28 Navigation Reminders

CRITICAL REMINDERS

1. Measure distance from latitude scales.
2. Take all bearings in degrees magnetic.
3. Always verify depth: surface + depth

"Sounding Checks with Chart"

Six Rules of DR (p.11)

1. At least once per hour
2. At every course change
3. At every speed change
4. At time of single LOP (gives an EP)
5. A time of a fix or running fix
6. Always starts from a fix

LOP's and Fixes (p.10)

1. Maintain good separation for navaids.
2. Avoid reciprocal navaids (180º apart).
3. Maintain a consistent fix interval.
4. Record all bearings in bearing book.
5. Record slowest changing LOP (off bow or stern) first. Keeps times closer together.

Charts Labeling (p.17)		Time	1422,
DR	Semicircle + dot	Course	C-084º
C Fix	Circle + dot	Speed	S-5.3
E Fix	Triangle + dot	Set	Direction
EP	Square + dot	Drift	Speed

Coastal Navigation
by
John C. Kelly, © 2003

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Types of Navigation

Piloting – refers to navigating in restricted waters associated with harbors and channels where man made navaids such as lights and buoys will play a significant role. There will be little need to take conventional fixes.

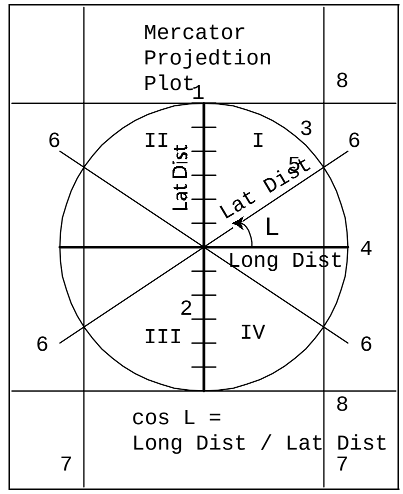
Coastal – refers to navigating in coastal waters in sight of land where hydrographic and topographic navaids will be used to take conventional fixes to determine position.

Celestial – refers to navigating in the open ocean without the aid of landmarks where a sextant is used to measure one's position relative to the stars and other celestial bodies.

Electronic or GPS – refers to navigating with the aid of a Geographic Positioning System (GPS) which uses satellites to determine a near exact electronic fix. When in restricted waters, traditional piloting should be used.

Annapolis is in
Coast Guard District 5

Universal Plotting Sheet



L	cos L	L	cos L
0	1.00	50	0.64
10	0.98	60	0.50
20	0.94	70	0.34
30	0.87	80	0.17
40	0.77	90	0.00

Universal Plotting Sheet

L = Latitude
λ = Longitude
D_L = Dist between Lat lines
D_λ = Dist between Long lines

1. Draw a vertical line. Pick a center point.
2. Mark off six equidistant lines above and below the center point.
3. Draw a circle of radius six. (any units)
4. Draw a horizontal line through the center.
5. Draw two faint lines through the center of the circle at an angle equal to the latitude L above and below the middle horizontal line.
6. Note the four points where these lines intersect the circle.
7. Draw vertical lines through these points on each side. These are properly spaced lines of longitude.
8. Draw two horizontal lines tangent to the top and bottom of the circle. These are lines of latitude. The six divisions represent 10º or 10’ of latitude depending upon the scale.
9. Add additional lines of LAT and LONG as needed. For celestial navigation, the lines of LAT and LONG are usually one degree apart representing 60 miles. The scale must be tailored to your needs.

Note: $D_\lambda = D_L \cos L$

Latitude and Longitude

A nautical chart is a three dimensional representation of the earth’s surface over land and water.

Latitude – is the north/south coordinate, measured in degrees (00º - 90º) north or south of the equator. It can be expressed in seconds or decimal in the following forms:

dd° mm’.m N or S
dd° mm’ ss” N or S

Latitude lines are called parallels, and the distance between them is always equal. One minute of latitude equals one nautical mile. Distance measures should **always** be taken from the latitude scale.

Longitude – is the east/west coordinate, measured in degrees (000º - 180º) east or west of the prime meridian in Greenwich England. It can be expressed in seconds or decimal in the following forms.

ddd° mm’.m E or W
ddd° mm’ ss’ E or W

Longitude lines are called meridians and the distance between them varies depending upon how close the latitude is to the north or south poles. The meridians converge as they get closer to the poles. The longitude scale should **never** be used as a distance scale.

