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OPERATIONAL EVALUATION OF TUG/BARGE SYSTEMS.(U)

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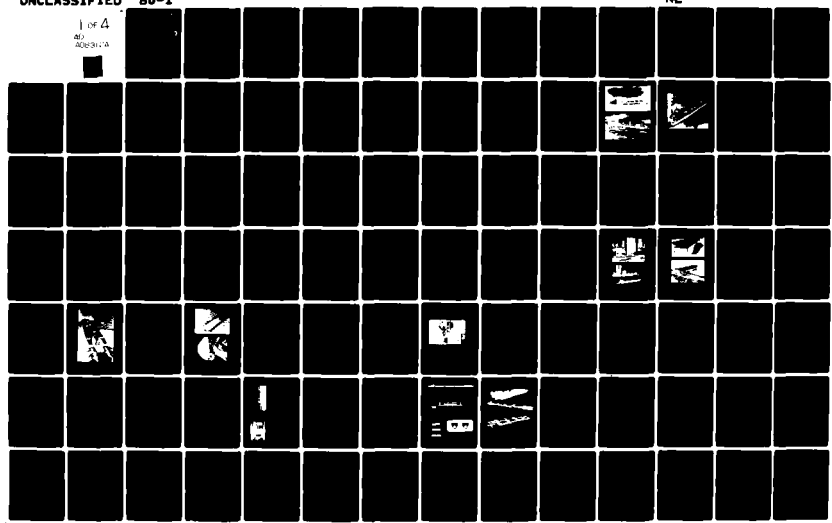
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APPLICATIONS OF
OCEAN-GOING TUG-BARGES TO
MILITARY OPERATIONS

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Under the General
Supervision of

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Massachusetts Institute of Technology
M.I.T. Report #80-1

Performed Under Office of Naval Research
Contract No. N00014-78-C-0295

Sponsored by the Department of the Navy
Military Sealift Command

July 1979

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) <u>OPERATIONAL EVALUATION OF TUG/BARGE SYSTEMS</u>		5. TYPE OF REPORT & PERIOD COVERED Final Report 3/1/78 - 6/30/79
7. AUTHOR(s) <u>Jonathan D. Kaskin</u>		6. PERFORMING ORG. REPORT NUMBER M.I.T. Report #80-1
9. PERFORMING ORGANIZATION NAME AND ADDRESS M.I.T. Dept. of Ocean Engineering Cambridge, Mass. 02139		8. CONTRACT OR GRANT NUMBER(s) <u>NG00014-78-C-0295</u>
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Analysis Programs (Code: 431) Office of Naval Research Arlington, VA 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS <u>65152N</u> <u>R0145</u> NR 274-296
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) <u>Final rept.</u> <u>1 Mar 78-30 Jun 79</u>		12. REPORT DATE <u>11 Jul 79</u>
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. Reproduction in whole or in part is permitted for any purpose of the U.S. Government.		13. NUMBER OF PAGES 330
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) <u>14) 80-1</u>		15. SECURITY CLASS. (of this report) Unclassified
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Tugs, Barges, Tug-Barge Systems, Integrated Tug Barges, Ocean-Going Tug Barges, Marine Transportation Economics, Sealift		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The purpose of this report is to identify the potential military roles of the commercial Ocean-Going Tug-Barge (OGTB) fleet and to suggest how it may be efficiently used in military operations. The overall conclusion is that the commercial fleet of OGTB's in conjunction with our nation's extensive tug and barge building facilities provides a substantial sealift capability in support of the Military Sealift Command (MSC) peacetime, contingency, and mobilization operations. In many instances it is determined that OGTB's are		

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superior to ships in fulfilling cargo transport, Naval Fleet Auxiliary, and scientific support missions due to their ability to separate propulsion unit (tug) from cargo/functional unit (barge). This separability allows drop-and-swap operation where specialization of function: tugs for transport and barges for storage and shoreside operations may result in mission accomplishment at less cost than if ships were used. Additionally, this flexibility of separability allows the same propulsion unit to be used in any of MSC's three mission areas as demands and priorities dictate.

Given that OGTB's can be efficiently and effectively utilized in both MSC's peacetime and wartime operations, it is recommended that MSC consider adopting an overall OGTB fleet strategy that would integrate peacetime OGTB assets with contingency/mobilization assets. This would require MSC's peacetime fleet of ships to be gradually replaced with OGTBs capable of augmentation with existing commercial and mobilization OGTBs during contingency/mobilization operations. This strategy would result in a peacetime fleet that could be rapidly expanded for wartime operations with the integration of commercial/-reserve OGTB assets.

The report is organized so that the reader is led from a point where no knowledge of OGTBs is assumed to a point where the concept of an overall OGTB fleet strategy is established as a reasonable and logical method of providing contingency and mobilization sealift capacity. This is done through the use of five chapters that (1) introduce the OGTB concept and related technology, (2) discuss the commercial economics involved in their operation, (3) establish their usefulness in military operations, and (4) suggest what National Defense Features that should be included on OGTBs constructed with subsidies. Chapter 5 suggests how a peacetime military fleet of OGTBs using their commercial advantages discussed in (2) can be expanded by use of commercial/reserve OGTB assets during contingency/mobilization operations so that the military advantages discussed in (3) can be achieved most expeditiously. The text is augmented by five appendices that list particulars on (1) Tank Barges over 50,000 Bbl capacity (2) Cargo Barges over 2,500 GRT, (3) Ocean-Going Tugs over 3,000 HP, (4) A computer model to evaluate the economics of operating OGTBs in a drop-and-swap versus integral mode, and (5) a bibliography of OGTB literature.

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ABSTRACT

The purpose of this report is to identify the potential military roles of the commercial Ocean-Going Tug-Barge (OGTB) fleet and to suggest how it may be efficiently used in military operations. The overall conclusion is that the commercial fleet of OTGBs in conjunction with our nation's extensive tug and barge building facilities provides a substantial sealift capability in support of Military Sealift Command (MSC) peacetime, contingency, and mobilization operations. In many instances it is determined that OTGBs are superior to ships in fulfilling cargo transport, Naval Fleet Auxiliary, and scientific support missions due to their ability to separate propulsion unit (tug) from cargo/functional unit (barge). This separability allows drop-and-swap operation where specialization of function: tugs for transport and barges for storage and shoreside operations may result in mission accomplishment at less cost than if ships were used. Additionally, this flexibility of separability allows the same propulsion unit to be used in any of MSC's three mission areas as demands and priorities dictate.

Given that OTGBs can be efficiently and effectively utilized in both MSC's peacetime and wartime operations, it is recommended that MSC consider adopting an overall OTGB fleet strategy that would integrate peacetime OTGB assets with contingency/mobilization assets. This would require that MSC's peacetime fleet of ships to be gradually replaced with OTGBs capable of augmentation with existing commercial and mobilization OTGBs during contingency/mobilization operations. This strategy would result in a peacetime fleet that could be rapidly expanded for wartime operations with the integration of commercial/reserve OTGB assets.

The report is organized so that the reader is led from a point where no knowledge of OTGBs is assumed to a point where the concept of an overall OTGB fleet strategy is established as a reasonable and logical method of providing contingency and mobilization sealift capacity. This is done through the use of five chapters that (1) introduce the OTGB concept and related technology, (2) discuss the commercial economics involved in their operation, (3) establish their usefulness in military operations, and (4) suggest what National Defense Features that should be included on OTGBs constructed with subsidies. Chapter 5 suggests how a peacetime military fleet of OTGBs using their commercial advantages discussed in (2) can be expanded by use of commercial/reserve OTGB assets during contingency/mobilization operations so that the military advantages discussed in (3) can be achieved most expeditiously. The text is augmented by five appendices that list particulars on (1) Tank Barges over 50,000 Bbl capacity, (2) Cargo Barges over 5,000 GRT, (3) Ocean-Going

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ACKNOWLEDGEMENTS

I wish to take the opportunity here to express my appreciation to those individuals who have provided me guidance and assistance during the preparation of this report. First I would like to thank Prof. E. G. Frankel of M.I.T. and Mr. J. A. Brogan of the Military Sealift Command for arranging the funding for the research presented here since without their efforts this report on a subject of current military interest could never have been accomplished. I would also like to thank Prof. H. S. Marcus of M.I.T. for his assistance and moral support throughout the two years that it took to complete this research. Finally, I would like to thank all the individuals of the OGTB industry, their names are too numerous to list here, who provided me invaluable data, illustrations, and advice.

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EXECUTIVE SUMMARY

Scope

Today, the U.S. Merchant Marine fleet contains several thousand ocean-going tugs and barges. They range from small, slow-speed, hawser-towed systems suitable for outsize cargo and shallow water movements to very large (up to 55,000 DWT), moderate speed (up to 16 knots), push-towed systems capable of performing the same roles as ships of equal size and speed. Although these vessels, especially the new shiplike systems, have significant military potential for use in contingency and mobilization operations, they have received little attention by military planners.

It is therefore the purpose of this report to identify the potential military roles of the commercial Ocean-Going Tug-Barge (OGTB) fleet and to suggest how it may be efficiently utilized by the military in peacetime, contingency, and mobilization operations. (1) The report concentrates on OGTBs with bulk (primarily POL), deck, and RO/RO barges and makes no mention of special purpose (derrick, pipelay, and sludge, etc.) barges. Neither are river or other tugs and barges not classed for ocean service considered. And, only those military missions performed by the Navy's Military Sealift Command, that is, cargo transport, Naval Fleet Auxiliary and scientific support operations, are discussed.

Conclusions and Recommendations

It is the overall conclusion of this report that the commercial fleet of OGTBs in conjunction with our nation's extensive tug and barge building facilities provides a substantial sealift capability in support of military peacetime, contingency, and mobilization operations. In many instances OGTBs are superior to ships in fulfilling cargo transport and fleet support missions because of their ability to separate propulsion unit (tug) from cargo/functional unit (barge). This separability allows special-

(1) A contingency operation would involve only U.S. flag ships that are voluntarily chartered to the military or are called up via the Strategic Readiness Program. A mobilization operation would involve U.S. flag and allied shipping being requisitioned for military use via the imposition of national emergency measures as well as the construction of specially designed mobilization vessels.

ization of function: tugs for transport and barges for storage and shoreside operations.

It is also concluded that all of MSC's peacetime missions, cargo transport, Naval Fleet Auxiliary and scientific support operations, can be currently accomplished by OGTBs at little or no additional cost compared to ships. Missions involving long distance and/or transoceanic movements can be handled best by shiplike mechanically-linked push-towed OGTB systems while the shuttle and intra-area missions can be satisfactorily handled by less sophisticated OGTB linkage systems. Even if the separability of propulsion and cargo/functional unit did add to the construction cost as would be expected in the long run, the overall systems costs would be lower through efficient use of the interchangeable propulsion and cargo/functional units. Additionally, this flexibility of separability allows the same propulsion unit to be used in any of MSC's three mission areas as demands and priorities dictate.

Given that OGTBs can be efficiently and effectively utilized in both MSC's peacetime and wartime operations, it is recommended that MSC consider adopting an overall OGTB fleet strategy that would integrate peacetime OGTB assets with contingency/mobilization assets. This would require that MSC's peacetime fleet of ships to be gradually replaced with OGTBs capable of being augmented with existing commercial and mobilization OGTBs during contingency/mobilization operations. This strategy would result in a peacetime fleet that could be rapidly expanded for wartime operations with the integration of commercial/reserve OGTB units. However, prior to the implementation of such a strategy, the following additional research, study, and/or action would be needed to ensure the success of the concept:

(1) Evaluation of current commercial OGTB linkage designs to compare their relative military and commercial performance to include: linkage drags, costs of installation and retrofit, ease of retrofit on pull-towed designs, ease of linking/unlinking in various sea states, and ability to remain in push-tow operation in various sea states. The best system should be selected as MSC's standard linkage design.

(2) Inclusion of the MSC standard linkage design(s) as a National Defense Feature on OGTBs constructed with subsidy funds. This would ensure that these OGTBs are compatible with those in MSC's peacetime fleet and so would be immediately available to augment that fleet in contingency operations.

(3) Promotion of a standard linkage design(s) for non-subsidized OGTBs by the use of tax credit or other types of incentives. This would provide many commercial OGTB assets capable of immedi-

ately augmenting MSC's peacetime fleet in case of expanded operations.

(4) Identification of potential locations and configurations of barge yard facilities during a mobilization. This would ensure that these facilities could be rapidly brought online to expand the MSC wartime OGTB fleet. (Sufficient tug building facilities do appear to exist as a result of the offshore oil industry.)

(5) Evaluation of the disruption/impact on domestic commerce resulting from tank and deck OGTBs being committed to contingency operations. This would require a market survey of the commercial OGTB fleet to determine the amount of surplus/deficit capacity available presently and in the future as well as the ability of other transport modes to absorb the loss of OGTBs to military operations.

(6) Evaluation of the costs/benefits resulting from the conversion of obsolete ships of the National Defense Reserve Fleet (NDRF) into barges with linkages compatible with MSC's active and reserve OGTB fleet. This concept might extend the life of the NDRF fleet as well as provide reliable cargo transport capacity at rather low cost compared to other alternatives.

It is recognized that such a comprehensive OGTB fleet strategy is very ambitious and would require significant changes to current military planning concepts. The idea of revamping the military sealift fleet to make it more compatible with commercial assets, especially OGTBs, is just the opposite of the traditional strategy of using National Defense Features to make commercial vessels into military vessels. But such a change of thinking is required since the majority of the ships being built with the U.S. flag for foreign commerce are just not readily capable of serving as military auxiliaries due to their deep drafts and non-selfsustaining designs. Practically the only new vessels capable of operating in an austere military environment are the growing number of OGTBs, especially those with shiplike capability. As seen in this report, these OGTBs can provide the necessary sealift capacity at low cost if they are incorporated into an overall OGTB sealift strategy.

It should be realized that in the case of POL movements, OGTBs may offer the only means of providing shallow draft discharge capability in the future. This is either via direct shiplike port-to-port operation or via a drop-and-swap shuttle discharge of a supertanker. (The latter method should be more efficient since it uses the tug for transport and the barges for storage/transport.)

Given all their military potential, OGTBs certainly deserve a hard look before they are dismissed as an interesting but infeasible concept. Unless some other less expensive alternative can be found to provide equivalent sealift capabilities, the OGTB strategy presented here should be investigated further with vigor.

Report Organization

The text of the report is organized so that the reader is led from a point where no knowledge of Ocean-Going Tug-Barge systems is assumed to a point where the concept of an overall OGTB fleet strategy is established as a reasonable and logical method of providing contingency and mobilization sealift capacity. This is done through the use of five chapters that (1) introduce the OGTB concept and related technology, (2) discuss the commercial economics involved in their operation, (3) establish their usefulness in military operations, and (4) suggest what National Defense Features that should be included on OGTBs constructed with subsidies. Chapter 5 suggests how a peacetime military fleet of OGTBs utilizing the commercial advantages of OGTBs discussed in (2) can be expanded by use of commercial/reserve OGTB assets during contingency/mobilization operations so that the military advantages discussed in (3) can be achieved most expeditiously.

Chapter Summaries

In the first chapter the reader is introduced to OGTBs through a quick review of their availability and their military and commercial capabilities, as well as a review of all previous military research on OGTB systems. This is followed by a brief historical/economical summary of the development of various OGTB systems that are described in detail at the end of the chapter.

In the second chapter a detailed review of commercial OGTB economics is provided to compare the various types of OGTBs with each other and with ships. In addition, two different modes of operation are considered: the shiplike integral mode where the tug and barge remain continually together, and the drop-and-swap mode where the tug drops off a barge at a port and swaps it for one that has completed cargo operations. The comparison of the two modes is made with the use of an economic computer model that is described in detail in the appendices. Using the outputs of the model in conjunction with general economic principles, a prediction of the future of commercial OGTB operations is given in view of the probable regulatory environment.

In the third chapter the commercial economics of the previous chapter are evaluated against possible military peacetime, contingency, and mobilization cargo operations. It is determined that most military cargo transport operations via low throughput, shallow draft ports are especially suited to the OGTB drop-and-swap operation. In addition, it is demonstrated that OGTBs are very appropriate for shuttle/lightering and intra-area type operations. Then, the benefits of using OGTBs for MSC's other two missions, Naval Fleet Auxiliary and scientific support operations, are discussed. It is shown how Naval Fleet Auxiliary operations can use OGTBs as combination storage/transport facilities that eliminate the need for shoreside advanced bases, and how short term scientific support operations could use OGTBs to eliminate the costly inactivation of propulsion machinery.

At this point it has been determined that during peacetime OGTBs could be successfully used in all military sealift missions and during contingency and mobilization operation commercial OGTBs could provide substantial sealift capability. The fourth chapter then considers how these commercial assets could be made compatible with peacetime military assets with the use of National Defense Features. Following this, it is demonstrated that standardization of linkage design is desirable; however, since so few OGTBs are required to be built with National Defense Features some other means of incentive will have to be developed to ensure the desired flexibility.

In the last chapter it is shown how the transition from peacetime to wartime operation can be most expeditiously accomplished by augmenting a peacetime OGTB fleet with commercial/reserve OGTB assets. Several strategies are considered on how to obtain sufficient OGTB assets of compatible design for the peacetime to wartime expansion. These strategies include shifting tugs from low priority scientific support operations to cargo transport/Naval Fleet Auxiliary missions, use of Navy active and reserve tugs, use of NDRF barges, and use of commercial tug and barge fleet assets. Finally, it is demonstrated how any combination of these strategies may provide sufficient OGTB components until newly constructed mobilization components are delivered.

CHAPTER 1

INTRODUCTION

The purpose of this report is to review the military potential of ocean-going tug-barges (OGTBs) for peacetime and wartime operations. Although it may be thought that OTGBs are a known technology and that they have been discussed sufficiently elsewhere, this is not the case. Recent advances in push-towed OTGB technology which make these vessels much more useful for military purposes have been barely considered by military planners. Thus, this report will highlight the new OTGB technology and suggest how OTGBs may be utilized for various military operations.

This objective will be accomplished by first reviewing OTGB linkage development and technology in this chapter. The next chapter will consider how OTGBs equipped with these linkages have been beneficial to commercial operators. This will be followed by a chapter on how these same OTGBs could be of use to military operators. Additionally, OTGBs of special military configuration will be considered. Then, in the fourth chapter a listing of National Defense Features that could be added to commercial OTGBs to make them more useful for military operations will be provided. Finally, in the last chapter several strategies on how to obtain a fleet of OTGBs for military use in peacetime and wartime will be developed.

1.1 The Rationale for a Report on Ocean-Going Tug-Barges (OGTBs)

Ocean-going tug-barge systems (OGTBs) are not the most elegant or exciting of vessels. They are not among the fastest, largest, or most sophisticated of ocean-going vehicles. But with the recent developments in push-tow linkages, they have become one of the most versatile. This versatility makes these OTGBs of special military interest at this time and provides the motivation for the report.

It is the purpose of this section to first show the impact of the new linkage technology on OGTB operations. This will be followed by a discussion on how such new OGTB systems are much more versatile than ships for many military operations. After this, a review of previous military and government studies on OGTBs will be given to show that this report will provide new useful material for military planners.

1.1.1 Recent Advances in OGTB Technology

Usually when a military planner thinks of an ocean-going tug-barge system, he thinks of the types of tugs and barges that were used in Viet Nam or are used today in Arctic and Caribbean resupply missions. These OGTBs consist of shallow draft deck barges of less than 400 feet in length towed on a wire by a tug of few thousand horsepower. These OGTBs are primarily used for the trans-ocean transport of outsized cargoes such as construction equipments and for the movement of matériel through shallow draft waterways. The shallow draft and flat bottoms of these barges make them capable of beaching and of rapid discharge at unimproved port facilities.

These types of OGTBs are not usually considered for long distance carriage of general cargo or matériel because of their small size (usually less than 5000 GRT) and slow speed (usually less than eight knots). However, due to the recent advances in push-tow linkage technology discussed in Section 1.3, OGTBs can no longer be considered only for such specialized applications. They are now capable of carrying large cargoes (more than 55,000 long tons) of various types (Petroleum, Oil and Lubricants (POL); Dry-Bulk; Wheeled; and Containerized) at moderate speeds (at least sixteen knots) on either transoceanic or coastal trades. Such a transition from the small deck barges shown in Figure 1.1 to ship like ocean/coastal capable pushed-towed OGTBs shown in Figure 1.2 in just a decade is certainly remarkable and how it occurred is explained in Section 1.2. In any case, the OGTBs of today not only are just as capable as ships of equivalent size and speed but they also have the added versatility inherent in separable propulsion and cargo units. The advantages of such versatility are discussed in the next subsection.

1.1.2 Military Advantages of OGTBs over Ships

Many modern OGTBs have linkages that give them the same capability as ships of the same size and speed in either trans-ocean or coastal operations. It is this linkage that also gives them the added flexibility that is the result of separate propulsion and cargo components. Such versatility results in three significant advantages over ships. They are in (1) operational flexibility, (2) peacetime availability, and (3) wartime

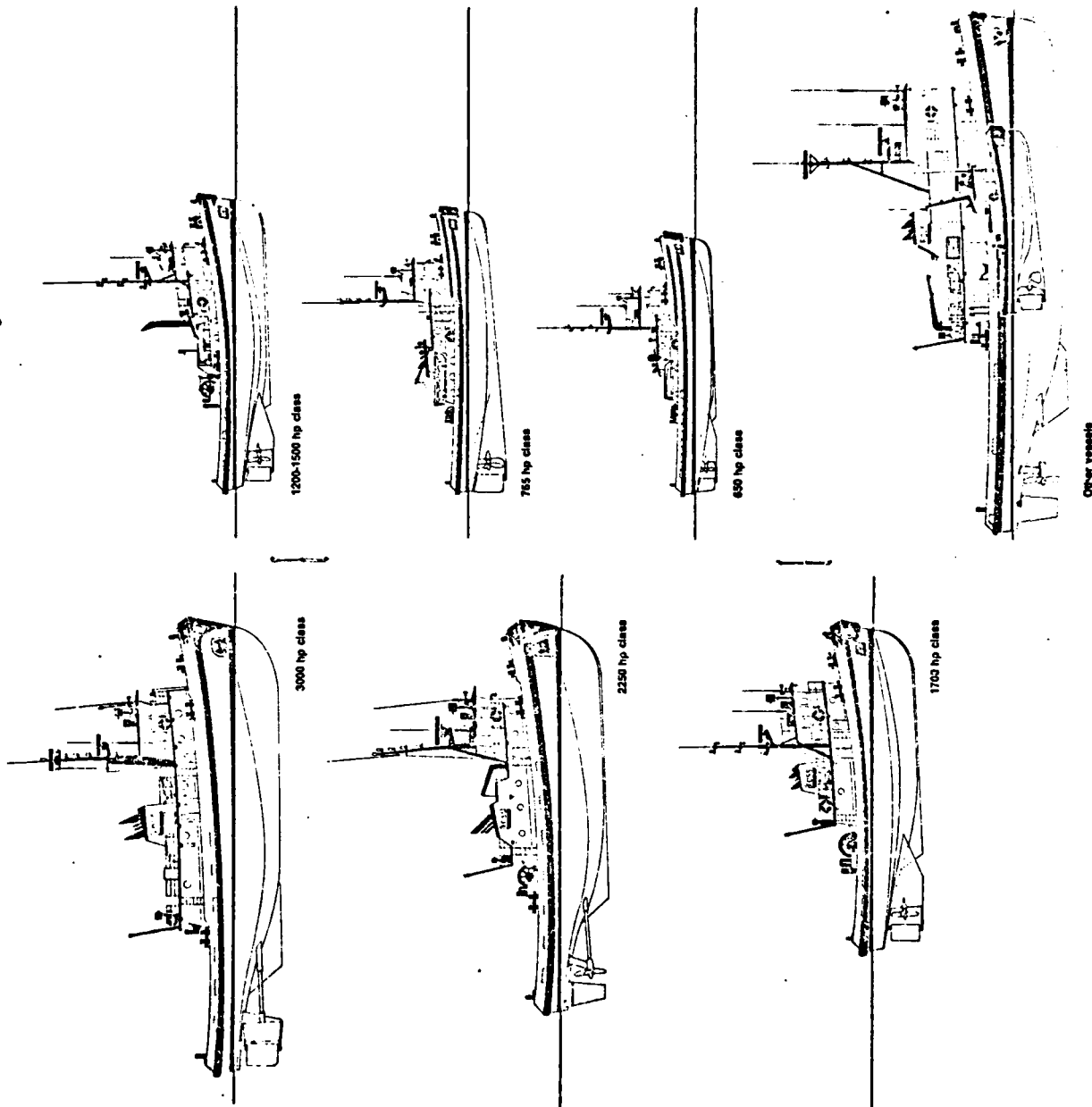
Foss' Puget Sound tug fleet

Foss tugs in the 3000 horsepower class range in length from 90' to 111' with beams from 31' to 34' with horsepower ratings from 2850 hp to 3000 hp.

Tugs in the 2250 horsepower class include vessels with lengths from 97' to 107' beams from 26' to more than 29' — all with a horsepower rating of 2250 hp.

All tugs in the 1700 horsepower class are 83' long and 25' wide and are rated at 1700 hp.

Figure 1.1
Typical Small Pull-Towed OGTBS: Tugs



Foss tugs in the 1200-1500 horsepower class are 72' long and 24' wide and range in horsepower from 1200 to 1500 hp.

All 765 horsepower Foss tugs are 70' in length with beams 21' wide. Horsepower ratings are 765 hp.

The 650 horsepower tugs are 65' long, 21.5' wide and are rated at 650 hp.

Other Foss vessels available for the myriad of jobs on Puget Sound range in length from 34' to 150' with beams ranging from 10' to nearly 33' and with horsepower ratings starting at 160 hp and ranging up to 6500 hp. In short, there is a Foss vessel available to meet every tug and barge need on Puget Sound.

Foss Barges

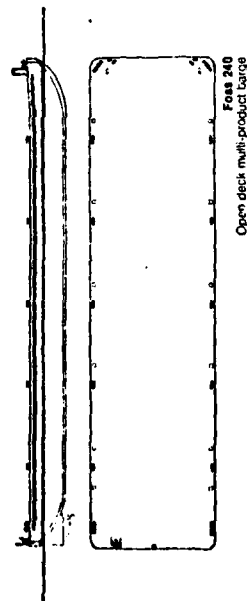
Figure 1.1...Continued
Typical Small Pull-Towed OGTBs: Barges

Foss Launch & Tug Company
ice-neck multi-product barges
are designed to accommodate
petroleum, grain and deck cargo.
These barges range up to 240' in
length and cargo capacities up to
4000 ST.

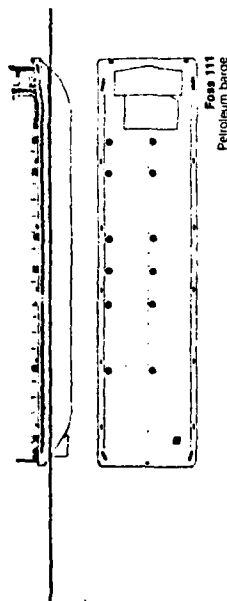
Foss' complete line of petroleum
cargoes range in length from 165'
to 230'. Petroleum barge
capacities are from 6500 bbls to
38,000 bbls.

Chemical barges are available
with capacities up to 20,000 bbls
or 4'60 M³. Lengths range from
160' to 317'.

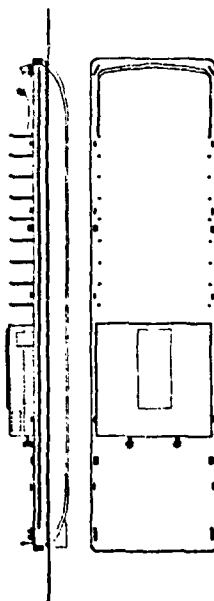
Foss Launch & Tug Company
raider barges can accommodate
from 15 to 24 raider's. Lengths
range from 260' to 320'.



Foss 240
Open deck multi-product barge



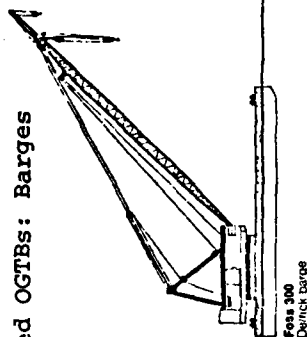
Foss 111
Petroleum barge



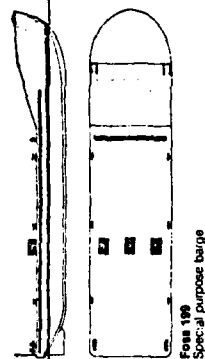
Foss 244
Chemical barge



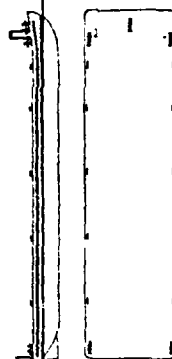
Foss 252
Raider barge



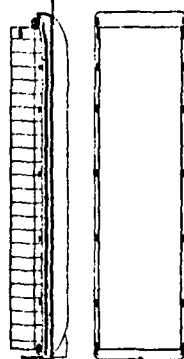
Foss 300
Derrick barge



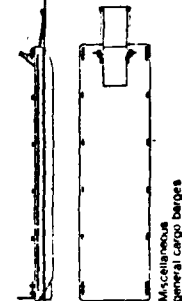
Foss 190
Special purpose barge



Foss 174
Sand and gravel barge



Foss 163
Wood chip barge



Miscellaneous
general cargo barges

Derrick barges are available up to
116' in length. Booms range to
125' with lift capacity up to 75 ST.

Foss special purpose barges,
including dump scoops, haul
everything from materials to
cement. Lengths range from 130'
to 230'. Capacities range to 6500
bbls or 1700 ST for the cement
barges, and 500 yds for dump
scoops.

Sand and gravel barges range
from 700 ST or 465 yds to 1520
ST or 1000 yds. Lengths are 110'
to 170'.

Foss wood chip barges are
devoted exclusively to the stable
wood products industry on Puget
Sound. These barges range in
length from 130' to nearly 200'.
Capacities range from 300 units
up to nearly 1,000 units.

Foss maintains a substantial
number of miscellaneous and
general cargo barges in most
almost every port. These barges
range in length from 32' to 236'.
Capacities start at 100 ST and
range up to 7000 ST.

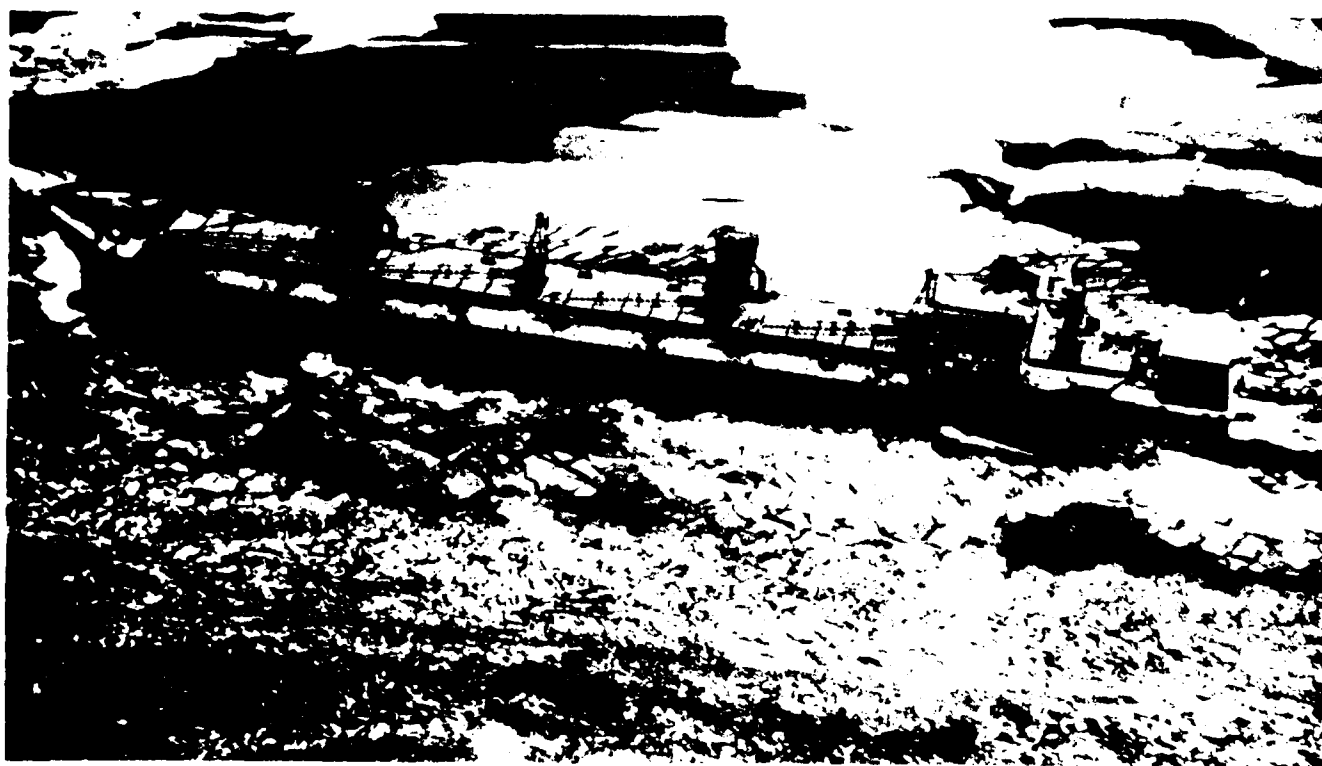
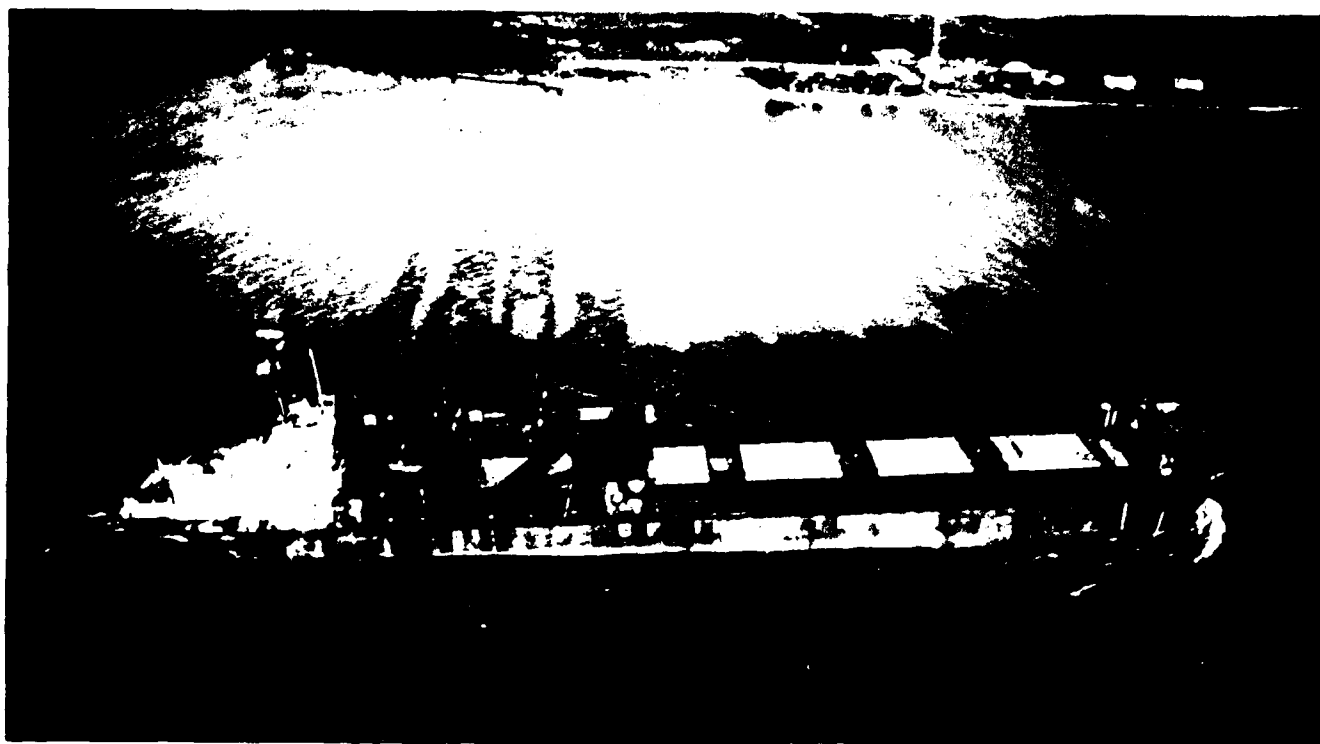


Figure 1.2

Typical Modern Large Push-Towed OGTB's

Source: Tug Barge Systems, Inc.
Company Brochure

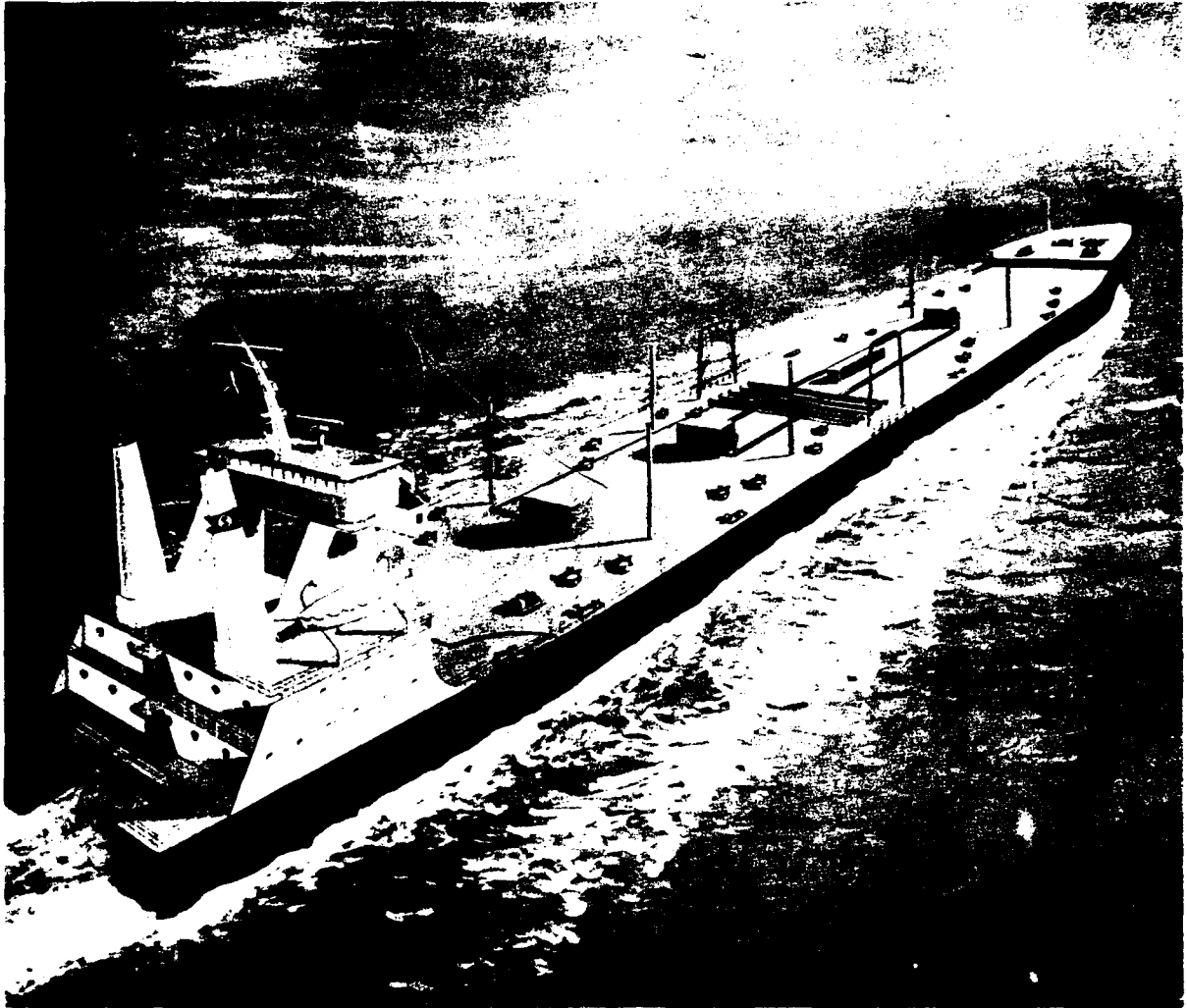


Figure 1.2 ... Continued

Source: Seabulk Corporation
Company Brochure

availability. Each of these advantages is considered separately below.

Operational Flexibility

The primary advantage of propulsion and cargo unit separability is the ability of OGTBs to operate in a drop-and-swap mode. In this method of operation the tugboat drops off the barge at a port to be unloaded and then proceeds independently or with an empty/loading barge to another port or operating area. This allows the costly tug and its crew to be utilized more efficiently since they will be spending more time transporting cargo rather than awaiting cargo operations. On the other hand, in many commercial operations this also results in lower barge utilization since it has to await the return of a tug before it can be moved. As shown in Section 2.2, this lower barge productivity may make drop-and-swap operation uneconomical in commercial trades where port times are short compared to sea times and/or where only a few large OGTBs or ships can handle the cargo movement requirements. However, many military operations have very long port calls at the discharge port. This is due to the queues that form at the beginning of an operation when a great amount of material arrives at the same time at a port unable to sustain a substantial increase in cargo throughput. Also, many military operations require discharge at shallow, undeveloped ports. This results in many small units being used which can only be discharged rather slowly via primitive cargo handling equipments, i.e., rough terrain forklifts. Thus, drop-and-swap operation would seem to be particularly appropriate for the initial stages of military cargo operations where it could improve propulsion unit utilization substantially. Further consideration of this hypothesis will be given in Chapter 3.

There is another considerable advantage that results from drop-and-swap operation in military mobilization actions. The barge that remains in port may be used as a seaside storage facility. That is, the barge does not have to be discharged immediately since no crew or propulsion unit is being tied up with it. Instead, the cargo can remain onboard until required so that the barge is used as a warehouse. In this manner, it is able to replace a shoreside storage facility, saving the cost of constructing such a facility. This floating warehouse may have other advantages, especially for the storage of POL. For example, the barges may be moved offshore to various locations, making it less vulnerable to hostile actions and making it less dangerous in case of explosion/damage. Also, it should be mentioned that since the barge does not require rapid discharge, cargo may be handled at a slower rate using less sophisticated

and less expensive port equipment. The barge can even be beached in locations that would damage ships and discharged via a simple pass-pass system using forklifts or barge mounted cranes.

There are also several safety advantages that result from drop-and-swap operation. One is that the tug crew may leave a warzone immediately after delivery of its cargo barge since it does not have to await the barge's discharge. Not only does this lessen the danger to the tug crews, it reduces the government's cost of operations since the tug crews will not be collecting war bonuses nor the insurance companies war-risk premiums for as long a period of time. Also, in case of enemy action, only the component that is damaged need be lost. The other component can be used as the crew lifeboat and later used with a replacement tug or barge.

Although the above discussion has been only with respect to military cargo movements, OGTBs operating in the drop-and-swap mode have many other potential military applications, particularly as Naval Fleet Auxiliaries. As discussed in Hawkins (1973) and Tomassoni (1974), vessels such as tenders, military hospitals, etc., which spend most of their time in port are amenable to be dropped off by a propulsion unit and picked up later when an occasional move is required. Also, as discussed in U.S. Navy (1977), drop-and-swap operation may be a very economical method of providing fleet support in the absence of a nearby advanced base for consolidating commercially carried cargoes. More mention of these studies will be made in the next subsection.

Peacetime Availability

Ocean-going tugs and barges make up a major component of our U.S. flag fleet. To show how important they really are, consider the following statistics:

In calendar year 1977, 33% of all U.S. waterborne commerce (including foreign flag traffic) and 66% of all U.S. domestic waterborne commerce was carried by barge. Additionally, 26% of all coastal domestic commerce was in OGTBs. Table 1.1 provides a breakdown of the types of cargo moved by barge. (Source: Department of the Army Corps of Engineers, Waterborne Commerce of the United States--Calendar Year 1977, Part 5, National Summaries)

As of today the U.S. flag ocean capable barge fleet consists of approximately 184 dry cargo barges of greater than 5,000 GRT capacity and 90 tank barges of greater than 50,000 Bbl. capacity. This is out of a total of approximately 5000 dry cargo barges and 600 tank barges operating on coastal trades. (Sources: Appendix A for large dry cargo barges, Appendix B for large tank barges, and The American Waterways Operators,

Table 1.1

DOMESTIC BARGE TRAFFIC* COMMODITY BY TYPE OF TRAFFIC
CALENDAR YEAR 1977
(IN TONS OF 2,000 POUNDS)

COMMODITY	BARGE TRAFFIC					PERCENT BARGE TO TOTAL DOMESTIC	TOTAL DOMESTIC TRAFFIC
	COASTWISE	LAKELINE	INTERNAL	LOCAL	INTRA- TERRITORY		
FARM PRODUCTS							
0101 COTTON, RAW-----	41		3,775			3,816	7,031
0102 BARLEY AND RYE-----	1,865		83,800			85,465	155,721
0103 CORN-----	344,438		23,150,204	85,171		23,579,813	23,599,328
0104 OATS-----	25,100		138,445			163,945	164,780
0105 RICE-----	49,100		313,226		1,655	363,981	573,168
0106 SORGHUM GRAINS-----	3,192		332,923			336,075	337,911
0107 WHEAT-----	224,817		10,098,460	59,461		10,378,738	11,779,129
0111 SOYBEANS-----	19,122		11,448,051	212,986		11,680,159	11,703,424
0112 FLAXSEED-----							291
0119 OILSEEDS, NEC-----	2,896		146,415	2,600		151,911	163,196
0121 TOBACCO, LEAF-----							10,016
0122 HAY AND FODDER-----	325		28,232			28,557	30,182
0129 FIELD CROPS, NEC-----	8,434		3,077			11,511	26,787
0131 FRESH FRUITS AND TREE NUTS-----	295,212				20,369	315,581	446,113
0133 COFFEE-----	952		3,607	137,677		142,236	165,921
0134 COCOA BEANS-----			21			21	1,331
0141 FRESH AND FROZEN VEGETABLES-----	500			300	21,122	21,922	206,638
0151 LIVE ANIMALS-----	28,921					28,921	29,573
0161 ANIMALS AND PRODUCTS, NEC-----	545		22		13	580	18,770
0191 MISCELLANEOUS FARM PRODUCTS-----	20					20	6,492
FOREST PRODUCTS							
0841 CRUDE RUBBER AND ALLIED GUMS-----			12,063			12,063	15,143
0861 FOREST PRODUCTS, NEC-----	82		997	2,800		3,479	138,924
FRESH FISH & OTHER MARINE PRODUCTS							
0911 FRESH FISH, EXCEPT SHELLFISH-----	21,750		7,192			28,942	978,049
0912 SHELLFISH, EXCEPT PREPARED-----	645					645	795,460
0913 MENHADEN-----			1,276			1,276	762,015
0931 MARINE SHELLS, UNMANUFACTURED-----			10,690,842	1,080,697		11,771,539	12,148,051
METALLIC ORES							
1011 IRON ORE AND CONCENTRATES-----	50	1,031,700	4,744,953			5,776,703	40,998,779
1021 COPPER ORE AND CONCENTRATES-----			19,217			19,217	19,217
1051 ALUMINUM ORES, CONCENTRATES-----			919,864	11,020		930,884	930,884
1061 MANGANESE ORES, CONCENTRATES-----			611,833			611,833	612,118
1091 NONFERRIOUS ORES, CONCENT, NEC-----	4,182		789,489			793,671	799,643
COAL							
1121 COAL AND LIGNITE-----	3,606,804		127,626,815	2,757,900		133,991,519	156,296,406
CRUDE PETROLEUM							
1311 CRUDE PETROLEUM-----	16,145		43,751,049	9,384,448		49,151,642	84,816,616
NONMETALLIC MINERALS, EXCEPT FUELS							
1411 LIMESTONE-----	91		1,709,535			1,709,626	28,667,136
1412 BUILDING STONE, UNWORKED-----							124
1442 SAND, GRAVEL, CRUSHED ROCK-----	2,939,966	541	48,674,231	5,178,626		56,793,364	58,982,578
1451 CLAY-----	3,529		1,435,966	10,425	83	1,450,003	1,833,042
1471 PHOSPHATE ROCK-----	8,303,371		1,003,573			9,306,944	9,621,611
1479 NATURAL FERTILIZER MATS, NEC-----	19,602		1,189		18	20,809	21,092
1492 SULPHUR, DRY-----	11,049		7,849			18,898	18,945
1493 SULPHUR, LIQUID-----			4,403,879	102,000		4,505,879	8,436,583
1494 GYPSUM, CRUDE AND PLASTERS-----	761				23	784	1,132,119
1499 NONMETALLIC MINERALS, NEC-----	104,328		5,052,668	53,494		5,210,490	6,256,492
ORDNANCE & ACCESSORIES							
1911 ORDNANCE AND ACCESSORIES-----	129					129	1,240
FOOD & KINDRED PRODUCTS							
2011 MEAT, FRESH, CHILLED, FROZEN-----	710				21,262	21,972	223,982
2012 MEAT AND PRODUCTS, NEC-----	95		6,402		74	6,571	119,313
2014 TALLOW, ANIMAL FATS AND OILS-----	27,204		163,195	74,227	42	264,668	269,062
2015 ANIMAL BY-PRODUCTS, NEC-----	137		5,180			5,297	41,113
2021 DAIRY PRODUCTS, NEC-----	848		867		1,981	3,296	59,230
2022 DRIED MILK AND CREAM-----	922		221		47	1,190	43,603
2031 FISH AND SHELLFISH, PREPARED-----	65,041		16	27		65,084	308,400
2034 VEGETABLES AND PREP, NEC-----	18,694		452			19,146	222,674
2039 PREP FRUIT AND VEG JUICE, NEC-----	1,981		24			2,005	838,859
2041 WHEAT FLOUR AND SEMOLINA-----	8,119		162,822		150	169,091	234,877
2042 PREPARED ANIMAL FEEDS-----	36,128		516,877	12,580	3,031	568,616	836,740
2049 GRAIN MILL PRODUCTS, NEC-----	90,916		5,469,411	25,080	1,841	5,587,228	5,830,111
2081 SUGAR-----	167,711		617,651		2,378	787,760	1,972,801
2082 MOLASSES-----	36,356		777,870	38,042	32,805	885,073	1,388,640
2081 ALCOHOLIC BEVERAGES-----	47,164		11,560		28,301	87,025	751,496
2091 VEGETABLE OILS, MARG, SHORT-----	37,503		852,740	276,012		1,166,255	1,198,388
2092 ANIMAL OILS AND FATS, NEC-----			47,696	11,805		59,501	63,182
2094 GROCERIES-----	37,983		16		2,706	40,705	246,262
2095 ICE-----							453,846
2099 MISCELLANEOUS FOOD PRODUCTS-----	113,184		25,306		48,484	178,894	598,874

*NON-SELF PROPELLED VESSELS.

Table 1.1...Continued

DOMESTIC BARGE TRAFFIC: COMMODITY BY TYPE OF TRAFFIC--CONTINUED

CALENDAR YEAR 1977

(IN TONS OF 2,000 POUNDS)

COMMODITY	BARGE TRAFFIC						PERCENT BARGE TO TOTAL DOMESTIC	TOTAL DOMESTIC TRAFFIC
	COASTWISE	LAKEWISE	INTERNAL	LOCAL	INTRA- TERRITORY	TOTAL		
TOBACCO PRODUCTS								
2111 TOBACCO MANUFACTURES-----	1,565		1,394			2,959	11.0	26,870
BASIC TEXTILES								
2211 BASIC TEXTILE PRODUCTS-----	875		19,897		182	20,954	27.0	77,741
2212 TEXTILE FIBERS, NEC-----	1,095		4,890		6,029	12,014	77.5	15,507
APPAREL & OTHER FINISHED TEXTILE PRODUCTS, INCLUDING KNIT								
2311 APPAREL-----	13,922				124	14,046	16.5	84,911
LUMBER & WOOD PRODS., EXC. FURNITURE								
2411 LOGS-----	562	17,779	611,022	24,714		654,077	99.4	658,297
2412 RAFTED LOGS-----								16,272,120
2413 FUEL WOOD, CHARCOAL, WASTES-----	72		542,096	28		542,194	98.5	550,217
2414 TIMBER, POSTS, POLES, PILING-----	10,641		57,408	1,627		69,676	86.5	80,577
2415 PULPWOOD, LOGS-----	1		1,394,648			1,394,649	97.6	1,428,431
2416 WOOD CHIPS, STAVES, HOLDINGS-----	14,680		2,119,374	82,388		2,216,442	99.5	2,224,794
2421 LUMBER-----	1,065,028		233,121	943	108	1,299,200	83.8	1,549,735
2431 VENEER, PLYWOOD, WORKED WOOD-----	71,295		126,415			197,710	76.7	257,751
2491 WOOD MANUFACTURES, NEC-----	89,132		20,658	90	73	109,953	50.7	184,142
FURNITURE & FIXTURES								
2511 FURNITURE AND FIXTURES-----	19,678		2,593		12,041	34,312	29.6	116,014
PULP, PAPER & ALLIED PRODUCTS								
2611 PULP-----	112,671		843,623	1,150		957,444	95.2	1,005,763
2621 STANDARD NEWSPRINT PAPER-----	7,616		117,284		49	124,949	63.7	196,184
2631 PAPER AND PAPERBOARD-----	26,358		680,363			886,421	60.7	1,132,336
2691 PULP AND PAPER PRODUCTS, NEC-----	63,745		1,378,982	4,467	2,209	1,449,403	83.8	1,729,842
PRINTED MATTER								
2711 PRINTED MATTER-----	617					617	3.0	20,401
CHEMICALS & ALLIED PRODUCTS								
2810 SODIUM HYDROXIDE-----	702,874		3,702,605	278,629		4,684,108	87.2	5,375,214
2811 CRUDE TAR, OIL, GAS PRODUCTS-----	218,830	8,217	1,410,975	302,636	3,796	1,942,454	86.6	2,243,235
2812 DYES, PIGMENT, TANNING MATS-----	80					80	.6	13,572
2813 ALCOHOLS-----	73,450	1,299	2,328,573	72,959		2,476,281	50.3	4,174,235
2816 RADIOACTIVE MATERIALS, WASTES-----								517
2817 BENZENE AND TOLUENE-----	104,490	13,313	3,328,927	361,009		3,807,739	82.8	4,597,824
2818 SULFURIC ACID-----	94,648		2,032,820	455,460	2,975	2,585,903	99.9	2,588,124
2819 BASIC CHEMICALS AND PROD. NEC-----	770,647	209,639	12,457,243	613,575	28,939	14,080,043	81.6	17,264,311
2821 PLASTIC MATERIALS-----	7,564		72,766	1,378	45	81,753	22.4	359,135
2822 SYNTHETIC RUBBER-----	90		128,502			128,592	76.9	167,125
2823 SYNTHETIC (MAN-MADE) FIBERS-----	30				166	196	9.9	1,539
2831 DRUGS-----	1,589				152	1,741	5.5	31,721
2841 SOAP-----	12,569				1,809	14,378	6.7	215,189
2851 PAINTS-----	1,969		10		3,370	5,349	10.3	52,174
2861 GUM AND WOOD CHEMICALS-----	2		326,546	16,657		343,205	87.7	391,141
2871 NITROGENOUS CHEM FERTILIZERS-----	319,060		2,936,017	76,180		3,327,237	97.4	3,417,620
2872 POTASSIC CHEM FERTILIZERS-----	137,601		333,612			471,213	90.8	518,695
2873 PHOSPHATIC CHEM FERTILIZERS-----	77,575		537,657			615,232	99.9	619,342
2876 INSECTICIDES, DISINFECTANTS-----	124		1,929			2,044	7.4	27,642
2879 FERTILIZER AND MATERIALS, NEC-----	159,326		3,062,893	6,332		3,228,551	99.7	3,232,689
2891 MISCELLANEOUS CHEMICAL PROD-----	59,991		475,248	2,979	214	538,432	65.2	813,829
PETROLEUM & COAL PRODUCTS								
2911 GASOLINE-----	16,920,415	462,693	38,982,758	5,620,055	149,407	54,135,328	57.1	94,880,064
2912 JET FUEL-----	712,282		4,071,177	1,557,941		6,341,400	50.1	12,655,830
2913 KEROSENE-----	319,621	27,229	1,365,675	708,203	16,325	2,428,053	44.5	5,453,241
2914 DISTILLATE FUEL OIL-----	9,706,584	730,599	25,886,861	12,931,320	511,000	49,767,164	55.5	89,664,153
2915 RESIDUAL FUEL OIL-----	10,457,317	1,425,151	48,848,275	27,782,596	1,807,071	90,320,410	67.4	133,599,797
2916 LUBRICATING OILS AND GREASES-----	205,369	4,820	2,472,242	192,735	290	2,675,456	49.7	5,751,437
2917 NAPHTHA, PETROLEUM SOLVENTS-----	206,763	1,590	2,657,988	280,305	321,059	3,469,705	59.3	5,854,671
2918 ASPHALT, TAR, AND PITCHES-----	1,685,795	81,026	4,185,490	315,820	1,876	6,269,808	66.3	9,455,731
2920 COKE, PETROLEUM COKE-----	7,680		2,327,657	251,773		2,587,110	93.8	2,758,194
2921 LIQUEFIED GASES-----	207,609	7	995,794	81,788		1,285,198	99.6	1,288,603
2951 ASPHALT BUILDING MATERIALS-----	9,810		1,172			6,982	33.4	22,931
2991 PETROLEUM AND COAL PROD. NEC-----	56,430	11,449	675,622	1,561,443	4,868	2,303,608	86.6	2,661,658
RUBBER & MISC. PLASTIC PRODUCTS								
3011 RUBBER AND MISC PLASTIC PROD-----	19,677		13,487		6,132	39,296	29.0	139,488
LEATHER & LEATHER PRODUCTS								
3111 LEATHER AND LEATHER PRODUCTS-----	402		1,129			1,531	9.1	16,983
STONE, CLAY, GLASS, & CONCRETE PROD.								
3211 GLASS AND GLASS PRODUCTS-----	9,863		31,011		351	36,425	35.0	104,019
3241 BUILDING CEMENT-----	1,599,981	204,574	4,180,810	83,857	89	6,069,319	62.6	9,696,497

NON-Self PROPELLED VESSELS.

Table 1.1...Continued

DOMESTIC BARGE TRAFFIC BY TYPE OF TRAFFIC--CONTINUED

CALENDAR YEAR 1977

(IN TONS OF 2,000 POUNDS)

COMMODITY	BARGE TRAFFIC						PERCENT BARGE TO TOTAL DOMESTIC	TOTAL DOMESTIC TRAFFIC
	COASTWISE	LAKEWISE	INTERNAL	LOCAL	INTRA- TERRITORY	TOTAL		
STONE, CLAY, GLASS, & CONCRETE PROD. (CONTINUED)								
3251 STRUCTURAL CLAY PRODUCTS-----	2,304		29,545		413	32,262	39.4	81,889
3271 LIME-----	523		871,747			872,270	99.2	879,360
3281 CUT STONE AND STONE PRODUCTS-----	82					82	2.3	3,573
3291 MISC NONMETALLIC MINERAL PROD-----	65,891		594,183	226	5,151	665,453	73.1	909,859
PRIMARY METAL PRODUCTS								
3311 PIG IRON-----			101,482			101,482	53.6	189,158
3312 SLAG-----	5,385		428,020	271,613		705,018	55.7	1,266,397
3314 IRON AND STEEL PRIMARY FORMS-----	11,172	3,505	503,725		41	518,443	91.6	566,022
3315 IRON, STEEL SHAPES, EXC SHEET-----	50,913		1,060,274	11,710	2,487	1,125,384	95.3	1,180,506
3316 IRON AND STEEL PLATES, SHEETS-----	13,869	45,345	2,747,382	8,717	32	2,815,345	97.3	2,892,710
3317 IRON AND STEEL PIPE AND TUBE-----	27,114		1,123,104	25,721		1,175,939	81.8	1,437,341
3318 FERROALLOYS-----		5,603	758,194			763,794	99.9	764,499
3319 IRON AND STEEL PRODUCTS, NEC-----	1,932		160,185			162,117	85.0	170,757
3321 NONFERROUS METALS, NEC-----	252		13,323			13,575	12.8	105,963
3322 COPPER ALLOYS, UNWORKED-----	12,952		70,275	121,312		204,539	96.0	212,955
3323 LEAD AND ZINC, UNWORKED-----	82		109,754	13,478		123,314	93.5	131,655
3324 ALUMINUM AND ALLOYS, UNWORKED-----	8,396		82,570		37	91,003	47.2	192,811
FABRICATED METAL PRODUCTS, EXCEPT ORDNANCE, MACHINERY, & TRANS. EQUIP.								
3411 FABRICATED METAL PRODUCTS-----	492,573	1,512	502,413	2,346	4,872	1,003,716	77.9	1,267,828
MACHINERY, EXCEPT ELECTRICAL								
3511 MACHINERY, EXCEPT ELECTRICAL-----	70,737		251,442	14,602	2,112	338,893	67.8	499,868
ELECTRICAL MACHINERY, EQUIPMENT & SUPPLIES								
3611 ELECTRICAL MACH AND EQUIP-----	23,307		112,498	248	3,448	139,501	46.6	299,376
TRANSPORTATION EQUIPMENT								
3711 MOTOR VEHICLES, PARTS, EQUIP-----	114,696		24,815	1,235	8,205	148,951	30.9	482,525
3721 AIRCRAFT AND PARTS-----	826		285	23		1,134	91.5	1,240
3731 SHIPS AND BOATS-----	12,438		37,480	1,070	33	51,013	40.7	125,477
3791 MISC TRANSPORTATION EQUIPMENT-----	71,514		3,871		36	75,421	91.5	82,435
INSTRUMENTS, PHOTOGRAPHIC & OPTICAL GOODS, WATCHES & CLOCKS								
3811 INSTR. TIME, PHOTO, OPT GOODS-----	1,778				32	1,810	10.3	17,554
MISC. PRODUCTS OF MANUFACTURING								
3911 MISC MANUFACTURED PRODUCTS-----	4,350		158,341	2,905	175	165,771	8.2	2,013,195
WASTE & SCRAP MATERIALS								
4011 IRON AND STEEL SCRAP-----	110,652	78,297	1,213,525	466,727	2,124	1,871,325	94.5	1,979,221
4012 NONFERROUS METAL SCRAP-----	554		27,939			28,493	50.2	56,719
4022 TEXTILE WASTE, SCRAP, SWEEP-----	12					12	.1	11,497
4024 PAPER WASTE AND SCRAP-----	20		2,714		17	2,751	7.3	37,889
4029 WASTE AND SCRAP, NEC-----	1,400		5,768,863	3,416,459	196,597	9,383,319	76.6	12,255,099
SPECIAL ITEMS								
4111 WATER-----	616		1,211,171	120,016	25,217	1,357,020	38.8	3,499,691
4112 COMMODITIES, NEC-----	439,223	315	352,036	43,021	32,683	867,276	31.2	2,781,120
TOTAL-----	64,606,058	4,366,196	494,142,113	73,785,802	3,342,966	640,163,135	65.8	972,966,806
TOTAL DOMESTIC TRAFFIC-----	245,083,336	109,079,945	528,704,658	83,444,472	3,654,395	972,966,806		
PERCENT BARGE TO TOTAL DOMESTIC-----	26.0	4.0	93.5	88.3	91.5	65.8		

*NON-SELF PROPELLED VESSELS.

Source: Waterborne Commerce of United States, Calendar Year 1977
 Part 5 - National Summaries; Lower Mississippi Valley Division
 U.S. Army Corps of Engineers, Vicksburg, Mississippi

Inc., 1975 Inland Waterborne Commerce Statistics for the total number of coastal barges)

As of today there are 364 U.S. flag ocean-capable tugboats of greater than 3000 horsepower certified for ocean towing service out of approximately 1600 tugboats of greater than 3000 horsepower operated in coastal waters. Additionally there at least 142 tugboats of greater than 3000 horsepower not certified for ocean tow service that could become ocean tow capable with little modification. (Source: Appendix C for the number of high horsepower tugs, certified or non-certified for ocean tow service; 1975 Inland Waterborne Commerce Statistics for the total number of tugs)

Of the 36 U.S. flag tankships of less than 25,000 DWT, none are less than 25 years of age. Of the 134 U.S. flag tankships between 25,000 and 50,000 DWT, only 16 are less than 10 years old, 27 less than 15 years old, and 52 less than 20 years old. Of the tank barges between 50,000 Bbl and 25,000 DWT only none is greater than 25 years of age and seventeen more than 10 years old. Of all the tank barges between 25,000 and 55,000 DWT, only one is more than 10 years of age. Additionally, most of these tank barges have some type of push-tow linkage that allows speeds of greater than 12-15 knots to be achieved when they are pushed by a high horsepower tug. (Sources: MSC P504, Military Sealift Command Ship Register, April 1979, for the tankship data; Appendix B for the tank barge data)

Of the 41 tankships built under U.S. flag in the last five years, only 13 have been of less than 50,000 DWT and none have been smaller than 35,000 DWT. Of the 27 tankships built between 1970 and 1974, only 3 were less than 50,000 DWT, two of 40,000 DWT and one of 27,000 DWT. In comparison, all of the tank barges built have been less than 55,000 DWT and of the 69 of greater than 50,000 Bbl capacity built since 1970, 55 have been less than 25,000 DWT (175,000 Bbl). (Sources: Same as the previous statistic)

As of today only four of the nine tank ships currently under construction in U.S. yards are less than 150,000 DWT. In comparison, there are five CATUG OGTBs being built of less than 50,000 DWT. Additionally, four deep notched tank barges between 20,000 and 55,000 DWT are under construction. (Source: U.S. Department of Commerce, Maritime Administration, U.S. Merchant Marine data sheet of April 1, 1979, for tank ship and CATUG construction; industrial sources for other tank barge construction)

As of today there are four roll-off/roll-on (RO/RO) ships being built in U.S. yards. In comparison there are two ARTUBAR

linked and two pull-towed OGTBs of significant size being built at this time. (Sources: Same as the previous statistic)

Some of the last statistics should point out a very important trend. More and more of the coastal liquid bulk traffic is being carried in barges. Today, only barges are being built to move liquid cargoes of less than 25,000 DWT and more barges than tankships are being built to move cargoes between 25,000 and 50,000 DWT. Therefore, it is apparent that the lack of new handy sized tankers has been caused by OGTBs being built in their place. Fortunately, many of these OGTBs, especially those of the mechanically-linked variety, have the same commercial capabilities as ships they replace. Others of the loose-linked push-tow type have at least ship-type capabilities on coastal trades. Thus, these tank OGTBs should be seriously considered by military planners for use in military contingencies as handy sized tankers.

The availability of OGTBs to military shipping operators is about the same as for ships of the same size. Some, such as the RO/RO barges are committed to common carrier trades between the continental United States and Caribbean, Alaskan, or Hawaiian ports. Removal of these assets from commercial trade for military operations could cause some severe disruptions in the flows of commerce to those areas if there were insufficient surplus capacity in those trades. Deck barges, on the other hand, are normally in the spot market and could be obtained without difficulty for military actions. The tank barges are in an intermediate position. Some, especially the chemical barges, are often company owned and have been built for dedicated coastal service. Although their removal from service could be compensated by increased truck and rail movements, transportation costs would increase dramatically for these companies. On the other hand most of the medium sized and some of the large POL barges are in the spot and short term charter markets. Thus, they could be obtained rather easily for military operations. The amount of this tonnage available has never been compiled (1) so it is recommended that a continuous market survey should be initiated to monitor this very important military asset. The impact of the removal of a large amount of this POL tank barge tonnage could be partially compensated by truck and rail movements. But it would be certain that POL distribution would be disrupted seriously since the other modes would not be able to handle the increased transport requirements. A study is warranted to estimate the magnitude of the impact of such a disruption.

(1) MTRB (1979) indicates that tank and deck barge supply exceeds current demands but this study does not provide a detailed supply/demand breakdown.

Wartime Availability

In case of a full scale mobilization, it is certain that OGTBs can and will play an important part. Currently, the Office of Ship Construction of the Maritime Administration is developing mobilization designs for ocean-going tug-barges and this is discussed in detail in Annex A and in Maritime Administration (1979b). In order to point out how much mobilization potential OGTBs have, consider the following statistics:

In 1978 there were at least 45 yards delivering more than 230 tugboats and other vessels of more than 100 feet in length. Most of these yards could construct medium and large sized ocean-going tug components of OGTBs. (Source: The Workboat, December 1978)

As of November 1979 there were several yards that could construct mobilization barges but would be too small to build mobilization ships. Specifically, there are 47 building locations capable of building a 600'x90' RO/RO barge, 14 more than are capable of building RO/RO mobilization ships. Total construction capability for RO/RO mobilization barges is 70 barges simultaneously, with multiple utilization of large building basins. There are also a total of 63 ways or basins capable of building the 540'x75' general purpose mobilization cargo barge, 30 more than are capable of building the Jumbo general purpose mobilization ship. Total simultaneous construction capability is 87 barges. (Source: Maritime Administration (1979b))

There are a considerable number of yards too small to build the large mobilization barges but are capable of constructing smaller general purpose cargo barges of about 300 feet in length and 75 feet in breadth. The Maritime Administration has identified U.S. yard capability to build 121 of these shorter barges simultaneously. (Source: Maritime Administration (1979b))

There are at least 506 ocean-going tugs and service craft of greater than 3000 horsepower, 74 of greater than 5000 horsepower, and 38 greater than 7000 horsepower. These power units could be used to push deep notched barges at rather respectable speeds if the barges are equipped with shipshape bows. For example, as seen in Table 1.2 only 6000 and 8500 horsepower were required to propel a 10,7000 DWT Victory ship at 15.5 and 16.5 knots respectively; 1400 HP were required to propel a 3925 DWT T-1 tanker at 10.0 knots; 6000 HP were required to propel a 16628 DWT T-2 tanker at 14.5 knots and 18,600 HP to propel a 26575 DWT T-5 tanker at 18 knots. Such speeds should be achieved by OGTBs of the same horsepower and deadweight if the barge were provided with a shipshape form and if the linkage drag were not too severe. (Source: Appen-

Table 1.2
AVERAGE CHARACTERISTICS CERTAIN MARITIME ADMINISTRATION DESIGNS

PROPUSSION/ OWNER	BBL	PASS	EM	HO 1/ 2/	REF	DRY	BR	LOA	RAD	HP 2/ 3/	SPD	WTR	FUEL	DWT	DFT	GROSS	CLASS	SC	SS	DESIGN	DES
DRY CARGO																					
LASH	500	7				1735	100	893	15	320	22.0	853	5800	40600	38	32269	AK	1	SS	C9-S-81d	C981
SEABEE	227	44	2000			1774	106	876	16	360	20.0	697	6346	38410	39	21667	AK	1	SS	C8-S-82a	C882
LASH	8	6	500	6		1516	100	820	13	375	22.5	793	5305	29820	35	26406	AK	1	SS	C8-S-81b	C881
FARRELL (CONT)	3	12		12	1006	1185	90	813	18	285	22.5	255	4456	27340	29	25000	AK	1	SS	C8-S-85d	C885
SEALAND (CONT)	12			5		1590	95	721	21	320	23.0	588	6484	26624	34	24000	AK	1	SS	C7-S-38a	C785
STATES (RO/RO)	4	12	30	1		1944	102	684	11	370	23.0	333	3739	19543	32	16000	AKR	1	SS	C7-S-95a	C795
US LINES (CONT)		4		6		1335	39	701	10	273	22.5	249	3350	20574	32	18876	AK	1	SS	C7-S-63a	C763
FARRELL (CONT)	3	12	70	9	224	1207	90	668	18	285	22.6	255	4439	19500	33	21150	AK	1	SS	C6-S-85a	C685
US LINES (CONT)		4		6		1047	76	661	13	192	20.0	257	2525	15523	29	15864	AK	1	SS	C6-S-1v	C61v
EXPORT (RO/RO, CONT)	14	12	70	7		1194	90	601	12	300	23.6	390	2904	15694	34	11757	AKR	1	SS	C5-S-78a	C578
EXPORT (CONT)	17	12	70	7	22	1018	82	605	17	240	20.8	608	3570	22208	35	15949	AK	1	SS	C5-S-75a	C575
LYNES	8	12	60	5		952	78	610	18	175	20.0	122	3450	16343	32	17902	AK	1	SS	C5-S-73b	C573
LYNES	6	4	80	6		790	69	592	21	99	17.4	227	2930	14286	30	11691	AK	1	SS	C4-S-37e	C537
PROBENTIAL	7	12	80	7	15	737	81	560	12	140	20.0	214	2287	12693	30	9322	AK	1	SS	C4-S-66a	C466
US LINES	10	4	70	6	152	504	75	544	17	170	21.0	279	3378	13264	32	11202	AK	1	SS	C4-S-64a	C464
MORRIS	9	12	75	6	40	628	75	551	14	173	21.0	212	2564	12763	31	10484	AK	1	SS	C4-S-60a	C460
FARRELL	8	12	60	7	29	630	75	572	16	165	20.0	254	2890	12728	31	11309	AK	1	SS	C4-S-58a	C458
US LINES	8	12	70	6	44	643	75	561	12	195	21.0	452	2538	13532	32	11105	AK	1	SS	C4-S-57a	C457
STATES	17	12	60	6	39	673	76	565	14	192	20.0	103	3766	14349	32	12693	AK	1	SS	C4-S-1u	C41u
TURBINE	8	12	60	7	30	736	76	564	12	175	20.0	257	2852	13498	30	9214	AK	1	SS	C4-S-1a	C41a
DELTA	11	4	75	6	44	603	70	522	15	117	18.5	200	2175	13039	31	10396	AK	1	SS	C3-S-76a	C376
EXPORT	12	12	50	6	25	663	73	493	13	137	18.5	160	1939	12525	31	11000	AK	1	SS	C3-S-46a	C346
LYNES	6	12	60	5	18	546	69	495	15	100	18.0	227	1998	11367	30	9459	AK	1	SS	C3-S-37d	C337
MORRIS	8	4	60	5	565	69	495	17	110	18.0	227	2827	12684	30	9296	AK	1	SS	C3-S-37c	C337	
DELTA	20	12	75	5	39	425	68	483	14	110	18.0	116	2317	12500	31	9259	AK	1	SS	C3-S-33a	C333
TURBINE	13	12	60	7	22	632	70	506	14	105	18.0	186	2208	13100	31	9827	AK	1	SS	C3-S-43a	C343
TURBINE	11	12	30	5	672	70	492	12	85	16.5	398	1609	12343	29	7950	AK	1	SS	C3-S-A2	C3	
TURBINE	8		30	5	546	63	459	16	60	15.5	417	1711	10500	27	6132	AK	1	SS	C2-S-B1	C2	
TURBINE	4	12	30	5	437	60	418	16	40	14.0	536	1241	9331	26	6711	AK	1	SS	C1B	C1B	
TURBINE	50	5	50	5	453	62	455	24	85	16.5	295	2881	10700	29	7612	AK	1	SS	VC2-S-AP3	V#3	
TURBINE	50	5	50	5	453	62	455	24	60	15.5	295	2881	10700	29	7612	AK	1	SS	VC2-S-AP2	V#2	

1/ HO - Number of Holds or Cargo Systems for Tankers

2/ HP - Normal Horsepower in Hundereds

IV

Source: U.S. Navy, Military Sealift Command, Ship Register, April 1979

Table 1.2...Continued

SA
SS

hp - Normal Horsepower in Hundreds

Number of Holds or Cargo Systems for Tankers

dix C for numbers of tugs of greater than the specified horsepower)

As estimated by the Shipbuilder's Council, about half of the \$8.1-13.6 billion expected to be spent annually on merchant ship construction from January 1979 to December 1983 will be spent on the building of small and non-propelled vessels (including barges).

From the above statistics it is apparent that tug and barge construction make up a large part of our shipyard/boatyard capabilities in peacetime. In the time of a general mobilization these same yards could provide substantial shipping capacity in the form of OGTBs. This could be done by the construction of new tugs and barges or by the conversion of existing tugs and barges into more militarily useful vessels. As an example of the latter possibility, many of the high horsepower offshore oil industry tugs that are currently in exploration service could be retrofitted with a push-tow linkage. These tugs could be mated with pull-towed barges that have been retrofitted with a matching linkage. With its new push-tow linkage, the barge's speed and transport capacity could be doubled from its hawser towed value. Also, many of the deep notched coastal OGTBs could be quickly converted to ocean service by the installation of an improved linkage such as the ARTUBAR discussed in Section 1.3. Such retrofitting of tugs has a very important advantage. It frees new propulsion machinery units, which will certainly be in short supply during a mobilization, for installation in Naval and large mobilization ships.

1.1.3 Previous Military and Government Studies on OGTBs

Considering the operational flexibility and the peacetime and wartime availability of OGTBs it would have been expected that much would have already been written on their military usefulness. Unfortunately, this has not been the case. Only three defense related studies have been completed so far, two sponsored by the Navy and the other by the Maritime Transportation Research Board (MTRB).

The first Navy study, U.S. Navy (1977), considered how OGTBs could be used as economic replacements of oilers (AO's) and ammunition ships (AE's) as shuttle ships in fleet support operations, particularly in the absence of advanced bases. An abstract of this report is provided in Annex B.

The other Navy study, Hawkins (1973), and its follow on report, Tomassoni (1974), discussed how OGTBs could be used as replacements for Naval Fleet Auxiliaries such as tenders and hospital ships that rarely move during peacetime or wartime. These

reports have recently generated congressional interest in OGTBs as destroyer and submarine tender replacements and there are currently two new studies being conducted (Keenan (1979)) to make an updated evaluation of whether OGTBs would be suitable for these ship missions. Abstracts of the two earlier reports are included in Annex B.

The MTRB study, MTRB (1979), briefly discussed the OGTB industry as part of an overall review of the defense utility of commercial vessels and craft. The report concentrated on pull-towed systems and made little mention of the new push-towed systems. An abstract of this report is provided in Annex B.

Probably the main reason why so little previous work has been done on OGTBs, particularly of the push-towed variety, is because they have had such a low profile since their inception. Even the Maritime Administration had pretty well neglected them since the early seventies when they had conducted some conceptual and preliminary economic studies on their potential. (2) (See Table 1.3 for a listing of MARAD sponsored studies on OGTBs.) The primary reason for OGTB's low visibility is because they had been until recently used exclusively in domestic commerce. This had made them ineligible for subsidies and the close scrutiny involved in the subsidy process. Also, lack of subsidy made them ineligible for National Defense Features, keeping them out of the military review process. Additionally, most OGTBs are operated by privately owned companies which have tended not to publicize their new technology to increase their competitive advantage. And since these OGTB operators have not had until recently any major lobbying organization such as the American Institute of Merchant Shipping to promote their legislative interest, they have tended to remain out of public sight. In actuality, OGTB operators have done their best to shy away from government assistance in order to avoid possible government regulation.

All of these factors have kept OGTBs from government notice. However, since the Maritime Administration sponsored the Ocean-Going Tug-Barge Planning Conference in March 1979 and since more OGTBs are being built with Construction Differential Subsidy funds, it is expected OGTBs will receive the attention they deserve in the future.

(2) The Maritime Administration only began including OGTBs in their U.S. Merchant Marine data sheet since September 1977. This is in spite of the fact that OGTBs of greater than 35,000 DWT had been operating since 1971.

Table 1.3

MARITIME ADMINISTRATION INDEX

The reports which are listed below were either completed by Maritime Administration staff, or under the direction of the Maritime Administration by outside contractors.

Brown, Donald L., Marriner, John E., and
Mc Farland, Doug

COMPUTER PROGRAM FOR THE ANALYTICAL ASSESSMENT OF
FLEXIBLY CONNECTED BARGE TRAINS

MARAD Report, Ma-RD-940-77088, Volumes 1 & 2, July 1977

Day, William G., Jr.

EXPERIMENTAL RESEARCH RELATIVE TO IMPROVING THE
HYDRODYNAMIC PERFORMANCE OF OCEAN-GOING
TUG/BARGE SYSTEMS, PHASE II, EXPERIMENTAL
EVALUATION OF CONCEPT DESIGNS, PART A,
RESISTANCE AND PROPULSION EXPERIMENTS

David W. Taylor Naval Ship Research and
Development Center, Bethesda, Md.,
Contract MA-400-2803

Filson, John J.

ADVANCED OCEAN TUG-BARGE SYSTEMS: A PROGRAM
FOR EVALUATING OCEAN GOING, CONNECTED TUG
BARGE FLOTILLAS BY LARGE SCALE, OPEN WATER
MODEL TESTING.

National Maritime Research Center, Galveston, 1972

Hautanen, R. W.

ECONOMIC FEASIBILITY REPORT ON SEMI-RIGID
LINKAGES FOR BARGE TRAINS (FLEXCR)

Maritime Administration NMRC-273-31200-R4, April 1975

Hirasaki, M. P.

LITERATURE ON FLEXIBLE CONNECTORS FOR BARGES

National Maritime Research Center, Galveston, 1974

MARITIME ADMINISTRATION INDEX

2.

Hirasaki, M. P.

PROGRAMS FOR THE DEVELOPMENT OF BARGE TRAIN
LINKAGE SYSTEMS

National Maritime Research Center, Galveston, 1973

Kazusky, Thomas A.

EXPANDED USE OF TUG BARGE TRANSPORTATION

National Maritime Research Center, Kings Point, 1974

Koeningsberg, E., Lathrop, D. S., Glosten, L. R., and
Bringlowe, J. T.

TRANSOCEAN TUG-BARGE SYSTEMS: A CONCEPTUAL STUDY

Maritime Administration, Contract MA-4500 Project
368-110, MT-45-T-Vol: 1-2-3, July 1970

Maritime Administration, Office of Domestic Shipping

AN ANALYSIS OF A POTENTIAL BULK TRADE BETWEEN
TAMPA, FLORIDA AND TOLEDO, OHIO

Division of Domestic Ocean Shipping, April 1977

[see Section II of this Program Notebook for
a detailed case study]

Maritime Administration, Office of Domestic Shipping

COASTWISE CARRIAGE, A COMPARITIVE MODAL ECONOMIC STUDY

Division of Domestic Shipping, July 1976

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MARINE TRANSPORT: STATE-OF-THE-ART

Reported completed, 1973

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EXPERIMENTAL RESEARCH RELATIVE TO IMPROVING THE
HYDRODYNAMIC PERFORMANCE OF OCEAN-GOING
TUG/BARGE SYSTEMS: VOLUME 4

David W. Taylor Naval Ship Research and Development
Center, Bethesda

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Woo, Everett L.

EXPERIMENTAL EVALUATION OF THE SEAWORTHINESS
CHARACTERISTICS OF THE BARGE TRAIN

MARAD Report, MA-940-70086, November 1975

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ADVANCED OCEAN TUG-BARGE SYSTEMS (A REVIEW
OF THE STATE OF THE ART OF OCEAN BARGE
DESIGN AND OPERATION)

Maritime Administration Report COM-74-10121,
May 1972

1.2 Historic/Economic Review of OGTB Technology

Probably the primary reason why commercial OGTBs have not been given serious consideration as militarily useful assets in the past is due to their historical use as low value bulk cargo coastal carriers with slow, sometimes unsafe, obsolete and/or surplus equipments. However, in the last two decades OGTBs have developed into ship sized, trans-ocean capable, medium speed carriers of low and high value cargoes with safe, modern and economical equipment. How such a rapid metamorphosis occurred will be explained in the following subsections.

1.2.1 Historical Development of OGTBs

In this country tugs and barges first began to appear on the East Coast during the late nineteenth century. This was the time when steam ships and the developing railroads began displacing the slower and less reliable sailing vessels in the coastal trades. Rather than scrapping all of these sailing ships, the enterprising shipping operators of the day decided to take advantage of their sound hulls and the new steam technology by converting the ships into barges and towing as many as four to six of them behind steam tugs. These tug-barge systems were very successful in low value bulk cargo trades, especially in the carriage of coal between Virginia and New England. Similarly, large ocean sailing vessels were occasionally converted into barges and successfully towed across the Atlantic. However, since such tug-barge systems depended on obsolete hulls, these trades began to fade out as the hulls deteriorated. So, by 1950 tug-barges became practically extinct on the East Coast, most coastal trades being served by WWII surplus Victory ships and T-2 tankers. (3)

However, on the West Coast tug-barge operations began to really take off at this time. This was because the WWII surplus BCLs, barge converted LSTs, 1200 HP Miki class tugs, and 1500 HP Navy ATA tugs were readily available at very low cost to carry the expanding West Coast and Alaskan bulk trades in cement, lumber, and other building materials. These tug-barge systems using converted military equipment continued in operation through the fifties. (4)

By 1960 the tug-barge operators on the West Coast and the coastal ship operators on the East Coast had to consider how to replace their aging WWII surplus equipment. There were several incentives for these operators to invest in new tug-barge systems

(3) For a more extensive history of East Coast tug-barge operations, see Hooper (1973).

(4) For a more extensive history of West Coast tug-barge operations, see Gloster (1965).

rather than ships, particularly in non-liner trades where speed was relatively unimportant. The primary incentive was in the much lower crewing expenses resulting from tug operation. This was because ship manning scales, due to aggressive union pressures and Coast Guard regulations, were more than four times (5) that of tugs and the average ship crewman's wage was significantly more than that of the average tugboat sailor. (6) As this was a time where fuel costs were low, crewing costs were the major operating expense so such savings were significant.

Another important incentive for the operators to choose tug-barge systems was that they cost much less to construct compared to ships of equal capacity. This was because the tugs, if under 300 GRT, were free from expensive governmental inspection procedures. (7) Also, barges which were designed for slow speeds could be built with simple inexpensive hull lines. Thus, in the early sixties several shipping operators built large barges for bulk trades, especially for oil, cement, and lumber. Practically all of these tug-barge systems were operated in the hawser pull-tow mode. But, as described in the next section push-towing was beginning to be seriously considered as an alternative operating method.

1.2.2 Development of Push-Towed OGTBs

The idea of a towboat or tugboat pushing a barge or integrated group of barges is not a new one. For several

(5) Ocean-going tugs under 200 GRT can under U.S. law be manned with approximately seven men on voyages of less than 600 miles. Longer voyages require crews of approximately eleven men. In comparison, in 1977 U.S. flag tankers had an average crew size of 33 men, with new tankers crewed with approximately 26 men. For detailed regulations pertaining to tugboat manning, see Annex A to Chapter 2.

(6) It has often been argued that the ship unions were able to achieve such high manning and wage scales because the liner shipping operators with vessels in foreign trades could pass their crewing expenses back to the government who was subsidizing their operational costs via the MARAD Operating Differential Subsidy (ODS) program. Unfortunately, the ship operators operating in domestic trades had to pay for similar union manning and wage scales, but without the benefit of subsidy due to the cabotage provisions of the "Jones Act". Tugboat crewmen, who are not required to be licensed by the Coast Guard and who are often trained on fishing or inland waterway vessels, have traditionally not been members of these ship unions so the inflated manning and wage scales did not pertain to them.

(7) For a list of the rules pertaining to the inspection of tugboats, see Annex A to Chapter 2.

decades, the river towboat operators have been taking advantage of the better control and lower drag resistance provided by push-towing over pull-towing a barge on a hawser.

The reason why push-towing allows the tug captain to have better control over the barge is obvious. Pulling a large barge at the end of a long wire provides little control over its direction except in the calmest seas or unless an active rudder or high resistance skegs (8) are installed on the barge hull. Additionally, maneuvering the barge in congested areas requires shortening the wire to allow better control. However, this can lead to a dangerous situation if the tug loses power or is underpowered so that the tug is run over or dragged off course by the barge. Due to these factors, hawser towing of barges greater than 20,000 DWT is usually considered impractical.

The reason why push-towing results in significantly less drag than pull-towing is because, when a barge is towed, both hulls develop their own wave making resistance. In push-towing only one hull form generates waves. Additionally, in pull-towing the hawser which forms a catenary in the water develops its own frictional resistance, and skegs that are used to prevent the barge from yawing too severely also can increase the barge frictional resistance by more than 30%. (9) This additional drag usually limits ocean-going barges towed on a hawser to speeds of 6 to 8 knots although average speeds of up to twelve knots have been achieved by light displacement shipshape RO/RO barges towed by a 9000 HP tugs. On the other hand, push-towed OGTB systems have achieved speeds in excess of 15 knots with tugs of less than 15000 HP and higher speeds could be achieved if desired.

Given these reasons why push-towing is superior to pull-towing, it would be expected that push-towing on the oceans would have developed long ago. However, the simple pin and wire/chain lashings used on the rivers to link the tugs and barges together were not capable of withstanding the forces generated by ocean winds and seas. Nevertheless, the advantages of push-towing were so compelling that in the fifties tug and barge operators began experimenting with push-tow operation.

The first push-tow tug-barge design was by George G. Sharp, Inc., for Cargill Grain Co.'s trade on the Great Lakes and the New York Barge Canal. This system, the Car-Port/G1, had a

(8) Skegs are fins that are added near the stern of the barge's underwater hull which by their lateral drag increase the barge's steerability and stability.

(9) As an example of the resistance penalty paid for pulling, one operator of a loosely-linked push-towed OGTB claims that the same system achieves an average speed of 10.8 knots when pushed and only 8.5 knots when pulled by a 7600 HP tug.

wedge-notch type linkage which was the prototype for the Breit/Ingram linkage design described in the next section. This rather small system (less than 5000 DWT) ran into serious difficulty with USCG manning authorities which eventually demanded that the tug be manned the same as a ship since it was not capable of safe independent operation. This forced the system into foreign-flag service where the tug-barge unit, and later an additional tug and two barges, operated successfully with standard tug crews in a drop-and-swap mode for many years. Although not successful in U.S. trade, the Car-Port system did prove the feasibility of push-tow operation.

