



Learning Locomotion Test 3.3 Results

TABLE OF CONTENTS

1	INTRODUCTION	2
2	TEST METHODS	2
2.1	TEST COURSES	2
2.2	COMMUNICATIONS	3
2.3	APPLICABLE DOCUMENTS	3
3	RESULTS: TYPE A TESTS	3
3.1	SUMMARY	3
3.2	DISCUSSION	7
3.3	INDIVIDUAL RESULTS.....	7
3.3.1	Carnegie Mellon University	8
3.3.2	The Institute for Human and Machine Cognition.....	9
3.3.3	Massachusetts Institute of Technology	10
3.3.4	Stanford University.....	11
3.3.5	The University of Southern California	12
4	RESULTS: TYPE B TESTS	13
5	RESULTS: TYPE C TESTS	14
5.1	SUMMARY	14
5.2	DISCUSSION	16
5.3	INDIVIDUAL RESULTS.....	16
5.3.1	Carnegie Mellon University	17
5.3.2	The Institute for Human and Machine Cognition.....	18
5.3.3	Massachusetts Institute of Technology	19
5.3.4	Stanford University.....	20
5.3.5	The University of Southern California	21

1 INTRODUCTION

This document describes Test 3.3 of the DARPA/IPTO Learning Locomotion Program, Phase II. The test was conducted at System Planning Corporation in Arlington, Virginia on December 17-18, 2008.

2 TEST METHODS

2.1 TEST COURSES

The terrain for Test 3.3A, Metric Steps, presented a barrier 9.8 cm high. Figure 1 illustrates the test configuration.

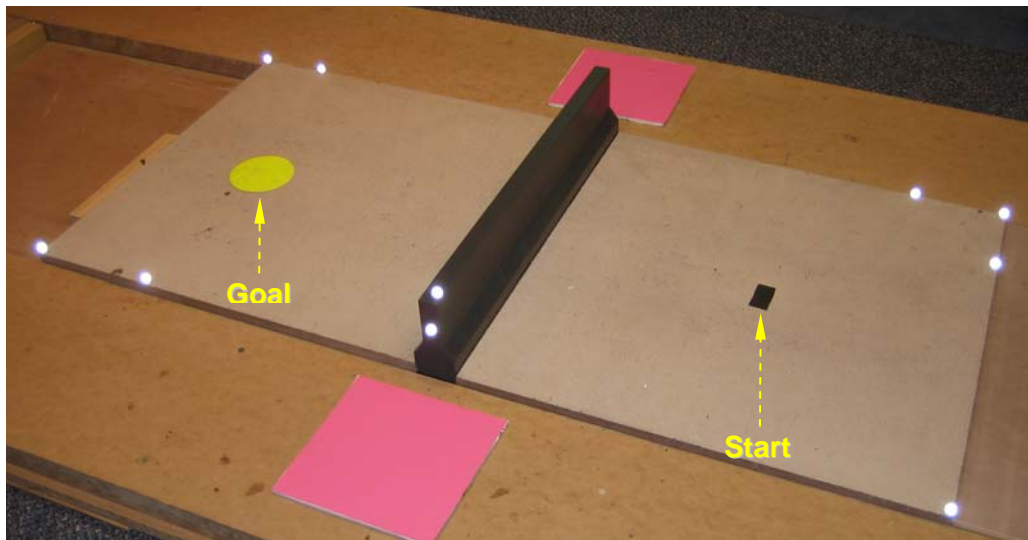


Figure 1 - The Test 3.3A Terrain

The terrain for Test 3.3B was similar to that used for Type A, but is not described in this report since it is reserved for blind testing.

The terrain for Test 3.3C was the Scaled Steps board. This configuration is 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 or black adhesive square. The Goal itself is a virtual vertical cylinder with 5 cm radius.