Nautical distances are measured in nautical miles (nm).

1 nautical mile = 1 minute of latitude (1')

Distance measures on a nautical chart must **always** be taken from the latitude scale of the chart or directly from a distance scale provided.

Conversions

1 nautical mile	= 1.15 land miles	
1 land mile	= 0.87 nautical miles	
1 meter (m)	= 3.28 ft	= 39.4 inches (in)
1 land mile	= 5280 ft	= 1609 m
1 nautical mile	= 6076 ft	= 1852 m
1 minute	= 60" (seconds)	
1 degree	= 60'	
1 circle	= 360º	= 21,600'
Earth circumference	= 21,600 nautical miles	
	= 24,480 land miles	

Great Circles and Rhumb Lines

The shortest distance between two points on a plan is a straight line. The shortest distance between two points on a sphere is an arc of a great circle. A great circle is formed by passing a plan through the center of a sphere. The shortest sailing distance between two points is called a rhumb line. It is a great circle arc and makes a constant angle with all meridians it crosses.

Two levels of accuracy are provided by GPS:

- Precise Positioning Service (PPS)
- Standard Positioning Service (SPS)

PPS is available only to the US military and its allies. SPS is available worldwide to anyone with a receiver. The accuracy of SPS is controlled by a deliberately introduced error called Selective Availability (SA). During times of war, the military can increase the amount of error introduced by SA. The standard accuracy with SA on is 100 meters, which is over 300 feet!

Differential GPS (DGPS)– The US government recognizes that 100-meter accuracy is not sufficient for making a safe harbor entrance so, through the USCG, they have introduced a system for increasing the accuracy in US coastal waters called DGPS. From known fixed locations on land, the USCG transmits correction signals (approximately 150 miles) over marine radio beacon frequencies. If a GPS receiver is properly equipped, the accuracy is guaranteed to be 10 meters but is commonly in the range of 1-3 meters (10 to 30 feet). There are 100's of these stations around the country. Information about the status and operation of DGPS is provide by the USCG at

www.navcen.uscg.gov

Global Positioning System (GPS)

How it Works
GPS is a position tracking system based upon 24 satellites, where at least four satellites are in view from any point on earth. The satellites complete an orbit approximately once every 12 hours. In addition to positional data, each satellite transmits a satellite ID, time of day, and other system data. A GPS receiver must use data from four satellites to determine a complete position consisting of four unknowns: latitude, longitude, altitude, and time.

GPS works a bit like celestial navigation. GPS measures distances between satellites in orbit and a receiver on Earth and computes spheres of position from those distances. The intersections of those spheres of position determine the receiver's position.

Theoretically, only three satellites are needed to uniquely determine position; however, in practice, four satellites are needed to obtain an accurate fix. This is due to something called receiver clock error.

GPS Altitudes – are only a approximation of the height above sea level. This is due to the fact that GPS assumes a mathematically smooth Earth by averaging mountains and valleys.

Knots
Speed is distance traveled per unit time. On land speed is measured in miles per hour (mph) or kilometers per hour (kph). On water, speed is normally measured in knots or nautical miles per hour (mph). In general, whenever the word miles is used, it assumed to be nautical miles. Sailboats typically travel in the range of four to eight knots.
Speed accounting for direction
When the direction of speed is taken into account speed is called velocity, which technically speaking is a vector with components of speed and direction. Mariners have developed many terms for speed depending upon the direction of travel.
Speed of Advance (SOA) – indicates the desired speed in the direction of an intended track. This is a planning speed accounting for current and leeway.
Speed Over Water (SOW) – is the speed you are making through the water. This is the speed as measured by the boats knot meter. Depending upon currents and leeway, it will most likely be different from speed over ground.
Speed Over Ground (SOG) – is the actual speed traveled between two points divided by the physical distance traveled.
Speed Made Good (SMG) – is a hypothetical speed computed by dividing the distance between two points and the time it took to get there.
Velocity Made Good (VMG) – is the speed made good in the direction of true wind.

Speed Formulas

Distance = Speed * Time

I remember this by the acronym

DST = Daylight Savings Time

Three Combinations of speed formulas

D = S * T
S = D / T
T = D / S

Time in Minutes
When working with minutes, you have two choices: (1) convert minutes to hours by dividing by 60 minutes per hour, or (2) multiple the distance times 60 and leave the time expressed in minutes.

