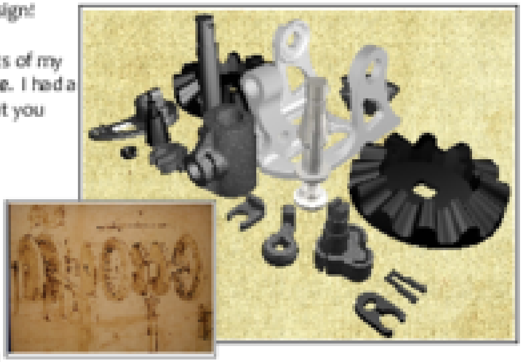
da Vinci Gear Machine

for the ***da Vinci Gear Challenge*** by
GrabCAD and ***Stratasys Education***

Designed by Clint K. Campbell

SUMMARY:

Thank you for your interest in my design!



This documentation covers all aspects of my design for the ***da Vinci Gear Challenge***. I had a lot of fun designing it, and I hope that you find it just as entertaining as I did.

DESIGN ORIGINS:

The concept for my design is based on the image displayed within the Challenge itself (https://grabcad.com/challenges/da-vinci-gear-challenge), along with a handful of images downloaded from sources with larger, more detailed images of da Vinci's drawing.

Part of the Challenge's requirements were to "Consider the ways in which 3d printing differs from Renaissance-era fabrication technologies and adjust the designs accordingly." I saw no reason to adhere to da Vinci's peg-based design, since modern technology provides much better mechanical solutions. However, I did want my design to loosely resemble da Vinci's original drawing, simply for aesthetic appeal and overall recognizably.

I also opted not to use da Vinci's original one-way gear mechanism, since I did not want my design to click as it rotates. My design includes a 2-position "slip-clutch" of sorts, to allow (and/or limit) rotation in either direction... with no obnoxious clicking.

My person 3d printing experience has been limited to FDM, thus far... so my design is engineered for that flavor of additive manufacturing. Specific print settings will be detailed later in this document. However, I will note that this design requires zero support material, and zero post-processing. (This, of course, depends on your FDM printer's settings. More detail about this will follow.)

During the entire design process, I engineered parts while taking their print orientation and assembly method into consideration. Large bases were used, whenever possible, to help with build surface adhesion. However, I also tried to avoid large areas of base layer material, to minimize warping…and I attempted to do this while using features that looked integral and appealing to the design.

Ironically, I own a ***da Vinci 1.0 Pro*** from ***XYZ Printing***… so my original design included tolerance values for that printer (with the default 0.4mm nozzle). Also ironically, my 3d printer developed a mechanical issue at the extruder, which I was unable to repair (or modify to an upgraded extruder design, more accurately).

Because of this technical difficulty, I was forced to use the ***Lulzbot TAZ-5*** where I work. (Yes, I use the term 'forced' quite facetiously.) However, this meant that I was forced to adjust my tolerances on many parts to accommodate TAZ's large 0.5mm nozzle. (In that sentence, the word 'forced' was much more literal.)

The entire design was modeled using **TurboCAD** v16, in native file format… then exported into STL, STEP, IGES, and OBJ formats. (I exported OBJ files for use in constructing an 'Assembly and Operation' video, which can be viewed at https://youtu.be/sJWM-WSHhrE)

TECHNICAL SPECS:

1) Part count: 16
2) Print settings (***Lulzbot TAZ-5*** w/0.5mm nozzle):
   1. Layer height 0.2mm
   2. Shell thickness 1.5mm
   3. Top/bottom thickness 1.5mm
   4. Infill density 20%
   5. Print speed 50mm/sec
   6. Filament:
      1. 3mm 'Husky Silver' PLA from **Orb Polymers** (silver parts)
      2. 3mm 'Black Bat' PLA from **Orb Polymers** (black parts)

PARTS LIST:

