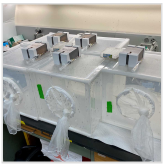

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# "Skeeter Pheeder": inexpensive 3D printed, battery-powered blood feeder for mosquitoes and other haematophagous arthropods

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DISCLAIMER

The author declares he has no competing interests.

ABSTRACT

A portable heated feeder for blood-feeding arthropods, the Skeeter Pheeder, has been designed to be constructed in the laboratory using conventional FDM 3D printing methods. Materials to fabricate this device are about 10% the cost of commercially produced heated blood-feeders. Being battery powered, the Pheeder is fully portable and can fit inside or on top of a cage with no wires or hot water tubes. It works with any feeding membrane and has superior blood-handling properties. In a test of its efficacy at feeding female *Aedes aegypti* mosquitoes, the Pheeder performed comparably to the water-heated blown-glass feeder.

PROTOCOL CITATION

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KEYWORDS

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IMAGE ATTRIBUTION

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GUIDELINES

It is expected that persons following this protocol have some experience with 3D printing or have expert assistance.

MATERIALS TEXT

**The attached table contains detailed information on parts, costs, and possible suppliers.**

**Bloodfeeder Parts & Costs.pdf**

**Electronic Handwarmer**. I selected a unit that advertised the lowest temperature setting.

**USB charger.** To recharge the handwarmer battery.

***3D printing filaments:***

- **PLA filament**. Thermochromic filament is ideal. I use Zi-Rui Tri Color Changing.
- **PETG filament**. Needed for End Clips with syringe holders that flex a little without breaking off.
- **Thermally conductive filament**. I use TCPoly's Ice9 Flex, 1.75 mm dia.
- **Cleaning filament.** For cleaning the printer's hot end with "cold pulls" after using Ice9 Flex.

**Blue painter's masking tape, wide.** For covering the print bed when printing Ice9 Flex filament.

**Polyethylene capillary tubing, ID 0.034".** 30 cm per Pheeder.

**2 blunt #20 hypodermic needles, 1".** These can be purchased or made for much less money by grinding the sharp tips off regular hypodermic needles using a Dremel grinder or equivalent.

**5 ml Luer lock disposable syringes.** To hold the blood.

**Brush-on epoxy coating.** To keep blood from seeping into seams in the 3D printed blood cell.

**1" foam brushes.** For applying epoxy.

**Epoxy mixing dishes.** Shallow. A disposable weighing dish is ideal.

**Wooden craft sticks.** For mixing epoxy. Cut the end square to facilitate scraping the bottom of the mixing dish.

SAFETY WARNINGS

3D printers have hot parts. Follow fire safety precautions and avoid touching hot parts with bare hands.

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BEFORE STARTING

Assemble the necessary tools and materials.

Tools Needed

1
- **Profile Gage**. Must have closely-spaced wire pins (not plastic). General Tools 837 works well.
- **Digital caliper** with 0.001 mm resolution. Mitutoyo makes good ones at a fair price.
- **3D printer**. FDM (fused deposition modeling) type printer that can print flexible filaments. Printers with direct drives that pull the filament, rather than Bowden drives that push it, are most reliable for printing flexible filaments. I used a Prusa MK3S.
- **0.4 mm and 0.8 mm brass print nozzles**. The 0.4 mm is standard and is used for PLA and PETG, but 0.8 mm is needed for printing Ice9 Flex (smaller nozzles will clog).
- **Tools for nozzle swaps.** Nozzle changes are done at high temperature. Find and follow instructions.

- **Brass bristled scrub brush, small**, for cleaning the hot print nozzle.
- **Dissecting microscope** to visualize careful cutting of the polyethylene fill tubing.
- **Scalpel or X-acto knife with pointed blade** – to cut the polyethylene fill tubing.

Materials Needed

2 **See Materials section**
A table is include with details, approximate costs, and possible suppliers.

Note: One can purchase blunt #20 hypodermic needles at a premium price or make them by grinding the tips off sharp hypodermic needles (I used a Dremel hand grinder). The needle shaft should be about 25 mm (1”) in length.

Modifying the Design

3 **Modeling Software**
3D printed parts were modeled in Fusion360 software from Autodesk, free for non-commercial use.
Fusion360 modeling files are available from the author for modification to fit a new model of handwarmer. See Licensing section at the end.
If you are not facile with Fusion360 software, work through the excellent online tutorial on parametric modeling before attempting to modify the files.

