



Learning Locomotion Test 3.1 Results

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1 INTRODUCTION

This document describes Test 3.1 of the DARPA/IPTO Learning Locomotion Program, Phase II. The test was conducted at System Planning Corporation in Arlington, Virginia on October 15-16, 2008.

2 TEST METHODS

2.1 TEST COURSES

The terrain for Test 3.1A, the Gap, was comprised of two flat boards separated by a horizontal gap of 14.5 cm. The finishing board was raised up by approximately the thickness of one board (4.2 cm) above the start, as illustrated in Figure 1.

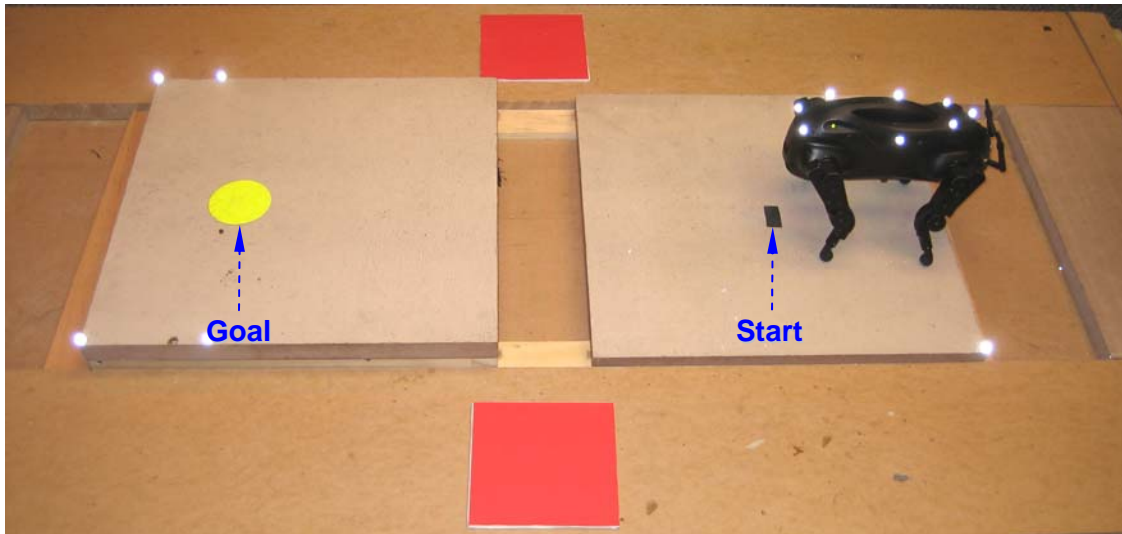


Figure 1 – The Test 3.1A Terrain

The terrain for Test 3.1B was similar to that used for Type A, but is not described in this test report since it is reserved for Government-only testing.

The terrain for Test 3.1C was the Truncated Rocks (“Tetons”) terrain used in Phase II testing. The rocks terrain was tilted so that the finishing board was approximately 7.2 cm higher than the starting board, as shown in Figure 2.

In all tests, an adhesive marker defined the start position. The ‘nose’ of the robot was placed up to the marker. This procedure provides a consistent start-to-goal distance among the performer teams, who employ different pre-run stances. The Goal position was measured using the Vicon motion capture system and indicated by a 5 cm radius yellow disk. The Goal itself is a vertical cylinder, as shown in the individual run plots later in the document.

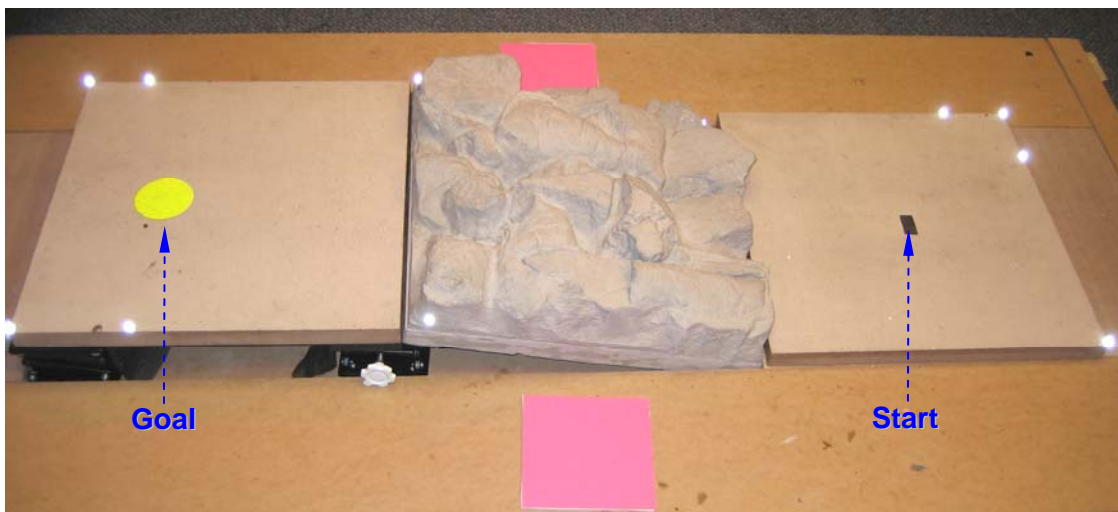


Figure 2 – The Test 3.1C Terrain

2.2 COMMUNICATIONS

Teams were able to watch Type A and Type C tests remotely via multicast video streams. During their test runs, each team held a teleconference with the Learning Locomotion Government Team (LLGT). Type B tests were conducted by the Government alone.

2.3 APPLICABLE DOCUMENTS

This test report addresses only the unique features of this Learning Locomotion test; therefore, it is not intended as a standalone reference. Related material includes:

- *Learning Locomotion Phase II Testing v2*, August 2007
- www.learninglocomotion.net web forums

3 RESULTS: TYPE A TESTS

3.1 SUMMARY

Each team performed three (3) test runs in a scheduled period of approximately one hour. Official scores and statistics were computed using the two best of the three scores for each team, using the teams' log files.

Table 1 displays the measured values and computed scores for the three test runs. Finishing run speeds meeting or exceeding the Phase III speed metric (7.2 cm/sec) are indicated by bold green type.



