Navigation for Offshore Sailing

MITNA
January 2015

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Scott Dynes
Steve Bussolari
“This new ship here, is fitted according to the reported increase of knowledge among mankind. Namely, she is cumbered, end to end, with bells and trumpets and clocks and wires which, it has been told to me, can call Voices out of the air or the waters to con the ship while her crew sleep. But sleep thou lightly...It has not yet been told to me that the Sea has ceased to be the Sea”

- Rudyard Kipling
Outline

• Review
  - Nautical chart types and scales
  - Bouyage system (IALA Region B)
  - Light characteristics
  - Rules of the Road
  - Tidal currents
  - Basic navigational inputs

• Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore pilotage
# Tools

- Pencil
- Eraser
- Paper
- Parallels
- Divider
- Clock
- Calculator
- Handheld Compass
- Binoculars
- Sextant
Worksheets

RFIX 1332 EDT
33° 05' N
065° 20' W

CALCULATED FIX:
33° 06' N
065° 20' W

CIRCA TO KITCHEN SHOAL: 138°
3 miles (30 km) to 50 mi range
Geographical Coordinate System
Projections

61 different projections listed at Wikipedia


Equirectangular

HEALPix

Robinson

Goode homolosine

Cassini
Mercator Projection

- Advantages
  - Easy to use rectangular grid
  - Straight lines cross Meridians at constant angle (Rhumb Lines)

- Disadvantages
  - Chart scale not constant with position
  - Distance between lines of latitude are exaggerated in polar regions
• Advantages
  - easy-to-use rectangular grid
  - straight lines cross meridians at constant angle (Rhumb Lines)

• Disadvantages
  - chart scale not constant with position
  - distance between lines of latitude are exaggerated in polar regions
Nautical Chart Scales

- Boston Harbor
  - large scale (1/25,000)
  - covers small area

- Newport to Bermuda
  - small scale (1/1,058,400)
  - covers large area
Chart Number 1

Chart No. 1
UNITED STATES OF AMERICA

Nautical Chart Symbols, Abbreviations and Terms

Eleventh Edition
November 2011
Chart 1: Q Bouys and Beacons

**Cardinal Marks:** indicating navigable water to the named side of the marks. In the illustration, all marks are the same in Regions A and B.

**UNLIT MARKS**
- Topmark: 2 black cones
- Black above yellow
- Yellow above black
- Yellow with black band
- Black with yellow band

**LIGHTED MARKS**
- Time (seconds) 15
- Period shown
- Light: White

**Isolated Danger Marks** stationed over dangers with navigable water around them.
- Body: black with red horizontal band(s)
- Topmark: 2 black spheres

**Safe Water Marks** such as mid-channel and landfall marks.
- Body: red and white vertical stripes
- Topmark of any: red sphere

**Special Marks** not primarily to assist navigation but to indicate special features.
- Body: shape optional, yellow
- Topmark of any: yellow X
- Light: yellow, rhythm optional

**Supplementary National Symbols**
- a: Bell buoy
- b: Gong buoy
- c: Whistle buoy
- d: Floating buoy (red and white vertical stripe)
Bouys: Identification

- 8 ways to identify a lateral mark
  - color (green, red)
  - shape (cylindrical, conical)
  - dayboard (green square, red triangle)
  - topmark (cylinder, cone)
  - light color (green, red)
  - reflector color (green, red)
  - ID number (odd, even)
  - sound (gong - clang, bell - ding)
Bouys: Light Rythms

• Fixed
• Occulting
• Isophase
• Flashing
• Quick
• Group or Composite Group
• Morse Code
• Fixed and Flashing
• Alternating
The Lateral Buoyage marking the channels is Red to Starboard, related to the Conventional Direction of Buoyage. Off the coast, the direction of buoyage in this area is from east to west, within the estuary, it is the direction taken by the mariner when approaching from seaward.
Navigation Rules
Tidal Currents

• **Set**: direction in which an object will travel at a given time if carried by the tidal current (displayed opposite to the way wind is represented)

• **Drift**: distance an object will travel in a given time if carried by the tidal current

• **Current** (or Flow): speed at which an object will travel at a given time if carried by the tidal current

• **Ebb**: tidal current in the *falling* phase of the tide

• **Flood**: tidal current in the *rising* phase of the tide
<table>
<thead>
<tr>
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<th>Time</th>
<th>Slack Water</th>
<th>Maximum Current</th>
<th>Slack Water</th>
<th>Maximum Current</th>
<th>Slack Water</th>
<th>Maximum Current</th>
<th>Slack Water</th>
<th>Maximum Current</th>
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<td>1503</td>
<td>-1.4</td>
<td>1813</td>
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</tbody>
</table>

BOSTON HARBOR (Deer Island Light)
Predicted Tidal Current: April, 2008
Flood Direction, 254 True.
Ebb (-) Direction, 111 True.
NOAA, National Ocean Service
TIDAL CURRENT CHART
PUGET SOUND, NORTHERN PART

Arrows show the direction and figures the speed in knots of the current at time indicated at bottom of chart.

