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Latest Developments in Coal Handling for Self-Unloading Ships and Barges

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Summary

The purpose of this paper is to describe the various types of self-unloading vessels and emphasize their economics. For most ship owners or designers, self-unloaders mean the Great Lakes type not realizing that the same or modified systems could be used elsewhere. Hopefully some clarifications are contained herein, together with explanations as to how the same, or modified, systems could be used for small ships and barges as well as for large ocean carriers. For the intercoastal movement of bulk materials, especially for powerhouse coal, self-unloading systems may be just the proper answer for which ship owners and system designers are searching.

1. Introduction

As the size of vessels increases, so does the time which they spend in ports. It has been proven that unloading bulk carriers at high rates, and sending them back to sea quickly, can be achieved only with conveyors. The modern self-unloading vessel was developed to accomplish these objectives.

History tells us that the first self-unloader was built in the USA in 1908 with pan conveyor type hold conveyor and a deck boom to operate on the Great Lakes. Yet Canada claims that two grain vessels were equipped with belt conveyors several years before, around 1903 or 1904.

The rapid industrial revolution during the first half of the century affecting the Great Lakes area demanded the moving of large quantities of raw materials for which self-unloaders were best suited. These vessels provided versatility without the requirements of investing in costly dock structures or shore installations. Self-unloading vessels are a North American invention and the operating and engineering know-how remained American for over eighty years. It is interesting to note that it is perhaps the only industrial know-how never adapted, exploited or copied by other industrial nations.

The handling efficiency of self-unloaders can never be matched by any shore mounted installations. The modern average Great Lakes self-unloader can unload itself at rates between 6,000 and 10,000 t/h. It is anticipated that during the remaining years of the 20th century, no single shore installation will be able to match these figures.

The classical configuration of the Great Lakes self-unloaders is rapidly changing, especially when considering ocean trades. Special designs which were introduced during the past 10 to 15 years offer intriguing possibilities even for extremely long hauls. The long standing concept or belief that self-unloaders can be justified only for short runs is now dispelled by considering specially designed vessels with specialized gear which make economic sense even for lengthened trade routes. If ecology, pollution control requirements for dust-free discharge or any other environmental considerations are potential problems, a modern self-unloader may represent just the right answer.

Self unloading vessels normally can maintain 90—95 % of their full rated discharge capacity throughout the unloading period, whereas shore mounted rigs do considerably less, about in the 50—60 % range. Even recently introduced costly, continuous ship-unloaders cannot match their performance.

This discussion will be limited to "gravity type" or "mechanically" assisted self-unloaders. Crane vessels, slurry carriers, and cement carriers are excluded for many reasons. A multitude of crane designs are used for many different ship configurations and are just about impossible to classify in a comprehensive form within this paper. The slurry carriers represent a small segment and their number, or significance, in the trade is not growing. Cement carriers are small in size, highly specialized in design, and represent a relatively small segment of the trade with low outputs.

The reasons for using self-unloaders on the Great Lakes are as follows:

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1. High unloading rates, thus quick turnaround time.
2. Independence from shore installations, consequently any user with direct access to the Lakes can be easily serviced.
3. Short routes, thus the reduction in time for unloading is dominating the overall economy.
4. Large yearly quantities of coal, limestone, pellets, salt and gypsum have to be delivered to individual users.
5. Low maintenance cost and versatility which cannot be matched by any other shore based unloading facilities.
6. Return cargoes are often available which contribute to the overall economy.
7. Shore based unloading facilities are gradually being phased out.

It is significant that in the past ten years only self-unloaders were built on the Great Lakes, a testament to their universal acceptance throughout the industry. It is evident that most of the reasons given for the economical existence of self-unloaders on the Great Lakes could also apply to intercoastal distribution of raw materials, especially in Europe, around the inland seas of Japan, and perhaps the Near East. When viewing ocean carriers, there are additional considerations in favor of self-unloaders:

1. Some materials, such as alumina and bauxite, are relatively difficult to handle with grab bucket type unloading gear.
2. While using grab buckets for loading, it is difficult to keep dust generation to acceptable levels.
3. Grabs, or buckets, may damage the cargo. United States steel plants prefer receiving pellets by self-unloaders.
4. Self-unloaders can increase the capacity of a port without adding costly shore installations.
5. Self-unloaders are ideal for intercoastal distribution of raw materials received from overseas in very large bulk carriers.
6. Environmental considerations favor using self-unloaders which can discharge practically dust-free.

Self-unloaders have the best dock utilization percentage of all carriers. The old rule that self-unloaders are competitive with standard bulk carriers and conventional unloading rigs only when the turnaround time is less than one week, is being challenged. As bulk carriers are built larger, not only the outreach of the shore based unloading equipment must also be increased, but also the unloading rates, to enhance the efficiency of the operation. However, the cost increase for these features may become so high as to be prohibitive, and the use of self-unloading gear may be the only answer. It logically follows that for large carriers, the old established rule of one week turnaround time must be revised. There is also a new tendency to establish transportation systems, transfer terminals, strategic stockpiles and local distribution systems. When considering these from the standpoint of economics, modern self-unloading vessels or barges may represent the logical answers. For these reasons let us examine the various designs which are available:

(1.0) Gravity Discharge Type

(1.1) Great Lakes type, boom forward (over 75 built)
(1.2) Lift conveyor, boom forward (about 10 built)
(1.3) Shuttle type, shuttle aft (8—10 built)
(1.4) Lift conveyor type, boom aft (about 15 built)

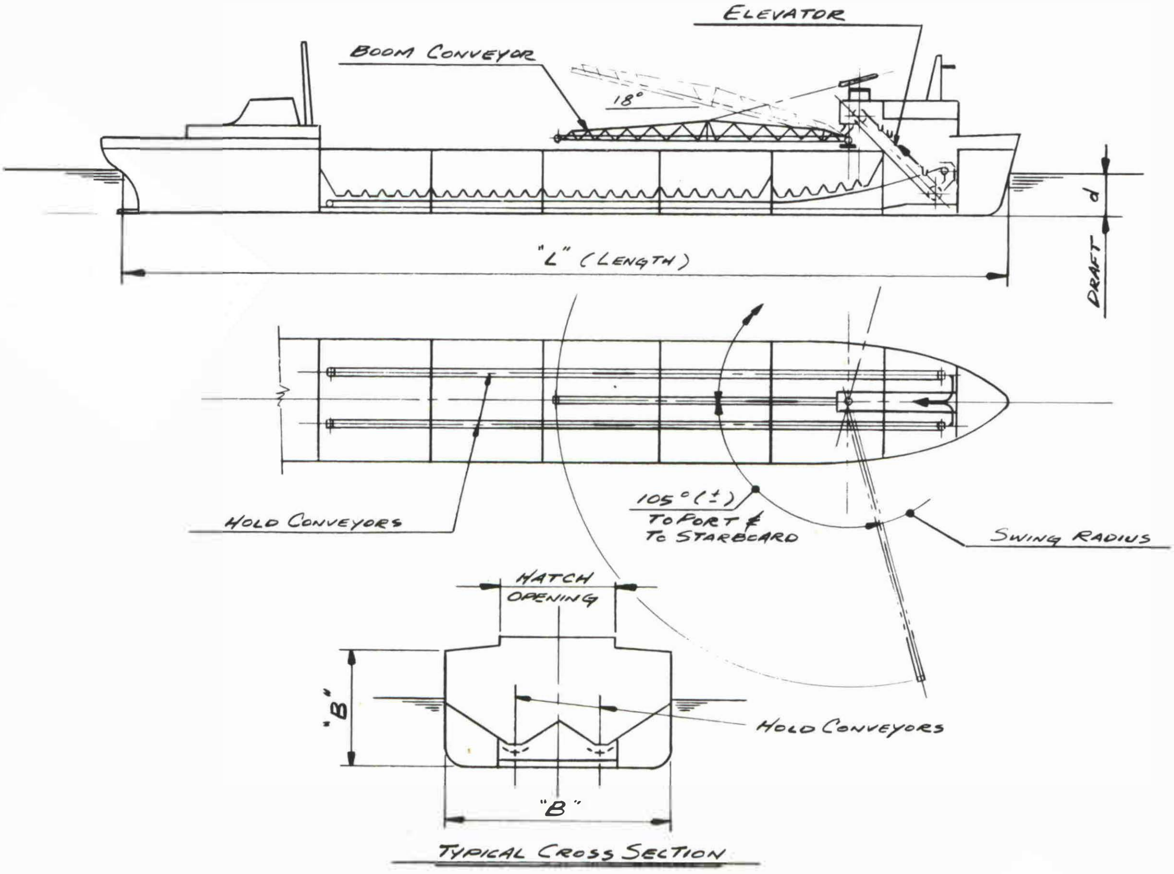


Fig. 1: Great Lakes type — boom forward

(2.0) Gravity and Mechanical Discharge Type
(2.1) Hold conveyor and hold cleaning machine (3—4 built)
(2.2) Hold conveyor and deck cranes (1 or 2 built)
(2.3) Hold conveyor and bulldozers (8 built)

These vessels were designed to handle a wide variety of materials and very few of them ever handled only one commodity. The most common materials handled by self-unloaders are coal, iron ore, iron ore pellets, gypsum, limestone, dolomite, cement stone, coke, bauxite, alumina, rock and solar salt, aragonite and various grain commodities.