S = (D * 60) / T or S = D / (T / 60)
D = S * (T / 60)

Examples
What is the speed when traveling 12 nm in 2 hr?
S = 12 / 2 = 6 mph or 6 knots

What is the speed when traveling 2 nm in 30 min?
S = 2 / 0.5 = 4 knots

What distance is traveled in 20 min at 3 knots?
D = 3 * (20 / 60) = 1 nm

Briefings

Watch Change: Watch Captain and Navigator

1. Brief current chart: course, track, shoal areas, navigation hazards, danger bearings, navaids,
2. All charts verified and staged for next watch.
3. Ships currently in sight
4. Sail configuration and rigging
5. Weather: wind, waves, pressure, forecast
6. Location of other boats in squadron
7. Ship traffic experienced
8. VHF correspondence
9. Tides and current
10. Times of sunrise/sunset, moonrise, moonset

Landfall – Prior Planning Prevents Poor Performance

1. Expected time of arrival.
2. Detailed pilot plan with light lists, buoy lists, planned course changes, danger areas, etc.
3. Every possible navigation hazard.
4. Wake/alert captain and brief crew.

Pilot Plan Light List – When approaching a harbor, channel, or other restricted area, consider making a list of all lights and navaids that will be used.

Nbr	Color	Type	Pattern	Action/Course

Ship's Log
(Possible Entries)

Navigation	
TIME	24 hour HHMM
ENG	ON / OFF
FIX	Type ▲ elec / ● conv
LAT/LONG	Lat/Long from fix
DEPTH	Sounding checks with Chart
LOG	Distance from log
COURSE/COG	Steering / Getting
SPEED/SOG	From knot meter / SOG
SAIL COMBO	Sail configuration
Weather	
BP	Barometric pressure mb
WIND DIR/SPD	Compass direction / Speed
WAVES	DIR / HT / PRD
CLOUDS	% cover / TYPE
TEMP	SEA / AIR
Boat Systems	
BILGE	Strokes
ENG	Hours, fluids, leaks, checks
FUEL	Hours and miles remaining
WTR	Gallons remaining
BAT 1/2/3	Voltage levels
Crew	
Watch Captain	Name
Navigator	Initials log entry

COMMENTS: Damage, weather, sickness, sail change, course change, problems, VHF messages, sightings, training, drills, issues with other boats in squadron.

Arrival Time Formulas

Estimated Time Enroute (ETE) is the distance between beginning position and the destination divided by estimated SOA to the destination.

ETE = Total distance / SOA

Estimated Time Remaining (ETR) is similar to ETE, except it is based upon the current position, not the beginning position. Some GPS devices call this **Time To Go (TTG).**

ETR = Distance remaining / SOA

Estimated Time of Arrival (ETA)

ETA = Current clock time + ETR

Three-Minute Rule – The distance of travel in **yards** in 3 minutes is equal to its speed in knots times 100. Note, there are 2000 yards in 1 nm.

Six-Minute Rule – The distance of travel in **nautical miles** in 6 minutes is equal to its speed in knots divided by 10.

8 Direction and Course

Direction is the angular position of one point relative to a reference point. Three reference points are commonly used:

- True North
- Magnetic North
- Ships Heading

Track – is the direction you intend to travel. It may not match the course you steer due to current and leeway. It is your planned direction or rhumb line.
Course and **Course to Steer (CTS)** – are the direction you intend to steer. It may not match your track if you are trying to adjust for current and leeway.
Course of Advance (COA) – is the direction you intend to make good over ground. Similar to SOA.
Course Over Ground (COG) – is the actual course you are getting. It is the direction between a vessel's last fix and its estimated position (EP).
Course Made Good (CMG) – is the resultant direction toward a destination or waypoint. Both COG and CMG may differ significantly from Course due to current and leeway.
Heading – is the direction a vessel is pointed at any given moment. It is an instantaneous course.
Bearing – is the direction to an external landmark from a vessel as measured in degrees from magnetic north. Reciprocal bearing = 180º - bearing.
Relative Bearing – is the direction of an external landmark as measured relative to the ship's heading, where 000º is dead ahead.

Danger Bearings 21

Danger bearings are used to indicate the safe side of a shoal, rock, or other navigation hazard. To draw a danger bearing, you must base it on a fixed navaid which is clearly identifiable beyond the danger area. On your chart, draw a LOP from the navaid which passes a safe distance from the danger area. The magnetic bearing of this of this LOP is your danger bearing.

If you need to keep the danger area safely to **starboard**, you must insure that the bearing to the navaid from your vessel is **never lower** than the danger bearing.

