
Project Kinetic Art: Mechanical Stingray

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1. About the Sculpture

The Mechanical Stingray Sculpture is an artistic and mechanical representation of a swimming stingray, designed to replicate the natural locomotion of the aquatic creature through a set of coordinated mechanical subsystems. This kinetic sculpture uses entirely mechanical means to replicate the stingray's fluid, wave-like motion, capturing its essence as it "swims" through space. The sculpture integrates cam-driven fin motion, a chain-driven rotating tail, and an oscillating head mechanism, all synchronized via a central crankshaft powered by a hand crank.

Figure 1. *Finished Sculpture*

1.1. Cam-Driven Fin Motion

The pectoral fins of the stingray are the most visually striking component, exhibiting a continuous wave-like undulation similar to real-life stingrays. Each fin is divided into multiple rigid segments, each linked to a follower mechanism riding on a rotating camshaft. The cam profiles are uniquely shaped to produce a smoothly phased vertical motion across the length of the fin, thereby creating a propagating wave.

Two camshafts, one for each fin, are driven in synchronization by the central crankshaft through a system of spur gears. This ensures that both fins mirror each other's motion symmetrically.

1.2. Rotating Tail with Chain and Sprocket Drive

Inspired by the organic, sweeping motion seen in underwater vehicles like the Gungan Submarine from Star Wars, the stingray's tail mimics this motion via mechanical rotation. The tail is composed of several rigid wave-shaped segments, connected along a rotating shaft.

Rotation is delivered using a chain and sprocket drive, where the main crankshaft drives a sprocket linked to the tail's central axis. The chain transmits rotary motion, which is then distributed through the tail segments, resulting in a visually rhythmic tail sweep.

1.3. Oscillating Head Mechanism

To simulate the gentle, reactive steering motion of a stingray, the head structure oscillates horizontally. This is implemented using a crank-slider mechanism placed beneath the head. The crank, mounted horizontally, converts rotational motion into linear displacement of a slider along a curved path.

The head is directly attached to this slider, causing it to move in a controlled arc from side to side. This subtle oscillation complements the more dynamic tail and fin movements, enhancing the sculpture's lifelike behavior.

1.4. Central Crankshaft and Power Distribution

The crankshaft receives input through a hand crank and is responsible for distributing mechanical power to all subsystems. It functions as follows:

- Fins: Drives the left and right camshafts via a gear train, ensuring synchronized wave propagation.
- Tail: Powers the chain and sprocket system to initiate tail segment rotation.
- Head: Driven by the fin camshafts via a bevel gear pair, which transmits motion to the crank-slider mechanism responsible for head oscillation.

The central crankshaft ensures that all motions are harmonized, allowing the sculpture to display a cohesive swimming action.