As mentioned in previous paragraphs, the description of crane vessels, slurry carriers and cement carriers are not included; however for scholars and serious students on the subject of self-unloaders, the above paragraphs (1.0) and (2.0) should be extended to complete the classifications.

(3.0) Crane Vessels with Deck Conveyors
(3.1) Revolving cranes and conveyors (3—4 built)
(3.2) Portal cranes and conveyors (several proposed)

(4.0) Crane Vessels (Self-Discharging Digging Apparatus)
(4.1) Traversing portal cranes (15—20 built)
(4.2) Fixed revolving crane (over 15 built)
(4.3) Traveling revolving cranes (over 15 built)
(4.4) Ships with continuous digging elevators (10 built)

(5.0) Slurry Carriers

(6.0) Cement Carriers
(6.1) Airslides with screw conveyors — cement pump discharge
(6.2) Airslides with belt conveyors — elevator discharge
(6.3) Airslides with belt conveyors — pump discharge

(7.0) Self-Unloading and Loading Vessels

2. Gravity Discharge Type

The classical configuration of the Great Lakes self-unloaders with forward boom is shown in Fig. 1, and just about all these vessels are operating on the Great Lakes. In its original form, two hold conveyors, each serviced by about sixty gates, discharged into an inclined chain and bucket elevator for lifting the cargo above deck. The elevator fed a hoistable and slewable boom conveyor for depositing the material on shore. The chain and bucket elevator restricts the unloading rates to about 6,500 t/h for limestone and pellets, and 3,000—3,500 t/h for coal. Because of these capacity limitations and since the elevator represents a high maintenance item, for about 25 years designers suggested different lifting devices as replacements.

Cell-type bucket wheels, circular elevators, flexible, walled conveyors with cleats, loop and "C" belts were proposed and furnished with the loop belt now established as the most favored replacement.

A loop conveyor is essentially a belt conveyor shaped into a "C" form to allow lifting the material above deck in one operation and without additional junctions. For accomplishing this, a second belt is added along the inside of the "C" portion of the conveyor to constrain the material as it is lifted. The inner and outer conveyor system forms a tube which confines the material as it is lifted. Closely spaced troughing idlers are used on the inner and outer strands to prevent spillage. Belt tensions are automatically regulated to have sufficient sealing forces between belts, especially along the steep vertical portion of the "C" configuration.

Loop belts work excellently when handling uniform material such as powerhouse coal or iron ore pellets, but are less desirable for handling large lumps or extremely fine materials, especially with an irregular feed. There are certain sticky and powdered fine materials which loop belts cannot handle and lift belts must be used. Self-unloaders listed under (1.1), (1.2) and (1.4) can be built with loop belts, provided the layout can satisfy certain ship parameters for cubic utilization and overall economics, since these loop belts are expensive.

It should be noted that the STEWART J. CORT was built with a cell-type bucket wheel lifting device, the forerunner of all "C" and loop belt designs. The CORT can unload at the impressive rate of 20,000 t/h but it is questionable whether a similar vessel will ever be built with such high unloading capacities. Such high unloading rates represent special problems, especially for the receiving installation on shore.

Lift conveyor, boom forward, type vessels (Fig. 2) were developed to eliminate the chain and bucket elevators. The bridge can be incorporated with the "A" frame in a more traditional form. The design is considerably less expensive than the elevator or loop belt type, and is suitable for a wide variety of cargoes which otherwise could not be handled either by the chain and bucket elevators or by loop belts.

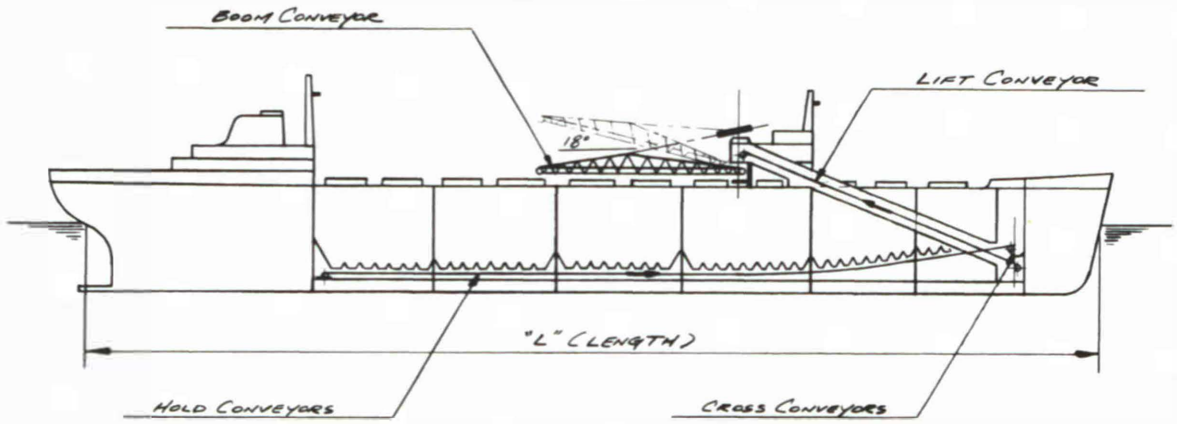


Fig. 2: Lift conveyor — boom forward type self-unloader

The shuttle type, shuttle aft, design is shown in Fig. 3 and is the most widely used type of self-unloader in ocean or salt water service today. These vessels are predominately used to handle gypsum, bauxite and alumina. All the conveyor equipment is located below deck and is completely protected from the elements. These type vessels require special receiving conveyors on the dock which can be completely enclosed. Although these vessels are operated by many companies, the shuttle locations and controls are standardized so that they can be interchanged between the various trades. These type vessels are the most inexpensive self-unloaders and the cubic loss due to the self-unloading equipment is negligible. These vessels are exceptional for handling pellets and the self-unloading gear can be designed practically without any unloading rate restrictions. The power consumption is less when compared to any other systems. Shuttle aft type vessels are built with two or more hold conveyors, depending on the width of the beam of the vessel. If the beam exceeds 90—95 ft, normally three hold conveyors are used and various designers prefer using different hold configurations and material routes.

Lift conveyor type, boom aft, vessels are the most versatile vessels for ocean service. Fig. 4 shows the boom located aft just forward of the engine room. The loss of cubic due to the self-unloading equipment is negligible, especially when considering medium density cargoes. Depending on the boom length, the cargo can be discharged independently at any shore installation. The cost of the self-unloading equipment is about the same as for the lift conveyor, boom forward, type as shown in Fig. 2. The "A" frame is incorporated into the ship's superstructure, allowing for sufficient bridge clearance. The hatches can be designed wide open and unobstructed for the loading operation. The entire design of the self-unloading equipment is compact, functional and economical. Different variations of this type vessel exist. In order to extend the outreach of the shuttle aft type vessel, the boom is replaced with a shuttle conveyor housed in a compartment just ahead of the engine room bulkhead. The advantages are in the higher shuttle belt elevation, more suitable for certain docks (thus larger hoppers can be used), and greater outreach. Several vessels of this type were built. Other variations are replacing the lift conveyor with a loop belt or a transverse lifting wheel arrangement. The loop belt variation is widely used on Great Lakes vessels for the new 1,000 footers where the loop belt can be sandwiched in between the two engine rooms. It allows for an extremely compact and economical arrangement. The tranverse lifting wheel arrangement was tried only once but may have significant possibilities for ocean going vessels which may have to be designed with coal fired boilers. The coal boilers are about twice the size of the oil fired counterparts and do not allow enough room to place the inclined conveyor trunks beneath the boilers through the engine room.

3. Gravity and Mechanical Discharge Type

The advantages of discharging a vessel through gravity and by conveyors were recognized for a long time by the industry, as were the restrictions associated with these types of designs. Basically a gravity type self-unloader can handle only cargoes which will safely flow from hoppers aided by the force of gravity. No sticky materials, or materials which may