If you need to keep the danger area safely to **port**, you must insure that the bearing to the navaid from your vessel is **never higher** than the danger bearing.

WARNING: Do not make the mistake of drawing a bearing line from your vessel to the danger area. The danger bearing must be based upon a fixed navaid beyond the danger area.

Light Visibility

Assumes height of eye is 10 feet
distance = 1.17 sqrt(H) + 1.17 sqrt(eye)
Formula assumes height of object is in feet

m	ft	nm	m	ft	nm
0	0.0	3.7	26	59.3	12.7
1	2.3	5.5	27	61.6	12.9
2	4.6	6.2	28	63.8	13.0
3	6.8	6.8	29	66.1	13.2
4	9.1	7.2	30	68.4	13.4
5	11.4	7.7	31	70.7	13.5
6	13.7	8.0	32	73.0	13.7
7	16.0	8.4	33	75.2	13.8
8	18.2	8.7	34	77.5	14.0
9	20.5	9.0	35	79.8	14.2
10	22.8	9.3	36	82.1	14.3
11	25.1	9.6	37	84.4	14.4
12	27.4	9.8	38	86.6	14.6
13	29.6	10.1	39	88.9	14.7
14	31.9	10.3	40	91.2	14.9
15	34.2	10.5	41	93.5	15.0
16	36.5	10.8	42	95.8	15.1
17	38.8	11.0	43	98.0	15.3
18	41.0	11.2	44	100.3	15.4
19	43.3	11.4	45	102.6	15.6
20	45.6	11.6	46	104.9	15.7
21	47.9	11.8	47	107.2	15.8
22	50.2	12.0	48	109.4	15.9
23	52.4	12.2	49	111.7	16.1
24	54.7	12.4	50	114.0	16.2
25	57.0	12.5	51	116.3	16.3

Compass Rose

Magnetic North and Variation – The earth's magnetic field is not aligned exactly north and south, that is, the magnetic north differs slightly from polar north. This difference is called variation, and it varies depending upon the location on earth. When sailing over thousands of miles and when doing celestial navigation, it is necessary to use true north. However, when sailing short distances it is preferable to measure and record all directions in magnetic, since this will minimize errors.

Compass Rose – The compass rose on a chart has two circles: an outer circle and an inner circle. The outer circle is in degrees true, and the inner circle is in degrees magnetic. It is the inner circle that we always want to use for courses and bearings. Note that charts are always aligned in the direction of true north. The variation is noted inside the compass rose. In the Annapolis area, it is 11º West. That means that to convert a magnetic direction to a true direction, we must add 11º. However, if you do all your work in magnetic, this conversion will not be necessary.

Compass Deviation – is the fluctuation in a compass reading due to the magnetic properties of the vessel. In most cases, this can be ignored, especially in sailboats.

Line of Position (LOP) – is a magnetic bearing to a navaid. When this line is plotted on a chart, the vessel must be somewhere on this line. The navaid should be **fixed, not floating**. Common navaids include:

- Beacons
- Fixed lights
- Edges of land
- Towers or other charted land based features
- Ranges – two lights or objects in alignment

Landmarks should be marked on the chart with a **circle and a dot** to be sure of their location.

Circle of Position (COP) – is the arc of a circle with a measured distance from a navaid. When plotted on a chart, the vessel must be somewhere on this arc. Especially useful with radar.

Conventional Fix – is the intersection of two or more LOPs or an LOP and a COP. It is called a conventional fix because it is not based on electronics or GPS. When only two LOPs are used, the fix should only be considered an **estimated position (EP)**. If at all possible, three LOPs should be used. Conventional fixes are labeled on a chart with a circle and a dot.

All fixes should be verified with sounding data.

"Sounding Checks With Chart"

Construction

The Portland plotter consists of a fixed rectangular portion and a rotating compass rose. The fixed portion has a large green arrow which is always pointed in the direction of the bearing or course.

Variation Compensation

Outside the compass rose on the fixed portion is a degree scale labeled TOTAL ERROR, EAST and WEST. This scale accounts for variation. If the variation is WEST, then the WEST side is used, similarly, if the variation is east, the EAST side is used.