Seeing the advantages and the feasibility of push-tow operation, the tug and barge operators began to seek some means of pushing their barges without being levied with increased manning scales similar to those imposed on the Car-Port. So, in the sixties, they began constructing their new large barges (some over 10,000 DWT) with stern notches for their tugs to push in. The notches in these first generation ocean-going barges were rather shallow so that push-tow operation could only be conducted in the calm waters of river estuaries, bays, harbours, and calm seas. However, since standard tugs were used for pushing these barges, no manning penalty was incurred. Later, the tug and barge operators wanted to increase the percentage of time that they could push the barges. This would allow them to take advantage of the increased speed as well as the better maneuverability available with push-towing. Thus, they began deepening the notches and using sophisticated cable/chain linking and chafing gear so that push-tow operation of these second generation OGTBs could be extended to all but severe seas.

The ultimate goal of the tug and barge operators, however, was 100% or all weather push operation with standard tugs with normal tug manning. This was first attempted in 1963 by L.R. Glosten & Associates, Inc., with the Sea-Link articulated tug-barge linkage. The linkage, described in detail in the next section, was prototype tested with only partial success in 1964 and 1965. However, it was shown that push towing with standard tugs was a viable concept so that experimentation continued in the development of improved linkages.

In the early seventies the technology was developed for the high horsepower diesel engines that could drive large barges (greater than 20,000 DWT) at moderate speeds and for linkages that would allow the tug and barge to remain linked together in all types of weather and seas. Three third generation linkages were developed in the U.S., two rigid, the Breit/Ingram and the CATUG designs, and one semi-rigid, the ARTUBAR design. These linkages, described thoroughly in the next section, have been built for OGTBs of up to 55000 DWT and have been designed for barges of up to 80-100,000 DWT. The Coast Guard determined that these tug-barge units were "mechanically linked" ships so that ship manning scales would pertain to them. However, since the

tugs were very highly automated, and had unattended enginerooms, they were certificated for the smallest manning possible--about thirteen men without including stewards and cooks. (10) This meant that these tug-barge units could be manned with approximately fourteen to sixteen men, substantially less than ships of the same capacity.

These low manning scales were very attractive to operators who needed to build new ships. They saw these mechanically linked third generation OGTBs as a way of reducing ship crewing costs substantially. Additionally, they found that they could obtain a tug-barge system at lower capital cost than the equivalent sized ship, even if the tug was built under Coast Guard inspection. (11) For these reasons several of these mechanically linked units were built to operate as psuedo-ships in coastal and foreign trades.

On the other hand, tug and barge companies operating with standard tugs and notched barges did not like these mechanically linked tug-barge systems. The linkages were expensive (12) and caused the tug to be modified so much that it usually could not be used for anything except pushing its own barge. But, the primary reason why operators did not accept these mechanically linked systems was because it would allow Coast Guard inspection of their tugs. This would substantially increase the cost of constructing the tugs and also increase the size and the licensing standards of their crews. This would in turn increase their operating and capital costs significantly, probably making their push-towed units uncompetitive in comparison with pull-towed units with tugs manned with standard tug crews and built without inspection.

Nevertheless, the tug and barge operators wanted to take advantage of push-towing 100% of the time. The better barge con-

(10) A typical manning certificate would require licensed Master, three Mates, Chief and Assistant Engineer, a Qualified Member of the Engine Department, and six Able Bodied Seamen (AB's).

(11) The reason for this construction cost saving is discussed in the next chapter. Basically, it is due to specialization of the tug and barge construction yards and due to the less sophisticated outfit equipment and the lower freeboard of the barge.

(12) Third generation OGTB mechanical linkages require special reinforcement of the barge notch and tug bow to absorb the stresses resulting from the linkage. This reinforcement as well as sophisticated coupling and decoupling gear can add approximately a million dollars to the cost of tug and barge. Additionally, the rigid linkage systems require heavier scantlings overall, increasing the hull steel weight and cost even further.

trol and fuel savings available, particularly in the longer distance coastal trades, with push-towing could not be denied. But since mechanical linkages would result in increased manning and capital costs, they instead began to develop improved cable/chain linkages (with some additional hardware) that allowed push-towing in practically all types of sea conditions but would not force their tugs to come under Coast Guard inspection. Recently several of these "loosely-linked" third generation OGTBs with barges of up to 55,000 DWT have been built for coastal liquid bulk trades replacing the overaged WWII jumboized T-2 tankers. Additionally, other linkage designs are being developed. Some of these current and proposed designs will be described in the next section.

So, today we have two different forces stimulating OGTB development. One is exerted by ship operators who are investing in the "mechanically-linked" OGTB designs. They see these pseudo-ship OGTBs as a means of reducing the crewing and construction costs of their domestic and foreign fleets. The other force is exerted by tug and barge operators who are investing in the "loosely-linked" OGTB designs. They see these OGTBs as a means of taking advantage of push-tow operation without any manning penalties for their domestic coastal trades. Therefore, one would expect that except for trades requiring high speeds and/or large vessel capacity that OGTBs would be displacing ships completely. However, small ships of moderate speed are being built in U.S. yards as well as OGTBs. An attempt to explain this situation will be presented in the following chapter.

1.3 Description of Various OGTB Systems

In this section many of the OGTB systems currently in U.S. flag operation or under active development will be discussed. Each system will be first described and then evaluated with respect to its commercial and military potential. The systems will be presented in the chronological order of their development. That is,

- A. Pull-Towed OGTBs: Tug-barge systems designed for towline operation only
- B. 1st Generation Push-Towed OGTBs: Tug-barge systems primarily designed for offshore work on a towline, but the barge will usually have a stern notch with the intention of the tug pushing in rivers, sounds and during good weather, in the open sea.
- C. 2nd Generation Push-Towed OGTBs: Tug-barge systems primarily designed for offshore work with deeper notch and hardware to permit the tug to push over half the time while offshore.
- D. 3rd Generation Push-Towed OGTBs: Tug-barge systems designed to permit the tug to push 100% of the time. (13)

These 3rd generation systems can be further sub-categorized with respect to their type of linkage. Specifically, they can be divided into rigid mechanically-linked (or integrated), semi-rigid mechanically-linked (or articulated), flexibly-linked, and loosely-linked systems.

Information additional to that given below can be obtained from the system operators, owners, or designers listed in Table 1.4.

1.3.1 Pull-Towed and 1st Generation Push-Towed OGTBs

Description and Commercial Potential

Most of the smaller and older barges were designed for hawser towing in which the barge follows the tug on a wire that is controlled by a winch on the after end of the tug. Some of the newer barges have been provided with a shallow stern notch which allows the barge to be push-towed in sheltered areas. These 1st generation push-towed OGTBs can be maneuvered much more safely in and out of port than hawser towed systems.

Although most existing OGTBs are of the pull-towed type because they were built prior to the development of the more so-

(13) This categorization of 1st, 2nd, and 3rd generation push-towed OGTBs was first presented in Wright (1973).

Table 1.4

OGTB Owners, Operators and Designers

Pull-Towed and 1st Generation Push-Towed OGTBs

Crowley Maritime Corporation
One Market Plaza
San Francisco, CA 94105
(415) 546-2500

Foss Launch & Tug Co.
Division of Dillingham Corp.
660 West Ewing Street
Seattle, WA 98119
(206) 281-3800

McAllister Brothers, Inc.
17 Battery Place
New York, NY 10004
(212) 269-3200

2nd Generation Push-Towed OGTBs

Deep Notch Design

Bulkfleet Marine Corporation
4600 Post Oak Place
Suite 161
Houston, TX 77027
(713) 840-1100

Interstate & Ocen Transport Co.
Three Parkway
Philadelphia, PA 19102
(215) 864-1200

Notchless Design

Krupp International, Inc.
Plants Division
550 Mamaroneck Ave.
Harrison, NY 10528
(914) 381-2000

3rd Generation Mechanically-Linked OGTBs

Breit/Ingram Design

Tug Barge Systems Inc.
(An Ingram Company)
4100 One Shell Square
New Orleans, LA 70139
(504) 588-2400

Table 1.4 ... Continued

CATUG DESIGN

Hvide Shipping Incorporated
1900 S.E. 17th Street Causeway
P.O. Box 13038
Port Everglades Station
Fort Lauderdale, FL 33316
(305) 527-1712

ARTUBAR DESIGN

ANDUL Engineering Inc.
2801 Sombrero Blvd.
Marathon, FL 33050
(305) 743-6800

Transway International Corporation
747 Third Avenue
New York, NY 10017
(212) 371-6464

Sea-Link Design

L.R. Glosten & Associates, Inc.
610 Colman Building
811 First Avenue
Seattle, WA 98104
(206) 624-7850

3rd Generation Loosely-Linked OGTBs

Bludworth Design

Mr. Robert Bludworth
Bludco Barge and Towing, Inc.
P.O. Box 12424
Houston, TX 77017
(713) 644-1595

Breit & Garcia Design

Belcher Towing Company
P.O. Box 011751
Miami, FL 33101
(305) 858-3400

Breit & Garcia
441 Gravier Street
New Orleans, LA 70130
(504) 581-5636

Table 1.4 ... Continued

CABLE-LOC

ANDUL Engineering, Inc.
2801 Sombrero Blvd.
Marathon, FL 33050
(305) 743-6800

3rd Generation Flexibly-Linked OGTBs

Barge-Train Design

Barge Train, Inc.
555 E. Ocean Boulevard
Long Beach, CA 90802
(213) 436-0218

phisticated push-towed OGTB designs, there are still reasons for their construction today. As explained in the next chapter, they are especially suited for short distance trades such as the movement of oil from East Coast refineries to nearby metropolitan ports or the movement of containers from major to minor ports. Barges used in this type of trade are shown in Figure 1.3.

Pull-towed systems also are the most flexible. They allow any tug of sufficient power to pull any barge or pair of barges in tandem. This enables separate ownership of tug and barge fleets which may provide economies due to specialization. This flexibility is also important to large multi-purpose fleet operators who must operate construction equipment barges, RO/RO barges, container barges, train barges, tank barges, pipe barges, and Arctic resupply barges, all with the same tugs. Pull-tow operation is a necessity in some of these operations since the line of sight from the tug's pilothouse would be blocked by the cargo during push-tow operation.

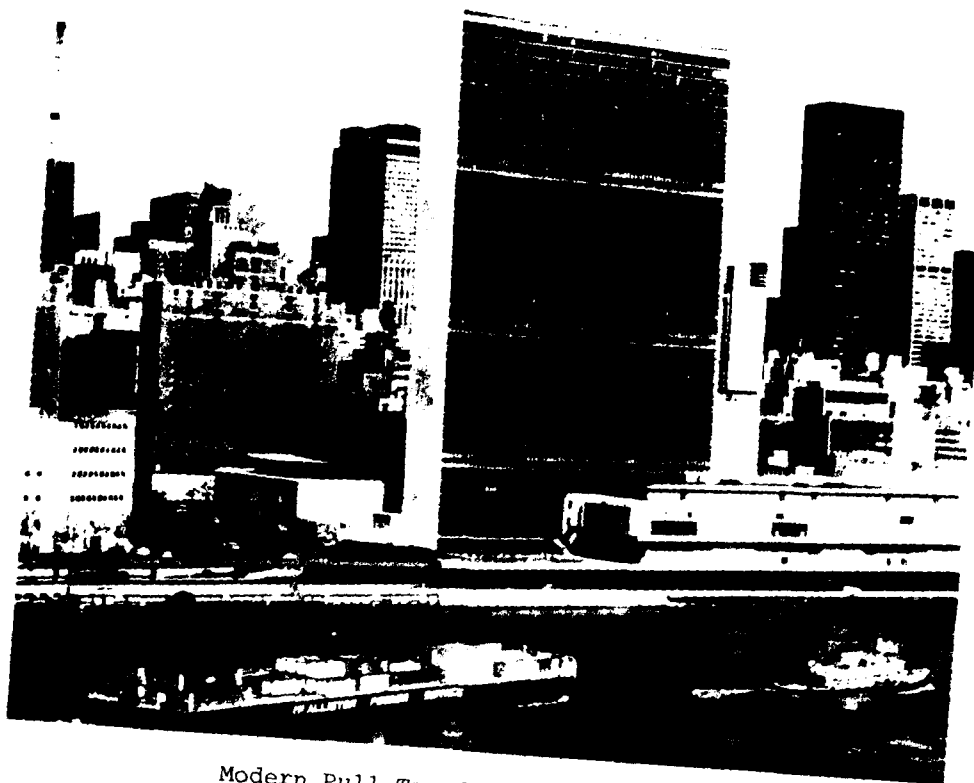
Military Potential

Pull-towed barges have been employed by the military for quite some time. They are still used annually in the Arctic and Caribbean resupply operations and had been used frequently in Viet Nam for the movement of construction equipment, housing modules, and materiel. Therefore, little additional discussion of these OGTBs will be provided here. It is safe to say that they are still useful for the trans-ocean movement of outsized cargoes, especially those which would block the pilothouse visibility of a push tug, even one with a raised pilothouse. Most of these OGTBs have flat bottoms and so are capable of beaching and/or ballasting down for the discharge of their cargo.

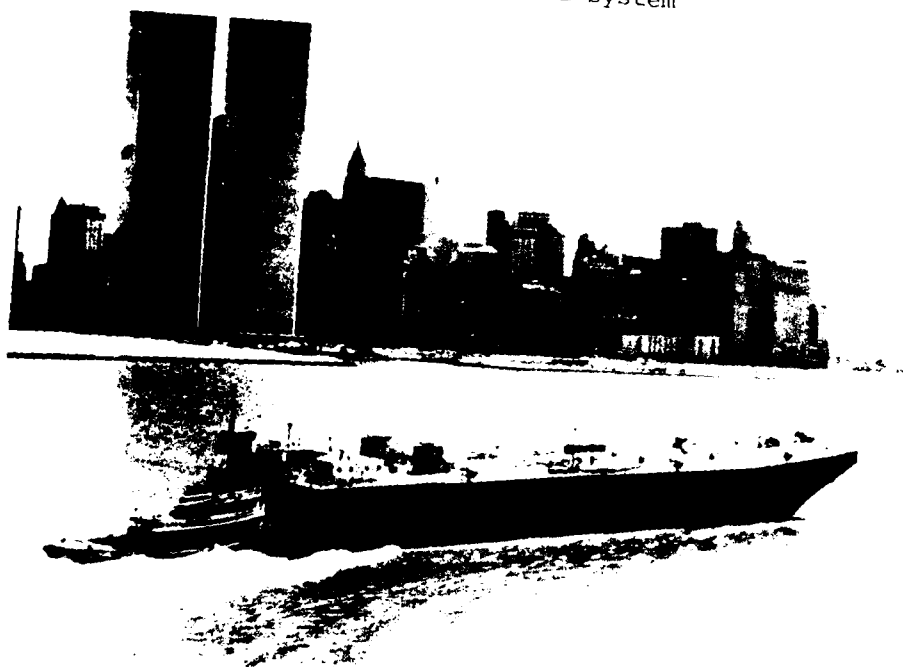
Many of these OGTBs, especially with tank and RO/RO barges, can be used for short distance shuttling operations and/or for the shoreside storage of POL, containers, and materiel. Some of the types of pull-towed OGTBs of military usefulness that could be readily obtained from commercial operators are shown in Figure 1.1. However, since most of these barges, except the newest such as the Crowley triple-deck RO/RO barges shown in Figure 1.4, have been built with spoon or other non-shipshape bows, they could not be transported rapidly overseas. (14) Even if they were converted to push-tow operation their hull forms would prevent them from making rapid headway. Thus, these types of barges are much more suited for coastal operations and/or storage after being towed to the operating area.

With respect to mobilization, standard tugs can be easily obtained from the commercial towing fleet (See Appendix C) or

(14) Speeds of advance of less than five knots are not uncommon with hawser towed barges on trans-ocean crossings.



Modern Pull-Towed OGTB System



Modern 1st Generation Push-Towed OGTB System

Figure 1.3

Source: McAllister Brothers, Inc.
 Advertisements in
 "Maritime Reporter and Engineering News"

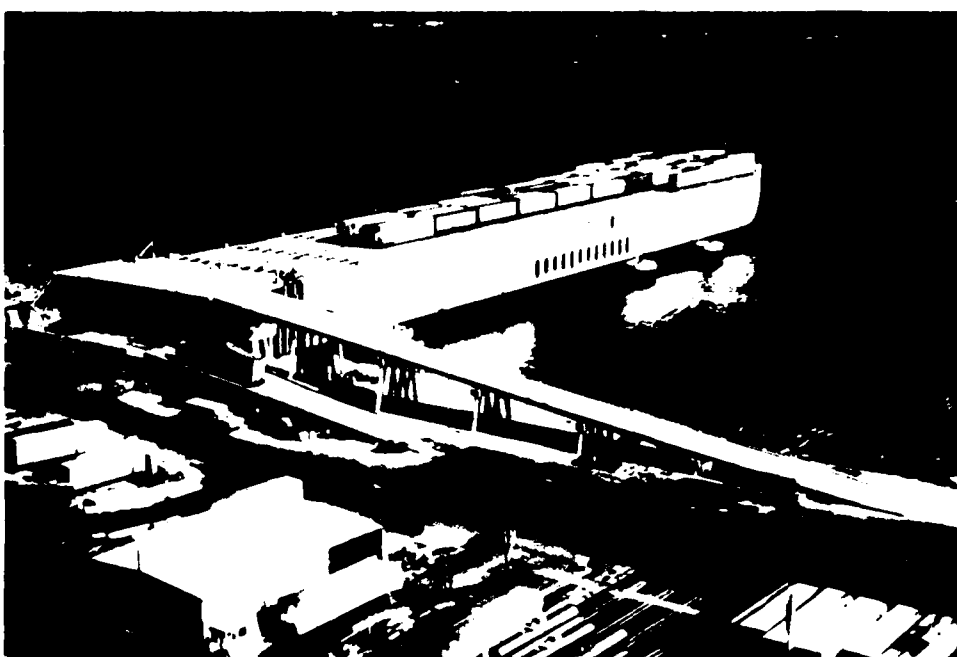
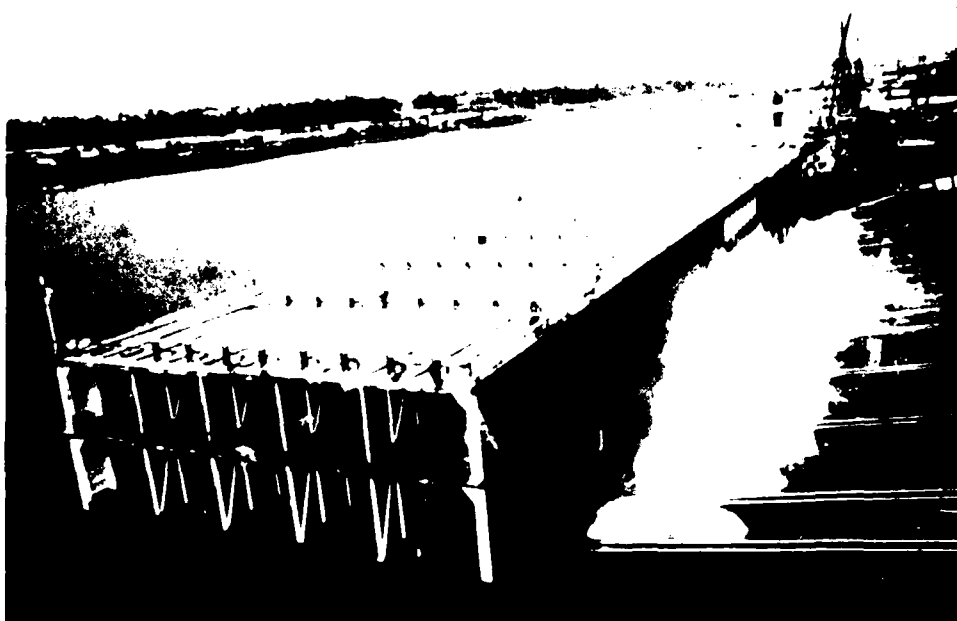


Figure 1.4

Crowley TMT Tri-Deck RO/RO Barge

Source: Trailer Marine
Transport Corp.

they can be rapidly produced at the many dozen tug and boat yards around the country. (15) Additionally, standard deck and tank barges can be readily obtained from the commercial fleet (See Appendices A & B) or can be rapidly produced by specialized barge yards. Delivery of a barge can be obtained much sooner than a ship of equivalent size since it has little machinery and is of rather simple hull shape. For example, even the sophisticated triple-deck RO/RO barges of Crowley Maritime could be completed in six months from keel-laying and only nine months from contracting. Follow on barges could be delivered in less than three months intervals if necessary. There is no doubt that the large U.S. fleet of standard tugs and barges and the boat and barge yard capacity can provide significant numbers of pull-towed OGTBs for mobilization operations. (16)

1.3.2 2nd Generation Push-Towed OGTBs

Deep-Notched Designs

Before the recent development of the 3rd generation loosely-linked OGTB designs, many coastal tankship operators, especially on the East and Gulf Coasts, pushed their barges with 2nd generation linkages. Almost all of these designs consisted of the tug pushing the barge in a deep stern notch while tensioned by cables to prevent separation from the barge. Such systems allowed push-towing more than 50% of the time. However, since the development of the loosely-linked designs, very few coastal operators are constructing 2nd generation designs except for those with linkages that allow pushing at least 90% of the time and so are approaching 3rd generation status.

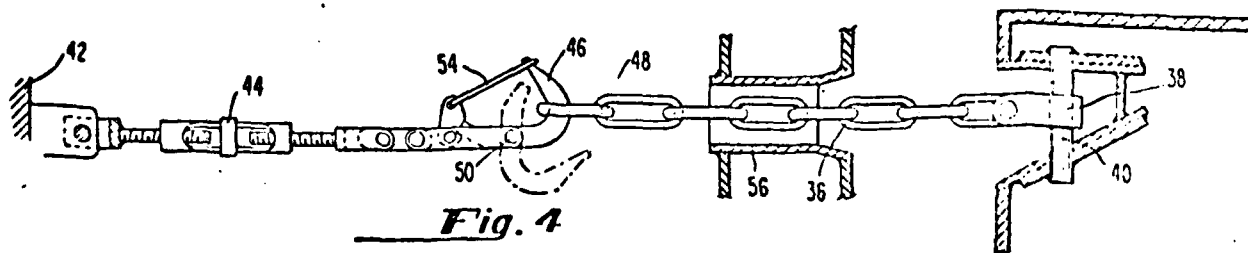
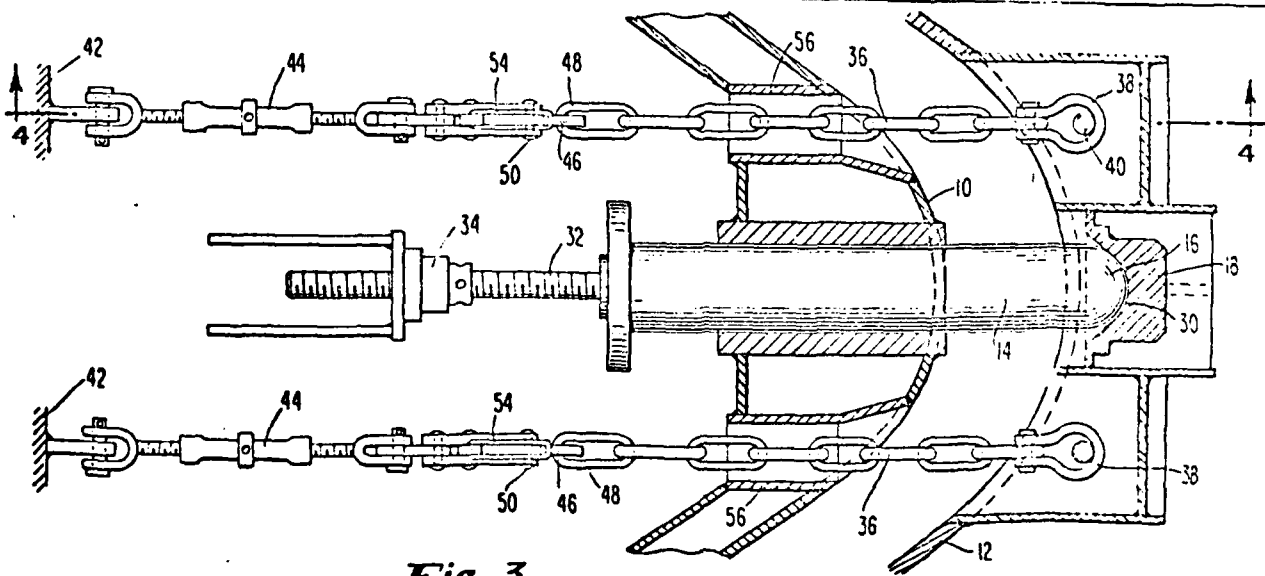
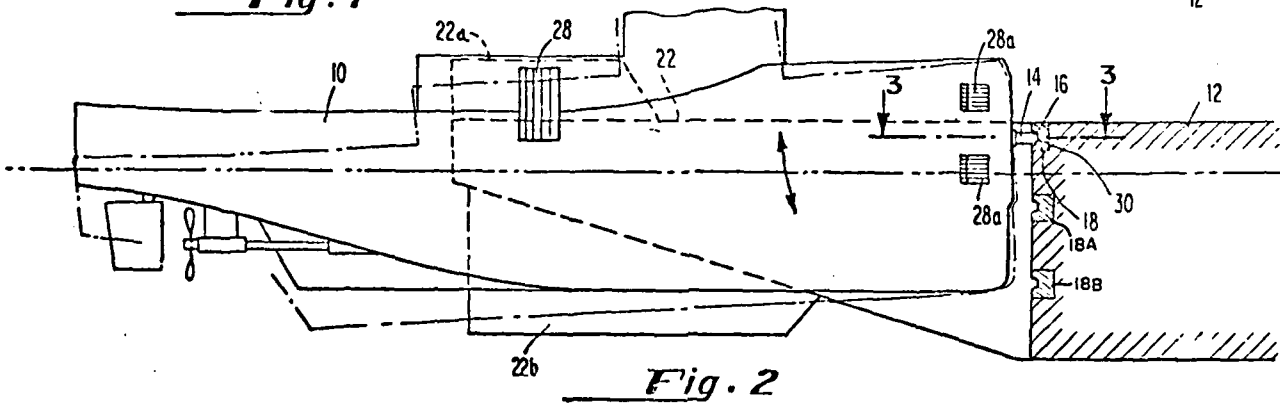
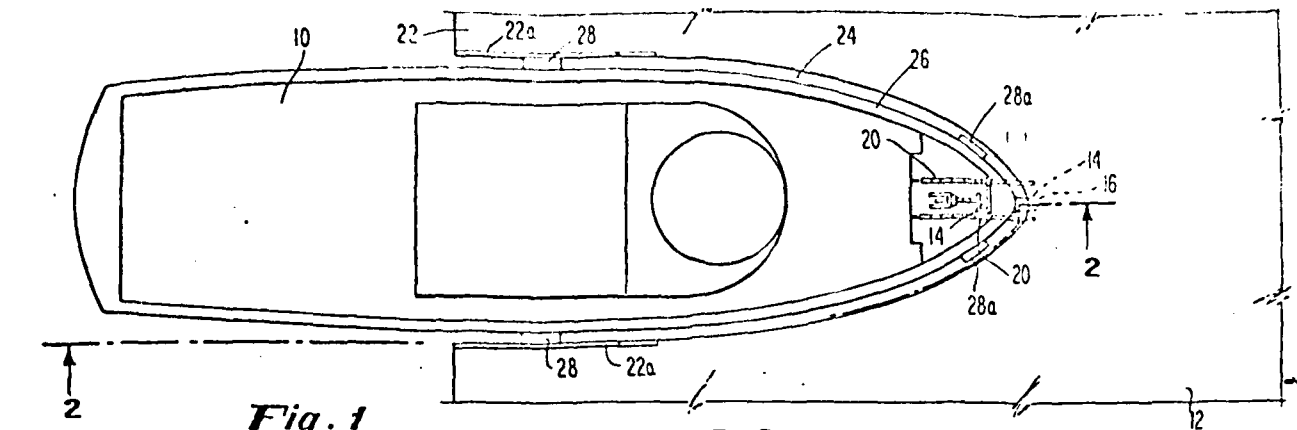
A representative of these new 2nd generation systems is shown in the Interstate and Ocean Transport patent drawings presented in Figure 1.5. This system uses a pin with a hemispherical convex frontal surface that fits into a corresponding concave hemispherical surface in the barge notch to restrain heave. Additionally, the linkage uses chain cables that provide the tension that prevents tug and barge separation. Relative roll between tug and barge is prevented by fenders installed at the after end of the tug. This linkage allows the tug to remain in the notch in up to nineteen foot seas although voluntary separation normally occurs when 12-15 foot seas are expected. Interstate has three barges (Ocean 262, Ocean 190, and Ocean States) and three 5600 HP tugs (Enterprise, Honour, and Valour) fitted with

(15) Most large tugs are twin-screw and powered by high speed diesel engines. Recently, some of the larger tugs have been built with medium or slow speed diesel machinery.

(16) See MTRB (1979) for a more detailed discussion of the availability and distribution of pull-towed OGTBs.

Figure 1.5
Patent Drawings for I.O.T. 2nd Generation
Linkage

U.S. Patent Nov. 23, 1976 Sheet 1 of 2 • 3,993,014



U.S. Patent Nov. 23, 1976 Sheet 2 of 2 3,993,014

this linkage. One of these OGTBs operating with this linkage is shown in Figure 1.6. Additionally, two new single-skin 20,000 DWT tank barges currently under construction for this company will be equipped with it. The linkage should be less expensive to install than most of the 3rd generation designs and provide almost the same capability.

Another deep-notched 2nd generation linkage system has been recently developed by Bulkfleet Marine Corporation, a subsidiary of McAllister. At least two and possibly five 25,000 DWT tank barges are expected to be built with this linkage. As shown in the preliminary line drawings of Figure 1.7, the tug is maintained in the close fitting notch by two sets of tensioned cables, one pair leading from the tug's forecastle and the other pair from its stern deck. Linkage forces are distributed over a wide area of the notch through an extensive system of fenders so that the system may operate in 12-13 foot seas without difficulty. In greater sea states the tug must separate from the barge. The first two tank barges will be powered by 7000 HP MAN medium speed diesel engines and are expected to average 12 knots in their Gulf Coast service.

Other barges with 2nd generation linkages are noted in Appendix B. As explained in the next chapter, it is not expected that many new systems will be constructed with this type of linkage. Some pull-towed systems, however, may be retrofitted with a 2nd generation linkage since it provides these OGTBs with the advantages of push-towing for the majority of operating time at little cost. This has been the case with the Crowley Maritime tank barges 450-1 through 450-5 on which deep notches were installed in the last year to allow them to be almost continuously push-towed on their West Coast and Pacific river trades.

The military potential of 2nd generation OGTBs is practically the same as the 3rd generation loosely-linked systems discussed in the next subsection except they must be hawser towed while transitting the ocean. Unfortunately, such hawser towage may mean that these systems can not participate in the initial stages of a contingency action. However, once they arrive at the operating area, they can provide substantial transport capacity by being used in the pushing mode in coastal and shuttling operations.

Notchless Design

The SEEBECKWERFT 2nd generation linkage of A-G Weser, a subsidiary of Krupp International, Inc., is included here even though it is not of American origin because it has some features that make it of commercial and military interest. The linkage as shown in Figure 1.8 is different from the other 2nd generation linkages in that it does not require a barge notch. Instead, the tug has a double roller fendering head at the bow that can either

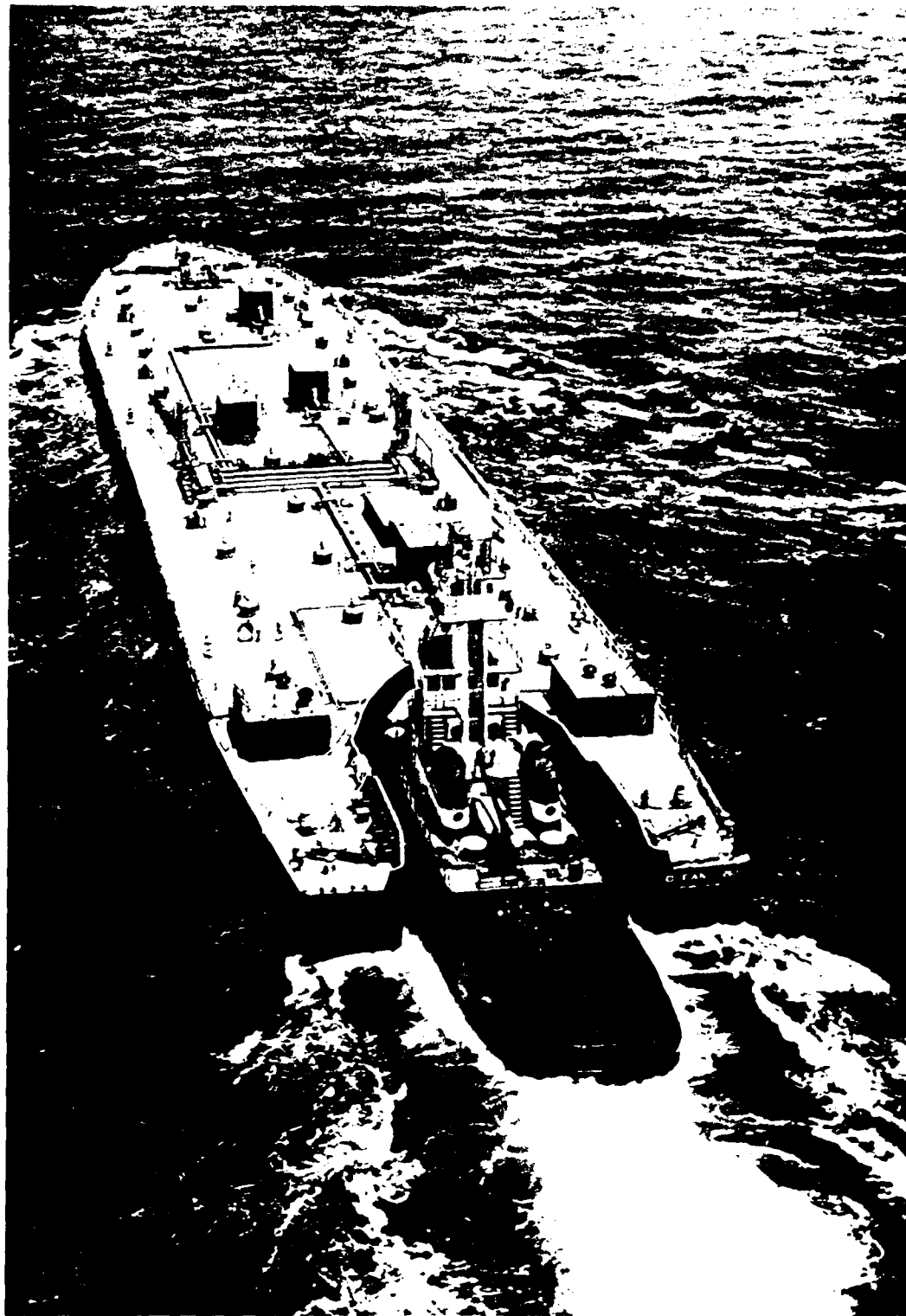


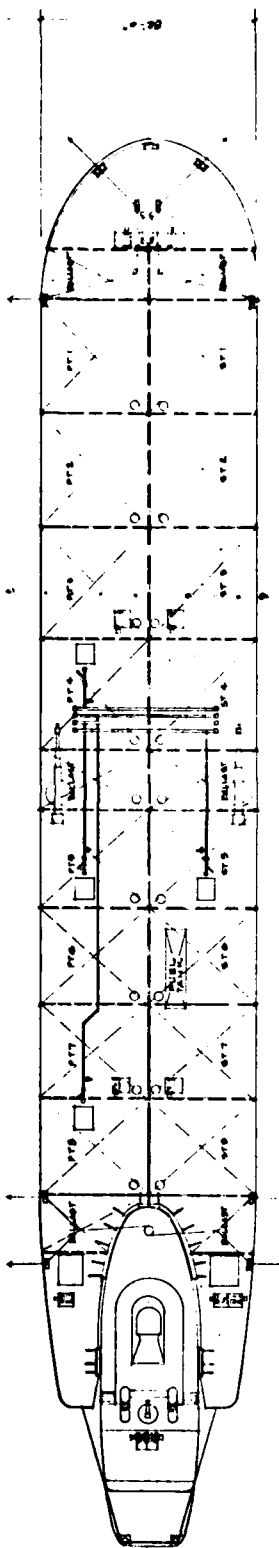
Figure 1.6

I.O.T. 2nd Generation PUSH-Towed OGTB

1-38

Source: Interstate and Ocean Transport
1978 Company Brochure

Bulkfleet Marine 2nd Generation OGTB System



PLAN AT MAIN DECK

PRINCIPAL CHARACTERISTICS

BARGE:	TUG:
LENGTH O.A.	Length O.A.
length B.P.	length B.P.
DRAFT	DRAFT
CARRY	CARRY
GROSS CANNITY	GROSS TONS
NETTOW	NETTOW

BULLFLEET MARINE CORPORATION 1000 Wilshire Beverly Hills, Calif. 90210		TELEPHONE (213) 875-1100		FAX (213) 875-1100	
GENERAL		SALES		SALES	
PRELIMINARY FINANCIAL STATEMENT					
DATE	12/31/99	PERIOD	12/31/99	PERIOD	12/31/99
DESCRIPTION	12/31/99	DESCRIPTION	12/31/99	DESCRIPTION	12/31/99
ASSETS		LIABILITIES		ASSETS	
CASH		ACCOUNTS PAYABLE		CASH	
RECEIVABLES		NOTES PAYABLE		RECEIVABLES	
INVENTORY		LONG TERM DEBT		INVENTORY	
PROPERTY, PLANT & EQUIPMENT		EQUITY		PROPERTY, PLANT & EQUIPMENT	
OTHER ASSETS				OTHER ASSETS	
TOTAL ASSETS		TOTAL LIABILITIES & EQUITY		TOTAL ASSETS	

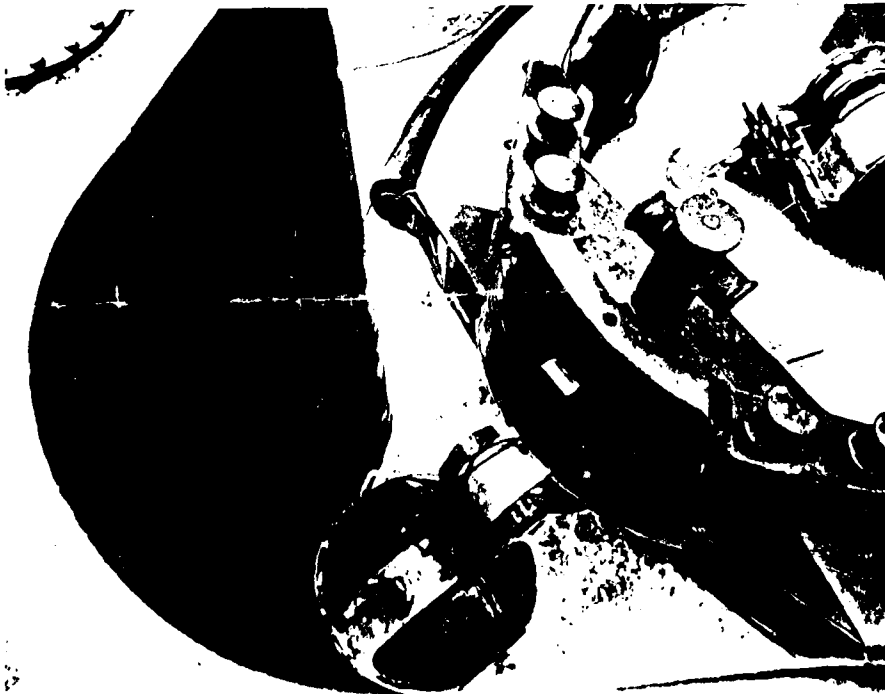
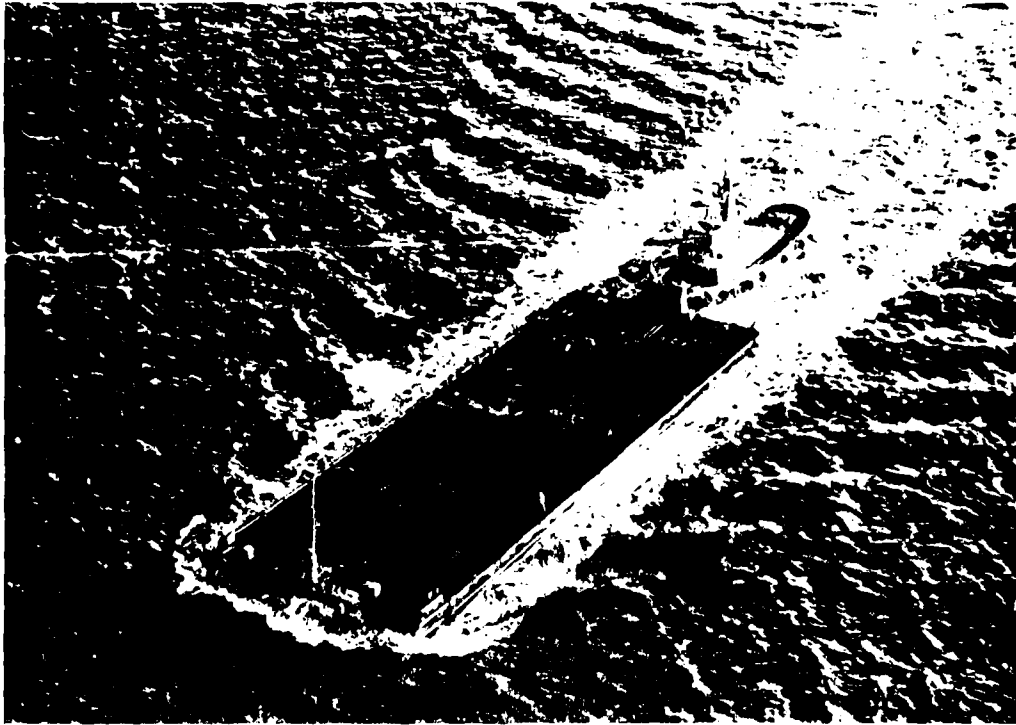


Figure 1.8

Seebeck 2nd Generation OGTB System

Source: A.G. Weser Seebeckwerft Brochure

rotate or roll up and down in a semi-cylindrical slide that is attached to the barge stern. This linkage allows the tug to roll, pitch or heave freely, yet retain its own buoyancy so there is no tendency for the tug to become submerged at the stern or lifted out of the water. The tug is kept in the slot by tensioned cables that lead from a twin-head towing winch on the after part of the tug to the corners of the barge stern. The lack of a notch also allows the tug to be used as an active rudder since it can push at an angle with respect to the barge centerline.

The reason that this design is included here is that it provides the ultimate in tug and barge interchangeability with push-tow operation. Any tug having the fender installed can push any notchless barge that has the slot installed. The cost of such an installation for an OGTB with a 20,000 DWT barge pushed by a 5000 HP tug is estimated by the local distributor to be approximately \$350,000.

Although this system has never been used in U.S. trade, it has been successfully operated by several foreign operators. It is very useful for coastwise service where seas no greater than state seven will be encountered. The only apparent disadvantage that this design will have compared to a deep notched 2nd generation OGTB is that it will likely develop greater linkage drag and so will require more horsepower to be propelled at the same speed. The local distributor believes that this is probably not the reason for its lack of acceptance in this country. It is more likely due to its precise fabrication requirements and its foreign origin. Nevertheless, it seems economically beneficial for retrofitting on pull-towed barges that operate on coastal trades.

As for SEEBECKWERFT's military potential, it seems to be the most flexible linkage available for coastwise and shuttling push-tow operations with moderate size barges (<20,000 DWT). It allows any tug to handle any barge and it can be quickly retrofitted (in less than two weeks if proper preparations are made) on most pull-towed barges and standard tugs without difficulty. The fendering head also allows the tug to be used independently for handling ships for docking. Given all of these potential advantages, the SEEBECKWERFT linkage should certainly be investigated thoroughly for its military potential. In particular, it should be determined in what sea states the linkage may operate without failure and how much additional linkage drag is developed compared to deep notched designs.

1.3.3 3rd Generation Mechanically-Linked OGTBs

There are currently three mechanically-linked OGTB system designs being used in U.S. trades at this time. Two, the Breit/Ingram and CATUG, have rigid linkages. The third, the

ARTUBAR, has a semi-rigid linkage. Additionally, another semi-rigid design, SEA-LINK, is being used by a foreign operator in coastal service. A summary of the particulars of the U.S. flag mechanically-linked OGTBs is presented in Table 1.5. More detailed information about their design and their commercial and military potential is presented in the following subsections.

Breit/Ingram--Rigid Linkage Design

Description: The Breit/Ingram design was the first to be used in U.S. flag trades after Car-Port and SEA-LINK had left the scene. The linkage system is similar to the Car-Port in that the tug is rigidly wedged into the sides and bottom of the barge stern notch. However, the Breit/Ingram design has the additional capability of rapid emergency tug-barge separation and safe independent tug operation. The details of the linkage system are shown and explained in Figure 1.9.

In addition to the particulars given in Table 1.5 about U.S. flag Breit/Ingram OGTBs in operation, the following information is of interest:

The Martha R. Ingram/IOS 3301 tank OGTB has six product segregation with fourteen epoxy coated tanks. The barge can be discharged in less than 24 hours by the use of six deep-well pumps that can pump a total of 20,000 Bbl/Hour. The barge has a 800 HP bowthruster and the tug has twin controllable-pitch propellers.

The Carole G. Ingram/IOS 3302 tank OGTB has four product segregation with twelve epoxy coated tanks. The barge can be discharged in less than 24 hours by the use of four deep-well pumps that can pump a total of 20,000 Bbl/Hr. The barge has a 800 HP bowthruster and the tug has twin controllable-pitch propellers.

The Jamie A. Baxter has two 40-ton gantries with clamshell buckets onboard which are capable of unloading two separate grades of cargo (phosphate fertilizer) simultaneously. The 25,000 tons of cargo can be unloaded into barges on either or both sides of the vessel in a total of 17 hours.

The Valerie F has four center holds designed to self-unload phosphate rock with four cranes and eight wing holds designed for rice carriage on backhaul voyages. These holds can be discharged via four spouts at a rate of 300 LT per spout per hour.

Considerable other information about the Breit/Ingram design is provided in Hukill (1972) and (1974), Pickersgill (1973), MARINE ENGINEERING/LOG (1976a), and SHIPPING WORLD AND SHIPBUILDER

Table 1.5

U.S. Flag Third Generation OCTBs

Linkage Design	Barge Type/Service	Name: Tug Barge	Dimensions (LxWxD): Tug Barge	Tug-Barge Draft Length	Tug-Barge HP/Design Speed DWT	When Built: Tug Barge	Where Built: Tug Barge	Owner/Operator
Breit/Ingram	Taconite Dry Bulk/ Great Lakes	Presque Isle Presque Isle	140.33'x54.0'x31.25' 974.5'x104.58'x46.50	29' 1000'	14,840/16mph 52,000	12/73 "	Halter Marine Erie Marine	Crocker National Bank/ U.S. Steel
Breit/Ingram	Clean Products Tank/Ocean	Martha R. Ingram 10S 3301	145.84'x46.0'x30.25' 584.5'x87.0'x46.33'	37'5" 620'	11,128/14.1 Kts 36,500	7/71 3/71	Southern Shipbuilding Alabama Drydock	Ingram Corp.
Breit/Ingram	Clean Products Tank/Ocean	Carole G. Ingram 10S 3302	145.84'x46.0'x30.25' 584.50'x87.0'x46.33'	37'5" 620'	11,128/14.0 Kts 37,500	3/72 "	Southern Shipbuilding Livingston Shipbuilding	Ingram Corp
Breit/Ingram	Rice-Phosphate Dry-Bulk/Ocean	Valerie F Valerie F	150.67'x54.0'x34.0' 620.0'x85.0'x45.0'	30'8" 656'	16,000/15.5 Kts 25,000	12/76 "	Southern Shipbuilding Maryland Shipbuilding	
Breit/Ingram	Fertilizer Dry-Bulk/Ocean	Jamie A. Baxter CF-1	125.0'x45.0'x27.75' 500.0'x75.25'x46.5'	32' 600'	7200 /12.5 Kts 22,500	6/76 12/77	Peterson Builders Avonsdale Shipyard	C.F. Industries
CATUG	Oil Tank/ Ocean	Seabulk Challenger SSC-3901	116.08'x90.44'x38.42' 581.0'x95.0'x46.0'	37' 629'	14,000/15.5 Kts 35,000	1/75 "	Galveston Shipbuilding (Kelso Marine)	Hvide Shipping/ Shell Oil
CATUG	Chemical Tank/Ocean	Seabulk Magnachem SSC-3902	116.08'x90.44'x38.42' 582.17'x95.0'x52.0'	40'1" 615'	14,000/15.5 Kts 40,000	2/77 "	Galveston Shipbuilding (Kelso Marine)	Hvide Shipping/ Diamond Shamrock
CATUG	Superphosphoric Acid/Ocean	Two or Three Systems to be Named	126'5"x90'4"x39' 626'6"x99 x50'	36' 677'10"	18,200 /15.5 Kts 41,250	80+	Avondale Shipyard	Occidental Oil
CATUG	Oil Tank/ Ocean	Two Systems to be Named	127'7"x90'4"x39' 645'x95.0'x61.6"	40'6" 699'4"	18,200/15.5 Kts 47,075	80-81	Halter Marine Bethlehem Steel	Amerada Hess
ARTUBAR (2-units)	Ro-Ro/ Ocean	JJ Oberdorf GR Moir Barge Names Unknown	140'x40'x 568'x85'x41'6"	19' 605'6"	7,500/-16 Kts 6450(165 40' containers 50 cars)	79-80	Marinette Marine Seatrain Shipbuilding	Coordinated Caribbean Transport

PUTTING IT TOGETHER...

The barge portion of the unit is built with a large notch in the stern into which the forward two-thirds of the tug fits with a minimum of clearance. Within the confines of the notch on the barge are two large box girders tapered at the stern end.

There is a hydraulic ram on the tug's bow, and aft on each of its sides are large wedge-shaped receptacles, integral parts of the entire hull. These wedge-shaped structures are lined with steel pads mounted on blocks of laminated elasticized material.

The taper of the barge's box girders fit the tug's wedge structures and are pulled by the hydraulic ram to a predetermined point that provides the required preloading to keep the tug motionless in relation to the barge.

The tug enters the notch under its own power and goes forward until grounded on the bottom of the notch. The hydraulic ram extends forward, locks to a structure on the barge and then retracts, pulling the tug wedges into a solid connection with the barge's box girders.

To detach the tug from the barge, the foregoing procedures are reversed. Disconnect time generally is accomplished in less than two minutes, and the entire operation is handled by one man operating a control console on the bridge.

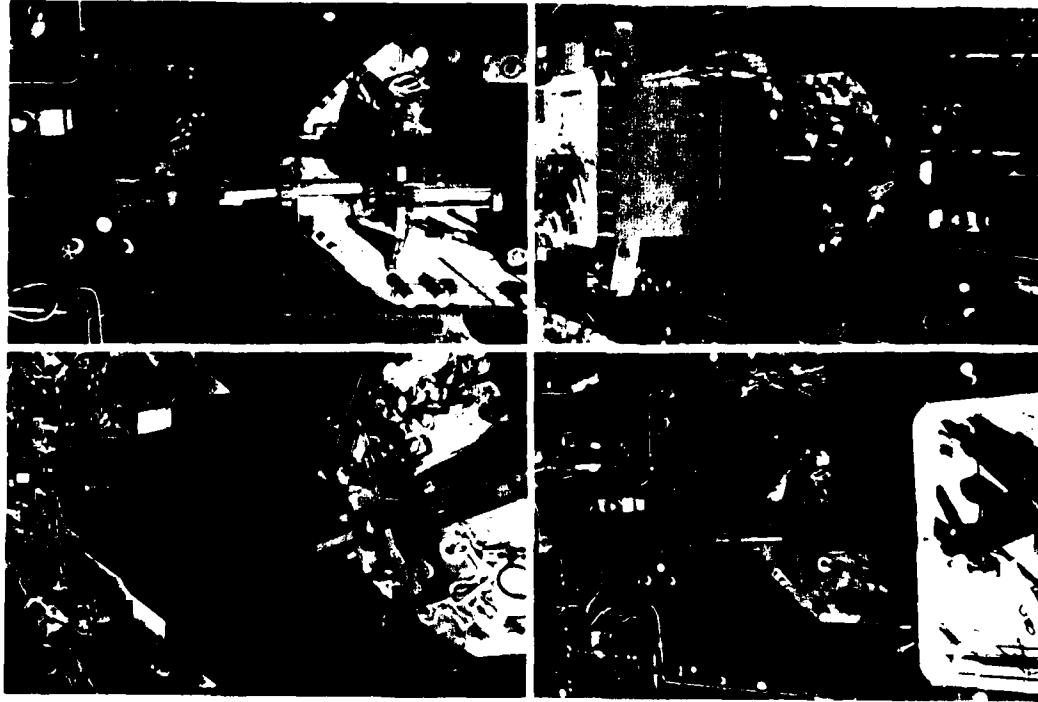


Figure 1.9

Title: Breit/Ingram Linkage

Source: Ingram Ocean Systems
Company Brochure

(1974b). Additional information can be obtained from the licensor listed in Table 1.4.

Commercial Potential: This design was an early commercial success. Since the construction of the Martha R. Ingram/IOS 3301 in 1971 four other systems have been put in U.S. trade, the latest being delivered in 1977. Additionally, three systems have been put into foreign flag service. One of these, for Japanese operation, consists of two tugs and six barges which are used in two drop-and-swap mode trades. This proves the ability of the design to operate in the drop-and-swap as well as integral mode. Also, one foreign flag system has the tug designed for high speed independent operation for salvage work. This proves that the tug, although not conventional in bow shape, has the flexibility to be used in non push-tow operations.

Currently no Breit/Ingram design OGTB is under contract or construction. Internationally, this may be due to the general downturn in ship construction; and domestically, it may be due to the tougher competition from other designs. The Breit/Ingram design does have some disadvantages in addition to those generally applicable to mechanically-linked OGTBs as discussed in Chapter 2. The primary disadvantage is that in order for the linkage to remain rigid while withstanding ocean forces, the hull scantlings have been designed heavier than for a comparable ship. Specifically, the tank barges have bottom scantlings 6.5% and deck scantlings 3.3% greater than those for a ship of equivalent size. These scantlings are also 12% greater than for a simple notched barge. These heavier scantlings, the five million pound force hydraulic ram, and the complex tug bow and barge notch lines make the linkage system quite expensive. These factors may have led to the recent interest in the CATUG design for transoceanic trades and the new loosely-linked designs for coastal trades.

Military Potential: The Breit/Ingram design has the potential of being used in any application that is handled by a moderate speed (<20 KTs) ship. It is proven trans-ocean capable and may be built to any militarily useful size. One design has even been developed for a 100,000 DWT barge at a 43 foot draft with the ability to carry 82,000 DWT at 38 feet.

As with any OGTB, this system has the flexibility of drop-and-swap and independent tug operation. Unfortunately, none of the U.S. flag tugs and barges are currently interchangeable so drop-and-swap operation with current assets is not feasible.

As there is no relative movement between tug and barge while underway, there is no reason why the barge cannot be manned if necessary. This would allow underway replenishment operations if required. Additionally, fuel and power connections between

the tug and barge can be easily designed to increase cruising range or to support habitability containers or weapons systems.

With respect to a mobilization, a newly constructed system of this type could probably be delivered months earlier than a ship of same size due to concurrent barge and tug construction at specialized yards. However, since this design requires a carefully engineered and complex linkage as well as a ballast system, it should take longer to construct than one of the simpler loosely-linked 3rd generation designs; and, it would not be viable for quick retrofitting onto a standard tug and barge.

CATUG--Rigid Linkage Design

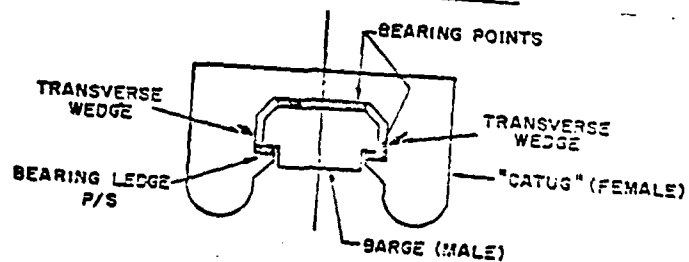
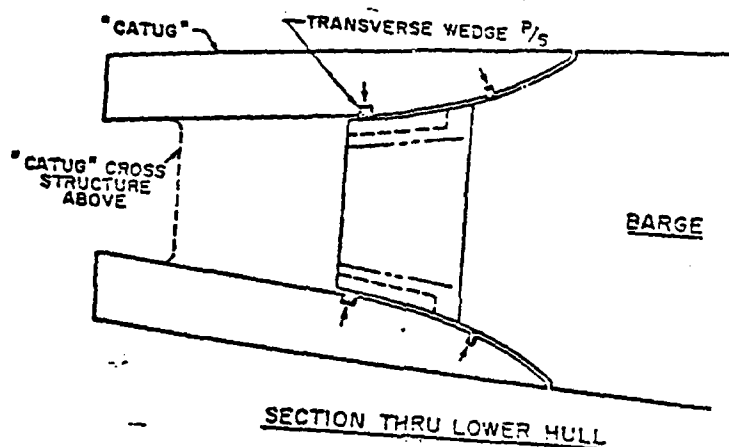
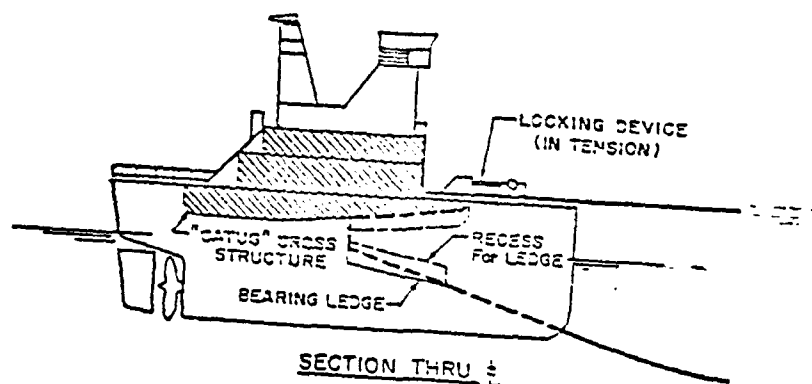
Description: The CATUG design followed the Breit/Ingram linkage by four years, the first CATUG OGTB being delivered in 1975. The linkage is practically the inverse of the Breit/Ingram design. That is, rather than having the tug bow wedged into a barge notch, the CATUG has a protruding barge extension wedged between a catamaran tug's twin hulls and under the connecting platform. The details of the linkage are shown in Figure 1.10.

In the linkage, the CATUG uses a gathering type wedge fit, in that the extension from the barge is tapered. Two tensioned hydraulically operated latches are provided on the tug foredeck which engage adjustable sockets on the barge afterdeck. These latches hold the tug on the barge extension and preload topside and bottomside bearing points in compression. There are four of these bearing points between the tug and barge units. Two are between the top of the barge and the underside of the catamaran cross structure platform, each off to the side. The other two are beneath, between the barge extension and a ledge-like extension on the inside of the CATUG hulls. These bearing points are surfaced with greenheart, a very dense and moisture-stable wood, and prevent relative transverse movements of the hulls. Separation of tug and barge can be accomplished in less than two minutes.

In addition to the particulars given in Table 1.5 about the U.S. flag CATUG OGTBs in operation or under construction, the following information is of interest:

The Seabulk Challenger tank OGTB has five product segregation with eighteen epoxy coated tanks. The barge can be discharged rapidly by five 4500 gpm diesel-driven deep-well pumps plus a 2500 gpm special products pump. The barge is equipped with a 920 HP bowthruster and each of the catamaran hulls of the tug has a 17 foot propeller.

The Seabulk Magnachem is a special products tank OGTB and thus has a sophisticated cargo arrangement to handle caustic soda, chlorinated hydrocarbons, and solvents. The barge has



SOURCE: Waller (1972)

Figure 1.10
CATUG OGTB LINKAGE DESIGN

an epoxy coated double-bottom and is divided into 22 tanks, all strengthened to carry cargoes of 1.62 specific gravity. These tanks are serviced by sixteen separate loading and discharging lines and by 20 pumps, 15 of which have 850 gpm pumping rates. All but the small forward center tanks are coated with Amercoat 75 and contain stainless steel heating coils. All deck lines servicing all but the forward tanks are steam traced and insulated. The tug is practically identical to the one on the Seabulk Challenger and the barge has a 1000 HP bowthruster.

The three CATUGs for Occidental Oil are being built with MARAD Construction Differential Subsidy (CDS) funds. They will be operated by a sixteen member crew (without a radio officer) between Florida and the Black Sea. These double-bottomed vessels will carry superphosphoric acid (SPA) in their center tanks and liquid cargoes in the wing tanks during backhaul legs. The five center tanks and associated pumps, piping, heating coils and exchangers are of stainless steel construction. These tanks are also heavily strengthened since SPA has a high specific gravity (2.0). All fifteen tanks are serviced by individual deep-well pumps that feed into two discharge headers, one for the wing tanks and the other for the center tanks. The tanks can be discharged in less than 24 hours at a rate of 2000 LT/Hr. Additionally, it should be mentioned that the barge will not be equipped with a bowthruster since the operator felt it unnecessary due to the maneuverability of the CATUG resulting from its widely spaced twin screws.

The two CATUGs being built for Amerada Hess are double-bottom tank barges carrying in thirteen cargo tanks 40,433 long tons at the 36'0" design draft and 47,075 long tons at the 46'6" maximum draft. Each barge has four product segregation and can discharge a cargo of diesel oil via thirteen 4000 GPM hydraulically driven deep-well pumps (one in each tank) in sixteen hours. The tanks are epoxy coated and have heating coils to allow carriage of heavy fuels. As with the Occidental CATUGs, no bowthrusters are installed on these barges.

Considerable other information about the CATUG design is provided in PORT OF GALVESTON (1973), JACKSONVILLE SEAFARER (1975), MARINE ENGINEERING/LOG (1976c), SHIPPING WORLD AND SHIPBUILDER (1974f), Stevens (1976), and Seabulk Corporation (1971?). Additional information can be obtained from the licensor listed in Table 1.4.

Commercial Potential: This design is currently the most commercially active of the mechanically-linked OGTBs, especially after the recent orders for five systems from Occidental Oil and Amerada-Hess. Four to six other systems are currently under negotiation with Amerada-Hess. The reason for such recent success may be due to a combination of aggressive marketing and some in-

herent advantages in the CATUG design. The two principal advantages resulting from twin vice monohull construction are (1) it provides better propulsive efficiency and maneuverability due to the wide spacing of the propellers, and (2) it results in smaller transverse and vertical tug-barge interface loads and barge rake torsional loads because the barge and tug rolling periods are more closely matched. This second advantage allows the tug-barge interface to be built with less reinforcement than that needed in the rigid-linked monohull designs. The money saved for this reason and because of the simplicity of the barge extension compared to a notch will at least equal the additional cost that results from the complex catamaran hull construction for the tug. Thus, the CATUG capital construction costs are found not much different than those of monohull designs.

The CATUG design does have less flexibility than the Breit/Ingram design. Its tug, although seaworthy, cannot be used for towing or any other independent mission satisfactorily. The barge could be towed independently if necessary, but it was not really designed for such operation. Besides the above comments, all the information concerning the commercial viability of mechanically-linked OGTBs discussed in Chapter 2 apply.

Military Potential: The CATUG design has the potential of being used in any application that is now handled by a moderate speed ship. It is proven trans-ocean capable and may be built to any military useful size. One design has been developed for a 85-102,000 DWT barge.

As with any OGTB, this system has the flexibility of drop-and-swap operation. Although there are currently an equal number of tugs and barges so that commercial drop-and-swap operation is not planned, the Seabulk Magnachem and Challenger or the Occidental and Amerada Hess CATUGs can exchange tugs and barges. This interchangeability might be useful for some military operations as discussed in Chapter 3.

As there is no relative movement between tug and barge while underway, there is no reason why the barge cannot be manned if necessary. This would allow underway replenishment operations if required. Additionally, fuel and power connections between the barge and tug can be easily added to increase cruising range or to support habitability containers and weapons systems.

With respect to mobilization, a newly constructed system of this type could be delivered months earlier than a ship of the same capacity due to concurrent barge and tug construction at specialized yards. However, since the CATUG is of complex form, this system might take longer to construct than a monohull design in most tug yards. Certainly, the CATUG system is not amenable for retrofit on standard tugs and barges due to its peculiar twin hull design.

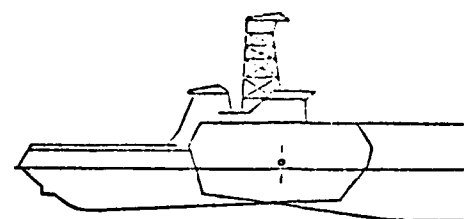
ARTUBAR--Semi-Rigid Linkage Design

Description: The ARTUBAR (ARTiculated TUG BARGE) linkage design was developed in the late sixties. However, it will not be until late 1979 that the first ARUTBAR system will be in U.S. flag operation even though a Japanese system has been operating since 1975. Reasons for this delay will be presented later.

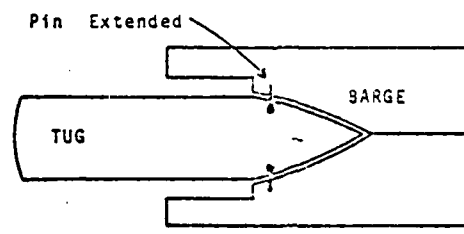
The linkage is conceptually simple. It consists of two large transverse pins that are hydraulically extended from both sides of the tug's bow into corresponding sockets in the barge's notch. The pins allow the tug to pitch in the notch so that the linkage forces are substantially smaller than those produced by a rigid linkage design. Also, there are fenders installed at the bow and side of the tug that prevent damage to the notch during pin alignment. The pins may be retracted in seconds and the tug and barge can be separated in any sea state. Additionally, the system can be designed so that the tug can link with the barge in up to 15 foot seas in just a few minutes. This is beyond the capability of the rigidly-linked designs. It should be noted that several sets of sockets can be installed to match the normal operating drafts in ballast and loaded conditions. This will reduce the need for expensive ballasting equipment for the tug. Besides the pin linkage, the ARTUBAR design may also include wing-wall skegs that make up the barge notch. Such wing-wall skegs reduce the barge's pull-tow frictional resistance by at least 50% compared to barges with standard skegs. Details of the ARTUBAR linkage including wing-wall skegs are shown in Figure 1.11.

The ARTUBAR linkage was originally designed to be installed onboard the Gulfcoast Transit Company's Betty Wood/Marie Flood in 1972. However, when the operator learned that the U.S. Coast Guard refused to reconsider its decision to require the tug to be inspected and have licensed crews, he decided to build the tug and barge with an ARTUBAR system without pins. It operates as a 2nd generation push-towed system with tug and barge linked together by cables. However, in seas greater than twelve feet, the tug must leave the notch and take the barge on a hawser.

Currently there are two RO/RO OGTB systems being built with MARAD CDS funds for Transway International's subsidiary Coordinated Caribbean Transport (CCT). The twin screw tugs have a very high pilot house sightline, 59 feet above the water, to allow good visibility over the light displacement RO-RO barge. The tug-barge profile is shown in Figure 1.12. The barge has the capability of carrying 165 40-foot trailers and 58 automobiles on its spar, upper, and main decks and tank top. It is loaded via a bow ramp and three side ports to the main deck and then through internal fixed ramps to the other decks. The barge is also equipped with a 1200 HP bowthruster.

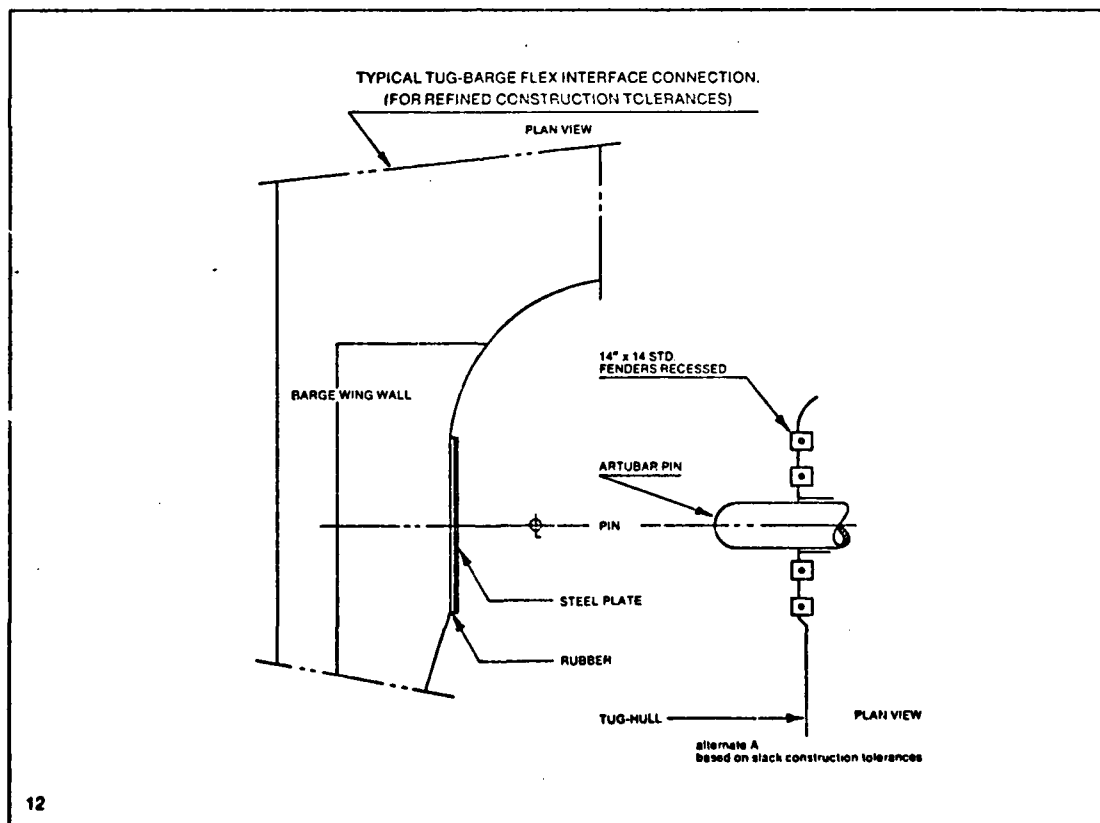


Deep Notch-Pinned "Artubar"



From the tug, port and starboard pins are extended toward the barge. The bullet shaped pins aid alignment. In the extended position, the pins fit into lubricated sockets within the barge.

Source: Waller (1977)



Source: Fletcher (1974)

Figure 1.11

ARTUBAR Semi-Rigid
OGTB Linkage

More information about the ARTUBAR design can be found in Fletcher (1968), (1969), (1970), (1974), (1975), MARINE ENGINEERING/LOG (1976e), and SHIPPING WORLD AND SHIPBUILDER (1969) or from the patent owner or designer listed in Table 1.4.

Commercial Potential: As the first units of this design will be put in U.S. flag operation in 1980, their commercial potential in U.S. foreign trades will only be learned later on. However, there are some points that can be made concerning their commercial viability compared to the rigid-linked designs discussed previously.

First, the ARTUBAR design should be significantly less expensive to construct than either of the two rigid designs. This is primarily because the barge scantlings and, consequently, its hull weight can be made quite a bit lighter. This is the result of the ABS rules requiring that the scantling length be determined from two-thirds of notch length forward of the barge stern to the barge bow rather than from the tug stern to barge bow as required for rigid designs. Additionally, the ARTUBAR system should be less expensive to build because it is essentially made up of a standard ocean-going tug and a deep notched barge with only a hydraulic pin assembly added. The designer estimates that the cost of such hardware for a 15-20,000 HP tug and a barge of up to 60,000 DWT would be about \$1,000,000.

The use of standard tug and barge units makes the ARTUBAR more flexible than the rigid designs. The tug could be used for any normal tug function including pushing or pulling (if towing winch is installed). The barge, with wing wall skegs, is especially designed for good steerability with less than usual resistance when pull-towed. Also, since the linkage connection is made via pins only, any ARTUBAR tug could operate with barges of various size and function. For example, the CCT tugs could operate with up to 60,000 DWT barges, if only slow speeds are required. And, as the system can link in moderate seas, it is also more suited for drop-and-swap operations. The Japanese system with two barges and one tug operates in this mode.

The ARTUBAR system does have the disadvantage of being more expensive to operate than the rigid designs since its hull lines are not as smooth. The additional resistance and fuel cost may be as much as 10%, although this might be reduced substantially if fairing flaps are added to smooth over the linkage area.

Military Potential: The ARTUBAR design has the potential of being used in any application that is now handled by a moderate speed ship. From the Japanese system it has been proven trans-ocean capable. It may be built to any military useful size, as one design has been developed for a 70,000 DWT barge.

As with any CGTB, this system has the flexibility of drop-and-swap operation. It is better capable than the rigid-linked designs to correct in moderate seas--up to 15 feet. This may be very useful in shuttle type operations where the barges are anchored offshore. It should be noted that the two CCT systems will have interchangeable tugs and barges although they will not be operated in drop-and-swap mode.

Although there is relative movement between tug and barge while underway, the motion near the pin linkage is practically nil. Thus, there is no reason why the barge cannot be manned and why personnel could not move between tug and barge. This would allow underway replenishment operations from the barge if necessary. Additionally, fuel and power connections between the tug and barge can be designed through the pins to increase cruising range or to support habitability/weapons systems.

With respect to mobilization, a newly constructed system of this type could probably be delivered months earlier than a ship of same capacity due to concurrent barge and tug construction at specialized yards. Additionally, ARTUBAR should be capable of being built more rapidly than the rigid linked designs since the tug and barge can be of standard form. Also, an ARTUBAR linkage is capable of being retrofitted on a standard tug and barge. The designer estimates that a retrofit could take place in 45 working days assuming that the ARTUBAR pin components were available. Such a retrofit could be easily done so that all tugs and barges of various sizes would be interchangeable.

Of all the mechanically-linked systems, the ARTUBAR system seems to have the most potential use for military application since it has an inherently more flexible design. Its tug and barge components not only can be interchanged in drop-and-swap operations but also can be used effectively as independent vessels.

SEA-LINK--Semi-Rigid Linkage Design

Description: The SEA-LINK linkage design was first proto-type tested on some standard tugs and barges in the mid 1960's. At that time, the linkage failed due to problems in fabrication and design. After extensive analysis and investigation, an improved linkage was developed that also restricted rolling movements between the tug and barge as well as yaw, sway, and surge which was restricted in the original design. In 1973 this new linkage was installed on a 1450 HP tug and three 800 DWT barges operated by the San Miguel Corporation (SMC) of the Phillipines. This system allows the tug to push either one barge or two barges in tandem.

The linkage was designed to approximate the ease of operation and rugged simplicity of a railroad coupler. This is of importance in the routine coupling and uncoupling of barge

flotillas in port as well as for emergency disconnect capability for safety.

The linkage between tug and barge is provided by a pushing frame hinged to the stern of the barge and pinned to the tug amidships. The frame acts essentially as a double pinned hinge with the hinge pin axes horizontal and transverse to the vessels. The tug and barge can be separated by either manually or hydraulically releasing the frame from the barge or the tug. The connection between the barges is the equivalent of a single pin hinge permitting relative pitch only. Thus, the barges must either be at nearly the same draft for linkage or the barges must be provided with a series of fittings at different heights. The linkage as installed on the SMC tugs and barges is shown in Figure 1.13.

More information about the SEA-LINK system can be found in Glosten (1967), (1972), (1973), (1975), San Miguel Corporation (1977?), MARINE ENGINEERING/LOG (1976d), and SHIPPING WORLD AND SHIPBUILDER (1974d) or by contacting the designers listed in Table 1.4.

Commercial Potential: The SEA-LINK installation for the San Miguel Corporation has been so successful that additional units were recently added to the flotillas. The linkage is capable of being installed on any conventional tug and barge, notchless or not. The cost of the installation depends on the forces expected which is a function of the sea states, speed of operation, and barge size. The SMC linkage weighs about 30 tons and would cost \$100-150,000 to construct. It operates without difficulty in 12 foot seas. Costs for the linkage on larger barges designed to operate in rougher seas are hard to predict, but the designer feels that systems of less than 8,000 DWT operating in non trans-ocean trades would be economically feasible.

The system can also operate with two barges in tandem. More barges are considered impractical due to the lateral bending moments generated at the linkages in long flotillas of linked barges. However, two tandem barge operation has been successful in the Phillipines and might be appropriate for certain coastal trades in the United States.

SEA-LINK has not been successful in U.S. trades probably because the proper conditions for its use were not found--rather small barges operated at low speeds in moderate seas. However, it is certainly an inexpensive system that allows 100% push-towing in trades for which it is suited.

Military Potential The SEA-LINK design does not have the same capabilities as the other 3rd generation mechanical linkages. It is not practical for use in trans-ocean crossings nor for barges of greater than 8,000 DWT. However, the system does seem appro-



Fig. 1 - 1450 horsepower tug SAN MIGUEL HOPSTER pushing two barges in tandem.



Fig. 2 - Sea-Link installation on SAN MIGUEL HOPSTER.

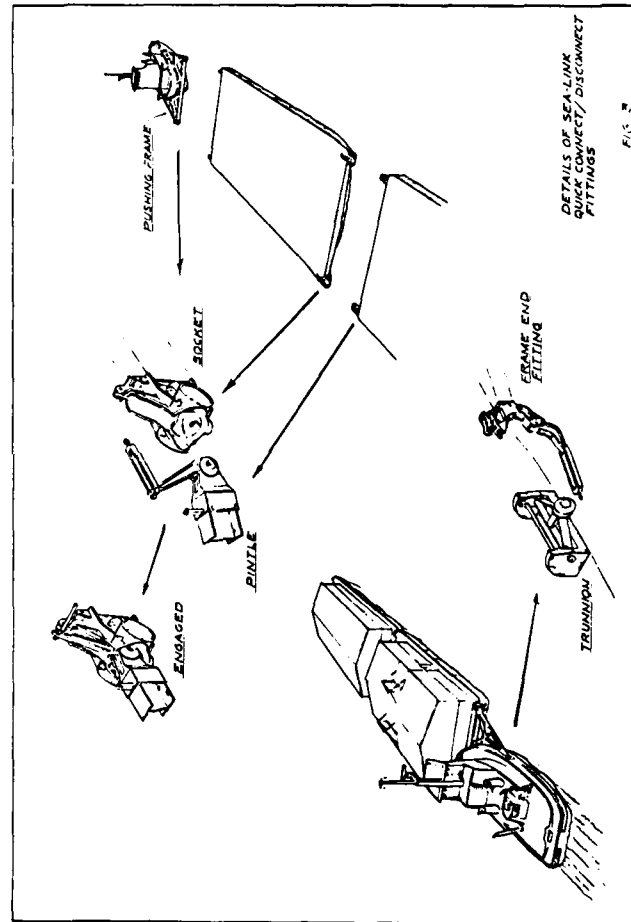


Figure 1.13
Sea-Link Semi-Rigid 3rd Generation OGTB System

Source: Glosten (1975)

prate for coastwise shuttling operations, i.e., the movement of POL and material from a major port to minor facilities. The tandem barge capability adds additional flexibility by allowing at least two ports to be served on a given voyage. Due to the simplicity of the linkage, a barge could be easily dropped off and used as a floating warehouse and then retrieved later when empty for resupply.

The SEA-LINK system is also militarily attractive in that a linkage could be installed on any standard commercial tug and barge very quickly and cheaply. Since all that is required is the fitting of the frame fittings on the tug and barge, the linkage could probably be installed and even built in the field, if necessary.

Also the linkage could be considered for use in the movement of barges from amphibious ships. Rather than having all the barges self-propelled, they could be handled by a fewer number of SEA-LINK equipped tugs, assuming that all the barges are not required at once. This would save money and make more efficient use of the powering units. Alternatively, each barge could have its own SEA-LINK equipped powering unit that could detach from the barge if it is damaged or is needed to remain at the beach. Such flexibility may be worth the additional cost of two component construction.

In any case, the SEA-LINK system should be considered in operations that require the movement of small amounts of cargo in coastwise and/or shallow draft areas under reasonable sea states. It allows the economic, safety, and flexibility advantages of push-towing at reasonable cost.

1.3.4 3rd Generation Flexibly-Linked OGTBs

There is only one flexibly-linked OGTB system under development in the U.S. at this time. Although not currently in commercial use, it has sufficient commercial and military potential to be mentioned here.

FLEXOR--Flexibly-Linked OGTB

Description: The FLEXOR linkage concept has been under development since the early 1970's. Although it is not used yet in commercial service it has been successfully full-scale proto-type tested and is being used as the new U.S. Navy pontoon bridge connecting device. The normal FLEXOR ocean-going installation consists of up to four barges of up to 8000 DWT per barge, a bow unit, and a tug unit, connected to each other by a pair of longitudinal steel/rubber pins called FLEXORs. The pins fit into receptacles that have been designed with a quick release guillotine mechanism. The FLEXORs have heads made of cast steel which

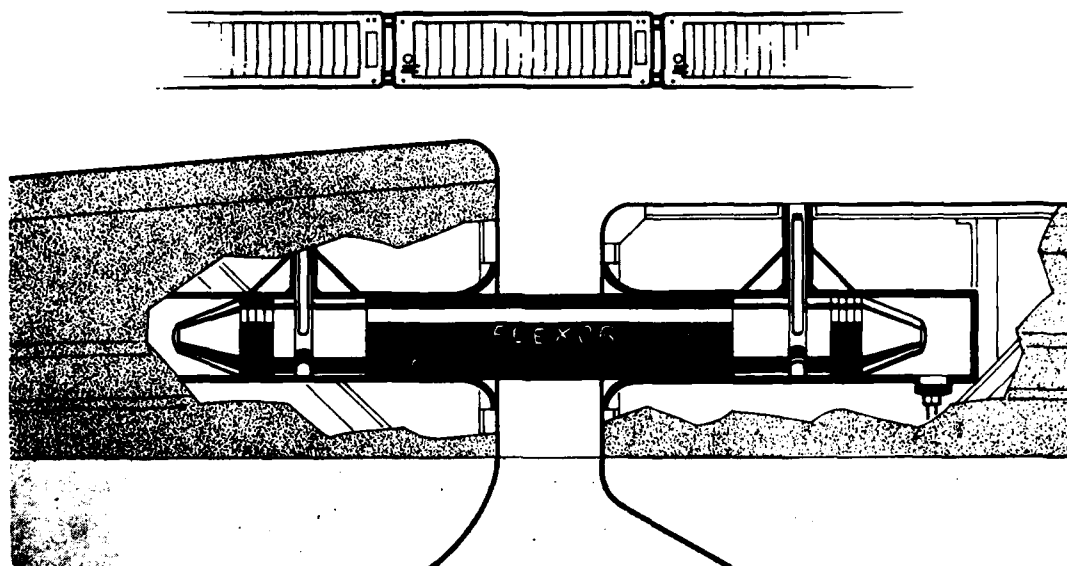
are separated by a urethane body interdisposed with steel plates. This method of construction makes these devices extremely strong and flexible. The body is pretensioned by cables connecting the heads. The flexibility of the FLEXOKs allow the different components to have some relative motions in all degrees of freedom which prevents build up of excessive force at the linkage area. Details of the linkage is shown in Figure 1.14 and artist illustrations of how a commercial FLEXOR system might look is shown in Figure 1.15. More information about the FLEXOR linkage system can be found in Marriner (1968) and (1972), Barge Train, Inc. (1971), (1973a), (1973b) and (1978), Appenbrink (1974), Brown (1977) and Hautanen (1975) or from the designer listed in Table 1.4.

Commercial Potential: The FLEXOR system has been developed for a different type of commercial operation than that suited for the loosely and mechanically-linked designs. Instead of being used to push single large barge in a point-to-point coastwise trade, it has been designed to push a series of smaller barges (<8000 DWT) in a train type operation. In this type of trade the barges would be dropped off and/or picked up at a series of ports during a single voyage. The advantages of such a type of operation are obvious. It has been used for quite some time on the great rivers of this country. It allows trains of different types of barges of various origins and destinations to be moved along the coast. The barges could be owned by the consignor, consignee, or barge company, and could be kept for storage as well. Essentially, FLEXOR allows the typical multibarge river system to become ocean capable.

There are several reasons why the FLEXOR has not yet been used in commercial trades. Probably the major one is that its use demands a type of operation radically different from the usual coastwise tug-barge operation. As the maritime industry is very conservative, such novelty is slow to be accepted. Additionally, in order to implement the barge train concept, several barges have to be built concurrently for different shippers who would be willing to coordinate their capital investments and movements. This might be a very difficult task for most U.S. coastal trades. Thus, FLEXOR might be first developed in a Great Lakes-river or river-coastal trade which would allow river barge systems to be moved on rougher waters.

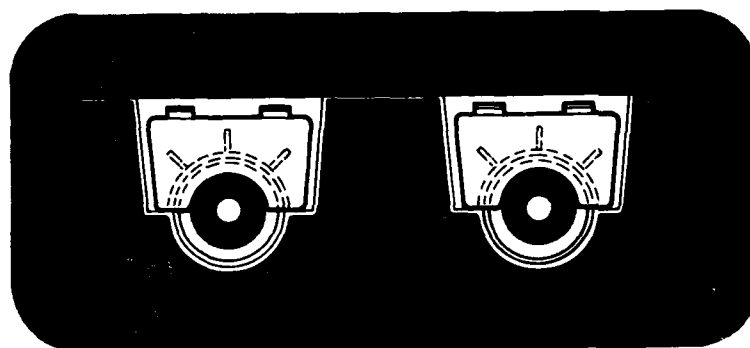
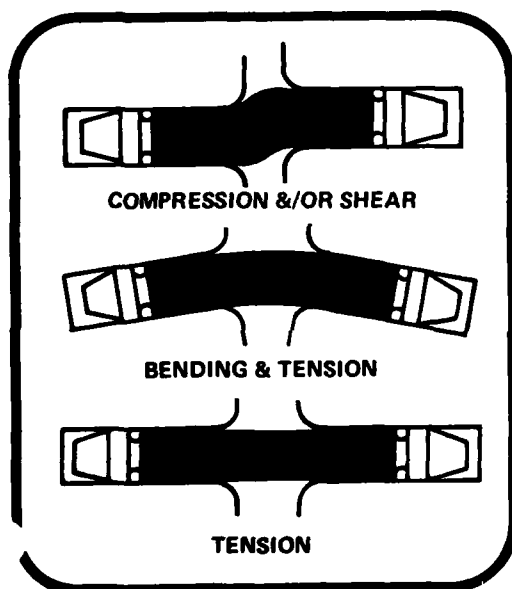
Military Potential: Although the FLEXOR is not designed for long distance or trans-ocean operation, it certainly could be very useful in coastwise or shuttling operations. The ability to push several small barges at the same time would allow several small shallow draft ports to be resupplied from various depots on a single voyage with one or two barges being dropped off and/or picked up at each port.

