MIT 2.008 Design and Manufacturing II
Spring 2022
March 16, 2022

- Closed Book
- All work for CREDIT must be completed in this quiz document
- You are allowed one double-sided, hand written 8.5” x 11” notes sheet
- Calculators are allowed

Name: __________________________

Problem 1		Out of 16 points
Problem 2		Out of 28 points
Problem 3		Out of 10 points
Problem 4		Out of 36 points
Problem 5		Out of 10 points
Total		**100 points**

Problem 1

Circle or write in the correct answer(s).

a) All else being equal, using a polymer that has a higher melt temperature will lead to (**higher / lower**) shrinkage in injection molding.

b) Improving the surface finish on a mold can help decrease flash defects. **True / False**

c) Increasing the crystallinity of a polymer can cause a change from rubbery to glassy at the same temperature. **True / False**

d) A stretch ratio of 10:1 is generally acceptable for thermoforming. **True / False**

e) **(Absorptivity, reflectivity, conduction, emissivity)** does not significantly impact the heating time in a thermoformed part.

f) You mill a pocket with a given set of parameters (depth of cut, width of cut, feed rate). If you double the spindle speed, while holding all other parameters the same, the power required (**stays the same / doubles**).

g) You are turning a part on a lathe with a constant surface speed, feed, and depth of cut. If you step down to a new diameter that is half of the original diameter, the cutting force (**decreases / stays the same / increases**).

h) In machining, it's possible to have zero thrust force. **True / False**

i) Molten polymers are (**shear thickening / Newtonian / shear thinning)** fluids.

j) Molten metals have a **(higher / same / lower)** thermal diffusivity than polymers.

k) Die casting requires **(larger / smaller)** runner cross sections than sand casting.

l) Die casting can have internal cavities. **True / False**

m) The insertion force for press fit is linear with press depth. **True / False**

n) Increasing the frequency at which you take sample means would decrease the distance between your UCL and LCL. **True / False**

o) With regards to process control, it is possible to be in control but out of spec. **True / False**

p) Your tolerances always have to be +/- 3 sigma. **True / False**

Problem 2 - Injection Molding

COVID-19 was just spiking in March 2020. You are working at Rhinostics, the company that supplies MIT their COVID test swabs, and need to analyze the manufacturing process in order to be able to produce defect-free parts as quickly as possible. Closer images of key features are also provided in **Appendix I**. The teaching staff also has several physical versions of the parts to inspect if needed. The middle of the swab is not hollow, the handle end is hollow, and the swab collection area teeth are 1 mm in height in either direction and spaced 1 mm apart.

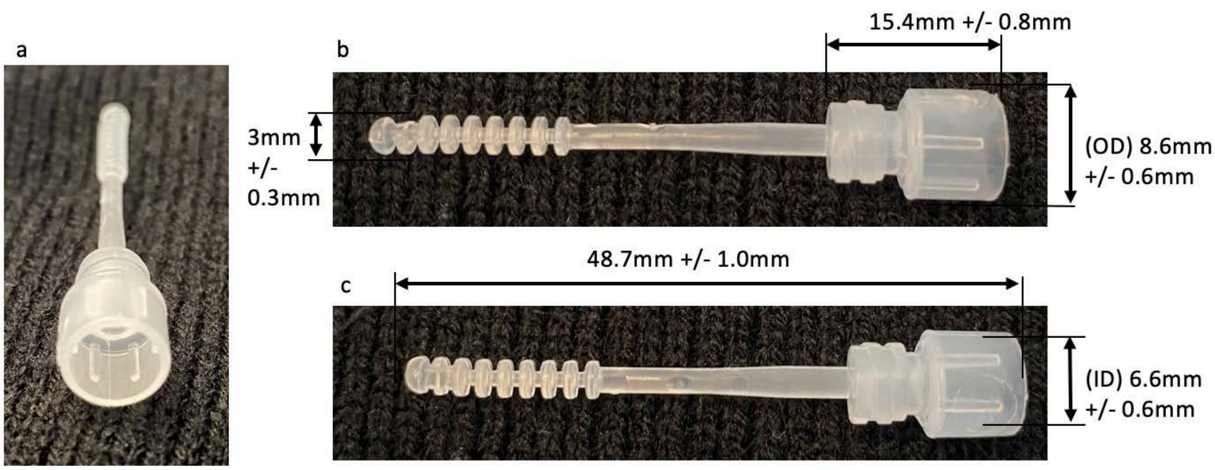


Figure 1 - Rhinostics nasal swab (a - end view, b - side-view, c - top-view)

