Learning Locomotion
Test 3.2 Results

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1 INTRODUCTION

This document describes Test 3.2 of the DARPA/IPTO Learning Locomotion Program, Phase II. The test was conducted at System Planning Corporation in Arlington, Virginia on November 18-19, 2008.

2 TEST METHODS

2.1 TEST COURSES

The terrain for Test 3.2A, Metric Steps, illustrated in Figure 1, presented three steps 10 cm high.

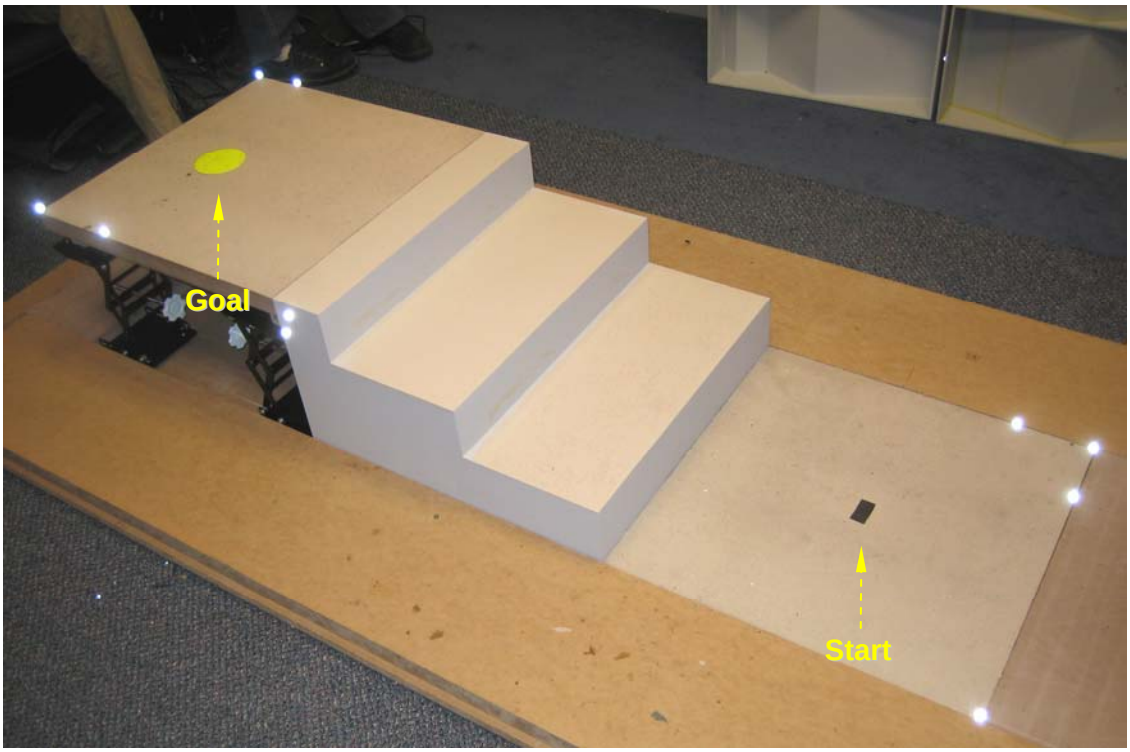


Figure 1 – The Test 3.2A Terrain

The terrain for Test 3.2B was similar to that used for Type A, but is not described in this report since it is reserved for Government-only testing.

The terrain for Test 3.2C was the V-Ditch, implemented using two of the Phase II Slope boards. This configuration is shown in Figure 2.

In testing, 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 or black adhesive square. The Goal itself is a 5 cm radius vertical cylinder.