The FLEXOR system installed on pontoon barges has proven itself in U.S. Navy Civil Engineering Laboratory exercises. Al-



TYPICAL INSTALLATION

**BARGE TRAIN, INC. FURNISHES FLEXORS AND FLARED CONNECTOR
PIPES COMPLETE WITH LATCH MECHANISM.**



SECTION THRU LATCH MECHANISM

Figure 1.14

FLEXOR Linkage

Source: Barge Train (1971)

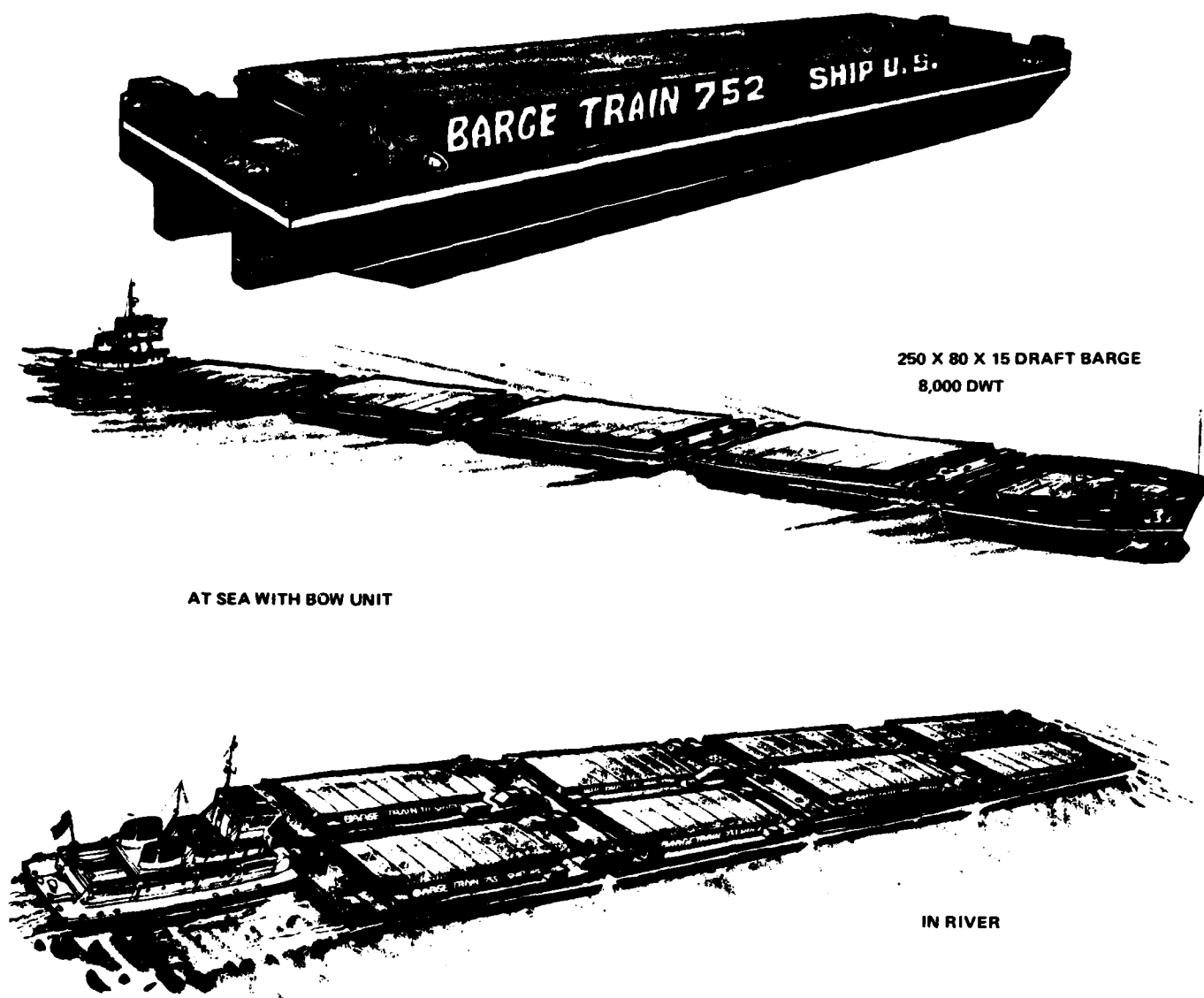


Figure 1.15

Artist Drawing of FLEXORS in Commercial
Flexibly-Linked OGTB Systems

Source: Barge Train (1974)

most two hundred of the 20'x100' pontoons which are carried onboard LSTs will be fitted with FLEXORs. The FLEXORs allow the pontoons to be assembled into LST causeways and then pushed onto the beach as a unit.

FLEXORs could be used also to allow several landing barges to be pushed by the same tug. As the system nears the beach, the units could be separated and individually discharged. The tug then could retrieve the barges, link them up again, and then return. Or the tug could leave immediately to pick up another group of barges or to just be out of the battle zone.

It should be mentioned that a barge train in a coastal run in a danger zone would be less vulnerable than a ship. If one barge is hit, it could be released and the remaining barges reconnected so that the system could continue. And of course, the tug can be used as a lifeboat if the barges explode or catch on fire.

With respect to mobilization, the FLEXOR system can be readily retrofitted onto existing flat-bow tugs and notchless barges. The designer estimates that the retrofit could take less than six months including engineering and installation and would cost approximately \$300,000 for a 5-6000 DWT barge. The FLEXOR for such a barge would be approximately 30" in diameter and would weigh about 12,000 pounds and cost about \$25,000 each. It should be mentioned that FLEXORs have to be rerubbbberized about every five years at a cost of about \$10,500.

1.3.5 3rd Generation Loosely-Linked OGTBs

There are several 3rd generation loosely-linked OGTB system designs under development at this time. One has been in operation for a few years and others are being installed on or contracted for new construction. The reasons for such a flurry of interest in these types of linkages are explained in detail in the next chapter. But to summarize, they are being built because they can be operated with 100% push-tow operation in coastal trades at less capital and operating cost than for the mechanically-linked systems and at little additional capital cost than for the 2nd generation OGTBs.

Since these OGTB designs are so new, there has been essentially nothing published about them in the professional journals or the trade literature. Therefore, the information presented in the following subsections has been obtained directly from the designers or operators, either through telephone conversations or company brochures/documents. Consequently, the data presented may not be complete for all designs, but it should be closely representative of the type of linkages that are now under development.

All of these loosely-linked OGTB linkages have the same purpose: to reduce the tug motion in the notch so that separation of the tug from the barge will not be required in any sea state expected during the voyage. Almost all of the designs utilize the same principles:

- (1) to restrict tug heave and pitch motion by the use of some non-jamming restraining device at the tug bow and/or by the use of frictional restraints (usually wedges) on the tug's sides,
- (2) to restrict tug surge by the use of tensioned cables connecting tug to barge stern, and
- (3) to restrict tug roll, yaw, and sway by closely fitting the tug's lines to the notch shape so that these movements are restrained by fenders or wedges.

Each design performs these functions in a different manner as discussed in the subsections below. These descriptions will be followed by a brief discussion of the commercial and military potential of loosely-linked OGTB systems.

Bludworth Loosely-Linked OGTB Design

The Bludworth linkage design was the first of the loosely-linked OGTB linkages to be put into operation. The first unit, the Ponciana, began operations in 1972. Details of the linkage are not available since the Bludworths are reluctant to divulge any information concerning its design. However, it is believed that the tug is held in the notch by tensioned cables and its movement is restrained by hydraulically controlled wedges located at the after end of each side of the tug. Additionally, the tug is restrained from heaving by a frictional device on the tug's stem that clamps onto a vertical rail located at the tip of the barge notch. This device is articulated so that the tug may pitch at the bow.

There are currently five OGTBs operating with the Bludworth linkage. The last two to be delivered, the Velasco and the Plaquemine, are 22,000 DWT double-bottomed tank barges. Although built for Dow Chemical they have been under a temporary charter to Belcher Oil since August 1978. The operator claims that when the barge is pushed by its 7000 HP tug, it has averaged 10.8 knots. The tugs and barges have never had to separate even when experiencing twenty foot seas. The operator believes the system capable of withstanding 30 foot seas without difficulty.

Currently two container OGTBs are being built by Union Carbide with this linkage. The 11,000 DWT single deck barges will carry somewhere between 200 and 300 thirty foot containers from Puerto Rico to U.S. ports. These systems will operate with

5600 HP tugs in a 76 1/2 foot deep notch. Delivery is expected in late 1979.

Breit & Garcia Loosely-Linked OGTB Design

The Breit & Garcia linkage design is the second of the 3rd generation OGTB designs to be installed on new construction. The linkage of this system differs from the other designs since the tug's bow is not restricted against heave. Instead, the tug bow is fitted with rubber rollers mounted on a horizontal axis to facilitate relative vertical movement between tug and barge. Additionally, the tug is secured to the barge notch laterally by four hydraulically operated laminated steel/plastic pads located on either side of the tug, fore and aft of amidships, which mate with matching units on the barge. Tensioning hawsers are led from the barge wings via rollers on each of the tug's quarters to hydraulic tensioning rams. These serve the dual purpose of holding the tug in position longitudinally and of providing the means for transmission of stern power. It should be mentioned that the tug is equipped with a towing winch and hawsers and is fully certified for operating in the towing mode if necessary.

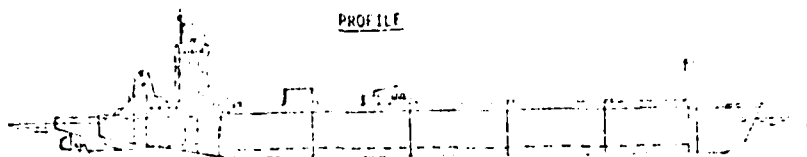
Two tank OGTBs are being built with this linkage design for Belcher Oil Company. The profile of this system and some particulars are given in Figure 1.16. The total cost for both systems was approximately \$50,000,000 and they are expected to operate in the push mode 100% of the time on their coastwise trades.

CABLE-LOC Loose-Linked OGTB Design

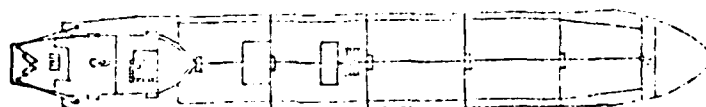
Recently E. H. Fletcher has developed a loosely-linked OGTB design to be installed on new or existing OGTBs. The linkage design is shown in Figure 1.17. There it is seen that a horizontal, cylindrically-shaped, constant-tension, energy absorption device is mounted on the tug's bow. This rubber device, which is about seven feet long for a 1500 LT displacement tug, transmits the tug's thrust energy evenly into a corresponding horizontal concave cylindrical slot in the barge notch. These slots can be fabricated at several drafts to allow for different ballast conditions. The tug and barge are held tightly together by tensioned chains and the tug's sides are fitted with hydraulic wedges to reduce vertical motions. The cost of the device to be retrofitted on a 23,000 DWT barge pushed by a 7000 HP tug is estimated to be less than \$250,000. Model basin tests have indicated that this system should be capable of operating in the push mode during any sea condition expected in its coastal trade.

ARTICULATED TUG/BARGE
BELCHER TOWING COMPANY

PROFILE



PLAN



37,700 SDWT UNIT

PRINCIPAL DIMENSIONS:

TUG:	L.O.A.	167'
	Beam	53'
	Draft	25'
	GRT	290
BARGE:	L.O.A.	585'
	Beam	92'
	Depth	41'
	GRT	21300
	T.P.I.	106
COMBINED UNIT:	L.O.A.	620'
	Beam	92'
	Depth	41'

55,000 SDWT UNIT

PRINCIPAL DIMENSIONS:

TUG:	L.O.A.	167'
	Beam	53'
	Draft	25'
	GRT	290
BARGE:	L.O.A.	640'
	Beam	105'
	Depth	46'
	GRT	31000
	T.P.I.	135
COMBINED UNIT:	L.O.A.	675'
	Beam	105'
	Depth	46'

37,700 SDWT UNIT

CARGO CAPACITY: (98%)

SDWT	37,700
at 35' S.W.	
Cubic Capacity	285,000 Bbls

SPEED/CONSUMPTION

12.0 knots/42 tons MVF plus
2.5 tons diesel fuel per day

CLASSIFICATION:

TUG:	ABS Class A1 Ocean-Towing Service
	IMCO (Solas 1960)
	International Load Line
BARGE:	U. S. C. G. Approved
	ABS Class + A1 Oil Barge

PROPULSION MACHINERY:

TUG:	One B & W-type 7L67GF
	7-cylinder, 2-cycle, maximum
	continuous rating 13,100 BHP
	at 119 RPM

AUXILIARY MACHINERY:

TUG:	Two 550 Kw. AC Generators
	driven by Caterpillar diesels.
	One emergency generator 135 Kw.
	A.C. driven by Detroit Diesel.
BARGE:	Two 150 Kw. generators driven
	by Caterpillar diesels. Cargo
	pump engines Detroit Diesels.

CARGO TANKS:

Ten, 5 Port, 5 Stbd.
Coating: Inorganic Zinc
Heating Coils: 2 1/2" Steel (1500 11n.ft.
tank)
Hot Oil Heater: "Vapor" 8.4 million BTU's
Up to 5 segregation available

55,000 SDWT UNIT

CARGO CAPACITY: (92%)

SDWT	55,000
at 39' S.W.	
Cubic Capacity	417,000 Bbls

SPEED/CONSUMPTION

11.0 knots/42 tons MVF plus
2.5 tons diesel fuel per day

CLASSIFICATION:

TUG:	ABS Class A1 Ocean-Towing Service
	IMCO (Solas 1960)
	International Load Line
BARGE:	U. S. C. G. Approved
	ABS Class + A1 Oil Barge

PROPULSION MACHINERY:

TUG:	One B & W-type 7L67GF
	7-cylinder, 2-cycle, maximum
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TUG:	Two 550 Kw. AC Generators
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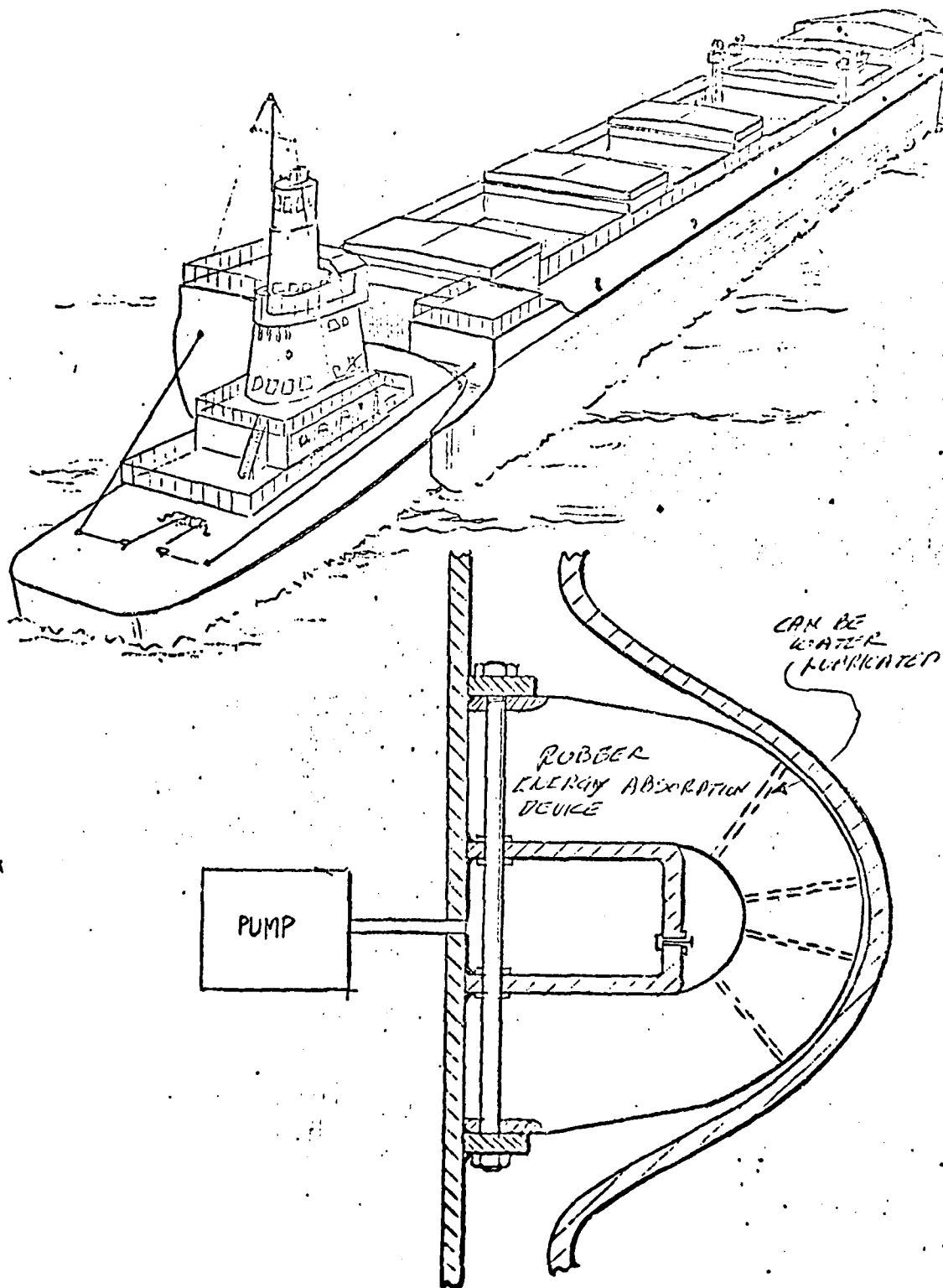
CARGO TANKS:

Ten, 5 Port, 5 Stbd.
Coating: Inorganic Zinc
Heating Coils: 2 1/2" steel (11n.ft.
ft tank)
Hot Oil Heater: "Vapor" 10.0 million
BTU's
5-grade segregation

Breit & Garcia Loosely-Linked 3rd Generation
OGTB System
Figure 1.16

Source: Belcher Towing Company

Figure 1.17.....Cont.



ROBBER ENERGY ABSORPTION DEVICE

Commercial Potential

The economic incentive for the development of these loosely-linked OGTBs is discussed in detail in the next chapter. It is their ability to provide 100% push-tow capability at little additional capital cost compared to pull-towed systems that have made them so popular. However, since most systems have not operated for a long period of time, it is not possible to really evaluate the commercial potential of one system over another at this time. Additionally, it is not known whether these systems are truly capable of push operation without damage in all sea conditions. Although they seem capable of withstanding between twenty and thirty foot seas, it is still questionable whether any or all of them could survive a major storm. This may not be of concern to most of the operators since their coastal trades allow their vessels to seek shelter when unfavorable sea conditions are expected. However, this may mean that none of them are trans-ocean capable or even suitable for some of the Northwest Pacific trades. On the other hand, if these systems are capable of operating in heavy seas, then it should be expected that they would penetrate these trades in the near future.

As for the cost of the linkage, it seems rather small, probably less than \$500,000. Additionally, all linkage systems should not interfere in the use of the tug for independent operation--for salvage, push-towing, or pull-towing. All of the linkage systems allow the barge to operate at different drafts without without major ballasting of the tug.

Military Potential

These loosely-linked OGTBs certainly have the potential to be used in shuttling or coastal operations especially for the movement of POL and vehicles from a coastal port to another coastal port or from a super size ship to a shallow draft port. They are proven capable of moderate speed operation (<16 KTs) and should provide considerably more ton-mile capacity than pull-towed systems due to this increased speed of operation.

Whether these systems are truly trans-ocean capable is yet to be seen. If they are, then they would be very militarily useful in that they could be brought to a warzone in almost half the time that it would take if they were pull-towed. Also, if the relative movement between the tug and barge is not too severe in moderate sea states, then these OGTBs might be capable of replenishment at sea operations as long as some safe connecting platform and some power/fuel linkage could be designed between tug and barge. Alternatively, the barge could be manned and any habitability or weapons equipment could be powered by generators onboard the barge.

All of the loosely-linked designs are capable of drop-and-swap operation. However, none of the systems in operation or being built are to be operated in this way since their barges can be loaded/discharged in a very short time. Unfortunately, none of the linkages allow interchangeability of tugs and barges among the different designs. Only the loosely-linked OGTBs of an individual operator may be exchanged, i.e., the two Bludworth Dow Chemical systems, the two Bludworth Union Carbide systems, or the two Belcher Oil systems. Thus, the potential use of this large commercial fleet of 3rd generation loosely-linked OGTBs for military drop-and-swap operations is not currently feasible.

With respect to mobilization, these systems could be newly constructed several months before a ship of equivalent capacity due to the concurrent construction of tug and barge in specialized yards. One shipyard believes that a large OGTB of this type could be in operation in less than 18 months after signing the contract, including engineering and design. Retrofitting of these systems can be quickly and easily done for any tug that can fit into the stern notch of a barge--2nd generation OGTBs would be of this type. Of course, if a stern notch must be added or significantly changed so that the tug fits more snugly, then retrofitting costs would be higher. Since today there is no standard tug bow or stern notch shape, there is little possibility of converting a large fleet of tugs and barges to 3rd generation loosely-linked operation with complete tug and barge interchangeability without expensive modification to many standard tug bows and barge notches.

Prior to proceeding to the next chapter one other mobilization advantage of these and the other 3rd generation OGTBs needs to be mentioned. This is with respect to their manning. It is apparent that since these OGTBs can operate in trans-ocean trades with no more than sixteen (mechanically-linked) or eleven (loosely-linked) men, the mobilization of a large fleet of these OGTBs will have a significantly smaller impact on the merchant marine than the mobilization of a large fleet of ships. This may be a very important consideration in times of scarce merchant marine manpower.

ANNEX A TO CHAPTER 1

TUG/BARGE MOBILIZATION MISSIONS (1)

This afternoon amidst all the discussions of the commercial utility and institutional constraints impacting on the future of tug/barges in foreign trade, it is rather easy to overlook an important non-commercial application. My objective today is to create an awareness and appreciation of the utility of ocean-going tug/barges, specifically integrated tug/barges, in the logistics support of U.S. military efforts.

The Declaration of Policy in the Merchant Marine Act of 1936, begins:

"It is necessary for the national defense and development of its foreign and domestic commerce that the United States shall have a merchant marine"

Note that "national defense" is mentioned first and remember that MarAd's mission is to carry out this policy. The Maritime Administration must provide shipping capability during a declared national emergency.

In 1974 MarAd established a "ship designs for mobilization" project to develop modern ship designs for wartime production. The resultant designs were intended to:

- a. Improve shipping capability in wartime;
- b. Replace wartime shipping losses; and
- c. Meet postwar trading requirements.

Working closely with elements of the Navy, the Army, and the Military Sealift Command we identified the design requirements, the constraints, and the mission profile for the required mobilization ship. The Maritime Administration design team then

(1) Remarks by Ronald K. Kiss, Director, Office of Ship Construction, Maritime Administration, on March 26, 1979, at the National Ocean-Going Tug/Barge Planning Conference held in New Orleans on 26-27 March 1979.

developed detailed preliminary designs for a number of optional configurations of a single hull form including a multi-purpose design, a jumbo version, an austere version, and a container oriented version.

After these designs were well along, we received some well reasoned suggestions to consider tug/barges for this mission and began some preliminary studies.

These four ship designs were presented for public review and discussion at a Government/Industry Mobilization Ship Conference last November in Washington, D.C. This Conference was a valuable forum resulting in copious detailed written comments and suggestions on areas where the designs could be improved.

In addition we received some major guidance at the Conference itself. First, the basic multi-purpose ship was too small for anticipated commercial services, and the Navy and MSC also decided the larger ship was more desirable for logistics support. Second, the anticipated 17 month construction period was much longer than we had hoped, for rapid replacement of wartime shipping losses.

Based on these significant conference results, the future steps of the mobilization ship have been altered. The contract design effort of developing detailed bidding plans and specifications will be for a larger multi-purpose vessel with increased beam. Concurrently we will be studying procedures for improving production planning and procurement cycles to reduce the total construction period. For example, Japanese yards indicate that less than 14 months would be required for delivery of this type vessel in peacetime. It is our intention to identify the bottlenecks in U.S. ship production schedules and seek to reduce the U.S. construction time.

The utility of tug/barges was also raised at the Mobilization Ship Conference and they are of considerable interest. Especially in view of the just mentioned findings. Increasing the size of the mobilization ship reduces the number of shipyards which can be used to construct them. Thus there may be a need for another design of smaller dimensions capable of being constructed at smaller shipyards. The need to construct large numbers of vessels in a minimum time period also enhance the attractiveness of ocean-going tug/barges. This will be especially true if the tug and barge can be kept as simple as practical given the mission requirements.

At this point in time, MarAd has prepared a number of concept designs for mobilization ocean-going tug/barges. These will be circulated within government, just as the present mobilization ship was, for review and discussion of its role and its desirability. Clearly the war scenario plays a major role in the design process. Present requirements indicate high speed, 20

knot convoys will be used. As noted earlier, these 20 knot ships are expected to take nearly one and a half years to be delivered. On the premise that some emergency shipping may be continued outside of convoys and that tug/barges should permit earlier deliveries, MarAd is pursuing this alternative. The tug/barge is not a substitute for the mobilization ship in logistics support, any more than it has been proposed as a substitute for a high speed container liner but it does appear to have a mobilization role.

Based on the foregoing, the design goals for a mobilization tug/barge have been initially established as follows:

- o Design for immediate replacement of lost shipping.
Here simplicity and ease of fabrication are essential to insure a short production period. Minimizing regions of hull surface double curvature and utilizing simple deck machinery and cargo handling equipment are two specific means towards obtaining this goal.
- o Design for cargo handling flexibility.
Self-loading and unloading capability will be required to allow the vessel to operate at ports with either sophisticated or primitive facilities.
- o Provide multi-purpose capability as a system.
This can be accomplished, and still meet reduced construction time goals, by having two or three standard designs, each of different limited cargo handling capability.
- o Finally, incorporate features to enhance commercial capability
Provision should be made in the design for carrying anticipated commercial cargoes, which will not always be the same as those transported in wartime. An alternative in this respect would be a mobilization hull configuration which could be easily and inexpensively modified at the end of the conflict.

The ocean-going tug/barge has a number of attributes which make it attractive as a complement to the mobilization ship. Consider first the problem of wartime production. Large coastal shipyards are likely to be overloaded with naval work and multi-purpose mobilization ship construction. Production time and expense could be reduced through separate construction of tugs and barges at specialized smaller yards not already operating at peak capacity. For designs below the maximum size limitations of the Saint Lawrence Seaway this could include facilities on the Great Lakes or inland waterways.

Where tug/barges exist, but the barge is not suitable for transporting the cargoes needed, new barges could be designed and built to be compatible with existing tugs. A viable transport

unit could be created without having to order long lead-time machinery.

For new construction of tugs, and also some barges, the use of existing designs and/or new standardized designs will help to maintain low building time. Standardized designs would have the added benefit of being specially configured to maximize construction efficiency.

In addition to production there are wartime operational considerations that are also attractive. The increased survivability accruing from the use of separable hulls will be a significant benefit, provided the de-coupling time is short.

As a system, the tug/barge has the potential of each tug serving more than a single barge. This is not normally done commercially due to the fast on and off loading of the cargoes typically carried, but may result in a decided advantage in military operations. With proper scheduling turn-around times could be minimized, since the power unit can be de-coupled from the incoming barge and connected to an empty for the return trip without delays for cargo handling. This requires the tug to be totally seaworthy in the disconnected mode.

Finally, at the end of the war all mobilization vessels would be either taken over by commercial owners or assigned to the reserve fleet. Where existing tugs or tug designs are used for mobilization the postwar commercial utility would be already demonstrated. It should also be less expensive and more productive to place barges in the reserve fleet than self-propelled ships.

Cargo anticipated for wartime carriage includes military vehicles and equipment, dry goods, food, and petroleum products. While it has already been stated that a tug/barge design need not have complete multi-purpose cargo handling capability, the transport system as a whole should be able to carry any cargo to any reasonable destination. As a result, several tug/barge variations will be required.

Mobilization tanker needs can be effectively met by existing tug/barge and conventional tankers modified by installing underway replenishment equipment. Therefore, a tank barge design is not being considered for design development.

However, concepts of a RO/RO barge (Figure 1.18) and a general purpose dry cargo barge (Figure 1.19) are being reviewed. A RO/RO vessel is the simplest and most efficient means to transport military vehicles to a war zone. In addition, the advantages ascribed to unitized cargo and quick unloading make the RO/RO vessel well suited for valuable and high priority items, such as electronics, aircraft spare parts, etc., which can

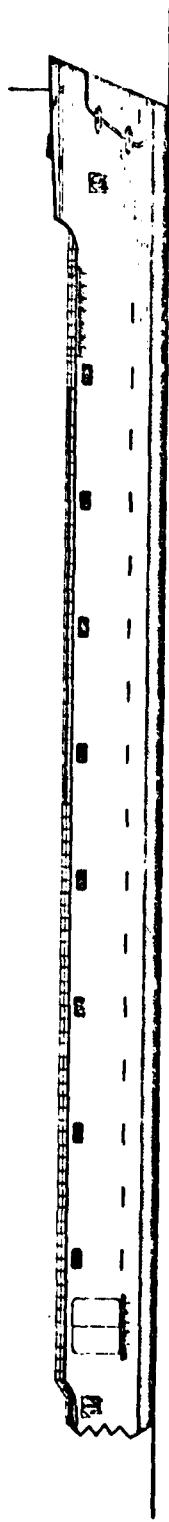


Figure 1.18

RO/RO BARGE FOR MOBILIZATION

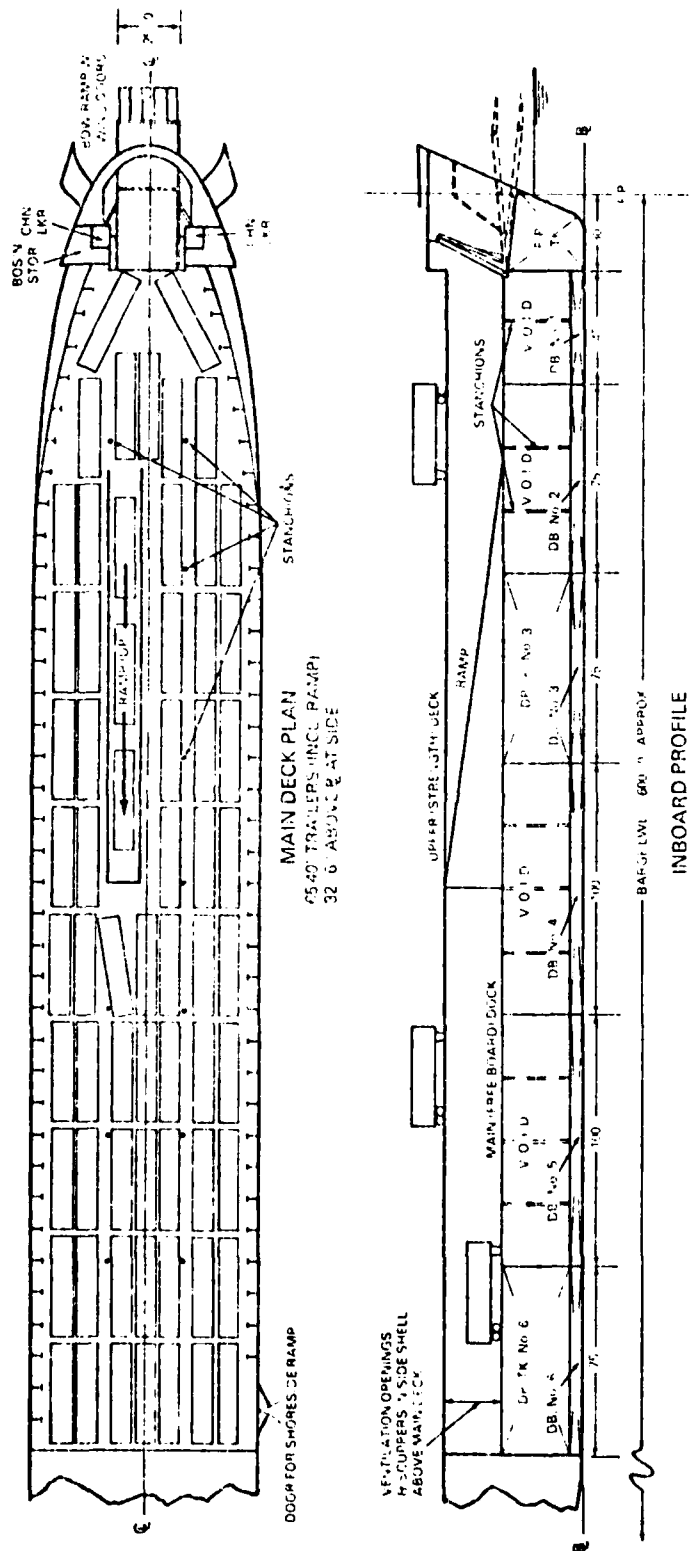


Figure 1.18cont'd

RO/RO BARGE FOR MOBILIZATION

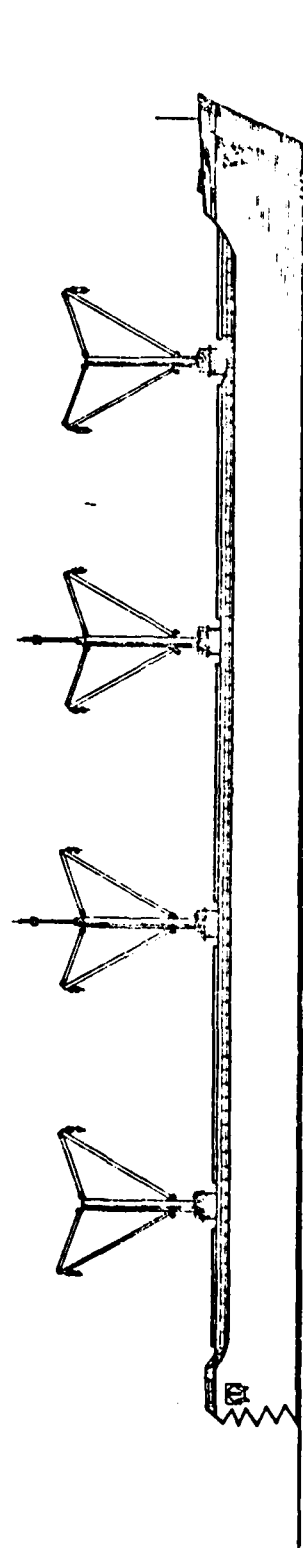


Figure 1.19

DRY-CARGO BARGE FOR MOBILIZATION

be loaded in trailers or containers on chassis. Large items of unusual shape or size, such as helicopters or boats, can also be accommodated.

Because an inexpensive and simple design is desirable, the RO/RO barge will not be equipped with multi-purpose cargo handling capability. In fact, the RO/RO barge has been constrained to have only one self-contained off-loading ramp and a minimum number of internal ramps and watertight doors. The combination of hatch covers, stationary ramps running through holds, numerous watertight doors, and non-RO/RO cargo handling gear which characterize a truly multi-purpose ship, is not compatible with short and inexpensive construction. The main deck has been designed as the freeboard deck, there are no subdivision bulkheads restricting RO/RO traffic. RO/RO stowage below the main deck has not been provided to avoid the complication of watertight doors in bulkheads and/or elevators.

Primary access is through a single forward ship-contained bow ramp with wing doors. A bow ramp was selected in lieu of somewhat simpler side ramp to permit greater flexibility in cargo discharging, including at-sea transfer to other vessels.

When this design originated a speed of 20 knots was set as a goal mainly to determine if it was in the realm of practicability. Therefore, a low displacement-length ratio and low prismatic coefficient were necessary. To obtain these hull coefficients no provision was made for cargoes other than roll-on/roll-off (thereby keeping displacement low) and as a result there are extensive void spaces below the main deck. Ultimately the service speed with 18,000 HP and a 25 percent power margin was estimated to be approximately 19 knots. The actual required speed is, in my opinion, still an open issue.

The purpose of the dry-cargo barge is to transport containers, neo-bulk, break-bulk, or dry-bulk cargoes. Flexibility for handling these cargoes can be obtained in a variety of ways, not all of which are compatible with mobilization goals. As a general guideline in keeping with the objective of uncomplicated design, the cargo handling system does not include items such as mechanized hatch covers and large sophisticated cranes. The dimensions of the barge make it suitable for transitting the Saint Lawrence Seaway to and from the Great Lakes.

A service speed of 14 knots with 7,000 HP was estimated. At 18,000 HP the service speed would be around 18 knots.

For commercial purposes the hold configuration can be matched

with more sophisticated cargo handling equipment if desirable, such as the rotating crane shown on the mobilization ship earlier. (Figure of mobilization ship not included.)

The tug design and the linkage remain open issues. A special study will be necessary to fully develop a tug design which will be best suited for mobilization construction. Objectives for this tug design will include:

- o Quick and inexpensive fabrication including machinery availability
- o Seaworthiness without a barge
- o Ability to be utilized for conventional tugboat purposes, for example, towing, marshaling ships and barges, aiding in docking and undocking, and lastly
- o Postwar commercial utility

In conclusion, the tug/barge has the potential to perform an essential role in the event of a mobilization effort. This role will consist of providing quickly available shipping capacity in the early stages of a conflict and also supplementing the services of the mobilization ship with single vessel sailings throughout the duration of the war.

The government is now examining alternative barge and tug configurations.

The eventual goal, after the completion of the preliminary designs, will be the development of a set of contract plans and specifications hopefully followed by construction of a prototype.

During the workshop discussions tomorrow and in your independent development of the tug/barge concept I would urge you to keep the mobilization mission in mind. We believe ocean-going tug/barges have a place in that mission and proper planning and development will assure that that place is filled.

ANNEX B TO CHAPTER 1

ABSTRACTS OF MILITARY SPONSORED RESEARCH ON OGTB'S

AD-A083 124

MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN E--ETC F/6 15/5
OPERATIONAL EVALUATION OF TUG/BARGE SYSTEMS.(U)
JUL 79 J D KASKIN

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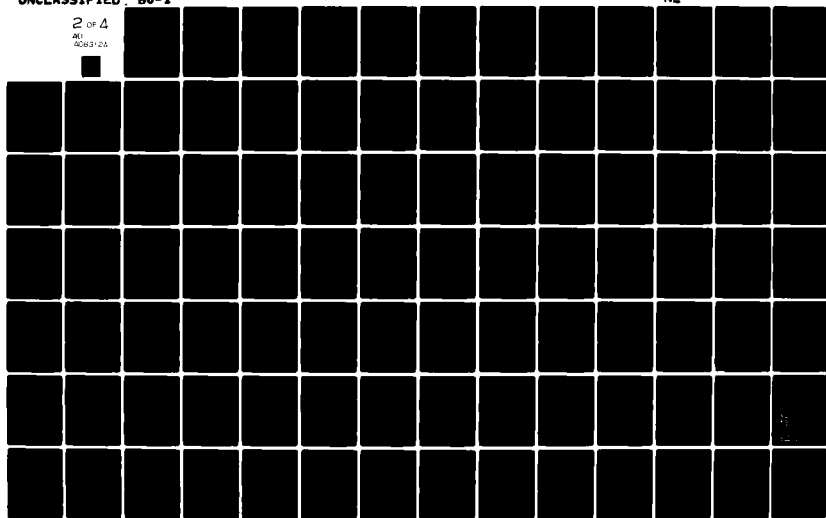
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STAYPOWER: SYSTEM OF TRANSPORT AFLOAT YIELDING
PIVOTAL POWER THROUGH WELL BALANCED AND ECONOMIC RESUPPLY

by

U. S. NAVY
Commander, Service Group One

30 June 1977

The STAYPOWER study examines the feasibility of increasing fleet readiness for worldwide operations while sharply reducing attendant support costs. The concept entails introduction of integrated tug-barge units to perform interface, storage and transportation functions now performed by fixed advanced bases and UNRE" shuttle ships (AO, AE, T-AO). The integrated tug-barge units would utilize proven hardware such as those already constructed and in operation under INGRAM or CATUG patents.

The barges would have tanker hulls fitted to carry standard containers on deck, disposed so as to permit destuffing at sea. Large merchant tankers and self-sustaining container ships would offload directly to the barges in a sheltered anchorage. (In the absence of self-sustaining capability, a floating crane would be required to handle containers). The loaded barges would be moved as needed by an integrated tug to the task force operating area where it would consolidate with an AOE/AOR "station ship", using the station ship's rigs; isolated units, detached from the task force, would be replenished using a fuel rig and a cargo rig installed on the tug. Number of barges required is related to predicted pipeline ship capacity and arrival frequency; number of tugs needed is related to shuttle resupply requirements for supported task forces and detached units. Fork trucks would be used for destuffing containers aboard the barge during consolidation with the station ship. An AFS could be used to manage incoming and outgoing cargo at the advanced anchorage interface. Crew size of the tug would not be adequate for major consolidation; the station ship would provide personnel to man the barge evolution during consolidation.

The study concludes that the STAYPOWER integrated tug-barge concept is feasible and that a shuttle force comprised of such units is potentially an extremely attractive alternative to current and projected shuttle ship forces in terms of cost, manning, and primary mission accomplishment. The attractiveness of the integrated tug-barge shuttle unit justifies further development of that concept through detailed technical feasibility design and costing studies.

NAVAL APPLICATIONS
OF
OCEANGOING PUSH TUG/BARGE (MULTI-SECTION SHIP) SYSTEMS

by

Seth Hawkins
Naval Ship Research and Development Center

Report 4224--July 1973

This report documents the results of a study to analyze a surface ship concept of interest to the U.S. Navy; of interest because it saves money, uses fewer people, increases operational flexibility, and requires little development time or money. The concept is that of a multi-section ship and is derived from what are called, commercially, ocean-going push or integrated tug/barge systems. Systems of this type are analogous to tractor trailers in the trucking industry.

By utilizing a rigid type linkage it is possible to approximate conventional surface ship speed-power and other measures of performance for all but the highest speed naval surface ships such as destroyers, escorts, cruisers and aircraft carriers. Thus, the concept appears to be applicable to a wide variety of existing naval support missions.

Dollar savings from utilization of the multi-section ship concept would arise due to lower system first-costs, lower personnel costs because of fewer personnel, more efficient use of equipment (pusher unit power plants), and increased maintenance flexibility. Operational flexibility is enhanced since the motive-force part of a ship system can either remain with the functional unit or proceed elsewhere with another functional unit. Technically, it is concluded that little stands in the way of designing such a system today.

MULTI-SECTION SHIP FEASIBILITY
AND CONCEPT DESIGN STUDY

by

Carlos Tomassoni, Logan Sharrah,
Thomas Sauer, Horton Lain
and John Slager
HYDRAUTICS, INCORPORATED

Technical Report 7224-6 March 1974

Certain technical problem areas are addressed involving the use of the multi-section ship (MSS) concept for naval ships. The MSS concept involves the construction of a ship in two distinct, separable parts, a pusher unit and a functional unit. A standard pusher unit is determined to be feasible for all missions not requiring high speed (above 20-22 knots). One such standard pusher is synthesized and examined in detail as to characteristics, performance, manning and costs. The use of the standard pusher with three selected functional units replacing conventional ships--a submarine tender, a replenishment oiler, and an attack cargo ship--is investigated. The differences are noted between the MSS versions and their existing counterparts with respect to size, speed, manning and cost.

Potential problem areas in the application of the concept are identified, studied, and evaluated (i.e., manning, power supply, fuel storage and handling, auxiliary propulsion requirements, coupling and uncoupling maneuvers). No unsolvable potential problem areas are found that would preclude the successful application of the concept to naval support missions. The capability of the pusher unit is also examined. Four such representative missions are intelligence gathering, anti-submarine warfare, surface warfare and mobile hospital. These missions are accomplished by using modular equipment mounted on the pusher. The performance of the missions is considered acceptable with no detrimental effects on the pusher.

DEFENSE UTILITY OF COMMERCIAL VESSELS AND CRAFT

by

COMMITTEE ON DEFENSE UTILITY OF COMMERCIAL MARITIME ASSETS
MARITIME TRANSPORTATION RESEARCH BOARD
of the
NATIONAL RESEARCH COUNCIL

1979

This report identifies military functions required in contingencies whose performance may require the use of vessels and craft that are not formally included in current contingency planning; and identifies the types, characteristics, and potential availability of vessels and craft that appear to have utility for these functions. Its scope excludes (a) vessels owned or operated by the Department of Defense and the Coast Guard; (b) oceangoing commercial cargo ships, which already are included in national contingency planning; and (c) foreign-owned vessels.

Vessel types included are: ocean-classed tugs, ocean-classed barges, crane and derrick barges, offshore service and supply vessels, drillships and semisubmersibles, five categories of fishing vessels, oceanographic research vessels, dredges, floating drydocks, motor yachts and small craft, passenger-vehicle ferries, marine salvage vessels, and advanced marine vehicles (air cushion vehicles, surface effect ships, and hydrofoils).

The report identifies 13 general military functions that could be filled in whole or in part by the types of vessels studied and provides eight basic information sources to military planners and concerned industry personnel. Three summary tables permit quick identification of (1) the relative suitability of vessel types for each general military function, (2) the relative essentiality of vessel capabilities for each military function, and (3) the relative capabilities of each vessel type. The report also provides (4) a general description of each industry sector, covering basic vessel uses, manning, commercial arrangements, geographical distribution, and availability; (5) Vessel Characteristics forms that summarize, for each vessel class, typical characteristics that are important for evaluation by military planners; (6) general layout drawings or illustrations of most of the vessel classes; (7) a listing of principal vessel owners, operators, and industry associations, with addresses, from whom more specific information can be obtained; and (8) a selective bibliography of further vessel information sources.

CHAPTER 2

OGTB COMMERCIAL ECONOMICS

In Chapter 1 a brief history of OGTB systems was given with some mention of the economic incentives for their development. The impression was given that 3rd generation OGTBs were, except for high speed and large unit capacity trades, very satisfactory and inexpensive ship replacements. However, ships of OGTB size and speed are still being built, so either there are a lot of misguided ship operators or OGTBs may really not be so attractive as they first might seem, for certain types of trades. In this chapter the pros and cons of OGTBs, push and pull-towed, will be discussed in comparison with ships. This will be followed by a brief discussion of the economics of the different modes of OGTB operation. And, this will be followed by a discussion of the possible future of OGTBs in U.S. maritime commerce.

2.1 Economic Comparison of OGTBs with Ships

To explain why ships and OGTBs of various linkages are being built today, the economic advantages and disadvantages of each system must first be compared. This is done by different cost/operational categories in the following subsections. For the reader's benefit a summary of these comparisons is provided in Table 2.1.

2.1.1 Manning Size (Refer to Annex A)

The crews onboard U.S. flag ships at the end of 1977 averaged between 30-40 men. Although recently crew sizes have decreased, few ships of over 1000 GRT are manned with less than 25 men. Only a few tank ships are manned with less, notably the 35,000 DWT Chevron gas turbine tankers which are manned with 17 men.

Mechanically-linked OGTBs have been manned with crews of approximately fourteen men. There are three reasons why these

Table 2.1
Economic Comparison of OGTBs and Ship
by Cost/Operational Category

Cost/Operational Category	Ship	Mechanically-Linked OGTB	Loosely-Linked OGTB	Pull-Towed OGTB
Manning Size	Highest (20-30)	Intermediate (13-17)	Lowest (7-11)	Same as Loosely-Linked
Coast Guard Crew Licensing Requirements	Most Stringent	Same as Ship (unattended Engine Room)	Few Requirements	Same as Loosely-Linked
Union Control Over Manning	Strong	Weak	Almost None	" "
Crew Costs	Highest	Intermediate	Lowest	" "
Coast Guard Inspection Requirements	Most Stringent	Same as Ship	Apply to Barge Only	" "
Freeboard	Ship Rules	25% reduction for Unmanned Barge	Same as Mechanically-Linked OGTB	" "
Construction Costs	Highest	Somewhat Less (70-90%) than Ship	Somewhat more than Pull-Towed OGTBs	Lowest
Fuel Cost at a Given Speed	Least	Intermediate (~5% more than Ship)	Intermediate (10-15% more than Ship)	Greatest (~30% more than ship)
Operational Safety	Most safe	About the same as Ship	Somewhat less safe than mechanically linked OGTB	Least Safe
Cargo Insurance Cost	Lowest	About the same as Ship	Probably somewhat more than mechanically-linked OGTB	Highest
Hull & Machinery Insurance Cost	Highest	Somewhat less than Ship	Somewhat more than Pull-Towed OGTB	Lowest
Protection & Indemnity Insurance Cost	Highest	Intermediate	Intermediate	Lowest
Maintenance & Repair (Not performed by crew)	Lowest	Intermediate	Intermediate	Highest
Flexibility	Least	Little less Flexible than Loosely-Linked OGTB	Little less Flexible than Pull-Towed OGTBs	Most

systems, although Coast Guard inspected and certificated, have substantially smaller crews than ships of equivalent deadweight.

The first reason is because their enginerooms are highly automated, typical of diesel tugs, so that they are classed for unattended service. This means that only a Chief Engineer, an Assistant Engineer, and another Qualified Member of the Engineroom Department are normally required for engineroom staff.

The second reason is that since the barges are classed as unmanned for the purpose of freeboard reduction, no crew is permitted on them for maintenance while underway. This allows the deck department to be reduced to the Master plus nine men who are used primarily for underway watch standing.

The third reason why these mechanically-linked OGTBs have such small crews is because when they first came on the scene the crews were either non-union or company union members. Consequently, they did not pressure the owner to increase the manning level to match the national ship union manning scales. Additionally, they were permanently assigned to the same vessel which increased their familiarity with the ship, resulting in improved productivity and the need for fewer personnel. Later when other systems came into operation, the pattern of small crews had been established so that the national unions accepted them even when manned with their personnel. Besides, the large unions probably have come to the realization that if they attempt to inflate the crew sizes, the operators will tend to invest in the loosely-linked designs which require even fewer personnel.

Loosely-linked 3rd generation OGTBs and pull-towed OGTBs have even smaller crews. Since their tugboats are uninspected and usually under 200 GRT, there are practically no international or Coast Guard regulations pertaining to their manning. Thus, they can operate with two watches, usually of three men each on voyages of less than six hundred miles and three watches on longer voyages. Consequently, crews range from seven to eleven men.

To see how the different OGTBs and ships are currently manned, the reader may refer to Table 2.2. There the manning levels by rate are given for typical tank OGTBs and ships.

2.1.2 Coast Guard Licensing Requirements (Refer to Annex A)

Ships must have officers licensed in accordance with Coast Guard regulations. The deck officer knowledge and experience requirements differ somewhat as a function of the gross tonnage of the ship. Likewise, the engineering officer requirements differ somewhat as a function of the type and size of plant.

Table 2.2
Typical Manning Scales for Tank OGTBS and Ships

Vessel Type Department	Typical Modern Tanker	Chevron Gas Turbine Tanker	Mechanically-Linked Tug-Barges	Loosely-Linked or Pull-Towed Tug-Barges (Voyages less than 600 mi.)	Loosely-Linked or Pull-Towed Tug-Barges (Voyages greater than 600 mi.)
Deck Licensed	Master Chief Mate 2nd Mate 3rd Mate	Master (3) Mates	Master (2-3) Mates	Uninspected Towboat Operator* 2nd Class Uninspected Towboat Operator*	Uninspected Towboat Operator* (2) 2nd Class Uninspected Towboat Operator*
Deck Unlicensed	Boatswain (6) AB's	(6) AB's	(4) AB's or (6) AB's (2) Ordinaries	(3) AB's	(3) AB's
Engineering Licensed	Chief Engineer (2) 2nd/3rd Ass't Eng.	Chief Engineer (3) Assistant Engineers	Chief Engineer (2) Ass't Engineers or Ass't Engineer and QMED		
Engineering Unlicensed	Pumpman (3) QMED			Engineer (No license Required) Oiler	Chief Engineer (License suggested but not re- quired) Ass't Engineer (2) Oiler/Utility
Steward Department	Cook (2) Stewards	(2) Cook/ Stewards	Cook/Steward	Cooking done by Crew	Cook/Ordinary Seaman
Others	Radio Officer (2) General Utility (D/E)	Radio Officer	General Utility		
<u>Total</u>	<u>25</u>	<u>17</u>	<u>14-15</u>	<u>7</u>	<u>11</u>

*Requires Coast Guard Certificate rather than License

Mechanically-linked OGTBs must also have licensed deck and engineering officers. The master and mate requirements are now based on the combined gross tonnage of the tug and barge, so that they are essentially the same as for equivalently sized ships. Engineering officer requirements are the same as those for diesel ship plants of the same horsepower.

Loosely-linked 3rd generation and pull-towed OGTBs (including 1st and 2nd generation push-towed systems) have relatively few requirements for the crews if the tug is less than 200 GRT. The deck watch officers must only be a certified Operator or Second-Class Operator of Uninspected Towing Vessels. These Operators are required to fulfill substantially less stringent knowledge and experience requirements compared to the licensed officers onboard the mechanically-linked OGTBs. The Coast Guard does not even consider these certificated men as officers. Engineers, if included, require no license at all. The only requirement on the crew overall is that 65% of the crew must be certificated as AB or above. It should be mentioned that many of the tug and barge operators, for the sake of safety, do hire licensed personnel and urge their crewmen to become licensed.

2.1.3 Overall Crewing Costs

Given the above information concerning manning levels and licensing requirements, it is apparent that ships, having the largest crew sizes and the most stringent licensing requirements, will cost the most to man. Mechanically-linked OGTBs cost substantially less (probably at least one-third less) to man because they have crews that number almost half that onboard the equivalently sized ships. And, loosely-linked OGTBs cost significantly less to man than their mechanically-linked counterparts since they can again reduce their crews almost by half. The crew that does remain onboard has practically no licensing requirements and so can be paid a lower average wage. One tug-barge operator has estimated that he saved at least \$600,000 in crewing expenses by having a loose rather than mechanical linkage in his OGTB system. Such saving in crewing expenses certainly provides strong incentive for many shipping operators to invest in OGTBs, especially of the loosely-linked variety.

2.1.4 Capital Construction Costs

In this subsection the construction costs of large OGTBs (greater than 10,000 DWT) and ships of equivalent capacity and speed are compared in relative terms. That is, the features that make one system inherently different and more or less costly than another is discussed. In addition, one shipyard's estimate of the construction cost of the different systems is provided in An-

nex B. From this Annex the reader can get some appreciation of the actual pricetag for the differences among the various systems.

Certainly, the cheapest systems to construct are the hawser or pull-towed OGTBs. The tugs are the least expensive of the powering units to build since they are of standard designs that can be built at a great number of small vessel construction yards and without Coast Guard inspection. As these types of yards specialize in small boat construction, they do not require expensive building docks or ways. This allows their overhead costs to be significantly less than those of multi-purpose shipyards. The barges, except for the very largest, can also be built in specialized barge construction yards. These yards also have rather low overhead costs since barges, having little outfit material and machinery, can be built with lesser skilled workers. Additionally, since pull-towed barges can make only slow speeds, they can be designed with very simple hull lines with very little curvature. This means that most of the barge can be reduced to simple flat plate and frame construction which allows for inexpensive automated fabrication techniques. And finally, the linkage between the tug and barge is the cheapest of all systems, being only a towing winch and wire. For all of these factors, pull-towed OGTBs cost the least to construct.

Almost as inexpensive to build are the 1st and 2nd generation push-towed OGTBs. The tugs for these systems are still of standard designs. They require little additional hardware, possibly some extra bits and fairleads, for wires linking the tug and barge during push-tow operation. The deeper notch systems may also have some additional equipment to reduce heave or pitch in moderate seas. As for the barges, their notch will make them a little more expensive to build. But, the notch and other linkage costs should not add more than a couple of percent to the total cost of the system.

The loosely-linked third generation OGTBs will be somewhat more expensive to build than their 1st and 2nd generation counterparts. The tug, although of basically standard design, may require some special care in the fabrication of its hull form so that it mates closely with the barge notch. The tug may also require special modification to accommodate the machinery for the linkage devices. The barge cost should also be a little more expensive to build than its 1st and 2nd generation counterparts since its notch has to be built with closer tolerances to match the tug bow. Its notch also requires considerable reinforcement to accommodate the forces generated from operation at higher speeds or from severe sea conditions. Also, since these loosely-linked barges are normally operated at significantly greater speeds, their hull forms will require more shape and curvature to reduce hydrodynamic resistance, increasing their cost even more. The linkage will also be substantially more expensive. For example, in most systems the tugs will have some

cable/wire tensioning device to keep the tug snug in the notch. Additionally, some type of friction device that dampens the tug's motions in the notch is usually provided. The cost of these equipments can range from \$250,000 to \$500,000. This is in addition to a towing winch which is usually also installed on the tug for emergency pull-towing purposes or for increasing the operational flexibility of the tugboat. Thus, though loosely-linked push-towed OGTBs are built with uninspected tugs, they are quite a bit more sophisticated and approximately 5% more expensive to build than systems designed mainly for pull-towing.

The mechanically-linked OGTBs are substantially more expensive to construct than the other OGTBs. This is primarily because they come under all of the extensive construction requirements inherent to all vessels inspected by the Coast Guard. These requirements are designed to ensure that inspected vessels are as safe as possible--but safety costs money. For example, having redundancy in and/or a larger size of steering gear is certainly a nice safety feature, but it makes an inspected tug more expensive compared to its uninspected counterpart. Also, since inspected tugs have much larger crews, they require more accommodation facilities, increasing their cost more. And, since these tugs are designed for 100% push operation, the visibility requirements of the tug's pilothouse is based on the tug-barge combination. This may force the tug to have a very tall pilothouse which may have to be compensated by a costly ballast system to ensure adequate tug stability and comfort. Additionally, the tugs are often of very non-standard and sophisticated designs. The CATUG and Breit/Ingram designs are certainly good examples of such sophistication. This results in their cost being considerably higher than a standard design tug with equivalent horsepower. For all of the above reasons, it is apparent that the tugs of mechanically-linked OGTBs should be considerably more expensive to construct than the tugs of other OGTBs.

The barges of semi-rigid mechanically-linked OGTBs should not be much more costly than their loosely-linked counterparts. They require only some additional expense for the engineering and fabrication of the notch to ensure it is built to the close tolerances required by the linkage. The barges of rigid mechanically-linked OGTBs should be somewhat more expensive to build than those of their semi-rigid counterparts because they must be built with heavier scantlings in accordance with ABS rules. The linkage of any mechanically-linked system will certainly be a very expensive affair. The cost may range from \$1,000,000 for a semi-rigid linkage to more than twice that amount for the rigid linkages. In all cases, the systems require special hydraulics for establishing the linkage and some form of quick release mechanism to provide emergency separation. Certainly, all of the above considerations make the mechanically-linked OGTB systems considerably more expensive to build than the other OGTB systems.

Ships, however, are the most expensive vessels to build. Probably the major reason why they cost so much more to construct than mechanically-linked OGTBs is because they are built in general purpose shipyards. The lack of specialization of these yards forces them to construct ships with higher overhead rates than those available from the more specialized tug and barge yards. This increased overhead seems to outweigh the linkage costs incurred by constructing the vessel as a mechanically-linked tug and barge. Even in the case that a ship and a mechanically-linked OGTB with identical cargo handling equipment and carrying capacity are built in the same yard with the same overhead rates, there are some reasons why ships might cost more to construct even though they need no expensive linkage. First of all, since ship crews are almost double that onboard mechanically-linked OGTBs, ship accommodations will be considerably more expensive. Secondly, ships cannot take advantage of the 25% freeboard reduction allowed by the 1966 International Convention on Loadlines for unmanned barges. This increases the depth and therefore the cost of weight limited ships by a few percent. Also, ships cannot take advantage of the less heavy scantlings allowed by ABS rules for the semi-rigid mechanically-linked OGTBs. This increases the ships' hull weight and cost by a few more percent.

And finally, another important consideration that makes ship construction more expensive is the time value of money. That is, tugs and barges can be built concurrently and delivered several months earlier than a ship built in a single yard. (1) In this time of high inflation, such early delivery may result in several hundred thousand dollars reduction in capital interest expenses to both the shipyard and the vessel owner.

It should also be mentioned that shipowners usually specify considerably more sophisticated outfit equipment onboard ships than that commonly used on OGTBs. For example, tank barges usually have deep well pumps for their cargo handling equipment while ships normally have more expensive internal piping systems. Such "gold-plating" of ship outfit equipment increases a ship's cost substantially without adding any major real benefit--at least in the OGTB operator's point of view. In any case, all of these factors combine to make OGTB construction from 15% to 30% less expensive than ship construction for vessels of similar deadweight capacity and speed.

(1) This assumes that the ship is not built with modern modular construction practice as will usually be the case when the yard receives an order for only one or two vessels. This is because the engineering costs required in modularization is worthwhile only for large series construction.

2.1.5 Fuel Expenses

The most fuel efficient way to move a given amount of cargo at a given speed at sea is by ship. This is because the ship's lines and propeller are designed to provide the designed speed with the minimum engine power. Care is taken to ensure that the hull form produces the least amount of hydrodynamic resistance and provides good flow to the propeller.

Rigidly-linked OGTBs are designed to have hull forms similar to those of ships. That is, when linked together the tug and barge lines are designed to join into smooth ship-like lines. Although the match is not perfect, the hydrodynamic resistance of these OGTBs should be no more than 5% greater than for a ship of equivalent size driven at the same speed. Consequently, fuel expenses for these OGTBs should not be more than 5% greater than for ships.

Semi-rigid and loosely-linked OGTBs have tugs that resemble the more standard tug forms. Thus, when the tug and barge are mated, the lines of the two vessels do not match well, particularly if there are significant draft differences between the two units. This results in turbulence being generated at the linkage area and in disturbed flow to the tug's propeller. These effects might cause the resistance and power requirements of these OGTBs to be up to 15% greater than for ships of the same size and speed. This 15% figure is based on the model test results presented in Robinson (1976). Since these tests were conducted on rather crude forms, the increased resistance estimates may be high. In any case, linkage fairing flaps can be designed to reduce this added resistance by several percent. Unfortunately, practically no hydrodynamic model test results for currently operating semi-rigid and loosely-linked OGTBs have been published so the true amount of additional resistance caused by various linkage designs is not known.

1st and 2nd generation OGTBs probably have even more linkage drags than the deeper notched loosely-linked OGTBs when in the push-tow mode. Unfortunately, there is again no hydrodynamic resistance data available for these systems so the resistance and fuel consumption penalties incurred by them can only be guessed. Yet, at the slow speeds at which these OGTBs are usually operated, this fuel penalty is probably not significant.

Certainly, the least fuel efficient OGTB system is the pull-towed variety. Here, both tug and barge forms develop waves so that the total wave making resistance of the tug and barge exceeds that which would be developed if the tug pushed the barge. Additionally, barge skegs required for barge steerability and the hawser wire add frictional resistance drag. Thus, the pull-towed tug barge system will usually require at least 25% more power to pull than push the same barge form at the same speed. Although considerable work has been done on reducing the

resistance of barge skegs, there has been little work on the resistance developed by the total pull-towed tug-barge system. Only crude resistance algorithms are available to provide the tug-barge operator an estimate of what horsepower is needed for moving a given barge tow at a given speed.

Given the above information about push and pull-towing fuel efficiency, it is apparent that the fuel costs of 1st and 2nd generation OGTBs depend on the percentage of time the tug is pushing or pulling, fuel efficiency improving in proportion to the amount of pushing. And, it should be remembered that due to the control and handling difficulties involved, only barges of less than 20,000 DWT are usually towed for ocean voyages and at speeds lower than 10 knots. Higher speeds are impractical because of the severe frictional and drag resistances developed by the pull-towed system.

2.1.6 Operational Safety

There is no doubt that pull-towed OGTBs are inherently less safe than any other ocean transport system. The tug only has tenuous control over the barge. If the tow wire is severed, the barge may not be recovered before it is grounded or wrecked, particularly in bad weather. If the tug loses power, it may be run over by the barge. And, if the tug has insufficient reserve power, it may be dragged into trouble by the barge when seas or winds are severe. Certainly, the tug captain has much less maneuvering control over his barge when pull-towing rather than push-towing.

In principle, mechanically-linked push-tow operation should be as safe as ship operation. However, there are some differences between the two operating methods. Ships may be considered safer in some respects because they are usually manned with larger crews which can provide more emergency and firefighting manpower. Also, ships usually are provided with more extensive firefighting and ballasting/deballasting equipment than that onboard unmanned barges. On the other hand, tug-barge systems may be considered safer because their separability allows either unit to be used as the lifeboat of the other unit in the case it must be abandoned. As the damage or causes of damage on tankships usually occur in the cargo section of the ship, separability of the manned machinery section, the tug, may be assumed to provide an additional safety margin.

The other push-towed OGTB systems may be considered a little less safe than the mechanically-linked ones. This is because the crew is smaller, providing less firefighting or other emergency manpower. Also, since the tugs are uninspected they are not subject to many of the more stringent safety equipment standards pertaining to inspected vessels. Additionally, when

1st and 2nd generation systems are in the pull-tow mode, they are subject to the same unsafe conditions as other pull-towed OGTBs.

2.1.7 Maintenance and Repair Costs

The maintenance and repair costs of any ocean going vessel will depend on the maintenance policy of the operator. The better maintained the vessel, the less the casualty repair costs. Maintenance can either be provided by the onboard crew or by shoreside personnel.

It has long been the philosophy of ship operators to have the personnel onboard do most of the ship's preventative and corrective maintenance. This makes quite a bit of sense if the ship is deployed on long voyages to ports far from the operator's home base. Shoreside personnel can then take care of almost any casualty so that expensive repair delays away from home port can be reduced to the minimum.

Tug and barge operators, on the other hand, have opted to reduce their vessel crews to the minimum needed for operations. They have found it economical to leave most maintenance to less costly shoreside engineering personnel. This is a reasonable policy when the OGTB system makes short voyages to ports where shoreside personnel are readily available. If the maintenance cannot be accomplished without delaying the sailing, shoreside personnel are then sometimes embarked onboard the tug to accomplish tug maintenance. It should be remembered that since the barge is normally classed as an unmanned vessel, no routine maintenance and repair can be done on it while underway at its unmanned freeboard. This may not be a problem since practically no barge equipment is used while underway.

Given the above arguments, it would be expected that maintenance and repair costs of ships and OGTBs would be the least possible for their traditional trades. The question is raised what happens to these costs if OGTBs are sent on long voyages without additional maintenance crew or if ships are operated in short coastal trades. It would seem plausible that OGTBs might be insufficiently maintained by their small crews if they continually remain on long distance trades. This would result in expensive casualties and/or frequent scheduled maintenance delays. Whether this is the fact may only be determined after systems like the Occidental CATUGs have operated for some time on trans-oceanic trades. On the other hand, coastal ships might be quite overmanned if adequate maintenance can be provided by less costly shoreside personnel as it is done for OGTBs. Whether this is the case may be determined from the maintenance and repair history of the large coastal OGTBs. But, since most coastal systems are only a few months old, it will be some time before it can be determined whether these OGTBs are adequately maintained to prevent expensive casualties or deterioration in the long term.

2.1.8 Insurance Costs

Marine insurance is made up of several different premiums: cargo, protection and indemnity (P&I), and hull and machinery (H&M). Insurance rates are determined by the underwriters, primarily from the operators previous operating record. (2) However, the different OGTB systems and ships have some inherent differences that affect insurance cost. These are discussed below.

First consider cargo insurance where premiums are ultimately based on the safety record of the vessel as well as the value of the cargo. Since pull-towed OGTBs are inherently less safe than other OGTB modes, cargo insurance premiums for these systems are usually significantly higher, sometimes twice that for ships. The push-towed OGTBs have, based on their good safety records, cargo insurance premiums about the same as for ships.

Protection and Indemnity insurance is marine liability insurance. It is predominately a function of the crew size since the larger the crew, the greater the risk of a crewman being injured. Since ships have the largest crews, they would have the largest P&I premiums. Conversely, the uninspected tugs of loosely-linked or pull-towed OGTBs have the smallest crews and thus the lowest P&I premiums. The premiums for mechanically-linked OGTBs would fall between those of ships and uninspected tugs since their crews are of intermediate size.

Hull and machinery insurance protects the operator against casualty or damage to his vessel's hull and machinery. Its premium is a function of the vessel's market value which is usually a function of the its capital cost. Since ships have higher capital costs and market values than OGTBs, they usually experience the highest premiums. It should be mentioned that H&M insurance is also a function of the repair and maintenance policy of the vessel. The better maintained vessels experience fewer casualties resulting in lower H&M claims and premiums. Thus, OGTBs with insufficient crews to maintain them could have such severe repair problems that they will have larger H&M premiums than other more costly and better maintained vessels.

It should also be added that pull-towed systems are also subject to a tower's legal liability insurance. This insurance protects the operator from any damage caused by the barge if the

(2) Since cargo insurance is paid by the shipper to protect himself against loss or damage of his cargo, its premium is based on the shipper's rather than the operator's record. However, if the shipper predominately uses a particular OGTB system type, his cargo insurance premium will reflect the operating record of the operator.

tugboat loses control of it during a voyage. Its premium depends on the safety record of the operator and the type of cargo.

2.1.9 Flexibility

Up to this point we have considered an OGTB as a system of one tug and one barge operating in a shiplike mode, that is, with the tug and barge remaining linked together at all times. However, OGTBs do have the advantage of being able to separate the propulsion component--tug from the cargo component--barge. This flexibility may be advantageous for several reasons. The primary advantage is that it allows tug and barge systems to operate in the same manner as truck tractors and trailers where the propulsion component drops and swaps the cargo components. The trades for which this type of operation is advantageous will be discussed in detail in Section 2.2.

There are several other reasons why tug and barge separability provides useful system flexibility and cost savings. For example, if either a tug or a barge of a system requires repair, the other operating component can be utilized if there are other interchangeable operational components in the overall system available to be mated with it. Also, only the component that requires repair will need to be drydocked for hull repairs. This will result in significant savings if the small-sized tug needs such repairs more often than the large-sized barge.

Separability also provides flexibility in the long term investment policy of the operator. It allows him to trade, scrap or convert a barge if it becomes obsolete or unprofitable and replace it with one that can operate profitably with the same tug unit. Or, the tug component of many of the OGTB designs can be sold or operated as an independent ocean-going tug for pull-towing, salvage, or other purposes. Certainly, such flexibility allows the OGTB operator many more options than that are available to the ship operator. It even allows separate ownership of the tugs and barges.

It should be remembered that as the linkage design becomes more sophisticated, less flexibility is allowed by the system. For example, the most flexibility is provided by pull-towed OGTBs. Any tug of sufficient horsepower can pull any barge. Additionally, since the tugboat is in front, it will not experience any of the pilothouse visibility problems incurred by the push-tow operators when pushing barges with tall deck cargoes. 2nd generation and loosely-linked push-towed OGTBs are not so flexible. Although the tugs and barges are capable of pull-tow operation, the barges can usually only be pushed by tugs and barges designed for their notches. The tugs and barges of mechanically-linked OGTBs, except for the ARTUBAR system, are not designed for pull-towing. The tugs are restricted to pushing

barges designed for their linkage system or to salvage operations. But, even these systems have the advantage over ships of having either the tug or barge as the lifeboat for the other vessel in case of emergency.

2.1.10 Overall Economic Comparison of OGTBs and Ships

After reviewing the comparison of the various OGTB systems and ships by cost/operational categories shown in Table 2.1, some generalizations may be made concerning the trades for which a particular system might be most appropriate. Such generalizations are provided by vessel types in the paragraphs below.

Pull-Towed OGTBs: These types of OGTBs are the least expensive to construct and man but are also the least fuel efficient at sea. Thus, they are most appropriate for trades with short distance voyages where sea time is not a large proportion of the total voyage time or where speed is totally unimportant as in the transport of constructed facilities. In these trades the extra fuel costs are outweighed by capital and crewing savings. These systems are also the most flexible to operate since any ocean-going tug of sufficient horsepower can be matched with any barge. Thus, operators with large multipurpose tug and barge fleets tend to favor this towing mode. It allows them to use the same tug for towing cargo barges, for moving oversize construction equipment without visibility problems, and for salvage. If necessary, they can charter in or out their tugs and barges from or to other operators without worrying about the linkage match.

1st Generation Push-Towed OGTBs: These are basically pull-towed OGTBs with the additional capability of push-towing with any standard tug in calm waters. This ability to push in congested waters rather than taking the barge on a short wire makes these OGTBs much safer. If the hardware and/or shallow notch of these systems does not interfere with the barge's operational flexibility, it would seem reasonable that the greater safety provided by these systems over pull-towed systems would be well worth the investment. Thus, I would expect that most OGTBs predominately operating in the hawser tow mode to be built as 1st Generation OGTBs.

2nd Generation Push-Towed OGTBs: These systems are transitionally between 1st generation and 3rd generation loosely-linked OGTBs. That is, they allow more than 50% of the sea voyage to be in push-tow mode but in severe seas, say greater than eight to twelve feet, the tug and barge must resort to pull-tow operation. Although these systems are more fuel efficient than 1st generation OGTBs since they can push-tow for a larger percentage of the voyage, such fuel savings would not warrant the extra costs for a deeper barge notch and a sophisticated linkage in short distance trades. They also would not be useful

in moderate distance trades when heavy seas might often force the tug out of the notch. This maneuver can be rather dangerous. So for these and longer distance trades, it would probably be worth the moderate additional cost for installation of the new 3rd generation loosely-linked OGTB linkages, assuming that they allow push-towing in all sea-states expected during a voyage. As confirmation of this hypothesis, one 2nd generation OGTB operator has recently contracted for designs to convert his system into a 3rd generation loosely-linked system. It should also be realized that 2nd generation OGTB linkages reduce the operational flexibility of the barge since only tugs designed for the notch can be used for push-towing.

3rd Generation Loosely-Linked Push-Towed OGTBs: These OGTBs allow considerable fuel savings over the previous designs since 100% push-tow operation is achieved. However, continuous push-towing is obtained at the cost of a rather sophisticated and expensive linkage system. Whether this extra cost is warranted depends on how much can be realized in fuel savings. Since fuel savings would be greater the longer the system is at sea, these OGTBs are most suitable for long distance trades with rather short port times. As these systems do require tugs and barges specially designed to match each other and since there are no designs that predominate at this time, the operator has little opportunity to take advantage of the separability of his units except in drop-and-swap mode operation. However, the tugs are basically of standard designs and so could be used for pull-towing if necessary. It should be mentioned that these designs (Bludsworth, Breit/Garcia, Fletcher) have not operated for very long so it has not been proven that they could be operated in the push-mode in very severe seas as would be experienced in transoceanic crossings. This is not of much importance to their owners since they are expected to be only used in coastal trades. However, it may reduce their ability to be speedily mobilized for foreign area operation.

3rd Generation Mechanically-Linked Push-Towed OGTBs: These OGTBs have little to offer over their loosely-linked counterparts. They are a little more fuel efficient since the tug and barge hull lines are designed for smoothness. They are also certain to be capable of push-towing in all ocean sea states, which has yet to be proved for the loosely-linked designs. And, they probably are somewhat safer since they have larger crews and the tugs are built under Coast Guard inspection. However, these improvements are achieved with a large increase in the system's capital and manning costs which result from the tug being built and manned under Coast Guard supervision. It would seem that these marginal improvements would only be warranted in very long trans-ocean or trans-coastal trades. For these trades the increased fuel efficiency and safety would be most important. The larger crews would also be useful for handling the preventative and casualty maintenance that would normally be done by shoreside personnel for the other OGTB systems.

Ships: Ships are certainly the most fuel efficient of all these systems. Their hull lines are designed for the greatest hydrodynamic efficiency. This would make them most suited for the same types of trades for which the mechanically-linked OGTBs are most economic. But, whether these fuel savings are worth the additional capital and manning costs incurred by ships over those incurred by mechanically-linked OGTBs of equivalent size and speed is subject to careful economic analysis. (3) Consideration must be given to the usefulness with respect to safety and for maintenance of the larger crews onboard ships. On the other hand, consideration must be given to the additional flexibility of operation available with OGTBs--particularly the ability to operate in a drop-and-swap mode. The economic ramifications of such flexibility is explained in the next section.

As of today, more and more mechanically-linked OGTBs are being constructed instead of ships for long distance trades. This indicates that at this time they are more economical to own and operate than ships of small unit capacity (<100,000 DWT) and moderate speed (<20 KTs). For the large unit capacity and faster trades, however, ships still have no competition.

(3) One mechanically-linked OGTB operator estimates that the operating expenses for a 35,000 DWT/11,000 HP system would be 40% less than the equivalent conventional ship operating at the same speed.

2.2 Economic Comparison of OGTB Operation in the Drop-and-Swap Versus Integral Mode

In the previous section an economic comparison of the different OGTB systems and ships was made, primarily based on tug-barge operation with the tug remaining with the barge at all times. This is because almost all OGTBs except for a few of the pull-towed and 1st generation OGTBs have been operated in this way. However, this method of operation does not take advantage of the one inherent feature that all OGTBs have that is not available to ships. That is their ability to separate the propulsion unit from the cargo carrying unit. This flexibility can be used to increase system efficiency through increased utilization of expensive propulsion units and through the storage capability of the detached cargo units. It may be that many of the current 3rd generation loosely and mechanically-linked OGTB users, being previously experienced in only ship operations, have just overlooked the potential benefits of the separability of their assets, or it may be that it is not economically profitable to utilize this capability in the trades in which they operate. However, since foreign operators such as Mitsui of Japan have operated fleets of tugs and barges in drop-and-swap operation for several years, it is certain that there are some trades for which this mode of operation is most economical.

It is the purpose of the economic model developed in Appendix D to investigate under just what conditions the separability feature of OGTBs should be utilized. When the model's output indicates that there are few existing or potential trades where this feature may be used, then it would be expected that the economics for OGTB integral mode operations discussed in the last section would solely apply. However, when the model's output indicates that there are many trades which could take economic advantage of this feature, then it might be expected that OGTBs, especially of the mechanically-linked design, would displace ships in these trades.

2.2.1 Detailed Description of the Different Modes of Operation

As it is the separability feature of OGTBs that make them more versatile than ships, more mention should be made on how this feature can be profitably used. The major benefit is the same as that enjoyed by tractor trailers over single unit trucks. That is, the propulsion unit (tractor or tug) can be detached from the cargo unit (trailer or barge) while the cargo unit is used for loading, discharging, or storage. It then can be used for transporting another cargo unit that is available for movement. This method of operation, the drop-and-swap mode, obviously increases the utilization of the costly propulsion unit as compared to the integral mode of operation in which the pro-

pulsion unit always remains with the cargo unit. However, as can be seen in the simple port pair system shown in Figure 2.1, the drop-and-swap mode will require at least two more barges than tugs in a balanced trade or at least one more barge than tugs in an unbalanced trade (where the tug remains with the barge in one port). Certainly, the drop-and-swap mode would be of most benefit in those trades in which loading/discharging times make up a significant part of the voyage time. Here, then, is the most potential in increasing tug utilization, especially in multi-tug fleets which can often be scheduled so that a tug arrives with a barge for discharge just at the time when a barge in port has completed its cargo operations and is available for transport. In this case tug utilization can approach 100%. Also, in trades with long port times, the barges remaining in port in the drop-and-swap mode of operation are used essentially as floating warehouses, replacing shoreside assets. Since port time is a function of the barge cargo capacity and both terminals' loading and discharging rates, and since sea time is a function of port separation distance and OGTB speed, these four parameters are critical in determining whether the drop-and-swap mode should be used over the integral mode. Because the cost relationships that are functions of these parameters (e.g., fuel cost is a function of the tug-barge size and form, OGTB speed, and port separation distance) are rather complicated, it is not intuitively obvious when one mode is superior to another. A systematic analysis, such as that performed by a computer, is required to determine where the tradeoff point is for the modes. A computer model designed to do this analysis is briefly described in the following subsection.

2.2.2 Brief Description of the Drop-and-Swap Computer Model

The economic tradeoff analysis between drop-and-swap and integral mode OGTB operation is accomplished by the computer model described in detail in Appendix D. This model analyzes the simple port pair trade shown in Figure 2.1. This case was chosen since it is the simplest and is appropriate for many of the bulk trades (repetitive voyages from the same loading port to the same discharging port). This port pair trade can be defined essentially by three sets of parameters: (1) port separation distance, (2) terminal loading and discharging rates, and (3) annual cargo flows between ports.

Given the specifics of the trade, the model then determines the barge size (and form) and OGTB speed that will yield the minimum required freight rate (rfr) for both the integral and drop-and-swap modes (balanced and unbalanced). The rfr is defined as the freight rate that should be charged for a unit of cargo that will recover all capital and operating costs plus a desired level of profit on a present-valued discounted cash flow basis (taxes and depreciation ignored). Although specific details on how these costs are obtained is given in Appendix D

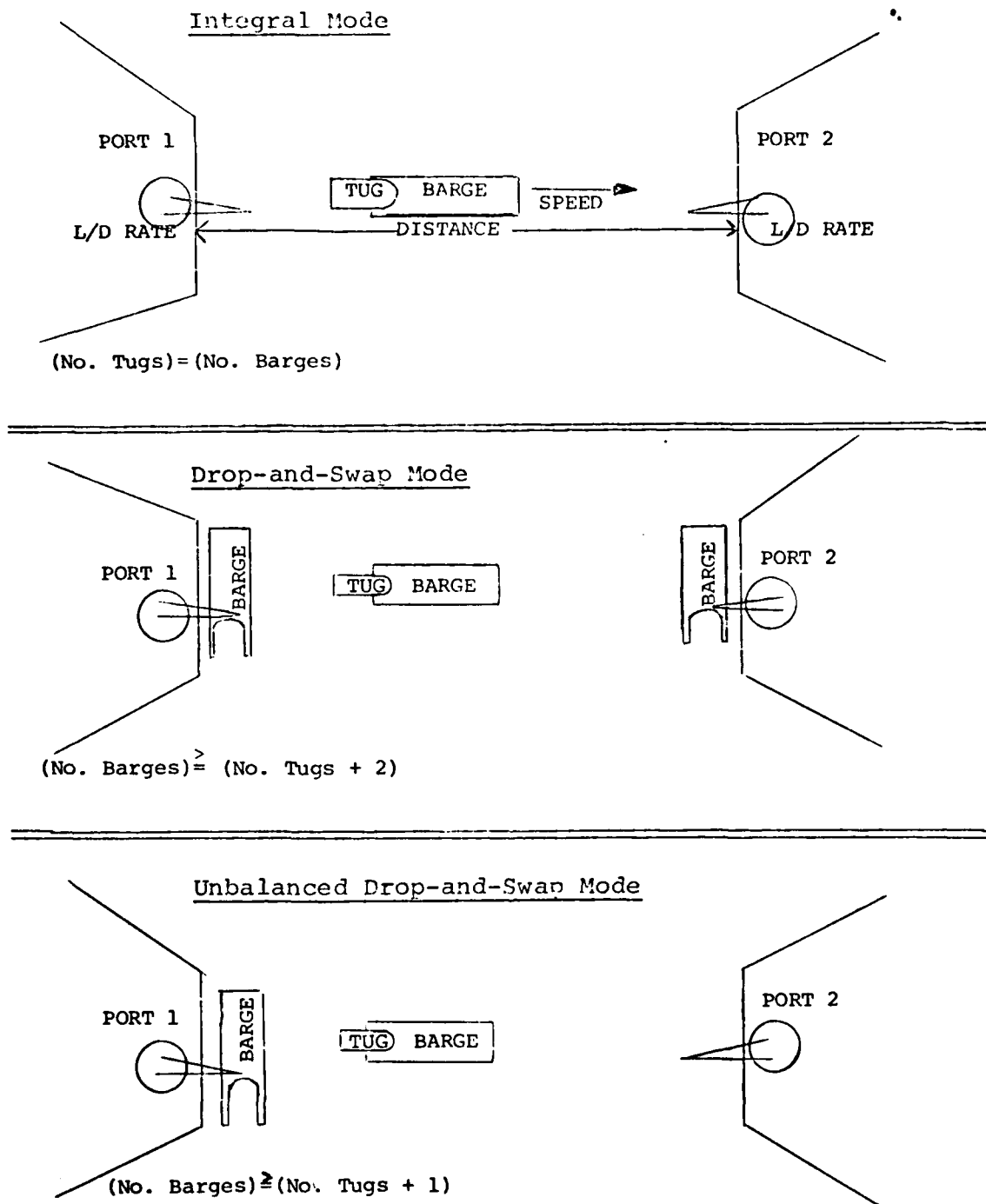


Figure 2.1

Port Pair Trades: Integral and Drop-and-Swap Modes

and Kaskin (1979), some mention about the general assumptions used in obtaining them is given here so that the reader can appreciate the results presented in the next section without reading the Appendix. Specifically, with respect to capital and operating costs the following was assumed:

1. Barge capital costs were assumed to be a direct function of barge hull weight with the addition of outfit cost determined via a regression equation found in George G. Sharp (1975). The hull weight as a function of barge size and form was obtained via regression equations developed from output of the barge design program presented in Kaskin (1979). This program is applicable to single-skin tank barges joined by a 3rd generation semi-rigid linkage to the tug. These types of barges were used since they are the simplest to model and since they are most prevalent of the large OGTBs in use. The semi-rigid rather than rigid linkage was used since it results in less stringent scantling requirements under ABS rules, and in less barge cost. Mechanical rather than loose linkages were used since the tugs with these linkages might be more appropriate for military operations that could demand larger crews and more redundant and safe machinery. However, the model can easily be modified to take in account loosely-linked designs if desired. This rather complicated approach was taken since no reliable barge cost estimate could be obtained from the little available data on OGTBs. In addition, the variation in hull weight as a function of barge form parameters provided by the subprogram is needed for weighing the capital versus operating cost aspects of a barge form.

2. Tug capital costs was determined via a regression equation found in George G. Sharp (1975) and adjusted to conform with prices reported in recent trade literature and government publications. Since many tugs have been built recently, this approach seemed reasonable. Some adjustment is made for the cost of the linkage, which is not extraordinary for semi-rigid linkages.

3. Storage capital costs were calculated for oil storage tanks. The costs were based on recent cost figures provided by a major oil company.

4. Tug fuel costs were determined as a function of tug-barge resistance and voyage duration. Tug-barge resistance, a function of barge form and speed, was determined with the use of full-bodied, bulbous bowless, single-screw tank barge resistance data. This was the only series resistance data that could be found to approximate OGTB hull forms. An additional 10% resistance was added to account for linkage interferences to conform with the estimates found in Robinson (1976).

5. Other operating costs were calculated by using the equations found in George G. Sharp (1975) and then inflating them to yield a current estimate--for 1 January 1979.

6. Port facility costs were not considered.

Although the economic model has been specifically developed for the tank barge case, it should still be indicative of costs for other bulk trades. Barge outfit cost would probably be the only major change for other trades. Thus, any results obtained from the tank barge model, even for trades with very long port times which are not usual for oil barge trades, should not be in great error.

2.2.3 Base Case Results of Computer Model

At this point we consider what can be learned from the model. To do this, the model was run for five one-way trades with annual cargo flows of 100,000; 600,000; 1,000,000; 6,000,000; and 10,000,000 long tons. The user specified inputs and the values of the semi-fixed parameters used in these runs are shown in Table 2.3 and Figure 2.2, respectively. Essentially, in these base case runs the model finds the optimum barge size, speed, and form within the system parameter ranges specified in Table 2.4 for port pair trades with port separation distances of 500, 2000, 3500 and 5000 nautical miles (NM) and for a reasonable range of loading/discharging rates. In these base case trades, it is assumed there are no draft or beam restrictions. Barge length, however, is limited to 750 feet since the ABS rules used in the barge design model are applicable only to barges less than this length. Additionally, barge size is limited to 100,000 DWT since this is the maximum size that designers have even considered for barge construction. (4) Finally, it is assumed that there are no costs associated with terminal loading/discharging or storage facilities. The value of the cargo is assumed to be \$200 per long ton and the other cost parameters are as discussed in Appendix D.

Graphical output from these runs of the required freight rate as a function of loading/discharging (L-D) rate for four port separation distances (500, 2000, 3500 and 5000 nautical miles) is shown in Figures 2.3-2.7. The printed outputs from these runs are voluminous and so cannot be included here. However, some of the results, including the range of optimum barge deadweights and tug speeds, have been extracted and presented in Table 2.5. In addition, some observations that can be made concerning all the runs are presented in the next subsection. This is followed by a discussion of points of inter-

(4) The largest barge currently in operation is the Breit/Ingram tug-barge system Presque Isle of 53,000 DWT operating on the Great Lakes. The largest ocean-going barge will be the 55,000 DWT tank barge being built for Belcher Oil.