This chart is designed for use with the predicted times and speed of current for Almavista Inlet (Off Bush Point). These predictions are contained in the Pacific Coast Current Tables published in advance for each year by the National Oceanic and Atmospheric Survey, National Ocean Survey.

ONE HOUR BEFORE MAXIMUM EBB OFF BUSH POINT. (E-1)
Tidal Currents: Rules

Hour 1
1/3 C (nm)

Hour 2
2/3 C (nm)

Hour 3
3/3 C (nm)

Hour 4
3/3 C (nm)

Hour 5
2/3 C (nm)

Hour 6
1/3 C (nm)

Max Current C (kt)

Slack Water

Drift

Slack Water

Current (kt)

0 .5C .9C C .9C .5C 0

Rule of Thirds

50/90 Rule

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Basic Navigational Inputs

• Your eyes
  - Look around
  - Orient the chart
  - Relate your visible surroundings to the chart

• Log/Clock
  - Speed
  - Distance run

• Depth Sounder
  - Local depth

• Compass
  - True Heading
  - Variation
  - Magnetic Heading
  - Deviation
  - Compass Heading
## Declinations

<table>
<thead>
<tr>
<th>Location</th>
<th>Declination</th>
<th>Change (Minutes per year)</th>
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<tbody>
<tr>
<td>Nassau</td>
<td>8°3' W</td>
<td>0° 5' West per year</td>
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<tr>
<td>Punta Gorda Belize</td>
<td>0°19' E</td>
<td>0° 8' W</td>
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<tr>
<td>Boston, MA, USA</td>
<td>14°49' W</td>
<td>0° 4' E</td>
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<td>San Diego, CA, USA</td>
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<td>0° 5' W</td>
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<td>Athens, Greece</td>
<td>4° 10' E</td>
<td>0° 6' E</td>
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<tr>
<td>Wellington, NZ</td>
<td>22° 25' E</td>
<td>0° 4' E</td>
</tr>
<tr>
<td>Graves Lighthouse</td>
<td>14° 54' W</td>
<td>0° 4' E</td>
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<tr>
<td>Graves Lighthouse</td>
<td>14° 55' W</td>
<td>0° 4' E</td>
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<tr>
<td>Sommerville</td>
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<tr>
<td>IGRF12</td>
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</table>
The Poles are Moving
## Changes in magnetic declination for Graves Light, Boston Harbor

<table>
<thead>
<tr>
<th>Date</th>
<th>Lat</th>
<th>Long</th>
<th>Magnetic Declination</th>
<th>Annual Change minutes/year</th>
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<tr>
<td>1/21/2015</td>
<td>42.3649 North</td>
<td>70.8691 West</td>
<td>14° 55.14' West</td>
<td>3.6 East</td>
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<td>70.8691 West</td>
<td>14°14.64' West</td>
<td>-5.2 West</td>
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</tbody>
</table>
Outline

- Review
  - Nautical chart types and scales
  - Bouyage system (IALA Region B)
  - Light characteristics
  - Rules of the Road
  - Tidal currents
  - Basic navigational inputs

- Basic Navigation Skills
  - Planning a course to steer
  - Estimating your position
  - Knowing where you are
  - Inshore pilotage
Planning a Course to Steer

- Course to Steer is what you tell the helm to steer
  - by reference to a clear, distant, motionless visual mark (best)
  - by reference to the compass at the helm (not as good)
  - by reference to the wind (e.g., close hauled, broad reach)

- Use the chart plotter or parallel rulers on the chart to determine the direction to your destination
  - this will be a True Course
  - correct for leeway and current to get Course to Steer (in degrees True)
  - correct for variation and deviation to get Course to Steer (in degrees Per Steering Compass, or “PSC”)

- Whatever system you use, be clear and consistent
  - you will be reading the chart when you are tired and seasick
  - others will read the chart under similar conditions
Conventions

0130

054

06
## Conventions

<table>
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<tr>
<th>Time</th>
<th>Description</th>
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<td>1:30 AM</td>
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<tr>
<td>054</td>
<td>54°</td>
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<tr>
<td>06</td>
<td>6 knots</td>
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## Conventions

<table>
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<th>Description</th>
<th>Conventional Code</th>
<th>Reference</th>
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</thead>
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<td>1:30 AM</td>
<td>054M</td>
<td>54° Magnetic</td>
</tr>
<tr>
<td>054</td>
<td>54°</td>
<td>054T</td>
<td>54° True</td>
</tr>
<tr>
<td>06</td>
<td>6 knots</td>
<td>054CTS</td>
<td>Course To Steer</td>
</tr>
</tbody>
</table>
Plotting a Course

Arrowhead indicates a course
Prefix C indicates Course
Suffix T or M indicates True or Magnetic

C 061°T or C 077°M

If there is no leeway or current, you can correct this for Variation and Deviation and hand up to the helm as Course to Steer. Note the compass course in the ship’s log.
Correcting for Leeway

If there is no leeway or current, you can correct this for Variation and Deviation and hand up to the helm as Course to Steer. Note the compass course steered in the ship’s log.

