Collision between Liquefied Gas Carrier *Genesis River* and *Voyager* Tow Houston Ship Channel, Upper Galveston Bay, Texas May 10, 2019

Marine Accident Report

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National
Transportation
Safety Board

490 L'Enfant Plaza, SW
Washington, DC 20594

National Transportation Safety Board. 2021. ***Collision between Liquefied Gas Carrier*** **Genesis River** ***and*** **Voyager** ***Tow, Houston Ship Channel, Upper Galveston Bay, Texas, May 10, 2019*****.** **Marine Accident Report NTSB/MAR-21/01. Washington, DC.**

Abstract: This report discusses the May 10, 2019, collision of the 754-foot-long liquefied gas carrier *Genesis River* with a 297-foot-long tank barge being pushed ahead by the 69-foot-long towing vessel *Voyager* on the Houston Ship Channel in Upper Galveston Bay. Immediately after the outbound *Genesis River* had passed an inbound liquefied gas carrier of similar size at the southern end of the Bayport Flare, it approached the channel's west bank, sheered to port, and crossed over to the opposite side of the channel where, in the barge lane ahead, the *Voyager* was pushing two tank barges breasted together side by side. In the ensuing collision, two cargo tanks in the starboard barge were breached, spilling over 11,000 barrels of petrochemical cargo into the waterway, and the port barge capsized. No injuries were reported. Safety issues identified in this report include the challenges of navigating large vessels in the Bayport Flare area of the Houston Ship Channel and vessel speed while transiting in a narrow channel. As part of its accident investigation, the National Transportation Safety Board makes four new safety recommendations to K-Line Energy Ship Management and the Houston Pilots, and reiterates two recommendations to the US Coast Guard.

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Acronyms and Abbreviations

AB	able-bodied seaman
ABS	American Bureau of Shipping
AIS	automatic identification system
ARPA	automatic radar plotting aid
BRM	bridge resource management
BRM/BTM	bridge resource management/bridge team management
hp	horsepower
ECDIS	electronic chart display and information system
ECR	engine control room
EOT	engine order telegraph
GRT	gross register tons
kW	kilowatts
IMO	International Maritime Organization
LPG	liquid propane gas
MLLW	mean lower low water
NOAA	National Oceanic and Atmospheric Administration
OS	ordinary seaman
PPU	portable pilot unit
rpm	revolutions per minute
SMS	safety management system
SOLAS	*International Convention for the Safety of Life at Sea*
USACE	US Army Corps of Engineers
VDR	voyage data recorder
VHF	very high frequency
VTS	vessel traffic service

Executive Summary

Accident

On May 10, 2019, at 1516, the 754-foot-long, 122-foot-wide liquefied gas carrier *Genesis River* collided with a 297-foot-long tank barge being pushed ahead by the 69-foot-long towing vessel *Voyager*.[1] As a result of the collision, two cargo tanks in the barge were breached, spilling petrochemical cargo into the waterway, and a second barge in the *Voyager* tow capsized.

The *Genesis River* had been outbound on the Houston Ship Channel when, a few minutes prior to the collision, it met the inbound 740-foot-long, 120-foot-wide liquefied gas carrier *BW Oak* in the intersection of the Houston Ship Channel and the Bayport Ship Channel, known as the Bayport Flare. After the *Genesis River* and the *BW Oak* passed each other port side to port side, the *Genesis River* approached the southern terminus of the flare and a 16-degree port turn in the channel. As the *Genesis River* exited the flare and entered the turn, it crossed over to the opposite side of the Houston Ship Channel and subsequently struck the starboard barge in the *Voyager*'s two-barge tow. The *Genesis River*'s bow penetrated through the barge's double hull and breached its center cargo tanks. The force of the collision capsized the port barge in the tow, and the *Voyager* heeled considerably before its face wires parted and the vessel righted itself.[2] Over 11,000 barrels of reformate, a gasoline blending stock, spilled into the waterway from the starboard barge's breached cargo tanks.

The Houston Ship Channel was closed to navigation for two days during response operations and did not fully open for navigation until May 15. The total cost of damages to the *Genesis River* and the barges was estimated at $3.2 million. The cost of reformate containment and cleanup operations totaled $12.3 million. There were no injuries reported.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the collision between the liquefied gas carrier *Genesis River* and the *Voyager* tow was the *Genesis River* pilot's decision to transit at sea speed, out of maneuvering mode, which increased the hydrodynamic effects of the Bayport Flare's channel banks, reduced his ability to maintain control of the vessel after meeting another deep-draft vessel, and resulted in the *Genesis River* sheering across the channel toward the tow.

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[1] (a) In this report, all times are central daylight times (CDT), based on a 24-hour clock, and all miles are nautical miles. (b) A *liquefied gas carrier* is a type of tank ship that has been designed to carry gases such as natural gas, propane, or butane in liquefied form in insulated, pressurized, and/or refrigerated tanks.

[2] A *face wire* is one of a set of Kevlar or wire ropes that fasten a barge or flotilla of barges to a towing vessel when a tow is being pushed ahead. When used in this report, "face wire" is referring to the cables attached nearest to the bow of the towing vessel. A *long wire* (also known as a wing wire), which will be discussed later in this report, is also a cable that runs from the stern or near the stern of the towing vessel forward to the barge or barges.

Safety Issues

The safety issues identified in this accident include the following:

- **Challenges of navigating large vessels in the Bayport Flare area of the Houston Ship Channel.** Due to the narrowness of the channel, the large amount of vessel traffic, and the size of the vessels transiting the channel, the Houston Ship Channel is challenging to navigate and requires significant training and experience. The asymmetric shape of the channel in the vicinity of its intersection with the Bayport Ship Channel, known as the Bayport Flare, makes navigation particularly difficult due to varying hydrodynamic forces acting on a vessel's hull. When larger vessels meet in the intersection while transiting at a relatively high speed, the risk of loss of control is much greater.

- **Vessel speed while transiting a narrow channel.** Transiting a narrow channel at or near a vessel's maximum speed provides little room for error and little ability to increase propeller wash over the rudder to recover if control is lost. The margin for error is even more limited on ships with slow-speed, direct-drive diesel propulsion engines transiting at Nav. Full (navigation full), an engine mode designed for higher speeds in open ocean waters where the ability to change engine revolutions per minute (rpm) on short notice is significantly restricted.

Findings

1. Pilot and crew credentialing and experience, use of alcohol or other tested-for drugs, fatigue, and environmental conditions were not factors in the accident.
2. Mechanical and electrical systems on the *Genesis River* and *Voyager* operated as designed, and their functionality was not a factor in the accident.
3. Although the *Genesis River* master's decision to place the vessel's automated radar plotting aid (ARPA) in standby and turn off the electronic chart display and information system (ECDIS) deprived the bridge team of critical tools with which to monitor the pilots' actions and ensure that the vessel transited safely, the status of this equipment was not a factor in the accident.
4. The *Genesis River* helmsman properly executed the rudder orders of the pilot, and his performance was not a factor in the accident.
5. Although the helmsman in training properly executed the orders of the pilot, placing him at the helm without informing the pilot was contrary to good bridge resource management practice.
6. Maintaining stern trim while under way would have improved the handling characteristics of the *Genesis River*.
7. The combined effect of the speed of the *Genesis River* and the passing of another large vessel in the asymmetrically shaped channel at the southern terminus of the Bayport Flare resulted in an uncontrollable sheer to port by *Genesis River*, initiating a chain of events that led to the collision.

8. The *BW Oak* pilot's maneuvering of his vessel to prepare for the meeting with the *Genesis River* was routine and did not impede the *Genesis River*'s ability to pass.
9. Wide-beam, deep-draft vessels meeting in the Houston Ship Channel in the vicinity of the northern and southern terminuses of the Bayport Flare have a higher risk of loss of control due to complex and varying hydrodynamic forces.
10. Once the *Voyager* and its tow began the turn to port, the collision was unavoidable.
11. An increase in engine rpm to arrest the *Genesis River*'s initial sheer, even if promptly executed after it was ordered by the pilot, would not have prevented the collision.
12. The pilot transiting the wide-beam, deep-draft *Genesis River* at sea speed through the shallow and narrow lower Houston Ship Channel left little margin for error and introduced unnecessary risk.
13. The *Genesis River* pilot's decision not to use emergency full astern or the anchors to avoid the collision was reasonable.
14. The actions of the *Voyager* relief captain to attempt to avoid the collision by crossing the channel were reasonable, given the information available to him at the time he had to make the decision to maneuver.
15. The *Genesis River* pilot's early and frequent communications with the *Voyager* mitigated the impacts of the accident and likely prevented loss of the towing vessel and injuries to its crew.
16. Coast Guard Vessel Traffic Service Houston–Galveston's response to the collision was timely and appropriate.
17. The Bayport Flare, as well as other intersections within the Houston–Galveston Vessel Traffic Service area, would benefit from regular risk assessments and the consideration of additional vessel routing measures.

Recommendations

New Recommendations

As a result of its investigation of this accident, the National Transportation Safety Board makes the following four new safety recommendations:

To K-Line Energy Ship Management

Review your safety management system and develop formalized procedures for watch team reliefs to ensure embarked pilots are informed of a change in personnel, particularly a change in helmsmen. (M-21-1)

To the Houston Pilots

Revise guidance to operators of the *Genesis River* and similar vessels to require vessels be sufficiently trimmed by the stern prior to transiting the Houston Ship Channel. (M-21-2)

Advise your members to avoid conducting any passing arrangements between wide-beam, deep-draft vessels in the northern and southern terminuses of the Bayport Flare. (M-21-3)

Advise your members to avoid transiting wide-beam, deep-draft vessels at sea speed in the lower Houston Ship Channel. (M-21-4)

Previously Issued Recommendations Reiterated in This Report

As a result of its investigation of this accident, the National Transportation Safety Board reiterates Safety Recommendations M-16-16 and M-16-21, which are currently classified as "Open—Acceptable Response":

To the US Coast Guard

Develop a continuous risk assessment program to evaluate and mitigate safety risks for each vessel traffic service (VTS) area in the US Coast Guard VTS system that includes input from port and waterway stakeholders. (M-16-16)

Establish a program to periodically review each of the 12 vessel traffic service (VTS) areas and seek input from port and waterway stakeholders to identify areas of increased vessel conflicts or accidents that could benefit from the use of routing measures or VTS special areas, and establish such measures where appropriate. (M-16-21)

1 Factual Information

Figure 1. *Genesis River* under way in Bolivar Roads near Galveston, Texas, two weeks after the accident. (Source: William J. Leach, Jr., VesselFinder.com)

1.1 The Accident

Preparing to Get Under Way. On the morning of May 10, 2019, the *Genesis River*, a 754-foot-long, 122-foot-wide Panama-flagged liquefied gas carrier (see figure 1), was berthed at the Targa Resources Galena Park Marine Terminal, located just east of Houston, Texas, on the upper Houston Ship Channel.[3] Following a full onload of liquid propane gas (LPG) cargo, the vessel was scheduled to get under way at noon for an outbound transit of the Houston Ship Channel. With the cargo, the *Genesis River* had a displacement of 69,249 long tons (70,360 metric tons) and was on an even keel at a draft of 36.8 feet (11.2 meters).[4]

The Houston Ship Channel is about 55 nautical miles in length from the turning basin at the Port of Houston to the sea buoy offshore from Galveston (see figure 2). The upper channel, which runs from the turning basin to the entrance to Galveston Bay at Morgan's Point, contains numerous turns and varies in width from as little as 250 feet to over 750 feet.

[3] A *liquefied gas carrier* is a type of tank ship that has been designed to carry gases such as natural gas, propane, or butane in liquefied form in insulated, pressurized, and/or refrigerated tanks.

[4] *Even keel* is a condition of a ship in which the forward and aft drafts are equal.

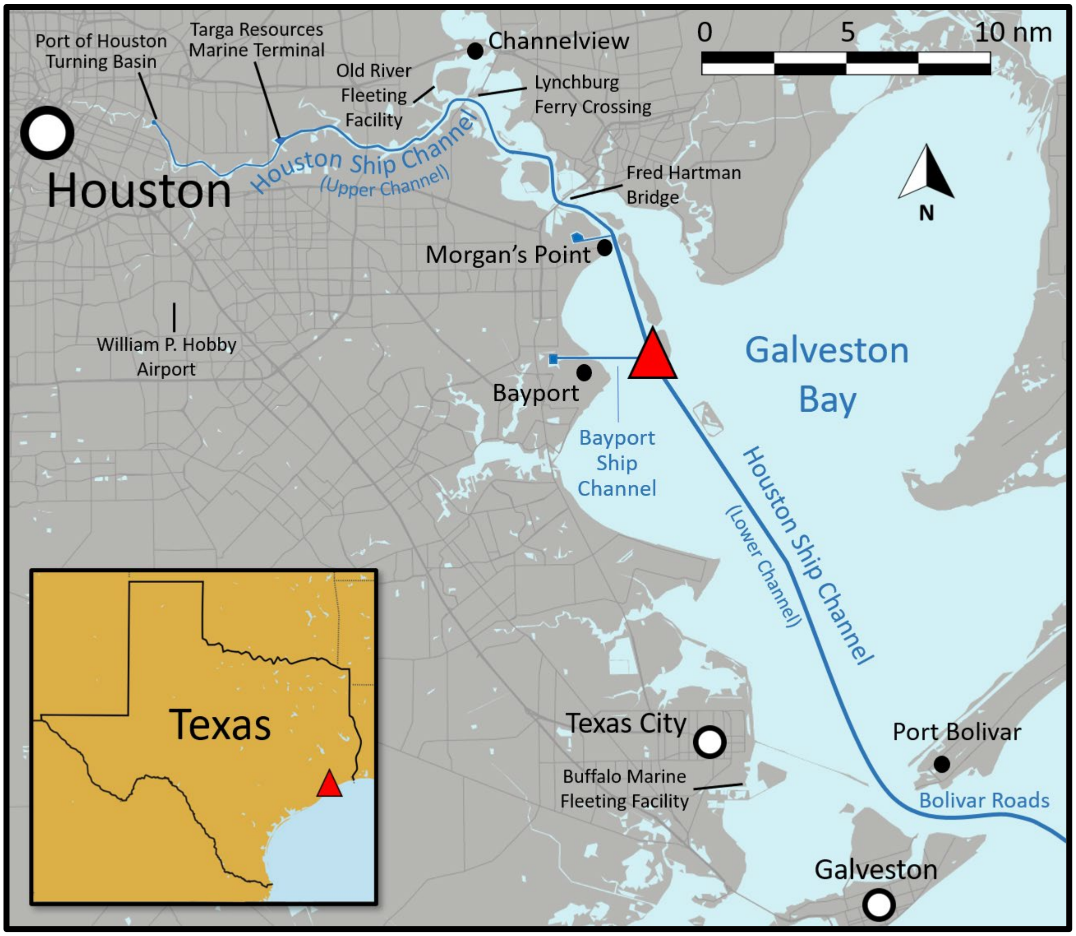

Figure 2. The accident location, as shown by the red triangle. (Background source: Google Maps)

The lower channel transits through Galveston Bay from Morgan's Point to Bolivar Roads near Galveston. This section is comprised of longer, straight segments, with a 530-foot-wide main channel dredged to a project depth of 45 feet. The lower channel also has separate barge lanes located on either side of the main deep-draft vessel channel, each 235 feet wide with a project depth of 12 feet (see figure 3). Navigational beacons marking the lower Houston Ship Channel are located to the outside of the barge lanes. As viewed from an outbound vessel, the navigational buoys and beacons marking the right side of the Houston Ship Channel are green, and those marking the left side are red.

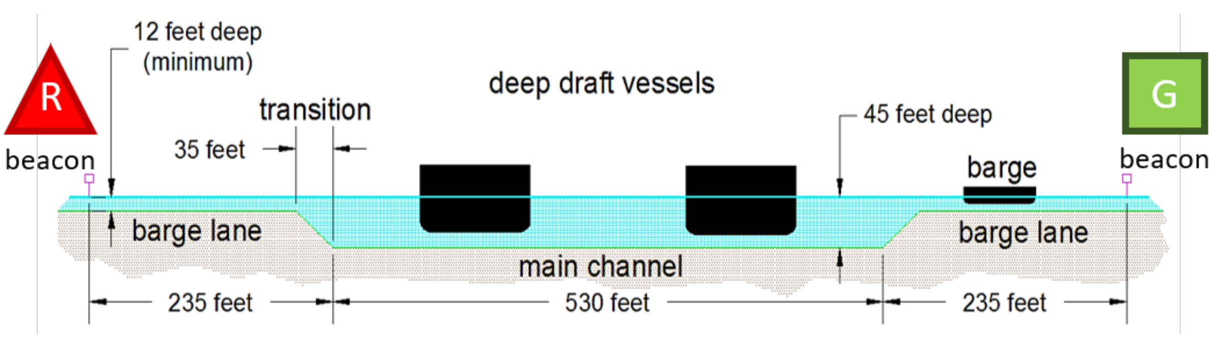

Figure 3. Lower Houston Ship Channel profile (outside of the Bayport Flare—see figure 4), with navigation beacons as viewed by an outbound vessel.

The *Genesis River* had a crew of 28 on board, as well as two pilots required for the transit through the channel.[5] Two pilots were assigned, in accordance with a Houston Pilots policy, to prevent fatigue while handling "wide-bodied vessels" (vessels whose width exceeded 120 feet) for extended periods.[6] During two-pilot jobs, each pilot normally conned the vessel for about half of the transit. Neither pilot held authority or seniority over the other pilot, and each acted independently while at the conn (unless the conning pilot specifically requested the assistance of the other).

The two pilots boarded the *Genesis River* at the terminal and were escorted to the ship's bridge, arriving at 1148.[7] The pilot who would conn the vessel first (hereafter known as Pilot 1) was given a pilot card—a three-page summary of the ship's particulars, engine speeds, and steering and navigation equipment—at his request. While Pilot 1 reviewed the card, the second pilot (Pilot 2) set up a portable pilot unit (PPU).[8] The master of the vessel arrived about 2 minutes later and greeted Pilot 1.

In addition to the master, the *Genesis River* bridge team included the officer of the watch (the fourth officer), a helmsman (an able-bodied seaman [AB]), and a cadet.[9] As the bridge team prepared to get under way, Pilot 2 requested that the crew turn off all radar alarms, telling the crew that since the vessel would be passing other vessels at short distances throughout the transit, the alarms indicating closest point of approach would be sounding often and would be a distraction. The safety management system (SMS) for the *Genesis River*'s management company required that both of the ship's radars be kept on at all times while in areas of high traffic density and near navigational hazards. However, during a postaccident interview, the master told investigators that the alarms on the vessel's automatic radar plotting aid (ARPA) system that displayed the radar data could not be turned off, so to comply with Pilot 2's request to silence the alarms, he instructed the officer of the watch to put the radars in standby.[10] The SMS also required that one of the vessel's electronic chart display and information systems (ECDISs) be regularly monitored, but the master stated that alarms on these systems likewise could not be silenced, so he told the fourth officer to turn off the online ECDIS as well. The *Genesis River* had two ECDISs on board, which met the *International Convention for the Safety of Life at Sea* (*SOLAS*) requirements for

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[5] A *pilot* is retained by the ship to provide local knowledge of the waterway, familiarity with tides and currents in the area, understanding of local procedures, and a thorough knowledge of the topography of the waterway. Pilots usually operate by issuing maneuvering instructions (such as heading, rudder angle, and speed orders) to the crew under the supervision of the master or the officer in charge of the navigation watch, or both. Foreign-flagged vessels and US-flagged vessels under register are required to carry a state pilot when under way in Galveston Bay.

[6] Houston Pilots, *Houston Pilots: Working Rules, Including Navigation Safety Guidelines for the Houston Ship Channel*, Houston, Texas: Houston Pilots, 2019.

[7] In this report, all times are central daylight times (CDT), based on a 24-hour clock, and all miles are nautical miles.

[8] A *PPU* is a compact laptop computer or tablet with electronic navigation and charting software that pilots use for navigation, in addition to the vessel's own navigation equipment. PPUs are normally equipped with an independent GPS antenna, as well as a plug that allows the unit to access information from the ship's installed systems, such as GPS and automatic identification system (AIS).

[9] A *cadet* is an officer in training. Most often, cadets are students at maritime academies who are detailed to operational vessels for a period of time to gain experience at sea as part of their learning curriculum.

[10] *Standby* is a status of a radar when it is energized but not rotating or radiating. When in standby, the radar does not provide any information.

redundancy.[11] With the ECDISs off, the master instructed the fourth officer to monitor the vessel's position visually by sighting landmarks, navigation buoys, and beacons, and by monitoring the pilot's PPU. Pilot 1 told investigators that he was aware that the ECDIS was off and that the radars were in standby, but he was not concerned because he had the PPU to rely on and had good visibility for seeing navigation aids.

Transiting the Upper Channel. The *Genesis River* took in lines and got under way shortly after noon. Pilot 1 told investigators that within the first few turns in the channel, he determined that the ship had a "small rudder" and that it responded sluggishly to the rudder commands. He stated that he needed to apply 20 to 30 degrees of rudder to make course changes.

After a short time, Pilot 2 departed the bridge, eventually proceeding to the pilot room (a small lounge and bunkroom located behind the wheelhouse) at 1245. About the same time, the *Genesis River*'s second officer arrived on the bridge to relieve the fourth officer as officer of the watch. When he arrived on the bridge, the second officer noted that the ECDIS was off and that the radars were in standby. The master told him why the equipment was secured and instructed him to continue monitoring the *Genesis River*'s position visually.

At the 6–8 knot ship speed listed in the *Genesis River*'s passage plan, the channel transit was anticipated to take several hours. Sometime after 1300, the master called the chief officer to the bridge to relieve him so that he could eat lunch. The company's SMS normally required the master to be on the bridge while the ship was under pilotage but allowed the chief officer to relieve the master during long navigational transits. Before leaving the bridge, the master briefed the chief officer on the status of the ECDIS and radars and once again instructed the crew to monitor the ship's position visually. The master told the chief officer that he would return to the bridge around 1500.

