The Argument for Twin Screw Tankers

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Abstract

According to the CTX tanker casualty database, machinery failures are an important cause of tanker oil spillage. This paper argues that the current large (over 10,000 deadweight) tanker fleet is experiencing at least two full losses of power or steering per day, and probably more than ten. If this fleet were twin screw, properly implemented, this number would be cut by a factor of one thousand. At the same time, tanker low speed manueverability would be improved dramatically. All this could be done for a net cost of less than that of the double hull.

Keywords

Tanker; Twin Screw; Redundancy; Maneuverability;

1 Background

1.1 Introduction

Table 1 is a summary of the CTX Tanker Casualty Database as of May, 2007. For present purposes, what's important is the importance of Machinery Failure. In terms of deaths and spillage, structural failure is by far the most important cause. But machinery failure is the most frequent type of casualty reported and the second most important cause of spillage. Machinery failures have killed at least 111 tankermen and put over one million cubic meters of oil into the sea. Table 1 suggests that we would do well to examine means for improving tanker machinery redundancy. The obvious possibility is twin screw. By *twin screw*, I mean two fully redundant, totally independent engine rooms.

Table 7 shows all the spills in the CTX Tanker Casualty Database over 150 cubic meters in which twin screw might have helped. Most of these casualties are machinery failures, but not all. There are some casualties in which twin screw's far better low speed maneuverabilty and/or lack of stern swing might have made a difference. The column labeled ? indicates how likely, in CTX's opinion, it is that twin screw would have helped. Y in this column means Nearly Certain, P (Highly Probable), M (Possibly). It is an impressive list including some of the largest and most famous spills of all time. It also includes some of the most deadly such as the CORINTHOS (26 killed) and the ALVA CAPE (33 killed).[1]

1.2 Disguising Machinery failures

The importance of machinery failure is obscured in most tanker casualty databases because almost all these machinery failures (the cause) show up as groundings or fires, which are consequences, not causes. For example, one of the top twenty tanker spills of all time is the WAFRA. The WAFRA stranded off Cape Agulhas, South Africa in February, 1971. Upon grounding all six port cargo tanks were breached, and two of the six center tanks as well. She eventually was refloated, towed out to sea, and scuttled with the remaining cargo on-board. In all the WAFRA lost 40 million liters of oil into the sea. In most spill databases the cause is listed as "grounding". In one database, the cause of the spill is listed as "structural failure".

In fact the WAFRA spill was caused by loss of engine power. The loss of engine power was caused by engine room flooding. The WAFRA was a steam turbine ship. The steam turbine cycle requires lots of sea water to condense the steam back to water. The engine room flooded because of a fracture in the piping that brings this sea water to the condenser. The real cause of the WAFRA spill was a machinery failure. If the WAFRA had been a twin screw, two engine room ship, this failure would almost certainly not have resulted in a spill nor the loss of the ship. But this fact is obscured in almost all the tanker spill compendiums of which I am aware.

[1] If you are viewing this paper on line, the ship names in SMALL CAPS are links to the casualty's *precis* file in the CTX database. There you will find descriptions of the casualty drawn from various sources and/or links to such descriptions.

[2] Under-designed and under-built steering gear flange failed. With loss of hydraulic fluid, the rudder flailed back and forth destroying the steering gear. Fully loaded MIMOSA suffered almost exactly the same casualty. This should have been another Amoco Cadiz. See also SCORPIO and MOBILOIL

Other examples are legion. The AMOCO CADIZ[2] (steering gear failure) is often listed as a grounding. The BRAER[3] (loss of power) is usually listed as grounding. Ditto GENERAL COLOCOTRONIS[4] and OLYMPIC BRAVERY[5] The BRITISH AMBASSADOR[6] and ANDRON (both essentially same failure as WAFRA) are called sinkings. Ditto GEZINA BROVIG[7] The NASSIA[8] (loss of steering) and BALTIC CARRIER[9] (ditto) are called collisions.

An extreme example of this inability to distinguish between cause and effect is the WESTCHESTER spill. In November 2000, the fully loaded 88,000 ton tanker WESTCHESTER had a main engine crankcase explosion in the Mississippi River. Crankcase fires are a problem to which all big two-stroke diesels are prone. What happens is that oil vapor builds up in the space above the crankshaft and below the piston, usually due to a leak or a control problem in the lube oil system. Once that occurs all that is required is a source of ignition, and with all the rotating machinery in the crankcase, there are lots of possible sources. This is such a common problem, that the engines are fitted with blow-out panels to minimize the damage to the engine in the event of a crankcase explosion.[10]

Without power, the WESTCHESTER drifted aground about 50 miles downriver from New Orleans, holed a tank, and spilled 2 million liters of her cargo. This was a high profile spill, receiving extensive media coverage. Almost all these reports decried the fact that the ship was a single hull. Not one of them, at least not any that I have come across, even noted that the ship was single screw with nil propulsion redundancy. *This includes the official USCG investigation report.*

In 1996, there was an even more high profile casualty when the bulk carrier Bright Field lost power and rammed into the crowded Poydras Street wharf in New Orleans. Miraculously, no one was killed but at least 62 were injured. This generated a 99 page report by the National Transportation Safety Board.[11] The proximate cause was that the main engine tripped due to low lube oil pressure. The NTSB report goes into great detail about the engine room deficiencies (see the disgusting list in the report's Appendix), but never mentions the fact that the casualty would have been prevented by twin screw.

Conversely, it seems that even the most spectacular machinery failure will receive little or no attention unless there's a big spill or a lot of non-crew deaths. In February, 1999, the HYDE PARK lost power at Mile 92 on the Mississippi River. She was fully loaded with 25,000 tons of highly flammable gasoline. The HYDE PARK then went on a 13 mile rampage, drifting downriver, causing multiple collisions including sinking a crew boat and a barge containing caustic soda, before power was restored. But the only damage to the tanker itself was a holed bunker tank and a 16,000 liter bunker spill. This miraculous escape received almost no publicity.

1.3 Low Speed Maneuverability

There are a number of non-machinery failure spills in which twin screw could have made a difference. Current tankers are under-powered and under-ruddered. The IMO maneuverability requirements, basically a turning circle diameter of no more than five times the ship's length, are so lax that it is difficult to design a steerable ship that violates them. Moreover, these are (nearly) full speed, deep water requirements. In shallow water, where maneuverability becomes paramount, the turning ability decreases by a factor of two or more. Slowing down doesn't help. As power decreases, the turning ability does not improve. The turning circles stay about the same — even though the ship is going slower. And then at still lower speeds, the ship loses steerage completely. For a big tanker, this happens at about four knots. This puts a huge burden on the pilot to get it right very early in the process. He has little ability to correct any errors.

In some weather conditions, he is helpless. The AEGEAN SEA is the most famous example. This ship was at anchor off La Coruña when she was ordered into port. Weather was 25 knot squalls from the west. The ship needed to make a nearly 180 degree turn in order to enter the harbor. She was proceeding at low speed both because she had just picked up her anchor, and immediately after making the turn she needed to pick up the pilot. After raising the anchor, the weather suddenly deteriorated as a squall with winds over 60 knots came through. The master was turning to port. On a single screw ship, this means the rudder must push the stern to starboard. But on a fully loaded tanker all the windage is aft. At the low forward speed, the rudder was not strong enough to push the stern to starboard, even though the master correctly went to full ahead. The ship went aground well before completing the turn.

[3] Pipes on deck destroyed bunker tank vent putting sea water into fuel. With no redundancy, engine room blacked out.
[4] Lost power off Eleuthera. Worst spill ever in the Bahamas.
[5] This VLCC fortunately was in ballast when she lost power multiple times, drifted ashore in Brittany, and broke up.
[6] Condenser inlet line fractured, then poorly maintained sea valve failed.
[7] Piston came thru crankcase, broke SW main, engine room flooded, sank.
[8] This is the second worst spill of all time in the Bosporus, killing 42. See also ESSO BRUSSELS, 16 dead.
[9] Steering gear failed. BALTIC CARRIER suddenly turned into path of oncoming ship. Incredibly, IMO blamed watch keeping on other ship.
[10] Fairly recently (2005-09), the YIOMARAL, a fully loaded VLCC, had a crankcase fire just off the tip of Denmark. Thanks to uncharacteristically good weather, the ship was able to anchor just off the west coast of Denmark and effect repairs, which took several days.
[11] www.ntsb.gov/publictn/1998/mar9801.pdf.

The ship was a double hull OBO. Oil leaking into the double bottom caught fire, the ship was rocked by a series of explosions, and she ended up being destroyed and losing essentially all of her 77,000 ton cargo.

Both the master and pilot were blamed, despite the fact they had done nothing wrong other than fail to predict an abnormal weather occurrence. This was not a guidance error; it was a design fault. Nowhere in all the commentary on this spill that I have seen has anyone pointed out that the casualty would have been avoided if the ship were twin screw.