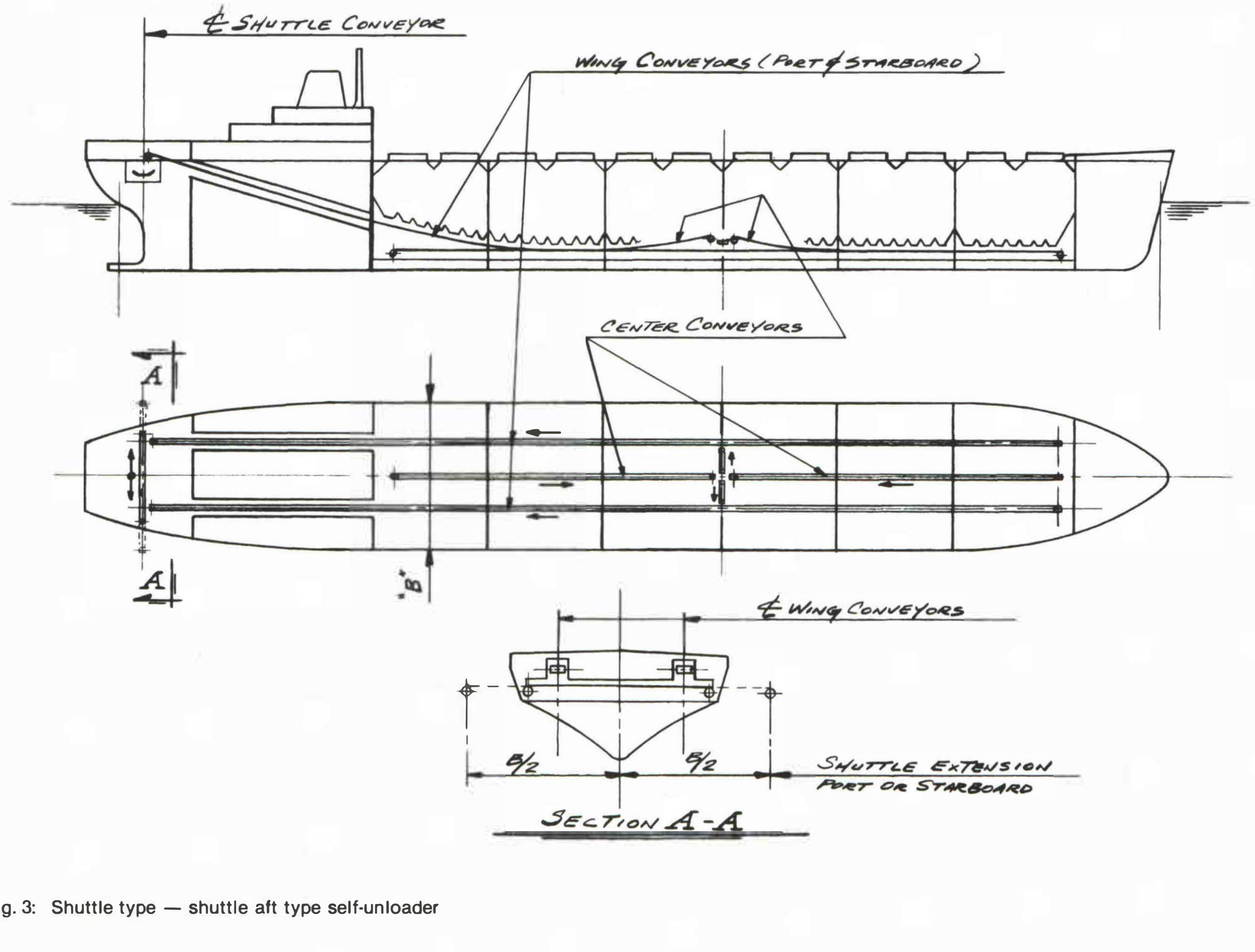


Fig. 3: Shuttle type — shuttle aft type self-unloader

set up in holds, can be transported. In addition, fine, sticky iron ore, certain types of phosphates, and wet, fine gypsum which tends to arch and plug, cannot be handled. Therefore, designers have attempted to built self-unloaders which could handle a wider variety of cargoes, even those which would arch, not readily flow from hoppers, or would set up solidly in holds. As a result, a new family of self-unloaders, the gravity and mechanical discharge type, was born.

It should be emphasized that this family of vessels was designed primarily to handle difficult cargoes, but also the provide maximum cargo space for low density commodities (coal and grain), thereby reducing the initial ships' cost.

The importance of free-flowing characteristics of the cargo for gravity discharge type vessels cannot be emphasized enough. Any difficulties with the material in the hoppered holds, including arching, can considerably slow the discharge. If the material will not flow at all, discharging is impossible. To assure positive discharge, mechanical means have to be introduced to move the material to the conveyors. Experience has shown that all types of sticky and non free-flowing materials can be handled on conveyors once the material is agitated to flow, and is kept moving. Consequently, if the material starts to flow and is agitated, it can be discharged from the holds.

The gravity and mechanical discharge type vessels were developed first to handle materials with non free-flowing characteristics. The design also provided a bonus benefit of providing maximum hold utilization for low density materials, and it allowed using a hold configuration commonly used for standard bulk carriers thereby reducing the ships' cost. This family of vessels is sometimes nicknamed the "poor man's" self-unloader because the overall design is less expensive and is better adapted for conversion of existing vessels. The only disadvantages are that high unloading rates had to be sacrificed and the operating or maintenance costs increased because of the added mechanical clean-up or agitating devices.

The hold conveyor and hold cleaning machine type vessels can be designed with one, two or three hold conveyors, although one is the most economical and is shown in Fig. 5.

The hold conveyors can run forward or aft. It is always advantageous to have the conveyors running aft through the engine room, as this gives the best hold configuration for maximum cubic utilization. The cargo hold has to be uninterrupted without subdivisions except when several clean-up units are used. Regulatory agencies, such as ABS (American Bureau of Shipping), have special rules covering such designs and only long operating experience with these vessels will entirely eliminate the objections brought against the single hold arrangement. The hold cleaning machine shown on the sketch is essentially a screw type reclaimer with screws over 6'-0 diameter and several of this type are built. Different types of hold cleaning machines will intrigue the designers imaginations for a long time to come because they offer an optimum solution for handling lower density cargo and hard to handle sticky materials.

The "poor man's" self-unloader is actually the hold conveyor and crane combination as shown in Fig. 6. This design is most adaptable for conversion of ocean going vessels. It utilizes the principle of conveyors which have the capability of moving material faster at lower cost, combined with the operation of a gantry crane on a predetermined short cycle where this type of unit is the most efficient. Most of the cargo can be discharged by gravity and the crane will only have to pile the remaining material on top of the conveyor hoppers. The operation of the crane can be easily automated, thus allowing the use of inexperienced operators. The discharge rate will be relatively high at the beginning of the