Estimate your leeway angle (in this case 9°)
If there is no current, correct for Variation and instruct the helm to steer 068° on the binnacle compass (corrected for Deviation if necessary)

Remember: This is the course you are trying to make good through the water

Note the compass course steered in the ship’s log (068° PSC)
With current, we must distinguish between the Course we make good through the water and our Desired Track.

The Track is often called the “Course Made Good Over the Bottom”

Since the Track will be different than our Course made good through the water, we label it differently.
Correcting for Current

Draw a vector with the estimated 1 hour current set (direction) and drift (distance)
Label it as a current vector
Correcting for Current

Connect the current vector to the desired track using estimated distance the boat will travel through the water in the same interval (1 hour).
Correcting for Current

Wind

TR 061°T

C 050°T

Label the desired course made good through the water
Correcting for Current

Correct for leeway and label as course to steer (if desired)
Correct for variation and deviation and hand up to the helm
Note compass course steered (057° PSC) in ship’s log

Wednesday, 21 January 2015
Correcting for Current

Wind

CTS 041°T

TR 061°T

C 050°T

Alternate Labeling Technique

Construct current correction triangle on a separate plotting sheet or clear area on chart.

Plot Course to Steer directly on Track.
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<table>
<thead>
<tr>
<th>Time</th>
<th>Log</th>
<th>Course</th>
<th>Weather</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
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<td>33.5</td>
<td>057 PSC</td>
<td>NNW10, 1005mb, Fair</td>
<td>GPS Fix, GPS OFF</td>
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</tbody>
</table>

Wednesday, 21 January 2015
<table>
<thead>
<tr>
<th>Time</th>
<th>Log</th>
<th>Course</th>
<th>Weather</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>33.5</td>
<td>057 PSC</td>
<td>NNW10, 1005mb, Fair</td>
<td>GPS Fix, GPS OFF, Close hauled on Port Tack</td>
</tr>
<tr>
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<td></td>
<td>062 PSC</td>
<td>N10</td>
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<td>2000</td>
<td>39.5</td>
<td>062 PSC</td>
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<td>Close hauled, Port</td>
</tr>
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<td>Time</td>
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<tr>
<td>2100</td>
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<td>322 PSC</td>
<td>N10, 1005mb, Fair</td>
<td>Tacked, Close hauled, Stbd</td>
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</table>
## Ship’s Log

<table>
<thead>
<tr>
<th>Time</th>
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<th>Course</th>
<th>Weather</th>
<th>Remarks</th>
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<td>33.5</td>
<td>057 PSC</td>
<td>NNW10, 1005mb, Fair</td>
<td>GPS Fix, GPS OFF, Close hauled on Port Tack</td>
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<tr>
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<td></td>
<td>062 PSC</td>
<td>N10</td>
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<td>322 PSC</td>
<td>N10, 1005mb, Fair</td>
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</tr>
</tbody>
</table>

Where are we?  
What do we do next?
Estimating Your Position

• Plot a Dead Reckoning Position
  – Course steered and distance logged
  – Use ship’s log as the source of information

• Plot an Estimated Position
  – Position adjusted for leeway and current
Plotting a Dead Reckoning Position

GPS 1900

CTS 041°T

TR 061°T
Plotting a Dead Reckoning Position

From 1900 to 2000, compass course steered was 062°PSC and log difference is 6nm (39.5-33.5)

Course steered was 046°T (remember TVMDC)
Plotting a Dead Reckoning Position

Draw a line from the 1900 position, along the course steered (046°T) and mark a point at the distance traveled (6nm)

Label this as the 2000 DR position (DR is not corrected for leeway or current)
Plotting an Estimated Position

Plot a line representing your Course Made Good through the water (i.e., the course steered, adjusted for leeway)

In this case it is $046^\circ T + 9^\circ = 055^\circ T$

Make the length of the line the distance traveled from 1900-2000 (6nm)
Plotting an Estimated Position

Since nothing changed between 2000 and 2100, you can simply lay your plotting tool along a line between the 1900 GPS Fix and the 2000 EP and mark the 2100 EP along the extension of that line.
Plotting an Estimated Position

The distance between the 2000 EP and the 2100 EP should be the same as between the 1900 GPS Fix and the 2000 EP.
Assess the Situation

On the present tack, the helm is steering 322¢ (306T)
Accounting for leeway, the boat is making 297T through the water at ~6 knots
Even accounting for current, this looks like a bad tack
Instruct the watch captain to return to port tack and remain close-hauled. If the wind backs, the helm can stay with it up to 057 PSC, then maintain 057 PSC to parallel the desired track.