Table 1 – Test 3.1A Individual Test Run Data

| Individual Trials | | L _c | L _g | t | t _s | F | S | v | | |
|-------------------|----------|-----------------------|-------------------|------------------------|------------------|------------------|----------------------------|-----------|------------------|----------------------------|
| Team | Test Run | Goal Reached (yes/no) | Course Length (m) | Remaining Distance (m) | Elapsed Time (s) | Scoring Time (s) | Course Completion Fraction | Run Score | Run Speed (cm/s) | Finishing Run Speed (cm/s) |
| CMU | 1 | Yes | 1.02 | 0.00 | 18.6 | 18.6 | 1.00 | 1.31 | 5.48 | 5.48 |
| | 2 | Yes | 1.03 | 0.00 | 18.1 | 18.1 | 1.00 | 1.35 | 5.69 | 5.69 |
| | 3 | Yes | 1.01 | 0.00 | 17.5 | 17.5 | 1.00 | 1.37 | 5.77 | 5.77 |
| IHMC | 1 | Yes | 1.03 | 0.00 | 15.6 | 15.6 | 1.00 | 1.57 | 6.60 | 6.60 |
| | 2 | Yes | 1.02 | 0.00 | 15.5 | 15.5 | 1.00 | 1.57 | 6.58 | 6.58 |
| | 3 | Yes | 1.02 | 0.00 | 15.7 | 15.7 | 1.00 | 1.55 | 6.50 | 6.50 |
| MIT | 1 | No | 0.98 | 0.28 | 12.2 | 11.3 | 0.71 | 1.04 | 6.17 | 0.00 |
| | 2 | No | 0.98 | 0.29 | 12.2 | 11.3 | 0.71 | 1.04 | 6.15 | 0.00 |
| | 3 | No | 0.99 | 0.28 | 11.9 | 11.2 | 0.72 | 1.08 | 6.34 | 0.00 |
| Stanford | 1 | Yes | 0.98 | 0.00 | 18.2 | 18.2 | 1.00 | 1.28 | 5.38 | 5.38 |
| | 2 | Yes | 0.95 | 0.00 | 18.8 | 18.0 | 1.00 | 1.26 | 5.28 | 5.28 |
| | 3 | Yes | 0.94 | 0.00 | 17.6 | 17.6 | 1.00 | 1.27 | 5.34 | 5.34 |
| USC | 1 | Yes | 0.97 | 0.00 | 13.3 | 13.3 | 1.00 | 1.74 | 7.29 | 7.29 |
| | 2 | No | 0.99 | 0.51 | 7.8 | 7.7 | 0.49 | 0.73 | 6.29 | 0.00 |
| | 3 | Yes | 0.98 | 0.00 | 14.3 | 14.3 | 1.00 | 1.63 | 6.85 | 6.85 |

- Elapsed Time denotes time from the start to the end of the run.
- Scoring Time is the time from the start of the run to the point of closest approach to the goal. Elapsed Time equals Scoring Time for runs that reach the goal.

Table 2 displays summary statistics. The “Mean Speed Top 2 Runs” column shows the average of the top two fastest runs. If a run does not complete the course, zero is included in the average. The values in this column will be compared to the program speed metric – values exceeding the Phase III metric are indicated in bold.

Table 2 – Test 3.1A Statistics

| | Runs Completed (out of 3) | Fastest Finishing Run Speed (cm/s) | Mean Speed Top Two Runs (cm/s) |
|----------|---------------------------|------------------------------------|--------------------------------|
| CMU | 3 | 5.8 | 5.7 |
| IHMC | 3 | 6.6 | 6.6 |
| MIT | 0 | 0.0 | 0.0 |
| Stanford | 3 | 5.4 | 5.4 |
| USC | 2 | 7.3 | 7.1 |



Figure 3 displays the average speed of each team's top two runs, with the Phase II and III program metrics overlaid for reference. Figure 4 shows the "Finishing Run Speed" for each test run, where runs not finishing receive a zero speed.

