Wind Speed and Direction:
True and Apparent

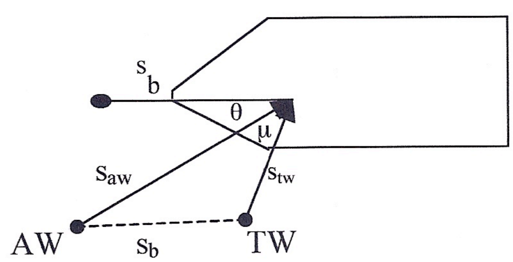
A vessel in motion will experience an *apparent wind* that is a combination of the true wind and the oncoming wind created by the boat's forward motion. For a sailboat the calculation of true wind speed and direction is important for the setting of the sails. For a power boat the calculation is much less important.

Modern technology embeds the calculations in digital anemometers that convert apparent wind speed information to true wind speed datarelieving the boater from the need to understand the conversion. This note outlines the mathematics underlying that conversion.

Consider Figure 1. The boat is moving in the leftward direction at speed s_b; the length of the vector is the boat's forward speed. An apparent wind is coming from angle θ off the bow, its speed indicated by the length of the vector s_{aw}. If the boat is not moving, the apparent wind will coincide with the true wind, but as the boat gains speed the apparent wind shifts so that it comes from a direction closer to the forward boat motion.

Thus, the true wind will be coming from a direction aft of the apparent wind direction, but at what angle $(\theta + \mu)$ and at what speed (s_{tw}) ?

Figure 1



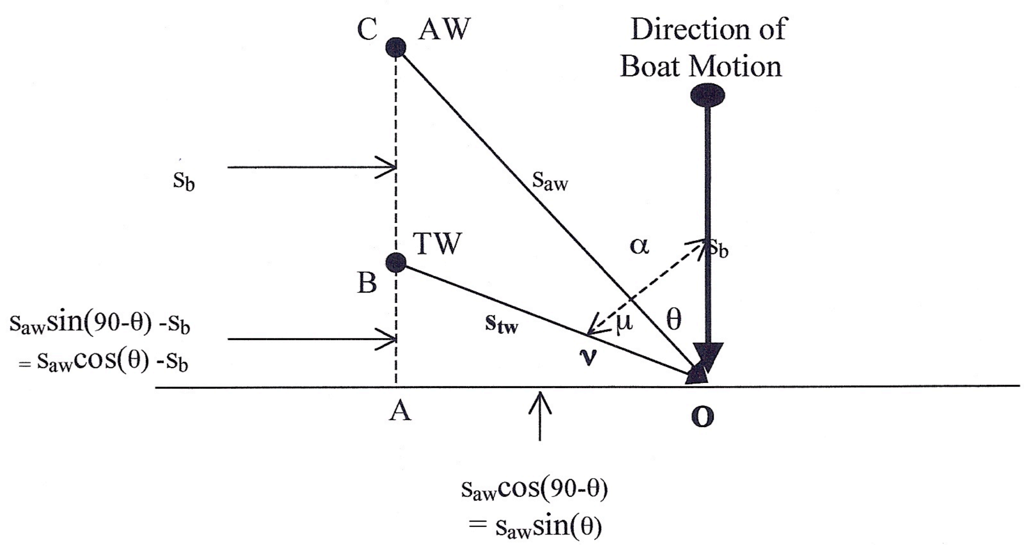
Forward wind (FW) coming from directly ahead at boat speed s_b
Apparent wind (AW) coming from $\theta°$ off the bow at speed s_{aw}
True wind (TW) coming from $(\theta + \mu)°$ at speed s_{tw}

The Trigonometry of True Wind Speed and Direction

Figure 2 demonstrates the calculation of true wind speed and direction. The boat's position is shown at the origin. Angles are computed relative to vessel motion. The boat is moving at speed s_b creating a boat wind (BW) in the aft direction. The apparent wind (AW) is flowing from $\boldsymbol{\theta}°$ off the port at speed $\mathbf{s_{aw}}$. The (as yet unknown) true wind (TW) is flowing from $\alpha°$ off the port bow at speed $\mathbf{s_{tw}}$. The goal is to find $\mathbf{s_{tw}}$ and α from the known values $\mathbf{s_{aw}}$, $\mathbf{s_b}$, and $\boldsymbol{\theta}$.