The simple fact is that big, single screw ships are nearly unmaneuverable at low speed. Consider the dilemma facing the pilot of the VLCC Diamond Grace entering Tokyo Bay at 10 in the morning of 1997-07-02. Weather is calm, visibility is good. He is confronted with two fishing vessels dead ahead. No room on either side. The only way he can avoid them is to go to dead slow. Unfortunately, at dead slow, the ship has no rudder, no steerage way. A fully loaded, 250,000 ton ship drifts aground, spilling 1.5 million liters. This was called "pilot error" by the Japanese press.

Other examples abound. In the case of the Mobil Vigilant, the pilot went very slow and his ship turned into the Marine Duval as a result of bank suction overwhelming rudder forces. In the case of the Vic Bilh, the Afran Stream proceeded fast enough to maintain steerageway and as a result sucked the Vic Bilh off her discharging berth generating a fire and a spill. Either way you are screwed.

The best way of obtaining low speed maneuverability is twin screw. The main reason for mandating twin screw is engine room redundancy. But an important by-product will be far better slow speed maneuverability. The slower the speed the more important and the more effective twin screw is. One of the worst of our Guidance casualties is the Edgar M Queen's hitting the Corinthos at Marcus Hook in January, 1975. The Queeny had part discharged at the Monsanto terminal and then had to proceed further up the Delaware River to complete her discharge. To do this, she had to make an 180 degree turn to starboard in the river. The ship was equipped with a bow thruster but it clearly wasn't enough. The pilot backed and filled for four minutes before proceeding upriver. But he still hadn't turned the ship far enough to miss the Corinthos which was discharging at a berth on the far side of the river. When this became clear, the Captain panicked and ordered full astern. But the rudder was still hard to starboard. The rudder responded to the prop wash. The vessel's rate of turn slowed and, at a forward speed of less than two knots, the Queeny slid into the non-inerted Corinthos. 26 people were killed and 11 injured in the ensuing fire. Twin screw almost certainly would have prevented this killer casualty.

Something similar happened in the Alva Cape/Texaco Massachusetts collision. The two ships travelling at very low speed had agreed a port to port passage. But the pilot of the burdened Alva Cape decided he needed more time to let the Massachusetts clear, so he went astern. He lost steerage way, his bow swung into the path of the Massachusetts. 33 dead; 19 injured.

Twin screw also allows the pilot the option of turning the vessel without stern swing. A rudder does not turn a ship in the direction the helmsman steers. Rather it swings the stern in the opposite direction, and only then does the ship start to go in the desired direction. In close quarters, stern swing can be critical. If you are right on the edge of a channel, you can't turn a single screw ship back into the middle. If you are too close to a ship passing port to port, you can't go to starboard without swinging your stern into the oncoming vessel. The worst stern swing casualty I'm aware of is the Pacific Glory/Allegro collision. Both loaded tankers were going in the same direction on slightly converging courses. Due to an ambiguity in the Rules of the Road, both ships thought they were the stand on vessel, and stood on. At the last minute, both ships sheered away. Their sterns came together with such force that the Pacific Glory exploded killing 13 and spilling 6 million liters of crude. In the case of the High Endurance collision, the Merkur Bridge managed to clip two ships with stern swing in the same casualty. Just a month later, the Bergitta was also a victim of stern swing. If you are a lightering ship and screw up your approach to the mother ship, you can't turn away. Turning a twin screw by differential throttle swings the bow in the direction you want to go. Unlike a rudder, you can actually use your maneuverability when you need it most.

In many of the casualties in Table 7 and quite possibly in the case of the Tasman Spirit the largest spill since 2003, twin screw maneuverability could very well have made an important difference. A great deal of uncertainty surrounds the Tasman Sea spill. Some claim the channel into Karachi had been allowed to shoal. Some claim the ship was brought in on the wrong tide. Some claim pilot error. Some claim machinery failure. What it clear is that the pilot was attempting to negotiate a difficult channel in difficult weather with a ship that had very poor maneuverability. And in extremis he could not use what maneuverability he had due to stern swing.

2 Frequency of Machinery Failures

2.1 Casualties in the Suez Canal

Table 8 shows all the non-CGMIX tanker casualites in the CTX database for which twin screw might

[12] The USCG MIX casualties are discussed separately in Section 2.5.

have helped in the last five years (since 2002 inclusive).[12] Almost all of these are machinery failures. We can be sure that the number of machinery failures in the CTX database is a very small percentage of machinery failures actually experienced by tankers. Just about the only time we hear about a machinery failure is if it leads to a grounding or a collision, or the ship is so desperate it is willing to sign a Lloyds Open Form. Nearly 40% of the machinery failures in Table 8 occurred in a few localized chokepoints including the English Channel (Area code EC), and the other waters around Britain (UK), the entrances to the Baltic (KT), the Bosporus/Dardanelles (BD), and the Suez Canal (SC). It is not that machinery failures are more common in these few hotspots. Rather they are more difficult to hide.

But how small a percentage? One way to get a handle on this is to look at the Suez Canal, that is those casualties which have an SC in the Area column. So far we have had none reported in 2007. There were two in 2006, one of which resulted in a 5000 ton spill.[13] None reported in 2005 One in 2004, plus two suspicious groundings. One in 2003 for which we have incomplete data. One in 2002, plus one suspicious.

We can be sure that there are incidents that go unreported. For one thing a ship can get lucky, have a loss of power and recover before hitting everything. More importantly, no owner or Class will report a casualty unless forced to.

At 0605 of 2002-12-31, one of our ships, the Hellespont Embassy, in ballast was southbound in the Canal at about km 73 doing about 8 knots. The pilot called for hard port, and then hard starboard. When the helmsmen executed the second order, the steering failed to respond. The ship struck the bank hard in way of 1 Port. But the ship bounced off the bank. The crew was able to fix the problem before anything else bad happened.

The impact resulted in a large hull indent; but, thanks to the 30 mm steel, no penetration. (Modern VLCC's have around 20 mm plating in this area.) Still Class required the ship to drydock before she was allowed to load; and the repair required some 50 tons of steel. There was an insurance claim, and plenty of paperwork. Yet this casualty has never made it into any of the public databases. I suspect this is true in the majority of such cases.

But for sake of argument, let's say one loss of power/steering failure per year in the Canal. The Suez Canal is pretty secretive. It publishes only total annual transits and annual tanker transits. So far I have been unable to locate this data. But a Panama Canal study offers a glimpse. [R.K Johns and Associates, Suez Canal Pricing Forecast, 2005-2025, www.pancanal.com/esp/plan.pdf] This report claims the Suez has 224 tanker transits in Aug 2001, 247 in August 2003, and 208 in August 2005.

We can be sure that some of these tanker transits were ships smaller than 10,000 dwt. But for the sake of argument, let's generously assume 3000 tanker transits per year. The ships are in transit for just a little over 12 hours. Let's say 16 hours. Under these assumptions, we are talking about 2000 tanker-days per year transiting the Suez or about 5.5 tanker-years. If tankers are suffering 1 loss of power/steering gear failure per year in the Canal, this indicates that the tanker fleet is experiencing such a failure at least once every six ship-years.

I'm sure this number is conservative, but, using it, the 3600 large tanker fleet over 10,000 dwt is experiencing 600 major loss of power/steering gear failure, of which about 10 make it into the database. If we adjust for all the biases in the above calculation, the actual number is very likely more than 100 per reported case. In short, this reasoning suggests that the large tanker fleet is experiencing 2 to 4 losses of power/steering failures per day.

2.2 The V-Plus Experience

Another way to approach this problem is through the very small sample of ships that I actually know something about. My firm built four 442,000 ton tankers in Korea 2001 and 2002. These ships were built to far above Class standards. The supervision by our team was so rigorous that the Koreans made it clear we would not be welcomed back. They were manned by some of the best tankermen in the world. To my shame, they were single screw. We called these ships the V-Plus class.

Shortly after the first of our new superships was delivered in 2002, we began receiving disturbing reports from our Chief Engineers about the machinery. It began with main engine fuel oil piping leaks. On one ship, the Hellespont Tara, the fuel oil piping began leaking on her maiden laden voyage while headed down the east coast of Africa. This ship had so many of these leaks, that the Chief quickly went thru his entire stock of spares. He was forced to shut down one cylinder. More pipes began leaking on him, and we were forced to go to the manufacturer, Sulzer, and ask if the engine could be operated with two cylinders down. The reply "Maybe, if you, go slow enough". The Chief managed to make a temporary repair of some of the pipes and the Tara, with 420,000 tons of cargo, limped down the coast to East London, where we were able to helicopter out some spares.

This experience turned out to a harbinger. By the time, we sold these four ships in early 2004, the V-Plus class had amassed a total of 3500 at-sea days. During that time, we had:

1) Ten involuntary total losses of power including one catastrophic liner failure.

[13] The FRONT VANGUARD had a black out. The next ship in the convoy was the Anna P.C. She went astern to avoid a collision. But on a single screw ship, going astern pushes the stern to port. The stern kicked to port; she hit the bank, and spilled 5000 tons. This casualty demonstrates both features of single screw: no redundancy and no low speed manueverablility.