**Inserting a new handwarmer profile into Fusion360**
Electronic handwarmers are a commodity. Models change frequently and exact dimensions with them. You might need to customize the internal contours of the printed parts for a new hand warmer model. Positions of holes in the Lower Block for accessing control buttons and viewing LEDs may also change. These holes are convenient but optional, since the handwarmer can be removed from the device to turn it on or off.

Use a profile gage to capture the cross-sectional shape of the handwarmer as shown in the photo below. Other dimensions of the handwarmer can be measured with a digital caliper.

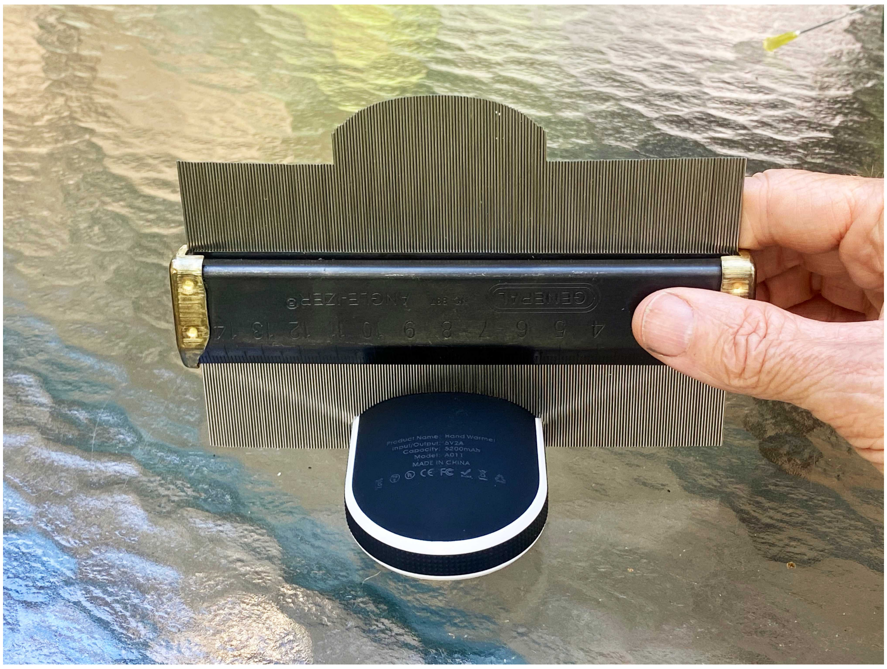

Fig. 1. General Tools 837 profile gage is pressed onto a handwarmer to capture its cross-sectional shape and dimensions.

- Trace the profile onto paper and draw a horizontal 10 cm line for scale just below the profile.
- Scan the page and convert to SVG format.
- In Fusion360, start a sketch and draw a 10 cm line from the center to the right.
- Import the SVG file into a Fusion360 sketch, and scale it so the 10 cm line in the SVG import matches the 10 cm line you previously drew in Fusion360.
- Create a new sketch on the same plane and fit the traced profile with a fit-point spline curve. Incorporate this new curve into the model to shape the bodies to the profile of the new handwarmer.

Completed model bodies are exported as STL files for slicing and printing.

3D Printing the Parts

4 **Filament type needed for each 3D printed part:**

- Lower Block – PLA (preferably thermochromic)
- Upper Block – PLA (preferably thermochromic)
- Ring – PLA (preferably thermochromic)
- End Clips – PETG
- Thermal Block – Ice9 Flex™ TPE

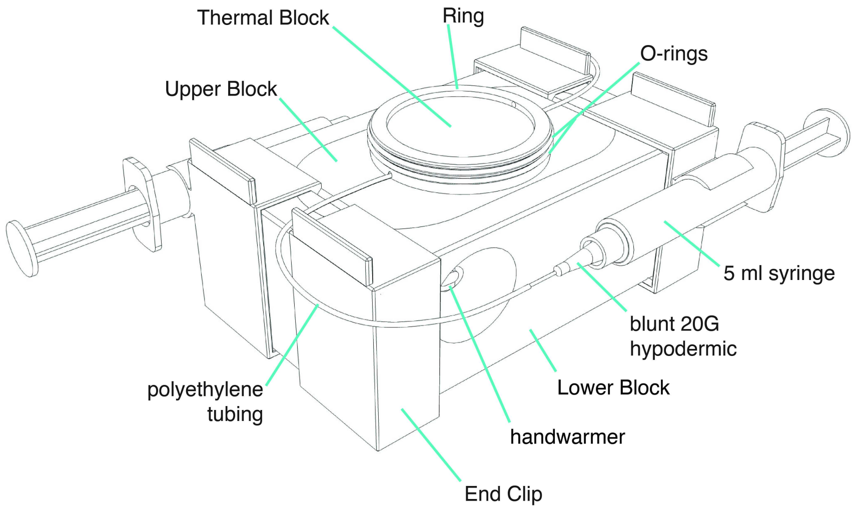


Fig. 2. Skeeter Pheeder assembled. Feeder membrane is not shown.

