

MIT 2.008 Design and Manufacturing II

Spring 2022

Quiz 2 - Part A, In-Class Component

May 4, 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:

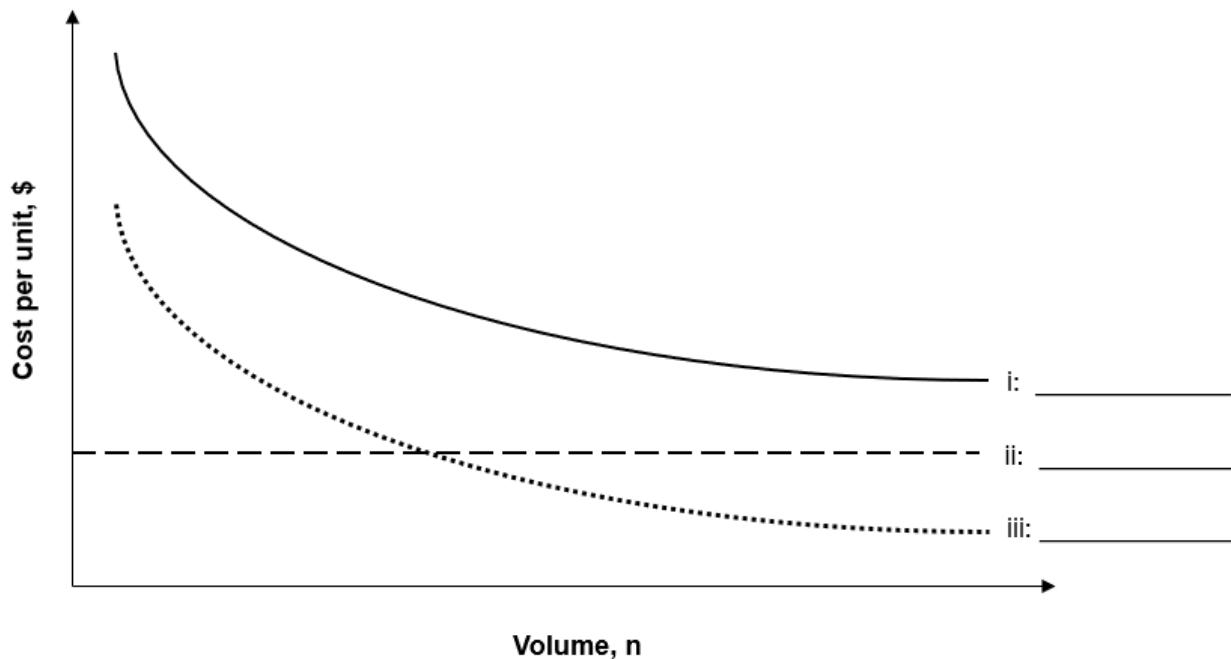
Part A, In-Class Component		
Problem 1		Out of 10 points
Problem 2		Out of 40 points
Part B, Take-Home Component		
Problem 3		Out of 50 points
Total		100 points

Problem 1: Short Answer, Multiple Choice (10 pts, 1 pt each blank)

For each of the following questions, circle all correct answers or write in the correct answer(s).

Cost

a. A plot of cost per unit vs. volume for a typical part is shown below. The plot features 3 curves, label each curve with the correct title.



- i. Total cost
- ii. Variable cost
- iii. Fixed cost

Manufacturing Systems

b. In a real manufacturing line with finite buffers, improving a machine that is not the bottleneck **[does/does not]** improve the average production rate.

c. Consider a transfer line with a bottleneck machine and non-zero buffers. Given a choice of sequencing the machines differently, do you prefer the bottleneck to be the first machine or the last machine?

- i. First
- ii. Last
- iii. Does Not Matter

Forming

d. When evaluating the Design for Manufacturing of a forged part, it is important to consider:

- i. **Parting line and flash**
- ii. **Draft angle**
- iii. **Radii of part features**
- iv. **Lubrication**

Additive Manufacturing

e. The layer thickness in an Fused Deposition Modeling (FDM) machine is determined by the extruder-die's **[height / diameter / feed rate]**.

f. For Stereolithography, a **[ultraviolet / infrared / microwave]** laser beam is focused on a selected surface area of the photopolymer and then moved around in the x-y plane to **[melt / solidify]** that cross-section of the part.