2. Technical Drawings

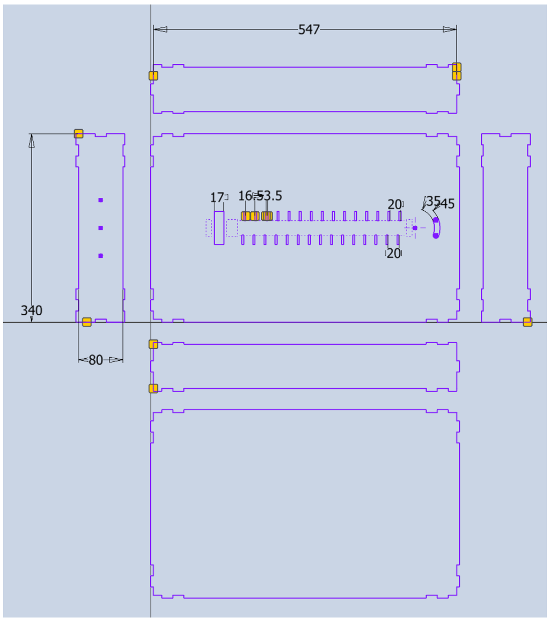

Figure 2. *Box (Parts 1 - 5, 10)*

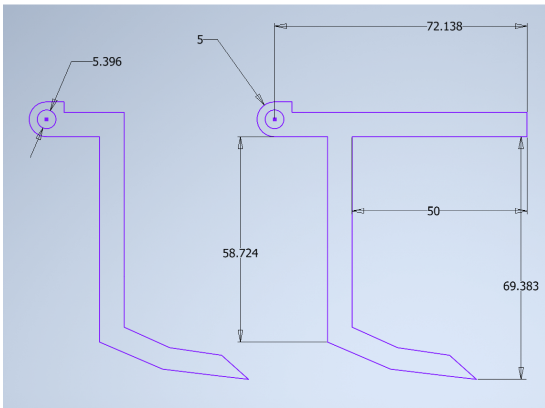

Figure 3. *Cam Followers (Part 6)*

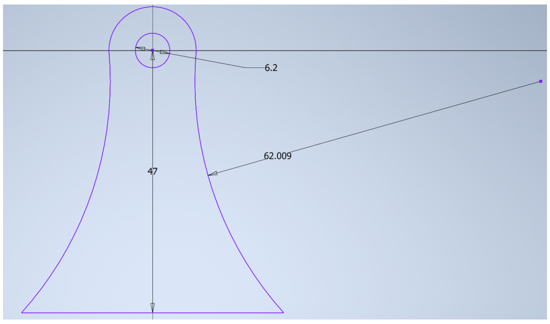

Figure 4. *Camshaft Supports, Pivot Shaft Supports and Tail Shaft Supports (Parts 7, 8, 9 - The hole diameter is the same for all three parts, however for the tail the height is 30 mm, for the pivot the height is 47 mm and for the camshaft the height is 40 mm. The part is scaled accordingly)*

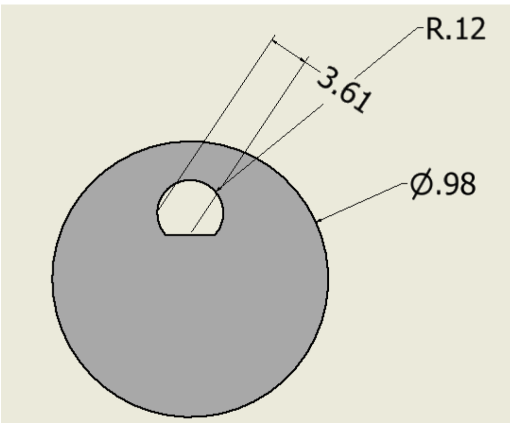

Figure 5. *Cams (Part 11, however each cam has its hole rotated by 24 degrees with respect to the previous cam, and there are two sets of cams*