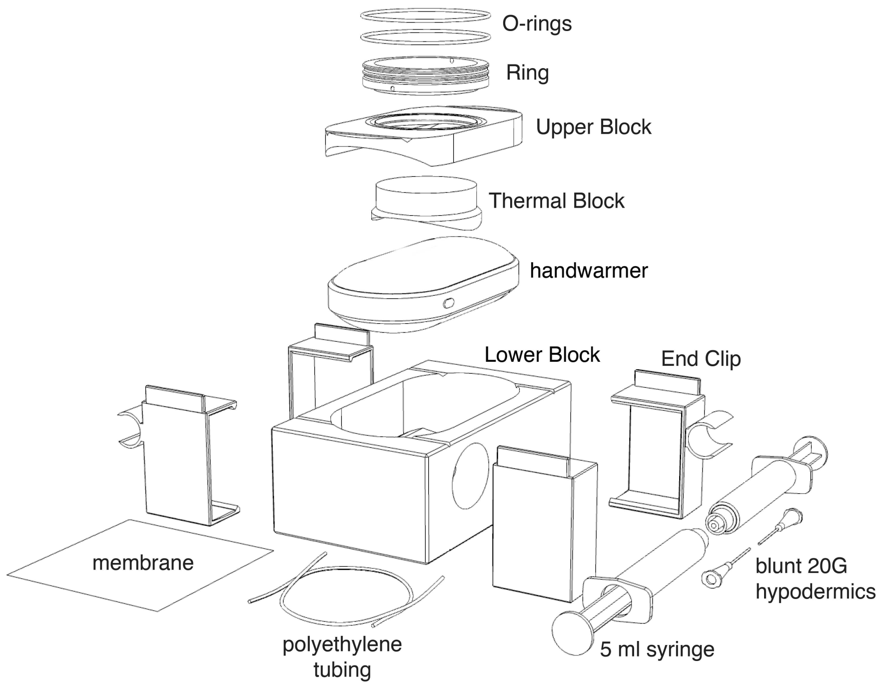


Fig. 3. Skeeter Pheeder parts. Names of 3D-printed parts are capitalized (O-rings are not 3D-printed).

5 **Slicing the STL files**

3D models in STL format need to be converted to gcode, a text file of instructions that guide the printer's actions. Gcode conversion is accomplished by a “slicer” program.  I used the free PrusaSlicer to generate Gcode, but the Cura slicer will work as well.

Filaments can be sliced, starting with generic profiles for PLA, PETG, and Flex respectively, and modifying the profiles with the settings below:

**Part: Lower Block**
Material: PLA
Nozzle: 0.4 mm
Face on bed: no change (flat side down)
Configuration: generic PLA
Layer thickness: 0.2 mm quality
Infill: 15%, cubic or gyroid (for insulation)

**Part: Upper Block**
Material: PLA
Nozzle: 0.4 mm
Face on bed: upside down (flat side down)
Configuration: generic PLA
Layer thickness: 0.2 mm quality
Infill: 15%, cubic or gyroid (for insulation)

**Part: Ring**
Material: PLA
Nozzle: 0.4 mm
Face on bed: upside down (flat side down)
Configuration: generic PLA
Layer thickness: 0.1 mm detail (to produce smooth serpentine paths for the polyethylene tubing)
Infill: 15%, cubic or gyroid (for insulation)
Seam position: Align to rear

**Part: End Clips**
Material: PETG
Nozzle: 0.4 mm
Face on bed: largest side down
Configuration: generic PETG
Layer thickness: 0.2 mm quality
Infill: 100%

**Part: Thermal Block**
Material: Ice9 Flex™ TPE
Nozzle: 0.8 mm
Face on bed: upside down (flat side down)
Configuration: generic FLEX, modified with settings below
Layer thickness: 0.4 mm quality
Infill: 100% rectilinear (or 95% to reduce build-up on nozzle)
Seam position: Align to rear
*Speed*
Perimeters: 30 mm/s
Small perimeters: 20 mm/s
External perimeters: 20 mm/s
Infill: 40 mm/s
Top solid infill: 30 mm/s
Acceleration control: 200 mm/s (all accel. settings)
Max print speed: 40 mm/s
*Extrusion Widths*
Default extrusion width: 0.9 mm
First Layer: 0.84 mm
Perimeters: 0.9 mm
External perimeters: 0.9 mm
Infill: 0.9 mm

Solid infill: 0.9 mm
Top solid infill: 0.8 mm
Slice gap closing radius: 0.098 mm
Nozzle width: 0.8 mm

## 6 Filament handling

Store filament spools in an airtight bag or container with silica desiccant. I recommend color-indicating silica gel beads.