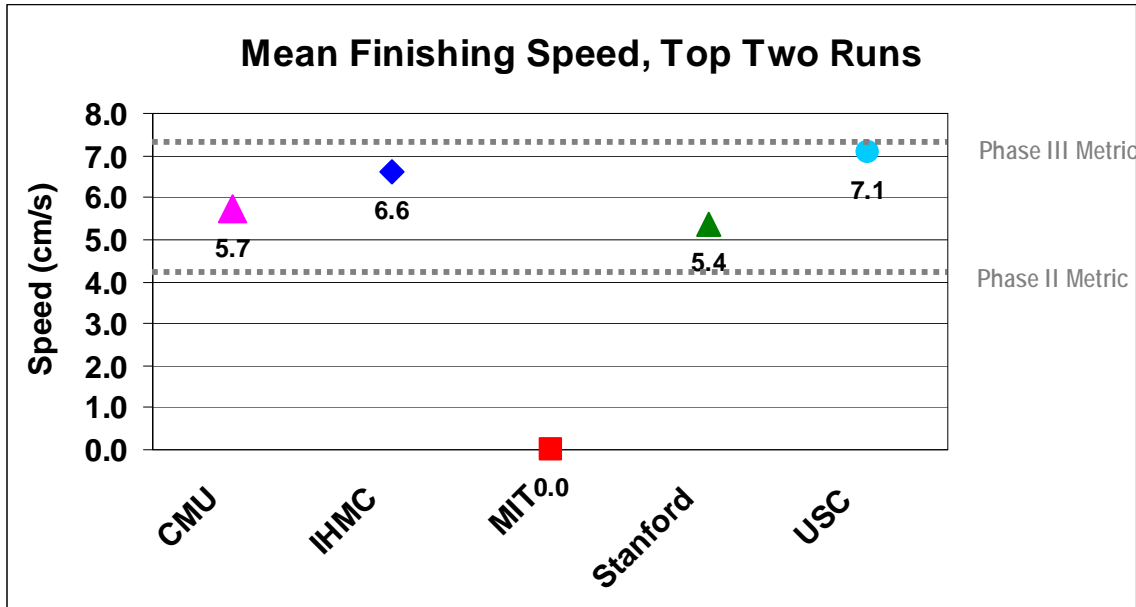


Figure 3 – Mean speed of the top two finishing runs

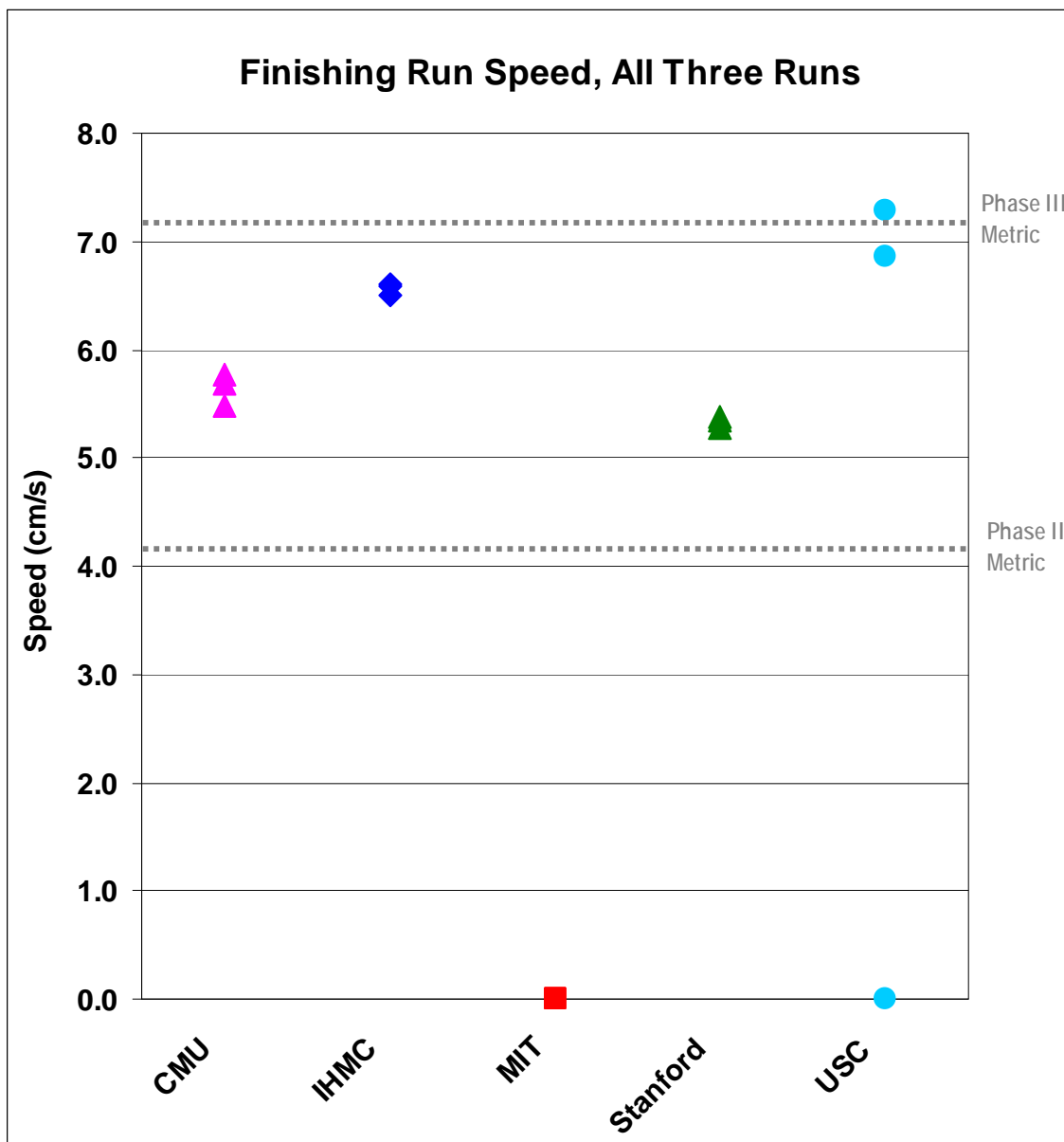


Figure 4 – The speed of individual test runs, where non-finishing runs receive zero.

3.2 DISCUSSION

In Test 3.1A, four out of five teams crossed the new, longer gap at least twice, and one of these runs was over the metric speed. Subjectively, this is a good start to the new phase. Most teams admitted that they are still in the process of cleaning up their software environment from last phase, and have not yet optimized their code for speed.

3.3 INDIVIDUAL RESULTS

The following sections describe the individual teams' performance. Directions are described with respect to the vehicle and its path.



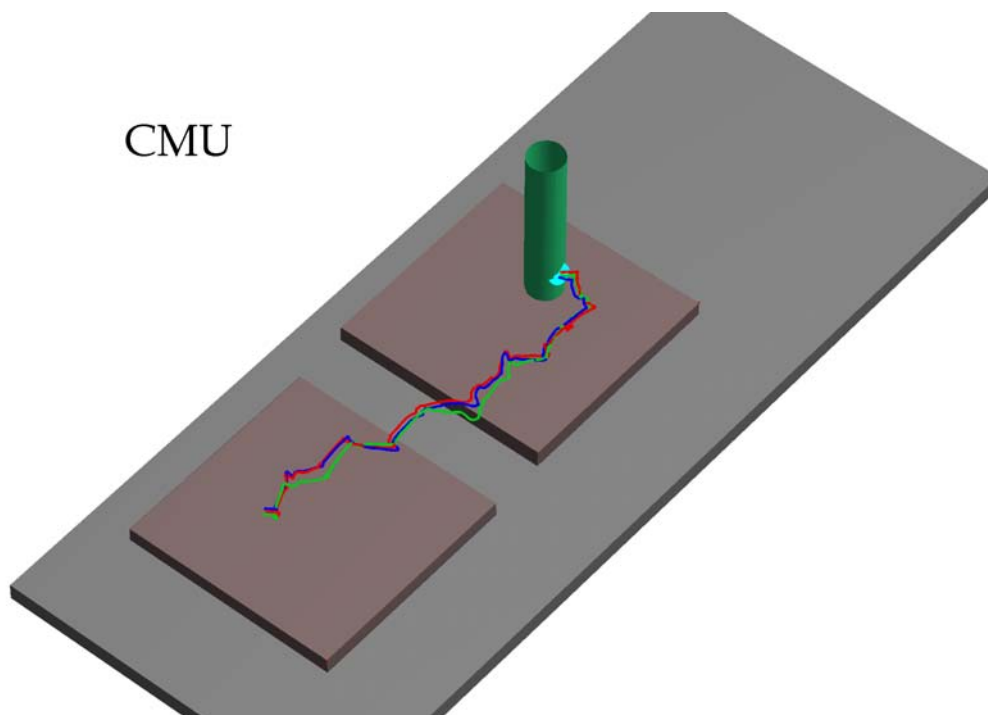
For each team, the 3D tracks of the centroid of the robot's body are plotted over a rendered version of the terrain. The three run scores are plotted in run order using red, green, and blue, respectively.