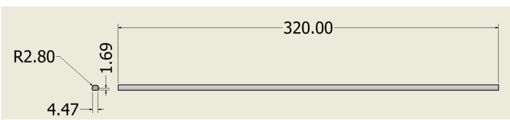

Figure 6. *Camshafts (Part 12)*

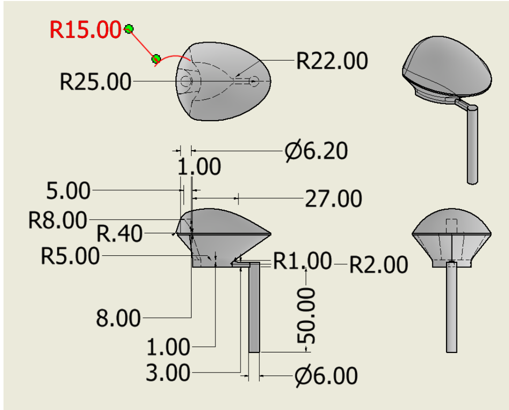

Figure 7. *Head (Part 13)*

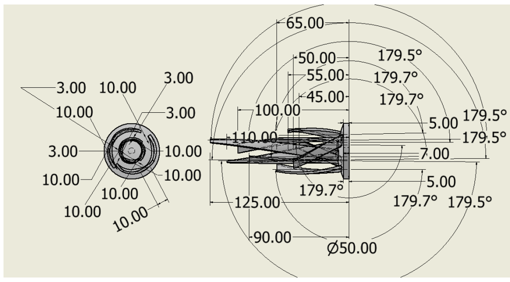

Figure 8. *Tail (Part 14)*

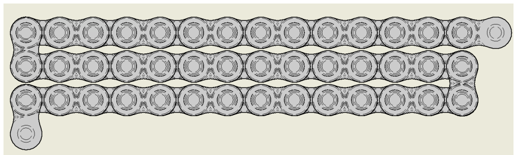

Figure 9. *Chain (Part 15)*

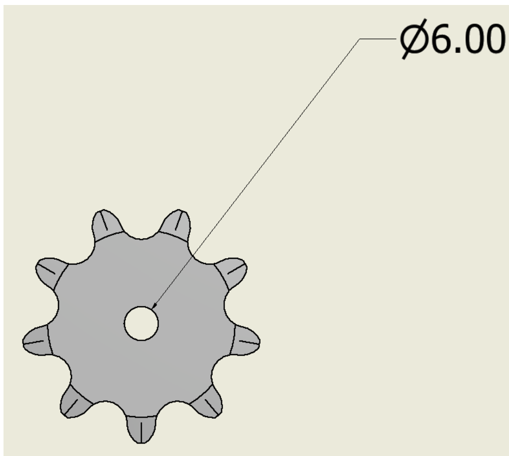

Figure 10. *Sprocket (Part 16)*

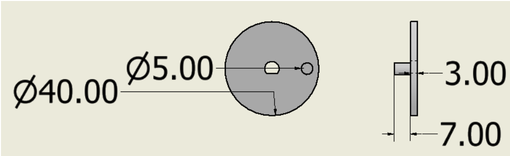

Figure 13. *Head Support (Part 20)*

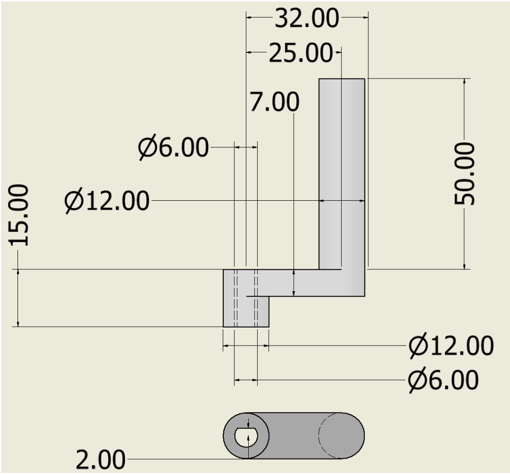

Figure 11. *Crank (Part 17)*

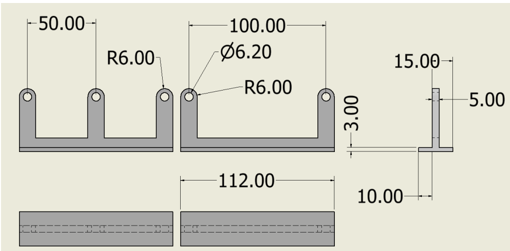

Figure 12. *Three and Two Holed Supports (Parts 18 and 19)*

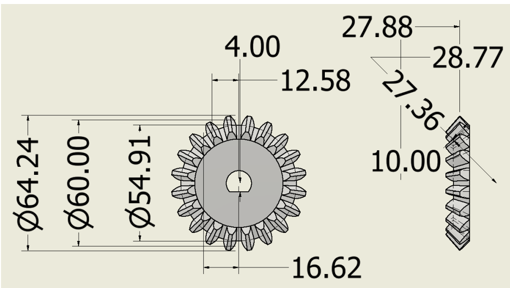

Figure 14. *Bevel Gear (Part 21)*

The washers can be dimensioned and printed/cut out as needed based on the tolerances provided by the laser cutter and the 3D-printer currently available (obtained experimentally).

