Trimble MB-Two Benchmark Test White Paper

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Section 1: Introduction to Benchmark Testing

This white paper shows Trimble's findings of multiple product heading/attitude performance testing scenarios involving the Trimble MB-Two receiver (firmware version 3.00*), several other Trimble boards and a few additional leading competitor units. Overall, results found that the Trimble MB-Two performance in all tests is statistically equal to or better than the other test participants.

Disclaimer: Strictly speaking, version 3.00 didn't exist at the time of Benchmark testing. The test was done with pre-final internal FW releases which became the official version V3.00 in Feb 2016. Updates are subject to change.

Trimble MB-Two Receiver

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Section 2: Testing Concept & Methodology

Trimble's Product Marketing team defined three primary scenarios for comparative testing:

- Group 1: Open sky static testing (antennas on the roof, receivers indoors)
- Group 2: Near the wall static L1/L2 testing (antennas and receivers outdoors)
- Group 3: Near the wall static L1-only testing (antennas and receivers outdoors)
- Group 4: Kinematic testing (antennas on a car roof)

In each group of tests, the following performance parameters were computed and compared:

- Attitude availability (heading, pitch / roll)
- Attitude reliability (heading, pitch / roll)
- Time to First Attitude (TTFA) after antenna re-connection or after going from under bridge (for dynamic testing)
- Attitude accuracy (heading, pitch / roll)

In all tests, the products worked in autonomous mode and computed on-board attitude (heading, pitch / roll). No external augmentation (corrections) was provided to any of the boards under test.

- Tests of Group 1: Trimble applied antenna power cycle – each cycle 10 minutes, power off time was 30 seconds
- Tests of Group 2: Trimble applied antenna power cycle – each cycle 30 minutes, power off time was 15 minutes
- Tests of Group 3: Trimble applied antenna power cycle – each cycle 30 minutes, power off time was 15 minutes
    - Prior to the test, antenna baseline was estimated, which was used in MB-Two during attitude computation.
- Tests of Group 4: Trimble drove repeatable loops passing under the bridges. In each test, there were repeatable trials of antenna blockages and corresponding signals re-acquisition.

Within each group, Trimble Product Marketing chose 3 types of antennas (AV34, LV59, AV33), and applied different baselines in range 1 - 3 meters.

All boards were in equal environmental conditions, with no preference to any board given. True trajectory for Group 4 was computed using robust averaging of all 5 trajectories, rather than selecting any particular one as true reference. No original data was removed or corrected, aside from the only exception that started and ended epochs for the 5 receivers, which was aligned.

Section 3.1: Testing Results, Group 1 (Static, Open Sky, L1/L2)

Test Description:

- Six tests completed: Combination of baselines - 1, 2 and 3 meters and two different types of antenna: AV34 and LV59
- Antenna power cycle: Each cycle 10 minutes, power off time was 30 seconds
- Receiver configuration: L1/L2 GPS + GLONASS
- Trimble MB-Two options: [@1] [X] **[Y]** [N] [G] [W] [D]

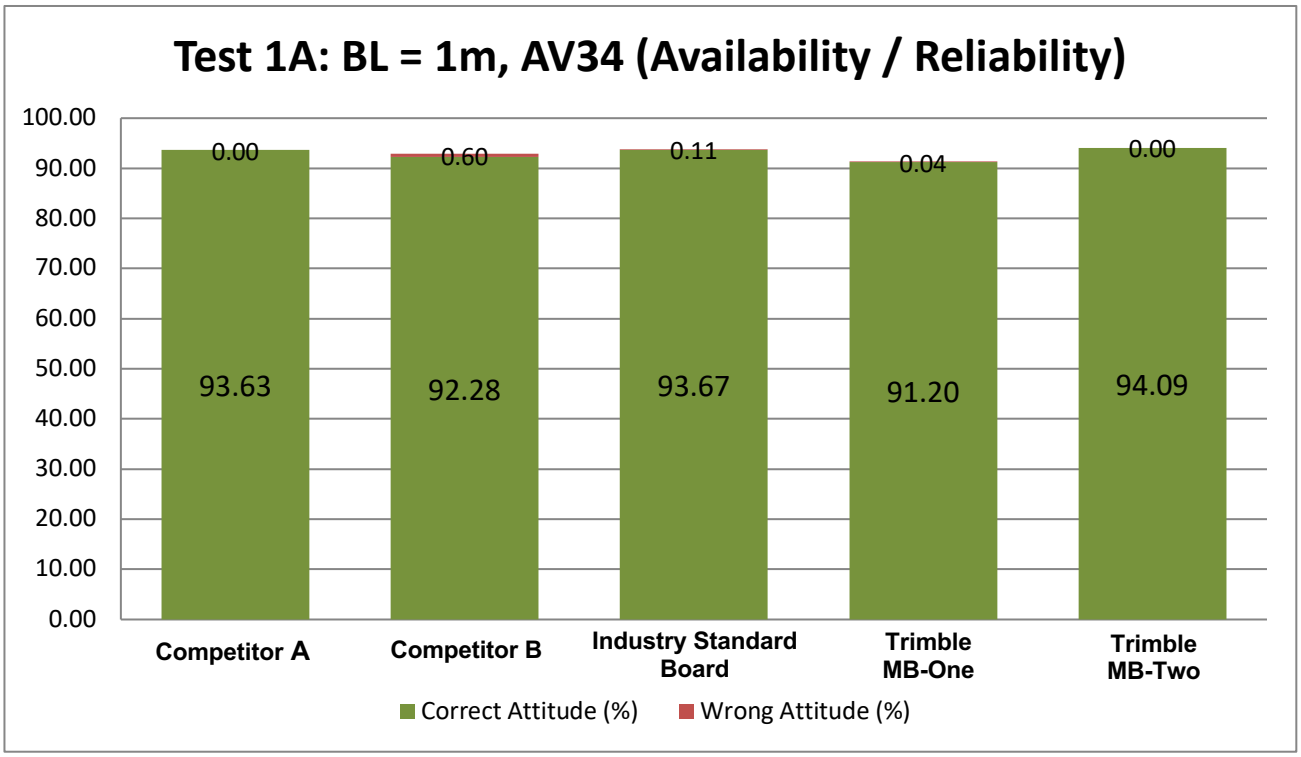
Test environments: Open Sky, Static Rooftop Test

Equipment used: (1 x Trimble MB-One) + (1 x Trimble MB-Two) + (1 x Industry Standard Board) + (2 x competitor units) connected in parallel with antenna splitter. Current antenna rack can house 2 antennas with a specific baseline that can be modified. Cables used: 5m or 10m TNC-TNC Antenna Cable (LMR400).