Figure 2

Trigonometric Analysis:
Apparent versus True Wind



In Figure 2 the arrows show the directions of wind flow relative to the forward direction. The boat is moving vertically, creating a downward wind flow on it. The origin (O) is the current position of the boat. The AW direction is from $\boldsymbol{\theta}°$ off the port bow and the AW speed is s_{aw}; both $\boldsymbol{\theta}$ and s_{aw} are known. The triangle OCA represents the known apparent wind status; AC = $s_{aw}\sin(90\text{-}\theta)$ and AO = $s_{aw}\cos(90\text{-}\theta)$ are the sides of that triangle. Noting the trigonometric identities $\sin(90 - \boldsymbol{\theta}) = \cos(\boldsymbol{\theta})$, and $\cos(90 - \boldsymbol{\theta}) = \sin(\boldsymbol{\theta})$, we can rewrite the sides of oca as

$$\text{Sides of OCA:} \quad AC = s_{aw}\cos(\boldsymbol{\theta}), \quad \text{and} \quad AO = s_{aw}\sin(\boldsymbol{\theta}).$$

We want to determine the true wind angle (θ) and speed (s_{tw}) from the angles and sides of the true wind triangle, oba. These sides of oca are

Sides of OBA: AC = AC - BC = $s_{aw}\cos(\boldsymbol{\theta})$ - s_b

AO = $s_{aw}\sin(\boldsymbol{\theta})$

The true wind direction and speed can be derived as

$$\text{TW Direction: } \alpha = 90 - \nu$$
$$= 90 - \tan^{-1}(AB/AO)$$
$$= 90 - \tan^{-1}\{[s_{aw}\cos(\theta) - s_b]/[sa_w\sin(\theta)]\}$$

$$\text{TW Speed: } s_{tw} = \text{sqrt}(AC^2 + AO^2)$$
$$= \{[s_{aw}\cos(\theta) - s_b]^2 + [sa_w\sin(\theta)]^2\}^{½}$$

For example, suppose that the boat speed is 10 knots, and apparent wind speed is 16 knots at direction at $\theta = 35°$. The true wind direction is 71.3°, and true wind speed is 9.6 knots.

True Wind Tables

In the days before computers it was cumbersome to carry books with pages for calculating rtrue wind speeds and angles for each possible boat speed and apparent wind angle. Fortunately, the calculations can be reduced to a single page by noting that the relationships hold if all speeds are divided by the boat speed, that is, if speed is defined in "boat speed units (bsu)."Thus, we define $s'_{aw} = s_{aw}/s_b$ as apparent wind speed in bsus; also, $s'_{tw} = s_{tw}/s_b$ is true wind speed in boat speed units. This allows easy construction of a table for true wind speed and true wind angle without direct reference to boat speed. The resulting ratios can then be multiplied by boat speed to obtain actual wind speeds and angles.

In the example above the boat speed in bsus is, by definition, $s'_b = 1.0$. An apparent wind speed of 16 knots and boat speed of 10 knots translates to $s'_{aw} = 1.60$. The apparent wind angle isl 35°. The true boat wind speed is 0.96 bsus, so the actual true wind speed is $s_{tw} = (0.96)*(10) = 9.6$ knots.

This can be verified in the attached tables for true wind speed and true wind speed angle. The rows are apparent wind speeds in bsus, ranging from 0.20 to 5.0. The columns are apparent wind speed angles, from 5° to 180° . Finding the cell in the table for the column headed 1.60 and the row headed 35° yields a true wind speed of .79 bsus (7.9 knots at 10 knot boat speed) in Table 1 and a true wind angle of 71.3° in Table 2.