As the *Genesis River* transited through the upper Houston Ship Channel, Pilot 1 used varying speeds between dead slow ahead and half ahead, combined with large rudder angles, to navigate through the multiple turns in the first half of the voyage. In a straight section of the channel south of the ferry landing at Lynchburg, Texas, the pilot increased speed to full ahead for a brief period "just to see how the ship would respond." The vessel's speed reached 9.6 knots before the pilot slowed the ship in preparation for passing a barge terminal. At 1411, the *Genesis River* met the inbound *Stolt Inspiration*, a 580-foot-long partially laden tanker. After passing the vessel at a speed of 7.1 knots, the *Genesis River* swung to port due to the hydrodynamic forces acting on the vessel in the narrow channel. Pilot 1 told investigators that he had to use hard starboard (35 degrees) rudder to stop the swing. Additionally, he had to use an "engine kick"—a

[11] The *SOLAS* Convention is generally regarded as the most important of all international treaties concerning the safety of merchant ships. The main objective of the Convention is to specify minimum standards for the construction, equipment, and operation of ships, compatible with their safety. Flag states are responsible for ensuring that ships under their flag comply with its requirements. The first version of the SOLAS Convention was adopted in 1914 in response to the *Titanic* disaster. The current version in force is the 1974 Convention, as amended on numerous occasions. Source: International Maritime Organization (IMO), *International Convention for the Safety of Life at Sea* (*SOLAS*), 1974, http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx.

temporary increase in engine revolutions per minute (rpm)—to increase water wash over the rudder to improve its effectiveness.

Entering the Lower Channel. Pilot 2 returned to the bridge about 1440 in preparation for taking the conn from Pilot 1 near Morgan's Point. Pilot 2 stated that when he arrived, he listened to the radio communications to get a sense of the vessel traffic. He also observed Pilot 1 as he maneuvered the *Genesis River* past the inbound 600-foot-long tanker *Marvel* at 8.0 knots. Regarding the passing with the *Marvel*, Pilot 1 stated, "Once again, I had to use a kick to get the [*Genesis River*] to stop swinging after I met the ship."

At 1444, Pilot 2 took the conn from Pilot 1. After Pilot 2 issued his first rudder order, he asked Pilot 1, "Y'all over the place?" Pilot 1 responded, "Yup," and added, "She's takin' lotsa wheel…typical Japanese ship, got a little bitty rudder on her." Pilot 1 remained on the bridge for the next 15 minutes, discussing various topics with Pilot 2, including an extended dialogue about the handling characteristics of ships such as the *Genesis River*. The pilots expressed concerns about large ships that were difficult to handle, with Pilot 2 stating, "Yeah, I've sweated a couple times not knowing if they were gonna check-up [stop swinging] after meetin' a wide body there."

At 1446, Pilot 2 ordered the engine to full ahead. A little more than a minute later, as the *Genesis River* was clearing Morgan's Point and steadying on its first long leg of the lower Houston Ship Channel, Pilot 2 asked, "Mate or captain, [do] you have a 10-minute notice we can increase to?" In requesting "10-minute notice," the pilot was asking the crew to increase engine rpm to *sea speed*, which took the engine control system out of maneuvering mode and into navigation full mode.[12] In navigation full mode, the ability to change speed was limited, and the 10-minute time referred to by the pilot was the amount of prior notice that he would give, under normal circumstances, before requesting another speed change (see section 1.3.1 for additional information). Pilot 2 told investigators that it was common to increase to sea speed once a vessel entered the lower Houston Ship Channel, and interviews with other pilots confirmed that this was a regular practice among many of them.

The second mate responded yes, and 15 seconds later he asked, "Do you want me to increase now?" Pilot 2 answered, "Yes, that would be great." Following this exchange, an audible tone was captured on the voyage data recorder (VDR) audio, indicating that the *Genesis River*'s engine order telegraph (EOT) lever had been moved, and the telegraph test record registered a change in the EOT to the Nav. Full [navigation full] position.[13] The engine speed, which had been at 60 rpm, then began to slowly increase.

At 1450, the *Genesis River*, transiting at 10 knots, passed the inbound 473-foot-long, 82-foot-wide tanker *Crimson Ray* portside to portside without incident. Nine minutes later, the

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[12] *Sea speed* is a term for the speed at which a commercial vessel transits in open water and is generally the maximum or near maximum efficient speed of the vessel.

[13] *VDR*s maintain continuous, sequential records of data relating to a ship's equipment and its command and control. They also capture audio from certain areas in the pilothouse and on the bridge wings. According to the SOLAS Convention, VDRs must be installed on all passenger ships and all cargo ships of 3,000 or more gross tons built on or after July 1, 2002.

Genesis River, now traveling at 11 knots, passed the inbound 440-foot-long, 73-foot-wide tanker *Nordic Aki*, again without incident.

At 1500, Pilot 1 left the bridge and proceeded to the pilot room. About the same time, an ordinary seaman (OS) requested permission from the second officer to take the helm of the *Genesis River* under the observation of the AB assigned to the helmsman watch. The OS explained to investigators that he was training for promotion to an AB position with the ship's operating company. The second officer gave permission, and the OS took the helm. In a deposition taken in October 2019, the AB stated that he had also requested permission from Pilot 2 to turn over the helm to the OS. However, Pilot 2 told investigators that he was not informed that the OS was at the wheel, and the VDR did not capture audio of the AB or any other crewmember requesting permission from Pilot 2 to change helmsmen. The AB stated that, after turning over the helm, he stood next to the OS and verified that rudder orders were properly executed.

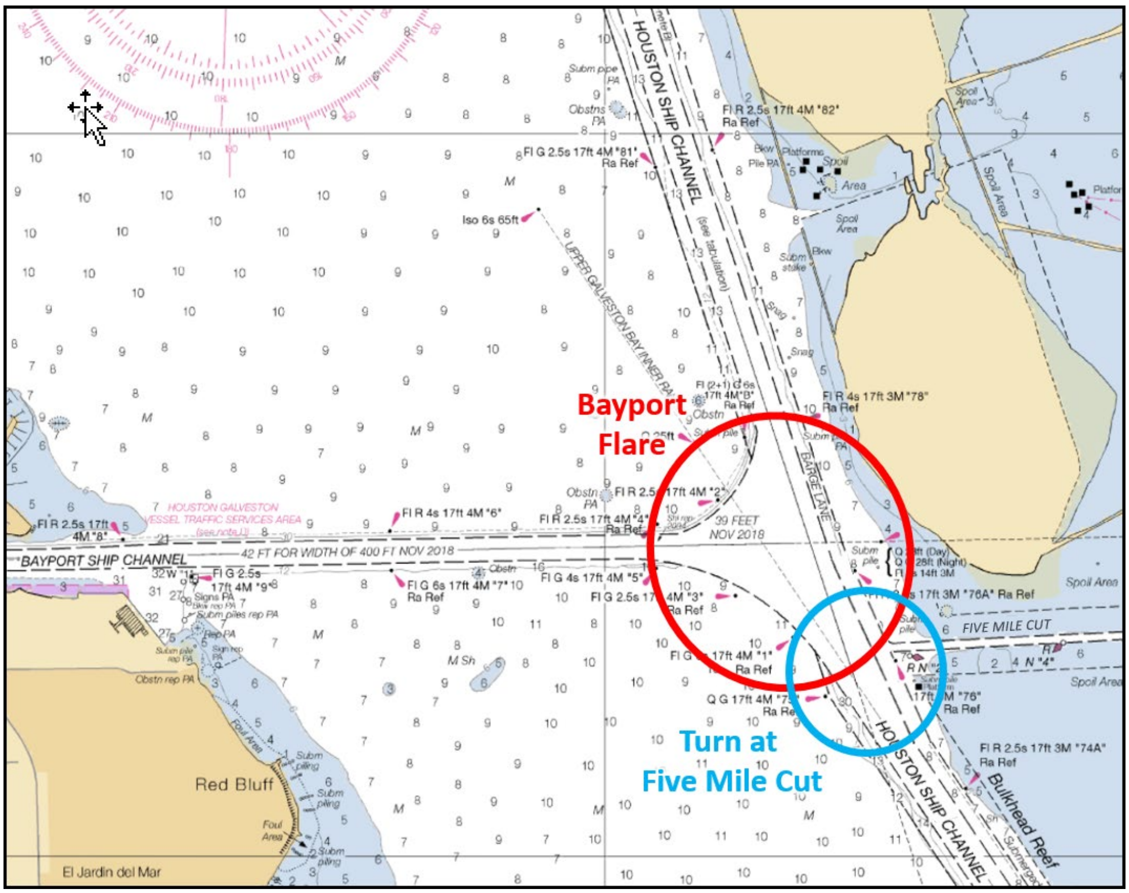

Figure 4. Bayport Flare and turn at Five Mile Cut. (Background source: National Oceanic and Atmospheric Administration [NOAA] chart 11327[14])

[14] Channel borders on NOAA chart 11327 do not reflect a brief widening of the Houston Ship Channel on the eastern side of the turn at Five Mile Cut. The NTSB has modified this chartlet and other instances of chart 11327 throughout this report to reflect the widening, based on a US Army Corps of Engineers (USACE) drawing of the widening dredge plan. The locations of selected feature labels within the chart have also been adjusted for readability and simplicity.

Meeting with the *BW Oak*. In the Upper Galveston Bay, the Houston Ship Channel is intersected from the west by the Bayport Ship Channel, which provides access to container, automobile, and petrochemical terminals in Bayport, Texas. Where the two channels intersect, the Bayport channel widens into a funnel shape to allow ships to negotiate the turn from one channel to the other. This area is known as the "Bayport Flare" (see figure 4). At the southern terminus of the Bayport Flare, in the vicinity of Five Mile Cut (a shallow channel that extends to the east of the Houston Ship Channel), the Houston Ship Channel makes a 15.7-degree turn to the east.

At 1505, a pilot on the inbound *BW Oak*, a 740-foot-long, 120-foot-wide liquefied gas carrier, contacted Pilot 2 via VHF radio channel 13 to make passing arrangements, and the pilots agreed to a port-to-port passing. At the time, the *Genesis River* was about a mile north of the Bayport Flare. Pilot 2 told investigators that, using the tools on his PPU, he knew that the *Genesis River* would pass the *BW Oak* near the southern part of the Bayport Flare. He stated that the location of the planned passing caused him no concern, as he had met other ships there before. Each of the other Houston Pilots that investigators spoke with stated similarly: they felt comfortable passing in that location or considered it a safe area to pass.

As the *Genesis River* transited south through the channel, its engine speed continued to slowly increase until it reached between 72 and 73 rpm, which crewmembers stated was the programmed rpm setpoint for Nav. Full, between an available range of 60 to 89 rpm. The vessel's speed over ground was 12 knots.

At 1509, the *Genesis River* entered the Bayport Flare from the north on a course of 161 degrees.[15] Beginning at 1509:22, Pilot 2 set up for the passing with the *BW Oak* by ordering courses to starboard, between 163 and 165 degrees. According to VDR data, the helmsman used up to 25 degrees starboard rudder input and 24 degrees port rudder input to maintain the ordered courses.

As the *BW Oak* entered the turn at Five Mile Cut from the south, the pilot on board the vessel altered course to starboard at 1510:23. Before the turn, the *BW Oak* had been in the center of the channel, and the pilot told investigators that he ordered the turn earlier than he normally would have so that the ship would be on the starboard (eastern) side of the channel when it met the *Genesis River* (see figure 5).

[15] The base course of this section of the channel is 161.7 degrees, as defined by range markers to the south of this channel section.

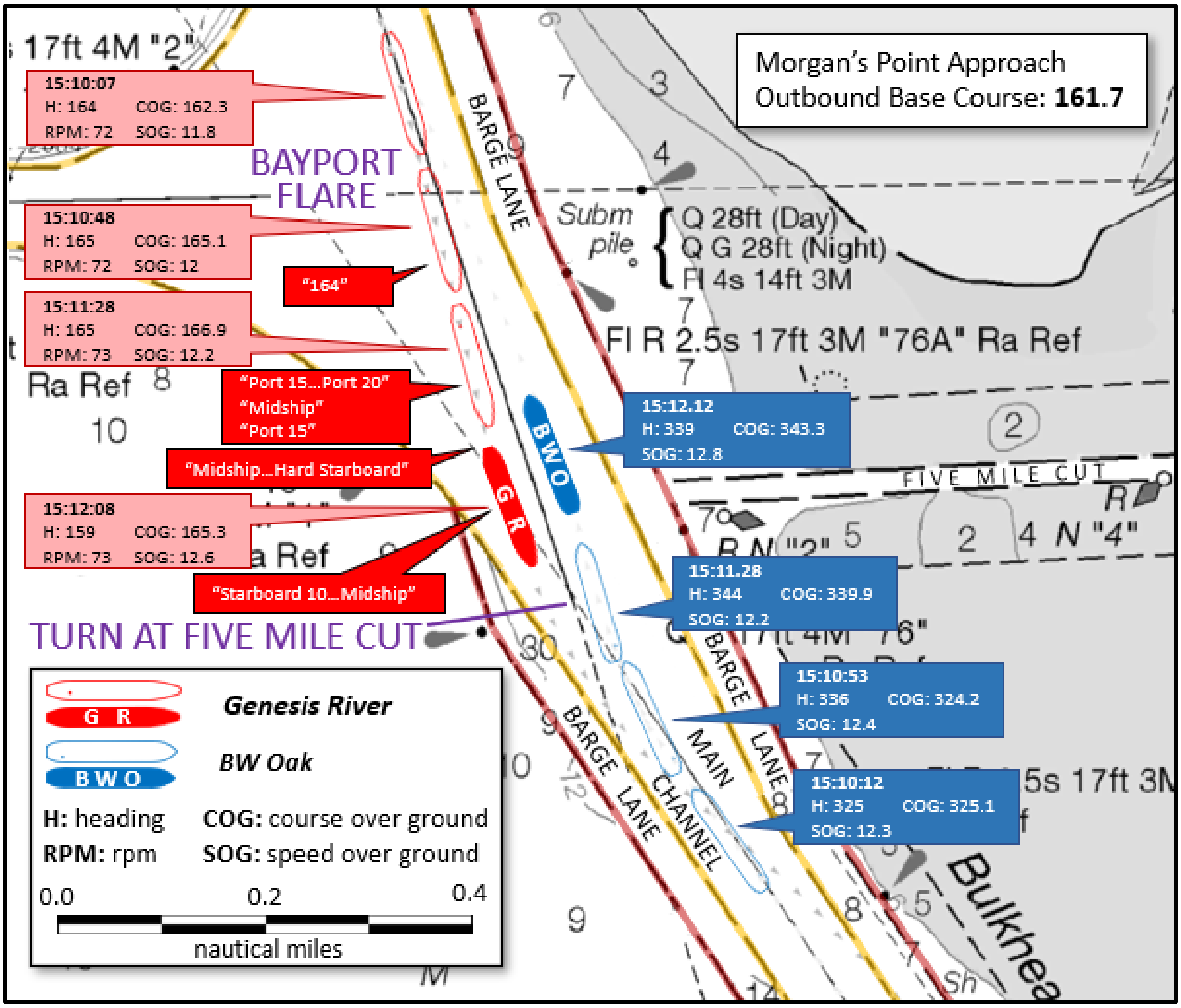

Figure 5. Pilot 2 helm orders as *Genesis River* and *BW Oak* passed in Bayport Flare. Positions based on automatic identification system (AIS) reporting data from each ship. (Background source: NOAA chart 11327)

At 1511:32, when the bows of the *Genesis River* and *BW Oak* were about 0.11 miles apart, Pilot 2 on the *Genesis River* ordered port 15 degrees rudder and then, shortly thereafter, port 20 degrees rudder. Four seconds later, he ordered the rudder to midship. The ship's heading was 164 degrees when he issued the midship order.

At 1511:48, Pilot 2 ordered port 15 degrees rudder, and the rudder moved to the ordered angle as the bow of the *Genesis River* passed the bow of the *BW Oak*. Nine seconds later, the pilot ordered rudder midship, followed almost immediately by hard starboard rudder. The helmsman repeated the command, and the rudder moved to starboard 35 degrees at 1512:07. A second later, with the ship at a speed over ground of 12.6 knots, Pilot 2 issued an order to ease the rudder to starboard 10 degrees, followed 2 seconds later by an order of rudder midship. The rudder began moving to midship, reaching centerline at 1512:20 just as the stern of the *Genesis River* passed the stern of the *BW Oak*. During this 32-second period, the *Genesis River*'s heading shifted 6 degrees to port, to 158 degrees.

The base course of the channel after the turn at Five Mile Cut (at the southern terminus of the Bayport Flare) was 146 degrees. As the *Genesis River* entered the turn, the vessel was on the western side of the main deep-draft channel. The recorded water depth under the keel, which had been between 4 and 5 meters while the ship transited the Bayport Flare, was now 3 meters.

The Collision. At 1512:25, as the ship's heading continued shifting to port and passed 155 degrees, Pilot 2 ordered starboard 20 degrees rudder to stop the swing of the ship. The rudder moved to 20 degrees starboard until the pilot ordered the rudder back to midship at 1512:32 (see figure 6). Five seconds later, as the ship's heading passed 151 degrees, Pilot 2 ordered hard starboard rudder. The rudder moved to starboard, reaching 35 degrees at 1512:45, with the ship's heading passing 149 degrees.

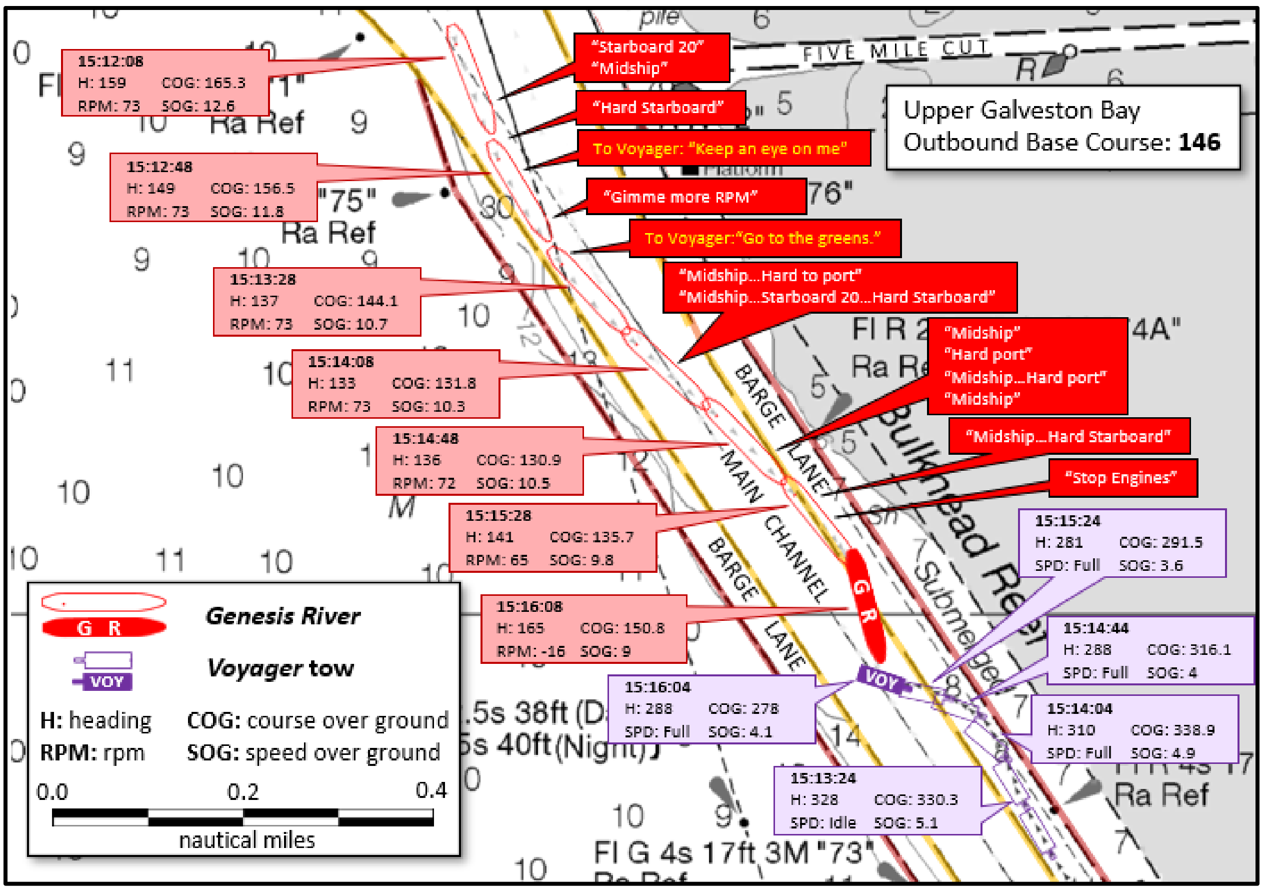

Figure 6. Pilot 2 orders and communications before the collision. (Background source: NOAA chart 11327)

After ordering hard starboard rudder, the pilot hailed the towing vessel *Voyager* (see figure 7) on VHF radio channel 13. The *Voyager*, with a crew of four, was pushing ahead two tank barges breasted together side by side, with the barge *30015T* to starboard and the barge *MMI3041* to port. Both barges were fully loaded with a cargo of reformate, a gasoline blending stock. With these loads, the barges each had a draft of 10 feet (3.1 meters) and a freeboard of 2 feet (0.6 meters).

Figure 7. *Voyager* moored in Channelview, Texas, following the accident.

The *Voyager* and its tow were inbound in the barge lane on the eastern side of the Houston Ship Channel, en route from the Buffalo Marine fleeting facility in Texas City, Texas, to the Kirby fleeting facility in Channelview, Texas. Both of the *Voyager*'s engines were at full throttle, and the tow was making about 5.3 knots speed over ground. The *Voyager*'s relief captain, who had been at the helm of the vessel since taking the watch at noon, answered Pilot 2's radio call. The pilot told him, "[I'm] that ship lookin' at you. Trying to check this thing up. Just keep an eye on me." The relief captain responded, "Roger, Roger." At this time, the *Genesis River* and the tow were 0.7 miles apart.

The *Genesis River*'s heading continued to swing to port. When the heading reached 143 degrees (3 degrees to port of the channel base course) at 1513:07—a little less than 3 minutes before the collision—Pilot 2 ordered the mate on watch to "gimme more rpm" and repeated the order a few seconds later. The second mate answered, "Yes, yes, yes." Pilot 2 told investigators that he wanted more engine rpm to improve the rudder's effectiveness.

The *Genesis River*'s bow was now pointed toward the eastern side of the channel, directly at the *Voyager* and its tow. Pilot 2 radioed the *Voyager* again, stating, "She's not checkin' up, *Voyager*." While answering Pilot 2 on the radio, the *Voyager* relief captain moved the towing vessel's throttles to neutral. "What do you need me to do, Captain?" he asked. Pilot 2 responded, at 1513:25, "Go to the greens," meaning the *Voyager* tow should cross the channel to the western side marked by green navigation beacons. When interviewed after the accident, Pilot 2 stated that, because the *Genesis River* was crossing from the western side to the eastern side of the channel, he intended for the two vessels to pass starboard-side to starboard-side once the *Voyager* reached the opposite side of the channel.