The colored balls in the plots denote success and failure. The tracks end in cyan balls for runs reaching the goal. Magenta balls show the closest approach of an unsuccessful run. Orange balls indicate where a run did not receive full credit for its closest approach, such as when a robot falls forward. Missing tracks are the result of absent or corrupt log data.

Speed averages described in the following sections are the mean of the top two (of three) fastest runs. Runs that do not finish were assigned a score of zero.

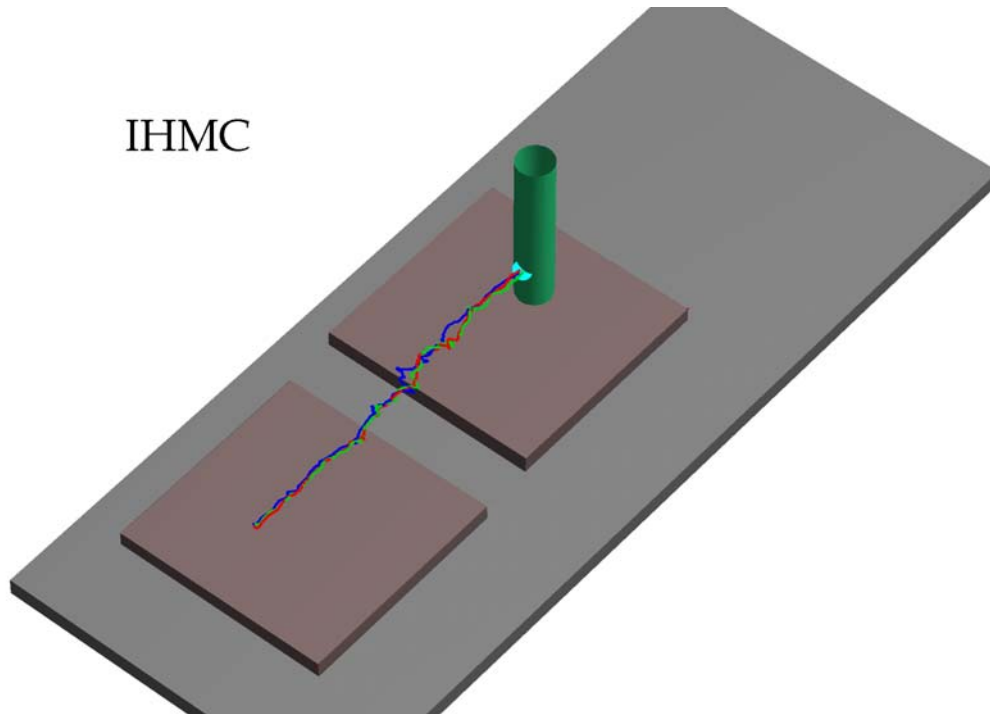
3.3.1 Carnegie Mellon University

CMU completed three traversals of the gap at the third-fastest speed, 5.7 cm/s. Their technique was to angle the body substantially when crossing the gap. As a result, there was pronounced arc in the body path to the goal that can be seen in the figure below.



3.3.2 The Institute for Human and Machine Cognition

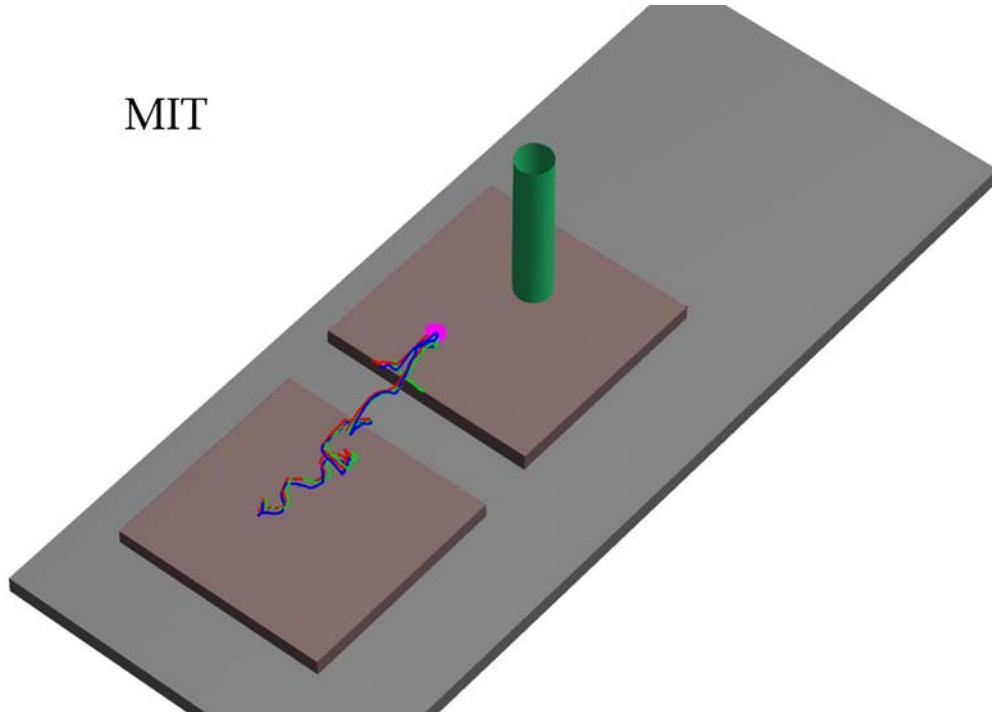
IHMC completed all three runs with the second fastest time, 6.6 cm/s. The body path tracked straight across the gap. It was observed that when crossing the gap, one of the back feet pushing off was *extremely* close to the edge of the board.