TABLE 1
TRUE WIND SPEED

Apparent Wind Direction (° Relative to Bow)	*Apparent Wind Speed Relative to Boat Speed* 0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00
0	0.80	0.60	0.40	0.20	0.00	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00
5	0.80	0.60	0.41	0.22	0.09	0.22	0.41	0.60	0.80	1.00	1.20	1.40	1.60	1.80	1.99	2.19	2.39	2.59	2.79	2.99	3.19	3.39	3.59	3.79	3.99
10	0.81	0.62	0.43	0.26	0.17	0.26	0.43	0.62	0.81	1.00	1.19	1.39	1.59	1.78	1.98	2.17	2.37	2.57	2.76	2.96	3.16	3.35	3.55	3.75	3.94
15	0.82	0.64	0.47	0.32	0.26	0.33	0.47	0.64	0.82	1.00	1.19	1.38	1.57	1.76	1.95	2.14	2.33	2.53	2.72	2.91	3.10	3.30	3.49	3.68	3.87
20	0.83	0.66	0.51	0.39	0.35	0.40	0.51	0.66	0.83	1.00	1.18	1.36	1.54	1.73	1.91	2.10	2.28	2.47	2.66	2.84	3.03	3.22	3.40	3.59	3.78
25	0.84	0.69	0.56	0.47	0.43	0.47	0.57	0.70	0.85	1.01	1.18	1.35	1.52	1.69	1.87	2.05	2.22	2.40	2.58	2.76	2.94	3.12	3.30	3.48	3.66
30	0.86	0.73	0.62	0.54	0.52	0.55	0.63	0.74	0.87	1.02	1.17	1.33	1.49	1.65	1.82	1.98	2.15	2.32	2.49	2.66	2.83	3.00	3.17	3.34	3.51
35	0.87	0.76	0.68	0.62	0.60	0.63	0.69	0.79	0.90	1.03	1.17	1.31	1.46	1.61	1.76	1.92	2.07	2.23	2.39	2.55	2.71	2.87	3.03	3.19	3.35
40	0.89	0.80	0.73	0.69	0.68	0.71	0.76	0.84	0.94	1.05	1.17	1.30	1.43	1.57	1.71	1.85	1.99	2.14	2.29	2.43	2.58	2.73	2.88	3.02	3.17
45	0.91	0.85	0.79	0.77	0.77	0.79	0.84	0.90	0.99	1.08	1.19	1.30	1.42	1.54	1.66	1.79	1.92	2.05	2.18	2.31	2.45	2.58	2.72	2.85	2.99
50	0.94	0.89	0.85	0.84	0.85	0.87	0.91	0.97	1.04	1.12	1.21	1.30	1.41	1.51	1.62	1.73	1.84	1.96	2.08	2.19	2.31	2.43	2.56	2.68	2.80
55	0.96	0.93	0.91	0.91	0.92	0.95	0.99	1.04	1.10	1.17	1.24	1.32	1.41	1.50	1.59	1.69	1.78	1.88	1.99	2.09	2.19	2.30	2.40	2.51	2.62
60	0.98	0.97	0.97	0.98	1.00	1.03	1.07	1.11	1.17	1.22	1.29	1.36	1.43	1.50	1.58	1.66	1.74	1.83	1.91	2.00	2.09	2.18	2.27	2.36	2.45
65	1.00	1.01	1.02	1.05	1.07	1.11	1.15	1.19	1.24	1.29	1.35	1.40	1.46	1.53	1.59	1.66	1.73	1.80	1.87	1.94	2.01	2.09	2.16	2.24	2.31
70	1.02	1.05	1.08	1.11	1.15	1.19	1.23	1.27	1.32	1.37	1.42	1.47	1.52	1.57	1.63	1.68	1.74	1.80	1.86	1.92	1.97	2.03	2.10	2.16	2.22
75	1.04	1.08	1.13	1.17	1.22	1.26	1.31	1.36	1.40	1.45	1.50	1.54	1.59	1.64	1.69	1.74	1.79	1.83	1.88	1.93	1.98	2.03	2.08	2.13	2.18
80	1.06	1.12	1.18	1.23	1.29	1.34	1.39	1.44	1.49	1.54	1.59	1.63	1.68	1.73	1.77	1.82	1.86	1.91	1.95	1.99	2.04	2.08	2.12	2.16	2.21
85	1.08	1.15	1.22	1.29	1.35	1.41	1.47	1.53	1.58	1.63	1.68	1.73	1.78	1.83	1.88	1.92	1.97	2.01	2.05	2.10	2.14	2.18	2.22	2.26	2.30