Basic Swab Specifications:

Material:	Polypropylene
Viscosity:	1000 Pa-s
Density:	ρ = 905 kg/m^3
Specific heat:	c_p = 1920 J/kg-K
Thermal conductivity:	k = 0.16 W/m-K

a) Sketch a cross section of the mold used to make this part, **identifying and labeling** all critical features of the part and components of the mold.

b) Estimate the clamping force for a single part. Ignore the teeth and just consider the simplified geometry of the cap and the main swab as shown in Figure 2. The pressure drop in the part is 70 MPa. What is the maximum number of parts that you could produce in a single mold with the BOY XXS that has 80kN maximum clamping force?

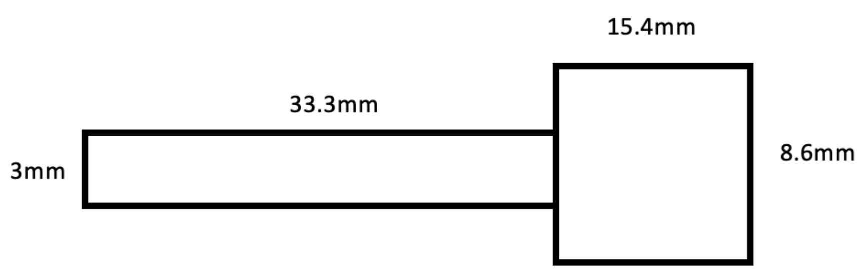


Figure 2 - Swab geometry simplification

c) Estimate the maximum number of swabs that you could produce in an hour assuming that all other cycle time contributions besides the cooling time are negligible and that $(T_{melt} - T_{mold}) \approx 10(T_{ejection} - T_{mold})$.

d) Upon first manufacturing, there was a significant flash on the end of the swab. Why is that problematic for this particular part given its use? Propose 3 ways to fix the flash using different injection molding parameters and mold/material properties. For full credit, also use a process window to defend your answer.

e) You acquire a larger machine and design an 8-part mold by creating a linear array of swabs as seen below in Figure 3. What types of differences (defects) would you expect between parts 1 and 2? Describe what would be a better layout for the multi-part mold, considering both those defects and space efficiency?

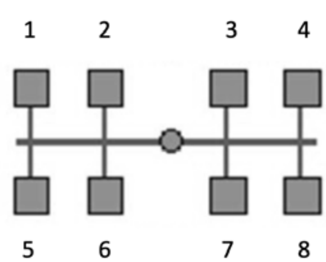


Figure 3 - Multi-part swab mold layout

Problem 3 - Casting

While many high end bicycles use cold forged aluminum alloy or carbon composite cranks, cast aluminum alloy cranks are widely utilized in high volume, low cost applications. Figure 4a shows a rider on a bicycle and 4b shows detail of the drive side crank and chainring.