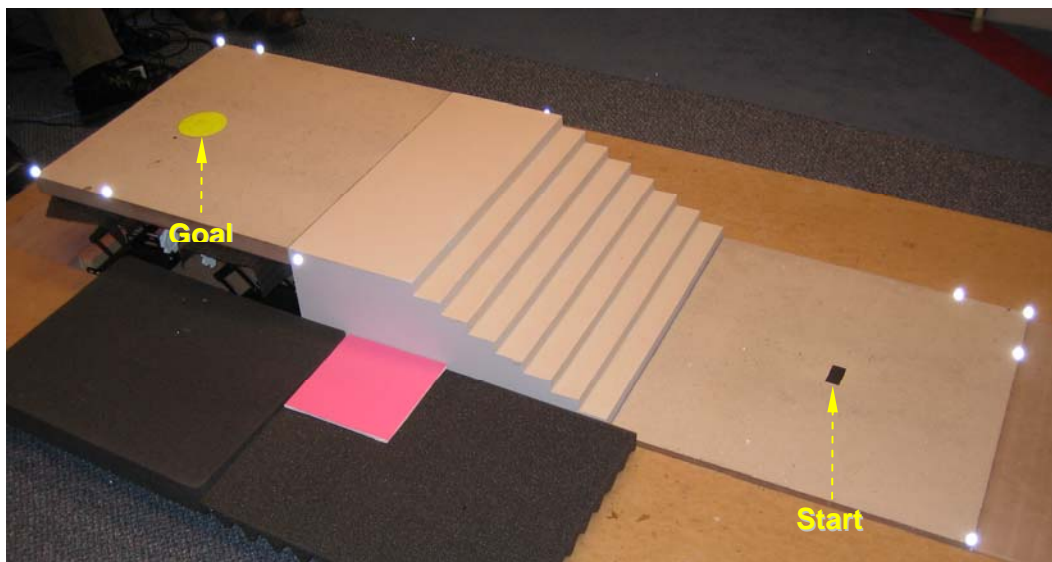


Figure 2 – The Test 3.3C Terrain

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 3.3A 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	0.90	0.00	14.6	14.6	1.00	1.47	6.16	6.16
	2	Yes	0.92	0.00	15.2	15.2	1.00	1.44	6.05	6.05
	3	Yes	0.92	0.00	15.1	15.1	1.00	1.45	6.09	6.09
IHMC	1*	Yes	0.88	0.00	11.0	11.0	1.00	1.90	8.00	8.00
	2*	Yes	0.87	0.00	9.9	9.9	1.00	2.09	8.79	8.79
	3*	Yes	1.01	0.00	10.4	10.4	1.00	2.31	9.71	9.71
MIT	1	Yes	0.95	0.00	11.7	11.7	1.00	1.93	8.12	8.12
	2	Yes	0.89	0.00	11.3	11.3	1.00	1.88	7.88	7.88
	3	Yes	0.91	0.00	11.4	11.4	1.00	1.90	7.98	7.98
Stanford	1	No	0.94	0.88	9.1	2.1	0.06	0.04	2.86	0.00
	2	Yes	0.96	0.00	8.5	8.5	1.00	2.69	11.29	11.29
	3	No	0.95	0.73	11.2	4.0	0.23	0.30	5.50	0.00
USC	1	Yes	0.96	0.00	16.5	16.5	1.00	1.39	5.82	5.82
	2	Yes	0.90	0.00	16.0	16.0	1.00	1.34	5.63	5.63
	3	Yes	0.90	0.00	16.1	16.1	1.00	1.33	5.59	5.59

* Data files were corrupt, therefore preliminary results stand.

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

Table 2 – Test 3.3A Statistics

	Runs Completed (out of 3)	Fastest Finishing Run Speed (cm/s)	Mean Speed Top Two Runs (cm/s)
CMU	3	6.2	6.1
IHMC *	3	9.7	9.2
MIT	3	8.1	8.1
Stanford	1	11.3	5.6
USC	3	5.8	5.7

* Data files were corrupt, therefore preliminary results stand.



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 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.

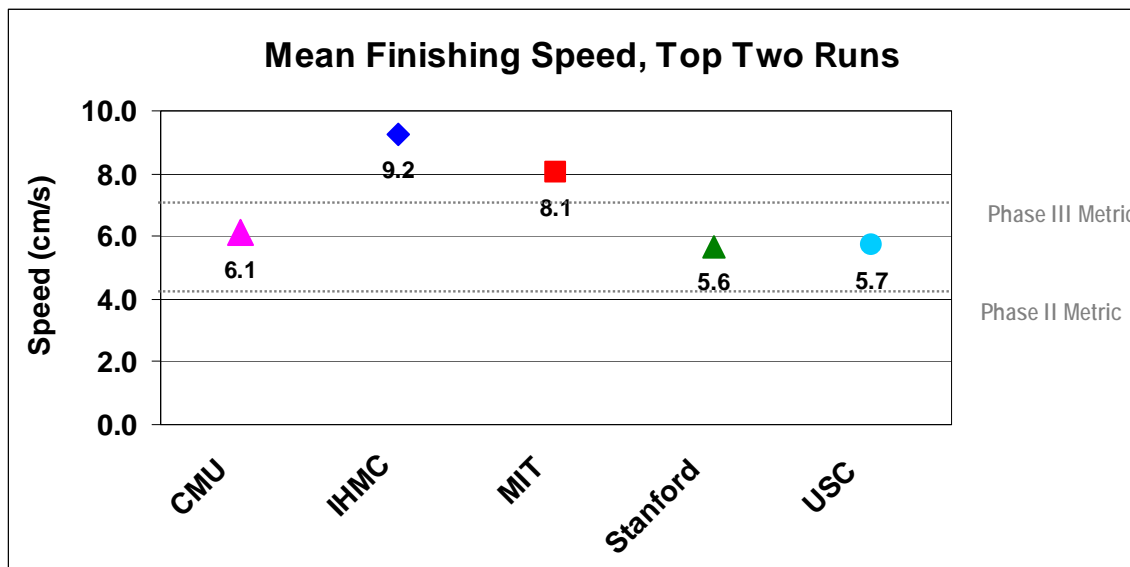


Figure 3 - Mean speed of the top two finishing runs



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



3.2 DISCUSSION

Test 3.3A challenged teams' ability to traverse a very high barrier, which all teams were able to do successfully. Three teams did so with at least one run above the metric speed: IHMC, MIT, and Stanford. In general, it appears that the barrier could not be traversed by stepping over; each team developed a custom gait that supported the body on the barrier when moving one pair of front or back legs across.