90	1.10	1.18	1.26	1.34	1.41	1.48	1.55	1.61	1.67	1.73	1.79	1.84	1.90	1.95	2.00	2.05	2.10	2.14	2.19	2.24	2.28	2.32	2.37	2.41	2.45
95	1.11	1.21	1.30	1.39	1.47	1.55	1.63	1.70	1.77	1.83	1.90	1.96	2.02	2.08	2.14	2.19	2.25	2.30	2.35	2.41	2.46	2.51	2.55	2.60	2.65
100	1.12	1.24	1.34	1.44	1.53	1.62	1.70	1.78	1.86	1.94	2.01	2.08	2.15	2.22	2.29	2.35	2.41	2.48	2.54	2.60	2.66	2.72	2.77	2.83	2.89
105	1.14	1.26	1.38	1.48	1.59	1.68	1.78	1.87	1.96	2.04	2.13	2.21	2.29	2.36	2.44	2.52	2.59	2.66	2.73	2.81	2.88	2.95	3.02	3.08	3.15
110	1.15	1.28	1.41	1.53	1.64	1.75	1.85	1.95	2.05	2.15	2.24	2.33	2.42	2.51	2.60	2.69	2.77	2.86	2.94	3.02	3.11	3.19	3.27	3.35	3.43
115	1.16	1.30	1.44	1.56	1.69	1.80	1.92	2.03	2.14	2.25	2.35	2.46	2.56	2.66	2.76	2.86	2.95	3.05	3.15	3.24	3.34	3.43	3.53	3.62	3.71
120	1.17	1.32	1.46	1.60	1.73	1.86	1.98	2.11	2.23	2.35	2.46	2.58	2.69	2.80	2.92	3.03	3.14	3.25	3.36	3.46	3.57	3.68	3.79	3.89	4.00
125	1.17	1.33	1.49	1.63	1.77	1.91	2.05	2.18	2.31	2.44	2.57	2.69	2.82	2.94	3.07	3.19	3.31	3.44	3.56	3.68	3.80	3.92	4.04	4.16	4.28
130	1.18	1.35	1.51	1.66	1.81	1.96	2.11	2.25	2.39	2.53	2.67	2.81	2.94	3.08	3.21	3.35	3.48	3.62	3.75	3.89	4.02	4.15	4.28	4.42	4.55
135	1.18	1.36	1.53	1.69	1.85	2.00	2.16	2.31	2.46	2.61	2.76	2.91	3.06	3.21	3.35	3.50	3.65	3.79	3.94	4.08	4.23	4.37	4.52	4.66	4.80
140	1.19	1.37	1.54	1.71	1.88	2.04	2.21	2.37	2.53	2.69	2.85	3.01	3.17	3.32	3.48	3.64	3.79	3.95	4.11	4.26	4.42	4.57	4.73	4.88	5.04
145	1.19	1.38	1.56	1.73	1.91	2.08	2.25	2.42	2.59	2.76	2.93	3.10	3.26	3.43	3.60	3.76	3.93	4.10	4.26	4.43	4.59	4.76	4.92	5.09	5.25
150	1.19	1.38	1.57	1.75	1.93	2.11	2.29	2.47	2.65	2.82	3.00	3.17	3.35	3.53	3.70	3.88	4.05	4.23	4.40	4.57	4.75	4.92	5.10	5.27	5.45
155	1.20	1.39	1.58	1.77	1.95	2.14	2.32	2.51	2.69	2.88	3.06	3.24	3.42	3.61	3.79	3.97	4.16	4.34	4.52	4.70	4.88	5.07	5.25	5.43	5.61
160	1.20	1.39	1.59	1.78	1.97	2.16	2.35	2.54	2.73	2.92	3.11	3.30	3.49	3.68	3.86	4.05	4.24	4.43	4.62	4.81	5.00	5.18	5.37	5.56	5.75
165	1.20	1.40	1.59	1.79	1.98	2.18	2.37	2.57	2.76	2.95	3.15	3.34	3.54	3.73	3.92	4.12	4.31	4.50	4.70	4.89	5.08	5.28	5.47	5.66	5.86
170	1.20	1.40	1.60	1.79	1.99	2.19	2.39	2.59	2.78	2.98	3.18	3.37	3.57	3.77	3.97	4.16	4.36	4.56	4.75	4.95	5.15	5.35	5.54	5.74	5.94
175	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	2.99	3.19	3.39	3.59	3.79	3.99	4.19	4.39	4.59	4.79	4.99	5.19	5.39	5.59	5.78	5.98
180	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00