	PART NAME:	FILE NAME:	VOLUME:
1)	Stand	Stand_fixed.STL	17.7509 in^3
2)	Left gear	Gear left_fixed.STL	16.1711 in^3
3)	Right gear	Gear right_fixed.STL	16.1091 in^3
4)	Central gear	Central_gear_fixed.STL	3.9666 in^3
5)	Pivot shaft	Pivot_fixed.STL	3.4235 in^3
6)	Axle	Axle_v2_fixed.STL	2.6203 in^3
7)	Carrier	Carrier_fixed.STL	7.3796 in^3
8)	Ratchet	Ratchet_fixed.STL	2.3775 in^3
9)	Ratchet Handle	Ratchet_handle_fixed.STL	0.6917 in
10)	Handle Arm	Handle_arm_fixed.STL	2.4122 in
11)	Handle Clip 1	Handle_clip_1_fixed.STL	0.6511 in

12) Handle Clip 2	Handle_clip_2_fixed.STL	0.0632 in
13) Handle	Handle_fixed.STL	0.7770 in
14) Pivot Retainer Clip	Pivot_clip_fixed.STL	0.2892 in
15) Axle Retainer Clip	Axle_clip_fixed.STL	0.1771 in
16) Ratchet Retainer Clip	Ratchet_clip_fixed.STL	0.0457 in

PRINTING INSTRUCTIONS:

I printed all parts using a ***Lulzbot TAZ-5*** with a 0.5mm nozzle, and Lulzbot-*Edition* **Cura** software. I design in inches, and **Cura** does not have an option to import files in inches (unlike ***XYZware*** for my ***da Vinci 1.0 Pro***). Depending on which slicing software you use, you may need to scale all parts up by 25.4% in order to fit properly.

All parts files have been rotated to proper printing orientation, centered on the X/Y axes, and are sitting on the Z plane. All files have been run through the ***Model Repair Service*** at https://netfabb.azurewebsites.net/ (thus the "[filename]_fixed.STL" name of all files), to ensure that they are watertight and 3d-printable for most FDM printers.

All parts were designed to be printed without using support material, a raft, or a brim. However you may opt to add support structures to the Stand part, due to the vertical holes. (My stand printed just fine without using support.)

Only one of each part needs to be printed. Due to my time frame, I used 10% rectilinear infill for most parts; a layer height of 0.3mm; and a 1.0mm wall thickness. My temperatures were 205°C for the extruder, and 60°C for the heated PEI build surface. I used two different colors of 3mm PLA from **Orb Polymers**. My print speed was 50mm/sec for all prints, which were printed in 3 separate sessions.

ASSEMBLY INSTRUCTIONS:

1) Position the Left Gear and Right Gear on either side of the Carrier, and hold them together while lowering them into position between the uprights of the Stand. (The left gear has a small hole, and the Right Gear has a larger square hole. The slot in the Carrier should face up.) For best operation, lubricate the inside faces of the shaft openings with a graphite lubricant.

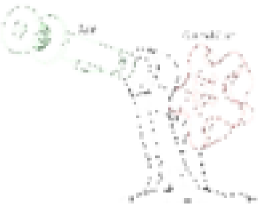
2) Insert the Pivot through the right side of the Stand and through both Gears, the Carrier, and the left side of the Stand. The square hubs of the Pivot should fit into the square opening of the Right Gear. For best operation, lubricate the outside of the shaft with a graphite lubricant.

3) Ensure that both Gears rotate freely, and independent of each other. If not, you may need

to ream the holes slightly, or sand some parts until there is very little friction between them.

4) Once you are satisfied with the fit, snap the Pivot Retaining Clip onto the end of the Pivot shaft. The top of the Clip should rest inside the left side of the Stand to prevent the Clip from rotating with the Shaft. NOTE: The clip will require a bit of pressure in order to push onto the end of the Pivot shaft.

5) Lower the Central Gear into position by rotating the Left and/or Right Gears, then insert the Axle through the front of the Stand and through the Central Gear, until it comes to rest inside the Carrier. For best operation, use graphite to lubricate the inside of the shaft opening on the Stand, and a 1-inch area of the Axle shaft, directly behind the "spool" portion, and the end section of the Axle shaft.



The Central Gear will need to be rotated until the tapered spline of the Axle slips into one of the six notches in the Central Gear.

