MIT 2.008 Design and Manufacturing II

Spring 2021

March 31, 2021

- 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. Please submit a copy of your sheet to Canvas
- Calculators are allowed

Problem 1		Out of 16 points
Problem 2		Out of 20 points
Problem 3		Out of 16 points
Problem 4		Out of 24 points
Problem 5		Out of 24 points
Total		**100 points**

Problem 1
Circle or write in the correct answer(s).

Injection Molding
Your injection molding machine has a fixed maximum injection pressure. If you are producing two parts of equivalent volume, a _______ **(small, thick part / large, thin part)** has the greatest risk of a short-shot defect.

Venting air can be a reason for choosing a parting line location. **True / False**

Using a ______ **(higher/lower)** viscosity material would reduce the clamp force.

The packing pressure is usually ______ **(higher/lower)** than the injection pressure.

Thermoforming
Draft angles are needed on both thermoformed and injection molded parts. **True / False**

Additive Manufacturing
A larger build volume directly increases your rate of production. **True / False**

SLA normally has _______ **(higher/lower)** resolution than FDM parts.

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

If you double the feed rate, the cutting force _____ **(stays the same / doubles)**

A major assumption to simplify the geometry for analysis is ______ **(orthogonal/oblique)** cutting.

You can have a negative rake angle. **True / False**

When the shear angle increases, the shear strain _______ **(increases / decreases).**

Variation / Quality Control
If you set the tolerance of a shaft/stem diameter as 0.50" +/- 0.01", it is the ____ **(UCL / USL).**

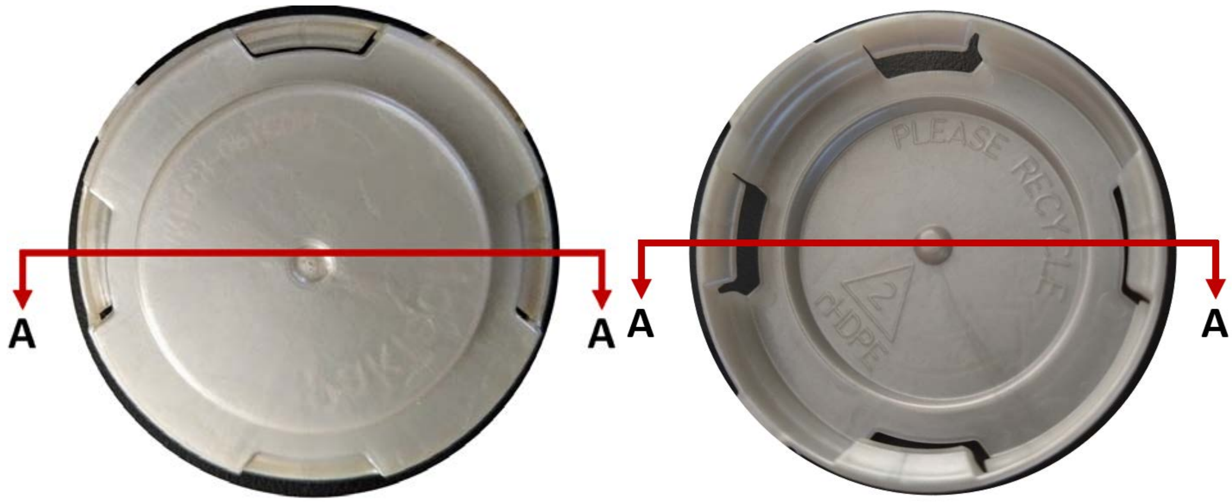
According to the central limit theorem, _____ **(more/less)** samples increase the precision of the estimate of the average.

As the subgroup size decreases, the UCL and LCL move _____ **(closer/further)** to the center line, making the control chart ____ **(more/less)** sensitive to shifts in the mean.

Problem 2 - Injection Molding

Recall the **Can Carrier** for holding aluminum cans that we saw in the lecture breakout session. A few images of the product are shown below.

a) Sketch a cross section of the mold used to make this part, identifying and labeling critical features. Additional, full size images are included in the appendix for further inspection. For simplicity, sketch the mold at section A-A shown in the figure below, and only draw for a single can portion of the part:



b) Estimate the cycle time to make the part, if the fill time is 2 seconds. Treat the part as a single flat disk with a diameter of 60 mm and thickness of 1 mm. The part is made of HDPE (high density polyethylene) polymer, with properties given below:

- Melting point = 130 C
- Thermal conductivity = 0.44 W/m-K
- Density = 960 kg/m^3
- Specific heat capacity= 1880 J/kg-K

Explain your calculations and reasoning.

c) Estimate the clamping force required for the whole 4 can part, if the injection pressure is 3 MPa. You can neglect the interconnecting sections and center holding tab in your calculation.