3.3.3 Massachusetts Institute of Technology

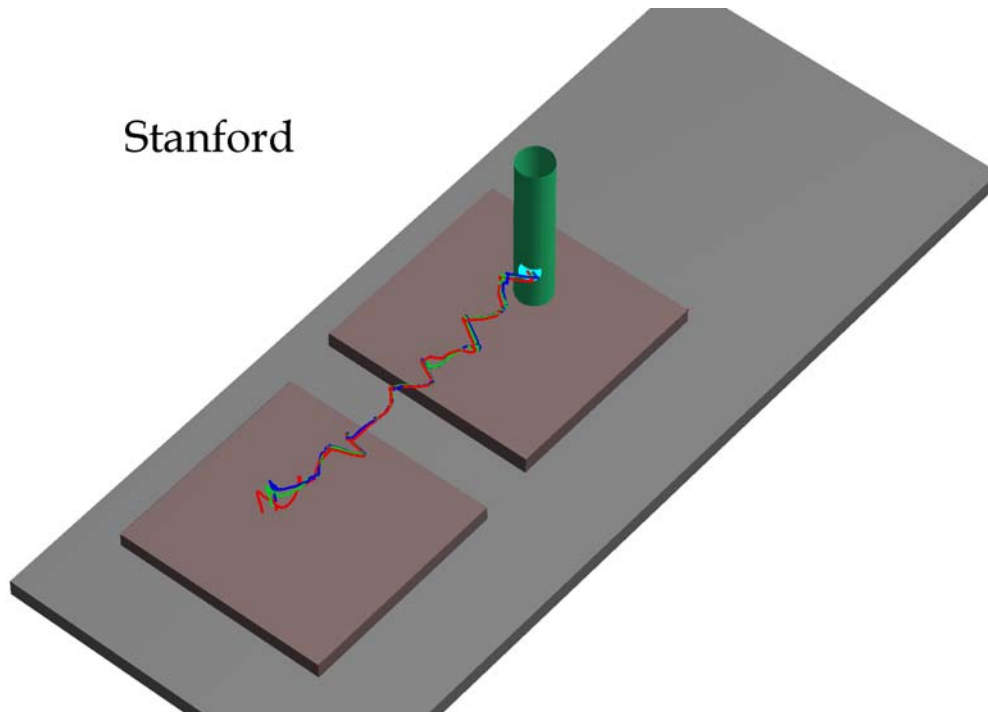
MIT did not successfully complete the course. In each test run, as the right rear leg was stepping over the gap, a body shift pulled the left rear leg off the rear board, causing the robot to slip down into the gap.

MIT



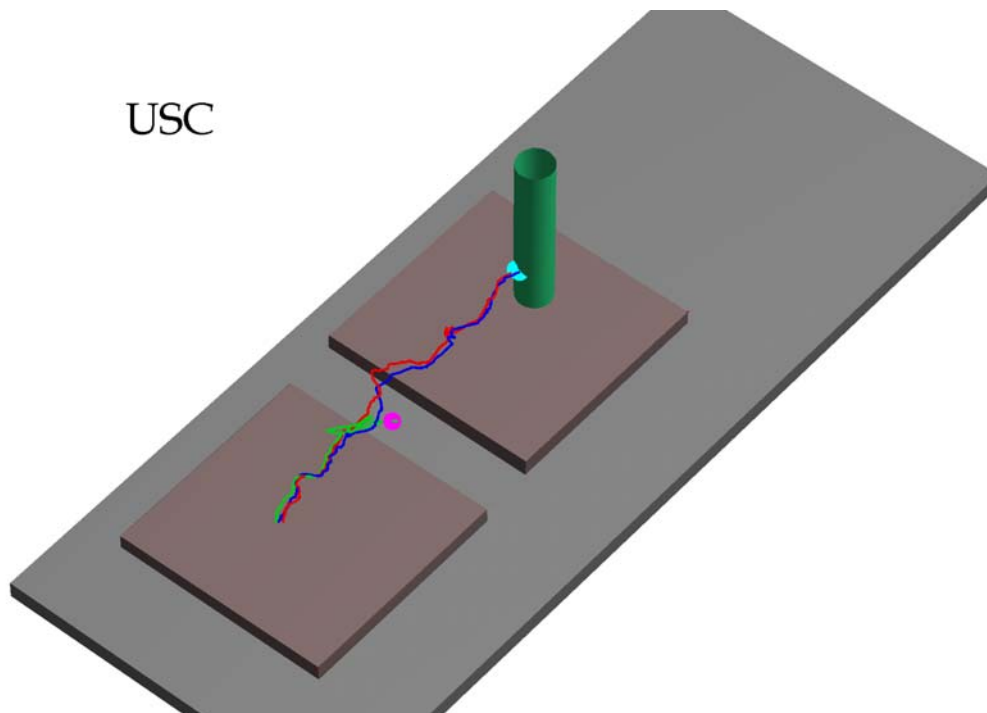
3.3.4 Stanford University

Stanford crossed the gap three times with the fourth fastest speed at 5.4 cm/s. A long body stretch and a pause in the middle lengthened the run time.



3.3.5 The University of Southern California

USC completed the course twice, falling back into the gap once. Congratulations are in order - at 7.3 cm/s, USC had the only run of the test to meet the Phase III metric. On most runs the robot appeared to be near the edge of its control envelope.





4 RESULTS: TYPE B TESTS

Test 3.1B presented a similar, but not identical, configuration of the Test 3.1A terrain. The testing method was the same as for Type A tests.

Table 3 summarizes the results.

Table 3 – Test 3.1B Statistics

| | Runs | Successful | Fastest Finishing | Mean Speed |
|----------|------------|------------|-------------------|--------------|
| | Completed | Plan | Run Speed | Top Two Runs |
| | (out of 3) | (Y/N) | (cm/s) | (cm/s) |
| CMU | 2 | Y-N-Y | 5.9 | 5.5 |
| IHMC | 3 | Y-Y-Y | 7.1 | 7.0 |
| MIT | 0 | Y-Y-Y | 0.0 | 0.0 |
| Stanford | 3 | Y-Y-Y | 5.5 | 5.4 |
| USC | 1 | Y-Y-Y | 7.3 | 3.6 |

5 RESULTS: TYPE C TESTS

5.1 SUMMARY

The methods for Type C testing were the same as for Types A and B.

Table 4 displays the measured values and computed scores for the three test runs. Finishing run speeds meeting or exceeding the Phase III speed metric (7.2 cm/sec) appear in bold green type.

