

新式高效齒輪

— $14\frac{1}{2}^\circ$ 不定中心距離、漸伸線制—

賈魯青 編著

魏振蓀 校閱

大東書局出版

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藏 书 章

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新式高效齒輪內容提要

本書詳述 $14\frac{1}{2}^\circ$ 不定中心距離齒輪的計算原理及其強度、切削用的刀具等。書中舉例甚多，並附有各種不定中心距離正齒輪、斜齒輪、人字齒輪等基本寸法表，可資計算者之參考。

新式高效齒輪

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編著者	賈魯青
校閱者	魏振蓀
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第一章 漸伸線齒形的基本理論

1. 漸伸線齒形的特性

把一條細線繞在基圓 O 上，然後把線拉緊漸漸自基圓上解開，則線的尖端所形成的軌跡就叫做漸伸線。

漸伸線的畫法如圖 1， s 是基點，令基圓的切線 $aa_1 = \widehat{sa}$ ，求出 a_1 點，再令切線 $bb_1 = \widehat{sb}$ ，求出 b_1 點，繼續用同樣方法求出 $c_1, d_1, e_1, f_1, \dots$ 各點來，這些 $a_1, b_1, c_1, \dots$ 點就是細線尖端的軌跡，連結起來形成一條漸伸線。切線 $aa_1, bb_1, \dots$ 等稱為曲線上 $a_1, b_1, \dots$ 各點的曲率半徑，切點 $a, b, \dots$ 等各為 $a_1, b_1, \dots$ 點的運動瞬時中心，因此細線永遠與曲線垂直。

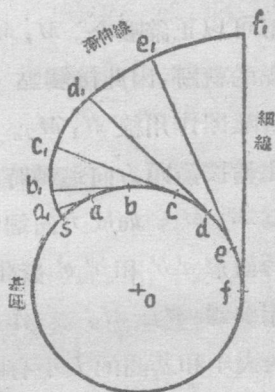


圖 1 漸伸線

現在試用漸伸線作成一對齒輪，在圖 2 中 APB, CPE 各為齒輪 O_1, O_2 的節圓，作斜線 $M_1 M_2$ 通過節點 P ，再作 $O_1 O$ 的同心圓 S_1, S_2 與 $M_1 M_2$ 切於 M_1, M_2 點，以 $S_1 S_2$ 為基圓作漸伸線 ab 和 de ，以 ab, de 所作成之齒形於任意位置上接觸，兩者的接觸點為 Q ，圓 S_1 的切線 QM_1 為漸伸線 ab 上 Q 點的曲率半徑，與 ab 成直角。圓 S_2 的切線 QM_2 為漸伸線 de 上 Q 點的曲率半徑，與 de 成直角。在切點上兩曲線的共同垂直線只有一條，因此 QM_1 和 QM_2 原是一條直線，和 S_1, S_2

的共同切線 $M_1 M_2$ 是一致的。
 $M_1 M_2$ 原是通過 P 點的，所以
 接觸齒形的共同垂線也必須通過
 節點。在相似三角形 $O_1 M_1 P$ 、
 $O_2 M_2 P$ 中：

$$\frac{O_1 M_1}{O_2 M_2} = \frac{O_1 P}{O_2 P}$$

用上列關係的基圓作成漸伸線
 齒形可以正確嚙合。 $M_1 M_2$ 為接
 觸點的軌跡，因此接觸點 Q 永遠
 不會離開作用線 $M_1 M_2$ 。以 O_1
 作主輪按箭頭方向迴轉時，作用
 線為 $M_1 M_2$ ，如反方向迴轉則對
 側的齒形 $a' b'$ 和 $d' e'$ 發生作用，
 作用線為 $M_1' M_2'$ 。作用線傾
 角的大小和基圓的大小有關，因

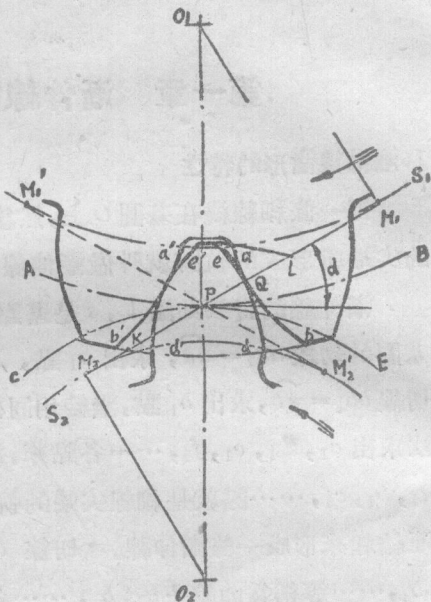


圖 2 漸伸線齒的形成

而影響到漸伸線作用，所以需要互換的一對齒輪，作用線的傾角必須一
 定。作用線的傾角一般叫作壓力角，用 α 來表示。通常多採用 $14\frac{1}{2}^\circ$
 $\sim 20^\circ$ 。但實際上齒的嚙合並沒有 $M_1 M_2$ 那麼長，而是由一齒的頂端
 開始到另一齒的頂端終了。 L 和 K 就是極限點。有時因為齒頂過高，
 L 或 K 點落在 $M_1 M_2$ 的外邊，但是漸伸線在基圓內部是不存在的，這
 種情況下的嚙合，應該以超過的 M_1 或 M_2 點為極限點。

漸伸線齒形在嚙合方面並不見得勝於其他齒形，但是曲線比較簡
 單，齒輪中心距離即使變更，對於嚙合也不會發生影響，同時齒條的齒
 形是直線，如果用來作切齒的刀具是很容易做得準確的，切出來的齒
 輪也比較正確，在實用上很適合，所以一般多使用這種齒形。漸伸線

的最大優點是可以自由選擇，在圖 3 中 O 是基圓， sf 是漸伸線，由 sf 上的任意點 a' 引基圓 O 的切線交於 a 點，那麼 $\angle a'ou$ 是 a' 點的壓力角， $a'a$ 是曲率半徑。再在曲線上取 b' 點，自 b' 點引 O 圓的切線交於 b 點，則 $\angle b'ob$ 是 b' 點的壓力角， $b'b$ 是曲率半徑。由上面可知壓力角和曲率半徑越接近基點 s 越小，離基點 s 越遠越大，在基點上是零。

