mud dredge. Incidental damage to scallops using a keti-ami was under 2%, where as for the mud dredge catch damage was as high as 12%.

New Bedford Dredge

Sea scallops (*Placopecten magellanicus*) are taken from the north west Atlantic by United States and Canadian fishermen using New Bedford (off-shore) dredges. Originally called the airplane drag, this dredge is used by virtually all dredge vessels in waters deeper than 40 m (Smolowitz & Serchuk 1988).

Figure 4 The New Bedford (or Off-shore) Dredge

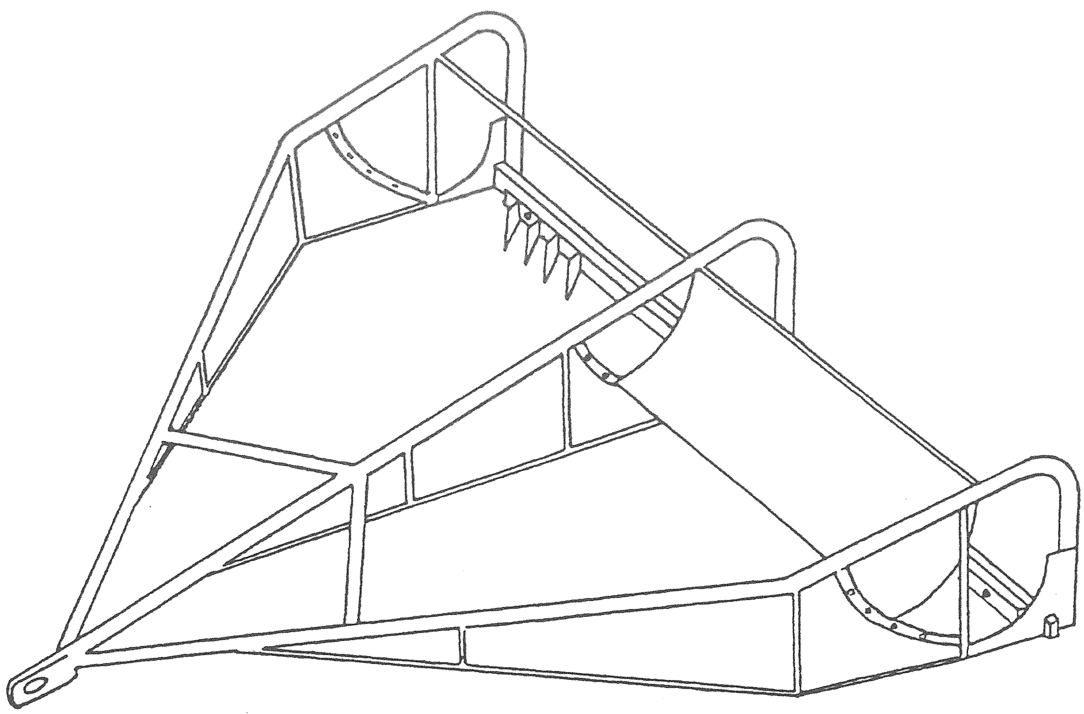


The New Bedford dredge (Figure 4) consists of a heavy steel bale and rectangular head frame towing a collecting net with mesh top and chain link bottom. The bottom of the frame consists of a steel cutting bar resting on a pair of steel shoes. Attached to the top is a hydrodynamic depressor plate. Attached to the shoes is a sweep chain, sometimes with additional tickler chains in front. The collecting net is laced to the sides and top of the head frame, to the sweep chain and at the rear to a 'club stick' or dumping bar. Rock chain systems are often used to reduce the capture of rocks. Dredge size is from 3 to 5m wide (Smolowitz & Serchuk 1988).

The St Brieuc Dredge

The St Brieuc dredge (Figure 5) incorporates a curved depressor plate and tooth bar into the head frame of a flexible ring mesh bag type dredge. The dredge has evolved for use in French off-shore scallop fisheries (Dupouy 1982).

Figure 5 St Brieuc Dredge, Redrawn from Dupouy (1982)



Tumbler Drag

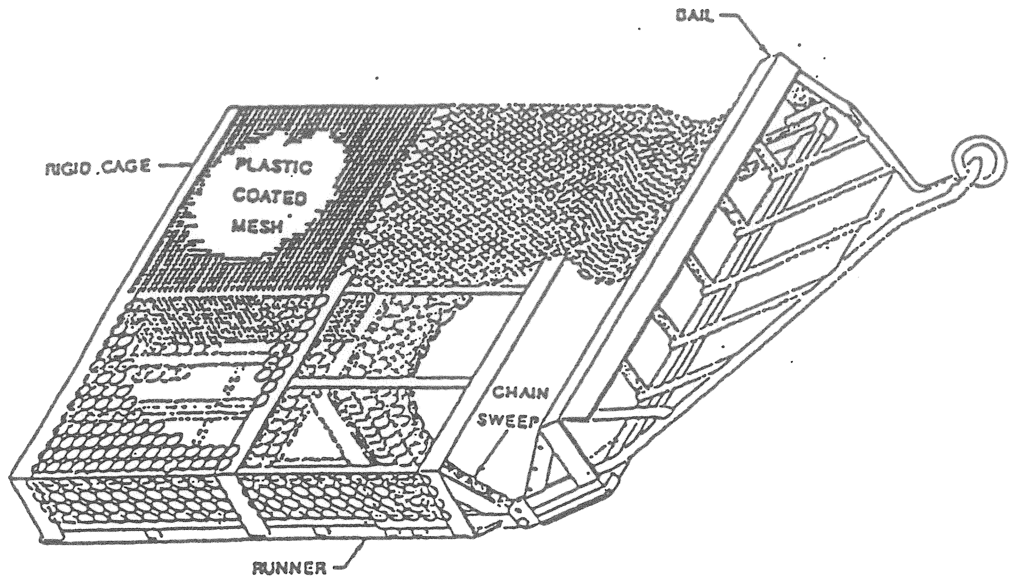
Tumbler dredges of 2 - 3m in length are used to capture Calico scallops (*Argopecten gibbus*) in the western Atlantic off the southern USA coast and the Gulf of Mexico (Cummins 1971). This dredge is similar in design to the individual units used in the Digby drag shown in Figure 9. The main features of the dredge are the three point tow chain arrangement and a simple head frame that can be towed either way up. The flexible bag is constructed form steel rings (approximately 50mm) both top and bottom.

4.2.2.4 Hybrid designs

US/Canadian Experimental

This dredge is based on an attempt to incorporate a rigid box into the New Bedford style dredges used in the American and Canadian scallop fisheries. Such a design could incorporate the best features of both the rigid box and the flexible ring mesh bag type dredges.

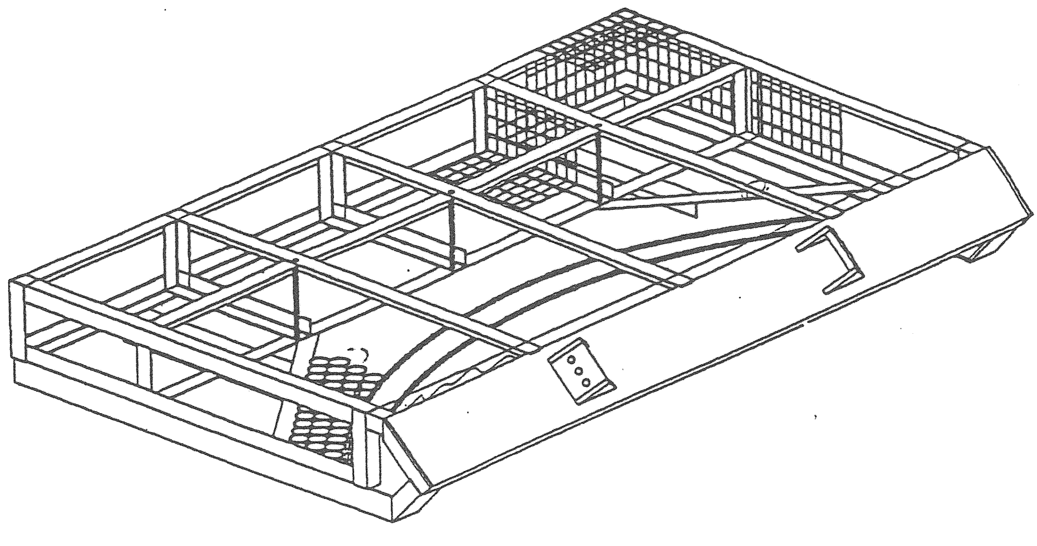
Figure 6 **American/Canadian Experimental Drag**



Southern Scallop Harvester

The American/Canadian experimental dredge has been further modified by the CSIRO to become the 'southern scallop harvester'. The primary modification by the CSIRO was to replace the towing frame (or bail) with a depressor plate and towing chains similar to that of the toothed mud dredge. This alteration allows the dredge to be operated from a standard Australian tipper.

Figure 7 **The CSIRO Southern Scallop Harvester**



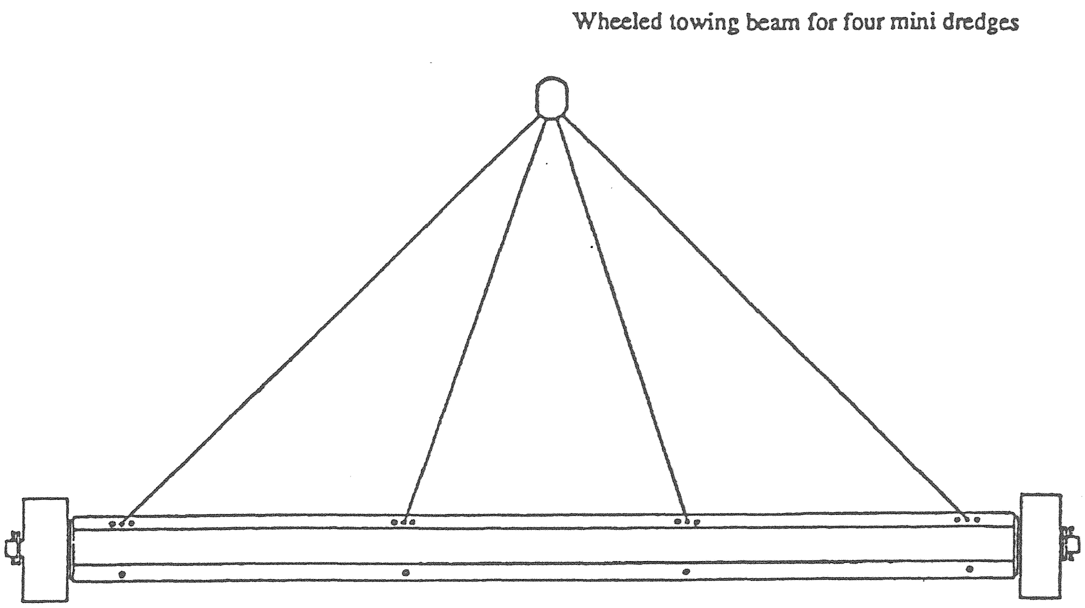
4.2.2.5 Multiple Units

The Scottish Dredges

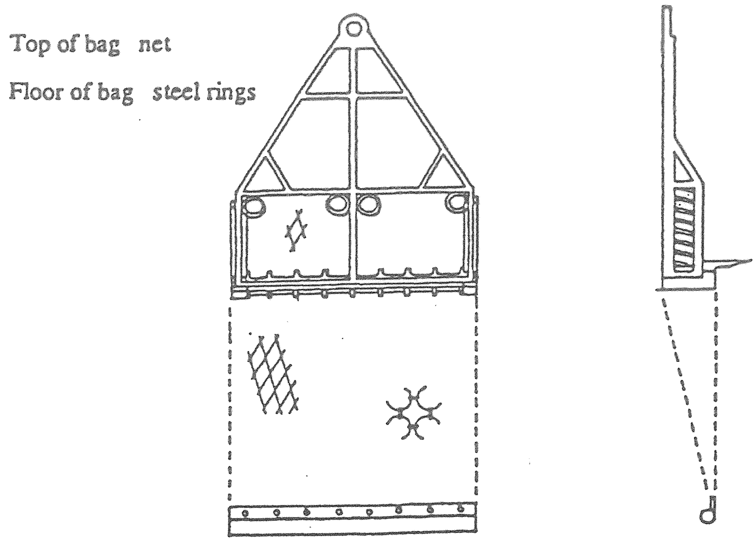
In the British Isles, the scallops *Pecten maximus* and *Chlamys opercularis* (Queen scallops) are taken commercially by 0.8m wide toothed Scottish dredges fished in gangs of three to six per side of the fishing vessel. Queen scallops which are better swimmers however, are more readily taken using modified trawl gear.

The Scottish dredges have sprung teeth, a rigid frame and a flexible bag. These are towed behind a beam which contains a wheel on each end. The small units evolved in response to perceived improvements in efficiency.

Figure 8 The Scottish Dredge



Plan and side view of sprung toothed mini dredge



In the 1960's dredges were 1.2m wide with fixed teeth protruding 51mm at 76mm spacing. The dredges were fished in gangs from a towing bar attached to the warp by means of a bridle with the number of dredges used depending on the size of the vessel. The towing bar did not always have a rubber wheel at each end. One bar was towed over each quarter and each had two to five dredges attached (Mason, 1983). The traditional dredge was replaced on rougher grounds by dredges fitted with a spring loaded toothbar which moves back when obstacles are encountered, thus reducing shock load and damage to the teeth (Chapman et al, 1977).

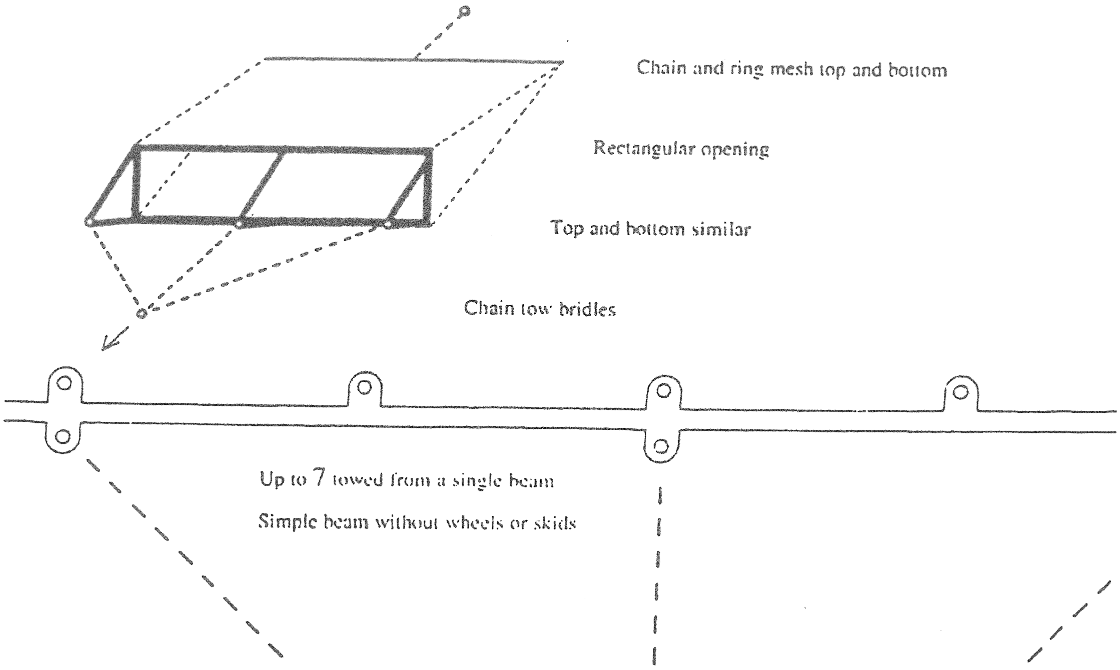
A comparison of the two types of Scottish dredge showed that the newer 0.84m wide dredge always outfished the older 1.30m wide dredge (Howell, 1983). The current gear in general use is the smaller unit using a 0.8m wide toothbar with 10 sprung teeth protruding 70mm.

The Digby Drag

The Digby drag is generally small (0.9 to 1.2 m) with a steel head frame and chain link bag (Robert & Lundy, 1989) and normally towed in multiples from a beam not unlike the Scottish dredges.

The Digby dredge is the same top and bottom and will fish equally well either side up and is used primarily in inshore waters along the Gulf of Marine and Canadian coast.

Figure 9 The Digby Drag, after Bourne (1969), and Robert & Lundy (1989)



4.2.2.6 Scallop Trawls

The Calico Scallop Fishery

Calico scallops *Argopecten gibbus* occur in the western Atlantic from Cape Hatteras to Brazil including the Gulf of Mexico (Cummins, 1971). They form a valuable fishery to the south east of the United States where they are harvested by large (2 - 3 m) tumbler dredges and by modified trawl gear.

On hard sand bottoms the trawl gear out fishes the dredge, sometimes by as much as six to one (Rivers, 1962). Apparently many of the scallops congregate in depressions in the otherwise smooth bottom. The rigid dredges, unable to dig into the hard sand, seem to slide over the tops of these depressions; whereas the more flexible trawls follow the bottom, dip down into the depression, and obtain the greater catch (Rivers, 1962).

Most of the boats used by the calico scallop fishery are modified 'Gulf style' shrimp boats 20 to 25m in length. Each boat commonly fishes two modified shrimp trawls, one from each side. The trawls are fished for 20 to 30 mins after which the catch is landed on deck.

The Sea Scallop Fishery

Modified trawl gear is also used on the relatively smoother ground in the mid Atlantic fishery for sea scallops (*Placopecten magellanicus*).

The Saucer Scallop Fishery

A fishery for the Saucer scallop (*Amusium balloti*) exists in Queensland and Western Australian waters (Dredge et al, 1988). In these fisheries Saucer scallops are taken by modified prawn trawling gear similar to that used to catch calico scallops to the south east of the United States.

Scallop trawls were tried in Tasmanian waters where they showed better size selectivity and no incidental damage compared to a dredge (Wolfe, 1986).

4.2.2.7 Hydraulic/Power Assisted Systems

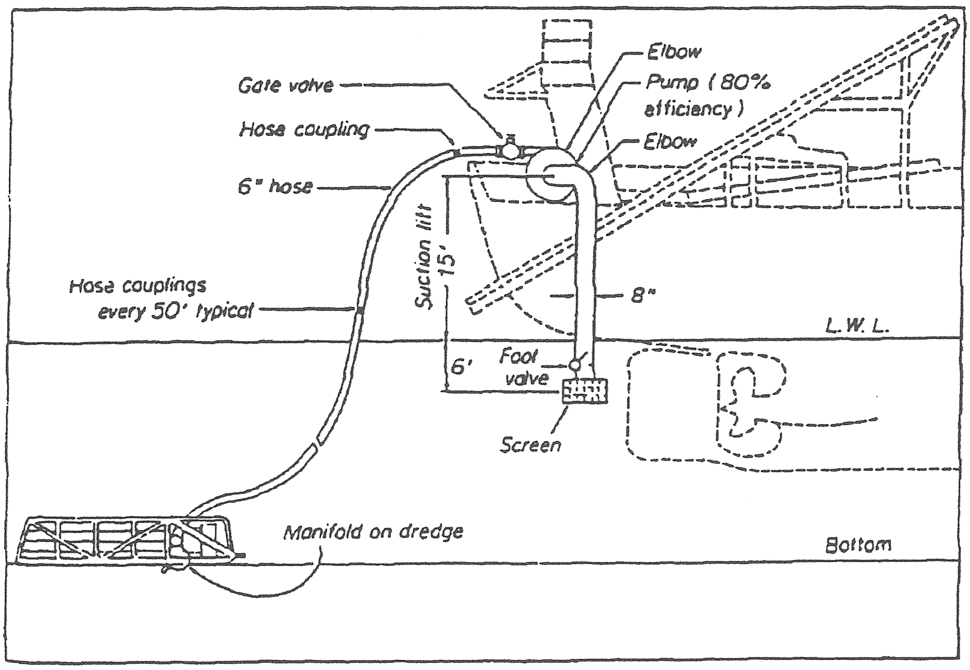
The Magnus Dredge

The French designed Magnus Effect dredge utilises two hydraulically driven rollers working towards each other to create a vacuum in front of the dredge which causes molluscs on the sea bed to be sucked into the trailing net (Anon, 1989). It is claimed that no damage occurs to the catch as the molluscs come into contact with the bottom of the net only and the catch is of greater quality than that achieved by dragging teeth.

The Quahog Dredge

Quahog and surf clam dredges utilises a pump to lift bottom dwelling organisms and also those imbedded in the substrate plus the substrate via a large diameter flexible hose into the fishing boat.

Figure 10 **Surf Clam and Ocean Quahog Hydraulic Dredge (Smolowitz & Nulk, 1982)**



4.2.3 Gear Performance

4.2.3.1 Catching Efficiency

Caddy (1971) defines dredge efficiency or overall gear efficiency as the ratio of the number of scallops caught to the number of scallops in the dredge path. He also defines "efficiency of capture" as the ratio of scallops entering the dredge to the scallops in the dredge path and "gear selectivity" as the ratio of the number of scallops caught to the number of scallops entering the dredge. Because the fishing gear is selective for size the efficiency of capture will be higher than the overall efficiency.

Catching efficiency can be measured as absolute efficiency as a percentage in terms of numbers caught to the numbers present in the swept area or more easily measured in relative or comparative terms as the number caught per swept area for different catching devices (must be trialed at the same time and same location).

Catch (C), effort (f) and catch per unit effort (cpue) are useful parameters for managing fish stocks and can be related to fishing mortality (F), abundance (N) and catchability (q) (Gulland 1983). If cpue = q N and assuming N is constant over short sampling periods then cpue can be used as a comparative measure of catchability.

The catching efficiency of scallop harvesting gear is generally quite low with estimates of efficiencies between 5% and 30% over a wide range of gear for different scallops and habitats (see Table 4.3).

Table 4.3 Efficiencies by dredge type and region

Dredge/Region	Efficiency	Source
Australian toothed mud dredge	12%	McLoughlin *et al* (1991)
Traditional UK 1950's dredge	5% - 20%	Baird (1959)
New Bedford dredge on Georges Bank	15.4%	Caddy (1971)
Scottish dredge	13-14%	Chapman *et al* (1977)
French dredge	6.8 - 28.3%	Shafee (1979)
NZ dredge in Foveaux Strait	6% - 16%	Allen & Cranfield (1979

The toothed mud dredge has received much criticism for its inefficiency, high rates of catch damage and post harvest mortality. Flexible chain or net mesh bag type dredges are in use in other parts of the world, and trials over Tasmanian scallop grounds with the Japanese keti-ami dredges have shown that it consistently outfished the mud dredge while the incidence of damage to scallops was much less (Zacharin, 1991).

More recent comparative trials off Ninth Island in southern Bass Strait by the CSIRO and Tasmanian Sea Fisheries (1992) have shown that other dredge designs also outfished the toothed mud dredge, with less damage. In these comparative trials the New Zealand dredge outfished all others and also exhibited the lowest damage rates (Zacharin, pers com).

4.2.3.2 Engineering Efficiency

In general terms efficiency can be defined as: efficiency = output/input . This definition can be applied to practically any aspect of scallop dredge performance, for example, it may be of value to define the engineering efficiency as: swept area per unit of time (output) for a given vessel thrust (input). This swept area per unit time value can be considered as a fishing performance index and will have a significant effect on the catch rate.

Optimising both catching efficiency and engineering efficiency has the effect of improving the economic efficiency which can be measured as the value of scallops caught (output) per dollar invested in fishing (input).

Improving engineering efficiency can have the effect of reducing the level of effort necessary to take a given catch just as effectively as improving catching efficiency. In other words:

Catch per unit effort = catch/effort = catchability x abundance (Gulland, 1983)

A more engineering efficient harvesting system will reduce the level of effort needed to take the catch and will effectively increase catchability. For trawling and scallop dredging operations, effort is most conveniently measured as the time spent trawling or dredging. If the more efficient effort levels are maintained without limiting the total catch then the long term abundance may be compromised.

4.2.3.3 Drag Measurements

Results of a bollard pull test on 19 Victorian fishing boats found average warp load under normal conditions to be 2261 N (230.7 kg) per meter of dredge width at a normal towing speed of 6 knots (3.06m/s) (Hughes 1973). Rearranging these figures we would expect a warp load of 7460 N at a tow speed of 6 knots for a standard 3.3m (11 ft) dredge.

The maximum intermittent load for a 3m (10 ft) dredge operating on rough bottom was 1600 kg (Hughes, 1973). This would imply a maximum warp load of 17250N for a standard 3. m dredge.

It has been noted that warp loads fell and became steadier as the dredge filled up (Hughes, 1973). The explanation offered was that the centre of gravity changed, tending to lift the front of the dredge thus reducing the bite.

4.2.3.4 Incidental Damage

High incidental scallop damage has been noted in many scallop fisheries. For example in the north west Atlantic scallop fishery, dredging caused appreciable lethal and sub lethal damage to scallops left in the track (Caddy, 1973). In the south eastern Australian scallop fishery, incidental damage to scallops caused mortality to the extent that almost all the remaining scallops on the bed died within eight months of closing the grounds (McLoughlin *et al*, 1991)

Caddy (1973) noted fine sediments lifted into suspension and appreciable roughening of the seabed with damage to scallops by way of broken shell margins and hinge breakage. He also noted predators being attracted to the dredge tracks.

McLoughlin *et al* (1991) recognise three components of indirect fishing mortality:

1 Scallops damaged by the action of the dredge and left on the sea bed in the dredge track.
2 Those damaged by the dredge, landed on deck and subsequently discarded at sea during sorting of the catch.
3 A post fishing mortality from subsequent disease or lethal stress.

4.2.3.5 Handling

The design of dredges must take into account their stability during shooting away and whilst in mid water. In the south east Australian and New Zealand fisheries, the dredges are shot away and towed from the stern. The handling of other types of dredges in other fisheries depends on the vessel design and often shooting away and retrieval from the side is adopted. Most dredges are designed and rigged to be stable in mid water and to avoid turn-overs. The Digby dredges are designed so that they will fish equally well either way up.

The declination angle of the towing warp has long been recognised as an important factor in dredge performance since a towing warp imparts upward and horizontal force components to the gear in use. The effect of cable weight and cable drag also become important in deep water situations. This was recognised in the investigations by Baird (1955). When a sisal rope is used for towing, a backward curve is formed by the warp. If the speed of tow is slightly increased the resistance of the rope may lift the dredge off the bottom. With a wire towing rope the weight of the warp is greater than the drag at low speeds and the tendency of the dredge to lift is reduced. The shape of a wire tow cable is close to that of a catenary (Fridman, 1973).

Dredges in the south east Australian scallop fishery are emptied using a dredge tipper. This device allows safe, hands off retrieval, emptying and shooting away of dredges under even adverse conditions. Flexible ring mesh bag type dredges are emptied by use of an overhead lift which must be connected to the dump bar by a deckhand. Multiple unit type dredges must all be emptied separately by this method. Fishermen who have used Scottish dredges indicate that this is often a difficult and dangerous task.

4.2.3.6 Hydrodynamic Effects

Hydrodynamic effects are apparent in the form of lift and drag forces acting on the dredge. Lift and drag are the result of the distribution of pressure and velocity around an object moving through a fluid.

Depressor plates are used to keep scallop dredges tending bottom by producing downward directed hydrodynamic lift. The pressure and velocity distribution around these plates may in turn also contribute to the scallop catching process by creating hydrodynamic forces on individual scallops and the substrate.

The use of a 'diving plate' at the optimum angle allows an increase in towing speed (Baird, 1959). The Baird Sledge, locally known as the Sputnik dredge used a diving plate which was designed to give stability and to keep the dredge on the bottom (Baird, 1965). The angle of the diving plate was about 23 degrees to the horizontal.

The box type dredges currently used in Australia have a depressor plate at an angle of 45 degrees. This would act as a stalled wing with reduced efficiency and effectiveness in terms of optimising the downward force. Gorman and Johnson (1972) recommended that the angle be reduced to 30 degrees. The New Bedford type or Off-shore Scallop Drag also uses a diving plate while the French St Brieuc Off-shore Drag uses a curved pressure plate which improves efficiency and makes it possible to tow at higher speeds (Dupouy, 1982).

The pressure drop and turbulent pressure fluctuations behind a depressor could provide a means of agitating and lifting scallops from the sea bed (Vaccaro & Blott, 1987). Tow tank experiments indicated that angles of 60 to 75 degrees and a gap ratio of 0.267 result in the best conditions of turbulent wake and low pressure cavity behind a simple depressor plate (Vaccaro & Blott, 1987). This contrasts strongly with the angles used in practice. Streamlined high lift foil shapes did not appear to produce an adequate wake to lift scallops at the tow speeds being considered (Vaccaro & Blott, 1987). Therefore they tested only simple flat plate at stalled angles.

4.3 Survey of Box Dredges Used in the South East Australian Scallop Fishery

4.3.1 Introduction

A survey of dredges commonly used in the fishery was undertaken by measuring up dredges and interviewing scallop fishermen. Dredge dimensions and frequently used modifications have been summarised.