The *Voyager*'s relief captain told investigators that when Pilot 2 had first called him, he considered various options in case he needed to maneuver his vessel to avoid the *Genesis River*. He stated that he believed that he could not stop or slow down due to vessel traffic behind him (the towing vessel *Provider*, pushing two barges ahead, was about 0.6 miles astern and transiting at a faster speed) and because he felt that stopping would still leave his vessel in the path of the *Genesis River*. He said he could not turn the tow to starboard because there was a sunken bulkhead just outside the barge lanes (on navigation charts, this bulkhead appears as a dotted line outside the channel on the eastern side, labeled "submerged bulkhead"). He was concerned that hitting the bulkhead with the barges would stop the tow and leave his vessel stranded in the path of the ship bearing down on him. He could not increase speed because the towing vessel had been at full power. With the *Genesis River* pointed directly at him, he felt that his only course of action was to cross the channel to the western side. He stated that the pilot's direction over the radio to do so confirmed what he had already determined was the best action, so he immediately increased the *Voyager*'s engine throttles back to full power and put the vessel's rudders over hard to port. Automatic identification system (AIS) data showed that the two vessels were 0.55 miles apart when the head of the tow began turning to port at 1513:35.[16] About the same time, the relief captain sounded the general alarm and radioed the deckhand on watch, instructing him to find the captain to tell him to come to the wheelhouse.

Meanwhile, the *Genesis River*'s engine rpm had remained at the programmed Nav. Full speed of 73 rpm (parametric data from the VDR showed the engine demand signal—the input to the engine control program from the EOT—was also at 73 rpm). Pilot 2 once again asked for more rpm, and the second officer answered, "Yes, sir. Yes, sir. We are going to full." A few seconds later, Pilot 2 told the crew to summon Pilot 1 to the bridge.

At 1513:43, 36 seconds after Pilot 2's initial request for more rpm and 14 seconds after his second request, the *Genesis River* VDR recorded the second officer, speaking in his native language, talking on the ship's phone to the engine control room (ECR). Translated, he said, "Yes, sir, now give us maximum rpm, whatever you can give." After taking the call in the ECR, the first engineer adjusted a fine tuner dial on the side of the ECR EOT lever, changing the Nav. Full speed setting from 73 rpm to 85 rpm. According to the chief engineer, the second officer did not indicate that there was an emergency, so the first engineer and the chief engineer left the ECR to make a round of the engine room, leaving the electrical officer behind in the control room. Parametric data from the VDR showed that the rpm demand signal did not increase after the ECR EOT adjustment. The actual engine speed sporadically registered 74 rpm, but otherwise remained at 73 rpm until just before the collision.

About 1513:46, the *Voyager* captain, who had been exercising in the engine room when the deckhand summoned him, arrived in the wheelhouse. He asked the relief captain what was happening, and the relief captain stated that he responded, "Look!" while pointing out the wheelhouse windows toward the *Genesis River*. After taking a few seconds to survey the situation,

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[16] *AIS* is a maritime navigation safety communications system. At 2- to 12-second intervals on a moving vessel, the AIS automatically transmits vessel information, including the vessel's name, type, position, course, speed, navigational status, and other safety-related information, to appropriately equipped shore stations, other vessels, and aircraft. The rate at which the AIS information is updated depends on vessel speed and whether the vessel is changing course. AIS also automatically receives information from similarly equipped vessels.

the captain asked the relief captain if he wanted the captain to take the conn. The relief captain said that he responded, "No, I got it." The captain remained in the wheelhouse to assist the relief captain.

As the *Voyager* tow turned, its speed over ground slowed, dropping to as low as 3.6 knots. Pilot 2 told investigators that the tow did not turn and cross the channel as quickly as he expected. He again radioed the *Voyager*, stating "You need to go straight to the greens. Take a ninety to the greens, cuz I'm going to go your way again probably." The *Voyager* relief captain responded "Roger, Roger. Straight over."

Meanwhile, as the *Genesis River* crossed the center of the channel toward the eastern side (with the water depth under the keel increasing again to 5 meters), the ship's rate of turn to port slowed and then ceased, on a heading of 132 degrees. Then the ship began to swing back to starboard. During this time, Pilot 2 issued a series of rudder orders: first midship, then hard to port, back to midship, then starboard 20 degrees, and finally hard to starboard. The OS at the helm responded when ordered, with the rudder reaching 34 degrees to starboard at 1514:24.

The assigned helmsman on the *Genesis River* (the AB), who was monitoring the OS, recognized that an emergency situation was developing and took back the helm. Seconds later, Pilot 2 ordered the rudder to midship. The rudder returned to centerline at 1514:33. During these rudder movements, Pilot 1, who had returned to the bridge, asked the second mate if both steering pumps were online. The mate responded, "Yeah, already."

Pilot 2 radioed the *Voyager* again, stating, "Go, *Voyager*, go! Go, go, go!" The *Voyager* relief captain responded, "I'm hooked up, hard over, there, brother." At 1514:44, Pilot 2 ordered the rudder hard to port. He told investigators that he knew the ship would swing back across to the western side of the channel, so he ordered the port rudder in an attempt to hold the ship on the eastern side of the channel until it had passed the *Voyager* tow. The helmsman acknowledged the order, and the rudder began swinging to port.

By this time, the *Voyager* tow was crossing the deep draft channel, yet it was still on the eastern side making about 4 knots. The *Genesis River* was still swinging to starboard, and Pilot 2 realized that the port rudder was not going to be effective in holding the ship along the eastern side of the channel. Consequently, he radioed a warning to the *Voyager*. "I'm gonna probably hit ya…sound your general alarm there, *Voy[ager]*…get everybody up." A response from the *Voyager* was not captured on audio recordings.

At 1514:54, the *Genesis River* second officer called the master in his stateroom, telling him to come to the bridge immediately. The master arrived on the bridge about 30 seconds later.

At 1515:00, Pilot 2 ordered the rudder to midship, then immediately ordered the rudder hard to port again. Ten seconds later, Pilot 2 warned the *Voyager* again over the radio, stating, "Wake everybody up on that, uh, *Voyager*." The towing vessel relief captain responded, "We got it, brother. We got 'em. Appreciate it." At 1515:12, Pilot 2 ordered the rudder to midship again, and the helmsman brought the wheel to midship.

The *Genesis River*'s rate of turn back to starboard increased as it approached the bank on the eastern side of the channel. As the ship passed heading 139 degrees, Pilot 2 radioed the

Voyager, "I'm gonna be swingin' your way real soon. She's comin' your way. You gotta push on it." The *Voyager* relief captain responded, "She's all she's got there, brother; all she's got."

Shortly thereafter, with the *Genesis River*'s rudder at midship, the second mate said, "Go to the port. Go to the port." He told investigators that he was speaking to Pilot 2 at the time, although the pilot did not acknowledge him.

At 1515:29, as the *Genesis River*'s heading passed 143 degrees and back toward the *Voyager*, Pilot 2 ordered the rudder to midship (the rudder was already at midship), then immediately ordered the rudder to hard starboard. The helmsman acknowledged the order, and the rudder began moving to starboard, reaching 35 degrees at 1515:37. About the same time, the second officer said to Pilot 2, "Hard port, sir, hard port." He received no reply. Pilot 2 told investigators that, at that point, he knew that the ship was going to collide with the tow, so he turned to starboard to ensure that the *Genesis River* struck the barges and not the towing vessel. He stated that his principal concern was the people on the *Voyager*. After issuing the starboard rudder order, he radioed the *Voyager*, stating, "You got it hard over there, *Voyager*?...Work with me….We're gonna collide." The *Voyager* relief captain responded, "Roger, Roger. Roger, Roger," while the *Voyager* captain sounded the general alarm.

As Pilot 2 was struggling to control the ship, Pilot 1 ran out to the port bridge wing. He told investigators that from this position, he could see that the *Genesis River* was now in the barge lane on the eastern side of the channel. He said, "As the bow went into the bank on the red [eastern] side, the ship swung into the bank, and the whole ship just rolled up…. We touched bottom."

At 1515:43, when the *Genesis River*'s bow was about 600 feet (0.1 miles) from the *Voyager* tow, Pilot 2 ordered "stop engines." The master, who had returned to the bridge, repeated the engine order to the second officer. At 1516:03, seconds before the collision, the master ordered the engine to emergency full astern (also known as "crash astern"). The emergency full astern input to the engine control system overrode the normal propulsion control program and executed an accelerated shift to maximum astern thrust.

At 1516:09, the *Genesis River*'s bow struck barge *30015T* midship on the starboard side (see figure 8), penetrating through the double hull and breaching the no. 2 starboard cargo tank. The gas carrier's bow continued through the barge's hull into the no. 2 port cargo tank. The force of the collision capsized barge *MMI3041*, the tow's port barge, although no tanks were breached. When the *Genesis River* impacted the *30015T*, the port face and long wires securing the barges to the *Voyager* parted. As the barges were pushed sideways by the *Genesis River*, the *Voyager* pivoted on the starboard face wire until the towing vessel's starboard side contacted the stern of the *30015T*. As the *Voyager* continued to be pulled, it heeled significantly to starboard until the last face and long wires gave way, allowing the relief captain to regain control of the vessel. The loose end of the parted starboard long wire, which had fallen into the water, then fouled the *Voyager*'s starboard propeller, stalling the engine.

Figure 8. Screen capture from wheelhouse video on board the *Voyager* at the moment that the *Genesis River* struck barge *30015T*. (Source: Kirby Inland Marine, LP)

Just prior to the collision, the *Voyager* captain had sent the deckhand down to close the engine room door on the starboard-side main deck of the towing vessel. Company policy stated that all main deck doors were to remain closed while the vessel was in operation, but the captain had opened the door to allow air into the engine room while he was exercising. The deckhand reached the door just as the *Genesis River* struck the tow. He was able to close the door, but not before about 200 gallons of water entered the engine room.

With the *Genesis River* engine remaining at emergency full astern, the ship began to back away from the barges once the forward motion of the *Genesis River* ceased. Reformate in the breached cargo tanks escaped into the channel from the hole in the *30015T*'s hull. Pilot 2 radioed the Houston Pilots dispatcher, stating, "Bad collision. Shut down the channel." Pilot 1, who had begun communicating with the US Coast Guard Sector Houston–Galveston Vessel Traffic Service (VTS) via his cell phone when the collision was imminent, informed Coast Guard VTS about the accident.[17] The VTS watchstander, who was monitoring vessel traffic in the area and had heard the VHF radio communication between the *Genesis River* and *Voyager* when he received the call from Pilot 1, reported the accident to higher authority and the Coast Guard Command Center, allowing response efforts to commence. VTS watchstanders then advised other vessels in the Houston Ship Channel of the accident and redirected traffic as necessary.

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[17] The purpose of a *VTS* is to provide active monitoring and navigational advice for vessels in particularly confined and busy waterways. VTS watchstanders use a wide range of techniques and capabilities aimed at preventing vessel collisions and groundings in the harbor, harbor approach, and inland waterway phase of navigation. They also expedite ship movements, increase transportation system efficiency, and improve all-weather operating capability. Source: US Coast Guard (https://www.navcen.uscg.gov/?pageName=vtsMain). See also section 1.7.3.

Once the vessels were clear of each other, Pilot 1 radioed the *Voyager* crew to check on their status. The relief captain radioed back, “Everybody’s good on the *Voyager*.” The *Genesis River* anchored in the channel, awaiting further direction from VTS, while the *Voyager*, reduced in maneuverability due to the loss of the starboard engine, made up to the towing vessel *Provider*. The *Genesis River* was eventually directed to a lay berth in Bayport, and the vessel proceeded to the berth under its own power, mooring at 1736 that evening. The *Voyager* was towed to the Kirby facility at Old River, Texas, arriving at 2120.

1.2 Response Operations

Approximately 11,276 barrels (473,600 gallons) of reformate spilled into the waterway from the damaged barge *30015T*. When the accident was reported to VTS, the Coast Guard captain of the port closed the Houston Ship Channel to navigation. At 1541, the incident command system was activated, and an incident command post was established at Coast Guard Sector Houston–Galveston headquarters (the post would later move to a location near Bayport). At the same time, Kirby Inland Marine implemented its spill response plan, hiring various providers to conduct response operations. By 1935, oil spill containment booms had been deployed around barges *30015T* and *MMI3041*, and additional booms were being installed across inlets and other sensitive marine areas around Galveston Bay. Oil skimmers were deployed to recover reformate/water mixture in the vicinity of the accident site, with a total of seven skimmers used during the cleanup.

As cleanup efforts continued, residents in neighborhoods surrounding Galveston Bay reported a petrochemical odor, prompting air quality testing in the areas most affected. Throughout the response, 15,016 air samples measuring for atmospheric flammability and concentrations of benzene and volatile organic compounds were collected. Thirty-nine readings detected benzine or volatile organic compounds at or above 0.5 parts per million, but secondary readings for these instances determined that levels were not sustained above actionable levels. Reports indicated that a fish kill impacting between approximately 100 and 1,000 fish, shrimp, and crabs occurred on a limited stretch of shoreline, along with other wildlife impacts. Out of 2,700 water samples taken between Friday (the accident day) and Sunday, none showed pollution levels requiring action.[18]

At 0400 on May 12, the captain of the port opened the Houston Ship Channel for navigation to outbound traffic only. At 1505 that day, lightering of reformate cargo from barge *30015T* commenced and was completed at 2345 on Tuesday, May 14.[19] In all, 14,000 barrels of pure reformate and 4,530 barrels of reformate/water mixture were recovered from the vessel. Once the offload was completed, the barge was towed to a shipyard in Channelview for assessment.

Offloading of cargo from the capsized barge proved more difficult. On Tuesday, May 14, the barge *MMI3041*—still capsized—was towed to a location off the main channel (allowing the channel to reopen for navigation of two-way traffic on May 15) for lightering. Lightering commenced at 1447 and was completed at 1710 the next day. On Sunday, May 26, the *MMI3041*

[18] Wesner Childs, Jan, “Houston Shipping Channel Ship Collision Cleanup Continues After Toxic Spill, Reports of Fish Kill,” *weather.com*, May 2019.

[19] *Lightering* is the process of discharging a cargo from one vessel to another vessel.

was parbuckled (righted using rotational leverage) and towed to the shipyard in Channelview. All 25,392 barrels of reformate cargo was recovered from the *MMI3041*.

1.3 Vessel Information

1.3.1 *Genesis River*

The *Genesis River* was owned by FPG Shipholding Panama 47 S.A., and managed and operated by K-Line Energy Ship Management Co. Ltd. It was classified by the American Bureau of Shipping (ABS).[20] Built in Sakaide, Japan, by Kawasaki Heavy Industries Ltd., the *Genesis River* was delivered in November 2018, less than 6 months before the accident. Vessel particulars of the *Genesis River* are as follows:

Length	754 ft (229.9 m)
Beam	122 ft (37.2 m)
Draft	36.8 ft (11.2 m)
Tonnage	46,794 GT ITC[21]
Engine	Kawasaki-MAN B&W 7S60ME-C8.2, diesel; 17,567 hp (13,100 kW)

Unlike most tank vessels of its size, the *Genesis River* did not have a bulbous bow. Rather, the vessel was designed with Kawasaki Heavy Industries' proprietary "SEA Arrow" bow shape, which, according to the company, provided improved propulsion performance by reducing bow wave resistance. The vessel also had a unique rudder employing a "bulb system with fins" designed to reduce fuel consumption. According to the vessel's deck log, the rudders and engine were tested satisfactorily prior to getting under way on the accident date. The crew reported no mechanical issues during the voyage.

Main Propulsion System. The *Genesis River*'s main propulsion system was comprised of a single, centerline-mounted, slow-speed, turbocharged diesel engine directly connected to a fixed-pitch, five-bladed, 7.3-meter-diameter propeller. The engine's maximum continuous output was rated at 17,567 horsepower (hp) (13,100 kilowatts [kW]) at 89 shaft rpm, and its normal output (85 percent maximum continuous output) was rated at 14,939 hp (11,140 kW) at about 84 rpm. Due to the slow rotational speed of the engine, the propulsion system did not require a reduction gear between the engine and propeller. To stop the propeller, the engine had to be stopped. The engine would then have to be restarted by admitting compressed air directly into the combustion cylinders, depending on the engine's firing sequence, to meet the next ordered command (ahead or astern).

[20] *Classification societies* such as ABS are nongovernmental organizations that establish and maintain standards for shipbuilding and operations. They may also be delegated by a flag state to perform certain flag-state vessel inspection and certification functions.

[21] *GT ITC*, or *gross tonnage - international tonnage convention*, is the international standard for the measurement of the volume of all enclosed spaces on a vessel, as defined in the *International Convention on Tonnage Measurement of Ships, 1969*.

Main Propulsion Control System. In addition to a local controller in the engine room, the main propulsion engine could be controlled from either the bridge or the ECR via a Nabtesco M-800-V Main Engine Remote Control System. The user interfaces at both remote locations were identical and included an EOT lever and a small control panel. The EOT lever controlled the direction of the engine (and thus, the propeller), either ahead or astern, and the position of the lever set the rpm of the engine (see figure 9). Next to the lever was a scale divided into the standard engine orders of stop, dead slow, slow, half, and full. In the ahead direction, the EOT also included the Nav. Full engine order position, and, in the astern direction, the Emerg. Full [emergency full] position. A pointer attached to the EOT lever showed the position of the lever corresponding to these speed divisions. As the telegraph lever was moved ahead or astern, detents stopped the lever at set rpm speeds for each standard engine order. A fine tuner dial on the side of the lever then allowed the user to make small adjustments to the rpm. In normal practice, the fine tuner was not employed by the bridge team, and the telegraph operator moved the lever to the detent position corresponding to the given order. Any time the EOT lever was moved, a tone would sound at the watchstation.

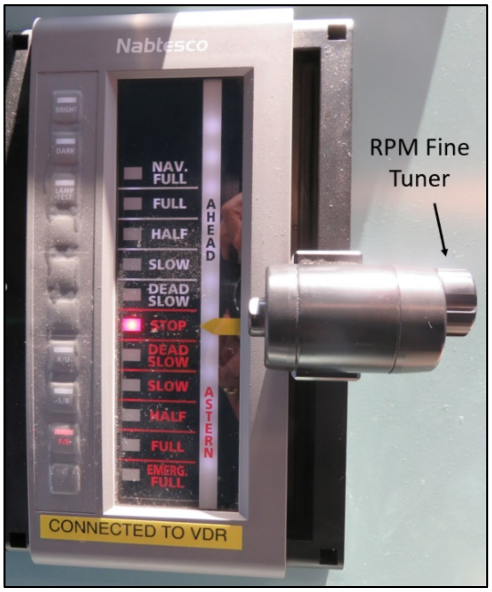

Figure 9. *Genesis River* bridge EOT lever.

The control panel for the system included a display and several illuminated pushbutton switches (see figure 10). The display provided various system parameters, such as engine rpm and start air pressure, as well as alarm indications in the case of a system malfunction. When engine speed order was changed at the EOT, the corresponding rpm value of the ordered speed was shown on the display. The pushbutton switches initiated various normal and emergency actions, such as starting and stopping the engine, and shifting control of the engine between the engine room, ECR, and bridge.

Figure 10. *Genesis River* bridge control panel for remote engine control system.

When in bridge control, the EOT directly controlled the engine, and any changes in the ECR EOT position would have no effect on engine speed. However, according to the Nabtesco specification sheet for the system installed on the *Genesis River*, the maximum rpm that could be ordered by the bridge EOT was limited by the rpm setting at the ECR EOT. If the position of the EOT lever on the bridge was set higher than the ECR EOT, the engine speed would not exceed the limit set at the ECR EOT, and an indication of “LIMITED

SPEED" would be displayed at the control panel on the bridge. When the engine was operating at limited speed and increased rpm was required, bridge watchstanders had to call the ECR to request an increase to the limit.

On commercial vessels, such as the *Genesis River*, with a direct-coupled, slow-speed diesel engine, the vessel's engine is normally placed in "maneuvering mode" when a range of engine orders is anticipated, such as when operating in confined waters or entering and leaving port. When in maneuvering mode, the engine room is generally manned and the engine is able to respond to orders (dead slow ahead, slow, half, and full, as well as astern orders) on demand. When maneuvering mode is no longer required, such as transits in open ocean, the EOT is normally set to Nav. Full (or equivalent), and "sea speed" is set by the engineering watchstanders at a designated rpm. On the *Genesis River*, the rpm could be set to between 60 and 89 rpm, and prior to the accident, the vessel's sea speed rpm had been set to about 73.

When the *Genesis River* was operating in maneuvering mode and a change in speed was ordered from the EOT, the engine accelerated at a rate of 2 rpm per second (120 revolutions/minute[2]) until the desired rpm was reached, according to the control system manufacturer. When the EOT was placed in Nav. Full or the rpm order was increased or decreased while in Nav. Full mode (between 60 and 89 rpm), a control program was initiated that changed engine speed at a much slower, measured rate until the desired rpm was attained. Although Nav. Full allowed the engine to operate at a higher rpm, the control program limited the crew's ability to change rpm on demand (hence, the pilot's reference to "10-minute notice" when he ordered the speed increased after Morgan's Point).

The control program function was designed to protect the engine against overload conditions and avoid high thermal stresses and excessive vibration. When the speed was increasing or decreasing and the control program was in effect, a "LOAD UP/DOWN PROGRAM" indicator illuminated on the system control panels on the bridge and in the ECR. Depending on the ordered rpm and the load on the engine, it could take up to 40 minutes under the load up program to reach an ordered rpm at Nav. Full, according to the *Genesis River* chief engineer. (When the *Genesis River* went from full ahead to Nav. Full on the accident voyage, it took 21 minutes to increase from 60 to 72 rpm.)

If immediate changes to engine rpm were required while the *Genesis River* was operating in Nav. Full, the load up program could be bypassed by depressing a "PROGRAM BYPASS" button on the control panel on the bridge or in the ECR. According to the manufacturer, upon depressing the program bypass button, the load up program was cancelled, which allowed the rpm to increase rapidly, and the torque/load limiter setting on the engine was increased by approximately 10 percent. The chief engineer stated that when increased rpm was requested from the bridge just prior to the collision, the program bypass button was not pressed in the ECR because engineering watchstanders were unaware that there was an emergency. Furthermore, the chief engineer said that it was the responsibility of the bridge watchstanders to press the bypass button, since they had the understanding of the maneuvering situation. At the time of the accident, the engine was in bridge control.