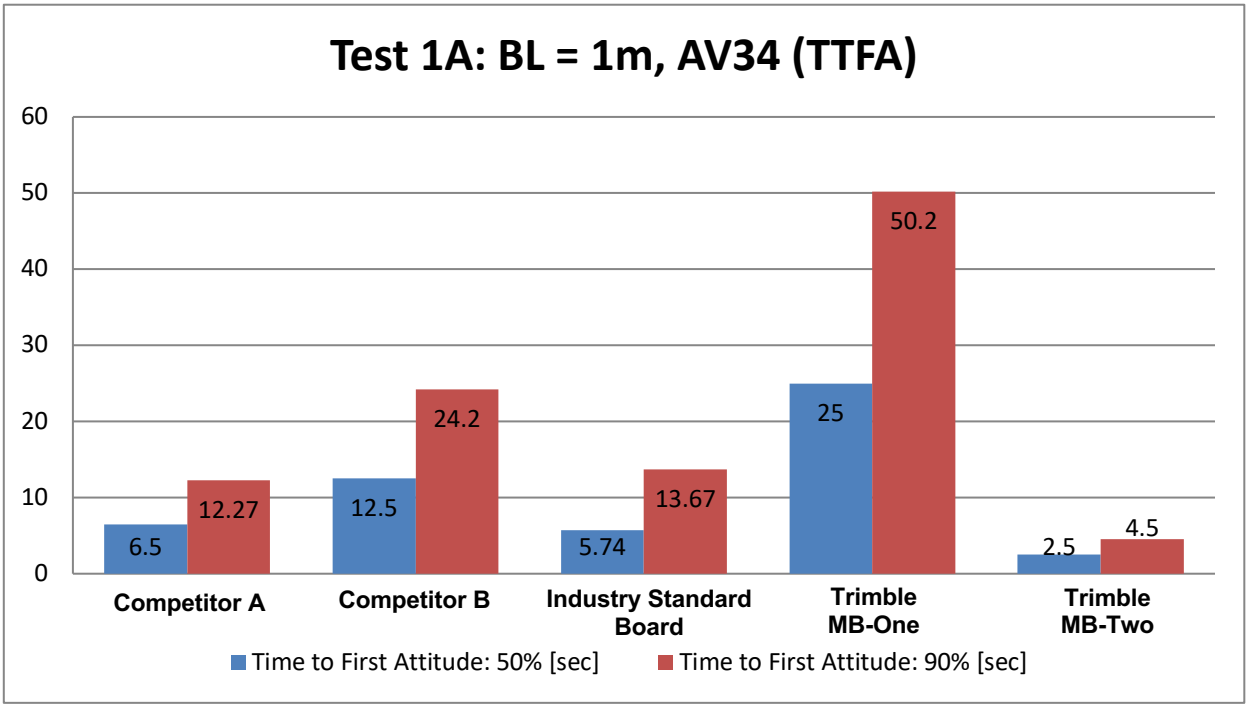
Group 1 (A) Baseline = 1m, Antennas - AV34 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 07:17:57.00 - 15:24:39.00 29202.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	27,343	27,125	27,385	26,645	27,476
Availability (%)	93.63	92.89	93.78	91.24	94.09
Mean Heading (deg)	130.12	130.15	130.16	130.14	130.01
Mean Pitch (deg)	0.02	0.1	0.08	0.03	0.15
Heading RMS (deg)	0.18	0.27	0.26	0.19	0.26
Pitch RMS (deg)	0.37	0.68	0.61	0.36	0.48
Heading Outliers (epochs)	0	115	2	12	0
Heading Outliers (%)	0	0.42	0.01	0.05	0
Heading Reliability (%)	100	99.58	99.99	99.95	100
Pitch Outliers (epochs)	0	176	31	0	0
Pitch Outliers (%)	0	0.65	0.11	0	0
Pitch Reliability (%)	100	99.35	99.89	100	100
Number of TTFH observations	39	39	39	39	39
Time to First Attitude: 50 %	6.5	12.5	5.74	25	2.5
Time to First Attitude: 90 %	12.27	24.2	13.67	50.2	4.5
Time to First Attitude: Max (s)	14	67	38	58	5
Time to Last Attitude: 50 %	0.5	0.5	0.5	0.5	0.5
Time to Last Attitude: 90 %	0.9	0.9	0.9	0.9	0.9
Time to Last Attitude: Max (s)	1	1	1	1	1

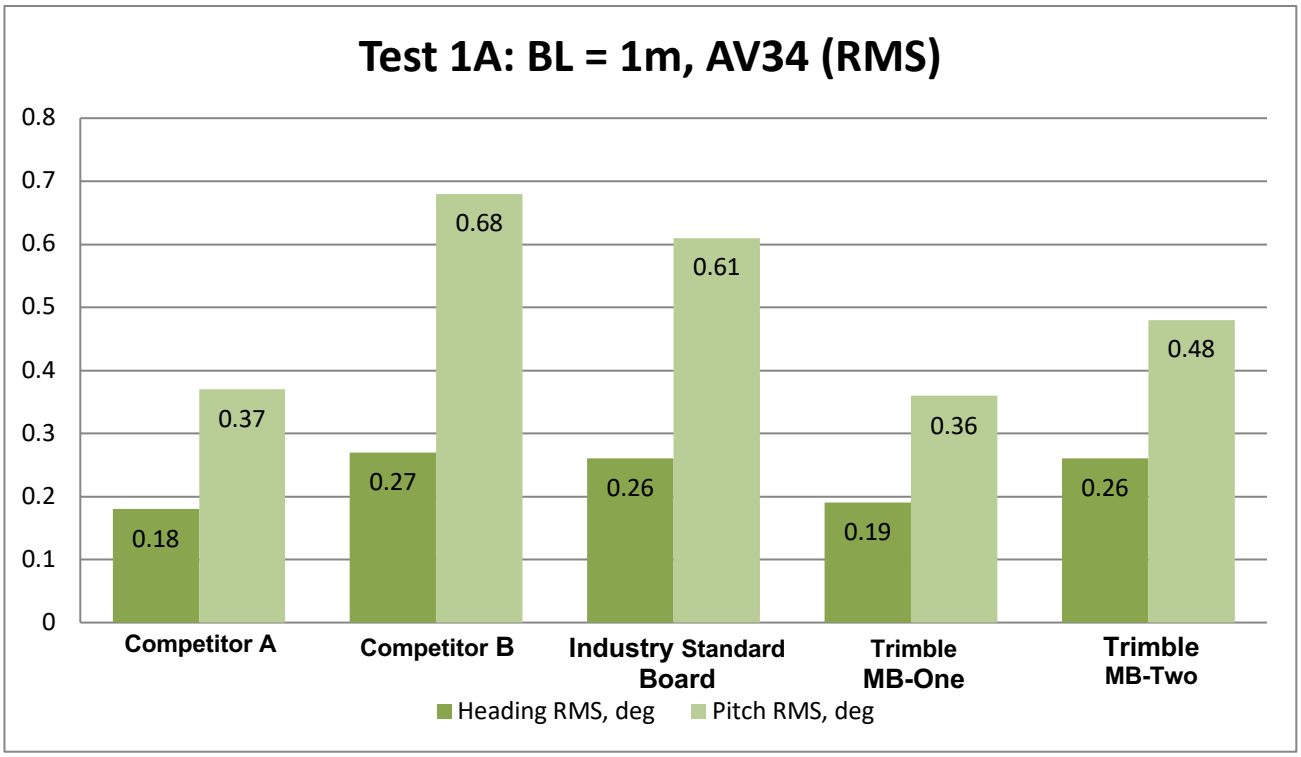
Group 1 (A) Availability / Reliability Plot:



Group 1 (A) TTFA Plot:



Group 1 (A) RMS Plot:



Note: The remaining test results can be found in the appendix at the conclusion of this white paper.