3.3 INDIVIDUAL RESULTS

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

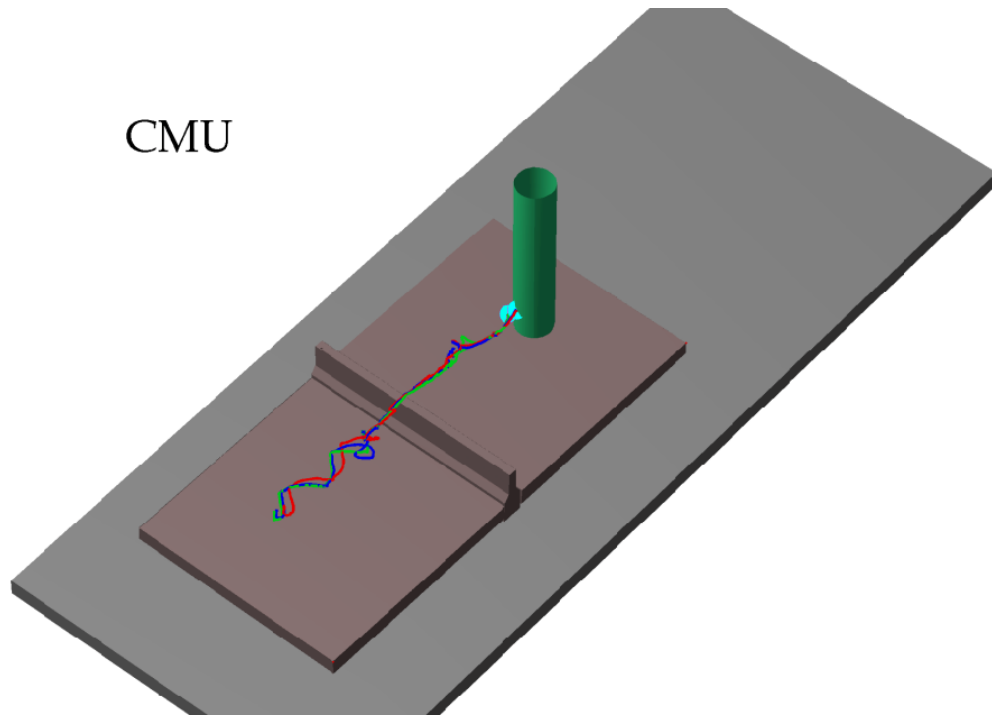
For each team, the 3D tracks of the centroid of the robot's body are plotted over a rendered version of the terrain. The three run scores use red, green, and blue to indicate run order.

Colored balls in the plots denote success and failure. Tracks end in cyan balls for runs reaching the goal, while 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 traversed the barrier three times at a mean speed of 6.1 cm/s.





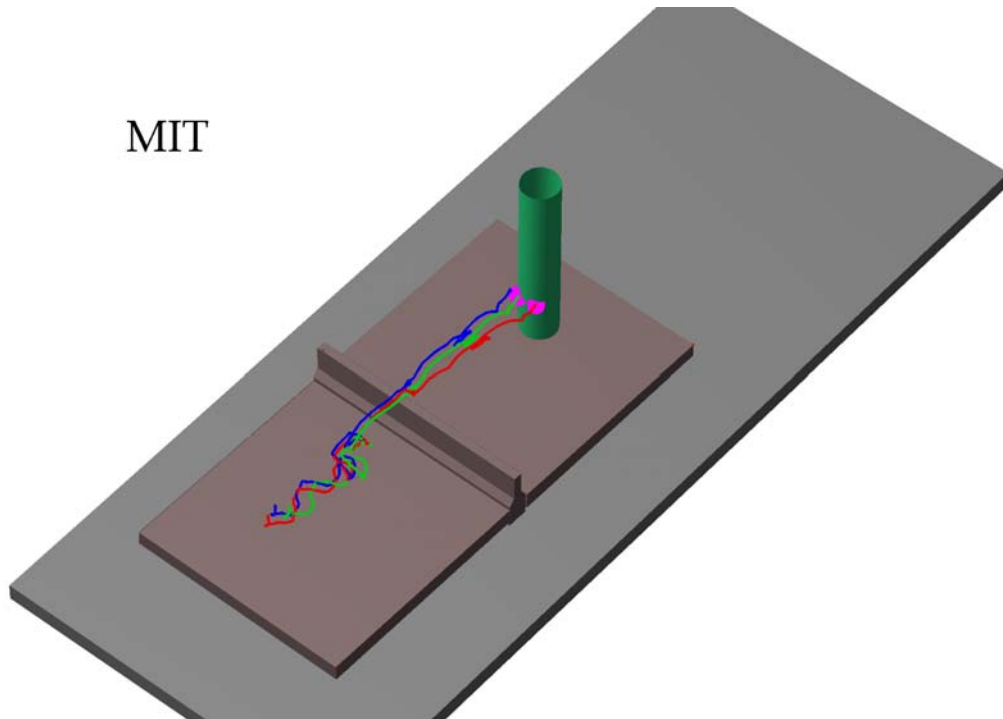
3.3.2 The Institute for Human and Machine Cognition

IHMC's data files did not parse correctly, therefore the body path figure could not be generated. IHMC crossed the barrier three times at a speed of 9.2 cm/s, the fastest mean time of Test 3.3A.