3. Analysis and Calculations

This section outlines the core mechanical calculations that informed the design and synchronization of the sculpture's moving elements, including the fins, tail, and head.

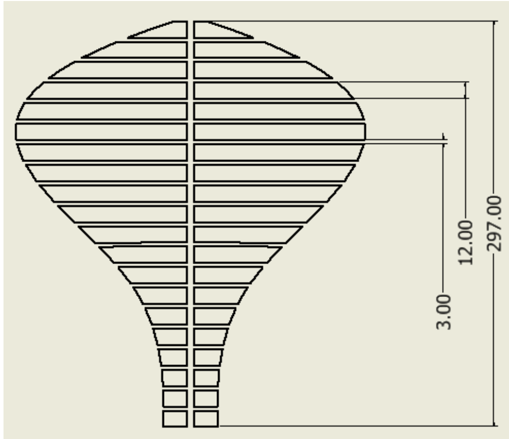

Figure 15. *Body Panels (Part 29)*

3.1. Gear Ratios and Motion Transmission

The sculpture's movement is powered by a central crankshaft, which distributes rotational input to three subsystems: fins, tail, and head.

- **Fins (Camshaft Gear Train):**
  The fin camshafts are driven via gear trains connected to the main crankshaft. The gear ratio between the crankshaft and each fin camshaft is $3 : 2$. If the crankshaft rotates once, then:

  $$\text{Camshaft rotation} = \frac{2}{3} = 0.67 \text{ rotations}$$

  Thus, for every full rotation of the crankshaft, each fin camshaft completes **0.67 rotations**.

- **Tail (Chain and Sprocket):**
  The chain and sprocket system transmits motion directly from the crankshaft to the tail shaft without a gear ratio.

  $$1 \text{ rotation of crankshaft} = 1 \text{ rotation of tail shaft}$$

- **Head (Bevel Gear with Fin Camshaft):**
  The crank-slider mechanism controlling head oscillation is linked via $1 : 1$ bevel gears to one of the fin camshafts. Since the camshaft completes 1.5 rotations per crankshaft rotation,

  $$\text{Head crank-slider also completes} = 0.67 \text{ rotations}$$

3.2. Cam Profile and Fin Motion Calculation

The pectoral fins are designed with 15 individual segments (follower points), each driven by a custom cam mounted along the camshaft. To generate a wave-like propagation across the fin:

- Total angle of rotation in one camshaft cycle: 360°
- Number of segments (followers): 15
- Angle per segment:

$$\frac{360°}{15} = 24°$$

Thus, every **24° of camshaft rotation** advances the wave by one fin segment, enabling a smooth ripple effect.

Each cam is shaped to provide vertical displacement to its follower. The **cam lift** (maximum follower displacement) was set based on physical testing and kinematic comfort, designed to provide a visually dynamic yet mechanically feasible motion.

3.3. Head Oscillation via Crank-Slider Mechanism

The head of the stingray is connected to a slider that oscillates through an arc to replicate natural side-to-side head motion.

- Total angular oscillation of the head: 40° (±20° from center)

To achieve this, the crank radius r of the crank-slider mechanism was calculated using the arc approximation formula:

$$\theta = 2 \cdot \arcsin\left(\frac{r}{L}\right)$$

Where:

- $\theta = 40°$ is the total angular motion,
- L is the horizontal length of the slider guide (5 cm)

Solving for r:

$$20° = \arcsin\left(\frac{r}{5}\right)$$
$$\Rightarrow \frac{r}{5} = \sin(20°)$$
$$\Rightarrow r = 1.7cm$$

Therefore, the crank radius required is approximately 1.7 **cm**, which was used to design the crank-slider linkage for accurate head oscillation.