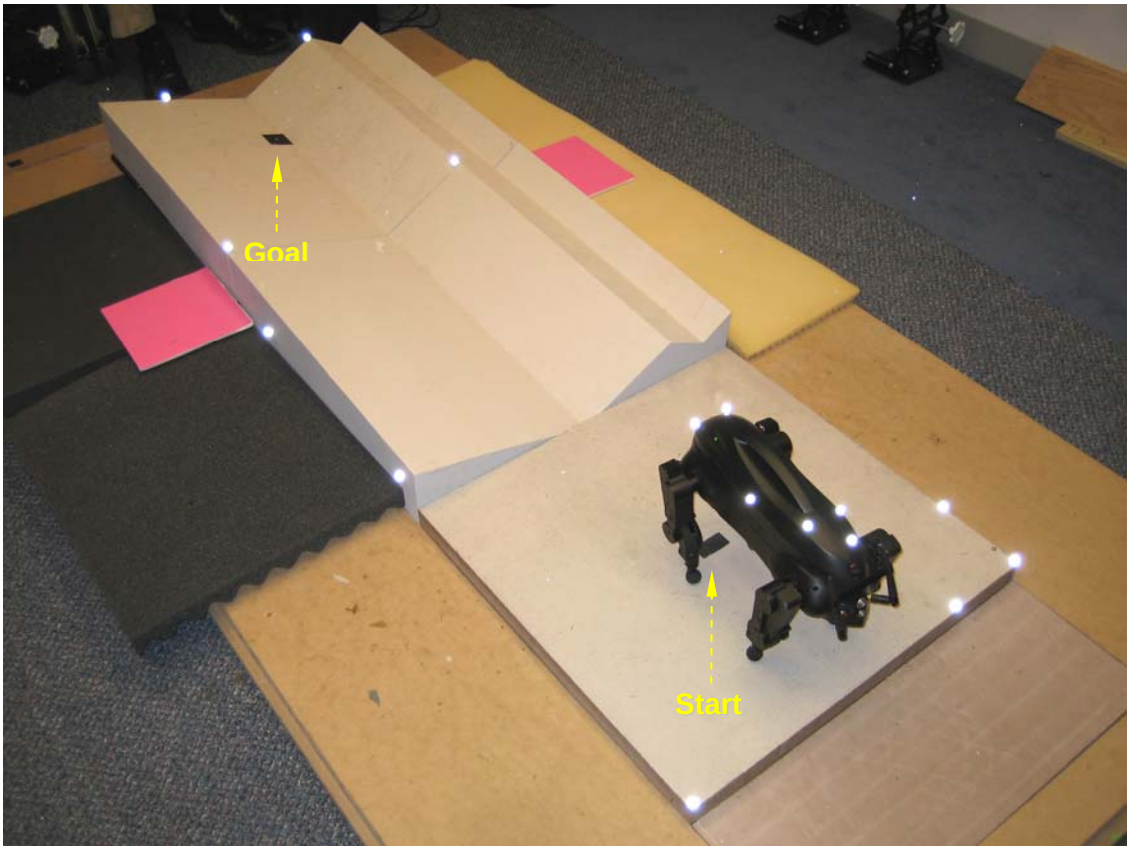


Figure 2 – The Test 3.2C Terrain

2.2 COMMUNICATIONS

Teams were permitted 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 official (3) test runs. 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 3.2A 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	No	1.51	0.82	17.4	13.4	0.46	0.55	5.12	0.00
	2	No	1.50	0.35	24.4	23.9	0.77	0.87	4.79	0.00
	3	No	1.51	0.82	18.5	12.9	0.46	0.58	5.31	0.00
IHMC	1	Yes	1.53	0.00	38.8	38.8	1.00	0.94	3.93	3.93
	2	Yes	1.49	0.00	40.9	40.9	1.00	0.86	3.63	3.63
	3	Yes	1.50	0.00	38.8	38.8	1.00	0.92	3.85	3.85
MIT	1									
	2			*MIT did not participate in Test 3.2*						
	3									
Stanford	1	Yes	1.53	0.00	16.9	16.9	1.00	2.15	9.03	9.03
	2	Yes	1.48	0.00	16.9	16.9	1.00	2.08	8.73	8.73
	3	No	1.52	0.36	24.3	18.6	0.76	1.13	6.21	0.00
USC	1	Yes	1.53	0.00	40.4	40.4	1.00	0.90	3.78	3.78
	2	Yes	1.48	0.00	39.5	39.5	1.00	0.89	3.73	3.73
	3	Yes	1.51	0.00	40.0	40.0	1.00	0.90	3.76	3.76

- 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 (7.8 cm/s) are indicated in bold.

Table 2 – Test 3.2A Statistics

	Runs Completed (out of 3)	Fastest Finishing Run Speed (cm/s)	Mean Speed Top Two Runs (cm/s)
CMU	0	0.0	0.0
IHMC	3	3.9	3.9
MIT			
Stanford	2	9.0	8.9
USC	3	3.8	3.8

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.