In a deposition taken in October 2019, the second officer stated that he did not depress the bypass button on the bridge because "we might lose our engines in the middle of the channel…it could have created a drastic changes of major—major damage to the engine." He added that he had been trained by the vessel's current and former chief engineers that depressing the button would damage the engine, and that pressing the button required the permission of the master or chief officer. The chief officer also stated in a deposition that depressing the bypass button could result in engine failure "in extreme cases." According to the engine manufacturer, it is difficult to quantitatively evaluate the extent of damage to an engine operated in bypass over a short or long term. However, the engine's torque limiter or scavenging air pressure limiter will activate during a "very severe engine situation," and therefore "the engine will not be damaged immediately" if the control program is cancelled using the bypass button. Activation of these limiters (torque and scavenging air pressure) will prevent or slow further acceleration of the engine.

As previously noted, setting the telegraph to Emerg. Full (crash astern) resulted in an accelerated reversal of the engine (as compared to normal commands from EOT). Crash astern sea trial data for the *Genesis River*, which was based on testing done with a sister ship (the *Sumire Gas*), showed that when crash astern was initiated with the vessel moving at a forward speed of 12.5 knots (59 rpm) in maneuvering mode, it took 3 minutes 22 seconds for the shaft to be stopped from turning in the forward direction and another 1 minute 53 seconds before the shaft was rotating at full speed in the astern direction. The total time that it took for the ship to come to a stop was 7 minutes 31 seconds at a distance traveled of 1 mile (1,854 meters). The crash astern test on the sister ship was conducted while the vessel was in a "trial ballast" condition in open water (sea depth greater than 200 meters).[22] A majority of marine engineering research has shown that, at best, stopping distances are unaffected by shallow water, and, more likely, they are increased.[23] Pilot 2 told investigators that he considered ordering crash astern while he worked to regain control of the vessel prior to the collision, but once the *Voyager* tow began crossing to the western side of the channel he opted not to.

Anchors. The *Genesis River* had anchors on either side of the bow, with 13 shackles of chain on the port anchor and 12 shackles of chain on the starboard anchor.[24] The anchor windlass associated with each anchor chain had a brake holding force of 228.5 long tons (232.2 metric tons).

During the accident voyage, a deck crew was stationed at the bow of the *Genesis River* to release either or both anchors if the need arose. When interviewed after the accident, Pilot 2 stated that he considered dropping the anchors to slow the ship prior to the collision but chose not to. He said, "At that kind of speed, that kind of momentum, you've got the guy on the bow, drop of the anchors is very unsafe. And once you do that, you have no control whatsoever of that vessel."

Voyage Data Recorder. The *Genesis River* was required to carry a VDR under Regulation 20 of SOLAS Chapter V. The vessel's VDR was a JCY-1900 VDR system

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[22] *Ballast* is material, usually seawater, taken aboard a ship when it is lightly loaded or empty in order to increase draft and improve maneuverability.

[23] Duarte, Heiter, Enrique López Droguett, Margaretta Lützhöft, and Pedro Pereira, "Review of Practical Aspects of Shallow Water and Bank Effects," *The International Journal of Marine Engineering*, London: Royal Institution of Naval Architects, 2016.

[24] A *shackle*, also called a *shot*, of anchor chain is 15 fathoms (90 feet) in length.

manufactured by Japan Radio Co.. It was capable of recording navigation, propulsion, control surface, alarm, and AIS data, as well as bridge audio and communications audio channels.

A performance test was conducted on the *Genesis River*'s VDR in October 2018 (prior to the ship's delivery), and the resultant ABS certificate of compliance indicated that the equipment was being maintained in the appropriate operational condition. Approximately 12 hours of fair quality audio and 22.5 hours of parametric data were extracted from the VDR following the accident.

When reviewing the data, NTSB investigators and engineers noted a delay between the extracted audio recording and the parametric data logging. Thus, when the VDR data was played back using the manufacturer-supplied software, parametric data such as changes to the position of the rudder angle indicator or the EOT position were not registered until several seconds after audio indicators corresponding to the changes. The delay between the audio and parametric data was consistent throughout the *Genesis River*'s entire transit of the Houston Ship Channel, from the Targa Terminal to the accident location.

This offset was rectified by aligning aural cues in the audio recording with their associated parameter in the recorded data.[25] Specifically, when the engine order telegraph (EOT) position was changed, an accompanying tone sounded on the bridge. The timing of that tone on the VDR audio recording was aligned with the "Telegraph Position" parameter as recorded in the VDR parametric data. The delay for every change in EOT position from the beginning of the recording to the time of the accident was calculated, and the average of the time differences was implemented. These 52 samples resulted in moving the audio transcribed data forward by 8.1 seconds.

The times used for VDR audio in the accident narrative, section 1.1, are the corrected values from this analysis. It should be noted that the time value for the voice command had a fidelity of 1 second, and the rudder sensor angle and demand were recorded by the vessel's VDR once every second. As such, the relative position of the voice command with the corresponding rudder action may have been off by as much as 1 second.

Accident Damage. The collision opened an S-shaped gash in the *Genesis River* hull about 7.5 feet (2.3 meters) below the waterline and 36 feet (11 meters) aft of the bow on the starboard side, causing the vessel's partially filled fore peak tank to flood. The estimated cost of repairs to the *Genesis River* was $406,000.

1.3.2 *Voyager*

The towing vessel *Voyager* was owned and operated by Kirby Inland Marine LP. ABS was designated as the "third party organization" for the purpose of validating compliance with Coast Guard regulations, and the vessel's last survey was completed in December 2018. The *Voyager* had a valid certificate of inspection issued by the Coast Guard in January 2019. Built in Channelview, Texas, by Glendale Boat Works Inc., the vessel was delivered in 1975. The *Voyager*

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[25] For more information, see *Voyage Data Recorder Report Errata, Specialist's Factual Report*, October 6, 2020, in accident docket.

had four previous owners before being acquired by Kirby Inland Marine in 1999. Vessel particulars of the *Voyager* are as follows:

Length	68.9 ft (21 m)
Beam	26.1 ft (8 m)
Draft	8.5 ft (2.6 m)
Tonnage	155 GRT[26]
Engine	2 x Cummins K38-M, diesel, EPA-Tier-2-certified; 1,700 hp (1,268 kW)

Engineering Systems and Maintenance. The *Voyager*'s two main propulsion diesel engines were each coupled to a fixed pitch propeller via a Twin-Disc transmission. The engines and transmissions were controlled from the wheelhouse by a pneumatic throttle system. The vessel had two steering rudders and four flanking rudders controlled via tiller handles in the wheelhouse.[27] Although there were two tillers in the wheelhouse for the steering rudders, they were operated in tandem; that is, the rudders could not be individually controlled, and the movement of one tiller also moved the other tiller. The flanking rudders likewise had two tillers in the wheelhouse that operated in tandem.

According to records provided by the company, major shipyard maintenance and repair periods were conducted on the vessel in 2010, 2013, 2016, and 2018. The main propulsion engines were overhauled in 2013, and a post-maintenance thrust pad test confirmed a combined horsepower of 1,757.5. According to the *Voyager* crew, the rudders and engines were tested satisfactorily prior to getting under way on the morning of the accident date, and the crew reported no mechanical issues during the voyage.

Accident Damage. The *Voyager* received only minor damage during the accident.

1.3.3 Barges

The barges *30015T* and *MMI3041* were also owned and operated by Kirby Inland Marine. The unmanned barges were designed to carry petroleum products and were inspected under Coast Guard regulations. They were constructed by Trinity Marine Products Inc. (now Arcosa Marine Products), the *30015T* being built in Houston in 1996 and the *MMI3041* being built in Ashland City, Tennessee, in 2003. The barges were nearly identical in size and construction, each measuring 297.5 feet (90.7 meters) in length and 54 feet (16.5 meters) in beam. The barges were "double skin"; that is, they were built with inner and outer hulls to protect the cargo in case of a breach in the outer hull. In the *30015T*, the distance between the outer hull and the cargo tanks was 3 feet 4 inches (see figure 11). Each barge had six cargo tanks arranged two wide by three long and separated by single bulkheads. Barge *30015T* was carrying 26,023 barrels (3,527 long

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[26] *GRT*, or *gross register tonnage*, is a US national standard for the measurement of the volume of all enclosed spaces on a vessel. For most vessels 79 feet and over in length, ITC is the primary tonnage measurement system under the law in the United States. For vessels less than 79 feet in length, GRT is used in all cases. Source: Coast Guard, *Simplified Measurement Tonnage Guide 1*, TG-1, 2009.

[27] *Flanking rudders* are rudders positioned forward of the propellers that increase the maneuverability of the vessel, particularly in the astern direction.

tons/3,584 metric tons) of reformate, and barge *MMI3041* was carrying 25,392 barrels (3,442 long tons/3,497 metric tons).

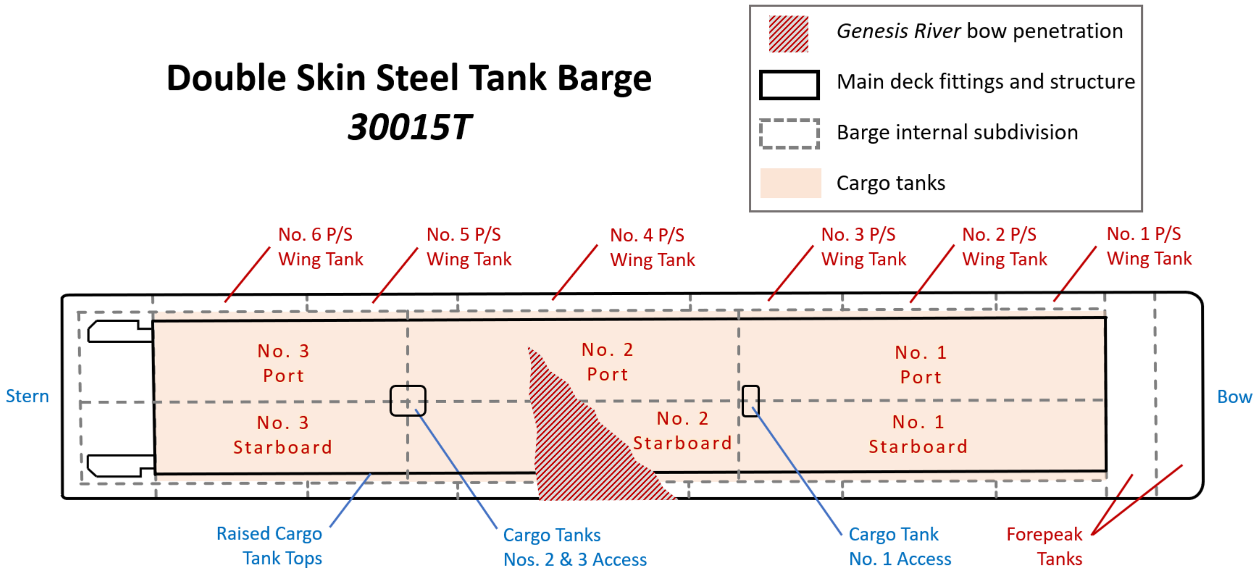

Figure 11. Barge *30015T* simplified plan with area of major damage.

Accident Damage. Barge *30015T* sustained a 23-foot-by-30-foot triangular-shaped gash in the starboard side, as well as bent or broken plating, framing, and piping throughout the vessel (see figure 12). The void space surrounding the cargo tanks on the *30015T* was at the point of impact. Although double-hull requirements are intended to prevent the majority of spills from grounding or lesser impacts, the high-energy collision with the much larger *Genesis River* (displacing nearly 70,000 long tons at the time of the accident), which struck the *30015T* hull with its narrow, SEA Arrow bow at over 10 knots, exceeded the protection afforded by the barge's double hull.

Barge *MMI3041* sustained inset or buckled plating along the wing tanks on both sides of the vessel. Additionally, several holes were made in the hull during salvage operations. Both barges were later determined to be constructive total losses and scrapped, with a combined insured value of $2,789,643.

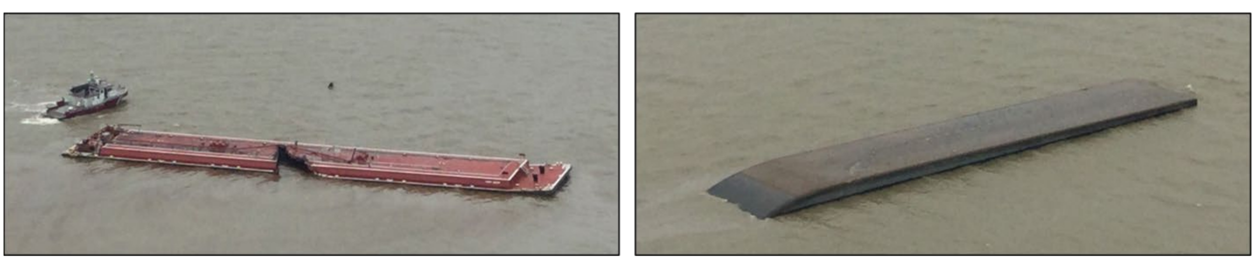

Figure 12. Barges *30015T* (left) and *MMI3041* (right) postaccident.

1.4 Personnel Information

1.4.1 Houston Pilots

The Houston Pilots are an association of ship pilots licensed by the state of Texas and the Coast Guard to serve on vessels transiting the Houston Ship Channel. The Board of Pilot Commissioners for the Ports of Harris County, Texas, oversees the Houston Pilots. According to the presiding officer of the Houston Pilots, each pilot is "an independent contractor." State law requires the completion of a 3-year deputy training period before licensing as a full branch pilot, and deputies are trained via a standardized program. Full branch pilots share resources such as pilot boats and centralized dispatching services. The pilots aboard the *Genesis River* were members of the Houston Pilots. The *Voyager* did not have nor was it required to have a pilot on board.

Genesis River Pilot 1. Pilot 1 held a valid Coast Guard credential as a First Class Pilot Of Vessels Of Any Gross Tonnage Upon The Houston Ship Channel and a valid commission from the State of Texas as a Branch Pilot, the Houston Ship Channel and Galveston Bar. Pilot 1 told investigators that he had 38 years of experience as a credentialed merchant mariner. He was accepted into the Houston Pilots in 1995, and, after completing a 2-year training program as a deputy pilot, was designated a full pilot in 1997.[28] At the time of the accident, he had made 5,680 transits as a pilot on the Houston Ship Channel and surrounding waters. He stated that he had completed a bridge resource management (BRM) for pilots course about 2 years prior.

Genesis River Pilot 2. Pilot 2 had the conn of the *Genesis River* during the accident. He held a valid Coast Guard credential as a First Class Pilot Of Vessels Of Any Gross Tonnage Upon The Houston Ship Channel and a valid commission from the State of Texas as a Branch Pilot, Houston Ship Channel and Galveston Bar. He had about 22 years of experience as a credentialed merchant mariner and 13 years of experience as a Houston Pilot: 3 years as a deputy pilot and 10 years as a full pilot. At the time of the accident, Pilot 2 had made 1,947 transits as a full pilot on the Houston Ship Channel. He stated that he had completed a BRM course but could not recall if it had been specifically designed for pilots or when he had completed the course.

1.4.2 *Genesis River* Crew

Master. The master held a valid Certificate of Competency as Master of a Foreign-going Ship issued by the Government of India. He had 17 years of sailing time as a merchant mariner, with nearly 10 years' experience as a master. At the time of the accident, he had been master of the *Genesis River* for 3 months. He stated that he had transited the Houston Ship Channel as master of a vessel about three times. He last completed a bridge resource management/bridge team management (BRM/BTM) with ship simulator course in 2016. According to the master, the BRM/BTM course he attended included training involving operations in coastal waters with pilots.

[28] At the time that Pilot 1 was accepted into the Houston Pilots, the training period as a deputy pilot was 2 years in length. The training period was lengthened to 3 years in the period between when Pilot 1 and Pilot 2 joined the association.

Chief Officer. The chief officer of the *Genesis River* had been the senior officer on the bridge of the vessel until the master returned just prior to the collision. The chief officer held a valid Certificate of Competency as Master of a Foreign-going Ship issued by the Government of India. He told investigators that he had about 18 years of sailing time as a merchant mariner. He joined the *Genesis River* in February 2019 and had not served on the ship before. He had previously served as the chief officer on a very large crude carrier and another LPG carrier (not a sister ship to the *Genesis River*). According to records provided by the company, the *Genesis River* chief officer last completed a BRM/BTM (with ship simulator) course in 2018. The chief officer stated that the BRM/BTM course included training involving operations with a pilot on board.

Second Officer. The second officer was the officer of the watch during the accident and was responsible for monitoring the ship's position and the actions of the watch team. He also operated the EOT when ordered by the pilot and master. He held a valid Certificate of Competency as Second Mate of a Foreign-going Ship issued by the Government of India. He told investigators that he had 8 years of sailing time as a merchant mariner, with 18 months served as a second officer. He joined the *Genesis River* when it was delivered from the build-yard to the company, about 6.5 months prior to the accident. He had previously served as the second officer on an ammonia carrier and two LPG-carrier sister ships of the *Genesis River*, the *Fountain River* and the *Galaxy River*. He stated that he had transited the Houston Ship Channel 15–20 times, 5–6 of which were as second officer. According to records provided by the company, the *Genesis River* second officer completed a Refresher and Updating Training for Deck Officers (Operational Level) course in 2016 and last completed a BRM/BTM course in 2018. The second officer told investigators that the BRM/BTM course included training involving operations with a pilot on board.

Able-bodied Seaman. The AB was the assigned helmsman during the accident voyage. The AB had the helm from the time the vessel got under way until about 1500, when the OS was allowed to take the helm under the supervision of the AB. The AB held valid certificates for Ratings Forming Part of the Navigation Watch and Able Seafarer Deck issued by the Government of the Republic of the Philippines. He told investigators that he had 8 years of sailing time as a merchant mariner and had served on eight different ships. He had been a helmsman on four ships, including the *Grace River*, a sister vessel to the *Genesis River*. He joined the *Genesis River* at delivery, about 6.5 months prior to the accident.

Ordinary Seaman. The OS that took the helm prior to the accident held valid certificates for Ratings Forming Part of the Navigation Watch and Able Seafarer Deck issued by the Government of the Republic of the Philippines. As such, he was qualified by international standards to stand a helmsman watch. He told investigators that he had 5 years of sailing time as a merchant mariner and had served on three different ships—one being a sister ship of the *Genesis River*, the *Summit River*. In 2014, he had completed a ship steering course provided by the company, and at the time of the accident he was training to be promoted to an AB position with the company. He joined the *Genesis River* at delivery, about 6.5 months prior to the accident, and had been training on the helm for 2–3 months, standing 1.5–2 hour watches a day, 4–5 times a week. The OS stated that he had previously steered the *Genesis River* for training on both inbound and outbound transits of the Houston Ship Channel. In a postaccident interview with investigators, Pilot 2 stated that the helmsman, the OS, had followed his orders as expected. However, at a Coast Guard hearing 4 months after the accident, Pilot 2 stated that the helmsman "wasn't doing the proper orders given."

1.4.3 *Voyager* Crew

Captain. The captain of the *Voyager* was not on watch during the accident but came to the wheelhouse when the relief captain sounded the general alarm prior to the collision. He held valid Coast Guard credentials as a Master Of Towing Vessels Upon Great Lakes, Inland Waters and Western Rivers and a Master Of Self-Propelled Vessels Of Less Than 200 Gross Register Tons (GRT) Upon Inland Waters. The captain told investigators that he had been employed with Kirby Inland Marine for 16 years, as a captain for 7 years on board the *Voyager*. He stated that he had made over 100 transits of the Houston Ship Channel. He said that he had attended Wheelhouse Pilot Management, as well as other training courses including simulators, on a recurring basis every 3 years. The captain's normal work rotation was 21 days on the vessel followed by 10 or 11 days off. He had been scheduled to be off cycle starting on May 3 but had requested and been granted an extension to remain on board as captain for an additional 7 days. He was due to be relieved at the completion of the accident voyage.

Relief Captain. The relief captain was second overall in charge of the *Voyager* and was at the helm during the accident. He held a valid Coast Guard credential as a Master Of Towing Vessels Upon Great Lakes, Inland Waters and Western Rivers. The relief captain told investigators that he had been employed with Kirby Inland Marine, working on towing vessels and barges, for nearly 21 years. He had been a wheelman (a crewmember qualified to conn the vessel) for 13 years and a relief captain on the *Voyager* for 12 years. He stated that he had made the inbound transit of the Houston Ship Channel "hundreds" of times. He said that he had last attended a BRM course in 2016. The relief captain's normal work rotation was 21 days on the vessel followed by 10 or 11 days off. On the day of the accident, he was on the sixteenth day of his work cycle.

1.5 Work/Rest History

1.5.1 Houston Pilots

Genesis River Pilot 1. Work/rest/sleep records for Pilot 1 were not collected after the accident because he was not at the conn during the collision and therefore did not affect its outcome. Pilot 1 told investigators that he got about 8 hours of sleep overnight before the accident voyage, waking at 0930.

Genesis River Pilot 2. According to information submitted to the Coast Guard, Pilot 2 had 23 hours of sleep in the 72 hours before the accident and had slept 9 hours the night before the collision. He had worked about 15.5 hours over the same period. He told investigators that he had consumed no alcohol the night before and his sleep had been "really good."

1.5.2 *Genesis River* Crew

Master. A work/rest log provided by the company showed that the master had 24.5 hours of work and 47.5 hours of rest in the 72 hours prior to the accident. The International Maritime Organization (IMO) standard form used to log work and rest did not specify times of sleep during the rest periods. The master told investigators that the night before the accident, he had gone ashore with the second officer and first-assistant engineer, and, between 2130 and 2230, he consumed three alcoholic drinks (beer). He and other crewmembers returned to the ship about 0400 after being delayed due to the unavailability of taxis, and the master went to sleep immediately after returning. He was awoken between 0930 and 1000 to review cargo documentation. He stated that the quality of his sleep was "good." During the accident voyage, the master went to his cabin after eating lunch. He stated that while in his cabin, he took a nap, sleeping for about 45 minutes and waking when the second officer called him to report the impending accident.