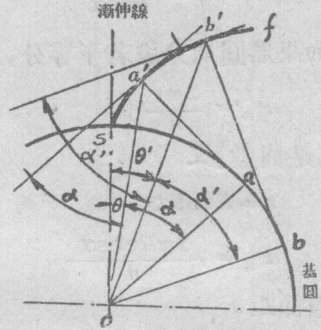


圖 3 漸伸線的選擇

在齒輪上所謂 $14\frac{1}{2}^\circ$ 標準齒輪，就是節圓正好通過曲線上的 $14\frac{1}{2}^\circ$ 的地方。現在假定在一對 $14\frac{1}{2}^\circ$ 標準齒輪上，使節圓通過曲線上 18° 的地方而將中心距離延長，則這對齒輪的壓力角增到 18° 。但是為了獲得較大壓力角而採取這種方法，則齒隙過大而不實用；因此設計一對在任意地方啮合的齒輪時，可以選擇接觸時間長、作用齒面大而滑動較小的漸伸線上的一部分。這樣一來，齒數少的齒輪能夠免去沉割，增加齒的強度，延長齒的壽命。

漸伸線可以用三角法來計算，在圖 4 中 Q 是曲線上的任意一點， α 和 θ 用弧度來表示，則

$$b = \widehat{SM} = r(\theta + \alpha)$$

$$\text{又 } b = r \tan \alpha$$

$$\text{所以 } r(\theta + \alpha) = r \tan \alpha$$

$$\theta = \tan \alpha - \alpha \quad (1)$$

θ 為 α 的函數，一般叫作漸伸線函數。

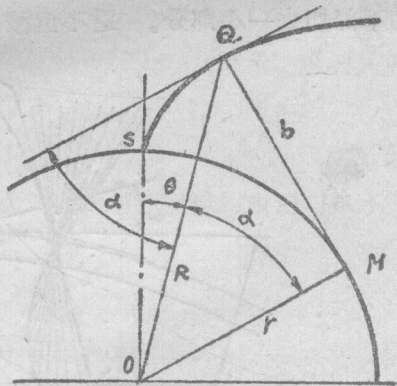


圖 4 漸伸線三角法

在齒輪中 α 為壓力角, r 為基圓半徑, 則節圓半徑 R :

$$R = \frac{r}{\cos \alpha} \quad (2)$$

如果將圓周分成若干等分, 則法節距 P_n :

$$P_n = \frac{2\pi r}{n} \quad (3)$$

n 是齒數。又

$$r = R \cos \alpha$$

$$P_n = \frac{2\pi R \cos \alpha}{n} \quad (4)$$

但節距 P

$$P = \frac{2\pi R}{n}$$

$$\therefore P_n = P \cos \alpha \quad (5)$$

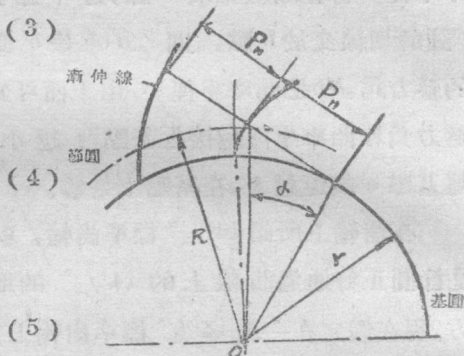


圖 5 法節距

2. 齒的干涉

當 A 齒輪的齒頂伸到 B 齒輪的基圓內時, 這時和漸伸線嚙合作用無關的 A 齒頂端想在 B 齒的基圓內獲得活動的餘地。例如在圖 6 中齒條活動的軌跡進入了基圓內, 侵犯了小齒輪的齒底, 同時還將漸伸線的下部切去一小部分。這不但減少了齒的強度, 對於齒面也是大大不

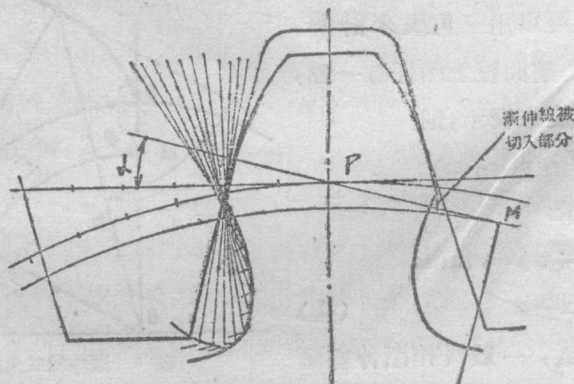


圖 6 齒條與小齒輪發生干涉時的情況

利的。爲了避免干涉，齒條的齒頂必須退到 MN 線的外邊去（圖 7）。 M 點是作用線與基圓的切點， MN 爲由 M 點所引的齒條節線的平行線， M 點叫做干涉點。 A 稱爲干涉半徑。

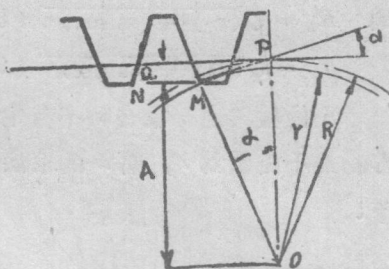


圖 7 不產生干涉的齒條

A = 小齒輪中心到干涉點的最

小距離

r = 基圓半徑

R = 節圓半徑

α = 壓力角

f = 齒條型鏟刀頂上的圓弧部分

則

$$A = r \cos \alpha = R \cos^2 \alpha \quad (6)a$$

如果考慮到齒條型鏟刀的頂端，

則

$$A = R \cos^2 \alpha - f \quad (6)b$$

齒條齒頂極限高度：

$$a = R - A = R(1 - \cos^2 \alpha) = R \sin^2 \alpha \quad (7)a$$

如果考慮到齒條型鏟刀的頂端，

則

$$a = R \sin^2 \alpha + f \quad (7)b$$

如果是兩個有限直徑的齒輪相嚙合時，則各齒輪的齒頂圓都不許越過對方基圓與作用線的切點。

在圖 8 中：

R_1' = 不產生干涉的小齒輪齒頂圓半徑的最大值

R_2' = 不產生干涉的大齒輪齒頂圓半徑的最大值

C = 兩齒輪中心距離

$$\text{則 } R_1' = \sqrt{(r_1)^2 + (c \sin \alpha)^2} \quad (8)$$

$$R_2' = \sqrt{(r_2)^2 + (c \sin \alpha)^2} \quad (9)$$

小齒輪與齒條嚙合時不發生干涉的最小齒數為 n ，則 n 的求法如下：

$$\text{令 } R = \frac{nM}{2}$$

$$a = \frac{nM}{2} \sin^2 \alpha$$

$$\therefore n = \frac{2a}{M \sin^2 \alpha} \quad (10)$$

$$\text{設 } \alpha = 14\frac{1}{2}^\circ \quad \text{則 } \sin^2 14\frac{1}{2}^\circ = 0.0625$$

$$a = M$$

$$\therefore n = \frac{2M}{M \times 0.0625} = 31.8 \approx 32$$

按 M = 模數

在第 10 式中如去掉 n 的小數點以後的值，則為干涉的極限齒數，如進為整數則為不發生干涉的極限齒數。由第 6 式和第 10 式我們可以知道增加壓力角 α ，或減少齒頂 a 都可以降低 n 的值；所以侏式齒的干涉極限齒數比較小。例如 $14\frac{1}{2}^\circ$ 標準齒輪是 31 齒； 20° 標準侏式齒是 13 齒； 20° 全深齒是 17 齒；斐氏 (Fellows) 20° 侏式齒是依節距和鏟刀的直徑而不同，如果用公稱直徑 75 公厘和 100 公厘的鏟刀切削時干涉的最大齒數為 15 齒，最小為 12 齒，這些齒雖然在干涉問題上比標準齒強；但是滑動率的最大絕對值較小，接觸率也小，這是侏式齒的最大缺點。