3.3.3 Massachusetts Institute of Technology

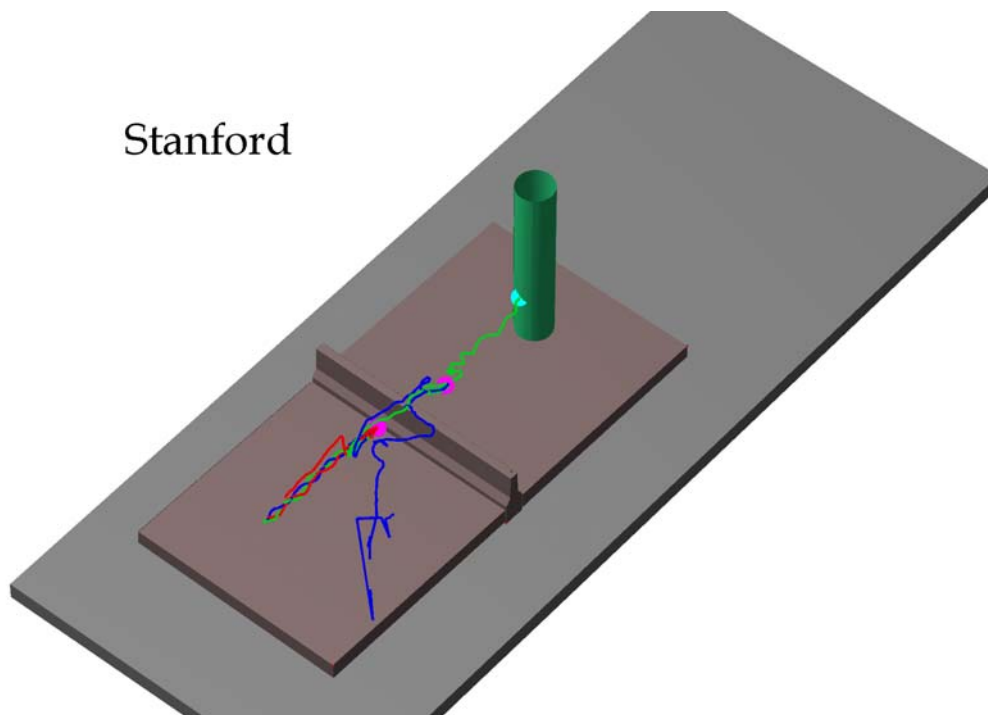
MIT jumped over the barrier three times at a mean speed of 8.1 cm/s, the second fastest mean time.

MIT



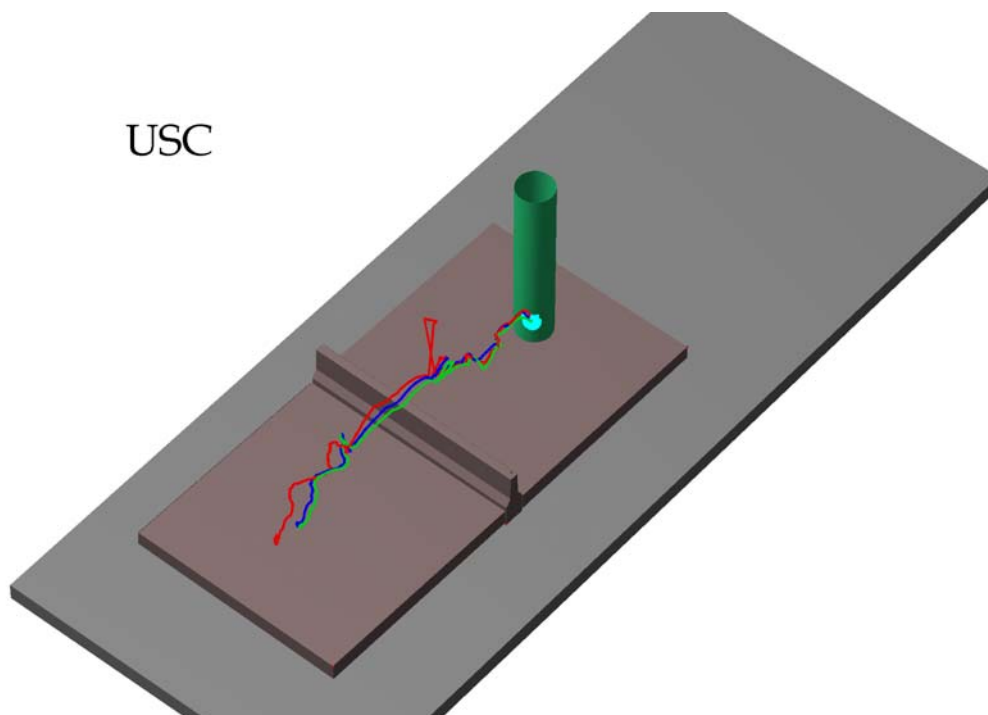
3.3.4 Stanford University

Stanford cleared the barrier once with a very fast time of 11.3 cm/s. In the other two runs, the robot flipped over.



3.3.5 The University of Southern California

USC traversed the barrier three times at a mean speed of 5.7 cm/s.



4 RESULTS: TYPE B TESTS

Test 3.3B presented a similar, but not identical, configuration of the Test 3.3A terrain (Barrier). The testing method was the same as for Type A tests.

