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Evaluation of 3-D Printed Elastomer Tracks for Small Robots

GVR-BOT Evaluation Report

Tyrus Valascho
1-23-2017

Executive Summary: 3-D Printed Drive Tracks and Flipper Tracks for the GVR-BOT small research robot were tested at TARDEC-GVR in January, 2017. The 3-D printed parts were distinguishable from their OEM counterparts when crucial mobility characteristics of the parts were measured.

In addition, performance tests were run. It was found that the Drive Tracks did not perform well enough for fielding on the GVR-BOT. The Flipper Tracks did perform acceptably and further study is recommended for their use as a temporary replacement for OEM Flipper Tracks.

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Introduction

On January 20, 2017 one 3-D printed Drive Track and one 3-D printed Flipper Track were received from David Sabanosh and James Zunino at Picatinny Arsenal, NJ. These evaluation units were photographed and measured, then a functional test was performed on them to verify equivalent operation with the Original Equipment Manufacturer (OEM) parts.

Photographs of the two received parts are provided in Figure 1 and Figure 2.

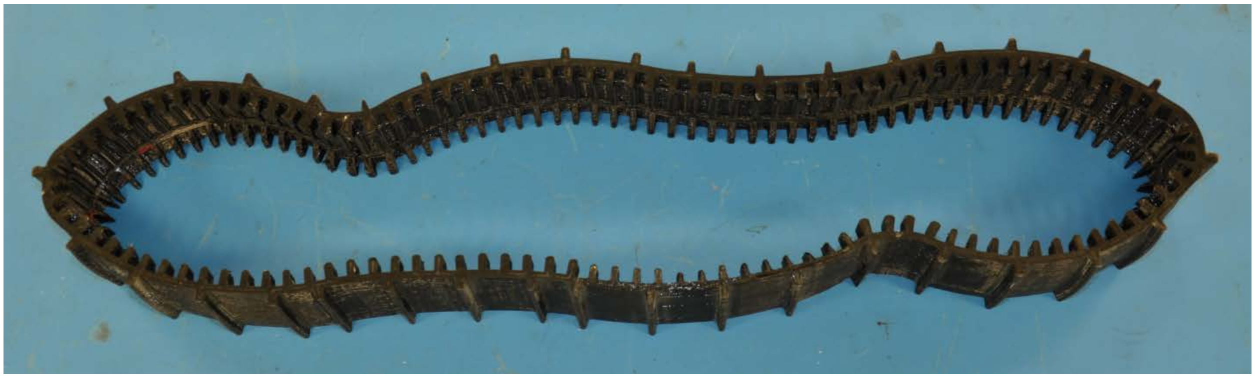

Figure 1 - 3-D Printed Drive Track

Figure 2 - 3-D Printed Flipper Track

The parts were printed using a Lulzbot TAZ 4 3-D printer with Flexystruder Tool Head. The tracks were constructed from a thermoplastic elastomer material called NinjaFlex, made by NinjaTek. The specifications of these machines and the material are provided in the Appendices of this document.

Initial Measurements and Comparison

Drive Tracks

The GVR-BOT platform moves the Drive Tracks by actuating two DC brushed motors through a series of gears which move the Drive Wheels. The Drive Wheels have ridges that fit within corresponding channels in the Drive Tracks and cause the tracks to move as the wheels spin. There are left and right Drive Tracks on the robot which can be moved independently in either direction.

One important characteristic of the drive tracks is the channel that the ridges of the drive wheel interface with. The channels within the right side Drive Tracks and the ridges on the right side Drive Wheels are identified in Figure 3 and a closer and more detailed view provided in Figure 4.