Plotting an LOP

1. Assume the variation is 10º west and the LOP to be plotted is 156º. Rotate the compass rose until 156º is directly under 10º on west side of the TOTAL ERROR.
2. Align the plotter with the green arrow pointed in the direction of the navaid.
3. Put one outside edge of the rectangle on the navaid corresponding to the LOP.
4. Move the entire rectangle until the grid in the compass rose is perfectly aligned north/south. Do this by sliding the plotter until a grid line aligns with a lat/long line on the chart. The two green arrows in the compass rose should be pointed directly north.
5. The edge of the plotter on the navaid is the LOP.

Three tools are commonly used for plotting LOPs:

- Parallel Ruler
- Rolling Ruler
- Portland Plotter

Parallel Ruler – is the traditional tool used for 100's of years. It consists of two rulers which are hinged together in such a way that they must move in parallel when they are slid apart of moved together. One edge of the ruler is aligned to the magnetic compass rose according to the measured bearing, and parallel ruler is walked to the navaid so the LOP can be drawn.

Rolling Ruler – is a single ruler with two small wheels, which allow it to roll across the chart. Like the parallel ruler, the roller ruler is aligned to the magnetic compass rose, and from it, it is rolled to the navaid for plotting the LOP. Both the parallel ruler and the rolling ruler are easily misaligned while walking or rolling. The roller may be more stable than the roller, especially if the roller has been enhanced with rubber wheels.

Portland Plotter – is uniquely different from the previous plotting devices, as it does not use the compass rose directly. The Portland plotter has a compass rose built into it, and the magnetic variation is dialed into the plotter, allowing it to be placed anywhere on the chart with no risk of jolting.

Derivation of the Term DR
DR comes from the term "deduced reckoning" which morphed into "ded reckoning" which morphed into "dead reckoning" or just DR.

Definition of DR
DR is a plot of the anticipated track based upon course and speed. It does not take into account current and leeway. When current and leeway are accounted for, the position is called an estimated position (EP).

Six Rules of a DR

1. At least once per hour
2. At every course change
3. At every speed change
4. At time of single LOP (gives an EP)
5. A time of a fix or running fix
6. Always starts from a fix (circle + dot)

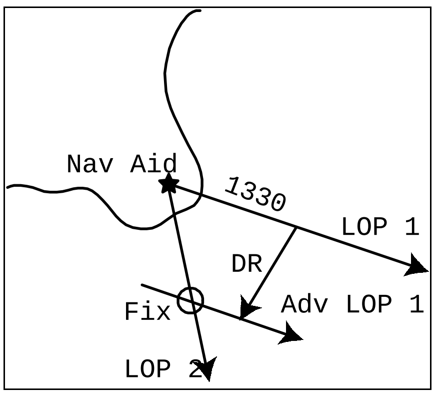
Points to Remember

1. Plot two intervals out.
2. Plot endpoint as a semicircle + dot.
3. Label semicircle with 2400 time
4. Label above course line as C-085º.
5. Label below course line as S-5.2.
6. Based on steering compass and knot meter.
7. Interval <= ½ time to reach land.
8. Erase old second DR's to avoid clutter.

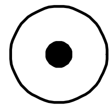
Running Fix

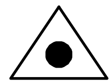
A running fix uses two LOPs from one navaid to derive a fix.

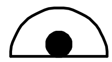
1. Plot an LOP_1 and note time.
2. Sail constant course.
3. Sail until 50º - 90º angle opens.
4. Plot another LOP_2 on same object.
5. Note time and distance sailed.
6. If no course change, use the existing DR to mark off distance sailed. If necessary draw a new DR from anywhere on LOP_1.
7. Adv LOP_1 to appropriate distance on DR.
8. Inters of Adv LOP_1 and LOP_2 is the fix.
9. Label as “R Fix.”

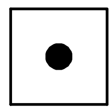


Navigation Symbols

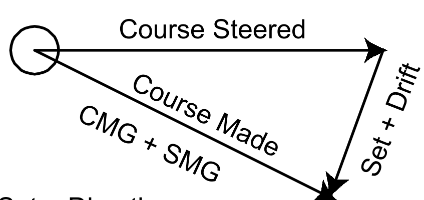

Conventional Fix


Electronic Fix


DR Position


Estimated Position
Current + Leeway

Current Vector



Set = Direction
Drift = Speed

Logarithmic Speed Scale

The logarithmic speed scale is based on the same principles as a slide rule:

1. Log (A*B) = Log A + Log B
2. Log A = Distance (1,A) = D(1,A)
3. Log (A*B) = D(1,A) + D(1,B)
4. D(A,B) = log B – log A

Now consider D = S * T

Where	D	= Distance in nautical miles
	S	= Speed in knots
	T	= Time in hours
	M	= Time in minutes = T/60

Log D = log (S*T)
= log S + log M – log 60
= log S – (log 60 – log T)

Exmple: Speed = 7 knots, Time = 15 min
Find distance traveled in nautical miles.