用齒條型鏟刀切削的齒輪，當齒面發生干涉時，其漸伸線齒面被切

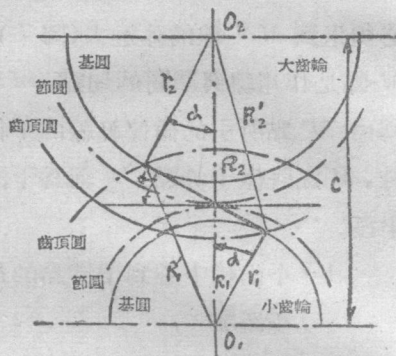


圖 8 避免干涉的齒頂圓的限制

削部分計算如下。

a = 齒條型鏟刀的齒頂

m = 超過干涉極限切入的
深度

x = 由基圓到干涉頂點的
高度

Q = 干涉頂點的半徑

$$\text{則 } x = \frac{m^2}{6r \sin^2 \alpha} \quad (11)$$

$$Q = r + x \quad (12)$$

$$m = A - (R - a) = A + a - R$$

$$R'' = R - a$$

將此值代入前式

$$\text{則 } m = A - R''$$

$$\text{又 } r = R \cos \alpha \quad (13)$$

現在把韋氏 (Ernest Wildhaber) 的計算式列於下面。

鏟刀的壓力角

$$14\frac{1}{2}^\circ \quad x = \frac{2.7448m^2}{R} \quad (14)$$

$$15^\circ \quad x = \frac{2.5758m^2}{R} \quad (15)$$

$$17\frac{1}{2}^\circ \quad x = \frac{1.9327m^2}{R} \quad (16)$$

$$20^\circ \quad x = \frac{1.5158m^2}{R} \quad (17)$$

$$22\frac{1}{2}^\circ \quad x = \frac{1.2320m^2}{R} \quad (18)$$

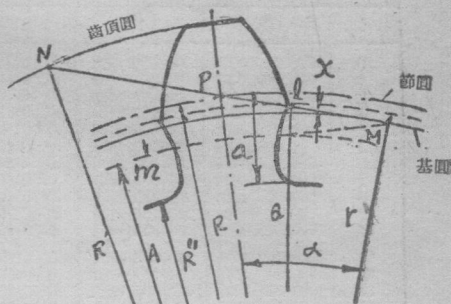


圖 8 齒面沉割部份

第1表 漸伸線函數表

°	0°	1°	2°	3°	4°	5°
0	.00000000000	.00000177241	.0000141844	.000047902	.00011364	.00022220
1	.00000000008	.00000186252	.0000145421	.000048705	.00011507	.00022443
2	.00000000006	.00000195564	.0000149058	.000049517	.00011651	.00022668
3	.00000000022	.00000205181	.0000152755	.000050339	.00011796	.00022894
4	.00000000052	.00000215108	.0000156512	.000051169	.00011943	.00023123
5	.000000001026	.00000225351	.0000160331	.000052010	.00012090	.00023352
6	.000000001772	.00000235913	.0000164211	.000052857	.00012239	.00023583
7	.000000002814	.00000246801	.0000168153	.000053715	.00012389	.00023816
8	.000000004201	.00000258019	.0000172158	.000054582	.00012541	.00024049
9	.000000005981	.00000269572	.0000176226	.000055458	.00012693	.00024284
10	.000000008205	.00000281464	.0000180358	.000056344	.00012847	.00024522
11	.000000010920	.00000293701	.0000184554	.000057239	.00013002	.00024761
12	.000000014178	.00000306288	.0000188814	.000058144	.00013158	.00025001
13	.000000018026	.00000319230	.0000193140	.000059058	.00013316	.00025243
14	.000000022514	.00000332531	.0000197531	.000059981	.00013474	.00025486
15	.000000027691	.00000346197	.0000201988	.000060914	.00013634	.00025731
16	.000000033606	.00000360232	.0000206512	.000061857	.00013796	.00025977
17	.000000040310	.00000374642	.0000211103	.000062810	.00013958	.00026225
18	.000000047850	.00000389431	.0000215762	.000063772	.00014122	.00026474
19	.000000056276	.00000404604	.0000220488	.000064744	.00014287	.00026726
20	.000000065638	.00000420166	.0000225283	.000065726	.00014453	.00026978
21	.000000075984	.00000436122	.0000230148	.000066717	.00014621	.00027233
22	.000000087364	.00000452478	.0000235082	.000067719	.00014790	.00027489
23	.000000099827	.00000469237	.0000240085	.000068731	.00014960	.00027746
24	.000000113423	.00000486405	.0000245160	.000069752	.00015132	.00028005
25	.000000128199	.00000503988	.0000250305	.000070784	.00015305	.00028266
26	.000000144207	.00000521989	.0000255522	.000071826	.00015479	.00028528
27	.000000161495	.00000540413	.0000260812	.000072878	.00015655	.00028792
28	.000000180212	.00000559266	.0000266173	.000073941	.00015831	.00029055
29	.000000200108	.00000578553	.0000271608	.000075013	.00016010	.00029325
30	.000000221531	.00000598279	.0000277116	.000076096	.00016189	.00029594
31	.000000244431	.00000618447	.0000282698	.000077190	.00016370	.00029864
32	.000000268857	.00000639065	.0000288355	.000078294	.00016552	.00030137
33	.000000294859	.00000660135	.0000294087	.000079408	.00016736	.00030410
34	.000000322486	.00000681664	.0000299894	.000080533	.00016921	.00030686
35	.000000351787	.00000703656	.0000305777	.000081668	.00017107	.00030963
36	.000000382810	.00000726116	.0000311737	.000082814	.00017294	.00031242
37	.000000415607	.00000749049	.0000317774	.000083971	.00017483	.00031522
38	.000000450224	.00000772461	.0000323898	.000085138	.00017674	.00031804
39	.000000486713	.00000796355	.0000330081	.000086317	.00017866	.00032088
40	.000000525122	.00000820737	.0000336352	.000087506	.00018059	.00032374
41	.000000565501	.00000845612	.0000342701	.000088706	.00018253	.00032661
42	.000000607898	.00000870984	.0000349131	.000089917	.00018449	.00032950
43	.000000652363	.00000896960	.0000355640	.000091139	.00018646	.00033241
44	.000000698946	.00000923243	.0000362230	.000092372	.00018845	.00033533
45	.000000747695	.00000950139	.0000368900	.000093616	.00019045	.00033827
46	.000000798660	.00000977552	.0000375653	.000094871	.00019247	.00034123
47	.000000851889	.00001005487	.0000382487	.000096137	.00019450	.00034421
48	.000000907433	.00001033950	.0000389404	.000097415	.00019654	.00034720
49	.000000965341	.00001062946	.0000396403	.000098704	.00019860	.00035021
50	.000001025661	.00001092479	.0000403486	.000100004	.00020067	.00035324
51	.000001088443	.00001122553	.0000410653	.000101316	.00020276	.00035628
52	.000001153737	.00001153176	.0000417905	.000102639	.00020486	.00035934
53	.000001221591	.00001184350	.0000425241	.000103974	.00020698	.00036242
54	.000001292056	.00001216081	.0000432663	.000105320	.00020911	.00036552
55	.000001365179	.00001248375	.0000440171	.000106678	.00021125	.00036864
56	.000001441011	.00001281235	.0000447765	.000108047	.00021341	.00037177
57	.000001519600	.00001314667	.0000455447	.000109428	.00021559	.00037492
58	.000001600997	.00001348676	.0000463215	.000110821	.00021778	.00037809
59	.000001685250	.00001383267	.0000471072	.000112225	.00021998	.00038128
60	.000001772408	.00001418445	.0000479017	.000113642	.00022220	.00038448