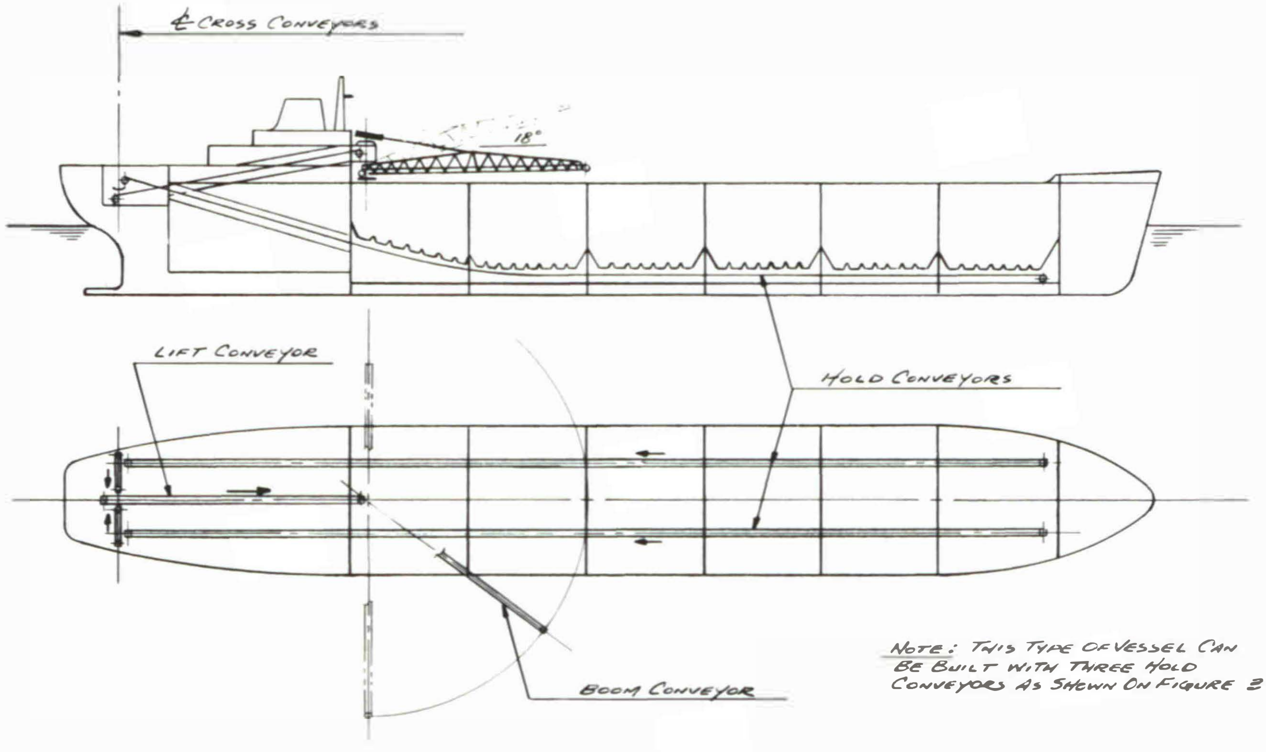


Fig. 4: Lift conveyor type — boom aft type self-unloader

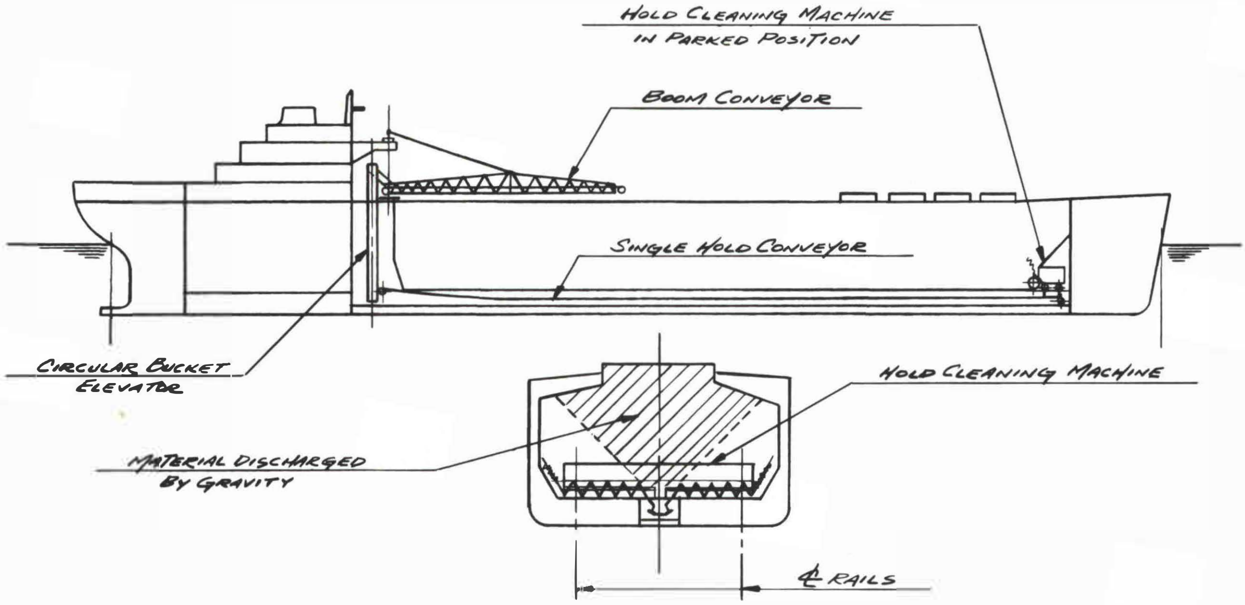


Fig. 5: Hold conveyor and hold cleaning machine

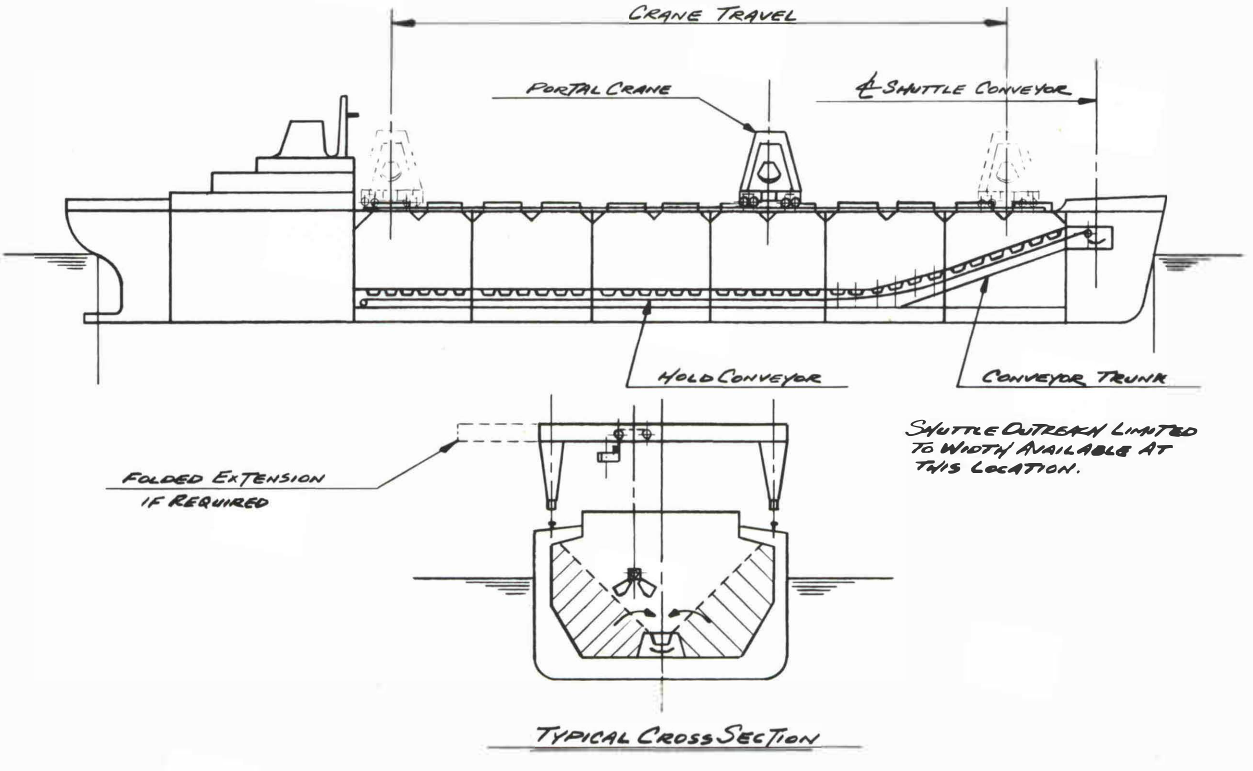


Fig. 6: Hold conveyor and crane arrangement

unloading cycle since it is a combination of gravity flow and crane discharge capability. Only after the holds are discharged by gravity will the unloading rate drop back to the design capacity of the crane. Bulldozers may also be used to facilitate clean-up. Fig. 6 shows the conveyor trunk above the tank top which is the preferred configuration for a conversion. It could be recessed and make the vessel capable of handling other cargoes, such as containers or structural steel shapes on the return run. "Poor man's" self-unloaders will have a better acceptance and a more promising future if a simplified crane is available, especially with reliable electrical components. For this type of unloading gear, cranes represent the largest single maintenance expenditure.

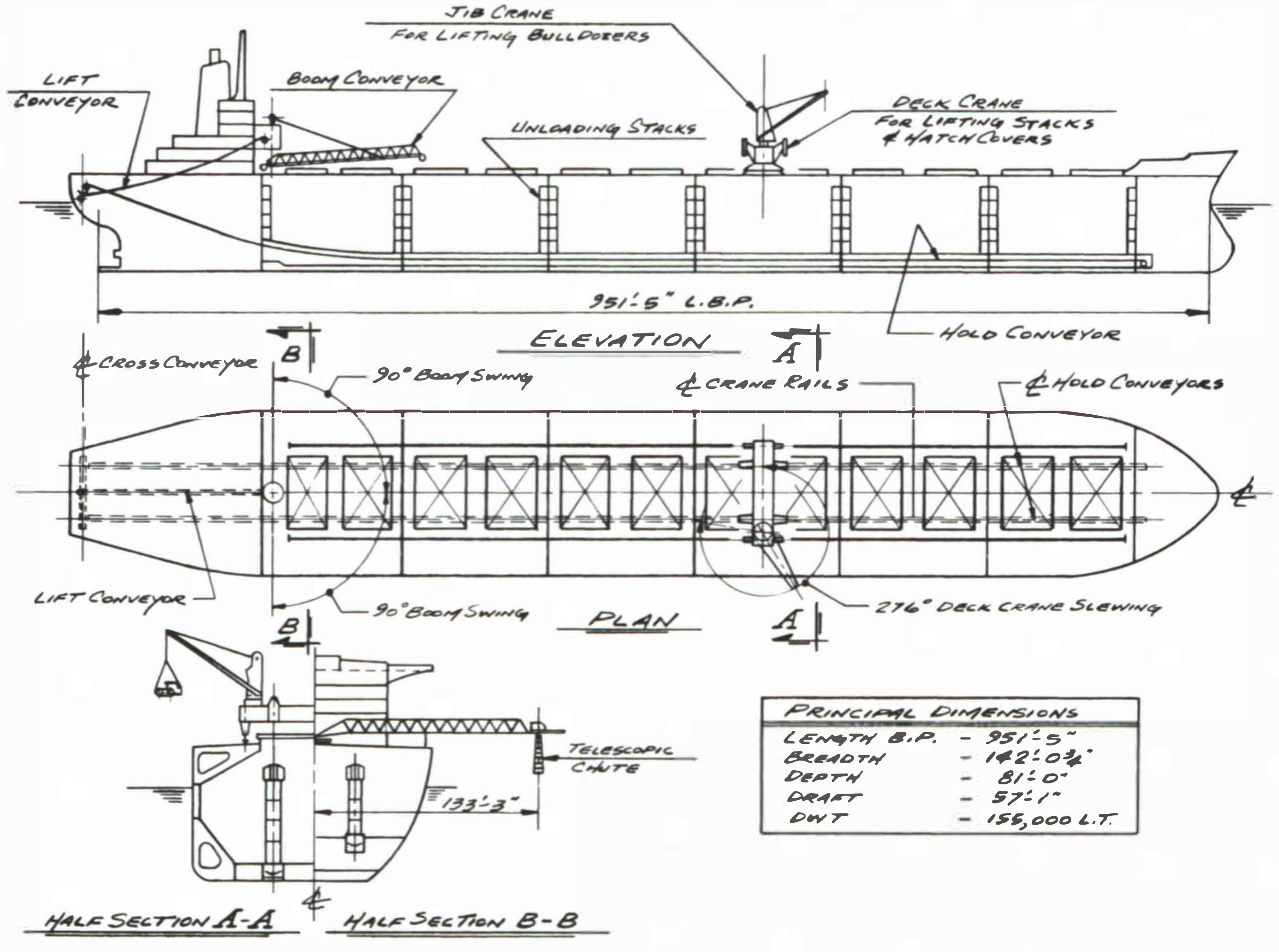
Ship cranes can be costly and, in order to have constant outputs, require skilled operators. Cranes also require a runway, electric cables on deck, sufficient generating capacity to absorb surge loads and being tied down before leaving port, which is time consuming. At certain ports longshoremen will, by contract, operate the cranes themselves for which they are not necessarily qualified. Historically, there has been an increased maintenance cost because of nonqualified operators, and again repairs have to be made at shipyards where the costs are high. Logically it follows that if the cranes could be eliminated and replaced with other equipment (such as bulldozers), most of the objections could be eliminated. While it is true that bulldozers also require operators, perhaps even longshoremen by contract, bulldozers are easier to operate and are built more fool-proof. Most likely bulldozers will have to be used for clean-up; therefore the question can be asked, why not use them all the way for assisting the unloading operation. Several bulldozers may be used at relatively low cost and they can even be rented. A deck crane will still be required to handle the bulldozers, but this crane will be relatively small and less complicated; more in the class of the normally available cargo gear. Such cranes can also handle the hatch covers which, through simpler design, would be less expensive.