Section 3.2: Testing Results, Group 2 (Static, Canopy, L1/L2)

Test Description:

- Six tests completed: Combination of baselines - 1, 2 and 3 meters and two different types of antenna: AV34 and LV59
- Antenna power cycle: Each cycle 30 minutes, power off time was 15 minutes
- Receiver configuration: L1/L2 GPS + GLONASS
- Trimble MB-Two options: [@1] [X] **[Y]** [N] [G] [W] [D]

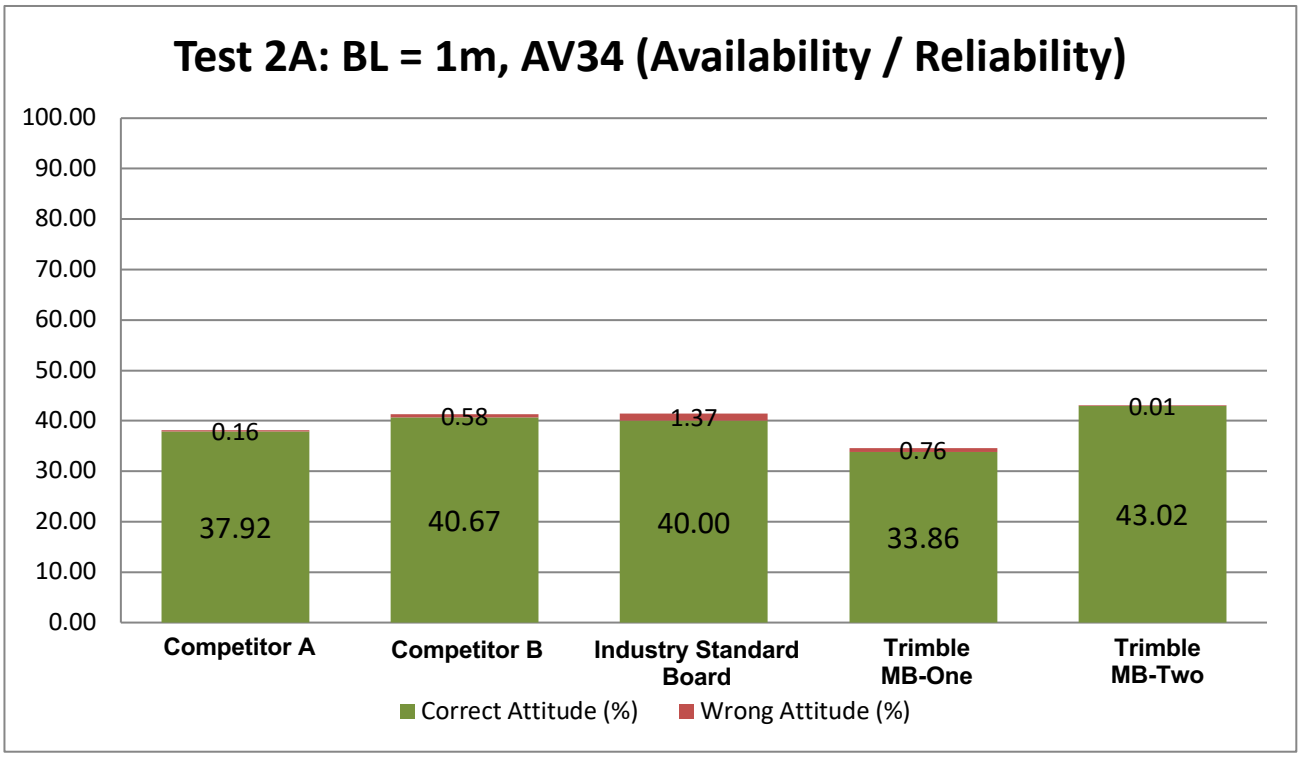
Test environments: Static tests in partly shaded environment, close to building

Equipment used: (1 x Trimble MB-One) + (1 x Trimble MB-Two) + (1 x Industry Standard Board) + (2 x competitor units) connected in parallel with antenna splitter. Current antenna rack can house 2 antennas with a specific baseline that can be modified. Cables used: 5m or 10m TNC-TNC Antenna Cable (58957-05-INT).

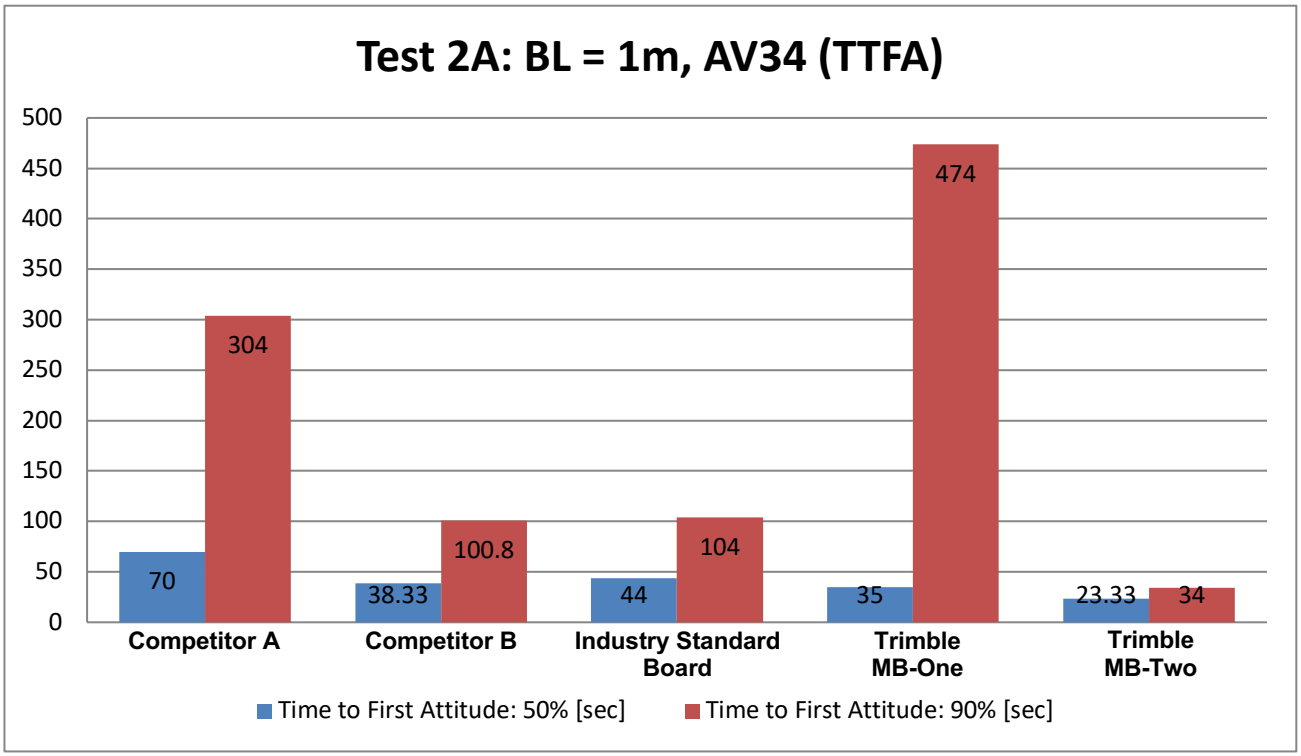
Group 2 (A) Baseline = 1m, Antennas – AV34 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 08:56:29.00 - 17:29:37.00 30788.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	11,724	12,700	12,739	10,658	13,248
Availability (%)	38.08	41.25	41.38	34.62	43.03
Mean Heading (deg)	272.82	272.88	273.01	272.9	272.95
Mean Pitch (deg)	-4.75	-4.85	-4.62	-4.68	-4.75
Heading RMS (deg)	0.59	0.64	0.8	0.7	0.62
Pitch RMS (deg)	0.91	1.07	1.15	0.95	0.89
Heading Outliers (epochs)	48	180	423	233	4
Heading Outliers (%)	0.41	1.42	3.32	2.19	0.03
Heading Reliability (%)	99.59	98.58	96.68	97.81	99.97
Pitch Outliers (epochs)	18	40	27	140	0
Pitch Outliers (%)	0.15	0.31	0.21	1.31	0
Pitch Reliability (%)	99.85	99.69	99.79	98.69	100
Number of TTFH observations	16	16	16	16	16
Time to First Attitude: 50 %	70	38.33	44	35	23.33
Time to First Attitude: 90 %	304	100.8	104	474	34
Time to First Attitude: Max (s)	345	104	119	633	44
Time to Last Attitude: 50 %	1	1	1	5.33	0.5
Time to Last Attitude: 90 %	1.8	1.8	1.8	9.6	0.9
Time to Last Attitude: Max (s)	2	2	2	203	1