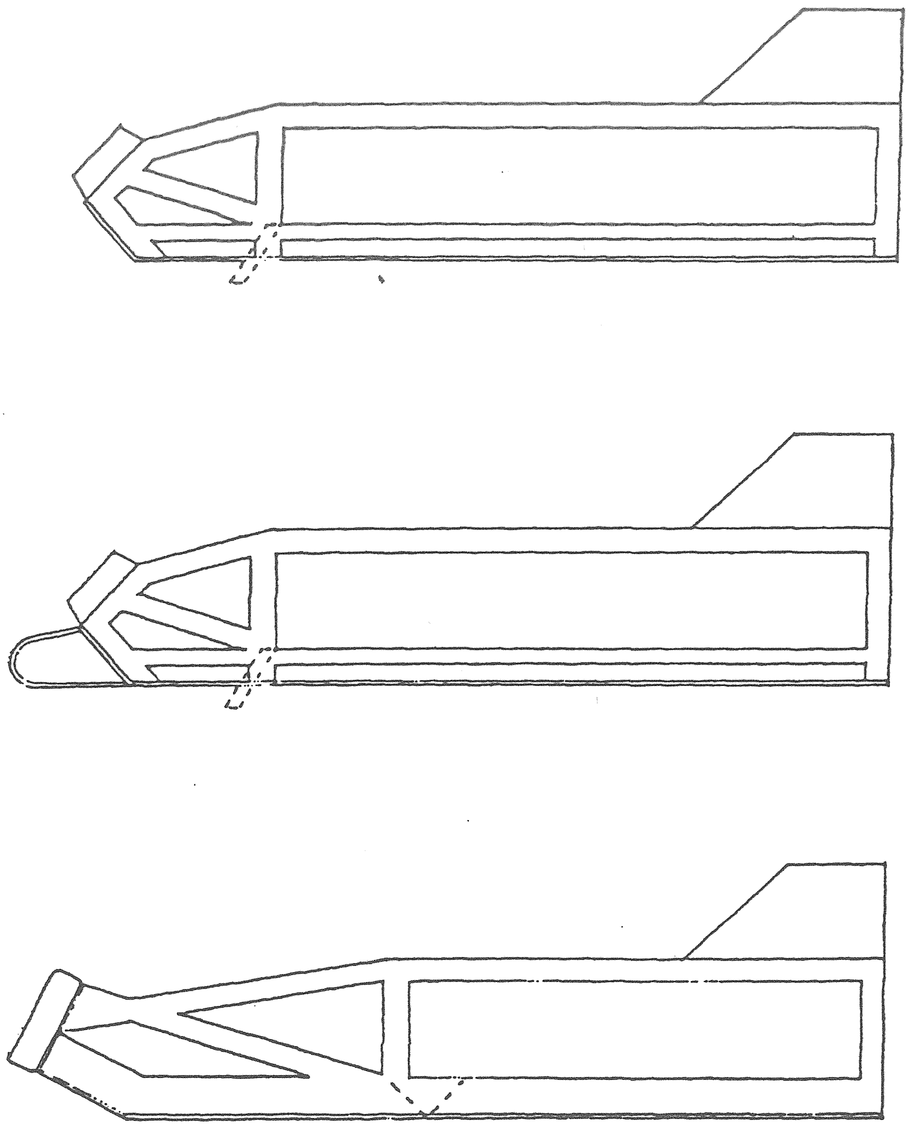
4.3.2 Results

In the south east Australian scallop fishery the local fishermen exclusively use a box type dredge in conjunction with a dredge tipper. This is due to the systems ease of operation and safe handling characteristics. The current dredge known as the toothed mud dredge has been described by (Gorman & Johnson, 1972, Hughes 1972, and Dix 1982). It is a heavy (300 +/- 150kg) steel structure composed of a steel mesh box on skids with a bottom contacting tooth bar or cutter bar and forward mounted depressor plate which also serves as the attachment point for the tow bridle. Figure 11 shows a schematic view of a toothed mud dredge.

The width of this dredge is generally about 3.3m but is varied to suit the size of the boat, the width of the sorting tray and the vessel's towing capacity. The width of commercially used dredges range from 2.2m to 4.6m.

Fore to aft (length) dimensions vary only slightly between dredges irrespective of width. Typically the measurement from the back of the box to the tooth bar is about 1.2m. The box is raised 80 to 100mm above the skids. The skid length varies significantly, being 1.5m in a typical dredge, however forward extensions as in the Peninsula dredge modification (Figure 11) can add up to 0.45m, while rear extensions of up to 0.3m are also common. The forward extension of the skids is a modification designed to reduce the tendency of the dredge to ride on its nose. Similarly the objective of the rearward extension is to reduce any tendency for the dredge to ride on its rear.

Figure 11 Dredge Designs and Modifications. Top: Typical Toothed Mud Dredge, Middle: Peninsula Dredge, Bottom: Bay Dredge



A dredge height of 0.4m from bottom of skids to top of the box is generally adopted. Short stabilising fins are usually incorporated on each side at the rear and add an additional 0.25m to overall height.

The box type dredge generally referred to as the toothed mud dredge is often used with a devices other than the tooth bar. In Port Phillip Bay it is more usual to fit a cutter bar which does not protrude below the depth of the skids. Alternatively a new device referred to as the 'mouth organ bar' has been utilised on a trial basis. In Bass Strait or Tasmanian waters a tooth bar with teeth protruding 20mm to 60mm below the skids is fitted. The teeth are made from a hardened steel with the tips treated with hard face welding.

A variant of the box dredge known as the Bay dredge (see Figure 12), has a long history of use in Port Phillip Bay. This dredge has the depressor plate set well forward of the box and low to the ground. This dredge is normally towed at a speed of five to eight knots. In one of the dredges observed, the cutter bar was angled aft in a manner which would not function at all in digging up scallops from the sea bed. The Bay dredge depressor plate approximates the criteria cited by Vaccaro & Blott (1987) for optimising the pressure drop behind a stalled horizontal wing in proximity with the ground. It is possible that this dredge is a hydrodynamic scallop catching device that has evolved over a period of time by trial and error.

On several dredges used in the fishery an old rubber tyre and length of chain is towed from the top rear of the box. This addition may serve to help hold the back of the dredge in ground contact or serve to damp dynamic movement on rough or undulating terrain.

Dredges which have seen extensive use show high wear at the leading edges of the skids. In most cases this wear zone is patched or reinforced with hard facing weld. Dredges from Port Phillip Bay which have been extensively used exhibit thinning of the skids toward the rear. This may be due to the dredges riding harder on the rear of the skids when full, the result of using a short tow cable or from wear occurring mainly during shooting away and haul back.

4.4.0 Engineering Performance Appraisal of Scallop Dredges

4.4.1 The Toothed Mud Dredge

4.4.1.1 Introduction

A box dredge with dimensions typical of the gear used in the south east Australian scallop fishery was constructed. This dredge labelled 'FRDC 1' was used throughout a series of flume tank and sea trials to ascertain the forces acting. Tests in the flume tank involved suspending the dredge in the flow by load cells. This gave a measure of the downward and horizontal forces acting on the dredge due only to the flow of the water (hydrodynamic).

The 'standard' toothed mud dredge was the largest item ever tested in the flume tank. This created some constraints on the testing that could be carried out due to the risk of damage to the facility.

Sea trials of the standard dredge allowed the total drag (including ground effect) to be measured and diver observations of the operational dynamics.

4.4.1.2 Methods and Materials

Vertical Forces

The vertical forces acting on an operating dredge are: the weight, downward directed hydrodynamic lift from the depressor plate, and the upward component of the tow cable tension.

The weight of the dredge is partially reduced by buoyancy effects. The weight in water of the standard dredge was measured by suspending it in the flume tank by 'load cell' tension meters.

The hydrodynamic downward directed lift is the force exerted at right angles to the direction of flow by the deflecting action of the depressor plate. Hydrodynamic theory concludes that lift and drag fundamentally increases with the square of tow velocity. These forces were measured over a range of water speeds in the flume tank.

The upward component of tow cable tension depends on the declination angle of the tow cable at the dredge and the total drag acting on the dredge. The declination angle of the tow cable at the dredge was calculated using warp length to depth ratios. Owing to the shallow depths chosen during the sea trials, straight line geometry was assumed. Under this assumption, the declination angle was checked using an inclinometer on the tow cable at the surface. For a rigorous treatment, the weight and hydrodynamic drag of the tow cable should also be considered. Since the effect of cable weight and drag are relatively small for shallow depths they have been omitted from the following calculations.

The net downward force is the sum of all the vertical forces and must be greater than zero for the dredge to stay in bottom contact. Mathematically these three components of the vertical forces can be summed and analysed with respect to speed as follows:

The force due to weight (W) is constant

The hydrodynamic lift force (L) can be expressed as

$L = {}^1/_2\, \rho\, A\, C_L\, v^2$ where ρ = density of water

A = area of depressor

C_L = lift coefficient of depressor

v = velocity

The upward component of the tow cable tension (U) can be expressed as

U = Total Dredge Drag x Sin θ θ = declination angle of the tow cable

or alternatively

U = Total Dredge Drag x $^1/$cable length to depth ratio

The net downward force (N) is the arithmetic sum of all the vertical forces.

$$N = W + L - U$$

Drag Forces

The horizontal forces acting on the toothed mud dredge are the tow force (horizontal component of tow cable tension) and the drag forces that it opposes. The total drag of the dredge is made up of hydrodynamic drag, friction and ploughing forces.

The total drag was determined during sea trials from measurements of tow cable tension over a range of tow speeds and different warp length to depth ratios.

Hydrodynamic drag is generated by the fluid flow around the depressor plate and the structure of the dredge. This force was measured in the flume tank by suspending the dredge in the flow without bottom contact.

Friction is a mechanical force and can be considered to be independent of speed while dependent on the net downward force acting on the dredge. In operation the net downward force increases with speed therefore it is expected that the friction force acting will also increase with speed.

The ploughing force from the teeth could be considered a simple friction effect, fundamentally independent of speed. In most situations, a ground shear effect also exists and is determined by the speed of the dredge, which would lead to the ploughing force being speed sensitive. Friction combined with ploughing was calculated using the difference between total drag measured at sea and hydrodynamic drag measured in the flume tank.

Mathematically these horizontal forces can be summed and analysed with respect to speed as follows:

The hydrodynamic drag force (D) can be expressed as

$D = {}^1/_2\ r\ A\ C_D\ v^2$ where A = frontal area of dredge

C_D = drag coefficient of dredge

The normal expression for friction (F) is

$F = m\,N$ where m = coefficient of friction

N = nett downward force

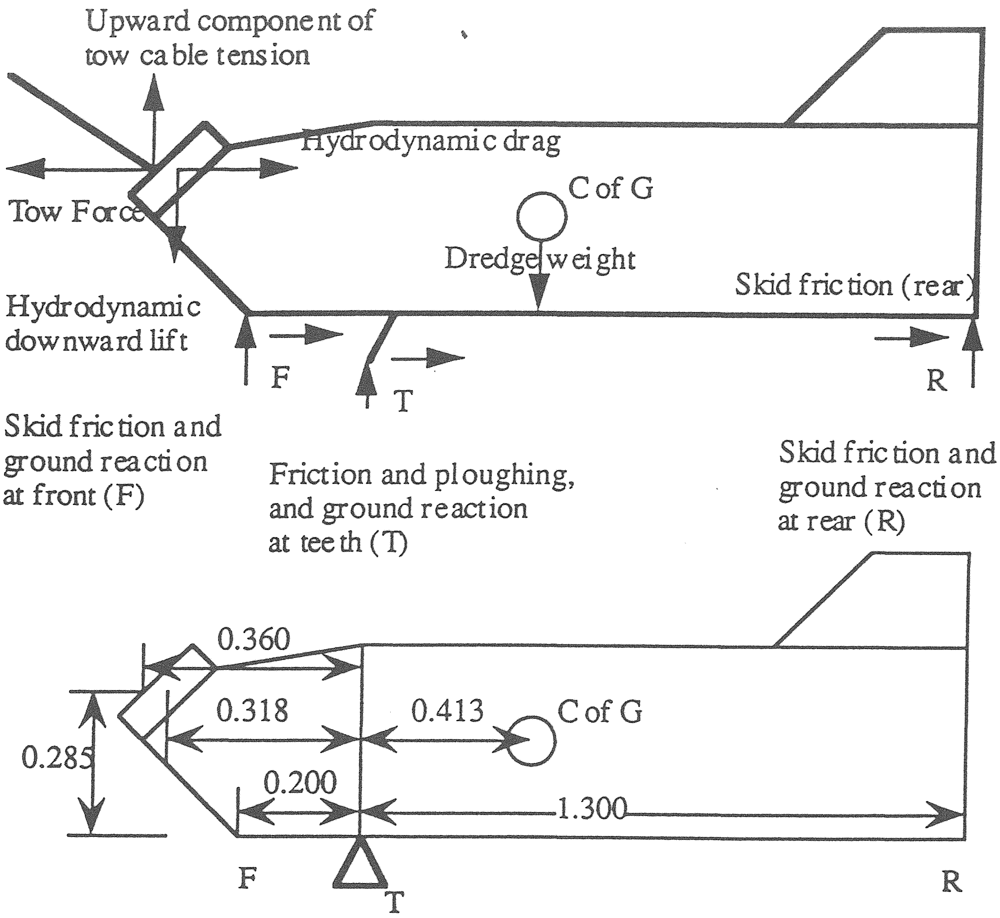
The towing force (T) is the arithmetic sum of all the drag forces

$T = D + F + P$ where P = ploughing force

Turning Moments

An analysis of the turning moments acting due to the forces applied on the dredge, allowed an insight into the characteristics of the ground support forces with respect to speed and cable length to depth ratio. The forces and lever arms associated with the acting turning moments are described in Figure 12.

Figure 12 **Diagram of Forces and Lever Arms acting during operation of the Toothed Mud Dredge**



From equilibrium considerations the following conditions must exist:

The sum of the moments about any point = 0

The sum of the vertical forces = 0

Ground reaction forces must each always ≥ 0

In terms of the system under investigation these conditions translate to the following:

Sum of Moments about teeth (D) = (Tow force - Hydrodynamic drag) x 0.285
- Weight x 0.413
- Upward component of tow cable tension x 0.360
+ Hydrodynamic downward directed lift x 0.318
- F x 0.200
+ R x 1.300
= 0

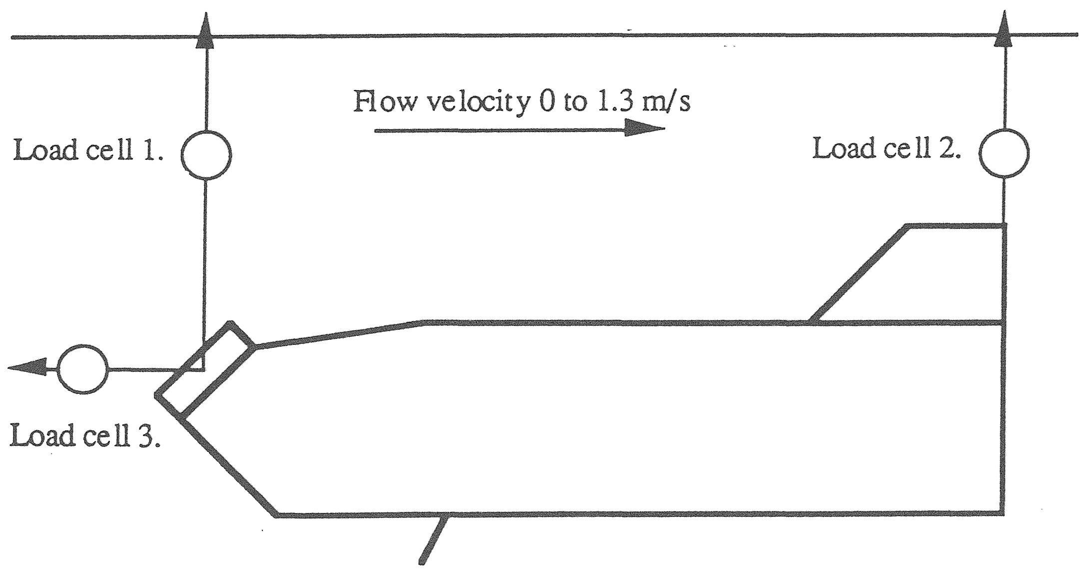
Sum of vertical forces = Weight + Hydro. down. - Cable up. - F - T - R
= 0

These conditions were used to model the tendency of the toothed mud dredge to rotate fore and aft about the teeth and therefore calculate the magnitude of ground reaction forces.

Flume Tank Test Rig

Figure 13 shows the arrangement used for testing the toothed mud dredge in the flume tank. The toothed mud dredge was suspended in the tank using a harness which allowed the downward forces to be measured at the front and back. The downward forces were measured using load cells 1 & 2 (see Figure 13). Similarly the tow force on a horizontal warp was measured using a third load cell.

Figure 13 **Toothed Mud Dredge in Flume Tank**

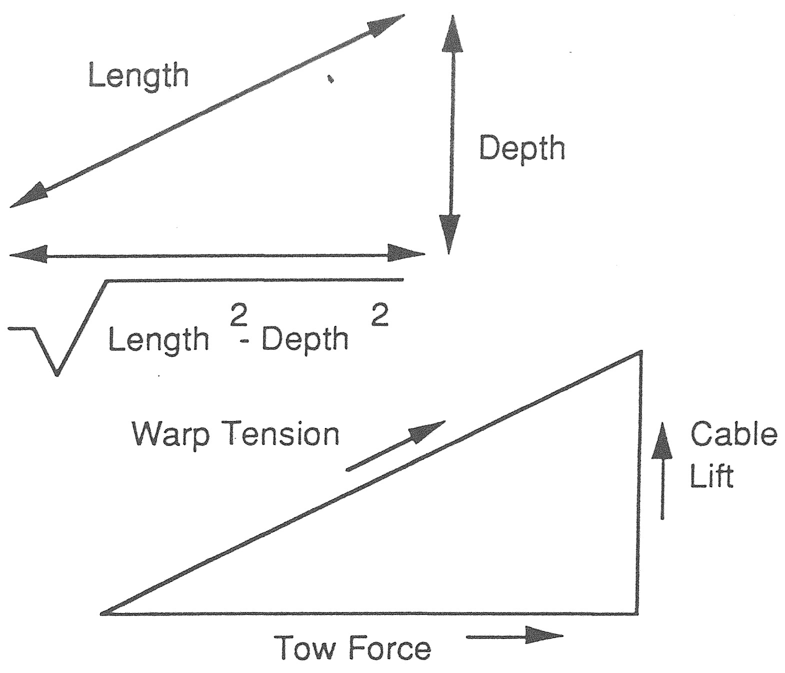


The toothed mud dredge was tested in the flume tank in the speed range 0 to 1.3m/sec.

Warp Considerations

In the vertical and horizontal force calculations the angle of the towing warp needed to be considered because the measured warp has both horizontal and vertical components. This problem was overcome by recording warp length to depth ratio (L:D) and as a check, by measuring the declination angle at the block. From the angle of the towing warp the warp tension could be divided into its lift and tow components (see Figure 14). The drag from the cable and its weight can effectively be neglected in shallow water with short lengths of tow cable.

Figure 14 The Effect of the Warp Length to Depth Ratio on the Lift and Tow Components of the Warp Tension



$$\text{Tow Force} = \text{Warp Tension}\left(\frac{\sqrt{\text{Length}^2 - \text{Depth}^2}}{\text{Length}}\right)$$

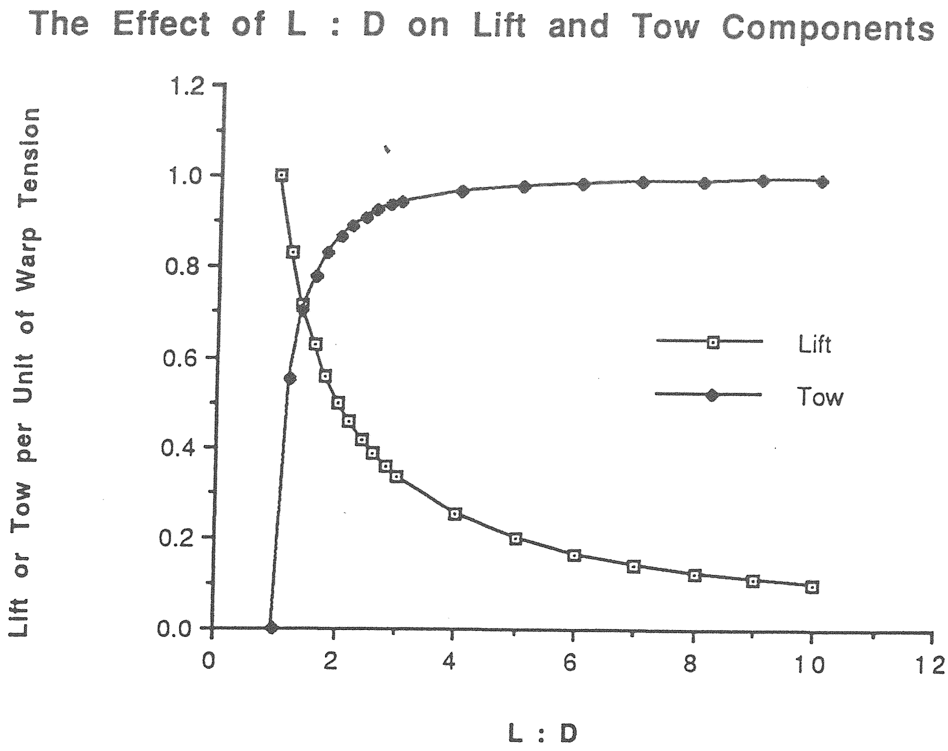
$$\text{Cable Lift} = \text{Warp Tension}\left(\frac{\text{Depth}}{\text{Length}}\right)$$

Figure 15 shows the magnitude of cable force components as a function of warp length to depth ratio. Table 4.4 shows the appropriate values used during the tests on the toothed mud dredge.

Table 4.4 Tow and Lift Forces for the range of L:D used in Sea Trials

Length to Depth Ratio	Tow Force	Lift Force
3	0.943 x Warp Tension	0.333 x Warp Tension
4	0.968 x Warp Tension	0.250 x Warp Tension
5	0.980 x Warp Tension	0.200 x Warp Tension
6	0.986 x Warp Tension	0.167 x Warp Tension

Figure 15 Lift and Tow Forces per unit of Warp Tension



Dynamics

The dynamics occurring during normal operation were analysed from underwater video footage and from continuous warp tension data using a chart recorder. A theoretical interpretation of the phenomenon is presented.

4.4.1.3 Results

Vertical Forces

The downward forces measured at the front and the back of the toothed mud dredge while in the flume tank are given in Appendix A and shown graphically in the Figure 16.

4.4.1.3 Results

Vertical Forces

The downward forces measured at the front and the back of the toothed mud dredge while in the flume tank are given in Appendix A and shown graphically in the Figure 16.

At zero tow speed the downward forces constitute the weight of the dredge:

weight at front = 1650N

weight at rear = 1400N

From the above data the distance to the centre of mass (Figure 16) can be determined.

Figure 16 **Vertical Forces Front and Back as a function of water speed**

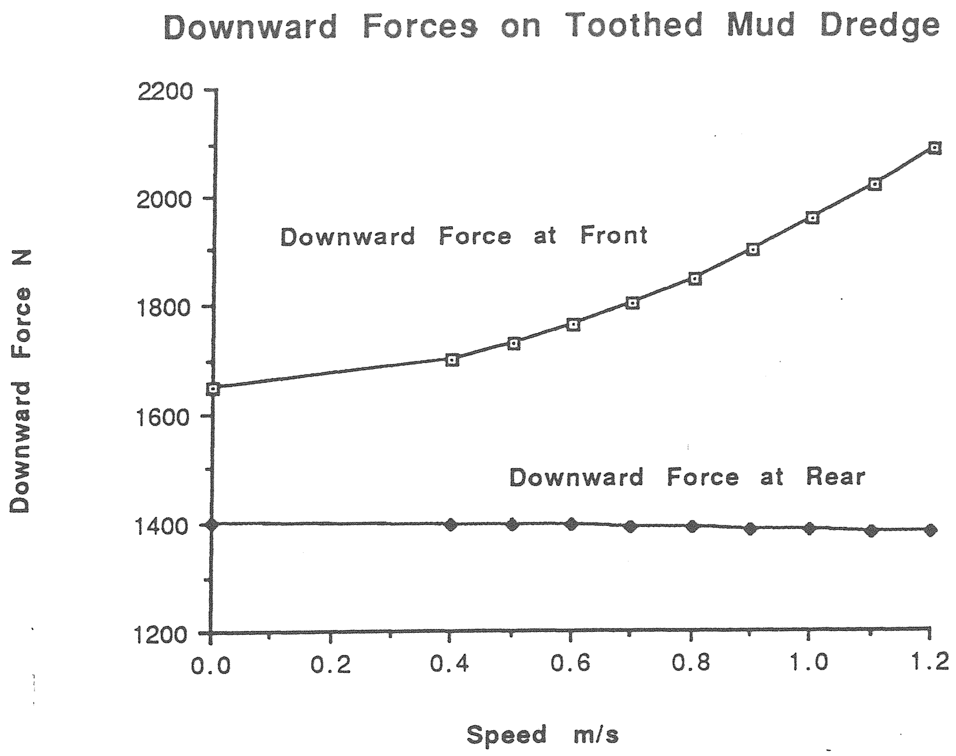
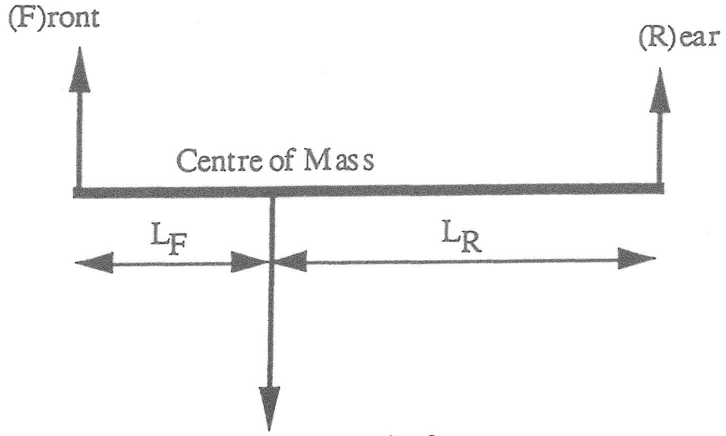


Figure 17 **Centre of Mass calculation**



Taking moments about the front

$$R \times (L_R + L_F) - (F + R) \times L_F = 0$$

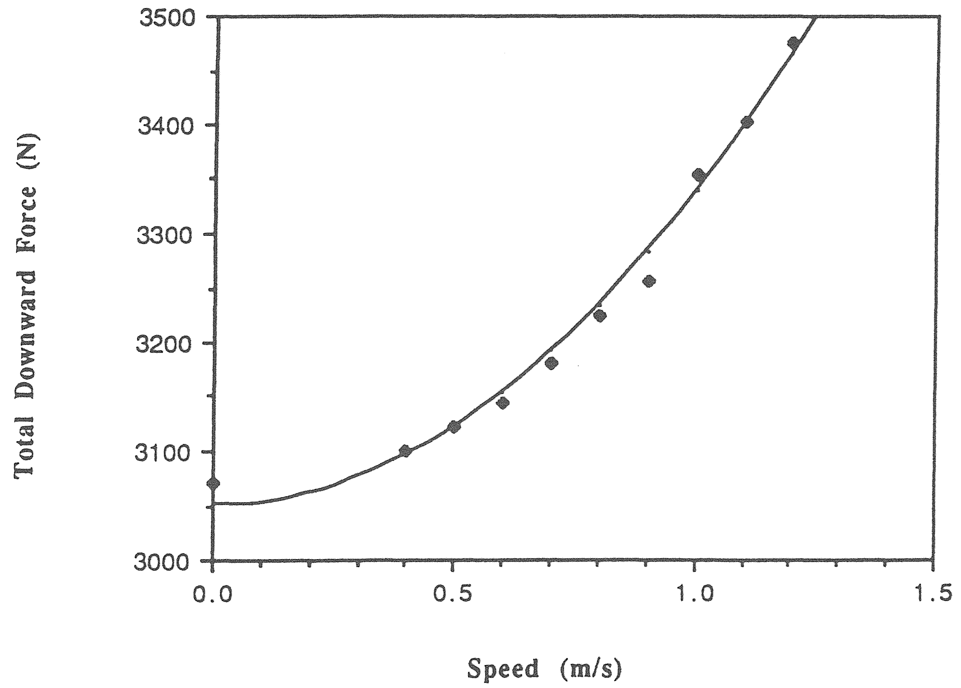
$$L_F = R \times (L_R + L_F) / (F + R)$$

Substitution into the above expression for the centre of mass location gives:

$$\begin{aligned} L_F &= R \times (L_R + L_F) / (F + R) \\ &= 1388 \times (1.7) / (1388 + 1669) \\ &= 0.77\text{m} \end{aligned}$$

Figure 18 shows the sum of the downward forces measured at the front and back of the dredge over the speed range considered.

Figure 18 **Total Downward Force on Toothed Mud Dredge**



Given that the following expression shows the components of this downward force:

Downward force = Weight + Hydrodynamic (downward directed) lift

It is appropriate to fit the following model by regression to the data:

Downward force = $W + C_L' * V^2$ where $C_L' = 1/2 \; r A \; C_L$

ie Downward force = $3050 + 288.8 * V^2$ ($r^2 = 0.995$)

Drag Forces

The hydrodynamic drag results obtained from the flume tank tests are given in Appendix A and shown graphically in the Figure 19.