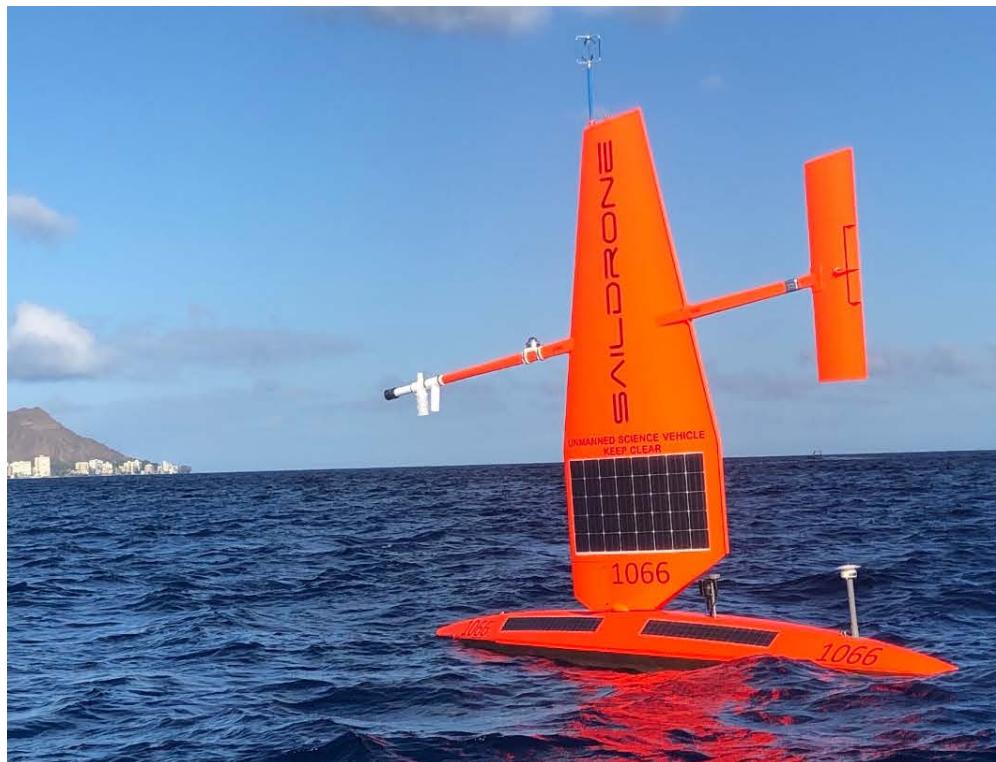
Layered MFG

g. Which of the following images shows an isotropic etch? **(a)**



Problem 2: Bending, Manufacturing Systems, and Additive Manufacturing (40 pts)

There is widespread interest in using distributed networks of Uncrewed Surface Vehicles (USV) to map and monitor the oceans. One manufacturer of a widely deployed USV system is Saildrone, shown in Figure 1.



Courtesy of NOAA.

Figure 1: Saildrone USV (Unmanned Surface/Science Vehicle)

You are tasked with making brackets for a mast base assembly to mount the mast to the hull of the vessel. The designs call for right angle brackets, which will be made from bending 3 mm thick sheets to an initial radius of curvature of 25 mm.

- You are evaluating three different materials for the bracket: an aluminum alloy, a titanium alloy, and a stainless steel alloy. Rank the following materials in order of **decreasing** spring back, so the material with the most springback is 1st. You do not have to calculate spring back, but make sure to show your work (how you got to your rankings) to get full credit. **(6 pts)**

Material	Yield Stress [MPa]	Elastic Modulus [GPa]	Rank

Aluminum Alloy	293	74	3rd
Titanium Alloy	862	105	1st
Stainless Steel Alloy	965	195	2nd

Aluminum Alloy Y/E = $293\text{MPa}/74\text{GPa} = 0.00396$

Titanium Alloy Y/E = $862\text{MPa}/105\text{GPa} = 0.00821$

Stainless Steel Alloy Y/E = $965\text{MPa}/195\text{GPa} = 0.00495$

1 pts for each of 3 rankings

1 pt for each of 3 Y/E calculation/reasonings

b. The production line of the mast base involves bending brackets with a press and then welding the brackets to a machined mast hub. This line can be represented by a simple Transfer Line. For quality control, you barcode every bracket and scan it at every station. Your time logs show that on average a bracket spends 10 minutes in the buffer waiting for the welder.

The Bending Station consists of one operator on a sheet metal press and they bend each bracket in approximately 1 minute.

The Welding Station comprises 3 welders working in parallel, where each welder takes approximately 5 minutes to weld a bracket to a machined mast hub.

You can also assume that the capacity of the buffer between the bending operation and the welding station is infinite and that there are on average 5 parts in that buffer.