Table 4 – Test 3.1C Individual Test Run Data

| Individual Trials | | | L _c | L _g | t | t _s | F | S | v | |
|-------------------|----------|-----------------------|-------------------|------------------------|------------------|------------------|----------------------------|-----------|------------------|----------------------------|
| Team | Test Run | Goal Reached (yes/no) | Course Length (m) | Remaining Distance (m) | Elapsed Time (s) | Scoring Time (s) | Course Completion Fraction | Run Score | Run Speed (cm/s) | Finishing Run Speed (cm/s) |
| CMU | 1 | Yes | 1.50 | 0.00 | 28.1 | 28.1 | 1.00 | 1.27 | 5.34 | 5.34 |
| | 2 | Yes | 1.48 | 0.00 | 30.6 | 30.6 | 1.00 | 1.15 | 4.84 | 4.84 |
| | 3 | Yes | 1.47 | 0.00 | 26.5 | 26.5 | 1.00 | 1.32 | 5.55 | 5.55 |
| IHMC | 1 | Yes | 1.51 | 0.00 | 43.4 | 43.4 | 1.00 | 0.83 | 3.48 | 3.48 |
| | 2 | No | 1.50 | 0.92 | 12.5 | 10.7 | 0.39 | 0.50 | 5.42 | 0.00 |
| | 3 | Yes | 1.51 | 0.00 | 36.3 | 36.3 | 1.00 | 0.99 | 4.16 | 4.16 |
| MIT | 1 | No | 1.50 | 1.09 | 13.5 | 13.5 | 0.27 | 0.20 | 3.04 | 0.00 |
| | 2 | No | 1.50 | 1.11 | 17.7 | 17.7 | 0.26 | 0.14 | 2.20 | 0.00 |
| | 3 | No | 1.49 | 1.11 | 9.2 | 9.2 | 0.26 | 0.25 | 4.13 | 0.00 |
| Stanford | 1 | No | 1.50 | 0.87 | 17.8 | 14.9 | 0.42 | 0.42 | 4.23 | 0.00 |
| | 2 | Yes | 1.44 | 0.00 | 33.3 | 33.3 | 1.00 | 1.03 | 4.32 | 4.32 |
| | 3 | Yes | 1.45 | 0.00 | 48.2 | 48.2 | 1.00 | 0.72 | 3.01 | 3.01 |
| USC | 1 | No | 1.52 | 0.83 | 20.5 | 20.0 | 0.45 | 0.37 | 3.45 | 0.00 |
| | 2 | No | 1.52 | 0.83 | 12.8 | 10.4 | 0.45 | 0.72 | 6.63 | 0.00 |
| | 3 | N/A | - | - | - | - | - | - | - | - |

USC did not execute the third run for safety reasons

- Elapsed Time denotes time from the start to the end of the run.
- Scoring Time is the time from the start of the run to the point of closest approach to the goal. Elapsed Time equals Scoring Time for runs that reach the goal.

Table 5 displays summary statistics. The “Mean Speed Top 2 Runs” column shows the average of the top two fastest runs. If a run does not complete the course, zero is included in the average. The values in this column will be compared to the program speed metric – values exceeding the Phase III metric are indicated in bold.

Table 5 – Test 3.1C Statistics

| | Runs | Fastest Finishing | Mean Speed |
|----------|------------|-------------------|--------------|
| | Completed | Run Speed | Top Two Runs |
| | (out of 3) | (cm/s) | (cm/s) |
| CMU | 3 | 5.5 | 5.4 |
| IHMC | 2 | 4.2 | 3.8 |
| MIT | 0 | 0.0 | 0.0 |
| Stanford | 2 | 4.3 | 3.7 |
| USC | 0 | 0.0 | 0.0 |

Figure 5 displays the average speed of each team’s top two runs, with the Phase II and III program metrics overlaid for reference. Figure 6 shows the “Finishing Run Speed” for each test run, where runs not finishing receive a zero speed..