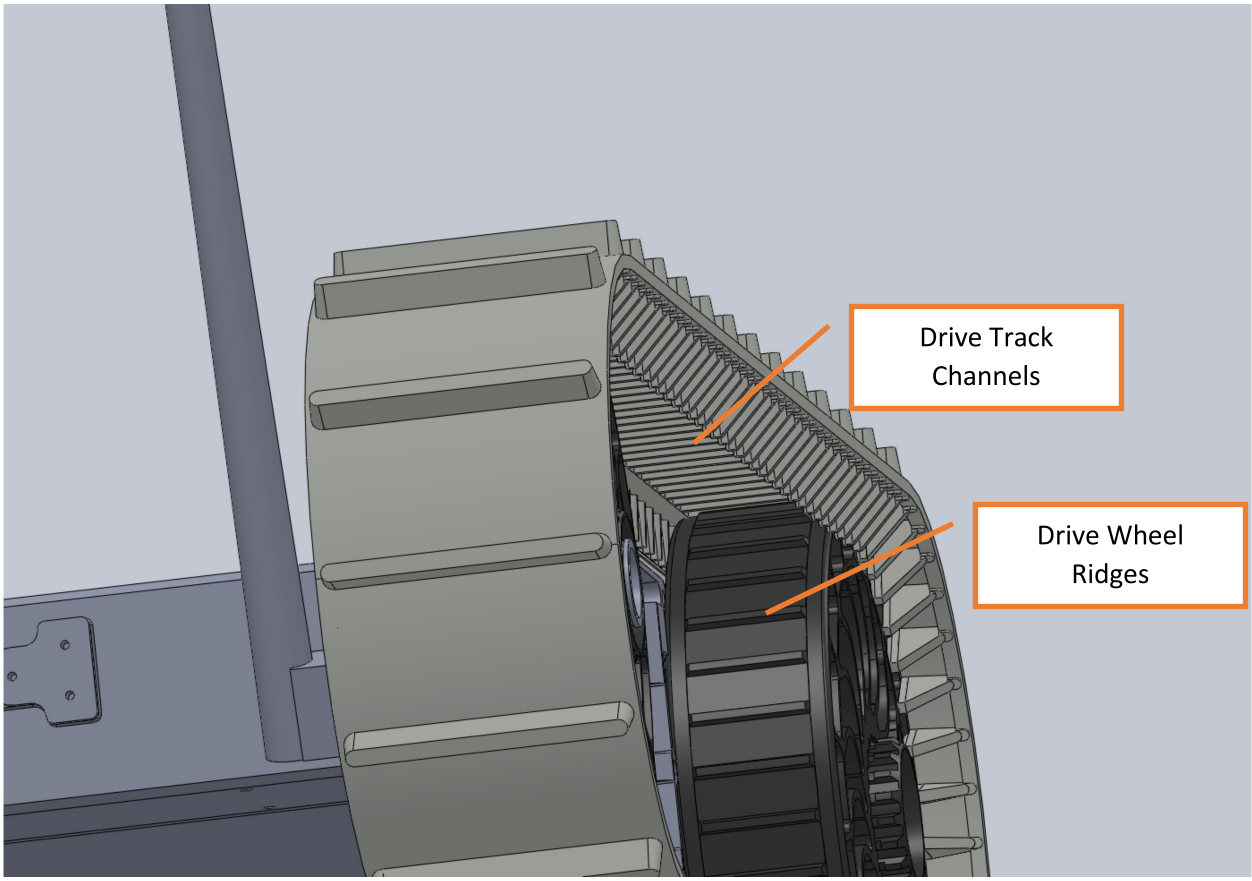

Figure 3- Drive Track Channels and Drive Wheel Ridges Identified

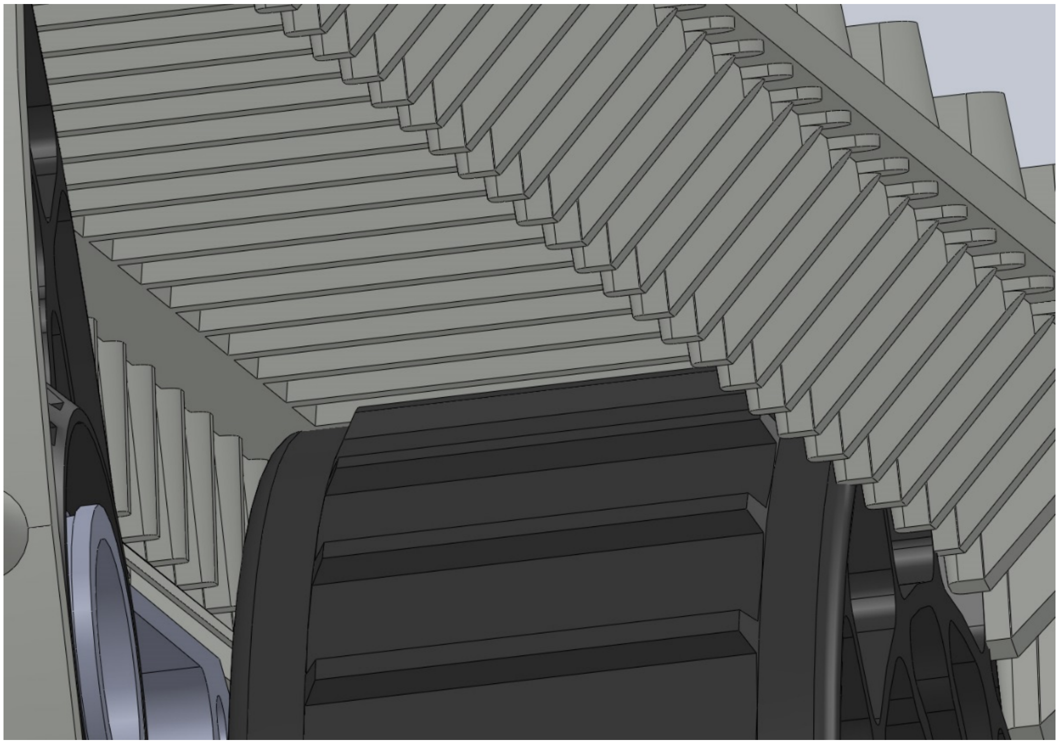

Figure 4- Channel / Ridge Interface Detail

Approximately 2/3 of the Drive Wheel is in contact with the Drive Track at any given time. The most effective instantiation of this design is when every channel and every ridge that is in contact is correctly interfacing – that is, the leading edge of the ridge is pushing against the inside lead edge of the corresponding channel. These ridges and channels appear to be consistent on the original GVR-BOT and during the 15 years of continuous use that these robots have experienced, very few problems in this area have been reported.

Distances between Leading Inside Channel Edges

To evaluate the 3-D printed Drive Tracks the distances between leading inside edges of channels were measured, as shown in Figure 5.