3.4. Summary of mechanisms and motions

1. Chain and Sprocket: For the tail
2. Gear Train with a specific gear ratio: For connecting the crank and the camshafts
3. Cam Follower: For the fins
4. Different Gear Types: Spur and Bevel (shafts and head motions)
5. Oscillatory Motion: Head
6. Linear Motion: Fins
7. Rotatory Motion: Tail
8.

4. Assembly Instructions

1. Laser cut the box panels and supports and any other component mentioned in the part list and bill of materials at the end of the document.
2. Use 1.75 mm PLA filament to 3D-print the camshafts, cams, head, supports, gears, washers, cam separators, shaft connectors, crank and any other 3D-printed component mentioned in the part list and bill of materials at the end of the document.
3. Number each set of cams from 1 to 15 in order (every subsequent cam is rotated 24 degress with respect to the previous one) with a marker to prevent confusion.
4. Prepare the aluminium rod of diameter 5 mm according to the dimensions mentioned in section 2.
5. Paint all the exposed surfaces of the panels in your desired colour, and also paint both sides of the body panel pieces.
6. Confirm if all the required parts are present by cross-checking it with the list of parts in the part list and bill of materials at the end of the document.
7. To begin with the assembly, first slide each set of cams in order on a cam shaft, putting a 14 mm long cam separator in between each cam, and put two 3 mm thick washers on each camshaft, but on opposite ends.
8. Slide a 4 cm tall acrylic support six cams away from the tail end of each camshaft, and use washers to bridge the remaining gap between the cams.
9. Slide the two holed support one cam away from the head end of each camshaft, and use washers to bridge the remaining gap.
10. Slide the tail end of each camshaft through the three holed support.
11. Slide the tail end of each camshaft into the three holed support, and attach a connector on the tail end of each shaft to extend it. Attach a connector to the head end of the right shaft (with respect to the head side facing away from you). Now, attach camshafts to extend the original length.
12. Take the aluminium rod and slide in the cam followers. Do this in sets of two, and make sure that the contact ends of each follower set point in opposite directions. Between each follower set, make sure that there is a 14 mm washer to bridge the gap. Keep this aside.
13. Now, take a moment to ensure that there are no gaps between any of the cams washers and connectors as this will affect the motion of the cam-follower mechanism.
14. Slide the two larger gears on the tail side of the camshafts, and take another cam shaft and slide one of the sprockets through it, followed by the smaller gear through. Ensure that there is one washer on each side of all the gears.
15. Slide the camshaft with the smaller gear through the central hole of the three holed support so that it is between the two main camshafts.
16. Ensure that the camshafts are aligned in the same direction (the position of the first cam can be considered as a reference), and interlock the gears with each other.
17. Slide the shaft through holes in the 5 mm MDF side panel taking care to not disturb the gear assembly's positioning.
18. Move the cam assembly to one side, and refer to the technical drawings of the top plate in section 2 to make markings on the bottom plate to position the supports on the base plate,