The Apparent Wind Speed is the apparent wind speed in boat speed units. If the boat speed over ground is 15 knots and the apparent wind speed is 25 knots, the Apparent Wind Speed in this table is 1.67 bsu (=25/15).

Table 2
TRUE WIND ANGLE

Apparent Wind Direction (° *Relative to Bow*)	*Apparent Wind Speed Relative to Boat Speed* 0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00
5	178.75	176.68	172.59	161.05	92.50	28.15	17.18	13.21	11.19	9.96	9.14	8.55	8.11	7.77	7.49	7.26	7.08	6.92	6.78	6.66	6.56	6.47	6.39	6.31	6.25
10	177.52	173.46	165.71	146.78	95.00	48.90	32.70	25.76	22.03	19.71	18.13	17.00	16.14	15.46	14.92	14.48	14.11	13.80	13.53	13.30	13.09	12.91	12.75	12.61	12.48
15	176.33	170.42	159.73	137.66	97.50	62.87	45.81	37.20	32.24	29.05	26.84	25.23	24.00	23.03	22.25	21.61	21.07	20.61	20.22	19.88	19.58	19.31	19.07	18.86	18.67
20	175.19	167.64	154.80	132.22	100.00	72.73	56.61	47.38	41.68	37.88	35.18	33.18	31.64	30.42	29.43	28.60	27.91	27.33	26.82	26.38	25.99	25.64	25.34	25.06	24.81
25	174.11	165.15	150.93	129.12	102.50	80.20	65.56	56.35	50.31	46.13	43.09	40.80	39.01	37.58	36.41	35.44	34.62	33.92	33.31	32.78	32.31	31.90	31.53	31.19	30.89
30	173.10	162.99	148.02	127.52	105.00	86.26	73.12	64.26	58.16	53.79	50.55	48.05	46.09	44.50	43.19	42.09	41.16	40.36	39.67	39.06	38.53	38.05	37.63	37.24	36.90
35	172.19	161.16	145.91	126.91	107.50	91.42	79.64	71.30	65.32	60.91	57.56	54.94	52.85	51.15	49.74	48.55	47.53	46.65	45.89	45.22	44.63	44.10	43.63	43.20	42.81
40	171.37	159.66	144.48	126.98	110.00	95.98	85.40	77.62	71.87	67.52	64.14	61.47	59.32	57.54	56.05	54.79	53.71	52.78	51.96	51.24	50.60	50.03	49.52	49.05	48.63
45	170.65	158.48	143.61	127.52	112.50	100.12	90.58	83.38	77.90	73.68	70.34	67.67	65.48	63.67	62.14	60.84	59.71	58.74	57.88	57.12	56.44	55.84	55.29	54.80	54.35
50	170.03	157.59	143.20	128.40	115.00	103.97	95.33	88.67	83.50	79.44	76.19	73.55	71.38	69.55	68.00	66.68	65.53	64.52	63.64	62.85	62.15	61.52	60.96	60.44	59.97
55	169.52	156.96	143.15	129.55	117.50	107.59	99.75	93.59	88.74	84.87	81.73	79.16	77.01	75.20	73.65	72.32	71.16	70.15	69.25	68.45	67.73	67.08	66.50	65.97	65.48
60	169.11	156.59	143.41	130.89	120.00	111.05	103.90	98.21	93.67	90.00	87.00	84.50	82.41	80.63	79.11	77.78	76.63	75.61	74.70	73.90	73.17	72.52	71.93	71.39	70.89
65	168.80	156.43	143.93	132.39	122.50	114.38	107.84	102.59	98.34	94.88	92.02	89.62	87.60	85.87	84.37	83.07	81.93	80.92	80.02	79.22	78.49	77.84	77.24	76.70	76.20
70	168.59	156.47	144.65	134.02	125.00	117.60	111.61	106.76	102.80	99.54	96.83	94.54	92.60	90.92	89.47	88.20	87.08	86.09	85.20	84.41	83.69	83.04	82.45	81.90	81.41
75	168.48	156.68	145.55	135.74	127.50	120.74	115.25	110.76	107.08	104.02	101.45	99.28	97.42	95.81	94.41	93.18	92.09	91.12	90.26	89.48	88.77	88.13	87.54	87.01	86.52
80	168.47	157.06	146.59	137.54	130.00	123.82	118.77	114.62	111.20	108.33	105.92	103.86	102.09	100.55	99.21	98.03	96.97	96.04	95.19	94.43	93.74	93.12	92.54	92.02	91.53
85	168.54	157.57	147.76	139.41	132.50	126.83	122.19	118.36	115.18	112.51	110.24	108.30	106.63	105.16	103.88	102.75	101.74	100.83	100.02	99.28	98.62	98.01	97.45	96.94	96.46
90	168.69	158.20	149.04	141.34	135.00	129.81	125.54	122.01	119.05	116.57	114.44	112.62	111.04	109.65	108.43	107.35	106.39	105.52	104.74	104.04	103.39	102.80	102.26	101.77	101.31