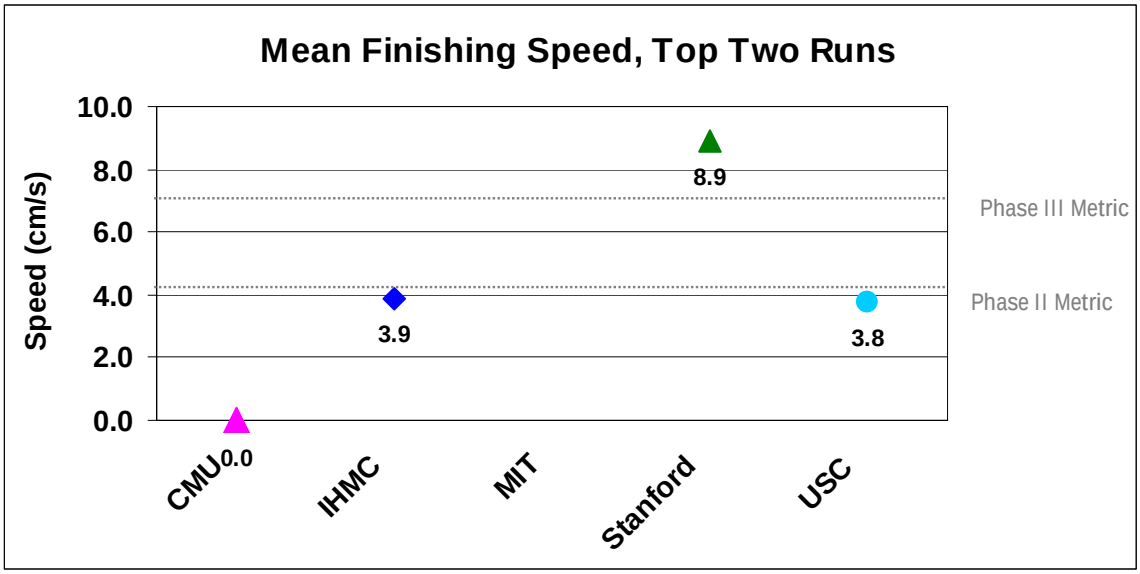


Figure 3 – Mean speed of the top two finishing runs

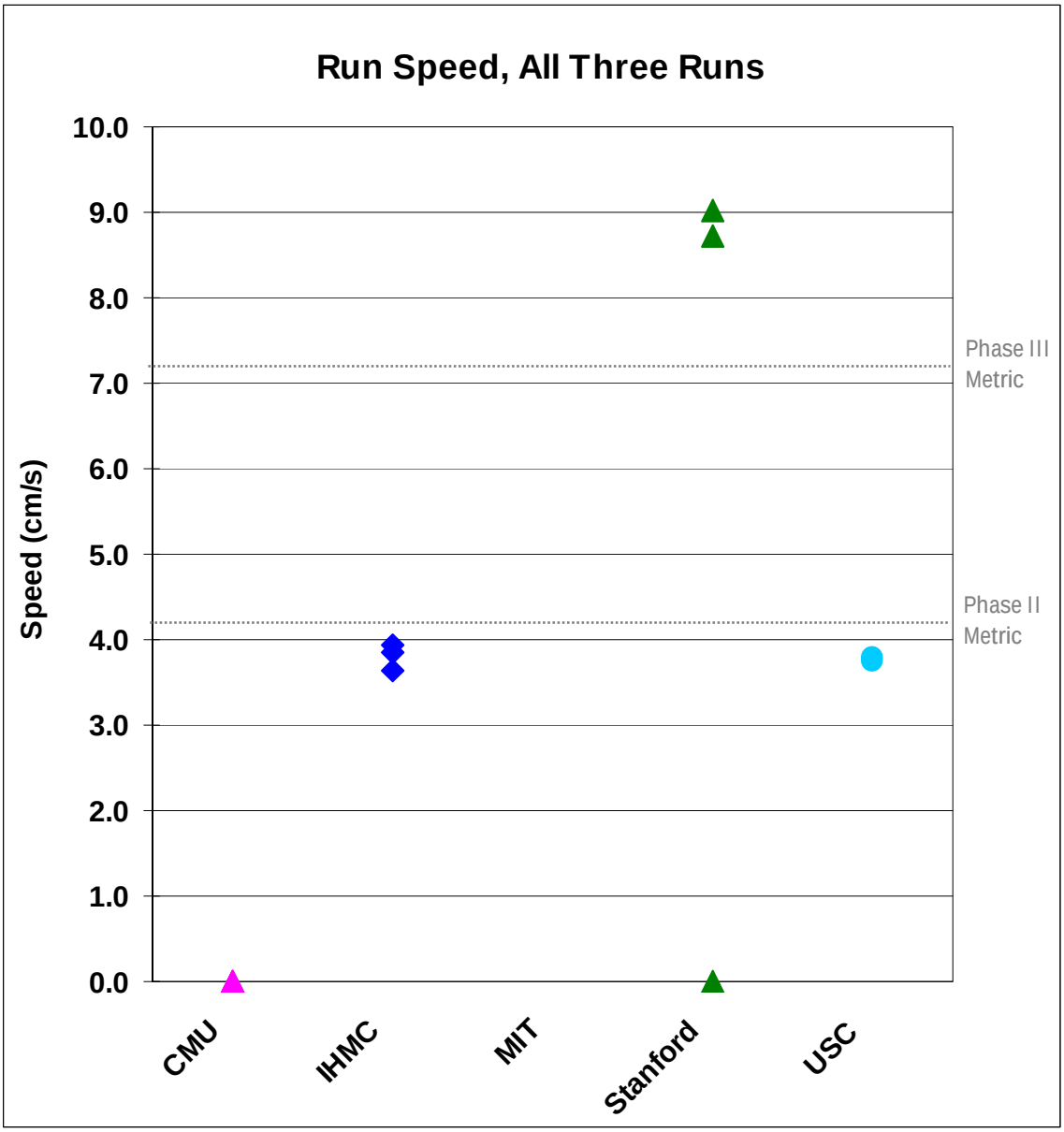


Figure 4 – The speed of individual test runs - non-finishing runs receive a speed of zero.

3.2 DISCUSSION

The height of the steps board is quite high relative to the dimensions of Little Dog, presenting a significant challenge. Teams addressed this terrain using various gaits, with varying success. Stanford and USC demonstrated a very interesting gait that incorporated a headstand while moving the back legs onto the step. Stanford was very successful in using this specialized gait to beat the Phase III metric handily, the only team to do so. Both USC and IHMC reached the goal three times, but at approximately half of the metric speed. CMU was not able to complete the course, and MIT did not submit code this month.