Table 2.3
Summary of Inputs Used in Base Case Runs

aflowave1	minrate	mindist	mindwt	mincb	minlb	minbt	minspeed	Changes to Semifixed Parameters	
aflowave2	maxrate delrate	maxdist deldist	maxdwt deldwt	maxcb delcb	maxlb dellb	maxbt delbt	maxspeed delspeed		
100,000	1,000	500	5,000	0.77	6.0	2.0	6.0	None	
0	10,000	5,000	50,000	0.84	6.6	3.0	12.0		
	1,500	1,500	2,500	0.01	0.2	0.5	1.0		
600,000	2,000	500	5,000	0.77	6.0	2.0	6.0	None	
0	12,000	5,000	70,000	0.84	6.6	3.0	13.0		
	2,000	1,500	2,500	0.01	0.2	0.5	1.0		
1,000,000	2,000	500	5,000	0.77	6.0	2.0	6.0	None	
0	14,000	5,000	100,000	0.84	6.6	3.0	13.0		
	2,000	1,500	5,000	0.01	0.2	0.5	1.0		
6,000,000	6,000	500	5,000	0.77	6.0	2.0	7.0	None	
0	54,000	5,000	100,000	0.84	6.6	3.0	14.0		
	8,000	1,500	5,000	0.01	0.2	0.5	1.0		
10,000,000	10,000	500	30,000	0.77	6.0	2.0	8.0	None	
0	80,000	5,000	100,000	0.84	6.6	3.0	16.0		
	10,000	1,500	5,000	0.01	0.2	0.5	1.0		

This is the semi-fixed parametric data file.

tugopdays	350.00
bargeopdays	350.00
tlink (hrs)	4.00
tunlink (hrs)	4.00
servmargin	0.20
fuelmarg	0.20
sfc (lb/HP-hr)	0.36
cfuel (\$/LT)	140.00
clube (\$/gal)	1.75
nrcrew	16.00
cwage (\$/yr)	65000.00
csubs (\$/yr)	3500.00
csteelt (\$1000/LT)	2.94
coutfitt (\$1000/LT)	15.08
csteelb (\$1000/LT)	1.10
coutfitb (\$1000/LT)	12.82
ltug (ft)	140.00
wmisc (LT)	460.00
aother (\$/yr)	30000.00
admin (\$/yr)	150000.00
cfixport1 (\$/call)	0.00
cfixport2 (\$/call)	0.00
cvarport1 (\$/DWT)	0.00
cvarport2 (\$/DWT)	0.00
cfixterm (\$/DWT-day)	0.00
cvarterm (\$/DWT)	0.00
cfixstor (\$/DWT)	0.00
cvarstor (\$/DWT)	0.00
delay1 (hrs)	4.00
delay2 (hrs)	4.00
max1 (ft)	999.00
maxb (ft)	999.00
maxt1 (ft)	99.00
maxt2 (ft)	99.00
disrate	0.10
econlife (yrs)	20.00
inflafctr	0.00
vcargo (\$/DWT)	200.00

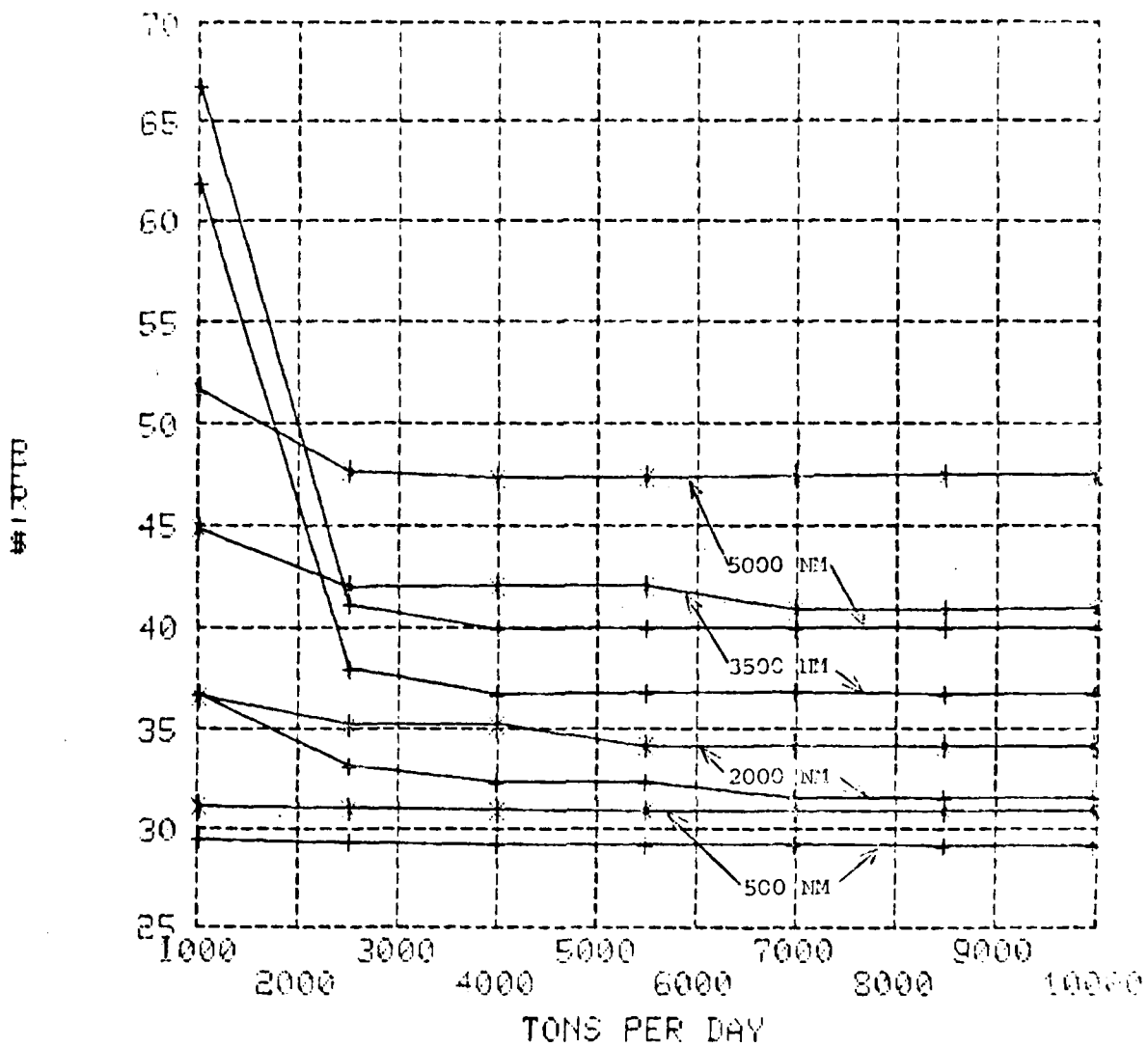
Base Case Values For
Semi-Fixed Parametric Data

Figure 2.2

Table 2.4
Ranges for System Parameters

Parameter	Lower Bound	Upper Bound	Restrictions/ Comments	Reason for Bound
Barge DWT	9,000 6,000	80,000 100,000	Reduced confidence range	Sharp (1975) Valid ranges for operating cost formulae
Barge Length	100'	750'		ABS (1973) Valid ranges for barge hull weight formula
Froude Number	0	0.22	$F_n = \frac{0.298 \text{ Tug Speed}}{\sqrt{\text{Two-Barge Length}}}$	Tsuchida (1969) Valid range for residual resistance coefficients
Barge C_B^*	0.775 0.75	0.835 0.85	Reduced confidence range	" " "
Tug-Barge L/B*	6.2 6.0	7.6 8.0	Reduced confidence range	" " "
Barge B/T	2.46 2.00	2.76 3.25	Reduced confidence range	" " "
Barge L/D	0	16.0		ABS (1973) valid range for barge hull weight formula
Tug IHP	5000 3000	35,000 35,000	Reduced confidence range	Sharp (1975) Valid range for operating cost formulae and tug capital cost formula

*Either C_B or L/B can be in the reduced confidence range, but not both.

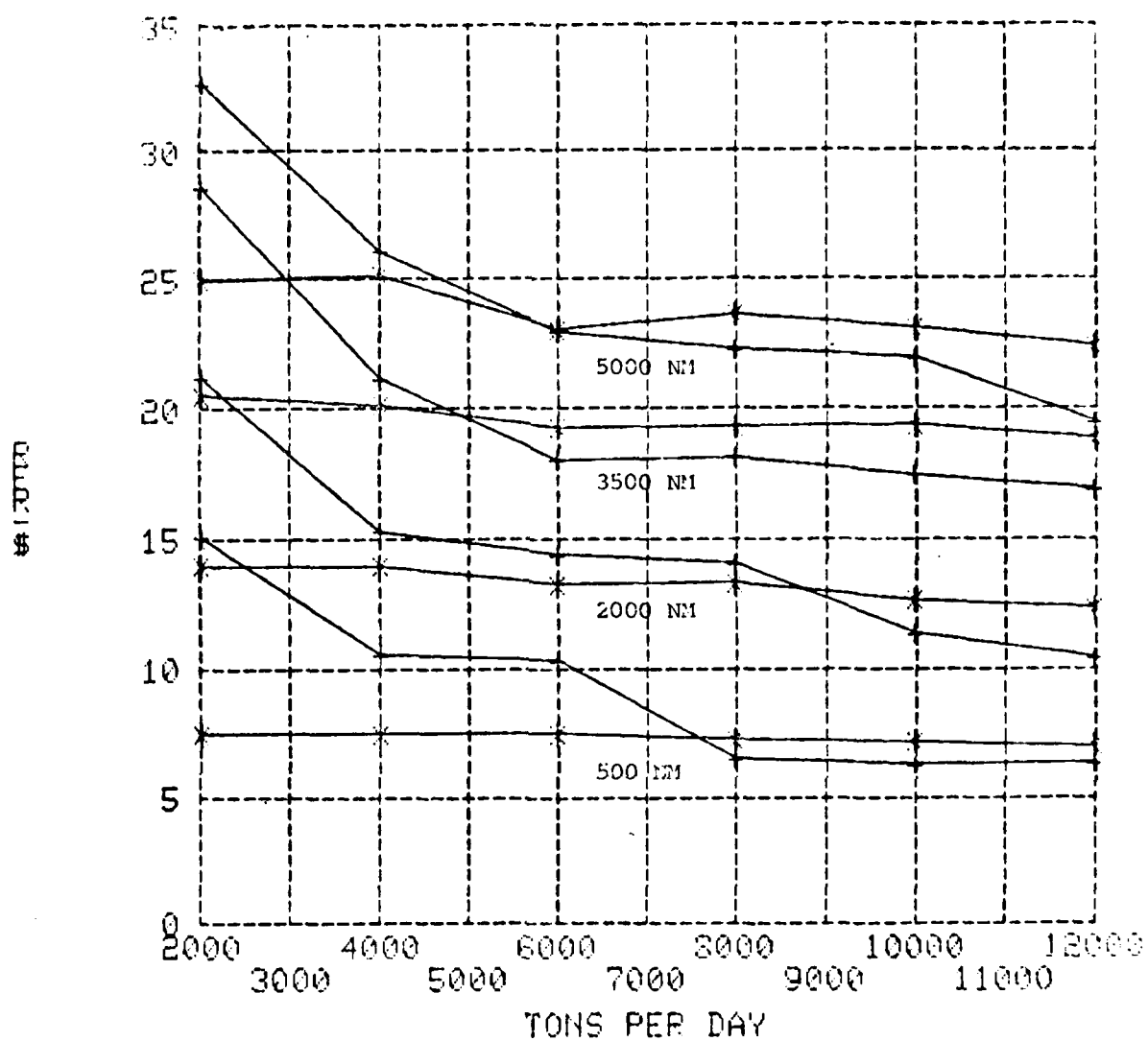


KEY: x -- DROP-AND-SWAP MODE
 + -- INTEGRAL MODE

Figure 2.3

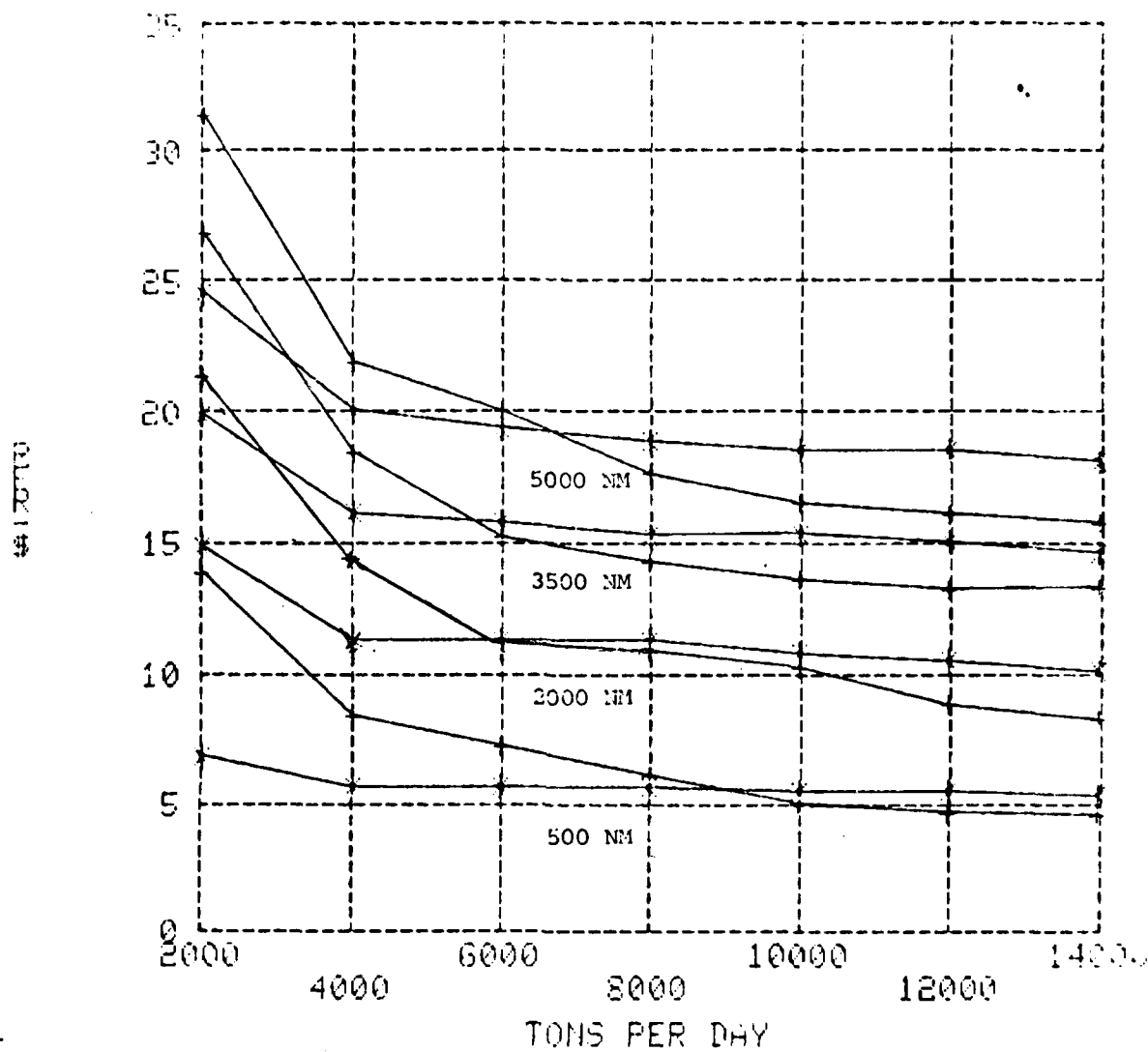
Plot of RFR Vs. Terminal L-D Rate

Base Case Run: Annual Cargo Flow of 100,000 LT



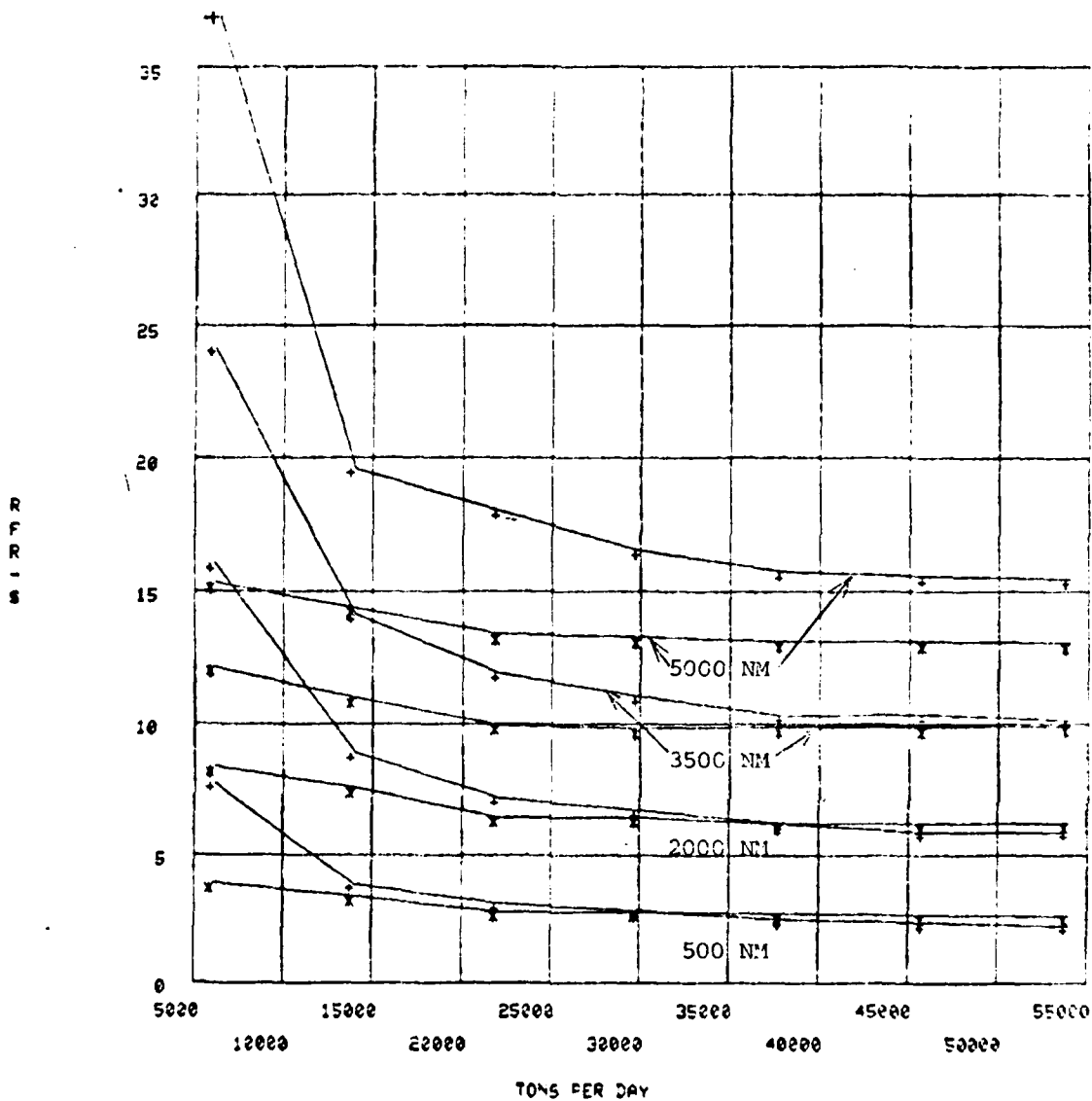
KEY: x -- DROP-AND-SWAP MODE
 + -- INTEGRAL MODE

Figure 2.4
 Plot of RFR Vs. Terminal L-D Rate
 Base Case Run: Annual Cargo Flow of 600,000 LT



KEY: x -- DROP-AND-SWAP MOLE
 + -- INTEGRAL MODE

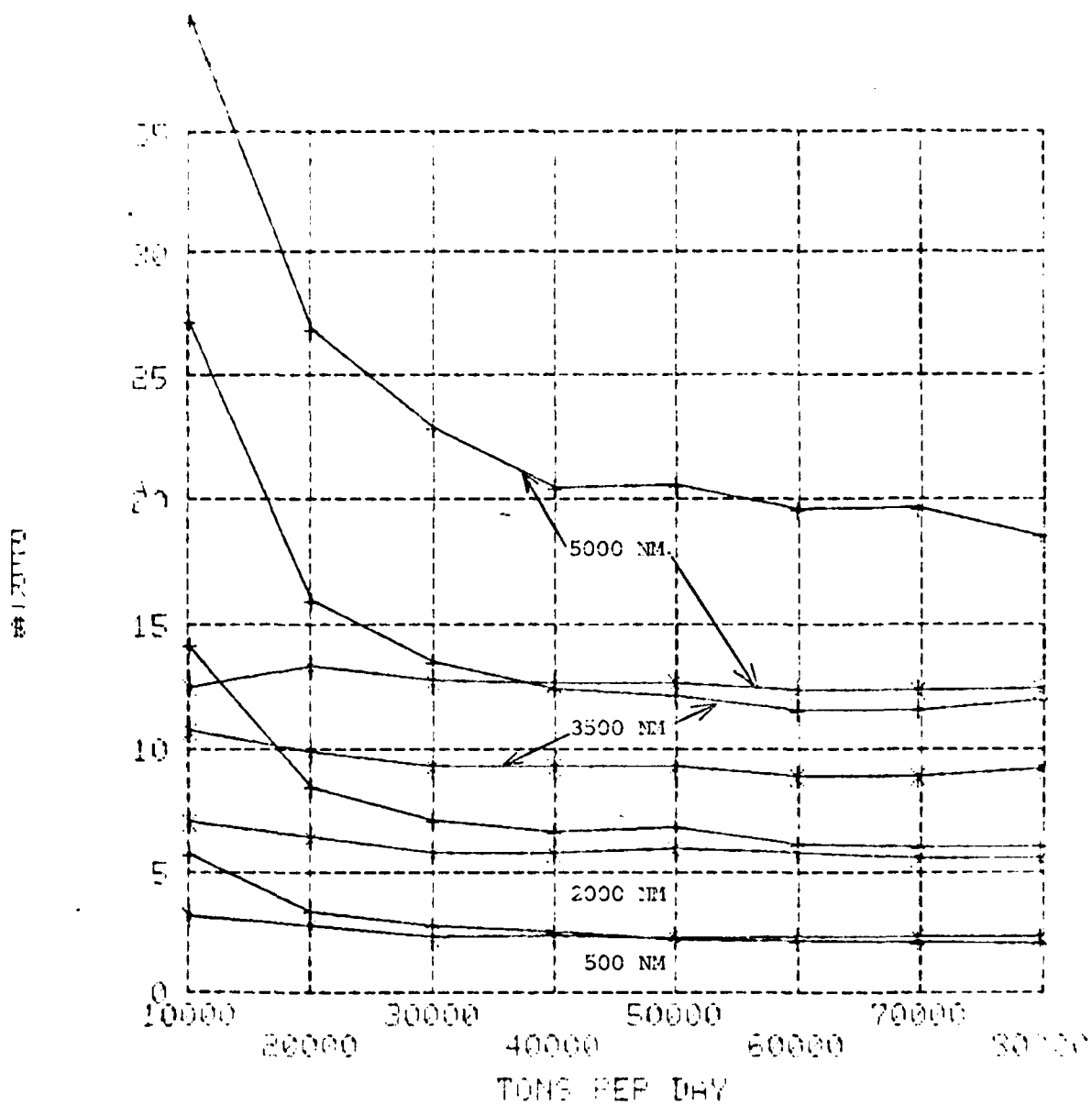
Figure 2.5
 Plot of RFR Vs. Terminal L-D Rate
 Base Case Run: Annual Cargo Flow of 1,000,000 LT



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 + -- INTEGRAL MODE

Figure 2.6

Plot of RFR Vs. Terminal L-D Rate
 Base Case Run: Annual Cargo Flow of 6,000,000 LT



KEY: x -- DROP-AND-SWAP MODE
 + -- INTEGRAL MODE

Figure 2.7
 Plot of RFR Vs. Terminal L-D Rate
 Base Case Run: Annual Cargo Flow of 10,000,000 LT

Table 2.5
Tabular Output Summary for Base Case Runs

Port Separation Distance (Nautical miles)	OUTPUT PARAMETER	a f l o w a v e l (LT)					
		100,000	600,000	1,000,000	6,000,000	12,000,000	
500	DAS Mode Speed Range (Kts)	6	7-9	7-10	8-10	8-10	
	Integral Mode Speed Range (Kts)	6-9	6-9	6-12	7-10	8-10	
	DAS Mode DWT Range (1000 LT)	5	10-15	15-25	30-70	30-70	
	Integral Mode DWT Range (1000 LT)	5	10-15	15-25	30-70	30-70	
	DAS Integral Mode L-D Rate Tradeoff Point (LT/day)	none; Integral mode always favorable	Between 6000 & 8000	Between 8000 & 10000	Between 30,000 & 38000	Between 40,000 & 50,000	
2000	Porttime is of Total Voyage Time at L-D Rate Tradeoff Point	--	44-31	72-59	45-39	37-38	
	DAS Mode Speed Range (Kts)	7-8	8-12	8-10	8-9	9-10	
	Integral Mode Speed Range (Kts)	6-9	7-12	7-12	8-9	9-10	
	DAS Mode DWT Range (1000 LT)	7.5	32.5-42.5	30-80	75-95	85-100	
	Integral Mode DWT Range (1000 LT)	7.5	32.5-42.5	30-80	75-95	85-100	
3500	DAS Integral Mode L-D Rate Tradeoff Point (LT/day)	near 1000	Between 8000 & 10,000	Near 6000	Near 39000	None: DAS Mode always favorable	
	Porttime is of Total Voyage Time at L-D Rate Tradeoff Point	57	35-22	49	23	--	
	DAS Mode Speed Range (Kts)	10-13	8-9	8-11	9-10	9	
	Integral Mode Speed Range (Kts)	6-9	8-12	8-10	10-12	12-13	
	DAS Mode DWT Range (1000 LT)	10 - 12.5	32.5-37.5	40-100	90-100	90-100	
5000	DAS Integral Mode L-D Rate Tradeoff Point (LT/day)	Between 1000 & 2500	Between 4000 & 6000	Between 4000 & 6000	None: DAS Mode always favorable	None: DAS Mode always favorable	
	Porttime is of Total Voyage Time at L-D Rate Tradeoff Point	29	43-29	48	--	--	
	DAS Mode Speed Range (Kts)	8-10	8-10	8-10	9-10	9-12	
	Integral Mode Speed Range (Kts)	6-7	8-11	8-10	10-13	13-15	
	DAS Mode DWT Range (1000 LT)	12.5-17.5	37.5-50	45-90	90-100	60-100	
	DAS Integral Mode L-D Rate Tradeoff Point (LT/day)	Between 1000 & 2500	Near 6000	Between 6000 & 8000	None: DAS Mode always favorable	None: DAS Mode always favorable	
	Porttime is of Total Voyage Time at L-D Rate Tradeoff Point	29	29	36-32	--	--	

est that pertain to an individual run. And, this is followed by some conclusions that can be drawn from the whole series of base runs.

General Observations Pertaining to All Base Case Runs

The following general observations can be made after examining the printed output of the base case runs:

1. The optimum barge form for all the port pair trades has the smallest allowable length-breadth (6.0) and breadth-draft (2.0) ratios. These ratios result in the shortest barge with the least amount of hull steel for a given deadweight capacity. Apparently, at the slow speeds that these tug-barge systems operate, the capital cost savings achieved by constructing short, blunt barges outweigh any cost penalties associated with the higher residual resistance of these forms.

2. The optimum block coefficient for all the port pair trades varies from 0.78 to 0.81. The 0.78 value is usually associated with tug-barge units advancing at eleven knots or faster while the 0.81 value is usually found with systems advancing at nine knots or slower. However, for small tug-barge units, less than 15,000 DWT, a block coefficient of as low as 0.78 may be found for speeds as low as nine knots.

3. Port pair trades with longer port separation distances and faster L-D rates usually have optimum systems with larger barges.

4. Port pair trades with longer port separation distances and slower L-D rates usually have optimum systems with a greater number of tug and barge units.

Observations that are peculiar to an individual base case and not already summarized in Table 2.5 are presented in the following four subsections.

Base Case Results: Annual Cargo Flows of 100,000 LT

When annual cargo flows are as low as in this case, all of the cargo can usually be moved less expensively in a single small barge operating in the ship-like integral mode. The drop-and-swap mode is not competitive due to the extra barge or barges needed to be stationed in port. As can be seen from Figure 2.3, the only time that the drop-and-swap mode can be of advantage is when L-D rates are very low (less than 2000 LT/day) in trades with long port separation distances. In these trades, the extensive in-port time forces integral mode operations to require more than one tug unit to handle the annual cargo flows. This makes integral mode operation uncompetitive compared to drop-and-swap mode operation with only one tug.

Base Case Results: Annual Cargo Flows of 600,000 and 1,000,000 LT

Both of these cases are similar in that for port pair trades with low L-D rates, the drop-and-swap mode will be less expensive. Conversely, for those trades having high L-D rates, the integral mode will be less expensive. As seen in Figures 2.4 and 2.5, the major difference between these cases is that for the 1,000,000 LT case, the L-D rate tradeoff points are usually larger than for the 600,000 LT case. It was observed from both cases that for a given port separation distance, the L-D rate tradeoff point between the two modes usually occurs when the optimal integral mode begins to require only one more tug than the optimal drop-and-swap mode. Then, above the tradeoff L-D rate, the extra cost of the barges needed to remain in port for drop-and-swap mode operation begin to outweigh the capital cost savings resulting from the one fewer tug.

Base Case Results: Annual Cargo Flows of 6,000,000 LT

As seen in Figure 2.6, for this case the drop-and-swap mode will be the most economical method of operation for all port pair trades with port separation distance greater than 3500 NM. This is because with large cargo flows, the savings resulting from economies of scale push the optimum barge size to the upper constraint of 100,000 DWT. Due to this constraint, the optimum number of integral tug-barge units cannot be reduced (at economical speeds of operation) sufficiently fewer than the number of drop-and-swap tugs to make the integral mode economically competitive. Thus, when barge size is constrained, the higher tug utilization at a given speed achieved by the drop-and-swap mode of operation outweighs any barge capital cost savings inherent in the integral mode. For the shorter port separation distance (500 and 2000 nautical miles) the barge size is not binding so that the integral mode does become more economical, but at comparatively high L-D rates. It should be noted that when barge size is not binding the optimal system speeds vary between seven and eleven knots. However, when the barge size approaches the upper limit, the optimum integral mode speeds become as high as thirteen knots.

Base Case Results: Annual Cargo Flows of 10,000,000 LT

In this case the barge size constraint causes the drop-and-swap mode to be the operating mode of choice for all port pair trades except for some with port separation distance of 500 NM. For those trades, the integral mode will be favored when L-D rates exceed 45,000 LT/day. Again, it should be noted that barge size constraints have forced the optimum integral mode systems to operate with speeds of up to fifteen knots.

Conclusions From Base Case Runs

After reviewing all the output from the base case runs, a few general conclusions can be drawn concerning tug-barge systems operating on a port pair trade in either the drop-and-swap or integral mode. The major conclusion is that port pair trades can be broken up into three groups, primarily based on the amount of annual cargo flow and secondarily based on the port separation distance. These groups are 1) trades for which the integral mode will be the operating method of choice for all L-D rates, 2) trades for which the drop-and-swap mode will be the operating method of choice for all L-D rates, and 3) trades for which the drop-and-swap mode will be optimum for low L-D rates and the integral mode will be optimum for high L-D rates.

The first group consists of trades with annual cargo flow requirements less than the ton-mile capacity of a single small (less than 25,000 DWT) tug-barge unit operating at an economical speed (6 to 9 knots). In these trades, since all the cargo can be easily transported in a single tug-barge unit, the higher tug utilization available from drop-and-swap operation is unnecessary. Thus, the integral mode will always be the operating method of choice in these trades.

The second group consists of trades with annual cargo flow requirements much greater than the ton mile capacity of two or more tug-barge units of maximum carrying capacity. The constraint on barge size prevents full use of economies of scale in the integral mode of operation. This, in turn, prevents operation in the integral mode at economical speeds with sufficiently less capital equipment to make up for the increased tug utilization savings inherent in the drop-and-swap mode of operation. Thus, the drop-and-swap mode will always be the operational mode of choice in deadweight constrained trades.

The third group consists of trades not falling within the first two groups. That is, trades for which annual cargo flows are too large to be carried in one tug-barge unit but too small to be carried in several maximum sized units. It is for these trades that there will be a L-D tradeoff point below which the drop-and-swap mode and above which the integral mode will be the operational method of choice.

In general, for trades with greater annual cargo flows and longer port separation distances, this tradeoff point is at greater L-D rates. This is because these trades demand more ton-mile transport capacity which can be met by either increasing the number or size of the tug-barge units. If the number of units is increased, then the additional barges that must remain in port in the drop-and-swap operations become less significant. If the barge size is increased, the increase for the drop-and-swap mode operation will be less than for integral mode operations due to the higher tug utilization efficiency. In ei-

ther case the drop-and-swap mode is favored in these trades more than the integral mode.

It should be mentioned that trades with very short port separation distances (i.e. 500 NM) have L-D tradeoff points at higher values than for longer distance trades. This is because the percentage of the total voyage time spent in port (about 40% at the L-D tradeoff point) is large for these trades, favoring the higher tug utilization efficiencies achieved by drop-and-swap mode of operation.

From the base case runs, certain conclusions can also be drawn concerning the form and speed of the optimum barge. It appears that since the Froude number is so low (less than 0.16) at the optimum tug-barge speeds of seven to eleven knots that residual resistance does not have much significance. Thus, optimum barge forms have the greatest draft and breadth possible to reduce the length; and, consequently, the barge capital cost. This saving outweighs any resistance penalty caused by the blunt barge forms. The only concession made for the effect of resistance is with respect to block coefficient. For tug-barge speeds greater than ten knots finer lines are required while blunter lines are suitable at slower speeds.

2.2.4 Sensitivity Runs of Computer Model

Sensitivity runs were made to see the effect on required freight rates and L-D rate tradeoff points of changes in some of the semi-fixed parameter values used in the base case runs. Specifically, changes to the value of the cargo, the shoreside storage costs, and the maximum barge draft were investigated.

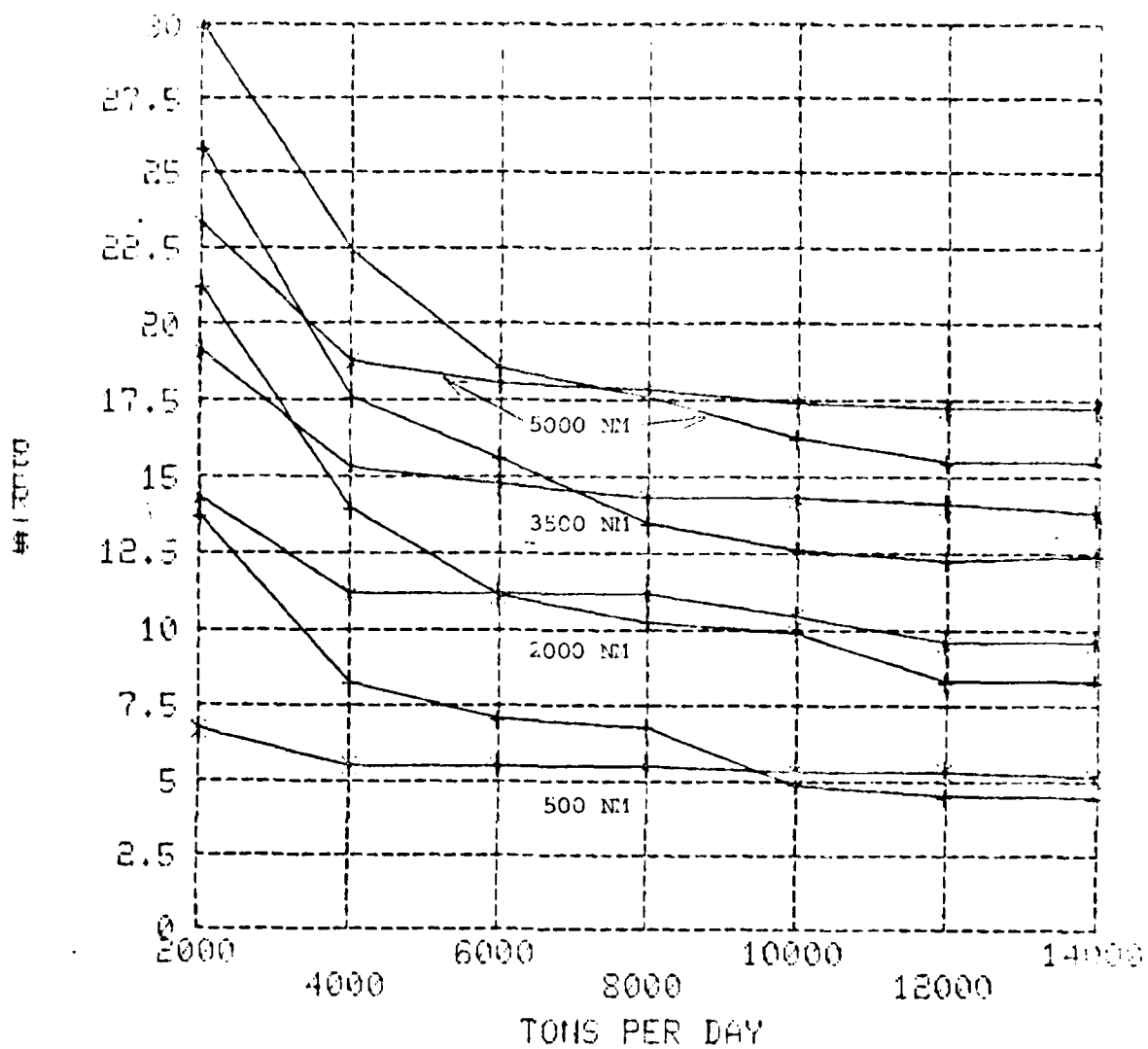
Due to the cost of these runs, an exhaustive set, including a wide range of variation of a single parameter or combination of parameters, could not be made. However, the runs whose inputs are given in Table 2.6 should give an indication, although not conclusive, of the effects of changes to their values. In the three subsections that follow, an analysis is made of the output from the sensitivity runs.

Sensitivity Run: Change in Cargo Value

A sensitivity run was made to see what effects a change in the cargo value from \$200 to \$0 per long ton would have on the 1,000,000 LT annual cargo flow base case. As seen in Figure 2.8 and Table 2.7, this reduction in cargo value reduces the required freight rate by less than \$.20 for trades with port separation distance of 500 NM to over \$1.00 for trades with a port separation distance of 5000 NM. As to be expected, the reduction is in proportion to the port separation distance, which is indicative of the sea time and the time value of the cargo. It was also

Table 2.6
Summary of Inputs Used in Sensitivity Case-Runs

aflowave1	minrate	mindist	mindwt	mincb	minlb	minbt	minspeed	Changes to
aflowave2	maxrate	maxdist	maxdwt	maxcb	maxlb	maxbt	maxspeed	Semixed
	delrate	deldist	deldwt	dclcb	dcllb	dclbt	delspeed	Parameter
1,000,000	2,000	500	5,000	0.78	6.0	2.0	6.0	vcargo = 0
0	14,000	5,000	100,000	0.82	6.0	2.0	13.0	
	2,000	1,500	5,000	0.01			1.0	
6,000,000	6,000	500	30,000	0.78	6.0	2.0	7.0	cfixstor = 48
0	70,000	5,000	100,000	0.81	6.0	2.0	15.0	
	8,000	1,500	5,000	0.01			1.0	
1,000,000	4,000	500	5,000	0.78	6.0	2.0	6.0	cfixstor = 48
0	16,000	5,000	100,000	0.81	6.0	2.0	13.0	
	2,000	1,500	5,000	0.01			1.0	
1,000,000	3,000	500	5,000	0.78	6.0	2.0	6.0	cfixstor = 48
0	24,000	5,000	100,000	0.81	6.0	2.0	13.0	cvarstor = 1
	3,000	1,500	5,000	0.01			1.0	
1,000,000	3,000	500	5,000	0.78	6.0	2.0	5.0	cfixstor = 48
0	24,000	5,000	100,000	0.81	6.6	3.0	12.0	maxt1 = maxt2 = 38
	3,000	1,500	5,000	0.01	0.2	0.5	1.0	
1,000,000	2,000	500	5,000	0.75	6.0	2.0	6.0	maxt1 = maxt2 = 38
0	14,000	5,000	100,000	0.83	6.4	3.0	13.0	
	2,000	1,500	5,000	0.01	0.2	0.5	1.0	



KEY: x -- DROP-AND-SWAP MODE
 + -- INTEGRAL MODE

Figure 2.8

Plot of RFR Vs. Terminal L-D Rate
 Sensitivity Run: Annual Cargo Flow of 1,000,000 LT
 With Cargo Value of \$0

Table 2.7

Tabular Summary for Sensitivity Runs

Port Separation Distance (Nautical Miles)	OUTPUT PARAMETERS	SENSITIVITY RUN PARAMETERS			
		aflowavel=1,000,000 Base Case	aflowavel=1,000,000 vcargo = 0	aflowavel=6,000,000 Base Case	aflowavel=6,000,000 cfixstor=48
500	RFR at Specified L-D rate, D&S mode	\$ 6.85 @2000	\$ 6.71 @2000	\$ 3.87 @6000	\$ 3.87 @6000
	RFR at Specified L-D rate, Integral mode	11.84 "	13.69 "	7.71 "	7.94 "
	RFR at Specified L-D rate, D&S mode	5.49 @12000	5.32 @12000	2.55 @54000	2.55 @54000
	RFR at Specified L-D rate, Integral mode	4.65 "	4.47 "	2.17 "	2.30 "
	RFR at L-D Rate Tradeoff Point	About \$5.55	About \$5.35	About \$2.68	About \$2.65
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Between 8000 & 10000	Between 8000 & 10000	Between 30000 & 38000	Between 30000 & 38000
2000	RFR at Specified L-D rate, D&S mode	\$14.35 @2000	\$14.31 @2000	\$ 8.35 @6000	\$ 8.35 @6000
	RFR at Specified L-D rate, Integral mode	21.48 "	21.23 "	16.03 "	16.45 "
	RFR at Specified L-D rate, D&S mode	10.46 @12000	9.56 @12000	6.17 @54000	6.17 @54000
	RFR at Specified L-D rate, Integral mode	8.79 "	8.27 "	5.84 "	6.03 "
	RFR at L-D Rate Tradeoff Point	11.67	11.13	6.14	6.15
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Near 6,000	Near 6,000	Near 38,000	Between 38,000 & 46000
3500	RFR at Specified L-D rate, D&S mode	\$19.91 @2000	\$19.16 @2000	\$12.08 @6000	\$12.08 @6000
	RFR at Specified L-D rate, Integral mode	26.82 "	25.82 "	24.28 "	24.84 "
	RFR at Specified L-D rate, D&S mode	15.03 @12000	14.10 @12000	9.35 @54000	9.85 @54000
	RFR at Specified L-D rate, Integral mode	13.25 "	12.24 "	10.08 "	10.26 "
	RFR at L-D Rate Tradeoff Point	15.85	about \$14.50	---	---
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Between 4000 & 6000	Between 6000 & 8000	None: D&S mode always favorable	None: D&S mode always favorable
5000	RFR at Specified L-D rate, D&S mode	\$24.56 @2000	\$23.26 @2000	\$15.31 @6000	\$15.31 @6000
	RFR at Specified L-D rate, Integral mode	31.42 "	29.99 "	37.28 "	37.79 "
	RFR at Specified L-D rate, D&S mode	18.55 @12000	17.31 @12000	12.97 @54000	12.97 @54000
	RFR at Specified L-D rate, Integral mode	16.07 "	15.50 "	15.43 "	15.61 "
	RFR at L-D Rate Tradeoff Point	About \$19.25	About \$17.95	---	---
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Between 6000 & 8000	Between 6000 & 8000	None: D&S mode always favorable	None: D&S mode always favorable

Table 2.7Cont.
Tabular Summary for Sensitivity Runs

Port Separation Distance (Nautical Miles)	OUTPUT PARAMETERS	SENSITIVITY RUN PARAMETERS			
		aflowave1=1,000,000 cfixstor=48	aflowave1=1,000,000 cfixstor=48 cvastor = 1	aflowave1=1,000,000 cfixstor=48 maxtl=38	aflowave1=1,000,000 maxtl=38
500	RFR at Specified L-D rate, D&S mode	\$ 6.95 @2000	\$ 5.65 @3000	\$ 5.65 @3000	\$ 6.85 @2000
	RFR at Specified L-D rate, Integral mode	14.18 "	11.61 "	10.61 "	13.84 "
	RFR at Specified L-D rate, D&S mode	5.49 @12000	5.49 @12000	5.52 @12000	5.52 @12000
	RFR at Specified L-D rate, Integral mode	5.04 "	6.09 "	5.36 "	5.07 "
	RFR at L-D Rate Tradeoff Point	5.48	---	About \$5.50	About \$5.55
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Near 10000	None: D&S Mode always favorable	Near 12000	Between 10000 & 12000
	% Port Time is of Total Voyage Time at L-D rate Tradeoff Point	57	---	48	48-29
2000	RFR at Specified L-D rate, D&S mode	\$14.85 @2000	\$12.50 @3000	\$14.43 @3000	\$16.05 @2000
	RFR at Specified L-D rate, Integral mode	22.31 "	16.85 "	19.47 "	22.84 "
	RFR at Specified L-D rate, D&S mode	10.46 @12000	10.46 @12000	12.84 @12000	12.84 @12000
	RFR at Specified L-D rate, Integral mode	9.37 "	11.05 "	12.39 "	12.05 "
	RFR at L-D Rate Tradeoff Point	About \$10.70	About \$10.00	About \$12.80	About \$13.45
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Between 10000 & 12000	Between 18000 & 21000	Between 9000 & 12000	Between 6000 & 8000
	% Port Time is of Total Voyage Time at L-D rate Tradeoff Point	48-29	32-27	32-24	37-32
3500	RFR at Specified L-D rate, D&S mode	\$19.91 @2000	\$16.34 @3000	\$20.11 @3000	\$22.90 @2000
	RFR at Specified L-D rate, Integral mode	27.95 "	23.01 "	26.72 "	30.89 "
	RFR at Specified L-D rate, D&S mode	15.03 @12000	15.03 @12000	18.85 @12000	18.85 @12000
	RFR at Specified L-D rate, Integral mode	14.04 "	15.04 "	18.79 "	18.29 "
	RFR at L-D Rate Tradeoff Point	About \$5.30	About 15.04	About 19.00	About \$20,000
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Near 8000	12000	Between 6000 & 12000	Between 6000 & 8000
	% Port Time is of Total Voyage Time at L-D rate Tradeoff Point	36	24	24-17	26-24
5000	RFR at Specified L-D rate, D&S mode	\$24.56 @2000	\$21.24 @3000	\$25.10 @3000	\$29.72 @2000
	RFR at Specified L-D rate, Integral mode	33.00 "	29.35 "	32.87 "	39.44 "
	RFR at Specified L-D rate, D&S mode	18.55 @12000	18.55 @12000	24.25 @12000	24.25 @12000
	RFR at Specified L-D rate, Integral mode	17.20 "	20.20 "	24.28 "	23.72 "
	RFR at L-D Rate Tradeoff Point	About \$19.00	About \$18.05	About \$24.25	About \$24.60
	D&S/Integral mode L-D rate Tradeoff Point (LT/day)	Near 8000	Near 15000	12000	Between 8000 & 10000
	% Port Time is of Total Voyage Time at L-D rate Tradeoff Point	36	19	17	25-19

noticed that in the base case run, that the optimum system speeds would sometimes be one, two, or even three knots faster than the sensitivity run. This confirms what is to be expected, that higher cargo values result in higher optimum system speeds. Thus, it is seen that unless the time value of cargo is included in any transportation system optimization model, the transport vehicles will be optimized at too slow a speed.

Sensitivity Runs: Changes to Shoreside Storage Costs

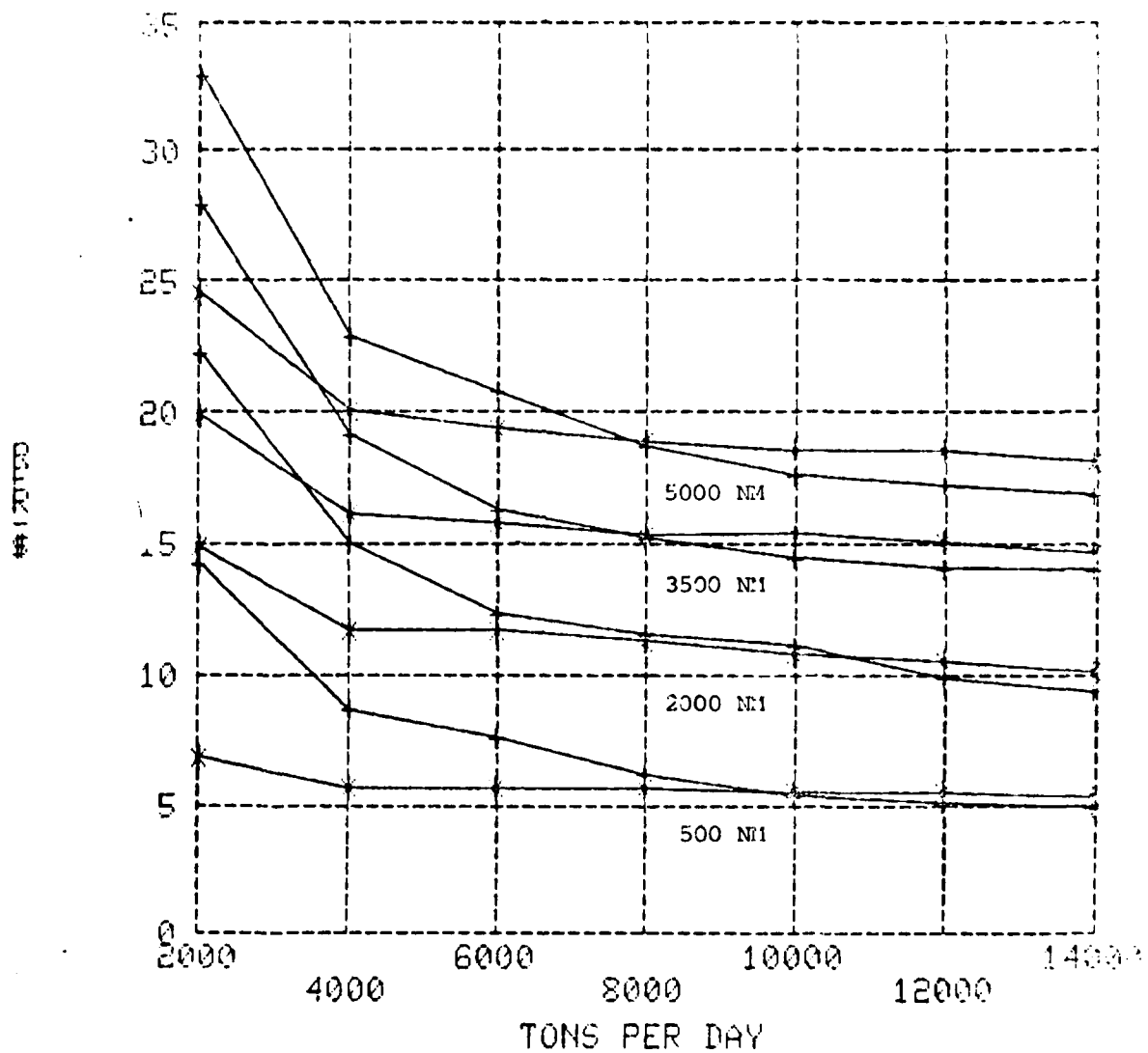
Two sensitivity runs were made to determine what effects the inclusion of shoreside storage capital construction costs of \$48 per long ton storage capacity (5) would have on the 1,000,000 and 6,000,000 long ton annual cargo flow base cases. In addition, a run was made to determine the effect on the 1,000,000 long ton base case when a \$1.00 per long ton storage facility throughput charge was also included.

It would be expected that since shoreside storage costs are applicable to the integral mode only, the inclusion of such costs would favor the drop-and-swap mode of operation. This expected result is confirmed by the graphical and tabular output of the runs presented in Figures 2.9-2.11 and Table 2.7. From both runs it is seen that the effect of the capital cost of shoreside storage on the integral mode becomes more pronounced with longer port separation distances. This is because these port pair trades demand the larger barges and consequently, larger and more expensive storage tanks. (6) Also, the effect of storage is greater in trades with low L-D rates since these trades require more shoreside loading and discharging terminal facilities to handle the annual cargo flows.

The combined results of both of these effects is that the L-D tradeoff point is shifted to higher values, especially for trades with longer port separation distances and that the advantage the drop-and-swap mode has for trades with low L-D rates becomes more pronounced.

(5) This value for storage capacity capital costs was obtained from a major oil company and is indicative of oil tankage construction costs for large tanks as of January 1979. Also, the model assumes that the amount of shoreside storage capacity for a given port pair trade is equal to the product of the number of terminal facilities in the port times the deadweight of the optimum barge operating in the integral mode for that port pair trade.

(6) For the 1,000,000 LT annual cargo flow trades, the present valued annual capital charges for storage amount to approximately \$0.0564 per 10,000 LT of tankage and cargo flow.



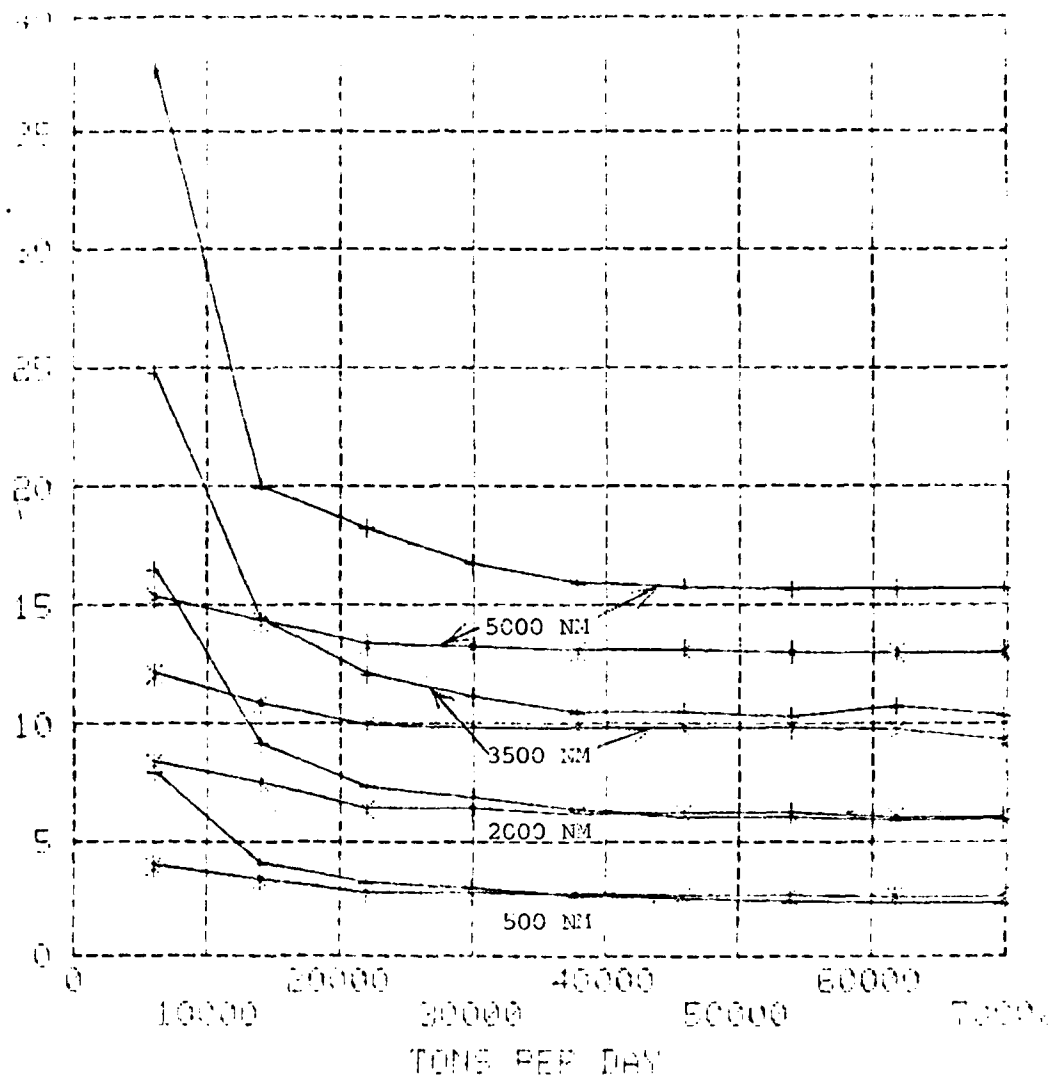
KEY: x -- DROP-AND-SWAP MODE
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Figure 2.9

Plot of RFR Vs. Terminal L-D Rate

Sensitivity Run: Annual Cargo Flow of 1,000,000 LT
 With Storage Facility Capital Cost of \$48/LT

CUBA 14

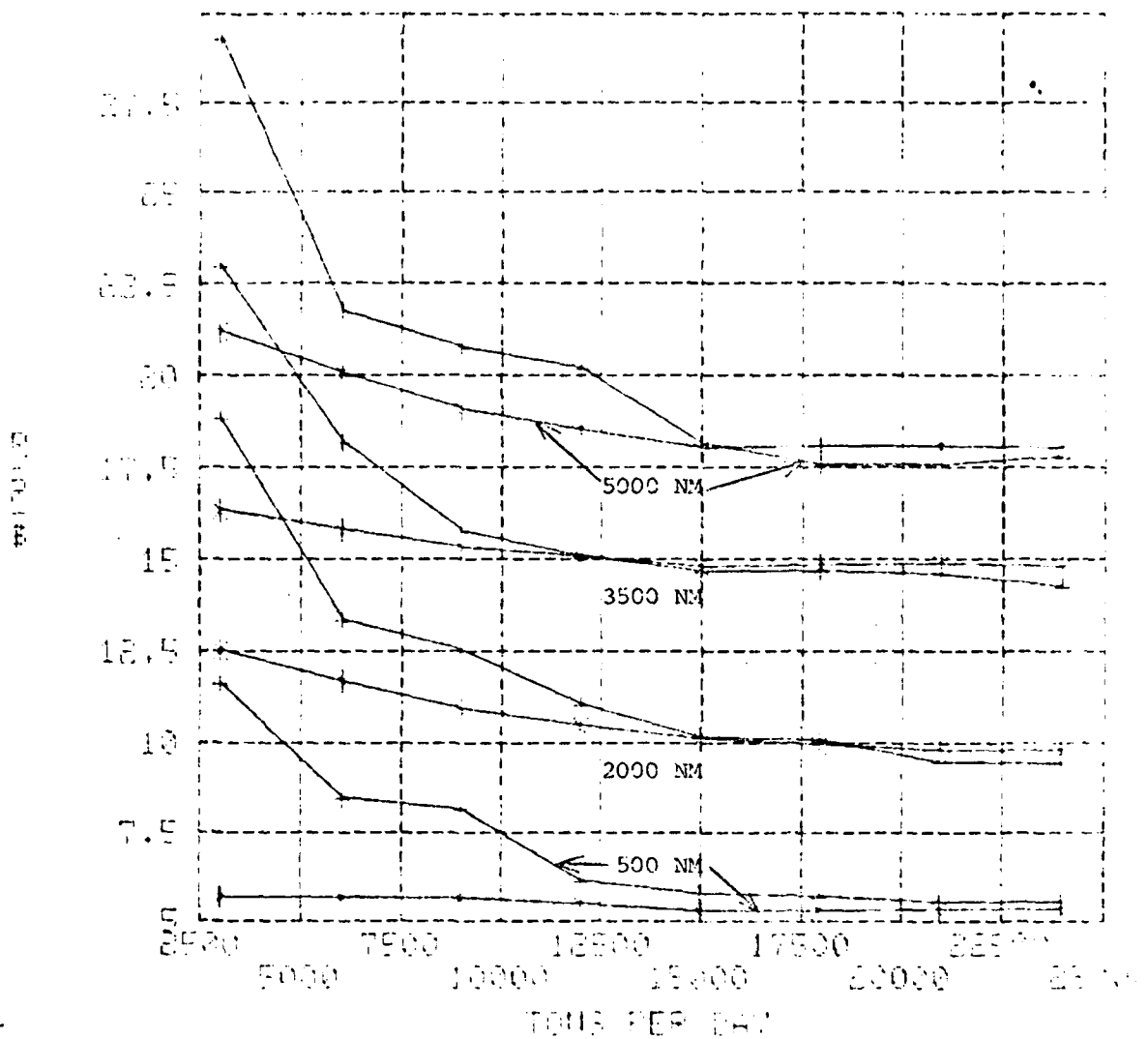


KEY: x -- DROP-AND-SWAP MODE
 + -- INTEGRAL MODE

Figure 2.10

Plot of RFR Vs. Terminal L-D Rate

Sensitivity Run: Annual Cargo Flow of 6,000,000 LT
 With Storage Facility Capital Cost of \$48/LT



KEY: X -- DROP-AND-SWAP MODE
 + -- INTEGRAL MODE

Figure 2.11

Plot of RFR Vs. Terminal L-D Rate

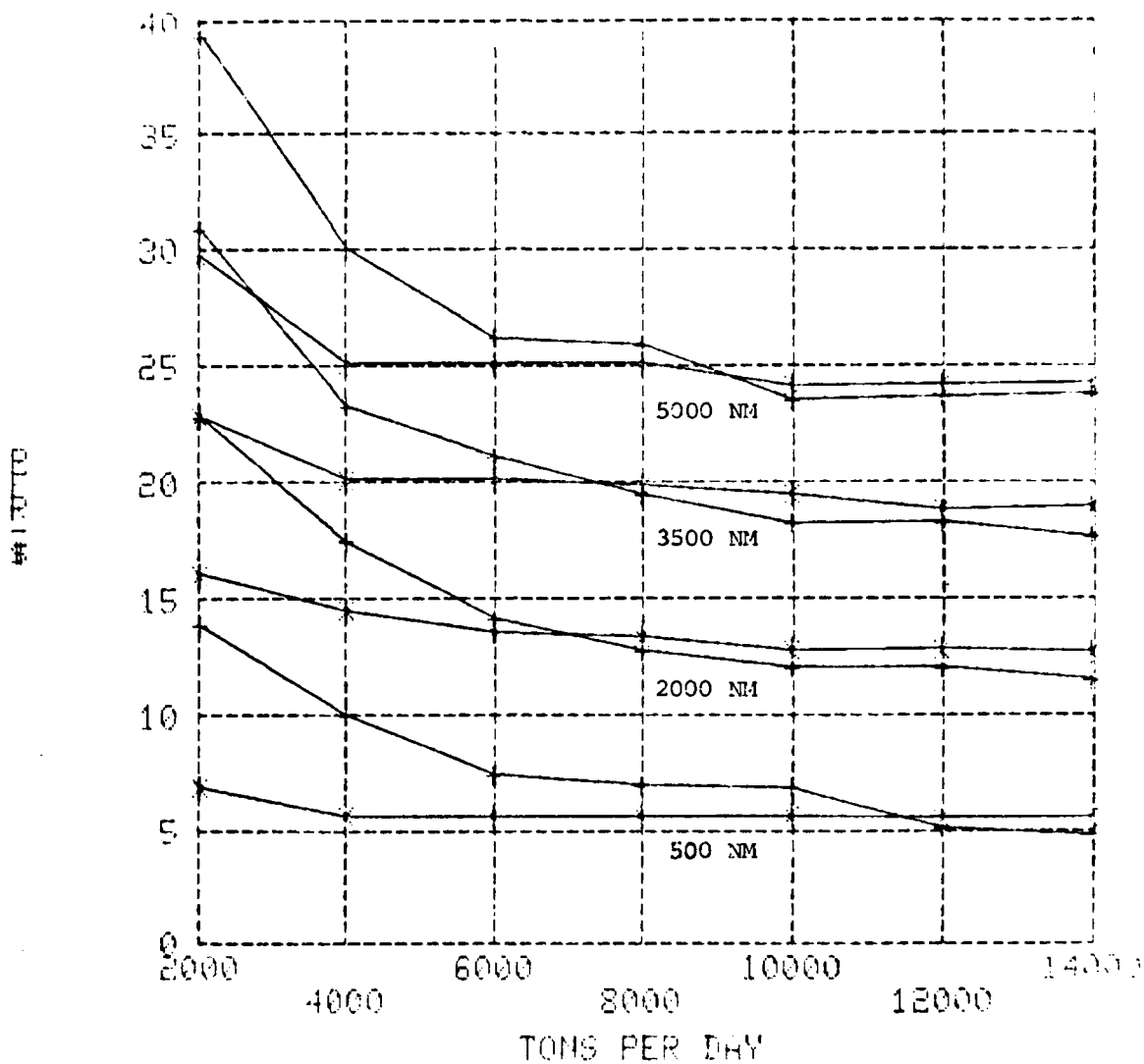
Sensitivity Run: Annual Cargo Flow of 1,000,000 LT
 With Storage Facility Capital Cost of \$48/LT
 With Storage Facility Operating Cost of \$1/LT

The addition of the \$1.00 storage operating cost favors the drop-and-swap mode even more than the storage capital costs. This is because it essentially increases all the integral mode trades' rfr's by \$1.00, equivalent to the annualized capital cost for over 175,000 LT of tankage. As seen by comparing Figures 2.10 and 2.11, this results in a shift of the integral mode curves by \$1.00 so that the L-D tradeoff point moves to a much higher value. For the port pair trades with a separation distance of 500 NM, where the integral mode has rfr's only marginally lower than the drop-and-swap mode at high L-D rates, the inclusion of the operating storage costs increases the integral mode rfr so much that the drop-and-swap mode dominates for all L-D rates. Since the differences between the drop-and-swap and integral rfr curves is more pronounced with large port separation distance, the tradeoff point shift is not as great for these trades. However, it is apparent that if shoreside storage costs are included in the economic analysis, the trades for which the drop-and-swap mode will be optimal will be extended to those of significantly higher loading/discharging rates.

Sensitivity Runs: Inclusion of Port Draft Limit

A sensitivity run was made to investigate the effects that a draft limitation would have on the 1,000,000 LT annual cargo flow base case. Additionally, another run was made to see if a similar effect occurred in the 1,000,000 LT trades when a \$48 per long ton storage terminal capital cost was included with the draft limitation. The graphical and tabular results of these runs are shown in Figures 2.12 and 2.13 and Table 2.7.

Comparing these figures with the unrestricted draft cases shown in Figures 2.5 and 2.9, it was observed that there was little effect on trades which were optimized with small barges, those of less than 450 feet or 25,000 DWT. However, the effect was very pronounced in those trades which in the unrestricted draft case would be optimized with large barges. In those trades, both the drop-and-swap and integral mode rfr's were increased by several dollars. This is because the draft restrictions forced the optimum feasible barges of a given dead-weight capacity to have greater lengths and, consequently, greater capital cost. Additionally, since barge length was constrained to be less than 750 feet, the maximum barge size was limited to less than 65,000 DWT. This forced those trades which were optimized in the unrestricted draft cases to obtain the necessary ton-mile capacity by either increasing the speed of the tugs or the number of tug-barge units in operation--both requiring the rfr to increase even further. The draft limitation affects both the drop-and-swap and integral mode trades. However, since the majority of unlimited draft port pair trades are optimized with larger barges in the integral than the drop-and-swap mode, the effect is somewhat greater for the integral mode. Thus, the L-D trade-off point is shifted to somewhat



KEY: x -- DROP-AND-SWAP MODE
 + -- INTEGRAL MODE

Figure 2.12

Plot of RFR Vs. Terminal L-D Rate

Sensitivity Run: Annual Cargo Flow of 1,000,000 LT
 With Barge Draft Limited to 38'

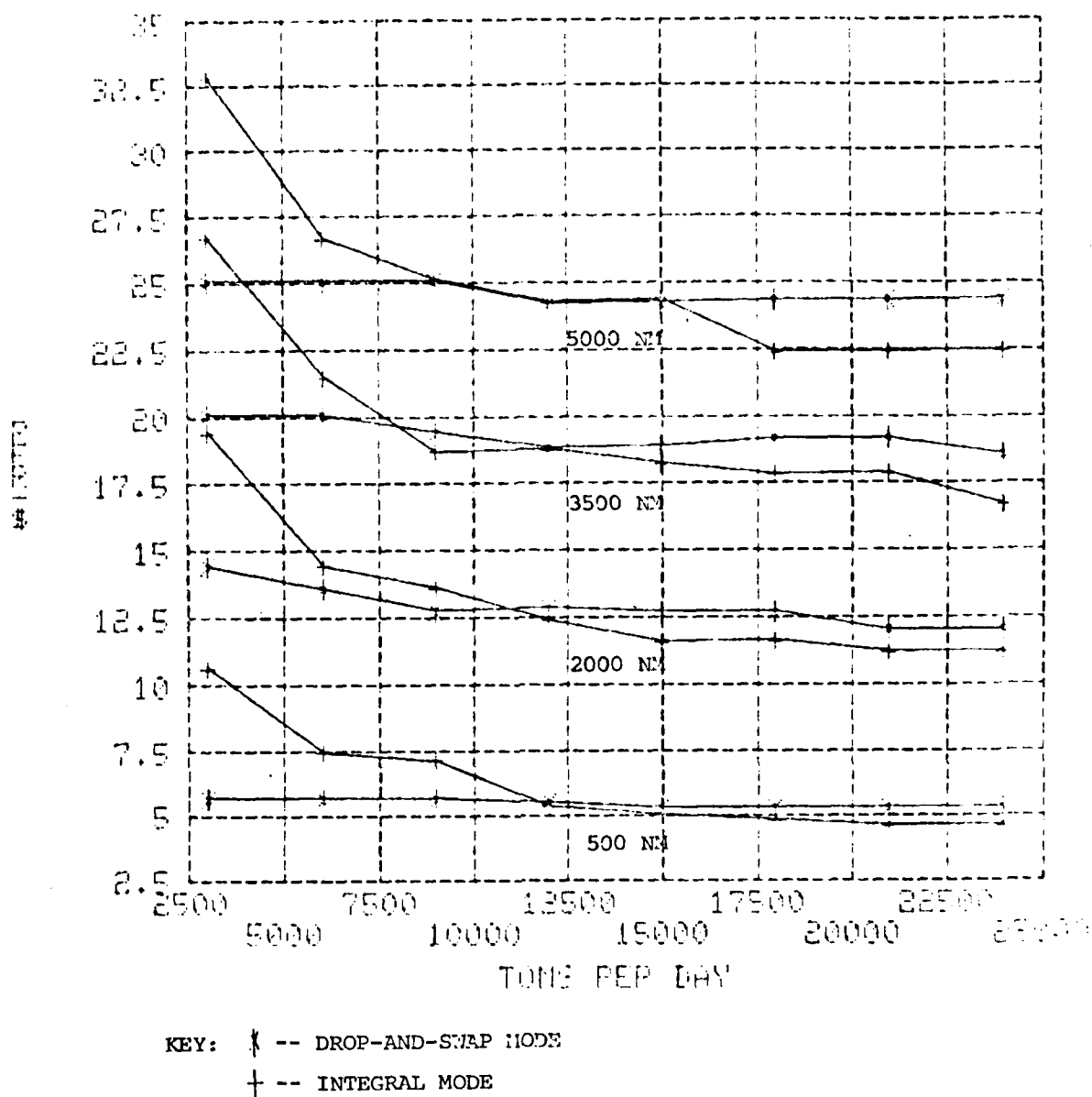


Figure 2.13

Plot of RFR Vs. Terminal L-D Rate

Sensitivity Run: Annual Cargo Flow of 1,000,000 LT
With Barge Draft Limited to 38'

With Storage Facility Capital Cost of \$48/LT

higher values in the longer distance trades where larger barges are predominant. Nevertheless, the shift is not very great.

Generally, it is seen that port draft restrictions are very costly in trades which have large annual cargo flows and/or long port separation distances and thus would normally take advantage of the economies of scale inherent in large barges. These trades, however, are slightly more favorable to the drop-and-swap mode of operation.

2.2.5 Summary of Computer Model Results

To summarize, the results of the computer model's base and sensitivity runs show that the drop-and-swap mode of operation will be favored in trades where:

- (1) There are size restrictions (draft, length, or beam) that prevent the required annual cargo flows from being carried on a few large deep-draft ships or integral mode operated OGTBs.
- (2) There is such a great annual cargo flow requirement that it must be carried in many vessels. This is just (1) in a different form since some size restriction causes the need for the large number of vessels.
- (3) Shoreside storage facilities are expensive.
- (4) Terminal loading/discharge rates are low so that port time becomes a large part of the total voyage time.
- (5) Port separation distances are very short so that port time again becomes a large part of the total voyage time since the sea time is short.

2.3 Future Prospects for OGTBs

From the historical prospective and economic analysis presented previously, it has become apparent that OGTBs have developed primarily to take advantage of the less expensive manning and construction opportunities available to them under current Coast Guard regulations. Very few systems have been developed to take advantage of their inherent flexibility of separability. Thus, the future prospects of OGTBs will depend highly on whether these regulations change in the future. In this section the latest regulatory developments will be discussed, including their potential impact on the commercial OGTB industry.

2.3.1 Current Coast Guard Regulatory Initiatives

Currently the Coast Guard is attempting to change two aspects of the regulatory structure pertaining to OGTBs. One is with respect to tank barge construction and the other is with respect to inspection of push-towed systems.

First consider tank barge construction. At this time there are no special regulations pertaining to the construction of oil tank barges. They may be single-skinned, double-bottomed, or double-hulled. However, there are two different sets of proposed rules that have been published by the Coast Guard in the Federal Register in recent months that would change this situation.

The first set of rules, published in the 12 February 1979 issue of the Federal Register, pertains to clean product ships and barges of greater than 30,000 DWT and crude oil ships and barges of greater than 20,000 DWT. They essentially implement the proposed IMCO tanker anti-pollution standards, summarized in Table 2.8, and the provisions of the Port and Tanker Safety Act of 1978. Included in these regulations is the requirement for protective segregated ballast on new and existing ships and barges.

The second set of rules, published in the 14 June 1979 issue of the Federal Register, pertains to barges of smaller size. In summary, these regulations require that clean product barges of less than 30,000 DWT and crude oil barges of less than 20,000 DWT built after 31 December 1979 have double hulls of greater than 24" separation and between which no product can be carried. No existing single-skin barge can be operated after 1985 after they have reached twenty years of age unless they are retrofitted with end voids and a double-bottom or double-sides or unless they are operated in restricted trades in which there would be a negligible probability of a polluting spill.

By the way that these proposed regulations are currently written, there would probably be little impact on the tank OGTB industry. The first regulations for the large vessels affect all ships and all types of OGTBs alike. Therefore, no system would benefit over another. The second regulations for the smaller vessels pertain only to barges and as written are not applicable to ships. Thus, it might be possible for a small self-propelled barge to be built with a single-skin, while a non-propelled barge of the same size would have to have a double-hull. However, it is not likely that this would occur. The costs resulting from the ship's crew and propulsion machinery being under Coast Guard licensing and inspection would certainly outweigh any hull steel savings due to single-skin construction. Also, as these regulations pertain to all OGTBs, no linkage design would be favored over another.

The overall economic impact of these regulations should be comparatively small. They do increase the cost of constructing new tank barges (7) but this is compensated for by lower oil spill cleanup costs and a cleaner environment. Also, since existing single-skin barges may operate for up to 15-20 years without retrofit of segregated ballast tanks or double-hulls, the impact on these operators will be rather small, on a present-valued basis. So, although they will have to raise their rates to pay for the expeditious removal of single-skin barges, the rise can be gradual so that tank barge operators should not be seriously hurt by other competing transport modes.

Next consider tug inspection. It is the Coast Guard's contention that a loosely-linked OGTB with a 13,000 horsepower tug pushing a 35,000 DWT barge is no different than a ship with the same horsepower and deadweight. Therefore, the system should be subject to the same inspection and licensing requirements pertaining to an equivalent ship. However, under current law, the Coast Guard has no legal justification for writing regulations to enforce its contention. The law states that any motor powered vessel under 300 GRT is not subject to Coast Guard inspection and if it is under 200 GRT then it is also not subject to officer licensing. Since the pusher tug in a loosely-linked OGTB is a tug vessel capable of independent service, it comes under the provisions of this law. Apparently the only way that the Coast Guard could assert inspection jurisdiction over these tugs is if the law is changed. Given the realities of the situation, change in the law is unlikely unless one of the super-sized loosely-linked tank barges is involved in a serious accident

(7) The percentage increase in construction costs due to double-hulls is reduced as the barge becomes larger. One operator believes that the cost of a double-hull becomes negligible for barges of greater than 30,000 DWT.

which results in the pollution of a popular beach or fishing ground. The public outcry will then likely induce a change in the law making those tugs subject to Coast Guard inspection. However, it should be realized that unless the law is changed so that all motor driven transport vessels of less than 300 GRT and greater than so many horsepower come under Coast Guard inspection, then the operators of the loosely-linked OGTB systems may decide to operate their systems in the much more hazardous pull-tow mode if the additional fuel and insurance expenses incurred are less than the increased manning and construction costs resulting from such inspection.

2.3.2 Future of Mechanically-Linked OGTBs versus Ships

In the economic analysis presented in Section 2.1, it was mentioned that mechanically-linked OGTBs have capital construction and crewing costs less than those of a ship of equivalent capacity. Additionally, OGTBs were said to be more flexible due to their separability. The only disadvantage that a mechanically-linked OGTB was said to have compared to a ship would be its higher fuel cost resulting from the hydrodynamic flow disturbances caused by its linkage. However, if we scrutinize the first two OGTB advantages, in construction and manning; we may see that they might be only transitory phenomena.

Consider first construction costs. It was mentioned previously that OGTBs could be built less expensively because tug and barge could be constructed concurrently in specialized low-overhead yards. However, if there are advantages in building the propulsion and cargo units in separate specialized yards, the same can be done for a ship, as was demonstrated by the construction of the Great Lakes vessel Stewart A. Cort. (8) As for the lower manning of OGTBs, there is no technical or regulatory reason why ship crews can not be reduced to the same size as third generation OGTBs if they are as fully automated and follow the same maintenance policy. For example, the gas turbine 35,000 DWT Chevron tankers are certificated by the Coast Guard to be manned with fourteen men and they are crewed with seventeen, not much more than a mechanically-linked OGTB. So, in the future, a third generation mechanically-linked OGTB should not be any cheaper to construct or to man than an equivalent sized ship that is built and operated under the same conditions.

(8) The cargo component was built in a new modular construction yard which was ideal for the cargo unit specialization. The propulsive bow-stern component, however, was built at a large shipyard, probably to ensure that all construction would remain within company owned facilities. So, in this case only partial specialization of facilities was achieved.

In the long run, the only valid reason why an operator might want to build a mechanically-linked OGTB rather than a ship would be to take advantage of the flexibility allowed by its separability--useful for trades most economically run in the drop-and-swap mode of operation as discussed in the last section. However, since there are still these transitory economic advantages of mechanically-linked OGTBs over ships, they are still being built, but only in transoceanic and intercoastal trades. As demonstrated later neither ships nor mechanically-linked OGTBs are competitive any longer in coastal trades.

2.3.3 Future of Loosely-Linked and Pull-Towed OGTBs versus Ships and Mechanically-Linked OGTBs

Unless Coast Guard regulations change, both loosely-linked and pull-towed OGTBs will not have tugs subject to Coast Guard inspection. This will allow them to have substantially less crewing and construction costs compared to ships and mechanically-linked OGTBs. The only advantage ships and mechanically-linked OGTBs have over these other OGTBs is better fuel economy resulting from their smoother lines, better potential safety record resulting from Coast Guard inspection, and better maintenance achieved by the larger crew onboard. These advantages will probably not outweigh the disadvantages in short distance coastal trades where fuel savings will not be as great and where maintenance can be conveniently scheduled to be performed by shoreside personnel. As for safety, it has been argued that Coast Guard regulations cause ships to be overdesigned and that many of the inspection requirements have little real worth. Whether this is true may be learned from the future safety record of the OGTB systems.

Given the above arguments, it would be expected that in the future, loosely-linked and pull-towed OGTB systems should displace most small, moderate speed ships and mechanically-linked OGTBs from the coastal trades. Whether loosely-linked OGTBs will displace them from long distance foreign trades will depend on the magnitude of the resistance penalties caused by the linkage, the reliability of the linkage in ocean crossings, and the safety and mechanical reliability of the systems resulting from small crew size. Since none of these loosely-linked systems have been designed to operate in long distance ocean trades, it may be foolish to conjecture whether they would be the most economical system to operate in these trades. However, if the linkages are capable of withstanding ocean forces, it should not be unexpected to see these systems trading trans-ocean in the near future.

2.3.4 Future of Loosely-Linked OGTBs versus Pull-Towed OGTBs

Loosely-linked OGTBs are considerably more fuel efficient

than pull-towed OGTBs. Whether these fuel savings outweigh the costs and loss of flexibility incurred by the linkage probably depends on the distance of the trades and the flexibility desired by the operator. It would be expected that in the future, short distance trades, say from New York to Philadelphia, still could be operated most economically with pull-towed OGTBs since fuel saving from pushing would be small. However, for moderate runs, the advantages of push-towing should predominate and it would be expected that loosely-linked OGTBs will dominate these coastal trades.

2.3.5 Summary of OGTB Future Prospects

Given the above arguments, the following can be said for the future of OGTBs:

Ships should supplant mechanically-linked OGTBs in long distance trades for which drop-and-swap operation is not economical.

Loosely-linked OGTBs should supplant ships and mechanically-linked OGTBs in moderate distance coastal trades.

Pull-towed OGTBs should supplant ships and other OGTBs in short distance coastal trades.

The above assumes no major changes in the regulatory structure pertaining to OGTBs and ships. If the tugs of loosely-linked OGTBs later come under Coast Guard inspection, then I would expect that self-propelled barges would supplant them in the longer distance trades that are not amenable to drop-and-swap operation, and that the pull-towed OGTBs would supplant them in shorter distance trades.

The above also assumes that river type single tug-many barge (STMB) operations as could be provided by SEA-LINK or FLEXOR linkages do not penetrate the coastal trades. Although the initiation of such a concept is difficult, it may be that in the future that a single large shipper or a group of shippers will be willing to invest in the many units required for a successful STMB operation. If such an initial operation proves economically profitable, then STMB operations could become a major part of coastal trades.

ANNEX A TO CHAPTER 2

SUMMARY OF U.S. COAST GUARD REQUIREMENTS FOR OCEAN-GOING TUG-BARGE COMBINATIONS (1)

A. INTRODUCTION

It is generally thought, at least by some members of the Maritime industry, that ocean-going tug-barges have evolved to their present status, as replacements of conventional ships, due to one primary reason: to avoid certain "rules."*

Which rules? The ones generally cited are The Coast Guard regulations and Load Line regulations which affect these three areas:

1. Use of certain USCG standards and criteria in the construction of the vessel if it is inspected, but otherwise not necessarily applicable if the vessel is uninspected. (Certain aspects of those standards are regularly re-inspected during vessel operations.)
2. Use of deck officers and engineers having certain levels of "recognized" qualifications, such qualifications being "lowest" for uninspected motor tugboats below 200 GRT, except if it is "mechanically linked" to the barge.
3. Use of a reduced-freeboard load line for un-manned barges relative to conventional vessels of comparable size.

On the following several pages are summaries of the several sets of regulations which are thought to be the "rules" that OGTB's may possibly avoid to some extent, depending on their size, operation and "linkage" between tug and barge.

(1) This material is a corrected version of Section VII of Maritime Administration (1979) which was compiled from research data provided by the author.

*As with paying taxes, rule avoidance is legal, rule evasion is not.

B. TUGBOATS: INSPECTED OR UNINSPECTED

A tugboat is subject to Coast Guard inspection whenever any of these conditions obtain:

- (1) it is steam powered,
- (2) it is motor powered, sea-going, and over 300 gross tons,
- (3) it is carrying passengers, flammable or combustible liquids in bulk or other dangerous cargoes, or
- (4) it is "mechanically linked" to a seagoing barge.

Otherwise, tugboats require no Coast Guard inspection. All Coast Guard regulations pertaining to uninspected vessels are contained in parts 24-26 of Subchapter C of Title 46 of the Code of Federal Regulations (CFR). This Subchapter is comparatively short, less than twenty pages.

All Coast Guard regulations pertaining to inspected vessels are contained in Subchapter I of Title 46 of the Code of Federal Regulations. These regulations concern both construction and operation of these vessels as well as the inspection required. These regulations are very detailed relative to those for uninspected vessels.

C. BARGES: INSPECTION AND FREEBOARD

Barges require Coast Guard inspection if they are seagoing and over 100 GRT. Inland barges, except those carrying passengers or flammable or combustible liquid bulk cargoes or other hazardous/dangerous cargoes, do not require inspection.

Unmanned barges may be granted a 25% reduction in freeboard, relative to conventional (manned) vessels of comparable size, in accordance with the 1966 International Load Line Convention.

D. QUALIFICATIONS OF TUGBOAT OFFICERS

The knowledge and experience requirements for the officers of tugboats depend on whether the tugboat (i) is inspected or uninspected, (ii) is operating on the high seas or inland waters, and (iii) is greater or less than 200 GRT or 300 GRT.

For uninspected tugboats of (a) less than 200 GRT operating in any area, or (b) of any tonnage operating on inland waters, only the deck officer on watch must be licensed as an Operator or Second-Class Operator of Uninspected Towing Vessels in accordance with 46 CFR 10.16. Engineers for this class and size of vessel are not required to be licensed.

For uninspected tugboats between 200 and 300 GRT operating on the high seas, both the deck and engineering officer on watch must be

licensed in accordance with 46 CFR 10.15. The experience and knowledge requirements for the deck officers, masters and mate, on tugs of this size (200-300 GRT) are considerably more comprehensive than those required for Operators of Uninspected Towing Vessels (under 200 GRT). The requirements for the engineers are much less comprehensive than those required for those serving on inspected tugboats (above 300 GRT or mechanically linked).

For inspected motor tugboats greater than 300 GRT operating on the high seas the knowledge and experience requirements for deck officers must be at least in compliance with those specified in 46 CFR 10.05 for master and mate of Freight and Towing Vessels not more than 1000 GRT. These requirements are similar to those of other inspected ocean-going vessels. Engineering officers must meet the requirements specified in 46 CFR 10.10, which are the same as for any other vessel.

E. MECHANICALLY LINKED VESSELS

When the tug and barge are "mechanically linked," the combined unit must meet certain requirements that may be "avoidable" if the two components are linked by some other means.

Even if the tugboat part of a mechanically-linked unit is less than 200 GRT, both components must be constructed and regularly inspected under the supervision of the Coast Guard in accordance with Subchapter I of Title 46 of the CFR. In contrast, uninspected tugboats require no inspection while under construction or later, and are subject to a limited number of safety and operation regulations, as promulgated in Subchapter C of Title 46 of the CFR.

When the two components are mechanically linked, the number of officers and crew, as well as their qualifications, is determined by the Coast Guard. The deck officers (masters and mates) must at least be licensed as master or mate of Freight and Towing Vessel not more than 1000 gross tons in accordance with 46 CFR 10.05. Currently, they are required to have licenses based on the combined gross registered tonnage of the tug and barge. The engineers (chief and assistant) must have licenses in the same way as any ocean-going engineer, in accordance with 46 CFR 10.10. The minimum size crew certificated on these vessels has been fourteen persons.

In contrast, for uninspected tugboats under 200 GRT, frequently manned with 10 or less men, the only requirements on the number and qualification of the crew are:

- (a) deck watch officers must be licensed as Operator or Second-Class Operator of Uninspected Towing Vessels,

(b) crew must be divided into three watch sections on voyages of greater than 600 miles, and

(c) 65% of deck crew must be at least Able-Bodied Seamen.

An interesting note is that an Operator of Uninspected Towing Vessels is not considered a licensed officer nor is he considered crew for the determination of the number of AB's.

F. DESCRIPTION OF REGULATIONS

Regulation I:

The tugboat, while underway, must be under the actual direction or control of a Coast Guard licensed Operator of Uninspected Towing Vessels, or Second-Class Operator of Uninspected Towing Vessels if an Operator of Uninspected Towing Vessels is onboard. Persons so licensed may not work on a vessel while underway or perform other duties in excess of twelve hours in any consecutive twenty-four hour period except in case of emergency.

Regulation II:

65% of deck crew, exclusive of licensed officers and apprentices are to be of rating not less than Able Seamen. Requirements for Able Seamen are (1) to be at least 19 years of age, and (2) to have served at least 18 months on the Great Lakes, on bays and sounds, or at sea.

Regulation III:

The licensed officers and sailors, coal passers, firemen, oilers, and water tenders shall, while at sea, be divided into at least three watches except for those voyages of less than six hundred miles when the licensed officers and members of the crew other than coal passers, firemen, oilers, and water tenders may, while at sea, be divided into not less than two watches. Licensed officers or seamen in the deck or engine department shall not be required to work more than eight hours in one day, when governed by the three-watch provision.

Regulation IV:

If an uninspected vessel engages on a voyage of 12 hours or less, such vessel shall have a Master and Chief Engineer in charge of the watch continuously. If desired a mate may serve as navigating officer in charge of the watch as a relief for the Master. If desired, an Assistant Engineer may serve as the Engineer Officer in charge of the watch as relief for the Chief Engineer. If an uninspected vessel engages on a voyage of over 12 hours duration, such a vessel shall have a Master, Mate, Chief Engineer, and Assistant Engineer and such officers shall be in

charge of their respective watches continuously, except that an uninspected vessel which is equipped with full pilothouse control of the propulsion machinery, thus eliminating the necessity for a continuous fireroom watch, may be manned with an appropriate licensed Master and Mate who shall be in charge of their respective watches continuously, and an appropriately licensed Chief Engineer. All of the above officers shall be licensed by the Coast Guard.

Regulation V:

Every inspected tugboat shall have one licensed Master and two licensed Mates if under 1000 GRT. Every tugboat over 1000 GRT shall have in her service and onboard three licensed Mates, who shall stand in three watches while such vessel is being navigated.

Nothing above shall be so construed as to prevent the Coast Guard from increasing the number of licensed officers on any inspected tugboat if, in its judgment, such vessel is not sufficiently manned for her safe navigation.

Regulation VI:

On any inspected tugboat, the Officer in Charge, Marine Inspection, of the Coast Guard shall determine the minimum number of engineers and other crew necessary for the safe navigation of the vessel.

Regulation VII:

The Coast Guard shall license and classify the Masters, Chief Mates, Chief Engineers, and Assistant Engineers of all inspected vessels.

APPLICABILITY OF USCG REGULATIONS
PERTAINING TO MOTOR TUGBOAT MANNING

(see previous pages for description of regulations)

Vessel Size	Over 26' Under 100 grt	100-200 grt	200-300 grt	Above 300 grt
Regulation				
I	← Applicable (Note 1) →		← Applicable (Note 2) →	
II	Not Applicable	← Applicable (Note 3) →		
III	Not Applicable	← Applicable (Note 4) →		
IV	← Not Applicable →		← Applicable (Note 5) →	
V	← Not Applicable →			Applicable (Note 6)
VI	← Not Applicable →			Applicable (Note 6)
VII	← Not Applicable →			Applicable (Note 6)

Notes:

1. All uninspected tugs operating in any area, excepting those tugs in mineral and oil industry.
2. All uninspected tugs operating in inland waters.
3. All tugboats operating in any area except on rivers and smaller lakes and on bays and sounds connected with the sea.
4. All tugboats operating in any area except those navigating rivers, harbors, lakes (other than the Great Lakes), bays, sounds, bayous, and canals exclusively.
5. All uninspected tugs navigating the high seas.
6. All inspected tugboats.

References:

- | | | |
|---|--|--|
| I: 46USC405(b)
46CFR10.16
46CFR157.01-10(c)
46CFR157.30-45 | II: 46USC672, 672b
46CFR157.20-15(b)
46CFR157.20-15(b) | III: 46USC673
46CFR157.20-5
46CFR157.20-10 |
| IV: 46USC224a
46CFR157.10-15
46CFR157.30-10 | V: 46USC223
46CFR157.20-35
46CFR157.20-30 | VI: 46USC222, 224
46CFR157.20-35 |
| VII: 46USC224
46CFR10.02-10.10 | | |

ANNEX B TO CHAPTER 2

COMPARATIVE COSTS OF TUG-BARGE CONFIGURATIONS*

This presentation will first offer my judgment in the difference in costs between various forms of tug-barges. Then I will present some of the background that has been recently gained in the difference in costs between ITB's and ships of a rather similar nature.