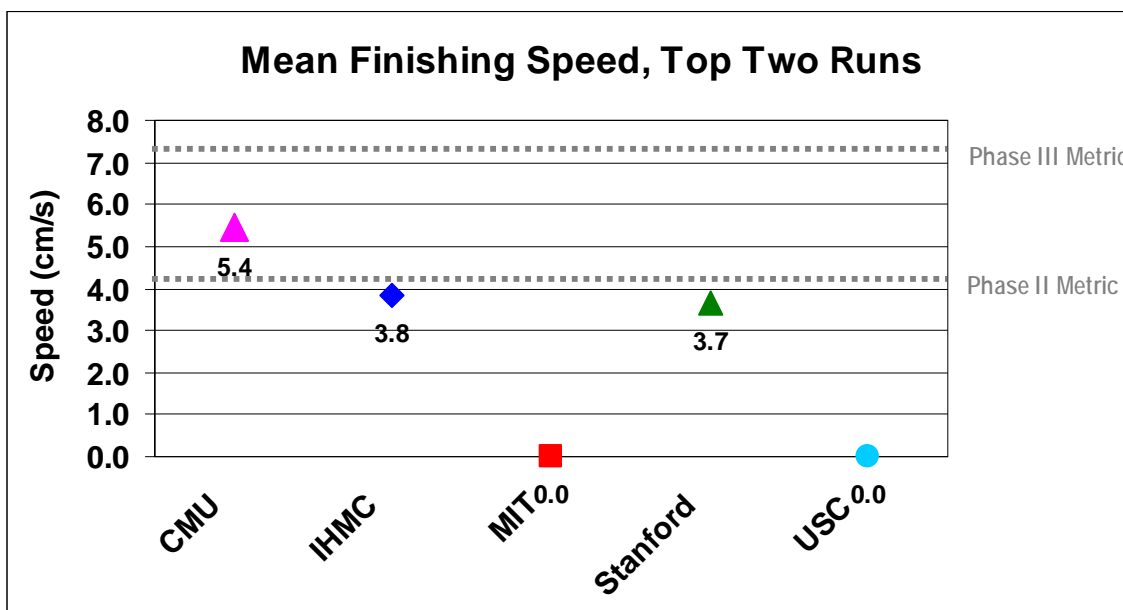


Figure 5 – Mean speed of the top two finishing runs

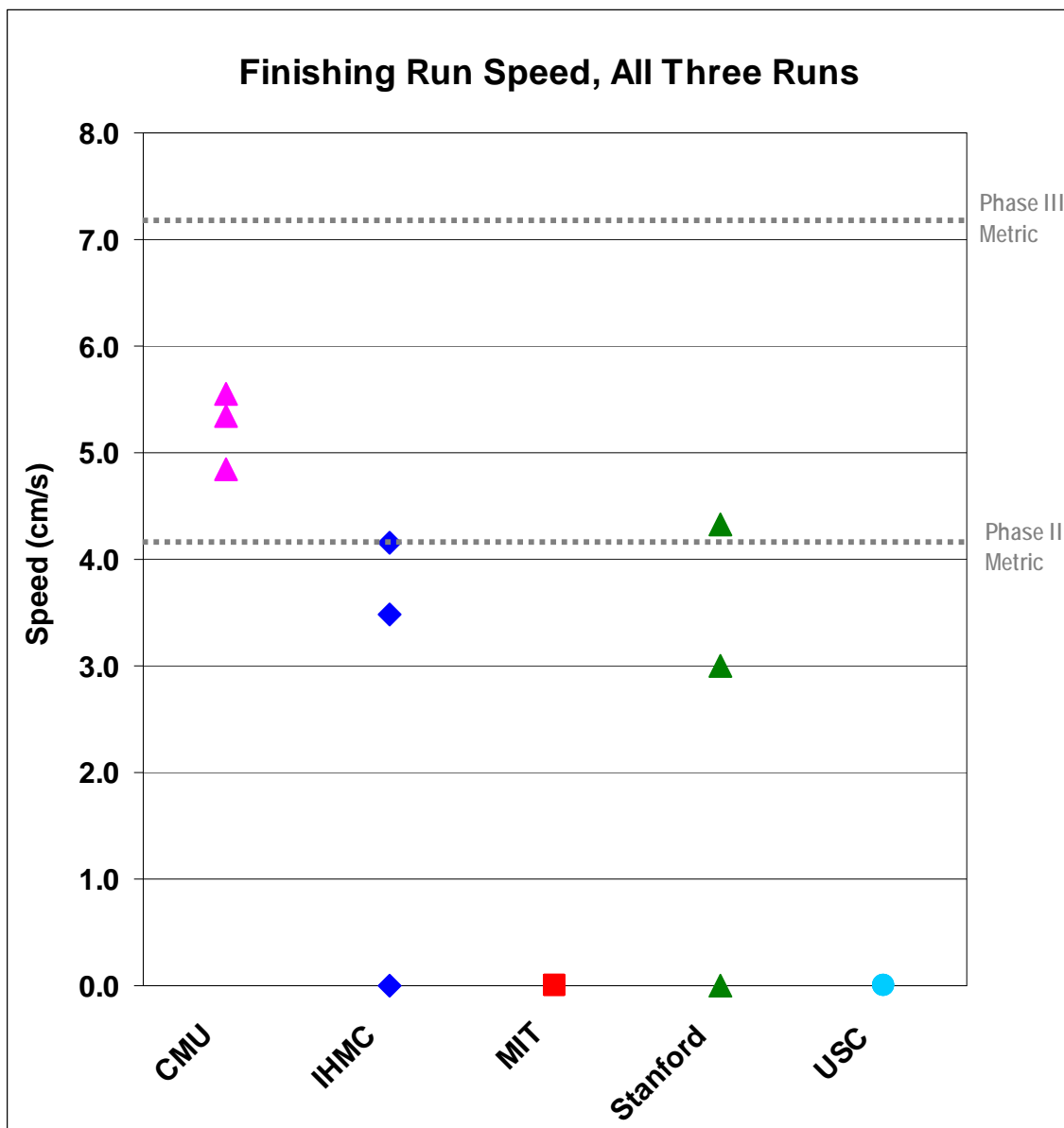


Figure 6 – The speed of individual test runs, where non-finishing runs receive zero.

5.2 DISCUSSION

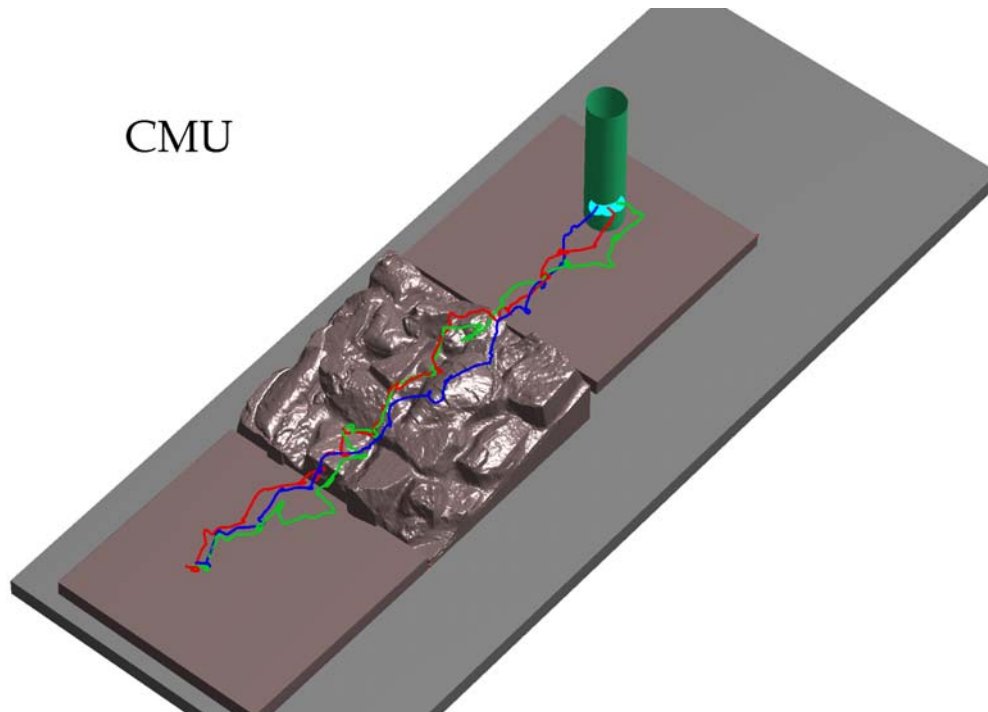
Teams were less successful at Test 3.1C than at 3.1A or 3.1B. Only one team (CMU) successfully crossed the board three times, and no teams met or were even close to the Phase III metric. The Truncated Rocks board remains a difficult challenge.