TPE flex filaments are notoriously hydroscopic. A filament that has absorbed moisture from the air will not print properly. Even with a new roll of flex, it's best to bake the spool for several hours at 70°C before printing (I use the PrintDry™ system, a modified food dryer).

Unlike TPE flex filaments, PLA and PETG filaments rarely need to be baked dry prior to first use, although it does happen. If a previously well-performing filament stops printing properly, it may need to be dried under heat.

## 7 3D Printing thermally conductive Ice9 Flex TPE filament

It is expected that persons following this protocol have some experience with 3D printing or have expert assistance on call. For those familiar with 3D printing in conventional plastics, Ice9 Flex filament has some atypical properties.

Before printing Ice9 Flex, create a single layer of blue painter's tape on the print bed as a print surface. Recalibrate the height of the first print layer to accommodate the raised print surface.

Ice9 Flex adheres to the printer's hot metal parts like bubblegum on hot asphalt, even worse than PETG, so a small brass wire brush is essential for cleaning the print nozzle after a print (the hot end can be re-heated if necessary).

A silicone protective sock on the hot end is risky; Ice9 Flex can find its way underneath making a big hot mess.

Ice9 Flex resembles molten lead in its heat retention; a small blob of Ice9 Flex dripping onto the print bed from the print nozzle can burn one's fingers long after every other plastic would have cooled to the touch.

When Ice9 Flex printing is complete, a series of "cold pulls" should be performed with the 0.8 mm nozzle in place to clean all the Ice9 from the inside of the extruder. If you don't do sufficient cold pulls, the printer may clog when you swap in the regular 0.4 mm nozzle and random streaks of black Ice9 Flex will appear in future prints.

Assembly

8 If you are using thermochromic PLA, chilling the printed parts in the freezer will resets the thermochromic dye following the extreme heat of printing.

Insert the Thermal Block with into the Upper Block, carefully aligning the underside contours before pressing into place. Position the Ring above the Thermal Block, aligned so the tube holes are in line with the long axis of the Upper Block. Press into place.
If the parts are not perfectly aligned, take them apart and try again.

Cut two 15 cm lengths of the polyethylene tubing and thread them into the serpentine channels in the Ring so that their ends extend inside the Ring 7-10 mm. Plug the ends with toothpicks or tape to keep epoxy out.