Assuming the Transfer Line is at steady state, what is the production rate that you can quote to your supervisor? **(8 pts)**

The average number of parts in the system is:

1 part (Bending station) + 5 parts (Buffer) + 3 parts (3x1 Welding stations) = 9 total

The average waiting time for a part in the system is:

1 min (Bending station) + 10 min (Buffer) + 5 min (Welding station) = 16 min

$$\bar{n} = \lambda * W$$

$$\lambda = \bar{n} / W = 9 \text{ parts} / 16 \text{ min} = 0.5625 \text{ parts/min}$$

3 pts for average number of parts (1 for each component)

3 pts for average waiting time (1 for each component)

1 pt for Little's Law

1 pt for calculation/answer

c. Your team opted to use Stainless Steel as the material for the bracket. An engineer proposes replacing the current mast base assembly, comprising 3 parts joined together, with a single stainless steel part produced via additive manufacturing. **(20 pts)**

i. What is the name of the additive manufacturing process that the engineer proposed? **(2 pt)**

Powder Bed Fusion (or Selective Laser Sintering or Selective Laser Melting)

ii. Make a sketch of the machine used to make this part, with key components of the system labeled. **(6 pts)**

Sketch showing Laser, X-Y mirror, powder bed, and build platform

1 pt for each of the 4 labeled components

2 pts for sketch/location

iii. Describe the physics of the process, explaining how each layer of the part is formed. **(2 pts)**

A laser melts metal powder and fuses it together to form a layer as the melt pool solidifies. The build platform lowers, a new layer of metal powder is spread over the top of the previous layer, and the laser fuses the melted metal to the underlying layer.

1 pt for melting and fusing

1 pt for powder spreading

iv. After the machine has produced the part, what additional steps must be taken before the part can be put into use? **(2 pts)**

The part will have support structures that will need to be manually removed by a technician. In addition, the surface finish is rough and typically the part undergoes a secondary machining operation to improve the quality of critical features.

1 pt post-processing step 1

1 pt post-processing step 2

v. Compare the material, tooling, equipment, and direct labor costs of the mast base produced with the original processes (bending + welding) vs the mast base

produced with additive manufacturing. For each respective cost, state which process you expect to have a higher cost and whether that cost is **Fixed** or **Variable**. (8 pts)

	Bending + Welding	Additive Manufacturing
Material Cost	Sheet metal and metal stock are comparatively less expensive, though these processes result in scrap which lowers the material utilization. Variable Cost	Metal powder is more expensive per unit mass than metal stock, so the material cost would be higher. Variable Cost
Tooling Cost	Sheet metal bending requires a die, which would be included in tooling cost. Fixed cost	No tooling is required
Equipment Cost	A metal press and welding station are common equipment and comparatively less expensive. Fixed cost	SLM machines are highly specialized pieces of equipment and are more expensive than the equivalent bending + welding setup. Fixed cost
Direct Labor Cost	The press operator and the welder can only operate one machine at a time. Therefore the labor can reasonably be expected to be higher. Variable cost	The SLM operator can operate multiple machines at a time, so the labor per machine can be expected to be lower. Variable cost

1 pt for each correct cost explanation

d. The Saildrone is a highly instrumented, autonomous sailing platform, utilizing solar panels to power on-board electronics. Recently there has been a widespread shortage of the computer chips necessary for some of the equipment. Chip manufacturers are

expanding production as quickly as possible, but new fabs take years before they are producing chips. **(6 pts)**

- i. Define lead time and in one sentence explain the supply chain issue of requiring this new equipment. **(2 pts)**

Lead time is how long it takes for a delivery to occur from the moment it is ordered. The minute they don't have the equipment necessary then not only do they need to wait for it to be delivered but it also postpones the wafers entering their system.

1 pt lead time definition

1 pt supply chain issue

- ii. New fabs have shifted from 8" silicon wafers to 12" silicon wafers. The larger wafer fabs employ more layers and finer feature sizes to achieve a higher memory density. In addition, the new fabs have a lower defect density. With this in mind, define the yield of a wafer and how it relates to production rate. **(2 pts)**

The yield of a wafer is the number of functional dies produced per wafer. A lower defect rate corresponds to an increased yield. Additionally, the larger wafer size enables more dies to be produced per wafer. Since the production rate is the number of parts per unit time, the larger wafer fab has an increased production rate.

1 pt yield definition

1 pt increases production rate

- iii. Wafer handling also plays a crucial role as the wafer size increases, as it becomes difficult to reduce the number of process steps due to the die density. Discuss why increasing the number of process steps can be problematic with regards to the average wait time of the wafer. **(2 pts)**

Little's Law. More wafers in the system at any time increases the WIP(work in progress) of the system. If the production rate stays the same, this increases the wait time.

1 pt more L

1 pt higher W

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