3.3 INDIVIDUAL RESULTS

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

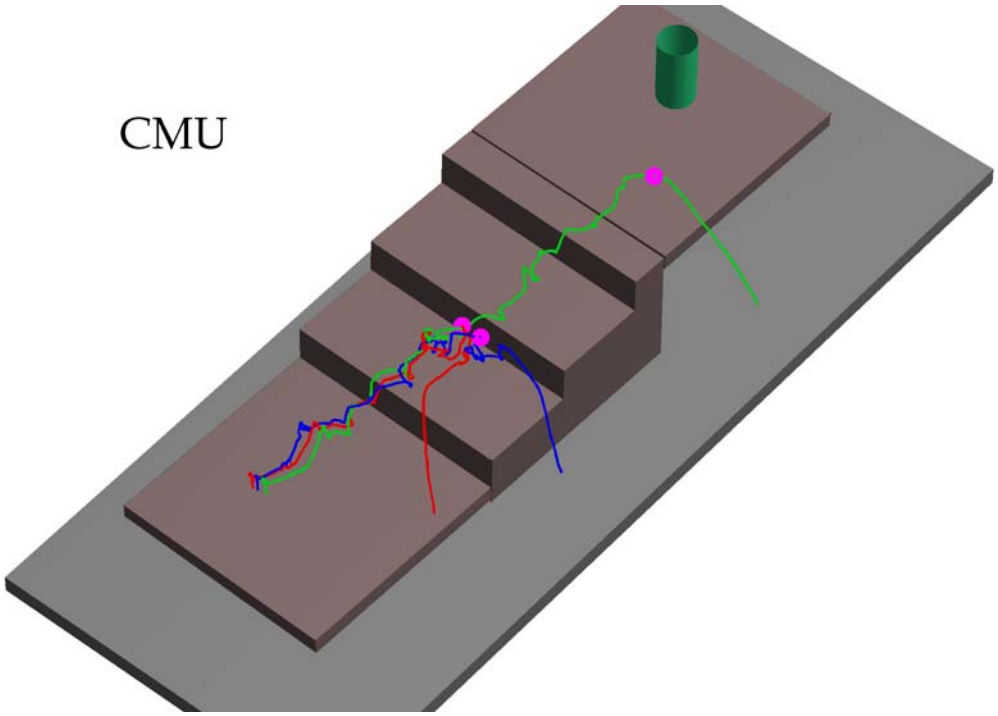
For each team, the 3D tracks of the centroid of the robot's body are plotted over a rendered version of the terrain. The three run scores are plotted in run order using red, green, and blue, respectively.

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.

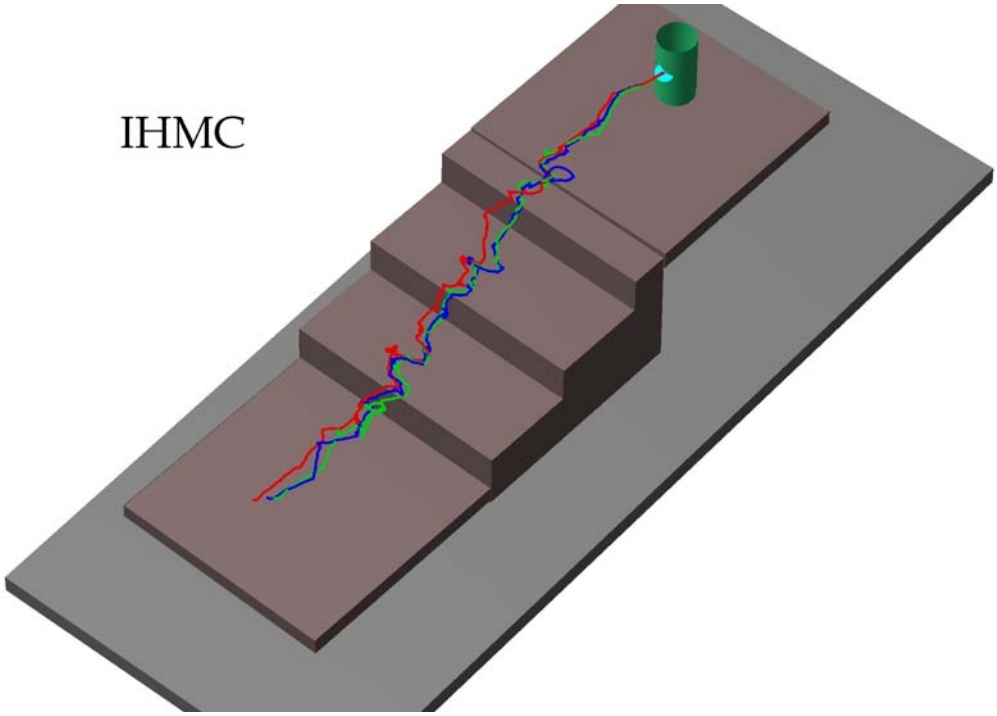
3.3.1 Carnegie Mellon University

CMU did not complete any of the three runs. The second run (in green) appeared to be progressing well until the robot was up on the flat board. Then it swerved right and fell off the terrain. CMU's gait was"crabbed", keeping the robot's body aimed to the right as it climbed.



3.3.2 The Institute for Human and Machine Cognition

IHMC completed three runs at an average speed of 3.9 cm/s. IHMC's gait was a straight walk toward the goal.