Problem 3 - Thermoforming + Additive Manufacturing + Defects

Inspect the plastic can carrier images further.

a) On the largest image in Problem 2, find and label all of the part's gates. What quality consideration did the manufacturer make with regards to the gate design/location?

b) You find out from your customers that the can carriers keep breaking at the weld line locations that we saw in class. To counteract this issue, you decide to reduce to one gate, keeping it in the same location. Comment on an issue with this design change and another defect that it might cause instead. Support this with any fundamental analysis.

c) Instead of reducing the gates, you instead try to use the same locations but make the connectors 10x as thick to avoid fracturing. Comment on an issue with this design change and another defect that it might cause instead.

d) Suggest two ways to avoid these weld lines without changing the design of the part/tooling.

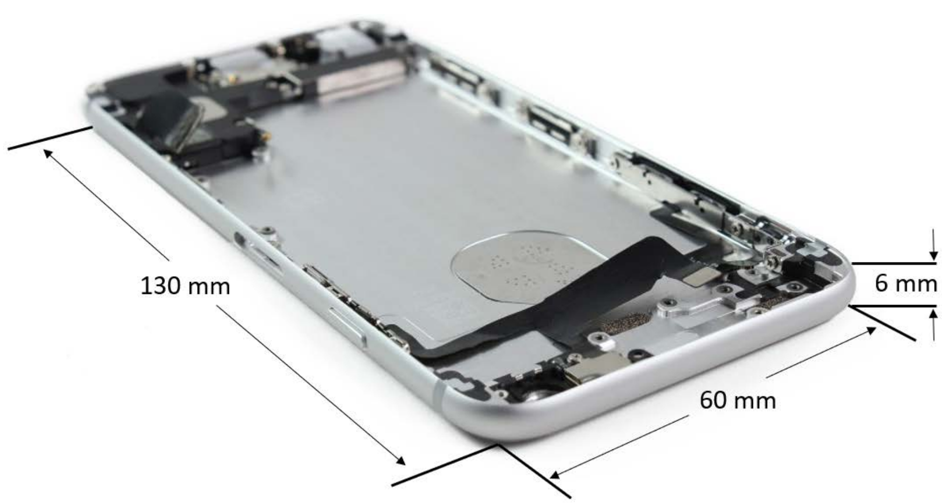
e) Give two reasons why the manufacturer would not have used thermoforming for this part. Be specific about the issue and location/region affected.

f) What would be an issue with using FDM to make tooling for a thermoformed part? Could this be eliminated using SLA for the tooling instead?

Problem 4 - Cutting

One example of a high volume, machined consumer product was the iPhone 6 chassis, shown in the figure below:

You are tasked with machining the pocket for the chassis. For this analysis, you can simplify the geometry and features - treat this operation as milling a rectangular pocket with dimensions of 130 x 60 x 6 mm.



The part material is 6061-T6 aluminum alloy with the following properties:

- Density ρ = 2700 kg/m^3,
- Specific heat capacity = 900 J/kg·K
- Thermal diffusivity = $6.9*10^{-5}$ m^2/s
- Specific energy = 0.8 W·s/mm^3

a) You have a coated carbide end mill (3 flute) that is 6 mm in diameter and are roughing the whole depth of 6 mm in a single pass. The end mill manufacturer states that the following conditions are suitable given your tool/workpiece material combination:
   - Feed = 0.2 mm/tooth
   - Speed = 1400 m/min

   How long would it take you to perform this machining operation, assuming you use a 100% stepover (a width of cut of 6 mm) and your machine has no limitations in it's capability?

b) In reality your mill has performance limitations. You have a HAAS VF2 mill rated at:
   - Max Power = 22.4 kW (30 HP)
   - Max Spindle Speed = 15,000 RPM

   Is your machine capable of performing the above operation in the amount of time you calculated in part (a)?

c) With the max spindle speed from part (b), what is the power required to perform the operation?

d) After a few highly publicized incidents of users bending their phone chassis, a design engineer suggests switching to a **titanium alloy** to improve stiffness while maintaining the same dimensions. **Qualitatively**, in 1-2 sentences, how does this change in material impact your operation time and tool requirements? Use table 24.2 from Kalpakjian below to help you with your answer.