First, regarding the difference in costs of various tug-barge combinations, we will consider a barge of about 25,000 deadweight tons as the basis for comparison, the barge being a double-bottomed product carrier towed at the end of a hawser by a 7,000 horsepower tug. Using the acquisition costs per deadweight ton as the measure of relative costs between the tug-barges and ships, we can construct a table as shown below, in which other variations include the use of larger power plants, slow speed diesels, notches, linkages, ITB-configurations, and larger ships and ITB's.

RELATIVE COSTS OF TUG-BARGES AND SHIPS

<u>Vessel</u>	<u>\$/DWT</u>	<u>%</u>
25,000 DWT barge towed by hawser with 7,000 BHP tug	668	Base
25,000 DWT barge towed at the end of towline by 13,000 BHP Belcher type tug	964	+44%
25,000 DWT barge push-towed in an average notch with a 7,000 BHP tug	675-688	+1% to +3%
25,000 DWT barge push-towed by a 7,000 BHP tug in a notch that allows heave between tug and barge	691-711	+3 1/2%-6 1/2%
25,000 DWT JAMIE BAXTER type ITB with 7,000 BHP tug	1168	+75%

*A paper presented by Melvin Colen, Avondale Shipyards, Inc., New Orleans, at the MARAD sponsored Ocean-Going Tug-Barge Planning Conference at New Orleans on 26-27 March 1979. This paper represents practically the only publicly available information concerning the relative costs of the different OGTB systems.

25,000 DWT ITB powered by 13,000 BHP medium speed diesels	1200	+80%
25,000 DWT ship powered by 14,000 BHP slow speed diesel	1300-1450	+95% to 117%
47,000 DWT ITB with 16-17,000 BHP	975	Base
45,000 DWT ship with 14-16,000 BHP	1120	+15%

NOTE: All 25,000 DWT vessels are designed for clean products of 8.5 BBl/Ton.

The above numbers are my judgment of relative costs on an industrywide basis and do not represent any particular ships. The relationship can shift with individual specifications, numbers of vessels, and size ranges, as fixed program costs vary significantly among the different types of vessels. Deviations of as much as 25% are possible, but the indicated trend is considered generally valid.

Comparative Costs of ITB versus Ships

About a year ago I had the opportunity of jointly directing the design of a 41,000 DWT Superphosphoric Acid Carrier. This ship would trade on long ocean voyages. This ship as developed reflected a specification standard, which is high and suitable for charter to major oil companies without significant additions. The structure reflected our design practices. The ship competed against an ITB for a transportation agreement and cost. We also bid the ITB and offered an alternate structural design reflecting a system similar to that designed for the ship. Our bid was accepted. Therefore the two vessels were designed to a constant structural system, eliminating that variable. The pertinent data for each vessel is as follows:

<u>Item</u>	<u>ITB</u>	<u>Ship</u>
Price	\$47 Million	\$55 Million
LOA	592' 2"	602' 4"
LBP	572' 0" approx.	570' 0"
Beam	95' 0"	105' 10"
Depth	50' 0"	55' 0"
Draft (designed)	37' 0"	37' 3"

Horsepower, MCR	18,200	14,200
SPA Cubic 100%	822,010	667,555 .
Oil Cubic 100%	874,755	972,500
Ballast Cubic 100%	435,720	524,121
Total Cubic	2,132,485	2,164,176
Steel Weight	+250 LT	Base
Accommodations	Base	+\$400K to \$500K
Propulsion	Twin Screw	Single Screw
Double Bottoms	Yes	Yes
Number of Cargo Tanks	28	28
Pumping System	Fromo	Fromo

There were many specification and system differences reflecting the experience and thinking of the two different operators with different backgrounds, but individual difference was of an order of magnitude that would not explain major portions of the cost difference.

Obviously we have a paradox. The industry's experience is too limited to definitely answer the paradox at this time, but I believe that some of the significant factors are as follows.

Specification Requirements ITB's do not have the room, and the operators have the orientation of austerity. Ship operators are accustomed to satisfying charter requirements of major oil companies which increase the numbers and quality of the items of supply in virtually every category. The vessels are not to equal standards, and the cumulative effect is significant.

Estimating Standards Barges and tugs are estimated using historic returns for tugs and barges, while ships reflect their historic costs. As programs have been conducted differently, cost histories are different. Some of the factors affecting cost histories are discussed below.

Hull Form In the example given above, the block coefficient for the ITB was about 0.79, while the ship's was 0.73. There is about a 1 1/4 knot speed advantage for the ship at the same power, and the ship will use far less fuel. But the cost of the ship is correspondingly higher, as fine ends cost more.

Program Administration Tugs and barges have traditionally required less contract administration, less engineering, less trials, a lower level of inspection, and generally less of all administrative work. This is a significant cost difference when we are dealing with small quantities of vessels. As ITB's become larger and as more ship-oriented people become involved, this and other differences will narrow.

Building Period For reasons of administrative work, procurement lead time and other factors, tugs and barges have been constructed in shorter periods of time than ships. This could be a significant cost saving. However, as ITB's get larger and use more sophisticated equipment such as slow speed diesel engines, this advantage will narrow and may disappear.

.....
In summary, a significant cost difference presently exists between ITB's and ships. For the long range, this difference is controlled by the ship owners. If equal standards are maintained throughout, there is no engineering reason why the costs cannot be equalized; however, the nature of discipline to reduce ship costs has not been applied to date.

CHAPTER 3

APPLICATION OF OGTB'S TO MILITARY OPERATIONS

The Military Sealift Command has three primary mission areas in peacetime:

- (1) Cargo Transport
- (2) Naval Fleet Auxiliary
- (3) Scientific Support

The first two areas, cargo transport and Naval Fleet Auxiliary, must be enormously expanded to fulfill the increased logistic demands generated by contingency or mobilization operations.

It is the purpose of this chapter to show how OGTBs can be successfully used in peacetime to satisfy many of the requirements generated by the three mission areas and to show how OGTBs have enormous potential to satisfy the expanded requirements of contingency and mobilization operations. This will be done by discussing each mission area separately in the following sections.

3.1 OGTBs for Military Cargo Transport Missions

3.1.1 Peacetime Operations

In peacetime most commercial cargo, both dry (break/bulk, containerized, and wheeled) and liquid (POL), is moved long distances through large, high-throughput port facilities. These types of movements are most economically served by the large, specialized and highly productive commercial vessels of the U.S. merchant marine. These large vessels are economical due to

savings resulting from economies of scale. (1) They are very productive because they move large cargoes rapidly and spend little time in port. (2) The short port times are the result of the ship being designed to interface with sophisticated port facilities that have specialized cargo handling equipments. Even in the case of RO/RO vessels which only require properly configured quays to accept the ship's stern and sideport ramps, the port must have sufficient draft to accept the vessel for discharge and pier space to marshal its cargo.

The above discussion certainly applies to peacetime military movements as well; and today, most military dry cargo is moved by these large, fast vessels. On the other hand, little POL is moved by supertankers. This is because most of the military POL terminal facilities have neither the draft nor the tankage to accept such large vessels. Nor do most of them have the throughput requirements to warrant the improvements required to allow them to accept such large vessels. Thus, many of these long distance POL trades are being served by rather small vessels. This is uneconomical since small ships cost several times more per ton-mile than a supertanker. As explained later, OGTBs may offer a solution to this dilemma.

Although most military cargo is moved rather long distances, some is also moved intra-area. Many of these types of trades are similar to the commercial coastal trades discussed in Chapter 2 and would be most economically served by OGTBs, either in the integral or drop-and-swap mode. This is discussed further in the next subsection.

(1) By economies of scale it is meant that the cost per ton-mile transport capacity becomes smaller as the ship becomes larger. This is the result of the lower capital and operating cost per deadweight ton of the larger vessels. Construction cost per deadweight ton becomes smaller because as a ship's capacity increases cubically its surface area and thus its hull cost only increases quadratically. Operating costs per deadweight ton also decrease with larger ships because (1) the crew size remains practically the same for any size vessel and (2) the fuel consumption per deadweight ton decreases with size. The latter is due to both the smaller frictional and residual resistance per deadweight ton of larger vessels. In addition, port facilities also exhibit economies of scale.

(2) Ships are transport vehicles. So, the less time they spend in port and the more time they are at sea moving cargo, the more productive they are in their primary function. On the other hand, since OGTBs are a separable combination of propulsion and cargo units, the propulsion unit need not be tied to the cargo unit during port operations; so, an OGTB's overall system productivity is not as sensitive to cargo operations.

Peacetime Coastal Operations

Most military intra-area operations require movement of dry and liquid cargo short distances for discharge at shallow draft ports. These are similar to the conditions faced by many U.S. coastal shippers of oil products and other bulk commodities. As discussed in Chapter 2, such trades are more economically served by OGTBs and the same holds true for military intra-area movements. For very short distance movements, say less than 150 miles, inexpensive 1st generation OGTBs would be adequate. For longer distances, 2nd or 3rd generation OGTBs would be appropriate. In any case, OGTBs should be seriously considered as a less expensive ship replacement in many current military coastal cargo transport operations. They would be particularly appropriate for use in the shallow draft, short distance Japan-Korea POL and Gulf Coast/Caribbean Island replenishment operations.

Most of these intra-area trades have rather small throughput requirements so that integral mode of operation would usually be most appropriate. However, there may be some trades that fall within the criteria listed in Section 2.2.5 that would make drop-and-swap operation more economical. This would be the case if draft limitations forced the operation to be handled by several small barges or if the barges remaining in port could be used instead of, or supplement to onshore storage facilities. Certainly, the ability to operate in drop-and-swap mode makes these intra-area OGTBs potentially more economical when cargo requirements increase, as in the case of a contingency operation. All that is needed to change from integral to drop-and-swap operation is the addition of some barges.

Peacetime Shuttle Operations

As previously discussed, many long distance shipments of POL occur in rather uneconomical small ships, often smaller than 30,000 DWT. This is primarily because most discharge ports cannot accept the large deep draft tankers. (3) This results in the transport costs for this oil to be at least three times (4) as great as would be possible if the larger ships were utilized. There are two alternatives that might result in lower system expenses.

(3) It is recognized that in peacetime that most U.S. refineries do not have shoreside tankage large enough to provide a supertanker size cargo of refined products. In this case shuttle type consolidation might be needed in the loading area.

(4) This figure is based on the different worldscale values reported for recent time charters of tankers of 22-40,000 DWT versus tankers of 100-130,000 DWT.

One is to utilize one port or safe anchorage in the overseas operational area as a major POL storage terminal capable of storing the cargo of one or more supertankers. If this port had insufficient draft then it could have the supertankers discharge at anchorage via an offshore single point mooring or via lightering operations using OGTBs as the means of shuttling the cargo from supertanker to shore. If insufficient shoreside storage capacity was available, then some barges could remain loaded and moored alongside a POL reception area or anchored out in a safe area until ullage was available for the product. Then, as the other POL terminals in the area required products, the still loaded or newly loaded (from shoreside storage) barges could proceed in a coastal type operation as previously discussed. Whether the OGTBs used for the lightering operations are also used for the coastal operations will depend on their size and capabilities. (5)

The other alternative to using small tankers for long distance movements would be to use the supertanker as a temporary storage tank while it is offloaded by OGTBs that shuttle its cargo directly to the intra-area POL terminals. The supertankers could remain stationary or could proceed to anchor off the intra-area terminals where shorter distance shuttles could occur. This alternative requires fewer OGTBs but delays the supertankers for longer periods of time.

The decision of which shuttling method to use and whether the supertanker should move or remain stationary depends on (1) the size of the supertanker and the shuttling vessels, (2) the distances between ports, (3) the capabilities of the OGTBs, that is, whether they can operate in the push mode between the intra-area ports as well as in protected waters, (4) the speed of the shuttle OGTBs, and (5) the per diem costs of the supertankers and OGTBs. Since so many factors whose values depend on a given situation are involved, it is not possible to generalize which strategy is optimum. A careful analysis of each specific situation is required.

(5) Lightering operations of this sort are conducted regularly in this country by some of the major oil companies. Supertankers full of crude arrive at the Gulf Coast for discharge. Due to their deep draft these supertankers must be lightered. The crude is then refined and distributed throughout the Gulf and East Coast via the use of OGTBs. It might be expected that such lightering operations would be very expensive since the supertanker is delayed several days while it occurs. However, it is apparent that the savings entailed by using such large ships rather than several smaller ones for the long distance delivery of the oil outweighs the cost of such delays.

It should be mentioned that the above discussion does not pertain only to POL movements. Commercial operators such as SEALAND have realized the benefits of the economies of scale for some time. They reserve their large, high speed SL-7's for trans-ocean crossings and then trans-ship their containers to the other area ports via small feeder vessels which operate in a coastal or shuttle trade. (6) The same type of operation could pertain to military dry-cargo movements if such large high-speed vessels, i.e., large RO/RO ships, become part of the military sealift fleet. In these trades OGTBs with deck barges would be very suitable shuttle craft.

3.1.2 Contingency Operations

In a contingency operation, the amount of dry and liquid cargo to be moved will be substantially more than during peacetime operations. Additionally, much of the cargo will probably have to be delivered through relatively primitive shallow draft ports and/or beaches. Both of these conditions tend to favor the use of OGTBs as explained below.

Shallow Draft Dry Cargo Operations at Undeveloped Ports

Certainly the most cost effective means of moving the large amounts of material demanded by a contingency operation is in the same way most cargo is moved during peacetime: via large, speedy container, RO/RO, and tank ships through high throughput, deep-draft terminals. Unfortunately, the availability of deep-draft high-throughput terminals in a contingency operating area is doubtful at best. They might never have existed or could have been destroyed by hostile actions. The absence of the appropriate high-throughput terminals poses serious problems for military logistics planners. For several years they have been attempting to find expeditious means of discharging these vessels offshore, especially the RO/RO and non self-sustaining container vessels. But, even if rapid discharge methods could be found (7)

(6) It should be mentioned that McAllister Bros., Inc., operates a pull-towed OGTB along the East Coast as a container feeder service for several liners that call New York.

(7) One non self-sustaining container ship discharge method involves the use of a temporary container discharge facility (TCDF), a concept being developed by the U.S. Navy, Facilities Engineering Command. This facility consists of a vessel on which are mounted gantry or rotating cranes that are used to remove the containers from the ship and to place them on lightering craft. There is no reason why these TCDFs could not be large OGTBs that have been pushed to the operating area by shuttle tugs. These tugs could then be used in the operating area for other purposes.

it is most likely that insufficient shoreside depot facilities would be available to handle all the cargo and that local commanders would probably require that the vessels temporarily remain in queues offshore. This is intolerable for these costly vessels which are totally unproductive while remaining in queues.

There are at least three possible solutions to the above queuing problem:

- (1) transfer the cargo from the ships to deck barges at the operating area which would shuttle the cargo to the port facility
- (2) offload the cargo from the ships at developed ports nearby the operating area from which cargo is shuttled to the operating area by OGTBs
- (3) ship the cargo solely via shallow draft OGTBs from the loading terminals.

The first approach is to have the large, highly productive ships discharge their cargoes onto inexpensive deck barges which could act as offshore storage facilities, freeing the large ships for transport. (8) These deck barges could be then later pushed or pulled ashore where they could be beached and discharged via forklift or ramp. (9) Of course, if sufficient storage capacity was available onshore, the cargo could be discharged directly

Additionally, the containers could be shuttled ashore via small OGTBs in either a drop-and-swap or integral mode type of operation.

(8) See Appendix A for a listing of some of the largest freight and deck barges available in the U.S. domestic fleet, many of which could be chartered immediately. Since these barges would be needed rather soon after the start of a contingency operation, it would be desirable that they could be quickly push-towed into position. Unfortunately, few, if any, of the deck barges have this capability. Thus, for this strategy to be successful, the deck barges would have to be chartered at the start of the contingency, even before the large ships are loaded. This will ensure that they will arrive at the operating area not much later than the ships.

(9) Most deck barges are flat-bottomed and of shallow draft which gives them the ability to ballast down and lie on properly prepared beaches. Since these barges are maneuvered by tugs, they may be beached head on or side to. Also, because few deck barges have push-notches, installation of a SEA-LINK or SEEBECKWERFT linkage might be appropriate to provide these barges with the speed and better control available from push-tow shuttle operation.

from the large vessel into small lightering craft, i.e., LCU's or small OGTBs, and landed immediately.

A second approach would be to have the large fast ships discharge their cargoes at a high capacity, high-throughput advanced shore base not too far away from the operating area, say less than 1000 miles. Then the cargo could be shuttled to the contingency area in OGTBs. As large amounts of cargo will be moved through rather small vessels, and since cargo discharge time could be rather long due to the queues caused by backlogs or inventory control, drop-and-swap operations would be appropriate.

A third approach would be to have the cargo loaded into OGTBs at the distant supply depot rather than using the high productivity ships. Then these OGTBs (10) could drop off their barges at the operating area and return with an empty barge or with the tug steaming independently. The barge could later be pushed to the beach for discharge or lightered by smaller shuttle OGTBs.

The decision of which approach to utilize will depend principally on the availability of the required assets. The availability of at least some RO/RO and container ships is rather assured due to the MSC Strategic Readiness Program. Although deck barges are not part of this program, most are readily available for spot charter. However, few of the commercially available deck barges are presently capable of fast speed push-tow operation and thus would be suitable mainly for shuttle and other short distance movements. On the other hand, some of the multi-deck and newer shipshape deck barges are capable of moderate speed pull-tow operation and so could be used for longer movements. Unfortunately, most of these barges are in common carrier trades and would be more difficult to charter. In either case, whatever barges that are available must be chartered quickly to ensure their arrival at the contingency port areas in time to operate with larger vessels. It should be added that those which are small enough to fit into the deep wells of an LPH or similar type vessel or onboard a LASH/SEABEE could be quickly transported to the contingency area and used for shuttle operations until the larger assets arrive later.

POL Operations at Undeveloped Terminals

Most of the above discussion for dry cargo movements pertains to POL operations as well. That is, during a

(10) For such long distance operations moderate speed would be important. So it would be expected that 3rd generation trans-ocean capable OGTBs with ship shape barges would be used. All of the "mechanically-linked" and some of the "loosely-linked" systems have this capability.

contingency, large quantities of POL will have to be transferred ashore through primitive low throughput and low storage capacity terminals. The least expensive means of providing the long distance movement of the POL will be by supertanker for the same reasons given in the section on peacetime operations. The problem is to find a way of offloading the supertanker quickly at such a primitive terminal which cannot accept its cargo nor its draft. There are at least three possible solutions to this problem:

- (1) use the supertanker as an offshore storage tank, transferring its cargo when needed via a portable offshore mooring buoy connected to a shoreside discharge manifold,
- (2) transfer the supertanker's cargo into barges nearby the terminal which will be shuttled as needed to a close-to-shore portable mooring buoy or a shallow draft berth where its contents can be discharged through a shoreside manifold. Cargo not immediately needed will remain stored in the barges, or
- (3) transfer the supertankers contents to a nearby major POL terminal from which the OGTBs would shuttle the POL when needed to the outports for discharge in a similar manner as in (2) above.

In all three cases little or no shoreside storage capacity is needed at the contingency area. Storage is provided by the supertanker, the barges, or nearby major terminal, respectively. Certainly, there is the alternative of not using supertankers at all. In this case handy-sized tankers and OGTBs would provide the whole transport movement from loading to discharging terminal. However, this method should be the most expensive since no economies of scale are utilized.

The decision of which of the above strategies to use will primarily depend on the availability and cost of supertankers, tank OGTBs, and portable discharge facilities. There are relatively few U.S. flag supertankers; however, many are currently readily available for purchase due to the worldwide glut in supertanker tonnage. There are also many tank OGTBs, many of push-tow capability, available in the spot or term charter market. As for portable discharge facilities, the ones currently available in the military system can only handle vessels of less than 25,000 DWT with use of a multi-leg mooring system. Products can be pumped ashore via 6" lines to portable rubber bladder tanks of 10,000-50,000 Bbl capacity.

Expanded Coastal and Shuttle Operations

In most contingencies, there will be the requirement for a considerable amount of coastwise cargo movement. In this case, the discussion given previously for peacetime operations applies.

Additionally, drop-and-swap operation would most likely be appropriate due to the probable need for many small OGTBs to operate through undeveloped ports that only allow cargo to be discharged slowly. Although drop-and-swap operation with its increased barge requirements would not be necessary if port handling and storage facilities were better developed at the contingency ports, investment in such facilities for a short term contingency operation would not usually be warranted. The overall system costs would be less by using (1) low throughput rate, inexpensive, temporary port facilities to handle the cargo, (2) barges for offshore storage until the cargo can be discharged, and (3) tugs only to drop-and-swap barges. It should be remembered that the barges could be returned to commercial operation or reserve fleet after the contingency while expensive port facilities may not be utilized at all after operations are completed.

3.1.3 Mobilization Operations

During a mobilization, the amount of dry and liquid cargo to be moved will be enormously more than during a contingency operation. As with contingency operations, much of the cargo will have to be delivered through relatively primitive shallow draft ports and/or beaches. Thus, the discussion in the previous subsection for such type operations apply for mobilizations as well. But, in the case of a mobilization, the cargo transport requirements cannot be only met with the use of the MSC controlled fleet and the ships available from the U.S. merchant marine. Additional assets will have to be obtained from allied countries and/or the reserve fleet. However, as our aging reserve fleet (most cargo ships are 35 years old) becomes smaller and as allies become more independent, such assets may become insufficient to fulfill the logistical demands generated by a mobilization. In this case new construction will be required. OGTBs should have a significant role in this new construction since they have several important advantages:

- (1) rapid and extensive construction capability
- (2) small crew operation

- (3) high utilization and throughput capacity through use of drop-and-swap operation
- (4) less vulnerability and other military advantages.

Each of these advantages are discussed separately in the following subsections.

Rapid and Extensive Construction Capability

As mentioned previously, OGTBs can be delivered more rapidly than ships of equivalent size and speed. This is because the propulsion and cargo components can be constructed concurrently in specialized tug and barge yards. Of course, during a mobilization shipyards could be organized to build vessels in an assembly line process where ship modules could be built by specialized construction groups. This would reduce the advantage that the specialized yards would have over the general purpose shipyards.

But, there are a limited number of general purpose shipyards, many of which will be occupied with Naval and major ship construction during a mobilization. In this case the tug and barge yards will have to take up much of the burden for transport vessel construction.

Fortunately, there are many tug yards currently in operation that could take up such a burden. (11) They are currently building the high horsepower tugboats needed for the offshore oil and coastal bulk cargo transport industries. There would no difficulty for these yards to build several hundred tug components of OGTBs annually, assuming that the propulsion machinery were available.

The situation is not so good with respect to barge yards. Although there are many barge yards capable of building small shuttle-type barges of up to 300 feet in length, there are few yards such as FMC and Galveston Shipyard that can build larger ones useful for long distance and/or large capacity movements. The biggest tank and RO/RO barges have even been built in shipyards. (12) Although during a mobilization there would be some shipyard ways too small to build large mobilization and Navy

(11) To get an indication of the number of tug yards currently building large tugs, just examine the builders column of Appendix C for tugs built in the last few years.

(12) To get an indication of the number of bargeyards and shipyards building large barges, just examine the builders column of Appendices A and B for barges built in the last few years.

ships, there would probably be an insufficient number of barge building facilities for the larger barges--certainly an insufficient number to match the tug output. In this case new barge yards would have to be established.

It should be remembered, as mentioned in Section 1.3, several of the OGTB systems could be rather quickly converted into much more capable systems, i.e., trans-ocean push-tow capable, via the installation of more sophisticated linkages. Thus, some of the barge yard capacity should be reserved for such conversion operations. This puts even more pressure on the few barge yards able to drydock large barges and provides more incentive for the construction of new barge yards.

Fortunately, barge construction is much less complicated than ship construction due to barges having simple hull lines and little outfit machinery. Therefore, setting up barge yards would be much easier than shipyards since the only major capital equipment needed would be building ways and automated steel plate handling facilities.

Given that several new barge yards would be needed during a mobilization to match tug yard output, a study of the proper location and configuration of such yards would be useful to speed up their establishment. Their output in conjunction with that provided by existing tug and barge yards could provide a substantial number of OGTBs for the type of cargo transport operations described previously.

Small Crews

As mentioned in Chapter 1 and its Annex A, OGTBs currently require much smaller crews than ships of equivalent size and speed. It was also mentioned that these differences were mainly caused by artificial forces, that of regulation and of union pressures. Therefore, in a mobilization it would be expected that new ships and OGTBs of equivalent size, speed, automation, and mission would be manned equally due to the exigencies of the mobilization action.

However, OGTBs do provide manning savings in those trades in which drop-and-swap operation is feasible. In these cases, the propulsion unit and its crew is utilized more efficiently so that fewer tugs and men are required to move the same amount of cargo.

Another crew saving may be achieved by converting some old ships to barges, replacing their propulsion machinery by tugs

with much smaller manning. (13) This would certainly be feasible in ships with enginerooms aft so that area could be converted into a pushing notch for the tug. Additionally, the crew that would normally be onboard for cargo operations could be stationed at the ports so that they perform this specialized task on a continual basis.

Drop-and Swap Operations

During a mobilization large amounts of cargo will have to be transported via many vessels through ports that will usually have draft restrictions and long discharge times. As seen in Section 2.2.5, this type of situation is ideal for OGTB operation in the drop-and-swap mode. This method of operation is most efficient since it uses the tugs mainly for propulsion and the barges for storage and transport. This results in OGTBs providing more transport capacity at less cost and with fewer men than the equivalent number of ships of the same size and speed--saving these scarce resources for other purposes.

Vulnerability and Other Military Considerations

As mentioned in Sections 1.1 and 1.3, all OGTBs have several military advantages over ships that result from their separability. The primary advantage is that the crew is less vulnerable to military action.

While at sea, it will usually be the cargo component that will be subject to damage due to its large size and draft. If this is the case, then the tug crew can separate from the barge, using the tug as a lifeboat. Certainly, if the tug is damaged instead, the tug crew could abandon it and drift about in the barge until rescued.

While in port, the tug does not have to remain with the barge if it is dropped off near a hostile area. The tug can either leave the danger area with an empty barge or can just await completion of cargo operations in a safer area.

It may be thought that OGTB's slow speed, especially the very slow speed of pull-towed systems, would make them quite vulnerable to submarine attack. This is quite true, but they should not be much more vulnerable than the faster transport ships since neither can nowadays outrun the new attack submarines. These submarines could easily catch up with 20 or 25 knot convoys. On the other hand, sailing many small OGTBs independently might lessen their vulnerability since their dispersion would make their

(13) For example a T-2 crew of 43 could be replaced by a 11 or 16 man tug crew.

detection more difficult. So, OGTBs might not be any more vulnerable than ships overall.

3.2 OGTBs for Fleet Support Operations

The Navy's task forces require logistical and service support in order to continue their operations away from established bases. Logistical support of stores, ammunition, and POL is usually provided on station via replenishment-at-sea operations from multi-product fleet support ships. These ships obtain their products from single-product ships that shuttle their supplies from advanced bases. Service support such as for ship repair and troop hospitalization are usually provided by ships located at advanced bases. Both of these support functions can be improved with the use of OGTBs as explained in the following two subsections.

3.2.1 OGTBs for Fleet Support Logistics

In peacetime the Navy's task forces are on a reduced operating schedule which does not require them to be away from major logistic support bases for long periods of time. Thus, their replenishment needs can be met by the Navy's current fleet of multi-product station ships (AOE's and AOR's) and single-product shuttle/station ships (AO's, T-AO's, AE's, and AFS's).

However, in a contingency or mobilization action, task forces most likely will have to operate continuously away from their support bases. In this case the fleet will have to be replenished via the multi-product station ships which will receive their products from the single-product ships that shuttle their cargoes from the nearest logistical support base. In this case the number of station ships required depends on the number and size of the task forces. The number of shuttle ships required depends on these factors as well as the distance the task forces operates from the support bases. (14) It is apparent that if the military or political situation prevents the use of support bases near the task force operating area, then the shuttle pipeline may require a substantial number of shuttle ships--probably many more than is currently in our inventory of such ships.

There are three possible remedies for this shortfall of shuttle vessels:

- (1) build more shuttle vessels,

(14) If it is assumed that the loading/discharging time of a shuttle-ship is short compared to its travel time, then the number of ships required will be approximately proportional to the shuttle distance, i.e., to double the shuttle distance would double the required number of shuttle ships.

- (2) convert some of the MSC tankers into shuttle vessels, or
- (3) use a fleet of OGTBs to provide advanced base support and shuttle service.

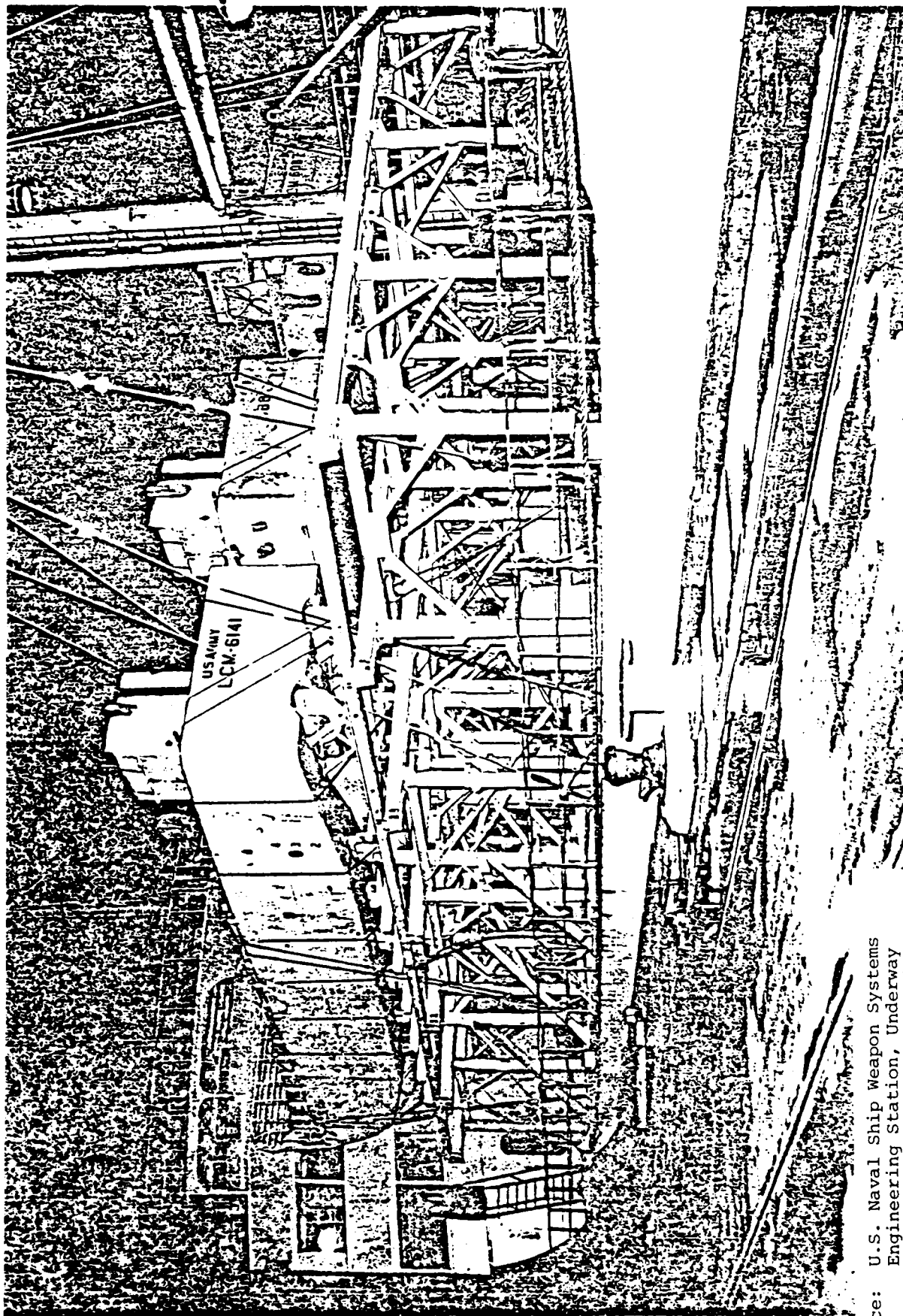
The first alternative of building more shuttle vessels would certainly solve the problem, but it would be very expensive. Additionally, these vessels would only be required during the appropriate contingency or mobilization operations. They would be very expensive to maintain during peacetime when they are practically never used.

The second alternative of converting some tank ships to shuttle operation does have some potential. As demonstrated in the study "Merchant Shuttle Ships to Augment AO/AE/AFS" prepared by the Underway Replenishment Department of the Naval Ship Weapon Systems Engineering Station in March 1978, any tankship can be converted rather quickly and inexpensively for shuttle operation with the installation of some sliding pad-eyes and a modern version of the "Meccano" deck over its pipe deck. This "Meccano" deck is a "erector set" type platform that allows containers full of stores and ammunition to be loaded onto the tankers at the advanced bases. (See Figure 3.1 for a drawing of such an installation.) As the tanker proceeds on its shuttle to the station ships, forklifts will unstuff pallets of cargo from the containers. Then, when the ship reaches the station ships, it will simultaneously transfer palletized cargo via its sliding pad-eyes and its POL via its fuel rigs.

The problem with the above solution is that there are only a limited number of tankers available for conversion to shuttle ships. The best candidates would be the USNS tankers but these vessels are already fully utilized during peacetime for point-to-point POL movements. If they were pulled away for shuttle operations, they would have to be replaced by small commercial tankers. This might be possible for a small contingency, but it is certain that a large contingency or mobilization operation would demand that these tankers be used for point-to-point POL movements to support ground and air troop operations. Thus, it is probable that USNS tankers capable of shuttle operations would be unavailable for such a mission during any large scale operation. Fortunately, OGTBs may provide a solution to this problem.

OGTBs may solve the shuttle ship problem because their separability allows their barges to be used as storage units as well as cargo transport units. That is, a group of barges may be gathered in a protected anchorage and loaded from supertankers and container ships. (15) The barges would store the POL below

(15) Self-sustaining container ships would be preferred in this



Source: U.S. Naval Ship Weapon Systems
Engineering Station, Underway
Replenishment Department, "Merchant
Shuttle Ships to Augment AO/AE/AFS"
March 1978

Figure 3.1

MECCANO Deck Installation

deck in tanks and the containers on deck. Then the barges would be shuttled by the tugs to the station ships as they are needed, those remaining providing temporary storage. On the way, the containers would be unstuffed by forklifts so that their contents could be transferred to shuttle ships via standard rigs. In this manner, the barges act as floating advanced bases located near the task forces and provide the interface between commercial ships and the shuttle tugs. This is in addition to their role as shuttle barges. Thus, these OGTBs establish advanced bases off-shore where they are needed--close to the task forces and do not require the use of vessels committed to other missions. They perform this mission at less cost and with less manpower than the single-product shuttle ships because they require few tugs with low manning to handle many barges that have only shuttle capability.

The feasibility of the above approach, particularly the use of OGTBs as replacements for aging single-product shuttle vessels, was considered in great depth in CONSERVGRUONE'S STAYPOWER study (U.S. Navy (1977)), the abstract of which is included in Annex B to Chapter 1. In this study it was concluded that:

The true comparative advantage of the integrated tug-barge concept (over a fixed ship system) lies in its flexibility, i.e., the functional element (the barge) is not irrevocably married to the power drive element (the tug). This capability can result in:

Fewer tugs than barges required with concomitant reductions in acquisition, operating costs and manning levels.

Increased availability of individual elements. One element can be in a repair status (overhaul, RAV, etc.) while the other remains available for tasking. The same considerations would apply for major casualty to either element.

Increased overall survivability. Loss of one element due to hostile action or catastrophe would not necessarily result in loss of entire unit and crew.

The utilization of the integrated tug-barge in the shuttle ship role is considered feasible. There appears to be no technical restriction, including the attainment of 20 knot speed, to preclude such a role.

... since they could discharge their containers directly on barges. However, if they were not available, then some temporary container discharge facility would be required at an advanced base to provide the container transfer.

The nominal integrated tug-barge shuttle unit developed upon the basis of stated assumptions and study guidance, shows clear advantage over current and projected shuttle ships in primary mission accomplishment, i.e., station ship support and pipeline ship interface compatibility and cost. For secondary missions, i.e., station ship backup and dispersed combatant support, the nominal integrated tug-barge shuttle unit is at a distinct disadvantage primarily due to limited delivery capability. The disadvantages such as decreased maintainability at sea, minimum communications capability, etc. are all basically functions of the mission oriented element (barge) design and manning levels. Every disadvantage could be reduced or eliminated by increased manning levels and/or equipment installation which would also serve to decrease the significant cost advantage generated.

The integrated tug-barge has high potential for application to the limited mobile advance base concept.

The above study was thoroughly reviewed and its conclusions seem valid. OGTBs could very well be used as inexpensive replacements for the aging shuttle ships. However, as explained in the study, these OGTBs are really not as militarily versatile as the AO's, AE's, and AFS's they replace. Reviewing Table 3.1, it is seen that they are not really suitable as direct replacements for single-product station ships even though they have limited capacity for resupplying combatants directly. Of course, with additional investment these systems can be made as capable as shuttle ships. In Tomassoni (1974) it was shown that an OGTB oiler could be obtained at about the same cost as the ship it replaces. So, overall, OGTBs seem a very reasonable alternative to new single-product ship construction.

As the study was completed a few years ago, it only considered the rigidly-linked OGTBs (Breit/Ingram and CATUG). It is recommended that at least the semi-rigid linked systems (ARTUBAR) also be considered. The military and economic advantages of this linkage type is provided in Chapter 1. To summarize, this type of linkage is less expensive and allows the tug to be used for other purposes as well. It does have some disadvantages--it has higher hydrodynamic resistance and it does allow some relative movement between the tug and barge. This movement may prevent cargo transfer rigs from being utilized onboard the tug so that this system might not be capable of transferring palletized cargo to combatants. Whether this is the case will be better seen after the new RO/RO systems have begun operation.

The study also requires some type of container discharge facility if non self-sustaining ships are utilized. There are no such facilities yet in our military inventories although their

Table 3.1
Risk Matrix

Nominal integrated tug-barge compared to individual current and projected shuttle ships (AO/T-AO/AE).

+ Better than
0 Equal to
- Less than
NA Not applicable

	<u>AO-177</u>	<u>T-AO 143</u>	<u>AE</u>
<u>UNREP Capability</u>			
Multi-Product Capacity	+	+	+
Single Product Capacity	+	0	-
<u>Task Force Integration</u>			
Communications	-	-	-
Self-Defense	0	0	0
<u>Interface Capability</u>			
Station Ship - Multi-Product	+	+	+
- Single Product	0	0	0
Combatant - Multi-Product	+	+	+
- Single Product	-	-	-
Stock Point - Liquid	0	0	NA
- Dry	NA	NA	+
Pipeline - Liquid (Sea)	-	-	NA
- Liquid (Inport)	0	0	NA
<u>Redundancy</u>			
	-	-	-
<u>Vulnerability</u>			
- Speed	0	0	0
- Size	-	0	-
- Self Defense	0	0	0
- DC	0	0	0
<u>Adaptability</u>			
Revised Product Demand	+	+	+
Other Tasks	+	+	+
<u>Maintainability</u>			
- Sea	-	-	-
- Inport	+	+	+
<u>Availability</u>			
	+	+	+
<u>Manning</u>			
	+	+	+
<u>Cost</u>			
	+	+	+

Source: U.S. Navy (1977)

need has been recognized for some time for the discharge of these ships in military cargo transport operations. This is another potential application for these facilities and their procurement might be enhanced if shuttle OGTBs are constructed.

It should be mentioned that even if the STAYPOWER concept with shuttle barges is not funded, there are some aspects which might still be utilized with little cost. For example, an advanced base could be established just with the use of standard tank and deck barges chartered from commercial operators. Containerships could unload containers onto and pickup empties off of deck barges and supertankers could offload onto the tank barges. Then the contents of the containers from the deck barges and the POL from the tank barges could be transferred to shuttle ships, either of the single-product type or of the converted tanker type, at the advanced base. This concept allows a shortened shuttle pipeline utilizing currently available commercial assets and so extends the capabilities of the current shuttle vessels. However, it does not provide any new or replacement shuttle ship capacity.

In any case, it should be obvious that OGTBs have several potential applications in fleet support operations. The question is whether new militarily capable shuttle barges should be constructed with the shuttle tugs or whether only current OGTB assets should be utilized. The former is more costly but provides more certain capabilities. Some suggestions for obtaining the required military assets are provided in the next chapter.

3.2.2 OGTBs for Fleet Support Service

Any Navy task force that is deployed for any length of time will require various services to be provided from a nearby advanced base. Such services might include tender repair, medical hospital support, as well as fleet tug support. Many of these services can be less expensively provided through the use of OGTBs as explained below.

Tenders and Hospital Ships

Ships such as tenders and hospital ships seem ideally suited for replacement with OGTBs. Since they rarely move, they do not require the use of a propulsion unit very often. Instead, they could be easily push or pull-towed onto station and left there to operate on their own until a change of station is required.

Several detailed evaluations of just such a type of operation have been completed. Abstracts of two studies, Hawkins (1973) and Tomassoni (1974), have been included in Annex B to

Chapter 1. The studies conclude that using OGTBs for such service ship missions would be feasible and cost effective.

Recently due to a requirement in Senate Report No. 95-326 on the FY 1979 Military Appropriation Authorization Bill, the Navy is conducting two new internal studies (one being Keenan (1979)) to evaluate the eventual replacement of destroyer and submarine tenders with OGTBs. Preliminary indications are that these reports will support such a concept.

Fleet Tugs

MSC Fleet Tugs have several missions including salvage, ship rescue, firefighting, pollution cleanup, etc. These and other missions would not prevent these small vessels from also being used as the propulsion component of a push-towed OGTB. This would be particularly true for an OGTB with an ARTUBAR semi-rigid linkage which only requires the installation of the retractable pins and associated machinery onto the fleet tug.

Thus, MSC's fleet of Fleet Tugs can be considered as a potential reserve fleet of tug components that could be used with appropriate barges in contingency/mobilization cargo transport or Naval Fleet Auxiliary missions. This is in addition to their use as the propulsion unit of the fleet service barges described in the previous section. This assumes that linkage gear is retrofitted onto existing assets and included on new vessels. It should be mentioned that current Fleet Tugs without any modification could pull-tow barges, but their low horsepower would result in very slow speeds of advance.

Certainly, the reverse of the above is also true. The tug component of any OGTB could be utilized in Fleet Tug missions with only the addition of specialized gear. This is probably the major alternate mission of the tug component of OGTBs. Therefore, any military OGTB specially designed for cargo transport and fleet support missions should also have its tug designed to perform some Fleet Tug missions.

3.3 Special Projects (Scientific Operations)

MSC has the mission of operating vessels in scientific or other special projects for sponsors in any defense or other governmental agency. Currently, either converted reserve fleet or newly constructed ships are used in the projects. But, there is no reason why OGTBs could not be used instead. They can be built of sufficient size and horsepower to handle any of the scientific operations. Additionally, the use of OGTBs in these projects could be advantageous due to the ability of the functional unit containing the sponsors' men and equipment being able to separate from the MSC manned propulsion unit.

One advantage resulting from such separability is that the propulsion unit can be used for other operations including fleet support or cargo transport upon completion of the project. New/revised projects only require the construction/conversion of a barge to provide the capabilities desired by the new sponsor. Ships, on the other hand, must have their propulsion unit inactivated every time they are put out of commission. This is an expensive and wasteful routine, particularly for range-tracking and other such ships that come in and out of service rather frequently.

Another advantage of using OGTBs in special projects or scientific operations is that the propulsion unit could be readily made available for contingency and mobilization operations. In such operations it would be expected that fleet support or cargo transport missions would have higher priority than the special project missions. Thus, the scientific operations fleet could be considered as an immediate reserve inventory of propulsion units for other OGTB missions.

The above discussion points out an important requirement for OGTBs used in military operations if such interchangeability of missions is to be possible. The OGTBs used for different missions need to have standardized linkages. Otherwise, interchangeability will be impossible. Means of obtaining a fleet with this capability will be discussed in the following chapter.

CHAPTER 4

NATIONAL DEFENSE FEATURES APPLICABLE TO OGTB'S

In Chapter 3 commercial OGTBs were shown to have many military applications as Navy logistic and fleet support vessels. To facilitate this conversion from commercial to military use, it would be prudent to have certain special equipments and design features installed on board the OGTBs. As explained in the next section, these National Defense Features (NDFs) can be required to be installed only on OGTBs constructed with subsidy funds. This is unfortunate since very few OGTBs have been built with such funds. (1) Thus, most of the OGTBs previously constructed do not have the NDFs currently considered useful (specified in Section 4.2) or those that would give them even more military potential (specified in Section 4.3). However, until the law is changed, it is not expected that this situation will change.

4.1 Current NDF Legal Structure

National Defense Features (NDFs) are changes in commercial ship designs suggested by the Secretary of the Navy to provide ships capable of serving as Naval/military auxiliaries in time of war or national emergency and to provide for the maximum survivability of ships that may be used by the government in nonmilitary wartime roles. Such changes are required to be installed on vessels constructed with the use of Construction Differential Subsidy (CDS) funds. These funds, provided under the provisions of Title V of the Merchant Marine Act of 1936, are used to induce American shipowners to construct these foreign trading vessels in U.S. shipyards by paying the difference in costs between having a ship constructed in a foreign shipyard and having the same ship constructed in a U.S. shipyard. If the NDFs are of no commercial value to the shipowners, then their costs will also be borne by the government through additional expenditures of Title V funds. On the other hand, if the shipowner makes use of the NDFs then he must pay back a portion of their cost.

(1) As of 30 June 1979 only five OGTBs were being built with CDS funds, the two CCT RO/RO and the three Occidental Oil tank OGTBs.

The normal procedure for deciding which NDFs to install is as follows. First, the Maritime Administration (MARAD) forwards the conceptual or preliminary designs received from the applicants for CDS to the Secretary of the Navy (SECNAV) for comment. These conceptual and preliminary designs are referred to the Chief of Naval Operations (CNO) for appropriate action. The objective of this early submittal is to embody the NDF concepts at the earliest practical stage prior to the submission of firm plans and specifications. MARAD will later forward these firm plans and specifications of proposed new construction merchant ships to SECNAV for approval. Again they will be forwarded to CNO who will forward them to the Chief of Naval Material (CNM) who will collaborate with COMSC and Department of Defense common user services when appropriate. CNM, following the guidance of OPNAVINST 4700.13C presented in the following section, will in coordination with MARAD review these designs early enough to make recommendations for meaningful NDFs before plans are finalized. These recommendations are then forwarded through the chain of command for the Secretary of Navy's signature. Then, MARAD will take action to have these NDFs included as part of the ship's building plans.

4.2 Current NDF Requirements

Current guidance specifying which NDFs are appropriate for various types of vessels is promulgated in the Chief of Naval Operation's OPNAV INSTRUCTION 4700.13c of 6 December 1978. The enclosure to this instruction provides general NDF considerations, basic NDF standards, and specific NDF criteria applicable to new ship construction. In the following subsection excerpts of this instruction specifically pertaining to OGTBs are provided.

4.2.1 National Defense Feature Considerations

The enclosure to the instruction first summarizes the rationale for NDFs and what generally must be considered in their selection. The text is as follows:

1. NATIONAL DEFENSE FEATURES CONSIDERATIONS

a. The Navy's objective regarding the installation of National Defense Features (NDFs) in merchant ships is to have ships available to meet the sealift requirements of the Department of Defense and that are suitable for economical and speedy conversion to naval or military auxiliaries or would otherwise be useful to the U.S. Government in time of war or national emergency. Under this objective, ship designs having potential use as naval or military auxiliaries could carry out certain military support functions such as: Amphibious Force Resupply; Logistics over the Shore (LOTS); Underway replenishment of wet or dry cargo; Military Personnel Transport; Container Offloading; and Heavy Lift Transport.

b. Ships required for essential economic support of the nation in time of war or national emergency would not be expected to participate in the direct military support role. Such operations would include transport of fuel, raw materials, equipment and supplies on ocean or intercoastal routes supporting commerce. Ships dedicated to these operations should be designed for maximum survivability.

c. The Navy, in cooperation with the Maritime Administration, will conduct design reviews of new construction and conversion of merchant ships to establish national defense feature goals, examine cost and feasibility of desired NDF installations, and assess the impact of such installations on the commercial viability of the ships. Each ship design will be reviewed on its own merit and in light of its probable use to the government. After support

missions or functions suitable for the designs have been selected, NDFs which would best support those functions will be recommended for installation. Early consideration of proposed new merchant ship designs will provide for an efficient design review and will facilitate incorporation of the NDFs and subsequent hardware installation. The Navy, in cooperation with the Maritime Administration, is prepared to collaborate with prospective ship owners, designers, and shipbuilders at the earliest opportunity to address NDF requirements and, where needed, provide specific interpretation of the guidance contained herein.

d. Studies undertaken should take into consideration Maritime Administration advice regarding the commercial use of the proposed ships and insure that any feature suggested for incorporation in peacetime does not unduly compromise the competitive position of the operators in commercial trade. The National Defense Features listed herein should as of the date of this instruction, insofar as basic features are concerned, be considered all-inclusive. However, future commercial ship design concepts and changing national defense requirements may dictate the need for additional or revised National Defense Features.

4.2.2 Basic NDF Standards

The enclosure to the instruction then goes on to specify basic NDF standards applicable to all vessels, including OGTBs. Excerpts of the enclosure applicable to deck, tank, or RO/RO OGTBs are included since these are the only types of OGTBs currently in operation that would have military usefulness.

2. BASIC NDF STANDARDS. Compartmentation shall be provided that will, as a minimum, ensure the ship's survival in the event of flooding of any single compartment. Hull scantlings, fire preventive and firefighting equipment, firepump capacities, boats, and life saving equipments shall meet or exceed the minimum requirements of MARAD, the American Bureau of Shipping, and the U.S. Coast Guard. PANAMAX designs (those ships capable of transiting the Panama Canal) and ship designs with full load draft less than 33 feet are more desirable than larger ships due to greater flexibility of operations, and port accessibility.

2.1 SPEED

c. The speed of integrated tug barge units and self propelled barges will be judged on their individual merit.

2.2 SHOCK RESISTANCE. Resistance to damage by shock stresses shall be provided by the general exclusion of gray cast iron in equipment and systems which affect the survival capability of the vessel. In lieu of gray cast iron more shock resistant materials will be used.

2.3 ELECTRICAL POWER. The generating plant capacity shall be increased, where necessary, or space and weight reservation shall be made for the future installation of additional generating units and/or power distribution units for the ship design under consideration. In all cases, with due consideration to ship type and employment potential by the Department of Defense, a reasonable margin of the proposed capacity either should be available or be sought to meet such contingencies as future expansion of the power system for reefer containers, habitability modules, self defense systems, and to otherwise facilitate conversion to naval auxiliaries.

2.4 DISTILLING CAPACITY

a. Distillation and feed/potable tankage capacity shall be provided based on naval criteria, where appropriate, sufficient to facilitate the possible conversion of proposed ships to naval auxiliaries. Provision shall be made for embarked military personnel, and equipment which requires fresh water washdown such as operational helicopters and vehicles.

b. Embarked military personnel require 25 gallons per man per day (g/m/d) distilling capacity and 40 g/m stowage capacity. Helicopters performing shipboard operations require 100 gallons per day for washdown.

2.5 PROPULSION SYSTEMS. Gas turbine, diesel, steam and nuclear power propulsion plants are all considered appropriate for merchant ships. The propulsion system is normally dictated by economic considerations of the trade in which the ship will be employed in peacetime. The capability to burn Navy standard fuel is considered advantageous for emergency use.

2.6 NUCLEAR, BIOLOGICAL AND CHEMICAL (NBC) WASHDOWN SYSTEM. Water washdown systems shall be provided to enhance the passive defense of merchant ships against NBC attack. The washdown system shall consist of clips and brackets for attaching standard fire hose nozzles in coun-

termeasure washdown position for each weather deck fire station. The clips and brackets shall be located so that the greatest spray coverage is obtained for lifeboats, weather decks, housetops and bulkhead areas. Provide for installation of radiological monitoring equipment.

2.7 EMBARKED MILITARY PERSONNEL. Military personnel will not accompany military cargo under normal circumstances. However, consideration shall be given to providing austere living facilities for those personnel such as drivers/technicians who may accompany military equipment and vehicles under certain circumstances on some ship types such as RO/ROs. When sizing hotel loads such as steam, fresh water and electrical, the needs of 50 additional personnel should be provided for on suitable ships.

2.8 COMMUNICATIONS

a. In addition to FCC requirements, ships should be equipped with at least: (a) one HF transmitter (2-30 MHz) of 1000 watts power output capable of A1, A3A, A3H, A3J and F1 modes of emission and having synthesized frequency control and antenna tuning capability; and (b) two HF (2-30 MHz) synthesized receivers. Installation of Digital Selective Calling and Simplex Teletype Over Radio (SELCAL/SITOR) shall be considered. A space reservation of 180 cu. ft. shall be provided for the future installation of satellite communications equipment; provision should be made for reserve electrical power and cooling capacity. The strengthening of masts for additional antenna installations shall be considered.

b. Provision for future installation of ship to ship communications and night lighting at underway replenishment stations will be considered for ships capable of fleet resupply.

2.9 CARGO GEAR/CARGO OPERATIONS

b. Provision should be made for additional deck strength and lashing/tie down systems for military cargo and vehicles as required.

c. Bollards, cleats, etc., should be provided on deck at the deck edge to enable craft and barges to tie up alongside in open stream discharge.

d. Lighting should be provided to illuminate the ship's cells, decks and access ways.

It should be mentioned that with respect to speed, the instruction does specify that ships having potential use as naval/military auxiliaries should have a minimum sustained speed of 20 knots. 25 knots is preferred for cargo vessels and a speed of 16 knots is considered acceptable for tankers, provided that they can maintain a speed of 15 knots while pumping two products at a minimum of 3000 g.p.m. each with ensured separation. The Occidental Oil OGTBs will practically fulfill these requirements but the CCT RO/RO's with their 15-16 knots speeds are not as fast as normally desired for RO/RO ships.

As for the other basic NDF standards, none should require significant changes to the designs of "mechanically-linked" OGTBs. Due to its size the tug component has little room to accommodate additional embarked personnel unless they were housed in self-sustaining modules. These NDF standards might require considerable upgrading of the "loosely-linked" and other Coast Guard uninspected tugs. How much upgrading would be required is not known since none of these tugs has ever been built with CDS funds and so has never undergone a CDS NDF review.

4.2.3 Specific NDF Criteria

The criteria for determining the specific NDFs to be installed on OGTBs are as follows:

3.9 INTEGRATED TUG BARGE, SELF PROPELLED BARGES AND MISCELLANEOUS VESSELS. Tug/barge designs suitable for ocean service have potential for various uses in time of emergency. Due to the numerous configurations anticipated in this type vessel, specific mission areas will not be addressed. Consideration should be given to adequate deck strength, tie down, and stowage area for military vehicles, mobile cranes and outsize cargo. An integrated tug-barge combination shall be examined according to the missions and National Defense Feature requirements of the corresponding ship type. Thus, a RO/RO barge shall meet the same standards as a RO/RO ship; a product barge shall meet those of an equivalent sized tanker, etc.

This section essentially says that the specific NDF requirements for OGTBs should be the same as a ship of similar type. As RO/RO and tank OGTBs are the types that would normally be built with CDS funds, the specific NDF criteria for these types of barges as specified in the instruction are provided in the next subsections.

Specific NDF Criteria for RO/RO and Combination OGTBs/Ships

3.4 RO/RO AND COMBINATION SHIPS have mission potential for:

- a. 1.3a. Port to port delivery.
- b. 1.3b. Port to point delivery of wheeled or tracked vehicles.
- c. 1.3c. Port to port delivery of outsize cargo.
- d. 1.3e. Port to point delivery of containerized cargo.
- e. 1.3f. Fleet Resupply.
- f. The actual installation will include ramps of adequate design to allow onloading and offloading of military tanks (60 long tons) with the ship at anchor in the open stream. Deck areas should be as clear as possible to enable helicopter operations and military (portable) adaptations for open stream discharge.
- g. The installation shall also include all necessary foundations, power requirements and appropriate accessibility to allow the future installation of two to four sliding pad-eyes on the starboard side to accommodate replenishing to Navy auxiliary ships. Consideration should be given to the installation of one thirty (30) long ton crane with 30 foot outreach. Access doors, sideports and ramps shall have a minimum clear headroom of 15 feet as should at least 30% of the cargo decks.
- h. RO/ROs, by the nature of their construction, should have broad deck areas that lend themselves to utilization as a helicopter carrier/helicopter fly-off delivery ship. Thus, it is desirable, where feasible, that fuel piping and deck modifications be considered to provide helicopter transport and fly-off capabilities.

Specific NDF Criteria for Tank OGTBs/Ships (<100,000 DWT)

3.7 TANKERS have mission potential for:

- a. 1.3h. Port to port delivery of POL.
- b. 1.3i. Port to point delivery of POL.
- c. 1.3j. Fleet re-supply or consolidation of POL.

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MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN E--ETC F/6 15/5
OPERATIONAL EVALUATION OF TUG/BARGE SYSTEMS.(U)

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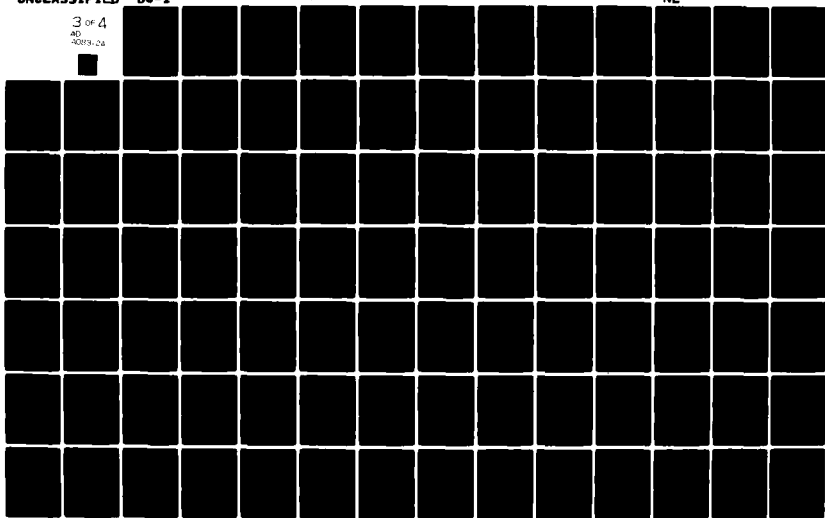
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d. 1.3k. Port to port opportune lifts of outsize military cargo.

e. 1.31. Serve as deployable platform for 2 large capacity mobile cranes for the purpose of unloading nonself-sustaining containerships; i.e., a Temporary Container Discharge Facility (TCDF) and heavy/outsize cargo lift transporter.

f. For military purposes, tankers of less than 40,000 DWT are generally more suitable than tankers in excess of 40,000 DWT. Tankers in excess of 40,000 DWT are more susceptible to certain influence mines with coarse settings, and they lack the maneuverability and versatility provided by equal capacity in several smaller ships. Tankers in excess of 40,000 DWT do have value in moving large quantities of fuel between ports which can accommodate them, consolidation of petroleum products to a naval replenishment ship, and in use as floating storage sites in low vulnerability areas.

3.7.1 TRANSPORT AND LOAD/DISCHARGE CONFIGURATION. The major bulk fuels used by DOD include JP-4, JP-5, Diesel Fuel Marine (DFM) and gasoline. Naval fleet support requires only DFM and JP-5. The following transport, load/discharge capabilities, and construction features should be considered.

a. Tankers of less than 40,000 DWT have high potential for use as naval auxiliaries; both for general POL transportation and operating with naval units at sea. They must have coated tanks and be capable of transporting at least four grades of product with positive separation. Tankers shall have 10 ton lift capability to bring aboard terminal sea hoses. Provision is to be made for two (2) refueling at sea stations, both port and starboard, highline transfer capability, and future possible installation of fueling at sea sending rigs and probable installation of astern fueling rigs. All such items to be in accordance with Military Sealift Command standards. Each refueling station shall be capable of transferring product at a minimum of 3000 GPM while maintaining a speed of 15 knots. Consideration shall be given for stations to receive double hose rigs (probe/conventional combination) for naval units.

b. Tankers larger than 40,000 DWT, but less than 100,000 DWT, shall be as above with the exception that complete cargo tank coating shall be considered on a case-by-case basis, and the tanker must be capable of transporting at least two grades of product.

c. Tankers by the nature of their construction have broad deck areas that lend themselves to the transport of outsize military cargo on deck. Thus, it is considered desirable that, where feasible, piping and deck fittings be arranged to provide maximum clear deck space for lifts of opportunity and, where possible, limited capability for helicopter operations.

4.3 Suggestions for an Additional NDF for OGTBs

The criteria specified in the last section for determining the appropriate NDFs for OGTBs certainly appear reasonable. They basically insist that OGTBs have the same NDFs as ships of the same class or function. However, as stated often before, OGTBs differ from ships due to their linkages that allow separability. Thus, some NDF ought to be considered with respect to OGTB linkages.

As discussed in Chapter 3, OGTBs may be utilized more efficiently during a contingency or mobilization if operated in a drop-and-swap mode. This method of operation requires that all the tugs and barges be interchangeable. For a pull-towed system this is no problem since a wire is used to provide the linkage. For push-towed systems, drop-and-swap operation requires that the notch or other linkage be especially designed for interchangeability. Unfortunately, at this time there is no NDF criterion providing for such interchangeability.

Therefore, it is suggested that a NDF criterion be developed to ensure interchangeability of tug and barge components. It could either be a requirement for a single standard linkage design or at least a requirement that all OGTBs with a given linkage design have interchangeable tugs and barges.

Presently, due to the lack of published research concerning the various linkages, no specific design is recommended here. However, some of the potential benefits of the various linkage types were included in Section 1.3. It is highly recommended that in depth research be conducted on the comparative performance of the several linkage designs. Some of the major objectives of such research should be:

- (1) A comparison of the commercial performance of the various linkages including their cost, ability to operate in heavy weather, linkage drag, etc.
- (2) A comparison of the military performance of the various linkages including their vulnerability, ability to link/unlink in moderate seas, ability to conduct military missions such as replenishment at sea and beaching, etc.
- (3) A comparison of the mobilization potential of the various linkages including cost and ease of installing them on current and newly constructed tugs and barges to make them compatible with current OGTBs.

This research should also determine which linkage system would be appropriate for OGTBs operated by MSC during peacetime in cargo

transport and fleet support missions as well as the linkage that might be used for reserve fleet OGTBs.

It should be realized that this whole discussion has been predicated on the assumption that OGTBs built under CDS should have some standard linkage to allow interchangeability. Unfortunately, few of the many OGTBs have been or are being built with such funds. This is because OGTBs are usually more appropriate for short distance shuttle or coastal trades primarily found in domestic commerce. According to the law such domestic trades are not eligible for CDS funds and so OGTBs built for them cannot be required to have standardized linkages. This is unfortunate, in a military point of view, since it prevents the interchangeability of most OGTBs that might be utilized in contingency operations. However, since the operators see technical and proprietary advantages in developing their incompatible linkage types, there is little that can be done to remedy the situation. Only if the government sponsored research proves one system so superior to the others or if the law is changed to provide economic incentives for linkage standardization on OGTBs used in domestic commerce will standard OGTB linkages become a reality. Otherwise, there will be insufficient economic motivation for the industry to standardize on its own.

CHAPTER 5

PROCUREMENT STRATEGIES FOR A MSC OWNED/OPERATED OGTB CONTINGENCY FLEET

5.1 General Contingency Operation Considerations

In any contingency operation the demand for ships to carry logistic material will expand dramatically. For example, MSC's Controlled Fleet expanded from 201 vessels on 1 July 1965 to 448 vessels on 1 July 1966 to accommodate increased logistic requirements in the Viet Nam area. In addition, other ships will be required to help support the stepped up activity of Navy task forces. Part of this increased demand can be met through the small Ready Reserve Force (RRF) and the Strategic Readiness Program (SRP). However, for all but minor contingencies, the RRF will be insufficient and only a limited number of the 540 ships (271 dry cargo and 269 liquid bulk) of the active privately owned U.S. Merchant Marine can be removed from commercial service via the SRP without irreparable harm to U.S. flag domestic and foreign shipping. Besides, many of the modern, highly productive vessels, such as non-selfsustaining container ships and supertankers, cannot be efficiently used in contingency operations without the use of some special ship-to-shore discharge facility as discussed in Chapter 3. It is unlikely even with these facilities that these vessels will achieve any where near their commercial productivity in military operations. Therefore, in a major contingency operation, even all the vessels provided by the RRF and SRP may be insufficient to handle the contingency transport requirements.

The probable shortfall in ship transport capacity can eventually be met through increased shipyard construction of the appropriate types of ships. However, the leadtime for the delivery of such vessels is at least 12-18 months; so, for many contingency operations these vessels would be delivered far too late to be of any use.

The only other way to meet the shortfall would be by activating the National Defense Reserve Fleet (NDRF). However, today the NDRF consists of only 130 Victory ships and 21 other merchant vessels of various types in addition to about one hun-

dred Naval vessels. Almost all of the merchant ships are at least 35 years old. Even if these vessels were reliable, which is questionable due to the age of their deck and propulsion machinery, they still would not provide even half of the vessels used during the Viet Nam operations.

Given the above argument, it would seem that the transport requirements of a major contingency action like Viet Nam might not be met without either a major disruption to the commercial fleet or the investment of new additions to the NDRF. Neither policy is currently economically or politically viable. Certainly, having new vessels constructed for the NDRF would be infeasible at a time when even Navy warship construction is at its nadir.

The above discussion, typical of most evaluations of contingency transport capability, has completely ignored OGTBs. However, OGTBs may provide the transport capacity needed to eliminate or at least reduce the shortfall. When used in a shuttle/storage operation, they serve to reduce the port time of the large, fast ships and thereby increase these ships' productivity substantially. And, when used in a drop-and-swap mode, they make most efficient use of propulsion and cargo components so that fewer propulsion units and men can transport the same amount of cargo.

The question is, where can these tugs and barges be obtained? Part of the answer is given in Chapter 3 where the availability of commercial OGTBs was discussed for cargo transport missions. It was noted, though, that few current OGTBs, other than pull-towed systems, are capable of the more efficient drop-and-swap operation. Although some suggestions were given on how to convert some OGTBs to allow interchangeability of tugs and barges, it is apparent that the lack of linkage standardization has reduced the usefulness of commercial OGTBs for military drop-and-swap and shuttle operations. And, as discussed in Chapter 4, this situation is unlikely to change since few OGTBs could be required to have a NDF providing for standardized linkages.

There is only one way for the military to ensure the existence of a fleet of highly efficient push-towed OGTBs with interchangeable tugs and barges. That is by operating or owning such a fleet in peacetime which could be expanded during a contingency with the addition of reserve tugs and barges. This is not such an outlandish idea since in Chapter 3 it was shown that all three of MSC's primary missions, cargo transport, Naval Fleet Auxiliary and scientific support operations, could be economically and efficiently performed by OGTBs.

It certainly would be possible for the new and replacement vessels added to MSC's fleet to be OGTBs with interchangeable linkages rather than single unit ships. Then, after a few years, the whole fleet would be made up of the more flexible OGTBs.

And, when mission requirements change, the tugs and barges could be utilized most efficiently to handle the new mission requirements. For example, during a contingency, tug units could be removed from scientific support barges and used to help handle the increased cargo transport requirements via drop-and-swap operation. The same could be done to help support increased Navy task force activity, the added tugs used to shuttle barges from a temporary advanced base.

Even with the increased capabilities achieved with drop-and-swap and shuttle operations, there still may be a need for more OGTB assets to fulfill all transport requirements. The additional tugs and barges could be obtained from a reserve fleet of such vessels. Fortunately, due to the separability of the tugs and barges, this reserve fleet can be effectively utilized during peacetime, thereby eliminating most economical and political arguments against its existence. How this may be done is explained in the subsections given below.

5.1.1 Reserve Tugs

There are at least two possible sources of tugs that could be available to augment MSC's peacetime OGTB fleet during contingency operations:

- (1) Navy Active and Reserve Fleet tugs, and
- (2) commercial tugs converted for military operation.

Navy Active and Reserve Fleet Tugs

One potential source of tug units for OGTBs would be from a fleet of Navy Fleet Tugs manned with Navy Active Duty and Reserve personnel. These tugs could have standard linkage gear installed to allow them to mate with military barges used in contingency operations for cargo transport and/or fleet support. In peacetime, these tugs could perform several useful missions including salvage, firefighting, pollution control, offshore defense, etc. Those not needed for immediate requirements could be used as Naval Reserve training ships. The tugs would be ideal for such a function since they are simple to maintain, require few men, and would be relatively inexpensive to build and operate. Most of the super-powered commercial tugs have cost less than \$15 million to build and are manned with less than 16 men. A Navy tug even with double the manning ought not to cost more than twice its commercial equivalent when fully equipped with linkage and military gear. Therefore, a fleet of such Active Duty and Naval Reserve manned tugs would be an inexpensive means of providing a reserve force of OGTB tug components as well as an important new mission for the Naval Reserve.

Converted Commercial Tugs

There are several possible strategies that would ensure that at least some commercial tugs could be used to augment the Naval Reserve fleet of OGTB tugs. One simple one would be to require that all OGTBs built with CDS funds in the future have Navy standard linkages so that they could be used to mate with Navy barges. This would allow them to be used with barges especially tailored for military operations rather than their commercial barges that would be of questionable military value, i.e., dry bulk barges.

Another strategy would be to choose as the Navy standard linkage a design that could be easily retrofitted onto many of the commercial tugs currently in operation. A linkage such as ARTUBAR which could accommodate differences in the tugs' bow and barges' stern notch shape might be suitable for this purpose. In this case, during a major contingency those tugs previously determined suitable for such a conversion would be retrofitted with linkage gear at one of the many tug yards. All this strategy requires are the identification and stockpiling of the proper linkage gear, identification of suitable tugs for conversion, and identification of the yards able to perform the conversion. With a minimal amount of planning and expense, a large number of commercial tugs could be made available as military OGTB components.

5.1.2 Reserve Barges

There are at least three possible sources of barges that could be available to augment MSC's peacetime OGTB fleet during contingency operations:

- (1) NDRF ships converted into barges,
- (2) prepositioned, preloaded warehouse/storage barge facilities, and
- (3) commercial barges converted for military operation.

NDRF Barges

As mentioned previously, the NDRF consists primarily of 35 year old Victory ships with deck and propulsion machinery of questionable reliability. However, most of these ships have sound hulls. Rather than trying to upgrade or replace their antiquated propulsion plants, it might be more feasible to convert these vessels into barges capable of moderate speed push-tow operation. Such a conversion would not be without cost since the propulsion machinery and deckhouse would have to be removed and a notch incorporated into the stern. This cost could be reduced

substantially if the machinery component were left intact, but this would somewhat reduce the vessel's volume and weight capacity. In either case, there are several advantages to a ship-to-barge conversion strategy. After conversion no machinery would be inactive, since the propulsion tugs would be operating in a Naval Reserve fleet or as commercial tugs. Additionally, the barges would be considered reliable and immediately available reserve assets as long as their hulls remained sound. All that is needed to mobilize a barge would be to activate or install its deck machinery and then it could be mated with any available tug of the Naval Reserve Fleet or any commercial tug converted to military use.

Although this strategy may require substantial investment, it should be the least expensive way of extending the life of the NDRF and to ensure its ability to mobilize rapidly. It is therefore recommended that this approach be studied to determine its cost and feasibility.

Warehouse/Storage Barge Facilities

Another possible source of reserve barges could be in floating warehouse/storage/tank facilities. That is, much of the military's war reserve and inactive stocks could be prepositioned onboard barges which could be moored in protected anchorages or along quays at major supply centers. These barges, capable of mating with any Reserve tug, would be designed so as to be accessible for stock removal and rotation as well as quick discharge at contingency ports. Since these barges will require minimal machinery they should be very inexpensive to maintain. To reduce their maintenance cost even further they could be built of new materials such as prestressed concrete which do not require an anti-corrosion maintenance program. The weight penalties of such type of construction should not be important since most military cargo is volume rather than weight limiting.

Converted Commercial Barges

Commercial tank and deck barges could be used to augment the other reserve OGTB barges in the same manner as commercial tugs augment Naval Reserve tugs. That is, any new barge with potential military usefulness built with CDS funds could be required to have a linkage capable of mating with military OGTB tugs. In addition, the standard Navy linkage should also be designed to be easily retrofitted onto as many commercial barges as possible. In this way, a large number of commercial barges would be made available as military OGTB cargo components.

These are just a few of the possible strategies for providing the assets needed to augment the peacetime fleet of OGTBs for contingency operations. Although none of these strategies is without cost, they do allow reserve OGTBs to be used for various peacetime missions. There should be sufficient applications to justify their procurement as part of a total Navy OGTB fleet strategy.

APPENDIX A

OCEAN GOING BARGES GREATER THAN
2500 GROSS REGISTERED TONS

Explanation of Chart of
Ocean Going Barges > 2500 GRT

Column

- 1 Barge name
- 2 Gross registered tonnage
- 3 Length (feet)
- 4 Breadth "
- 5 Depth "
- 6 Draft "
- 7 Service

TNK tank

FRT freight

FCH Covered Hopper

FDK Deck

FDH Deck House

FCO Covered

FCN Container

FVC Vehicle Carrier

FBC Bulk Cargo

FCF Car Float

FHO Hopper

FCC Cement Carrier

COT Covered and Tank

LGT Lighter

ITN Independent Tank Carrier

GCA general cargo

- 8 Year constructed
- 9 Owner
- 10 Yard of construction
- 11 Port of Registry
- 12 Linkages
 - 1 - 1st Generation
 - 2 - 2nd Generation
 - 3 - 3rd Generation

Ocean Going Barges > 2500 GRT

	1	2	3	4	5	6	7	8	9	10	11	12
Paustina	16528	470	85	48	34	PCH	75	Agrico Shipping Co.	Todd Shipyards	Tampa, FL		
CP-1	16248	500	75	47	33	PCH	77	C. P. Industries	Avondale Shipyards	Minneapolis, MN		
Pierce	16210	470	85	48		PCH	76	Agrico Shipping	Todd Shipyards	Tampa, FL		
Marie Flood	15034	540	85	45	32	FBC	73	Gulfcoast Transit	Levingston Shipbuilding	Tampa, FL		2
Internac 600	15189	500	120	33	25	PCH	73	J. Ray McDermott	Avazu Shipbuilding	Wilmington, DE		3
Valerie P.	14393	620	85	45	31	PCH	76	Bulk Food Carriers	Maryland SB & DD	Wilmington, DE		
Isla del Sol	13175	400	100	20	14	PDH	74	Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA		
Isla Bonita	13174	400	100	20	14	PDH	74	San Diego Transportation	Bethlehem Steel Corp.	San Francisco, CA		
Ceanic 93	11676	450	150	30	21	PDH	76	J. Ray McDermott	Mitsui Ocean Dev. & Eng.	Wilmington, DE		
Freeport 1	10631	473	80	43	30	PCH	68	Midland Enterprises	Avondale Shipyards	Cincinnati, OH		
Freeport 2	10351	473	80	43	30	PCH	68	Midland Enterprises	Avondale Shipyards	Cincinnati, OH		
Alaska	10127	399	80	25	20	PDH	76	Crowley Maritime Corp.	NW Marine Iron Works	San Francisco, CA		
Oregon	10127	399	80	25	20	PDH	76	Crowley Maritime Corp.	NW Marine Iron Works	San Francisco, CA		
Louise Howland	10071	462	82	30	22	PRT	44	R. W. Denny & Buckley	Tampa Ship Repair & DD	Wilmington, DE		
Ocean Revolver	9927	433	75	39		PRT	44	R. W. Denny & Buckley	Avondale Shipyards	New York, NY		
Davy D.	9315	430	80	33	23	PCH	66	Dixie Carriers	Avondale Shipyards	Wilmington, DE		
DAE 1830	9815	430	80	33	23	PCH	66	Ray Houston Towing	Avondale Shipyards	Galveston, TX		
Holly P.	9560	303	90	22	20	PDH	77	Bulk Food Carriers	Seatrail Shipbuilding Corp.	Wilmington, DE		
Antone F.	9560	303	90	22	20	PDH	77	Bulk Food Carriers	Seatrail Shipbuilding Corp.	Wilmington, DE		
Philip F.	9560	303	90	22	20	PDH	77	Bulk Food Carriers	Seatrail Shipbuilding Corp.	Wilmington, DE		
Pearle Jahn	9542	420	80	40	29	PCH	67	Gulfcoast Transit	Gulfport Shipbuilding Corp.	Tampa, FL		
SP 4000	9028	400	100	25		PCH	78	Santa Fe-Pomeroy Marine	China Shipbuilding	Wilmington, DE		
Jureau	8963	400	76	20	14	PDH	70	United Transportation	Bethlehem Steel Corp.	San Francisco, CA		
Martna B.	8944	420	80	37	27	PCH	65	Midland Enterprises	Bethlehem Steel Corp.	Wilmington, DE		
Adelaide	8512	420	80	35	24	PCH	63	Atlantic Cement Co. Inc.	Bethlehem Steel Corp.	Wilmington, DE		
Alexandra	8512	420	80	35	24	PCH	63	Atlantic Cement Co. Inc.	Avondale Shipyards	Wilmington, DE		
Caribbean	8224	474	75	35	25	PCH	66	Caribbean Barge Corp.	Bethlehem Steel Corp.	Wilmington, DE		
Fairbanks	8169	400	76	20	14	PDH	68	Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA		
Ketchikan	8136	350	100	25	15	PLK	66	Brown & Root, Inc.	Bethlehem Steel Corp.	San Francisco, CA		
Bar 267	7998	420	80	35	25	PCH	66	Gulfcoast Transit	Avondale Shipyards	Houston, TX		
Barbara Vaught	7998	420	80	35	25	PCH	66	Gulfcoast Transit	Gulfport Shipbuilding Corp.	Tampa, FL		
Louise Kirkpatrick	7998	420	80	35	25	PCH	64	Gulfcoast Transit	American Bridge Div., USS	Tampa, FL		
Wanda Wheelock	7996	385	68	39	32	TNK	43	Tide 119 Co.	American Bridge Div., USS	Tampa, FL		
Interstate 140	7996	385	68	39	32	TNK	43	Tide 119 Co.	Alabama DD & SB	Wilmington, DE		
Thelma Collins	7825	420	80	35	25	PCH	67	Gulfcoast Transit	Gulfport Shipbuilding Corp.	Tampa, FL		
El Conquistador	7825	420	80	35	25	PCH	67	Gulfcoast Transit	F. M. C. Corp.	Tampa, FL		
La Reina	7815	394	100	25	20	PDH	77	Crowley Maritime Corp.	P. M. C. Corp.	San Juan, PR		
CNC 450-10	7258	418	57	37	28	FDK	77	Harbor Tug & Barge	Mitsubishi Heavy Industry	San Francisco, CA		
Arthur M. Huddell	6718	402	90	22	12	FDK	64	J. Ray McDermott	St. Johns River Shipbuilding	Jacksonville, FL		
McKerrott Oceanic No. 91	6642	400	100	20	14	FDK	73	Harbor Tug & Barge	Alabama DD & SB	New Orleans, LA		
Ata	6642	400	100	20	14	FDK	74	Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA		
Barge 406	6642	400	100	20	14	FDK	74	Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA		
Barge 407	6642	400	100	20	14	FDK	74	Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA		
Barge 408	6642	400	100	20	14	FDK	74	Peoples Nat Bk WA Ttee	Bethlehem Steel Corp.	San Francisco, CA		
Barge 409	6642	400	100	20	14	FDK	74	Peoples Nat Bk WA Ttee	Bethlehem Steel Corp.	San Francisco, CA		

Ocean Going Barges > 2500 GRT

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Barge 410	6642 400 100 20 14 FDK 74 Peoples Nat Bk WA Ttee	Bethlehem Steel Corp.	San Francisco, CA
Barge 411	6642 400 100 20 14 FDK 74 Peoples Nat Bk WA Ttee	Bethlehem Steel Corp.	San Francisco, CA
Barge 414	6642 400 100 20 14 FDK 75 San Diego Transportation	Bethlehem Steel Corp.	San Francisco, CA
Barge 415	6642 400 100 20 14 FDK 75 San Diego Transportation	Bethlehem Steel Corp.	San Francisco, CA
Barge 416	6642 400 100 20 14 FDK 75 San Diego Transportation	Bethlehem Steel Corp.	San Francisco, CA
Barge 417	6642 400 100 20 14 FDK 75 San Diego Transportation	Bethlehem Steel Corp.	San Francisco, CA
Barge 419	6642 400 100 20 14 FDK 75 San Diego Transportation	Bethlehem Steel Corp.	San Francisco, CA
Barge 420	6642 400 100 20 14 FDK 75 San Diego Transportation	Bethlehem Steel Corp.	San Francisco, CA
Ponce	6621 400 100 20 14 FDK 70 Harbor Tug & Barge	Gunderson Brothers	San Francisco, CA
Agattu	6490 418 57 37 28 FRT 45 MC Inc.	Delta Shipbuilding Co.	Portland, OR
Arlington	6074 350 66 32 23 FRT 64 Sheridan Towing	Avondale Shipyards	Philadelphia, PA
James Sheridan	6074 350 66 32 23 FRT 65 Sheridan Barge	Avondale Shipyards	Philadelphia, PA
Kathleen Sheridan	6074 350 66 32 23 FRT 66 Sheridan Towing	Avondale Shipyards	Philadelphia, PA
Patricia Sheridan	6074 350 66 32 23 FRT 68 Tug New York Co.	Avondale Shipyards	Philadelphia, PA
Sea Star	5993 250 76 17 12 FDK 69 Harbor Tug & Barge	Todd Shipyards	San Francisco, CA
Barge 251	5920 336 98 21 17 FDK 70 Puget Sound Tug & Barge	Gunderson Brothers	Portland, OR
Isia Verde	5418 330 60 27 20 FDK 64 Dillingham Tug & Barge	Albina Engine & Machine Works	Honolulu, HI
DIB 25	5400 350 68 26 18 FRT 61 Gulf Bulk Carriers	American Marine Corp.	Wilmingon, DE
Alpha 200	5279 303 90 22 18 FDK 76 Bulk Food Carriers	Seatrain Shipbuilding Corp.	Wilmingon, DE
Christina P.	5279 303 90 22 18 FDK 76 Bulk Food Carriers	Seatrain Shipbuilding Corp.	Wilmingon, DE
Lisa P. Giant 380	5234 383 68 26 18 FDK 44 Cargos Unltd. Transfer	San Shipbuilding	New Orleans, LA
Gulf Giant 380	5167 350 100 17 20 FDK 77 Candies Towing	Tampa Ship Repair & DD	Houma, LA
C. C. 350	5057 324 74 23 17 COT 66 Greyhound Leasing	Todd Shipyards	Seattle, WA
Cordova	5051 400 76 20 14 FDK 69 Bay Cities Transportation	Bethlehem Steel Corp.	San Francisco, CA
Kenai	5051 400 76 20 14 FDK 69 Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA
Kodiak	5051 400 76 20 14 FDK 69 Alaska B.C. Trans.	Bethlehem Steel Corp.	San Francisco, CA
McKinley	5051 400 76 20 14 FDK 69 Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA
Nikiski	5051 400 76 20 14 FDK 68 United Transportation	Bethlehem Steel Corp.	San Francisco, CA
Palmer	4939 300 93 22 15 FDK 64 J. Pay McDermott	Alabama DD & SB	New Orleans, LA
McDermott Jet Barge No. 2	4860 400 100 20 14 FDK 70 Harbor Tug & Barge	Todd Shipyards	San Francisco, CA
Isla Grande	4860 400 100 20 14 FDK 70 Harbor Tug & Barge	Todd Shipyards	San Francisco, CA
Misal	4860 400 100 20 14 FDK 70 Harbor Tug & Barge	Todd Shipyards	San Francisco, CA
TMT Jacksonville	4836 400 100 20 14 FDK 76 Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA
San Juan	4836 400 100 20 14 FDK 76 Harbor Tug & Barge	Bethlehem Steel Corp.	San Francisco, CA
TMT Portaleza	4717 300 105 20 17 FDK 76 Harbor Tug & Barge	Gunderson Brothers	San Francisco, CA
Arctic Challenger	4643 416 57 29 14 FDK 42 Peter Kiewit & Sons	Seatrain Shipbuilding	San Francisco, CA
Savy Crockett	4561 272 68 19 16 GCA 59 United Towing	Houston Shipbuilding	San Francisco, CA
Cedar	4547 383 68 24 19 FDK 42 Heavy Lift Inc.	Albina Engine & Machine Works	San Francisco, CA
Ocean Hauler 20	4487 272 68 19 15 FRT 66 Permanente Steamship	Sun Shipbuilding & DD	New Orleans, LA
Permanente 272	4375 403 57 25 13 43 General Metals	Gunderson Brothers	San Francisco, CA
Twin Harbor	4340 293 90 20 16 FDK 77 Gulf Mississippi Marine	Bethlehem-Parfield Shipyard	Tacoma, WA
Gulf Fleet 290	4340 293 90 20 16 FDK 77 Gulf Mississippi Marine	Gulf Overseas Engineering	New Orleans, LA
Gulf Fleet 291	4340 293 90 20 16 FDK 77 Gulf Mississippi Marine	Gulf Overseas Engineering	New Orleans, LA

Ocean Going Barges > 2500 GRT

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Intermac 504	4259 350	80 25 20	FDK 69	Oceanic Contractors	Gulfpport Shipbuilding Corp.	New Orleans, LA
I 51	4233 300	68 24 20	TNK 76	Allied Partners, Inc.	Gretna Machine & Iron Works	St. Louis, MO
Westchester	4179 317	60 26 22	TNK 75	Pittston Marine	Avondale Shipyards	New York, NY
PAC 312-1	4126 312	68 19 14	PRT 69	Grayhound Leasing	Gunderson Brothers	Seattle, WA
Caribe	4114 305	70 23 17	PCN 65	Guif Atlantic Transport	National Steel & SB	Jacksonville, FL
Forest	4114 272	68 24 18	TNK 59	A & S Transportation	Todd Shipyards	New York, NY
Nat'l Forest	3935 292	68 24 18	TNK 59	A & S Transportation	Kaiser Company	New Orleans, LA
Foss 343	3863 343	72 26 20	PBC 45	Railway Equipment Leasing	Pacific Coast Engineering	Seattle, WA
Vorton Sound	3862 328	76 18 14	PDK 75	Foss Launch & Tug	Todd Shipyards	Portland, OR
Yaguina	3846 320	68 25 15	PCO 66	Pacific Hawaiian Line	Nashville Bridge Co.	New Orleans, LA
Ocean Hauler 10	3807 305	68 24 17	FDK 68	Sause Brothers	Kaiser Company	New Orleans, LA
Kelly	3793 335	64 20 17	TNK 55	Heavy Lift Inc.	Ingalls Shipbuilding	Norfolk, VA
AL 702	3747 340	63 27 20	PBC 63	Eagle Leasing Corp.	American Bridge Div., USS	Washington, DE
AL 703	3747 340	63 27 20	PBC 61	Eagle Leasing Corp.	American Bridge Div., USS	Washington, DE
Charlie F.	3616 284	72 26 17	FDK 45	Bulk Food Carriers	Kaiser Company	New Orleans, LA
Marine Flasher	3616 284	72 26 17	FDK 45	World Services	Kaiser Company	New Orleans, LA
Marine Jumper	3616 284	72 26 17	FDK 45	World Services	Kaiser Company	Washington, DE
Elizabeth S.	3606 285	64 23 17	TNK 69	Stewart Transportation	S. B. A. Shipyards	Seattle, WA
Foss 207	3562 309	50 25 12	PRT 44	Foss Launch & Tug	Jeffersohville B & M	Seattle, WA
Maure	3548 350	60 20 16	TNK 72	Seaboard Shipping	Todd Shipyards	Washington, DE
Krude Island	3546 288	72 20 16	TNK 66	Moranta No. 200 Inc.	Todd Shipyards	Washington, DE
Moranta No. 200	3498 218	55 15 12	FDK 69	Sause Brothers	Manitowoc Shipbuilding	Minneapolis, MN
Consolidator	3421 272	68 19 16	PRT 59	Permanent Steamship	Nashville Bridge Co.	Portland, OR
Seward	3419 329	68 19 16	TNK 64	Washington Barge Co.	Albion Engine & Machine Works	San Francisco, CA
Griffson	3403 295	50 20 18	PCN 63	Matson Navigation	Gunderson Brothers	Seattle, WA
Islander	3397 300	72 18 14	PRT 76	Mallister Brothers	Bethlehem Steel Corp.	Honolulu, HI
Mallister Transporter	3397 309	50 25 15	PRT 44	Atlantic Gulf & Pacific	Seatrains Shipbuilding Corp.	New York, NY
Spadafora	3384 327	50 24 15	PRT 43	Kenai Salmon Packing	Jeffersonville B & M	New York, NY
Kavalaska	3384 309	50 25 15	PRT 43	Alaska Brick Co.	Bethlehem Steel Corp.	Juneau, AK
TYONEK	3382 282	78 18 15	FDK 77	Marine Leasing	Kaiser Company	Seattle, WA
AL 280	3382 282	78 18 15	FDK 73	Marine Leasing	Marine Power & Equip.	Seattle, WA
AL 281	3302 286	72 19 15	FDK 72	Otto Candies	Equitable Equipment Co., Inc.	Houma, LA
CC 300	3302 286	72 19 15	FDK 72	Otto Candies	Equitable Equipment Co., Inc.	Houma, LA
CC 301	3293 309	64 19 15	TNK 69	Grayhound Brothers	Wyatt Industries	New York, NY
Mallister 56	3293 309	64 19 15	TNK 69	Grayhound Brothers	Gunderson Brothers	Seattle, WA
PAC 312-2	3272 312	68 19 15	FDK 69	Grayhound Leasing	National Steel & Shipbuilding	San Francisco, CA
Oliver J. Olson III	3253 275	68 20 14	PRT 64	Crown Zellerbach Corp.	R. T. C. Shipbuilding	Norfolk, VA
ATC 6300	3216 304	47 26 20	PCO 53	Allied Towing Corp.	West Gulf Marine Works	Honolulu, HI
DTB 40	3202 286	76 18 14	FDK 77	Dillingham Tug & Barge	West Gulf Marine Works	Portland, OR
Foss 286 1	3202 286	76 18 14	FDK 77	Foss Launch & Tug	West Gulf Marine Works	Seattle, WA
Foss 286-2	3202 286	76 18 14	FDK 78	Foss Launch & Tug	West Gulf Marine Works	Seattle, WA
Foss 286-3	3202 286	76 18 14	FDK 78	Foss Launch & Tug	West Gulf Marine Works	Seattle, WA
P 7 & S 286-1	3202 286	76 18 14	FDK 78	Foss Launch & Tug	West Gulf Marine Works	Long Beach, CA