Table 3 and Table 4 summarize the results.

Table 3 – Test 3.3B Statistics

	Runs	Successful	Fastest Finishing	Mean Speed
	Completed	Plan	Run Speed	Top Two Runs
	(out of 3)	(Y/N)	(cm/s)	(cm/s)
CMU	3	Y-Y-Y	5.7	5.7
IHMC	3	Y-Y-Y	9.2	8.3
MIT	0	Y-Y-Y	0.0	0.0
Stanford	3	Y-Y-Y	10.6	10.3
USC	3	Y-Y-Y	5.7	5.7

* IHMC data files were corrupt, therefore preliminary results stand.

Table 4 – Test 3.3B Individual Test Run Data

<i>Individual Trials</i>			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	0.93	0.00	16.2	16.2	1.00	1.37	5.74	5.74
	2	Yes	0.93	0.00	16.2	16.2	1.00	1.37	5.74	5.74
	3	Yes	0.93	0.00	16.2	16.2	1.00	1.37	5.74	5.74
IHMC	1*	Yes	0.94	0.00	15.0	15.0	1.00	1.49	6.27	6.27
	2*	Yes	0.94	0.00	12.8	12.8	1.00	1.75	7.34	7.34
	3*	Yes	0.94	0.00	10.2	10.2	1.00	2.19	9.22	9.22
MIT	1	No	0.94	0.40	7.0	6.6	0.57	1.12	8.18	0.00
	2	No	0.94	0.55	9.4	7.0	0.41	0.55	5.57	0.00
	3	No	0.94	0.56	9.8	4.7	0.40	0.78	8.09	0.00
Stanford	1	Yes	0.94	0.00	10.1	10.1	1.00	2.22	9.31	9.31
	2	Yes	0.94	0.00	9.4	9.4	1.00	2.38	10.00	10.00
	3	Yes	0.94	0.00	8.9	8.9	1.00	2.51	10.56	10.56
USC	1	Yes	0.94	0.00	16.5	16.5	1.00	1.36	5.70	5.70
	2	Yes	0.93	0.00	16.7	16.7	1.00	1.33	5.57	5.57
	3	Yes	0.93	0.00	16.5	16.5	1.00	1.34	5.64	5.64

* Data files were corrupt, therefore preliminary results stand.

5 RESULTS: TYPE C TESTS

5.1 SUMMARY

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

Table 5 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 5 – Test 3.3C 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	1.51	0.00	22.10	22.1	1.00	1.63	6.85	6.85
	2	No	1.44	13.50	13.50	12.9	-8.36	185.96	-93.47	0.00
	3	No	1.51	9.70	9.70	7.9	-5.41	133.46	-103.63	0.00
IHMC	1	Yes	1.51	0.00	26.7	26.7	1.00	1.35	5.67	5.67
	2	Yes	1.48	0.00	44.6	44.6	1.00	0.79	3.33	3.33
	3	No	1.48	0.85	20.2	14.7	0.43	0.44	4.31	0.00
MIT	1	Yes	1.51	0.00	29.7	29.7	1.00	1.21	5.10	5.10
	2	Yes	1.48	0.00	31.9	31.9	1.00	1.11	4.65	4.65
	3	Yes	1.47	0.00	33.3	33.3	1.00	1.05	4.42	4.42
Stanford	1	Yes	1.52	0.00	15.2	15.2	1.00	2.39	10.02	10.02
	2	Yes	1.48	0.00	14.8	14.8	1.00	2.39	10.02	10.02
	3	Yes	1.45	0.00	10.8	10.8	1.00	3.20	13.45	13.45
USC	1	Yes	1.51	0.00	29.0	29.0	1.00	1.24	5.22	5.22
	2	Yes	1.51	0.00	27.6	27.6	1.00	1.31	5.48	5.48
	3	Yes	1.51	0.00	28.2	28.2	1.00	1.28	5.37	5.37

- 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 6 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 6 – Test 3.3C Statistics

	Runs	Fastest Finishing	Mean Speed
	Completed (out of 3)	Run Speed (cm/s)	Top Two Runs (cm/s)
CMU	1	6.8	3.4
IHMC	2	5.7	4.5
MIT	3	5.1	4.9
Stanford	3	13.5	11.7
USC	3	5.5	5.4

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.