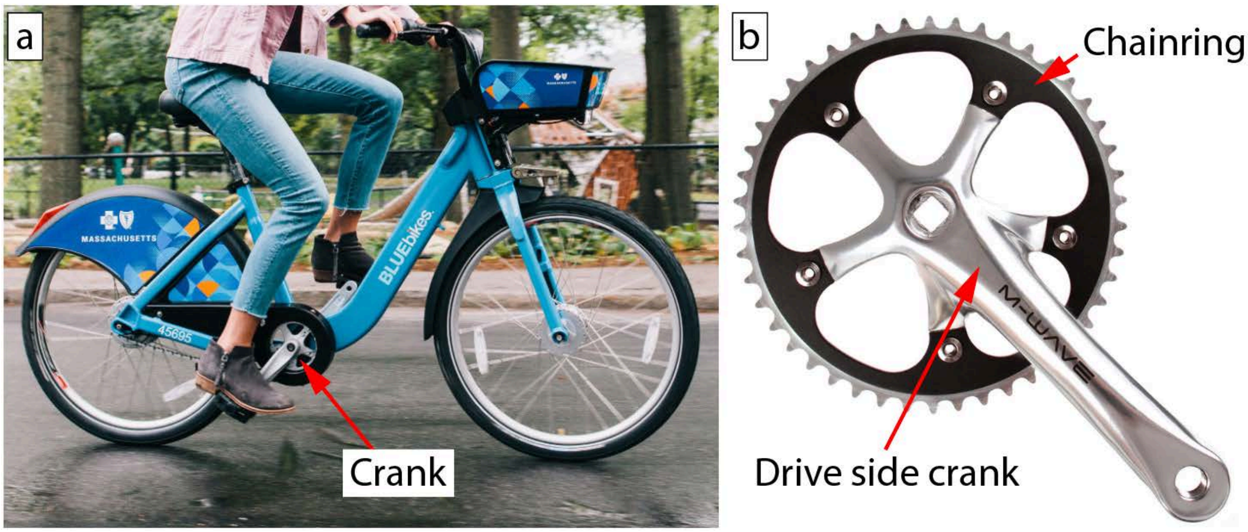


Figure 4: (a) Cyclist pedaling a crank and (b) drive side crank and joined chainring.

Shown below in Figures 5-8 is the drive side crank of a cast crankset, consisting of an arm and an integrated spider (the features that hold the chainring).

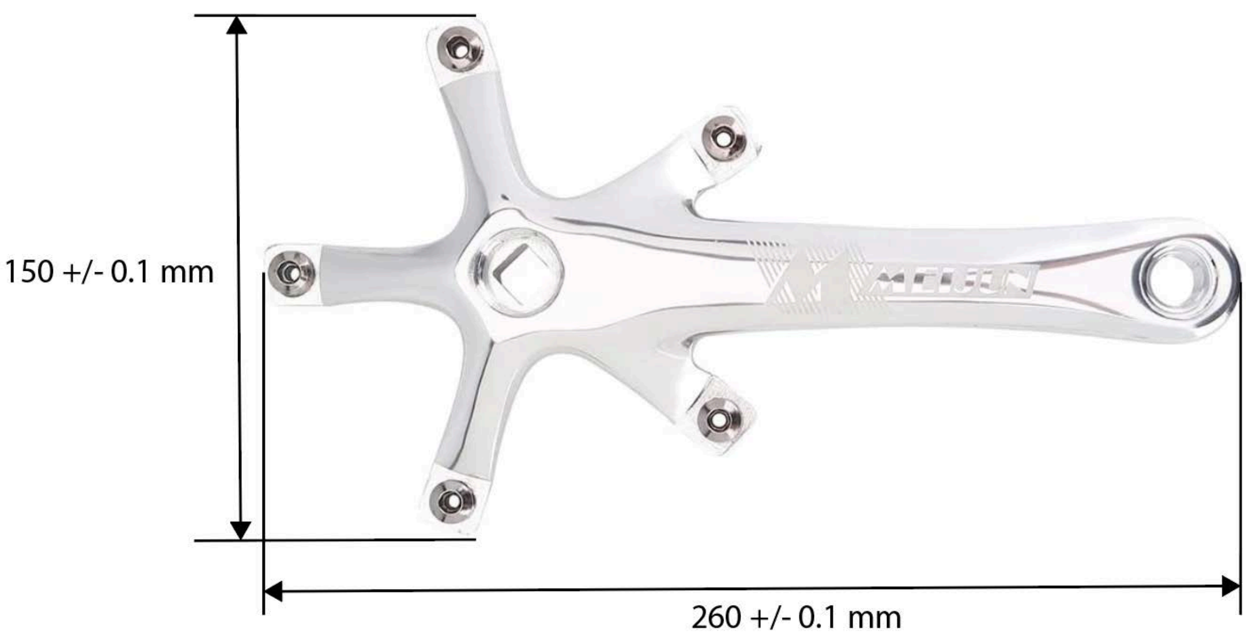


Figure 5: Drive side crank with dimensions.

Figure 6: Isometric view of drive side crank.

Figure 7: Backside of drive side crank.