Regression of the following hydrodynamic model to the data:

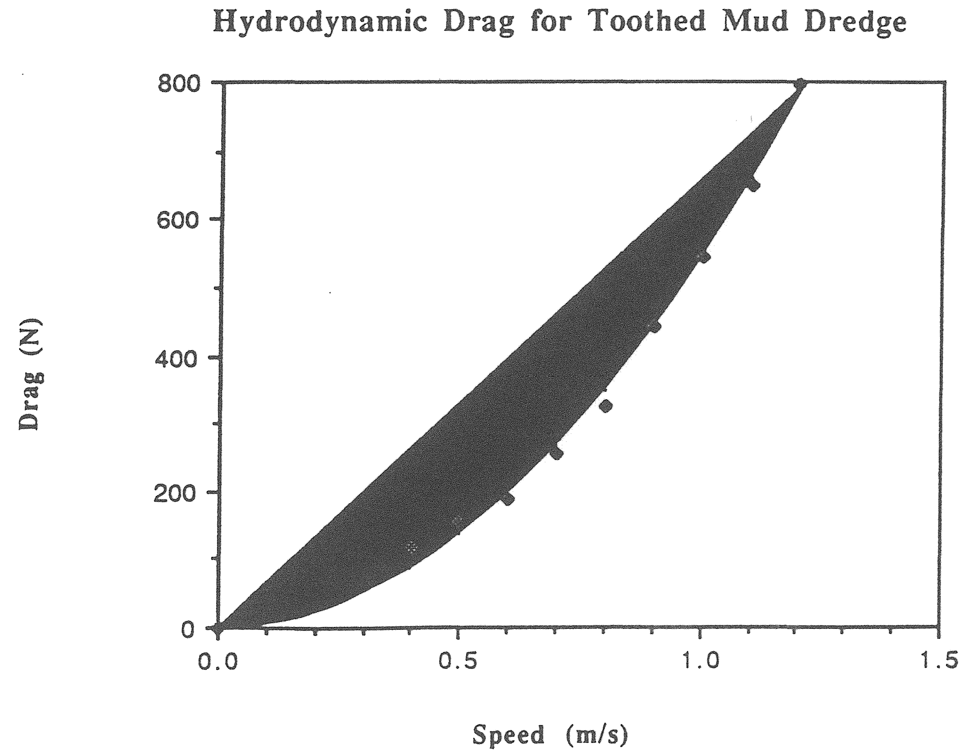
Hydrodynamic drag = $C_D' * V^2$ where $C_D' = 1/2 \; r \; A \; C_D$

gave the result below:

Hydrodynamic drag = $543.8 * V^2$ ($r^2 = 0.997$)

It can be seen that hydrodynamic drag increases to 1762N (180 kg) at 1.8m/s (3.5 knots) and 3536N (361 kg) at 2.55m/s (5 knots)

Figure 19 **Hydrodynamic Drag from Flume Tank**



Appendix A and Figure 20 show the warp tension measurements taken during sea trials in Badger Bay for different warp length to depth ratios. The horizontal component of these forces are equivalent to the tow forces involved and also equate to the total drag of the operating dredge.

Figure 20 **Warp Tension for Toothed Mud Dredge at Various Length to Depth Ratios**

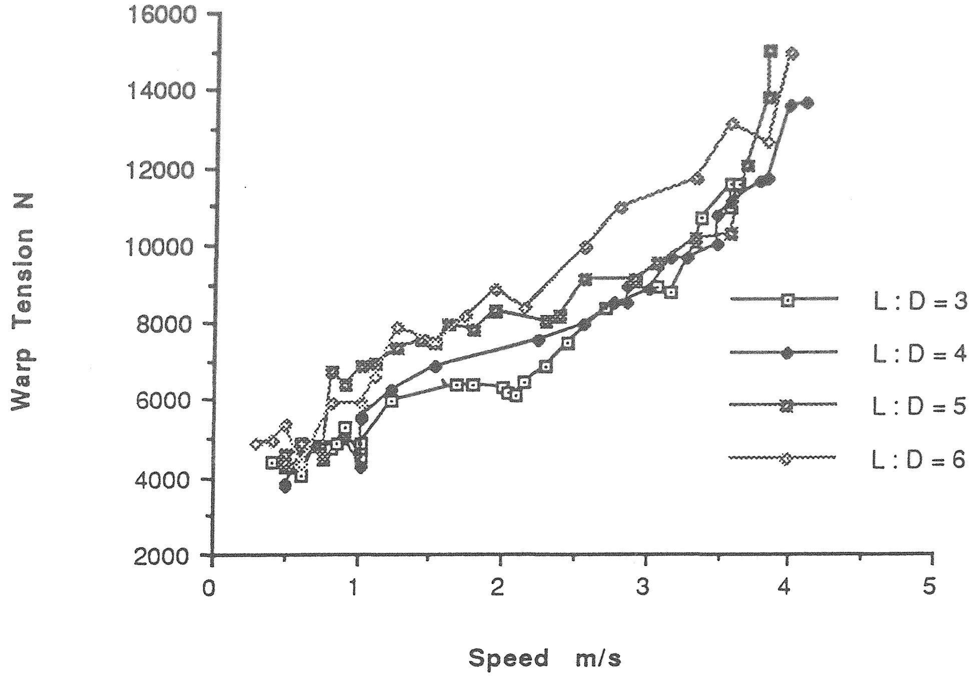


Figure 21 **Horizontal Forces Acting on the Toothed Mud Dredge from Regression of Flume Tank and Sea Trial Data for L : D = 6**

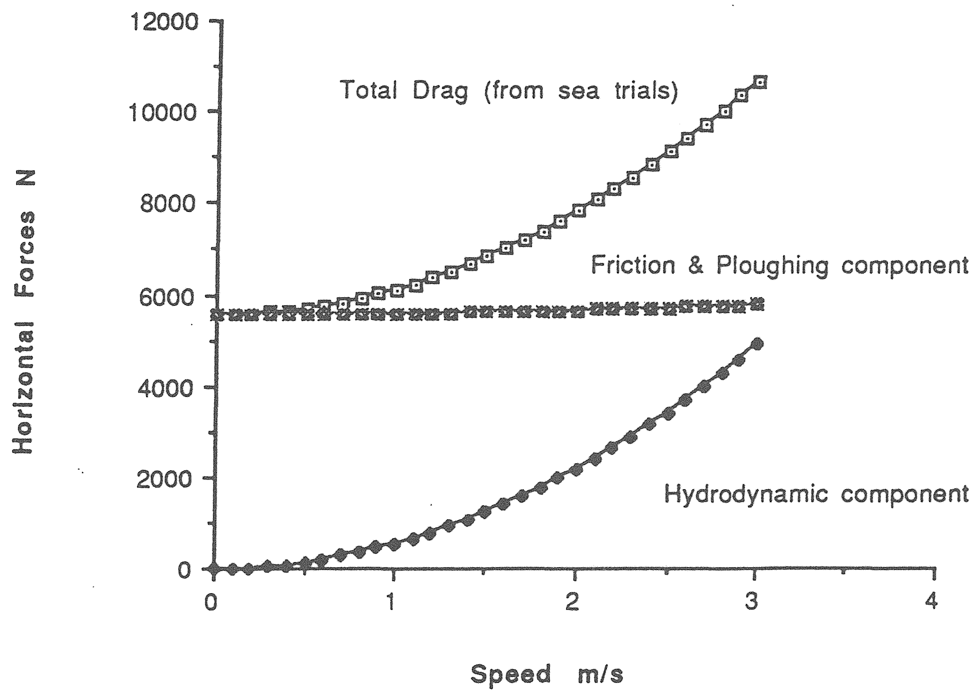


Figure 21 combines the above two data sets for a warp length to depth ratio of 6 and also shows the difference between total drag and hydrodynamic drag, which corresponds to the friction and ploughing drag that is occurring.

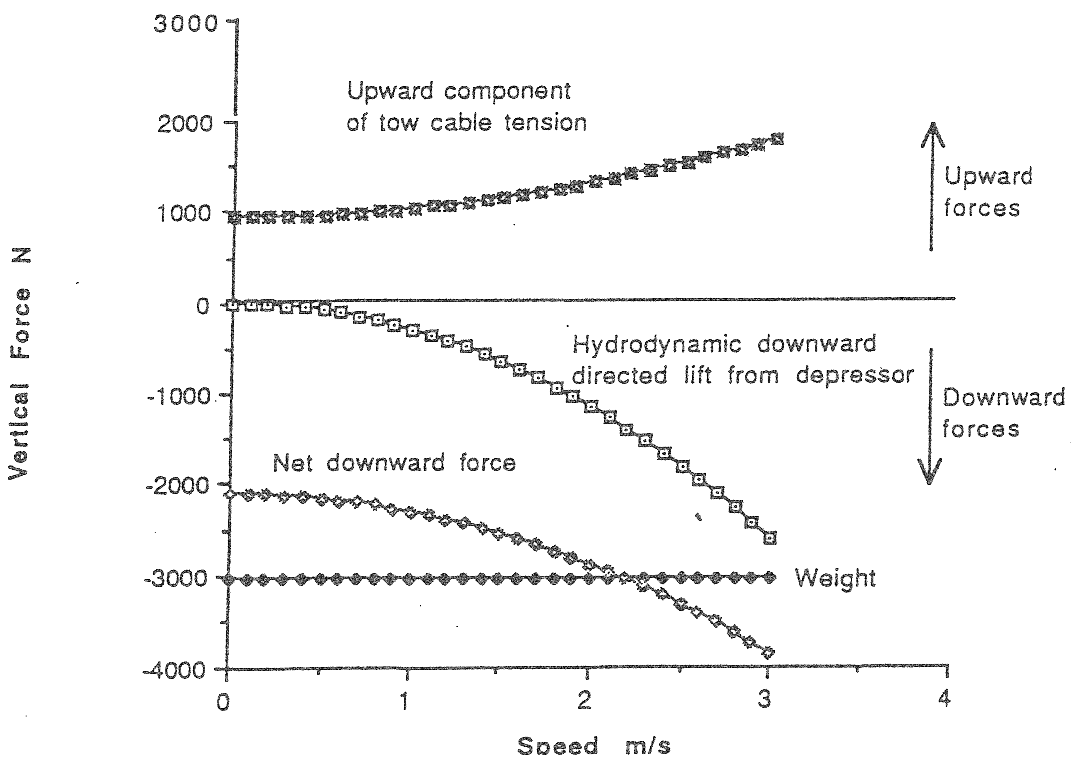
Vertical Force Model

Figure 22 shows a vertical force model for the toothed mud dredge at a cable length to depth ratio of 6. This figure indicates the magnitude of all vertical forces acting. The upward force from the cable was derived from the cable tension measured at sea while the weight and hydrodynamic downward lift were measured in the flume tank. The resultant downward force is shown to increase with speed for this situation.

At zero tow speed the net downward force was 2100N. Considering that the area of skids in bottom contact on flat terrain is $0.34m^2$, then the corresponding skid pressure is 6.18kPa.

At a towing speed of 3.5 knots (1.8m/s) the net downward force is 2750N and the corresponding skid pressure is 8.09kPa (This is approximately half of that exerted by an average man through his boot soles). In practice actual contact pressures experienced by the seabed can be much greater because of higher speeds and non uniform skid contact.

Figure 22 **Vertical forces model**



The configuration of all the forces acting on the toothed mud dredge are such that a turning moment may exist causing the dredge to rock forward onto its nose or to rock back onto the rear of the skids. Dredge wear patterns indicate that this phenomenon commonly occurs.

Turning Model

The turning moments and ground reaction forces for two specific cases were derived from the experimental data and the configuration of forces.

Figure 23 depicts the situation where the combination of forces and their lines of action combine to cause the dredge to roll forward onto the nose. This occurred when the cable length to depth ratio is greater than 7.

Figure 23 **Ground Support Forces for Toothed Mud Dredge under conditions of an empty dredge on hard sand bottom using 50mm tooth projection (below skids) and a warp length to depth ratio of 8**

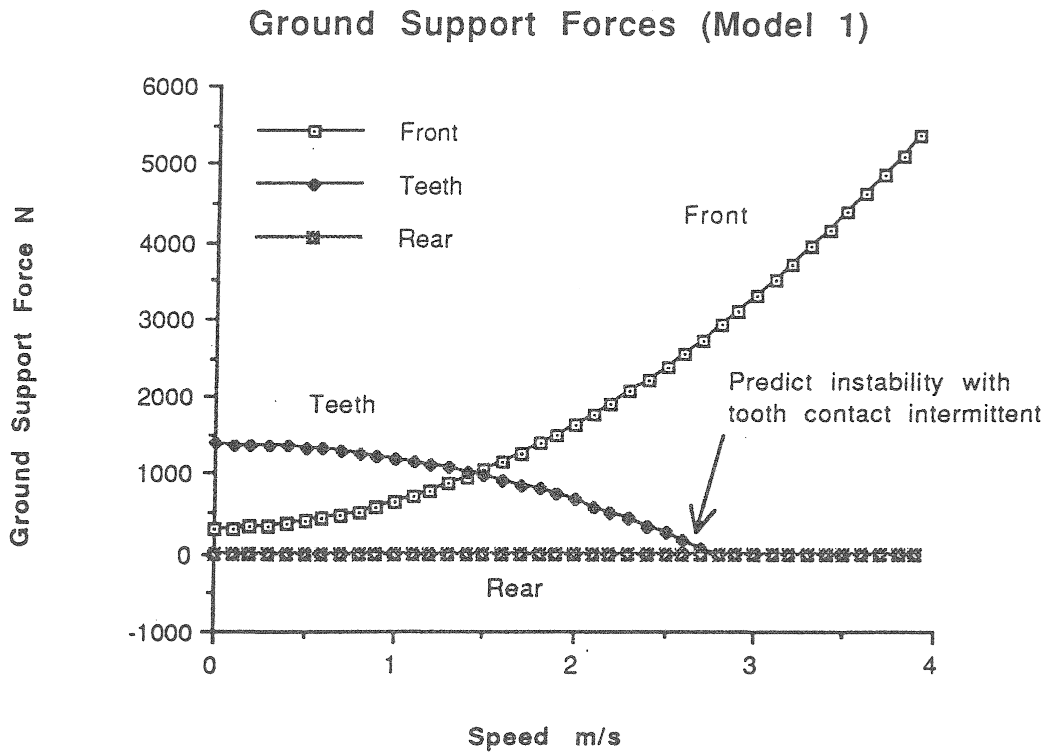
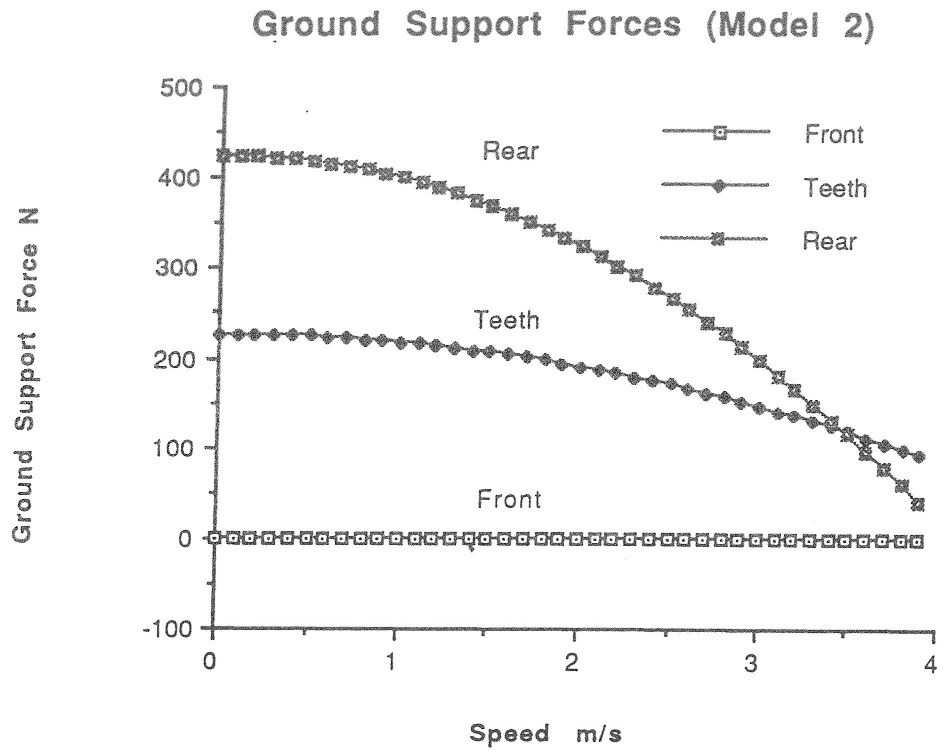


Figure 24 **Ground Support Forces for Toothed Mud Dredge under conditions of an empty dredge on hard sand bottom using 50mm tooth projection (below skids) and a warp length to depth ratio of 3**



Changes in substrate characteristics, tooth projection, cable length to water depth ratio or tow speed can greatly change the overturning effect. For example, a short length to depth ratio may experience a front lifting moment with most of the downward force coming on to the rear of the skids. Figure 24 shows the situation for a cable length to depth ratio of 3. In this case the dredge rides more heavily on the rear of the skids.

The Dynamics Occurring During Normal Operation

An observed feature of toothed mud dredge operation on hard sand bottom was a pronounced pulsing in warp tension and oscillating pitch orientation. This feature was affected by altering the warp length and speed and is likely to have some effect on catching performance (although not tested). Sea trial warp tension measurements using a chart recorder yielded oscillations in tension with periods of the order of two seconds and an amplitude up to 30% of the mean value.

Approaching this phenomenon from a theoretical point of view, the dredge can be considered as having a pitching moment of inertia about a fixed point (the teeth) and operated on by forces in the form of disturbing and restoring forces (or torque's).

The moment of inertia can be determined by the weight and shape of the dredge and is constant for a particular dredge. This can be calculated by:

$I = S\ m\ r^2$ where I = moment of inertia

m = mass of component

r = radius of gyration.

The disturbing forces applied to the dredge, include the dynamic forces transmitted by the warp from the sea way and forces due to the undulations in the terrain. These forces have the potential to supply large amount of energy to the dredge across a wide spectrum of frequencies, dependent on the response of the dredge at these frequencies. The pitching motion of the dredge caused by the disturbing forces will mainly be concentrated in the spectral range close to its natural frequency of oscillation, because this is where the dredge is most responsive.

The restoring torque, which in part determines the pitching response of the dredge, varies with pitch angle in a very non-linear way, rendering it and its derivative with respect to pitch angle very difficult to calculate. However a natural period of oscillation must exist and will depend on the restoring torque characteristics and the pitching moment of inertia of the dredge as shown below.

$$T = 2\,p \sqrt{\frac{I}{\frac{dt}{dq}}}$$

T = natural period t = restoring torque q = pitch angle

Further progress in this area would rely on obtaining a good mathematical description of the restoring torque characteristics of the dredge, after which its response to various disturbances could be investigated using a computer simulation of the system.

4.4.1.4 Discussion and Conclusions for the Toothed Mud Dredge

The downward force acting on the toothed mud dredge is 4000N at about 3.5 knots and is relatively high, relative to other dredge designs. This force consists primarily of the considerable weight of the steel structure (3050N) and therefore the contribution from the hydrodynamic depressor plate at this speed is relatively minor, contributing only 936N. At the higher tow speed of 5 knots the hydrodynamic downward component increases significantly to 1878N. The increase in hydrodynamic downward force completely offsets the increase in the upward force exerted by the tow cable at L:D = 6 (due to the higher drag forces created at the higher speeds). For this situation the net downward force on a moving dredge is therefore always greater than the 2000N that occurs at zero speed.

The hydrodynamic drag forces acting are relatively low at speeds up to 5 knots. At 5 knots the hydrodynamic drag is 3536N, only 33% of the total drag. Therefore, it is unlikely that significant reduction is possible or worthy of investigation. The majority of the hydrodynamic drag is due to the pressure plate. At very high speeds (ie 6 to 8 knots) this drag becomes an important consideration and is the component which limits towing speed.

The friction and ploughing drag from the skids and teeth is the most significant component of the warp load, accounting for 66% of the horizontal pull at tow speeds of 5 knots. Since friction is related to the level of downward force acting, reducing the weight and downward hydrodynamic loads could significantly reduce frictional drag. These ground effect forces could also be reduced by altering the nature of the contacting surfaces (eg the toothbar). For the dredges using a cutter bar or mouth organ bar (which does not protrude below the skids) the ploughing component of drag will be much reduced.

Hughes (1973) concluded that the average bollard pull for fairly standard dredges towed by a range of vessels in the Victorian scallop fleet using a standard speed of 6 knots was of the order of 6,782N, with a maximum intermittent load on rough ground of 15,680N. The standard dredge trialled in Badger Bay gave comparable results at 6 knots with drags of from 9,250N to 11,000N.

The overturning moment acting on the dredge during normal use occurs because of the configuration of forces acting. This will cause a concentration of downward force at the front and lightening of the rear of the dredge, which may be sufficient to physically lift it off the bottom. This condition will change as the dredge fills.

Dredges which have had considerable use, show wear at the leading edge of the skids, and in many cases this region is reinforced by 'hard facing', or patched. This appears to confirm the concentration of the downward forces and the high ground reaction force at the front of the dredge. A feature observed in locally made dredges in recent years is the Peninsula dredge modification, featuring an extension of the skids forward of around 0.3m compared to the 'standard' mud dredge. This helps to counteract the turning moment by increasing the lever arm of the ground reaction force at the front. Some locally made dredges also often include a length of heavy chain and an old rubber tyre attached to the back of the dredge, perhaps to help counteract overturning. The overturning moment could be detrimental, causing the tooth bar (or scraper bar) to have reduced contact with the substrate.

As the dredge fills during fishing the new configuration of forces will tend to reduce overturning. Some theories postulate that changes in the centre of gravity during filling may lift the front of the dredge and reduce warp loads. Support sighted for this is the long term wear patterns on some Port Phillip Bay dredges showing thinning of the skids toward the rear of the skids. This thinning however can be explained by the wear that occurs during shooting and hauling, since at this time the dredge has a high tilt angle as it contacts and leaves the seabed.

Hughes (1973) noted that warp loads fell and became steadier as the dredge filled up. This must be due somehow to changes in the configuration of the forces acting causing changes in the nature of the contact between dredge and sea floor, eg reducing the 'bite' of the tooth bar. This feature is well known to experienced scallop fishermen, who use a drop in hydraulic pressure at the winch as an indication that the dredge is full and lifting off the bottom (McLoughlin *et al* 1991). A possible explanation for this phenomenon is that a full dredge when bumped into an orientation whereby it has an angle of attack to the oncoming flow, may literally be able to fly partially clear of the sea bed. The efficiency of a dredge is likely to vary significantly over the length of the tow. An empty dredge may commence operation with a fairly high efficiency and decline as the dredge fills.

The toothed mud dredge is poorly designed for good bottom following characteristics over undulating terrain. The rigid design and the configuration of forces when in use contribute to instability which becomes apparent as a rocking or jumping action and a periodic pulsing in warp tension.

The high weight of the toothed mud dredge will give it a high pitching moment of inertia, which will result in a relatively slow reaction to dynamic turning moments and have a long natural period of oscillation. For good bottom following characteristics the natural rocking wavelength should be less than the prevailing wavelength of bottom undulations. At a speed of 2.5m/sec and a period of oscillation of 2 sec the natural wavelength would be 5m. This is clearly larger than many undulations occurring on scallop grounds. Additionally, response to undulations with wavelengths of less than 3m is impossible simply due to the length of the dredge (1.5m). In severe cases the rocking action is likely to take the form of jumping, in which bottom contact is only intermittent. Pitching and jumping is almost certain to reduce catching efficiency and certainly contribute to scallop damage through spiking and crushing of scallops by the teeth.

Both the overturning moment and the natural rocking frequency are controllable to some extent by the angle of the towing cable (or warp length to depth). A short L:D will reduce the drag, reduce the overturning moment, and slow down the natural rocking frequency, a good strategy on flat terrain. A longer L:D will suffer higher drag, higher overturning moment and subject the dredge to a faster rocking frequency. The faster rocking frequency will help improve bottom following on undulating terrain.

The towing speed will also have a significant effect on dredge performance. The high level of downward forces means that the dredge will stay in bottom contact at quite high tow speeds (to above 8 knots). Higher tow speeds will produce high drag forces, increase the overturning moment, and speed up the rocking frequency. Despite the faster rocking frequency, the faster rate of movement across the terrain means that bottom following ability is not likely to be improved.

To the scallop fisherman the L:D and tow speed are the most powerful means by which they can change the performance of any particular dredge. For undulating terrain a longer L:D and slower speed will best tune the dredge for bottom following and reduce scallop damage. Good bottom following on terrain with oscillations less than 3m between crests is likely to be difficult to achieve and significant rearranging of the substrate and damage to scallops is the likely outcome.

Local manufacture and evolution of the toothed mud dredge has meant that significant variation has occurred away from the original design. The effectiveness of any scallop harvesting device will depend to a large degree on the local conditions of bottom terrain, depth, current, seas, towing power, as well as the skill and local knowledge of the fishermen. Baird (1955) on scallop grounds around the British coast using a rigid toothed dredge found lower efficiencies (about half) when a seabed consisting of ridges of coral gravel about 150 to 200mm high with about 600mm between crests was encountered. He did not consider that these conditions were common. However observations of Tasmanian scallop beds by diving and by remote underwater camera vehicles have shown these conditions to be common. It would be of use to catalogue bottom terrain types for known scallop beds and use this information to optimise local scallop harvesting methods. Good bottom following ability is necessary on rough and undulating terrain, but much less important if the bottom terrain is flat.

The Port Phillip Bay scallop fishery operates on a soft mud bottom of varying consistency and of generally flat topography with only occasional mounds and hollows (Parry, pers com). Whereas the Jervis Bay fishery operates over a sea floor consisting of large grained, firm white sand shaped in roughly parallel ridges (Butcher *et al*, 1981). At the present time, essentially the same harvesting gear (with only minor modifications) is used in both fisheries. With such a great contrast in bottom conditions it is likely that very different gear would be optimal for each location.

The presence of stabilising fins either side of the rear of the dredge indicate directional instability problems have been encountered, however some preliminary flume tank tests have also shown that they can significantly improve roll stability while the dredge is in midwater. The high yawing moment of inertia (about changes in direction) means that intermittent direction changes from deflecting forces caused by contact with seabed obstacles, will be evident for some considerable period of time. This means that the dredge may follow a meandering path, thus supporting claims of local fishermen that the dredges do not tow a straight path. A narrower dredge would suffer from this problem to a lesser extent.

4.4.2 Engineering Comparison of Box Dredge to Scallop Harvesting Gear Used Outside Australia

4.4.2.1 Introduction

Three types of scallop dredges from fisheries outside Australia were obtained for comparison to the toothed mud dredge. These dredges were:

- The New Zealand dredge. This dredge comprises a flexible chain/ring mesh bag, tickler chain and towing frame. In the New Zealand scallop fishery most vessels use a pair of ring bag dredges of up to 2.5m in width with heavy tickler chains (Bull 1988).
- The Japanese keti-ami dredge. This dredge contains a flexible ring mesh bag with looped tickler chains mounted behind tines for use on hard mixed and rocky ground. It is designed to ride over rocky obstacles and not to pick up rocks.
- The Scottish mini dredges. Each mini dredge incorporates sprung teeth for use on hard and rocky grounds and are highly selective, not picking up rocks and other debris (Franklin, Pickett & Connor, 1980). The Scottish mini dredges are normally towed in gangs of three or more from a wheeled towing beam.

Scallop dredges have as common features: a towing harness, a bottom contacting frame, a tickling up device and some sort of receptacle for retaining caught scallops. The towing harness connects the dredge to the towing warp in such a way that the upward component of tow cable tension is countered by sufficient downward force to keep the frame in bottom contact. The harness also significantly affect the towing configuration through the way it transfers the forces from the tow cable to the rest of the dredge. A well designed harness also maintains the dredge in a stable and upright configuration in mid water during shooting away and haul back. The bottom contacting frame generally incorporates skids which transfer the net downward force acting on the dredge to the substrate. These skids experience considerable wear from the sliding contact with the seabed. Tickling up devices are generally in the form of teeth, tines, scraping bars or some tickler chain configuration. Retaining mechanisms found on scallop harvesting gear include rigid mesh boxes and flexible mesh bags, either completely constructed of steel ring mesh or consisting of a ring mesh floor with a heavy net mesh top.

The engineering comparison performed was in the following areas: downward forces, contact pressure, drag and swept width characteristics.

4.4.2.2 Methods and Materials

Appendix B shows engineering drawings for the four harvesting systems tested. Much of the scallop harvesting gear used world wide is composed of multiple and flexible elements. In such systems forces act on each element and interact between elements. The downward forces, their position, arrangement and combined effects were analysed by identifying all components within each system and determining all the forces acting.

With the majority of gear tested, the principle downward force acting was weight.. The total weight and component weights for all systems were measured by suspending the appropriate objects from load cells. Weight in air was then converted to weight in water by correcting for buoyancy effects.

ie Weight in water = Weight in air x correction factor

where the correction factor for steel in sea water = 0.87

Hydrodynamic downward forces were determined by identifying any components that would produce downward directed hydrodynamic lift and calculating the effect based on:

$$\text{Lift} = {}^{1}/_{2}\ r\ A\ C_L\ v^2$$

where r = density of water

A = area of depressor

C_L = lift coefficient

v = velocity

The appropriate C_L was estimated from values given in the literature.

The upward force produced by the tow cable was considered in the same manner as for the toothed mud dredge.

After determining all the vertical forces acting on each system component that contacts the seabed, the net downward force was determined. The contact pressure was then calculated by distributing this force over the area of contact. Contact pressures will however vary as the harvesting system moves dynamically across the sea bed. This variation was not determined and the results given are the average pressures that will occur.

The total drag of each system was measured during sea trials using load cells and the same procedure as adopted for the toothed mud dredge. The flexible nature of the gear used outside Australia made it impractical to measure their hydrodynamic drag from flume tank tests as the tests need to be conducted in midwater.

In the absence of flume tank data an estimate of the relative contribution to total drag by hydrodynamics and seabed effects was obtained by assuming that ground contact effects are predominantly friction like in nature and therefore constant irrespective of speed. With this assumption the zero speed intercept of the total drag verses speed relationship is an estimate of seabed drag and the drag above this level can be attributed to hydrodynamic effects.

4.4.2.3 Results

Downward Forces and Contact Pressures

The downward contact pressures for all four dredge types is compared in Table 4.5. In this table, estimates of contact pressure for all components having bottom contact are given.

The rigid components of the harvesting systems are predominantly made of steel sections and transfer their weight to the substrate via skids and sometimes via teeth or other bottom contacting features. The skid pressures generated are the net result of weight plus downward directed hydrodynamic lift, less the upward component of tow cable tension all acting through the bottom contacting area of the skids. Point contact loads such as those generated by teeth or tines will exert extremely high contact pressures.

In the case of flexible ring mesh structures such as that used in the New Zealand dredge, the resulting pressure is exclusively from the weight of the joined elements. For example with the New Zealand dredge the rings are constructed from 6mm steel rod rolled into a circle of 65mm inside diameter. Each ring has a mass of approximately 55g and the rings are joined together in a square pattern by the use of 5mm chain links which have an inside long diameter of 30mm and a mass of 13g. The arrangement is such that the joining links being the lowest part of the ring mesh also supports the weight of the rings. Therefore each link carries the weight of one ring plus its own weight (ie 68gwt).