Chief Officer. The work/rest log showed that the chief officer had 27.5 hours of work and 44.5 hours of rest in the 72 hours prior to the accident. He remained aboard the ship the night before the accident and had consumed no alcoholic beverages on May 9 or 10. According to the work/rest log, he had 10 hours of rest between 1430 on the May 9 and 0030 on May 10. He then worked for 1.5 hours, had another rest period for 2.4 hours, then worked from 0430 to 0830. He could not recall the exact number of hours of sleep he had that night but described it as "a good rest." The chief officer stated that he took a 30-minute nap on the morning of the accident, after cargo documentation had been completed and before the vessel got under way, and the work/rest record shows a period of rest between 0830 and 1000. The chief officer worked from 1000 onward through the accident period.

Second Officer. The work/rest log for the second officer showed that he had 28.5 hours of work and 43.5 hours of rest in the 72 hours prior to the accident. The hours of work listed in the form corresponded to a regular watch/duty schedule of 0000–0430 and 1200–1700 daily and included an entry for a 0000–0430 watch on the morning of the accident. However, the second officer told investigators that between about 2200 the night before and 0400 that morning he had been "on shore leave" with the master. He said that he did not consume any alcoholic beverages while ashore. The form notes that the second officer began his day watch on the accident date 1 hour early, at 1100, prior to getting under way. The second officer stated that, between 0400 and 1100, he had slept. He described the quality of his sleep as "sound."

Able-bodied Seaman. The work/rest log showed that the AB had 24 hours of work and 48 hours of rest in the 72 hours prior to the accident. His hours of work corresponded to a regular watch/duty schedule of 0000–0400 and 1200–1600 daily. The AB stated that he had about 6–7 hours of sleep the night before the accident, which he described as "good sleep."

Ordinary Seaman. The work/rest log provided by the company showed that the OS had 27 hours of work and 45 hours of rest in the 72 hours prior to the accident. His hours of work corresponded to a regular watch/duty schedule of 0400–0800 and 1600–2000 daily, as well as additional hours of work beginning at 1200 on the accident date related to deck operations for getting under way and his training watch on the helm. The OS said that he got about 6 hours of "good sleep" prior to his 0400–0800 cargo watch on the accident date. He also stated that he had napped for about 20–30 minutes after his morning watch, prior to going to his station for getting under way.

1.5.3 *Voyager* Crew

Captain. A work/rest record provided by the company for the credentialed crewmembers of the *Voyager* was divided by on-watch and off-watch time. The record showed that the captain had 36 hours on watch and 36 hours off watch during the 72 hours prior to the accident, which corresponded to his regular watch schedule of 0500–1200 and 1700–2200 daily. He told investigators that he had slept about 6.5 hours before his morning watch on the accident date, and the quality of his sleep was "good."

Relief Captain. The work/rest record provided by the company showed that the relief captain had 36 hours on watch and 36 hours off watch during the 72 hours prior to the accident, which corresponded to his regular watch schedule of 1200–1700 and 2200–0500 daily. He stated that he had slept about 6 hours on the morning of the accident before assuming the watch, and the quality of his sleep was also "good."

1.6 Toxicological Testing

1.6.1 Houston Pilots

Pilot 1 and Pilot 2 were administered required postaccident breathalyzer tests for alcohol about 1900 on the accident date after disembarking the *Genesis River*. Results for both pilots were negative. The *Genesis River* pilots also underwent required postaccident urine drug testing, with negative results.[29]

1.6.2 *Genesis River* Crew

About 1800 on the accident date, after the *Genesis River* had moored in Bayport, all crewmembers on the *Genesis River* were administered postaccident breathalyzer tests for alcohol, and the results were negative. Later that evening, the crew underwent postaccident urine drug testing, and the results were also negative.

1.6.3 *Voyager* Crew

Between 1800 and 1832 on the accident date, all four members of the *Voyager* crew were administered postaccident breathalyzer tests. All results were negative. The crew also underwent postaccident urine drug testing, with negative results.

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[29] Urine drug testing is limited to identifying urinary metabolites of cocaine, codeine, morphine, heroin, phencyclidine (PCP), amphetamine, methamphetamine, methylenedioxymethamphetamine (MDMA), methylenedioxyamphetamine (MDA), methylenedioxyethylamphetamine (MDEA), tetrahydrocannabinol (THC), oxycodone, oxymorphone, hydrocodone, and hydromorphone.

1.7 Waterway Information

1.7.1 Port of Houston

The Port of Houston is one of the busiest ports in the world, ranking second among US ports in terms of cargo tonnage, according to the Coast Guard. In 2018, the average daily traffic in the Coast Guard Sector Houston–Galveston VTS area totaled about 629 vessel transits (including tankers, freighters, tows, and ferries, among others), with nearly 40 ships docked in port.[30]

1.7.2 Houston Ship Channel Maintenance

The US Army Corps of Engineers (USACE) maintains the Houston Ship Channel and its tributaries at authorized widths and depths by conducting periodic dredging operations. The frequency of dredging varies, with areas that historically shoal (become shallow due to sediment) at a faster rate being dredged at shorter intervals. A USACE representative stated that the periodicity of dredging is also dependent on available funding. Dredging plans are updated as needed, based on regular depth sounding surveys of the channel. Surveys are conducted at intervals not less than 6 months and can also be requested on an ad hoc basis by the Coast Guard, the Houston Pilots, or other users of the channel. Dredging may also be conducted to improve the safety of traffic flow on the channel. In 2017, USACE dredged the southern side of the Bayport Flare and the eastern side of the turn at Five Mile Cut, widening the flare and the channel so that large inbound vessels can more safely navigate both the turn at Five Mile Cut and the turn into the Bayport channel.

Figure 13 below shows USACE's January 2019 periodic survey results for the turn at Five Mile Cut. Blue tones indicate deeper water, while yellow/red tones indicate shallower water. The sounding data in feet are indicated by the numbers in the image. Figure 14 shows the results of a survey that was requested by the Houston Pilots immediately following the accident in May 2019. Note the area highlighted by a red box in each figure, which shows shoaling had occurred in the turn of the channel in the 4 months between the surveys, as depicted by the change in depth contour colors.

When asked by investigators, the USACE representative confirmed that shoaling was common in turns of the channel. She also stated that the area of the channel in the vicinity of the Bayport Flare and just south of the flare was prone to shoaling, but that it was "not one that is commonly brought up as a concern." Prior to the accident, the channel in the vicinity of the turn at Five Mile Cut had last been dredged in late 2017. In November 2019 (5.5 months after the accident), planned maintenance dredging of the Houston Ship Channel in this area commenced.

[30] Tonnage and traffic statistics from US Coast Guard, *State of the Waterway 2018*, Houston, Texas, 2019, available at https://lonestarhsc.org/dir/wp-content/uploads/2019/04/SWW2019.pdf. Accessed February 21, 2020.

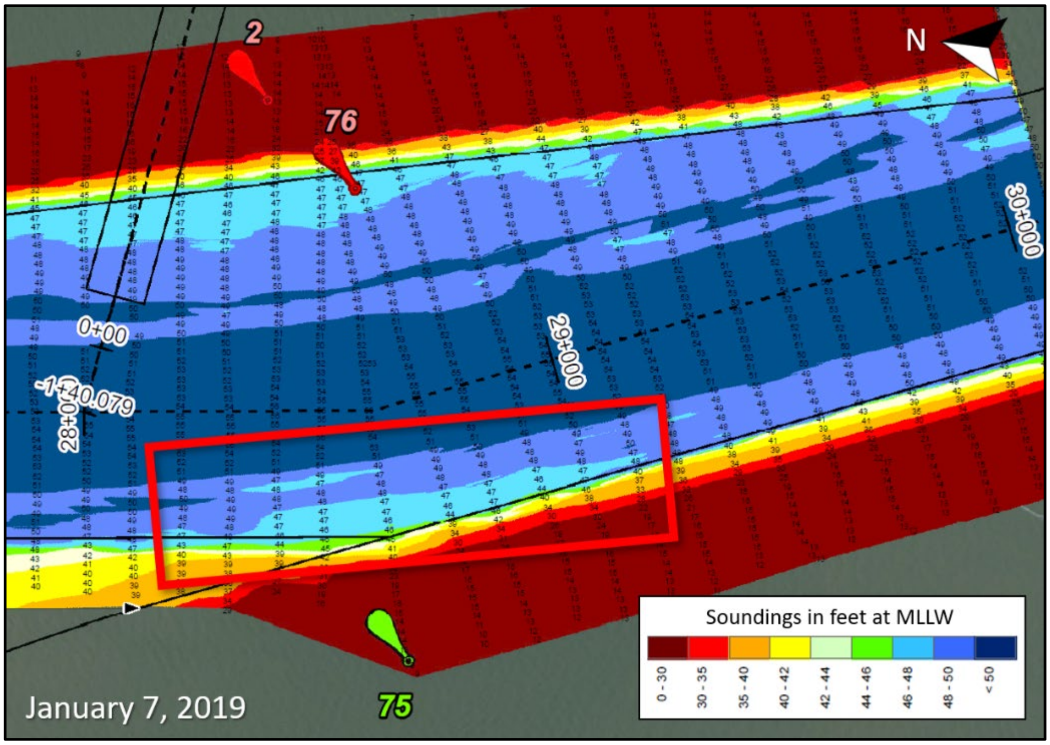

Figure 13. January 2019 sounding survey data in feet at mean lower low water (MLLW)(the average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch) for the Houston Ship Channel at the turn at Five Mile Cut. The red box shows the area on the western side of the channel where shoaling would occur in the 4 months that followed. The “75” and “76” indicate the channel beacons in the vicinity of the turn. (Source: USACE)

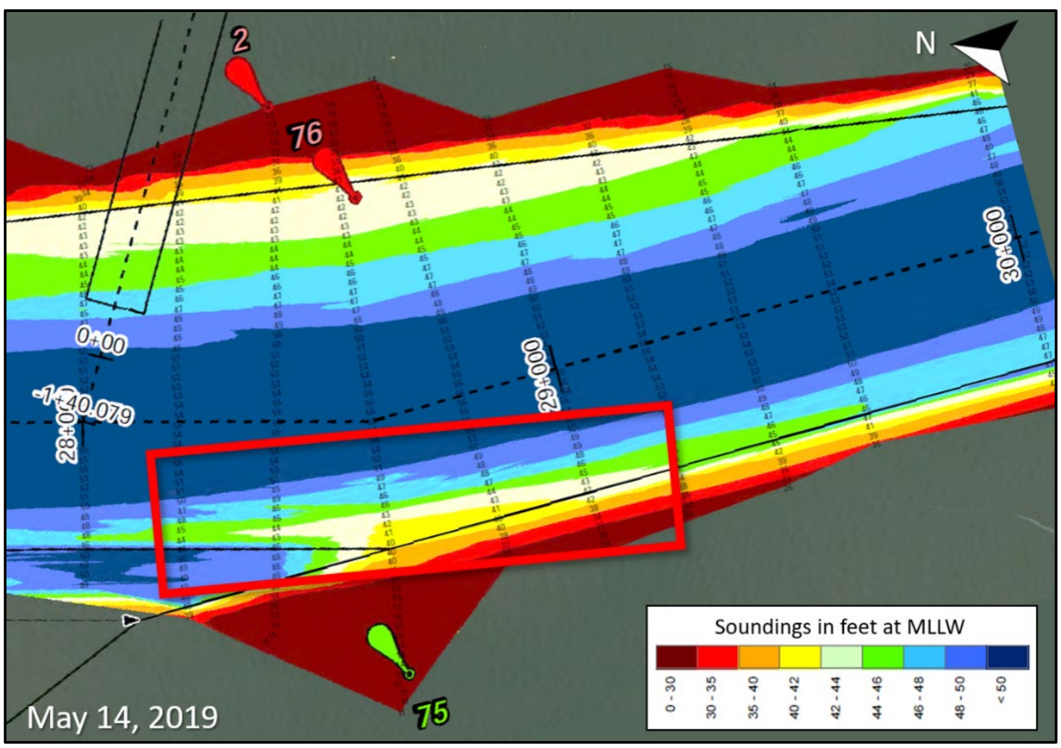

Figure 14. May 2019 sounding survey data in feet at MLLW for the Houston Ship Channel at the turn at Five Mile Cut. The red box shows the area on the western side of the channel where shoaling occurred in the 4 months since the January survey. (Source: USACE)

1.7.3 Vessel Traffic Service Houston–Galveston

VTS provides mariners with information including position, identity, and intentions of vessels operating in the VTS area; meteorological information; status of aids to navigation; traffic congestion; and waterway restrictions. VTS controllers monitor this information using AIS tracking, radar, VHF radio, and in some cases closed-circuit television. VTS also offers navigational assistance, at the request of a vessel operator, by providing information about the operator's own vessel, such as course and speed; position in the waterway relative to the channel axis; landmarks and aids to navigation; and the positions, intentions, and identities of surrounding vessel traffic. VTS services to mariners are primarily advisory, but controllers are authorized to issue outcome-based directions. Certain vessels transiting the waterway are required to check in with VTS before entering the VTS area and at designated reporting points in the waterway. The section of the waterway where the accident occurred was monitored by VTS Houston–Galveston, co-located with Coast Guard Sector Houston–Galveston in the city of Houston.

1.7.4 Vessel Hydrodynamics

When a vessel transits a narrow, shallow-water channel such as the Houston Ship Channel, various hydrodynamic effects that are not present during open-ocean, deepwater transits influence the maneuverability of a vessel.

Squat and Trim. When a vessel is in motion in shallow water, it will experience both sinkage (squat) and a tendency for its forward and aft drafts (trim) to change. The effects of squat and trim vary by the square of the ship's speed. Squat is also affected by the passing of another vessel, increasing the effect by 50 percent.[31] How a vessel's trim changes while transiting in shallow water is primarily a factor of the vessel's "fullness," that is, the shape of the vessel relative to a rectangular block of the same length, width, and depth. Fullness is expressed numerically by the "block coefficient" (C_B) and a full-form vessel is one having a C_B greater than 0.7.[32] The *Genesis River*'s C_B on the accident date was calculated to be 0.75.[33] Full-form vessels have a tendency to trim by the bow (also known as "trim by the head"); that is, the draft at the bow will increase, and the draft at the stern will decrease. According to a study commissioned by the Coast Guard, the *Genesis River* would have trimmed by as much as 7.4 feet by the bow in the narrow, shallow channel.[34]

Bank Cushion and Suction. As a ship approaches the bank of a narrow channel, an area of high pressure builds near the bow, which tends to push, or sheer, the bow away from the bank, an effect known as "bank cushion." Conversely, an area of low pressure forms near the stern and tends to pull the stern into the bank, an effect known as "bank suction" (see figure 15).

[31] Falzarano, Jeffrey, *Hydrodynamic Forces and a Dynamic Path Stability Analysis of the LPG Carrier Genesis River*, 2020, page 8.

[32] The *block coefficient* of a ship at any particular draft is the ratio of the volume of displacement at that draft to the volume of a rectangular block having the same overall length, breadth, and depth.

[33] *Genesis River* block coefficient from Falzarano, "Genesis River Hydrodynamic Analysis: Channel Suction," 2020, page 1.

[34] Falzarano, *Hydrodynamic Forces and a Dynamic Path Stability Analysis of the LPG Carrier Genesis River*, page 8.

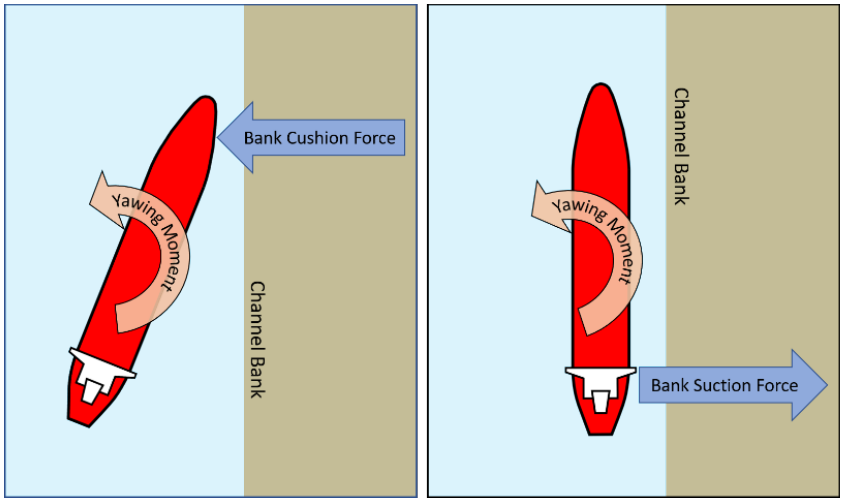

Figure 15. Bank cushion and bank suction.

Ship-to-Ship Interaction. Two ships passing in a narrow channel introduce additional hydrodynamic effects. In the case of two vessels meeting head-on (see figure 16), the bow wave ahead of each vessel creates repulsive forces between the two vessels (toward opposite banks) as they approach. When the ships are side by side during the meeting, the interactive forces between the vessels are reversed and become attractive, tending to bring the vessels toward one another. As the vessels pass stern to stern, the forces become repulsive again, which tends to turn the vessels back toward the center of the channel.[35] In a straight channel with symmetrical banks, the forces of bank cushion and bank suction are also acting on the two passing vessels.

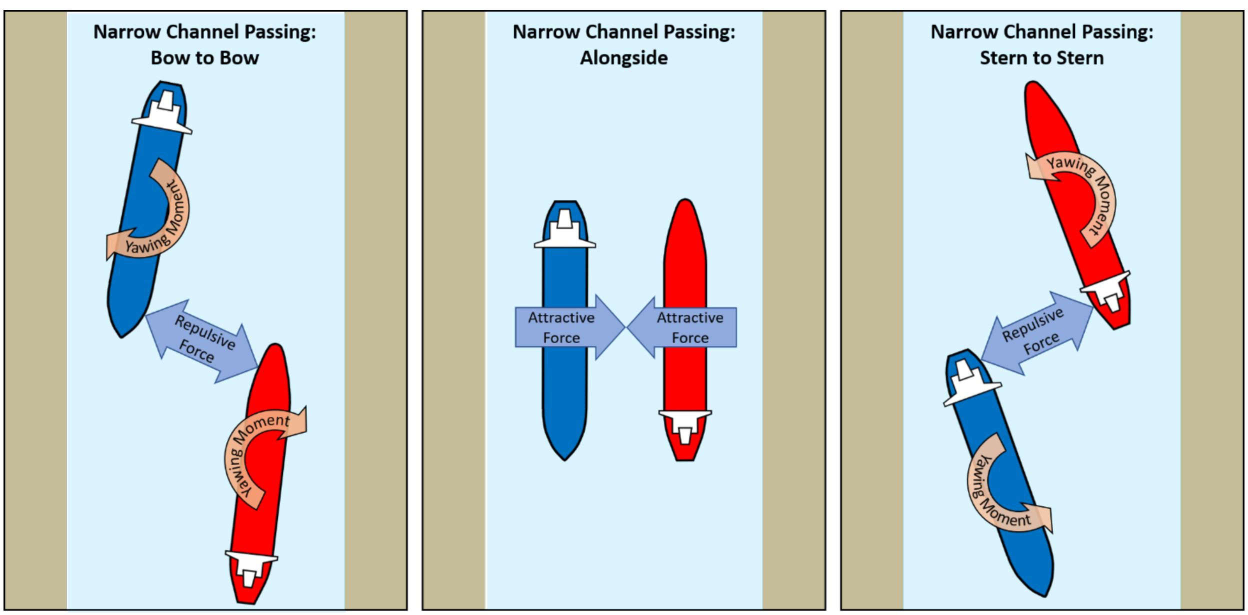

Figure 16. Forces created by vessels passing in a narrow channel. Bank cushion and suction, in effect during a vessel passing, are not shown.

[35] Falzarano, page 25.

Ship Maneuvering in a Narrow Channel. When operating in a narrow waterway such as the Houston Ship Channel, pilots use a combination of rudder orders to either counteract the hydrodynamic forces or use them to advantage in order to safely transit the channel and pass other vessels. When transiting a straight section of the channel with symmetrical banks, the pilot will usually position the vessel in the center of the channel. This allows the hydrodynamic forces on either side of the vessel to be in balance and minimizes the amount of rudder needed to maintain course.

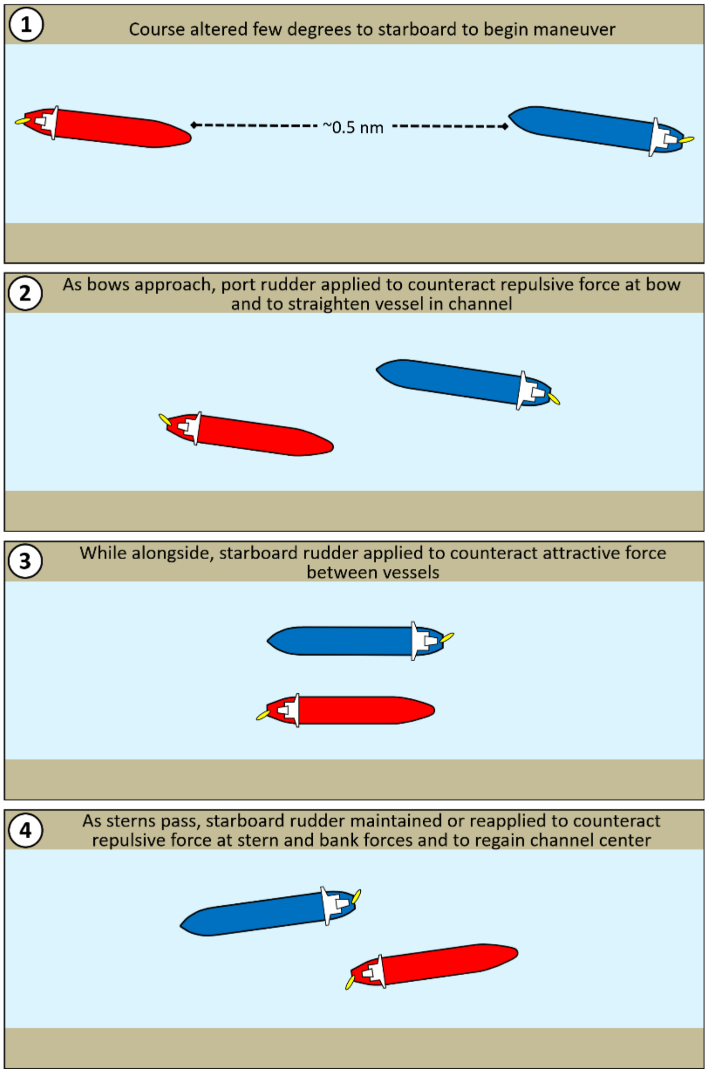

Figure 17. Typical steering sequence during head-on meeting in a narrow, symmetrical channel. (Not to scale.)