TABLE 24.2

General Recommendations for Milling Operations (Note That These Values Are for a Particular Machining Geometry and Are Often Exceeded in Practice)

		General-purpose starting conditions		Range of conditions	
Material	Cutting tool	Feed, mm/tooth	Speed, m/min	Feed, mm/tooth	Speed, m/min
Low-carbon and free-machining steels	Uncoated carbide, coated carbide, cermets	0.13–0.20	100–472	0.085–0.38	90–425
Alloy steels					
Soft	Uncoated, coated, cermets	0.10–0.18	100–260	0.08–0.30	60–370
Hard	Cermets, PcBN	0.10–0.15	90–220	0.08–0.25	75–460
Cast iron, gray					
Soft	Uncoated, coated, cermets, SiN	0.10–0.20	160–440	0.08–0.38	90–1370
Hard	Cermets, SiN, PcBN	0.10–0.20	120–300	0.08–0.38	90–460
Stainless steel, Austenitic	Uncoated, coated, cermets	0.13–0.18	120–370	0.08–0.38	90–500
High-temperature alloys Nickel based	Uncoated, coated, cermets, SiN, PcBN	0.10–0.18	30–370	0.08–0.38	30–550
Titanium alloys	Uncoated, coated, cermets	0.13–0.15	50–60	0.08–0.38	40–140
Aluminum alloys					
Free machining	Uncoated, coated, PCD	0.13–0.23	1200–1460	0.08–0.46	300–3000
High silicon	PCD	0.13	610	0.08–0.38	370–910
Copper alloys	Uncoated, coated, PCD PCD	0.13–0.23	300–760	0.08–0.46	90–1070
Plastics	Uncoated, coated, PCD PCD	0.13–0.23	270–460	0.08–0.46	90–1370

Source: Based on data from Kennametal, Inc.
Note: Depths of cut, *d*, usually are in the range of 1–8 mm. PcBN: polycrystalline cubic-boron nitride; PCD: polycrystalline diamond. See also Table 23.4 for range of cutting speeds within tool material groups.

Problem 5 - Quality Control and Variation

a) A can carrier is defective if the cans will not snap into the carrier correctly. Assume the cans themselves have no variation. To succeed with such low profit margins, the can carrier manufacturer must have less than 5 defective parts out of every 1000. This is an idealization, as injection molding defect rates would probably be much less in practice. The target mean diameter is 60mm. The standard deviation is 0.1mm. A z-table is located in the Appendix.

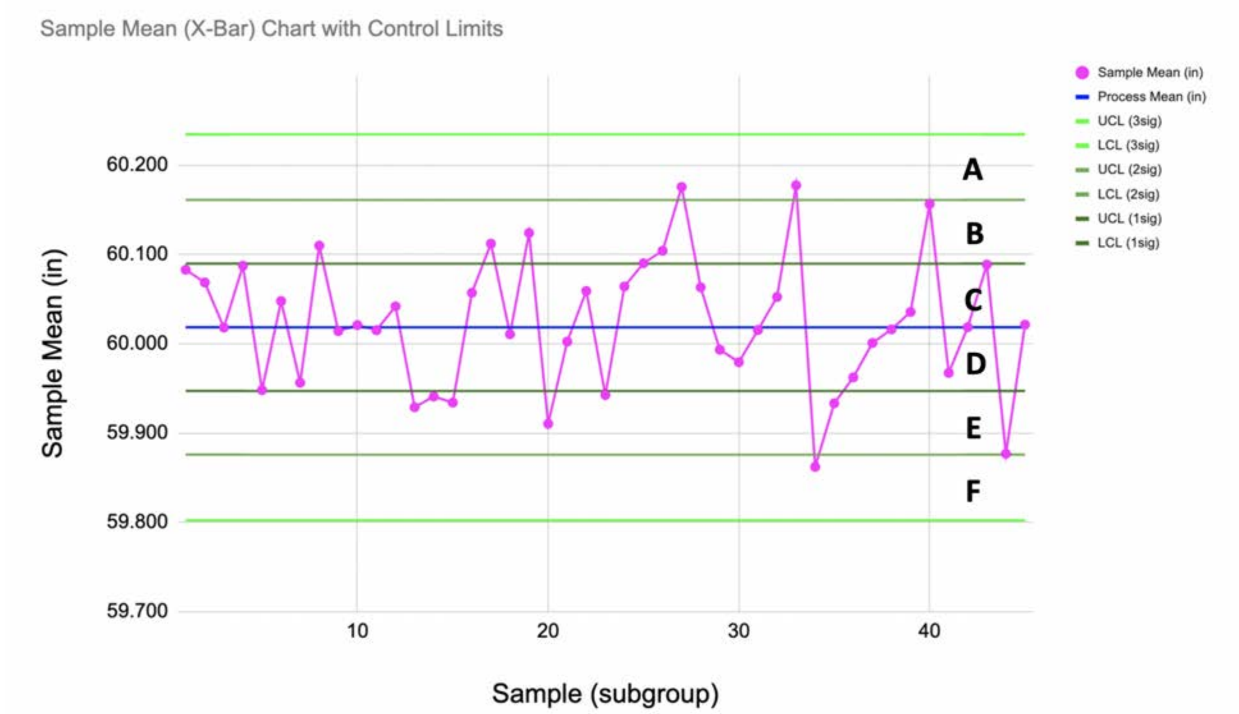
i. What are the USL and LSL?