After tacking, make a log entry and get some sleep...
You can string multiple tacks together with multiple current estimates.

This is particularly helpful with tidal currents and longer passages.
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Knowing Where You Are

- Position by immediate observation
- Position fixes defined by lines
- Running fix
Log Entry:

1535: abeam red bell #2 three and one-half fathoms ledge
Position Defined by Lines

Try to select objects whose LOPs will intersect at 45° or more
Position Defined by Lines

Poor Cut
small errors in bearing produce large position errors

Good Cut
less sensitive to bearing errors

Try to select objects whose LOPs will intersect at 45° or more
Sources of Lines of Position

• Ranges
  - “Official” range set up for navigation
  - “Unofficial” range based on charted objects

• Compass bearings on objects
  - Quality depends on compass, observation conditions, and position stability of object

• Depth contours
  - Quality depends on bottom contour, condition, and tide

• Distance off
  - Measured by RADAR
  - Measured by sextant
  - Dipping of object of known height (typically lighthouses)
Using a Single Line of Position

Let’s say that you are keeping a series of estimated positions, using your estimates of your course made good through the water and current set and drift.
Using a Single Line of Position

At 1600 you get a good single LOP from a mark.
Using a Single Line of Position

You can update your estimated position by moving it from your initial estimate to the closest point along the LOP

This is *not* a fix. It is simply an adjusted estimated position
Running Fix

Some time later you get another LOP on the same mark.
Running Fix

Plot your course made good through the water and estimated current set and drift just as you would for an Estimated Position.
Running Fix

Advance the earlier line of position in the direction and distance you estimate that you've traveled over the bottom.

Label it as an advanced LOP.
Running Fix

Plot your running fix and label it as such
Running Fix: Caution

The running fix appears precise, but it is only as accurate as your ability to estimate your distance and direction traveled over the bottom.

Your LOPs should subtend an angle of no less than 45-60 degrees.

Running fixes are a very blunt navigational tool, but sometimes they’re all you have.
Doubling Angle on the Bow
Running Fix: Special Cases

Doubling Angle on the Bow

Distance AB is equal to distance from B to lighthouse. Bearing from lighthouse completes the fix.

45-90 Doubling Angle

Distance AB is equal to distance from B to LIGHTHOUSE. Bearing from lighthouse completes the fix.
### Running Fix: Special Cases

1. **Doubling Angle on the Bow**
   
   *Distance AB is equal to distance from B to lighthouse. Bearing from lighthouse completes the fix.*

2. **45-90 Doubling Angle**
   
   *Distance AB is equal to distance from B to Lighthouse. Bearing from lighthouse completes the fix.*

3. **Beam Bearing Drift Rate**
   
   *When abeam the mark, the distance between B and the mark is equal to the time (in minutes) that it takes the bearing angle to change (in degrees) an amount equal to the vessel speed (in knots).*

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Inshore Pilotage

• In waters crowded with bouys, beacons, and hidden hazards, there is often no time for formal chartwork

• Typically these occur at beginning or end of a passage - often in unfamiliar waters

• Procedures must be simple to set up and follow

• Most navigation aboard X-Dimension in and around Boston Harbor is inshore pilotage
Clearing or Danger Bearing
Inshore Pilotage Tips

• For complex harbor entries, plan ahead with appropriate bearings and informal ranges

• For landfall in low visibility, bias your course to steer so you know which way to turn when shore becomes visible

• Keep a chart on deck with you and refer to it often, even in familiar waters

• “Prove” your bearings with informal ranges where possible to account for current

• Communicate clearly to helm and crew - give them time to prepare

• Check and double-check your information
Double-Check Everything
Celestial Navigation

“Sextant: an entertaining, albeit expensive, device, which, together with a good atlas, is of use in introducing the boatman to many interesting areas on the earth’s surface which he and his craft are not within 1,000 nautical miles of.”

- Beard and McKie
“I looked in the Nautical Almanac and found that on that very day, June 7, the sun was behind time 1 minute and 26 seconds, and that it was catching up at a rate of 14/67 seconds per hour. The chronometer said that at the precise moment of taking the sun's altitude it was 25 minutes after 8:00 in Greenwich. From this date it would seem a schoolboy's task to correct the Equation of Time. Unfortunately I was not a schoolboy.”

- Jack London, The Cruise of the Snark