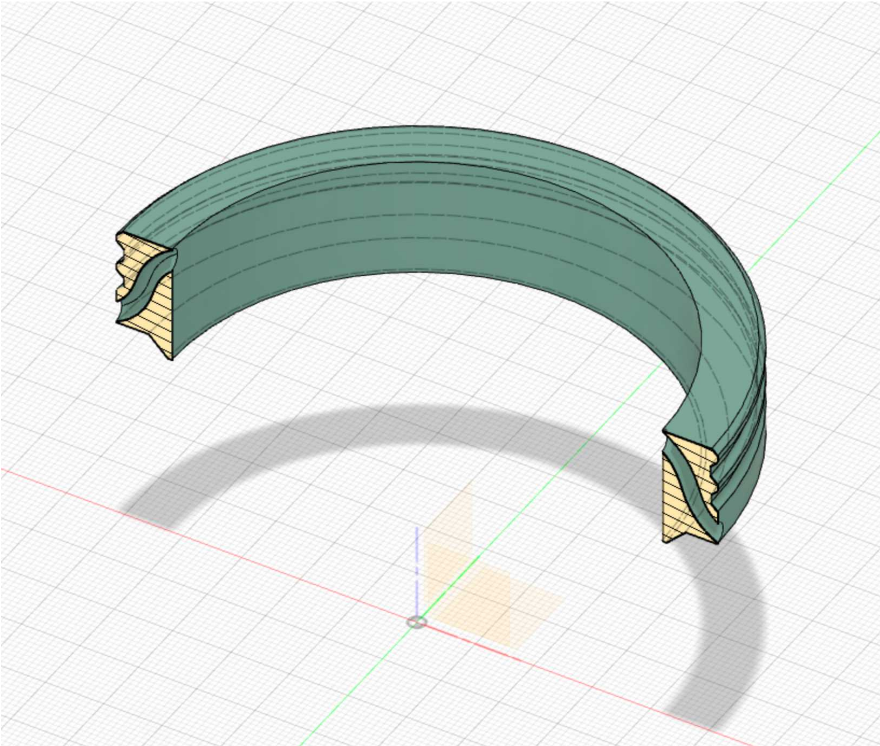

Fig. 4. Cross-section of the Ring in Fusion360, showing the two serpentine channels for inserting the polyethylene tubing through the Ring wall into the blood cell. Two grooves on the outside are for O-rings that hold the feeding membrane in place.

Mix 4.5 ml of epoxy coating in the EXACT proportions recommended by the manufacturer. I use Smooth-On™ XTC-3D High Performance 3D Print Coating. Disposable syringes help to get the proportions of Part A and Part B exactly 2:1.

A shallow mixing tray dissipates heat from the epoxy, keeping it workable longer than if mixed in a deeper tray. Mix slowly so as not to introduce bubbles.

Using a 1" foam brush, apply epoxy to the flat blood surface of the Thermal Block and the inside of the Ring. Brush and rebrush the epoxy to coat evenly and eliminate bubbles, then allow to sit while the epoxy levels and sets. Be sure to coat the tubing where it emerges from the Ring, but avoid getting epoxy inside the tubing. You have the option of adding a second epoxy coat after the first coat sets.

The next day when the epoxy is hard, place the assembly under a dissecting microscope and use a scalpel or X-acto knife to trim the polyethylene tubing flush with epoxy coating the inner surface of the Ring. Try to get a clean cut.

If you make a mess the first time, the Ring can be cut apart after the epoxy hardens and the Thermal Block salvaged by sanding the epoxy flat. Print another Ring from PLA and try again.

If one is making Pheeders in quantity, a pourable silicone rubber such as Sylgard™ might be a good substitute for the clear epoxy because it takes longer to set, allowing the bubbles to be sucked out under vacuum.

## Operation

9 To use the Skeeter Pheeder, place a charged handwarmer into the Lower Block, fit the Upper Block on top, and slip on the end clips so that one hypodermic holder is at each end.

Turn on the handwarmer. To save time, one set the temperature to high while setting up the Pheeder, then turn it down to the low setting for operation.

Place an 8 cm dia square of your chosen membrane over the Ring.

To secure the membrane on the Ring, fit two O-rings (Oil-Resistant Buna-N O-Ring, 1.5 mm Wide, 47 mm ID, USA Sealing, Inc.) over the membrane and press them into the outer grooves in the Ring.

Fit one blunt #20 hypodermic needle onto a 5 ml disposable Luer-lock syringe, draw 3 ml blood into the syringe, and purge the syringe of air (try to avoid bubbling the blood). Blood is often mixed with a little ATP to enhance the feeding response.

Insert the blood-loaded hypodermic needle into one loose end of tubing and the extra needle with no attached syringe into the other.

Tip the Pheeder at about 60° on end, blood-tube down and inject the blood into the Pheeder's blood compartment so the air bubble gradually shrinks around the upper tube.

When the air bubble is small, attach the second syringe to the upper needle and pull back on the plunger to purge the rest of the air bubble in the blood compartment.

Fit both syringes into the end clips.

*Optional:* to make the membrane more attractive to hematophagous arthropods, rub it against human skin or use another O-ring to clip on a piece of nylon stocking that is soaked in human sweat.

Place Pheeder in desired location, inverted on the screen outside the cage or blood-side up inside the cage.

If you turned up the heat to max for quick heating, remember to turn it back down to the lowest setting.

## Cleaning after use

10 Immediately after use, the parts that contact blood must be disassembled and rinsed under cold running water to keep blood from adhering.

Avoid kinking the polyethylene tubing or stretching it while removing the hypodermic needles.

Instruct users to catch the ends of the tubing and push/scrape it free of the hypodermic needles, rather than attempting to pull it free by tugging on the tubing.

## Permissions and Licensing

11 Academic and non-profit researchers interested in reproducing the Skeeter Pheeder can contact the author <stoddard@fiu.edu>. I will first provide you a simple noncommercial license to be executed by your institution, and upon completion, editable Fusion360 design files or STL files. For-profit organizations or researchers interested in commercial production of the Skeeter Pheeder can contact FIU's Office of Technology and Management and Commercialization at FIU (Intellectual Property <inteprop@fiu.edu>).