Following the aforementioned logic, the hold conveyor and bulldozer type self-unloaders were developed. This type of ship can handle the widest variety of bulk materials. For the safe operation of bulldozers within the holds, a unique movable stack system was developed. The segments of the stack are pulled up and the cargo is bulldozed into the stacks where it falls free into the hoppers and through regulating gates onto the conveyor belts. When free-flowing cargo is anticipated, the stacks are lifted in sequence and the main portion of the cargo is being discharged by gravity. Bulldozers then are used to maintain safe operating levels and as required for clean-up. The arrangement of this type of self-unloader is shown on Fig. 7. Again, different conveyor arrangements can be used; shuttle or boom discharge, single or double hold conveyors and various lengths of booms at different locations.

The bulldozers assisted design basically was developed for cargoes such as evaporated salt, which solidify on the Pacific run. The hardened salt has to be cut by the bulldozer blades and pushed into the stacks in a condition suitable for the conveyor operation. However, any owner who has to handle different cargoes not as difficult as evaporated salt, may take advantage of the design on different routes where the port installation has equipment with only limited unloading capacities or outreach available. With this arrangement, the owner can utilize maximum vessel size for providing economical transportation yet the vessels have a relatively inexpensive material handling system combined with maximum hold utilization for low density cargoes.

There is a possibility of designing without stacks and utilizing only bulldozers. However, such design would be more suitable for smaller vessels or barges. Fig. 8 shows such arrangement. The bulldozers for this arrangement are more hold cleaning machines, available for starting the flow of material to the hoppers.

When considering the bulldozer assisted self-unloading system, it should be recognized that it has certain advantages



PRINCIPAL DIMENSIONS	
LENGTH B.P.	- 951'-5"
BREADTH	- 142'-0¾"
DEPTH	- 81'-0"
DRAFT	- 57'-1"
DWT	- 155,000 L.T.

Fig. 7: Hold conveyor and bulldozer type movable stack system

and disadvantages which should be properly evaluated. Bulldozer assisted discharging equipment can handle even the most difficult cargoes and it maintains ideal, or desirable, hold configurations. However, the requirements for additional bulldozer operators and higher maintenance cost should be weighed against the use of all hopper type gravity discharge vessels if the cargo is suitable for such arrangement. Only a detailed cost analysis will show which design is more favorable based on overall operating economy.

4. Tug/Barge Combination — Latest Developments

The latest development in marine transportation, pusher-type barges, may open an entirely new field for self-unloader designs. Pusher barges have comparably smaller dimensions, particularly draft, for the same deadweight as conventional vessels. They are less expensive to build and the combination can be operated with smaller crews. Various unloading gears can be installed in comparison to the bulldozer assisted type shown in Fig. 8. Presently available designs for the connections between barges and tugs allow safe operation in up to 10 ft swells or waves. Above 10 ft, the barge has to be disconnected and towed by the tugboat.

Following the development of the self-unloading fleets on the Great Lakes in the early thirties, self-unloaders were also introduced on the East Coast handling coal for electric generating stations. Several of the Great Lakes type were built following the classical concept of hold conveyors, pan conveyor or elevator forward, and with various boom lengths between 162′-0 and 185′-0. The vessels operated successfully and became the front runners for a series of additional vessels developed for the coastal trade after World War II to handle gypsum, bauxite, alumina, phosphates, grain and aragonite. The pan conveyor design, in its original form, was not suited for the salt water operation and corrosion became one of the main operating problems. In those days little was known about proper corrosion protection using sophisticated painting systems. Consequently, designers introduced the shuttle conveyor concept where all conveyors were below deck, protected from the elements. With the experience gained with these vessels, and the development of better painting systems, additional vessel types were developed and the life span was extended to 25—30 years, approaching those in Great Lakes operation where vessels last over forty years.

The fleet of ocean going self-unloaders is steadily expanding, and covers vessel sizes from about 10,000 DWT to 160,000 DWT. Several self-unloading barges are also in service with the latest unit being a 36,600 DWT phosphate barge going into service this summer.

Following the trend to burn coal in power plants, New England power and Light will start receiving coal in 1983 from a new 36,250 DWT Collier presently being built by General Dynamics Quincy Shipbuilding Division. This vessel is essentially a gravity discharge, lift conveyor, boom forward type with a 260′-0 long boom. The general arrangement of the vessel is shown in Fig. 9.

The self-unloading system was designed to handle powerhouse coal at the rate of 3,500 t/h. Two 48″ hold conveyors are used, which are fed by 80 hydraulically operated gates, manually controlled. An additional gate feeds the lift conveyor directly. Coal is transferred to the lift conveyor by 60″ cross conveyors driven hydraulically from the hold conveyor drives. The 72″ lift conveyor elevates the material above deck onto a 72″ boom conveyor which can swing 115° to port and starboard, and can be raised to 18 degrees from horizontal.

The boom forward arrangement is necessary to deposit coal into an existing storage yard which was originally provided with tunnel reclaiming and serviced with a grab bucket type ship unloader. The ship has to dock bow forward to the port because of navigational requirements and therefore the boom length and slewing range was selected to cover the entire storage pile thereby using the existing feeder arrangements.

In general, the ships' layout follows the latest trend in self-unloader design where vessel size and conveyor layouts are optimized to comply with existing navigational and dock conditions. The design of the vessel is extremely compact and the hopper configurations, combined with the use of 4′-0 x 5′-0 wide gate openings, allows maximum cubic utilization for coal which has a relatively low density of 50 lbs/ft³. The ship will have coal fired boilers, a first for ocean going self-unloaders. The boilers are fed with coal from a separate bunkering system using densifiers. The size of these bunkers is determined by the fuel consumption and anticipated voyage time. Oil can be used as alternate fuel and will be burned while in port to comply with environmental regulations. Coal from the cargo holds can be transferred to the bunkers if required or dictated by unexpected delays.