2) Plus 13 forced reductions/shut downs mostly from leaking high pressure fuel oil piping. We had a total of 38 reported incidents of fuel oil piping leaks.
3) Plus 5 crankshaft and 1 camshaft bearing failures we know about.
4) At least five trips from the Piston Cooling Oil (PCO) system.
5) Plus two badly cracked turbo-charger diffusers.

Most of the total loss-of-power incidents were quite short as Table 2 shows. (I will call this type of failure, a *minor* loss of power, even though applied to tankers the phrase is oxymoronic.) But one of the casualties was a catastrophic failure of a cylinder liner. (Continuing my pattern of understatement, I will call this sort of failure a *major* loss of power.) Very roughly a *minor* loss of power lasts an hour or less. A *major* loss of power lasts a day or more. In between take your pick. Needless to say, there is nothing minor about any total loss of power on a big tanker.

The liner failure was by far the worst. In these enormous engines, the cylinders are not bored as they are in your car. Rather each cylinder is made up of a separate very thick walled piece of pipe called a liner. This piece of pipe is about 1 meter in diameter and about four meters long. Each liner weighs about 5 tons. It is drilled with inlet ports, and all sorts of cooling and lubricating passages. On April 19, 2003, the main engine on the Hellespont Alhambra suddenly shut itself down. The crew discovered that one of the nine liners had split into two pieces. The top part was still in place but the bottom two thirds was totally detached and had fallen down about 10 mm. The only thing that was keeping the bottom portion from falling onto the crankshaft was that it had hung up on some lubricating fittings. If that had happened, the ship would have been helpless until a tug arrived. The main engine would have had to be totally rebuilt.

As it was, we were very lucky.[14] The Alhambra had just finished discharging in the Gulf of Mexico, so she had no cargo on-board. The Master let the ship coast past a nearby offshore oil platform until he was five miles away. Although they were sixty miles offshore, the water was still shallow enough so they could anchor. They anchored and gingerly removed the piston and failed piston liner. They could then move to a safer anchorage under reduced power, and replace the liner with the ship's spare. There is no record of this major casualty in any public database, other than CTX's.

Of course, if you ask any tanker owner, he will tell you that his engine rooms have performed far better than ours did. I am convinced he is either lying or misinformed. The V-Plus were better speced, better built, and better manned than just about any modern tanker out there. In a normal tanker operation, almost all minor loss of power incidents are not even reported to the owner. The crews know that however blameless they are the incident will be a black mark. On ships that are run by third party managers even if the crew reports a minor loss of power to the manager, there's a very good chance the manager will not transmit the report to the owner. More importantly, they know the owner doesn't want to know. The owner probably knows about a major loss of power incident but, unless he decides to make an insurance claim, nobody else does. Even then it doesn't become public. No Classification Society will violate an "owner's privacy" for fear of losing a customer. This silence is written into Class contracts. It is a legal requirement. The only time we hear about a loss of power incident is when it results in a spill or the ship is so desperate that it calls for a tug.

2.3 The Valdez Numbers

There are a few exceptions. The Coast Guard grabbed the Bright Field logs before they could be sanitized. They found that the Bright Field had had at least two major loss of power incidents in the 11 months prior to the "minor" loss of power which caused her to clobber the Poydras Wharf. One lasted four days, the other a little over a day. That's twenty times the V-Plus major loss of power experience.

After the Exxon Valdez spill in 1989, ships loading at Valdez, Alaska were subject to unusual scrutiny. Based on Alyeska records, the Anchorage Daily News reported on 1992-11-22 (page A13) that, in the two plus years since the Exxon Valdez, there had been five loss of power incidents on laden tankers in Prince William Sound alone. Here's a brief summary of the casualties in this article. Remember these are outbound (loaded) tankers only.

1989-09-20, Atigun Pass Lost power between Bligh Reef and Glacier Island. Escort vessel held ship in shipping lane until power was restored one hour later.

1990-06-20, Southern Lion Lost power at about the same spot as Atigun Pass. Ship did not drift out of shipping lanes before regaining power. Sailed to Knowles Head for repair.

1990-08-04, Kenai Lost power near Rocky Point. Stayed in shipping lanes. Did not require help from escort vessels.

1991-04-01, Arco Sag River Discovered a mechanical problem with its propulsion system while passing through Valdez Arm. Sailed under own power to an anchorage at Knowles Head.

1992-09-09, Brooks Range Lost power in Valdez Arm. Regained power before it required aid from escort vessels.

[14] The bulk carrier Selendang Ayu was not so fortunate. In 2004, she also suffered a broken cylinder liner, but drifted ashore on Unalaska Island, and broke in two. Six crew died, a USCG helicopter crashed, and a large bunker spill occurred.

1992-10-20, Kenai Problem with steering system and headed toward Middle Rock. USCG estimates ship was about 100 yards from the rock, when escort vessel turned the ship back on course.

At the time Valdez was loading two to three tankers per day and these ships are in laden passage in Prince William Sound for less than 8 hours per trip. We are talking four total loss of power incidents – plus one loss of steering – in at most 2.5 ship-years of operation. This is roughly double the V-Plus numbers. And it is consistent with the numbers we derived in Section 2.1.

2.4 DNV Loss Of Control Number

DNV uses a figure of 6.8e-5 per hour for "loss of control due to technical reasons". See Dahle et al, Strategic Action Program for the Red Sea and Gulf of Aden, DNV Report 97-1388, 1997-04-29. The text of this report indicates that the DNV number combines both loss of steering and loss of power. Thanks to Class confidentiality, we cannot look at the data this DNV number is based on. But it is a safe bet that it is better than anything that is publicly available. On the other hand, it is quite unlikely that even DNV learns about minor losses of power.

In any event, the DNV number is equivalent to 1 loss of power/steering every 1.7 ship years. If this number is correct, then overall the large tanker fleet is suffering about six losses of power/steering per day.

2.5 USCG MIX Casualties

By far, the best source of machinery failure data is the USCG Marine Incident eXchange (MIX) database. About 2001/2002, the US Coast Guard convinced American pilots that it was in their interest to report any problem that occurred while a ship was under their control. Almost overnight the reported frequency of LOP's went up by an order of magnitude or more. These reports end up in the USCG MIX database. Table 3 summarizes the total loss of power/steering incidents in the MIX data for tankers over 10,000 deadweight in 2003. There are 42 such casualties of which I've called four major. These four LOP's have an E2 code of LP; a minor LOP is coded Lp.

According to the Maritime Administration, there were 18,503 port calls by tankers over 10,000 dwt in the USA in 2003, of which 6% were somehwere in the Mississippi River. I do not have any data on how long these ships were under pilotage, but on average, it was probably less than half a day, and almost certainly less than a day. In the former case, we are talking 42 LOP's in about 25 ship-years of operation; in the latter 42 LOP's in about 50 years. This assumes conservatively that the MIX database is capturing all the LOP's under pilotage.

2.6 Humber Estuary Casualties

Section added 2010-05.

The Humber port authority issues an annual report listing all casualties reported to the Humber Vessel Traffic System (VTS). The report includes a brief summary of each casualty. The casualties are categorized as Defects (mostly loss of power or steering), Anchorage Problems, Close Quarters, Groundings, Contact with Sea marks, Contact with Structures, Contact with Vessels, but thanks to the summary it is usually possible to identify the Loss of Power/Steering casualties.

In 2007, CTX was able to identify 98 LOP casualties in the annual report. In that year, the Humber VTS recorded 16,216 inward movements, and 35,664 total movements. Approximately, 10% of the movements were internal. VTS Humber advises "Tanker and bulk carriers of over 40k dwt and 11.5 draft, are passage plan for 3.5 hrs transit frm Humber Light Float to berth." So four hours per movement would seem a reasonable, if conservative, figure. Using this number, the 2007 data represents about 143,000 ship hours or 16.3 ship years. The Humber 2007 data points to 6 losses of power or steering per ship-year.

As Table 4 shows, the Humber numbers for 2008 are very similar to those for 2007, but the numbers for 2009 are down a surprising 40%. Overall the Humber numbers point to about 5 losses of power/steering per ship-year.

The Humber data includes all sorts of vessels. But there is no a priori reason for believing tankers are much different from other ships in this regard.

2.7 Summary

Table 5 summarizes these estimates. Needless to say, it is very uncomfortable to work with such fragmentary data; but, as long as the world allows the tanker regulatory system to operate under a code of silence, we have no choice. Interestingly the first five bits of evidence all end up in the same ballpark, indicating that the large tanker fleet is experiencing two to twenty losses of power/steering per day. The Bright Field, clearly a "bad ship" is roughly speaking an order of magnitude higher. But there are a lot of bad ships out there. After the Sea Witch lost steering and rammed the Esso Brussels killing 16, it was discovered that she had had at least 12 losses of steering in her 5 year life. The Humber data suggest an LOP rate about half-way between the Bright Field and the other sources.

The bottom line is that today — this very 24 hours — there is good reason to believe that at least 10 big tankers will go adrift with a complete LOP, and at least one of these failures will be Major. The question society must ask itself is: is this acceptable?