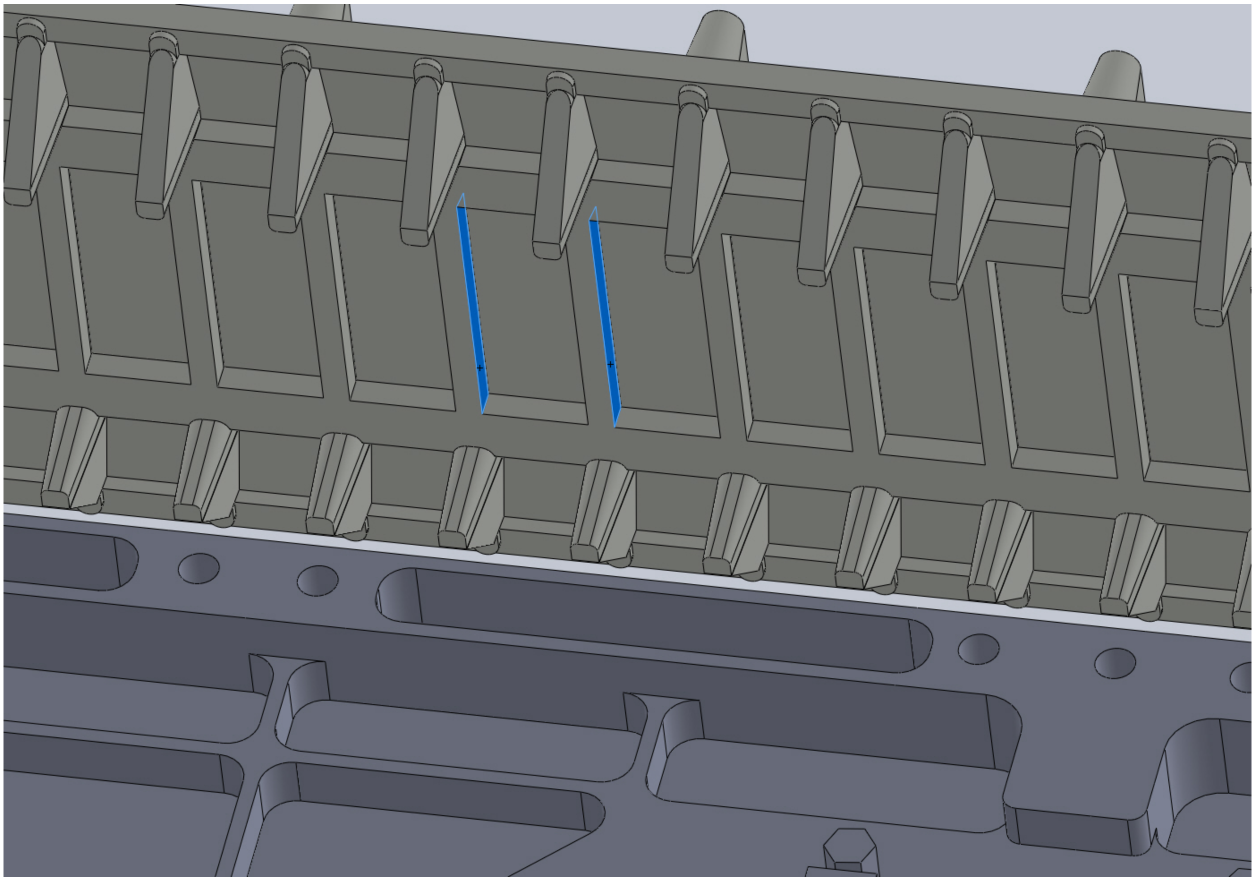

Figure 5 - Measurement of Inside Leading Edges of Drive Track Channels

Solid models of the PackBot are available from 3-D scan data and used as a baseline of distances for comparison with an OEM Drive Track and the new 3-D printed Drive Track. Because the Government does not possess the Technical Data Package of the PackBot, the true specifications are not know and the CAD model is used in lieu of the actual information, and without any known tolerance.

20 measurements of each track were made and averages, maximums, minimum, and standard deviations of the data calculated.

The results are provided in Table 1 and the raw values are in Appendix D - Drive Track Distance between Leading Channel Edges Measured Values.

Table 1 - Drive Track Distance between Leading Channel Edges

	Model (mm)	**Original (mm)**	**3-D Printed (mm)**
Average	14.12	13.73	12.27
St Dev	0	0.17	0.80
Max	14.12	14.00	13.20
Min	14.12	13.40	9.40

General Observations

It was noted that several parts of the 3-D printed Drive Tracks had inconsistencies, some of which may have an effect on performance. Figure 6 displays three such observations: inconsistent tooth size and shape, a deep channel where a ridge should be, and a minor print misalignment.