Ocean Going Barges > 2500 GRT

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P T & S 286-2	3202	286	76	18	14	FDK	76	Poss Launch & Tug	West Gulf Marine Works	Long Beach, CA
P T & S 286-3	3202	286	76	18	14	FDK	77	Poss Launch & Tug	West Gulf Marine Works	Long Beach, CA
Interstate 52	3164	300	62	20	16	TNK	69	Interstate Marine	Avondale Shipyards	Wilmington, DE
PAC 312-3	3157	304	68	18	16	PRT	63	Puget Sound Tug & Barge		Seattle, WA
Silver Bay	3154	302	72	19	14	PRT	75	Silver Bay Barge Co.	Todd Shipyards	Seattle, WA
PAC 270	3106	272	70	18	14	FDK	75	Zidell Inc.	Zidell Explorations	Seattle, WA
Pampa	3093	378	56	26		TNK	76	Du Pont De Nemours	West Gulf Marine Works	Portland, OR
CF 105 B	3084	298	53	14		TNK	67	A. I. Alonso, Trustee	West Gulf Marine Works	Wilmington, DE
CF 106 B	3084	298	53	14		TNK	68	A. I. Alonso, Trustee	Wyatt Industries	New York, NY
Makani	3083	268	60	19	15	PRT	69	Young Brothers	Wyatt Industries	New York, NY
Manitowoc	3050	349	65	22		PCF	26	Norfolk & Western Railway	Albion Engine & Machine Works	Honolulu, HI
Tonkawa	3074	250	72	16	11	FDK	67	Santa Fe Paceroy Marine	Manitowoc Shipbuilding	Detroit, MI
San Juan 1	3035	280	60	22	17	TNK	64	San Juan Barge Co.	Bethlehem Steel Corp.	Wilmington, DE
Poss 201	3021	309	50	25	16	PRT	45	Poss Launch & Tug	Avondale Shipyards	San Juan, PR
Poss 202	3039	309	50	25		PRT	45	Poss Launch & Tug	Bethlehem Steel Corp.	Seattle, WA
Poss 202	3039	309	50	25		PRT	45	Poss Launch & Tug	Bethlehem Steel Corp.	Seattle, WA
Sea Horse No. 1	3008	290	60	19		TNK	66	Connecticut Light & Power	Chicago Bridge & Iron Co.	New London, CT
Suffolk	2956	285	60	18	14	TNK	63	Interstate Marine Transp.	Wiley Manufacturing, Inc.	Wilmington, DE
Varliner 236	2935	266	76	17	13	FDK	73	Poss Launch & Tug	Zigler Shipyards, Inc.	Seattle, WA
Barge 254	2971	250	76	17	13	FDK	73	Poss Launch & Tug	Kaiser Steel	Seattle, WA
Barge 255	2971	250	76	17	13	FDK	73	Poss Launch & Tug	Kaiser Steel	Seattle, WA
Brandon	2955	272	70	18	14	FDK	75	Sause Brothers	Seatrail Shipbuilding Corp.	Wilmington, DE
B. F. T. No. 50	2940	310	64	21	17	TNK	68	Interstate Marine	Gunderson Brothers	Seattle, WA
Interstate 48	2948	290	60	19	15	TNK	72	B. F. T. No. Three Corp.	Gunderson Brothers	Seattle, WA
Antie Name	2928	270	60	25	19	TNK	62	Stewart Transportation	Zidell Explorations	Portland, OR
Razina	2904	272	70	18	15	FDK	75	Zidell Inc.	Jeffboat Inc.	Boston, MA
Poss 203	2859	309	50	25	15	PRT	43	Poss Launch & Tug	Dravo Corporation	Wilmington, DE
Magna	2866	352	44	22		PRT	96	Merritt Chapman & Scott	Zidell Explorations	Portland, OR
Alamo 3000	2866	380	53	13		TNK	63	Alamo Chemical Trans.	Chicago Bridge & Iron Co.	Seattle, WA
BVG 3003	2866	380	53	13		TNK	65	B. F. Goodrich	Bethlehem Steel Corp.	Cleveland, OH
Katmai	2864	309	50	25	15	FDK	45	Alaska Brick	Dravo Corporation	Cleveland, OH
Poss 288	2850	286	76	17	13	FDK	76	Poss Launch & Tug	Todd Shipyards	Seattle, WA
Makana	2847	268	60	19	15	PRT	68	Young Brothers	Albion Engine & Machine Works	Honolulu, HI
CF 102 T	2840	298	53	14		TNK	66	Greyhound Leasing	Aerojet-General Shipyards	San Francisco, CA
CF 104 T	2840	298	53	14		TNK	66	Greyhound Leasing	Aerojet-General Shipyards	San Francisco, CA
Alamo 3001	2816	270	53	13		TNK	63	Alamo Chemical Trans.	Houston, TX	Houston, TX
Alamo 3004	2813	355	53	13		TNK	68	Alamo Chemical Trans.	Bethlehem Steel Corp.	Houston, TX
Harpo 1	2798	295	53	14	8	ITN	67	Hercules, Inc.	Wyatt Industries	Wilmington, DE
Poss 204	2796	309	50	25	15	PRT	43	Poss Launch & Tug	Dravo Corporation	Seattle, WA
Poss 209	2736	309	50	25	15	PRT	45	Poss Launch & Tug	Bethlehem Steel Corp.	Seattle, WA
Poss 210	2796	309	50	25	15	PRT	45	Poss Launch & Tug	Bethlehem Steel Corp.	Seattle, WA
Diamond W Offshore St 64	2777	309	50	25	15	PRT	43	John D. Askev	Dravo Corporation	Houston, TX

Ocean Going Barges > 2500 GRT

	1	2	3	4	5	6	7	8	9	10	11	12
Sparkling Waters												
Harpo II	2776	298	50	21	15	TNK	67	Hygrade Disposall	Avondale Shipyards	New York, NY		
Klinkwan	2773	283	53	14	8	ITN	67	Hercules, Inc.	Wyatt Industries	Wilkinson, DE		
PAC-560	2768	270	70	18	15	FDK	73	Halvorsen Towing	Gunderson Brothers	Ketchikan, AK		
I 50	2767	278	66	20	15	FRT	64	Puget Sound Tug & Barge	Pacific Coast Engineering	Aberdeen, WA		
Texaco 40	2748	300	54	18	16	TNK	75	Allied Partners, Inc.	Gretna Machine & Iron Works	St. Louis, MO		
Gulf Fleet 260	2740	285	60	18	14	TNK	60	Interstate Marine	Todd Shipyards	Wilkinson, DE		
Gulf Fleet 261	2736	260	72	17	14	FDK	73	Gulf Mississippi Marine	American Marine Corp.	New Orleans, LA		
J. Waintry	2725	272	69	17	13	TNK	57	Crown Zellerbach	Pacific Coast Engineering	New Orleans, LA		
CP 101 L	2653	298	53	14	TNK	66	Greyhound Leasing	Aerojet-General Shipyards	Aerojet-General Shipyards	Portland, OR		
CP 103 L	2653	298	53	14	TNK	66	Greyhound Leasing	Aerojet-General Shipyards	Aerojet-General Shipyards	San Francisco, CA		
Patnaz	2675	303	60	27	TNK	74	Pittston Marine Trans.	Todd Shipyards	Todd Shipyards	San Francisco, CA		
Richmond	2674	300	60	17	TNK	75	Pittston Marine Trans.	Todd Shipyards	Todd Shipyards	New York, NY		
SLC 409	2674	300	60	17	TNK	70	Stewart Transportation	Todd Shipyards	Todd Shipyards	Wilkinson, DE		
SLC 410	2674	300	60	17	TNK	71	Stewart Transportation	Todd Shipyards	Todd Shipyards	Wilkinson, DE		
SLC 411	2674	300	60	17	TNK	75	Stewart Transportation	Todd Shipyards	Todd Shipyards	Wilkinson, DE		
SLC 412	2674	300	60	17	TNK	75	Stewart Transportation	Todd Shipyards	Todd Shipyards	Wilkinson, DE		
ARB 59	2656	273	68	18	14	FDK	70	Puget Sound Tug & Barge	Todd Shipyards	Wilkinson, DE		
Poss 256	2656	250	76	17	13	TNK	70	Poss Launch & Tug	Todd Shipyards	Seattle, WA		
Barge 250-1	2658	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Barge 250-10	2658	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Barge 250-11	2658	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Barge 250-9	2658	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Poss 255	2637	250	76	17	13	FDK	70	Foss Launch & Tug	Todd Shipyards	Seattle, WA		
MA 262	2627	250	75	16	FDK	65	Brown & Root	Gulport Shipbuilding Corp.	Gulport Shipbuilding Corp.	Houston, TX		
Barge 250-3	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Barge 250-4	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Barge 250-6	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Barge 250-8	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
Santo Domingo	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
St. John	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
St. Maarten	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
St. Thomas	2624	250	76	17	13	FDK	76	Harbor Tug & Barge	Todd Shipyards	San Francisco, CA		
MA 240	2622	250	75	16	11	FDK	64	Brown & Root	Gulport Shipbuilding Corp.	Houston, TX		
DB 300	2614	255	76	15	8	FDK	75	Northwestern Construction	Pacific Coast Engineering	Houston, TX		
Hygrade 42	2596	300	43	24	18	TNK	68	Tanker Hygrade No. 42	Todd Shipyards	New York, NY		
Ball Run	2584	260	54	16	12	FDK	70	Wood Oceanics	Levingston Shipyard	Wilkinson, DE		
McDermott Tidelands 017	2576	240	72	17	13	FDK	77	J. Ray McDermott	McDermott Shipyard	Wilkinson, DE		
Tidelands 015	2576	240	72	17	14	FDK	77	J. Ray McDermott	Gretna Machine & Iron Works	Wilkinson, DE		
Tidelands 016	2576	240	72	17	14	FDK	77	J. Ray McDermott	Gretna Machine & Iron Works	Wilkinson, DE		
McDermott Tidelands No. 012	2570	240	72	17	12	FDK	73	J. Ray McDermott	Avondale Shipyards	Wilkinson, DE		
McDermott Tidelands No. 014	2570	240	72	17	12	FDK	73	J. Ray McDermott	Avondale Shipyards	Wilkinson, DE		
McDermott Tidelands No. 015	2570	240	72	17	12	FDK	73	J. Ray McDermott	Avondale Shipyards	Wilkinson, DE		
Belcher No. 35	2551	260	64	19	17	TNK	76	Belcher Towing Co.	Houston Shipyards	Miami, FL		
McDermott Tidelands 011	2545	240	72	17	12	FDK	67	J. Ray McDermott	Pacific Coast Engineering	Morgan City, LA		

Ocean Going Barges > 2500 GRT

1	2	3	4	5	6	7	8	9	10	11	12
Jim Brown	2527	250	72	16	FDK	76	Misener Barge & Boat	Misener Industries		Tampa, FL	
Tunwater	2526	190	50	12	10	FDK	72	Puget Sound Freight Lines	Zidell Explorations	Seattle, WA	
McBermott Tidelands No. 08	2509	240	72	17	12	FDK	67	J. Ray McBermott	Alabama DD & SB	New Orleans, LA	
McBermott Tidelands No. 09	2509	240	72	17	12	FDK	67	J. Ray McBermott	Alabama DD & SB	Morgan City, LA	
McBermott Tidelands No. 010	2509	240	72	17	12	FDK	67	J. Ray McBermott	Alabama DD & SB	Morgan City, LA	
CBC 261	2502	295	50	14	TNK	67	Canal Barge Co.	Todd Shipyards		New Orleans, LA	
CBC 263	2502	295	50	14	TNK	67	Canal Barge Co.	Todd Shipyards		New Orleans, LA	
Exxon Barge No. 222	2502	298	54	14	TNK	66	Exxon Corp.	Dravo Corporation		Wilmington, DE	

APPENDIX B

OCEAN GOING TANK BARGES GREATER
THAN 50,000 BARREL CAPACITY

Explanation of Chart of
Ocean Going Tank Barges > 50000 BBL

Column

- 1 Tank Barge Name
- 2 Gross registered tonnage
- 3 Hull Information

Side Code

*Single Side Skin

0 Non water tight (independent tanks)

W Double sides

Bottom Code

* Single bottom/skin

P Partial double bottom

F Full double bottom

- 4 Year of construction
- 5 Length (feet)
- 6 Breadth
- 7 Draft
- 8 Operator/owner
- 9 Hull Type- Refers to tank barge hull type indicated on "Certificate of Inspection"
 - 1 Type I
 - 2 Type II
 - 3 Type III

If no hull type indicated on "Certificate of Inspection," Type III is assumed.

- 10 Grade of Cargo - refers to highest product grade that may be carried as indicated on "Certificate of Inspection".

Highest Grade Certified

Subchapter Title "D"

Grade A	AA
Grade B	BB
Grade C	CC
Grade D	DD
Grade E	EE

Liquefied Petroleum Gases

Butane	LF
Propane	LF
Propylene	LF

Subchapter Title "D/0" and "0/I"

Grade A	AX
Grade B	BX
Grade C	CX
Grade D	DX
Grade E	EX
Grade 0 and other	XX

Liquefied Petroleum Gases

Butadiene	LF
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Motor Fuel Anti-Knock Compounds TL

Acids

Hydrochloric	AH
Phosphoric	AP
Sulphuric	AS

Anhydrous Ammonia	NH
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Caustic Soda	SC
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Chlorine	CL
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Class B Poisons	BP
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Phosphorous, Elemental	PH
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Sulfur, Molten	MS
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- 11 The total capacity is indicated by amount in:
 - B number of barrels
 - G number of gallons
 - T number of short tons
- 12 Yard of Construction
- 13 Port of Registry
- 14 Linkages
 - 1 - 1st Generation
 - 2 - 2nd Generation
 - 3 - 3rd Generation

Ocean Going Tank Barges > 50000 BBL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
527-3901	20982	**	75	581	95	37	Port Everglades Towing	1	BB	320000	B Kelso Marine		Miami, FL	
103-3302	15758	**	72	585	87	37	Ingram Ocean Systems Inc.	3	BX	293692	B Livingston Shipbuilding		Wilmington, DE	
300-3902	18671	**	77	582	95	40	Hvide Shipping Inc.	2	AX	291080	B Kelso Marine		Miami, FL	
Ocean 262	16660	**	56	563	90	45	Interstate Ocean Trans.	3	BB	282912	B Bethlehem Steel		Wilmington, DE	
103-3301	15579	**	71	595	87	37	Ingram Ocean Systems Inc.	3	BB	270000	B Alabama DD & SB		Wilmington, DE	
Ocean 240	14678	**	70	546	85	32	Interstate & Ocean Trans.	3	AA	255000	B Bethlehem Steel		Wilmington, DE	
Ocean 255	14630	**	71	548	86	32	Interstate Oil Transport	3	AA	255000	B Bethlehem Steel		Wilmington, DE	
New York	14137	WF	70	508	90	33	Moran Maritime Assoc.	3	AA	250000	B Gulfport Shipbuilding		Wilmington, DE	
Ocean Cities	14579	**	72	546	85	32	Interstate Oil Transport	3	AA	250000	B Bethlehem Steel		Wilmington, DE	
Coramally I	14172	**	71	520	85	32	Sabine Towing & Trans.	3	AA	235000	B Bethlehem Steel		Wilmington, DE	
Texasco 337	11032	**	73	455	84	30	Texasco Inc.	3	BB	191000	B Todd Shipyards		Wilmington, DE	
Ocean 628	11032	**	73	455	84	30	Texasco Inc.	3	BB	191000	B Todd Shipyards		Wilmington, DE	
Ocean 95	10608	**	75	476	84	28	Interstate Oil Transport	3	AA	185427	B Avondale Shipyards		Wilmington, DE	
Ocean States	10608	**	75	476	84	28	Interstate Oil Transport	3	AA	185427	B Avondale Shipyards		Wilmington, DE	
Chemtran I	11496	PF	74	551	69	31	Chemical Transportation	1	AX	163094	B Norfolk SS & L Corp.		Wilmington, DE	
Plumtree	10829	**	78	470	76	30	Security Pacific Equip.	2	AA	162666	B Galveston Shipbuilding		Wilmington, DE	
Velluac	10809	**	78	470	76	30	Marine Equipment Ship	2	AA	162666	B Galveston Shipbuilding		Wilmington, DE	
Uppco 142	8483	**	75	465	70	24	Marine Towing & Trans. Co	1	AA	150000	B Kelso Marine		San Francisco, CA	
Barge 102	7970	**	70	430	60	22	Dixie Carriers	3	AA	150000	B Gunderson Brothers		San Francisco, CA	
Barge 109	8038	**	71	424	60	22	Dixie Carriers	3	AA	150000	B Gunderson Brothers		San Francisco, CA	
Ocean 155	9401	**	74	450	80	26	Interstate & Ocean Trans	3	AA	150000	B Avondale Shipyards		Wilmington, DE	
Barge 140	8478	**	72	465	70	24	Owego Barge Corp.	3	AA	148000	B Gretna Machine & Iron Works		Wilmington, DE	
Barge 450-1	8123	**	76	400	100	20	San Diego Transportation	1	AA	145000	B Bethlehem Steel		San Francisco, CA	
Barge 450-2	8123	**	76	400	100	20	San Diego Transportation	1	AA	145000	B Bethlehem Steel		San Francisco, CA	
Barge 450-3	8123	**	76	400	100	20	San Diego Transportation	1	AA	145000	B Bethlehem Steel		San Francisco, CA	
Barge 450-4	8123	**	76	400	100	20	San Diego Transportation	1	AA	145000	B Bethlehem Steel		San Francisco, CA	
Barge 450-5	8185	**	76	400	100	19	San Diego Transportation	1	AA	145000	B Bethlehem Steel		San Francisco, CA	
Ocean 135	7739	**	69	435	74	24	Interstate Oil Transport	3	AA	132000	B Gulfport Shipbuilding		Philadelphia, PA	
Citro New York	7912	**	76	376	78	25	Montaux Oil Trans. Co.	3	BB	120037	B Todd Shipyards		New York, NY	
New Bucket	7859	**	45	385	68	32	Allied Towing Corp.	3	BB	115630	B Sun Shipbuilding		New York, NY	
Corpus Christi Sun	7297	**	70	405	72	25	Sun Transport Co.	3	AA	115000	B Avondale Shipyards		Philadelphia, PA	
Ocean 115	6430	**	68	400	70	22	Interstate Oil Transport	3	AA	105362	B Gretna Machine & Iron Works		New York, NY	
B. No. 115	6411	**	74	340	74	25	B. No. 115 Corporation	1	AA	105362	B Gretna Machine & Iron Works		New York, NY	
B. No. 125	6411	**	75	340	74	25	B. No. 125 Corporation	1	AA	105362	B Gretna Machine & Iron Works		New York, NY	
Barge 101	6678	**	68	281	80	23	United Transportation	3	AA	105000	B Gunderson Brothers		San Francisco, CA	
B. No. 105	5576	**	71	340	70	23	Boulevard Transportation	3	AA	102662	B Gretna Machine & Iron Works		New York, NY	
Peck Ship	5566	**	72	340	70	23	Boulevard Transportation	3	AA	102662	B Gretna Machine & Iron Works		New York, NY	
B. No. 95	5369	**	72	346	70	23	Puerto Rico Oil Co.	3	AA	98491	B S. B. A. Shipyards		New York, NY	
Ocean 90	6409	**	67	390	66	22	Interstate & Ocean Trans	3	AA	95452	B Avondale Shipyards		New York, NY	
Verde 95	6293	**	67	390	66	22	Interstate & Ocean Trans	3	AA	95452	B Avondale Shipyards		New York, NY	
Poseidon	7022	WF	73	414	68	27	Chemical Barge Co.	2	AX	95416	B Kelso Marine		Houston, TX	
Ocean 96	6278	PF	69	400	66	22	Interstate Marine Trans	3	AA	95028	B Avondale Shipyards		Philadelphia, PA	
Jo Anne	9841	WF	72	500	68	21	Union Carbide Corporation	1	LF	95025	B Kelso Marine		New York, NY	
Bel. Port Manatee 23	6231	**	71	370	74	21	Belcher Oil Co.	3	BB	90000	B Haller Marine Fabrications		Miami, FL	

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Ocean Going Tank Barges > 50000 BBL

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Exxon Barge No. 33 Hug	3082 4939		71 300 77 330	56 18	Exxon Company							Gretna Machine & Iron Works Gretna Machine & Iron Works	Wilmington, DE Norfolk, VA

APPENDIX C

TUGS GREATER THAN 3000 HP

Explanation for Chart of
Tugs > 3000 HP

Column

- | | |
|----|--------------------------------|
| 1 | Vessel name |
| 2 | Vessel type |
| | TG Tug |
| | TS Tug/Supply |
| | SU Supply |
| | SL Salvage |
| 3 | Year Built |
| 4 | Length Overall x Draft (ft) |
| 5 | Continuous horsepower |
| 6 | Speed-Maximum without towing |
| 7 | Gross registered tonnage |
| | A < 200 |
| | 200 ≤ B ≤ 300 |
| | C > 300 |
| 8 | Towing Certification |
| | OTS - +A1 Ocean Towing Service |
| 9 | Operating Fleet/Owner |
| 10 | Port of Registry |
| 11 | Yard in which constructed |
| 12 | Linkage Type |
| | 1 - 1st Generation |
| | 2 - 2nd Generation |
| | 3 - 3rd Generation |

TUGS > 3000 HP

1	2	3	4	5	6	7	8	9	10	11	12
Valerie Y.	TG 76	151x31	16000	C	OTS	Interstate & Ocean	Wilmington, DE	Southern Shipbuilding Corp.			3
Seabulk Challenger	TG 75	116x32	14000	16	C	OTS Seabulk Tankers, Ltd.	Port Everglades, FL	Kelso Marine, Inc.			3
Seabulk Magnachem	TG 77	116x32	14000	16	C	OTS Ctl Nal Bk Cleve. Ttee	Miami, FL	Kelso Marine, Inc.			3
Carole G. Ingram	TG 72	146x26	11128	C	OTS	Ingram Ocean Systems	Wilmington, DE	Southern Shipbuilding Corp.			3
Martha R. Ingram	TG 71	146x26	11128	C	OTS	Ingram Ocean Systems	Wilmington, DE	Southern Shipbuilding Corp.			3
Dearborn 48	TS 76	204x14	9000	15	B	Dearborn Marine Service	Burton Shipyards	Burton Shipyards			3
Dearborn 201	TS 75	204x14	9000	15	B	Dearborn Marine Service	Burton Shipyards	Burton Shipyards			3
Pye Theriot	TG 76	142x20	8500	13	A	OTS Noly J. Theriot, Inc.	Houma, LA	Equitable Equipment Co., Inc.			3
Dennis Hendrix	TG 77	180x 9	8400	C	OTS	American Com. Barge Line	Wilmington, DE	Jeffboat, Inc.			3
Joe Bobzien	TG 78	180x 9	8400	C	OTS	American Com. Barge Line	Wilmington, DE	Jeffboat, Inc.			3
A. W. Martin	TS 75	191x16	8000	12	C	Andrew Martin Sea Serv.	New Orleans, LA	Halter Marine Services, Inc.			3
Moon Tide	TS 77	197x16	7500	16	C	Tidewater	New Orleans, LA	Tacoma Boat Building Co., Inc.			3
San Tide	TS 77	197x16	7500	16	C	Tidewater	New Orleans, LA	Tacoma Boat Building Co., Inc.			3
Andrew Martin	TG 76	140x21	7500	15	A	OTS Andrew Martin Sea Serv.	New Orleans, LA	Halter Marine Services, Inc.			3
Eichel Trader	SU 77	199x18	7312	15	C	Bienl Offshore, Inc.	Houston, TX	Campbell Industries			3
Bienl Traveler	SU 77	199x18	7312	15	C	Bienl Offshore, Inc.	Houston, TX	Campbell Industries			3
Anly Martin	TS 75	175x14	7200	12	B	OTS Andrew Martin Sea Serv.	New Orleans, LA	Halter Marine Services, Inc.			3
Cavalier	TG 76	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Centurion	TS 76	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Commander	TG 76	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Crusader	TG 74	136x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Dearborn 202	TS 76	186x14	7200	14	B	OTS	New Orleans, LA	Burton Shipyards			3
Dr. Jack	TG 76	141x21	7200	13	A	OTS Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.			3
Eliska Theriot	TG 75	142x20	7200	13	A	OTS Noly J. Theriot, Inc.	Houma, LA	Equitable Equip. Co., Inc.			3
Ensign	TG 77	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Explorer	TG 75	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Gladiator	TG 75	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Grizzly Bear	TS 74	186x	7200	14	C	Petrol Marine	Morgan City, LA	Far East - Livingston Shipbuilding			3
Gulf Brent	TG 76	140x20	7200	13	A	OTS Gulf Mississippi Marine	St. Louis, MO	Halter Marine Services, Inc.			3
Gulf Commander	TS 75	142x20	7200	14	A	OTS Gulf Mississippi Marine	St. Louis, MO	Equitable Shipyards, Inc.			3
Gulf Majesty	TG 76	142x20	7200	14	A	OTS Gulf Mississippi Marine	St. Louis, MO	Equitable Equip. Co., Inc.			3
Hunter	TG 77	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Invader	TG 74	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Janet Theriot	TG 77	125x28	7200	13	C	OTS 1st Nat'l Bk. MN Trustee	Minneapolis, MN	McDermott Shipyards			3
Joshua T.	TS 75	142x20	7200	13	A	OTS Noly J. Theriot, Inc.	Houma, LA	Peerson Builders, Inc.			3
Marina	TG 76	142x20	7200	13	A	OTS Noly J. Theriot, Inc.	Houma, LA	Equitable Equip. Co., Inc.			3
Martha Theriot	TG 77	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Monitor	TG 74	142x20	7200	13	A	OTS Noly J. Theriot, Inc.	Houma, LA	Equitable Equip. Co., Inc.			3
Navigator	TS 75	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Nica Theriot	TG 75	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Patriarch	TG 76	129x17	7200	14	A	OTS Noly J. Theriot, Inc.	Houma, LA	Equitable Equip. Co., Inc.			3
Pilot	TG 77	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3
Pioneer	TG 75	129x17	7200	14	A	OTS Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			3

TUGS > 3000 HP

	1	2	3	4	5	6	7	8	9	10	11	12
Polar Bear	TS 74 186x	7200 14 C	7200 14 C	7200 14 C	7200 14 C	7200 14 C	7200 14 C	7200 14 C	7200 14 C	7200 14 C	7200 14 C	7200 14 C
Ranger	TS 76 129x17	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A
Santry	TS 77 134x	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A
SW	TS 77 134x	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A
Coys Alario	TS 76 129x17	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A
Warrior	TS 75 129x17	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A	7200 14 A
Ann Bonney	TS 75 170x15	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B
Black But	TS 74 170x15	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B
Capt. Kidd	TS 74 170x15	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B
Enterprise	TS 73 179x16	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B
Ranger	TS 73 179x16	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B
Resolute	TS 73 179x16	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B
Vigilant	TS 73 179x16	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B	7040 12 B
Adventurer	TS 76 129x17	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
Betty Wood	TS 73 136x21	7000 12 A	7000 12 A	7000 12 A	7000 12 A	7000 12 A	7000 12 A	7000 12 A	7000 12 A	7000 12 A	7000 12 A	7000 12 A
Bulwark	TS 76 129x17	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
Defender	TS 76 129x17	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
Guantlet	TS 76 129x17	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
Guadalupe	TS 71 143x18	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
Satoco	TS 76 129x17	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
Sentinel	TS 76 129x17	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
Stalwart	TS 76 129x17	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A	7000 14 A
J. J. Oberdorf	TS 78 135x22	6840 15 B	6840 15 B	6840 15 B	6840 15 B	6840 15 B	6840 15 B	6840 15 B	6840 15 B	6840 15 B	6840 15 B	6840 15 B
Newpark Sun-God	TS 76 127x17	6480 12 A	6480 12 A	6480 12 A	6480 12 A	6480 12 A	6480 12 A	6480 12 A	6480 12 A	6480 12 A	6480 12 A	6480 12 A
Newpark Sunlight	TS 78 136x	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C
Ocean Fin	TS 77 136x16	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C
Ocean King	TS 77 136x16	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C
Ocean Marlin	TS 77 136x16	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C
Ocean Ray	TS 78 136x15	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C
Ocean Tarpon	TS 78 136x15	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C	6480 16 C
Gov. Herbert H. Lehman	TS 65 294x59	6400 C	6400 C	6400 C	6400 C	6400 C	6400 C	6400 C	6400 C	6400 C	6400 C	6400 C
Goifather	TS 75 141x21	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A
Master Durby	TS 77 141x21	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A
Master Pete	TS 76 141x21	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A	6200 13 A
Defender	TS 74 179x12	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B
Volunteer	TS 74 179x12	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B	6160 12 B
Century	TS 75 185x14	6000 12 B	6000 12 B	6000 12 B	6000 12 B	6000 12 B	6000 12 B	6000 12 B	6000 12 B	6000 12 B	6000 12 B	6000 12 B
North Star III	TS 45 437x29	5850 C	5850 C	5850 C	5850 C	5850 C	5850 C	5850 C	5850 C	5850 C	5850 C	5850 C
Alberta Tide	TS 76 175x15	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B
Alex Tide	TS 76 175x15	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B
Anthony P. St. Philip	TS 75 141x17	5750 14 A	5750 14 A	5750 14 A	5750 14 A	5750 14 A	5750 14 A	5750 14 A	5750 14 A	5750 14 A	5750 14 A	5750 14 A
Arctic Seahorse	TS 73 170x14	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B	5750 14 B
Atlantic Seahorse	TS 75 186x14	5750 15 A	5750 15 A	5750 15 A	5750 15 A	5750 15 A	5750 15 A	5750 15 A	5750 15 A	5750 15 A	5750 15 A	5750 15 A
Barbara McAllister	TS 67 77x14	5750 A	5750 A	5750 A	5750 A	5750 A	5750 A	5750 A	5750 A	5750 A	5750 A	5750 A

Far East - Livingston Shipbuilding
McDermott Shipyard
McDermott Shipyard
Modern Marine Tower
Equitable Equipment Co., Inc.
McDermott Shipyard
Halter Marine Services, Inc.
Halter Marine Services, Inc.
Halter Marine Services, Inc.
McDermott Shipyard
McDermott Shipyard
McDermott Shipyard
McDermott Shipyard
McDermott Shipyard
California Shipbuilding Corp.
McDermott Shipyard
McDermott Shipyard
McDermott Shipyard
McDermott Shipyard
Main Iron Works, Inc.
McDermott Shipyard
McDermott Shipyard
Marinette Marine Corp.
Service Machine & Shipbuilding
Service Machine & Shipbuilding
American Marine Corp.
American Marine Corp.
American Marine Corp.
American Marine Corp.
American Marine Corp.
Halter Marine Services, Inc.
Halter Marine Services, Inc.
Halter Marine Services, Inc.
Southern Shipbuilding Co.
Southern Shipbuilding Co.
Burton Shipyard
Burton Shipyard
Behlshen-Fairfield Shipyard
Halter Marine Services, Inc.
Halter Marine Services, Inc.
Southern Shipbuilding Co.
Burton Shipyard
Burton Shipyard
Nolty J. Theriot, Inc.

Morgan City, LA
San Francisco, CA
San Francisco, CA
Houston, TX
Houston, TX
San Francisco, CA
New Orleans, LA
New Orleans, LA
New Orleans, LA
Hartford, CT
Hartford, CT
Hartford, CT
Hartford, CT
San Francisco, CA
Tampa, FL
San Francisco, CA
San Francisco, CA
San Francisco, CA
San Francisco, CA
San Francisco, CA
Baltimore, MD
San Francisco, CA
San Francisco, CA
Miami, FL
Port Arthur, TX
Morgan City, LA
Houston, TX
Houston, TX
Houston, TX
Houston, TX
Houston, TX
New York, NY
Corpus Christi, TX
Corpus Christi, TX
Corpus Christi, TX
Hartford, CT
Hartford, CT
Houston, TX
Seattle, WA
New Orleans, LA
New Orleans, LA
Tampa, FL
Morgan City, LA
Morgan City, LA
Wilmington, DE

TUGS > 3000 HP

1	2	3	4	5	6	7	8	9	10	11	12
Parents Seahorse	TS 74	170x14	5750 15	B	OTS	Seahorse, Inc.	Morgan City, LA	Burton Shipyards			
Bed Theriot	TC 67	118x14	5750 14	A	OTS	Molty J. Theriot, Inc.	Houma, LA	American Marine Corp.			
Cecile B.	TC 74	128x19	5750 13	A	OTS	Molty J. Theriot, Inc.	Houma, LA	Main Iron Works, Inc.			
Celtic Seahorse	TS 74	170x14	5750 15	B	OTS	Seahorse, Inc.	Morgan City, LA	Burton Shipyards			
Chippy T.	TC 70	141x16	5750 12	A	OTS	Molty J. Theriot, Inc.	Houma, LA	Southern Shipbuilding Co.			2
Clipper	TC 69	130x17	5750 14	A	OTS	Interstate & Ocean	Wilmington, DE	Main Iron Works, Inc.			
Constitution Service	TS 76	188x15	5750 14	B	OTS	Zapata Marine Service	Houston, TX	Campbell Industries			
Croyle Tide	TS 76	180x15	5750 14	B	OTS	Tidewater	New Orleans, LA	Halter Marine Services, Inc.			2
Enterprise	TC 77	137x17	5750 12	A	OTS	Interstate & Oceans.	Wilmington, DE	Main Iron Works, Inc.			
Esther Moran	TC 63	112x17	5750 14	C	OTS	Moran Towing & Trans.	New York, NY	Jakobson Shipyard, Inc.			
Florida Martin II	TS 76	150x14	5750 15	B	OTS	Andrew Martin Sea Serv.	New Orleans, LA	Mangone Shipbuilding Co.			
Freedom Service	TS 78	182x15	5750 14	B	OTS	Zapata Marine Service	Houston, TX	Campbell Industries			
Fritz Tide	TS 75	160x15	5750 14	B	OTS	Tidewater	New Orleans, LA	Halter Marine Services, Inc.			
Gout Tide	TS 76	175x15	5750 14	B	OTS	Tidewater	New Orleans, LA	Halter Marine Services, Inc.			
Guardian	TC 70	129x17	5750 14	A	OTS	Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyards			1
Gulf Duke	TC 77	127x18	5750 13	A	OTS	Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.			
Gulf Fleet No. 14	TS 75	167x14	5750 13	A	OTS	Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.			
Gulf Rambler	TC 74	140x21	5750 14	B	OTS	Gulf Mississippi Marine	New Orleans, LA	Halter Marine Services, Inc.			
Heritage Service	TS 78	182x15	5750 14	B	OTS	Zapata Marine Service	Houston, TX	Campbell Industries			
Highland Light	TS 76	175x13	5750 12	C	OTS	Offshore Logistics	Morgan City, LA	Halter Marine Services, Inc.			
Hippo	SU 69	183x14	5750 15	B	OTS	Petrol Marine	Morgan City, LA	Levingston Shipbuilding			2
Honor	TC 75	131x18	5750 12	A	OTS	Interstate & Ocean	Wilmington, DE	Main Iron Works, Inc.			
Independence Service	TS 77	188x15	5750 14	B	OTS	Zapata Marine Service	Houston, TX	Campbell Industries			
Intrepid	TC 70	130x17	5750 14	A	OTS	Interstate & Ocean	Wilmington, DE	Main Iron Works, Inc.			2
Jabbar	TC 78	126x	5750 12	A	OTS	McAllister Brothers	New York, NY	Main Iron Works, Inc.			
Jason Alario	TS 75	128x19	5750 13	A	OTS	Molty J. Theriot, Inc.	Houma, LA	Nashville Bridge Co.			
Juanita Candies	TS 75	187x16	5750 14	B	OTS	Otto Candies, Inc.	Houma, LA	McDermott Shipyards			
L. E. Stewart	TC 75	168x20	5750 15	C	OTS	J. Ray McDermott	Wilmington, DE	Halter Marine Services, Inc.			
Leo Tide	TS 76	175x15	5750 14	B	OTS	Tidewater	New Orleans, LA	Campbell Industries			
Liberty Service	TS 78	182x15	5750 14	B	OTS	Zapata Marine Service	Houma, LA	Nashville Bridge Co.			
Ludwig Candies	TC 75	115x16	5750 14	A	OTS	Otto Candies, Inc.	Houma, LA	Gulport Shipbuilding Corp.			
M. Moran	TC 61	112x17	5750 14	C	OTS	Portsmouth Curtis Bay	Morgan City, LA	Mangone Shipbuilding Co.			
Mammoth	SU 71	170x14	5750 15	B	OTS	Petrol Marine	New Orleans, LA	Quality Equipment Inc.			
Margaret George	TC 76	118x16	5750 12	A	OTS	Dapco Marine Corp.	Seattle, WA	McDermott Shipyards			
Mars	TC 70	129x17	5750 14	A	OTS	Pudzet Sound Tug & Barge	Morgan City, LA	Mangone Shipbuilding Co.			
Mastodon	SU 70	170x14	5750 15	B	OTS	Petrol Marine	Morgan City, LA	Halter Marine Services, Inc.			2
Morning Light	TS 75	175x13	5750 12	C	OTS	Offshore Logistics	Morgan City, LA	Main Iron Works, Inc.			
Navigato	TC 72	131x17	5750 14	A	OTS	Inter-Cities Navigation	Wilmington, DE	Service Machine & Shipbuilding			
Newpark Sunbeam	TC 75	127x17	5750 12	A	OTS	Newpark Offshore Marine	Morgan City, LA	Main Iron Works, Inc.			
Newpark Sundial	TC 76	130x17	5750 12	A	OTS	Newpark Offshore Marine	Morgan City, LA	Service Machine & Shipbuilding			
Newpark Sunrise	TC 75	127x17	5750 12	A	OTS	Newpark Offshore Marine	Morgan City, LA	Burton Shipyards			
North Seahorse	TS 73	170x14	5750 14	B	OTS	Seahorse, Inc.	Morgan City, LA	Halter Marine Services, Inc.			
Northern Light	TS 76	175x13	5750 12	C	OTS	Offshore Logistics	Morgan City, LA	Burton Shipyards			
Pacific Seahorse	TS 75	186x	5750 15	B	OTS	Seahorse, Inc.	Morgan City, LA	Burton Shipyards			

TUGS > 3000 HP

1	2	3	4	5	6	7	8	9	10	11	12
Paris Theriot	TC 67	118x14	5750	14	A	OTS	Nolty J. Theriot, Inc.	Houma, LA	Nolty J. Theriot, Inc.		
Pathfinder	TC 70	129x17	5750	14	A	OTS	Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyard		
Pioneer Service	TS 78	182x15	5750	14	B	OTS	Zapata Marine Service	Houston, TX	Campbell Industries		
Reeves Tide	TS 77	175x15	5750	14	B	OTS	Tidewater	New Orleans, LA	Halter Marine Services, Inc.		
Rhino	SU 69	183x14	5750	15	B	OTS	Petrol Marine	Pt. Arthur, TX	Levingston Shipbuilding		
Rita Candies	TS 76	187x16	5750	14	B	OTS	Otto Candies, Inc.	Houma, LA	Nashville Bridge Co.		
Robert Alario	TC 70	141x16	5750	12	A	OTS	Nolty J. Theriot, Inc.	Houma, LA	Southern Shipbuilding Corp.		
Sandy Alario	TC 74	128x19	5750	13	A	OTS	Nolty J. Theriot, Inc.	Houma, LA	Main Iron Works, Inc.		
Sea Flyer	TC 68	129x17	5750	14	A	OTS	Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyard		
Sea Swift	TC 68	129x17	5750	14	A	OTS	Crowley Maritime Corp.	San Francisco, CA	McDermott Shipyard		
Seafarer	TC 71	130x17	5750	14	A	OTS	Interstate & Ocean	Wilmington, DE	Main Iron Works, Inc.		2
Sellers Tide	TS 77	175x15	5750	14	B	OTS	Tidewater	New Orleans, LA	American Marine Corp.		
State Brigade	TS 73	170x14	5750	16	A	OTS	State Boat Corp.	Wilmington, DE	American Marine Corp.		
State Command	TS 74	170x14	5750	16	A	OTS	State Boat Corp.	Wilmington, DE	Service Machine & Shipbuilding		
TBN	TC 77	1'0x	5750				F & S Offshore Inc.	Metairie, LA	Main Iron Works, Inc.		2
Tara Lynn S.	TC 75	128x19	5750	13	A	OTS	Nolty J. Theriot, Inc.	Houma, LA	Main Iron Works, Inc.		
Valour	TC 75	131x18	5750	12	A	OTS	Interstate & Ocean	Wilmington, DE	Main Iron Works, Inc.		
Clipper	TC 69	130x19	5700	13	A	OTS	Interstate & Ocean	Philadelphia, PA	Southern Shipbuilding Co.		
Alice St. Philip	TC 76	141x	5603	16	A	OTS	St. Philip Towing	Tampa, FL	Nashville Bridge Co.		
Otto Candies	TC 77	116x13	5450	14	A	OTS	Otto Candies, Inc.	Houma, LA	Fraser Shipyards, Inc.		
John A. Downs	TC 66	112x17	5380				Great Lakes & Dock	New York, NY	Nashville Bridge Co.		
Scott Chotin	TC 48	112x	5200				C	Cincinnati, OH	McDermott Shipyard		
Theresa F	TC 68	138x18	5150				A	Cincinnati, OH	McDermott Shipyard		
Marine Challenger	TC 68	138x18	5150				A	Cincinnati, OH	McDermott Shipyard		
Alaskan Seahorse	TC 44	141x16	5040				B	Seattle, WA	McDermott Shipyard		
Arthur Foss	TS 76	182x14	5000	12	B	OTS	Seahorse, Inc.	Morgan City, LA	Bellinger Shipyards, Inc.		
Banda Seahorse	TC 44	141x16	5000	12	C	OTS	Foss Launch & Tug	Seattle, WA	Bellinger Shipyards, Inc.		
Deborah 204	TS 74	182x14	5000	16	B	OTS	Seahorse, Inc.	Morgan City, LA	Bellinger Shipyards, Inc.		
Deborah 206	TS 75	182x14	5000	12	B	OTS	OSCO	New Orleans, LA	Bellinger Shipyards, Inc.		
Henry Foss	TC 45	141x	5000				C	New Orleans, LA	Bellinger Shipyards, Inc.		
TBN	TC	140x	5000					Tacoma, WA	Marietta Manufacturing Co.		
TUN	TC	140x	5000					Metairie, LA	Bellinger Shipyards, Inc.		
TUN	TC	140x	5000					Metairie, LA	Bellinger Shipyards, Inc.		
TBN	TC	140x	5000					Metairie, LA	Bellinger Shipyards, Inc.		
Aquamarine 501	TS 74	164x13	4920	15	B	OTS	Aquamarine, Inc.	Houston, TX	Burton Shipyards		
Aquamarine 502	TS 76	164x13	4920	14	B	OTS	Aquamarine, Inc.	Houston, TX	South Texas Shipyard		
Aquamarine 503	TS 77	164x12	4920	14	B	OTS	Aquamarine, Inc.	Houston, TX	South Texas Shipyard		
Beaufort Seahorse	TS 76	186x13	4860	16	B	OTS	Seahorse, Inc.	Morgan City, LA	Equitable Shipyards, Inc.		
Indian Seahorse	TS 76	186x13	4860	13	B	OTS	Seahorse, Inc.	Morgan City, LA	Equitable Shipyards, Inc.		
Wister Richard	TC 70	118x16	4860	12	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Bludworth Shipyard, Inc.		
Robin IX	TC 75	120x14	4860	13	A	OTS	Robin Int'l Marine	New Orleans, LA	McDermott Shipyard		
Robin V	TC 73	120x14	4860	14	A	OTS	Robin Towing	New Orleans, LA	McDermott Shipyard		
Robin VI	TC 74	120x14	4860	14	A	OTS	Robin Towing	New Orleans, LA	McDermott Shipyard		

TUES > 3000 HP

12

11

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Robinson VII	TC 74	120x14	4860	13 A	OTS Robin Towing	New Orleans, LA	McDermott Shipyard
Robinson VIII	TC 74	120x14	4860	13 A	OTS Robin Towing	New Orleans, LA	McDermott Shipyard
Robinson X	TC 75	120x14	4860	13 A	OTS Robin Int'l Marine	New Orleans, LA	McDermott Shipyard
Robinson XI	TC 75	120x14	4860	13 A	OTS Robin Int'l Marine	New Orleans, LA	McDermott Shipyard
Robinson XII	TC 76	120x14	4860	13 A	OTS Robin Int'l Marine	New Orleans, LA	McDermott Shipyard
Abdon Martin	TC 76	115x13	4800	13 A	OTS Andrew Martin Sea Serv.	Houston, TX	Halter Marine Services, Inc.
Aquamarine 50s	TS 78	164x13	4800	13 B	Aquamarine Associates	New Orleans, LA	Halter Marine Services, Inc.
Calico Jack	TS 74	170x14	4800	13 B	OTS Euro-Pirates Int'l	New Orleans, LA	Halter Marine Services, Inc.
Capt. Francois Le Clerc	TS 75	170x15	4800	12 C	OTS Euro-Pirates Int'l	New Orleans, LA	Halter Marine Services, Inc.
Chevalier de Gramont	TS 75	170x15	4800	12 C	OTS Euro-Pirates Int'l	New Orleans, LA	Halter Marine Services, Inc.
Columbia Service	TS 75	166x13	4800	10 B	OTS Zapata Marine Service	Houston, TX	Burton Shipyards
Gaucha	TC 76	96x19	4800	12 A	OTS Du Pont de Nemours	Wilmington, DE	Bucco Barge & Towing, Inc.
Gerano	TC 67	121x13	4800	14 A	Crowley Maritime Corp.	Seattle, WA	Burton Shipyards
Gulf King	TC 67	121x13	4800	14 A	Gulf Mississippi Marine	New Orleans, LA	Burton Shipyards
Jean Lafitte	TS 74	170x14	4800	13 B	OTS Euro-Pirates Int'l	New Orleans, LA	Halter Marine Services, Inc.
L'Olonnois	TS 75	170x15	4800	12 C	OTS Euro-Pirates Int'l	New Orleans, LA	Halter Marine Services, Inc.
Mark McAllister	TC 67	x13	4800	A	Gulf Mississippi Western	New Orleans, LA	Burton Shipyard Co., Inc.
Orion	TC 43	142x16	4800	10 B	OTS Zapata Marine Service	Houston, TX	Marietta Manufacturing Co.
Republic Service	TS 75	165x13	4800	12 B	OTS Euro-Pirates Int'l	New Orleans, LA	Halter Marine Services, Inc.
Sir Henry Morgan	TS 74	170x14	4800	13 A	OTS Nalty J. Theriot, Inc.	Houma, LA	Main Iron Works, Inc.
Nit 1.	TC 74	110x17	4620	14 A	OTS Nalty J. Theriot, Inc.	Houma, LA	Main Iron Works, Inc.
Indian Seal	TS 74	185x16	4600	14 B	OTS Seal Fleet, Inc.	Galveston, TX	Burton Shipyards
E. B. McNaughton	TC 70	174x16	4400	A	OTS Hilo Trans. & Terminal	Hilo, HI	Gulfport Shipbuilding Corp.
Gale B	TC 63	114x18	4320	B	OTS Red Circle Transport	New Orleans, LA	Southern Shipbuilding Co.
Alice Moran	TC 76	120x14	4300	13 A	OTS Foss Launch & Tug	Seattle, WA	McDermott Shipyards
Barbara Foss	TC 76	120x14	4300	13 A	OTS Foss Launch & Tug	Houma, LA	McDermott Shipyards
Billy B.	TC 70	109x15	4300	12 A	OTS Nalty J. Theriot, Inc.	Wilmington, DE	McDermott Shipyards
Cape Cod	TC 76	106x13	4300	12 B	OTS Moran Towing & Trans.	Wilmington, DE	McDermott Shipyards
Cape Lookout	TC 75	120x14	4300	12 B	OTS Moran Atlantic Towing	New Orleans, LA	Halter Marine Services, Inc.
Chap Tide	TS 76	180x15	4300	14 B	OTS Tidewater Services, Inc.	Morgan City, LA	Halter Marine Services, Inc.
Chesapeake Seahorse	SU 78	164x	4300	12 A	Seahorse Services, Inc.	Wilmington, DE	Main Iron Works, Inc.
Corsair	TC 71	108x14	4300	A	OTS Inerstate & Ocean	Metairie, LA	McDermott Shipyards
Denise Defelice	TC 77	126x	4300	14	OTS Defelice Marine Const.	Houma, LA	Nashville Bridge Co.
Fritzi K. McAllister	TC 67	115x15	4300	12 A	OTS McAllister Brothers	Wilmington, DE	McDermott Shipyards
Heide Moran	TC 75	120x14	4300	14 B	OTS Foss Launch & Tug	Seattle, WA	McDermott Shipyards
Justine Foss	TC 76	120x14	4300	13 A	OTS Foss Launch & Tug	New Orleans, LA	McDermott Shipyards
Marty Defelice	TC 66	112x14	4300	12 A	OTS Defelice Marine Const.	Seattle, WA	McDermott Shipyards
Mercury	TC 66	112x14	4300	12 A	Alaska B. C. Trans.	New Orleans, LA	San Diego Marine Const.
Miriam H. Defelice	TC 74	120x14	4300	12 A	OTS Defelice Marine Const.	New Orleans, LA	McDermott Shipyards
Ocean Sun	TC 73	120x14	4300	13 A	OTS Inland River Trans.	St. Louis, MO	McDermott Shipyards
Oceanic Seahorse	TC 73	120x14	4300	13 A	OTS Inland River Trans.	St. Louis, MO	McDermott Shipyards
Prudent Candies	SU 79	164x	4300	12 A	Black Cloud Boats, Inc.	Morgan City, LA	Halter Marine Services, Inc.
	TC 75	100x14	4300	12 A	OTS Otto Candies, Inc.	Houma, LA	Houma Welders, Inc.

TUGS > 3000 HP

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Rusty B.	TG 70	109x15	4300	12	A	OTS	Molty J. Theriot, Inc.	Houma, LA	Southern Shipbuilding Co.
Sheila Moran	TG 75	120x14	4300	12	B	OTS	Moran Towing & Trans.	Wilmington, DE	McDermott Shipyards
TBN	TG 77	123x	4300				McAllister Brothers	New York, NY	Main Iron Works, Inc.
Texaco Diesel Chief	TG 77	123x	4300				McAllister Brothers	Wilmington, DE	Jakobson Shipyard, Inc.
Texaco Fuel Chief	TG 73	109x17	4300				Texaco, Inc.	Wilmington, DE	Jakobson Shipyard, Inc.
Texaco Tampa	TG 75	107x14	4300	14	B	OTS	Texaco, Inc.	Wilmington, DE	Wiley Manufacturing
El Bufalo Grande	TG 67	121x13	4200	10	A	OTS	Tidewater	Morgan City, LA	Burton Shipyards
El Zorro Grande	TG 66	121x13	4200	10	A	OTS	Tidewater	Morgan City, LA	Burton Shipyards
Gulf Cajun	TG 76	118x16	4200	13	A	OTS	Gulf Mississippi Marine	St. Louis, MO	Quality Equipment Inc.
Gulf Eagle	TG 76	118x16	4200	13	A	OTS	Gulf Mississippi Marine	St. Louis, MO	Quality Equipment Inc.
J. Ray McDermott	TG 73	110x14	4200	12	A	OTS	Otto Candies, Inc.	Houma, LA	McDermott Shipyards
Gus Candies	TG 67	133x16	4200	13	B	OTS	J. Ray McDermott	Houma, LA	Houma Welders, Inc.
Kelly Candies	TG 73	100x14	4200	12	A	OTS	Otto Candies, Inc.	Houma, LA	McDermott Shipyards
Pam Alario	TG 72	133x16	4200	11	A	OTS	Molty J. Theriot, Inc.	Houma, LA	Houma Welders, Inc.
Paul Candies	TG 75	100x14	4200	12	A	OTS	Otto Candies, Inc.	Houma, LA	McDermott Shipyards
Robin Alario	TG 72	133x16	4200	11	A	OTS	Molty J. Theriot, Inc.	Houma, LA	McDermott Shipyards
Constellation	SU 68	157x13	4000	14	B	OTS	Offshore Logistics	Morgan City, LA	Burton Shipyards
Cruiser	SU 72	161x12	4000	14	A	OTS	American Offshore, Inc.	Pl. Arthur, TX	Culport Shipbuilding Corp.
David P. Guldry	TG 68	103x15	4000				Red Star Marine Serv.	New York, NY	Main Iron Works, Inc.
Great Republic	TG 73	129x17	4000	10	A	OTS	American Offshore Fleet	Galliano, LA	Burton Shipyards
John Jones	TG 69	133x14	4000	10	B	OTS	Offshore Logistics	Morgan City, LA	McDermott Shipyards
Mister Andre	TG 76	114x16	4000	13	B	OTS	J. Ray McDermott	Morgan City, LA	Halter Marine Services, Inc.
Mister Charlie	TG 76	114x16	4000	13	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Mister Fred	TG 75	114x16	4000	13	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Mister Harold	TG 71	115x17	4000	14	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Mister Jean	TG 76	114x16	4000	13	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Mister John H.	TG 74	114x16	4000	13	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Mister Matt	TG 76	114x16	4000	13	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Raleigh Ann	TG 76	114x16	4000	13	A	OTS	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Roger W. Wilson	TG 66	133x16	4000	13	B	OTS	J. Ray McDermott	Morgan City, LA	McDermott Shipyards
Albassador	TG 76	118x15	3900	12	A	OTS	Interstate & Ocean	Philadelphia, PA	Main Iron Works, Inc.
Atlantic Star	TG 75	105x14	3900	13	A	OTS	Red Star Marine Serv.	New York, NY	Halter Marine Services, Inc.
Betty Culbreath	TG 68	113x18	3900	13	A	OTS	Gulfcoast Transit Co.	Tampa, FL	Culport Shipbuilding Corp.
Cape Hatteras	TG 67	103x15	3900				Moran Towing & Trans.	Wilmington, DE	Culport Shipbuilding Corp.
Cape Henry	TG 67	103x15	3900				Moran Towing & Trans.	Wilmington, DE	Main Iron Works, Inc.
Christine E.	TG 75	107x13	3900	11	A	OTS	McAllister Brothers	Wilmington, DE	Tampa Marine Corp.
Craig Foss	TG 45	115x15	3900	12	B	OTS	Foss Launch & Tug	Seattle, WA	Burton Shipyards
Elie Alerger	TG 77	125x15	3900	10	A	OTS	Elie Carriers, Inc.	New Orleans, LA	Burton Shipyards
El Bufalo Grande	TG 77	125x15	3900	10	A	OTS	Elie Carriers, Inc.	New Orleans, LA	Burton Shipyards
Elizabeth Moran	TG 76	131x14	3900	10	A	OTS	Tidewater	Morgan City, LA	Burton Shipyards
	TG 67	103x15	3900				Moran Towing & Trans.	Wilmington, DE	Culport Shipbuilding Corp.

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TUGS > 3000 HP

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Leland James	TG 44	117x12	3600	B	Tidewater	Portland, OR	Pullman Std. Car Mfg. Co.
Lewis G. Seabrook	TG 74	110x11	3600	A	Marine Cont. & Tow.	Charleston, SC	Levinston Shipbuilding
Monawk	TG 43	136x15	3600	10 C	Crowley Maritime Corp.	Seattle, WA	Brown Shipbuilding Co.
Peter W.	TG 45	138x 8	3600	12 A	Brusco Towboat Co.	Longview, WA	Halter Marine Services, Inc.
Rosalie G.	SU 78	186x	3600	12 A	Oil & Gas Rental	Morgan City, LA	Halter Marine Services, Inc.
TBN	SU 78	180x12	3600	15 A	Otto Candies, Inc.		Halter Marine Services, Inc.
TBN	SU 78	180x12	3600	15 A	Otto Candies, Inc.		Halter Marine Services, Inc.
TBN	SU 78	180x12	3600	15 A	Otto Candies, Inc.		Halter Marine Services, Inc.
Yard No. 524	SU 78	180x12	3600	15 A	Otto Candies, Inc.		Burton Shipyards
Yard No. 525	SU 78	180x12	3600	15 A	Otto Candies, Inc.		Modern Marine Power, Inc.
Claron	SU 78	180x12	3600	15 A	Otto Candies, Inc.		Quality Equipment Inc.
Gulf Fleet No. 26	TS 76	167x14	3520	12 A	Andre Ledeaux, Inc.	New Orleans, LA	Deimar Systems, Inc.
J. A. Belcher, Sr.	TG 77	103x13	3520	13 B	Belcher Towing Co.	Miami, FL	Modern Marine Power, Inc.
J. A. Orgeron	TG 77	103x13	3520	12 A	Belcher Towing Co.	Houma, LA	Quality Equipment Inc.
Paul L. E. Helliwell	TG 77	105x13	3520	12 A	Belcher Towing Co.	Port Manatee, FL	Deimar Systems, Inc.
Salem	TG 77	105x13	3520	12 A	Belcher Towing Co.	Baton Rouge, LA	Quality Equipment Inc.
TBN	TS 76	161x13	3520	13 A	Seafarer Corp.	Houston, TX	Todd Galy
Kerry Moran	TG 63	101x16	3514	B	Bludco Barge & Towing	Wilmington, DE	Jakobson Shipyard, Inc.
Patricia Moran	TG 62	101x16	3514	B	Moran Towing & Trans.	Wilmington, DE	Jakobson Shipyard, Inc.
Gulf Challenger	TG 69	121x13	3500	13 A	Moran Towing & Trans.	New Orleans, LA	Burton Shipyards
Gulf Fleet No. 8	TS 74	185x13	3500	13 A	Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.
Gulf Fleet No. 9	TS 74	185x12	3500	13 A	Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.
Gulf Fleet No. 30	SU 74	167x13	3500	13 A	Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.
L. A. C-geron	TG 76	105x14	3450	12 A	Montco, Inc.	Houma, LA	Modern Marine Power, Inc.
Stonington	SU 76	161x13	3450	13 B	Seafarer Corp.	Baton Rouge, LA	Wall Shipyard
Big Bill	TG 65	122x17	3400	B	Stewart Trans.	Piney Point, MD	Wiley Manufacturing
Crusader	TG 67	106x13	3400	A	Interstate & Ocean	Wilmington, DE	Main Iron Works, Inc.
Marta	TG 65	112x17	3400	10 B	G & H Towing	Galveston, TX	Southern Shipbuilding Co.
Marta	66	110x17	3400	B	Bulk Food Carriers	San Francisco, CA	
Mister Chip	TG 69	105x14	3400	13 B	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Mister Mike	TG 70	110x14	3400	13 A	Jackson Marine Corp.	Corpus Christi, TX	Halter Marine Services, Inc.
Pacific Titan	TG 77	92x10	3400	A	Pacific Far East Line	Long Beach, CA	PTB
Pacific Viking	TG 77	92x10	3400	A	Pacific Far East Line	Long Beach, CA	PTB
Robin III	TG 71	124x13	3400	12 A	Robin Towing	New Orleans, LA	McDermott Shipyards
Waldbeest	SU 73	175x11	3400	12 A	Primal Boat Co.	Morgan City, LA	Halter Marine Services, Inc.
Joel Robin	TG 69	105x14	3392	10 A	Robin Towing	New Orleans, LA	Halter Marine Services, Inc.
Miklona	TG 65	125x14	3334	10 C	Dillingham Tug & Barge	Honolulu, HI	Albina Engine & Machine Works
Annie Mae Candies	SU 72	163x12	3300	10 A	Otto Candies, Inc.	Houma, LA	Burton Shipyards
Aquamarine 101	TS 75	162x12	3280	14 B	Otto Candies, Inc.	Houston, TX	South Texas Shipyard
Cathleen E. Moran	TG 65	103x15	3280	B	Moran Towing & Trans.	Wilmington, DE	Diamond Manufacturing Co., Ltd.
Helen Moran	TG 65	103x15	3280	B	Moran Towing & Trans.	Wilmington, DE	Diamond Manufacturing Co., Ltd.
Kathrine Clevis	TG 64	112x17	3280	13 C	Gulfoast Transit Co.	Tampa, FL	Gulport Shipbuilding Corp.
Marianne McAllister	TG 66	115x15	3280	12 A	McAllister Brothers	Houma, LA	Avondale Shipyards

TUGS > 3000 HP

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Acadian Liberty	TS 75	142x12	3080	14	A	OTS	Acadian Marine Service	New Orleans, LA	Southern Shipbuilding Co.
Acadian Patriot	TS 75	169x12	3080	14	A	OTS	Acadian Marine Service	New Orleans, LA	Southern Shipbuilding Co.
Acadian Valor	TS 74	142x12	3080	14	A	OTS	Acadian Marine Service	Chicago, IL	Southern Shipbuilding Co.
Acadian Victory	SU 73	152x12	3080	15	A	OTS	Acadian Marine Service	Chicago, IL	Southern Shipbuilding Co.
Endeavor	TG 75	105x	3080	12	A	OTS	F & S Offshore Inc.	Wilmington, DE	Delmar Systems, Inc.
Enterprise	TG 75	105x12	3080	12	A	OTS	F & S Offshore Inc.	Wilmington, DE	Delmar Systems, Inc.
Lily M. Guidry	TG 73	107x13	3080	12	A	OTS	America Offshore Ltd.	Chicago, IL	Main Iron Works, Inc.
Northern Explorer	SU 75	166x12	3080	12	A	OTS	America Offshore Ltd.	Chicago, IL	Halter Marine Services, Inc.
Alaska Husky	SU 66	170x14	3060	12	C	OTS	Foss Launch & Tug	Seattle, WA	Todd Shipyards
Adriatic Seahorse	TS 74	167x13	3020	13	A	OTS	Seahorse, Inc.	Morgan City, LA	Quality Equipment Inc.
Aegean Seahorse	TS 74	167x13	3020	13	A	OTS	Seahorse, Inc.	Morgan City, LA	Quality Equipment Inc.
Ionian Seahorse	TS 74	167x13	3020	13	A	OTS	Seahorse, Inc.	Morgan City, LA	Quality Equipment Inc.
Timor Seahorse	TS 74	137x13	3020	13	A	OTS	Seahorse, Inc.	Morgan City, LA	Quality Equipment Inc.
Adele Cardies	SU 74	162x12	3200	13	A	OTS	Otto Candies, Inc.	Houma, LA	Equitable Equipment Co., Inc.
Agnes Foss	TG 70	114x13	3000	13	A	OTS	Foss Launch & Tug	Seattle, WA	McDermott Shipyards
Aleutian Command	SU 78	180x	3000	12	B	OTS	Aleutian Command Part.	Houma, LA	Quality Equipment Inc.
Amelia Candies	SU 74	162x12	3000	13	A	OTS	Otto Candies, Inc.	Houma, LA	Equitable Equipment Co., Inc.
Amy Moran	TG 73	101x14	3000	13	A	OTS	Moran Towing & Trans.	Wilmington, DE	McDermott Shipyards
Andrew McAllister	TG 67	108x15	3000	8	A	OTS	Port San Juan Towing	San Juan, PR	Barker Barge Lines
Ann Moran	TG 77	105x13	3000	13	A	OTS	Moran Towing & Trans.	Seattle, WA	McDermott Shipyards
Apache	TG 68	113x15	3000	13	A	OTS	Crowley Maritime Corp.	Seattle, WA	Halter Marine Services, Inc.
Black	TG 68	113x15	3000	13	A	OTS	Crowley Maritime Corp.	Seattle, WA	Halter Marine Services, Inc.
Blue Marlin	TS 77	164x12	3000	12	C	OTS	Garber Brothers	Morgan City, LA	Halter Marine Services, Inc.
Blue Wave	TS 77	154x12	3000	12	C	OTS	Garber Brothers	Morgan City, LA	Halter Marine Services, Inc.
Bretton Island	TS 76	185x12	3000	12	B	OTS	Arthur Levy Enterprises	New Orleans, LA	Halter Marine Services, Inc.
Brett Cardies	TS 76	185x12	3000	12	B	OTS	Arthur Levy Enterprises	New Orleans, LA	Halter Marine Services, Inc.
Burch Tide II	TG 72	100x13	3000	12	A	OTS	Otto Candies, Inc.	Houma, LA	Houma Welders, Inc.
Cape Charles	TS 74	165x12	3000	12	B	OTS	Tidewater	Morgan City, LA	Halter Marine Services, Inc.
Cape May	TG 72	92x13	3000	12	B	OTS	Tidewater	Boston, MA	Southern Shipbuilding Co.
Captain Bob I	TG 72	101x14	3000	12	B	OTS	Moran Towing & Trans.	Wilmington, DE	McDermott Shipyards
Captain Dunn	TG 73	101x14	3000	12	B	OTS	Moran Towing & Trans.	Wilmington, DE	McDermott Shipyards
Challenger	46	149x18	3000	12	A	OTS	Tidewater	Portland, OR	Quality Equipment Inc.
Champion	TG 76	116x14	3000	12	A	OTS	Dann Ocean Towing	Wilmington, DE	Zigler Shipyards, Inc.
Charleston	SU 70	170x13	3000	12	B	OTS	Offshore Logistics	Morgan City, LA	Zigler Shipyards, Inc.
Construct Tide	SU 70	170x13	3000	12	B	OTS	Offshore Logistics	Morgan City, LA	Zigler Shipyards, Inc.
Courageous	TS 78	185x12	3000	12	A	OTS	Catx Marine Corp.	New Orleans, LA	Halter Marine Services, Inc.
Daley Progress	SU 70	180x13	3000	11	B	OTS	Tidewater	Morgan City, LA	American Marine Corp.
Dixie Captain	SU 78	210x15	3000	12	C	OTS	Cont. IL Natl BK & Tt Chi	Chicago, IL	McDermott Shipyards
Dorothy Moran	TG 72	92x13	3000	12	A	OTS	Boston Tow Boat Co.	Boston, MA	McDermott Shipyards
Drew Foss	TS 78	103x	3000	12	A	OTS	Dixie Carriers, Inc.	Wilmington, DE	McDermott Shipyards
Endurance	TG 78	103x	3000	12	A	OTS	Dixie Carriers, Inc.	Wilmington, DE	McDermott Shipyards
Gasco Florida	TG 77	105x13	3000	13	A	OTS	Moran Towing & Trans.	Seattle, WA	McDermott Shipyards
	TG 77	120x14	3000	13	A	OTS	Foss Launch & Tug	Chicago, IL	McDermott Shipyards
	TG 78	210x15	3000	12	A	OTS	Offshore Logistics	Chicago, IL	McDermott Shipyards
	TG 69	109x15	3000	12	A	OTS	Gulf Atlantic Transport	Jacksonville, FL	Southern Shipbuilding Co.

TUGS > 3000 HP

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Gulf Fleet No. 20	TS 77	180x12	3000	12	B			Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.	
Gulf Fleet No. 21	TS 77	180x12	3000	12	B			Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.	
Gulf Fleet No. 29	SU 77	180x12	3000	12	B			Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.	
Gulf Fleet No. 31	SU 78	180x12	3000	13	A	OTS		Offshore Equipment Co.	New Orleans, LA	Quality Equipment Inc.	
Gulf Miss	TG 69	115x15	3000	13	A	OTS		Gulf Mississippi Marine	New Orleans, LA	Main Iron Works, Inc.	
Gulf Storm	TG 70	106x13	3000	13	A	OTS		Gulf Mississippi Marine	New Orleans, LA	Quality Equipment Inc.	
Gulf Whale	TG 77	116x14	3000	12	A	OTS		Seven Seas Towing	Houma, LA	Quality Equipment Inc.	
Cjs Tide	TS 74	168x12	3000	12	B	OTS		Tidewater	New Orleans, LA	American Marine Corp.	
Heritage	SU 78	210x15	3000	12	C			Cont IL Natl Bk & Tt Chl	Chicago, IL	McDermott Shipyards	
High Tide II	TS 74	165x12	3000	12	B	OTS		Tidewater	Morgan City, LA	Halter Marine Services, Inc.	
Hill Tide II	TS 74	165x12	3000	12	B	OTS		Tidewater	Morgan City, LA	Halter Marine Services, Inc.	
Hogue Tide	TS 74	165x12	3000	12	B	OTS		Tidewater	New Orleans, LA	American Marine Corp.	
Horvone	SU 77	169x12	3000	12	A	OTS		Oil & Gas Rental	Morgan City, LA	Halter Marine Services, Inc.	
IMT No. 1	TG 77	114x17	3000	10	A	OTS		Southern Leasing Part.	New Orleans, LA	Toche Enterprises, Inc.	
Inmar Count	TG 78	180x12	3000	12	B	OTS		First Inmar of Texas	New Orleans, LA	McDermott Shipyards	
Inmar Duke	TG 78	180x12	3000	12	B	OTS		First Inmar of Texas	New Orleans, LA	McDermott Shipyards	
Inmar Prince	TG 78	180x12	3000	12	B	OTS		First Inmar of Texas	New Orleans, LA	McDermott Shipyards	
Jarmac XVII	TG 71	113x13	3000	12	A	OTS		J. Ray McDermott	Morgan City, LA	McDermott Shipyards	
Jeffrey Foss	TG 70	114x13	3000	13	A	OTS		Foss Launch & Tug	Seattle, WA	McDermott Shipyards	
Juanita Patrick	TS 77	180x12	3000	12	B	OTS		Dapico Marine Corp.	New Orleans, LA	Quality Equipment Inc.	
Judy Moran	TG 73	101x11	3000	13	B	OTS		Moran Towing & Trans.	Wilmington, DE	McDermott Shipyards	
Kings Bishop	TG 76	121x11	3000	13				King's Marine Int'l.	New Orleans, LA	Rysco Shipyard, Inc.	
Kings Knight	TG 77	119x16	3000	12	A	OTS		King's Marine Int'l.	New Orleans, LA	Main Iron Works, Inc.	
La Madonna	TG 78	118x14	3000	10	A	OTS		Nautical Service, Inc.	Seattle, WA	McDermott Shipyards	
Leslie Foss	TG 70	114x11	3000	13	A	OTS		Foss Launch & Tug	Morgan City, LA	American Marine Corp.	
Lift Tide	SU 70	180x13	3000	12	B			Tidewater	New Orleans, LA	Toche Enterprises, Inc.	
Lombas Offshore No. 3	TG 78	114x16	3000	10	A	OTS		Lombas Offshore Marine	New Orleans, LA	Halter Marine Services, Inc.	
Long Island	TS 78	165x12	3000	12	B	OTS		Arthur Levy Enterprises	New Orleans, LA	McDermott Shipyards	
Luxe Z. Defelice	TG 71	114x13	3000	13	A	OTS		Defelice Marine Const.	New Orleans, LA	Main Iron Works, Inc.	
Mara	TG 76	118x15	3000	12	A	OTS		Dillingham Tug & Barge	Honolulu, HI	McDermott Shipyards	
Marcia Ann	SU 78	192x12	3000	12	B			Marcia Ann, Inc.	Morgan City, LA	McDermott Shipyards	
Mariner	TG 65	116x16	3000	13	B	OTS		Interstate & Ocean	Wilmington, DE	Main Iron Works, Inc.	
Mary Ann	SU 77	169x12	3000	12	A			Oil & Gas Rental	Morgan City, LA	Halter Marine Services, Inc.	
Mary Belcher	TG 75	89x12	3000	12	A			Belcher Towing Co.	Miami, FL	Atlantic Marine, Inc.	
Mary M. Coppedge	TG 75	96x14	3000	12	A	OTS		Florida Towing Corp.	Jacksonville, FL	McDermott Shipyards	
Mary Moran	TG 77	105x13	3000	8	A	OTS		Moran Towing & Trans.	Wilmington, DE	McDermott Shipyards	
Michael Turecamo	TG 78	105x14	3000	13	A	OTS		Vincent Turecamo, Inc.	Wilmington, DE	McDermott Shipyards	
Maara Holo	TG 77	120x14	3000	13	A	OTS		Dillingham Tug & Barge	Honolulu, HI	McDermott Shipyards	
Maara 1	TG 71	100x12	3000	13	A	OTS		Mobil Oil Corp.	New York, NY	Mattson Shipyard Co., Inc.	
Mobil 2	TG 71	100x12	3000	13	A	OTS		Mobil Oil Corp.	New York, NY	Mattson Shipyard Co., Inc.	
Mobil 3	TG 71	100x12	3000	13	A	OTS		Mobil Oil Corp.	New York, NY	Mattson Shipyard Co., Inc.	
Mustang Island	TS 78	169x12	3000	12	B	OTS		Arthur Levy Enterprises	New Orleans, LA	Halter Marine Services, Inc.	
P. E. Foote	SU 70	166x12	3000	14	A			Seahorse, Inc.	New Orleans, LA	Burton Shipyards	
Phillips Foss	TG 69	114x13	3000	13	A	OTS		Foss Launch & Tug	Seattle, WA	McDermott Shipyards	
Point Burrow	TS 78	185x12	3000	12	B	OTS		Point Marine, Inc.	Morgan City, LA	Halter Marine Services, Inc.	

TUGS > 3000 HP

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Point Conception	TS 76 169x12	3000 12 A	OTS	Point Marine, Inc.	Morgan City, LA	Halter Marine Services, Inc.
Point Dover	TS 78 185x12	3000 12 B	OTS	Point Marine, Inc.	Morgan City, LA	Halter Marine Services, Inc.
Point Success	TS 76 169x12	3000 12 B	OTS	Point Marine, Inc.	Morgan City, LA	Halter Marine Services, Inc.
Reliance	TC 74 96x12	3000 12 B	OTS	Providence Steamboat Co.	Providence, RI	Jacobson Shipyard, Inc.
San Jose Island	TC 75 96x12	3000 12 B	OTS	Providence Steamboat Co.	Providence, RI	Halter Marine Services, Inc.
Savannah	TS 77 185x12	3000 12 B	OTS	Arthur Levy Enterprises	New Orleans, LA	Halter Marine Services, Inc.
Seminole	TS 78 185x12	3000 12 A	OTS	Atlantic Towing Co.	Houma, LA	Halter Marine Services, Inc.
Sidney Foss	TC 68 113x15	3000 13 A	OTS	Crowley Maritime Corp.	Seattle, WA	McIntosh Shipyards
State Courage	TC 76 120x14	3000 13 A	OTS	Foss Launch & Tug	Seattle, WA	Bour & Dry Dock & Svc. Co.
State Justice	SU 77 195x14	3000 14 B		State Boat Corp.	Wilmington, DE	Bour & Dry Dock & Svc. Co.
Sybil Freeman	SU 78 195x13	3000 14 B		State Boat Corp.	Wilmington, DE	Quality Equipment Inc.
TBN	TS 77 160x	3000 12 B	OTS	Danco Marine Corp.	New Orleans, LA	American Gulf S. B.
TBN	TC 77 121x	3000		Libbeigh Crosby	Marrero, LA	Zikler
TBN	TC 77 110x	3000		Domar Ocean Trans.	Morgan City, LA	Quality Equipment
TBN	TC 77 116x	3000		Gulf Mississippi Marine	New Orleans, LA	Quality Equipment
TUN	TC 77 116x	3000		King's Marine Int'l.	Gretna, LA	Toche
TUN	TC 77 121x	3000		Louisiana Int'l Marine	Gretna, LA	Main Iron Works, Inc.
TBN	TC 77 118x	3000		Seasort, Inc.	Morgan City, LA	Burton Shipyards
J. G. Girder	SU 71 160x12	3000 16 A		Oil & Gas Rental	New York, NY	Halter Marine Services, Inc.
Ivonne	SU 77 169x12	3000 12 A		Acadian Marine Service	Morgan City, LA	Halter Marine Services, Inc.
Acadian TBN	TS 78 216x13	3000 13 A		Garber Brothers	Morgan City, LA	Halter Marine Services, Inc.
Blue Whale	TS 77 164x12	3000 13 C				

APPENDIX D

DROP-AND-SWAP COMPUTER MODEL:
FORMULATION AND ASSUMPTIONS

APPENDIX D

DROP-AND-SWAP COMPUTER MODEL: FORMULATION AND ASSUMPTIONS*

D.1 Model Formulation

The drop-and-swap computer model has been developed to make an economic comparison of the operation of push-towed ocean going tug-barge combinations in the drop-and-swap versus integral modes. As shown in the model formulation summary in Figure D.1, the model makes this comparison by determining for both modes the number of tugs and barges and the barge speed, size (DWT), and form (block coefficient--Cb, length-breadth ratio--L/B, breadth-draft ratio--B/T) that results in the minimum required freight rate for cargo transported on a port pair trade. (2) This is subject to the conditions that the system has sufficient ton-mile capacity to carry the annual cargo flows and sufficient number of terminal facilities at each port to handle the annual port throughput.

The objective function, the required freight rate (rfr), is equal to the system capital costs (tugs, barges, terminal and storage facilities) divided by a present value factor (3) plus system annual operating costs (fuel costs, crewing costs, storage and terminal costs, etc.) all divided by the annual cargo flows. As shown in Figure D.2, these capital and operating costs are nonlinear functions of the port pair trade parameters--port separation distance, terminal facility loading/discharging rates, and annual cargo flows--as well as the five continuous and three integral system variables--Barge DWT, Speed, Cb, L/B, B/T; Number of Tugs, Number of Barges--Port 1, and Number of Barges--Port 2.

*In this appendix computer program variables are enclosed in quotation marks. Their definition should be understood from context. If there is question about their meaning, detailed definitions are provided in Section D.5

(2) See Figure 2.1 and Section 2.2 for the definition of a port pair trade.

(3) The present value factor apportions the capital costs on an annual basis. It is a function of the capital's pre-tax discount rate or rate of return and the economic life of the system.

Objective Function:

Minimize (Required Freight Rate)

For a port pair trade defined by:

- (1) Port separation distance
- (2) Terminal facilities loading/discharging rates
- (3) Required annual cargo flows

Capacity Constraints:

$$\left\{ \begin{array}{l} \text{Ton-mile:} \\ (\text{No. Tugs}) \times (\text{Barge DWT}) \times \left(\frac{\text{No. Voyages}}{\text{Tug-Year}} \right) \geq (\text{Required Annual Cargo Flows}) \\ \\ \text{Terminal Facility:} \\ (\text{No. Facilities per Port}) \times \left(\frac{\text{Annual Thruput}}{\text{per Facility}} \right) \geq \left(\begin{array}{l} \text{Required Annual} \\ \text{Cargo flows} \\ \text{Through Port} \end{array} \right) \end{array} \right\}$$

Continuity Constraint:

$$(\text{No. Barges}) = (\text{No. Tugs}) + (\text{No. Barges-Port 1}) + (\text{No. Barges-Port 2})$$

Parameter Boundary Constraints:

$$\begin{array}{llll} \text{mindwt} & \leq & \text{Barge DWT} & \leq \text{maxdwt} \\ \text{minspeed} & \leq & \text{Tug-Barge Speed} & \leq \text{maxspeed} \\ \text{mincb} & \leq & \text{Barge } C_B & \leq \text{maxcb} \\ \text{minlb} & \leq & \text{Tug-Barge L/B} & \leq \text{maxlb} \\ \text{minbt} & \leq & \text{Barge B/T} & \leq \text{maxbt} \end{array}$$

Integrality Conditions

$$\left\{ \begin{array}{l} \text{No. Tugs} \\ \text{No. Barges - port 1} \\ \text{No. Barges - Port 2} \end{array} \right\} \text{ integer}$$

Figure D.1

Model Formulation

$$\text{Required Freight Rate} = \frac{\left\{ \begin{array}{l} \text{Capital Costs} \\ \text{PWF} + \text{Annual Operating Costs} \end{array} \right\}}{\text{Annual Cargo Flows}}$$

Capital Costs = (No. Barges) x (Barge Cost) + (No. Tugs) x (Tug Cost)
 + (Terminal Costs) + (Storage Costs)

{

 Barge Cost = f{Barge DWT, L/B, B/T, C_B}

 Tug Cost = f{Installed Horse power (IP)}

 IHP = f{Barge DWT, L/B, B/T, C_B, Tug-Barge Speed}

 Terminal Cost = f{Terminal Loading/Discharging Rates}

 Storage Cost = f{Barge DWT}
 }

Annual Operating Costs = Fuel Costs + Terminal Costs
 + Storage Costs + M&R Costs
 + Crewing and Subsistence Costs
 + Insurance Costs + Administrative Costs

Fuel Costs = Seetime x (Sea Fuel Consumption Rates)
 + Port time x (Port Fuel Consumption Rate)

{

 Seetime = f($\frac{\text{Port Separation Distance}}{\text{Tug-Barge Speed}}$)

 Port Time = f($\frac{\text{Barge DWT}}{\text{Terminal Facility L/D Rate}}$)

 Sea Fuel Consumption Rate = f($\frac{\text{Barge DWT, L/B, B/T}}{\text{Block Coefficient; Tug-Barge Speed}}$)

 Port Fuel Consumption Rate = f(Hotel Load) = constant
 }

Terminal Costs = f(Annual Cargo Flows)

Storage Costs = f(Annual Cargo Flows)

{

 Maintenance and Repair Costs

 Supplies and Equipment Costs

 Insurance Costs
 } = f(Barge DWT, Tug IHP)

{

 Crew Wages and Benefits

 Crew Subsistence
 } = f(crew size) = constant

Administrative Costs = constant

Figure D.2

Definition of Required Freight Rate

Since the last three variables must be integral, this makes the model's form a mixed-integer non-linear program. Programs of this type are not amenable for solution by optimization techniques. If they can be solved at all, it is usually by some sophisticated specialized technique that transforms the model to one that is easier to solve but with many more variables. Rather than taking this approach, I decided to use the brute force method of exhaustive enumeration because it is the simplest to program and because it provides good results at reasonable cost when the ranges of the variables to be considered are chosen judiciously. With this approach, I calculated for each port pair trade and for both modes of operation the required freight rate for all possible combinations of the discretized values (4) of the five continuous system variables. Given a specific combination of these variables, the capacity and continuity constraints determine the values of the three integer variables.

Since I used discretized values for the continuous variables, the minimum required freight rate found will most likely not be the true minimum. However, since the objective function was found to very flat near the optimum, the rfr found will be close to the true minimum even if rather large increments for the variables are used. And, of course, a more accurate estimate of the true minimum rfr can be obtained by using smaller increments, although the cost will probably not warrant the additional accuracy achieved.

Prior to proceeding to a discussion of the computer model's logic and assumptions in the next section, mention should be made of the parametric ranges of the system variables for which the model will produce valid results. These ranges, which are governed by the valid ranges of the formulae used in the model, are provided in summary form in Table 2.4.

D.2 Summary of Program Logic

A summary of the logic of the drop-and-swap computer program is shown in flow chart form in Figure D.3. A brief discussion of the overall logic in this section will be followed by a detailed discussion of each step in the next section.

The program begins by asking the user to specify the port pair trades to be considered as well as the parametric ranges and increments of the five continuous system variables. It then asks

(4) To limit the number of combinations to a finite and reasonable number, it was necessary to discretize these continuous variables by dividing their parametric ranges into equally spaced increments. The number of increments can vary from two to fifteen depending on the sensitivity of objective function to changes in the variable.

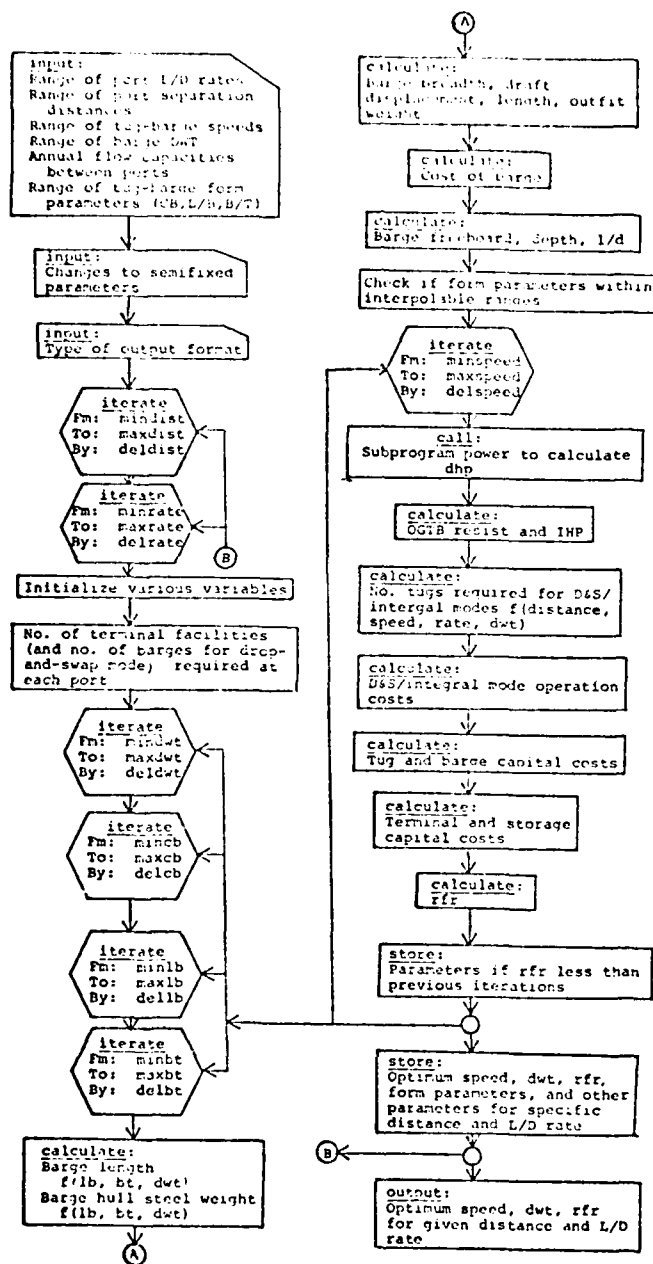


Figure D.3
Summary Flowchart for Drop-And-Swap
Computer Model

the user to specify whether he wishes to change any of the semi-fixed parameters that are used in the cost calculations. Following this, it asks the user to specify what form he wants the output. The program then begins the cost calculations for a specific port pair trade iteration defined by port separation distance and terminal loading/discharging rates. Given these port pair trade parameters, the model determines the number of terminal facilities with the specified loading/discharging rate (and the number of barges for the drop-and-swap mode) that are required at each port.

Then the program selects the next iterative values for the four barge size and form system variables--Barge DWT, Cb, L/B, and B/T. Given these values, it calculates the barge length, hull steel weight, cost, and the tug and barge principal dimensions. The program then checks to see if these system variables are feasible in that they fit within the interpolation table ranges for the tug-barge residual resistance coefficients. If not, the program skips to the next iteration of the four barge size and form variables. If so, the program selects the next iterative value of tug-barge speed and calculates the horsepower required to be delivered to the propeller of the tug, the tug-barge resistance, and finally the horsepower of the engine required to be installed onboard the tug. Given these values, the cost of the tug is calculated and then the number of tugs required to provide sufficient transport capacity for both drop-and-swap and integral modes. Then the operating costs and the total capital costs are determined for both modes. From these the rfr can be determined. If the rfr is less than that calculated during previous iterations of the five continuous system variables, it is saved; otherwise, it is ignored. After all iterations of the variables are examined, the minimum rfr found is stored for that port pair trade. After all of the port pair trades are examined the program can present the results in various graphical forms.

D.3 Drop-and-Swap Program Detailed Logic and Assumptions

The detailed logic and assumptions used in the drop-and-swap program are shown in flowchart form in Section D.4. It will be useful to refer to these flowcharts in the discussions to follow.

D.3.1 Input of Port Pair Trade and System Variables (Refer to Figure D.4)

After typing the execution command "drop_and_swap", the program reads from tape into memory the values of the loadline factor, residual resistance coefficient, self-propulsion factor, and propeller design coefficient arrays. The program then asks the user to "input via list format the following parameters:". (To input via list format, the user types in the value of the

drop_and_swap

Input via list format the following parameters:

Do you wish to specify individual port L-D rates?: no

minrate, maxrate, delrate: 2000.,14000.,2000.,

mindist, maxdist, deldist: 500.,5000.,1500.,

minspeed, maxspeed, delspeed: 6.,13.,1.,

mindwt, maxdwt, deldwt: 5000.,100000.,5000.,

aflowave1, aflowave2: 1000000.,0.,

mincb, maxcb, delcb: .75,.83,.01,

minlb, maxlb, dellb: 6.,6.4,.2,

minbt, maxbt, delbt: 2.,3.,.5,

input changes to semifixed data via get data format maxt1=38., maxt2=38.;

Do you want printed output?: y

Do you want detailed output?: y

Figure D.4

Sample Input for the Drop-And-Swap Model

requested parameter followed by a comma.) The first request is a question on the desired form of the terminal facility loading/discharging rates: "Do you wish to specify individual L-D rates?". If the user answers negatively ("no", "n", or "0"), then the program requests values for "minrate, maxrate, delrate". This is a request for a range of loading/discharging rates in tons per day per terminal facility to be investigated, from "minrate" to "maxrate" in "delrate" increments. It is assumed that the loading and unloading rates at both terminals will be the same ("rload1"="runload1"="rload2"="runload2"). Also, if "delrate" is set to zero, then a "delrate" equal to 1000 is assumed. If, on the other hand, the user answers affirmatively ("yes", "y", or "1") to the loading/discharging rate question, then the program requests values for "rload1, runload1, rload2, runload2". This is a request for a specific set of terminal facility loading and discharging rates for each port. In either case, any set of loading/discharging rates may be specified.