I submit it is not, especially since there is an easy fix: twin screw.

3 The Value of Redundancy

3.1 Total Loss of Power

Worldwide there are currently about 3600 tankers with a deadweight of 10,000 tons or more afloat. ***All but about 20 of these ships are single screw.*** 99.5% of all tankers have one main engine, one propeller, and one rudder. If our experience with the V-Plus (Section 2.2) is typical, this means that on average there are ten "minor" total loss-of-power incidents every day, even if you are crazy enough to call any loss-of-power that risks a major oil spill "minor". If my once every ten year number for "major" loss-of-power incidents is correct, then worldwide we are averaging one major tanker loss-of-power incident every calendar day. In fact, as we have seen, we have good reason to believe, that the V-Plus reliability was better than an average newbuilding. Given the consequences, any sane person has to regard these numbers as unacceptable.

They become totally unacceptable as soon as one realizes that total loss-of-power incidents can be reduced by several orders of magnitude or more by mandating twin screw, that is, two main engines, two propellers, and two rudders arranged in two engine rooms in such a manner that any failure in one engine room does not affect the other.

To get a feel for the power of this redundancy, we must make some assumptions about the length of the loss-of-power. Under the current regulatory system, ships don't report most failures, and the owners and Class won't tell us about the failures they know about. We have no real data on either Mean Time Between Failures nor the Mean Time To Repair. I have no choice but to make up numbers that seem reasonable.

For the sake of argument, let's use the V-Plus numbers. And let us further assume that a "minor" loss-of-power lasts one hour, and a "major" loss-of-power lasts a day. If we have a twin screw ship, then to have a total loss-of-power, the second loss of power must occur while the first incident is still happening.

If twin screw is properly implemented, so that loss-of-power incidents on-board a single ship are independent, then using the V-Plus numbers the probability per at-sea day of the second engine room going down in a second "minor" incident while the first is down in a "minor" incident is 1/3,195,000 or on average once every 8750 ship-years. The probability of the second engine room going down in a "minor" incident while the first is down in a "major" incident is 1/1,332,000 or once every 3650 ship-years on average. The probability of the second engine room going down in a "major" incident while the first is down in a "minor" incident is 1/31,950,000 or once every 87,500 ship-years The probability of the second engine room going down in a "major" incident while the first is down in a "major" incident is 1/13,320,000 or once every 36,500 ship-years. In a twin screw ships, there are two ways each of these loss of power combinations can happen. So for a twin screw ship, we must double these frequencies.

Table 6 summarizes these numbers. The second section of the table assumes first the entire fleet is single screw, and then the entire fleet is twin screw. One can easily argue with the particular numbers I've used. But the point is crystal clear. Propulsion redundancy — properly implemented — can reduce tanker total loss-of-power incidents not by 20%, not by 50%, but by a factor of 1000 or more.

This is just simple common sense. Airplane engines are orders of magnitude more reliable than tanker engine rooms. Yet no one in his right mind would use a single engine airplane across the Atlantic on a routine, commercial basis. In fact, one would probably be regarded as a bit of a dare devil to cross the Atlantic once on a single engine plane. You'll probably make it; but, if 3600 people try it, it is nearly certain that someone will not. Right now there are 3600 sizable tankers out there routinely playing daredevil.

4 The Cost of Twin Screw

The argument against twin screw is straightforward: it costs too much. In fact, twin screw would cost less than double hull, especially on big tankers. The first twin screw tanker I ever saw was a ULCC improbably called the Nanny. It was 1979 or 1980. My brother and I had a port agency in Cayman Brac which at the time was an important lightering area. When I went out to the ship, I couldn't help notice the twin funnels and the extreme beam. Then I saw the twin rudders, slightly canted. I knew I was looking at something special.

Once aboard all the crew could talk about was the marvelous maneuverability of the ship which they repeatedly demonstrated during the subsequent lighterings, once turning the ship in little more than twice her own length. The Cayman mooring masters couldn't believe it. It was a whole different ball game. But what turned me on was the fuel consumption.

The Nanny was the brainchild of Stig Bystedt of the Swedish yard Uddevallavarvet. The knock on twin screw for tankers was that, due to the blocky nature of the hull, you could not get a decent flow pattern around the propellers. The result was very poor fuel consumption. Bystedt solved this by utilizing a *twin skeg* design. An example is shown in Figure 1. In effect, each propeller has its own hull. Properly implemented, the flow into the propellers is as nearly as good as that for a well-designed single screw stern. But the ship can be much beamier. For the same deadweight, this means a shorter ship which generates important savings in hull steel. It also partly compensates for the additional wetted surface of the twin screw. And it results in a shallower draft ship, allowing larger cargoes into draft limited ports. Finally, the propellers are more lightly loaded which increases the propeller efficiency.[15]

The Nanny was a 499,000 ton ULCC. Her fuel consumption was nearly the same as that of a good single screw tanker of the same size and vintage. Since then considerable work has been done on twin screw tanker hulls. Much of this work has been done at SSPA, the Swedish state towing tank in Goteborg. SSPA now claims they can produce a twin screw tanker hull with 6% lower fuel consumption than a single screw ship of the same capacity. Tests for the 350,000 ton Marc Guardian indicated that twin screw required 6.5% less power than single screw at the same speed.

In 1993, we asked the Korean yards to quote a 3 million barrel twin screw ULCC. The price numbers they came up with, before any bargaining, were about 10% more than an equivalent single screw ships. Our own internally generated cost estimates were in the range of 5 to 8%. Best guess at what a double hull adds to the cost of a tanker is about 7%.

The relative affordability of twin screw has been clouded by the fact that, with one exception, all the recent twin screw tankers have been specialty ships. Twin screw has been used in North Sea shuttle ships. But these ships have all kinds of requirements that conventional tankers do not. Recently, nine twin screw tankers have been built for the US West Coast–Alaskan trade at more than double the cost of a same sized, single screw ship built in the Far East. But these American Flag ships must be built in the USA. Any ship built in San Diego will cost more than twice what it will cost in Ulsan.

The one "normal" twin screw tanker built in the last 25 years is the Stena V-Max class. These ships cost approximately 10 million dollars more than a Class minimum ship. But Stena builds to a considerably better Specification than Class requires. Probably 3 or 4 million of the extra dollars were due to to Stena's refusal to accept Class standards. Part of the remainder was due to the uniqueness of the project and the limited beam of the Hyundai building docks. If twin screw became the norm as double hull has, then the additional cost would become even less noticeable than the additional cost of the double hull has.

But it won't happen without regulation. Even a 10% increase in initial cost will be more than all but the most committed owner, such as Stena, will accept. And with some superficial justification. In 2002, Hellespont developed a twin screw ULCC. We then went to both Exxon-Mobil and Chevron-Texaco, who we figured would be the most environmentally oriented charterers. We asked them if they would pay a small premium for a twin screw tanker, pointing out the thousand-fold increase in reliability. They said no. Stena has had the same experience. The V-Max receive no premium in the spot market. Twin screw, like double hulls, will require regulation.

5 Implementing Twin Screw

The key requirements of a twin screw system are:

1. The ability to maneuver with the loss of one engine room including rudder.
2. Flooding of one engine room will not sink the ship even if she is loaded to tropical marks.
3. No interdependencies. Unless failures are truly independent, then the redundancy is a mirage.
4. The probability of a single failure taking out both engine rooms must be an order of magnitude less than the probability of both engine rooms going down independently.[16]
5. Don't screw up normal operations. The crew is part of the system. If you complicate their lives, then they become the interdependency.

(1) and (2) are more or less adequately addressed by the current Class twin screw rules such as ABS R2-S+ rating or DNV RPS. The maneuverability requirement implies (or at least should imply) that a twin screw ship must have considerably more power than current large, single screw tankers, more than 30% more power. This will be at least partly repaid during boom periods by the additional 1 to 2 knots extra speed.

The problems are (3), (4) and (5). Single failure here includes an engine room flooding or fire. In the Class Rules, the latter is addressed by requiring a watertight, A60 bulkhead between the engine rooms. But there is an inconsistency in that only an A0 bulkhead is required between the engine rooms and the pump room. The aft pump room bulkhead should also be A60. Otherwise a fire in one engine room has an easy path to the other thru the pump room. Or a fire in the pump room could take out both engine rooms.

One obvious implication of (3) and (4) should be that an at-sea black-out in one engine room must not take down the other engine room, even momentarily. However, current Class twin screw rules allow this major interdependency. The only thing worse than trying to bring back one blacked out engine room is trying to bring back two. (3) and (4) require sufficient generating capacity on-line in both engine rooms, so that the generator on each side can handle its engine room plus all essential common loads with a generous margin.

[15] Twin skeg ships are wider and ***less tall*** than a standard double hull of the same capacity. This means less outflow in casualties in which the inner bottom is breached. The depth and draft of the Stena V-Max (see below) is 25.6 and 19.0 m, The depth and draft of a single screw VLCC is about 31.25 and 22.25. The single screw VLCC with a 2.4 m higher oil column will spill something like 15 million liters more oil in an Exxon Valdez type casualty.