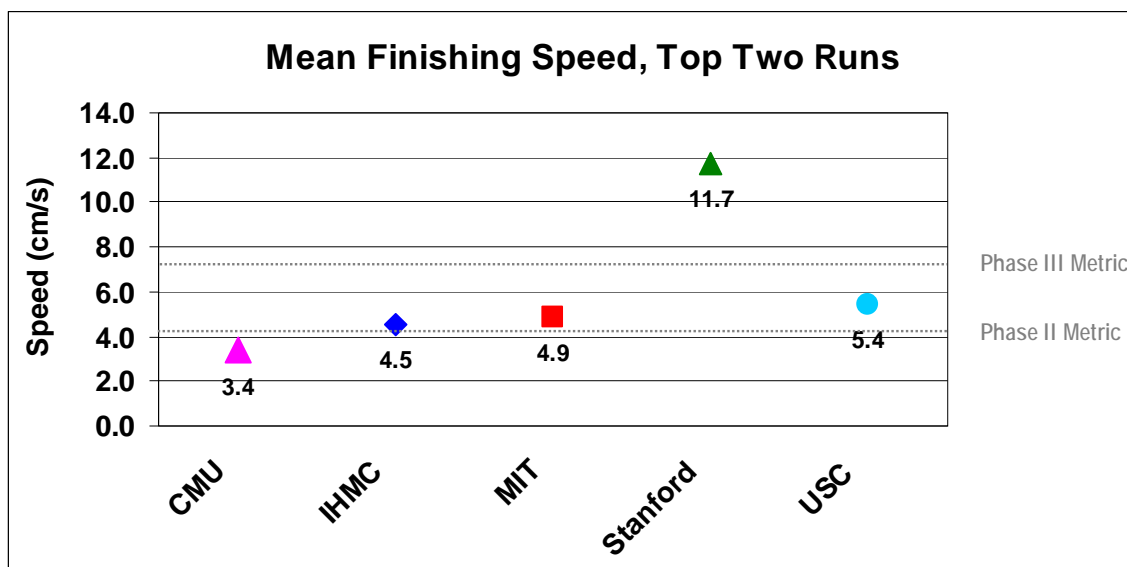


Figure 5 – Mean speed of the top two finishing runs

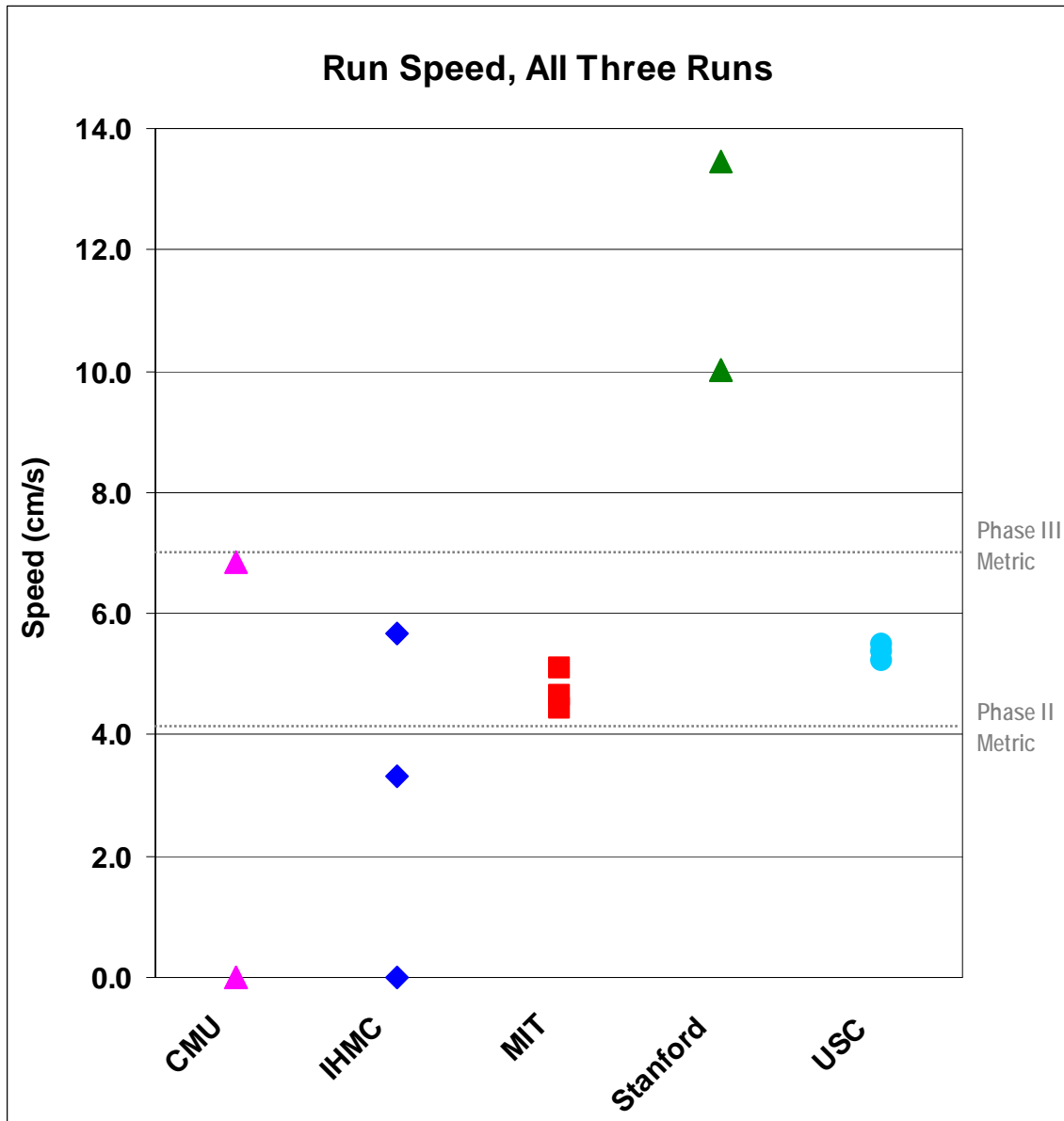


Figure 6 – The speed of individual test runs, where non-finishing runs receive zero.