19. Connect the tail side panel to the base plate, and position the cam assembly based on the markings in the previous step, and bring all the gears close to the side panel by moving them on the shaft, and attach the crank to the central shaft. Trim off the extra length of the camshafts, but ensure that there is no axial movement of the shafts.
20. Test the assembly for rotation, and move things around slightly until the rotation is smooth and satisfying. If not, identify possible points of error in manufacture of the parts and reprint/recut them.
21. Cut the chain to size so that the centre distance between the sprockets is about 8.5 cm, and attach the chain to the sprocket of the crankshaft (central shaft connected to the crank).
22. Connect a bevel gear to the extended camshaft at the head end (obtain its position from the drawings in section 2), attach washers on both sides of it.
23. Take the second bevel gear and slide in a camshaft through it. Align its teeth with the other bevel gear so that its teeth are pointing upwards, and its shaft is touching the base plate. Mark that location on the base plate, and glue a standoff there so that the shaft rotates smoothly through it.
24. Connect the support panel to the right side panel and slide the vertical bevel shaft through it. Also glue the two supports for the support panel to the base plate. Make sure that the bevel gears rotate smoothly, and if not make the necessary adjustments.
25. Slide a washer through the shaft onto the support panel, and let it rest on the support panel. Slide the head rotation disc through the bevel shaft onto washer on the support panel and ensure that it is flat and rotates freely.
26. Rest the top panel on the side panels, and slide the rod extending from the base of the head (head-rod) through the arc-shaped hole into the assembly cavity. Now connect the head-rod and the knob on the head rotation disc with a link, and add 3D-printed caps/rings to prevent them from dislocating. Trim off the extra length of the head-rod.
27. Take the aluminium rod and cam follower mechanism assembled before, and carefully slide each follower through their respective slots in the top panel.
28. Take the 3 cm tall 3D-printed supports and slide them on both sides of the rod, and make sure that the support with a pivot on the side is on the head end, and slide the hole in the head onto this pivot.
29. Ensure free rotation, and glue the supports in place to secure the aluminium rod.
30. Take the chain and bring it up and out of the top plate, ensuring that the teeth of the sprocket remain lodged in the chain slots.
31. Slide another camshaft through the second sprocket and connect the chain to it.
32. Slide 4.7 cm long supports through the chain shaft on both sides, and place them on the top plate based on measurements from section 2.
33. Ensure that the chain is taut and the rotations are smooth, and then connect the 3D-printed tail to the chain shaft's free end, and check the rotations once more.
34. Take the body panel pieces of the stingray and glue them onto the top of the cam followers. Ensure that the interface is rough enough for a good bond.
35. Check final rotation quality, add details using methods of your choice and you are finished with the assembly.

Part No.	Part Name	Material	Manufacturing method	Quantity
1	Box Side Panel	MDF (5 mm)	Laser Cut	2
2	Tail Side Panel	MDF (5 mm)	Laser Cut	1
3	Head Side Panel	MDF (5 mm)	Laser Cut	1
4	Base Plate	MDF (5 mm)	Laser Cut	1
5	Top Plate	MDF (3 mm)	Laser Cut	1
6	Cam Followers	Acrylic (3 mm)	Laser Cut	30
7	Camshaft Supports	Acrylic (5 mm)	Laser Cut	2
8	Pivot Shaft Supports	Acrylic (5 mm)	Laser Cut	2
9	Tail Shaft Supports	Acrylic (5 mm)	Laser Cut	2
10	Box Side Panel	Acrylic (5 mm)	Laser Cut	1
11	Cams	PLA	3D Print	30
12	Camshafts	PLA	3D Print	10
13	Head	PLA	3D Print	1
14	Tail	PLA	3D Print	1
15	Chain	PLA	3D Print	1
16	Sprocket	PLA	3D Print	2
17	Crank	PLA	3D Print	1
18	Three Holed Support	PLA	3D Print	1
19	Two Holed Support	PLA	3D Print	1
20	Head Support	PLA	3D Print	1
21	Bevel Gear	PLA	3D Print	2
22	Pivot Washers	PLA	3D Print	14
23	Shaft Spacers	PLA	3D Print	30
24	Washer Type 1	PLA	3D Print	10
25	Washer Type 2	PLA	3D Print	10
26	Washer Type 3	PLA	3D Print	10
27	Caps	PLA	3D Print	4
28	Washer Type 4	Acrylic (3 mm)	Laser Cut	12
29	Body Panels	MDF (3 mm)	Laser Cut	1 set (30 pieces)

Table 1. *List of Parts*

Material	Manufacturing Method	Total Unique Parts	Total Quantity
MDF	Laser Cut	6	7
Acrylic	Laser Cut	6	49
PLA	3D Print	17	162

Table 2. *Bill of Materials Summary*