Executive Summary

MarineSafety International (MSI), at the request of Downeast LNG (DELNG), performed a five-day proof of concept evaluation of the marine aspects of transiting from the Passamaquoddy Bay pilot boarding area (PBA) to the DELNG proposed terminal site at Mill Cove in Robbinston, Maine and return, a round trip distance of approximately 34 miles. At the time of this evaluation, the DELNG terminal is in the planning stages. Large liquefied natural gas carriers (LNGC) are not currently calling at Passamaquoddy Bay or other ports in the immediate vicinity.

Twenty-five simulations were conducted for this evaluation. Specific DELNG proof of concept simulation objectives were:

- Investigate the feasibility of navigating LNGC's up to 165,000m^3 cargo capacity from the pilot boarding area off East Quoddy Head to the proposed DELNG Terminal, in Mill Cove, Passamaquoddy Bay.
- Determine the adequacy of existing navigation aids for day arrivals and departures from the DELNG Terminal.
- Define escort tug requirements, tethering locations and speeds.
- Identify the appropriate number, size and bollard pull for assisting and escorting tractor tugs for DELNG marine operations.
- Identify wind and tidal current windows for LNGC transits and dockings.
- Identify tidal current meter requirements and locations.

Of the twenty-five simulations conducted, fifteen simulations were arrivals and ten were departures. Based on the pilots' recommendations, the simulated transits were conducted at high slack water or on an ebbing tide at velocities up to 2.5 knots. The prevailing practice of the local pilots is to avoid flood tide conditions between Cherry Islet and Dog Island due to the unpredictability of flood tide current patterns.

All dockings at the DELNG terminal were conducted bow up stream (head up). Departures from the terminal were conducted both head up stream and head down stream. Four Azimuth Stern Drive (ASD) tugs of 60 tonnes static bollard pull were used for fifteen simulations, three tugs were used for eight simulations, simulations with two tugs were not conducted and one simulation with one tug was conducted. The ASD tugs were used as tethered escorts and for ship docking assistance. At least one

tug was tethered in the vicinity of the pilot boarding area or at the starting point for each arrival simulation.

Environmental conditions simulated for this study were with winds up to 35 knots and tidal currents up to 2.5 knots. Low visibility conditions ranged down to 0.25 NM. All simulations were conducted during daylight. All of the simulations were conducted by three active pilots for the Passamaquoddy Bay area on a full mission simulator. The pilots based their conning decisions on visual observations of the area, effects of environmental forces on the LNGC and movement of the LNGC resulting from tug forces. The visual observations were supplemented by a radar display and an overhead visual presentation very similar to Electronic Chart Display Information System (ECDIS) equipment that would be accessible to the pilot in an actual shipboard situation. The pilots conning orders were executed by a fellow pilot in a manner that would be expected of a ship's bridge team, and a MSI systems operator in the case of assisting tugs.

The general conclusions that were reached as a result of the proof of concept simulation study were:

- A vessel of the principle dimension of the simulated 165,000m^3 membrane (299.5m in length x 46m beam x 11.5 m deep) LNGC can safely transit to and from the proposed DELNG Terminal at Mill Cove, Robbinston, Maine.
- Aids to navigation need to be upgraded in order that pilots have better positional awareness, particularly if LNGC's will be transiting at night.
- Four 60 tonne ASD tugs were considered adequate.
- Tethered escorting from the PBA is recommended
- Transits with winds of more than 25 knots are not recommended.
- As a general policy, transiting the Cherry Islet to Dog Island area should be avoided on a flood tide as well as on an ebb tide in excess of three knots. Additional work would be required to build a current table that illustrates the relationship between tide height, current velocity, and stage of the tide in this area if transits outside the current parameters are considered.
- Prior to operations current meters should be installed in the area between Cherry Islet and Dog Island, to advance the analysis and database regarding tidal current velocity determinations.