5.2 DISCUSSION

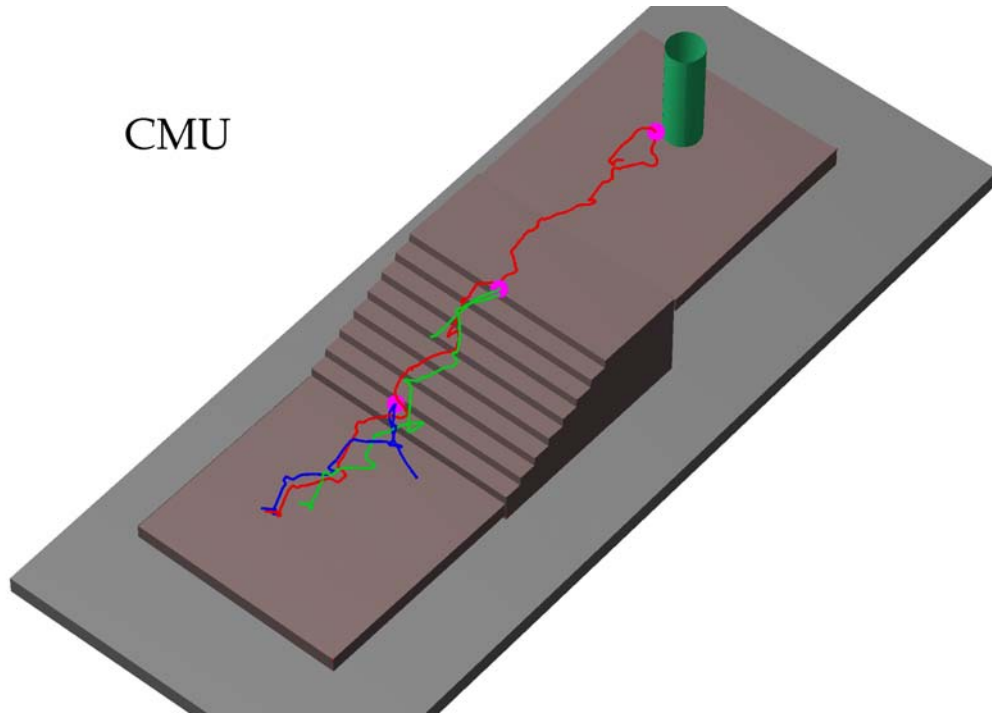
Three teams climbed the steps three out of three times: MIT, Stanford and USC. IHMC reached the goal twice, and CMU once. Stanford was the only team to beat the metric, with a very fast average time of 11.7 cm/s.

5.3 INDIVIDUAL RESULTS

The following sections describe the individual teams' performance.

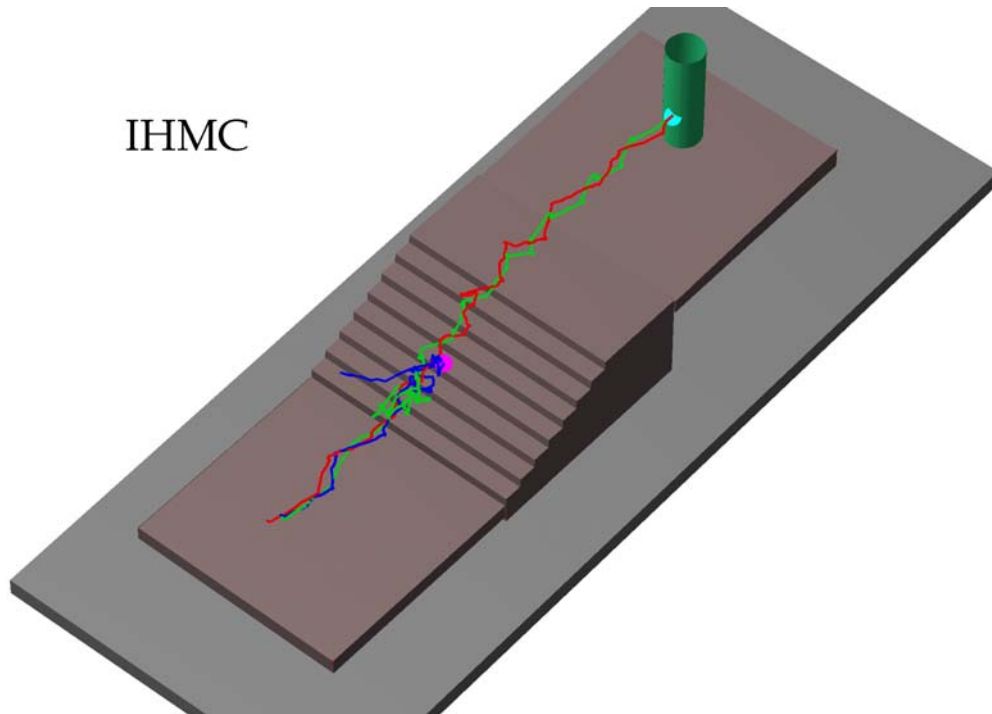
5.3.1 Carnegie Mellon University

CMU climbed the steps once out of three times, at 6.8 cm/s. The first run fell just short of the goal, but the LLGT gave it credit for success in the tables above. CMU's cost function was manually disabled for these runs because it showed each step as too small for a step.