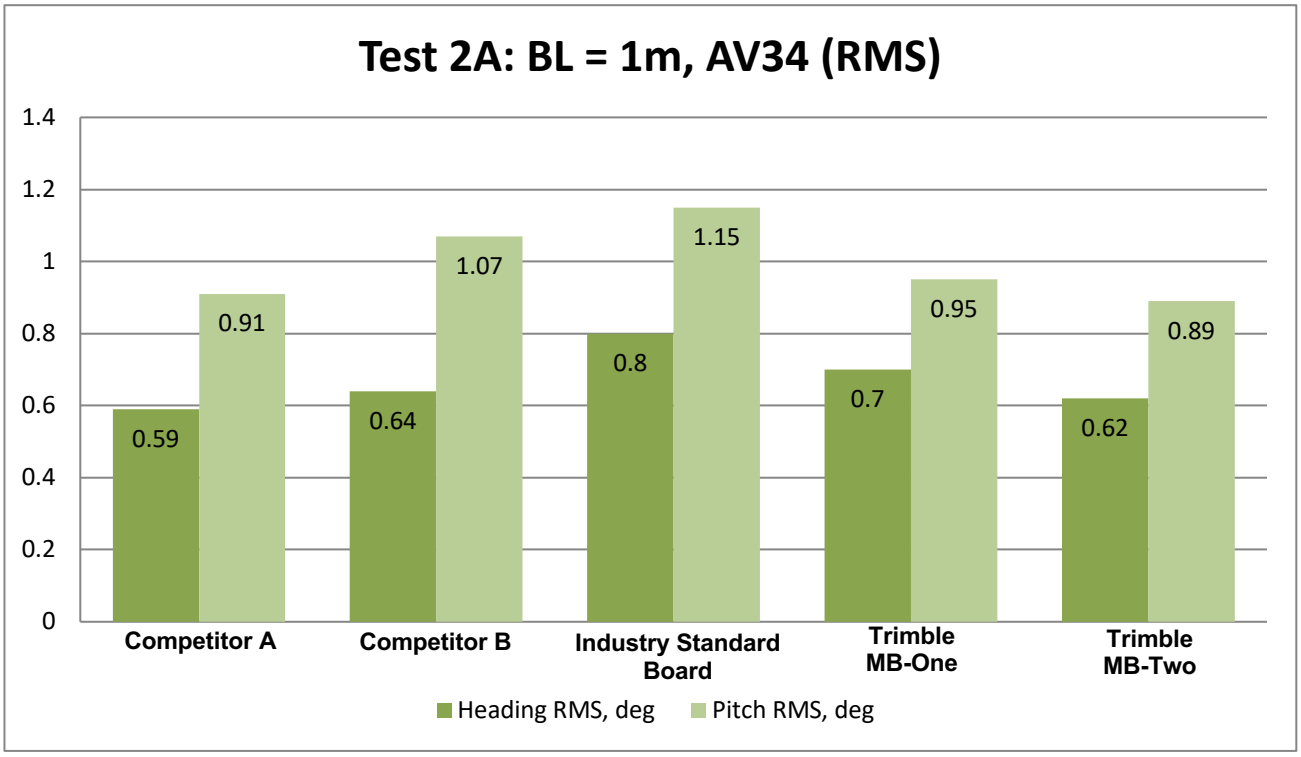
Group 2 (A) Availability / Reliability Plot:



Group 2 (A) TTFA Plot:



Group 2 (A) RMS Plot:



Section 3.3: Testing Results, Group 3 (Static, Canopy, L1 Only)

Test Description:

- Two tests completed: Baseline 1m with a combination of two different types of antenna: AV33 (L1 only) and ASH111660 (L1 only)
    - Baseline length was estimated prior the test and used during attitude computation
- Antenna power cycle: Each cycle 30 minutes, power off time was 15 minutes
- Receiver configuration: L1 GPS + GLONASS
- Trimble MB-Two options: [@1] [X] [N] [G] [W] [D]