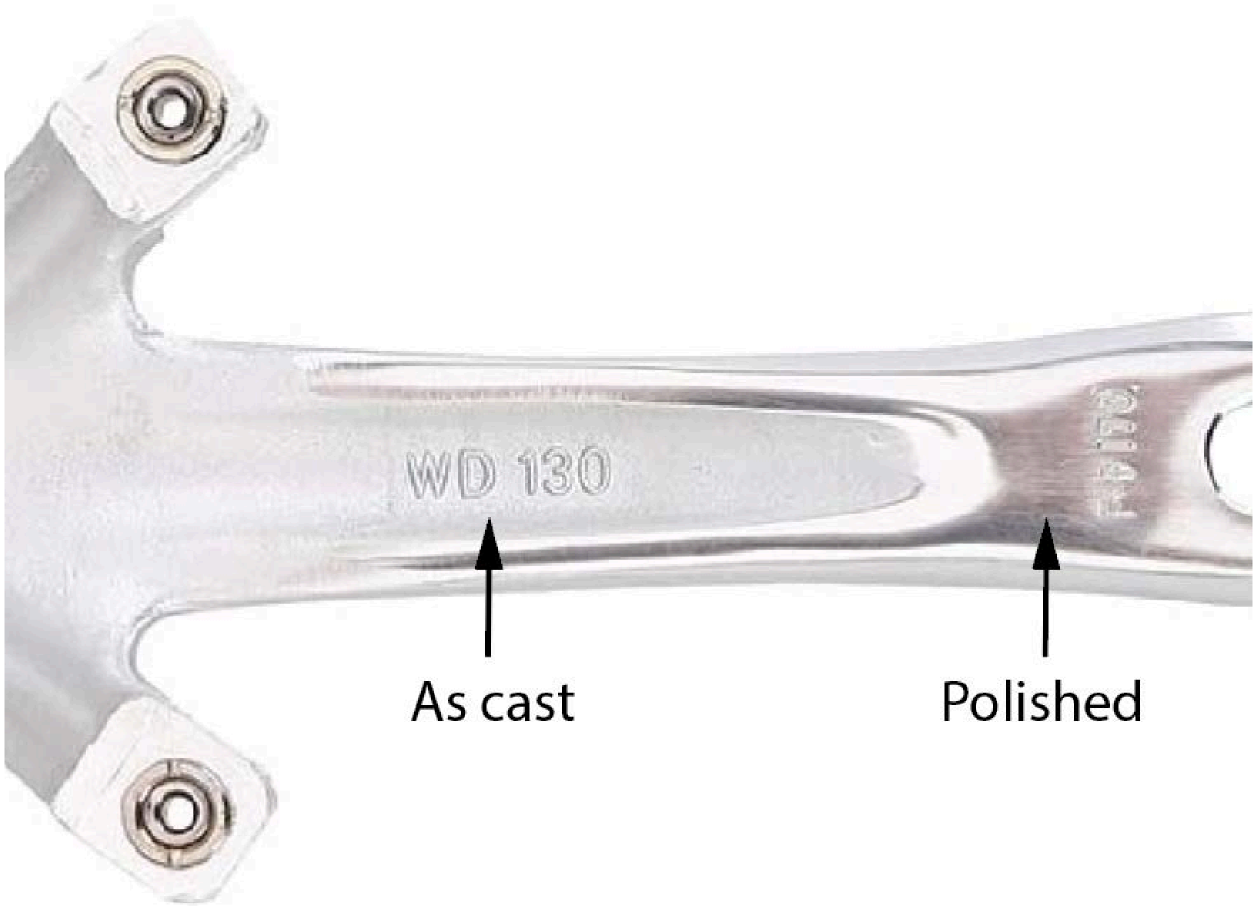


Figure 8: Backside detail of drive side crank.