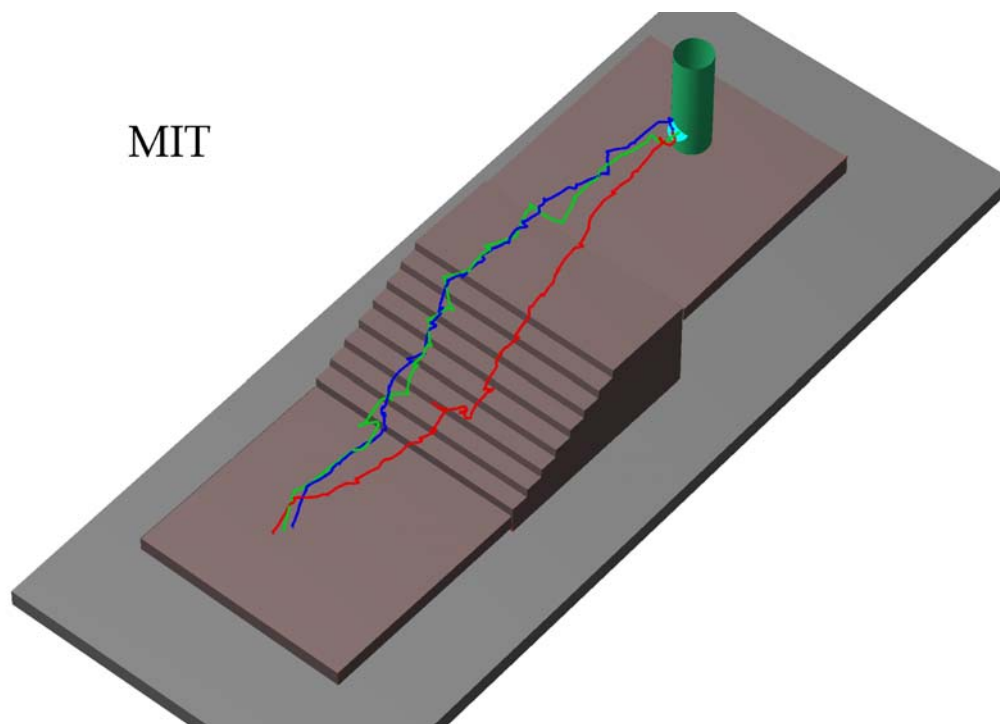
5.3.2 The Institute for Human and Machine Cognition

IHMC reached the goal twice at a mean speed of 4.5 cm/s.



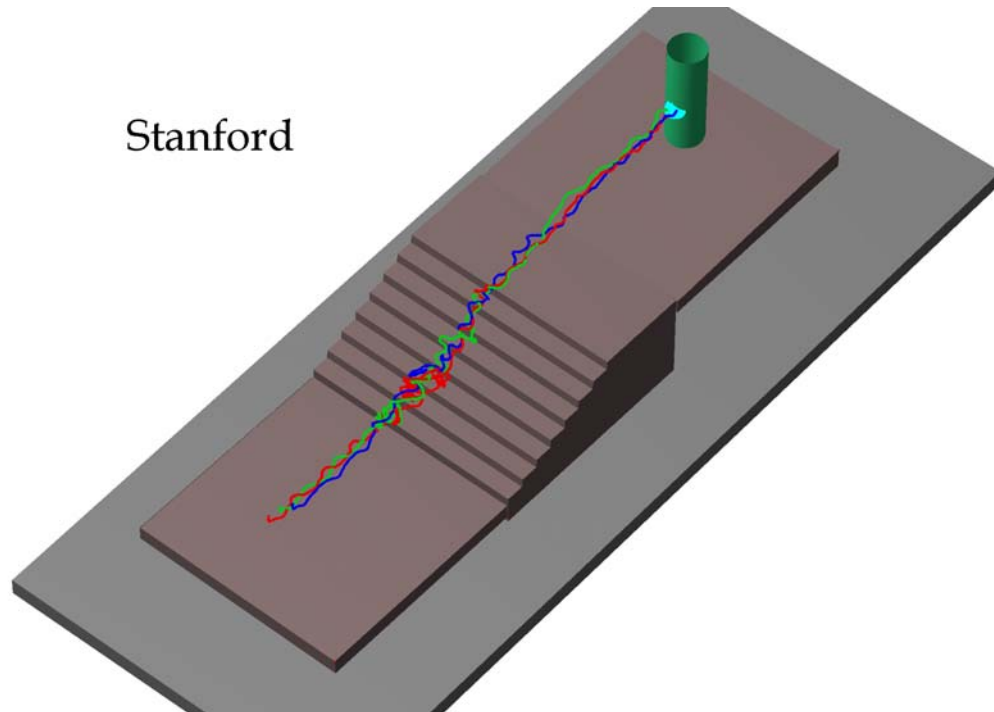
5.3.3 Massachusetts Institute of Technology

MIT reached the goal three times, with an average speed of 4.9 cm/s.



5.3.4 Stanford University

Stanford reached the goal three times - twice at 10.0 cm/s, and once at 13.5 cm/s.



5.3.5 The University of Southern California

USC reached the goal three times at an average of 5.4 cm/s.