[16] Usually this requirement is worded something like: no single failure can result in the loss of more than 50% power. But this is very dangerous short-hand, for it is impossible to implement, and attempting to do so can lead to stupid design decisions.

The Class definition of *essential* should not be used. To Class, an emergency fire pump is a non-essential load. And the Class load factors are, to put it politely, optimistic. Typically, the real installed power required is 25% or more larger than that calculated using the Class load factors, especially when an engine room is under stress. A load shedding system will be needed for the truly non-essential loads, and to make sure that power is not drained back to the blacked out engine room. This requirement will push the design toward shaft generators.

Eliminating interdependencies requires some careful thinking. In 1998, the MORUY lost steering and went aground in the St. Lawrence River. The cause was that the deck above the emergency switchboard leaked shorting out the emergency switchboard, and power to the steering gear was lost. I doubt if any of the recent twin screw tankers could maintain power to at least one steering gear in the face of an emergency switchboard failure. Obviously, we need two totally independent fuel systems as the BRAER proved.

(5) requires that we need good access between the engine rooms. Otherwise we make maintenance more difficult and that is exactly the wrong way to go. I'd accept the risk of large, normally closed doors in the centerline bulkhead at each flat rather than force the crew to climb out of one engine room to get to the other. And I'd accept the risk of a normally open when manned door between the two engine control rooms, with the combined engine control room A60 insulated from both engine rooms. 99.99% of the ship's life the two engine rooms will be operated as a single entity. Separating the control functions is clearly unattractive. Nor do I like a Master/Slave pair of control rooms. There's far two many possible interdependencies, and, since the Slave system will almost never be used by itself, it will be rarely tested and never completely. (The testing itself could take down both engine rooms.) If the combined engine room is wiped out by a rapid intra-control room fire while the intra-control room door is still open, I'd fall back on local control.

Currently, the Class twin screw rules – at least by my reading – allow neither a combined control room nor decent access. In an attempting to be bureaucratically pure, they are producing overly complex, hard to operate engine rooms.

Most importantly, twin screw must not be used as an excuse for still less robust machinery. Any further reduction in current paper-thin machinery design margins will produce a gargantuan jump in failure rates, and obviate the value of twin screw. Quite the opposite, we must design machinery more conservatively. Only then will we reap the full value of twin screw.

6 Conclusion

Twin screw offers a thousand fold increase in reliability and a dramatic increase in low speed maneuverability. Twin screw would have prevented many major casualties including the AMOCO CADIZ, the BRAER, the ALVA CAPE, and the CORINTHOS. Twin screw would have avoided something like a million tons of oil in the water and well over 100 deaths.

Yet twin screw net of private benefits costs little more than single screw.

So why aren't owners flocking to twin screw? The answer is simple. Twin screw costs the owner slightly more than single screw to build and operate. He bears all these costs. He bears almost none of the costs to the world of single screw, for he can easily insure himself out of these costs. If a single screw ship gets in trouble, however bad, the owner's cost is a modest deductable. An extreme example is the BRAER. When this 17 year old, pre-Marpol Aframax drifted onto the rocks in the Shetlands, her hull insurance was 12.7 million, and she had loss of hire insurance of 6.3. At the time the tanker market was in a slump. The Braer had a market value less than 5 million dollars. If the Braer had been twin screw, we would have avoided a 99 million liter spill, and the owner would have lost the better part of 15 million dollars.

We have set up a system where almost all the benefits of twin screw are external to the owner, almost all the costs are internal. As long as that is the case, twin screw will require regulation.

Table 1: Breakdown of CTX Casualties by Initial Event

Based on CTX Casualty Data Base as of 2007-07-10T15:36:25

	1960 ON			1995 0N		
Initial Event	NO.	Volume (Liters)	Dead	NO.	Volume(liters)	Dead
HULL STRUCTURAL FAILURE						
Hull, brittle failure	2	14,900,000	0	0		0
Hull crack	51	18,425,199	2	38	91,371	2
Hull, cant link to corrosion	46	1,912,830,000	474	1	0	0
Pipe failure/leak	3	7,778	0	2	7,460	0
Hull, lots of corrosion	10	215,672,000	51	5	135,519,000	1
Probable hull failure	16	284,678,950	147	2	113,550	0
Hull, probable corrosion	2	18,000,000	2	0		0
TOTAL	130	2,464,513,927	676	48	135,731,381	3
RULES OF THE ROAD SCREW UPS						
Bad giveway vsl response	5	27,689,500	41	1	83,500	0
Confirmed Dance of Death	4	178,690,000	55	0		0
Failed to detect other vsl	2	335,890,000	35	0		0
Rogue vessel in wrong lane	2	6,638,000	64	0		0
Uncoordinated manuever	3	29,800,000	0	3	29,800,000	0
Probable bad Rules of Road	25	146,675,000	13	12	6,276,000	1
Probable Dance of Death	8	290,162,000	156	1	9,450,000	0
TOTAL	49	1,015,544,500	364	17	45,609,500	1
MACHINERY FAILURE						
Blackout	6	48,100,000	42	2	6,000,000	0
Crankcase explosion	2	2,100,000	0	2	2,100,000	0
Generator/electrical	2	0	0	1	0	0
Engine room flooding	2	50,000,000	0	0		0
Crankshaft failure	4	0	0	4	0	0
Cylinder Liner Failure	1	0	0	1	0	0
Loss of steering	27	336,325,000	28	16	4,371,000	0
Shaft/Sterntube Failure	3	0	0	3	0	0
Stern tube leak	3	2	0	3	2	0
Sea Water Line leak	4	146,000,000	0	0		0
Boiler fire	4	3,000,000	10	1	0	1
Other/Unknown Machinery	69	110,382,800	4	37	1,652,800	0
Probable machinery failure	38	397,932,000	27	14	0	0
TOTAL	165	1,093,839,802	111	84	14,123,802	1
GUIDANCE/CONNING ERRORS						
Anchor dragged	6	10,200,000	0	2	0	0
Hit Berth, mooring/unmooring	3	7,638,000	0	2	8,000	0
Conning error	9	209,711,000	26	4	86,707,000	0
Ship too deep for depth, swell	3	1,817,000	0	1	0	0
Bad seamanship	1	99,600,000	0	0		0
Tug contact/tug screw up	10	1,792,800	23	7	257,800	0
Other Guidance error	3	0	0	3	0	0
Probable guidance error	27	69,681,622	142	15	2,289,522	0
TOTAL	62	400,440,422	191	34	89,262,322	0
NAVIGATION ERRORS						
Navigation error	14	260,446,000	7	1	0	0
Bad Charts on board	2	300,000	0	0		0
Probably navigation error	7	36,026,000	0	2	8,706,000	0
TOTAL	23	296,772,000	7	3	8,706,000	0
BAD INERTING/HOTWORK						
Inert gas not working/bad	13	56,604,000	87	1	12,600,000	21
Stupid hotwork	6	8,849,000	29	1	0	1
Lightning strike	3	6,980,000	8	0		0
Bad purging, gas-freeing	4	500,000	25	3	500,000	22
Probable bad IG/hotwork	19	31,646,000	152	4	5,000,000	22
TOTAL	45	104,579,000	301	9	18,100,000	66
Navaid bad/inoperative	1	5,000,000	0	0		0
Bad channel depth	1	4,700,000	0	1	4,700,000	0
Charts incorrect	4	54,476,400	0	1	91,400	0
Hit submerged object	3	22,520,000	0	1	120,000	0
Probably navaid error	3	146,900,000	1	2	35,200,000	0
TOTAL	12	233,596,400	1	5	40,111,400	0
CARGO TRANSFER PROBLEMS						
Deballasting screw up	1	4,760	0	1	4,760	0
Hose failure, not unmoored	13	4,138,480	0	11	4,138,480	0
Other transfer screw up	36	7,629,878	0	27	742,401	0
Came unmoored	16	57,548,360	29	10	423,060	0
TOTAL	66	69,321,478	29	49	5,308,701	0
EXTRENAL/WAR/PIRACY						
Piracy	1	14,100,000	30	0		0

Continued on next page

Initial Event	1960 ON NO.	Volume (Liters)	Dead	1995 0N NO.	Volume(liters)	Dead
External Tampering	1	0	0	1	0	0
War damage	4	0	5	2	0	1
TOTAL	6	14,100,000	35	3	0	1
INTENTIONAL DISCHARGE						
Intentional Discharge	3	1,170	0	2	1,170	0
TOTAL	3	1,170	0	2	1,170	0
TOTAL KNOWN INITIAL EVENT						
TOTAL KNOWN	561	5,692,708,699	1715	254	356,954,276	72
NO INITIAL EVENT						
TOTAL No Initial Event	295	763,578,693	458	138	54,377,293	59
TOTAL KNOWN AND UNKNOWN						
TOTAL ALL	856	6,456,287,392	2173	392	411,331,569	131

Table 2: V-Plus Total Loss of Power Incidents, 2002-2004

Date	Ship	Length	Problem
20030419	Alhambra	abt 24 hrs	Liner in two pieces
20031119	Alhambra	<15 min	Trip due bad setting #9 PCO DP Switch
20030320	Metropolis	0:13	Trip due low Jacket cooling water press
20021119	Tara	<15 min	#9 CYL PCO IN DP (SHUT DOWN)
20030525	Tara	<15 min	#8 CYL PCO IN DP (SHUT DOWN)
20030511	Fairfax	0:06	#8 PCO DIF PRESS 06:45
20030710	Fairfax	0:10	#5 PCO DIF PRESS 04:42
20031008	Fairfax	0:17	M/E LO LOW PRESS 16:16
20040129	Fairfax	0:05	M/E OVERSPEED 01:01
20040521	Fairfax	0:02	#1 D/G TRIP HH TEMP COOL FW

PCO stands for Piston Cooling Oil System.