Now the program continues with a request for the values of "mindist, maxdist, deldist". This is a request for a range of port separation distances in nautical miles to be considered from "mindist" to "maxdist" by "deldist" increments. If "deldist" of zero is inputted, then a "deldist" of 1000 nautical miles is assumed. Any set of port separation distances may be considered.

Next the program requests values for "minspeed, maxspeed, delspeed". This is a request for a range of tug-barge speeds in knots to be considered from "minspeed" to "maxspeed" by "delspeed" increments. If "delspeed" of zero is inputted, then a "delspeed" of 1.0 knot is assumed. Any set of speeds can be considered. However, a minimum speed of six knots and a maximum of twelve or thirteen knots will usually cover the optimum speed range and will not exceed the boundary restrictions for Froude number and LHP shown in Table 2.4.

Next the program requests values of "mindwt, maxdwt, deldwt". This is a request for a range of barge cargo deadweights in long tons (LT) to be considered from "mindwt" to "maxdwt" by "deldwt" increments. If "deldwt" of zero is inputted, then a "deldwt" of 5000 LT is assumed. Any set of deadweights from 5000 to 80,000 LT can be used.

Next the program requests values for "aflowave1, aflowave2". This is a request for the annual average cargo flows in long tons from Port 1 to Port 2 and from Port 2 to Port 1, respectively. Any pair of values can be specified, except that "aflowave1" must be greater than or equal to "aflowave2". For example, if a one way trade is desired, then "aflowave2" is set to zero.

Next the program requests values for the three barge form variables, "mincb, maxcb, delcb", "minlb, maxlb, dellb", and "minbt, maxbt, delbt". These three requests are for the ranges

of the barge block coefficient (C_b), tug-barge length-breadth ratio (L/B), and barge breadth-draft ratio (B/T) to be considered from "mincb", "minlb", "mintb" to "maxcb", "maxlb", "maxbt" by "delcb", "dellb", "delbt" increments, respectively. If "delcb", "dellb", or "delbt" of zero is inputted, then a value of 0.1, 0.2, or 0.1 is assumed, respectively. The valid ranges for these form parameters are given in Table 2.4. If the user does not input values within these ranges (including the reduced confidence ranges) then the program will ask the user to specify a new set of form parameter ranges. After the program has accepted the form parameter ranges, input of the system variable and port pair trade ranges to be considered has been completed.

D.3.2 Input and Modification of Semi-Fixed Parameters (Refer to Figure D.4)

Now the program outputs the statement, "Input changes to semifixed data via get data format". This is a request to the user to make any modifications to the semif-fixed parametric data that is used in the required freight rate calculations. The base case values of these parameters that are read from tape into memory are shown in Figure 2.2. Definitions of these parameters can be found in Section D.5. The user may modify the value of any of these semi-fixed parameters by simply typing the parameter name followed by an equal sign and then followed by the desired parameter value. Each parameter that is modified should be separated by a comma and the final one should be followed by a semicolon.

D.3.3 Selection of Output Format

Next the program asks the user to specify what type of format he desires for the program output. Specifically, it asks, "Do you want printed output?:". If the user answers in the affirmative, the program responds, "Do you want detailed output?:". If the user answers this question in the affirmative, the program will print out a line of output for every single iteration with respect to port pair trade and system variables. An example of this output for the input case shown in Figure D.4 is shown in Figure D.5. If the user answers negatively to the detailed output question, the program will print the system data associated with the iteration that resulted in the minimum required freight rate for both modes (drop-and-swap, then integral) for each port pair trade considered. An example of this output for the input case shown in Figure D.4 is shown in Figure D.6.

On the other hand, if the user answers negatively to the question about printed output, or after the program has completed printing output, the program will ask, "Do you wish graphic output?". If the user answers negatively, the program will start from the beginning, asking for a new set of inputs. Otherwise,

LT	SPD	RFR	CB	BLNGTH	L/R	B/T	L/D	A'OST	CTUG	CHARGE	IMP	NO	TUG/ITB	NRTRIPS	SEATIMET	PORTIMET	AFLOWCAP	T-ALTY/VS
(1000)(KTS)	(S)	(S)						(\$M)	(\$M)	(\$M)					(DAYS)	(DAYS)	(DAYS)	(DAYS)
5	6.0	16.18	0.78	200.9	6.00	2.00	7.0	14.180	5.041	1.194	516	5		44.06	7.94	0.00	220281	0.00
5	6.0	16.43	0.73	200.9	6.00	2.00	7.0	16.511	5.041	1.194	516	6		33.51	7.94	0.00	220281	0.00
5	6.0	16.68	0.68	200.9	6.00	2.00	7.0	18.882	5.041	1.194	516	7		28.51	7.94	0.00	220281	0.00
5	6.0	16.93	0.63	200.9	6.00	2.00	7.0	21.253	5.041	1.194	516	8		23.51	7.94	0.00	220281	0.00
5	6.0	17.18	0.58	200.9	6.00	2.00	7.0	23.624	5.041	1.194	516	9		18.51	7.94	0.00	220281	0.00
5	6.0	17.43	0.53	200.9	6.00	2.00	7.0	25.995	5.041	1.194	516	10		13.51	7.94	0.00	220281	0.00
5	6.0	17.68	0.48	200.9	6.00	2.00	7.0	28.366	5.041	1.194	516	11		8.51	7.94	0.00	220281	0.00
5	6.0	17.93	0.43	200.9	6.00	2.00	7.0	30.737	5.041	1.194	516	12		3.51	7.94	0.00	220281	0.00
5	6.0	18.18	0.38	200.9	6.00	2.00	7.0	33.108	5.041	1.194	516	13		0.00	7.94	0.00	220281	0.00
5	6.0	18.43	0.33	200.9	6.00	2.00	7.0	35.479	5.041	1.194	516	14		0.00	7.94	0.00	220281	0.00
5	6.0	18.68	0.28	200.9	6.00	2.00	7.0	37.850	5.041	1.194	516	15		0.00	7.94	0.00	220281	0.00
5	6.0	18.93	0.23	200.9	6.00	2.00	7.0	40.221	5.041	1.194	516	16		0.00	7.94	0.00	220281	0.00
5	6.0	19.18	0.18	200.9	6.00	2.00	7.0	42.592	5.041	1.194	516	17		0.00	7.94	0.00	220281	0.00
5	6.0	19.43	0.13	200.9	6.00	2.00	7.0	44.963	5.041	1.194	516	18		0.00	7.94	0.00	220281	0.00
5	6.0	19.68	0.08	200.9	6.00	2.00	7.0	47.334	5.041	1.194	516	19		0.00	7.94	0.00	220281	0.00
5	6.0	19.93	0.03	200.9	6.00	2.00	7.0	49.705	5.041	1.194	516	20		0.00	7.94	0.00	220281	0.00
5	6.0	20.18	0.00	200.9	6.00	2.00	7.0	52.076	5.041	1.194	516	21		0.00	7.94	0.00	220281	0.00
5	6.0	20.43	0.00	200.9	6.00	2.00	7.0	54.447	5.041	1.194	516	22		0.00	7.94	0.00	220281	0.00
5	6.0	20.68	0.00	200.9	6.00	2.00	7.0	56.818	5.041	1.194	516	23		0.00	7.94	0.00	220281	0.00
5	6.0	20.93	0.00	200.9	6.00	2.00	7.0	59.189	5.041	1.194	516	24		0.00	7.94	0.00	220281	0.00
5	6.0	21.18	0.00	200.9	6.00	2.00	7.0	61.560	5.041	1.194	516	25		0.00	7.94	0.00	220281	0.00
5	6.0	21.43	0.00	200.9	6.00	2.00	7.0	63.931	5.041	1.194	516	26		0.00	7.94	0.00	220281	0.00
5	6.0	21.68	0.00	200.9	6.00	2.00	7.0	66.302	5.041	1.194	516	27		0.00	7.94	0.00	220281	0.00
5	6.0	21.93	0.00	200.9	6.00	2.00	7.0	68.673	5.041	1.194	516	28		0.00	7.94	0.00	220281	0.00
5	6.0	22.18	0.00	200.9	6.00	2.00	7.0	71.044	5.041	1.194	516	29		0.00	7.94	0.00	220281	0.00
5	6.0	22.43	0.00	200.9	6.00	2.00	7.0	73.415	5.041	1.194	516	30		0.00	7.94	0.00	220281	0.00
5	6.0	22.68	0.00	200.9	6.00	2.00	7.0	75.786	5.041	1.194	516	31		0.00	7.94	0.00	220281	0.00
5	6.0	22.93	0.00	200.9	6.00	2.00	7.0	78.157	5.041	1.194	516	32		0.00	7.94	0.00	220281	0.00
5	6.0	23.18	0.00	200.9	6.00	2.00	7.0	80.528	5.041	1.194	516	33		0.00	7.94	0.00	220281	0.00
5	6.0	23.43	0.00	200.9	6.00	2.00	7.0	82.899	5.041	1.194	516	34		0.00	7.94	0.00	220281	0.00
5	6.0	23.68	0.00	200.9	6.00	2.00	7.0	85.270	5.041	1.194	516	35		0.00	7.94	0.00	220281	0.00
5	6.0	23.93	0.00	200.9	6.00	2.00	7.0	87.641	5.041	1.194	516	36		0.00	7.94	0.00	220281	0.00
5	6.0	24.18	0.00	200.9	6.00	2.00	7.0	90.012	5.041	1.194	516	37		0.00	7.94	0.00	220281	0.00
5	6.0	24.43	0.00	200.9	6.00	2.00	7.0	92.383	5.041	1.194	516	38		0.00	7.94	0.00	220281	0.00
5	6.0	24.68	0.00	200.9	6.00	2.00	7.0	94.754	5.041	1.194	516	39		0.00	7.94	0.00	220281	0.00
5	6.0	24.93	0.00	200.9	6.00	2.00	7.0	97.125	5.041	1.194	516	40		0.00	7.94	0.00	220281	0.00
5	6.0	25.18	0.00	200.9	6.00	2.00	7.0	99.496	5.041	1.194	516	41		0.00	7.94	0.00	220281	0.00
5	6.0	25.43	0.00	200.9	6.00	2.00	7.0	101.867	5.041	1.194	516	42		0.00	7.94	0.00	220281	0.00
5	6.0	25.68	0.00	200.9	6.00	2.00	7.0	104.238	5.041	1.194	516	43		0.00	7.94	0.00	220281	0.00
5	6.0	25.93	0.00	200.9	6.00	2.00	7.0	106.609	5.041	1.194	516	44		0.00	7.94	0.00	220281	0.00
5	6.0	26.18	0.00	200.9	6.00	2.00	7.0	108.980	5.041	1.194	516	45		0.00	7.94	0.00	220281	0.00
5	6.0	26.43	0.00	200.9	6.00	2.00	7.0	111.351	5.041	1.194	516	46		0.00	7.94	0.00	220281	0.00
5	6.0	26.68	0.00	200.9	6.00	2.00	7.0	113.722	5.041	1.194	516	47		0.00	7.94	0.00	220281	0.00
5	6.0	26.93	0.00	200.9	6.00	2.00	7.0	116.093	5.041	1.194	516	48		0.00	7.94	0.00	220281	0.00
5	6.0	27.18	0.00	200.9	6.00	2.00	7.0	118.464	5.041	1.194	516	49		0.00	7.94	0.00	220281	0.00
5	6.0	27.43	0.00	200.9	6.00	2.00	7.0	120.835	5.041	1.194	516	50		0.00	7.94	0.00	220281	0.00

DWT	SPD	RFR	CB	BLNGTH	L/B	B/T	L/D	ACOST	CTUG	CHARGE	IHP	NO	TUG/ITB	NRTRIPS	SEATIMET	PORTIMET	AFLOWCAP	T-ALTY/VS
(1000)(KTS)	(S)	(S)						(\$M)	(\$M)	(\$M)					(DAYS)	(DAYS)	(DAYS)	(DAYS)
5	6.0	16.18	0.78	222.6	6.00	2.50	8.9	14.300	5.014	1.315	502	5		44.06	7.94	0.00	220281	0.00
5	6.0	16.43	0.73	222.6	6.00	2.50	8.9	16.671	5.014	1.315	502	6		33.51	7.94	0.00	162653	0.00
5	6.0	16.68	0.68	222.6	6.00	2.50	8.9	19.042	5.014	1.315	502	7		28.51	7.98	0.00	263112	0.00
5	7.0	17.93	0.78	222.6	6.00	2.50	8.9	17.580	6.095	1.315	831	6		37.03	6.95	2.00	156533	0.00
5	7.0	17.93	0.78	222.6	6.00	2.50	8.9	17.580	6.095	1.315	831	7		37.03	6.99	2.00	156533	0.00
5	8.0	19.18	0.78	222.6	6.00	2.50	8.9	17.373	6.320	1.315	1262	4		40.38	6.21	2.50	233172	0.00
5	8.0	19.18	0.78	222.6	6.00	2.50	8.9	17.373	6.320	1.315	1262	5		40.38	6.21	2.50	233172	0.00
5	8.0	19.43	0.73	222.6	6.00	2.50	8.9	19.695	6.320	1.315	1262	4		40.38	6.21	2.50	233172	0.00
5	8.0	19.43	0.73	222.6	6.00	2.50	8.9	19.695	6.320	1.315	1262	5		40.38	6.21	2.50	233172	0.00
5	9.0	21.98	0.78	222.6	6.00	2.50	8.9	21.661	6.659	1.315	1293	7		33.20	5.54	5.00	161145	0.00
5	9.0	21.98	0.78	222.6	6.00	2.50	8.9	21.661	6.659	1.315	1293	7		33.20	5.54	5.00	161145	0.00
5	9.0	21.98	0.78	222.6	6.00	2.50	8.9	21.661	6.659	1.315	1293	7		33.20	5.54	5.00	161145	0.00
5	9.0	21.98	0.78	222.6	6.00	2.50	8.9	21.661	6.659	1.315	1293	7		33.20	5.54	5.00	161145	0.00
5	10.0	24.54	0.73	222.6	6.00	2.50	8.9	15.242	6.659	1.315	1033	5		67.17	5.63	2.50	215422	0.00
5	10.0	24.54	0.73	222.6	6.00	2.50	8.9	15.242	6.659	1.315	1033	5		67.17	5.63	2.50	215422	0.00
5	10.0	24.54	0.73	222.6	6.00	2.50	8.9	15.242	6.659	1.315	1033	5		67.17	5.63	2.50	215422	0.00
5	10.0	24.54	0.73	222.6	6.00	2.50	8.9	15.242	6.659	1.315	1033	5		67.17	5.63	2.50	215422	0.00
5	10.0	24.54	0.73	222.6	6.00	2.50	8.9	15.242	6.659	1.315	1033	5		67.17	5.63	2.50	215422	0.00
5	10.0	24.54	0.73	222.6	6.00	2.50	8.9	15.242	6.659	1.315	1033	5		67.17	5.63	2.50	215422	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
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5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
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5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
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5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
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5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	2626	3		35.84	4.50	5.00	338113	0.00
5	11.0	19.42	0.78	222.6	6.00	2.50	8.9	19.426	7.095	1.315	262							


```

attnave1 = 1000000 minrate = 2000 mindist = 500 minspeed = 6.00 mindwt = 5.00
attnave2 = 0 maxrate = 10000 maxdist = 5000 maxspeed = 13.00 maxdwt = 100000
delrate = 2000 deldist = 1500 delspeed = 1.00 deldwt = 5000

max1 = 999.00 tugdays = 350 servmargin = 0.20 csteelt = 2.94 cstealb = 1.10
max2 = 999.00 bargdays = 350 fuelmargin = 0.20 couflit = 15.08 couflib = 1.80
max3 = 38.00 tank = 4 sfu = 0.36 cwages = 65000.00 cfixport1 = 0.00
max4 = 38.00 tunlink = 4 cfuel = 100.00 csubs = 35000.00 cfixport2 = 0.00
max5 = 100.00 delays = 4 clube = 1.75 mrcrow = 16.00 cvarport1 = 0.00
max6 = delays = 4 vdrago = 100.00 cvarport2 = 0.00

actner = 30000.00 disrate = 0.10 mincb = 0.75 minlb = 6.0 minbt = 2.0 cvarstor = 0.00
amin = 150000.00 econlife = 20.00 maxcb = 0.83 maxlb = 6.4 maxbt = 3.0 cfixstor = 0.00
pvf = 8.51 delcb = 0.01 dellb = 0.2 delbt = 0.5 cvarterm = 0.00
inflactr = 0.00

Cat SPD RFR CB BLENGTH L/B B/T L/D ACOST CTUG CBARGE IHP NO TUG/ITB NRTRIPS SEATIME PORTIME AFLOWCAP TACT1/2
(1000)(KTS) ($)

rate = 2000
distance = 500 minbargel = 2 minbargel2 = 2 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
15 10.0 5.65 0.78 316.9 6.00 2.00 7.6 6.852 7.839 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
25 3.0 13.84 0.81 312.1 6.00 2.00 7.6 13.638 5.841 4.193 2273 4 17.00 5.54 15.00 255575 73

rate = 4000
distance = 500 minbargel = 1 minbargel2 = 1 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
15 10.0 5.65 0.78 316.9 6.00 2.00 7.6 5.645 7.839 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
25 3.0 8.78 0.78 426.1 6.00 2.50 9.8 8.779 8.009 4.513 4476 2 20.04 4.96 12.50 501063 70

rate = 6000
distance = 500 minbargel = 1 minbargel2 = 1 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
15 10.0 5.65 0.78 316.9 6.00 2.00 7.6 5.645 7.839 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
25 6.0 7.23 0.81 349.8 6.00 2.00 7.7 7.230 6.212 5.611 1051 2 25.10 7.28 6.67 501992 40

rate = 8000
distance = 500 minbargel = 1 minbargel2 = 1 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
15 10.0 5.65 0.78 316.9 6.00 2.00 7.6 5.645 7.839 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
15 7.0 6.95 0.81 312.1 6.00 2.00 7.6 6.952 6.434 4.193 1486 2 34.88 6.29 3.75 523132 37

rate = 10000
distance = 500 minbargel = 1 minbargel2 = 1 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
15 10.0 5.65 0.78 316.9 6.00 2.00 7.6 5.645 7.839 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
15 6.0 6.72 0.81 312.1 6.00 2.00 7.6 6.776 6.143 4.193 914 2 34.05 7.28 3.00 510611 29

rate = 12000
distance = 500 minbargel = 1 minbargel2 = 1 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
20 10.0 5.52 0.81 349.8 6.00 2.00 7.7 5.517 8.413 5.611 5219 1 51.22 5.17 1.67 1024399 1.67
35 7.0 5.07 0.79 508.4 6.40 2.50 10.7 5.072 7.035 12.403 2645 1 28.88 6.29 5.83 1010805 48

rate = 14000
distance = 500 minbargel = 1 minbargel2 = 1 4.294 4160 1 67.74 5.17 0.00 1016129 0.00
20 10.0 5.54 0.81 349.8 6.00 2.00 7.7 5.510 8.413 5.611 5219 1 53.07 5.17 1.43 1061372 1.43
20 11.0 4.78 0.78 355.1 6.00 2.00 7.7 4.777 9.149 5.724 6546 1 50.16 4.12 2.86 1003192 41

```

Figure D.6

Example Of Summary Output From Drop-And-Swap Model

if the user answers affirmatively, the program will ask a series of questions concerning the form of the graphical output. Samples of graphical output are found in Chapter 2.

D.3.4 Iterations With Respect to Port Pair Trades

At this point the program begins the first of its iterative loops. It now selects the next incremental value for the iterative variable "distance" within the range "mindist" to "maxdist". This specifies the port separation distance of the trade under consideration. Next, the program will either use the values of "rload1", "rload2", "runload1", and "runload2" specified at the beginning of the program or will set these variables to the value of the iterative variable "rate" within the range "minrate" to "maxrate". This specifies the terminal facility loading/discharging rates of the port pair trade under consideration.

After this, the program zeroes the arrays ("best1" and "best2") that store the characteristics of the tug-barge systems that have the lowest required freight rate for the given port pair trade. Then it calculates the monthly average cargo flows ("mflowave1" and "mflowave2") which are the annual flows apportioned on a monthly basis taking in account that the barge is available only "bargeopdays" of the year for service.

D.3.5 Calculation of the Number of Terminal Facilities (and Barges for Drop-and-Swap Mode) Required at Each Port

Now that the port pair trade characteristics have been defined, the program determines the number of terminal facilities with the specified loading and discharging rates that must be located at each port to handle the annual cargo flows. This is also the number of barges that must be handled simultaneously at each port for the drop-and-swap mode of operation. This number is determined by dividing the monthly cargo flows ("mflowave1" and "mflowave2") by the monthly terminal facility throughput capacity ($30.5 \times \text{L-D rate}$). The specific formulae used are shown in Table D.1. It should be mentioned that seven days a week operations were assumed.

D.3.6 Iterations With Respect to Barge Size and Form

Next the program begins the iterative loops with respect to barge size and form. First it selects the next incremental values for the iterative variable "dwt" within the range "mindwt" to "maxdwt". This specifies the barge cargo deadweight to be used in the calculations to follow. Then the program selects the next incremental values for the iterative form variables "cb", "lb", and "bt" within the ranges "mincb" to "maxcb", "minlb" to

Table D.1

Formulae for Determining Number of Terminal
Facilities/Barges at Each Port

Port	Special Conditions	Formulae
1	none	"minbargel"= $\text{ceil}(\frac{\text{"mflowave1"}}{30.5\text{"rload1"}} + \frac{\text{"mflowave2"}}{30.5\text{"runload1"}})$
	"rload1"=0	"minbargel"= $\text{ceil}(\frac{\text{"mflowave2"}}{30.5\text{"runload1"}})$
	"runload1"=0	"minbargel"= $\text{ceil}(\frac{\text{"mflowave1"}}{30.5\text{"rload1"}})$
2	none	"minbargel2"= $\text{ceil}(\frac{\text{"mflowave1"}}{30.5\text{"runload2"}} + \frac{\text{"mflowave2"}}{30.5\text{"rload2"}})$
	"rload2"=0	"minbargel2"= $\text{ceil}(\frac{\text{"mflowave1"}}{30.5\text{"runload2"}})$
	"runload2"=0	"minbargel2"= $\text{ceil}(\frac{\text{"mflowave2"}}{30.5\text{"rload2"}})$

Note: The function ceil in the above formulae is used to round to the next largest integer the expression in parenthesis.

"maxlb", and "minbt" to "maxbt", respectively. This specifies the tug-barge CB, L/B, and B/T to be used in the calculations to follow.

D.3.7 Calculation of Barge Hull Weight and Principal Dimensions:

Given the values of the barge DWT and form variables specified in the iterative loops discussed above, the program calculates the barge length (5) and hull weight values via quadratic interpolation with respect to block coefficient from the formulae provided in Table D.2. These formulae were derived from the output of the single-skin tank barge program discussed Kaskin (1979).

Next the program determines the barge breadth by dividing the tug-barge length ("litb") by the length-breadth ratio ("lb"). Similarly, the barge draft is determined by dividing the barge breadth by the breadth-draft ratio ("bt"). It should be noted that the tug-barge length is assumed to be equal to the barge length plus seven-tenths the tug length. This assumption closely approximates the lengths of the large articulated push-towed ocean going tug-barge systems now in operation.

Now the program begins a short iterative loop by using a formula found in Sharp (1975) to estimate the barge outfit weight as a function of barge length. Sample values from this formula are shown in Table D.3. The value of outfit weight summed with the cargo deadweight and with the barge hull steel weight is used to estimate the barge displacement. The barge displacement is used, in turn, to obtain an improved estimate of the barge length. This procedure is then repeated iteratively until the barge length as well as barge displacement and outfit weight converge to unchanging values. Given the value of outfit weight, the program calculates an estimate of the barge cost by summing the product of outfit weight times a cost per ton outfit factor (6) with the product of hull steel weight times a cost per ton hull steel factor. (7)

(5) Barge length used in these formulae refers to the distance at the waterline from two-thirds of the barge notch length forward of the stern to the barge stem. This is in accordance with ABS rules pertaining to articulated tug-barge systems presented in MARAD (1979).

(6) This factor is assumed to be \$12,820 per long ton outfit. This is based on the value found in George G. Sharp (1975) inflated by 30% to bring it to a January 1979 value.

(7) This factor is assumed to be \$1100 per long ton hull steel. This is based on .40 man-hours per ton at \$15 per man hour (including overhead) plus \$500 per ton material cost.

Table D. 2

Barge Hull Weight and Length Formulae

Parameter	Block Co-efficient	Formula
Barge Length "lbarge"	0.75	"lbarge75"=e ^{1.128 lb^{0.742} bt^{0.382} dwt^{0.336}}
	0.80	"lbarge80"=e ^{1.108 lb^{0.739} bt^{0.381} dwt^{0.336}}
	0.85	"lbarge85"=e ^{1.088 lb^{0.737} bt^{0.379} dwt^{0.336}}
Barge Hull Weight "wsteelb"	0.75	"hullwt75"=e ^{-6.206 lb^{1.348} bt^{0.884} dwt^{1.104}}
	0.80	"hullwt80"=e ^{-6.396 lb^{1.368} bt^{0.909} dwt^{1.111}}
	0.85	"hullwt85"=e ^{-6.569 lb^{1.391} bt^{0.930} dwt^{1.117}}

TABLE D.3

Barge Outfit Weight

Formula: "woutfitb" = max(50, 1.496x"lbarge"-284.24)

Barge Length	Outfit Weight
200	50.00
250	89.76
300	164.56
350	239.36
400	314.16
450	388.96
500	463.76
550	538.56
600	613.36
650	688.16
700	762.96
750	837.76

If the barge length is found to exceed 750 feet, which is beyond the feasible range of the model, then the program skips to the next iterative value for "cb". Otherwise, the program calculates the barge freeboard using the rules specified in the 1966 International Conference on Load Lines. The specific formulae and table values used are shown in Table D.4 and Figure D.7. It should be noted that in the freeboard calculations it was assumed that the barge had no sheer and that the barge is unmanned so that a 25% reduction in freeboard is allowed. After the barge freeboard is calculated, the barge depth is determined. At this point the program checks to see if the tug-barge unit's dimensions exceed any of the length, breadth, or draft limitations ("maxl", "maxb", "maxt1", or "maxt2") that may have been specified in the semi-fixed parametric data for the port pair trades under consideration. If any of these limitations are exceeded, the program skips to the next "bt" iteration. Otherwise, it checks to see if the form parameters "cb" and "lb" are within the table interpolation ranges specified in Table D.1. If they are not, the program skips to the next "lb" iteration; otherwise, it continues as described in the following section.

D.3.8 Iteration With Respect to Tug-Barge Speed and Calculation of Tug IHP and Cost

At this point the program begins the last of the iterative loops which is with respect to tug-barge speed. It selects the next incremental value for the iterative variable "speed" within the range "minspeed" to "maxspeed". Then the value of "speed" and the tug-barge principal dimensions ("lbarge", "bbarge", "tbarge", and "cb") are fed into the Subprogram "power". This program, described in detail in Kaskin (1979), returns the value of the horsepower required to be delivered by the propeller ("dhp") to propel the tug-barge system through the water at the specified speed. (8) From this value the shaft horsepower can be determined. It should be noted that a tug shaft efficiency of 98%, an appendage drag of 5%, and a linkage drag of 10% were assumed. (9)

(8) This program also calculates "chp", the power required to propel the tug-barge system through the water, from which the still water hull resistance can be determined. It also provides values for the self-propulsion factors ("wa", "th", and "hr") and open water propeller efficiency "propef".

(9) The assumptions for appendage and linkage drag are based on conversations with articulated tug-barge designers. They seem optimistic when compared to the results presented in Robinson (1976). However, this study used fairly crude prototype linkage forms and so probably overestimated the drag for the modern linkages which are well faired.

Table D.4
Minimum Freeboard Values

Barge Length	Minimum Freeboard	Barge Length	Minimum Freeboard	Barge Length	Minimum Freeboard
100'	9.8"	320'	43.2"	540'	86.3"
110	10.8	330	45.0	550	88.0
120	11.9	340	46.9	560	89.6
130	13.0	350	48.8	570	91.1
140	14.2	360	50.7	580	92.6
150	15.5	370	52.7	590	94.1
160	16.9	380	54.7	600	95.5
170	18.3	390	56.8	610	96.9
180	19.8	400	58.8	620	98.3
190	21.3	410	60.9	630	99.6
200	22.9	420	62.9	640	100.9
210	24.5	430	65.0	650	102.1
220	26.2	440	67.0	660	103.3
230	27.8	450	69.1	670	104.4
240	29.5	460	71.1	680	105.5
250	31.1	470	73.1	690	106.6
260	32.8	480	75.1	700	107.7
270	34.6	490	77.1	710	108.7
280	36.3	500	79.0	720	109.7
290	38.0	510	80.9	730	110.7
300	39.7	520	82.7	740	111.7
310	41.4	530	84.5	750	112.6

SOURCE: Table A, Chapter III, IMCO International Convention on Load Lines, 1966.

$$\text{Barge Freeboard (inches)} = \text{"fbd"} = 0.75 \times \left[\underbrace{\left(\frac{\text{Minimum Freeboard Value}}{\text{Found in Table 2.5}} \right) \times \left(\frac{\text{"cb"} + 0.68}{1.38} \right) + \text{"shrftact"} + \text{"ldfact"}}_{\text{"minfbd"}} \right]$$

Where: 0.75 accounts for the 25% freeboard reduction pertaining to unmanned barges

$$\text{"shrftact"} = \text{sheer factor correction} = 0.0375 \times \text{"lbarge"} + 3.75$$

$$\text{"ldfact"} = \text{length-depth ratio correction} = \begin{cases} = 0 & \text{if } \frac{\text{"lbarge"}}{\text{depth}} > 15 \\ = \left(\text{depth} - \frac{\text{"lbarge"}}{15} \right) \times \begin{cases} \frac{\text{"lbarge"} + 132.2}{12 \times 131.2} & \text{if } \frac{\text{"lbarge"}}{\text{depth}} < 15 \\ \frac{\text{"lbarge"} + 393.6}{12 \times 131.2} & \text{if } \frac{\text{"lbarge"}}{\text{depth}} < 393.6 \end{cases} & \text{if } \frac{\text{"lbarge"}}{\text{depth}} < 15 \\ = 4 \times \left(\text{depth} - \frac{\text{"lbarge"}}{15} \right) & \text{if } \frac{\text{"lbarge"}}{\text{depth}} < 15 \\ & \text{if } \frac{\text{"lbarge"}}{\text{depth}} > 393.6 \end{cases}$$

$$\text{where depth} = \left(\frac{\text{"minfbd"}}{12} + \text{"tbarge"} \right)$$

SOURCE: Chapter III of the IMCO International Conference on Load Lines, 1966

Figure D.7

Equations Used in the Calculation of Barge Freeboard

Given the value of the service margin (10) for the tug, the horsepower of the engines required to be installed onboard the tug can be determined. From this the cost of the tug can be estimated using the formulae found in George G. Sharp (1979), inflated 50% to bring them up to a January 1979 level. Sample values from these formulae are presented in Table D.5.

....D.3.9 Calculation of the Number of Tugs Required.

Now the program begins the calculations to determine the number of tugs required to provide sufficient movement capacity for the required annual cargo flows. It does this for the drop-and-swap modes, balanced and unbalanced, (11) and then the integral mode.

To determine the number of tugs required in the drop-and-swap modes, the program first calculates the time required for cargo operations in both ports ("tport1" and "tport2"). For "tport1", this is the barge cargo deadweight divided by the terminal facility loading rate plus the cargo deadweight--weighted by a balance factor if cargo flows are not equal in both directions--divided by the terminal facility discharging rate. A similar formula pertains for "tport2". Then the program calculates the sea voyage time for a round trip. This is twice the distance divided by the system speed plus linking and unlinking times if appropriate plus any other expected port delays. (12) For the drop-and-swap modes, these values are fed into an iterative routine that calculates the total tug voyage time ("ttript") which includes seetime plus any time that tug is required to wait for completion of cargo operations ("twait1" for Port 1 and "twait2" for Port 2). The routine also calculates the minimum number of tugs ("mintug") required for the trades.

(10) in the model's base case the service margin, the additional fraction of "ehp" required to ensure that the service speed is achieved in most seas, is assumed to be 0.20.

(11) The unbalanced drop-and-swap mode ("dsopt" = 1) is the case where it is assumed that the tug will remain with the barge in the port with the shortest time spent for cargo operations. This would be appropriate for one-way trades with short loading and long discharging times. In this case the waiting time for the port that the tug remains with the barge is equal to the cargo operations time, i.e., "twait1" = "tport1". The program selects the drop-and-swap mode that results in the lower rfr to be stored and printed.

(12) In the model's base case the port delay and tug-barge linking/unlinking times were estimated to be four hours. The port delay time takes in account the expected time for docking and undocking as well as time awaiting berth for the barge.

Table D.5
Tug Capital Costs

$$\text{Tug Hull Weight} = \text{"wsteelt"} = 0.64 \left(\frac{\text{IHP}}{1000} \right)^2 + 16.79 \left(\frac{\text{IHP}}{1000} \right) + 378$$

$$\text{Tug outfit Weight} = \text{"woutfitt"} = 0.1866 \left(\frac{\text{IHP}}{1000} \right)^2 + 2.733 \left(\frac{\text{IHP}}{1000} \right) + 154$$

$$\text{Tug Machinery Weight} = \text{"wmacht"} = -0.08889 \left(\frac{\text{IHP}}{1000} \right)^2 + 32.88 \left(\frac{\text{IHP}}{1000} \right) + 4.999$$

$$\text{Tug Machinery Cost} = 1,300 * (0.314 * \text{IHP} + 1730)$$

$$\text{Tug Cost} = 1,000 \left[2.94 \left(\frac{\text{Tug Hull Weight}}{\text{Weight}} \right) + 15.08 \left(\frac{\text{Tug Outfit Weight}}{\text{Weight}} \right) + \left(\frac{\text{Tug Machinery Cost}}{\text{Cost}} \right) \right]$$

IHP	Tug Hull Weight (LT)	Tug Outfit Weight (LT)	Tug Machinery Weight (LT)	Tug Machinery Cost (\$1000)	Tug Cost (\$1000)
2,000	414.14	160.21	70.40	3065.4	6,698.1
2,500	423.98	162.00	86.64	3269.5	6,958.1
3,000	434.13	163.88	102.84	3473.6	7,220.4
4,000	455.40	167.92	135.10	3881.8	7,752.0
5,000	477.95	172.33	167.18	4290.0	8,293.0
6,000	501.78	177.12	199.08	4698.2	8,843.3
7,000	526.89	182.27	230.80	5106.4	9,403.1
8,000	553.28	187.81	262.35	5515.6	9,972.3
9,000	580.95	193.71	293.72	5922.8	10,550.8
10,000	609.90	199.99	324.91	6331.0	11,138.7
12,000	671.64	213.67	386.76	7147.4	12,342.8
14,000	738.50	228.84	447.90	7963.8	13,584.4
16,000	810.48	245.50	508.32	8780.2	14,863.5
18,000	887.58	263.65	568.04	9596.6	16,180.2
20,000	969.80	283.30	627.04	10413.0	17,534.4
22,500	1079.78	309.96	699.80	11433.5	19,280.1
25,000	1197.75	338.95	771.44	12454.0	21,084.4
27,500	1323.73	370.27	841.98	13474.5	22,947.3
30,000	1457.70	403.93	911.40	14495.0	24,869.0

SOURCE: Sharp (1975)

*Cost factors inflated 30% from values given in source.

The logic of the iterative routine is rather simple. After the program assumes initial values for "mintug", "twait1" and "twait2"; it calculates new values for "twait1" and "twait2" based on the number of barges stationed at each port and the currently assumed value for "mintug". This is done by assuming the tugs are on equally spaced time schedules. Given the values of "twait1" and "twait2", the total voyage time "ttript" is determined. Given this value, the minimum number of tugs ("mintug") for the trade can be determined by comparing the required monthly cargo flows with the ton-mile capacity of each tug-barge unit. The program then will iterate and calculate new values for "twait1" and "twait2" until the total voyage time "ttript" converges on an unchanging value. If convergence does not occur, an error message is printed. If it is found that the total port waiting time exceeds the time that would be spent for cargo operations, then the program prints out a message stating that the drop-and-swap mode would not be appropriate. Otherwise, the program continues by calculating annual operating costs, as described in the next section.

To calculate the number of tugs required in the integral mode, a simpler approach is used than for the drop-and-swap mode. In this case, the total voyage time is equal to seetime and port time; and, the number of tugs required is simply the minimum that will provide sufficient flow capacity (number of tug-barges per month times barge cargo deadweight) to handle the monthly cargo flow requirements.

D.3.10 Calculation of Annual Operating Costs

Now that the program has determined (1) the duration of the tug seetime ("seatimet") which includes time for unlinking/linking and port delays, (2) the duration of in port time ("portimet") which includes the time that the tug must await cargo operation completion, (3) tug shaft horsepower ("shp") for achieving the specified speed, and (4) the tug engine size ("ihp"); it is now able to proceed to calculate the various components of the total annual operating cost per tug-barge unit. Discussion of the assumptions used in calculating each of the cost components is provided below.

Annual Diesel Fuel Cost. The annual diesel fuel cost is equal to the number of tug voyages per year ("nrtrips" = "tugopdays"/"ttript") times the amount of diesel fuel in long tons consumed per voyage ("fuelcons") times the cost per long ton diesel fuel. (13) The amount of fuel consumed per voyage ("fuelcons") is equal to the tug at sea time in hours ("seatimet") times the hourly at sea fuel consumption rate in

(13) In the model's base case, diesel fuel cost is assumed to be \$140 per long ton.

tons per hour ("rseafuel") plus the tug in port time in hours ("portimet") times the hourly in port fuel consumption rate ("rportfuel" = 0.125 ton/hr). The at sea fuel consumption rate ("rseafuel") in long tons per hour, is in turn equal to the product of the diesel engine's specific fuel consumption rate ("sfc") in pounds per horsepower-hour (14) and the tug's shaft horsepower ("shp"), all divided by 2240.

..... Annual Lube Oil Costs. The annual lube oil cost is equal to the number of tug voyages per year ("nrtrips") times the amount of lube oil in gallons consumed per voyage ("lubecons") times the cost per gallon for lube oil. (15) The amount of lube oil consumed per voyage ("lubecons") is assumed to be equal to the tug at sea time in hours ("seatimet") times the hourly at sea lube oil consumption rate in gallons per hour ("rlubeoil"). This hourly at sea fuel consumption rate has been assumed to be equal to the tug's shaft horsepower divided by 4000., in gallons per hour.

Annual Crew Costs. The annual crew costs are equal to the average annual crew member's wages and benefits ("cwages") plus subsistence expenses ("csubs"), all times the number of crew members onboard the tug ("nrcrew"). (16)

Annual Costs for Maintenance and Repairs, Insurance, and Stores, Supplies, and Equipment. The annual costs for maintenance and repairs ("amandr"), insurance ("ainsur"), and stores, supplies, and equipment ("asupplies") are determined from formulae found in George G. Sharp (1975). These formulae are functions of the tug engine size and total deadweight of the tug-barge unit. Sample values from these formulae, which have been inflated to bring them up to January 1979 levels, are presented in Table D.6.

(14) In the model's base case, a sfc of 0.36 is assumed. This is a reasonable value for the medium speed diesels currently used in high powered tugs. In the future lower sfc's and fuel costs may be obtained with the use of low speed diesels burning heavy fuels.

(15) In the model's base case, lube oil is assumed to be \$1.75 per gallon.

(16) In the model's base case the average crew size has been assumed to be sixteen, which is very close to the minimum manning level of fourteen that the U. S. Coast Guard has previously allowed for "mechanically-linked" push-towed ocean going tug-barges. (The extra two men are used to fill cook/steward positions.) As for the average crew member's wages and subsistence, they were assumed to be \$65,000 and \$3,500 respectively. These values are in reasonable agreement with the Maritime Administration data shown in Table D.7.

Table D.6

Annual Operating Costs for Supplies and Equipment,
Maintenance and Repair, and Insurance

Supplies and Equipment = "asupplies" = $1.3 \cdot (40 + 0.0018 \cdot \text{IHP} + 0.00025 \cdot \text{TDWT})$

Maintenance and Repair = "amandr" = $1.5 \cdot (128.8 + 4.539 \cdot (\frac{\text{IHP}}{1000}) - 0.04 \cdot (\frac{\text{IHP}}{1000})^2 + 2.477 \cdot (\frac{\text{TDWT}}{1000}) - 0.009107 \cdot (\frac{\text{TDWT}}{1000})^2)$

Insurance = "ainsur" = $1.5 \cdot (210 + 0.0036 \cdot \text{IHP} + 0.0018 \cdot \text{TDWT})$

TDWT	IHP	Supplies & Equipment (\$1000)	Maintenance & Repair (\$1000)	Insurance (\$1000)
5,000	2,000	58.4	224.8	339.3
"	6,000	67.7	250.1	360.9
"	10,000	77.1	273.5	382.5
"	14,000	86.5	295.0	404.1
20,000	2,000	63.4	275.4	379.8
"	6,000	72.8	300.7	401.4
"	10,000	82.2	324.1	423.0
"	14,000	91.5	345.6	444.6
35,000	2,000	68.5	319.9	420.3
"	6,000	77.9	345.2	441.9
"	10,000	87.2	368.6	463.5
"	14,000	96.6	390.1	485.1
50,000	2,000	73.6	358.2	460.8
"	6,000	82.9	383.5	482.4
"	10,000	92.3	406.9	504.0
"	14,000	101.7	428.4	525.6
"	18,000	111.0	447.9	547.2
65,000	2,000	78.7	390.4	501.3
"	6,000	88.0	415.7	522.9
"	10,000	97.4	439.1	544.5
"	14,000	106.7	460.6	566.1
"	18,000	116.1	480.1	587.7

SOURCE: Sharp (1975)

NOTE: TDWT=Cargo Deadweight + Fuel Weight +Miscellaneous Weight

*Inflation Factor to bring cost to 1 Jan 79 level

that shoreside storage facilities must be used for storage rather than the barges that remain in port for the drop-and-swap mode.

To show that the values resulting from the formulas and other assumptions used in calculating the operating costs are reasonable, a comparison of the model's output is made with some Maritime Administration tug-barge data in Table D.7.

D.3.11 Calculation of System Capital Costs

After the total operating costs are calculated, the program then determines the total system capital cost ("totcapcost") for the drop-and-swap and integral modes of operation. This total capital cost consists of the barge price times the number of barges in the system plus terminal and storage facility capital costs. These costs are adjusted to take account of the increased productivity that result from multi-unit orders by use of the learning curve factor formula found in George G. Sharp (1975). The barge and tug prices are equal to the tug and barge costs ("ctug" and "cbarge") calculated previously, but increased by 10% to take into account shipyard profit. The terminal facility cost is assumed to be some cost factor ("cfixterm") in dollars per ton-day times the sum of the terminal facility loading/discharging rates times the number of facilities per port. The storage facility cost, which pertains to the integral mode only, is assumed to be equal to the product of some cost factor in dollars per cargo deadweight ton ("cfixstor") times the barge cargo deadweight times the number of terminal facilities ("minbarge1" + "minbarge2"). This formula assumes that a storage facility equal to the barge capacity must be built onshore for each terminal facility. This is only one of many possible ways of estimating shoreside storage requirements and was used just to give an indication of how storage costs might affect the tradeoffs in operating in the drop-and-swap versus integral mode. In a real operating environment, the storage capacity will depend primarily on the ability of the tug-barge systems remaining on rigid schedules. (21)

D.3.12 Calculation of Required Freight Rates

At this point the program has completed all the calculations required to determine the required freight rate for recovering all operating and capital costs for the system. The required freight rate is simply the total system capital cost ("totcapcost") divided by the present value factor ("pvf") plus the total system operating costs ("totopcost"), all divided by the total annual cargo flows. Now all calculations have been

(21) in the model's base case terminal and storage facility capital costs were assumed to be zero.

Annual Port Charges. The annual port costs are equal to the number of voyages per year times the port charges per voyage. The voyage port charges consist of a fixed charge per port call ("cfixport1" and "cfixport2") plus a variable cost which is a function of the barge size ("cvarport1" x "dwt" and "cvarport2" x "dwt"). (17)

Annual Costs from the Time Value of Cargo. Since the cargo represents a significant capital investment for its owner, the cost of the capital that is tied up while the cargo is being transported should be considered in the total operating costs for the system. The annual cost for the time value of the cargo ("acargo") is equal to the product of the annual cargo flows ("aflowave1" + "aflowave2") times the sea time in years and times the discount rate for capital ("disrate").

Annual Terminal and Storage Operating Costs. The annual terminal operating costs ("atermop") are simply the product of the annual cargo flows ("aflowave1" + "aflowave2") and the average cost per ton cargo for loading/discharging operations ("cvarterm"). Similarly, the annual storage costs ("astorop") are simply the product of the annual cargo flows and the average cost per ton cargo for in port storage. (18)

Calculation of the Total Annual Operations Costs. At this point the total operating costs per tug-barge unit ("aopcost") can be determined. It is simply the sum of fuel, lube oil, crewing and subsistence, maintenance and repair, stores, supplies, and equipment, insurance, cargo value, port charges, and other miscellaneous ("aothor") (19) costs. The total operating costs ("totopcost") are then equal to the number of tug-barge units times the operating cost per tug plus the terminal operating costs plus fleet administrative costs ("admin"). (20) For the drop-and-swap modes 3% of the cost of the additional barges required to be stationed at the ports is added to take account for the maintenance and repair, stores, supplies and equipment, and insurance incurred by these additional units. For the integral mode, the annual storage costs are added to take in account

(17) In the model's base case, all the port charge factors ("cfixport1", "cfixport2", "cvarport1", and "cvarport2") are assumed to be zero.

(18) In the model's base case, all terminal and storage costs are assumed to be zero.

(19) In the model's base case it is assumed that the miscellaneous other costs amount to \$30,000 per year for each tug.

(20) In the model's base case it is assumed that the administrative costs per fleet amount to \$150,000 per year.

Table D.7

Comparison of Model and MARAD Data
for Annual Operating Costs

Vessel Type	Annual Crew Wages	Annual Subsistence Costs	Annual M&R Costs	Annual Supplies & Equipment	Annual Insurance	Annual M&R Supplies & Equipment	Other Annual Costs	Total Operating Costs
5,000 DWT 3,000 IHP cy 1978	658,152	23,725	200,000	63,270	496,000	759,270	36,000	1,477,147
Model 1 Jan 1979	845,000	45,500	231,321	60,710	344,700	636,731	30,000	1,557,231
33,500 DWT 15,000 IHP 1 Jan 77	821,250	47,815	405,150	127,385	542,755	1,075,290	29,200	1,973,555
Model 1 Jan 1979	1,040,000	56,000	390,966	98,423	486,450	975,839	30,000	2,101,839
40,000 DWT 18,000 IHP cy 1980	1,060,000	50,000	460,683	71,317	352,250	884,250	189,600	2,193,850
Model 1 Jan 1979	1,040,000	56,000	442,247	107,640	520,200	1,070,387	180,000	2,346,387
40,000 DWT 18,000 IHP cy 1980	1,100,000	60,000	705,000	220,000	561,000	1,486,000	20,000	2,666,000
Model 1 Jan 1979	1,040,000	56,000	442,747	107,640	520,200	1,070,387	30,000	2,196,387

SOURCE: Data Received from Maritime Administration Office of Ship Construction,
December 1978.

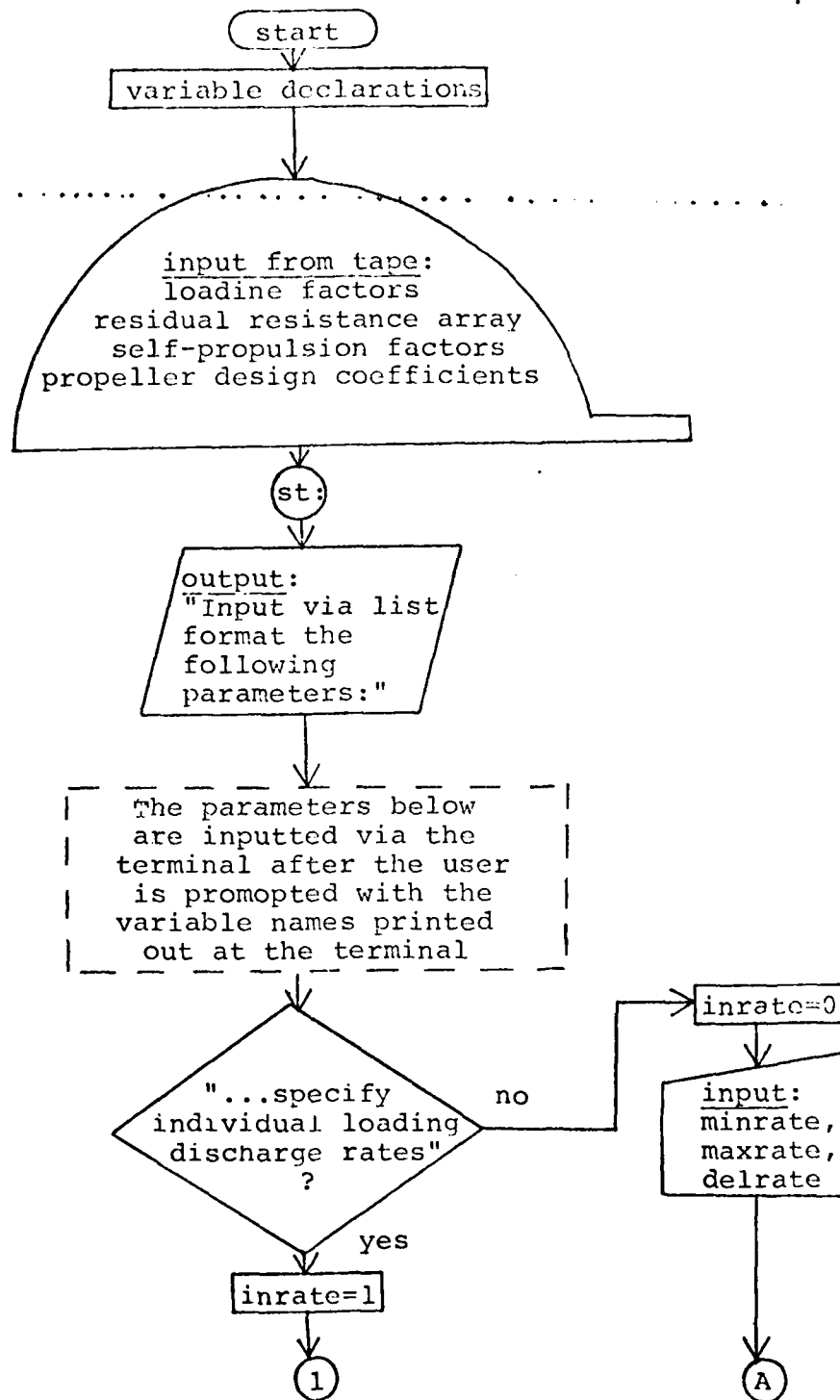
completed within the iterative loop. All that remains to be done is the storage within the computer program of the system variables and cost values for the iterations resulting in the lowest required freight rate for the port pair under consideration.

D.3.13 Storage of System Parameters for Minimum RFR Iterations

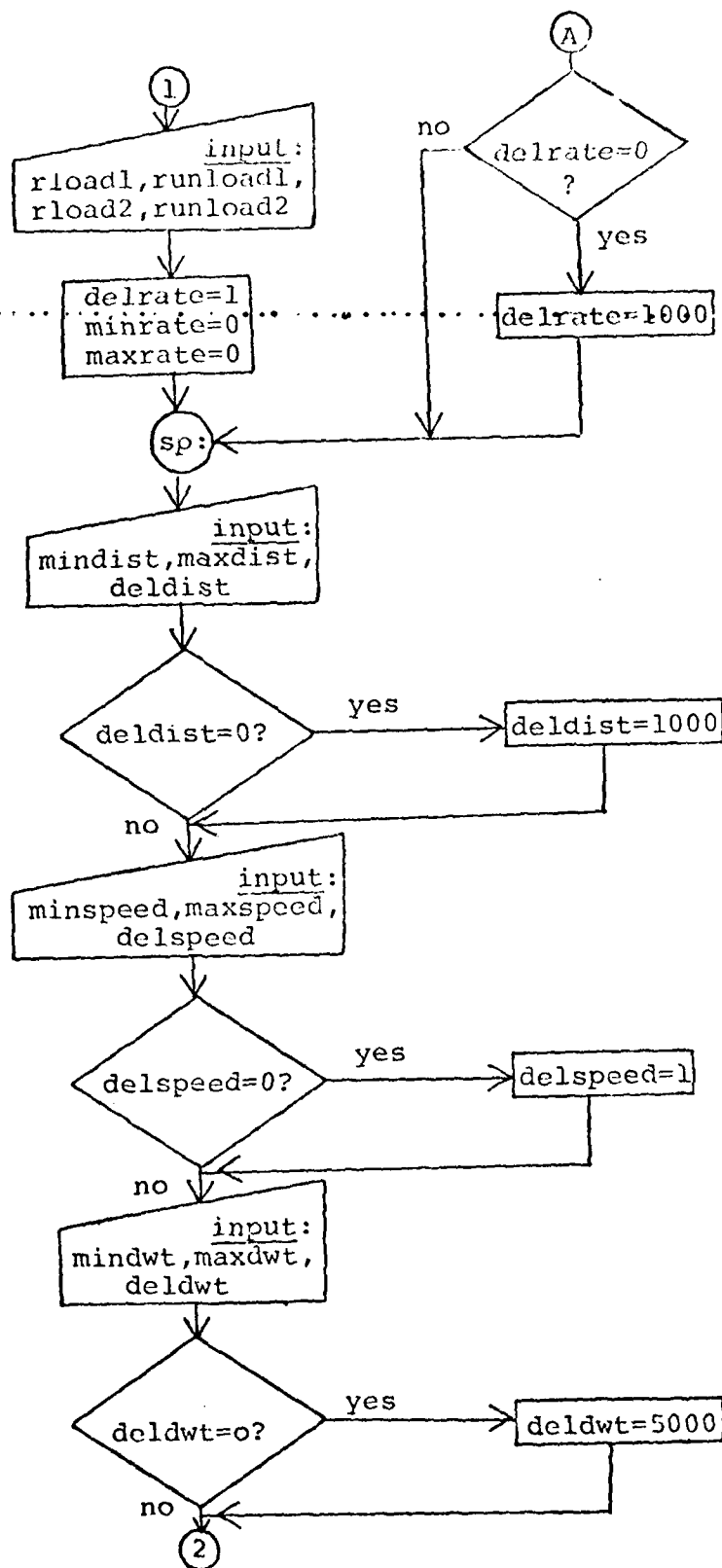
.....For each iteration of barge size, form, and speed, the program determines the associated required freight rate for the drop-and-swap, unbalanced drop-and-swap, and integral modes of operation. If for a particular iteration the rfr for either regular or unbalanced drop-and-swap mode is found to be lower than that found for previous iterations of the drop-and-swap modes, then the system values for that iteration replace those previously stored in the array "best1". The same pertains to the integral mode which has its optimum system values stored in the array "best2". So, at the end of all the iterations with respect to tug-barge DWT, Cb, L/B, B/T, and speed; the arrays "best1" and "best2" contain the system values for the drop-and-swap mode (the better of the balanced and unbalanced modes) and integral mode, respectively, that result in the minimum rfr. At this point the program will print out (if printed output was requested) the optimum system parameters for both drop-and-swap and integral modes for each trade specified by its port separation distance and loading/discharging rate. It also will store certain of the system parameters such as minimum rfr, optimum barge size and speed, etc., in storage arrays that will be used in the graphical output routines. Following this, the program will return to the beginning, requesting new inputs.

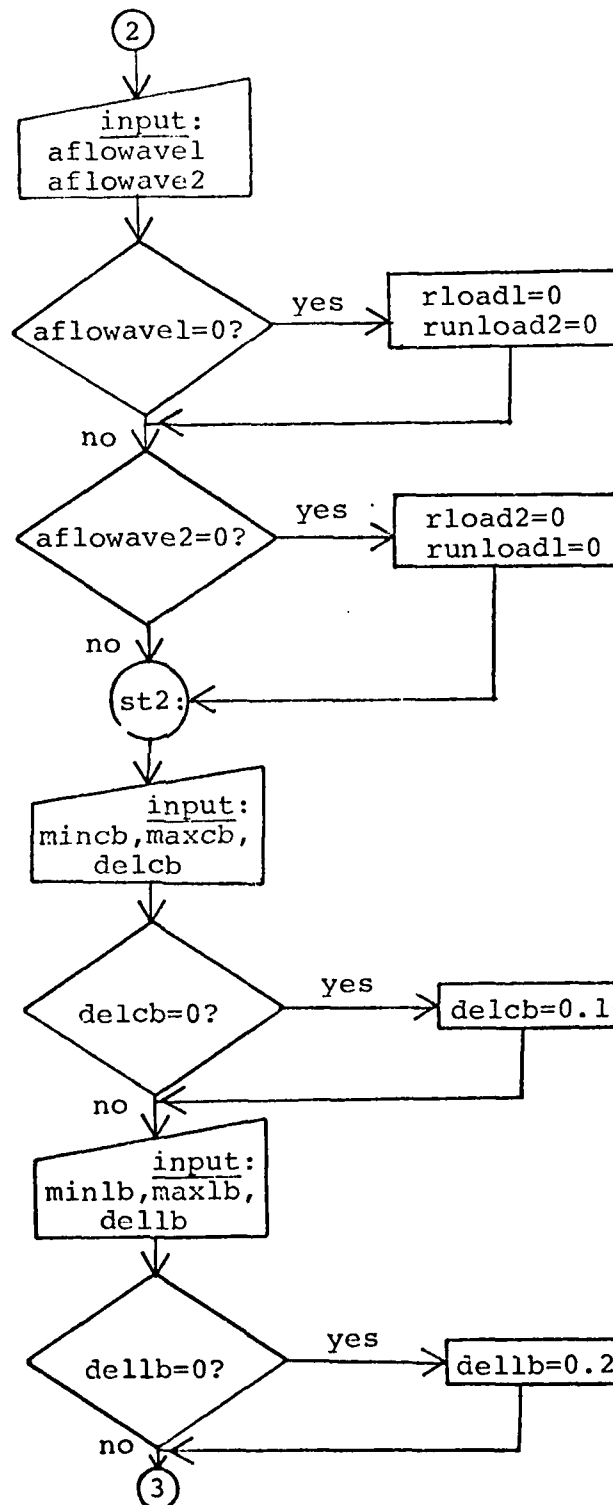
This concludes the detailed description of the drop-and-swap program. Discussion of the tug-barge powering and barge hull weight subprograms is provided in Kaskin (1979).

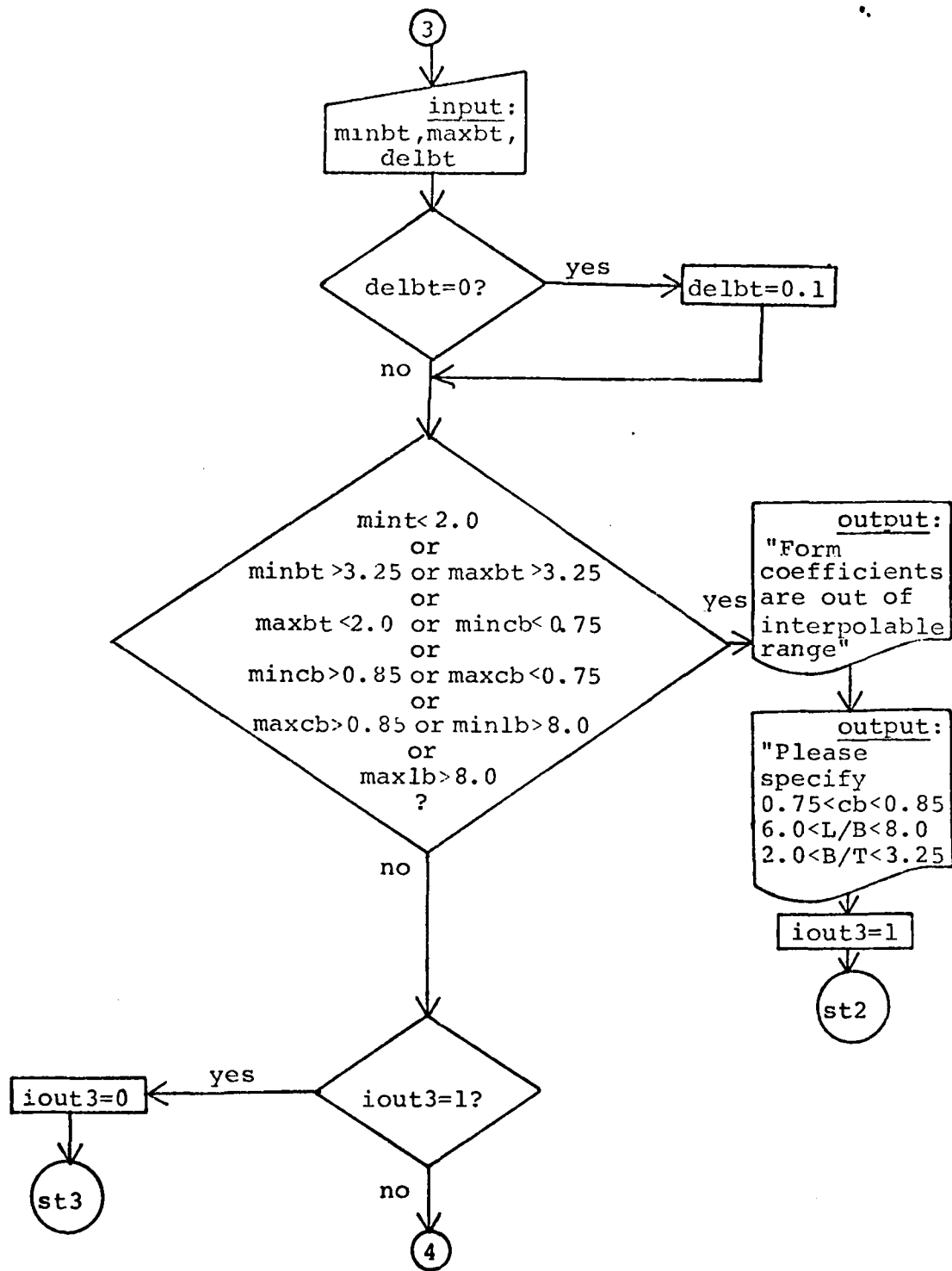
D.4 FLOWCHART OF THE DROP-AND-SWAP COMPUTER MODEL



Note: definition of the variable used in this flow chart are provided in the following sections:





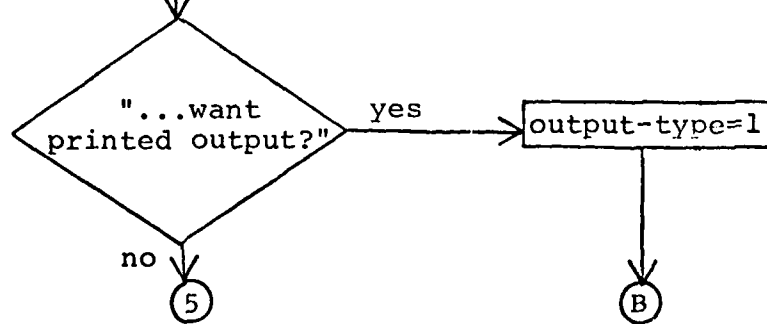


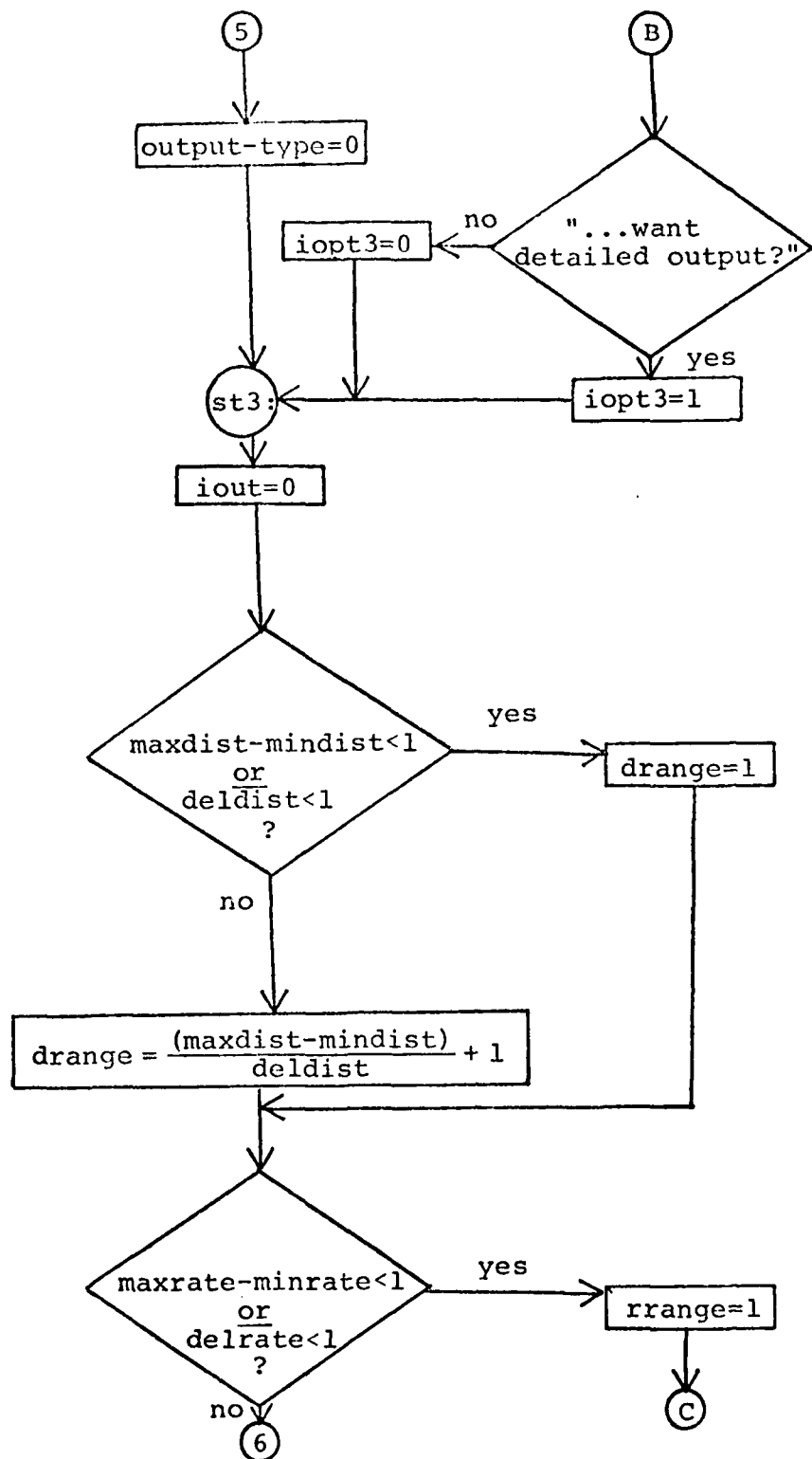
4

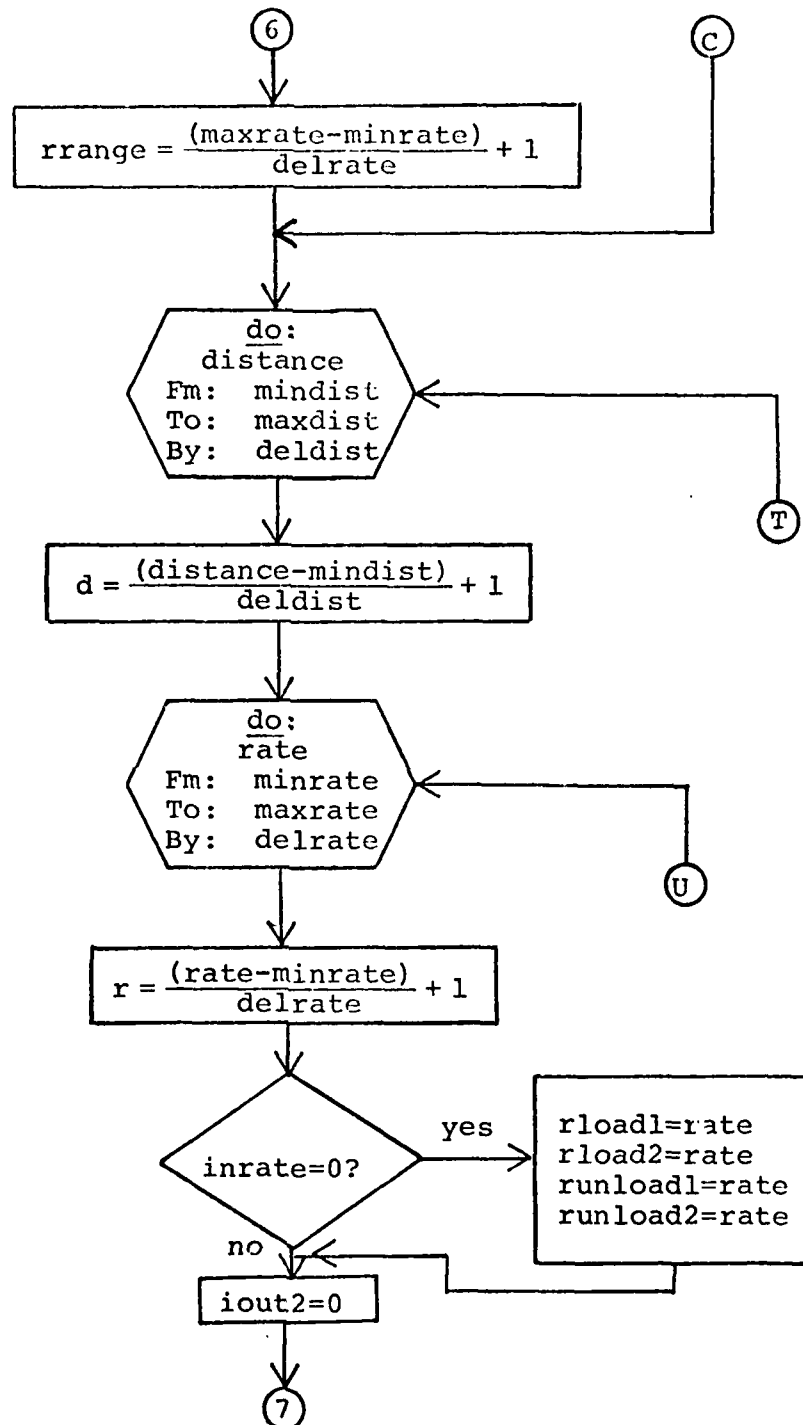
The program now opens and reads the data in the "semifixedparams" file containing the present values of the following parameters: tugopdays, bargeopdays, tlink, tunlink, servmargin, fuelfmargin, sfc, cfuel, clube, nrcrew, cwages, csubs, csteelt, coutfitt, csteelb, coutfitb, ltug, wmisc, aother, admin, cfixport1, cfixport2, cvarport1, cvarport2, cfixterm, cvarterm, cfixstor, cvarstor, delay1, delay2, max1, maxb, maxt1, maxt2, disrate, econlife, inflafctr, vcargo

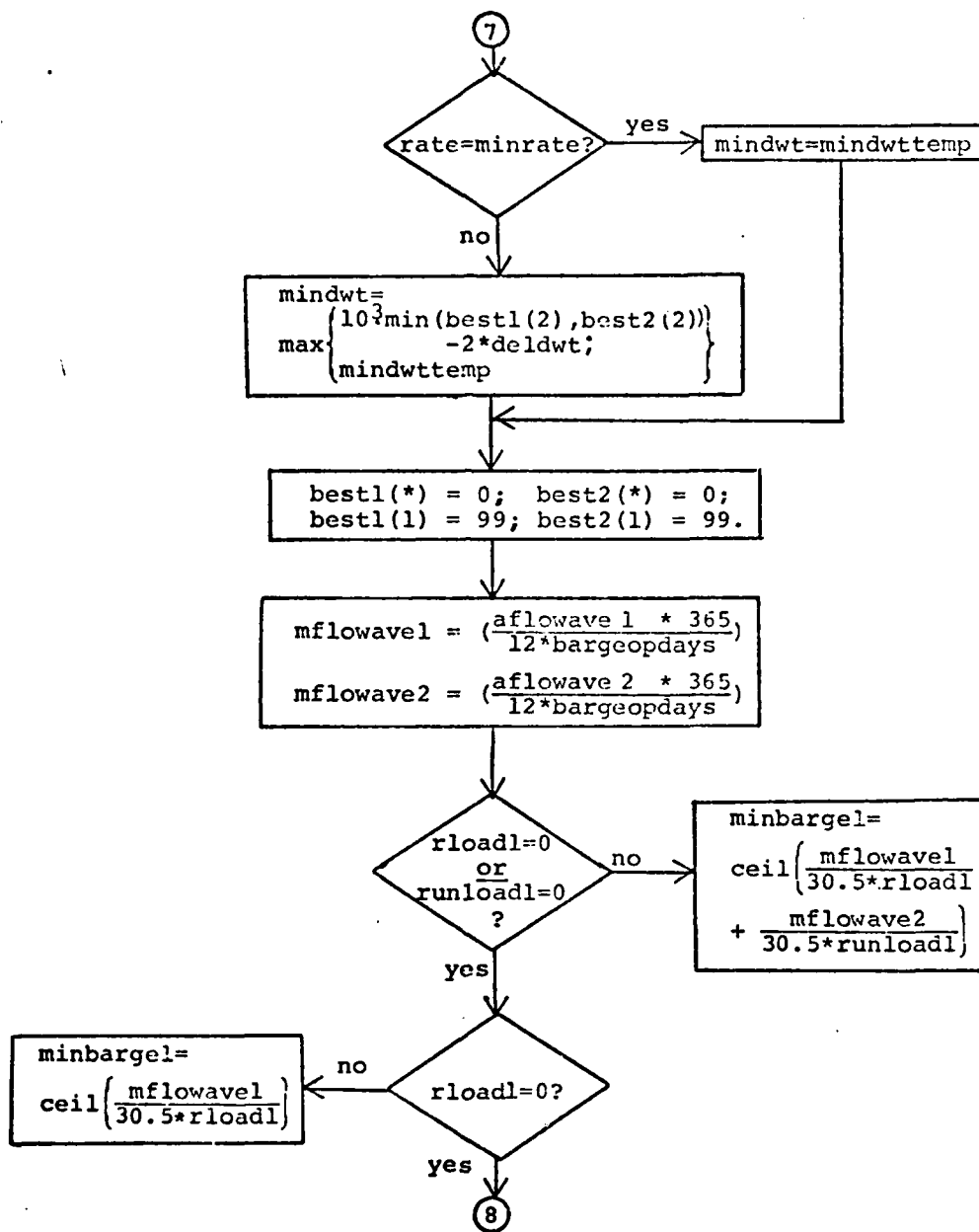
output:
"Input any changes to semifixed data via get data format"

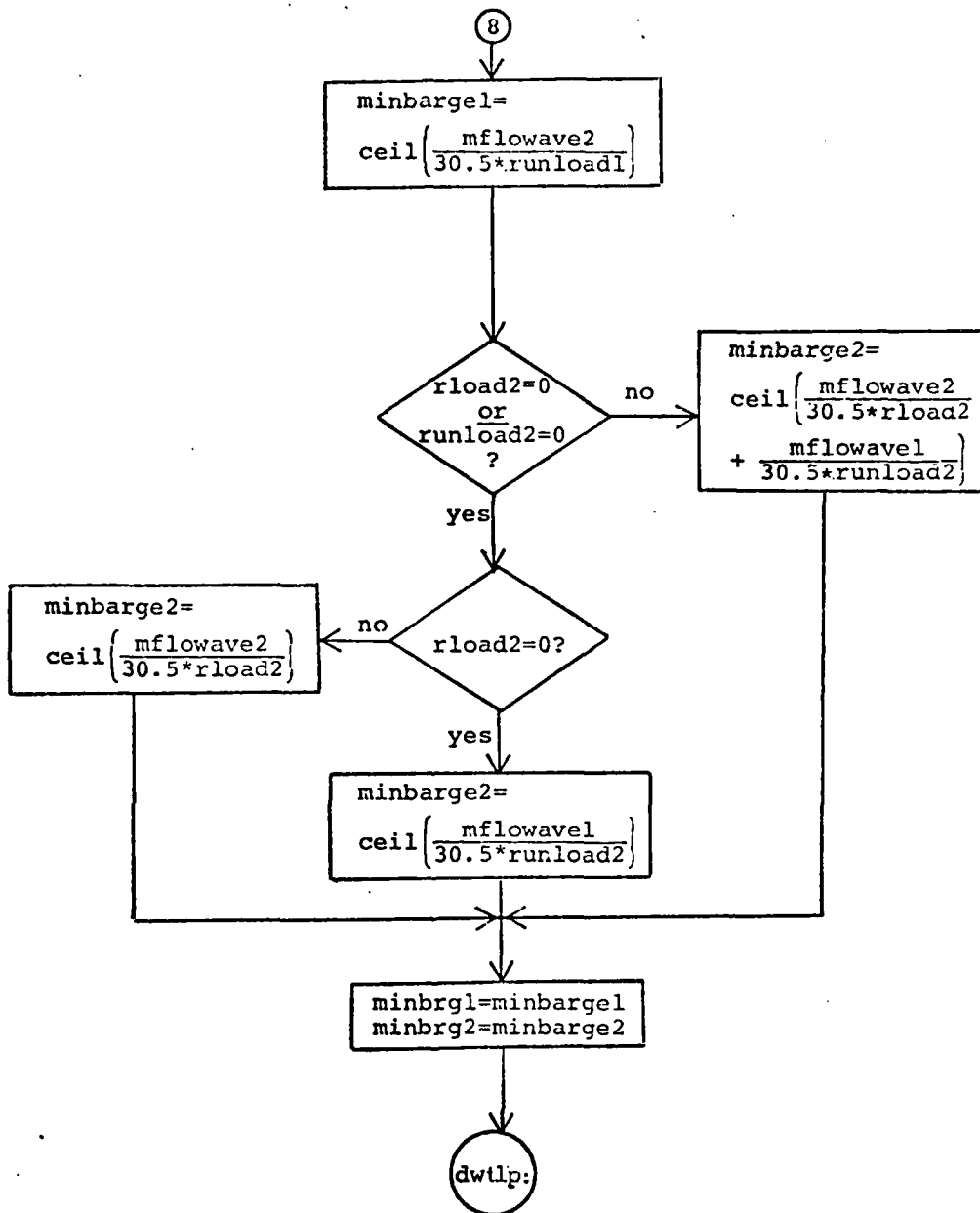
Any changes to the semifixed variables are inputted by writing "variable = value," The last change is followed by a semicolon

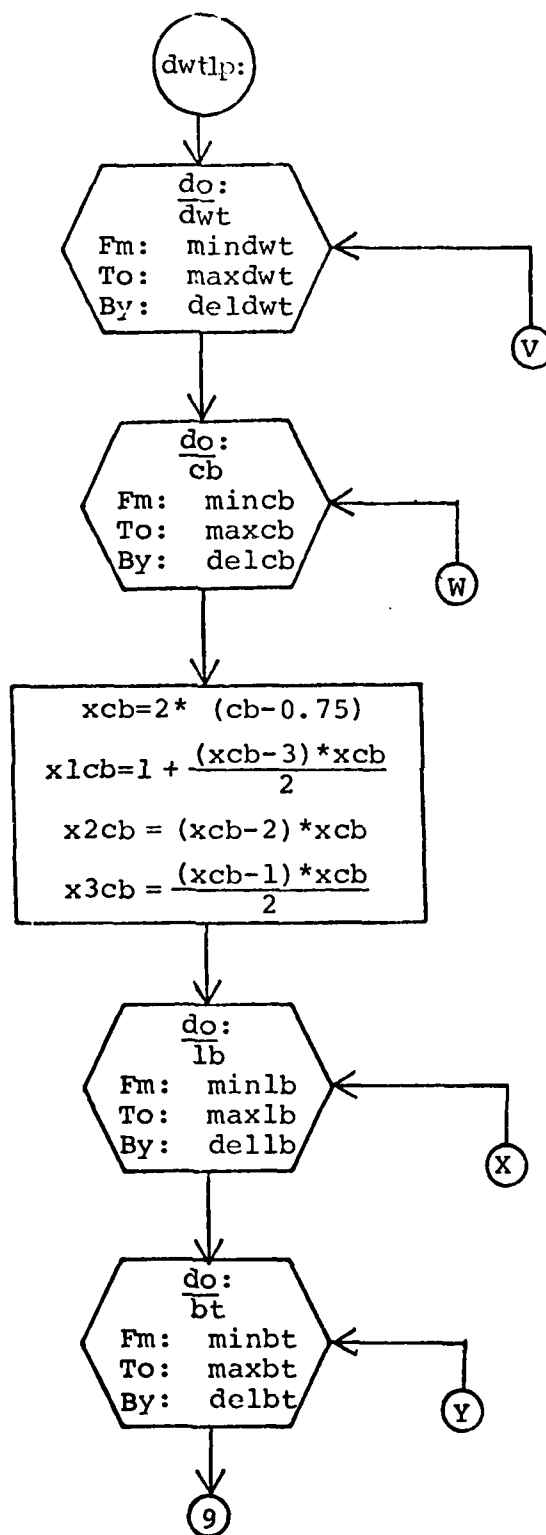












9

lbarge75=

$$e^{1.128 * lb^{0.742} * bt^{0.382} * dwt^{0.336}}$$

lbarge80=

$$e^{1.108 * lb^{0.739} * bt^{0.381} * dwt^{0.336}}$$

lbarge85=

$$e^{1.088 * lb^{0.737} * bt^{0.379} * dwt^{0.336}}$$

lbarge=

$$\begin{aligned} & lbarge75 * x1cb \\ & - lbarge80 * x2cb \\ & + lbarge85 * x3cb \end{aligned}$$

hullwt75=

$$e^{-6.206 * bt^{0.884} * lb^{1.348} * dwt^{1.104}}$$

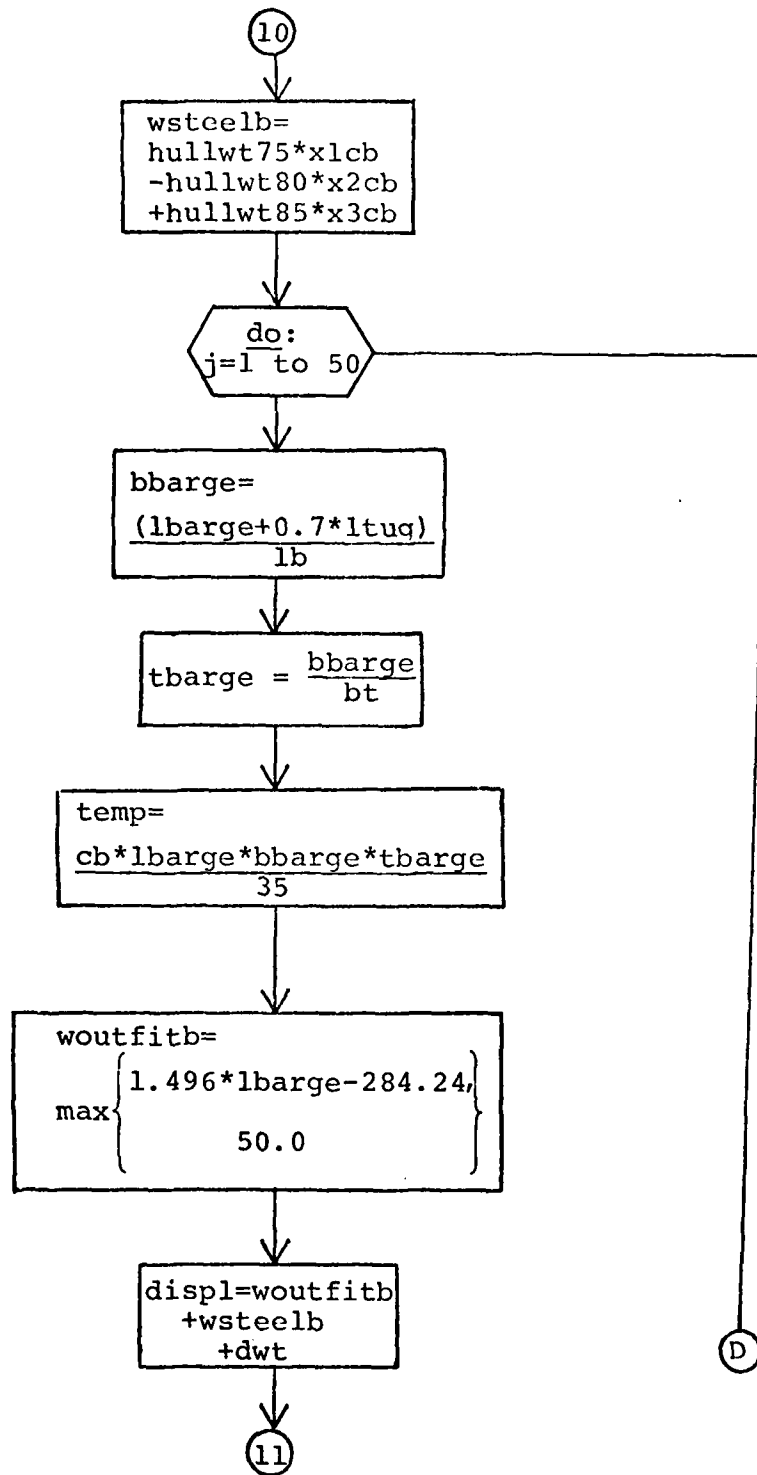
hullwt80=

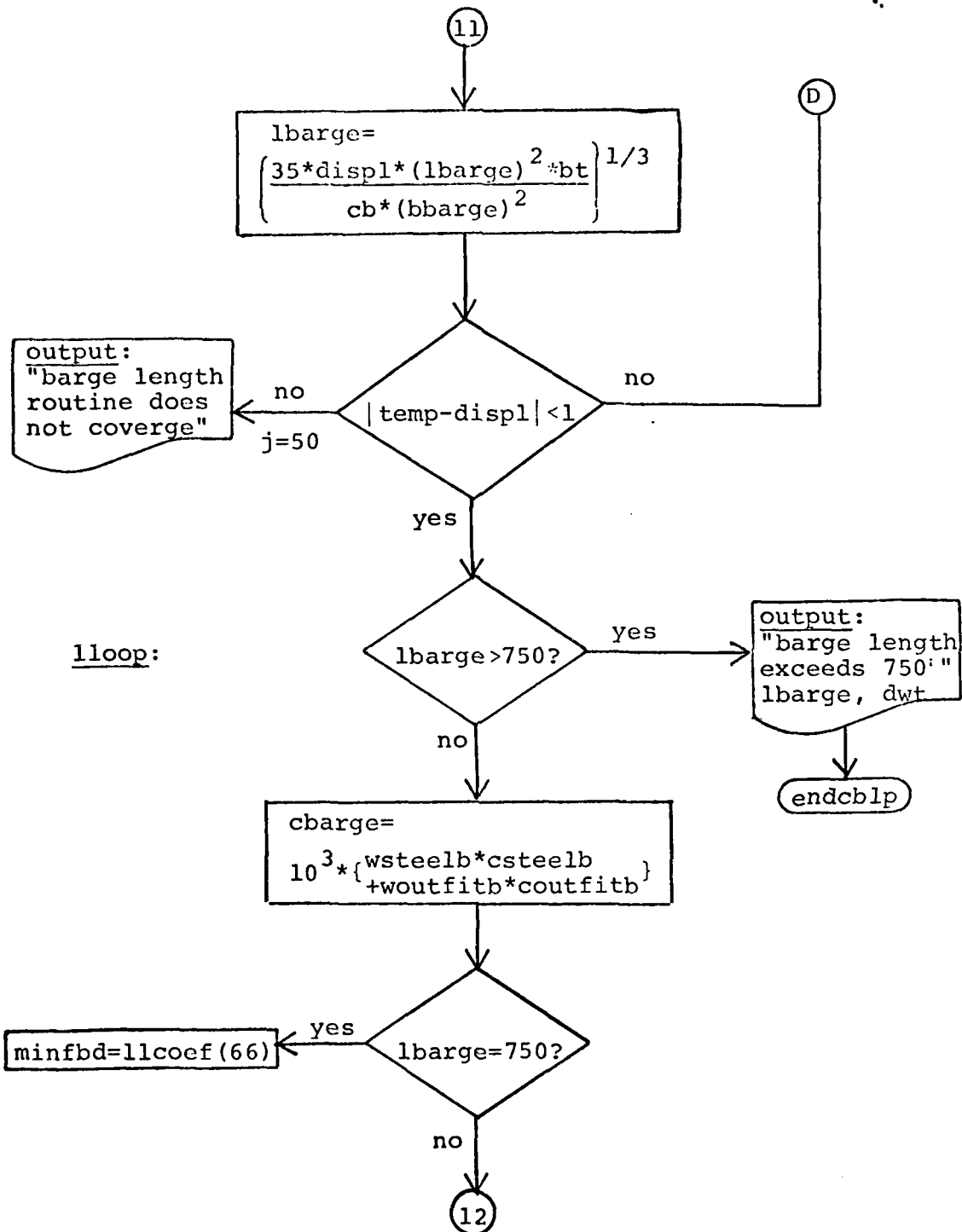
$$e^{-6.396 * bt^{0.909} * lb^{1.368} * dwt^{1.111}}$$