- Prior to conducting nighttime transits of the area, nighttime conditions should be simulated to get a full appreciation of the suitability of current aids to navigation for nighttime operations.

It was clear that passage to and from the DELNG Terminal was uneventful, even with equipment failures, as long as escort tugs were tethered and the previously identified environmental window limits were adhered to, particularly in the Cherry Islet to Dog Island area where a large turn is required. The main ship channel is deep and wide enough for LNGC engine and steering failures to occur without a major deviation from the intended travel if escort tugs are tethered and used effectively.

1.0 Introduction

1.1 Overview

Downeast LNG (DELNG) engaged MarineSafety International (MSI) to evaluate the marine aspects of navigating Liquefied Natural Gas Carriers (LNGC) of up to 165,000 m^3 cargo capacity from the pilot boarding area 1.5 nautical miles (NM) east of East Quoddy Head to the proposed site of the DELNG Terminal on the west side of Passamaquoddy Bay at Mill Cove in Robbinston, Maine, see Appendix 1. This 17 NM trip involves a transit of broad deep waterways with one major course alteration, at the junction of Head Harbor Passage and Western Passage. This study focuses on the areas that presented less facilitated transit characteristics (Head Harbor Passage, Western Passage, and the Northern end of Friar Roads) and the docking and undocking at the DELNG Terminal.

This study was conducted using a full mission simulator at MSI's Newport, Rhode Island facility 27-31 July 2001. Twenty-five simulations were conducted during a five-day period for this project. Fifteen runs were simulated arrivals and ten were simulated departures. Eight simulations were solely dedicated to docking and undocking.

Environmental conditions varied with sustained winds of 30 knots gusting to 35 knots with ebb tides ranging from high slack water to 2.5 knots of ebb tidal current.

Four ASD tugs of 60 tonnes static bollard pull were modeled for this evaluation. The tugs were employed for ship assist work when docking and undocking, and tethered escorts when making the passage from the pilot boarding area to the berth at the DELNG terminal. Four tugs were the normal practice, however, lesser numbers were used for various situations to evaluate the optimum number required for specific environmental situations.

Three local pilots with considerable experience in the Passamaquoddy Bay area were employed to conduct the simulations. Ship handling decisions were based on visual observations of the effects that environmental forces and tug forces imparted on the LNGC's. Ship control conning orders were issued by the pilots and executed by a fellow mariner, in a manner that would be expected of a ship's bridge team. In the case of the tugs, the pilot's orders were carried out by a MSI system operator with considerable marine experience and training with simulated ASD tugs.

1.2 Background

The Passamaquoddy Bay area is ideally suited for this type of project as the area is easily accessible by wide channels and does not require lengthy transits. DELNG has identified an appropriate area for a marine terminal that will be minimally affected by ship traffic. DELNG has contracted an engineering firm to investigate and design LNG terminal options that will take advantage of deep water in the area and will minimize the environmental impact. The simulated terminal design appears to provide a very viable option for daylight transit under specific environmental conditions. Nighttime transits were not the subject of this study, and an additional simulation study would be required to address transits during the hours of darkness.

1.3 Definitions and Conventions

1.3.1 Definitions

ASD	Azimuth Stern Drive Tractor Tug
BCF	Billion Cubic Feet
BP	Bollard Pull force in metric tonnes
CL	Ships Center Line
DELNG	Downeast LNG
DPM	Degrees Per Minute
ECDIS	Electronic Chart Display Information System
Fathom	Six Feet
FERC	Federal Energy Regulatory Commission
HP	Horse Power
ICW	Intercoastal Waterway
Kts	Knots (rate of speed equal to 1 nautical mile per hour)
KW	Kilowatt
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
M	Membrane
MHHW	Mean Higher High Water tidal datum
MHW	Mean High Water tidal datum

MLLW	Mean Lower Low Water tidal datum
MLW	Mean Low Water tidal datum
MSI	MarineSafety International
MSL	Mean Sea Level
MTL	Mean Tide Level tidal datum (roughly equivalent to MSL)
NM	One nautical mile (6080 feet)
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
PBA	Pilot Boarding Area
ROT	Rate of Turn
S	Spherical
SOA	Speed of Advance
Tonne	Metric Ton
USSACE	Unite States Army Corps of Engineers
USCG	United States Coast Guard
UKC	Under Keep Clearance
VSD	Visual Situation Display

1.3.2 Conventions

Diagrams, charts, track plots and figures are north up unless otherwise noted.