Table 3: Loss of Power Casualties, CGMIX, 2003

Based on CTX database as of 2007-07-23T12:42:08

Date	Ship	E1	E2	E3	LO	AC	Clas	Flag	?	Area	Synopsis
20030104	prince william	MY	Lp		H		AB	US	M	VZ	both boilers tripped due to low control air press
20030116	lepetsk	MY	Lp		H		AB	RU	P	NY	loss of power lving New York, break in TC lube oil piping
20030117	volga	MY	Lp	DT	T	L		LR	P	MR	loss of power mooring Miss R, low LO pressure
20030119	nile	MY	Lp	DA	H		AB	LR	P	NY	loss of power inbound New York, fuel control vlv
20030123	united triton	MY	Lp	DA	H	L	NV	LR	P	MR	loss of power inbound Miss R, hit anchored Clipper Faith
20030125	montana sun	MY	Lp		H		NV	LR	P	NY	loss of power inbound New York, no details
20030126	golden eagle	MY	Lp		H		LR	LR	P	NY	loss of power departing New York, no details
20030130	lion	GE	Lp	DA	H		NV	LR	M	DR	blackout blamed on ice in cool wtr suctions, wrong suction??
20030210	almudaina	MY	LP	DA	H		LR	PT	M	DR	mn eng tripped on lo lube oil pres, 1, 5 pistons leaking????
20030321	perseverance	M_	Lp		O		AB	US	Y	UE	lost power due to fuel pump failure, date probably wrong
20030326	stolt surf	MY	Lp	DT	H	L	NV	KY	M	MR	false hi temp alarm, tripped engine, towed to 12 mi anchorage
20030411	iver spring	M_	Lp	DT	T		NK	PA	M	NY	eng failed to start, claimed lo fuel temp
20030501	sichem princess	M_	Lp		H				P	NY	lost power in Newark Bay, dirt in starting air system
20030527	bow hunter	M_	Lp	DA	H	L	NV	SG	M	UE	lost bridge control of mn eng, pilot decided to stop
20030606	genmar boss	GE	Lp	DA	H	L	NV	MH	M	MR	lost power lded Miss R. gens triped hi temp, lo suctions open
20030628	eagle subaru	MY	Lp	DT	T	L	NK	SG	Y	MR	lost power mooring Chalmette, Miss R, tugs handled, no details
20030704	hyde park	MY	Lp	DT	T	L	LR	UK	Y	NY	lost power lving berth, New York, no details
20030704	delaware trader	GE	Lp	DA	H	L	AB	US	P	NY	wrong fuel vlv, lost power outbound NY, anchored, hit buoy
20030704	jo sequoia	MR	LP	CN	H	L	NV	NO	Y	GB	lost steering, hit 4 barges, grounded inbound Houston Ship Ch.
20030719	seabulk mariner	MB	Lp		H		AB	US	Y	MR	loss of power, blamed on a voltage surge???
20030720	chilbar	MB	Lp		H		AB	US	Y	MR	1 gen failed, other not big enough, blackout
20030812	east siberian s	MY	Lp	WS	H	L	LR	LR	Y	UE	loss of power leaving Charleston, grounded, no details
20030813	jo oak	MB	Lp		T		NV	NO	Y	MR	not enough gen power to run bow thruster, crew blamed
20030817	afragem	MY	Lp	DT	T				Y	GM	loss of power mooring Corpus, bad control vlv, fixed next day
20030823	sr galena bay	MK	LP				AB	US	Y	UW	connecting rod bearing failed, major LOP, West Coast USA
20030826	fandango	MY	Lp	DT	T		NV		Y	MR	loss of power lving terminal, blamed on fuse, NV tested OK
20030827	fandango	MY	Lp	DA	H		NV		Y	MR	loss of power bad cooling fan, EC power supply, long shut down
20030827	ncc asir	GE	Lp	DT	T		NV	NR	Y	MR	loss or power lving terminal, cooling vlvs wrong
20030923	seahawk freight	MY	Lp		H		NV	MH	Y	NY	lost propulsion leaving New York, no details
20030923	eagle corona	MR	Lp	WS	H	L	NK	SG	Y	SR	mop fell onto strng gear, grounded, not holed, Neches River
20031013	ncc jizan	MY	Lp		H	L	NV	NO	Y	UE	starting air control problem, loss of power, Savannah River
20031026	varg	ML	LP		T				M	NY	cracked cylinder liner discvd at Bayonne terminal
20031029	cygnus voyager	MB	Lp		R		AB	BS	Y	LA	6 min loss of power, generator over-load, off El Segundo
20031106	dromeas	MY	Lp		H		LR	BS	Y	MR	loss of power, bad control air, SW Pass, Mississippi
20031109	bow fighter	MY	Lp		H		NV	NO	Y	MR	loss of power, control air sys holed, Mississippi
20031111	sea venture	MR	Lp		H	B			M	DR	rudder stuck hard right downbound Delaware R, no cause info?
20031122	perseverance	MB	Lp		O		AB	US	Y	UE	black out and loss of power, reported by MSO Miami
20031127	spectrum	MY	Lp		H		LR	UK	Y	MR	main engine governor failure, Mississippi River
20031128	bravery	MY	Lp	DA	T	B	LR	MH	Y	MR	main engine failure, lving Motiva, Mississippi River
20031205	asphalt command	MY	Lp		H	L	AB	US	Y	UE	minor loss of power inbound Savannah River, no damage
20031214	kriti art	MY	Lp		H		AB	GR	Y	MR	main engine remote control failed, Mississippi River
20031217	kriti color	MY	Lp		H				Y	NY	loss of power due to 'stuck exhaust valve' Stapelton Anch.

Table 4: Total Loss of Power/Steering in the Humber Estuary

Year	LOP's	Movements	LOP/Ship-year
2007	98	35,664	6.0
2008	100	33,578	6.5
2009	60	33,580	3.9

Table 5: Total Loss of Power/Steering per day, 3600 tankers over 10,000 dwt

Suez Data 2002-2007	2 to 4
V-Plus 1999-2004	1 Major, 10 Minor
Valdez, 1989-1992	20 of which 10 to 20% major
DNV, 1997 Report	5 to 6 (probably mostly major)
CGMIX, 2003	1 to 2 Major, 10 to 20 Minor
Humber, 2007-2009	50 all kinds
Bright Field, 1995-1996	20 major, 200 minor

Table 6: Frequency of Total Loss of Power
Assumes V-Plus numbers, **independent** Poisson processes

	Individual Ship	
	MINOR	MAJOR
Single screw	1 per year	1 every 10 years
Twin screw	1 every 1,250 years	1 every 18,250 years
	3600 Ship Fleet	
	MINOR	MAJOR
Single screw	10 per day	1 per day
Twin screw	3 per year	1 every 5 years