	6°	7°	8°	9°	10°	11°	12°	13°
0	.0003845	.0006115	.0009145	.0013043	.0017941	.0023941	.0031171	.0039754
1	.0003877	.0006159	.0009203	.0013121	.0018031	.0024051	.0031302	.0039909
2	.0003909	.0006203	.0009260	.0013195	.0018122	.0024161	.0031434	.0040065
3	.0003942	.0006248	.0009318	.0013268	.0018213	.0024272	.0031567	.0040221
4	.0003975	.0006292	.0009377	.0013342	.0018305	.0024383	.0031699	.0040377
5	.0004008	.0006337	.0009435	.0013416	.0018397	.0024495	.0031832	.0040534
6	.0004041	.0006382	.0009494	.0013491	.0018489	.0024607	.0031966	.0040692
7	.0004074	.0006427	.0009553	.0013566	.0018581	.0024719	.0032100	.0040849
8	.0004108	.0006473	.0009612	.0013641	.0018674	.0024831	.0032234	.0041008
9	.0004141	.0006518	.0009672	.0013716	.0018767	.0024944	.0032369	.0041166
10	.0004175	.0006564	.0009732	.0013792	.0018860	.0025057	.0032504	.0041325
11	.0004209	.0006610	.0009792	.0013863	.0018954	.0025171	.0032639	.0041485
12	.0004244	.0006657	.0009852	.0013944	.0019048	.0025285	.0032775	.0041644
13	.0004278	.0006703	.0009913	.0014020	.0019142	.0025399	.0032911	.0041805
14	.0004313	.0006750	.0009973	.0014097	.0019237	.0025513	.0033048	.0041965
15	.0004347	.0006797	.0010034	.0014174	.0019332	.0025628	.0033185	.0042126
16	.0004382	.0006844	.0010096	.0014251	.0019427	.0025744	.0033322	.0042288
17	.0004417	.0006892	.0010157	.0014329	.0019523	.0025859	.0033460	.0042450
18	.0004453	.0006939	.0010219	.0014407	.0019619	.0025975	.0033599	.0042612
19	.0004488	.0006987	.0010281	.0014485	.0019715	.0026091	.0033736	.0042775
20	.0004524	.0007035	.0010343	.0014563	.0019812	.0026208	.0033875	.0042938
21	.0004560	.0007083	.0010406	.0014642	.0019909	.0026325	.0034014	.0043102
22	.0004596	.0007132	.0010469	.0014721	.0020006	.0026443	.0034154	.0043265
23	.0004632	.0007181	.0010532	.0014800	.0020103	.0026560	.0034294	.0043430
24	.0004669	.0007230	.0010595	.0014880	.0020201	.0026678	.0034431	.0043595
25	.0004705	.0007279	.0010659	.0014960	.0020299	.0026797	.0034575	.0043760
26	.0004743	.0007328	.0010722	.0015040	.0020398	.0026916	.0034716	.0043926
27	.0004780	.0007378	.0010786	.0015120	.0020497	.0027035	.0034853	.0044092
28	.0004817	.0007428	.0010851	.0015201	.0020596	.0027154	.0035000	.0044259
29	.0004854	.0007478	.0010915	.0015282	.0020695	.0027274	.0035144	.0044426
30	.0004892	.0007528	.0010980	.0015363	.0020795	.0027394	.0035285	.0044593
31	.0004930	.0007579	.0011045	.0015445	.0020895	.0027515	.0035428	.0044761
32	.0004968	.0007629	.0011111	.0015527	.0020995	.0027636	.0035572	.0044929
33	.0005006	.0007680	.0011176	.0015609	.0021096	.0027757	.0035716	.0045098
34	.0005045	.0007732	.0011242	.0015691	.0021197	.0027879	.0035860	.0045267
35	.0005083	.0007783	.0011303	.0015774	.0021299	.0028001	.0036005	.0045437
36	.0005122	.0007835	.0011375	.0015857	.0021400	.0028123	.0036150	.0045607
37	.0005161	.0007887	.0011441	.0015941	.0021502	.0028246	.0036296	.0045777
38	.0005200	.0007939	.0011508	.0016024	.0021605	.0028369	.0036441	.0045948
39	.0005240	.0007991	.0011575	.0016108	.0021707	.0028493	.0036588	.0046120
40	.0005280	.0008044	.0011643	.0016193	.0021810	.0028616	.0036735	.0046291
41	.0005319	.0008096	.0011711	.0016277	.0021914	.0028741	.0036882	.0046464
42	.0005359	.0008150	.0011779	.0016362	.0022017	.0028865	.0037029	.0046636
43	.0005400	.0008203	.0011847	.0016447	.0022121	.0028990	.0037177	.0046809
44	.0005440	.0008256	.0011915	.0016533	.0022226	.0029115	.0037326	.0046983
45	.0005481	.0008310	.0011984	.0016618	.0022330	.0029241	.0037474	.0047157
46	.0005522	.0008364	.0012053	.0016704	.0022435	.0029367	.0037623	.0047331
47	.0005563	.0008418	.0012122	.0016791	.0022541	.0029494	.0037773	.0047506
48	.0005604	.0008473	.0012192	.0016877	.0022647	.0029620	.0037923	.0047681
49	.0005645	.0008527	.0012262	.0016964	.0022753	.0029747	.0038073	.0047857
50	.0005687	.0008582	.0012332	.0017051	.0022859	.0029875	.0038224	.0048033
51	.0005729	.0008638	.0012402	.0017139	.0022966	.0030003	.0038375	.0048210
52	.0005771	.0008693	.0012473	.0017227	.0023073	.0030131	.0038527	.0048387
53	.0005813	.0008749	.0012544	.0017315	.0023180	.0030260	.0038679	.0048564
54	.0005856	.0008805	.0012615	.0017403	.0023288	.0030389	.0038831	.0048742
55	.0005898	.0008861	.0012687	.0017492	.0023396	.0030518	.0038984	.0048921
56	.0005941	.0008917	.0012758	.0017581	.0023504	.0030648	.0039137	.0049099
57	.0005985	.0008974	.0012830	.0017671	.0023613	.0030778	.0039291	.0049279
58	.0006028	.0009031	.0012903	.0017760	.0023722	.0030908	.0039445	.0049458
59	.0006071	.0009088	.0012975	.0017850	.0023831	.0031039	.0039599	.0049639
60	.0006115	.0009145	.0013048	.0017941	.0023941	.0031171	.0039754	.0049819