When meeting another vessel, the ship must offset to the side of the channel to safely pass, and in a typical portside-to-portside head-on meeting, the pilot begins the maneuver by altering course to starboard by a few degrees when the oncoming vessel is about 0.5 miles ahead (see figure 17). As the ships close, separation of the vessels is aided by the repulsive force created by the ships' bow waves. When the bows of the vessels are near, the pilot briefly applies a port rudder to counteract the repulsive force at the bow and to straighten the ship along the side of the channel, using the bank cushion on the starboard side to aid in turning the vessel's heading to port. As the two vessels are alongside each other, the pilot will apply starboard rudder to counteract the attractive force of the vessel passing to port and the bank forces on the starboard side. As the vessels' sterns pass, repulsive forces on the port stern of the vessel, as well as bank cushion and suction forces to starboard, will naturally turn the bow back toward the center of the channel. The pilot will maintain starboard rudder (or reapply rudder) to arrest this turn and steady the ship in the center of the channel. The timing of orders and amount of rudder used varies, based on the size and speed of the passing vessels, the channel dimensions and shape, and the pilot's own maneuvering preferences.

1.7.5 Studies of Accident Hydrodynamics and Kinematics

NTSB Kinematics Parameter Extraction Study.[36] To determine the cause of the *Genesis River*'s motion during the accident sequence and assess the role of hydrodynamic effects, the NTSB conducted a study based on extracted kinematic data from the ship's recorded motion to examine the forces on the *Genesis River*. Kinematics parameter extraction is a simulation-based technique that solves the equations of motion for the forces and moments that caused the recorded motion. The determination of required forces and moments is independent of the ship's simulation model. It is only dependent on the ship's motion, weight, and inertia. The study concluded that

> as the Bayport channel opened on the starboard side of the outbound *Genesis River*, the ship experienced a starboard yawing moment and side force from the channel. Rudder input was predominately port during this time to partially counter this yaw and side force from the east channel wall. The ship's path curved to starboard under control during this time. After the bow of the *Genesis River* and *BW Oak* passed each other, suction and bank affect from the approaching west bank yawed the *Genesis River* to port overwhelming full starboard rudder applied to counter this port yaw. The ship continued port across the channel where the encounter with the east bank curved the ship's path starboard and into the *Voyager*'s barge.

Coast Guard-Commissioned Study of Hydrodynamic Forces and Dynamic Path Stability.[37] In conjunction with its investigation into the accident, the Coast Guard commissioned a study to analyze the hydrodynamic forces affecting the *Genesis River* during the accident. The study examined the vessel's path stability as affected by loading, speed, water depth, and restricted channel effects.[38] It also estimated the hydrodynamic forces and moments that may have resulted from the effects of the restricted channel and the meeting with the *BW Oak*. The study concluded that

- the *Genesis River* met or exceeded the International Maritime Organization requirements for ship maneuverability;
- both speed and restricted off-centerline channel effects negatively affected the vessel's path stability;
- the very shallow depth may have improved the vessel's path stability, but given the vessel's speed prior to the incident and resulting sinkage and bow trim due to squat, the path stability was again reduced;
- overall, the pilot's decision to travel at "sea speed" in a shallow and restricted channel may have affected the vessel's loss of path stability; and

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[36] Crider, Dennis, Genesis River *Kinematics Parameter Extraction Study*, Washington, DC: NTSB, 2019.

[37] Falzarano, Jeffrey, *Hydrodynamic Forces and a Dynamic Path Stability Analysis of the LPG Carrier Genesis River*, 2020.

[38] *Path stability*, also known as *straight-line stability*, is defined by ABS in the following manner: "A vessel is straight-line stable on a straight course if, after a small disturbance, it will soon settle on a new straight course without any corrective rudder. The resultant deviation from the original heading will depend on the degree of inherent stability and on the magnitude and duration of the disturbance." Source: ABS, *Guide for Vessel Maneuverability*, 2006 (updated 2017).

- the increased speed may have reduced the vessel's ability to be controlled by accelerating (i.e., "a kick") when the vessel experienced a critical situation.

1.8 Environmental Conditions

At the time of the accident, the National Oceanic and Atmospheric Administration (NOAA) weather station at Morgan's Point (station MGPT2)—about 5 miles north of the collision location—recorded winds from the east at 10 knots, gusting to 12 knots. The air temperature was 74°F, and the water temperature was 75°F. At Houston's William P. Hobby Airport, located approximately 17 miles west of the accident site, visibility was reported at 10 miles or more, with scattered clouds at 2,000 feet above ground level. These weather conditions were consistent with the conditions reported by the *Genesis River* pilots during postaccident interviews.

On the night of May 9–10, over 4 inches of rain had fallen in the Houston area. Pilot 1 noted that while the *Genesis River* transited the upper Houston Ship Channel, it was affected by strong currents near the outflows of tributaries to the channel, likely the result of the heavy rainfall. When the accident occurred, the tide in Galveston Bay was nearing the end of the flood tide. The *Voyager* relief captain stated that when he had taken the watch on the vessel about noon, the flood tide was noticeable, but by the time of the collision, it was "slowing down, becoming slack." The predicted tide level at the Morgan's Point NOAA station at 1530 on the date of the accident was 1.73 feet above mean lower low water level (MLLW); however, the observed level was 3.14 feet above MLLW. The predicted range of tide was 1.70 feet, and the actual range of tide was 2.13 feet. The closest current observations were from the Fred Hartman Bridge, located in the upper Houston Ship Channel (station G0810)—approximately 7 miles north-northwest of the collision and 2 miles northwest of Morgan's Point. At 1531, the current was observed at 0.55 knots from the southeast, which is consistent with a flood tide.

1.9 Related NTSB Investigations and Study

1.9.1 Collision between Tankship *Shinoussa* and *Chandy N* Tow (1990)

On July 28, 1990, the 601-foot-long tankship *Shinoussa* collided with a tow being pushed by the towing vessel *Chandy N* near Red Fish Island in the Houston Ship Channel.[39] The inbound *Chandy N* had just been overtaken by the 820-foot-long tankship *Hellespont Faith* and was meeting the outbound *Shinoussa*. The *Shinoussa* sustained damage to its bow. One barge in the tow sank, and the other two barges were damaged. The *Chandy N* and the *Hellespont Faith* were not damaged. The NTSB determined that the probable cause of the collision was the *Shinoussa* pilot's use of excessive speed and the failure by the *Shinoussa* and *Hellespont Faith* pilots to adequately plan for the overtaking and meeting maneuver.

[39] NTSB, *Collision between the Greek Tankship* Shinoussa *and the U.S. Towboat* Chandy N *and Tow near Red Fish Island, Galveston Bay, Texas, July 28, 1990*, Marine Accident Report NTSB/MAR-91/03, Washington, DC, 1991.

1.9.2 Collision between Tankship *Eagle Otome* and Cargo Vessel *Gull Arrow* and Subsequent Collision with the *Dixie Vengeance* Tow (2010)

On January 23, 2010, the 810-foot-long oil tanker *Eagle Otome* collided with the 597-foot-long general cargo vessel *Gull Arrow* at the Port of Port Arthur, Texas.[40] A 297-foot-long barge, *Kirby 30406*, which was being pushed by the towboat *Dixie Vengeance*, subsequently collided with the *Eagle Otome*. The tankship was inbound in the Sabine-Neches Canal with two pilots on board, as called for by local waterway protocol. When the *Eagle Otome* approached the Port of Port Arthur, it experienced several bank sheering events, culminating in the *Eagle Otome* striking the *Gull Arrow*, which was berthed at the port, and then the *Kirby 30406*.[41] The NTSB determined that the probable cause of the collisions was the failure of the first pilot, who had navigational control of the *Eagle Otome*, to correct the sheering motions that began as a result of the late initiation of a turn at a mild bend in the waterway, as well as other contributing factors.

The *Eagle Otome* was evenly trimmed when it began its transit. Following the accident, the ship's operating company conducted a maneuvering study of the tanker. Based on the study results, the company took steps to mitigate possible future occurrences by ordering all of its vessels operating in that waterway to transit the area with a stern trim of at least 1 foot to provide increased vessel maneuverability.

1.9.3 Collision between Tankship *Elka Apollon* and Containership *MSC Nederland* (2011)

On October 29, 2011, the 799-foot-long tanker *Elka Apollon* was outbound on the lower Houston Ship Channel, and the 778-foot-long containership *MSC Nederland* was inbound on the same waterway.[42] The *MSC Nederland*'s destination was the Bayport Container Terminal at the western end of the Bayport Ship Channel. The pilots on the two vessels agreed by radio that their ships would meet and pass one another just south of the Bayport Flare. The pilot conning the *Elka Apollon* ordered a series of rudder commands as the vessel transited the Bayport Flare and approached the *MSC Nederland*. As the distance between the *Elka Apollon* and the *MSC Nederland* closed, the *Elka Apollon* crossed the centerline of the Houston Ship Channel and subsequently struck the port side of the *MSC Nederland*. The NTSB determined that the probable cause of the collision was the failure of the pilot conning the *Elka Apollon* to appropriately respond to changes in bank effect forces as the vessel transited the Bayport Flare, causing the vessel to sheer across the channel and collide with the *MSC Nederland*. Contributing to the accident was the combination of the narrow waterway, bank effects at the Bayport Flare, and traffic density at the time, which increased the challenges in a waterway with a limited margin for error.

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[40] NTSB, *Collision of Tankship* Eagle Otome *with Cargo Vessel* Gull Arrow *and Subsequent Collision with the* Dixie Vengeance *Tow, Sabine-Neches Canal, Port Arthur, Texas, January 23, 2010,* Marine Accident Report NTSB/MAR-11/04, Washington, DC, 2011.

[41] In this context, *sheer* is a deviation from the vessel's intended course.

[42] NTSB, *Collision of Tankship* Elka Apollon *with Containership* MSC Nederland*, Houston Ship Channel, Upper Galveston Bay, Texas, October 29, 2011*, Marine Accident Report NTSB/MAR-12/02, Washington, DC, 2012.

1.9.4 Collision between Bulk Carrier *Conti Peridot* and Tanker *Carla Maersk* (2015)

On March 9, 2015, the inbound 653-foot-long bulk carrier *Conti Peridot* collided with the outbound 600-foot-long tanker *Carla Maersk* in the Houston Ship Channel near Morgan's Point, Texas.[43] The collision occurred in restricted visibility after the pilot on the *Conti Peridot* was unable to control the heading fluctuations that the bulk carrier was experiencing during the transit. The NTSB determined that the probable cause of the collision was the inability of the pilot on the *Conti Peridot* to respond appropriately to hydrodynamic forces after meeting another vessel during restricted visibility, and his lack of communication with other vessels about this handling difficulty, as well as other contributing factors.

1.9.5 Study of Coast Guard Vessel Traffic Service System (2016)

From 2015–2016, the NTSB conducted a study to evaluate the effectiveness of the Coast Guard VTS by assessing its ability to (1) detect and recognize traffic conflicts and other unsafe situations, (2) provide mariners with timely warning of such traffic conflicts and unsafe situations, and (3) control vessel traffic movements in the interest of safety.[44]

Among the findings of the study, the NTSB determined that, although the Coast Guard has long recognized the importance of safety risk management, it had not been applying continuous risk assessment processes to its 12 VTS areas. Additionally, procedures for the collection and quality control of activity and incident data did not support effective quantitative assessments of risk and safety performance within each VTS area or across the VTS system. Because these data were not regularly analyzed to identify and mitigate adverse safety trends, it was difficult (and in some cases impossible) to make statistically valid assessments of how well VTS centers were achieving their goal of reducing collisions, groundings, and other accidents within their respective VTS areas.

As a result of its findings, the NTSB made 21 recommendations to VTS stakeholders, 17 of which were to the Coast Guard. These safety recommendations included the following:

- Develop a continuous risk assessment program to evaluate and mitigate safety risks for each VTS area in the US Coast Guard VTS system that includes input from port and waterway stakeholders. (M-16-16)
- Establish a program to periodically review each of the 12 VTS areas and seek input from port and waterway stakeholders to identify areas of increased vessel conflicts or accidents that could benefit from the use of routing measures or VTS special areas, and establish such measures where appropriate. (M-16-21)

In its April 2017 response to these recommendations, the Coast Guard addressed these recommendations collectively, stating that the service intended to implement a risk assessment program that evaluates risk in VTS areas on a continuing basis, using, among other things, stakeholder input. Pending development of the risk assessment program and its use to address the

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[43] NTSB, *Collision between Bulk Carrier* Conti Peridot *and Tanker* Carla Maersk*, Houston Ship Channel near Morgan's Point, Texas, March 9, 2015*, Marine Accident Report NTSB/MAR-16/01, Washington, DC, 2016.

[44] NTSB, *An Assessment of the Effectiveness of the US Coast Guard Vessel Traffic Service System*, Safety Study NTSB/SS-16/01, Washington, DC, 2016.

specific issues discussed in each recommendation, the NTSB classified the safety recommendations "Open—Acceptable Response." The NTSB has not received further information on this initiative after the Coast Guard's initial correspondence.

2 Analysis

2.1 Exclusions

2.1.1 Credentialing and Experience, Alcohol or Other Drug Use, Fatigue, and Environmental Conditions

The pilots aboard the *Genesis River* and the crews on the *Genesis River* and *Voyager* held the requisite or higher-level credentials and commensurate experience for the positions they were filling. Postaccident alcohol and drug tests of the *Genesis River* master, bridge team, and pilots and the *Voyager* crew were all negative. Records for pilots showed that they had adequate rest and sleep prior to the accident. Some of the crewmembers on the *Genesis River* and *Voyager* reported sleeping less than 7 hours the night and morning of the accident, and most people will experience fatigue with less than 7–8 hours of sleep in any 24-hour period. However, all crewmembers had ample time for sleep during rest periods in the preceding 72 hours, and in the case of the *Genesis River* master, chief officer, and OS, they also had restorative naps in the hours before the accident. Research has shown that taking naps during the day can improve performance and alertness and delay fatigue-induced performance degradation.[45] None of the pilots or critical watchstanders on the vessels reported any fatigue during the accident. Visibility was at least 10 miles, winds were moderate, and the current was less than 1 knot. The NTSB concludes that pilot and crew credentialing and experience, use of alcohol or other tested-for drugs, fatigue, and environmental conditions were not factors in the accident.

2.1.2 Mechanical and Electrical Systems

Crewmembers on the *Genesis River* and the *Voyager* tested their vessels' rudders and engines prior to getting under way on the accident date. All tests were satisfactory, and no mechanical or electrical issues were reported during the transit of each vessel prior to the collision. The NTSB concludes that mechanical and electrical systems on the *Genesis River* and *Voyager* operated as designed, and their functionality was not a factor in the accident.

2.1.3 ARPA and ECDIS Status

The K-Line Energy Ship Management SMS required that the *Genesis River*'s two radars and online ECDIS be monitored at all times when the vessel was under way, but these systems were placed in standby or turned off to comply with Pilot 2's pre-underway request to silence radar alarms. The crew was reliant on visual navigation marks and the pilot's PPU for navigation and avoidance of other vessels. Had visibility significantly decreased or the PPU malfunctioned, the bridge team could have lost situation awareness in the narrow confines of the Houston Ship Channel. However, throughout the accident voyage, visibility remained clear, the PPU operated as designed, and the pilot and bridge team were always aware of both the *Genesis River*'s location

[45] IMO, *Guidelines on Fatigue*, MSC.1/Circ. 1598, London, United Kingdom, 2019.

within the channel and the location and movements of other vessels. The NTSB concludes that, although the *Genesis River* master's decision to place the vessel's ARPA in standby and turn off the ECDIS deprived the bridge team of the critical tools with which to monitor the pilots' actions and ensure that the vessel transited safely, the status of this equipment was not a factor in the accident.

2.2 Helmsman's Actions

In the 15 minutes leading up to the accident, an OS was at the helm of the *Genesis River* under the supervision of the AB who was assigned to the watch. The OS told investigators that he was standing the watch for training because he was working toward a promotion (the certificates held by the OS qualified him, by international standards, to be a helmsman). The AB stated that he stood next to the OS and verified that rudder orders were properly executed. The chief officer and second officer were also charged with overseeing the OS on the helm and ensuring that orders were properly executed. During interviews, neither the AB nor the officers indicated that the OS improperly executed the orders of the pilot during the accident. Additionally, the pilot was monitoring the helmsman by checking the rudder order indicator each time he issued a rudder command. In his initial interview with investigators, Pilot 2 stated that the helmsman followed his orders correctly. At the Coast Guard hearing 4 months after the accident, Pilot 2 changed his assessment and said that the helmsman "wasn't doing the proper orders given." However, the pilot's later assessment appears to be based on uncorrected VDR information. The VDR audio and parametric data, when correctly aligned, showed that the OS responded to each of the pilot's helm commands correctly and with little-to-no delay. The NTSB concludes that the *Genesis River* helmsman properly executed the rudder orders of the pilot, and his performance was not a factor in the accident.

Pilot 2 stated that he was not aware that the OS had taken the helm for training. Although the AB stated in a later legal deposition that he requested permission from the pilot for the OS to take the helm, the AB, OS, and pilots did not recall this request in initial postaccident interviews, and no evidence of a request was recorded by the VDR. Effective BRM requires that all members of the navigation team have a shared understanding of the situation and the resources at their disposal. Although helmsman training is a vital part of shipboard workforce development, and it is not unusual for an OS to take the helm under instruction, the pilot and bridge team members must be aware of any changes to the watch team, particularly when navigating in restricted waters. The passing of the *Genesis River* and the *BW Oak* in the southern Bayport Flare involved complex and varying hydrodynamic forces that required skilled seamanship from all watchstanders. The crew should have requested the pilot's concurrence when placing the OS on the helm for training, and the pilot should have been given the opportunity to deny or delay the request. The NTSB concludes that, although the helmsman in training properly executed the orders of the pilot, placing him at the helm without informing the pilot was contrary to good BRM practice. Accordingly, the NTSB recommends that K-Line Energy Ship Management review its safety management system and develop formalized procedures for watch team reliefs to ensure embarked pilots are informed of a change in personnel, particularly a change in helmsmen.

2.3 Hydrodynamic Effects

Less than half an hour before the accident, the *Genesis River* met the tankers *Crimson Ray* and *Nordic Aki* as they transited inbound in the channel. Both meetings were in a straight section of the channel and were completed without incident. After the *Genesis River* met the *BW Oak* at the southern terminus of the Bayport Flare, however, the pilot lost control of the ship as it sheered to port.

Three principal factors distinguished the *Genesis River*'s meeting with the *BW Oak* from the meetings with the *Crimson Ray* and *Nordic Aki*. The first factor was vessel size. The *BW Oak*, at 740 feet long and 120 feet wide, was significantly larger than the 473-foot-long, 82-foot-wide *Crimson Ray* and 440-foot-long, 73-foot-wide *Nordic Aki*. With its larger size, the hydrodynamic effects of the *BW Oak* acting on the *Genesis River* were greater than the effects created by the smaller vessels.

The second distinguishing factor in the *BW Oak* meeting was the *Genesis River*'s speed. The pilot ordered the *Genesis River* from full ahead (59–60 rpm) to "10-minute standby" (Nav. Full, set at 73 rpm) just before the vessel passed the *Crimson Ray*, and the outbound ship's speed when the two vessels met was 10 knots at 63 rpm. When the *Genesis River* met the *Nordic Aki*, its speed was 11 knots at 67 rpm. As the *Genesis River* passed the *BW Oak*, its speed was 12.6 knots at 73 rpm. According to research on the causes and effects of hydrodynamic interaction, "The effectiveness of a rudder varies roughly as the *square* of its speed through the water and we have seen in the case of a ship running parallel to a bank that the moment induced varies as the *cube* of the ship's speed at high speeds. [emphasis added] This suggests that if the speed of the ship near to a bank is too high, the rudder may be less able to cope with the forces induced and control will be lost."[46] Thus, although the difference in the *Genesis River*'s speed was only 2.6 knots between the *Crimson Ray* and *BW Oak* meetings, the effect of this difference on bank forces would have been significant.[47]

Vessel speed also impacts a vessel's path, or straight-line, stability. Path stability is the tendency of a vessel to return to a straight course after it has been momentarily disturbed without any corrective rudder. A vessel that does not return to a straight course after being momentarily disturbed is path unstable. According to the Coast Guard study, path instability is common for vessels with a full form, such as the *Genesis River*.[48] Just before Pilot 2 took the conn of the *Genesis River* from Pilot 1, he asked, "Y'all over the place?" referring to the ship's motion. Pilot 1 answered yes, indicating that the vessel was difficult to handle.

The Coast Guard study also notes that trim by the bow decreases path stability, and the study found that the *Genesis River* may have trimmed as much as 7.4 feet by the bow. Note the photograph of the *Genesis River* in figure 1, which was taken as the vessel was outbound in the Houston Ship Channel with the same cargo load after it was released by the Coast Guard following the accident. The image shows the vessel down by the head as it transits the channel. Squat and trim vary by the square of the ship's speed, and thus small changes in speed can have significant

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[46] I.W. Dand, "The Physical Causes of Hydrodynamic Interaction and Its Effects," *Proceedings of the Conference on Ship Handling*, London: Nautical Institute, 1977.

[47] Relationship of speed to bank forces from Rowe, R. W., *The Shiphandler's Guide*, 2nd edition (London: The Nautical Institute), 2007, page 65.

[48] Falzarano, page 27.

impact on these forces as well. The *Genesis River*'s higher speed as it passed the *BW Oak* increased the magnitude of the bank forces, squat, and trim, and decreased path stability.[49]

In the 2010 collision of the *Eagle Otome* with the *Gull Arrow* and *Dixie Vengeance* tow, the *Eagle Otome*, a loaded tanker of similar size to the *Genesis River*, was evenly trimmed when it began its transit of the Sabine-Neches Canal. Following the accident, in which the vessel experienced several sheering events, the ship's operating company conducted a maneuvering study of the accident tanker. Based on the study results, the company took steps to mitigate possible future occurrences by ordering all of its vessels operating in that waterway to transit the area with a stern trim of at least 1 foot to provide increased vessel maneuverability.