If we consider the support area to be the side of one link (ie 5mm x 30mm) then the support area is 0.00015m^2 and the contact pressure exerted will be: the weight of ring and link over the support area calculated above.

ie Weight in water = $68 \times 10^{-3} \times 9.8 \times 0.87 = 0.58$N

Pressure = Force / Area = 0. 58/ 0.00015 = 3.87kPa

On soft ground where the links sink sufficiently into the substrate so that the rings come into contact, the pressure will be greatly reduced due to the increased contact area. The resulting pressure could then be as low as 0.42kPa.

The tickler chain used in the New Zealand dredge is usually either 13mm or 19mm section. Chain ground contact pressure can be estimated on the basis that each link carries its own weight on the area of one side. Pressure exerted = \f(mass per link x 9.8 x 0.87 length of link x width of link).

The pressures given in Table 4.5 are for 13mm and 19mm chain respectively.

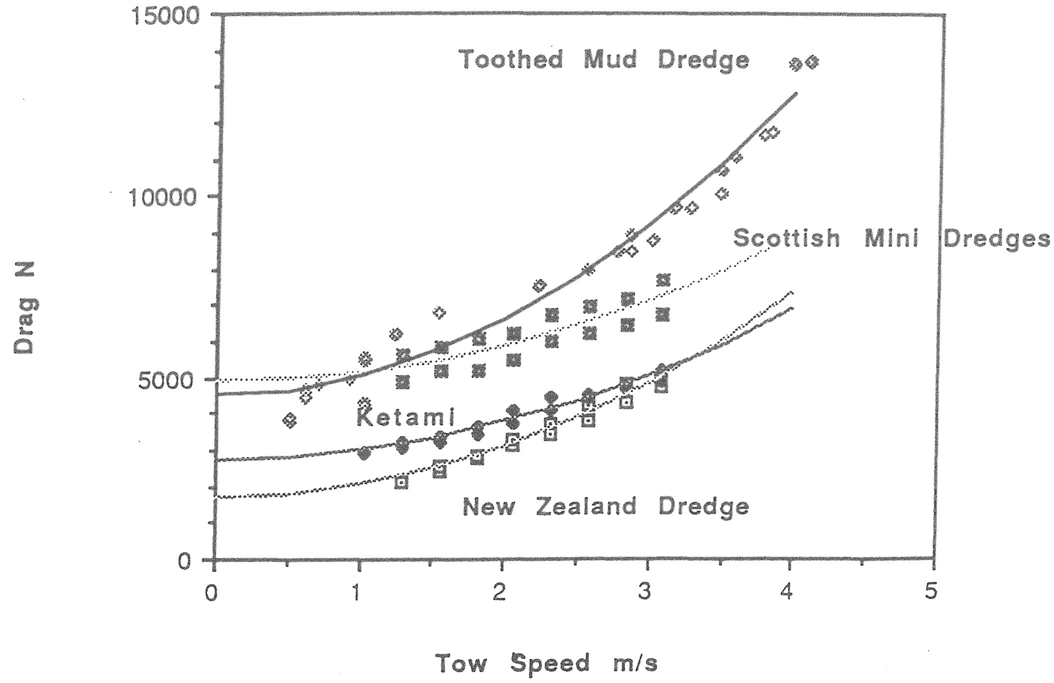
Table 4.5 Estimated Downward Contact Pressures for Scallop Dredges and their components

Dredge Type	Weight (in water)	Component	Contact Pressure	Dynamic Situation
Toothed Mud	310 kg or 3050 N	Skids (if in continuous contact)	12.7 kPa	
		Skids (if not in continuous contact)	extremely high	small contact area from for/aft rocking
		Tooth bar	extremely high	point loading
New Zealand	90 kg or 880 N	Skids	18.3 kPa	some bouncing
		Tickler chain	2.2 - 3.2 kPa	diffuse loading
		Chain and ring mesh belly	3.9 kPa	diffuse loading
Keti-ami	270 kg or 2645 N	Frame	10 kPa	small contact area
		Tines	extremely high	point loading bounces over obstacles
		Tickler chain	1.2 - 2.0 kPa	diffuse loading
		Chain and ring mesh belly	2.0 kPa	diffuse loading
Scottish	510 kg or 5000 N	Wheels	80 kPa	
		Teeth	extremely high	point loading
		Chain and ring mesh belly	7.5 kPa	diffuse loading

Drag Forces

The total drag forces (hydrodynamic + ploughing + friction) measured from sea trials for the over seas harvesting systems are given in Appendix C and summarised graphically in Figure 25.

Figure 25 **Drag Comparison for the Four Harvesting Systems**



The above graph shows the lines of best fit calculated from the drag verses speed data for each harvester. Below are the corresponding equations and r^2 values.

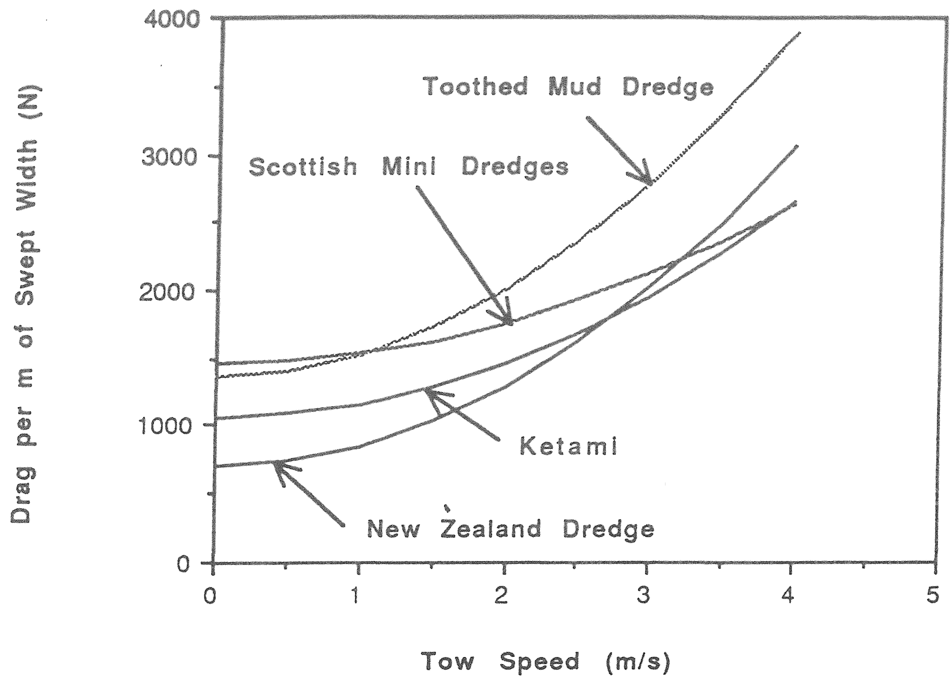
Toothed Mud Dredge (L:D = 4)	Drag = 4353.3 + 504.07 $Speed^2$	$r^2 = 0.969$
New Zealand Dredge	Drag = 1728.3 + 370.01 $Speed^2$	$r^2 = 0.967$
Keti-ami	Drag = 2835.2 + 265.90 $Speed^2$	$r^2 = 0.959$
Scottish Mini Dredges	Drag = 5050.5 + 259.03 $Speed^2$	$r^2 = 0.732$

In order to appraise the drag cost on an equal footing (engineering efficiency) the dredges have been compared on the basis of drag per unit of swept width in Figure 26.

Following are the equations for the modified regression lines used in Figure 26.

Toothed mud dredge catching width = 3.3m	$y = 5543.4 + 570.01\,x^2$
New Zealand dredge catching width = 2.4m	$y = 1652.2 + 346.60\,x^2$
Keti-ami catching width = 2.6m	$y = 2723.5 + 246.98\,x^2$
Scottish mini dredges catching width (4 units) = 3.36m	$y = 4823.7 + 242.51\,x^2$

Figure 26 **Comparison Dredge Types with Respect to their Drag per metre of Swept Width**



4.4.2.4 Discussion

Although the average downward contact pressure exerted by the toothed mud dredge is reasonably low, the point loading and dynamic action that exists will cause very high intermittent contact pressures to occur. The average downward contact pressure of the ring mesh bags on the other scallop harvesters is very low and not likely to vary to any large degree during operation. The teeth and cutter bars of the toothed mud dredge, the tines of the keti-ami and the sprung teeth of the Scottish dredge will exert high point loading. This very high contact pressure is likely to contribute to damage of the catch and damage to the environment.

The toothed mud dredge had the highest drag per meter of swept width of all the dredges tested and the New Zealand dredge had the lowest drag. The toothed mud dredge also had the highest level of ground effect drag as well as the highest hydrodynamic drag. The New Zealand dredge, by contrast had the lowest ground effect drag of all the dredges, while its hydrodynamic drag was almost as high as the toothed mud dredge. The low hydrodynamic drag of the keti-ami and Scottish dredges reflect their low frontal area and absence of depressor plate devices.

4.4.3 Drag Tests on Harvesters Selected For Industry Evaluation

4.4.3.1 Introduction

Drag measurements were conducted on four scallop dredges. These were:

- Australian mud dredge.
- Mouth organ dredge.
- Australian southern harvester.
- New Zealand circle dredge.

The first two dredges were tested off Lakes Entrance from the commercial vessel Alex Vanessa on the 20/2/93, while the last two dredges were tested from the AMC research vessel Riveresco in Badger Bay (Tasmania) on the 16/4/93.

4.4.3.2 Methods and Materials

Drag measurements for each dredge were taken via a 3 tonne electronic load cell at tow speeds of 1.5 and 2.5m/sec. The tow speed was determined by measurements taken from an oceanics propeller log with an electronic data display. The effect of ocean currents were accounted for by carrying out reciprocal tows and averaging the drag readings for each respective tow speed.

In general a replicate was taken so that confidence intervals could be constructed.

4.4.3.3 Results

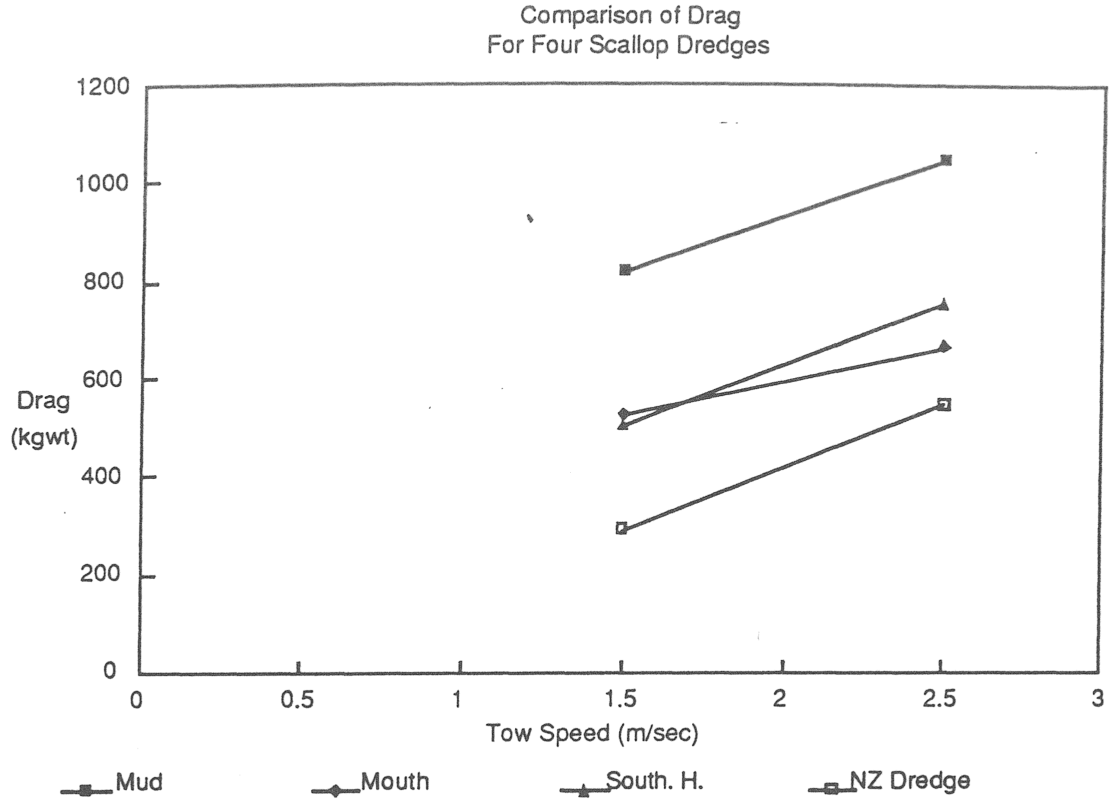
Significant ocean currents were found to exist off Lakes Entrance during the trials. These current were also found to vary spatially. Testing under these conditions was difficult and caused larger than normal variation between replicate data values. Additionally the weather conditions deteriorated during the day, contributing further to experimental error and causing a premature closure of trials such that a replicate trial for the mouth organ dredge was not conducted.

The weather conditions and ocean current situation at Badger bay for the second phase of tests was close to perfect.

Table 4.6 Drag Results (kg/wt) for Various Scallop Dredges at Two Tow Speeds

	1.5 m/sec	2.5 m/sec
Australian mud dredge	856.5 (53.7)	1095.7 (73.9)
Mouth organ	525 (na)	666 (na)
Southern scallop harvester	505.7 (14.5)	751.2 (17.3)
New Zealand circle	293 (0.7)	547.2 (3.9)

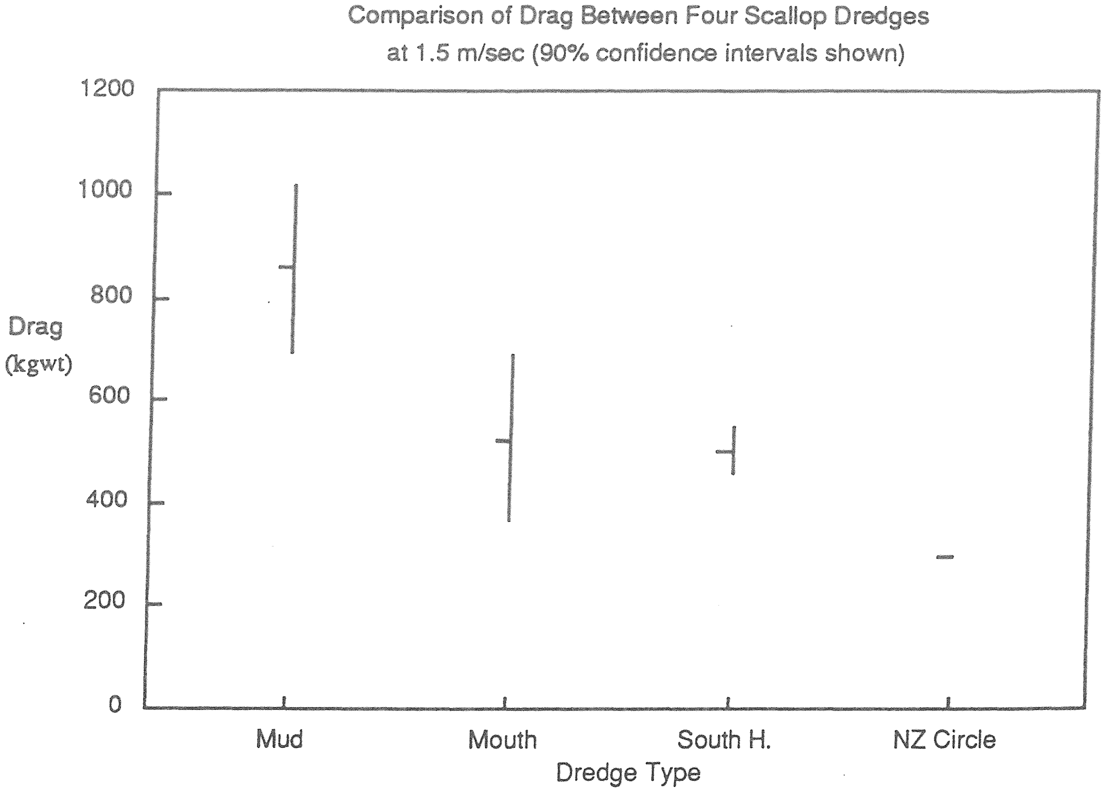
Figure 27



The raw data taken for all the trials is given in Appendix D. Table 4.6 has the tide corrected and averaged drag results for the four dredges at two tow speeds. Where possible standard errors are also given.

Figure 27 is a plot of all the drag results shown in Table 4.6, while Figure 28 shows a comparison of drag values (with 90% confidence intervals) for 1.5m/sec.

Figure 28



Confidence interval for mouth organ assumed equal to mud dredge.

4.4.3.4 Discussion

The mud dredge had the highest drag of those dredges tested. This would primarily be due to it being the only dredge containing teeth that extend into the sea floor.

At 1.5m/sec the southern scallop harvester had about 60% of the drag of the mud dredge. This dredge, like the mud dredge consists of a box on skids but it does not contain teeth. It has a tickler chain and a section of circle mesh on the forward part of the box floor.

The New Zealand circle dredge had the least amount of drag. At 1.5m/sec its drag was only 60% of the southern scallop harvester. Like the latter dredge it has a tickler chain and circle mesh in contact with the sea bed, however these features are incorporated into a flexible bag attached to a towing frame giving rise to a much lighter arrangement. For this reason the New Zealand dredge appears to return much less frictional resistance.

Diver observations were made of the southern scallop harvester and New Zealand dredge while in operation at 1.25m/sec. On previous trials the southern scallop harvester had shown some tendency to collect larger quantities of material at the edges of the box compared to the centre. Direct observation of the action of the tickler chain and flow patterns around the depressor plate provided no clues as to why this might occur. On this occasion the small amount of material collected by the dredge was uniformly distributed across the back of the box.

The New Zealand dredge despite its light overall weight appeared to be equal to the southern scallop harvester in terms of consistent bottom contact and interaction with the sea bed. One qualitative observation made was that the New Zealand dredge appeared to be more effective at catching commercial fish (i.e. large flat head and flounder) than the southern scallop harvester. This difference in finfish catching performance is likely to be due to the depressor plate on the southern harvester causing fish to be herded away from the box.

4.5.0 The Hydrodynamics of Flat Plates at High Angles of Attack in Close Proximity to a Boundary

4.5.1 Introduction

In the literature review (section 4.2.3.6) the work by Vaccaro & Blott (1987) was identified as providing some useful information on the flow around stalled flat foils and also discussion regarding the potential of using such phenomenon to aid in the capture of scallops. Vaccaro & Blott (1987) measured the pressure drop and shape of the pressure distribution around a hydrodynamic wing in close proximity to the bottom. Their work was conducted in a towing tank and produced by passing the test foil over a pressure sensor.

It was proposed to gather the same type of information, but in contrast use the flume tank which would involve having a stationary experimental rig and measuring pressure by use of a mobile pressure sensor. The advantages of this system would be that a much larger foil could be tested and the measurements at a particular location relative to the foil could proceed indefinitely rather than be constrained to an instantaneous measurement. In this way variation in flow characteristics over time can be investigated.

To have any value as a tickling up mechanism the change in pressure that has been the focus of research to date must have the ability to move objects or cause animals to become mobile. Such an ability has not as yet been adequately demonstrated and it is possible that the effect of turbulence or water movement might have a greater tickling up effect than that of a simple pressure drop. Turbulence may work as a tickling up mechanism by eliciting a behavioural response from the scallop and water movement might exert forces which could lift the scallop out of its recessed position on the sea floor and into the mouth of the harvester.

Due to the above considerations, tests to determine flow direction and velocity information for stalled flat foils in vicinity with the bottom was also conducted.

4.5.2 Methods and Materials

Pressure measurements were made at various locations on the flume tank floor, both for and aft of the test foils using a water manometer connected to a purpose built pressure sensor. By comparing the height of the water in the manometer with the fixed height of the water in the flume tank the pressure induced at each test point by the introduction of the foil was determined.

Pressure, velocity and the level of water above the test point are related by Bernouilles equation.

$$(h) + (P / r g) + (v^2 / 2g) = Z \text{ (constant)}$$

where r = density of water = 1000 kg/m^2

g = gravity = 9.8 m/s^2

h = level of water above test point (m)

P = pressure (gage) (Pa)

v = velocity m/s

Z = total head

or elevation head + pressure head + velocity head = Total Head (constant) (Webber, 1971).

By using a T shaped pick up (or static tube) with the manometer the velocity head component is eliminated, therefore the manometer effectively measures the sum of the first two terms in the above equation.

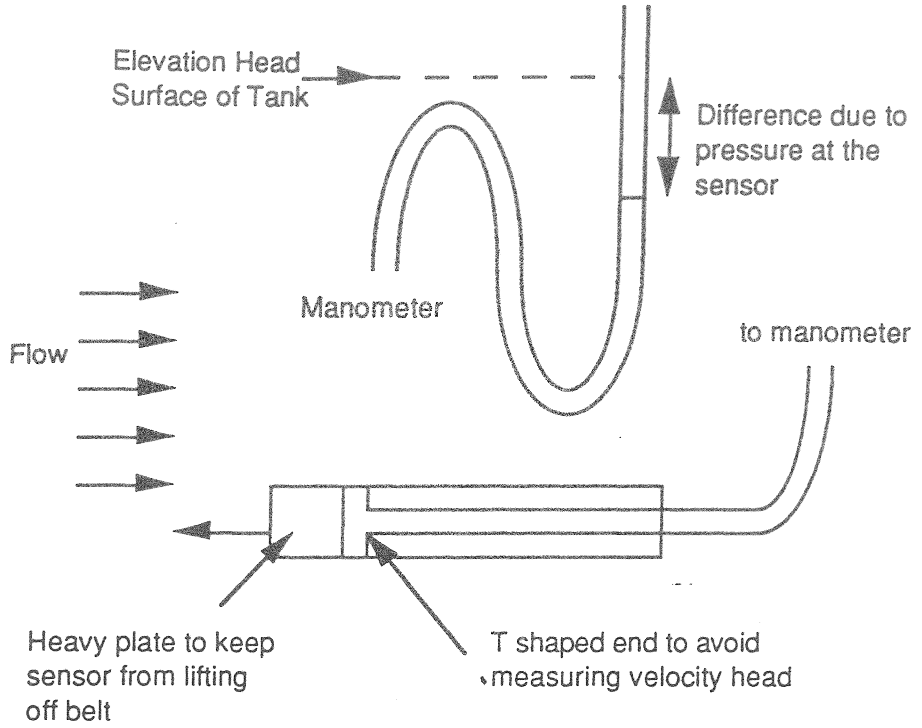
ie $h_m = h + P / r g + 0$

or $Dh = P / r g$

The above expression shows that the difference in height between the water level in the manometer and the water level in the flume tank gives the pressure disturbance induced by the foil (measured in mm of water) at the test point.

The T shaped pressure sensor and water manometer used for measuring the pressure in the vicinity of the foil is illustrated in Figure 29.

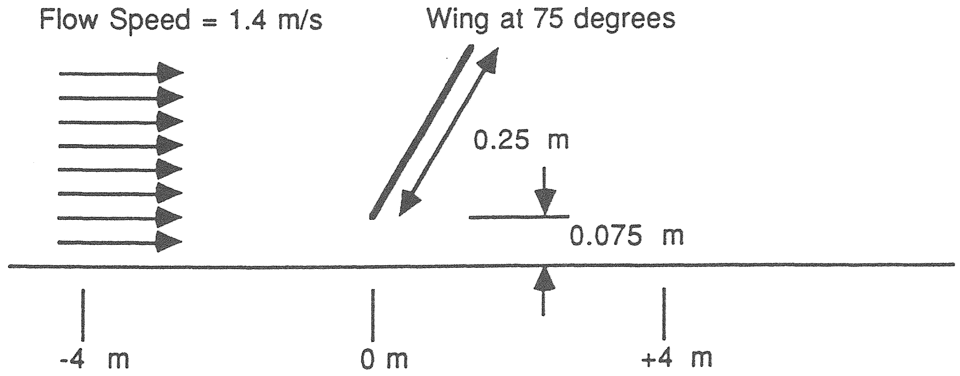
Figure 29 **Manometer and T shaped sensor**



Simple pressure measuring device consisting of manometer and T shaped pick up made from 4 mm i.d. plastic tube

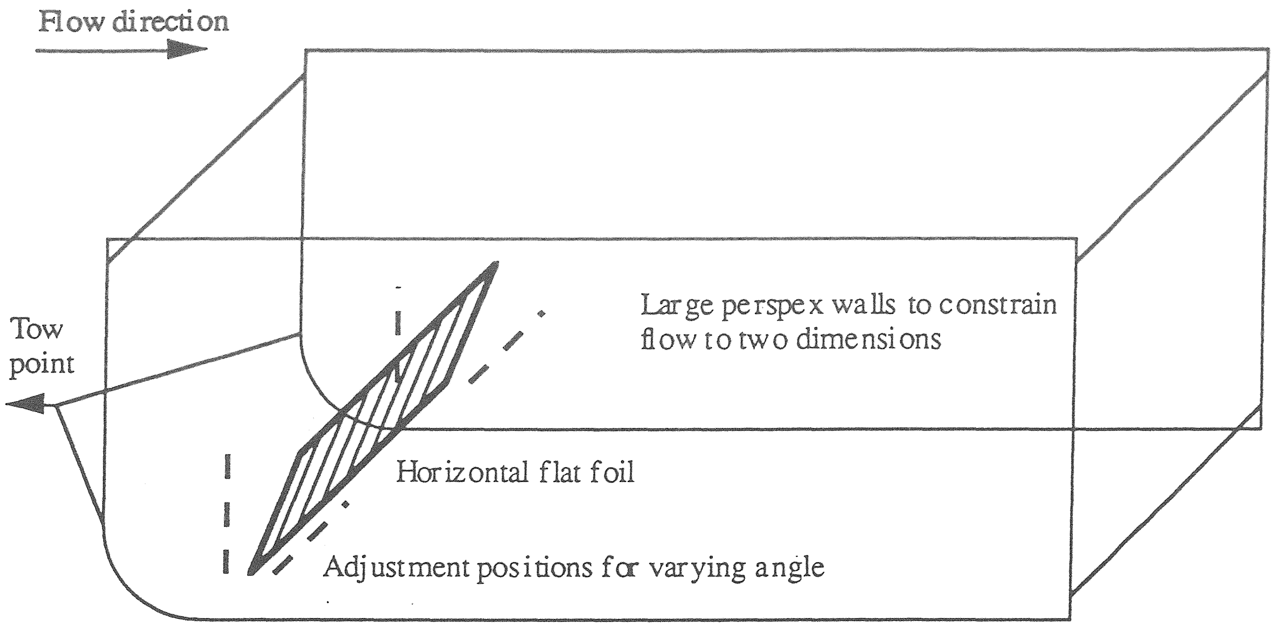
The arrangement and dimensions of the wing is shown in Figure 30. The wing was tested at angles of 75 degrees, 65 degrees, 55 degrees and 45 degrees and a gap cord ratio of 0.3. With the foil stationary in the flume tank, the pressure sensor was guided along the floor over a range of locations from 2m behind the foil to 2m in front. Pressure measurements were taken every 20cm along the way. Additional measurements were taken 3m fore and aft of the foil.

Figure 30 **Flat Stalled Foil in Proximity to the Bottom**



Flow direction around the foil in the flume tank was obtained by the use of tufts or tell tales which were pieces of wool attached at one end and otherwise free to follow the direction of flow. A tuft board was constructed to provide a grid of tell tales (0.1m longitudinal and vertical spacing) to give a general picture of flow direction. Another technique used was to observe the movement of introduced particulate matter in the flow region and analyse their movement by slow frame video. White particles were used so that they were easily observed against the dark background of the tuft board.

Figure 31 Flat Foil in Proximity with Bottom Test Rig



To ensure that the flow around the test foils was two-dimensional (ie no end effects) the foils were place between two large perspex sheets (0.5m x 2m) as per Figure 31. Information on flow direction and flow velocities around the foil was gathered for the foil in bottom contact and incident angles of 90 degrees, 70 degrees and 45 degrees. Additionally, identical tests were done for the foil positioned at 62.5mm off the bottom (gap to chord ratio of 0:25) and with an incident angle of 70 degrees.

Velocity measurements around the test foils were made using a mini speed log which operated on the principle of a small propeller (15mm diameter) rotating in response to the water flow. Due to the very small propeller size, the device was able to measure the average velocity over a very small region. Its short response time and digital display with 1 second update enabled large scale turbulence and velocity trends also to be measured.

4.5.3 Results

Pressure Disturbance For and Aft of the Wing

Pressure measurement results for the four angles of incidence tested are presented in Figures 32 to 35. Relevant characteristics of the pressure disturbance are summarised Table 4.7.