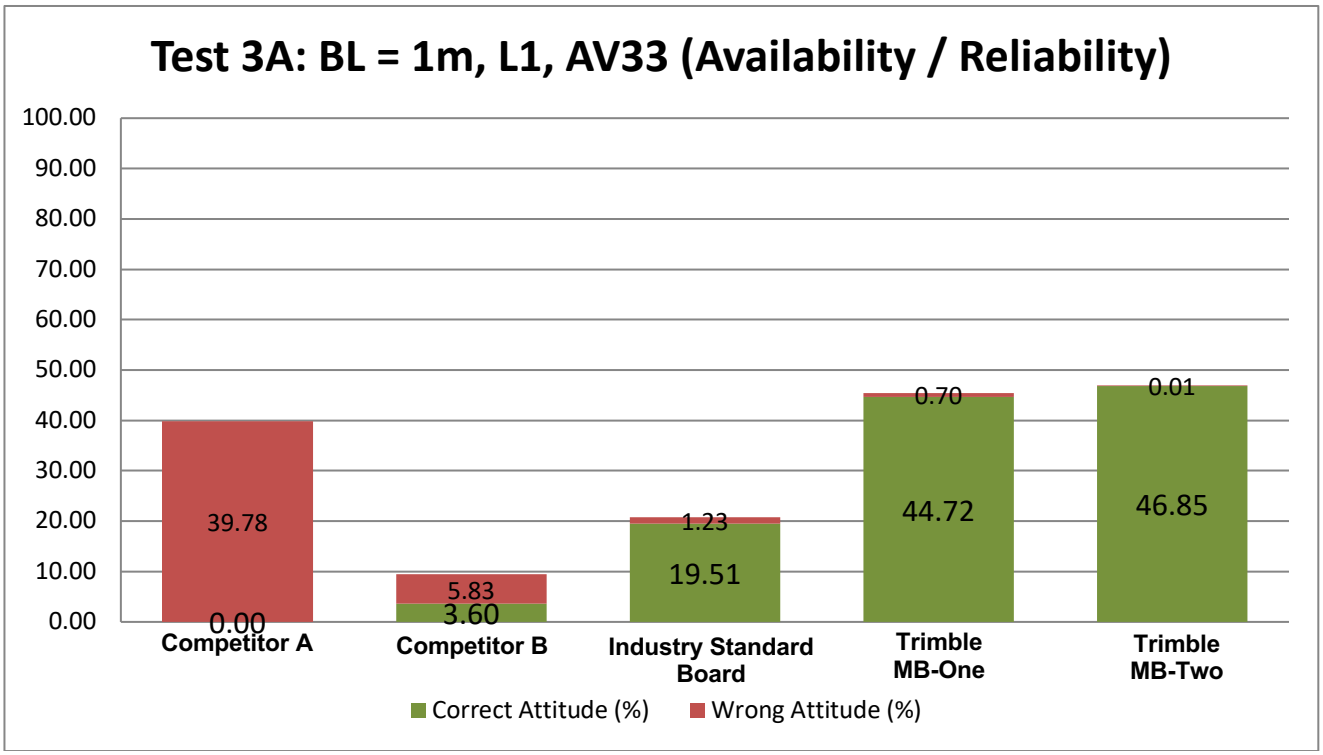
Test environments: Static tests in partly shaded environment, close to building

Equipment used: (1 x Trimble MB-One) + (1 x Trimble MB-Two) + (1 x Industry Standard Board) + (2 x competitor units) connected in parallel with antenna splitter. Current antenna rack can house 2 antennas with a specific baseline that can be modified. Cables used: 5m or 10m TNC-TNC Antenna Cable (LMR400)

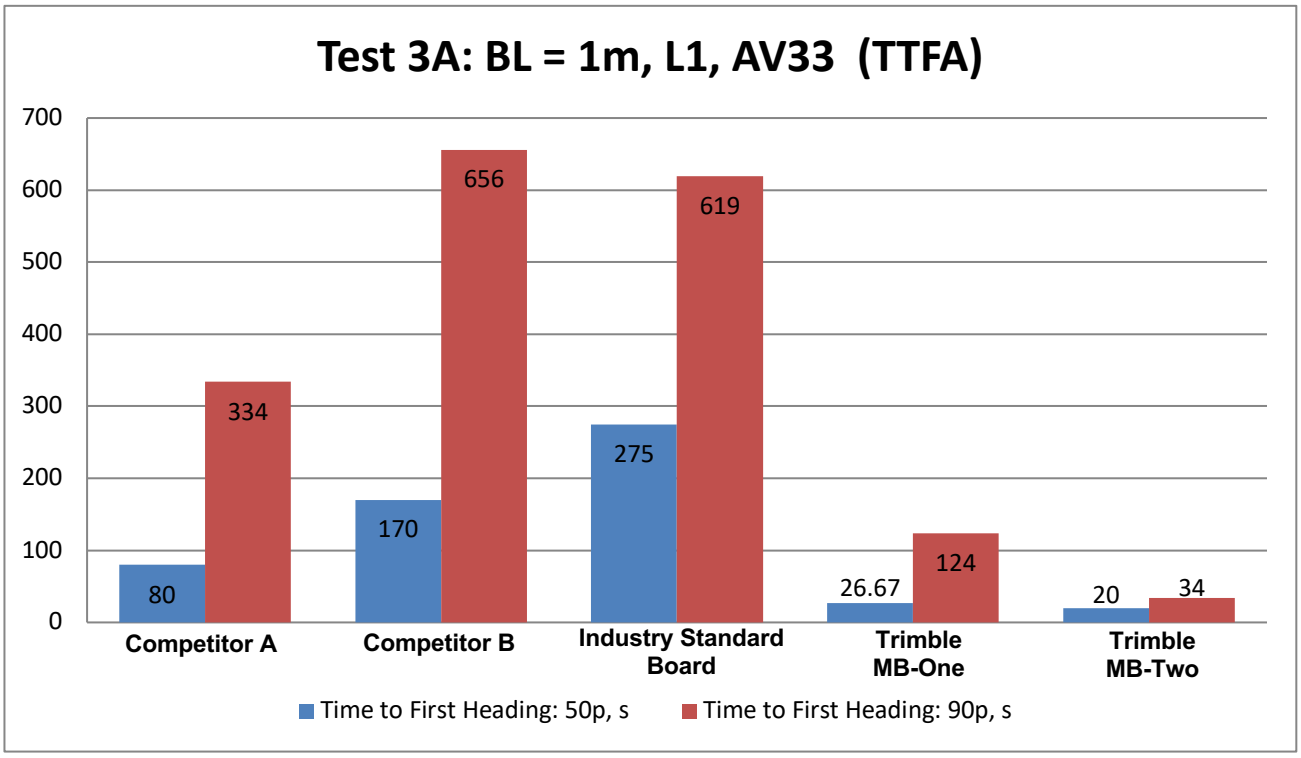
Group 3 (A) Baseline = 1m L1- only, Antennas – AV33 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 08:37:31.00 - 17:00:05.00 30154.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	11,995	2,845	6,254	13,695	14,132
Availability (%)	39.78	9.43	20.74	45.42	46.87
Mean Heading (deg)	268.89	273.11	275.18	275.2	275.25
Mean Pitch (deg)	5.33	2.63	1.75	1.85	1.87
Heading RMS (deg)	22.46	14	1.04	0.82	0.51
Pitch RMS (deg)	12.78	8.17	2.51	1.28	0.67
Heading Outliers (epochs)	11,995	1,759	371	210	4
Heading Outliers (%)	100	61.83	5.93	1.53	0.03
Heading Reliability (%)	0	38.17	94.07	98.47	99.97
Pitch Outliers (epochs)	3,887	215	35	93	0
Pitch Outliers (%)	32.41	7.56	0.56	0.68	0
Pitch Reliability (%)	67.59	92.44	99.44	99.32	100
Number of TTFH observations	16	14	11	16	16
Time to First Heading: 50p (s)	80	170	275	26.67	20
Time to First Heading: 90p (s)	334	656	619	124	34
Time to First Heading: Max (s)	347	684	832	157	70
Time to Last Heading: 50p (s)	1.5	130	1.5	0	1
Time to Last Heading: 90p (s)	2.7	296	2.7	0	1.8
Time to Last Heading: Max (s)	3	637	3	0	2