Table 7: Casualties in which twin screw might have helped

Based on CTX V2 database as of 2007-07-23T16:01:03

Date	Ship	Kilo liters	E1	E2	E3	LO	AC	Dead	?	Area	Synopsis
19780316	amoco cadiz	267000	MR	LP	WS	R	L	0	Y	BB	steering gear failure, grounded Britanny, broke up
19930105	braer	99600	GS	LP	WS	R	L	0	Y	UK	pipes on deck hit vents, sw in BFO, no power, grnded Shetland
19921203	aegean sea	87000	M_	WS	XT	H	L	0	P	LC	could not turn ship in bad weather, grounded Coruna, fire, OBO
19830107	assimi	60200	M_	XE	SK	O	L	0	M	AS	ER fire, Gulf of Oman, cause uncertain
19750110	british ambassa	56000	MW	MF	LP	O	L	0	Y	NP	sw inlet leaked N Pacif, vlv failed ER flooded, sank under tow
19831209	pericles gc	54100	M_	XE	SK	O	L	0	M	PG	ER fire east of Doha, sank
19710227	wafra	47000	MW	LP	MF	O	L	0	Y	EA	SW circ pump fracture, ER flooded, drifted aground SA, sunk
19760204	st peter	44300	MY	XE	LP	O	L	0	P	WS	'elec fire in ER' off West Coast of Columbia, sank
19750131	corinthos	42200	GC	CA	ST	T	d	26	P	DR	hit by E M Queeny, Marcus Hook, no IG, pilot error
19770527	caribbean sea	35200	M_	MF	LP	O	L	0	P	WS	ER flooded South of El Salvador, sank, cause unknown
20030727	tasman spirit	35200	E_	WS	ST	H	L	0	M	KC	chan?pilot?mach?, guess ship too deep for Karachi channel
19760218	scorpio	34900	MR	LP	WS	R	L	0	Y	GM	lost steering, grounded Gulf of Campeche, CTL
19821126	haralabos	31900	M_	XE	WS	H	L	0	M	RS	ER fire, Red Sea, cause unknown, beached, cgo transhipped, CTL
19891229	aragon	29400	MY	LP	HL	O	L	0	M	WA	lost power, big spill under tow near Azores, conflicting info
19671024	giorgio fassio	25000	MF	LP	SK	O	L	0	P	WA	Engine room flooded cause unknown, sank off SW Africa
19720331	giuseppe giulie	25000	MF	LP	SK	O	L	0	P	WE	ER flooded off C St Vincent, no power, sank
19810329	cavo cambanos	24300	M_	XE	SK	R	L	6	M	WM	fire in generator room Tarragona, fire, sank, cause?
19740723	theodoros v	23200	M_	XE	SK	O	L	9	M	WA	ER explosion off Dakar, cause unknown, sank,
19700114	albacruz	23000	MW	MF	LP	O	L	0	P	NA	main sw piping failed, er flooded, sank loaded in N Atlantic
19701007	anastasia j l	22000		MF	LP	O	L	0	P	NA	ER flooded, sank fully loaded NE Azores
19680426	assimi iii	20000	M_	XE	XT	R	L	5	M	CS	ER fire off Singapore, sank, nil info on initial cause
19680508	andron	20000	MW	MF	LP		L	0	Y	WA	ER pipe failed, ER flooded, sank off SW Africa
19700131	gezina brovig	18800	MY	LP	MF	O	L	0	Y	PR	piston thru crank case NW PR, broke SW main, ER flooded sank
19740926	transhuron	18600	MY	LP	WS	O	L	0	Y	IN	A/C nipple failed, water on swbd, no power, grounded SW India
19600627	george macdonal	17000	MF	LP	SK	T	L	0	Y	MH	massive condenser leak, ER flooded, sank
19611001	hess mariner	17000	MB	LP	MF	O	L	0	P	UE	Main prop gen overspd, holed condenser, ER flood, sank
19811121	globe assimi	17000		WS	SK	H	L	0	M	KP	grounded bad storm lving Klaipeda, broke up, slow to leave
19790302	messiniaki fron	14100	NA	WS	HL	R	L	0	M	WM	grounding Crete, radar on wrong scale, no visuals
19680303	ocean eagle	13200	G_	WS	SK	H	L	0	P	PR	slowed for pilot, lost control, grounded in hvy swell
19870623	fuyoh maru	11900	MR	LP	CN	H	L	6	P	WE	collision w Vitoria in Seine 'damage to helm'
19900629	chenki	9600	MR	LP	WS	H	L		P	SC	lost steering Suez Canal, grounded, holed, towed to Suez
19750513	epic colocotron	6700	M_	XE	ST	O	L	0	M	PR	OBO ER fire near San Juan, nil info on cause
19760724	diego silang	6200	VU	CN	HL	R	L	0	M	SM	Vysotsk crossed in front, went astern, turned into Braz Faith
19680307	general colocot	6000	MY	LP	WS	R	L	0	Y	UE	machinery failure cause unknown, grounded off Eleuthera
19701023	pacific glory	6000	VR	CN	XT	R	L	13	M	EC	coll w Allegro in Channel, one said overtaking, one crossing
20061020	front vanguard	6000	MB	Lp	WS	H	L	0	Y	SC	blackout Suez, grnded, Anna PC avoiding grnded, spilled 5000T
19761227	olympic games	5880	MY	Lp	WS	H	L	0	P	DR	engine failure, Delaware R, 39 ft draft, grounded
19730602	esso brussels	5000	MR	CA	ST	H	L	16	P	NY	rammed NY harbor by Sea Witch whose steering gear failed
19770415	universe defian	3000	MX	LP	SD	O	B	9	M	WA	Boiler room fire off West Africa, scuttled
20010329	baltic carrier	2900	MR	Lp	CN	R	L	0	Y	KT	steering failure Baltic, collision with Tern, 6 m penetration
19740118	keytrader	2790	VD	CN	WS	H	L	16	M	MR	dance of death w Baune in lower Mississippi River
19770327	anson	2330	MR	LP	WS	H		0	Y	OR	steering gear failure Orinoco, grounded
20001128	westchester	2100	MC	LP	WS	H	L	0	Y	MR	crankcase exp in Miss R, grounded, 1S holed

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Date	Ship	Kilo liters	E1	E2	E3	LO	AC	Dead	?	Area	Synopsis
19660616	alva cape	2066	VB	XT	CN	H	L	33	P	NY	coll w Tex Mass, went astern, lost steerage, bow swung to port
19900728	shinoussa	2000	GY	CN	HL	H	L	0	M	GB	pilot said stbd, helmsman went port, sunk dh barge, Galv. Bay
19850928	grand eagle	1640	MY	Lp	WS	H	L	0	Y	DR	ship lost power, grounded near Marcus Hook
19970702	diamond grace	1550	GC	WS	HL	H	L	0	P	TB	had to slow down in Tokyo Bay, lost steerage, grounded
19820820	corinthian	1470		XE	MF	R	B	0	M	FJ	engine room fire off Fujairah, flooded, sunk, no other info
20060227	grigoroussa i	1300	MR	Lp	WS	H	L	0	Y	SC	steering gear failure Suez, hit west bank, strange fire
19760124	olympic bravery	842	MY	LP	WS	R	B	4	Y	EC	'series of engine failures', VLCC drifted aground on Ushant
19960927	julie n	757	GC	AL	HL	H		0	M	UE	struck bridge Portland ME, 30m opening for 26m beam
19840319	mobiloil	624	MR	LP	WS	H	L	0	Y	CR	steering failure in Columbia River, grounded, 150 ft damage
19760705	capetan mathios	600	MR	LP	WS	R	B	0	P	FS	lost steering, grounded Bahamas Bank, some doubt story
19780321	aegis leader	586	MY	LP	WS			0	P	IA	grounded off Sumatra after machinery breakdown
19760119	irenes sincerit	582	MY	LP	WS			0	Y	BL	'stranded after engine trouble', Baltic, nil info
19730624	conoco britanni	500	MY	Lp	WS	S	L	0	Y	HU	lost power mooring Humber SBM, ran over own anchor
19831006	theodegmon	476		WS	HL	H	L	0	M	OR	grounded in Orinoco 'due to strong current', CTL, real cause ?
19810725	afran zenith	302	M_	LP	WS	H		0	P	WE	grounding Elbe after machinery problems
19901015	rio orinoco	200	MY	LP	DA	R	L	0	P	SL	mach problems, anchored, dragged, grounded G of St Lawrence
19990523	parnaso	151	MR	LP	CN	O	B	0	Y	CA	lost steering, collision South of Cuba

Table 8: Non-CGMIX Casualties in which twin screw might have helped, 2002+

Based on CTX V2 database as of 2007-07-24T13:59:24

Date	Ship	Kilo liters	E1	E2	E3	LO	AC	Dead	?	Area	Synopsis
20070701	eagle otome	N		WS		R			Y	GM	grounded, refloated early next day, prob. lightering ship
20070330	active	N	MR	LP					Y	WA	steering gear failure off Angola, tug mobilized
20070328	gorgona	N	MY	LP		R	B	0	P	BD	unspecified engine problems, Turkey, no other info
20070309	baltic pride	N	MY	Lp	CM	R		0	Y	BL	unspecified loss of power, near collision in Baltic
20070219	overseas housto	N	MY	LP	DT	O	B	0	Y	UE	major engine failure maiden voyage, towed to Tampa, no details
20070206	bow favour	N	MK	LP	DT	O	L	0	Y	EA	crankshaft failure off Seychelles, towed in
20070106	kashmir	N	MU	LP	XE		L		Y		turbocharger failure, fire, towed in, no other info
20061224	al barakat 1	N	MY	LP	DT		L		P	IN	engine breakdown, towed to Chittagong, no details
20061219	welsh venture	N	MR	LP	XE				Y	JA	steering gear failure off Honshu, fire in flat
20061205	**sten odin**	N	MY	LP		R	B	0	Y	UK	machinery failure Irish Sea, tug mobilized, see 2005-11-08
20061020	front vanguard	6000	MB	Lp	WS	H	L	0	Y	SC	blackout Suez, grnded, Anna PC avoiding grnded, spilled 5000T
20061016	balta			XE	LP		L		P	UE	engine room fire off Sandy Hook, towed in, no cause info
20060912	vaagen	N	MS			O	L	0	Y	NA	intermediate shaft failure off Azores, vsl diverted to Lisbon
20060502	chemical sprint	N	MY	LP		R	L	0	Y	EC	major loss of power, English Channel, no details
20060227	grigoroussa i	1300	MR	Lp	WS	H	L	0	Y	SC	steering gear failure Suez, hit west bank, strange fire
20051108	**sten odin**		M_	LP	DT	H	L		Y	UK	major loss of power Irish Sea, towed to Shetlands
20050916	**yiomaral**	N	MC	LP	DA	R	L	0	Y	KT	crankcase exp, loaded VLCC leaving Kattegat, anchored, fixed
20050430	bow fighter	N	MY	LP				0	Y		major loss of power, GA declared, no other info
20050424	chinook		MR	Lp	WS	H	L	0	P	BD	lost steering in Dardanelles, went aground,
20050318	maersk rosyth	N	M_	LP				0	M		no info other than LOF, guessing machinery failure
20050303	fjord champion	N		XE	WS	R	B	0	P	KT	big ER fire Kattegat, no cause info, drifted aground, CTL
20050219	gerrita	N	MY	LP	DT	O	B	0	Y	UK	major loss of power off Shetlands, towed Sullom Voe, cause?