Figure 32 Pressure Disturbance For/Aft of a Wing at 75 degrees incidence and a gap cord ratio of 0.3

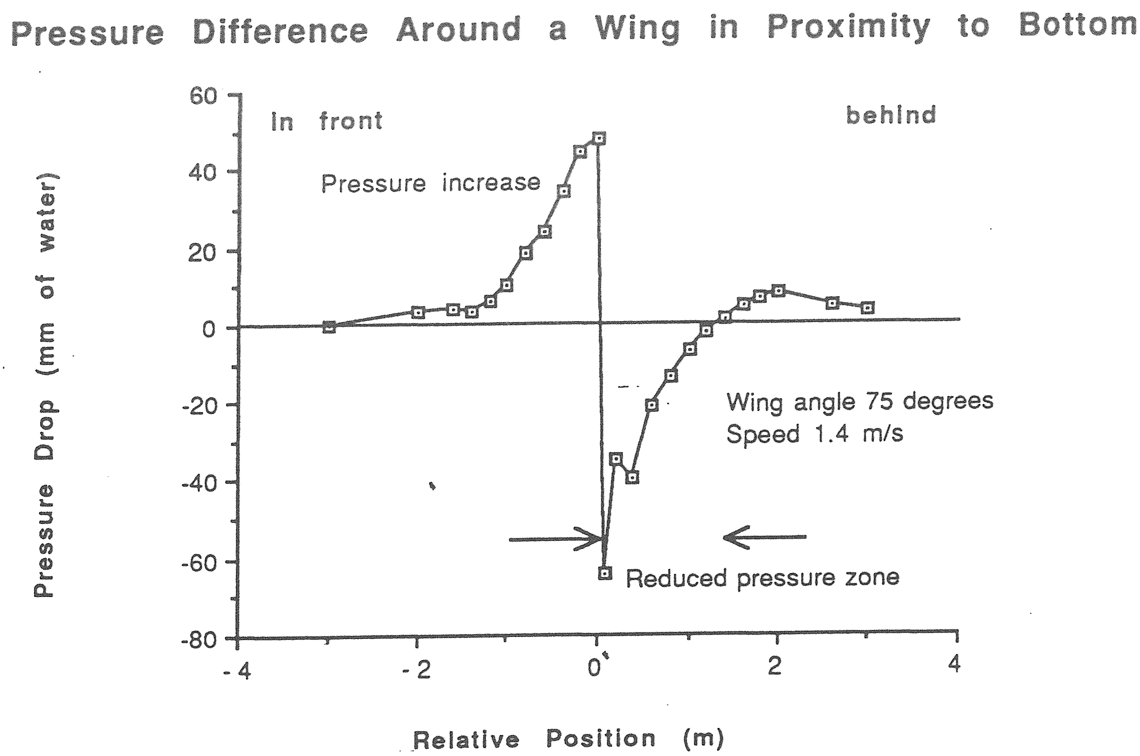


Figure 33 Pressure Disturbance For/Aft of a Wing at 65 degrees incidence and a gap cord ratio of 0.3

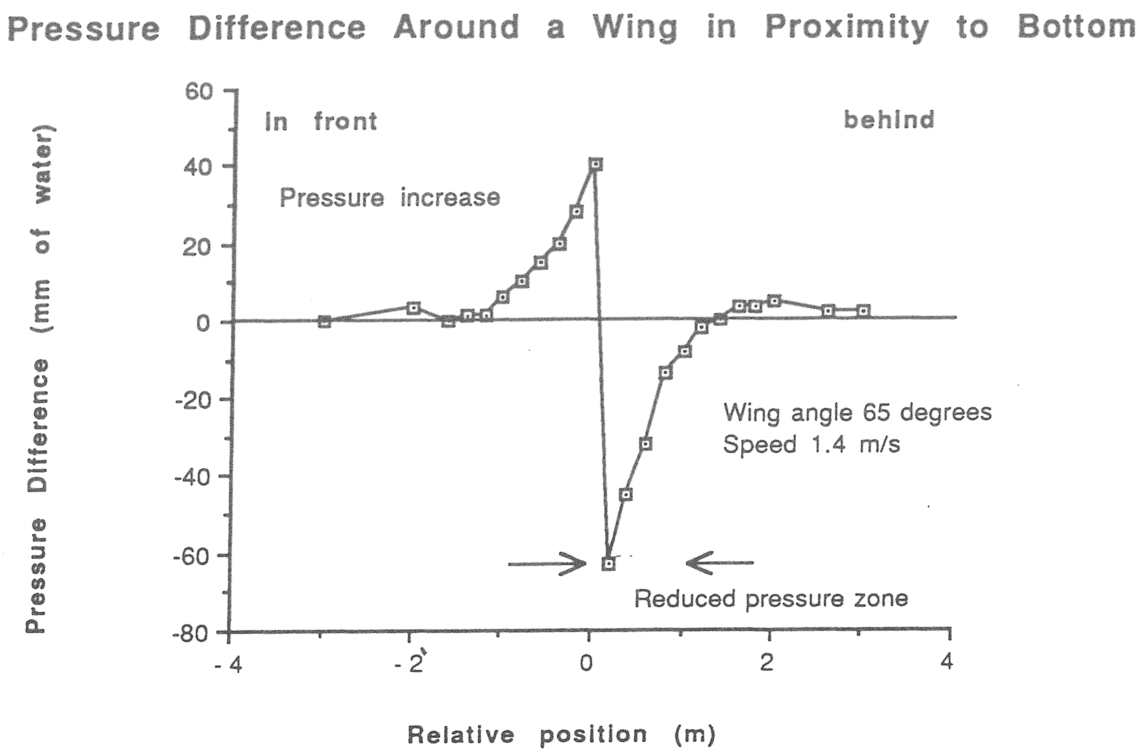


Figure 34 Pressure Disturbance For/Aft of a Wing at 55 degrees incidence and a gap cord ratio of 0.3

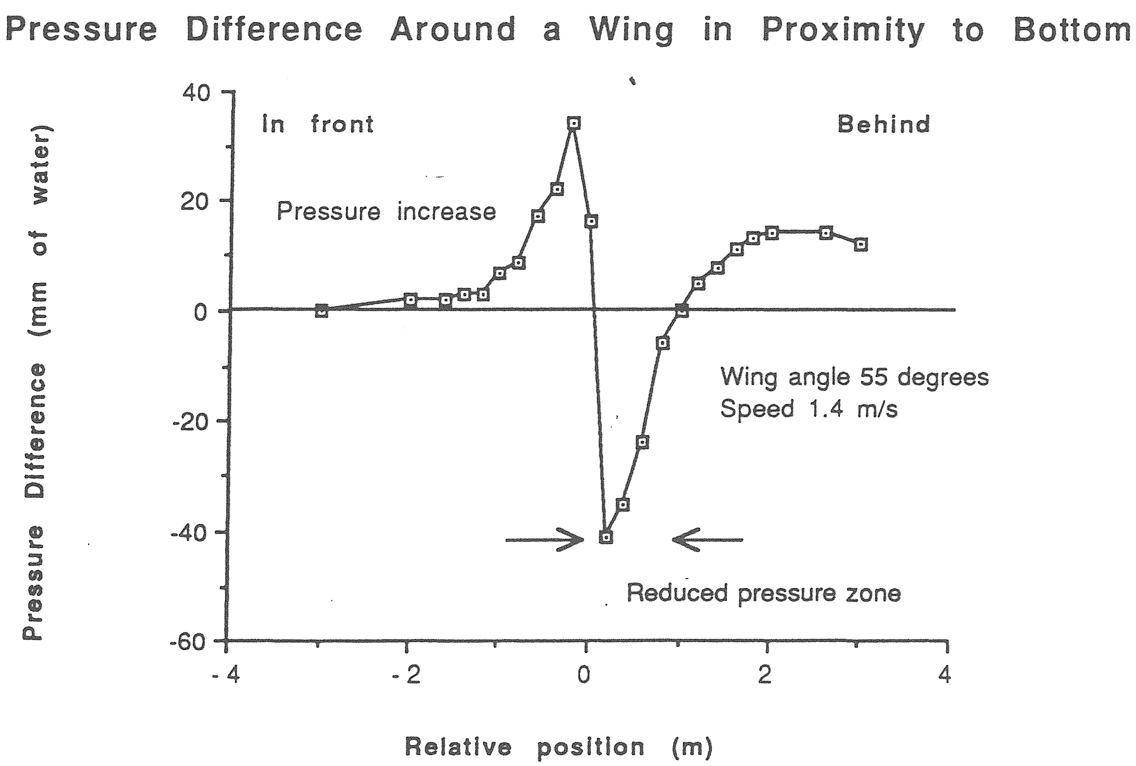
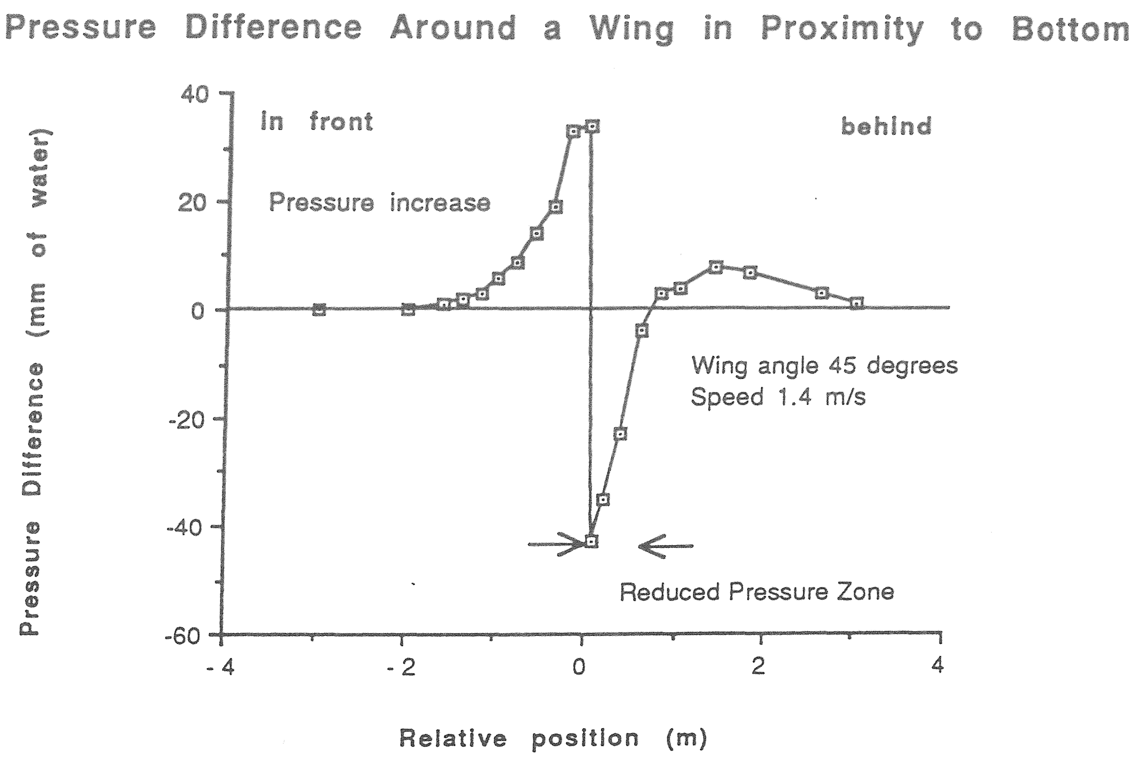


Figure 35 **Pressure Disturbance For/Aft of a Wing at 45 degrees incidence and a gap cord ratio of 0.3**



In all cases the pressure began to rise significantly at about 1m or four chord lengths in front of the foil. The maximum positive pressure disturbance in all cases (see Table 4.7 for various magnitudes) was measured at the first test point, 0.2m forward of the foil. The maximum negative pressure disturbance was always at the first test point aft of the foil. This constitutes a very large pressure gradient between these two points.

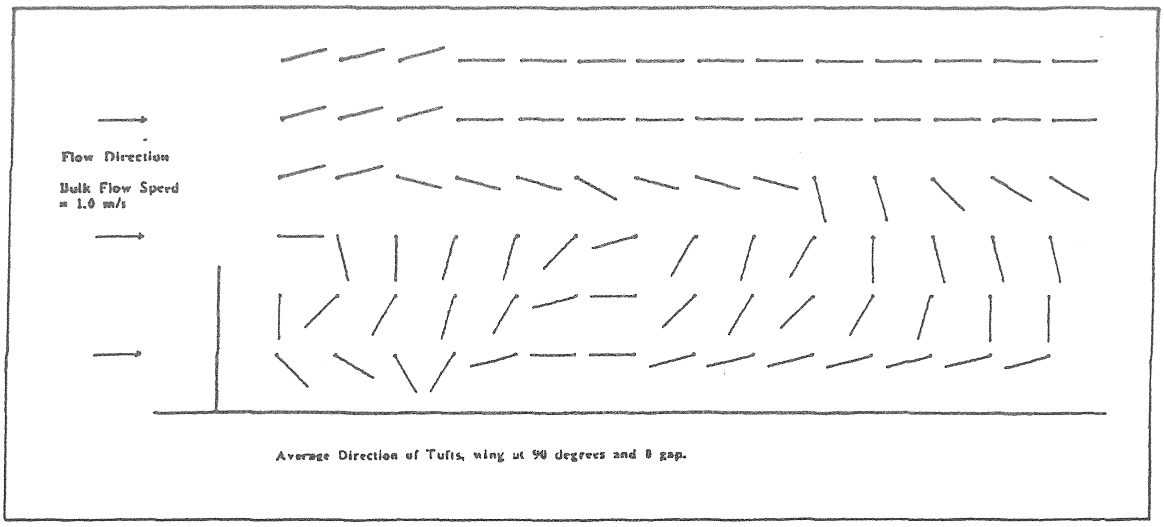
Table 4.7 Summary of Pressure Disturbance Characteristics

Wing Angle	Max Pressure Increase	Max Pressure Reduction	Width of Reduced Pressure Zone
75 degrees	48 mm of water	64 mm of water	1.2 m
65 degrees	40 mm of water	63 mm of water	1.2 m
55 degrees	34 mm of water	41 mm of water	0.8 m
45 degrees	34 mm of water	43 mm of water	0.6 m

Flow Direction Around the Wing

Diagrams based on tuft direction to indicate average flow direction for the four foil conditions tested are presented in Figures 36 to 39. The observations of particulate matter tended to confirm the tuft direction conclusions and are presented descriptively.

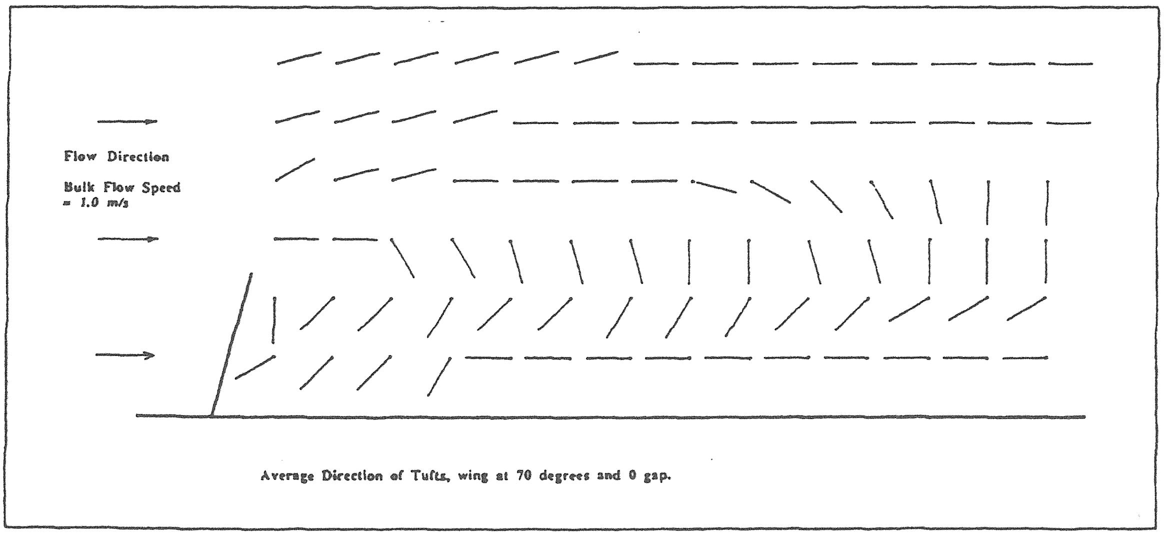
Figure 36 **Flow Direction (from tufting) around Wing at 90 degrees and Zero Gap**



Average Direction of Tufts, wing at 90 degrees and 0 gap.

In the first two chord lengths behind the wing at 90 degrees incidence, the water movement was effectively nil. Behind this region the flow direction was reversed and turbulent flow was apparent in respect to the random and fluctuating direction of the tufts.

Figure 37 **Flow Direction (from tufting) around Wing at 70 degrees and Zero Gap**



Average Direction of Tufts, wing at 70 degrees and 0 gap.

For the wing at 70 degrees and zero gap the water movement behind the wing was also slow and in parts reversed as in the 90 degree case. With a gap (62.5mm) beneath the wing however, the water close to the belt (in the lower 0.1m) continued in the same direction as the free stream for some distance until becoming significantly disrupted by turbulence at about three chord lengths behind the wing. Apart from this, the slowing down and flow reversal above this layer was similar to that observed in the previous two cases.

Figure 38 **Flow Direction (from tufting) around Wing at 70 degrees, Gap to Chord Length ratio of 0.25**

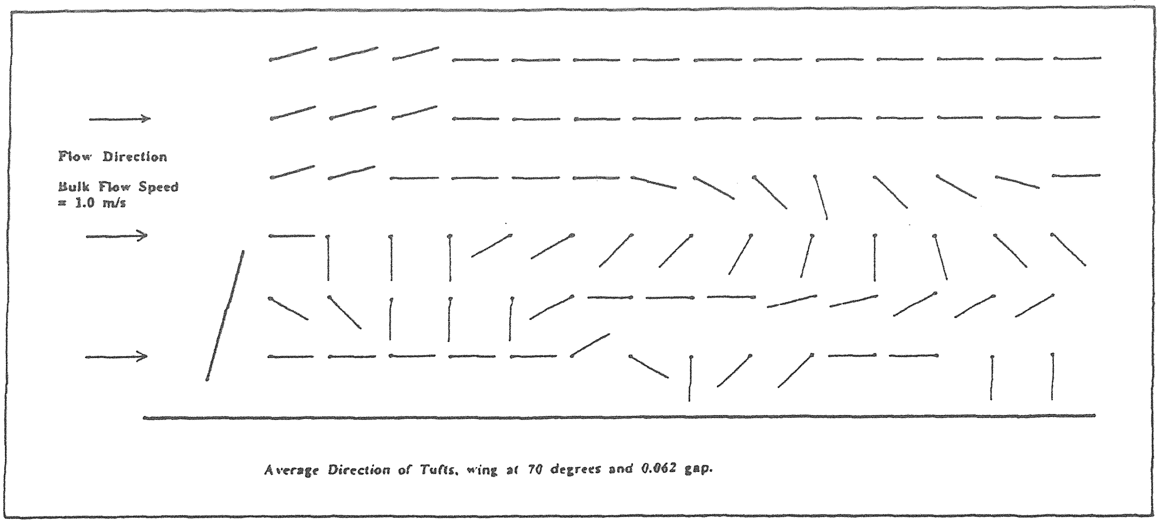
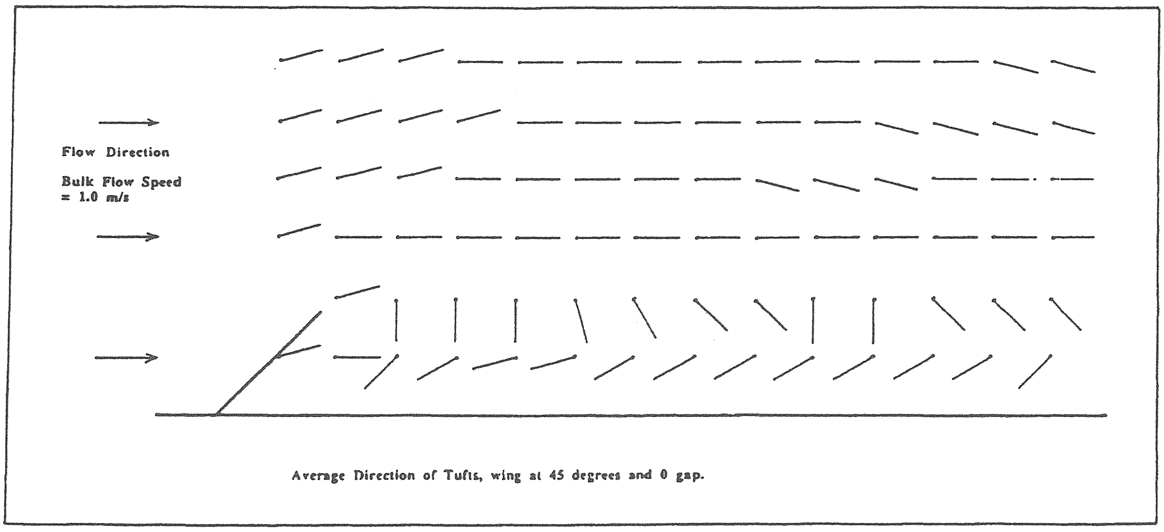


Figure 39 **Flow Direction (from tufting) around Wing at 45 degrees and Zero Gap**



Behind the 45 degree wing the water movement was similar to the other no gap tests, although the effects seemed to be less intense.

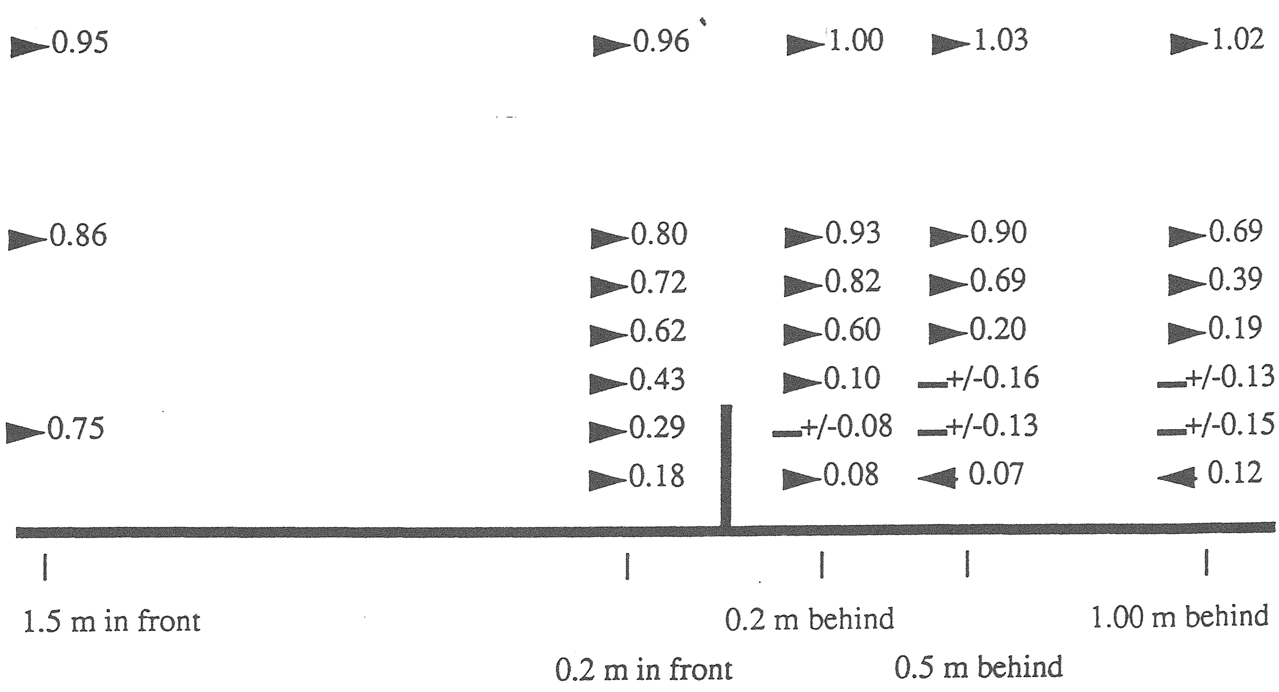
The observations above are consistent with the general conclusion that steeply inclined wings drag behind them a body of water which is slowly circulating in a turbulent manner back toward the wing.

The movement of particulate matter introduced into the towed body of water was that it would circulate toward the back of the wing and then drop to the belt to be carried backwards about four chord lengths before being picked up and wafted back toward the back of the wing again. Several circulations of this nature would often be observed before the particles escaped, usually by remaining very close to the belt during its aftward movement.

4.5.4 Horizontal Flow Velocity Components

Speed measurements taken with the mini speed log and their locations are presented in Figures 40 to 43. Observations of flow velocity made in front of the wings indicated that flow in the flume tank was not perfectly uniform. The flow velocity at the higher levels was significantly faster than at the lower levels. The discrepancy within the range of interest was about 20%. This artefact is a property of the tank and cannot be eliminated. Despite this the data still serves to convey quantitative estimates of the water flow velocities in various regions around the test foil.

Figure 40 Flow Velocities for Wing at 90 degrees and Zero Gap



Immediately in front (0.2m) of the 90 degree incidence wing, the flow velocity stagnates and becomes very slow. This water must eventually make its way over the top of the wing and must therefore be partially moving upwards. The upward velocity component was unable to be measured by the mini log since it was physically constrained in the horizontal direction.

Behind the wing and to a height of about one and a half times the chord, the horizontal flow velocity was significantly reduced and in some parts of the region was reversed in direction.

Figure 40 **Flow Velocities for Wing at 70 degrees and Zero Gap**

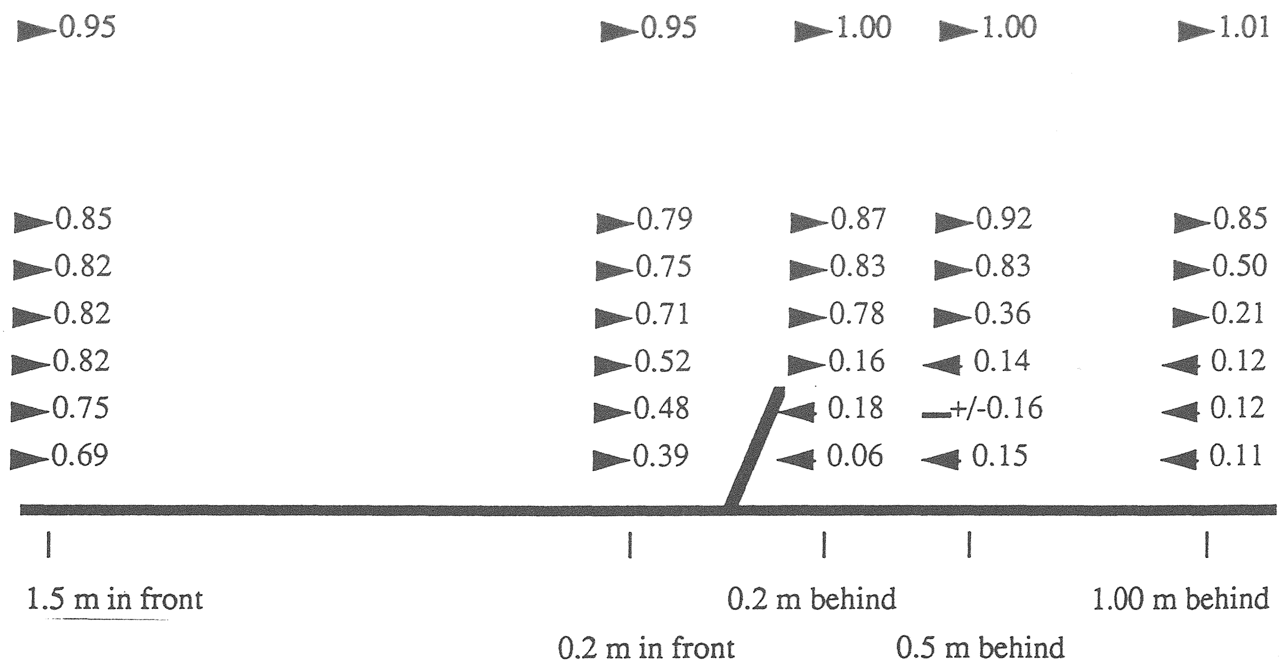
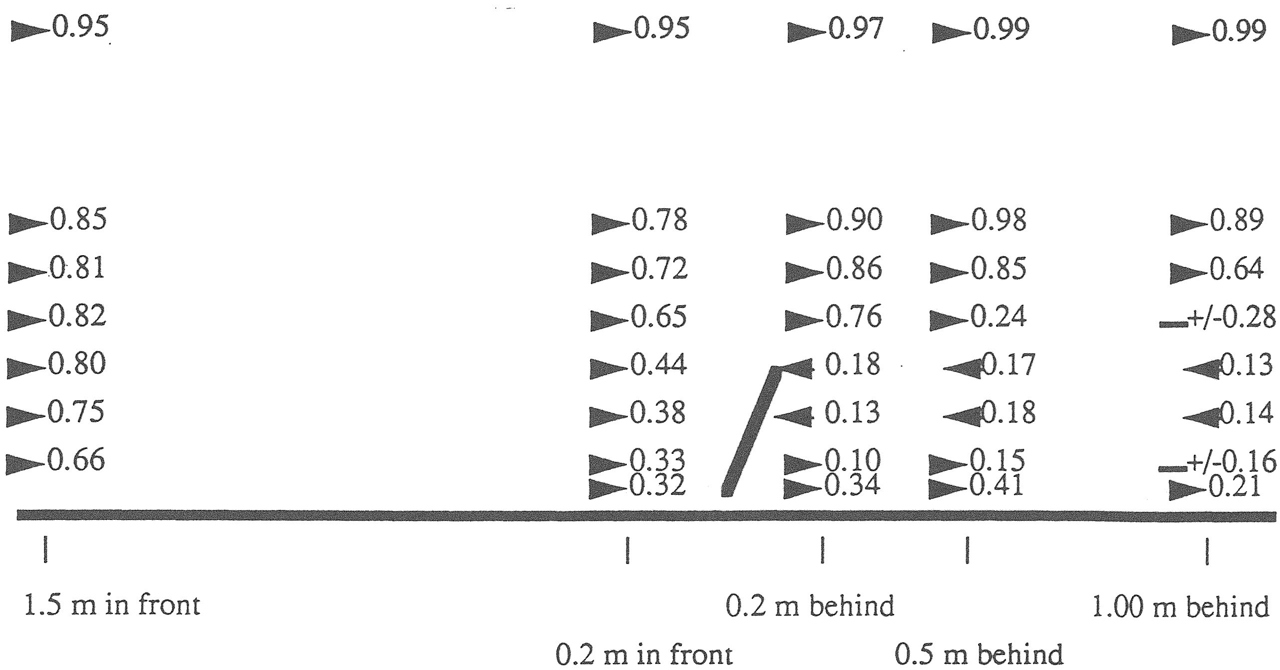
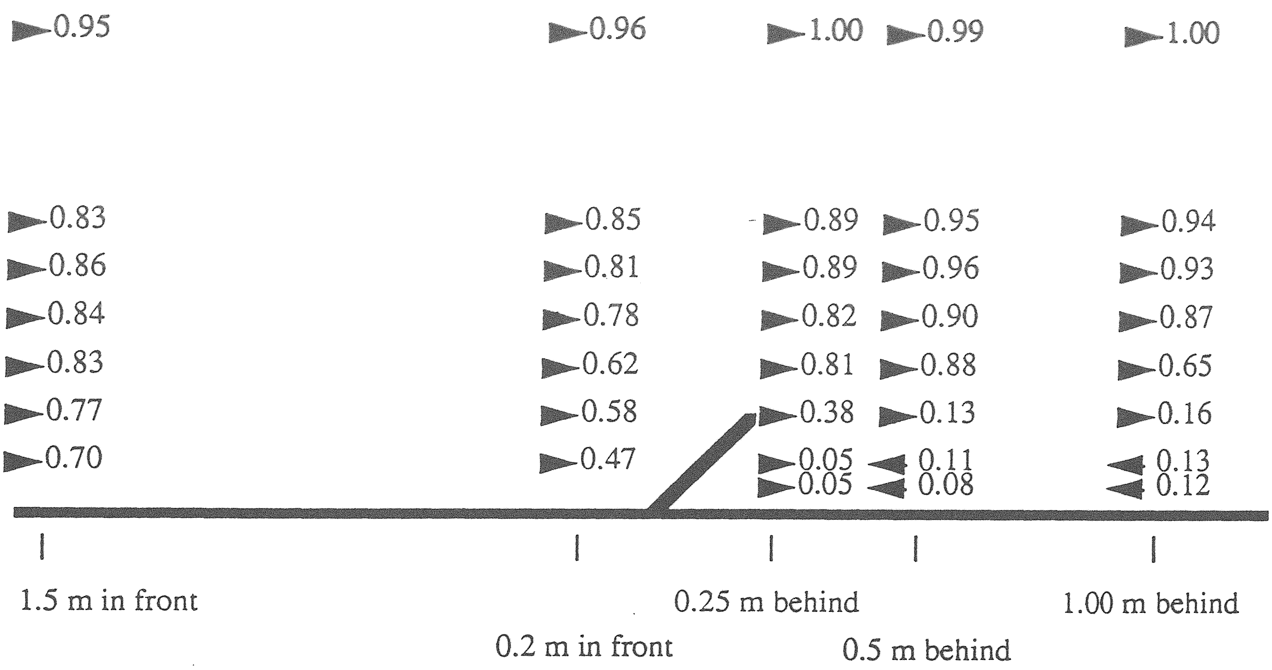


Figure 42 **Flow Velocities for Wing at 70 degrees and 0.062 Gap**



The magnitude of the reversed flow behind the wing appeared to be slightly greater for the wing at 70 degrees than it was for the wing at 90 degrees. The gap under the wing at 70 degrees incidence allowed water to pass with a speed measured to be about one third of the free stream velocity. This jet of water appeared to become partially absorbed into the wake region as it proceeded further behind the wing.