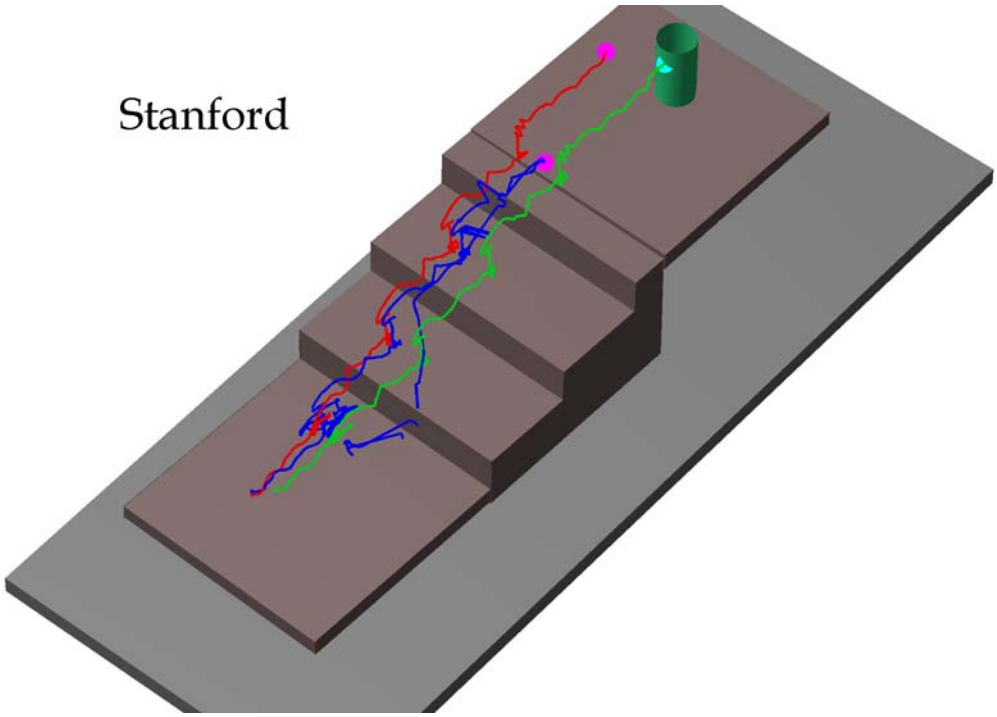


3.3.3 Massachusetts Institute of Technology

MIT did not send code for Test 3.2.

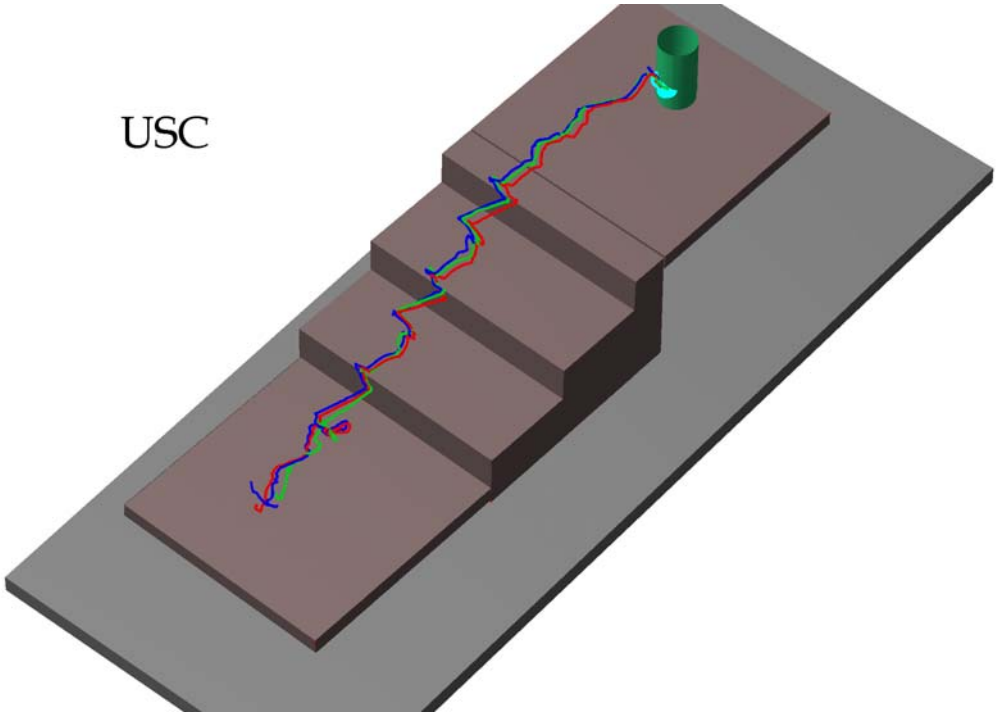
3.3.4 Stanford University

Stanford achieved the fastest performance on the steps, reaching the goal twice at an average of 8.9 cm/s. (Note that the first run in the figure below was given credit for reaching the goal, because the goal point was incorrectly specified.) This performance was achieved using a specialized stair-climbing gait and a rapid, small-step gait for the flat boards.



3.3.5 The University of Southern California

Using a specialized climbing gait that was similar to Stanford's, USC reached the goal three times at an average speed of 3.8 cm/s. As shown in the figure below, the movement was repeatable, but not up to metric speed.



4 RESULTS: TYPE B TESTS

Test 3.2B presented a similar, but not identical, configuration of the Test 3.2A terrain (Metric Steps). The testing method was the same as for Type A tests.

Table 3 summarizes the results. MIT did not send code for Test 3.2.