Environmental conventions:

Wind: The direction the wind is coming from.
Current: The direction the current is going toward.
Seas: The direction the seas are coming from.

Velocities are in knots or meters per second (m/s).
Engine orders are in maneuvering bells.

1.4 Simulation Objectives

- Investigate the feasibility of navigating LNGCs of up to 165,000 m^3 cargo capacity from the pilot boarding area off East Quoddy Head to the proposed Downeast LNG Terminal, in Mill Cove, Robbinston, Maine.

- Determine the adequacy of existing navigation aids for day arrivals and departures to and from the Downeast LNG Terminal.

- Identify the appropriate number, size and bollard pull for assisting and escorting tractor tugs for Downeast LNG marine operations.

- Define escort tug requirements, tethering locations and speeds.

- Identify wind and tidal current windows for LNGC transits and dockings.

- Identify current meter requirements and locations.

2.0 Site Condition

2.1 Navigational Route

The route from the pilot boarding area, 1.5 nm due east of East Quoddy Head, to the DELNG terminal at Mill Cove is 17.0 NM. The route to Passamaquoddy Bay takes the vessel from the Bay of Fundy through Head Harbor Passage, turning north to Western Passage and then up to Mill Cove near the entrance to the St. Croix River. The approach is through a deep and stable natural channel. Prior to arrival at DELNG, the shallowest water encountered along the route is 30 meters with the average depth being in the range of 50-75 meters.

Traffic encountered along this route includes commercial vessels calling at Eastport, Maine and north to Bayside, New Brunswick, fishing and lobstering vessels, and pleasure craft in the summer season. A vehicle ferry service is operated July–September and connects Eastport to Campobello Island and Deer Island.

Movement of commercial vessels in and out of these waters is one-way.

2.2 Environmental Conditions

Tidal current direction and velocity data was provided to MSI by DELNG for construction of the tidal current model. Tidal range in this area varies greatly and can be anywhere between 14 to 23 ft depending on the stage of the moon and weather conditions. This range of tide directly correlates to the tidal current velocity and “window of opportunity” for safe passage. Generally a lower tidal range increases the period of the transit window where the current does not exceed safe limits and a higher tidal range will decrease that window.

A whirlpool and eddies exist along the route and are most common in the vicinity of Cherry Islet. The Old Sow whirlpool is located between Deer Island Point and Dog Island at the entrance to the Western Passage. This naturally occurring feature tends to be most active three hours before high water. At the most active time, the least amount of current is found 275 meters north of Dog Island.

Prevailing wind direction and velocity information was obtained from the pilots. The most common wind is from the Southwest, (most frequently from April through August), occurring 25% of the time throughout the year. The second most common wind is from the Northwest 20% of the year with the Northeast being third at 16% of the year. The Northwest and Southeast winds were found to be of little consequence since these wind directions are parallel to the berth. Of the twenty-five simulated runs conducted, eleven were with winds from the Northeast, ten from the Southwest and four from the Northwest. See Appendix 2. Table A provides a wind direction summary for the simulated events.

TABLE A

Wind Direction Summary – Downeast LNG Simulation

Wind Direction	Arrival	Departure	Transit	Total
SW	3	0	7	10
NW	1	0	3	4
NE	1	6	4	11
Totals	5	6	14	25

Note: Arrival or Departure denotes actual docking evolution at DELNG
Transit denotes a partial run along the route between PBA and the DELNG terminal.