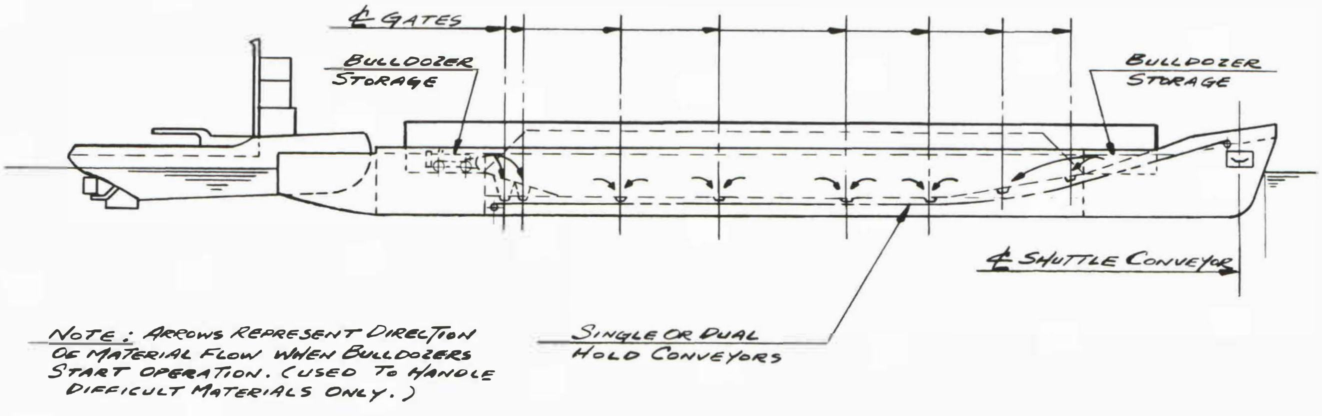
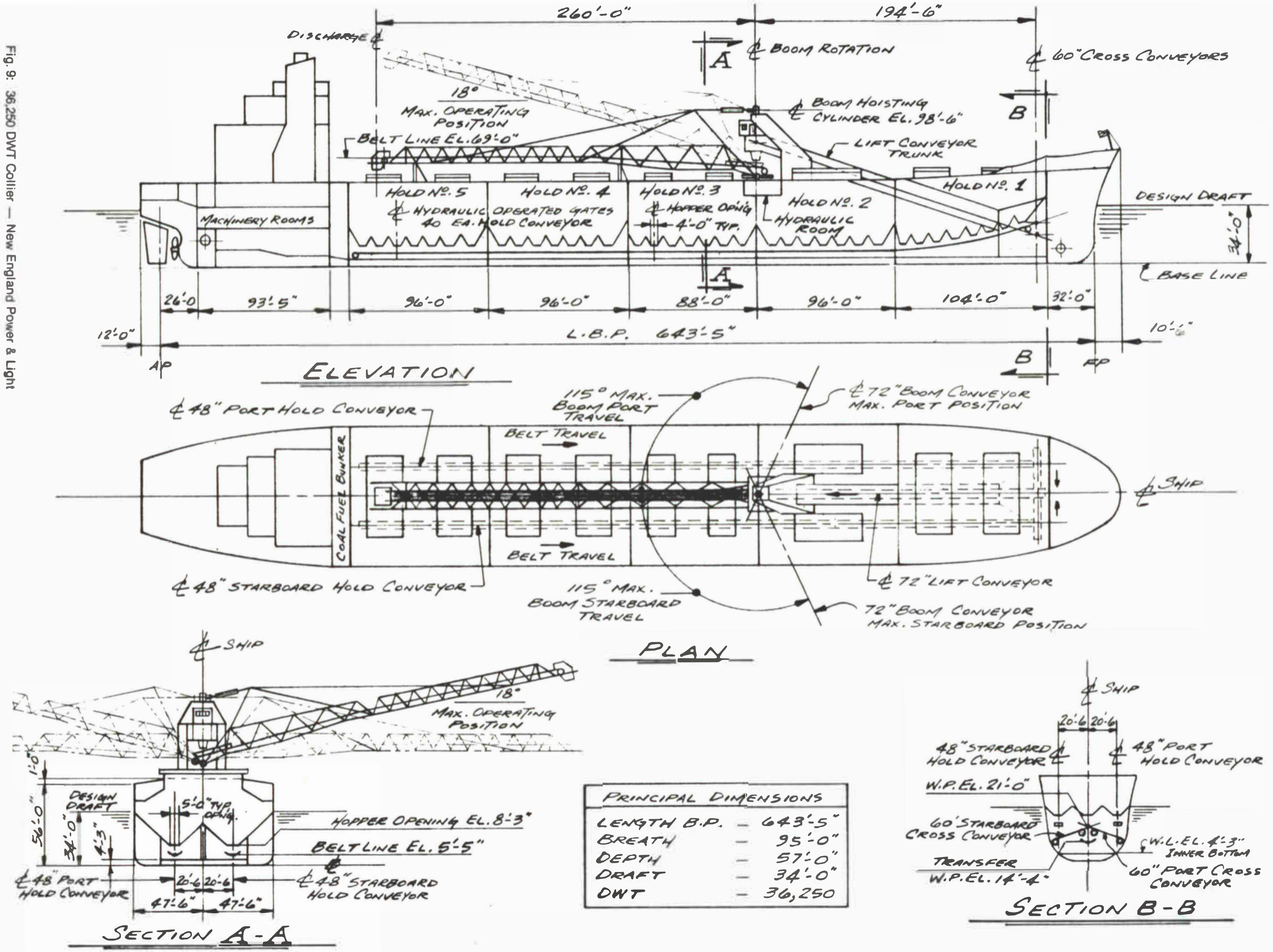


Fig. 8: Special self-unloading barge (hold conveyors and bulldozers)



PRINCIPAL DIMENSIONS

LENGTH B.P.	–	643'-5"
BREATH	–	95'-0"
DEPTH	–	57'-0"
DRAFT	–	34'-0"
DWT	–	36,250

Fig. 9: 36,250 DWT Collier — New England Power & Light

The auxiliary functions for the material handling equipment are powered by a centralized hydraulic system. Two 50 HP power units are provided for a nominal 4,000 psi high pressure system to be used for boom hoisting and slewing and also for operating the hatch covers. A 1,000 psi low pressure system is also supplied by the same pumps through pressure regulating valves for servicing the hydraulic gates and for powering the conveyor take-ups. The design of the hydraulic systems follows the established practice used for ocean going self-unloaders where centralized pumps, located in a separate pump room, service all the auxiliary functions of the material handling system. In contrast, the Great Lake vessels have separate pump units for each function. Ocean vessel operators prefer the centralized system because although it may cost more initially, it is simpler, has fewer components and lower maintenance costs.

The conveyors are driven by squirrel cage marine type motors through fluid drives. Each motor is started across-the-line at no load. Torque is gradually applied and the time of acceleration is regulated by limiting the current through electronic controls. All conveyors are started and stopped in sequence. The entire system is controlled from a console located in a centralized control room which is located in the "A" frame structure. The entire electrical system for the self-unloading equipment is controlled by programmable controllers incorporating all the modern safety features of conveyors operation. The lift conveyor is also equipped with a belt scale to monitor the rate, automatically totalize and record on a ticket print the delivered quantity of coal within plus-minus 1/4 %.

The design philosophy used for the new Collier presently under construction can also be used for barges. Fig. 10 shows such a possibility. A lift conveyor type configuration is used to enable handling a wide variety of cargoes. The system represents a balanced design with 50 degree hoppers to effectively handle all types of cargoes which will flow readily out of the hoppers.

5. Small, Self-Unloading Barges

It is not often recognized that self-unloading features can be applied to any size vessel or barge. Their economical advantages can be demonstrated from 2,000 DWT to over 160,000 DWT. In the late forties coke was moved on the Mississippi with small self-unloading barges. Presently six 6,000 DWT barges are used to move evaporated salt to a transfer port at Cedros Island (Mexico), where Panamax and 160,000 DWT self-unloading ships are loaded for the transpacific move to Japan. These barges are deck-type with a single hold conveyor, bulldozer assisted, and unload in about four hours. The barge fleet transfers over 20,000 tons every day.

Deck-type, hoppered, self-unloading barges are used to transfer dredged aragonite on a short run at Ocean Cay near the Florida coast to the man-made island transfer port. There the self-unloading barges provide an economic alternate to pumping over several miles. As in Mexico, the aragonite is loaded predominately into self-unloaders for East coast and Gulf ports distribution.

The aragonite self-unloading barges are shown in Fig. 11. Essentially they are deck-type barges, 1,800 DWT capacity, with hoppered superstructure and two 42″ wide conveyors capable of discharging at 3,000 t/h. Electric power for the conveyors, as on most barge applications, is furnished through plug-in type shore connections. The gates under the hoppers are hydraulically actuated.

The few examples cited in the previous paragraphs demonstrate the versatility of self-unloader designs with a specific economic consideration in mind. Similar designs would be equally applicable for handling coal for power plants, especially for oil-coal conversions, eliminating the costly shore based unloading rigs. The conveyors on the barges would merely connect to the yard conveyors servicing the ground storage areas. The use of self-unloading barges or vessels not only eliminates the unloading units, but also significantly reduces the cost of the dock construction. Normally only a few cells are required to secure the barge or vessel so that the material can be loaded safely into the shoreside hoppers.

6. Economics

All the various designs of self-unloaders have the attribute of providing efficient vessels or barges which can economically service modern transportation systems. There is now enough accumulated experience among designers to suggest that modifications or improvements in existing systems can be made to reduce the cost of handling various commodities. The efficiency of modern self-unloaders has to be witnessed in operation to appreciate the full impact of their effectiveness. Unloading is started before the ship is secured at the dock and most vessels achieve an average unloading rate very close to their design capacity. Self-unloaders are arriving and leaving on schedule and the availability is in the 98 %, or better, range over a span of many years. Their reliability is so exceptional that shore based grab bucket type unloading installations cannot even compare. The actual unloading cost of self-unloaders is only a fraction of the well documented figures accepted for the conventional unloaders.

When evaluating the possibility of using self-unloaders for a certain trade, the overall economics should be studied.

When comparing the various self-unloading systems with each other, regardless of whether they have conveyors only, conveyors in conjunction with mechanical clean-up devices, or a combination of cranes and conveyors, the following basic design principles should be understood.

A) With relatively free-flowing material and having a choice of conveyor configurations, the "gravity discharge-type self-unloader" is the most economical in the following order: (1) shuttle type, shuttle aft; (2) lift conveyor type, boom aft; (3) lift conveyor boom forward; (4) Great Lakes type boom forward. It should be re-emphasized that the shuttle aft type is the most economical with the lowest operating cost and, when equipped with standard hydraulically operated hopper gates, will have the lowest possible installation cost.