Figure 42 **Flow Velocities for Wing at 45 degrees and Zero Gap**

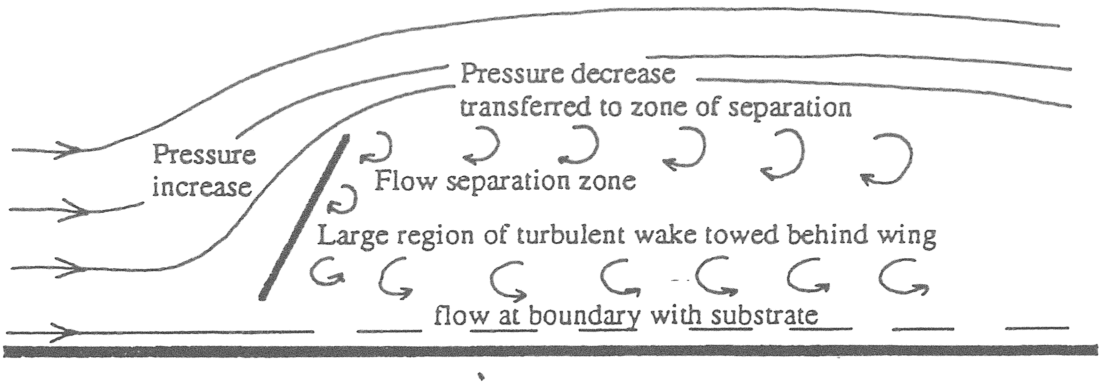


4.5.5 Discussion

The results obtained were generally smaller than those obtained by Vaccaro and Blott (1987), both in terms of the pressures measured and the distance in chord lengths behind the wing in which the effect was significant. For the 75 degree wing the decreased pressure was experienced for four chord length behind the wing compared to a decreased pressure for 15 chord lengths behind the wing measured by Vaccaro and Blott. The shapes of the graphs obtained from the results were otherwise similar to those obtained by Vaccaro and Blott . The discrepancies could be from the effects of scaling or from the experimental differences between using a towing tank compared to a flume tank.

The effect of a moving stalled flat foil in close proximity to a boundary (as simulated in the flume tank) is that a considerable body of turbulent water is towed along with the foil (Figure 43). The presence of a gap between wing and substrate slightly reduces the extent of the moving water body. However some gap is essential in practice so that objects on the sea floor can pass under the wing and into the body of the turbulent wake. Some of the water passing under the wing will not be absorbed into the wake for some distance and that fluid which is very close to the substrate may not become part of the turbulent wake at all.

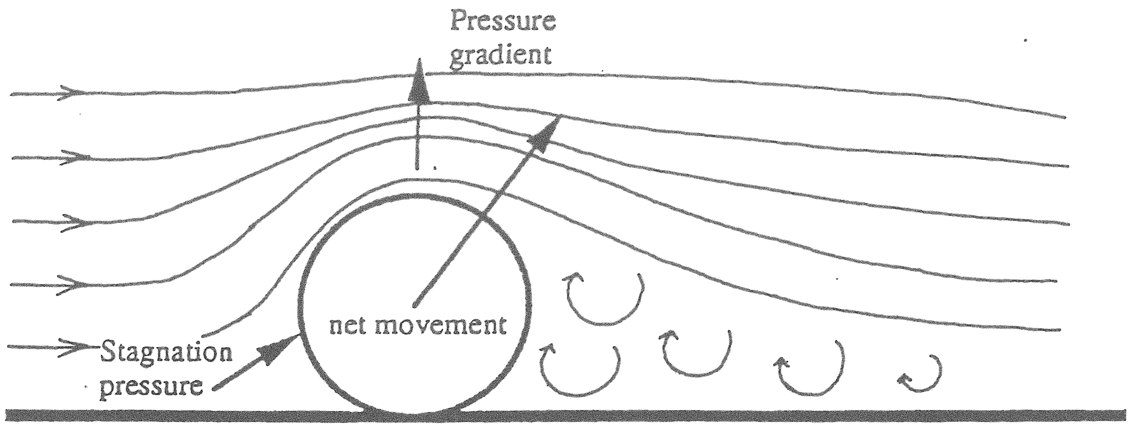
Figure 44 **Interpretation of Flow around a Stalled Foil Close to the Seabed**



From the scallop's point of view (or for any benthic object) it appears that the approaching wing will create a small pressure disturbance and be followed by a body of moving water travelling at or faster than the tow speed of the dredge. Any object on the bottom experiencing this fast moving water travelling over it may also experience a lift force (Figure 44) and will possibly be physically lifted off the bottom.

A hydrodynamic system using a simple flat foil or wing at a stalled angle of incidence and in close proximity to the sea floor therefore could perform well as a scallop catching mechanism. The hydrodynamic catching system may also be useful in other fisheries where the target species live in intimate proximity to the bottom.

Figure 45 Lift on an object in a stream flow in proximity with the bottom



4.6.0 Modification of New Zealand Dredge and Australian Tipper for Compatible Operation

4.6.1 Introduction

In view of the very positive results obtained for the New Zealand dredge in terms of catching performance and engineering performance (drag) it seemed logical to view this dredge seriously as an option for deployment in the south east Australian scallop grounds. A very serious impediment against acceptance of this harvester are the unfavourable handling aspects of the dredge.

All attempts to operate the dredge from Australian scallop boats were hampered by the difficulties in retrieving the dredge, emptying the contents and returning the dredge to the water. Much of the problem lay with the vessels not being adequately equipped for the exercise, particularly in terms of the overhead lifting gear extensively used by New Zealand scallop vessels. To implement the dredge under Australian conditions either the vessels need to be significantly modified or the dredge modified such that it is able to operate in an essentially standard Australian tipper.

Much of the feedback from industry regarding the New Zealand style of operation suggested that it was not suitable for operating dredges under Australian conditions due to the severity of weather and waves often experienced. Under these circumstances it was thought that the best solution would be to modify the New Zealand dredge so that it worked in conjunction with a standard tipper arrangement containing minimal changes from current tipper designs.

4.6.2 Methods

It was perceived that three principle modifications to the dredge/tipper system were required.

Firstly, longitudinal stiffness needed to be applied to the dredge so that it maintained its full length when tipped vertically to release the catch. Secondly, the long four point tow spider on the standard New Zealand dredge needed to be replaced by a much shorter arrangement which needed only be a two point spider if the longitudinal stiffeners also serve to stabilise the orientation of the towing frame during fishing. Thirdly, a floor of some type must be incorporated into the tipper so that the flexible bottom can be supported and also to transfer the caught scallops to the sorting table on having been tipped from the dredge.

A New Zealand dredge and a southern Australian tipper were modified in the above way at the AMC and trialed in the Tamar river to access the performance of the handling arrangement. Apart from fine tuning the resting orientation of the tipper to aid the correct connection of dredge and tipper during retrieval, their were no handling difficulties. The modified dredge did however appear to be somewhat unstable in midwater, where it had a tendency to roll onto its back. This was alleviated by adding a 360mm float to each end of the tow frame and an additional 10 kg weight each side to the bottom of the frame.

Following the Tamar trials the dredge/tipper combination was sent by freight to Queenscliff where it was fitted to a commercial boat and trialed in Port Phillip bay.

4.6.3 Results and Recommendations

Initial tests were positive in that catch rates appeared high compared to catch from dredges trialed previously. Further tests were disappointing though, since it was found that when the dredge contained a reasonable catch it became quite unstable in midwater and often rolled onto its back during retrieval.

Subsequent flume tank tests on a model dredge to investigate midwater stability showed that vertical fins attached to the rear of the dredge seemed to improve midwater stability. Such fins were fitted to the modified New Zealand dredge and further testing in the Tamar river showed that the dredge had become more stable in midwater. Appendix F shows engineering drawings for the final modified New Zealand dredge/tipper combination.

It is recommended that additional modifications be made to the New Zealand dredge to further improve its midwater stability. These untrialed modifications (also shown in Appendix F) provide larger fins positioned on the edges of the dredge. This can be achieved by realigning the longitudinal struts and gives a solid fin location that should put it in less disturbed water flow particularly when the dredge is full.

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Appendix 1

Sample size for Scallop Dredge Trials

Prepared by Kathy Haskard
CSIRO Biometrics Unit
CSIRO Division of Mathematics and Statistics
CSIRO Marine Laboratories, Hobart

The following is all based on data from the dredge modification trials undertaken in May 1991, where catches per tow were recorded to be between 6 and 295 scallops, with the middle half between 38 and 119. In the analysis of those data, it was appropriate to take the square root of the catch count as the response variable, and I will refer to this as Y. Y ranged from 2.4 to 17.2 with the middle half in 6.2 to 10.9.

In that experiment we obtained an estimate of the variance of Y as $s^2 = 6.285$, and we will apply this for the new experiment in lieu of any other information. Assuming we do r (eg 3) complete replications with n (eg 5) tows for each type of dredge in each replicate, and we do the five tows in succession, ie without changing the dredge between those 5 tows within a block (replicate), the appropriate analysis is really based on the means of those 5 tows, and the variance of that mean is $s^2/5$, or s^2/n in general. Once we have this estimate for s^2 we can use a relationship which links the following quantities:

- r, the number of complete replications;
- delta, d, the size of difference between mean of Y that we wish to detect as significantly different;
- alpha, a, the significance level we will use, commonly 5%;
- the probability 1-b with which we want to find a statistically significant difference if the true difference is d or larger, commonly 80% or 90%, we will use 80%;
- and s^2, for which we use our estimate s^2/n.

The relationship can be expressed as:

$$r = 2(Z_{a/2} + Z_b)^2(s/d)^2$$ (Steel and Torrie p 232)

or

$$d = (Z_{a/2}+ Z_b)\ \_2s^2/r$$

where $Z_{a/2}$ is the upper a/2 point and Z_b the upper b point of the standard unit normal distribution, e.g. 1.96 and 0.8416 respectively for a = 5% and b = 20% (for 5% tests with power of 80%). For given r and n this gives the approximate size of the detectable difference in Y (square root of the number of scallops) in our example as d = 9.93/_nr.

This suggests that d depends only on the total number of tows, nr. However, this formula does not take into account the degrees of freedom used in the tests, and for very small numbers of replicates this will make a considerable difference to the power of the tests. To adjust, we replace $Z_{a/2}$ and Z_b by corresponding values for the t-distribution with degrees of freedom (r-1)(t-1), where it is the number of treatments (dredges), 5 or 4 in our case.

Table 1 shows, for various combinations of the number of complete replicates r and the number of tows per dredge in each replicate, the approximate differences d you could expect to have 80% probability of detecting as significantly different at the 5% level.

Table 1a Difference d with trial of five dredge types

Number of replicates	Number of tows per dredge per replicate, n						
r	n=1	n=2	n=3	n=4	n=5	n=6	n=7
2	9.3	6.6	5.4	4.7	4.2	3.8	3.5
3	6.5	4.6	3.8	3.3	2.9	2.7	2.5
4	5.4	3.8	3.1	2.7	2.4	2.2	2.0
5	4.7	3.3	2.7	2.4	2.1	1.9	1.8
6	4.3	3.0	2.5	2.1	1.9	1.7	1.6

Table 1b Difference d with trial of four dredge types

Number of replicates	Number of tows per dredge per replicate, n						
r	n=1	n=2	n=3	n=4	n=5	n=6	n=7
2	10.4	7.4	6.0	5.2	4.7	4.3	3.9
3	6.9	4.9	4.0	3.4	3.1	2.8	2.6
4	5.6	3.9	3.2	2.8	2.5	2.3	2.1
5	4.8	3.4	2.8	2.4	2.2	2.0	1.8
6	4.3	3.1	2.5	2.2	1.9	1.8	1.6

Notice that increasing the number of replicates is more beneficial than increasing n, the number of tows per dredge. For example 4 replicates with 4 tows per dredge (a total of 16 tows per dredge) is as good as 3 replicates with 6 tows per dredge (a total of 18 tows per dredge), and better than 3 replicates with 5 tows per dredge (15 tows per dredge in total). However, this must be traded off against the increased time for changing dredges.

The size of difference in actual scallop catch will depend on the actual magnitude of the catch, e.g. for 5 dredges, for r=3 and n=5 as you suggested, d = 2.9 corresponds to detecting a difference if actual mean catches for two dredges are around 20 and 55, or if they are around 50 and 100, or around 95 and 160. To give an idea of what a given d corresponds to in terms of actual numbers of scallops, Table 2 shows such examples for several values of d.

Table 2

d	80% probability of finding a significant difference if the true mean catches are approximately:				
	20 and	50 and	100 and	150 and	200 and
1.5	36	73	132	189	245
2.0	42	82	144	203	261
2.5	49	92	156	217	277
3.0	56	101	169	232	294
3.5	64	112	182	248	311
4.0	72	123	196	264	329
4.5	80	134	210	280	348
5.0	90	146	225	297	366

Clearly *at least* 3 replicates are necessary. In that case, and with n=5, if one dredge gives a mean catch of around 50 scallops, a significant difference is likely to be found if another dredge has mean catches of more than 100. Do you expect to get differences this large? If not, but you still want to pick them up, you will want a smaller d, either by increasing the number of replicates, increasing n, or both.

In summary, three is the bare minimum number of replicates you should consider. You can see from the tables what mean sizes of catch you can expect to be able to differentiate between, with 80% probability. Bear in mind that these are only approximate, especially since we are using only an estimate for s^2.

I suggest you use the second table to decide what size differences you wish to detect, and hence the d you need, e.g. d = 2. Then go to the first table to see possible ways of achieving this, e.g. 4 replicates with 7 tows per dredge, of 5 replicates with 6 tows per dredge. Alternatively, Table 2 shows you the differences you could detect with, e.g. r=3 and n=5, namely for d approximately 3.0.

Finally, as discussed at length already, try to make your replicates as uniform within as possible and maximise the difference between replicates, and, very importantly, randomise - order of different dredges within replicates, order in which the tows in different directions are done within a replicate, and even order of doing the three replicates.

Appendix 2

ORIGINAL APPLICATION

FISHING INDUSTRY RESEARCH AND DEVELOPMENT TRUST FUND
NEW APPLICATION

Section 1 Project Title

Development of improved and environmentally sensitive scallop harvesting gear.

Section 2 Keywords

Scallop harvesting environmental sensitive

Section 3 Objectives

1 To design, develop and test equipment to harvest naturally occurring scallops with minimum disturbance to the sea bed and to uncaught scallops.
2 To assess improvements in efficiency, selectivity, handling and methods of deployment of improved scallop harvesting gear.
3 To facilitate the phased introduction of new scallop gear over a two year period.

Section 4 Justification

The south eastern Australian scallop fishery is intermittently one of the most valuable commercial fisheries for Victoria and Tasmania, worth upwards of $30 million to each state during good seasons. The method of catching scallops has, however, attracted much criticism with regard to possible environmental disturbance and reduction in yields through incidental mortality to scallops. Given the present awareness and acceptance of the need to protect the marine environment and habitats critical for fishery resources, it is incumbent on all of Australia's commercial fisheries managers and operators to adopt a philosophy of continuing to perfect environmentally sound fishing practices. While codes of practice are being discussed and introduced to many fisheries, the demand for more environmentally sensitive fishing practices to be developed and introduced will continue, particularly for those inshore fisheries such as scallops and prawns which are more open to public observation and which often co-exist with recreational fisheries.

In Victoria and Tasmania, the demand for active improvement to fishing practices has become intensively focussed on scallop fishing, particularly in recent months with the possibility of a return to fishing in Port Phillip Bay. This need for action has been voiced by the Commonwealth and State Government managers, who, in a joint statement on new management arrangements for the Bass

Strait scallop fishery (7 December 1990):

- expressed concern about the impact of tooth bar dredges on the ocean floor ecology,
- noted that trials would be conducted with a view to introducing more appropriate and environmentally sensitive harvesting technology; and
- warned that fishermen should not make any new investment in acquiring tooth bar dredges.

THE PROBLEM

Commercial scallops (Pecten fumatus) lie in recessed depressions on the sea bed which are often made by shell movements and respiratory currents. Consequently, they are caught by the action of the dredge penetrating deep enough into the sediment to extract the scallops from their depressions. The dredges' weight, pressure plate, tooth bar and scraper bar aid in this process, but in collecting scallops the gear also tends to fish through the top few inches of the soft or gravelly sediment. Divers have observed that in some cases, the dredge tracks on soft beds can be up to 6 - 7 cm deep. If dredges were lighter and skimmed across the surface without penetrating, most scallops would pass underneath. The main potential environmental effects therefore are probably the changes to the structure of the sediment, caused not so much by the tooth bar but by the action of the whole dredge passing through the top few inches of the sediment. On hard surfaces, physical breakage of epi-benthic animals, including scallops may be more prevalent. The commercial scallop of south eastern Australia is not as mobile as the saucer scallops of Western Australia and Queensland and is not effectively caught by trawling. Even if trawling for scallops were successful, the problem of incidental fish catches would be unacceptable in most areas of the scallop fishery. Furthermore, the depths and average scallop densities in most of the scallop grounds, including Port Phillip Bay mean that diving is not commercially realistic.

The Victorian and Tasmanian Scallop Industries understand and support the need to minimise environmental disturbance but having endured one of the longest and leanest periods in the history of the fishery, the majority of scallop operators are not in a position to invest immediately in new gear or to make expensive modifications to equipment or vessel configuration. World wide, fisheries for Pecten use dredges or modified beam trawls with tooth bars or scraper bars designed to dig out scallops from the sea bed. Sometimes, rows of two or three dredges are used and on some dredges, tooth bars are spring loaded for use on hard beds. Behind these devices, scallops are collected in chain mesh bags which are then emptied by inversion or by undoing a cod-end mechanism. This is a very slow and cumbersome method which is one of the reasons why, in south eastern Australia, scallop fishermen developed the very much more efficient and much safer self tipping gear. Although the soft mesh collectors used elsewhere may be lighter when empty, when full they would also cause similar disturbance to the sea bed. Apart from the environmental considerations, one of the major obstacles to the introduction of a satisfactory management plan for the Bass Strait scallop fishery has been the problem of acceptable minimum commercial sizes and the retention of undersized scallops in the catches. While the current management philosophy aims to protect adult scallops until they have spawned twice, in practice there are major difficulties in knowing how to find, age and selectively fish on such populations.

Management of the fishery faces a major problem in that the 'conditions' necessary to allow fishing to commence, particularly those aimed at protecting juveniles and spawning adults can, in practice, seldom if ever be met. The result has been prolonged closures, surveys and meetings which have been extremely expensive in both management and economic terms. A major part of the problem can be placed on the poor size selection characteristics of the fishing gear and the common perception of fishermen that "once a bed is fished, it might as well be fished to completion as experience has shown that few that are left survive for subsequent fishing". How then can spawning adults be protected effectively? Improvement to ageing techniques offers only a partial solution as the high growth variation from area to area and between years in a given area would require a heavy reliance on bed-by-bed monitoring. The present strategy of fishing to a less-than-ideal size limit is probably the best workable arrangement, but if active sorting on deck to that limit occurs, (as detected by knife-edge size frequency), closure of the fishery ensues. Clearly, any improvements to the size selection characteristics and to the survival of juveniles not retained by the gear would significantly reduce the gap between the conditions set by management and the practicalities of scallop fishing.

The purpose of this grant application is therefore to seek sufficient funds to design, modify, construct, test alternative scallop harvesting gear. It is important that any modifications to fishing gear are tested thoroughly under commercial conditions before scallop fishermen are required to make financial commitments to new gear.

Section 5 Proposal in Detail

i Method of procedure

Scallops cannot be collected from the sea bed without some disturbance to the sea bed and to uncaught scallops and the objective is to reduce this to a minimum. In order to achieve this, the scallop collector should;

- maintain as light a seabed contact as possible to reduce the tendency to bite into the sediment,
- maintain as far as possible the speed and efficiency achieved by the self tipping cradle; and
- be raised off the sea bed by a few centimetres (eg 4 - 6), by being mounted on skids.

The Australian dredge and tipper has evolved over a number of years of commercial use and is considered by the industry to be extremely efficient, particularly from the point of view of on-board handling. The thrust of the programme is that a range of options are tested, the best are then modified and refined and at the conclusion of the programme, improved gear would be ready to be introduced on an industry-wide basis. It is proposed therefore that the development of new equipment proceed on three fronts, as outlined below.

1 Modifications to the existing mud dredge to reduce the negative performance features including incidental mortality and sediment disturbance whilst retaining existing on board handling characteristics.
2 Importation and testing of a range of fishing gear successfully used in other fisheries, including further work on the Japanese keta-ami dredge.
3 Refinement of the best designs from 1 and 2 above, including engineering and hydrodynamic operation of the gear.

First Stage

During the first stage, it is intended to modify the existing dredge by raising the cage on skids such that spat and scallops passing through the mesh also pass safely underneath. The fishable scallops would then need to be lifted from the bed by a device mounted on the leading edge and options include;

- the use of long, forwardly-pointing tynes, with the tips projecting 3 - 4 inches below the skids,
- the use of a tickler chain, or
- a combination of these.

A number of different, modified scallop catching devices can be constructed and tested. Potentially, a dredge with the above features would combine the best elements of the Australian self-tipping method with the Japanese keti-ami dredge. The principle of the keta-ami dredge is that it uses very long tynes (about 40cm) to lift the scallops from the bed which are then collected in a soft mesh bag. Trials in Tasmania and in Port Phillip Bay using this dredge (provided by W Zacharin, Tasmanian Department of Primary Industry) indicated that it caught as efficiently as the conventional dredge between given marks but that it had some disadvantages of slowness of handling and when full, could still crush uncaught scallops in its path. The concept of the dredge to be tested is therefore that only the tips of the tynes actually penetrate through the surface of the seabed and being forwardly-pointed, lift and direct the scallops into the light but rigid collector. Apart from the lines made in the sediment by the tynes, most of the sediment surface would remain intact and would retain its structural integrity. In this respect, the fishing action of the proposed device would be fundamentally different from the present dredge. Although there is no scientific evidence of adverse ecological impacts being attributable to assumed or actual dredge-induced changes to benthic fauna and flora, intuitively it would be expected that gear which maintains the structural integrity of the sediment would have major ecological and fishery benefits, including an increased survival rate of newly-settled scallops on fished beds.

The proposed device could potentially provide a number of other significant advantages for the scallop fishery and its management. The distance between the tynes could provide an important mechanism in scallop size selectivity. Tyne spacings could be set to target commercially-sized scallops. Potentially, this could be a much more effective size selection method than the mesh size of the collector cage itself, which in conventional dredges, often becomes too clogged to work effectively with the result being the serious management problem posed by the unwanted capture of juvenile scallops. Furthermore, the mesh selection characteristics could also be much more effective in a collecting cage that is raised off the substratum than in one partially submerged into the substratum. The combination of tyne spacings and raised collector cage could therefore be an important extra facility to help solve the very vexed question of appropriate minimum sizes and sorting. Potentially the device could improve the ability of the industry to target scallops which are large enough to have spawned twice and to reduce the damage to those left behind. Scallops which pass between the tynes or through the mesh would not then be crushed by the collecting cage itself which should significantly reduce the incidental mortality to scallops.

A number of trial dredges (4) would be constructed for use in Victoria and Tasmania with the ability to alter tyne lengths, spacings, angle of forward projection of the tynes, tickler chain attachments, height of skids and weight of cage. The dredge would be attached to a commercial scallop fishing vessel and would be used alongside the fleet under commercial conditions. Under the guidance of the project officers in Victoria and Tasmania, data sheets would be completed recording catch rates and size frequencies each configuration of the gear, towing speed and warp length. These will be compared with commercial performances of vessels fishing alongside.

Second Stage

The import and subsequent trialing of the keta-ami dredge by W. Zacharin of the Tasmanian Sea Fisheries Division produced encouraging results although difficulties and problems remained. The project will, if necessary (depending on early success or otherwise of the modified mud dredge designs) import further dredges from other fisheries such as in Japan, Canada, Scotland or New Zealand. Whilst it will almost certainly not be possible to adopt an imported design into the fishery, innovative ideas could be obtained and applied to the evolving designs. Any imported dredges would be trialed in Tasmania and Victoria as appropriate.

Third Stage

It is proposed to develop the new equipment from an engineering and hydrodynamic aspect, such that in addition to the on-board assessment of effectiveness. This will include a study of the operation of the existing gear, followed by modifications, refinements and improvements to the new gear. Specifically, this phase of the work will concentrate on the following considerations:

- cost, in terms of construction, fuel (drag), on board handling time and handling equipment, and
- safety, particularly during operations at sea and in rough conditions.

These studies will complement the studies of effectiveness, incidental mortality and selectivity being conducted during Stages 1 and 2.

A schedule and task description for the contributing agencies is given in Figure 1. During the first year it is intended to narrow down the range of possible modifications and by the end of the first year, to have selected the most promising design or designs. During the second year, further refinement will be undertaken in preparation for full introduction to the fishery.

It may not be possible to produce a 'universal' collector suitable for all substrates and conditions encountered in the south eastern Australian scallop fishery and the project will need to take these differences into account. The importance of working alongside the commercial fishery for all stages of the work cannot be underestimated. For any modifications to the existing gear or new design to be acceptable to industry, they must have a key role in their development. The use of video and planned extension work will ensure a coordinated effort throughout the fishery. Commercial application must be proven prior to recommendation for general introduction.

It is proposed to test the dredge for up to 30 days equally divided between Port Phillip Bay and Bass Strait (from Lakes Entrance) and up to 15 days in Tasmania. A schedule and management plan for the project is given in Figure 1.

ii Facilities available.

The project will be conducted through a number of contributing agencies as follows:

- Victorian Fishing Industry Federation (VFIF), and the Victorian Scallop Association, with Dames & Moore providing supervision, data analysis and reporting for Phase 1 and 2 studies in Victorian areas;
- Tasmanian Department of Primary Industry, Sea Fisheries Division and Tasmanian Scallop Industry; for phases 1 and 2 in Tasmanian areas of the fishery;
- CSIRO; for underwater video usage, data analysis, extension of results and progress to the industry and for overall project coordination; and
- Australian Maritime College, for engineering and hydrodynamic studies of existing an improved catching equipment.

In addition, new or modified scallop fishing equipment will be available for joint participation in the Marine Science Laboratories existing study of effects of dredging as well as their proposed FIRDTA study to measure sedimentation characteristics of different dredges. This is seen as a logical and complementary part of the studies, aimed at obtaining some quantitative estimation of the sediment disturbing characteristics of the various dredge designs. The project will be jointly managed by the VFIF, whose conceptual initiative started the proposal and CSIRO, who have extensive previous experience in conducting dredge efficiency trials, will provide overall scientific, extension and administrative coordination.