Λ	14°	15°	16°	17°	18°	19°	20°	21°
0	.0049819	.0061498	.0074927	.0090247	.0107604	.0127151	.0149044	.0173449
1	.0050000	.0061707	.0075166	.0090519	.0107912	.0127496	.0149430	.0173878
2	.0050182	.0061917	.0075406	.0090792	.0108220	.0127842	.0149816	.0174308
3	.0050364	.0062127	.0075647	.0091065	.0108528	.0128188	.0150203	.0174738
4	.0050546	.0062337	.0075888	.0091339	.0108838	.0128535	.0150591	.0175169
5	.0050729	.0062548	.0076130	.0091614	.0109147	.0128883	.0150979	.0175601
6	.0050912	.0062760	.0076372	.0091889	.0109458	.0129232	.0151369	.0176034
7	.0051096	.0062972	.0076614	.0092164	.0109769	.0129581	.0151758	.0176468
8	.0051280	.0063184	.0076857	.0092440	.0110081	.0129931	.0152149	.0176902
9	.0051465	.0063397	.0077101	.0092717	.0110393	.0130281	.0152540	.0177337
10	.0051650	.0063611	.0077345	.0092994	.0110706	.0130632	.0152932	.0177773
11	.0051835	.0063825	.0077590	.0093272	.0111019	.0130984	.0153325	.0178209
12	.0052022	.0064039	.0077835	.0093551	.0111333	.0131336	.0153719	.0178646
13	.0052208	.0064254	.0078081	.0093830	.0111648	.0131689	.0154113	.0179084
14	.0052395	.0064470	.0078327	.0094109	.0111964	.0132043	.0154507	.0179523
15	.0052582	.0064686	.0078574	.0094390	.0112280	.0132398	.0154903	.0179963
16	.0052770	.0064902	.0078822	.0094670	.0112596	.0132753	.0155299	.0180403
17	.0052958	.0065119	.0079069	.0094952	.0112913	.0133103	.0155696	.0180844
18	.0053147	.0065337	.0079318	.0095234	.0113231	.0133465	.0156094	.0181286
19	.0053336	.0065555	.0079567	.0095516	.0113550	.0133822	.0156492	.0181728
20	.0053525	.0065773	.0079817	.0095799	.0113869	.0134180	.0156891	.0182172
21	.0053716	.0065992	.0080067	.0096082	.0114189	.0134538	.0157291	.0182616
22	.0053907	.0066211	.0080317	.0096367	.0114509	.0134897	.0157692	.0183061
23	.0054098	.0066431	.0080568	.0096652	.0114830	.0135257	.0158093	.0183506
24	.0054290	.0066652	.0080820	.0096937	.0115151	.0135617	.0158495	.0183953
25	.0054482	.0066873	.0081072	.0097223	.0115474	.0135978	.0158898	.0184400
26	.0054674	.0067094	.0081325	.0097510	.0115796	.0136340	.0159301	.0184848
27	.0054867	.0067316	.0081578	.0097797	.0116120	.0136702	.0159705	.0185296
28	.0055060	.0067539	.0081832	.0098085	.0116444	.0137065	.0160110	.0185746
29	.0055254	.0067762	.0082087	.0098373	.0116769	.0137429	.0160516	.0186196
30	.0055448	.0067985	.0082342	.0098662	.0117094	.0137794	.0160922	.0186647
31	.0055643	.0068209	.0082597	.0098951	.0117420	.0138159	.0161329	.0187099
32	.0055838	.0068434	.0082853	.0099241	.0117747	.0138525	.0161737	.0187551
33	.0056034	.0068659	.0083110	.0099532	.0118074	.0138891	.0162145	.0188004
34	.0056230	.0068884	.0083367	.0099823	.0118402	.0139258	.0162554	.0188458
35	.0056427	.0069110	.0083625	.0100115	.0118730	.0139626	.0162964	.0188913
36	.0056624	.0069337	.0083883	.0100407	.0119059	.0139994	.0163375	.0189369
37	.0056822	.0069564	.0084142	.0100700	.0119389	.0140364	.0163786	.0189825
38	.0057020	.0069791	.0084401	.0100994	.0119720	.0140734	.0164198	.0190282
39	.0057218	.0070019	.0084661	.0101288	.0120051	.0141104	.0164611	.0190740
40	.0057417	.0070248	.0084921	.0101583	.0120382	.0141475	.0165024	.0191199
41	.0057617	.0070477	.0085182	.0101878	.0120715	.0141847	.0165439	.0191659
42	.0057817	.0070706	.0085444	.0102174	.0121048	.0142220	.0165854	.0192119
43	.0058017	.0070936	.0085706	.0102471	.0121381	.0142593	.0166269	.0192580
44	.0058218	.0071167	.0085969	.0102768	.0121715	.0142967	.0166686	.0193042
45	.0058420	.0071398	.0086232	.0103066	.0122050	.0143342	.0167103	.0193504
46	.0058622	.0071630	.0086496	.0103364	.0122386	.0143717	.0167521	.0193968
47	.0058824	.0071862	.0086760	.0103663	.0122722	.0144093	.0167939	.0194432
48	.0059028	.0072095	.0087025	.0103963	.0123059	.0144470	.0168359	.0194897
49	.0059230	.0072328	.0087290	.0104263	.0123396	.0144847	.0168779	.0195363
50	.0059434	.0072561	.0087556	.0104564	.0123734	.0145225	.0169200	.0195829
51	.0059638	.0072796	.0087823	.0104865	.0124073	.0145604	.0169621	.0196296
52	.0059843	.0073030	.0088090	.0105167	.0124412	.0145983	.0170044	.0196765
53	.0060048	.0073266	.0088358	.0105469	.0124752	.0146363	.0170467	.0197233
54	.0060254	.0073501	.0088626	.0105773	.0125093	.0146744	.0170891	.0197703
55	.0060460	.0073738	.0088895	.0106078	.0125434	.0147126	.0171315	.0198174
56	.0060667	.0073975	.0089164	.0106381	.0125776	.0147508	.0171740	.0198645
57	.0060874	.0074212	.0089434	.0106686	.0126119	.0147891	.0172166	.0199117
58	.0061081	.0074450	.0089704	.0106991	.0126462	.0148275	.0172593	.0199590
59	.0061289	.0074688	.0089975	.0107298	.0126806	.0148659	.0173021	.0200063
60	.0061498	.0074927	.0090247	.0107604	.0127151	.0149044	.0173449	.0200538