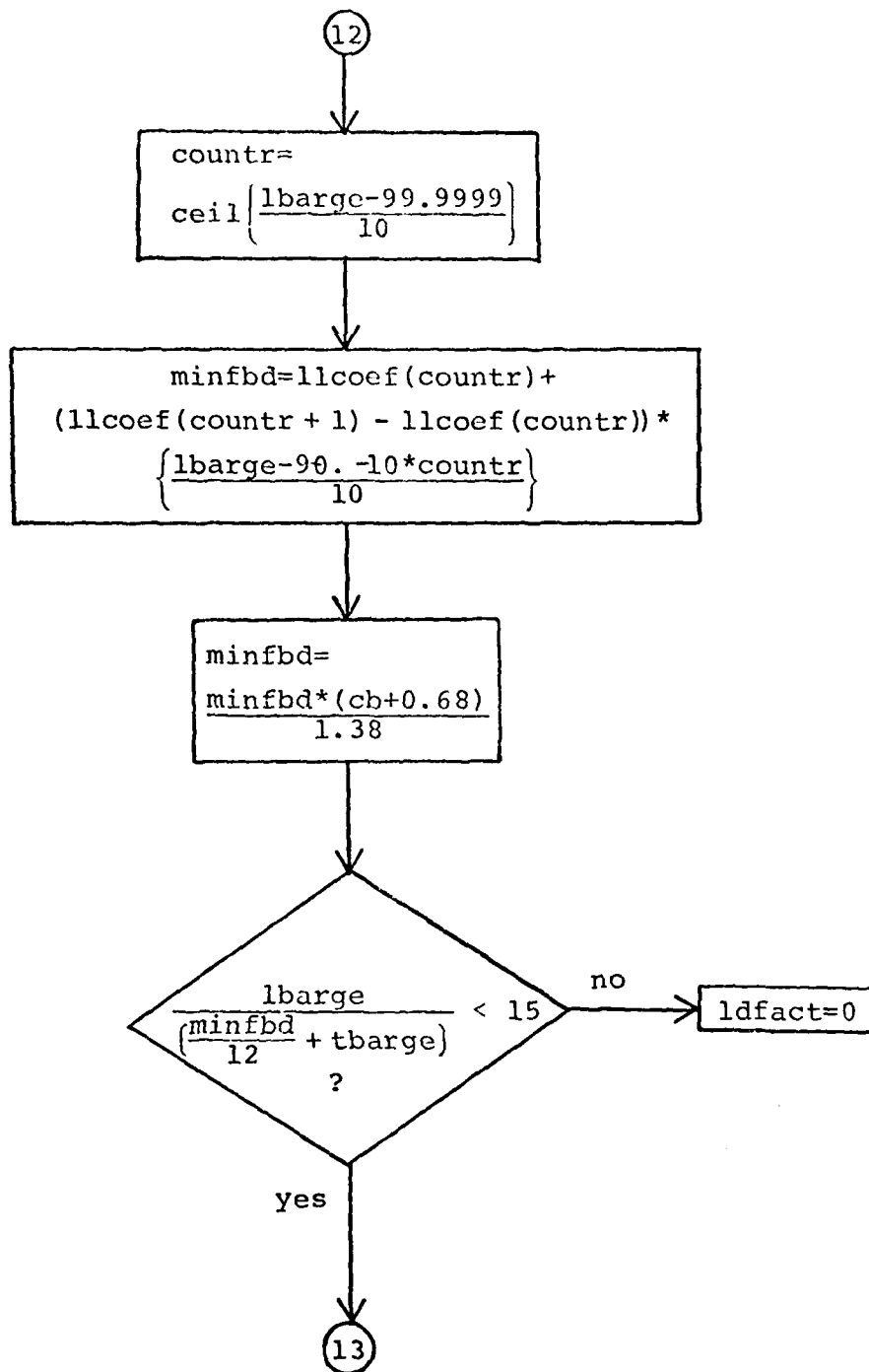
hullwt85=

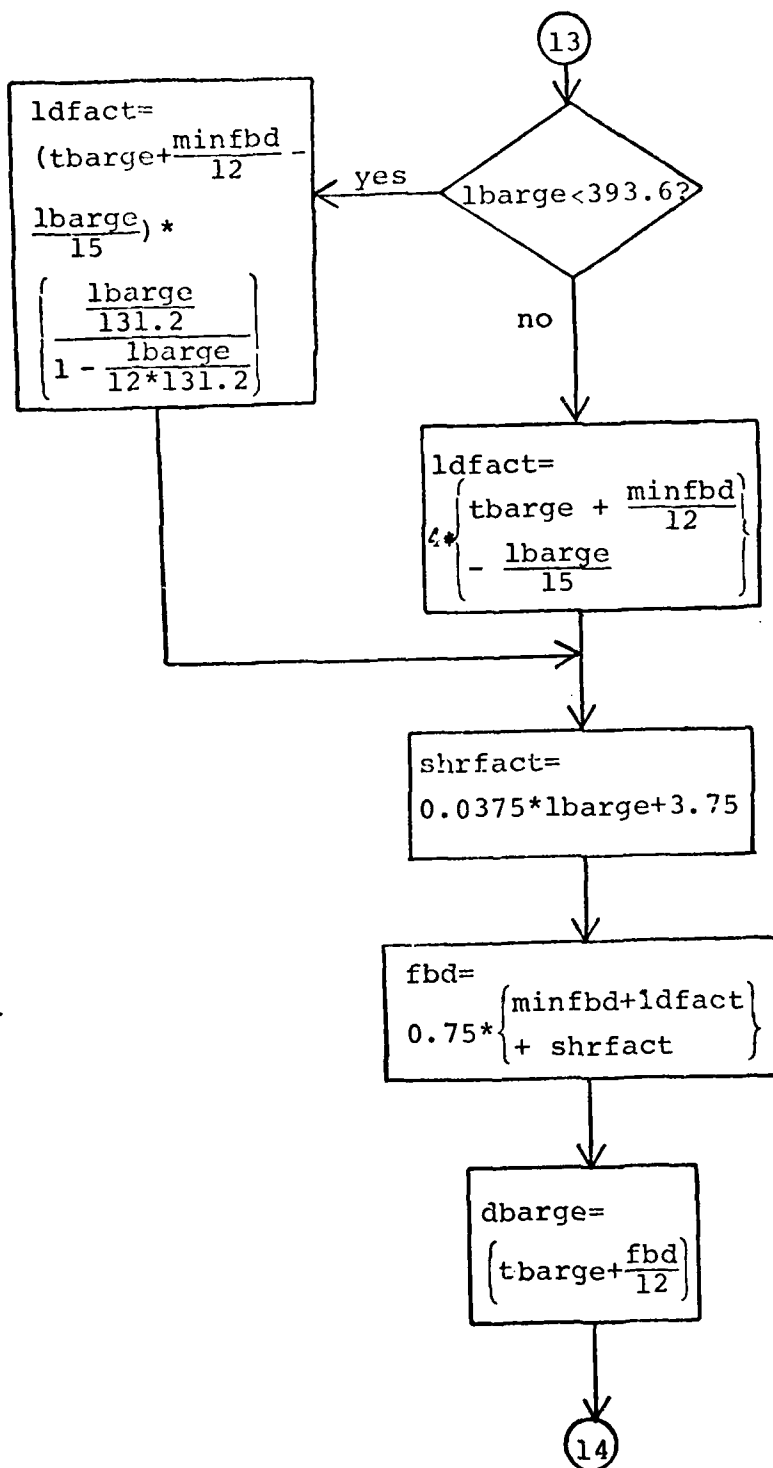
$$e^{-6.569 * bt^{0.930} * lb^{1.391} * dwt^{1.117}}$$

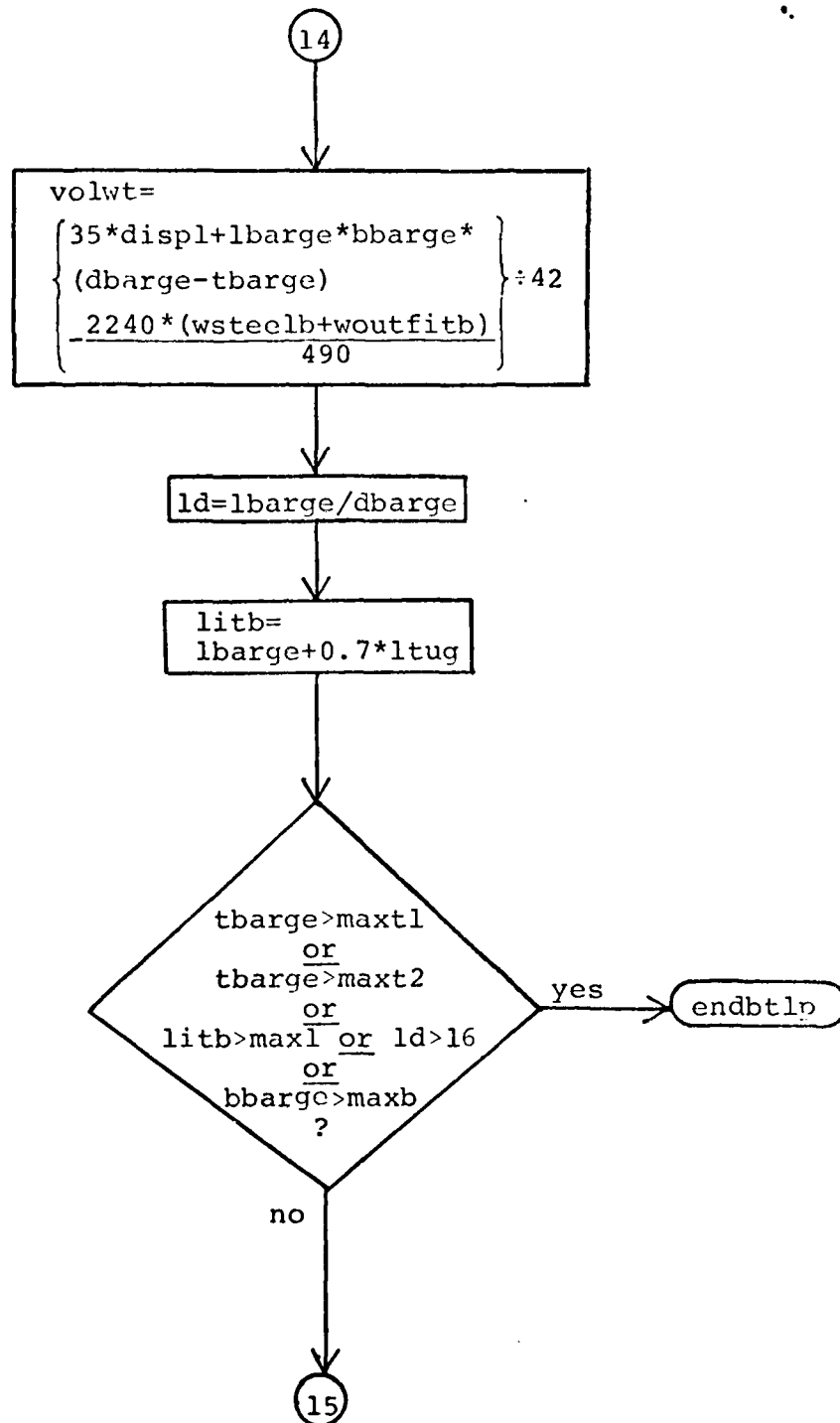
10

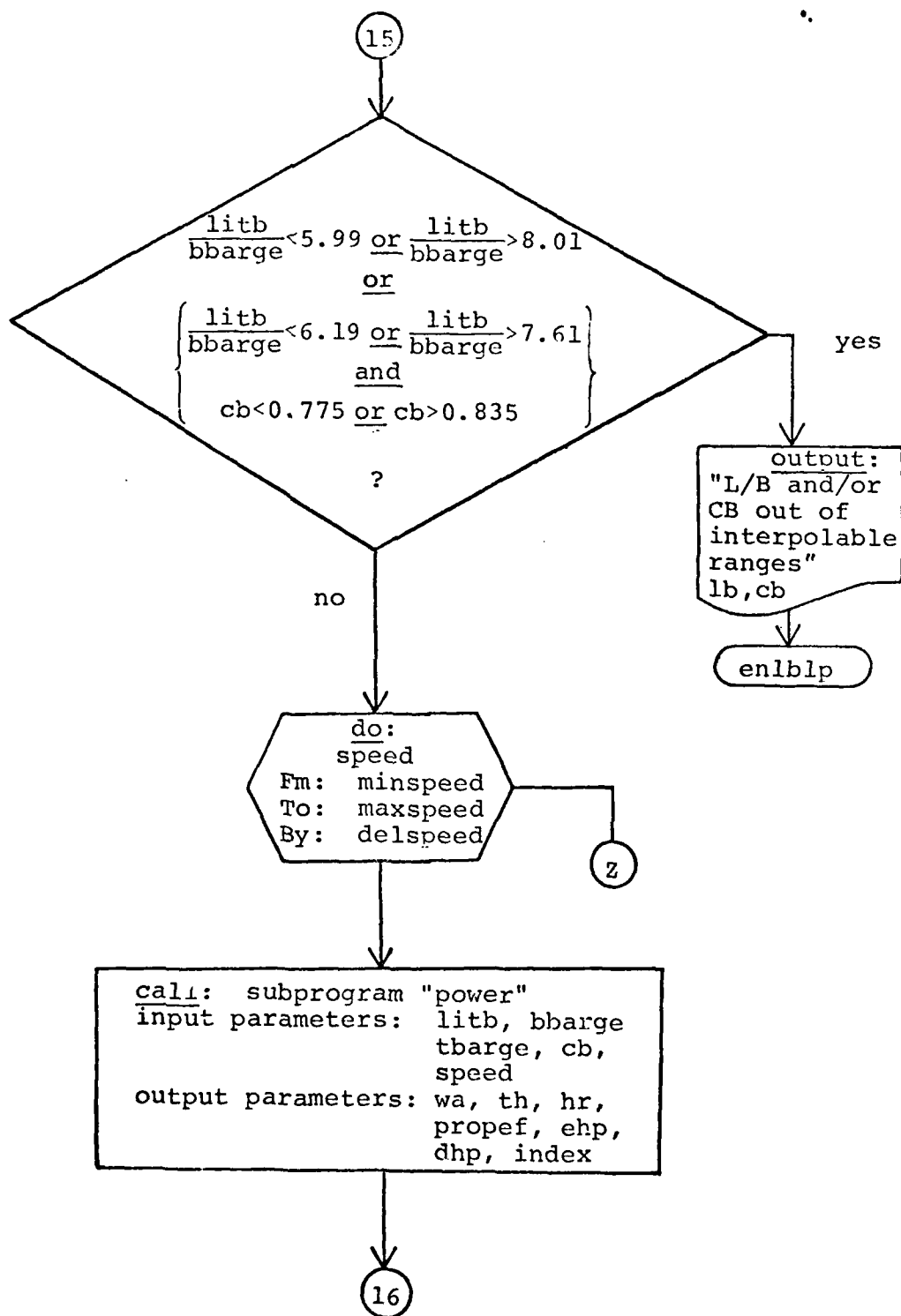


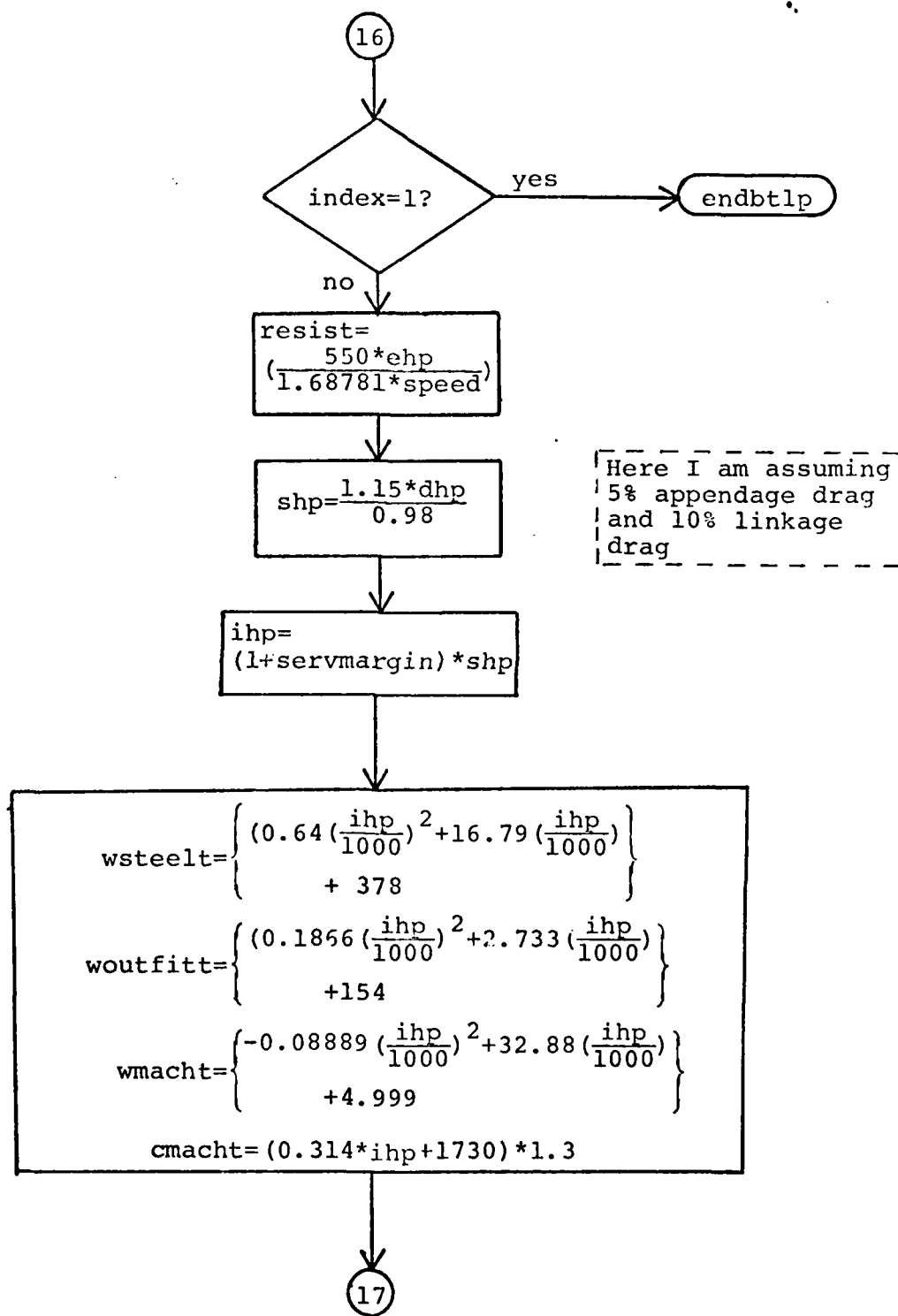


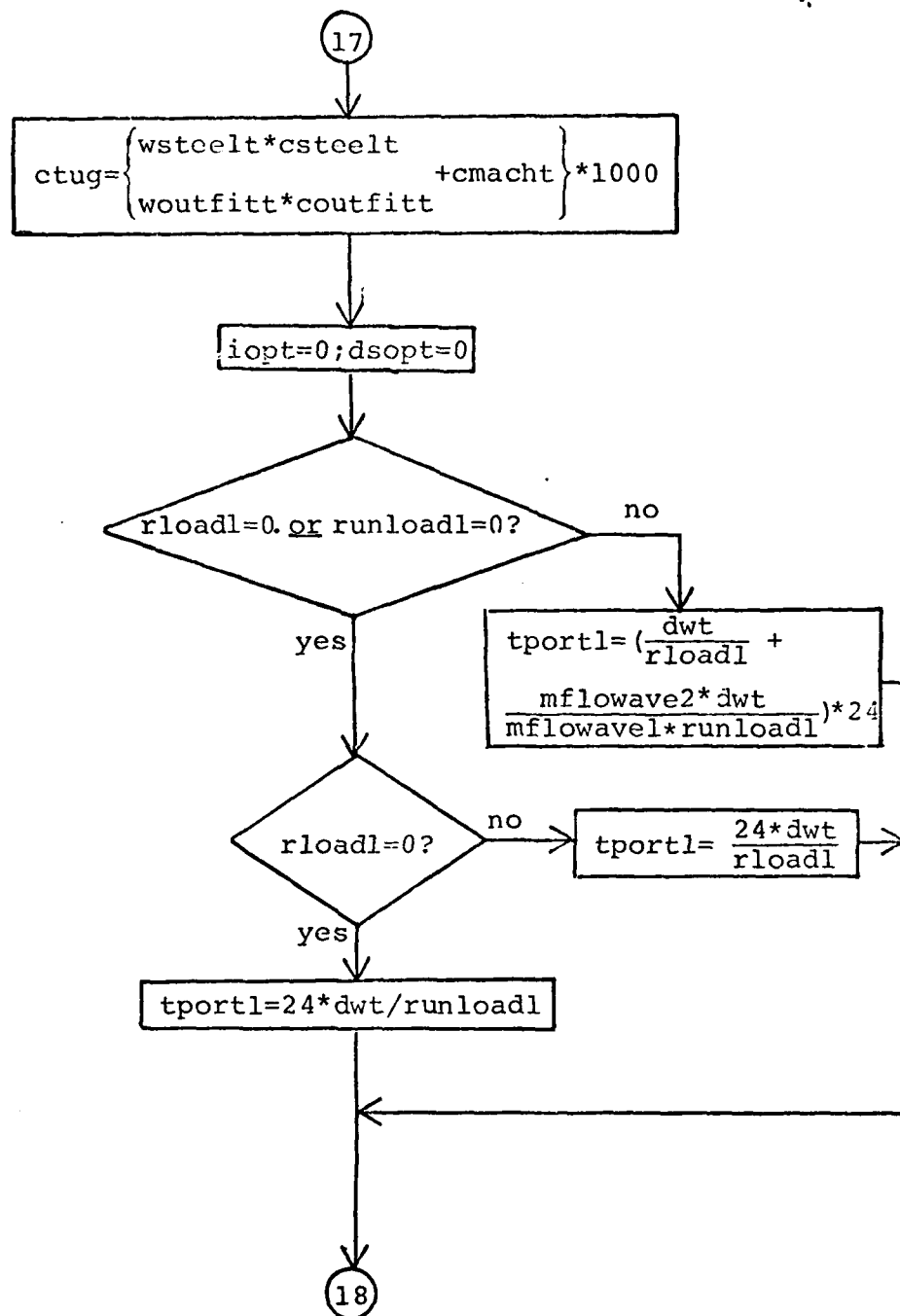


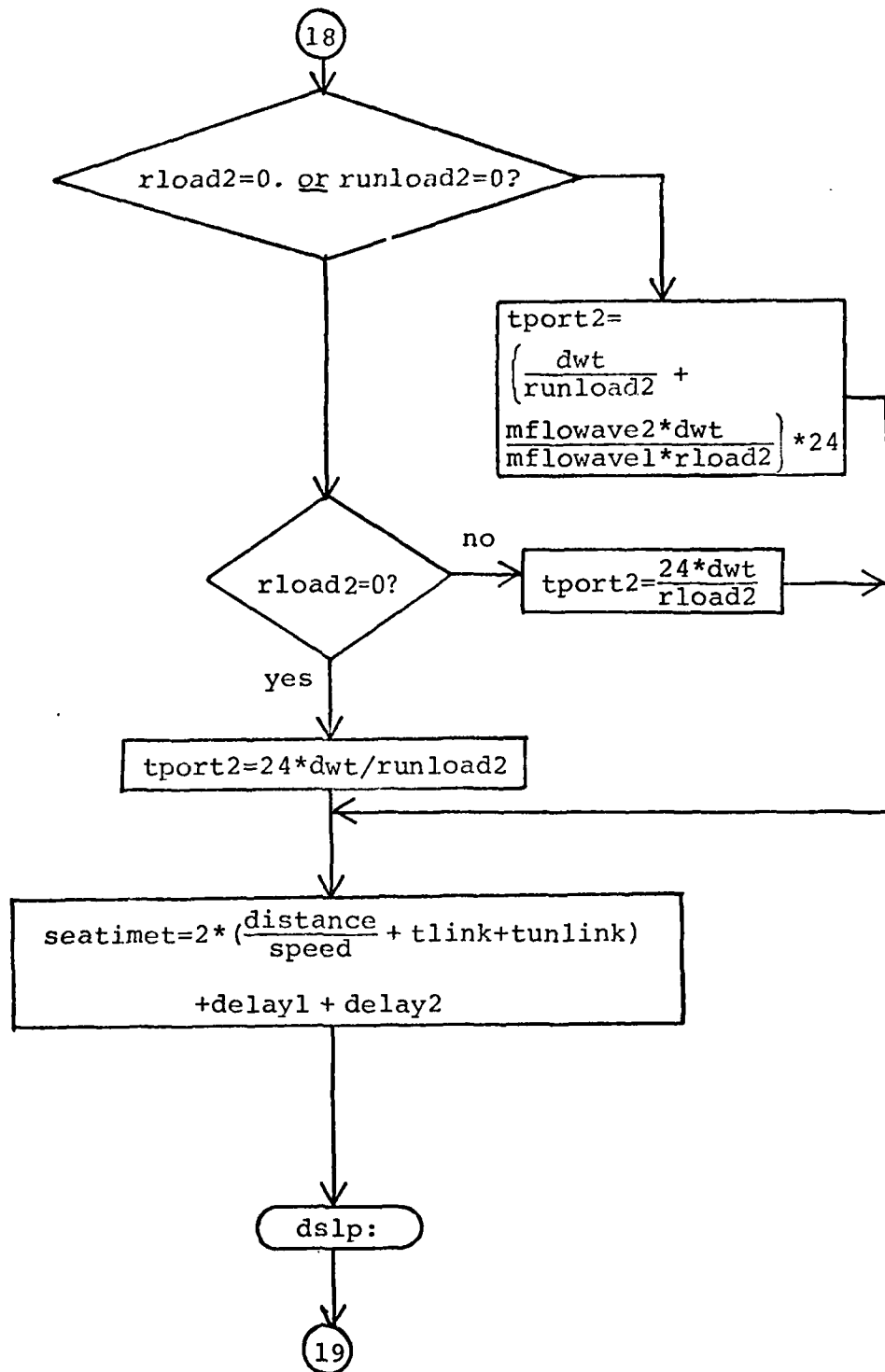


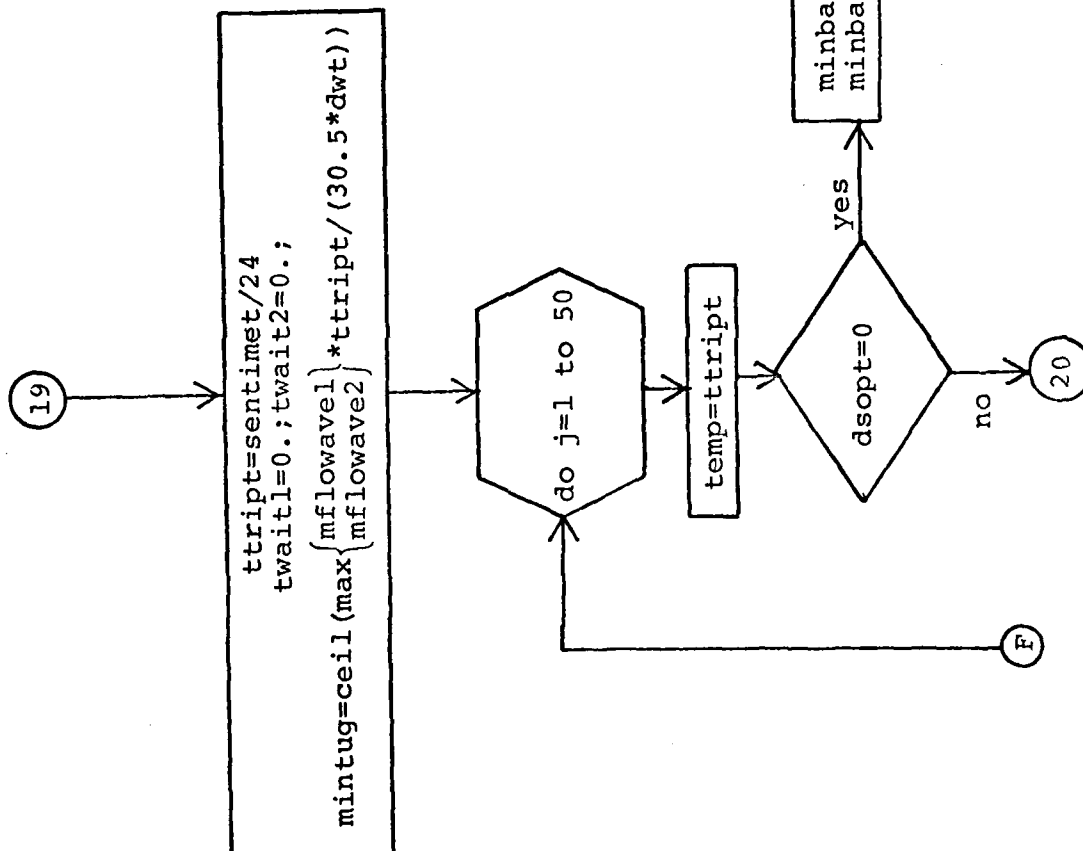




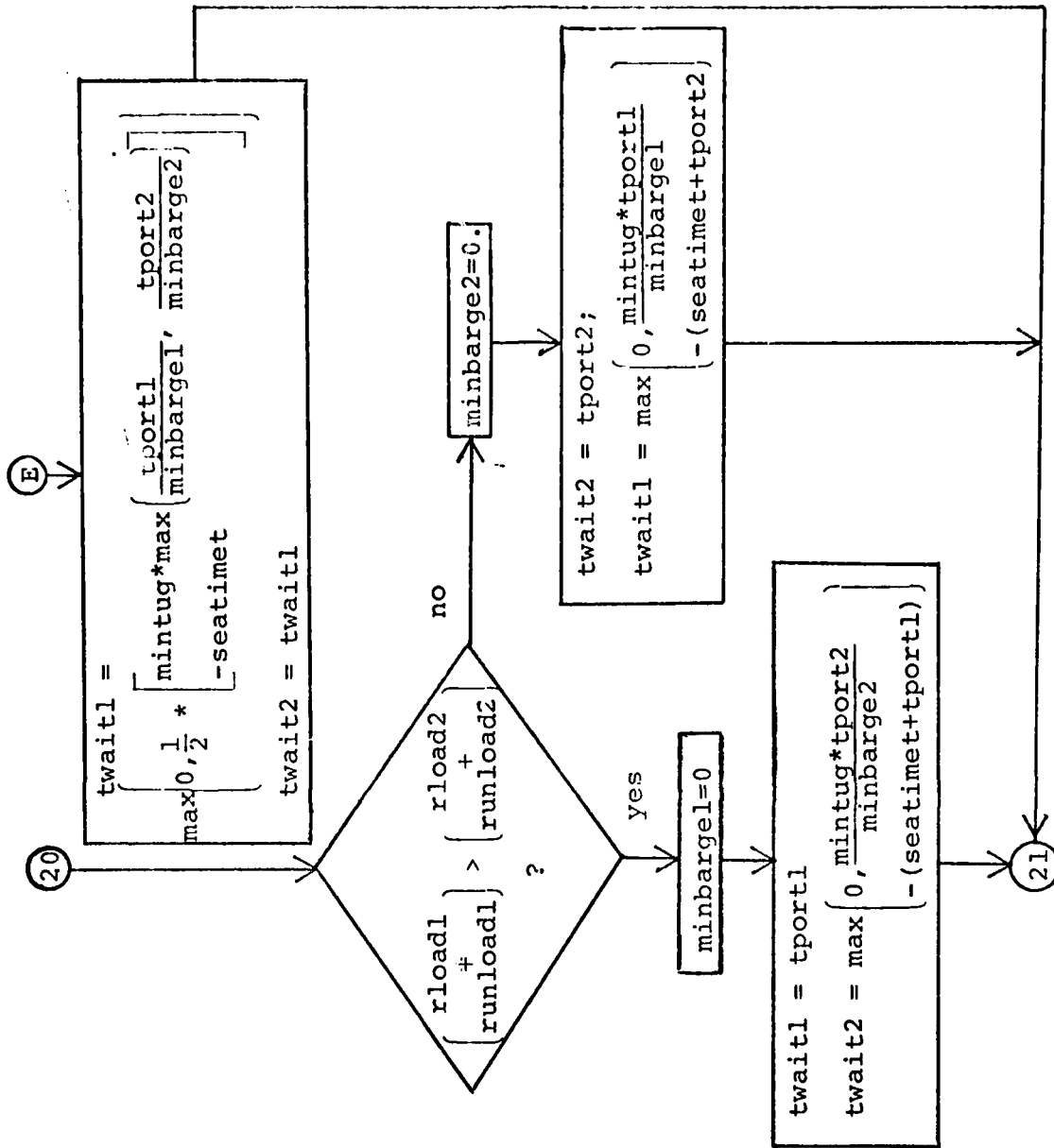


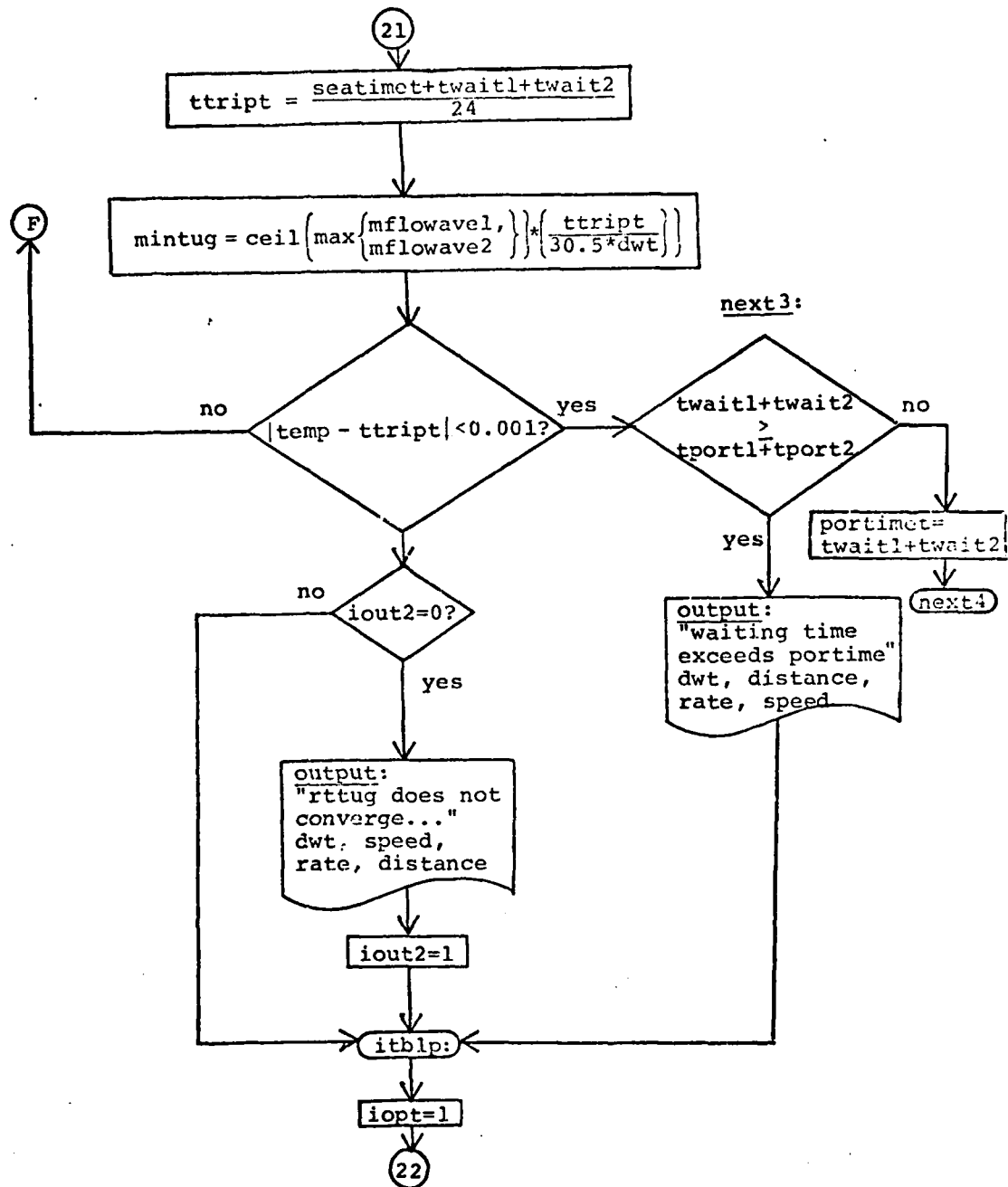


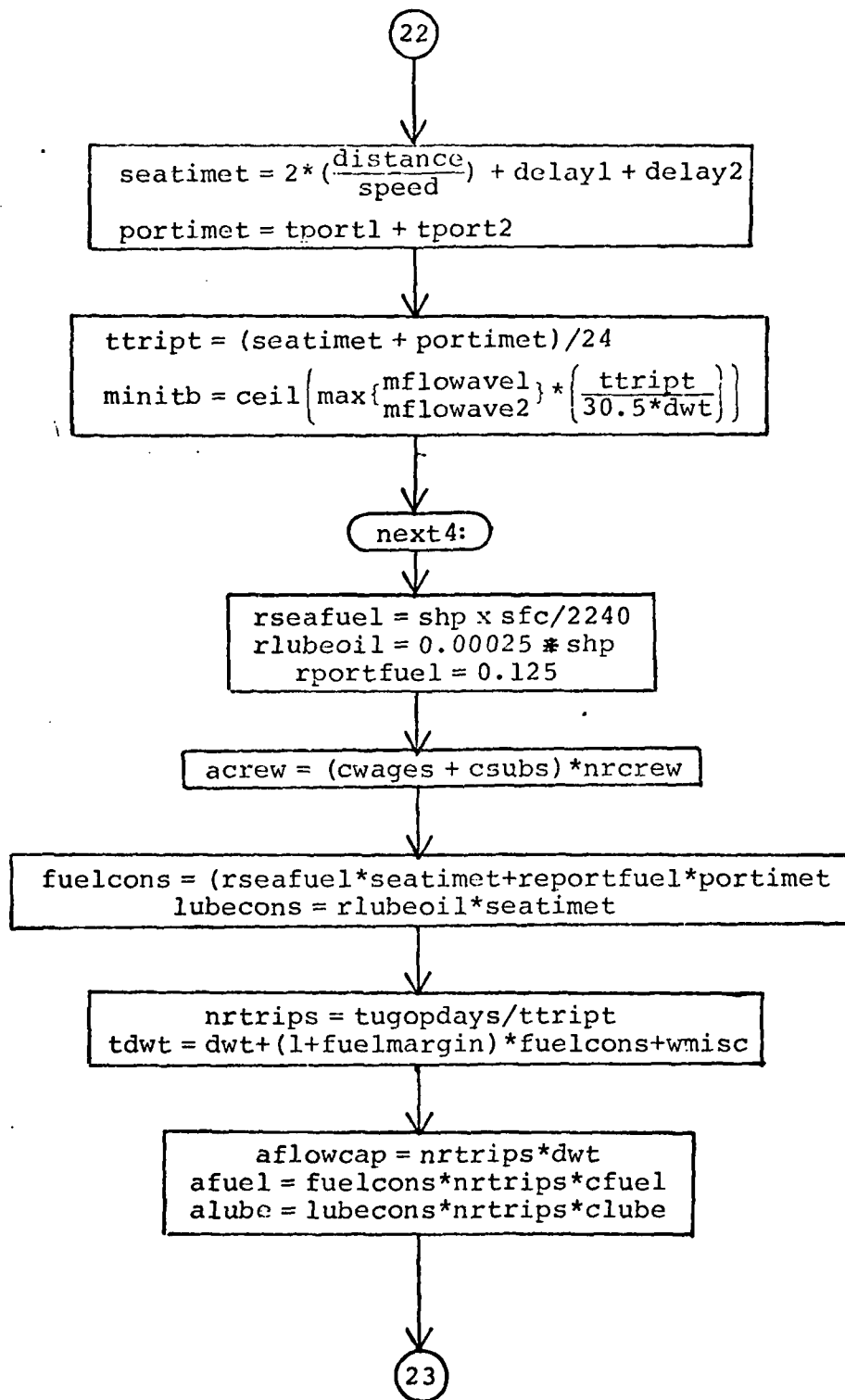




Below is the logic for determining the required tug waiting time for the drop and swap mode. For dsopt=0, barges are stationed at both ports. For dsopt=1, barges are stationed only at the port requiring longer port operations, none are stationed at the other port so the tug must wait for cargo operations there.







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$$amandr = \left\{ \begin{aligned} &128.8 + \frac{4.539 * ihp}{1000} - \left(\frac{0.2 * ihp}{1000} \right)^2 \\ &+ \frac{2.477 * tdwt}{1000} - 9.107 * 10^{-3} \left(\frac{tdwt}{1000} \right)^2 \end{aligned} \right\} 1500$$

$$ainsur = (210 + 0.0036 * ihp + 0.0018 * tdwt) 1500$$

$$asupplies = (40 + 0.0019 * ihp + 2.6 * 10^{-4} * tdwt) 1300$$

$$aport = (cfixport1 + cfixport2 + (cvarport1 + cvarport2) * dwt) * nrtrips$$

$$acargo = vcargo(aflowave1 + aflowave2) * disrate * \left(\frac{seatime}{48 * 365} \right)$$

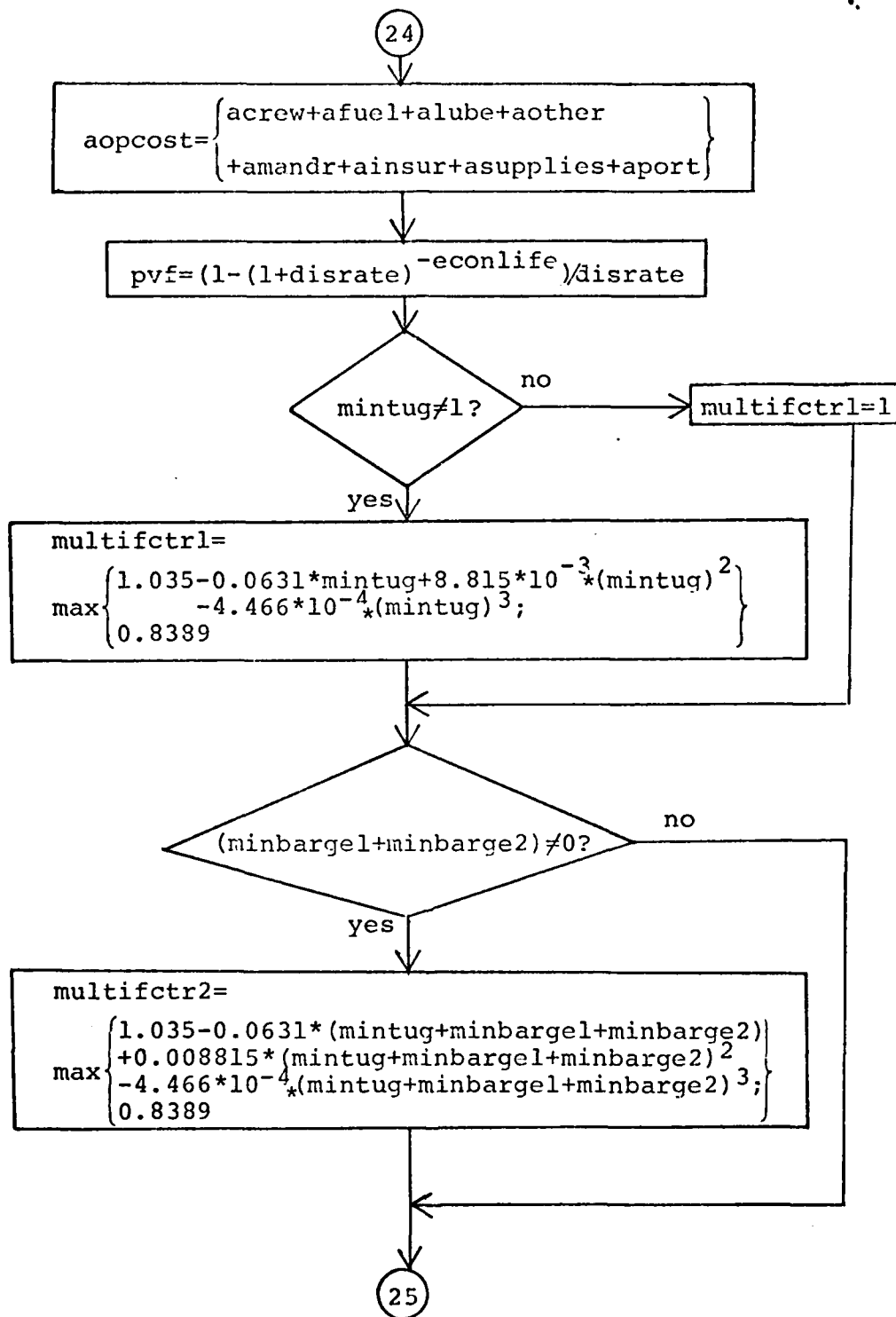
$$atermop = (aflowave1 + aflowave2) * cvarterm$$

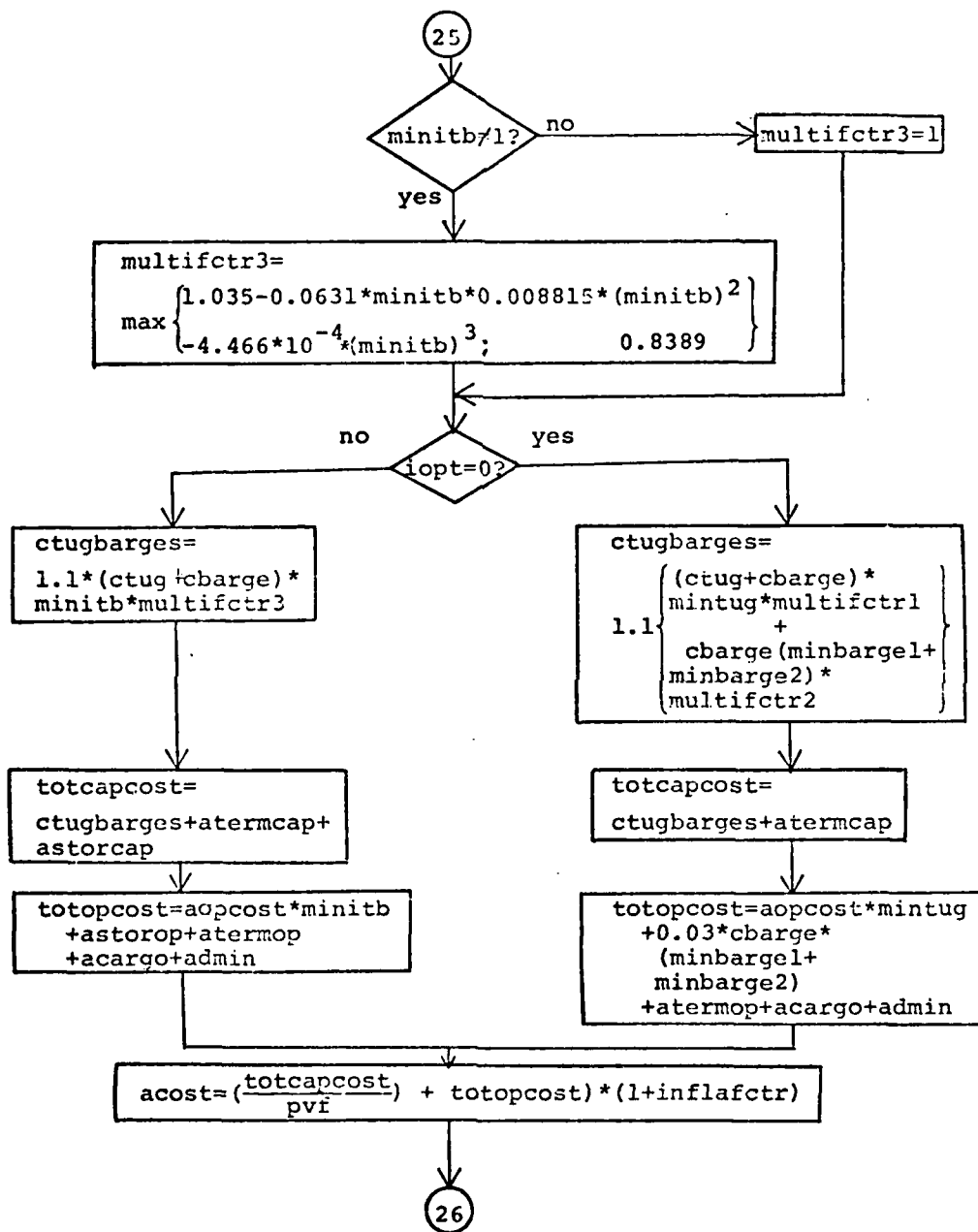
$$atermcap = ((rload1 + runload1) * minbrg1 + (rload2 + runload2) * minbrg2) * cfixterm$$

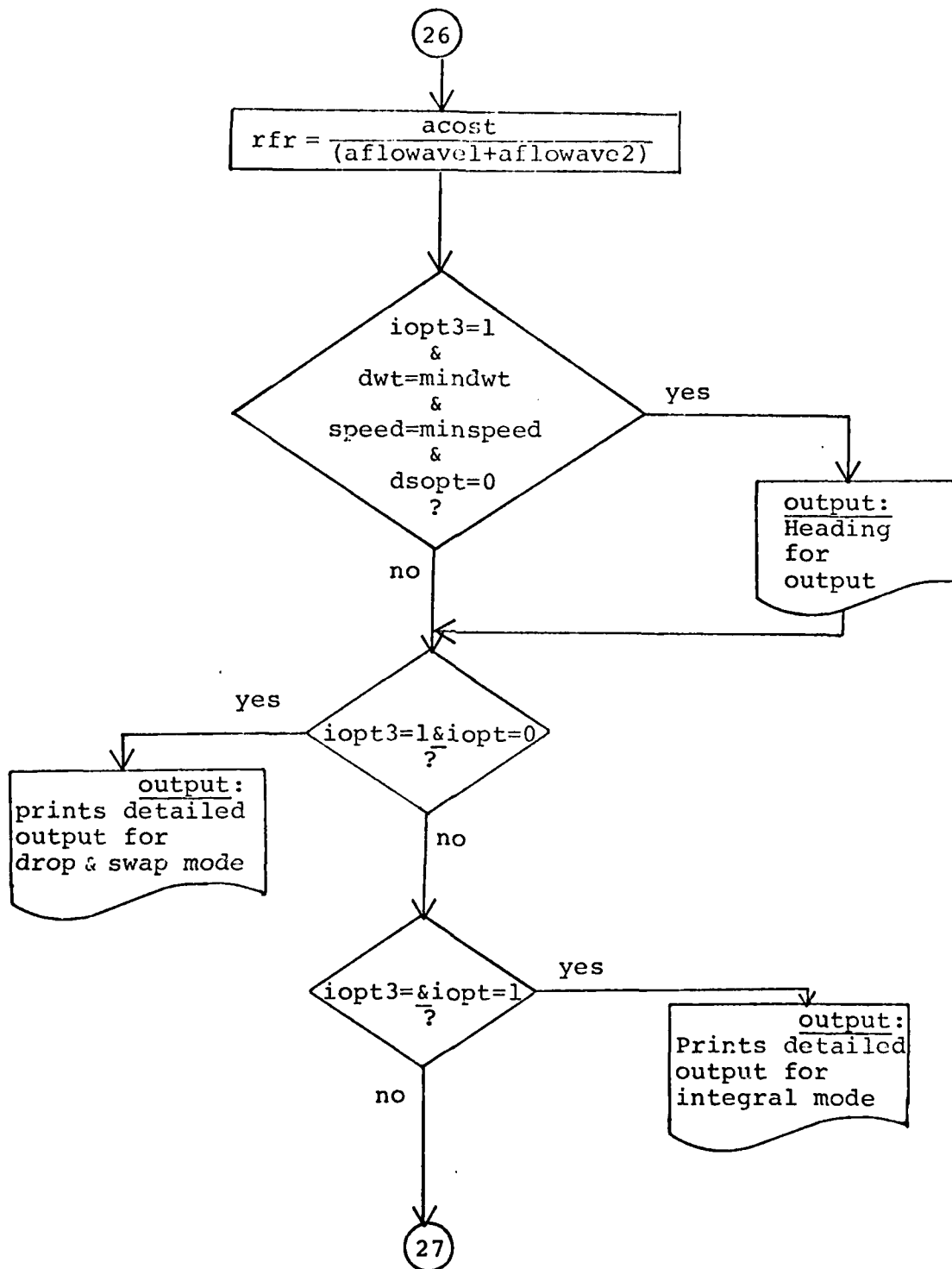
$$astorop = (aflowave1 + aflowave2) * cvarstor$$

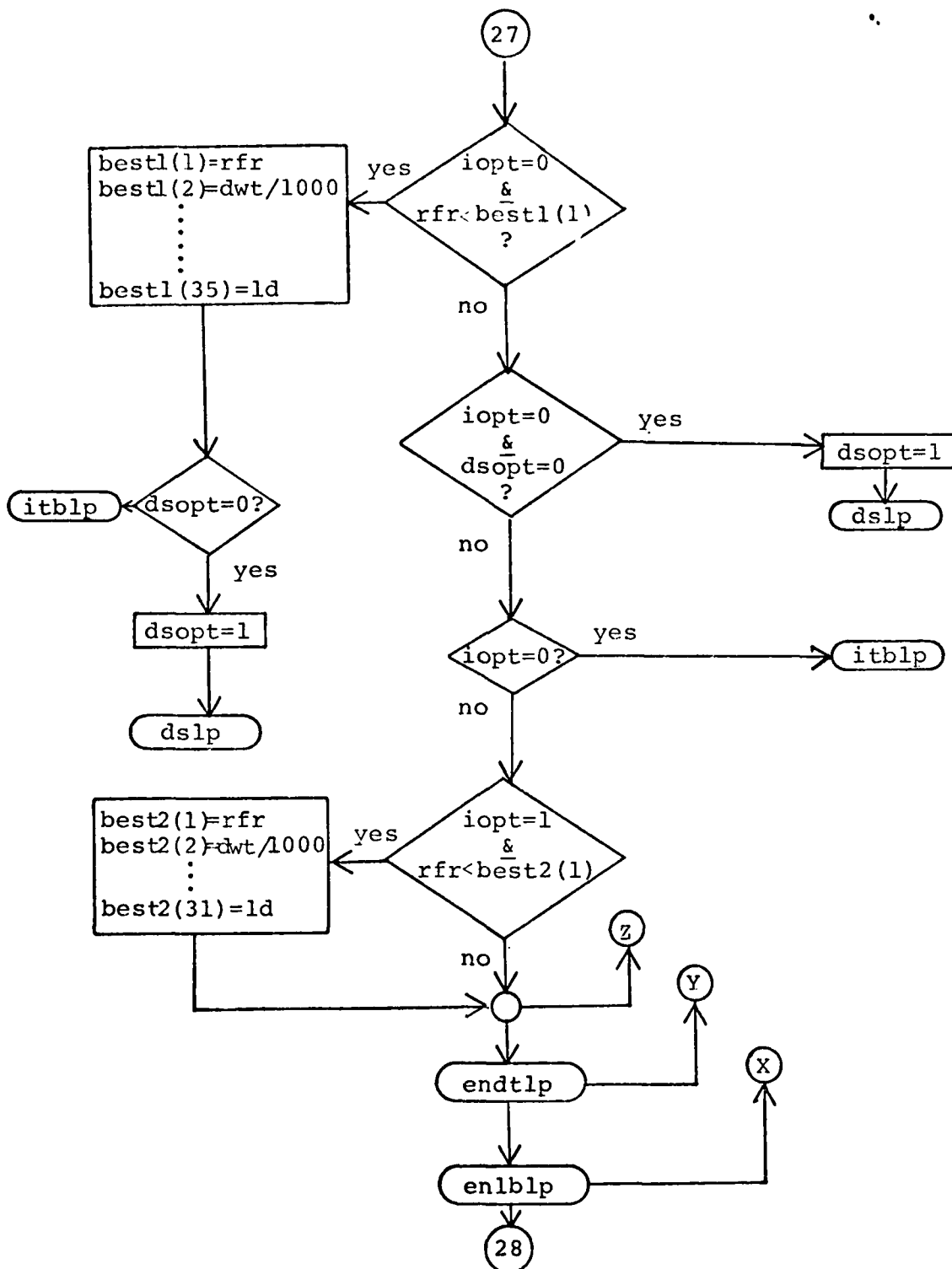
$$astorcap = dwt * (minbrg1 + minbrg2) * cfixstor$$

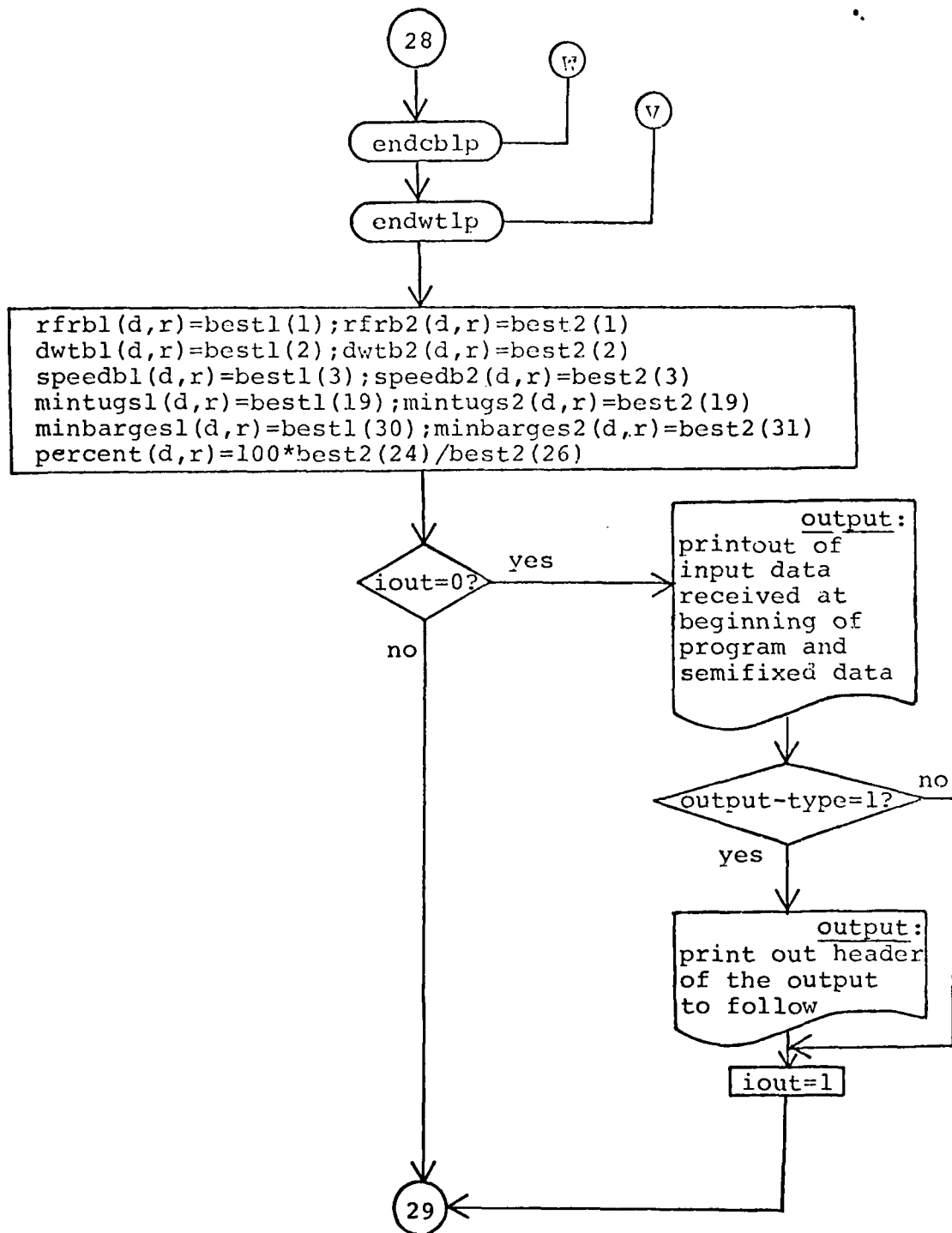
24











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MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN E--ETC F/G 15/5
OPERATIONAL EVALUATION OF TUG/BARGE SYSTEMS.(U)
JUL 79 J D KASKIN

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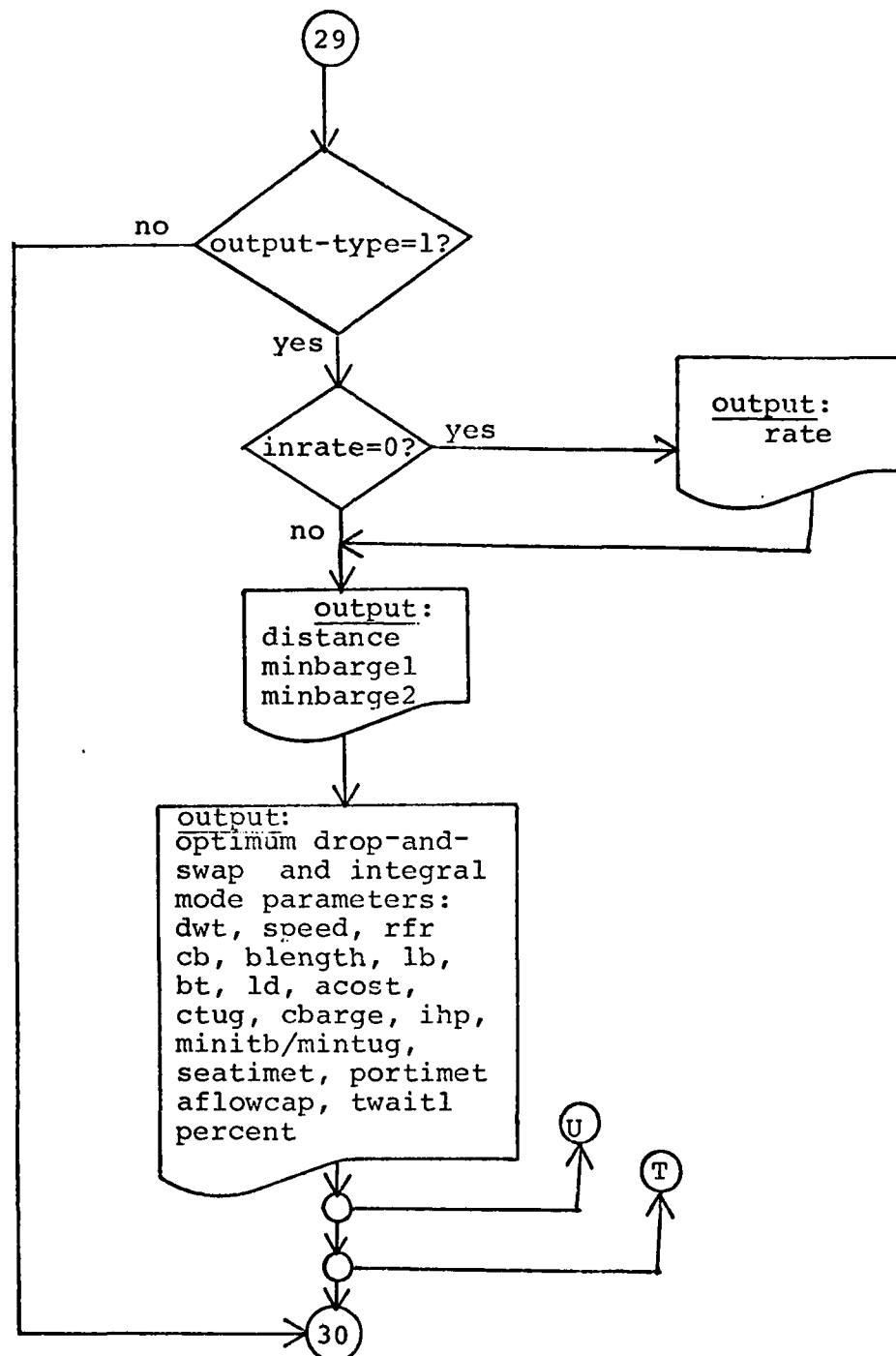
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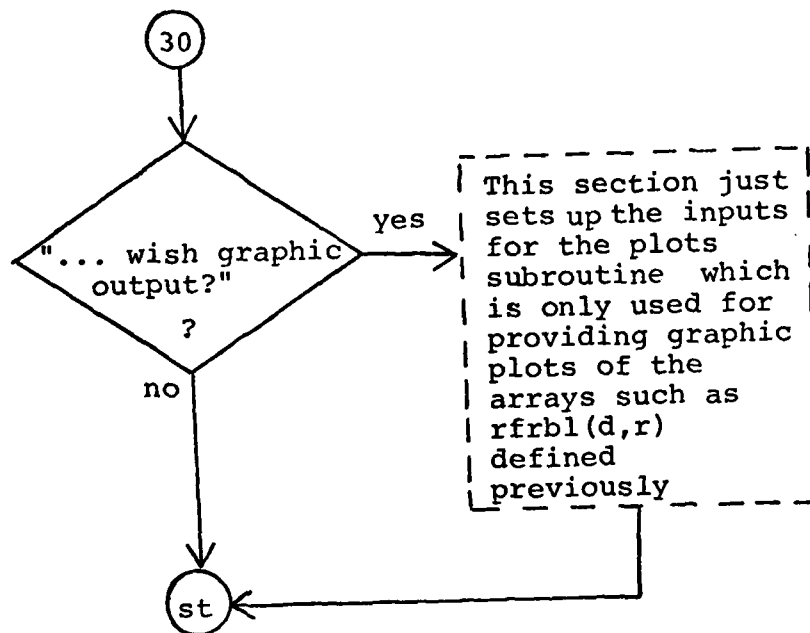
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D.5 DICTIONARY OF VARIABLES USED IN THE
 DROP-AND-SWAP COMPUTER MODEL

DEFINITION OF VARIABLES IN THE PROGRAM "drop-and-swap"

<u>Variable</u>	<u>Definition (units)</u>
acargo:	Annual Time Value for Cargo Cost. Total annual cost for the time value of the cargoes onboard the barge while being transported. The product of the annual discount rate times the seetime times the cargo_value. (\$)
acost:	Annual Cost. Total annual cost for either drop-and-swap or integral OGTB system, including annual operating costs and annualized present value share of capital costs. (\$)
acrew:	Annual Crew Cost. Annual costs for crew, including wages and subsistence, for a tug. (\$/tug)
admin:	Annual Administrative Costs. Annual costs for administration of tug. (\$/tug)
aflowave1:	Annual Average Cargo Flow from Port 1. Average annual flow of cargo to be loaded at Port 1 and discharged at Port 2. (cargo units)
aflowave2:	Annual Average Cargo Flow from Port 2. Average annual flow of cargo to be loaded at Port 2 and discharged at Port 1. (cargo units)
aflowcap:	Annual Flow Capacity. Annual amount of cargo capacity provided by each tug, product of barge DWT and number of tug voyages. (cargo units)
afuel:	Annual Fuel Cost. Annual cost for fuel for a tug; product of the number of tug voyages, fuel consumption per voyage, and unit cost of fuel. (\$/tug)
ainsur:	Annual Insurance Premiums. Annual cost for insurance for a tug-barge unit. (\$/tug-barge)

alube: Annual Lube Oil Costs. Annual cost for lube oil for a tug; product of the number of tug voyages, lube oil consumption per voyage and unit cost of lube oil. (\$/tug)

amandr: Annual M&R Costs. Annual cost for maintenance and repair of a tug-barge unit. (\$/tug-barge)

aopcost: Annual Operating Cost. Annual costs for operating a tug-barge unit. (\$/tug-barge)

aother: Annual Other Costs. Other annual miscellaneous operating costs not included in admin, afuel, alube, ainsur, amandr, acrew, asupplies, and aport. (\$/tug)

aport: Annual Port Charges. Annual costs for port charges for each tug, including variable and fixed charges for Port 1 and Port 2. (\$/tug)

astorcap: Annual Capital Cost for Storage Facilities. The cost for shoreside storage facilities required for the integral mode of operation. The product of the number of loading/discharging facilities, the barge size, and a cost factor ("cfixstor"). (\$)

astorop: Annual Operating Costs for Storage Facilities. The annual operating cost incurred for the operation or use of shoreside storage facilities required for the integral mode of operation. The product of the annual cargo flows and a cost factor ("cvarstor"). (\$/yr)

asupplies: Annual Supplies Cost. Annual costs for stores, supplies, and equipment for each tug-barge unit. (\$/tug-barge)

atermcap: Total Capital Cost for Loading/Discharging Facilities. The capital cost for shoreside terminal facilities. The product of the terminal facilities throughput rate and a cost factor ("cfixterm"). (\$)

atermop: Annual Operating Cost for Loading/Discharging Facilities. The annual operating costs incurred for the operation or use of the shoreside terminal facilities. The product of the annual cargo flows and a cost factor ("cvarterm"). (\$/yr)

best1(33)	lb
best1(34)	bt
best1(35)	ld

blurb1,2,3: Subroutine Plots input parameters representing title of graph, vertical axis, and horizontal axis.

bt: Breadth-Draft Ratio. The ratio of the tug-barge unit's breadth and draft. (ft)

ccharge: Cost of Barge. (\$)

c1,c2: Coefficient arrays used only as input parameters in the calling of subprogram "power"; values are used in subroutine "prop" of subprogram "power."

cb: Block Coefficient. The block coefficient of the tug-barge unit.

cf: Coefficient of Frictional Resistance for OGTB.

cfixport1: Fixed Port Charges for Port 1. Cost of fixed port charges of tug/barge at Port 1 per voyage. (\$/voyage)

cfixport2: Fixed Port Charges for Port 2. Cost of fixed port charges of tug/barge at Port 2 per voyage. (\$/voyage)

cfixstor: Storage Facility Capital Cost Factor. The cost per long ton for shoreside storage facilities used in the integral mode. (\$/LT)

cfixterm: Terminal Facility Capital Cost Factor. The cost per long ton per day throughput rate for terminal facilities. (\$/LT-day)

cfuel: Cost of Fuel. Diesel fuel cost per ton. (\$/LT)

clube: Cost of Lube Oil. Lube oil cost per gallon. (\$/Gal)

cmacht: Tug Machinery Cost. Cost of propulsion machinery onboard the tug; function of IHP. (\$1000/tug)

countr: Index for the loadline coefficient array(11coef) used in the calculation of the variable "minfbd".

countfitb: Barge Outfit Cost. Cost of a ton of outfit material onboard the barge. (\$1000/LT)

coutfitt: Tug Outfit Cost. Cost of a ton of outfit onboard the tug. (\$1000/LT)

csteelb: Barge Steel Cost. Cost of a ton of hull steel onboard the barge. (\$1000/LT)

csteelt: Tug Steel Cost. Cost of a ton of hull steel onboard the tug. (\$1000/LT)

csubs: Cost of Subsistence. Annual subsistence cost per crew member. (\$/man)

ctug: Cost of Tug. Initial capital cost of a tug as a function of steel and outfit weight and machinery cost. (\$/tug)

ctugbarges: Cost of Tug and Barges. Total capital cost of all tugs and barges in the system. (\$)

cvarport1: Variable Port Charges for Port 1. Cost per cargo unit capacity for port charges at Port 1 per voyage. (\$/cargo unit and voyage)

cvarport2: Variable Port Charges for Port 2. Cost per cargo unit capacity for port charges at Port 2 per voyage. (\$/cargo unit and voyage)

cvarstor: Storage Facility Operating Cost Factor. The cost per long ton stored in the integral mode. (\$/LT)

cvarterm: Terminal Facility Operating Cost Factor. The cost per long ton moved through a terminal facility. (\$/LT)

cwage: Cost of Wages. Annual benefit and wage cost per crew member. (\$/man)

d: Distance Index. Index used to represent the variable distance in optimum system arrays-rfrb1, rfrb2, dwtb1,...mintugs.

dbarge: Depth of Barge. (ft)

delay1: Port 1 Delay Time. Length of delay at Port 1 prior to and after cargo operations, including docking/undocking and awaiting berth time for the barge. (hrs)

delay2: Port 2 Delay Time. Same as "delay1" except for Port 2.

delbt: Breadth-Depth Ratio Increment. The incremental B/T to be used while varying the tug-barge breadth-depth ratio from its minimum to its maximum value.

delcb: Block Coefficient Increment. The incremental C_b to be used while varying the tug-barge block coefficient from its minimum to its maximum value.

deldist: Distance Increment. The incremental distance to be used while varying the port separation distance from its minimum to its maximum value. (nautical miles)

deldwt: Deadweight Increment. The incremental deadweight to be used while varying the barge deadweight from its minimum to its maximum value. (cargo units)

dellb: Length-Breadth Ratio Increment. The incremental l_b to be used while varying the tug-barge length-breadth ratio from its minimum to its maximum value.

delrate: Loading/Discharge Rate Increment. The incremental L/D rate to be used while varying the L/D from its minimum to its maximum value. (cargo units/day)

delspeed: Tug Speed Increment. The incremental tug speed to be used while varying the tug speed from its minimum to its maximum value. (kts)

dhp: Delivered Horsepower. Horsepower required to be delivered to the propeller to drive the tug-barge unit "speed" knots.

displ: Barge Displacement. (LT)

disrate: Discount Rate. Discount rate to be used in present value calculations.

distance: Port Separation Distance. Distance between Port 1 and Port 2 in miles. (nautical miles)

dq: Coefficient array used only as an input parameter in the calling of subprogram "power"; values are used in subroutine "prop" of subprogram "power."

drange: Distance Range. Number of port separation distances to be investigated.

dsopt: Drop and Swap Option. This option enables the program to investigate two types of drop-and-swap configurations. When dsopt=0, both ports have a minimum of one barge stationed for L/D. When dsopt=1, the port with lowest L/D time has no barges stationed for L/D and tug remains with barge while in port.

dt: Coefficient array used only as an input parameter in the calling of subprogram "power"; values are used in subroutine "prop" of subprogram "power."

dwt: Barge Deadweight. (cargo capacity units)

dwtb1: Array variable used to store the barge deadweight size of the optimum drop-and-swap system for given port separation distance and L/D rates. (cargo capacity units)

dwtb2: Same as dwtb1 except for integral system. (cargo capacity units)

econlife: Economic Life. Economic life of the OTGB system used in present value calculations. (yrs)

ehp: Effective Horsepower. Horsepower required to be delivered by the propeller to drive the tug-barge unit "speed". knots.

eta: Relative Rotative Efficiency Array. Array of relative rotative efficiency (x1000) values used as input parameters in the calling of subprogram "power"; values are used in subroutine "propfactors" of subprogram "power."

fbd: Barge Freeboard. (in)

fuelcons: Fuel Consumption. Amount of fuel consumed by the tug per voyage. (LT/voyage)

fuelmargin: Fuel Margin. Percentage of fuel above "fuelcons" required to be onboard tug after bunkering.

graph_type: Subroutine Plots inputs parameter used to designate type of graphical output. If equals 0, loading rate is abscissa; if equals 1, distance is abscissa.

hr: Relative Rotative Efficiency. Relative rotative efficiency (η_R) of tug-barge hull form.

hullwt75: Hull steel weight for tug-barge unit with $C_b=0.75$ as a function of lb, bt, and dwt. (LT)

hullwt80: Hull steel weight for tug-barge unit with $C_b=0.80$ as a function of lb, bt, and dwt. (LT)

hullwt85: Hull steel weight for tug-barge unit with $C_b=0.85$ as a function of lb, bt, and dwt. (LT)

i: Index Parameter used in do loop to solve for Co-efficient of Frictional Resistance for OGTB.

ibit: Subroutine "yesno" output value designating response of user to a question. If yes was signified, ibit equals 1; if no was signified, ibit equals 0.

ihp: Installed Horsepower. Horsepower of engines installed onboard tug. (horsepower)

index: Subprogram "power" Error Index. An index used to indicate if some calculation error occurred during the call of subprogram "Power".

inflafctr: Inflation Factor. A factor used to correct the total annual cost ("acost") for inflation after January 1979.

inrate: Loading/Discharging Rate Input Option Parameter. If equals 0, then the rate of loading and discharge at each port will be the same and equal at each port and will be systematically varied from the minimum to the maximum specified value. If equals 1, the loading and discharge rate at each port will be required input.

iopt: Drop and Swap/Integral Mode Option. This option is used in the main computations. When it equals 0, then drop-and-swap calculations are executed. When it equals 1, then integral mode calculations are executed.

iopt3: Detailed Output Option. This option is used to specify how much detail is desired in the output. When it equals 0, only the optimum drop-and-swap and integral system values are printed out for a given distance and loading/discharging rate. When it equals 1, drop-and-swap and integral mode

values are printed for every value of dwt, speed, distance, rate, cb, bt, and lb.

iout: Output of Input Data Option. This option is used to insure that the input parameter values are printed only once. When 0, input is printed; when 1, input is not printed.

iout2: Output of Nonconvergence Message Option. This option is used to insure that the message of nonconvergence of the waiting time routine is printed only once for a given L/D rate and port separation distance. If equals 0, message will be printed. When equals 1, message will not be printed.

iout3: Form Coefficient Under/Overflow Indicator. This variable is set to 1 if either lb, bt, or cb values are out of interpolable ranges. Otherwise its value is zero. It is used in the program to allow the user to revise his form coefficient inputs without having to input any other data.

j: Index parameter used in do loop to solve for waiting times, voyage times, and minimum tugs required in drop-and-swap mode. Also used in Yesno Subroutine.

lb: Lenth-Breadth Ratio. The ratio of tug-barge unit's length and breadth. (ft)

lbarge: Length of Barge. (ft)

lbarge75: Length of barge with $C_b=0.75$ as a function of lb, bt, and dwt. (ft)

lbarge80: Length of barge with $C_b=0.80$ as a function of lb, bt, and dwt. (ft)

lbarge85: Length of barge with $C_b=0.85$ as a function of lb, bt, and dwt. (ft)

ld: Length-Depth Ratio. The ratio of barge length and barge draft. (ft)

ldfact: Length-Depth Ratio Loadline Factor. This factor is used to correct the tabulated minimum free-board value (minfbd) for length-depth ratios less than 15.

litb: Length of Integrated Tug/Barge Combination. (ft)

llcoef: Minimum Loadline Coefficient Array. From this array the value of minfbd is found via linear interpolation with respect to length.

llfact: Minimum Loadline Coefficient File. The file in which llcoef is stored.

ltug: Length of Tug. (ft)

lubecons: Lube Oil Consumption. Amount of lube oil consumed by the tug per voyage. (gals/voyage)

maxb: Maximum Beam. Maximum barge beam allowed during voyage. (ft)

maxbt: Maximum Breadth-Draft Ratio. Maximum tug-barge bt value to be investigated.

maxcb: Maximum Block Coefficient. Maximum barge block coefficient to be investigated.

maxdist: Maximum Distance. Maximum port separation distance to be investigated. (nautical miles)

maxdwt: Maximum Deadweight. Maximum barge cargo deadweight capacity to be investigated. (cargo units)

maxl: Maximum Length. Maximum OGTB length allowed during voyage. (ft)

maxlb: Maximum Length-Breadth ratio. Maximum tug-barge L/B value to be investigated.

maxrate: Maximum Loading/Discharge Rate. Maximum port L/D rate to be investigated. (cargo units/day)

maxspeed: Maximum Speed. Maximum tug speed to be investigated. (kts)

maxt1: Maximum Draft Port 1. Maximum allowed draft in Port 1. (ft)

maxt2: Maximum Draft Port 2. Maximum allowed draft in Port 2. (ft)

mflowave1: Monthly Average Cargo Flow from Port 1. Average monthly flow of cargo to be loaded at Port 1 and discharged at Port 2. (cargo units)

mflowave2: Monthly Average Cargo Flow from Port 2. Average monthly flow of cargo to be loaded at Port 2 and discharged at Port 1. (cargo units)

minbargel: Minimum Barges/Terminal Facilities at Port 1. Minimum number of terminal facilities (and barges for drop-and-swap mode only) required at Port 1 in order to be compatible with Port 1 loading/discharging rates and flow requirements. (barges/facilities)

minbargel2: Same as minbargel except for Port 2. (barges/facilities)

minbarges1: Storage array for "minbargel" for the port pair trades under consideration. (barges/facilities)

minbarges2: Same as minbarges1 except for Port 2. (barges/facilities)

minbrg1,2: Storage variables for values of minbargel and minbargel2, respectively, used for drop-and-swap calculations when dsopt is 0.

minbt: Minimum Breadth-Draft Ratio. Minimum tug-barge B/T value to be investigated.

mincb: Minimum Block Coefficient. Minimum tug-barge Cb value to be investigated.

mindist: Minimum Distance. Minimum port separation distance to be investigated. (nautical miles)

mindwt: Minimum Deadweight. Minimum barge cargo deadweight capacity to be investigated. (cargo units)

mindwttemp: Temporary storage variable for the variable "mindwt" used for reducing the number of "dwt" iterations required.

minfbd: Minimum Freeboard. The uncorrected (or block coefficient corrected) minimum freeboard value as obtained after linear interpolation of the array llcoef.

minitb: Minimum OGTB. The minimum number of OGTB's required in the integral mode to provide sufficient flow capacity. (tug-barges)

minlb: Minimum Length-Breadth ratio. Minimum tug-barge

L/B value to be investigated.

minrate: Minimum Loading/Discharge Rate. Minimum port L/D rate to be investigated. (cargo units/day)

minspeed: Minimum Speed. Minimum tug operating speed to be investigated. (kts)

mintug: Minimum Tugs. Minimum number of tugs required in the drop-and-swap mode to provide sufficient flow capacity. (tugs)

mintugs1: Storage array for the minimum number of tugs required by the optimal drop-and-swap system for a given L/D rate and port separation distance. (tugs)

mintugs2: Storage array for the minimum number of OGTB's required by the optimal integral system for a given port L/D rate and port separation distance. (OGTBs)

multifctr13: Multiple Ship Cost Reduction Factors. Factors used to correct single unit costs for multi-unit orders for tugs and barges.

nextchar: Yesno Subroutine input variables used to test if yes or no response was given by user.

nrcrew: Number of Crew. Number of crew members required for a tug. (men)

nrtrips: Number of Trips. Number of voyages tug or OGTB can make during a year. (voyages/year)

o1,o2: Subroutine Plots Input Parameters representing the arrays of obscissa and ordinate coordinates of the points to be graphed.

output_type: Output Type Option. Allows user to designate whether printed output is desired. If equals 1, printed output is provided. If equals 0, printed output is not provided.

parameters: Name of file containing the semifixed parametric values used by the program.

percent: Array used to store the percentage that port time takes of the total voyage time for the port pair trades under consideration.

plot_: Subroutine used to graph output data.
 plot_scale: Subroutine used to set abscissa and ordinate scale minimum and maximum values.
 plot_setup: Subroutine used to set up the proper environment for the plot_ subroutine.
 portimet: Tug Porttime. Time tug or CGTB remains in port during a voyage. (hrs)
 power: Subprogram used to calculate the "dhp" and "ehp" as a function of the tug-barge system's principal dimensions and speed.
 powerdata: File used to store data required by subprogram "power".
 propef: Open Water Propeller Efficiency (η_o). The ratio of the power delivered by the propeller and the power delivered to the propeller in open water.
 pvf: Present Value Factor. Factor used in present value calculations; a function of the discount rate and economic life for the system.
 r: Iteration index used for port loading/discharging rates.
 rate: Loading/Discharging Rates. Daily amount of cargo which can be either loaded into or discharged out of a barge located at either port. Refers to each barge of the minimum required at that port. (cargo units/day)
 rc: Residual Resistance Array. Array of residual resistance coefficients used as input parameter for subprogram "power"; values are used in subroutine "resist" of subprogram "power."
 resist: Resistance. Total still water hydrodynamic resistance of the OGTB combination.
 rfr: Required Freight Rate. The amount of freight per cargo unit carried required to cover system operating and capital costs (present value annualized). (\$/cargo unit)
 rfrb1: Storage array for the minimum required freight rate found for a drop-and-swap system with

specified port L/D rate and port separation distance. (\$/cargo unit)

rfrb2: Same as for rfrb1 except for integral mode. (\$/cargo unit)

rload1: Loading Rate at Port 1. Daily cargo loading rate at Port 1. (cargo units/day)

rload2: Loading Rate at Port 2. Daily cargo loading rate at Port 2. (cargo units/day)

rlubeoil: Lube Oil Consumption Rate. Amount of lube oil consumed per hour. (gal/hr)

rportfuel: Inport Fuel Consumption Rate. Amount of Diesel fuel consumed per hour while tug is in port. (ton/hr)

rrange: Rate Range. Number of L/D rates to be investigated.

rseafuel: At Sea Fuel Consumption Rate. Amount of diesel fuel to be consumed per hour by the tug while steaming. (tons/hr)

runload1: Unloading Rate at Port 1. Daily cargo discharge rate per terminal at Port 1. (cargo units/day)

runload2: Unloading Rate at Port 2. Daily cargo discharge rate per terminal at Port 2. (cargo units/day)

seatimet: Tug Seetime. Time tug or OGTB is at sea; including delay time and linkage time (drop-and-swap mode only). (hours per voyage)

servmargin: Service Margin. Engine horsepower service margin used to calculate IHP.

sfc: Specific Fuel Consumption. Amount of diesel fuel consumed per horsepower per hour by the tug at sea. (lbs/hp-hr)

shp: Shaft Horsepower. Shaft horsepower required by tug to push OGTB through the water at the specified speed. (horsepower)

shrfact: Sheer Correction Factor. Correction to the free-board calculation due to lack of sheer expected in the barge form.

speed: Tug Speed. Tug designed service speed. (kts)
 speedb1: Storage array for the speed of the drop-and-swap system for a given port L/D rate and port separation distance. (kts)
 speedb2: Same as speedb1 except for integral mode. (kts)
 sysin: System input file
 sysprint: System output file
 t: Thrust Deduction Fraction Array. Array of one minus the thrust deduction fraction (x1000) values used as input parameter in the calling of subprogram "power"; values are used in subroutine "propfactors" of subprogram "power."
 tbarge: Barge Draft. (ft)
 tdwt: Total Deadweight of OGTB. Includes cargo deadweight capacity plus fuel and miscellaneous weights. (cargo units)
 temp: Temporary storage location used for various intermediate calculations.
 th: Thrust Deduction Fraction. Thrust deduction fraction (t) of the tug-barge form.
 tlink: Linking Time. Time required to link a tug with a barge for drop-and-swap operations. (hrs)
 toteapcost: Total Capital Cost. Total system capital costs for tugs, barges, terminal facilities, (and storage facilities for integral mode only). (\$)
 totopcost: Total Operating Costs. Total OGTB system operating costs. For drop-and-swap mode it includes M&R and insurance costs for those barges in excess of the number of tugs. (\$)
 tport1: L/D Time Spent in Port 1. Amount of time required for L/D operations at Port 1 per barge. (hrs)
 tport2: L/D Time Spent in Port 2. Amount of time required for L/D operations at Port 2 per barge (hrs)
 ttript: Tug Total Voyage Time. Amount of time required

by tug for a voyage. (days)

tugopdays: Tug Operating Days. Number of days during the year in which a tug is expected to be available for operations. (days)

tunlink: Unlinking Time. Time required to disconnect barge from tug for drop-and-swap operations. (hrs)

twait1: Port 1 Waiting Time. Time tug is required to wait for barge at Port 1 during drop-and-swap operations. (hrs)

twait2: Port 2 Waiting Time. Time tug is required to wait for barge at Port 2 during drop-and-swap operations. (hrs)

vcargo: Cargo Value. Value of cargo per long ton. (\$/LT)

volwt: Cargo Cubic Capacity. The amount of cargo that could fit within the cubic volume of the barge. (LT)

w: Wake Fraction Array. Array of one minus the wake fraction (x1000) values used as an input parameter in the calling of subprogram "power"; values are used in subroutine "propfactors" of subprogram "power."

wa: Wake Fraction. Wake fraction (W_T) of the tug-barge form.

wmacht: Tug Machinery Weight. (LT)

wmisc: Tug Miscellaneous Weight. (LT)

woutfitb: Barge Outfit Weight. (LT)

woutfitt: Tug Outfit Weight. (LT)

wsteelb: Barge Hull Steel Weight. (LT)

wsteelt: Tug Steel Weight. (LT)

x: Subroutine Plots variable used to represent abscissa array values.

xcb: Quadratic Interpolation Coefficient. Parameter used in the quadratic interpolation with respect

to block coefficient for the value of lbarge and wsteelb.

x1cb: Same as for xcb.

x2cb: Same as for xcb.

x3cb: Same as for xcb.

xmax,xmin: Subroutine Plots variables used to represent minimum and maximum range of abscissa axis.

y1,y2: Subroutine Plots variables used to represent ordinate array values for drop-and-swap and integral modes respectively.

ymax,ymin: Subroutine Plots variables used to represent minimum and maximum range of ordinate axis.

APPENDIX E

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