Within the Victorian and Tasmanian scallop industry, there are a number of scallop fishermen with experience in participating in scallop fishing surveys. Industry will provide vessels as part of the overall cost of the project. The Victorian and Tasmanian Scallop Fishing Industries have many contacts with manufacturers of fishing gear and equipment who would be available to make and assemble the required equipment. Many of the operators actually construct their own dredges and between themselves and the manufacturers, possess an extensive range of engineering and constructional expertise in developing fishing gear. In Victoria, it is proposed to include Dr David Gwyther of Dames & Moore as project officer, responsible for supervision, coordination of data collection from Victorian vessels, data analysis and report presentation to the project co-ordinator. All reporting will be channelled through VFIF to CSIRO project management. In Tasmania, the offices and staff of CSIRO and the Sea Fisheries Laboratories, Taroona are available to provide sea-going support, data collection, scientific analysis and collation, and to deploy the underwater video systems. The Australian Maritime College, through the operation of the flume tank has had a long history of involvement with the fishing industry in the testing and development of fishing gear. Considerable expertise in the fields of engineering and hydrodynamics and a range of monitoring equipment including load cells and underwater video equipment are available. There are also a range of workshop facilities and ample berthing for trial vessels.

There is a sum of $10 000 available from the Commonwealth Zone levy which will contribute to the overall costs of modifying the existing gear prior to the scheduled opening of the Bass Strait grounds in June. Thus progress in modifying existing dredges can proceed prior to the proposed commencement of the project. Funding from the levy is also available for State-based technical officers to administer the Bass Strait Management plan, and it is planned that they will be able to assist with on-board observations, under supervision during the course of the project.

SUPPORT DATA

i Previous work in this or related field

Modifying and testing fishing gear is second nature to most commercial fishermen and the combined experience of Victorian scallop fishermen will provide all the necessary experience and ability to test the proposed new device thoroughly. During the past 25 years, many informal experiments and modifications to scallop fishing gear have been carried out by fishermen, most designed to improve catching efficiency. The dredge and tipper gear is itself an example of the ingenuity of those in the scallop industry to design and develop equipment with the highest operating efficiency and safety of use on deck and has been universally acclaimed as such. However, this gear now needs modification to accommodate more demanding environmental standards and the determination and skills of those in the industry, combined with the complementary project to measure sedimentation (Marine Science Laboratories) will ensure that the best effort is made to achieve the objectives. While the basic concept to be tested will be as described in this proposal, it is difficult to predict exactly what the final outcome will be. In addition, it is proposed to include Dr. David Gwyther of Dames & Moore who has an intimate knowledge of the Victorian scallop fishery. He has previously successfully completed and reported (both to FIRDC and in the scientific literature) FIRDTA funded scallop research projects. It is important that projects of this nature are conducted and reported as rigorously and professionally as possible and his input will ensure that this is so.

W Zacharin of the Sea Fisheries Division, Department of Primary Industry, Tasmania has previously completed a previous FIRDTA project (87/69; "Development of Alternative dredge designs for the harvesting of wild and reseeded scallops beds in Tasmania:). The final report was submitted to FIRDC and was also published in the Proceedings of the Australasian Workshop, Hobart, 1988. During CSIRO's FIRDTA-funded studies of scallop stocks in Bass Strait, a number of aspects of the research were directed at studying dredge efficiency, incidental dredge mortality and underwater operation of dredges using underwater video camera as well as using experimental methodology. The final report has been completed and papers published in the scientific literature.

The Australian Maritime team will include gear technologists Ian Cartwright and David Sterling, both of whom have a background of practical fishing experience combined with academic qualifications. David Sterling has had considerable recent success with the development of an innovative prawn trawling sled, a project undertaken with FIRDTA assistance, in collaboration with a commercial fisherman and the South
Australian Department of Sea Fisheries. The College has previously undertaken gear trials with FIRDTA funding in Jervis Bay and the Spencer Gulf, both with industry involvement.

Section 6 Research Priority

The proposal meets two of the key criteria of FIRDC's 5-year plan,

- gear technology (fish resource assessment section), and
- reduction of damage to fish resources and promotion of habitat enhancement (environmental change section).

In addition, the proposal would fulfil a requirement of the Bass Strait scallop fishery management plan that dredge trials would be conducted with a view to introducing a more appropriate and environmentally sensitive harvesting strategy.

Section 7 Transfer of Results to Industry

This project is part of a phased plan for the introduction of improved scallop fishing gear. It is essential that from the very beginning, industry and research agencies work together and keep each other informed of the outcome of the trials. For this reason, it will be a closely collaborative project, with the supervising agency (CSIRO) taking overall responsibility for project extension. This will start even prior to the June opening, with videos of actions of existing equipment and recommendations for simple alterations being discussed. As the project progresses, so the recommendations will be refined in order to arrive at the best possible gear for use by the entire industry, though full implementation is not envisaged before 1993. If the new gear has higher catching efficiency than the existing dredge, operators are likely to introduce it possibly earlier than 1993.

FINANCIAL INFORMATION

i Industry contribution

Costs of labour of industry staff in organising, constructing and transporting the new equipment and preparing the chosen scallop vessel will be provided to the project at no cost. Funds from the Commonwealth Zone levy will also be available $10 000 for dredge modification and a similar amount for State based technical assistance.

ii Justification of information

Items costing in excess of $1000 are explained as follows.

- $5 000 (in addition to the $10 000 from the levy) for materials and construction of collector cages, skids of different heights, tynes and tyne attachments such that spacings and angles can be altered, tickler chains, $14 000 for importation of dredges used in overseas scallop fisheries and $5000 for modifications to tipper cradle to accommodate dredges with longer tynes.
- Vessel operating costs (total $14 000) are set at $400 per day for up to 20 days in Bass Strait and Tasmanian grounds and $300 per day for up to 20 days in Port Phillip Bay. These costs cover running and maintenance costs of the vessel and support crew. If, during commercial trials, quantities of scallops up to the daily quota were landed, revenue of sale would be independent of the project and daily costs to the project would apply notwithstanding. This is seen as the simplest mechanism to take into account the risk and uncertainty faced by the vessel operator undertaking the trials.
- Travel and accommodation costs ($5 874) for extension, meeting of project agencies and travel between ports
- Consultancy costs ($13 500 including $500 travel and accommodation) to Dames & Moore for project management, professional advice, sea time, supervision, data collation and report

writing (D Gwyther). ($10 500 in second year). $8500 to AMC for salary recoup of teaching staff and $9000 for time devoted to project and project management by R. McLoughlin of CSIRO.

- $3000 for use of flume tank at Amc.
- $5800 for use of CSIRO Video (staff salaries for on-board trialing of video).
- $5000 for project administration (CSIRO).

iii First payment

It is preferred that the entire costs of construction of dredge, modification of tipper and import of dredges ($24 000) plus 50% of the remainder be paid in the first instalment.

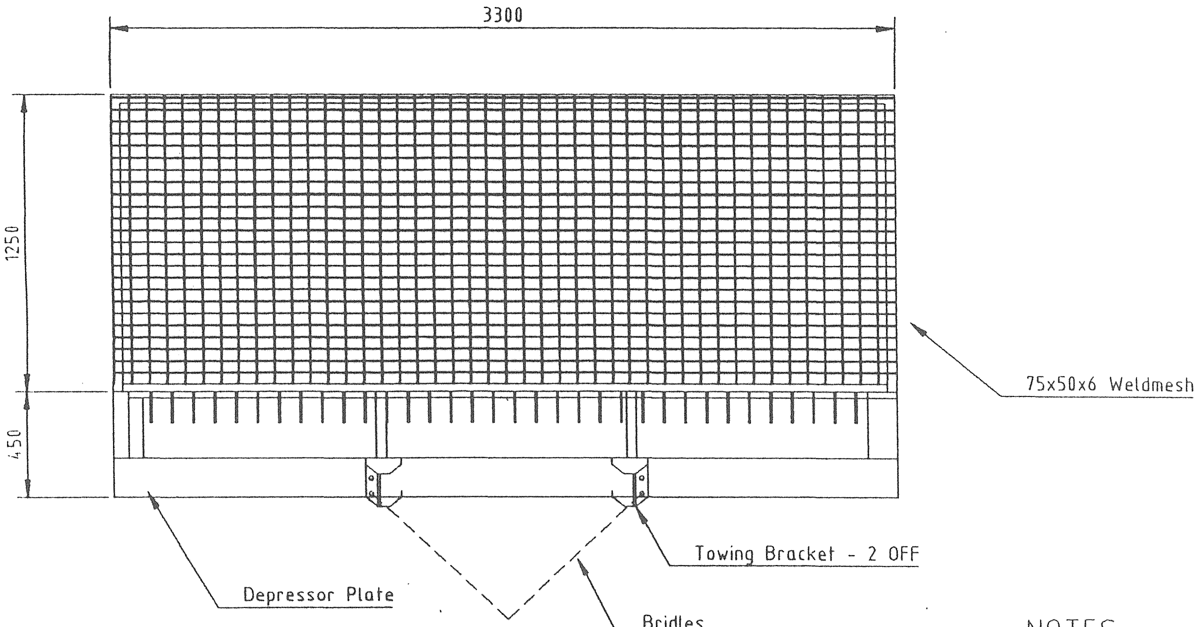
iv Commercial assessment

- There is no confidential or unpublished information associated with the project which could be regarded as intellectual property.
- The applicant does not own any patent. However, the idea of combining tyne action with rigid cage collector supported off the sea bed may be patentable, subject to advice from a patent lawyer. However, it is not the intention of the proposing agent to seek (at this time) advice or apply for any patent.
- The applicant is not aware of any other relevant patents.
- The applicant is not seeking funds for any other related project.

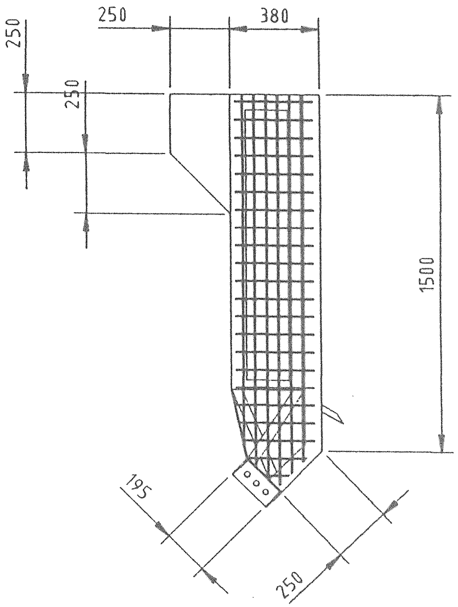
Appendix C

Engineering Drawings of Scallop Dredges

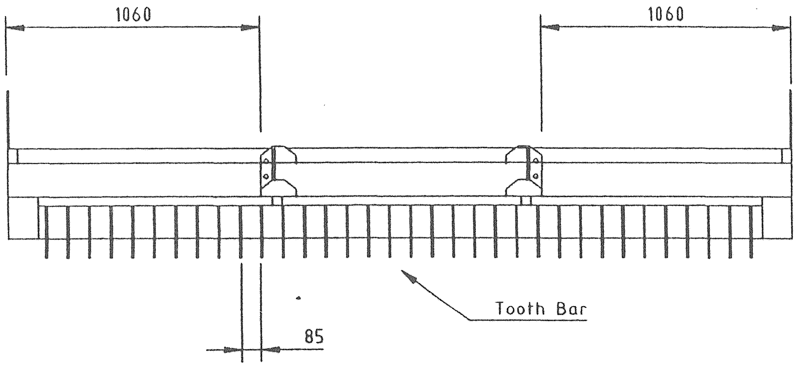
PLAN



SIDE ELEVATION



END ELEVATION

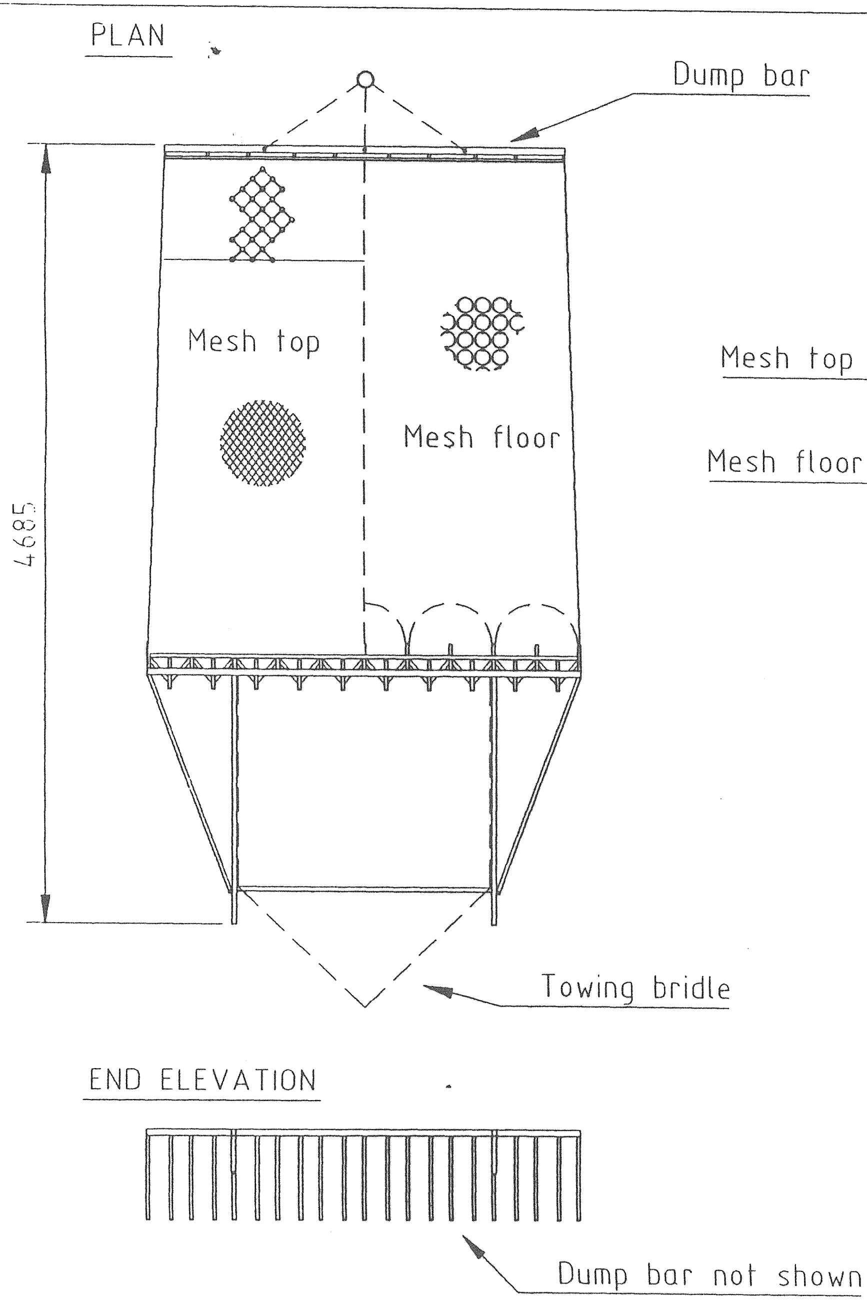


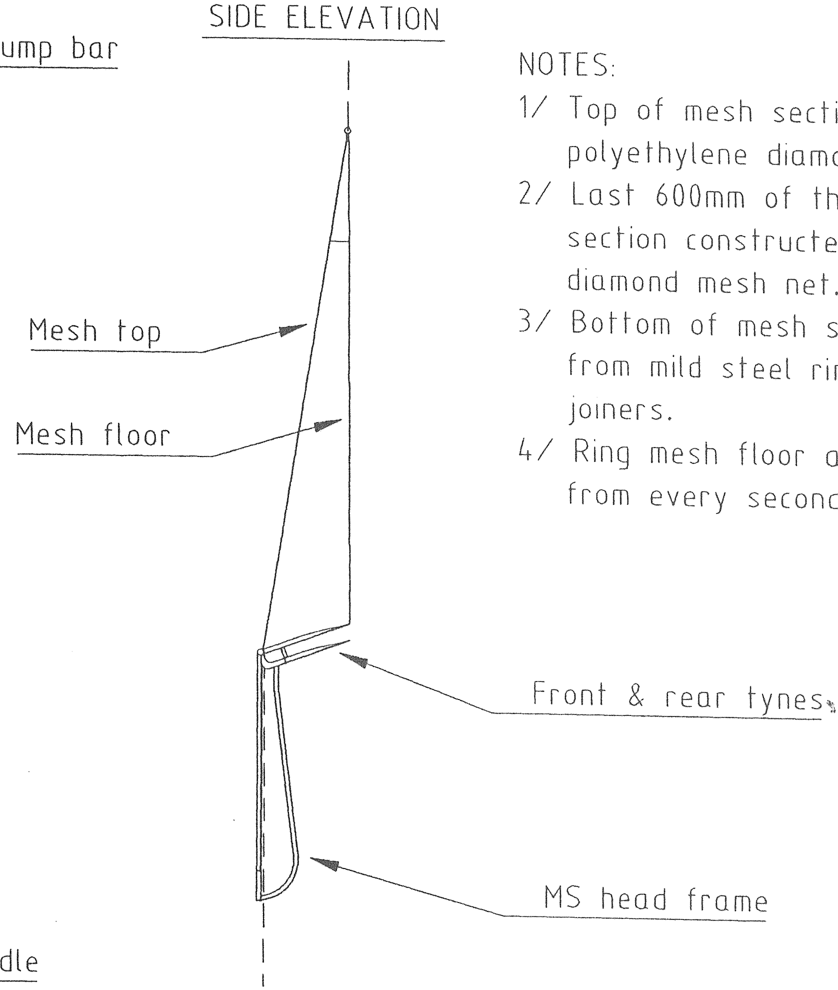
NOTES:

1/ Tooth Bar teeth from hardened steel

2/ Bridles (2 OFF) - 20mm M.S. Gal chain X 900mm

ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS	
	Aust. Maritime College	SCALE		PASSED	DATE 25/3/1994
	TOOTHED MUD DREDGE - As used by the AMC for comparative gear trials.	DRAWN	I.EDO		DRAWING NUMBER bd001a (1 of 1)
		TRACED			
		CHECKED			





NOTES:

1/ Top of mesh section constructed from polyethylene diamond mesh net.

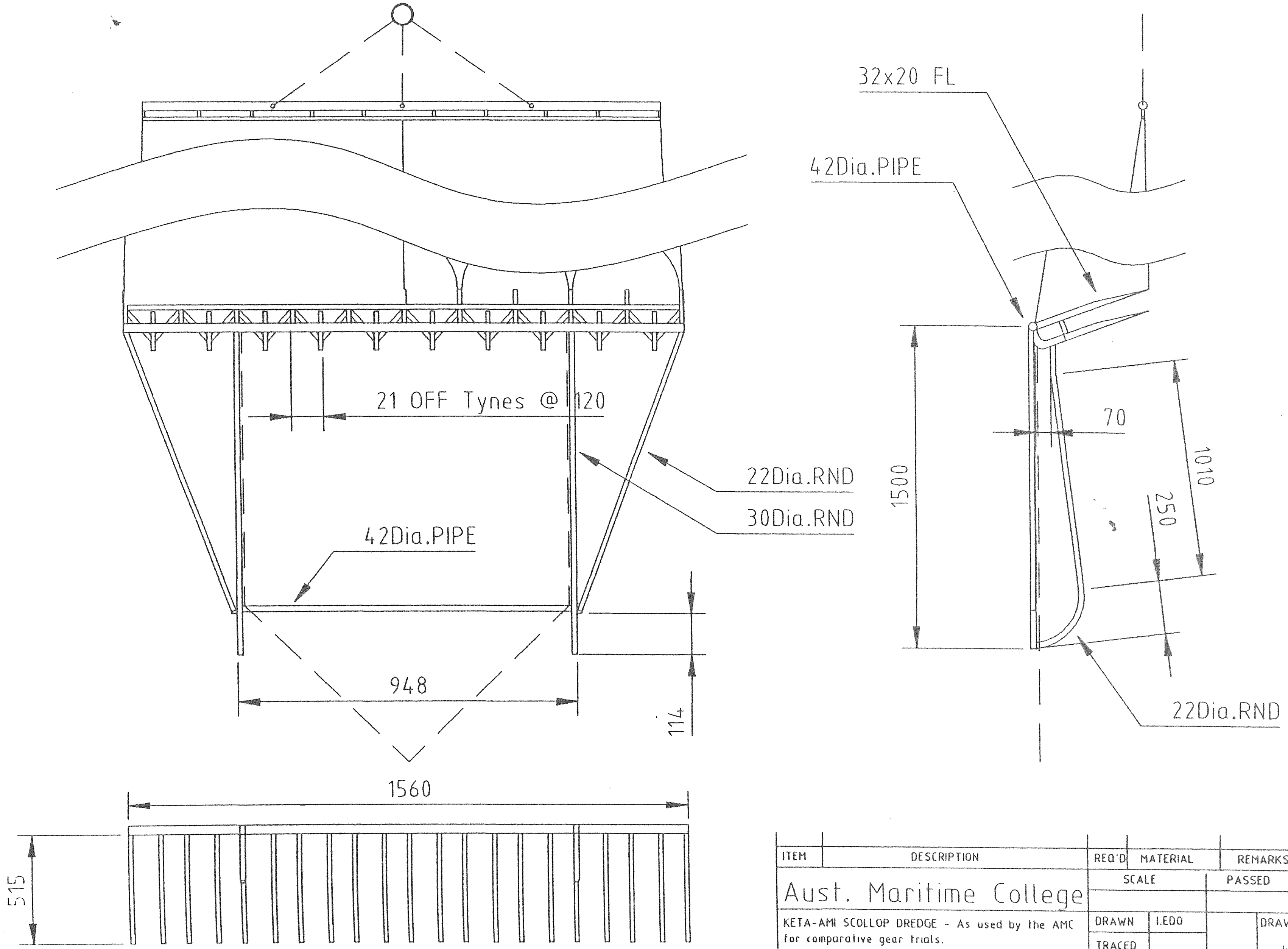
2/ Last 600mm of the top of the mesh section constructed from mild steel diamond mesh net.

3/ Bottom of mesh section constructed from mild steel rings and chain link joiners.

4/ Ring mesh floor and tickler chain hung from every second rear tyne.

ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS

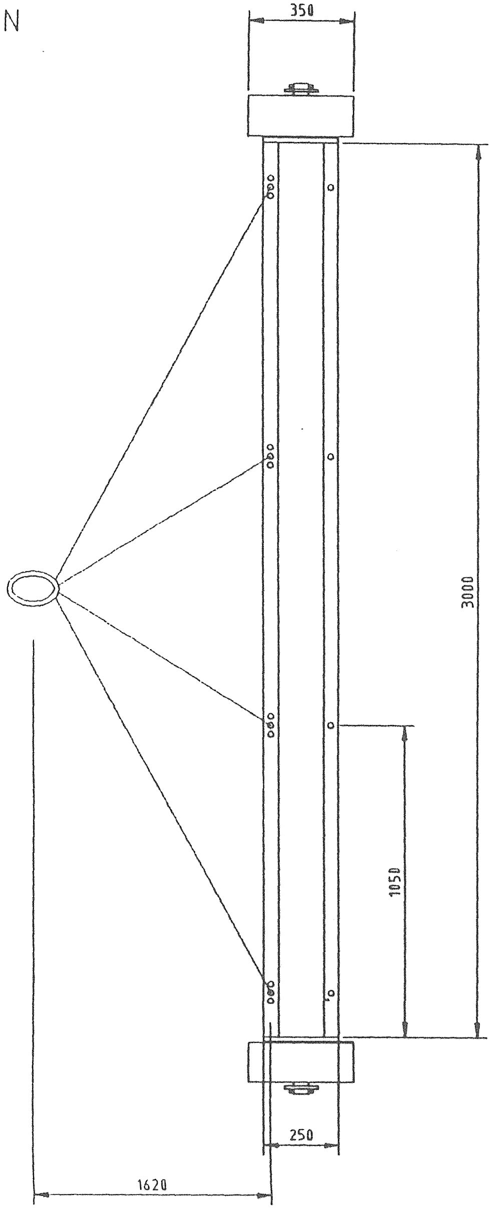
	SCALE	PASSED	DATE
Aust. Maritime College			25/3/1994
KETA-AMI SCOLLOP DREDGE - As used by the AMC for comparative gear trials. GENERAL ARRANGEMENT	DRAWN I.EDO		DRAWING NUMBER
	TRACED		k001a (1 of 2)
	CHECKED		



ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS
Aust. Maritime College		SCALE	PASSED	DATE
				25/3/1994
KETA-AMI SCOLLOP DREDGE - As used by the AMC for comparative gear trials.		DRAWN	I.EDO	DRAWING NUMBER
		TRACED		k001b
		CHECKED		(2 of 2)

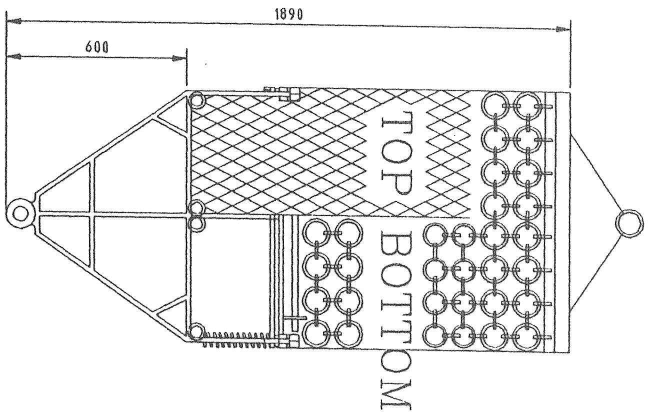
TOWING BEAM

PLAN

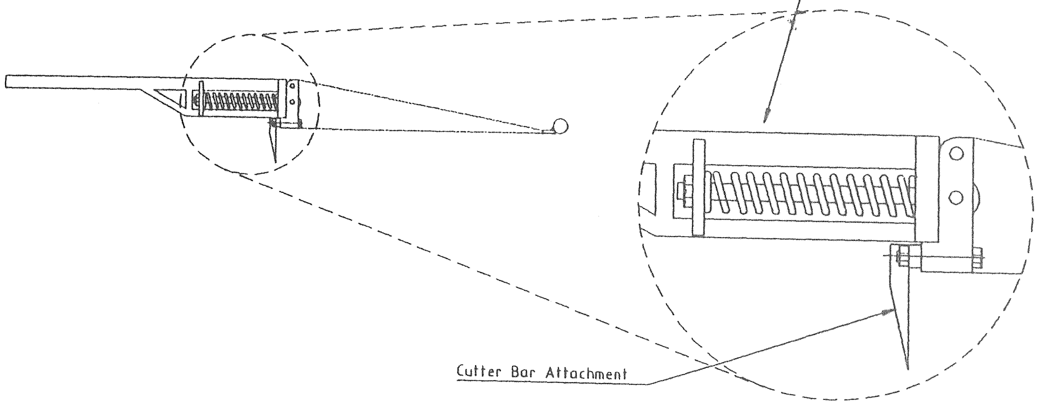


SCOTTISH MINI DREDGE

PLAN



SIDE ELEVATION

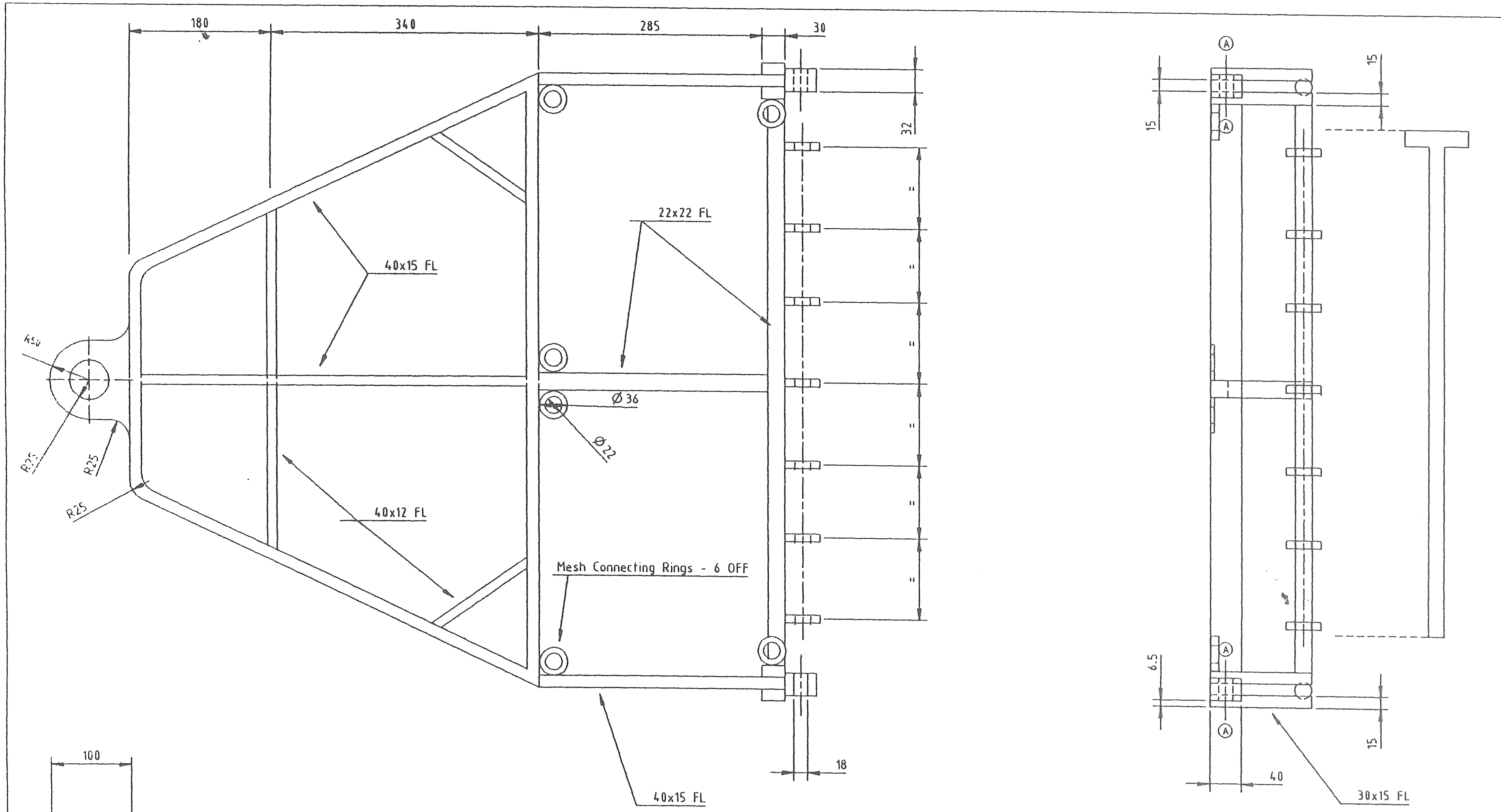


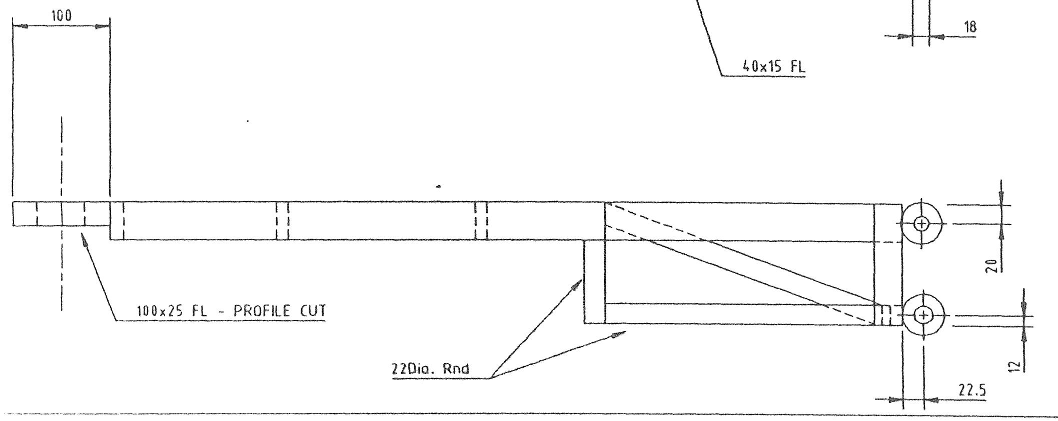
NOTES:

1/ Four Scottish Mini Dredges are towed behind the towing beam.
2/ Dredges are attached to towing beam using D shackle
3/ Top of netting section of each dredge constructed from Polyethylene diamond mesh net, except the last 250mm which is constructed from steel ring mesh.
4/ The bottom of the netting section is constructed from steel ring mesh.
5/ Wheels on the towing beam are solid rubber.
6/ The four towing beam bridles are linked to a single steel ring.

ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS

Aust. Maritime College	SCALE	PASSED	DATE
			22/3/94
Scottish Mini Dredge GENERAL ARRANGMENT AND TOWING BEAM	DRAWN I.EDO		DRAWING NUMBER
	TRACED		sm001a (1 of 3)
	CHECKED		



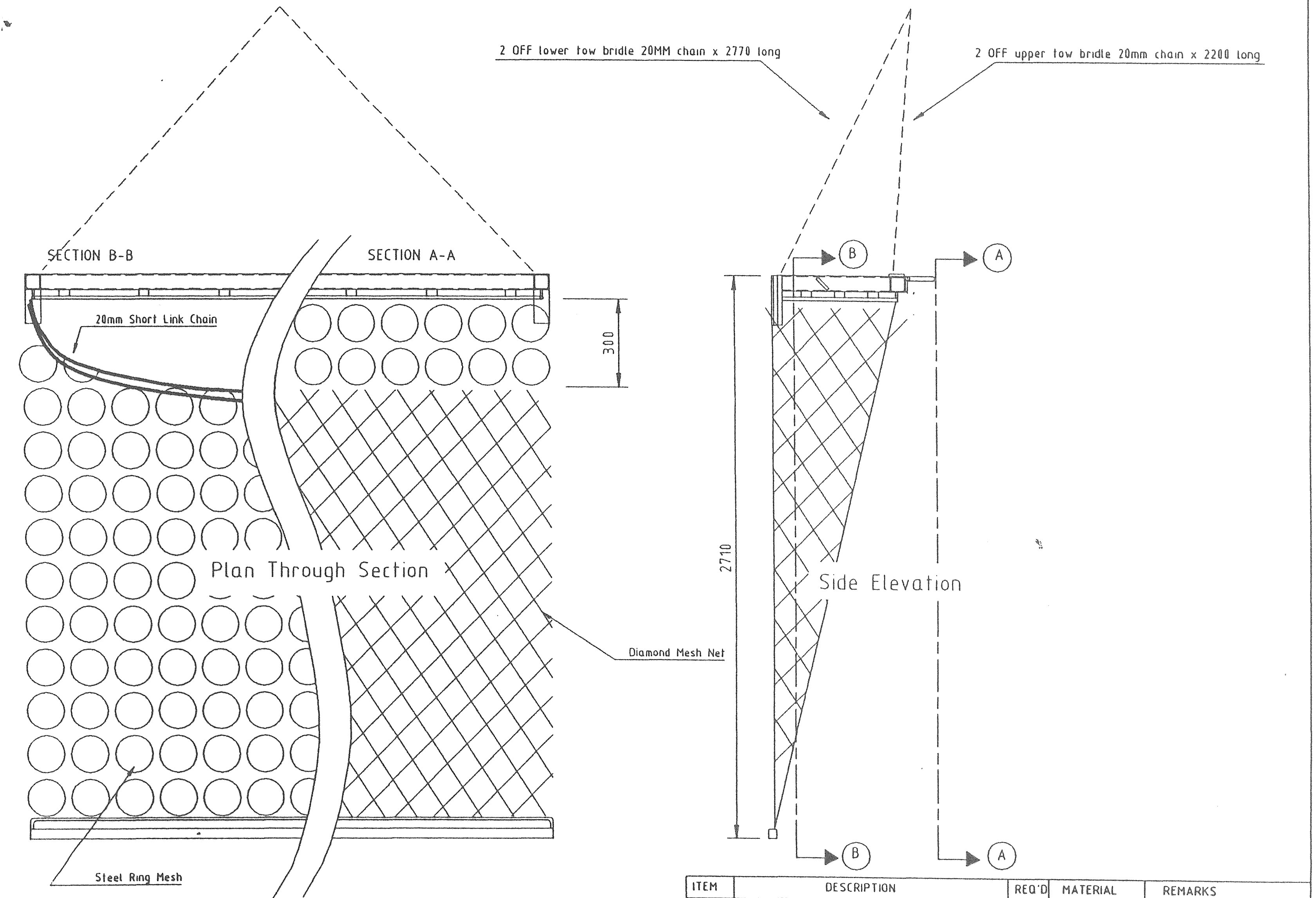


NOTES:

1/ Cutter Bar Attachment connected to Towing Frame through hinge point A-A.

ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS

Aust. Maritime College	SCALE	PASSED	DATE
			22/3/1994
Scottish Mini Dredge - As used by AMC for comparative gear trials	DRAWN I.EDO		DRAWING NUMBER
	TRACED		sm001b (2 of 3)
TOWING FRAME - Third Angle Proj.	CHECKED		



ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS

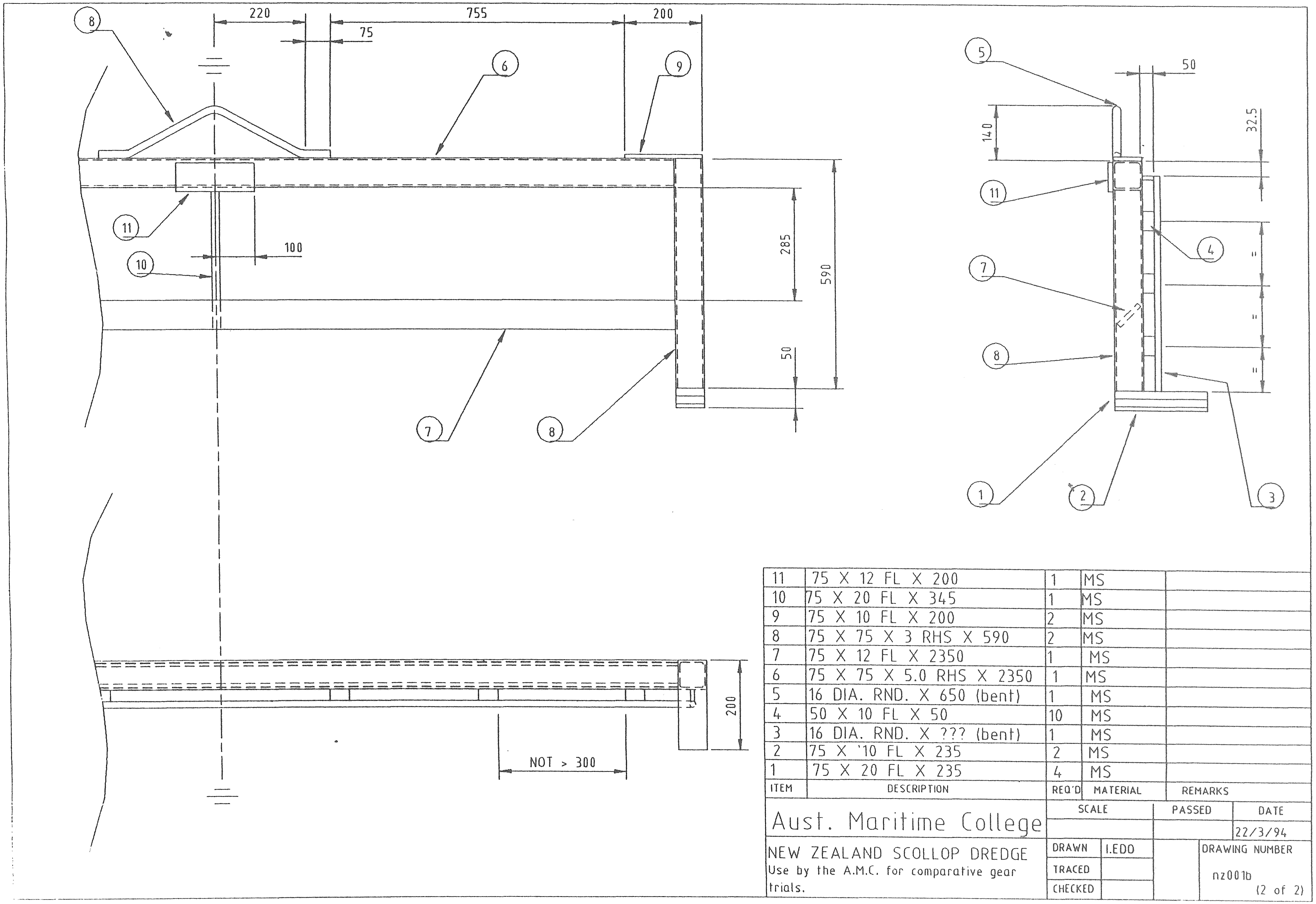
Aust. Maritime College

NEW ZEALAND SCOLLOP DREDGE
Use by the A.M.C. for comparative gear trials.

SCALE	PASSED	DATE
		22/3/94

DRAWN	I.EDO
TRACED	
CHECKED	

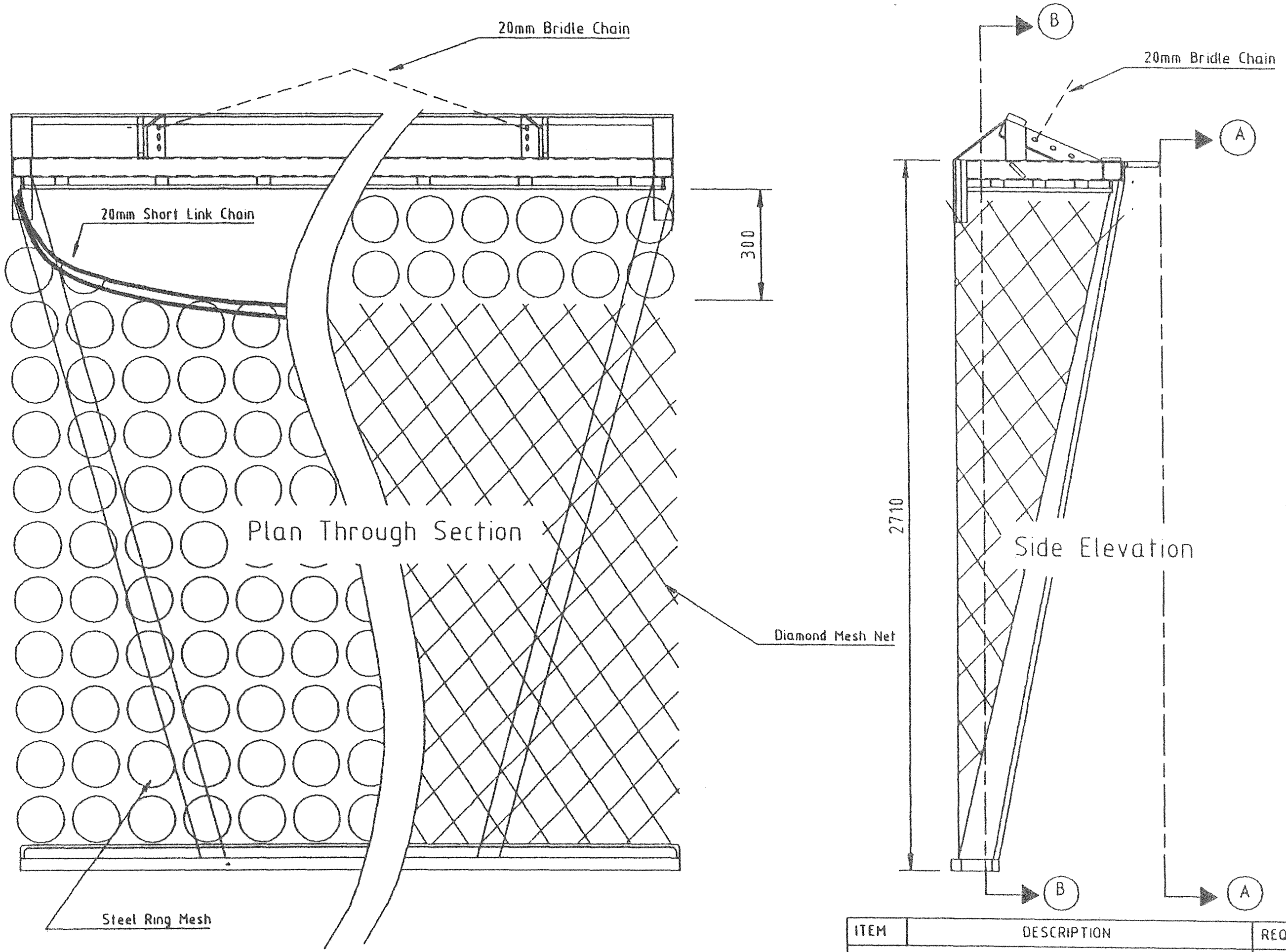
DRAWING NUMBER
nz001a
(1 of 2)



ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS
11	75 X 12 FL X 200	1	MS	
10	75 X 20 FL X 345	1	MS	
9	75 X 10 FL X 200	2	MS	
8	75 X 75 X 3 RHS X 590	2	MS	
7	75 X 12 FL X 2350	1	MS	
6	75 X 75 X 5.0 RHS X 2350	1	MS	
5	16 DIA. RND. X 650 (bent)	1	MS	
4	50 X 10 FL X 50	10	MS	
3	16 DIA. RND. X ??? (bent)	1	MS	
2	75 X '10 FL X 235	2	MS	
1	75 X 20 FL X 235	4	MS	

Aust. Maritime College	SCALE	PASSED	DATE 22/3/94
NEW ZEALAND SCOLLOP DREDGE Use by the A.M.C. for comparative gear trials.	DRAWN I.EDO TRACED CHECKED		DRAWING NUMBER nz001b (2 of 2)

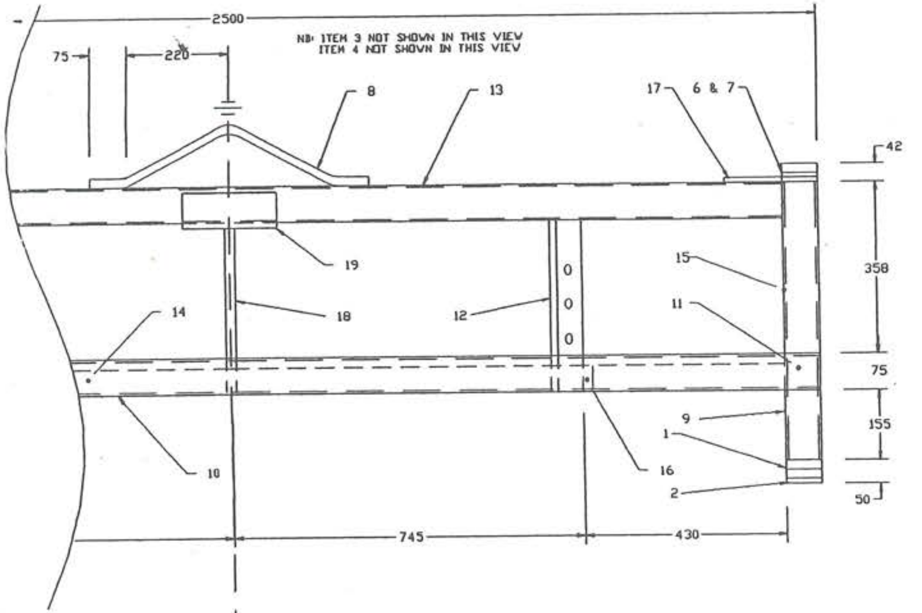
Appendix F

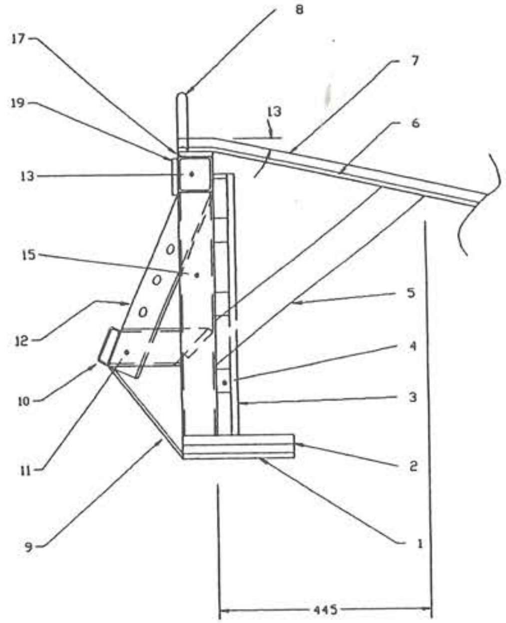


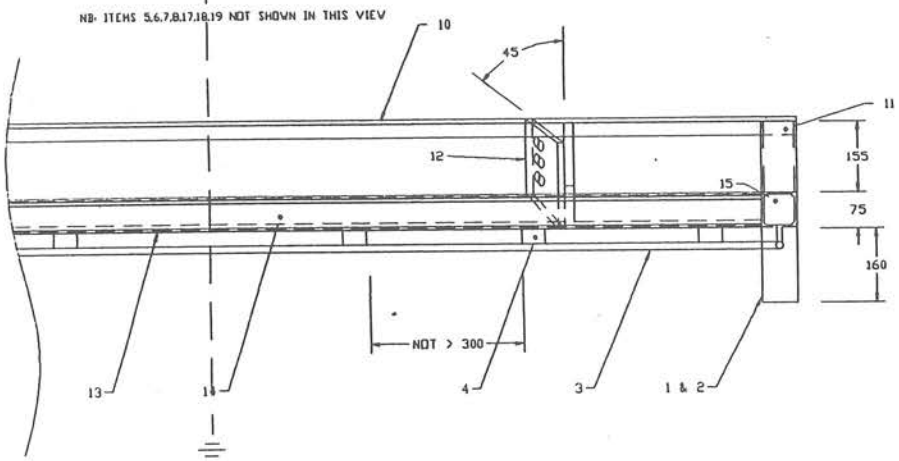
SECTION B-B

SECTION A-A

ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS
	Aust. Maritime College	SCALE	PASSED	DATE
				22/3/94
	Modified NZ SCOLLOP DREDGE	DRAWN	I.EDO	DRAWING NUMBER
		TRACED		mnz001a (1 of 3)
		CHECKED		

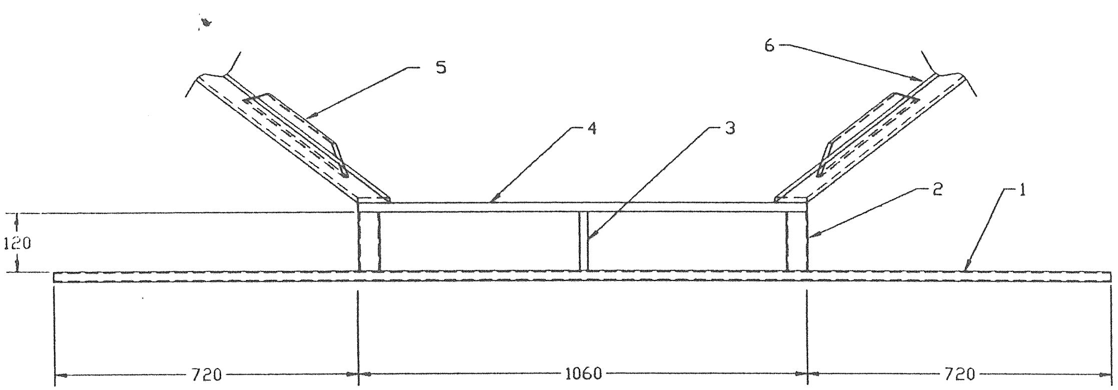


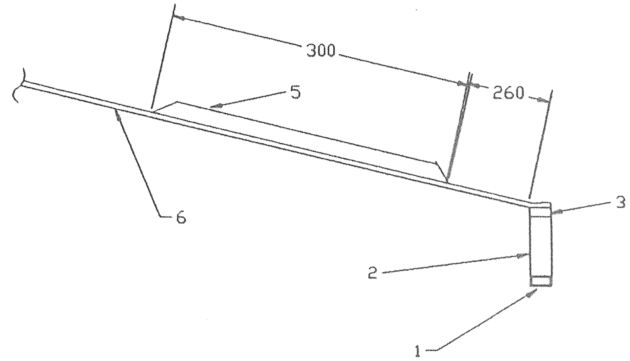


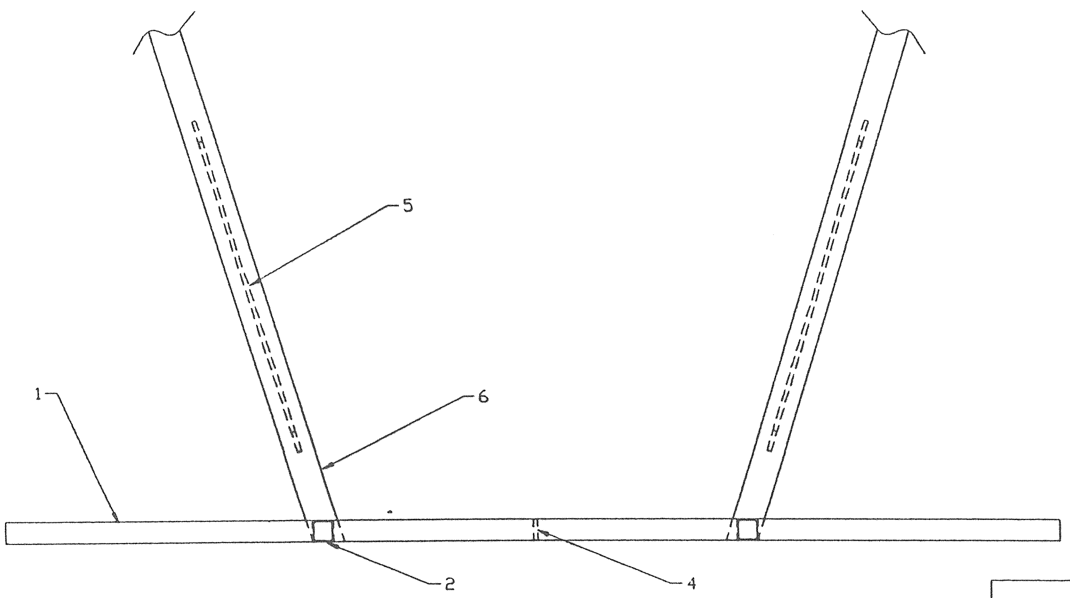


ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS
19	75 x 12 FL x 200	1		
18	75 x 20 FL x 345	1		
17	75 x 10 FL x 200	2		
16	75 x 20 FL x 215	2		
15	75x75x3.0RHSx590	2		
14	75 x 12 FL x 2350	1		
13	75x75x5.0RHSx2350	1		
12	75 x 20 FL x 425	2		
11	75x75x3.0RHSx155	2		
10	75x25x2.5RHSx2500	1		
9	75 x 12 FL x 250	2		
8	16DIA.RND x 650-bent	1		
7	75 x 20 FL x 450	2		
6	75 x 12 FL x ???	2		
5	75 x 12 FL x ???	2		
4	50 x 10 FK x 50	10		
3	16DIA.RND x ???-bent	1		
2	75 x 10 FL x 235	2		
1	75 x 20 FL x 235	4		

Aust. Maritime College	SCALE		PASSED	DATE
				22/3/94
Modified NZ SCOLLOP DREDGE	DRAWN	I.EDO		DRAWING NUMBER
	TRACED			mnz001b (2 of 3)
	CHECKED			

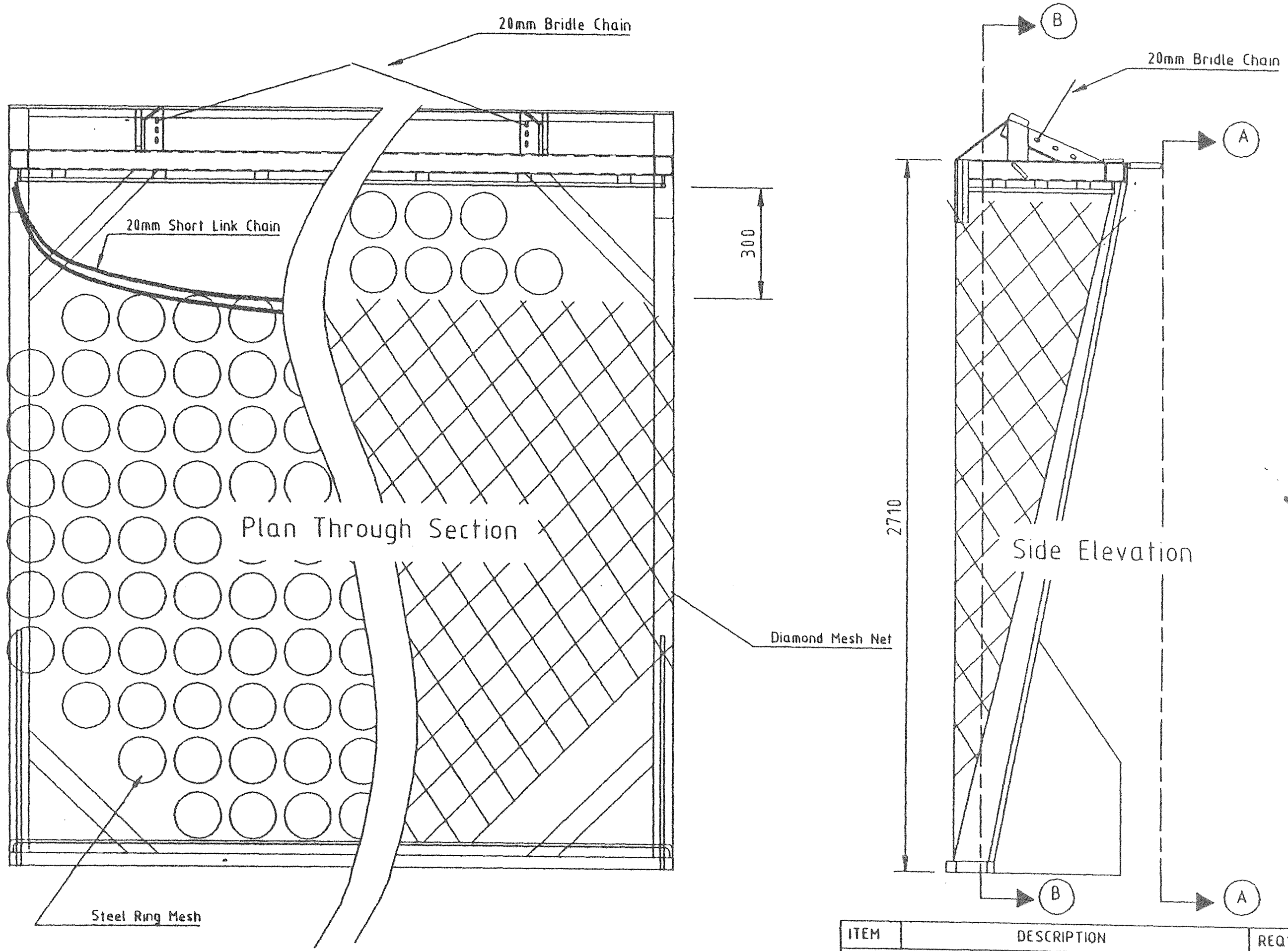






ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS
6	75x12FLx???(001A-R6)	2		
5	50x10FLx300	2		
4	50x20FLx120	1		
3	50x20FLx1060	1		
2	50x50x3RHSx120	2		
1	50x25x3RHSx2500	1		

Aust. Maritime College	SCALE	PASSED	DATE
			22/3/94
Modified NZ SCOLLOP DREDGE	DRAWN I.EDO		DRAWING NUMBER
	TRACED		mnz001c
	CHECKED		(3 of 3)



SECTION B-B

SECTION A-A

ITEM	DESCRIPTION	REQ'D	MATERIAL	REMARKS
	Aust. Maritime College	SCALE	PASSED	DATE
				22/3/94
	Proposed changes to modified NZ SCOLLOP DREDGE	DRAWN: I.EDO		DRAWING NUMBER
		TRACED		pnz001a
		CHECKED		(1 of 1)