	22°	23°	24°	25°	26°	27°	28°	29°
0	.0200538	.0230491	.0263497	.0299753	.0339470	.0382866	.0430172	.0481636
1	.0201013	.0231015	.0264074	.0300388	.0340162	.0383621	.0430995	.0482530
2	.0201489	.0231541	.0264652	.0301020	.0340856	.0384378	.0431819	.0483426
3	.0201966	.0232067	.0265231	.0301655	.0341550	.0385136	.0432645	.0484323
4	.0202444	.0232594	.0265810	.0302291	.0342246	.0385895	.0433471	.0485221
5	.0202922	.0233122	.0266391	.0302928	.0342942	.0386655	.0434299	.0486120
6	.0203401	.0233651	.0266973	.0303566	.0343640	.0387416	.0435128	.0487020
7	.0203881	.0234181	.0267555	.0304205	.0344339	.0388179	.0435957	.0487922
8	.0204362	.0234711	.0268139	.0304844	.0345038	.0388942	.0436789	.0488825
9	.0204844	.0235242	.0268723	.0305485	.0345739	.0389706	.0437621	.0489730
10	.0205326	.0235775	.0269308	.0306127	.0346441	.0390472	.0438454	.0490635
11	.0205809	.0236308	.0269894	.0306769	.0347144	.0391239	.0439289	.0491542
12	.0206293	.0236842	.0270481	.0307413	.0347847	.0392006	.0440124	.0492450
13	.0206778	.0237376	.0271069	.0308058	.0348552	.0392775	.0440961	.0493359
14	.0207264	.0237912	.0271658	.0308703	.0349258	.0393545	.0441799	.0494269
15	.0207750	.0238449	.0272248	.0309350	.0349965	.0394316	.0442639	.0495181
16	.0208238	.0238986	.0272839	.0309997	.0350673	.0395088	.0443479	.0496094
17	.0208726	.0239524	.0273430	.0310646	.0351382	.0395862	.0444321	.0497008
18	.0209215	.0240063	.0274023	.0311295	.0352092	.0396636	.0445163	.0497924
19	.0209704	.0240603	.0274617	.0311946	.0352803	.0397411	.0446007	.0498840
20	.0210195	.0241144	.0275211	.0312597	.0353515	.0398188	.0446853	.0499758
21	.0210686	.0241686	.0275806	.0313250	.0354228	.0398966	.0447699	.0500677
22	.0211178	.0242228	.0276403	.0313903	.0354942	.0399745	.0448546	.0501598
23	.0211671	.0242772	.0277000	.0314557	.0355658	.0400524	.0449395	.0502519
24	.0212165	.0243316	.0277598	.0315213	.0356374	.0401306	.0450245	.0503442
25	.0212660	.0243861	.0278197	.0315869	.0357091	.0402088	.0451096	.0504367
26	.0213155	.0244407	.0278797	.0316527	.0357810	.0402871	.0451948	.0505292
27	.0213651	.0244954	.0279398	.0317185	.0358529	.0403655	.0452801	.0506219
28	.0214148	.0245502	.0279999	.0317844	.0359249	.0404441	.0453656	.0507147
29	.0214646	.0246050	.0280602	.0318504	.0359971	.0405227	.0454512	.0508076
30	.0215145	.0246600	.0281206	.0319166	.0360694	.0406015	.0455369	.0509006
31	.0215644	.0247150	.0281810	.0319828	.0361417	.0406804	.0456227	.0509939
32	.0216145	.0247702	.0282416	.0320491	.0362142	.0407594	.0457086	.0510871
33	.0216646	.0248254	.0283022	.0321156	.0362868	.0408385	.0457947	.0511806
34	.0217148	.0248807	.0283630	.0321821	.0363594	.0409177	.0458803	.0512741
35	.0217651	.0249361	.0284238	.0322487	.0364322	.0409970	.0459671	.0513678
36	.0218154	.0249916	.0284848	.0323154	.0365051	.0410765	.0460535	.0514616
37	.0218659	.0250471	.0285458	.0323823	.0365781	.0411561	.0461401	.0515555
38	.0219164	.0251028	.0286069	.0324492	.0366512	.0412357	.0462267	.0516496
39	.0219670	.0251585	.0286681	.0325162	.0367244	.0413155	.0463135	.0517438
40	.0220177	.0252143	.0287294	.0325833	.0367977	.0413954	.0464004	.0518381
41	.0220685	.0252703	.0287908	.0326506	.0368712	.0414754	.0464874	.0519326
42	.0221193	.0253263	.0288523	.0327179	.0369447	.0415555	.0465745	.0520271
43	.0221703	.0253824	.0289139	.0327853	.0370183	.0416358	.0466618	.0521218
44	.0222213	.0254386	.0289756	.0328528	.0370921	.0417161	.0467491	.0522167
45	.0222724	.0254948	.0290373	.0329205	.0371659	.0417966	.0468366	.0523116
46	.0223236	.0255512	.0290992	.0329882	.0372399	.0418772	.0469242	.0524067
47	.0223749	.0256076	.0291612	.0330560	.0373139	.0419579	.0470120	.0525019
48	.0224262	.0256642	.0292232	.0331239	.0373881	.0420387	.0470998	.0525973
49	.0224777	.0257208	.0292854	.0331920	.0374624	.0421196	.0471878	.0526923
50	.0225292	.0257775	.0293476	.0332601	.0375368	.0422006	.0472759	.0527884
51	.0225808	.0258343	.0294100	.0333283	.0376113	.0422818	.0473641	.0528841
52	.0226325	.0258912	.0294724	.0333967	.0376859	.0423630	.0474525	.0529799
53	.0226843	.0259482	.0295349	.0334651	.0377606	.0424444	.0475409	.0530759
54	.0227361	.0260053	.0295976	.0335336	.0378354	.0425259	.0476295	.0531721
55	.0227881	.0260625	.0296603	.0336023	.0379103	.0426075	.0477182	.0532683
56	.0228401	.0261197	.0297231	.0336710	.0379853	.0426892	.0478070	.0533647
57	.0228922	.0261771	.0297860	.0337399	.0380605	.0427710	.0478960	.0534612
58	.0229444	.0262345	.0298490	.0338098	.0381357	.0428530	.0479851	.0535578
59	.0229967	.0262920	.0299121	.0338778	.0382111	.0429351	.0480743	.0536546
60	.0230491	.0263497	.0299753	.0339470	.0382866	.0430172	.0481636	.0537515