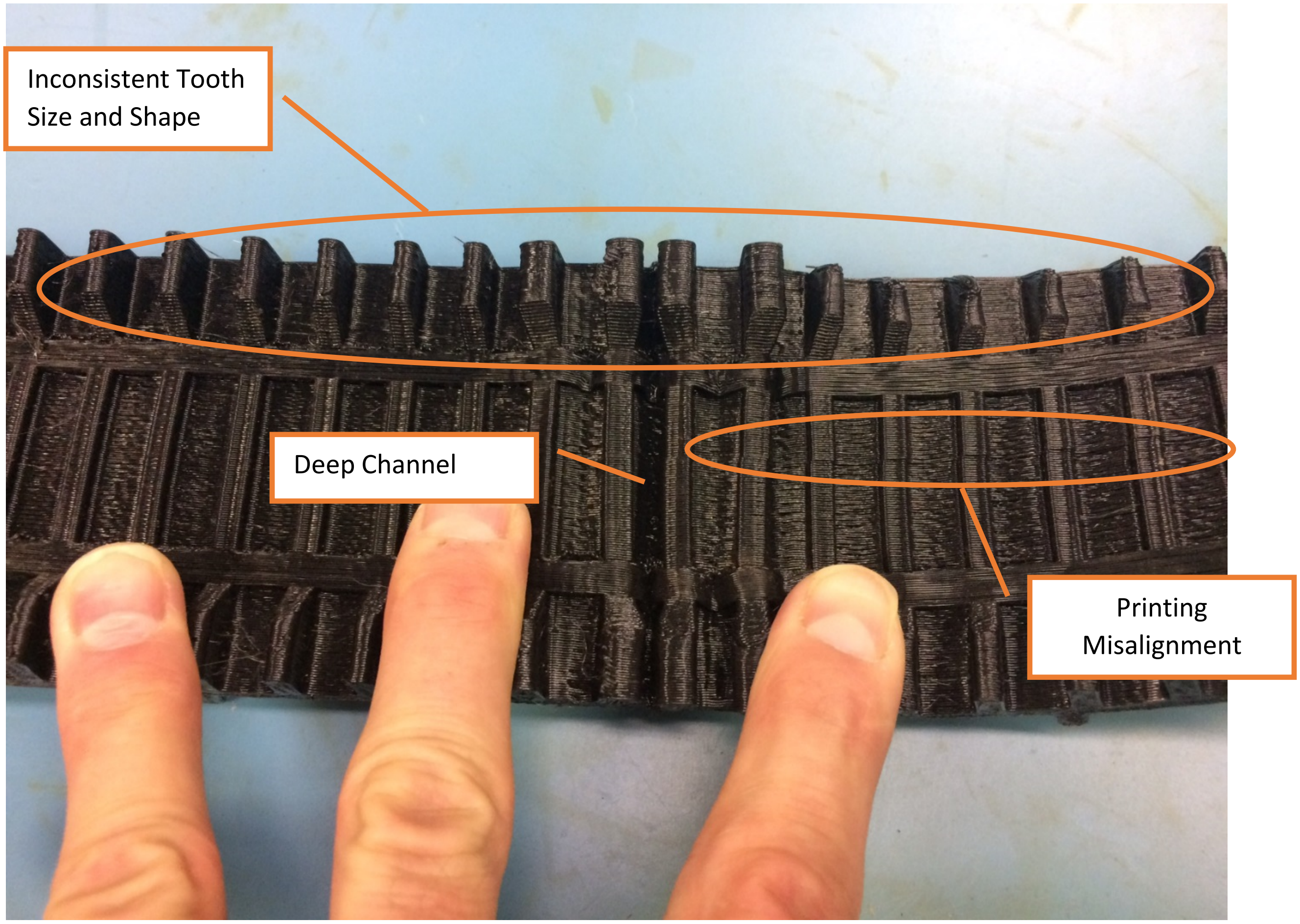

Figure 6 - Observed Inconsistencies

Of these three inconsistencies, the deep channel is likely the only one that would affect performance of the track. The depth of this channel shouldn't cause any issue by itself since the ridge would still fit within. However, it appears that the root cause of this inconsistency also caused the surrounding areas to be warped, which could reduce proper contact with the Drive Wheel and the ridges. Also, this general area of the track has incorrect spacing between the inside leading edges of the channels, shown previously to be a potential issue.

Another issue noted is that the edges of the channels have rounded edges, almost as if fillets were added to the upper and lower corners. The OEM channel edges are relatively sharp by comparison, and the advantage is more contact area with the mating ridges and a stronger "grip" as they are being moved. A visual comparison of the two products is provided in Figure 7.