When the *Genesis River* departed its berth, it had at least 7 feet of clearance beneath the keel and thus had sufficient depth to trim the vessel by the stern. Had the vessel gotten under way trimmed by the stern, as opposed to an even keel trim, the shift of the trim toward the bow resulting from the ship making way through the channel would have had less impact on its path stability and maneuverability. The NTSB concludes that maintaining stern trim while under way would have improved the handling characteristics of the *Genesis River*. To ensure the greatest possible maneuverability during future transits, the NTSB recommends that the Houston Pilots revise guidance to operators of the *Genesis River* and similar vessels to require vessels be sufficiently trimmed by the stern prior to transiting the Houston Ship Channel.

The final distinguishing factor between the *BW Oak* meeting and the earlier meetings on the accident voyage was the shape of the channel. The *Genesis River* passed the *Crimson Ray* and the *Nordic Aki* in the straight section of the channel north of the Bayport Flare. In this section, the banks were symmetrical and did not change in shape or direction throughout the approach, passing, and follow-on maneuvering. In contrast, the Bayport Flare where the *Genesis River* first met the *BW Oak* had no bank on the western side of the channel, and thus there were no bank forces acting on the starboard side of the accident vessel. As the two vessels were alongside each other, however, the *Genesis River* reached the southern terminus of the flare. The channel narrowed and turned, which brought the western channel bank abruptly in toward the vessel, and the bank effects on the starboard side quickly increased. The closer a vessel is to the bank, the stronger the bank effect forces.[50] These forces were likely exacerbated by the unreported shoaling that had occurred on the western side of the channel at the turn at Five Mile Cut.

Using the extracted data from the *Genesis River*'s recorded motion, the NTSB study compared the yawing moments and side forces generated during and after the meeting with the *Crimson Ray* and *Nordic Aki* to those of the meeting with the *BW Oak*.[51] The data shows that the *Genesis River* experienced a significant port yawing moment and a resultant port side force as its

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[49] Falzarano, *Hydrodynamic Forces and a Dynamic Path Stability Analysis of the LPG Carrier Genesis River*, pages 8–10.

[50] Letaire, Evert, Marc Vantorre, and Guillaume Delefortrie, "The Influence of the Ship's Speed and Distance to an Arbitrarily Shaped Bank on Bank Effects," *Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering* (New York: American Society of Mechanical Engineers), 2015, page 9.

[51] *Yawing moment* is a moment that rotates the vessel about its vertical axis. *Side force* is the force on the hull created when the vessel's direction of motion through the water is offset from its heading. The side force turns the path of the ship toward its heading. For more information, see Crider.

stern passed the stern of the *BW Oak* and the channel narrowed at the southern terminus of the Bayport Flare. This yawing moment and side force were not seen in the meeting with the *Crimson Ray* or the *Nordic Aki* (see appendix C for a graphical comparison of the moments and forces during *Crimson Ray* and *BW Oak* meetings). The NTSB study concluded that

> after the bow of the *Genesis River* and *BW Oak* passed each other, suction and bank effect from the approaching west bank yawed the *Genesis River* to port overwhelming full starboard rudder applied to counter this port yaw. The ship continued port across the channel where the encounter with the east bank curved the ship's path starboard and into the *Voyager*'s barge.

Although Pilot 2 gave rudder orders in an attempt to arrest the *Genesis River*'s sheer to port, the yawing moments and side forces caused by the *BW Oak* meeting and the increasing bank effects on the starboard side overwhelmed the rudder, and the sheer could not be overcome before the ship crossed the channel. The rudder had little effect as the *Genesis River* subsequently encountered the opposite bank and sheered to starboard, forcing the vessel back toward the *Voyager* tow. The NTSB concludes that the combined effect of the speed of the *Genesis River* and the passing of another large vessel in the asymmetrically shaped channel at the southern terminus of the Bayport Flare resulted in an uncontrollable sheer to port by the *Genesis River*, initiating a chain of events that led to the collision.

Prior to making the turn at Five Mile Cut, the *BW Oak* had been transiting down the center of the channel, which was normal when not passing another vessel. To make the turn and set up for the meeting with the *Genesis River*, the *BW Oak* pilot ordered starboard rudder, and the vessel altered course at 1510:23. When a ship turns while making way in the forward direction, it pivots about a point roughly one-third the length of the ship back from the bow.[52] As it pivots, the stern will swing in the opposite direction of the turn until steadied on a new course. The AIS antenna on the *BW Oak* was atop its deckhouse near the stern, and thus AIS position data from the ship initially moved toward the western side of the channel as it pivoted to make the turn at Five Mile Cut. Once the *BW Oak* steadied on course, AIS data showed that the vessel moved to the eastern side of the channel as it passed the *Genesis River*. As shown in figure 5, which overlays the vessel hull outline on the AIS data, the movement of the *BW Oak* was consistent with a normal meeting situation.

The widening of the eastern side of the channel in the vicinity of the turn at Five Mile Cut afforded the *BW Oak* pilot more room to starboard, and he could have moved his vessel more toward the eastern bank and provided more room for the *Genesis River* passing. However, the position of the *BW Oak* relative to the center of the channel and the *Genesis River* was comparable to other ship meetings observed by the NTSB and should not have affected the *Genesis River* pilot's actions when positioning his ship for the passing. The NTSB concludes that the *BW Oak* pilot's maneuvering of his vessel to prepare for the meeting with the *Genesis River* was routine and did not impede the *Genesis River*'s ability to pass.

The *Genesis River*/*Voyager* tow accident was the second accident investigated by the NTSB involving a major collision in the southern terminus of the Bayport Flare. The 2011 collision

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[52] The location of the pivot point one-third of the length of a ship aft of the bow when the ship is in forward motion is a common thumb rule used by mariners. The actual pivot point may vary depending on the ship's hull form.

between the outbound 799-foot-long tanker *Elka Apollon* and the inbound 778-foot-long containership *MSC Nederland* occurred in nearly the same location, as shown in figure 18. (Note that the 2011 accident occurred before the Bayport Flare and the eastern side of the turn at Five Mile Cut were widened.) The NTSB determined that the probable cause of the *Elka Apollon*/*MSC Nederland* collision was the failure of the pilot conning the *Elka Apollon* to appropriately respond to changes in bank effect forces as the vessel transited the Bayport Flare, which, like the *Genesis River* 8 years later, caused the *Elka Apollon* to sheer across the channel and collide with an oncoming vessel. Contributing to the accident were the narrow waterway, bank effects at the Bayport Flare, and traffic density—nearly the same factors as in the *Genesis River*/*Voyager* tow accident.

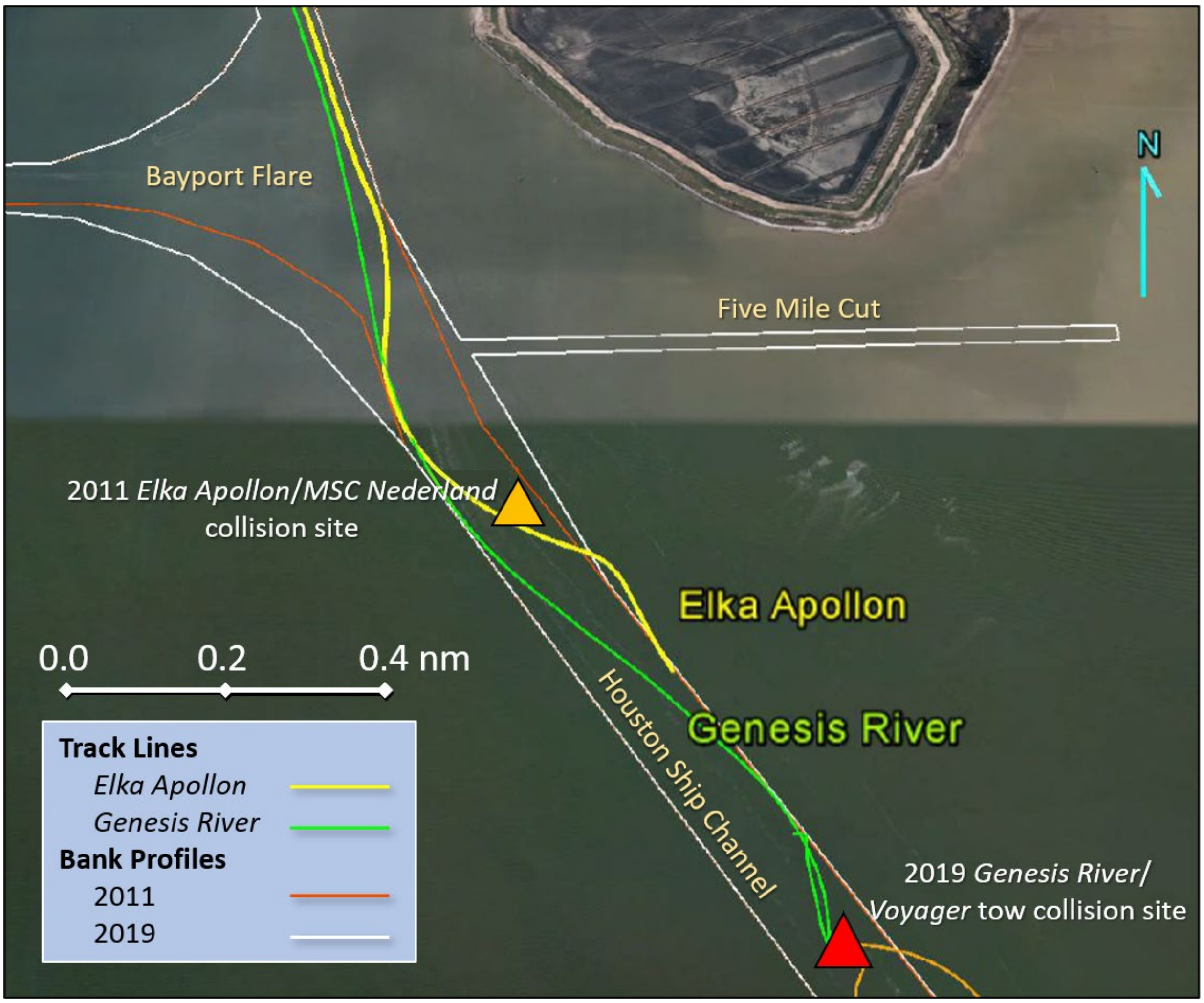

Figure 18. Tracks of the *Elka Apollon* (2011) and *Genesis River* (2019) during accident voyages. Note the changes in the channel bank profile between the two accidents, as indicated by orange and white lines.

Pilot 2 told investigators that, using the tools in his PPU software, he had determined ahead of time that the *Genesis River*'s meeting with the *BW Oak* would occur at the southern end of the Bayport Flare and that he was not concerned about the location. Other pilots told investigators that they had conducted passing arrangements in this area and believed that it was safe to do so. However, as these two accidents demonstrate, when two wide-beam, deep-draft vessels pass in the southern terminus of the Bayport Flare, the variance in hydrodynamic effects due to the channel shape greatly increases the challenges of navigating the waterway. This same variance increases the challenges for a passing in the northern terminus of the flare as well. In the southern terminus, the potential for shoaling in the turn at Five Mile Cut further increases the impact of these challenging hydrodynamic effects. This is particularly true when shoaling occurs at an accelerated rate without the knowledge of the pilots, as it did between January and May 2019. The NTSB concludes that wide-beam, deep-draft vessels meeting in the Houston Ship Channel in the vicinity of the northern and southern terminuses of the Bayport Flare have a higher risk of loss of control due to complex and varying hydrodynamic forces. Accordingly, the NTSB recommends that the Houston Pilots advise its members to avoid conducting any passing arrangements between wide-beam, deep-draft vessels in the northern and southern terminuses of the Bayport Flare.

2.4 Transiting Restricted Waters at Sea Speed

To stop the swing of the *Genesis River* following meetings with inbound vessels earlier in the transit, Pilot 1 had used temporary increases in engine rpm, or "engine kicks," to increase wash over the rudder and improve its effectiveness. When Pilot 2 could not stop the *Genesis River*'s sheer to port after it passed the *BW Oak* in the southern terminus of the Bayport Flare, he twice ordered increased engine rpm in an effort to improve steering effectiveness, the first being about 3 minutes before the collision. Because the *Genesis River* was at sea speed in Nav. Full mode, this increase could not be accomplished by moving the EOT as it could if the vessel was in maneuvering mode. Rather, a rapid increase in rpm while at Nav. Full required bridge watchstanders to contact the engineering watchstanders to change the maximum rpm setpoint in the ECR, depress the engine control program bypass button, and advance the EOT. After the pilot's second order for more rpm, *Genesis River* bridge crewmembers contacted the ECR and requested maximum rpm, and engineering watchstanders adjusted the maximum rpm setpoint to 85. However, neither the bridge nor the ECR watchstanders pressed the program bypass button. Thus, the actual engine rpm did not change between when the pilot ordered the increase, at 1513:07, and when the master ordered crash astern at 1516:03, six seconds before the collision.

In its analysis, the NTSB considered whether the outcome of the accident would have been different had the *Genesis River* crew effectively responded to the pilot's request for more engine rpm. While it may be impossible to accurately simulate such an outcome given available vessel performance data, the variables in channel conditions, and the inability to predict the pilot and crew's follow-on actions, a review of the timing of the accident events is revealing.

When the *Voyager* tow turned to port in an attempt to cross the channel and avoid the collision, the speed of the tow, which had been 5.3 knots at maximum power, decreased to as low as 3.6 knots (a decrease in speed is not unusual during a turn, particularly in vessels with inefficient hull forms, such as barges). Because of its slow speed, the *Voyager* was still on the eastern side of the deepwater channel when the accident occurred. The NTSB estimates that the stern of the *Voyager* was no more than 90 feet from the eastern deep-draft channel bank. Even if the *Voyager* relief captain had taken a course more perpendicular to the channel, it is likely that the tow would have been in a similar position relative to the bank, given the slow turning speed. Therefore, with its 122-foot beam, the *Genesis River* could not have safely passed behind the *Voyager*. At the same time, the head of the *Voyager* tow was well across the center of the deepwater channel, and thus it is unlikely that the *Genesis River* could have maneuvered to safely pass ahead of the tow. The NTSB concludes that once the *Voyager* and its tow began the turn to port, the collision was unavoidable.

Consequently, for an increase in engine rpm on the *Genesis River* to have changed the outcome of the accident, it would have needed to take effect before 1513:25 (2 minutes and 44 seconds before the collision), when Pilot 2 recommended that the tow "go to the greens" (the western side of the channel) and the *Voyager* relief captain executed the turn. Prior to this time, the pilot would have needed to detect a change in the rudder's effectiveness of sufficient magnitude to withhold his recommendation to the *Voyager* to cross the channel (or stop the *Voyager*'s turn, had the relief captain on the towing vessel acted unilaterally). The pilot's first order for increased engine rpm occurred at 1513:07. As discussed in section 1.3.1, to respond to this request appropriately, the *Genesis River* bridge crew would have first needed to call the ECR to request an increase to the engine rpm limit. Assuming an immediate response to the pilot from the bridge crew, clear communications between the bridge and the ECR, and rapid action by the ECR watchstanders, the NTSB estimates that the call and the ensuing action in the ECR would have taken no less than 15 seconds. The bridge crew would have also needed to depress the program bypass button and advance the EOT to its maximum setting. Assuming a best-case scenario with the bridge crew working as a team to effect the change, this could have been done concurrently with the call to the ECR. Once these actions were accomplished, and assuming that the rpm would have increased at the maneuvering mode rate of 2 rpm/second, it would have taken 8.5 seconds for the engine to accelerate from the initial setting of 72 rpm to the maximum continuous output of 89 rpm. Making the additional assumption that a measurable difference in rudder effectiveness could be achieved and detected by the pilot halfway through the acceleration period, 4 additional seconds would have elapsed. Added together, the time from the pilot's initial order for more rpm until a detectable change in the rudder performance would have been at least 19 seconds, at 1513:26—1 second after Pilot 2 radioed the *Voyager* to cross the channel. Even under the most favorable assumptions, there was not sufficient time for the pilot to gain additional rudder effectiveness before the *Voyager* initiated the turn, after which the accident was inevitable.

The preceding analysis assumes that additional engine rpm would have had an appreciable effect on the *Genesis River*'s rudder effectiveness. However, as witnessed in the 2010 *Eagle Otome/Gull Arrow* and 2015 *Conti Peridot/Carla Maersk* collisions, once hydrodynamic forces have overwhelmed a rudder's ability to control a sheering moment, it is difficult to regain control before the vessel interacts with the opposite bank. Pilot 1 noted early in the transit that the *Genesis River* had a "small rudder" and responded sluggishly to rudder commands. Even with additional engine rpms, it is unlikely that the rudder could have arrested the hydrodynamic forces acting along the entire hull of the *Genesis River* as it sheered off the banks. Given the length of time that it would have taken to increase the *Genesis River*'s engine speed and the unlikelihood that this increase would have had a substantial effect on vessel control, the NTSB concludes that an increase in engine rpm to arrest the *Genesis River*'s initial sheer, even if promptly executed after it was ordered by the pilot, would not have prevented the collision.

The second officer stated that he did not press the engine program control button because he feared that it would result in major damage to the engine, and the chief officer stated that it could lead to engine failure in extreme cases. Overriding the control program on a slow-speed diesel engine allows it to operate outside design parameters and risks degradation or failure. The engine manufacturer stated that the engine would not be immediately damaged if the control program was bypassed due to torque or scavenge air pressure limiters, but these limiters would restrict the ability of the engine to accelerate to higher rpms. Attempting to rapidly increase rpm while making large rudder movements at a high relative speed in a shallow, narrow channel could overtax the engine to sufficiently activate either limiter. Thus, additional engine rpm cannot be assumed to be immediately available when transiting at sea speed in Nav. Full.

By transiting the channel at sea speed, the *Genesis River* was subjected to greater hydrodynamic forces than it would have been had it been traveling at slower maneuvering speeds. Additionally, the higher speed resulted in the vessel trimming further down by the bow, and thus reduced path stability with increased speed due to the trim change. Finally, the maneuvering limitations imposed by being at Nav. Full prevented a rapid increase in engine speed when needed to improve rudder effectiveness. The Coast Guard study concluded the following:

> Based upon the calculations…analyzing the hydrodynamic forces acting upon the *Genesis River* from the maneuvers immediately preceding the collision of the *Genesis River* and Kirby barge, it appears that the pilot of the *Genesis River* was traveling too fast. Both the pilot and the vessel were therefore not able to react to the rapidly changing sequence of events. Since the pilot was already traveling at sea speed, he had little margin to accelerate and possibly regain control…

When determining vessel speed in any transit, pilots must consider the need for timely and continuous movement of commerce within the port. Interview comments and observations by NTSB investigators suggest that the speed over ground of the *Genesis River* was a commonly accepted rate through the accident vicinity. However, the demand to move commerce cannot override the necessity of maintaining safe passage through the waterway, and, when determining ship speed, the pilot must take into account the size and shape of the hull, the effectiveness of the rudder, and the ready availability of reserve engine power. When transiting a wide-beam, deep-draft vessel at sea speed, any mistake, misjudgment, mechanical failure, or other complication will be exacerbated and therefore be more difficult to overcome in an inherently challenging waterway. By transiting the *Genesis River* at sea speed in Nav. Full mode, with the limitations imposed by this condition, Pilot 2 had little room for error and no options to recover once control was lost. It should be noted that, had the *Genesis River* transited in maneuvering mode at an ordered speed of half ahead (about 10.2 knots at 51 rpm, according to the pilot card), it would have arrived at Bolivar Roads near the terminus of the Houston Ship Channel just 25 minutes later than had it successfully transited at sea speed. The NTSB concludes that the pilot transiting the wide-beam, deep-draft *Genesis River* at sea speed through the shallow and narrow lower Houston Ship Channel left little margin for error and introduced unnecessary risk.

In its investigation of the 1990 collision between the tanker *Shinoussa* and the *Chandy N* tow, the NTSB reached a similar conclusion: "The Safety Board believes that operating a large, deep-draft vessel at full sea speed in narrow and heavily trafficked waterways such as the [Houston Ship Channel] unnecessarily leaves too little margin for error and generally constitutes unsafe and imprudent navigation." Twenty-two years later, in its investigation of the collision of the tanker *Elka Apollon* with the containership *MSC Nederland*, the NTSB noted in a finding that the speed of the *Elka Apollon*, in combination with the narrow waterway, traffic density, and bank effects at the Bayport flare, increased the challenges for the pilot in a waterway with a limited margin for error. Interviews with members of the Houston Pilots indicated that it was common practice to transit the lower Houston Ship Channel at sea speed. However, based on the findings of this and previous investigations, the NTSB recommends that the Houston Pilots advise its members to avoid transiting wide-beam, deep-draft vessels at sea speed in the lower Houston Ship Channel.

2.5 Alternative Maneuvering Options for *Genesis River*

Upon the *Genesis River* sheering off the west bank with the *Voyager* ahead, Pilot 2 attempted to maneuver out of the sheer and avoid the collision using propulsion and the rudder. Investigators considered the alternate actions that the pilot could have taken once the sheer to port had begun, including use of emergency full astern or dropping anchors.

According to the *Genesis River*'s sea trials data, at 12.5 knots (a speed near the *Genesis River*'s speed when it passed the *BW Oak*), the vessel's engine would have required 3 minutes and 22 seconds to stop the propeller shaft turning in the forward direction after initiating emergency full astern. At the time the shaft was stopped, the ship's speed would still be just over 9 knots, after having traveled over a half mile. It would have taken another minute and 53 seconds before the propeller shaft would reach full speed in the astern direction. The total stopping time and distance would have been 7 minutes 31 seconds at a distance traveled of 1 mile (1,854 meters). The sea trials data was based on the vessel's main propulsion being in maneuvering mode (at 59 rpm), in ballast condition, and in deep water. At a sea speed of 73 engine rpm, fully laden with cargo, and transiting in shallow water, these times and distances likely would have been longer for the *Genesis River* just prior to the collision. Had Pilot 2 ordered emergency full astern the moment he detected that the ship was sheering to port off the western bank at about 1512:32, it is likely that at the time the collision occurred 3 minutes and 37 seconds later, the vessel's speed would have been about 9 knots ahead. Furthermore, as the shaft slowed to a stop, vessel control would have been substantially reduced. As stated in the Coast Guard study, "a stopping vessel has negative acceleration and is destabilized."[53] Given the *Genesis River*'s speed and momentum as it passed the *BW Oak* and encountered the bank forces on the western side of the channel, it is likely that the vessel would have still crossed the channel toward the *Voyager* tow.