Log D = log 7 – (log 60 – log 15)

1. Measure distance from 15 to 60.
2. Maintain divider distance.
3. Place right point on 7.
4. Read nautical miles on left point.
5. 1.75 nm

Measuring Distance Off

Closely related to a running fix is the process of measuring the distance from a vessel to point on land using some simple geometric relationships.

045º and 090º - is based on the property that the two short sides in a right triangle are equal and form 45º angles with the hypotenuse. Procedure: mark time and position when a navaid is 045º relative off the bow (starboard side: course + 045º, port side: course – 045º). Plot DR. When navaid is 090º relative off beam, the distance traveled will equal the distance to the navaid.

Procedure for running fix
1. Plot the LOP when the navaid is 045º relative.
2. Sail until navaid is 090º relative; mark time/course/speed; compute distance traveled.
3. Advance the LOP by distance traveled.
4. Draw arc around navaid, radius = dist traveled.
5. The intersection is a running fix.

Other angles
Recalling that tangent = opposite / adjacent where the opposite side is D (distance from navaid) and the adjacent side is R (distance run). We can create two more simple rules based on tan 26.5º=0.5, tan 63.4º=2.0:
26.5º and 90º - distance off = 0.5 * distance run
63.4º and 90º - distance off = 2.0 * distance run

D = S * (T / 60)

Minutes

Kts	5	6	10	15
3.0	0.25	0.30	0.50	0.75
3.2	0.27	0.32	0.53	0.80
3.4	0.28	0.34	0.57	0.85
3.5	0.29	0.35	0.58	0.88
3.6	0.30	0.36	0.60	0.90
3.8	0.32	0.38	0.63	0.95
4.0	0.33	0.40	0.67	1.00
4.2	0.35	0.42	0.70	1.05
4.4	0.37	0.44	0.73	1.10
4.5	0.38	0.45	0.75	1.13
4.6	0.38	0.46	0.77	1.15
4.8	0.40	0.48	0.80	1.20
5.0	0.42	0.50	0.83	1.25
5.2	0.43	0.52	0.87	1.30
5.4	0.45	0.54	0.90	1.35
5.5	0.46	0.55	0.92	1.38
5.6	0.47	0.56	0.93	1.40
5.8	0.48	0.58	0.97	1.45
6.0	0.50	0.60	1.00	1.50
6.2	0.52	0.62	1.03	1.55
6.4	0.53	0.64	1.07	1.60
6.5	0.54	0.65	1.08	1.63
6.6	0.55	0.66	1.10	1.65
6.8	0.57	0.68	1.13	1.70
7.0	0.58	0.70	1.17	1.75
7.2	0.60	0.72	1.20	1.80
7.4	0.62	0.74	1.23	1.85

D = S * (T / 60)

Minutes

Kts	15	20	30	60
3.0	0.75	1.00	1.50	3.00
3.2	0.80	1.07	1.60	3.20
3.4	0.85	1.13	1.70	3.40
3.5	0.88	1.17	1.75	3.50
3.6	0.90	1.20	1.80	3.60
3.8	0.95	1.27	1.90	3.80
4.0	1.00	1.33	2.00	4.00
4.2	1.05	1.40	2.10	4.20
4.4	1.10	1.47	2.20	4.40
4.5	1.13	1.50	2.25	4.50
4.6	1.15	1.53	2.30	4.60
4.8	1.20	1.60	2.40	4.80
5.0	1.25	1.67	2.50	5.00
5.2	1.30	1.73	2.60	5.20
5.4	1.35	1.80	2.70	5.40
5.5	1.38	1.83	2.75	5.50
5.6	1.40	1.87	2.80	5.60
5.8	1.45	1.93	2.90	5.80
6.0	1.50	2.00	3.00	6.00
6.2	1.55	2.07	3.10	6.20
6.4	1.60	2.13	3.20	6.40
6.5	1.63	2.17	3.25	6.50
6.6	1.65	2.20	3.30	6.60
6.8	1.70	2.27	3.40	6.80
7.0	1.75	2.33	3.50	7.00
7.2	1.80	2.40	3.60	7.20
7.4	1.85	2.47	3.70	7.40