95	168.92	158.94	150.40	143.31	137.50	132.74	128.82	125.56	122.83	120.52	118.54	116.83	115.34	114.04	112.88	111.86	110.94	110.12	109.37	108.70	108.08	107.52	107.00	106.52	106.08
100	169.22	159.78	151.85	145.33	140.00	135.64	132.04	129.04	126.52	124.37	122.53	120.94	119.55	118.32	117.24	116.27	115.41	114.63	113.92	113.28	112.69	112.15	111.66	111.20	110.78
105	169.59	160.70	153.36	147.37	142.50	138.51	135.21	132.46	130.13	128.15	126.45	124.97	123.67	122.53	121.51	120.60	119.79	119.05	118.39	117.78	117.22	116.71	116.24	115.81	115.41
110	170.02	161.70	154.93	149.45	145.00	141.36	138.34	135.82	133.69	131.86	130.29	128.92	127.71	126.65	125.70	124.86	124.10	123.41	122.78	122.21	121.69	121.21	120.77	120.36	119.98
115	170.51	162.77	156.55	151.55	147.50	144.19	141.44	139.14	137.18	135.51	134.06	132.80	131.69	130.71	129.83	129.05	128.34	127.70	127.11	126.58	126.09	125.64	125.23	124.84	124.49
120	171.05	163.90	158.21	153.67	150.00	147.00	144.50	142.41	140.63	139.11	137.78	136.63	135.61	134.70	133.90	133.17	132.52	131.93	131.39	130.89	130.44	130.02	129.64	129.28	128.95
125	171.64	165.08	159.91	155.81	152.50	149.79	147.54	145.65	144.04	142.66	141.45	140.40	139.47	138.65	137.91	137.25	136.65	136.10	135.61	135.15	134.74	134.35	134.00	133.67	133.36
130	172.27	166.30	161.65	157.97	155.00	152.57	150.56	148.86	147.41	146.16	145.08	144.13	143.29	142.54	141.88	141.27	140.73	140.23	139.78	139.37	138.99	138.64	138.31	138.01	137.73
135	172.94	167.57	163.41	160.14	157.50	155.34	153.55	152.04	150.75	149.64	148.67	147.82	147.07	146.40	145.80	145.26	144.77	144.32	143.92	143.54	143.20	142.88	142.59	142.32	142.06
140	173.64	168.87	165.20	162.32	160.00	158.10	156.53	155.20	154.06	153.08	152.23	151.48	150.81	150.22	149.69	149.21	148.77	148.38	148.01	147.68	147.38	147.09	146.83	146.59	146.36
145	174.37	170.20	167.01	164.51	162.50	160.86	159.49	158.34	157.35	156.50	155.76	155.10	154.52	154.01	153.54	153.12	152.74	152.40	152.08	151.79	151.52	151.27	151.04	150.83	150.63
150	175.13	171.55	168.83	166.71	165.00	163.60	162.44	161.46	160.62	159.90	159.26	158.70	158.21	157.77	157.37	157.01	156.68	156.39	156.12	155.87	155.64	155.42	155.23	155.04	154.87
155	175.91	172.93	170.67	168.91	167.50	166.35	165.38	164.57	163.88	163.27	162.75	162.28	161.87	161.51	161.17	160.88	160.61	160.36	160.13	159.92	159.73	159.55	159.39	159.24	159.09
160	176.70	174.32	172.52	171.12	170.00	169.08	168.32	167.67	167.12	166.64	166.22	165.85	165.52	165.23	164.96	164.72	164.51	164.31	164.13	163.96	163.81	163.66	163.53	163.41	163.30
165	177.52	175.73	174.39	173.34	172.50	171.81	171.24	170.76	170.35	169.99	169.67	169.40	169.15	168.93	168.73	168.56	168.39	168.24	168.11	167.98	167.87	167.76	167.66	167.57	167.48
170	178.34	177.15	176.25	175.56	175.00	174.54	174.16	173.84	173.57	173.33	173.12	172.94	172.77	172.63	172.50	172.38	172.27	172.17	172.08	172.00	171.92	171.85	171.78	171.72	171.66
175	179.17	178.57	178.13	177.78	177.50	177.27	177.08	176.92	176.79	176.67	176.56	176.47	176.39	176.32	176.25	176.19	176.14	176.09	176.04	176.00	175.96	175.93	175.89	175.86	175.83
180	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00