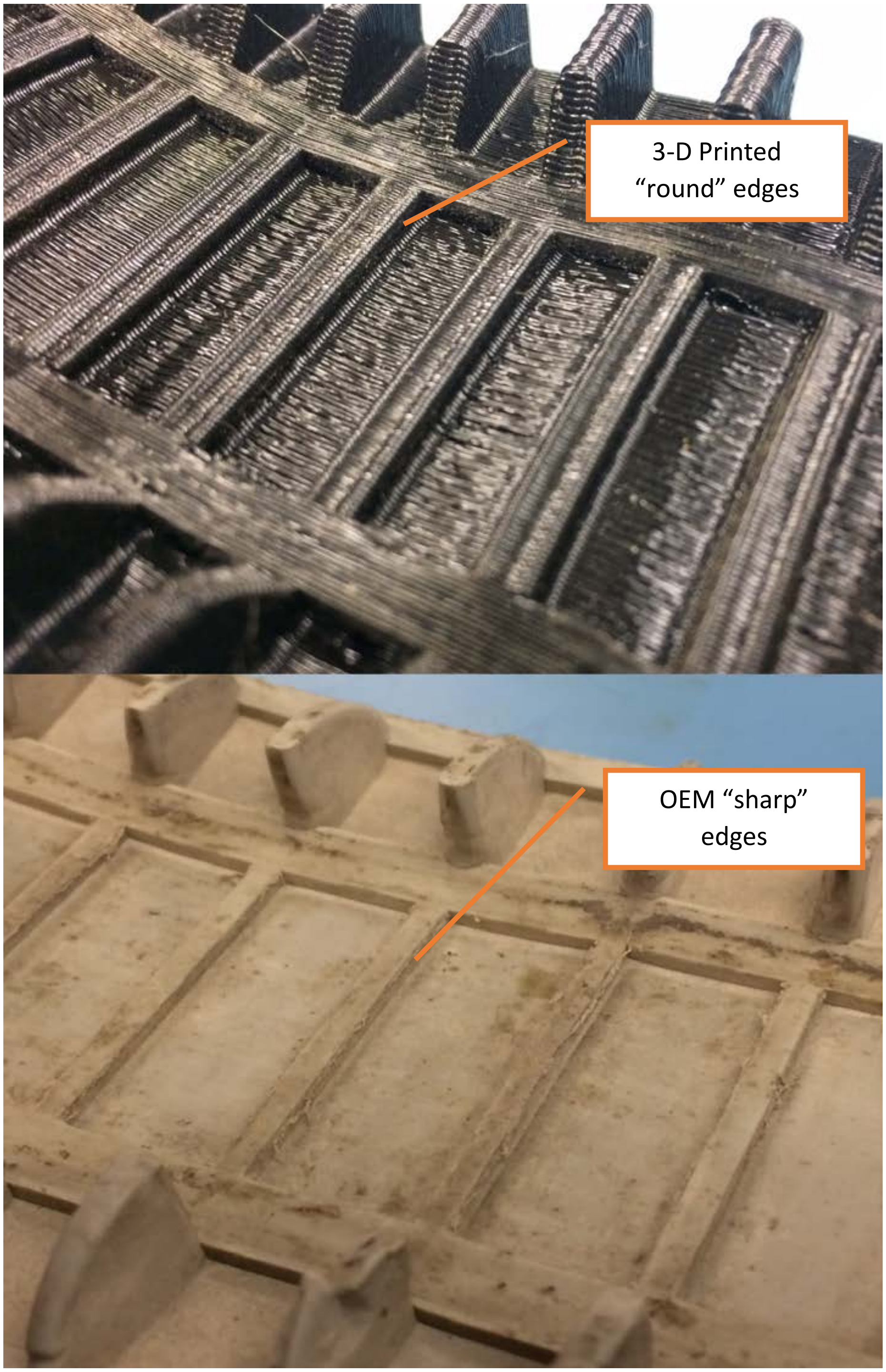

Figure 7 - Comparison of Channel Edge "Sharpness"

A final difference between the 2 tracks is the reversal of the tooth design. The teeth along the outer edge of the Drive Track helps keep the track centered and retained on the drive wheel. The 3-D printed Drive Tracks have reversed the design of these teeth, and the new design does not appear to retain the

Drive Track on the Drive Wheel as well. A view of the change in design as it sits on the Drive Wheel as viewed from the front of the robot is provided in Figure 8.

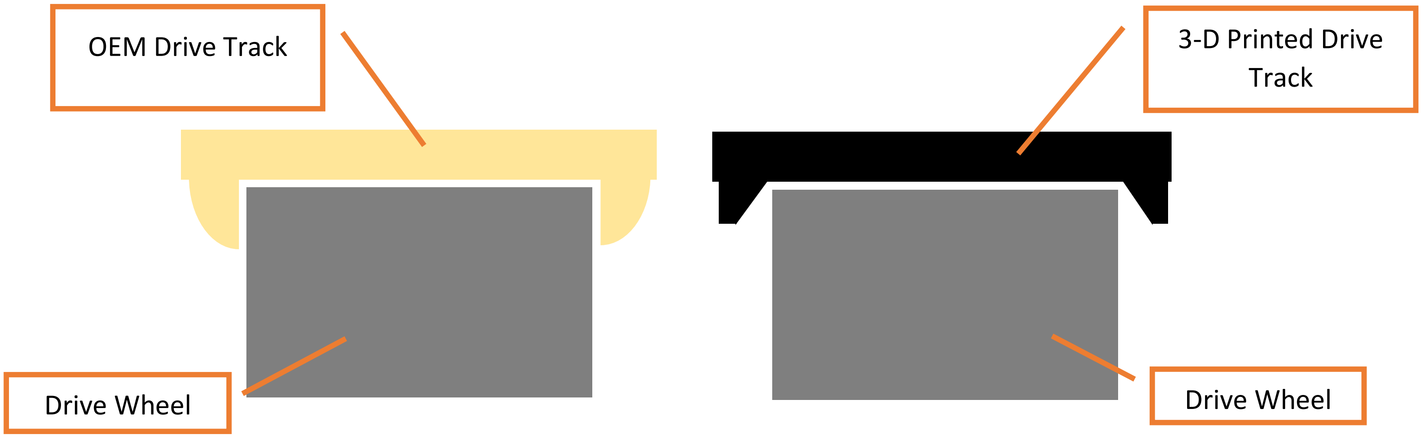

Figure 8 - Comparison of Drive Track Tooth Designs – Front View

The 3-D Printed Drive Track came off the robot at one point during testing and this difference in tooth design was a possible factor. Although the GVR-BOT lacks a track tensioner, OEM Drive Tracks have not been observed to come off the robot under any conditions except if the track has been damaged.

Flipper Tracks

The mechanism by which the Flipper Tracks are moved is similar to that of the Drive Tracks described previously. Both flippers of the robot are locked together mechanically by one flipper shaft, however, which is different than the independent movement of the left and right Drive Tracks.

The channel and ridge design is also similar, but in the case of the Flipper Track, the teeth of the track are on the inside in a single line and the channels and ridges are on the outside of the track in two lines. This design is the opposite of the Drive Track, which has two rows of teeth on the outside / inside and one row of channels in the middle. These features of the Flipper Track are labelled in Figure 9.