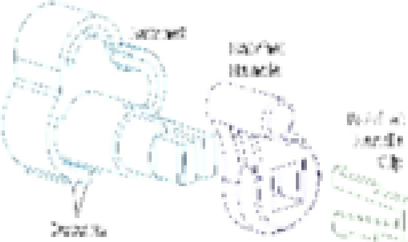
6) Test the rotation of the gears. They should mesh snugly, yet rotate smoothly. If not, you may need to make adjustments with a ream, sandpaper, et cetera.

7) Once you are satisfied with the fit, insert the Axle Retaining Clip into the slot at the top of the Carrier, and snap it onto the Axle. NOTE: The clip has a beveled side, and needs to be oriented with the beveled side of groove of the Axle. The will require a bit of pressure in order to push onto the end of the Axle.

8) Slide the shaft of the Ratchet into the hole at the front of the Stand, from the left side. The Ratchet has three spring-loaded arms, but only one of those arms has detents that mesh with the radial notches in the Stand. These detents should face downward. For best operation, lubricate the small diameter of the shaft with graphite, as well as the shaft opening in the Stand.

9) Push the Ratchet Handle onto the barbed end of the Ratchet's shaft. It should click snugly into place.

I also designed a slightly redundant Ratchet Handle Clip to ensure that the Ratchet Handle stayed secured to the Ratchet.



If you choose to use it, insert the forked end into the rectangular opening at the end of the Ratchet's shaft by gently squeezing the ends together. Push it in until it is flush with the end of the

Ratchet's shaft and Ratchet handle.

NOTE: The clip will require quite a bit of force in order to seat properly inside the Ratchet's shaft.

10) Place the Handle Arm onto the Pivot shaft by placing the rounded retention lug into the square opening at the end of the Pivot. Then, snap the Handle Clip into the Pivot and around the Handle Arm. The clip will require quite a bit of force, and will snap into place with a solid click.

11) Insert the small peg of the Handle into the hole at the end of the Handle Arm, then secure by snapping the Handle Retaining Clip over the end of the Handle. You may wish to lubricate the small peg with graphite, as well as the peg opening in the Handle Arm. NOTE: The clip has a beveled side, and needs to be oriented with the beveled side of groove of the Handle. The clip will require quite a bit of force in order to snap onto the end of the Handle.

12) Tie a length of string around the 'Spool' of the Axle, towards either the front of the threads, or the rear. Secure the string with a small dab of 5-minute epoxy, or adhesive of your choice. Allow the adhesive to cure.

13) Wrap the string around the "Spool" several times, following the small threads... which I added to aid in nice, neat spooling of string.

14) Tie a weighted object to the loose end of the string. Enjoy lifting and lowering the object.

Assembly is complete!

You may also refer to my brief Assembly and Operation animation video at https://youtu.be/sJWM-WSHhrE for further reference.

NOTE: All parts of my printed parts fit together perfectly. Due to limited time, I had to use lower-quality print settings than I generally use. Due to this, the top of the vertical holes did not print perfectly (as I expected), but were quite good enough to allow assembly without any processing.

OPERATION INSTRUCTIONS:

1) The handle turns the Right Gear in whichever direction you crank it, while the Left Gear rotates in the opposite direction. My assembly was quite stiff after assembly, but loosened up after a bit of "breaking in" by manually rotating the gears. This is why I suggest using graphite lubrication on all of the shafts and their respective openings.

2) The Ratchet prevents back-rotation due to forces imposed by the weight of the load being

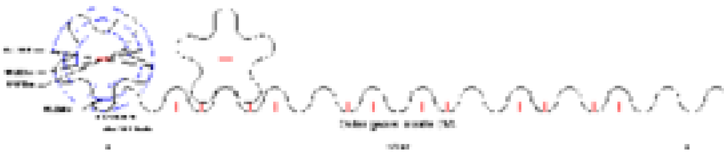
lifted by the axle. Depending on it's setting, it will allow only CW or CCW rotation (and/or lifting or lowering of the weight).