2.3 Berth Configuration

The berth is designed to be capable of handling LNGCs with a cargo capacity range 165,000 to 200,000m^3. Tidal flow in this area is parallel to the berth on both the ebb and flood tides. The maneuvering area off the berth allows for vessels to come alongside either head up stream or head down stream, allowing vessels to berth in the most advantageous manner with regards to the current.

3.0 <u>Simulated Ship and Tug Models</u>

This study involved four LNGC models of ships ranging from 125,000 m^3 to 165,000m^3 cargo capacity. Two of the models are ships currently carrying LNG cargos and calling at existing LNG terminals on the US East and Gulf Coasts. The two larger LNGC's were modeled from data provided for offshore LNG projects and based on extrapolated data from LNGC's existing at that time. Actual sea trial data does not exist for a comparative validation of the 145,000m^3 spherical and 165,000 m^3 membrane models. Accordingly, the verification process was done by extrapolation from data gathered and validated from actual ships that exist in MSI's library of ship models and using the extensive experience built by MSI in undertaking this type of project. Additionally, pilots from East Coast and Gulf Coast LNG ports, based on their experience with other LNGCs, consider these models as realistic.

The ASD tugs modeled for this study were based on the 92 foot 60 tonne bollard pull model built by Washburn & Doughty in East Boothbay, Maine. This tug is the most common ship assist ASD tug on the East Coast.

3.1 Simulated Ship Models

3.1.1 Simulated LNGCs

- 125,000m^3 Membrane LNGC MATTHEW

LOA	289.1 M
Beam	41.2 M

Draft Loaded	11.0 M
Draft in Ballast	10.0 M
Windage	5960 M^2
Propulsion	Steam Turbine

- 138,000m^3 Spherical LNGC LNG Rivers

LOA	277 M
Beam	43.4 M
Draft Loaded	11.4 M
Draft in Ballast	10.0 M
Windage	8600m^2

- 145,000m^3 Spherical LNGC

LOA	288 M
Beam	49 M
Draft Loaded	11.5 M
Draft in Ballast	10.3 M
Windage	8600m^2
Propulsion	Steam Turbine

- 165,000m^3 Spherical LNGC

LOA	299.5 M
Beam	46 M
Draft Loaded	11.5 M
Draft in Ballast	10.3 M
Windage	10,900 m^2
Propulsion	Steam Turbine

3.1.2 Simulated ASD Tugs

- Washburn and Doughty 65 tonne ASD tug

LOA	28.1 M
Beam	9.8 M
Draft	4.3 M
Horse Power	5000
Bollard Pull	65 tonnes

4.0 <u>Simulation Methodology</u>

4.1 Method

This study was performed using a Full Mission Bridge Simulator with full visual graphics. The participating pilots made conning decisions and issued conning orders based on observations of the vessel, the surrounding port and the resultant effects from tugs and environmental forces. This visual presentation was augmented with digital data readouts for the ships course, speed and rate of turn. A radar display and Visual Situation Display (VSD) similar to an Electronic Chart Display Information System (ECDIS) were available to the pilot; these are standard shipboard equipment. The pilots conning orders were executed by a fellow mariner and simulator systems operator in a manner comparable to that expected of a ship’s bridge team and attending assist tugs.

At the LNGCs starting location, the pilots specified heading and speed. Simulated transits and berthing operations were frequently terminated when the pilot felt he had good control during the latter stages of the transit or mooring procedure; the final stage is simply a breasting in process which is time consuming and reveals nothing new. This shortcut saved time and enabled more simulations than otherwise could have been achieved.

4.2 Analysis of Conditions

The simulation evaluation was conducted using environmental data provided by DELNG and the participating pilots. When storms and weather fronts pass through the area, winds can shift to northeast to east for brief periods of time

Currents for the simulation were based on data provided by DELNG. The tidal current model received adjustments based on the pilots comments during the database validation. Once the modifications were made to the current direction, thereby meeting the pilots’ expectations, the current velocity could be scaled to provide the desired magnitude. This database used MLLW as the datum for the tidal structure.