5.3 TYPE C TESTS INDIVIDUAL RESULTS

The following sections describe the individual teams' performance, displayed as previously described.

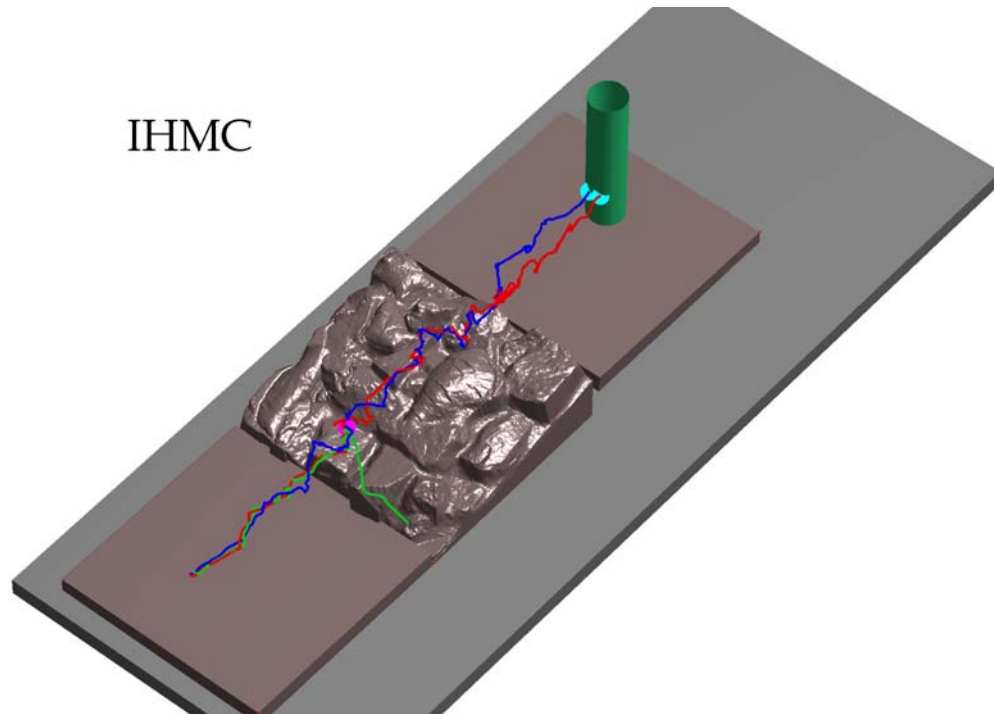
5.3.1 Carnegie Mellon University

CMU reached the goal on all three of the test runs, with a mean speed of 5.4 cm/s. This was the fastest performance on this Truncated Rocks configuration.



5.3.2 The Institute for Human and Machine Cognition

IHMC reached the goal twice, averaging 3.8 cm/s. The robot was seen to slip and reset itself, which is IHMC's recovery mode, on a number of occasions. This clearly affected the overall run speed.



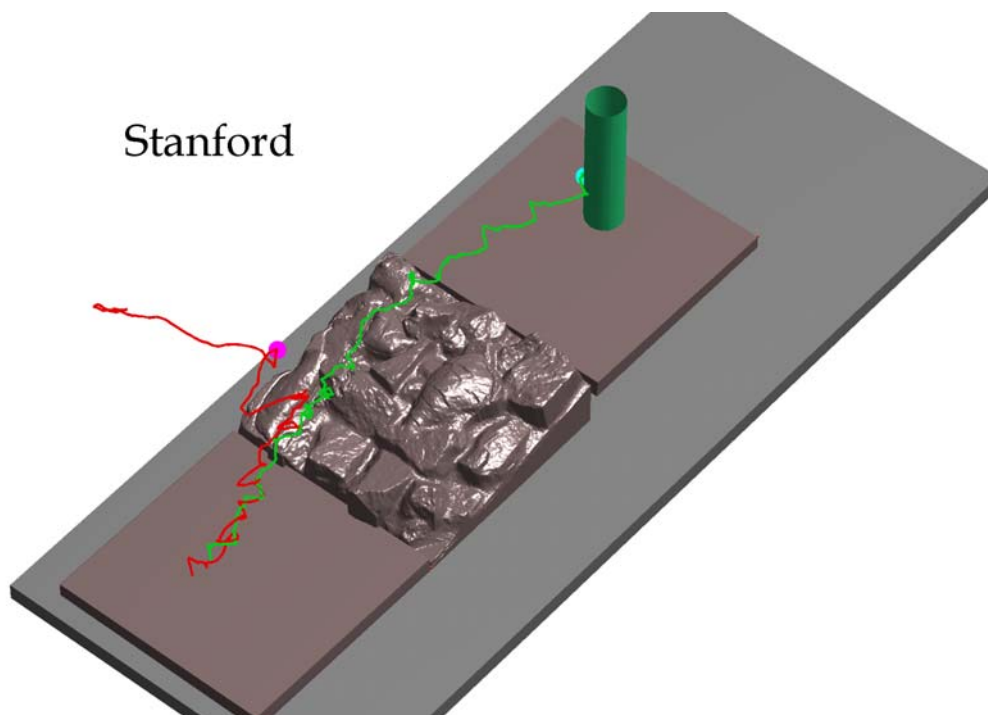


5.3.3 Massachusetts Institute of Technology

MIT was not prepared to be tested on the Truncated Rocks board, but for purposes of getting a baseline the LLGT ran the test anyway. The robot was not able to complete the Truncated Rocks terrain board on any test run. Unfortunately, due to LLGT operator error, log files are not available for this run, so no figure is shown below.

5.3.4 Stanford University

Stanford completed the Truncated Rocks board two out of three tries, with a speed of 3.7 cm/s. In The third run, which was successful, is not shown in the figure since the code crashed and the log file became corrupt.



5.3.5 The University of Southern California

USC also did not focus on the Truncated Rocks board for this test, and as a result was unable to cross the board on any trial. To be fair, the LLGT mistakenly put the terrain board in a different and likely more difficult orientation for USC's test runs. We regret the error, and we will institute processes to keep it from happening again.