Table 3 – Test 3.2B Statistics

	Runs Completed (out of 3)	Successful Plan (Y/N)	Fastest Finishing Run Speed (cm/s)	Mean Speed Top Two Runs (cm/s)
CMU	0	Y-Y-N	0.0	0.0
IHMC	3	Y-Y-Y	3.5	3.4
MIT				
Stanford	0	Y-Y-Y	0.0	0.0
USC	0	Y-Y-Y	0.0	0.0

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 3.2C 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	1.46	0.00	21.7	21.7	1.00	1.60	6.73	6.73
	2	Yes	1.43	0.00	21.8	21.8	1.00	1.56	6.56	6.56
	3	Yes	1.42	0.00	21.1	21.1	1.00	1.60	6.73	6.73
IHMC	1	Yes	1.49	0.00	22.4	22.4	1.00	1.58	6.65	6.65
	2	Yes	1.49	0.00	23.3	23.3	1.00	1.52	6.39	6.39
	3*	No	1.49	0.20	23.8	23.8	0.87	1.12	5.42	0.00
MIT	1									
	2				*MIT did not participate in Test 3.2*					
	3									
Stanford	1	No	1.49	0.75	15.5	12.9	0.50	0.68	5.74	0.00
	2	No	1.49	0.59	16.7	16.0	0.60	0.81	5.63	0.00
	3	No	1.49	0.79	9.5	7.0	0.47	1.12	10.00	0.00
USC	1	Yes	1.48	0.00	20.7	20.7	1.00	1.70	7.15	7.15
	2	Yes	1.41	0.00	19.8	19.8	1.00	1.70	7.12	7.12
	3	Yes	1.43	0.00	20.6	20.6	1.00	1.65	6.94	6.94

** Values estimated since no log data available*

- 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 3.2C Statistics

	Runs Completed (out of 3)	Fastest Finishing Run Speed (cm/s)	Mean Speed Top Two Runs (cm/s)
CMU	3	6.7	6.7
IHMC	2	6.7	6.5
MIT			
Stanford	0	0.0	0.0
USC	3	7.1	7.1

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.