Had the anchors been dropped when control of the *Genesis River* was lost, it is likely that the anchors would have dragged through the soft mud bottom of the channel, given the vessel speed. Further, the dragging anchors would have significantly affected the pilot's ability to gain any directional control of the vessel.

Use of either emergency full astern or the anchors would have taken away any possibility of regaining control of the vessel once it sheered off the western bank of the channel and may not have prevented a collision even if either option was attempted. Therefore, the NTSB concludes that the *Genesis River* pilot's decision not to use emergency full astern or the anchors to avoid the collision was reasonable.

[53] Falzarano, page 27.

2.6 *Voyager* Maneuvering Decisions

The *Voyager* relief captain told investigators that, when the *Genesis River* pilot radioed him, he felt his only option was to attempt to cross the channel to the western side. He said that stopping his tow risked collision from the towing vessel *Provider* astern of him and would also leave his vessel in the path of the *Genesis River*, which was bearing down on him. He believed that turning to starboard risked grounding the tow and would likewise leave his vessel stranded in the path of the *Genesis River*. Thus, he felt his only option was to turn to port.

It is possible that the accident could have been avoided had the relief captain ordered maximum astern propulsion or attempted to turn to starboard (although a turn to starboard risked grounding the tank barges on a submerged bulkhead, potentially breaching the cargo tanks). But it is important to note that, at the time that the *Voyager* relief captain had to make a decision to maneuver, the *Genesis River* was headed directly for his tow. Furthermore, he had no indication that, once the *Genesis River* reached the barge lane, it would turn back again toward the center of the channel. In fact, communications from the pilot on the *Genesis River* indicated that the *Genesis River* would not turn: "Trying to check this thing up. Just keep an eye on me"; "She's not checkin' up"; and finally, "Go to the greens." At the time he had to make a decision on what action to take, all indications were that leaving his vessel in the eastern barge lane would not have prevented the accident. The NTSB concludes that the actions of the *Voyager* relief captain to attempt to avoid the collision by crossing the channel were reasonable, given the information available to him at the time he had to make the decision to maneuver.

2.7 Communications

The NTSB has investigated several accidents in the Houston Ship Channel and similar waterways in which a lack of effective communications contributed to the cause or severity of accidents.[54] This was not the case, however, with the *Genesis River*/*Voyager* tow accident. Pilot 2 on the *Genesis River* radioed the *Voyager* as soon as he began having difficulty controlling his vessel, giving warning to the towing vessel's relief captain that an emergency situation was developing. The *Genesis River* pilot continued to communicate with the *Voyager*, informing the relief captain of his continued difficulty in controlling his ship. When the pilot determined that a collision was likely unavoidable, he informed the relief captain, telling him to "sound your general alarm…get everybody up." He repeated his warning again, radioing the *Voyager* to "wake everybody up on that, uh, *Voyager*." The pilot continued to keep the *Voyager* informed, stating "I'm gonna be swingin' your way real soon," and finally, "work with me…we're gonna collide." While communications between the two vessels could not prevent the accident, the *Genesis River* pilot gave the *Voyager* relief captain early warning of danger; allowed time for the *Voyager* captain

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[54] For examples, see 1) *Collision of Tankship* Eagle Otome *with Cargo Vessel* Gull Arrow *and Subsequent Collision with the* Dixie Vengeance *Tow, Sabine-Neches Canal, Port Arthur, Texas, January 23, 2010*, Marine Accident Report NTSB/MAR-11/04; 2) *Collision of Tankship* Elka Apollon *with Containership* MSC Nederland*, Houston Ship Channel, Upper Galveston Bay, Texas, October 29, 2011*, Marine Accident Report NTSB/MAR-12/02; 3) *Collision between Bulk Carrier* Summer Wind *and the* Miss Susan *Tow, Houston Ship Channel, Lower Galveston Bay, Texas, March 22, 2014*, Marine Accident Report NTSB/MAR-15/01; and 4) *Collision between Bulk Carrier* Conti Peridot *and Tanker* Carla Maersk*, Houston Ship Channel near Morgan's Point, Texas, March 9, 2015*, Marine Accident Report NTSB/MAR-16/01.

to be notified, come to the wheelhouse, and assist with the situation; and ensured that the crew was awake and alert when the accident occurred.

As the gas carrier and tow collided, a *Voyager* crewmember shut the engine room door on the main deck of the towing vessel, preventing significant flooding as the vessel heeled to starboard. The NTSB has investigated towing vessel accidents where an open door on the main deck resulted in rapid downflooding and sinking of the vessel after listing or heeling at relatively small angles.[55] Had the crew of the *Voyager* not been forewarned of the collision and not closed the main deck engine room door, the towing vessel possibly would have flooded and sunk, risking injury to the crew. The NTSB concludes that the *Genesis River* pilot's early and frequent communications with the *Voyager* mitigated the impacts of the accident and likely prevented loss of the towing vessel and injuries to its crew.

2.8 Vessel Traffic Service Houston–Galveston

VTS Houston–Galveston personnel were monitoring vessel traffic and radio communications during the accident and informed the Coast Guard command center and other authorities immediately, allowing response operations to commence expeditiously. In the aftermath, VTS watchstanders advised vessels in the area of the accident and redirected traffic as necessary to avoid further accidents and keep the area clear for response assets. The NTSB concludes that Coast Guard VTS Houston–Galveston's response to the collision was timely and appropriate.

In its 2016 VTS study, the NTSB recommended that the Coast Guard develop a continuous risk assessment program to evaluate and mitigate safety risks for each VTS area in the Coast Guard VTS system (M-16-16). The study further recommended that the Coast Guard establish a program to periodically review each of the 12 VTS areas and seek input from port and waterway stakeholders to identify areas of increased vessel conflicts or accidents that could benefit from the use of routing measures or VTS *special areas*, and establish such measures where appropriate (M-16-21). In citing the *Elka Apollon/MSC Nederland* and *Genesis River/Voyager* collisions, the NTSB has found that wide-beam, deep-draft vessels meeting in the terminuses of the Bayport Flare have a higher risk of loss of control. Given the higher risk, the NTSB concludes that the Bayport Flare, as well as other intersections within the Houston–Galveston VTS area, would benefit from regular risk assessments and the consideration of additional vessel routing measures. Accordingly, the NTSB reiterates Safety Recommendation M-16-16 and M-16-21 to the United States Coast Guard.

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[55] For examples, see 1) *Flooding and Sinking of Towing Vessel* Savage Ingenuity, Marine Accident Brief NTSB/MAB-18/12; 2) *Capsizing and Sinking of Towing Vessel* Gracie Claire, Marine Accident Brief NTSB/MAB-18/19; and 3) *Capsizing and Sinking of Towing Vessel* Ricky Robinson, Marine Accident Brief NTSB/MAB-18/27.

3 Conclusions

3.1 Findings

1. Pilot and crew credentialing and experience, use of alcohol or other tested-for drugs, fatigue, and environmental conditions were not factors in the accident.
2. Mechanical and electrical systems on the *Genesis River* and *Voyager* operated as designed, and their functionality was not a factor in the accident.
3. Although the *Genesis River* master's decision to place the vessel's automated radar plotting aid (ARPA) in standby and turn off the electronic chart display and information system (ECDIS) deprived the bridge team of critical tools with which to monitor the pilots' actions and ensure that the vessel transited safely, the status of this equipment was not a factor in the accident.
4. The *Genesis River* helmsman properly executed the rudder orders of the pilot and his performance was not a factor in the accident.
5. Although the helmsman in training properly executed the orders of the pilot, placing him at the helm without informing the pilot was contrary to good bridge resource management practice.
6. Maintaining stern trim while under way would have improved the handling characteristics of the *Genesis River*.
7. The combined effect of the speed of the *Genesis River* and the passing of another large vessel in the asymmetrically shaped channel at the southern terminus of the Bayport Flare resulted in an uncontrollable sheer to port by *Genesis River*, initiating a chain of events that led to the collision.
8. The *BW Oak* pilot's maneuvering of his vessel to prepare for the meeting with the *Genesis River* was routine and did not impede the *Genesis River*'s ability to pass.
9. Wide-beam, deep-draft vessels meeting in the Houston Ship Channel in the vicinity of the northern and southern terminuses of the Bayport Flare have a higher risk of loss of control due to complex and varying hydrodynamic forces.
10. Once the *Voyager* and its tow began the turn to port, the collision was unavoidable.
11. An increase in engine rpm to arrest the *Genesis River*'s initial sheer, even if promptly executed after it was ordered by the pilot, would not have prevented the collision.
12. The pilot transiting the wide-beam, deep-draft *Genesis River* at sea speed through the shallow and narrow lower Houston Ship Channel left little margin for error and introduced unnecessary risk.
13. The *Genesis River* pilot's decision not to use emergency full astern or the anchors to avoid the collision was reasonable.
14. The actions of the *Voyager* relief captain to attempt to avoid the collision by crossing the channel were reasonable, given the information available to him at the time he had to make the decision to maneuver.

15. The *Genesis River* pilot's early and frequent communications with the *Voyager* mitigated the impacts of the accident and likely prevented loss of the towing vessel and injuries to its crew.

16. Coast Guard Vessel Traffic Service Houston–Galveston's response to the collision was timely and appropriate.

17. The Bayport Flare, as well as other intersections within the Houston–Galveston Vessel Traffic Service area, would benefit from regular risk assessments and the consideration of additional vessel routing measures.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the collision between the liquefied gas carrier *Genesis River* and the *Voyager* tow was the *Genesis River* pilot's decision to transit at sea speed, out of maneuvering mode, which increased the hydrodynamic effects of the Bayport Flare's channel banks, reduced his ability to maintain control of the vessel after meeting another deep-draft vessel, and resulted in the *Genesis River* sheering across the channel toward the tow.

4 Recommendations

4.1 New Recommendations

As a result of its investigation of this accident, the National Transportation Safety Board makes the following four new safety recommendations:

To K-Line Energy Ship Management

Review your safety management system and develop formalized procedures for watch team reliefs to ensure embarked pilots are informed of a change in personnel, particularly a change in helmsmen. (M-21-1)

To the Houston Pilots

Revise guidance to operators of the *Genesis River* and similar vessels to require vessels be sufficiently trimmed by the stern prior to transiting the Houston Ship Channel. (M-21-2)

Advise your members to avoid conducting any passing arrangements between wide-beam, deep-draft vessels in the northern and southern terminuses of the Bayport Flare. (M-21-3)

Advise your members to avoid transiting wide-beam, deep-draft vessels at sea speed in the lower Houston Ship Channel. (M-21-4)

4.2 Previously Issued Recommendations Reiterated in This Report

As a result of its investigation of this accident, the National Transportation Safety Board reiterates Safety Recommendations M-16-16 and M-16-21, which are currently classified as “Open—Acceptable Response”:

To the US Coast Guard

Develop a continuous risk assessment program to evaluate and mitigate safety risks for each vessel traffic service (VTS) area in the US Coast Guard VTS system that includes input from port and waterway stakeholders. (M-16-16)

Establish a program to periodically review each of the 12 vessel traffic service (VTS) areas and seek input from port and waterway stakeholders to identify areas of increased vessel conflicts or accidents that could benefit from the use of routing measures or VTS special areas, and establish such measures where appropriate. (M-16-21)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III
Chairman

JENNIFER HOMENDY
Member

BRUCE LANDSBERG
Vice Chairman

MICHAEL GRAHAM
Member

THOMAS B. CHAPMAN
Member

Report Date: March 10, 2021

Appendix A
Investigation

The Coast Guard was the lead federal agency in this investigation. The National Transportation Safety Board (NTSB) launched the investigator-in-charge (IIC) to the accident scene May 11–17, 2019. While on scene, the IIC and Coast Guard investigators interviewed crewmembers and pilots involved in the accident, as well as watchstanders from Vessel Traffic Service Houston–Galveston. In addition, investigators documented the vessels' characteristics and damage, collected documentation relevant to the accident, and retrieved recorded data from the vessels' VDRs, charting systems, and other information systems. A few months later, from September 16 to 20, the Coast Guard conducted a formal hearing into the accident. During the hearing, Coast Guard and NTSB investigators questioned vessel crewmembers, pilots, company management, Coast Guard and USACE personnel, and waterfront stakeholders.

Appendix B
Consolidated Recommendation Information

Title 49 *United States Code* (*USC*) 1117(b) requires the following information on the recommendations in this report.

For each recommendation—

(1) a brief summary of the Board's collection and analysis of the specific accident investigation information most relevant to the recommendation;

(2) a description of the Board's use of external information, including studies, reports, and experts, other than the findings of a specific accident investigation, if any were used to inform or support the recommendation, including a brief summary of the specific safety benefits and other effects identified by each study, report, or expert; and

(3) a brief summary of any examples of actions taken by regulated entities before the publication of the safety recommendation, to the extent such actions are known to the Board, that were consistent with the recommendation.

To K-Line Energy Ship Management

M-21-1

Review your safety management system and develop formalized procedures for watch team reliefs to ensure embarked pilots are informed of a change in personnel, particularly a change in helmsmen.

Information that addresses the requirements of 49 USC 1117(b), as applicable, can be found in section 2.2 Helmsman Actions. Information supporting (b)(1) can be found on page 38; (b)(2) and (b)(3) are not applicable.

To the Houston Pilots

M-21-2

Revise guidance to operators of the *Genesis River* and similar vessels to require vessels be sufficiently trimmed by the stern prior to transiting the Houston Ship Channel.

Information that addresses the requirements of 49 USC 1117(b), as applicable, can be found in section 2.3 Hydrodynamic Effects, pages 38–39; (b)(2) can be found on page 39; and (b)(3) is not applicable.

M-21-3

Advise your members to avoid conducting any passing arrangements between wide-beam, deep-draft vessels in the northern and southern terminuses of the Bayport Flare.

Information that addresses the requirements of 49 USC 1117(b), as applicable, can be found in section 2.3 Hydrodynamic Effects, pages 38–43; (b)(2) and (b)(3) are not applicable.

M-21-4

Advise your members to avoid transiting wide-beam, deep-draft vessels at sea speed in the lower Houston Ship Channel.

Information that addresses the requirements of 49 USC 1117(b), as applicable, can be found in section 2.4 Transiting Restricted Waters at Sea Speed. Information supporting (b)(1) can be found on pages 43–46; (b)(2) can be found on pages 40-41; and (b)(3) is not applicable.

To the United States Coast Guard

M-16-16

Develop a continuous risk assessment program to evaluate and mitigate safety risks for each vessel traffic service (VTS) area in the US Coast Guard VTS system that includes input from port and waterway stakeholders.

Information that addresses the requirements of 49 USC 1117(b), as applicable, can be found in section 2.8 Vessel Traffic Service Houston–Galveston. Information supporting (b)(1) can be found on page 48; (b)(2) and (b)(3) are not applicable.

M-16-21

Establish a program to periodically review each of the 12 vessel traffic service (VTS) areas and seek input from port and waterway stakeholders to identify areas of increased vessel conflicts or accidents that could benefit from the use of routing measures or VTS special areas, and establish such measures where appropriate.

Information that addresses the requirements of 49 USC 1117(b), as applicable, can be found in section 2.8 Vessel Traffic Service Houston–Galveston. Information supporting (b)(1) can be found on page 48; (b)(2) and (b)(3) are not applicable.

Appendix C

Comparison of Kinematic Data between *Crimson Ray* Meeting and *BW Oak* Meeting

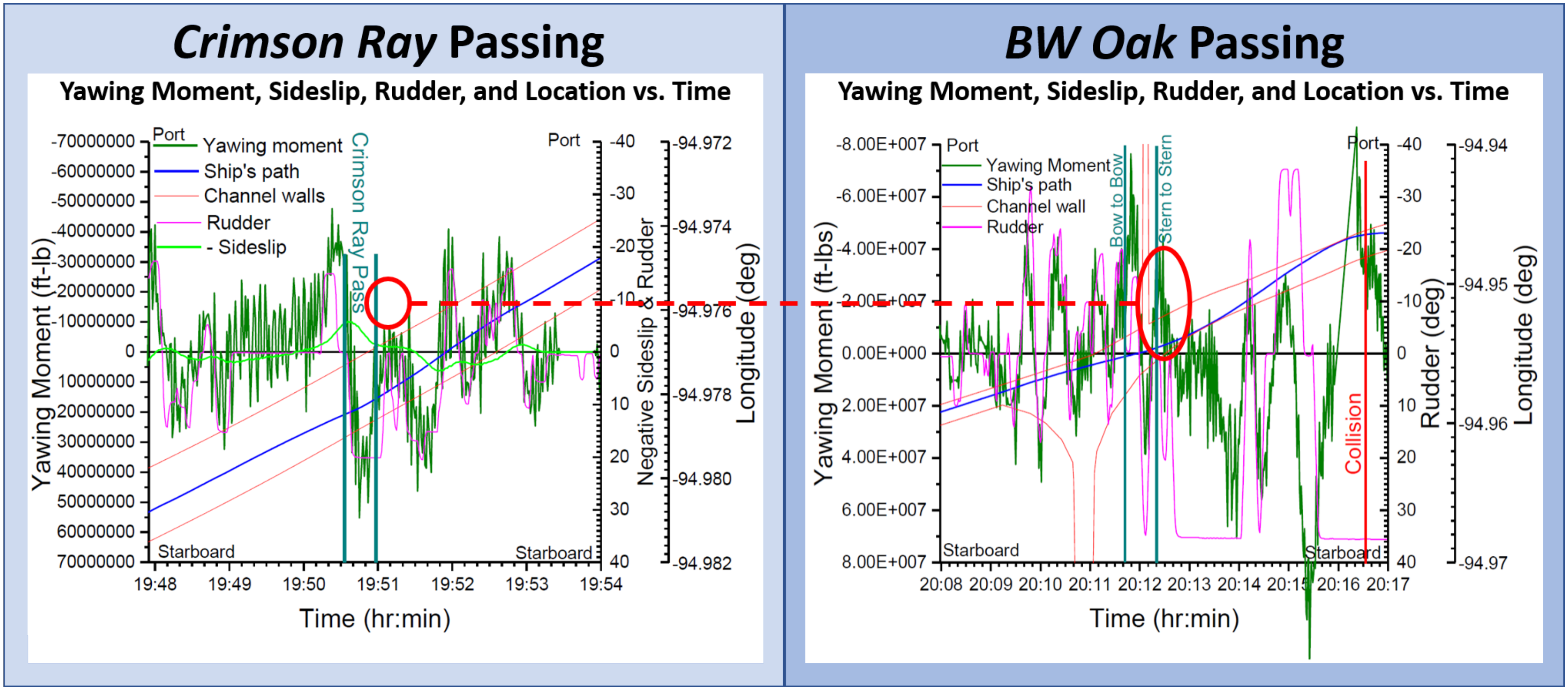

Figure 19. *Genesis River*'s yawing moment, sideslip, rudder angle, and location versus time for *Crimson Ray* passing (left) and *BW Oak* passing (right). Note the difference in yawing moment (represented by the dark green plot and encircled in red) when sterns pass in each case. (Source: NTSB Kinematics Parameter Extraction Study)

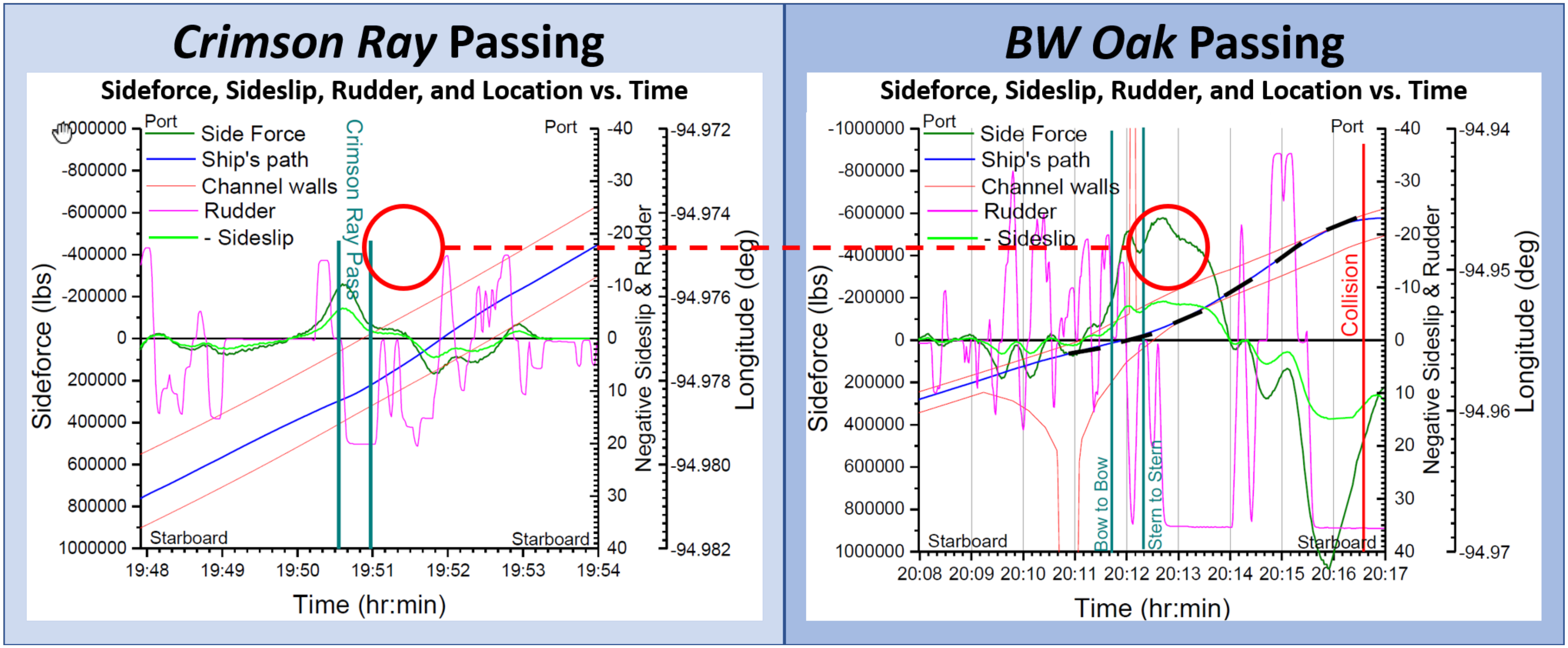

Figure 20. *Genesis River*'s sideforce, sideslip, rudder angle, and location versus time for *Crimson Ray* passing (left) and *BW Oak* passing (right). Note the difference in sideforce (represented by the dark green plot and encircled in red) when sterns pass in each case. (Source: NTSB Kinematics Parameter Extraction Study)

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