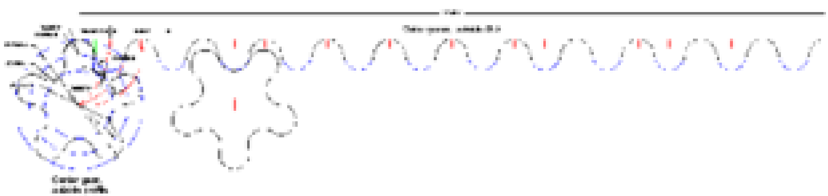
The Ratchet operates by applying pressure against the circumference of the main gears as they rotate, causing them to stop when rotated against the cam-style Ratchet arms. It may work "as is", or it may need a light coat of rubber cement applied to the surfaces that contact the main gears. In order to do this, you will need to remove the Ratchet from the Stand, and allow the cement to fully cure before reassembling.

Depending on your print settings/quality, it may also be necessary to coat the outer circumference of the Left and Right Gears with rubber cement. My Ratchet design requires friction between the main gears and the cams of the Ratchet… otherwise, it will not function.

THE DESIGN:

As soon as I saw this design challenge, I knew that I had to enter it… and what I wanted to do. So I set up the parameters of the gear mechanism using these drawings:





This gear design mimics da Vinci's original drawings, while using much more modern design theory and fabrication technology. Technically speaking, da Vinci's drawings are wrong. The large diameter of the outer gears produce a very high gear ratio with the center gear, which creates a higher rotational speed—and much more importantly, increased torque requirements—in order to lift the load that is suspended from the spindle. As a former crane operator and someone who designs and machines tools for a living, I knew this before starting my design. But I wanted to keep my design reminiscent of da Vinci's drawings.

My design includes four different "retention clips", each made to serve an individual purpose. For instance, the Axle Retaining Clip has a beveled edge. This was not done for aesthetic reasons, but technical reasons, due to the 3d printing process:

1) The Axle Retaining Clip has a beveled side to it. This is due to the orientation of the Axle, during printing... which involves a 45° slope in order to print successfully.

2) The Pivot Retaining Clip has a beveled side, which mates with the Pivot without much logic involved. It only fits one way, and it is quite obvious. The Pivot is printed in an orientation that requires a slope, in order to print correctly... thus, the clip shares that geometry.

3) The Handle Retaining Clip also has a beveled side, which mates with the Handle. The Handle is printed in an upright position that required me to design it with a bevel in the groove that holds the Retaining Clip.

4) The Ratchet Handle Retaining Clip is a very redundant part, as the Ratchet Handle fits onto the shaft of the Ratchet in a very perfect way. If you choose to use this part, it will require an enormous amount of pressure, but will eventually snap into place, and sound like it broke. (Yours might break. Mine did not... but it scared me.)

<u>**POLITICALLY CORRECT ENDING:**</u>

This design is not perfect, by any means. Generally speaking, I have a month or two to test and prove my designs (which I work on almost constantly). I love challenges like this, because they test my ability to work on yet another project... with yet another time-frame to schedule around my work schedule. I work best under stress... however, I don't see time constraints as an issue, anymore.

As one of my coworkers always says, "Quality, or Production. Choose one. You can never have both at the same time."

Given enough time, my design would work flawlessly. That's what I do for a living. I design tings... machine things... and make adjustments.

The flat side of the Carrier was intended to hold an entirely different "Ratchet" design, by the way. (And today, I'm thinking that design may have been the better option.)

<u>**CONCLUSION:**</u>

My design looks great, as I finally view it in reality... gathering light and reflections in the PLA filaments that I chose to print the parts with. It is beautiful, yet slightly menacing... resembling a Gatling gun from the 18th Century. My 11-year-old son told me, "Dad, if you don't win this challenge, those people are crazy." I'm not sure about that... there are a lot of good designs already posted, and I'm entering mine at the very last moment. (I'd love to stand by the old adage that "best comes last," but I don't subscribe to that line of thinking.

Every entry within this Challenge has some sort of merit, and I'm nervous as I submit my final files. "It's not good enough," I say to myself. (My designs never satisfy me, and always need updated, in my mind.)

God bless every entrance to this Challenge, as they are all worth the prize. If nothing else, hopefully we all had fun doing it, and learned something.

Good night, and may the best design win.

--Clint K. Campbell