B) Operating conveyors on board vessels is a proven and reliable operation, but the design of the conveyor components and auxilliary equipment requires special attention. Standard conveyor components should be altered for shipboard use according to an established practice prevalent in the USA. Conveyor design for self-unloader applications is not the same as for stationary or shore based conveyors and special attention should be given to: (1) idler configuration and design; (2) belt selection and training requirement under various list and trim conditions; (3) speed reducer design for conveyor drives, again for operating with tilt and list in the

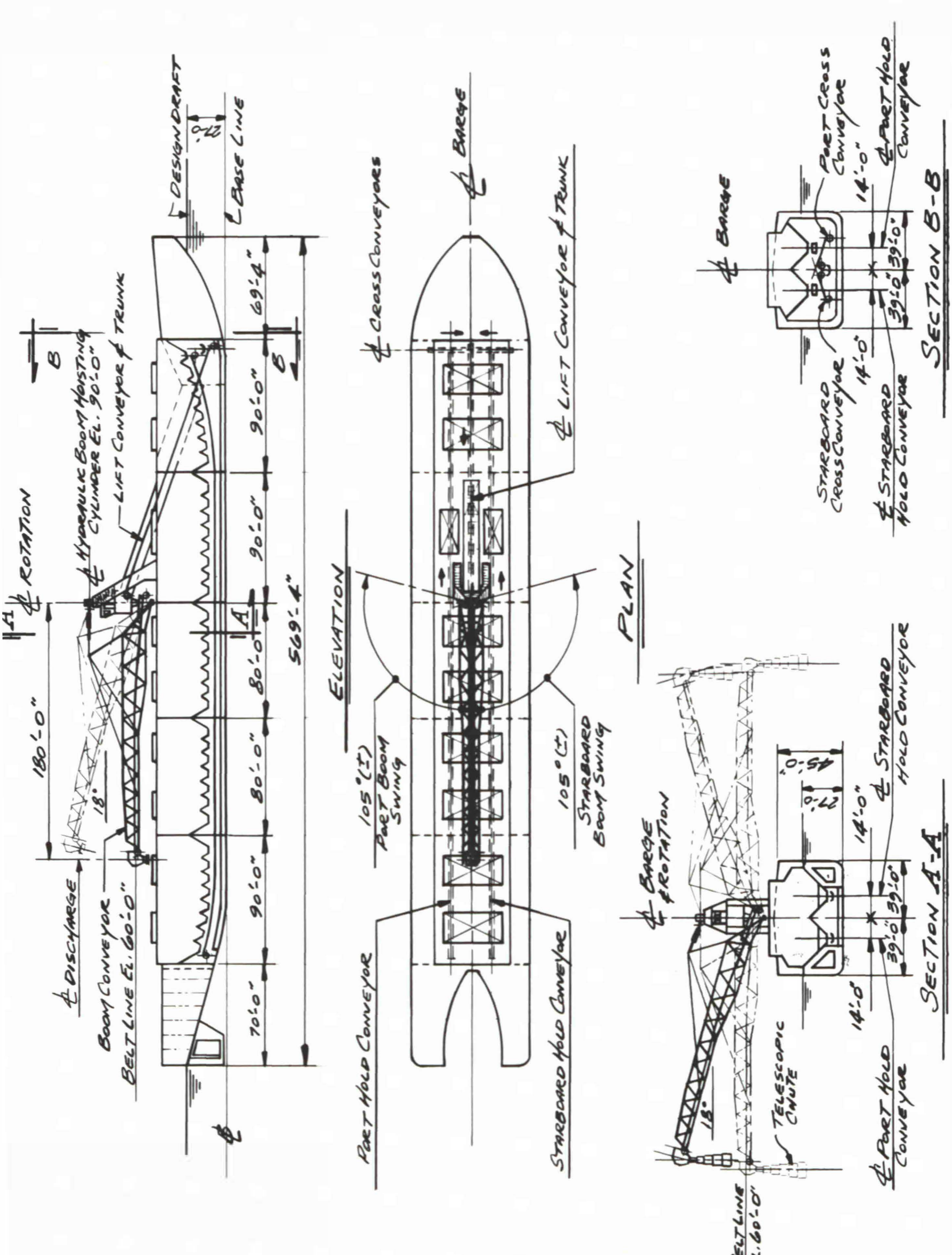


Fig. 10: Tug-barge self-unloader

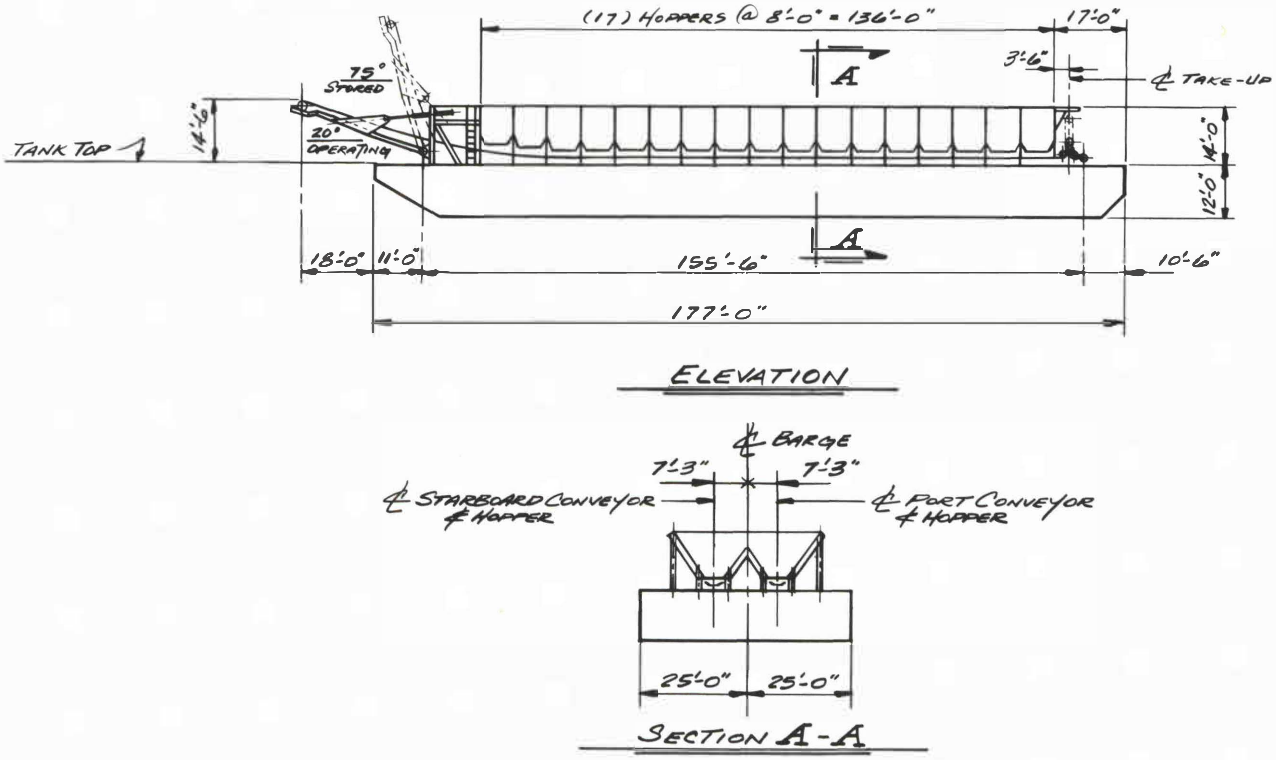


Fig. 11: Self-unloading deck barge (1,800 DWT)

vessel or barge; (4) chute and skirtboard designs for compactness and reduced transfer heights.

C) The unloading cost of different types of self-unloaders varies in the following order: Gravity type; gravity and mechanical discharge type; and all types of crane vessels. The unloading cost of crane vessels is always substantially higher than gravity type self-unloaders and will be comparable to the unloading cost of shore based installations.

D) The loss of cubic due to gravity type self-unloading equipment varies depending on the density of the principal cargo. It could be 2—7½ %, depending on vessel sizes for 50 lbs/ft³ coal, but is practically negligible if the vessel is over 75,000 DWT tons and has to handle 75 lbs/ft³, material such as gypsum and bauxite.

E) The additional cost of self-unloading equipment may not be as high as ship operators and owners believe. It is advisable to examine the combined cost in two steps: (1) obtain the price for a comparable DWT bulk carrier, and (2) add the price of the self-unloading and related equipment as delivered and installed by the shipyard.

Today computer programs are available to estimate the shipyard cost of self-unloading systems in various configurations and for a given size of vessels. For shipyards building their first self-unloader, a familiarization or difficulty factor should be considered. Incidentally, these factors are built into the program variables. If the overall evaluation of costs show a price difference over 15 % for medium (20—25,000 DWT) and over 10 % for the large (60,000—160,000 DWT) vessels, then the systems application and pricing should be examined. The review should include whether the correct type of self-unloading equipment is selected, or a different type may be substituted for overall economy, and whether the shipyard interpreted instructions correctly for assessing the difficulty factor, thereby quoting higher prices.

The above consideration does not apply to self-unloading barges where the difference in percentage figures may be considerably higher, especially in the low (6,000—10,000 DWT) range. In all cases, it is recommended to consult knowledgeable engineers for proper evaluation of shipyard bids.

For economical justifications, whether a self-unloader or standard bulk carrier is used, the attainable loading and unloading rates are of importance.

Technical publications and many experts suggested in the past using the following formulae for bulk carriers:

$$\text{Loading days} = \frac{\text{Cargo DWT}}{90{,}000} + 0.25$$

$$\text{Unloading days} = \frac{\text{Cargo DWT}}{28{,}700} + 0.25$$

In addition, when assuming bunkering and miscellaneous delays in entering and leaving ports or when navigating restricted waters, the total port days per round trip would be:

$$\text{Total Port days} = \frac{\text{Cargo DWT}}{22{,}000} + 2.0$$

Closer examination shows that the above formulae are based on an average loading rate of 4,000 t/h and an average unloading rate of only 1,200 t/h. It should be understood that the extra time allowances are applicable for trans-ocean movements and not for coastal or the Great Lakes trade.