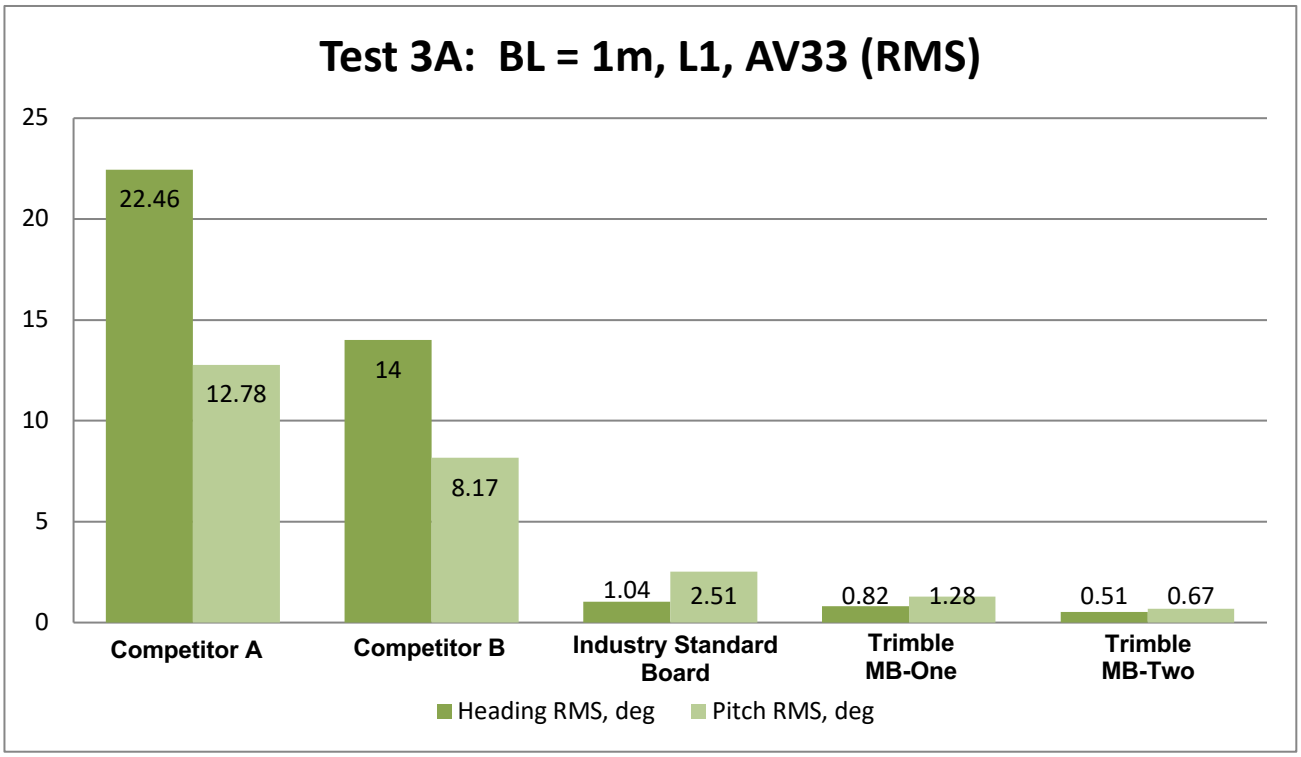
Group 3 (A) Availability / Reliability Plot:



Group 3 TTFA Plot:



Group 3 (A) RMS Plot:



Section 3.4: Testing Results, Group 4 (Drive test, L1/L2)

Test Description:

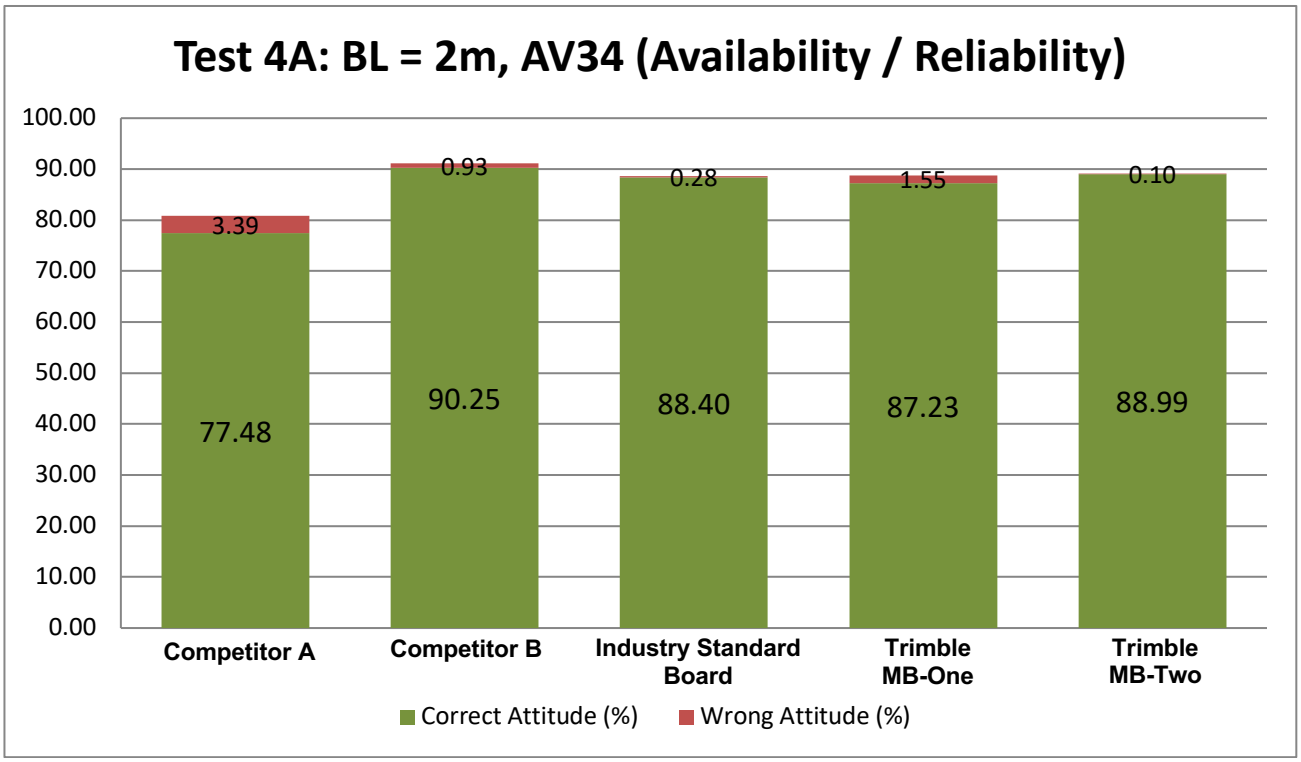
- Four tests completed: 2m baseline using two different types of antenna: AV34 and LV59 and two different set of options.
- Group 4 tests: Drove in repeatable loops passing under the bridges
    - Repeatable heading lose/acquisition trials performed in each test
- Receiver configuration: L1/L2 GPS + GLONASS and L1/L2 GPS + B1/B2 BeiDou,
- Trimble MB-Two options: [@1] [X] [Y] [N] **[G]** [W] [D] and [@1] [X] [Y] **[S]** [N] **[B]** [W] [D]