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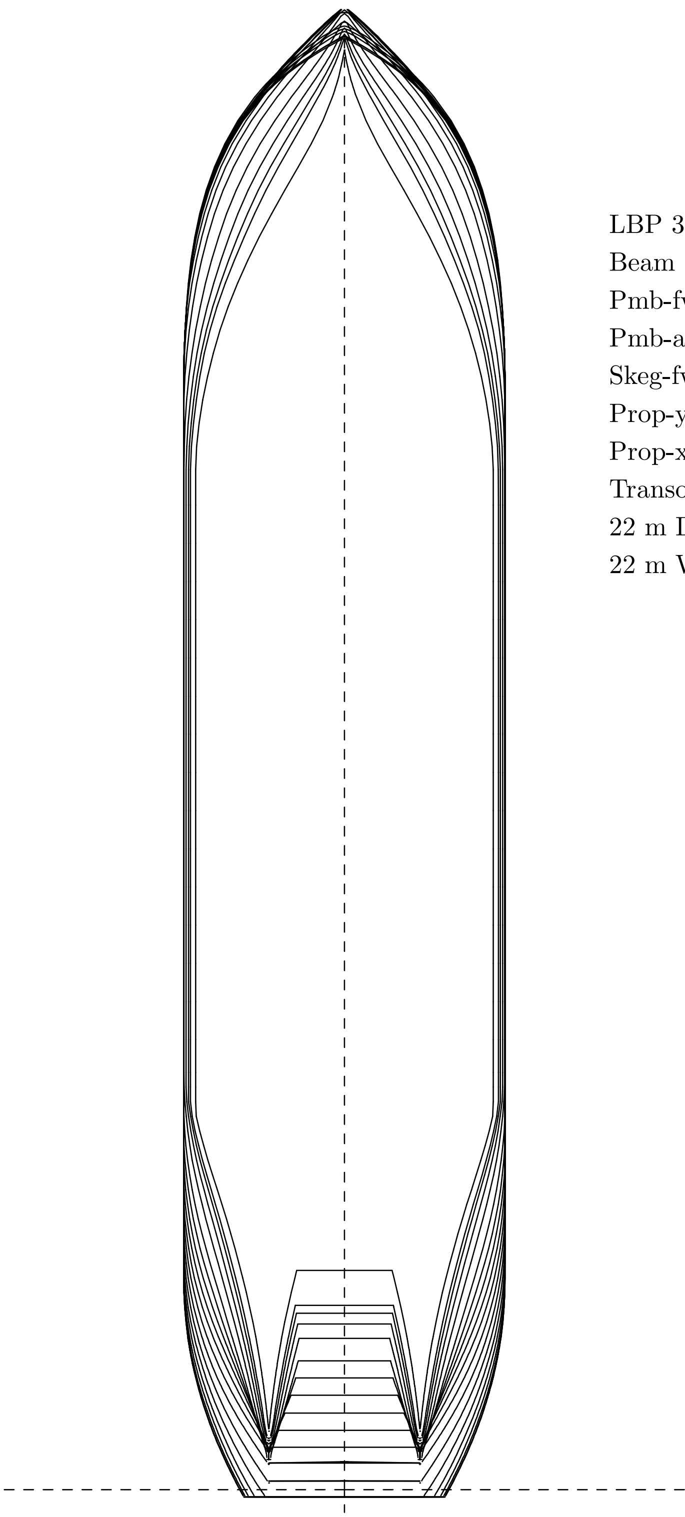
Date	Ship	Kilo liters	E1	E2	E3	LO	AC	Dead	?	Area	Synposis
20050205	eberhard	N	MY	LP	WS	H	B	0	Y	EC	major loss of power lving Antwerp, drifted aground, no details
20050131	radwan	N	MY	LP					Y	SA	major loss of power off South Africa, LOF, no details
20050128	frank	N	MY	LP		R	L	0	Y	EC	major loss of power off Guernsey, no details
20050113	eco princess		MY	LP			B		P		engine breakdown, LOF, no other info
20041214	al samidoon	Y	G_	AL	HL	H	L	0	M	SC	hit Suez bank avoiding dredge, probable pilot error, holed
20041106	tropic brillian	N	MR	Lp	WS	H	d	0	Y	SC	lost steering, grounded Suez, blocked Canal for 3 days
20041024	bergitta	N	VU	CN		R	L	0	M	KT	coll w MSC Eyra, 30kt closing spd, talk too late, stern swing
20040828	astro altair	N	MR	Lp	AL	H	L	0	Y	MR	lost steering, hit ferry landing Mississippi River
20040521	neptunus	N		XE		H	L	0	P	KL	ER fire Kiel Canal, no cause info,
20040416	front symphony	N		WS		H	L	0	M	SC	grounded very hard Suez Canal, no cause info
20040408	settebello	N		WS		H	B	0	M	SC	grounded Suez Canal, no cause info
20040406	theodora		MR	Lp	CN	R		0	Y	NS	steering gear failure Elbe, hit coaster
20040229	astro phoenix	N		WS	HL	H	L	0	M	SC	grounded Suez loaded, ballast tank flooded, no cause info
20030727	tasman spirit	35200	E_	WS	ST	H	L	0	M	KC	chan?pilot?mach?, guess ship too deep for Karachi channel
20030419	**hellespont alha**	N	ML	LP		O	B	0	Y	GM	underdesigned cylinder liner split in two, Gulf of Mexico
20030325	pactol river	N	MY	LP	DT	O		0	P	WM	adrift due engine problems off Tunisia, towed in
20030325	iran noor		MR	Lp	WS	H	L	0	Y	SC	lost steering, grounded Suez Canal, hull damage
20030223	highland faith		MR	LP	DT	O		0	P	NA	rudder jammed, towed in, Greenpeace's favorite OBO rustbucket
20030204	pharos	N	MY	LP	DT	O		0	P	WM	mach failure West Med, towed to Tarragona, no other info
20021224	bertora	N	MY	Lp		R	B	0	Y	NS	fuel valve failed North Sea, no main engine, Mayday
20021212	bharatidasan		MY	LP	DT	O			P	IN	machinery failure off Sri Lanka, towed, no other info
20021211	alphatank			WS	DT	H		0	M	SC	grounding Suez, no cause, blocked canal, had to be towed
20021210	sarah glory		GC	CN		H	B	0	M	SC	collision w HK Express forming up Suez convoy, poor VTS
20021127	hellenic star		MR	Lp	CN	H		0	Y	EC	lost steering, hit Western Trader, Rotterdam
20021102	pointe du caste	N	MY	LP	DT	O		0	P	BB	mach failure off NW Spain, towed
20021016	dendro gold		M_	LP	DT	O			P	IN	machinery failure off Nicobars, towed, no other info
20021010	kenai	N	MY	Lp	DE	R	L	0	P	VZ	lost steering lving Valdez, escort tug prevented grounding
20020726	**orpheus asia**	N	MK	LP	DT	O	L	0	P	CS	crankshaft failure, 30+ hr adrift off Taiwan
20020722	patriot			XE	DT	O	B	0	P	UE	ER fire off Abacos, towed in, cause?
20020525	cardissa	N	M_	LP	DT	R		0	P	EC	Unknown mach problem, ss North Sea shuttle tanker, towed in
20020502	**front tobago**	N	MY	LP	DT	O	L	0	Y		major engine failure, towed all around China Sea
20020330	yapi	N	MY	LP	XE	H	L	0	P	SC	machinery failure in Suez, maybe ER fire
20020211	south trader	N	MK	LP	DT	R	B	0	Y	EC	piston failure off Cornwall, towed in

Figure 1: Twin Skeg Hull Form



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Beam 85.000
Pmb-fwd-xs 268.773
Pmb-aft-xs 111.357
Skeg-fwd-xs 58.000
Prop-ys 20.000
Prop-xs 6.953
Transom-xs -1.950
22 m Disp 641474.7
22 m W.S. 45048