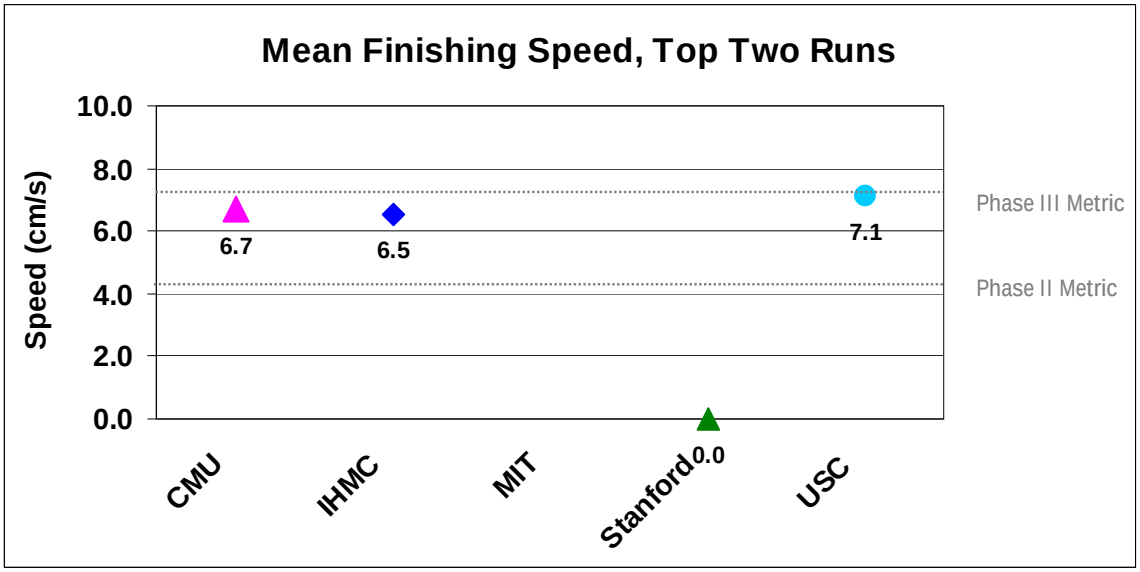


Figure 5 – Mean speed of the top two finishing runs

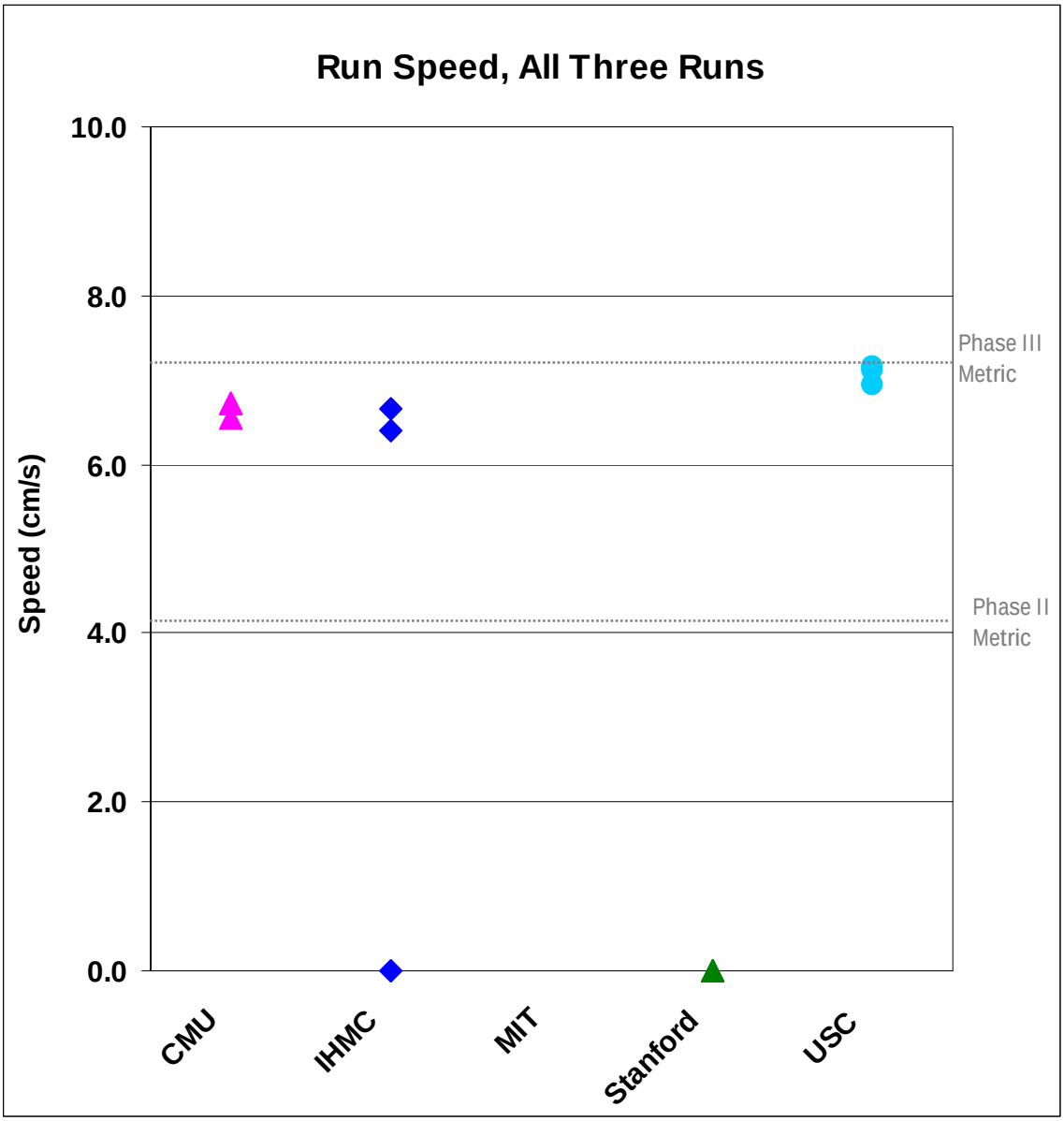


Figure 6 – The speed of individual test runs, where non-finishing runs receive zero.

5.2 DISCUSSION

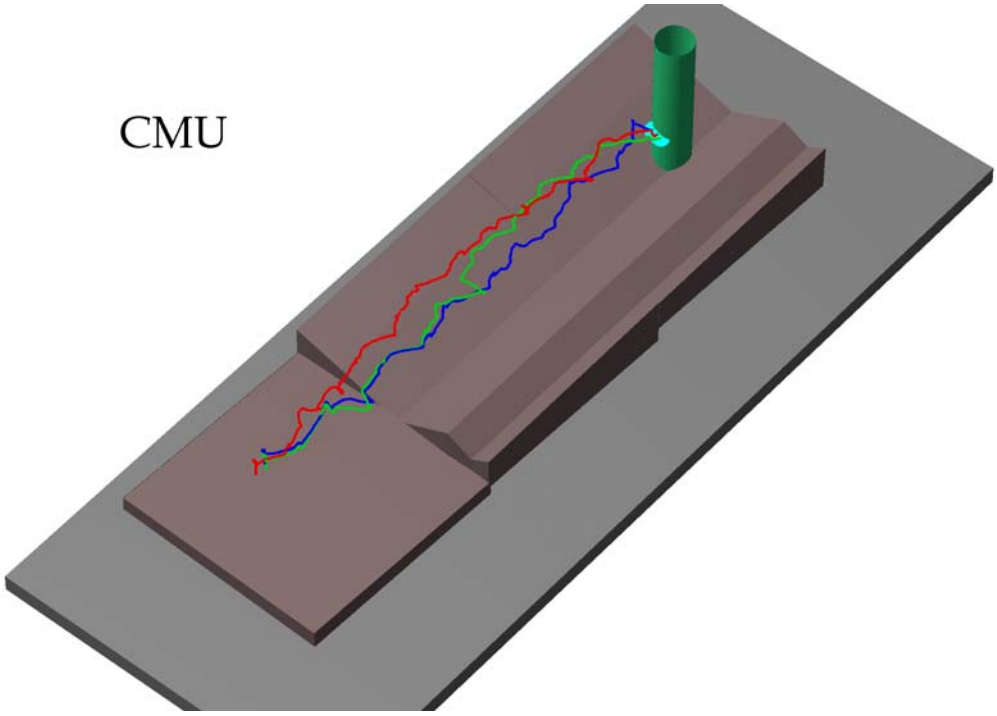
For most teams the V-Ditch was less of a challenge than the steps. Three of the four teams completed at least two runs at just below the Phase III metric. The successful teams used a straightforward walking gait, usually straddling the ditch. The most treacherous part of the terrain appeared to be the transition between the flat board and the first sloped board.

5.3 INDIVIDUAL RESULTS

The following sections describe the individual teams' performance.