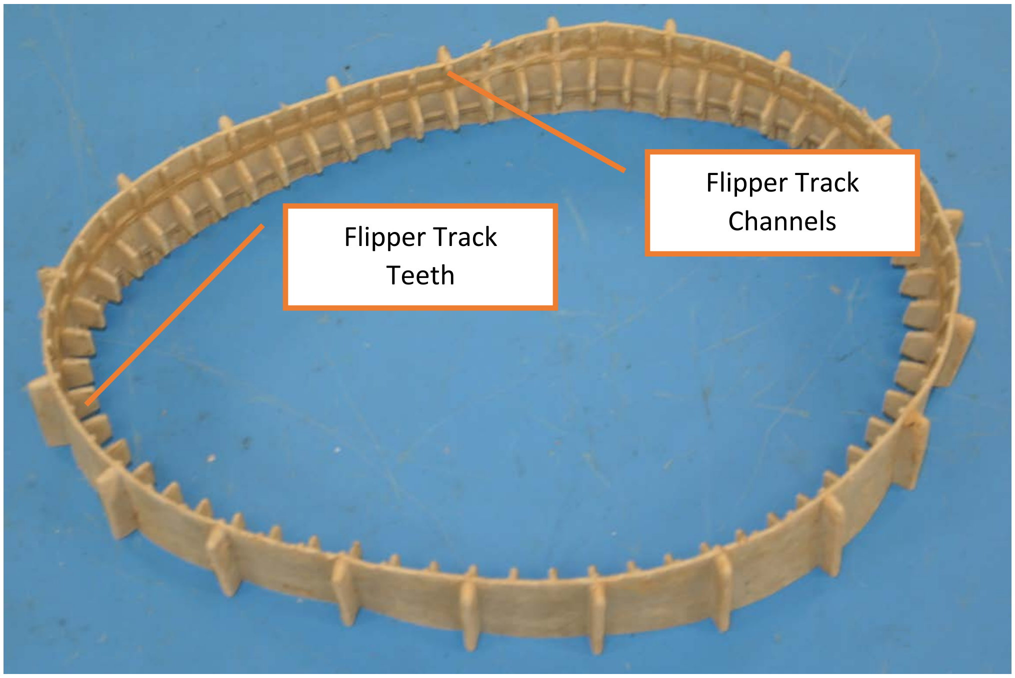

Figure 9 - OEM Flipper Track Components Labelled

Another difference between Drive Tracks and Flipper Tracks is in the shape of the “channels” – Flipper Track channels do not have a recessed rectangular shape like the Drive Tracks. They are composed of a single line of material to the edge of the track.

Distances between Leading Inside Channel Edges

The same measurements were made for the OEM and 3-D Printed Flipper Track Channels. A baseline value was again provided by the 3-D scanned model of this part.

The results are given in Table 2 and the raw data is in Appendix E - Flipper Track Distance between Leading Channel Edges Measured Values.

Table 2 - Flipper Track Distance between Leading Channel Edges

	Model (mm)	**Original (mm)**	**3-D Printed (mm)**
Average	13.76	13.76	14.63
St Dev	0	0.24	2.66
Max	13.76	14.40	25.00
Min	13.76	13.30	9.90

Examples of the wide range of distances that were seen in the part are provided in Figure 10 and Figure 11.

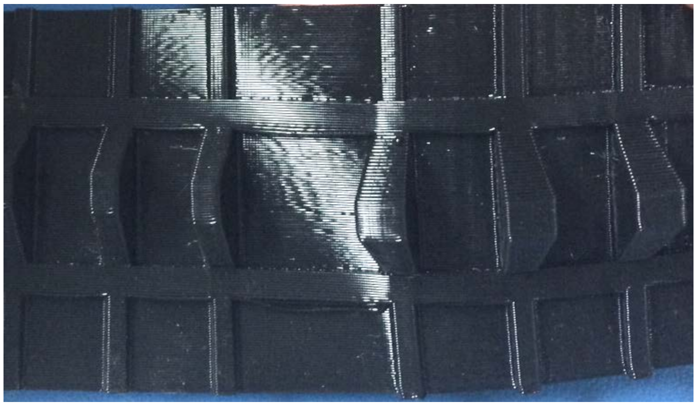

Figure 10 - Very Wide Distance between Channel Edges

Figure 11 - Very Narrow Distance between Channel Edges

The effect of these variances is seen by comparing the interface between Flipper Wheel and Flipper Track. This comparison is more easily made with the flipper because that interface is at the edge of the track and can be seen readily. Figure 12 compares the interface of the OEM Flipper Track to the 3-D Printed one.