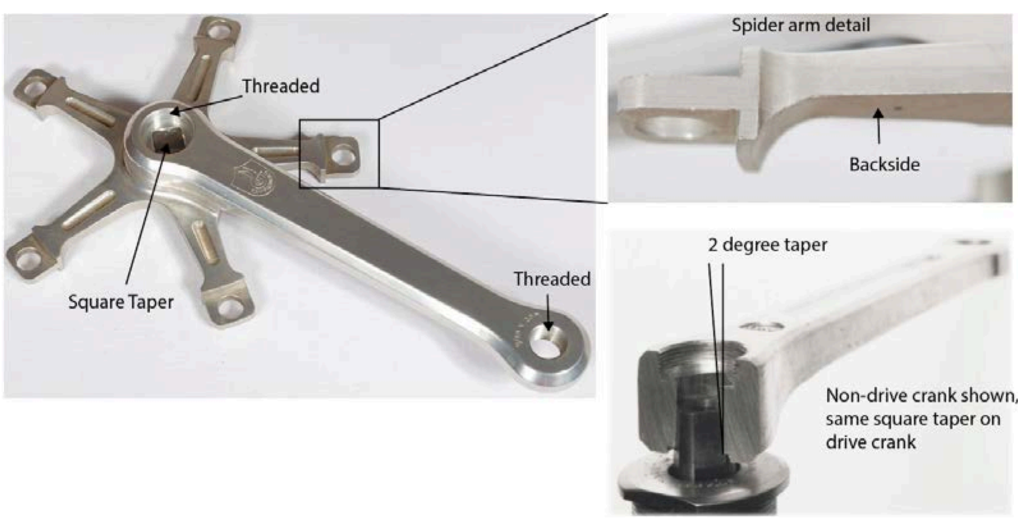
a) As shown in Figures 3 and 4, the crank has a maximum length of 260 +/- 0.1 mm, a total width of 150 +/- 0.1 mm, a volume of 150 cm^3, and a surface area of 260 cm^2. Given these specified dimensions, what would you estimate to be the solidification time to be for the part? You can assume that it has a uniform thickness.

For an aluminum alloy part and sand mold, use a constant C = 84.7 s/cm^2, or for an aluminum alloy part and steel mold, use a constant C = 1.4 s/cm.

b) While cast cranks find application in lower cost bikes, they are not suitable for high performance bikes with riders capable of generating a lot of force. Provide a reason for why this is the case, commenting on the grain structure and strength of cast parts.

Problem 4 - Cutting

You run a small bicycle manufacturer. A combination of high demand and massive supply chain and shipping delays have resulted in your shop having zero crankset inventory for your bike building operation. The crankset supplier estimated that it will be 5 months until they can ship you more cranksets. As this is the only part that you are missing, and you have a backlog of bike orders waiting to be fulfilled, you consider quickly supplementing crank production with CNC machined parts, similar to the Campagnolo cranksets widely used in the 70's and 80's.



a) The drive side crank has a volume of approximately 150 cm^3 and your stock is 27 x 16 x 4 cm. You have a number of HAAS VF-2SS CNC machines available to use, with spindles rated at 22.4 kW and 12,000 rpm. You are using a 12 mm diameter, 3 flute end mill. The range of machining conditions for aluminum alloys are a feed of 0.08 - 0.4 mm/tooth and a cutting speed of 300-3000 m/min. For your high efficiency milling application you choose a feed of 0.2 mm/tooth, a depth of cut of 20mm, and a width of cut of 3 mm. Additionally, the specific energy of your aluminum alloy is 0.8 W*s/mm^3. How long would you estimate the rough machining operation of the drive side crank to take?

b) Given your estimate, how would you expect the actual machining time to compare? Support your answer with a process plan for machining the part.

c) How would you expect the rate, quality, cost, and flexibility of milling and casting processes to compare for producing a part like the crank? What process would you use if you were a small builder producing 100 bikes per year, or a large builder producing 10,000 bikes per year?

	Process	
Attribute	**Milling**	**Casting**
Rate		
Quality		
Cost		
Flexibility		

Problem 5 - Variation / Quality Control

Refer to the dimensioned drawing of the nasal swab above and focus on the cap diameter. Those tolerances were set so that you would only scrap 1.24% of parts out of specification. Refer to **Appendix II** for z-tables if needed.

a) Assuming a centered process, what must be your process standard deviation?

b) What is the Cpk?

c) Just based on the 1.24% defect rate, how would you have known that the Cpk would be less than 1 without even calculating anything?

Appendix I: Additional Photos of Nasal Swab

Appendix II: Z-tables

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
–3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
–3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
–3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
–3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
–3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
–2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
–2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
–2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
–2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
–2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
–2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
–2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
–2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
–2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
–2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
–1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
–1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
–1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
–1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
–1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
–1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
–1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
–1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
–1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
–1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
–0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
–0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
–0.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
–0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
–0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
–0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
–0.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
–0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
–0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
–0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998