Equipment used: (1 x Trimble MB-One) + (1 x Trimble MB-Two) + (1 x Industry Standard Board) + (2 x competitor units) connected in parallel with antenna splitter. Cables used: 5m TNC-TNC Antenna Cable (LMR400)

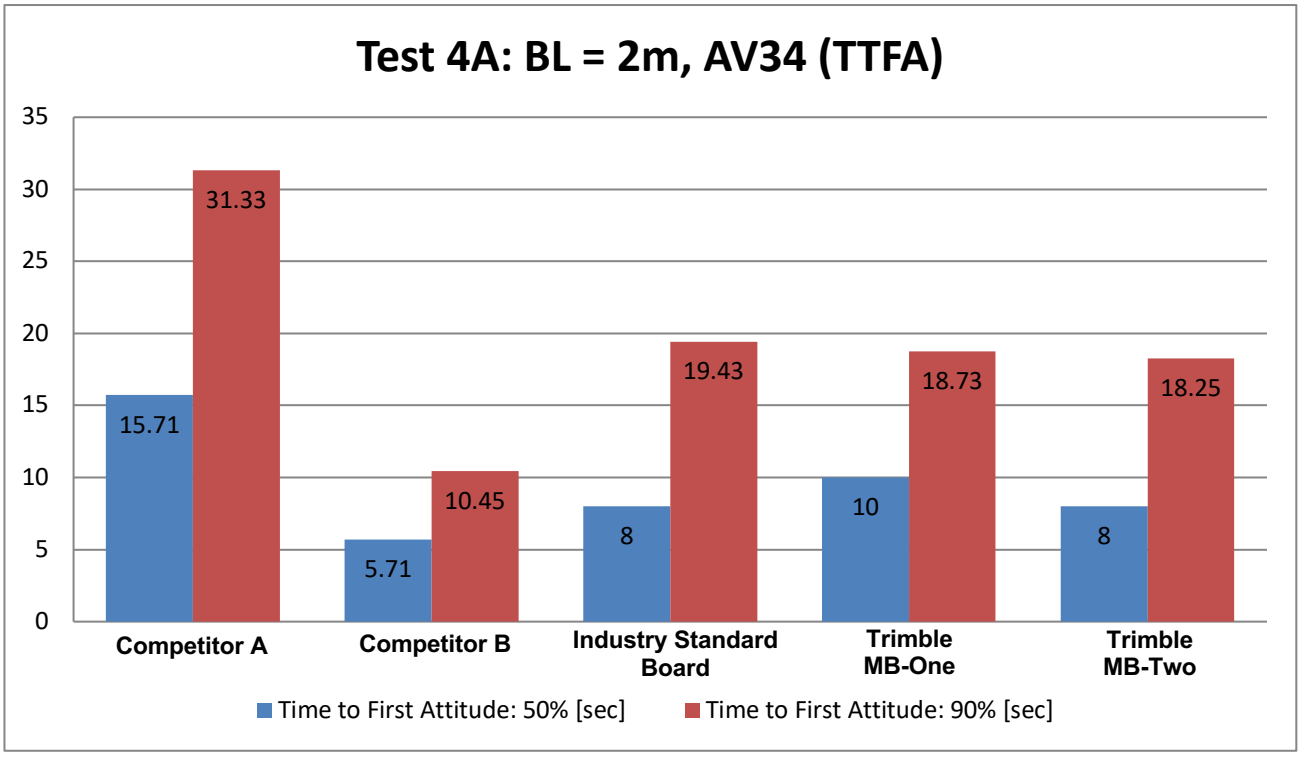
Group 4 (A) Baseline = 2m, Antennas – AV34, L1/L2 GPS + GLONASS. Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 10:06:43.50 - 11:14:34.70 4071.20s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	65,851	74,240	72,215	72,287	72,550
Availability (%)	80.87	91.18	88.69	88.78	89.1
Heading RMS (deg)	0.12	0.15	0.14	0.18	0.12
Pitch RMS, deg	0.33	0.48	0.37	0.45	0.31
Heading Outliers (epochs)	2760	242	143	799	83
Heading Outliers (%)	4.19	0.33	0.2	1.11	0.11
Heading Reliability (%)	95.43	98.78	99.67	98.26	99.51
Heading No Reference (epochs)	250	661	96	456	274
Heading No Reference (%)	0.31	0.85	0.12	0.56	0.36
Pitch Outliers (epochs)	2,666	755	232	1,261	73
Pitch Outliers (%)	4.05	1.02	0.32	1.75	0.1
Pitch Reliability (%)	95.2	97.57	99.08	97.24	99.11
Number of TTFH observations	24	24	24	24	24
Time to First Attitude: 50 %	15.71	5.71	8	10	8
Time to First Attitude: 90 %	31.33	10.45	19.43	18.73	18.25
Time to First Attitude: Max (s)	36.65	12.25	24.15	23.3	34.1
Time to Last Attitude: 50 %	4.2	0.47	0.43	0.8	0.47
Time to Last Attitude: 90 %	7.56	0.86	0.76	1.44	0.86
Time to Last Attitude: Max (s)	8.4	0.95	0.85	1.6	0.95