The channel dimensions constructed for this geographic database model were based on NOAA Charts #13396 and #13398.

4.3 Simulation Program

Three pilots intimately familiar with the Passamaquoddy Bay area conducted this evaluation. Three runs were conducted as full transits from the PBA to the DELNG Terminal. The remaining runs were started at specified points along the transit route approaching the point of where an equipment or tug failure would result in a worse case situation for the LNGC. All runs were daylight runs. Five runs were conducted in low visibility. Rudder, engine and tug failures, or a combination of the two, were introduced into fourteen runs.

A MSI simulator systems operator operated the simulated tugs. The simulated weather conditions were based on prevailing conditions provided by the pilots and DELNG for the area. Pilots were apprised of the environmental factors at the beginning of each run. They were able to make up and employ the tugs in any configuration of their choice.

When approaching the DELNG terminal, the pilot conned the vessel into a position parallel to, and, just off the berth, where he was comfortable with his control to complete the final docking sequence. At this point the simulation was terminated, evaluated and stored for the future retrieval.

4.4 Evaluation of Simulation

The conning pilot analyzed each simulation. After completion of the set of simulations, each track plot file and tug power record was evaluated. Further comments on these results were compiled into simulation run summary.

5.0 Conclusions and Recommendations

5.1 Conclusions

5.1.1 The waterway itself is more than adequate to navigate LNGC's of 165,000 m^3 cargo capacity with the dimensions simulated 300m x 46m from the Passamaquoddy Bay Pilot Boarding area to the planned DELNG Terminal site at Mill Cove, Robbinston, Maine.

5.1.2 Current aids to navigation need to be upgraded to provide the pilots with additional visual cues to quickly locate potential hazards and precisely identify intended navigation tracks, and improve situational awareness for all members of the pilotage team.

5.1.3 The pilots were steadfast about avoiding transits of the north end of Friar Roads and the Western Passage during flood tides due to the unpredictability of the current patterns in this area.

5.1.4 Four 60 tonne ASD tugs were used for the majority of simulations. Under the simulated conditions four tugs are considered appropriate.

5.2 Recommendations

5.2.1 Recommended improvements to aids to navigation are:

- Place a beacon and radar reflector on Clark Ledge so that this hazard to navigation can be quickly identified and accurately located at high tide when the ledge is submerged

- Change Buoy UH"4" from an unlighted nun buoy to a lighted buoy.

- Add a lighted range in the vicinity of Kendell Head to define the ideal inbound track line between Dog Island and Deer Island Point.

- Place a lighted beacon on the east side of Kendell Head to accurately determine the location of this hazard.

- Place a range in the vicinity of Eastport, Maine to accurately define the optimum inbound track line through Head Harbor Passage.

- Establish an inbound range 800 feet off the terminal dock for clear positional awareness when approaching the dock and slowing the ship.

- Place a light on west side of the Clam Cove Head Peninsula to accurately locate shoal water.

- Place a lighted buoy on the west side of Stovers Ledge.

5.2.2 That a table of data be assembled to clearly portray tidal current velocities for the area between Dog Island and Cherry Islet. This is the most critical area for any transit outside of the high water slack parameter. The table(s) should reflect:

a. The tidal range
b. Time after high slack water
c. Tidal current velocity

5.2.3 Improve the Bay of Fundy Vessel Traffic Service (Fundy Traffic) radar and VHF communications coverage to provide reliable surveillance and communications in the Passamaquoddy Bay area.

5.2.4 Ensure that all Passamaquoddy Bay area pilots receive integrated tractor tug training with tug operators and LNGC master approximately six months prior to the first LNGC delivery.

5.2.5 This project has focused on daylight operations. Changes in aids to navigation are recommended based on these daytime simulations. These changes to aids to navigation should be evaluated in a nighttime simulation environment prior to a final assessment.