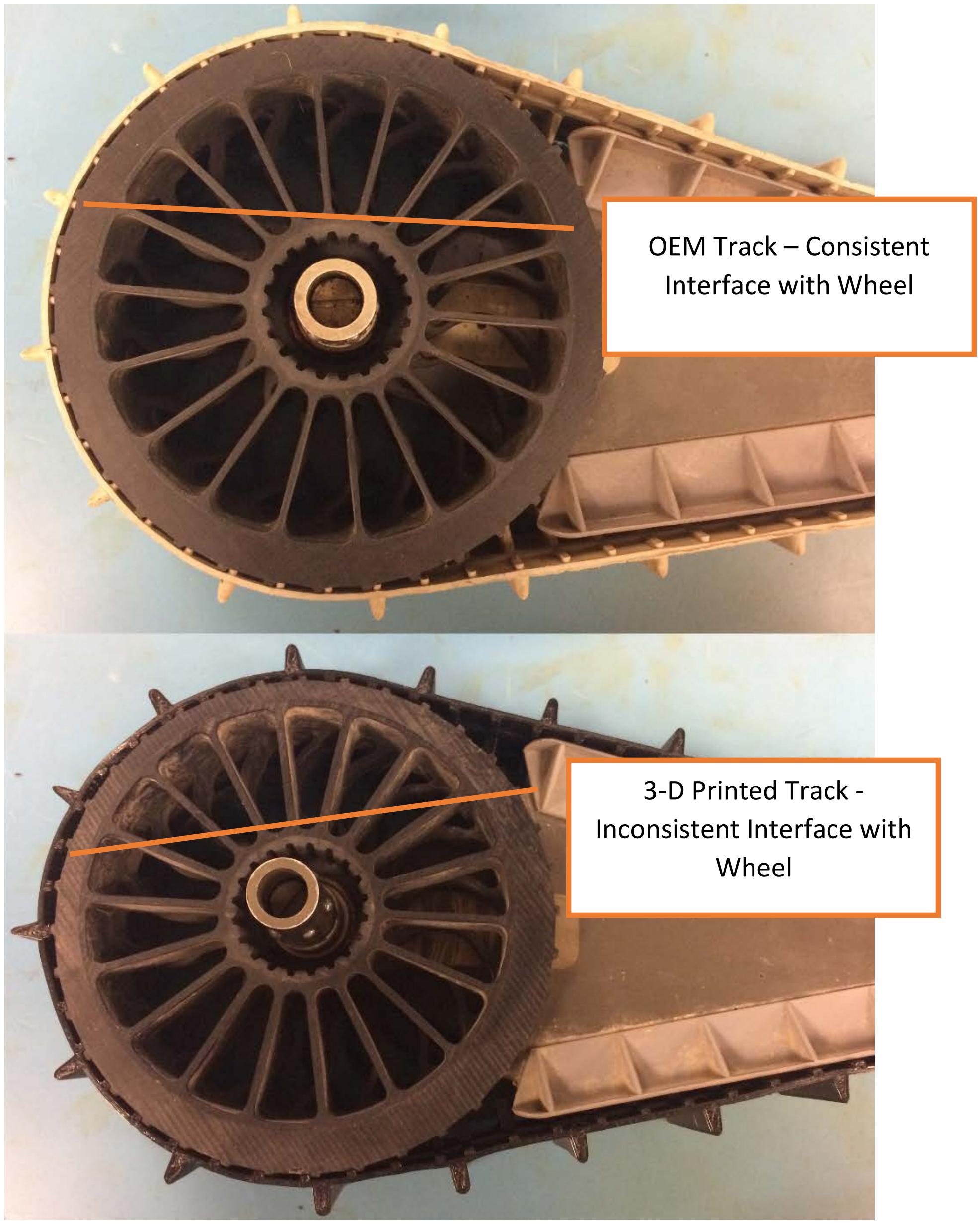

Figure 12 - Flipper Track / Wheel Interface Comparison

Performance Test Procedure

Drive Track Driving Test

1. Install Drive Track to be tested on the robot.
2. Drive robot at slow speed for 20 m in a straight line.
3. Record any loss of speed due to Drive Wheel / Drive Track slip.
4. Drive robot at medium speed for 20 m in a straight line.
5. Record any loss of speed due to Drive Wheel / Drive Track slip.
6. Drive robot at fast speed for 20 m in a straight line.

7. Record any loss of speed due to Drive Wheel / Drive Track slip.

Drive Track Turn in Place Test

1. Install Drive Track to be tested on the robot.
2. Turn robot in place on industrial carpet for 360 degrees at slow speed.
3. Record whether Drive Wheel / Drive Track slip occurs.
4. Turn robot in place on industrial carpet for 360 degrees at medium speed.
5. Record whether Drive Wheel / Drive Track slip occurs.
6. Turn robot in place on industrial carpet for 360 degrees at fast speed.
7. Record whether Drive Wheel / Drive Track slip occurs.

Flipper Track Test

1. Install Flipper Track to be tested on the robot.
2. Raise robot up into "prairie dog" mode (body of robot to approximately 60 degrees, vehicle weight resting on the flippers).
3. While in prairie dog mode, spin robot 360 degrees in place at low speed.
4. Record whether Flipper Wheel / Flipper Track slip occurs.

Performance Test Results

The Performance Test was performed on January 23, 2017 in the GVR-BOT Robotics Lab, bldg. 200C, Detroit Arsenal, Michigan.

An image of the robot that was used is provided in Figure 13.

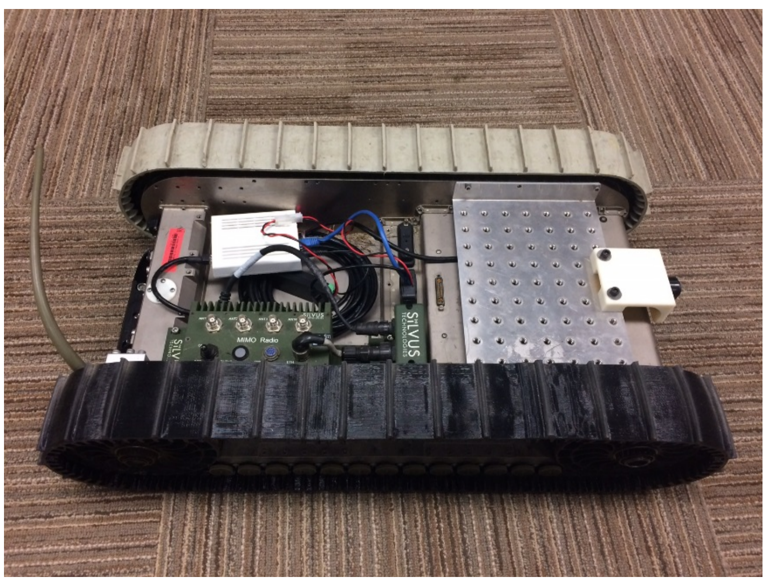

Figure 13 - Photo of Unit under Test

Test Conditions

Ambient Temperature (C): 21.7

Robot Serial Number: GVR-BOT-007

SW Release: GVR-BOT System SW 1.01

Test Operator: Ty Valascho

Drive Track Driving Test Results

Table 3 contains the results of the Driving Test.