ii. Calculate the process capability (Cp) needed to achieve that minimum defect rate. What does your resulting Cp suggest?

iii. While holding the same specification limits that you calculated in part (i), what is the most that your mean diameter could increase and still be able to achieve a Cpk of 0.8?

iv. If the manufacturers want their process to be certified as "six-sigma" (six standard deviations between the mean and the nearest specification limit), what does this mean their Cpk is? What would be the problem of trying to use the z-tables in the Appendix to calculate the defect rate for the six-sigma case?

b) Inspect the x-bar chart of the can carrier with process mean and control limits (UCL/LCL).



i. Assuming your process stays in control, what % of sample averages do you expect to be in regions C+D?

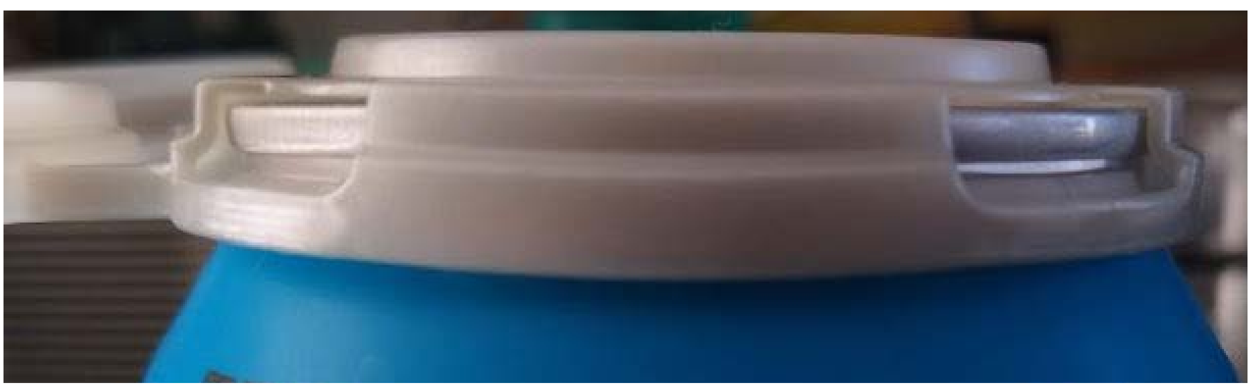
ii. D + E + F?

iii. F?

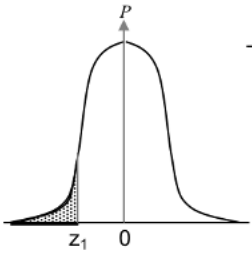
iv. How does your answer change if you identify that your process is out of control?

Appendix:


PATENT DETAILS:
PAKTECH-OPI.COM/PATENTS

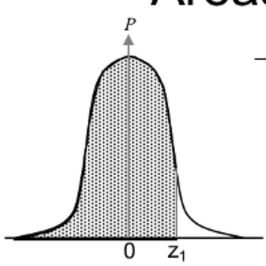


Areas under the Normal Distribution Curve



z	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
-2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
-2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
-2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
-2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
-2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
-2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
-2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
-1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
-1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
-1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
-1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
-1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
-1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
-1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
-1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
-0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
-0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
-0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
-0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
-0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
-0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359

Areas under the Normal Distribution Curve



z	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990