The formulae could be modified for any specific unloading rates, Q_U, and loading rates, Q_L, by using:

$$\text{Loading days} = \frac{\text{Cargo DWT}}{24\,Q_L} + 0.25$$

$$\text{Unloading days} = \frac{\text{Cargo DWT}}{24\,Q_U} + 0.25$$

$$\text{Total Port days} = \frac{\text{Cargo DWT}\,(Q_L + Q_U)}{24\,Q_U Q_L} + 2.0$$

When considering a more realistic 5,000 t/h average loading rate (6,000—7,000 t/h maximum), achieved by many modem loading ports on a 24 hour basis, and that at least two modem grab bucket type unloaders are available (2 x 2,000 t/h max.; 2 x 1,100 t/h average) the formula would read:

$$\text{Loading days} = \frac{\text{Cargo DWT}}{120{,}000} + 0.25$$

$$\text{Unloading days} = \frac{\text{Cargo DWT}}{52{,}800} + 0.25$$

$$\text{Total Port days} = \frac{\text{Cargo DWT}}{36{,}700} + 1.00$$

It is suggested to reduce the idle time allowance for round trips from 2 days to one day as expressed in the formula.

Obviously, for self-unloaders the loading days are equal to comparable bulk carriers, but when assuming a 6,000 t/h maximum for the self-unloaders, or a 5,100 t/h (85 %) average, but conservative unloading rate, the applicable formulae change to:

$$\text{Unloading days} = \frac{\text{Cargo DWT}}{122{,}400} + 0.25$$

$$\text{Total Port days} = \frac{\text{Cargo DWT}}{60{,}600} + 1.00$$

The following tabulation shows the time spent in port per voyage for various DWT vessels using the above formulae:

DWT vessel	40,000	60,000	100,000	150,000	200,000
Standard Bulk Carrier	2.09	2.63	3.72	5.09	6.45
Self-Unloader	1.66	1.99	2.65	3.48	4.30

These figures, when examined more closely, can have a significant impact upon the cost of transportation. For example, a 40,000 DWT standard bulk carrier would make 50 trips per year and, while delivering 2,000,000 tons, it would spend theoretically 104.5 days in port. On the same run, a comparable self-unloader would spend only 83.00 days in port; therefore, the vessel would be able to make 3.16 extra trips delivering 126,500 additional tons. Similar figures for a 150,000 DWT vessel and 20 trips per year are: 32 days saving in port time, 1.88 extra trips and 282,000 tons additional material delivered.

The aforementioned figures are shown for comparison purposes only, essentially to demonstrate that a self-unloader can deliver under certain circumstances, a significantly larger annual tonnage than conventional bulk carriers. Even when considering the deduction in DWT for the self-unloading equipment, the increase will be significant.

When using the previous examples for the 150,000 DWT carriers, the predicted annual tonnages are:

(a) Conventional Bulk Carrier:
20 trips x 150,000 tons = 3,000,000 tons/yr
(b) Comparable Self-Unloader:
21.88 trips x 150,000 tons x 0.98 = 3,216,000 tons/yr

(0.98 factor represents the 2 % weight deduction for the self-unloading equipment)
Increase: 216,000 tons/yr

Considering the freight rates applicable, the additional income could be significant, amounting to millions of dollars. The increase in actual operation may be even more since self-unloading vessels and their crew are geared for efficient operation.

The cost per ton of material delivered by a vessel is also a function of loading and unloading rates. Various equations were developed to demonstrate the importance of loading and unloading rates in connection with intercontinental or coastal movement of large quantities of bulk commodities. When applying the correct factors, it can be proven that for a given route, size restrictions exist if unloading rates are not sufficiently high at receiving ports. Although these equations were developed for straight bulk carriers with loading and unloading rates applying to the shore site installations, they equally apply to self-unloaders. The formulae can also be used to calculate "break-even" distances, when a smaller vessel can deliver bulk materials less expensively than larger vessels provided the loading and unloading rates are constant.

The old classical equation is:

$$y = \frac{C}{DWT}\left[\frac{2L}{Va} + \left(\frac{DWT}{Q_L} + \frac{DWT}{Q_U}\right) \times f\right]\frac{1}{24}$$

Where:

y = theoretical cost per ton of material ($/ton)
C = average operating cost of vessel ($/day)
DWT = net deadweight tons representing the actual weight of the cargo
L = average distance between ports (miles)
V_a = average speed of loaded and ballasted runs (miles/hour)
Q_L = average loading rates (t/h)
Q_U = average unloading rates (t/h)
f = factor representing delays normally encountered while loading and unloading, entering and leaving port, and waiting time. (The "f"-factor may have a wide variation; 1.15—1.5 are acceptable factors)

The above formula is called "old classical" because it considered "C" the average operating figure of the vessel which included (a) depreciation (capital recovery); (b) crew cost, maintenance, insurance, etc.; and (c) fuel cost. Before the OPEC increases, and during the time when shipyard costs were reasonably competitive, the operating cost ("C") consisted of 1/3 depreciation, 1/3 crew and maintenance cost, and 1/3 fuel cost. Today this distribution is no longer valid. Fuel cost and depreciation (especially for new buildings) represent the majority of operating costs and the crew cost is less significant.

Therefore it is recommended to consider either the capital and crew cost for "C" only and compute the fuel cost separately, or use the following expanded formula:

$$y = \frac{1}{DWT}\left[S_p F_p P_d + S_m F_m S_d + C_o (P_d + S_d)\right]$$

Where:

$$P_d = \frac{f}{24}\left(\frac{DWT}{Q_L} + \frac{DWT}{Q_U}\right) \text{ Number of days in port}$$

$$S_d = \frac{1}{24}\left(\frac{L_L}{V_L} + \frac{L_B}{V_B}\right) \text{ Number of days at sea}$$

L_L and L_B = Distances for loaded and ballasted runs
V_L and V_B = Loaded and ballasted speeds
S_p = Cost of diesel fuel while in port ($/ton)
S_m = Cost of fuel for main engine ($/ton)
F_p = Fuel consumption in port (tons/day)
F_m = Fuel consumption while at sea (tons/day)
C_o = Daily operating cost of vessel (capital cost, depreciation, crew cost, maintenance, etc., but no fuel cost)

The First component of the equation is the fuel cost in port while loading and unloading. The second is the fuel cost during the voyage and the third is the ships' operating cost.

The owner of a vessel seldom has control over loading rates; therefore, there is very little he can do to improve it. He has control only in the operating cost, in the speed, by varying the engine or tugboat size, and in the case of self-unloaders, the unloading rates.

On the Great Lakes and for coastal trades, very little can be done to reduce freight cost by increasing ship sizes, as is possible on the ocean, because of the restrictions in draft. Once size is restricted, the remaining variants are the speed and the unloading rates. However, increasing the speed means increasing fuel consumption which may be hard to justify, leaving the changing of the unloading rates the only variant.

For todays self-unloaders, 6,000—8,000 t/h unloading rates represent an economical limit. It is estimated that increasing unloading rates from 8,000 t/h to 10,000 t/h may add more than a million dollars to the cost of the vessel. There are also other problems associated with higher unloading rates: (1) as the maximum unloading (or even loading) rate increases, the average does not change proportionally; (2) actual port time does not decrease by the same ratio as the increase in unloading rates; (3) higher capacity unloading equipment weights more; therefore, the vessel will carry less; and (4) regardless of unloading rates, clean-up time remains the same.

Unfortunately, equipment cost for different unloading rates does not follow the ratio of the actual cost of various width conveyors. The cost of self-unloading gates varies insignificantly with the ratio of unloading capacities or the difference in conveyor widths. Installation cost and the weight of supporting steel remains reasonably constant while the cost of the electrical wiring differs only slightly since it is only affected by the material cost. Expenditures for booms, boom hoists and slewing drives remain reasonably constant throughout, as are costs for furnishing and installing hydraulics. The cost of contract management or engineering is the same regardless of conveyor size, and only the cost of motors and drive equipment will be in a reasonably linear relationship.

Experience has shown that the overall installed cost of self-unloading equipment for 30,000—40,000 DWT class vessels does not vary appreciably in the 3,000—6,000 t/h range and is slightly higher for 8,000 t/h mainly because of the added generating capacity. However, the cost will skyrocket when going over 10,000 t/h.

Back in the late 1950s a paper was presented by Mr. N. Mack Earle, then Chief Naval Architect at the Maryland Shipbuilding and Drydock Company. The paper applied to conversions of T-2 tankers, of World War II vintage, to various types of bulk carriers, especially self-unloaders. It is appropriate even today to quote Mr. Earle since many designers apparently have forgotten his teachings.

"Through evolution the Great Lakes bulk carrier has become one of the most efficient known means of transportation despite the present necessity for improving that efficiency.

The most efficient vessel is one that is designed for a specific cargo over a fixed route. Ship owners, however, usually desire that at least one alternate cargo or service be considered in design so that the vessel will not be totally restricted and earning power nullified. Resale value may be enhanced by such a design development.

Everything that does not improve the revenue of the vessel must be eliminated if cost is to be reduced. Complicated automated devices are warranted only when they pay their way.

Simplicity will usually be found less costly in both initial and operation expenses."

It is true today that the Great Lakes bulk carriers as self-unloaders are the most efficient means of transportation. They are, in the true sense, the "best workhorses". The same applies to those self-unloaders which are presently used for the trade along the U.S. East Coast and the few employed for transpacific routes. Nevertheless, they require improvements to stay competitive.

There is no question that self-unloaders could be fully automated. The average Great Lake self-unloader carries an extra three or four man crew and its ocean going sister up to an extra six men. It should be recognized that all these men cannot be eliminated since they also perform repairs or general preventative maintenance. The automation of self-unloading equipment should be incorporated into the automation of the engine room to be economical. Standing alone, it cannot be justified. Crew reduction through automation deserves consideration if it actually pays its own way.