	30°	31°	32°	33°	34°	35°	36°	37°
0	.0537515	.0599086	.0663640	.0734489	.0810966	.0893423	.0982240	.1077822
1	.0538485	.0599136	.0664776	.0735717	.0812290	.0894850	.0983776	.1079475
2	.0539457	.0600189	.0665914	.0736946	.0813616	.0896279	.0985315	.1081130
3	.0540430	.0601242	.0667053	.0738177	.0814943	.0897710	.0986855	.1082787
4	.0541404	.0602297	.0668195	.0739409	.0816273	.0899142	.0988397	.1084445
5	.0542379	.0603354	.0669337	.0740643	.0817604	.0900576	.0989941	.1086106
6	.0543356	.0604412	.0670481	.0741878	.0818936	.0902012	.0991487	.1087769
7	.0544334	.0605471	.0671627	.0743115	.0820271	.0903450	.0993035	.1089434
8	.0545314	.0606532	.0672774	.0744354	.0821606	.0904889	.0994584	.1091101
9	.0546295	.0607594	.0673922	.0745594	.0822944	.0906331	.0996136	.1092770
10	.0547277	.0608657	.0675072	.0746835	.0824283	.0907774	.0997689	.1094440
11	.0548260	.0609722	.0676223	.0748079	.0825624	.0909218	.0999244	.1096113
12	.0549245	.0610789	.0677376	.0749324	.0826967	.0910665	.1000802	.1097788
13	.0550231	.0611856	.0678530	.0750570	.0828311	.0912113	.1002361	.1099465
14	.0551218	.0612925	.0679686	.0751818	.0829657	.0913564	.1003922	.1101144
15	.0552207	.0613995	.0680843	.0753068	.0831005	.0915016	.1005485	.1102825
16	.0553197	.0615067	.0682002	.0754319	.0832354	.0916469	.1007050	.1104508
17	.0554189	.0616140	.0683162	.0755571	.0833705	.0917928	.1008616	.1106193
18	.0555181	.0617215	.0684324	.0756826	.0835058	.0919382	.1010185	.1107880
19	.0556175	.0618291	.0685487	.0758082	.0836413	.0920834	.1011756	.1109570
20	.0557170	.0619368	.0686652	.0759339	.0837769	.0922303	.1013328	.1111261
21	.0558166	.0620447	.0687818	.0760598	.0839127	.0923765	.1014903	.1112954
22	.0559164	.0621527	.0688986	.0761859	.0840486	.0925230	.1016477	.1114649
23	.0560164	.0622609	.0690155	.0763121	.0841847	.0926696	.1018057	.1116347
24	.0561164	.0623692	.0691326	.0764385	.0843210	.0928165	.1019637	.1118046
25	.0562166	.0624777	.0692498	.0765651	.0844575	.0929635	.1021219	.1119747
26	.0563169	.0625863	.0693672	.0766918	.0845941	.0931106	.1022804	.1121451
27	.0564174	.0626950	.0694848	.0768187	.0847309	.0932580	.1024389	.1123156
28	.0565180	.0628039	.0696024	.0769457	.0848679	.0934055	.1025977	.1124864
29	.0566187	.0629129	.0697203	.0770729	.0850050	.0935533	.1027567	.1126573
30	.0567196	.0630221	.0698383	.0772003	.0851424	.0937012	.1029159	.1128285
31	.0568206	.0631314	.0699564	.0773278	.0852799	.0938493	.1030753	.1129999
32	.0569217	.0632408	.0700747	.0774555	.0854175	.0939975	.1032348	.1131715
33	.0570230	.0633504	.0701931	.0775833	.0855553	.0941460	.1033946	.1133433
34	.0571244	.0634602	.0703117	.0777113	.0856933	.0942946	.1035545	.1135153
35	.0572259	.0635700	.0704304	.0778395	.0858315	.0944435	.1037147	.1136875
36	.0573276	.0636801	.0705493	.0779678	.0859699	.0945925	.1038750	.1138599
37	.0574294	.0637902	.0706684	.0780963	.0861084	.0947417	.1040356	.1140325
38	.0575313	.0639005	.0707876	.0782249	.0862471	.0948910	.1041963	.1142053
39	.0576334	.0640110	.0709069	.0783537	.0863859	.0950406	.1043572	.1143784
40	.0577356	.0641216	.0710265	.0784827	.0865250	.0951903	.1045181	.1145516
41	.0578380	.0642323	.0711461	.0786118	.0866642	.0953402	.1046797	.1147250
42	.0579405	.0643432	.0712659	.0787411	.0868036	.0954904	.1048412	.1148987
43	.0580431	.0644542	.0713859	.0788706	.0869431	.0956406	.1050029	.1150726
44	.0581458	.0645654	.0715060	.0790002	.0870829	.0957911	.1051648	.1152466
45	.0582487	.0646767	.0716263	.0791300	.0872228	.0959418	.1053269	.1154209
46	.0583518	.0647882	.0717467	.0792600	.0873628	.0960926	.1054892	.1155954
47	.0584549	.0648998	.0718673	.0793901	.0875031	.0962437	.1056517	.1157701
48	.0585582	.0650116	.0719880	.0795204	.0876435	.0963949	.1058144	.1159451
49	.0586617	.0651235	.0721039	.0796508	.0877841	.0965463	.1059773	.1161202
50	.0587652	.0652355	.0722300	.0797814	.0879249	.0966979	.1061404	.1162955
51	.0588690	.0653477	.0723512	.0799122	.0880659	.0968496	.1063037	.1164711
52	.0589728	.0654599	.0724725	.0800431	.0882070	.0970016	.1064672	.1166468
53	.0590768	.0655725	.0725940	.0801742	.0883483	.0971537	.1066309	.1168228
54	.0591809	.0656851	.0727157	.0803055	.0884898	.0973061	.1067947	.1169990
55	.0592852	.0657979	.0728375	.0804369	.0886314	.0974586	.1069588	.1171754
56	.0593896	.0659108	.0729595	.0805685	.0887732	.0976113	.1071231	.1173520
57	.0594941	.0660239	.0730816	.0807003	.0889152	.0977642	.1072876	.1175288
58	.0595988	.0661371	.0732039	.0808322	.0890574	.0979173	.1074521	.1177058
59	.0597036	.0662505	.0733263	.0809643	.0891998	.0980705	.1076171	.1178831
60	.0598086	.0663640	.0734489	.0810966	.0893423	.0982240	.1077822	.1180605