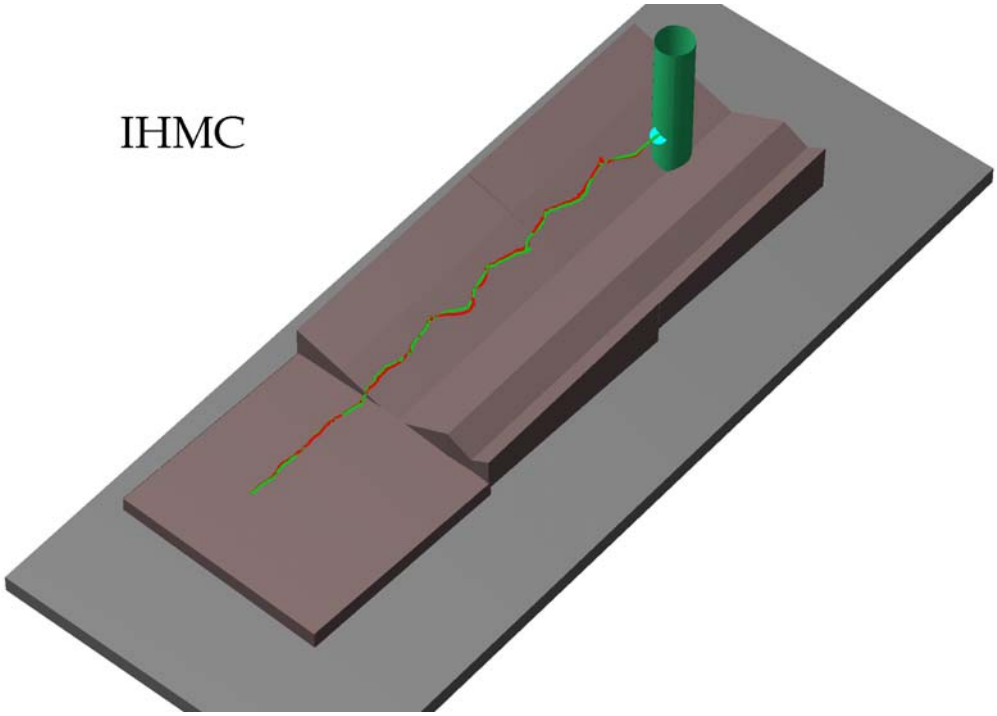
5.3.1 Carnegie Mellon University

CMU completed three runs at an average speed of 6.7 cm/s, the second fastest time. Two runs traversed mostly on the left surface, while the third straddled the ditch, yielding the fastest time.



5.3.2 The Institute for Human and Machine Cognition

IHMC completed two runs at an average of 6.5 cm/s. The third run was very similar, but stopped just before the goal and did not save a log file. All three runs straddled the ditch.

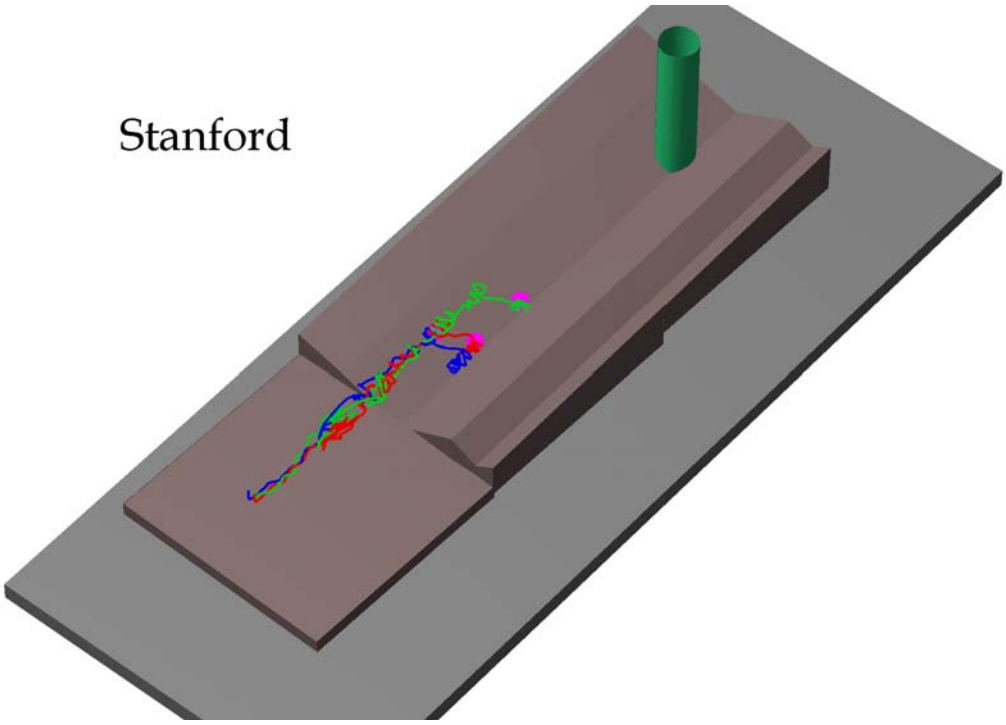


5.3.3 Massachusetts Institute of Technology

MIT did not send code for Test 3.2.

5.3.4 Stanford University

Stanford's code had difficulty with the V-ditch, not completing any of the runs.



5.3.5 The University of Southern California

USC demonstrated the best performance of Test 3.2C, making three runs at just barely below the metric speed. The gait was "smooth and unhurried", straddling the ditch.