Table 3 - Drive Track Driving Test Results

Test Run #	Speed	OEM Drive Track	3-D Printed Drive Track
1	Low	No Slip	No Slip
2	Low	No Slip	No Slip
3	Low	No Slip	No Slip
4	Medium	No Slip	No Slip
5	Medium	No Slip	No Slip
6	Medium	No Slip	No Slip
7	High	No Slip	No Slip
8	High	No Slip	No Slip
9	High	No Slip	No Slip

Additional Notes: none

Drive Track Turn in Place Test Results

Table 4 contains the Turn in Place test results.

Table 4 - Drive Track Turn in Place Test Results

Test Run #	Speed	OEM Drive Track	3-D Printed Drive Track
1	Low	No Slip	No Slip
2	Low	No Slip	No Slip
3	Low	No Slip	No Slip
4	Medium	No Slip	No Slip
5	Medium	No Slip	No Slip
6	Medium	No Slip	No Slip
7	High	No Slip	No Slip
8	High	No Slip	Slip
9	High	No Slip	Slip

Video footage of the slip occurring during a test run was too large to embed in this document, but is available upon request.

Additional Notes: the 3-D Printed Drive Track appears to sometimes slide out from underneath robot by about 13 mm while turning in place. It did not come loose from the robot during this test, but is not in the correct location. Figure 14 shows the track position when this occurred.

Figure 14 - Drive Track Slipping out during Turn in Place Maneuver

Note that the channels are visible and therefore not in the correct position.

The track would return to its correct position if the robot continued to turn in place. The correct position of the track can be seen in Figure 15.

Figure 15 – Correct Position of Track during Turn in Place Maneuver

Note that the channels are not visible in this image.

Flipper Track Test Results

Table 5 contains the Flipper Track test results.

Table 5 - Flipper Track Test Results

Test Run #	Speed	OEM Flipper Track	3-D Printed Flipper Track
1	Low	No slip	No slip
2	Low	No slip	No slip
3	Low	No slip	No slip

Additional Notes: none

Conclusions and Recommendations

From the measurements and test data, the 3-D printed Drive Tracks and Flipper Tracks can be distinguished from their OEM counterparts. The crucial parameters of the 3-D printed parts from a mobility perspective fail to meet the OEM specifications as understood by the testers.

Despite these differences, the performance of both parts is very similar to the OEM ones. In the case of the Drive Tracks, there were two instances of slip while turning in place and one instance of the track coming loose of the robot. In the high stress applications these robots are used in, any such failures would be unacceptable.

The flipper tracks performed the same as the OEM Flipper Tracks and pending durability test and qualification may be acceptable for field use.

It must be noted that all results and testing were performed on a single sample part. For more confidence in the results, a representative sample of parts should be tested.

Appendices

Appendix A - Lulzbot TAZ 4 Specifications

PRICE $2195

ASSEMBLED Yes

TECHNOLOGY FDM — Fused Deposition Modeling

MATERIALS 3mm ABS, PLA, HIPS, PVA, and wood filaments

BUILD SIZE 298mm x 275mm x 250mm / 11.7” x 10.8” x 9.8”

BUILD SPEED 200mm/s

RESOLUTION As low as 100 microns

INPUT .STL, .OBJ, .THING, file input

SIZE 680mm x 520mm x 515mm / 26.8” x 20.5” x 20.3”

WEIGHT 11kg / 24.25lbs

Appendix B - LulzBot TAZ Flexystruder Tool Head Specifications

Required filament diameter: 3mm

Hot end temperature range: 120°C - 300°C

Nozzle diameter: 0.6mm

Required power system: 24v

Using stiff, non-flexible filament with the green flexystruder is not advised as it can lead to premature extruder body wear and purging difficulty when switching between materials.

Fans: Heat sink and nozzle fans included

Appendix C - NinjaFlex by NinjaTek Specifications

Filament Specifications

Filament Diameter: 3mm (0.118 inches)

Amount of Filament: 0.75 kg (1.65 lbs)

Filament color may vary

Printing Specifications

Tool Head: LulzBot Flexystruder or FlexyDually Tool Head

Hot End Temperature: 230°C

Print Surface:To make removing 3D printed NinjaFlex objects easier, we strongly recommend applying a glue stick (such as UHU® brand) applied to the print surface prior to powering on your LulzBot 3D printer. Maintain the print surface by powering off your LulzBot and cleaning the glue stick residue with a soft cloth and water.

Print Surface Temperature: Off

Appendix D - Drive Track Distance between Leading Channel Edges Measured Values

Sample	Original	3-D Printed
1	13.70	12.80
2	13.90	12.70
3	13.80	12.40
4	14.00	12.40
5	13.80	12.20
6	13.90	12.00
7	13.70	12.60
8	14.00	12.40
9	13.80	12.60
10	13.50	12.00
11	13.80	12.50
12	13.50	12.80
13	13.60	11.40
14	13.70	11.90
15	13.40	12.50
16	13.60	12.00
17	13.80	9.40
18	13.50	13.20
19	13.90	13.10
20	13.60	12.40

Appendix E - Flipper Track Distance between Leading Channel Edges Measured Values

Sample	Original	3-D Printed
1	13.80	14.40
2	13.60	9.90
3	13.60	14.30
4	13.70	13.30
5	13.70	14.60
6	13.70	14.80
7	13.80	14.50
8	13.30	14.50
9	13.50	14.40
10	13.80	14.30
11	13.80	14.50
12	13.40	14.30
13	13.90	25.00
14	13.80	14.80
15	14.40	14.60
16	14.00	14.20
17	13.70	14.10
18	14.00	14.40
19	14.00	13.50
20	13.60	14.20