	38°	39°	40°	41°	42°	43°	44°	45°
0	.1180605	.1291056	.1409679	.1537017	.1673658	.1820235	.1977439	.2146018
1	.1182382	.1292965	.1411729	.1539217	.1676017	.1822766	.1980153	.2149929
2	.1184161	.1294876	.1413780	.1541419	.1678380	.1825300	.1982871	.2151843
3	.1185942	.1296789	.1415635	.1543623	.1680745	.1827837	.1985591	.2154760
4	.1187725	.1298704	.1417891	.1545831	.1683113	.1830377	.1988315	.2157681
5	.1189510	.1300622	.1419950	.1548040	.1685484	.1832920	.1991042	.2160605
6	.1191297	.1302542	.1422012	.1550253	.1687857	.1835465	.1993772	.2163533
7	.1193087	.1304464	.1424076	.1552468	.1690234	.1838014	.1996505	.2166464
8	.1194878	.1306389	.1426142	.1554685	.1692613	.1840566	.1999242	.2169398
9	.1196672	.1308316	.1428211	.1556906	.1694994	.1843121	.2001982	.2172336
10	.1198466	.1310245	.1430282	.1559128	.1697379	.1845678	.2004724	.2175277
11	.1200266	.1312177	.1432355	.1561354	.1699767	.1848239	.2007471	.2178222
12	.1202066	.1314110	.1434432	.1563582	.1702157	.1850803	.2010220	.2181170
13	.1203869	.1316046	.1436510	.1565812	.1704550	.1853369	.2012972	.2184121
14	.1205673	.1317985	.1438591	.1568046	.1706946	.1855939	.2015728	.2187076
15	.1207480	.1319925	.1440675	.1570281	.1709344	.1858512	.2018487	.2190035
16	.1209289	.1321868	.1442761	.1572520	.1711746	.1861087	.2021249	.2192996
17	.1211100	.1323814	.1444849	.1574761	.1714150	.1863666	.2024014	.2195962
18	.1212913	.1325761	.1446940	.1577005	.1716557	.1866248	.2026783	.2198930
19	.1214728	.1327711	.1449033	.1579251	.1718967	.1868832	.2029554	.2201903
20	.1216546	.1329663	.1451129	.1581500	.1721380	.1871420	.2032329	.2204878
21	.1218366	.1331618	.1453227	.1583752	.1723795	.1874011	.2035108	.2207857
22	.1220188	.1333575	.1455328	.1586005	.1726214	.1876604	.2037890	.2210840
23	.1222012	.1335534	.1457431	.1588263	.1728635	.1879201	.2040674	.2213826
24	.1223838	.1337495	.1459537	.1590523	.1731059	.1881801	.2043462	.2216815
25	.1225666	.1339459	.1461645	.1592785	.1733486	.1884404	.2046253	.2219808
26	.1227497	.1341425	.1463756	.1595050	.1735915	.1887010	.2049047	.2222805
27	.1229330	.1343394	.1465869	.1597318	.1738348	.1889619	.2051845	.2225805
28	.1231165	.1345365	.1467985	.1599588	.1740783	.1892230	.2054646	.2228808
29	.1233002	.1347338	.1470103	.1601861	.1743221	.1894845	.2057450	.2231815
30	.1234842	.1349313	.1472223	.1604135	.1745662	.1897463	.2060257	.2234826
31	.1236683	.1351291	.1474347	.1606414	.1748106	.1900084	.2063068	.2237840
32	.1238527	.1353271	.1476472	.1608695	.1750553	.1902709	.2065882	.2240857
33	.1240373	.1355254	.1478600	.1610979	.1753003	.1905336	.2068699	.2243878
34	.1242221	.1357239	.1480731	.1613265	.1755455	.1907966	.2071520	.2246903
35	.1244072	.1359226	.1482864	.1615554	.1757911	.1910599	.2074344	.2249931
36	.1245924	.1361216	.1485000	.1617846	.1760369	.1913236	.2077171	.2252962
37	.1247779	.1363203	.1487138	.1620140	.1762830	.1915875	.2080001	.2255997
38	.1249636	.1365202	.1489279	.1622437	.1765294	.1918518	.2082835	.2259036
39	.1251495	.1367199	.1491422	.1624737	.1767761	.1921163	.2085672	.2262078
40	.1253357	.1369198	.1493568	.1627039	.1770230	.1923812	.2088512	.2265124
41	.1255221	.1371199	.1495716	.1629344	.1772703	.1926464	.2091356	.2268173
42	.1257087	.1373203	.1497867	.1631652	.1775179	.1929119	.2094203	.2271226
43	.1258955	.1375209	.1500020	.1633963	.1777657	.1931777	.2097053	.2274282
44	.1260825	.1377218	.1502176	.1636276	.1780138	.1934438	.2099907	.2277342
45	.1262698	.1379228	.1504335	.1638592	.1782622	.1937102	.2102764	.2280406
46	.1264573	.1381242	.1506496	.1640910	.1785109	.1939769	.2105624	.2283473
47	.1266450	.1383257	.1508659	.1643232	.1787599	.1942440	.2108487	.2286543
48	.1268329	.1385275	.1510825	.1645556	.1790092	.1945113	.2111354	.2289616
49	.1270210	.1387296	.1512994	.1647882	.1792588	.1947790	.2114225	.2292695
50	.1272094	.1389319	.1515165	.1650212	.1795087	.1950469	.2117098	.2295777
51	.1273980	.1391344	.1517339	.1652544	.1797589	.1953152	.2119975	.2298862
52	.1275869	.1393372	.1519515	.1654879	.1800093	.1955833	.2122855	.2301950
53	.1277759	.1395402	.1521694	.1657217	.1802601	.1958527	.2125739	.2305042
54	.1279652	.1397434	.1523875	.1659557	.1805111	.1961220	.2128626	.2308138
55	.1281547	.1399469	.1526059	.1661900	.1807624	.1963915	.2131516	.2311238
56	.1283444	.1401506	.1528246	.1664246	.1810141	.1966613	.2134410	.2314341
57	.1285344	.1403546	.1530433	.1666595	.1812660	.1969315	.2137307	.2317447
58	.1287246	.1405588	.1532626	.1668946	.1815182	.1972020	.2140207	.2320557
59	.1289150	.1407632	.1534821	.1671301	.1817707	.1974723	.2143111	.2323671
60	.1291056	.1409679	.1537017	.1673658	.1820235	.1977439	.2146018	.2326789