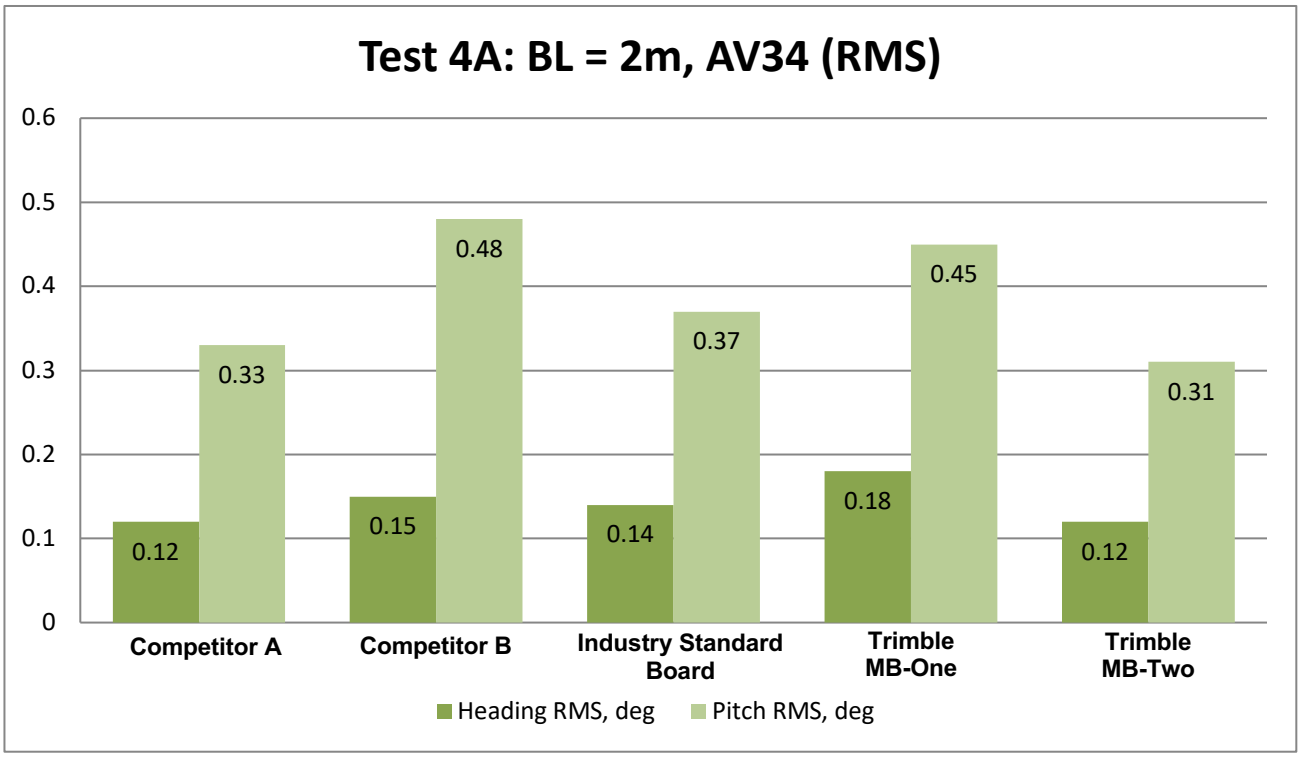
Group 4 (A) Availability / Reliability Plot:



Group 4 (A) TTFA Plot:



Group 4 (A) RMS Plot:



Section 4: Conclusions

Overall, results found that the Trimble MB-Two L1/L2 heading/pitch performance in all tests is statistically better than the other test participants. There were no heading or pitch biases detected between any of the receivers.

Competitor A's performance worsened in harsh environments, while other boards showed strong performance. In open sky conditions, the Trimble MB-One (L1 only) and Trimble MB-Two (L1/L2) heading performance is comparable, with not much benefit of L2 in these conditions. The Trimble MB-Two heading performance is further improved if "FIX" heading mode is applied, and this is true even for L1/L2 heading operation.

It should be noted that the Trimble MB-One board was always configured in so called "FIX" heading mode when baseline length is known and preset a priori ("FIX" mode is the default for L1-only heading). On the contrary, the Trimble MB-Two board was configured in so called "FLX" heading mode when baseline length is not preset ("FLX" mode is the default for L1/L2 heading) in all the tests except Group #3.

Appendix

The remaining data with the exception of Group A for each group and test can be viewed in accordance with each page in the appendix below:

**Please note:* *Group A's tests do not represent the most typical use cases. Each test group's results were unique to their own scenarios.*

Group 1 (Static, Open Sky, L1/L2):

Group 2 (Static, Canopy, L1/L2):

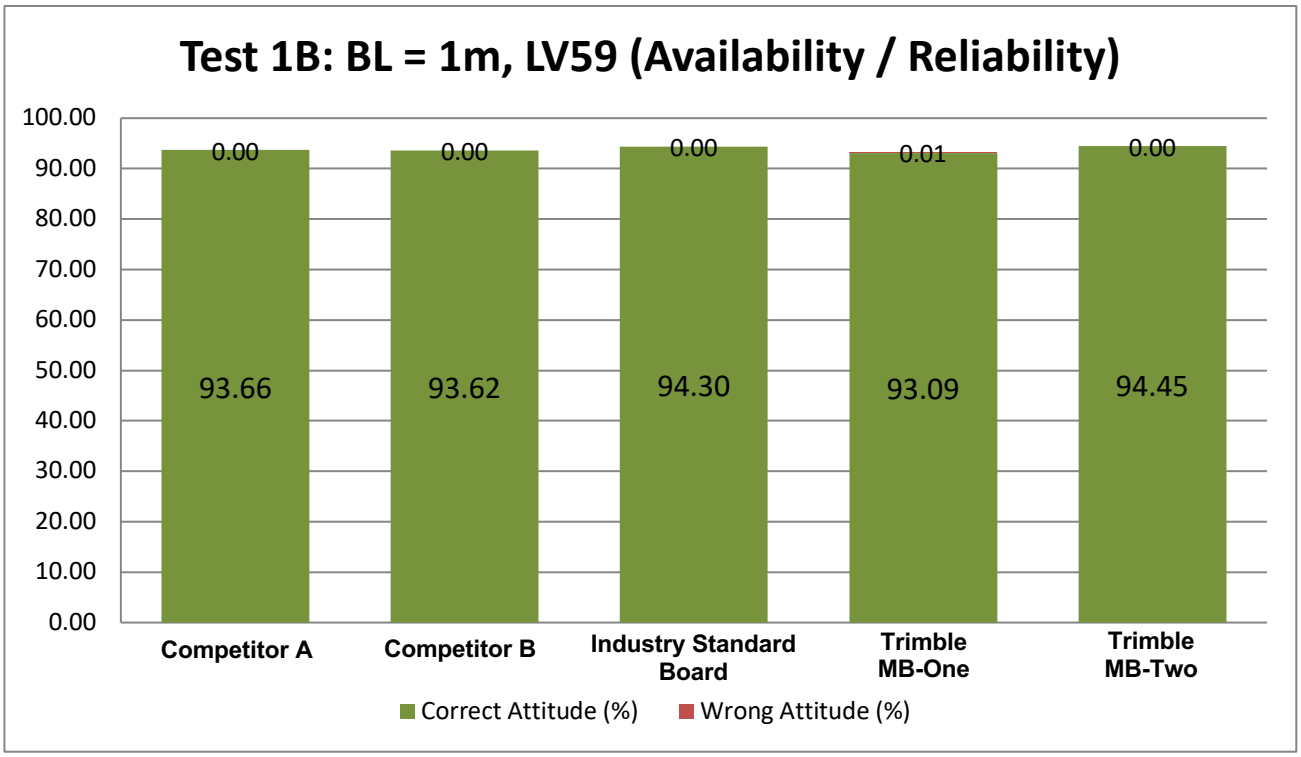
Group 3 (Static, Canopy, L1 only):

Group 4 (Drive test, L1/L2):

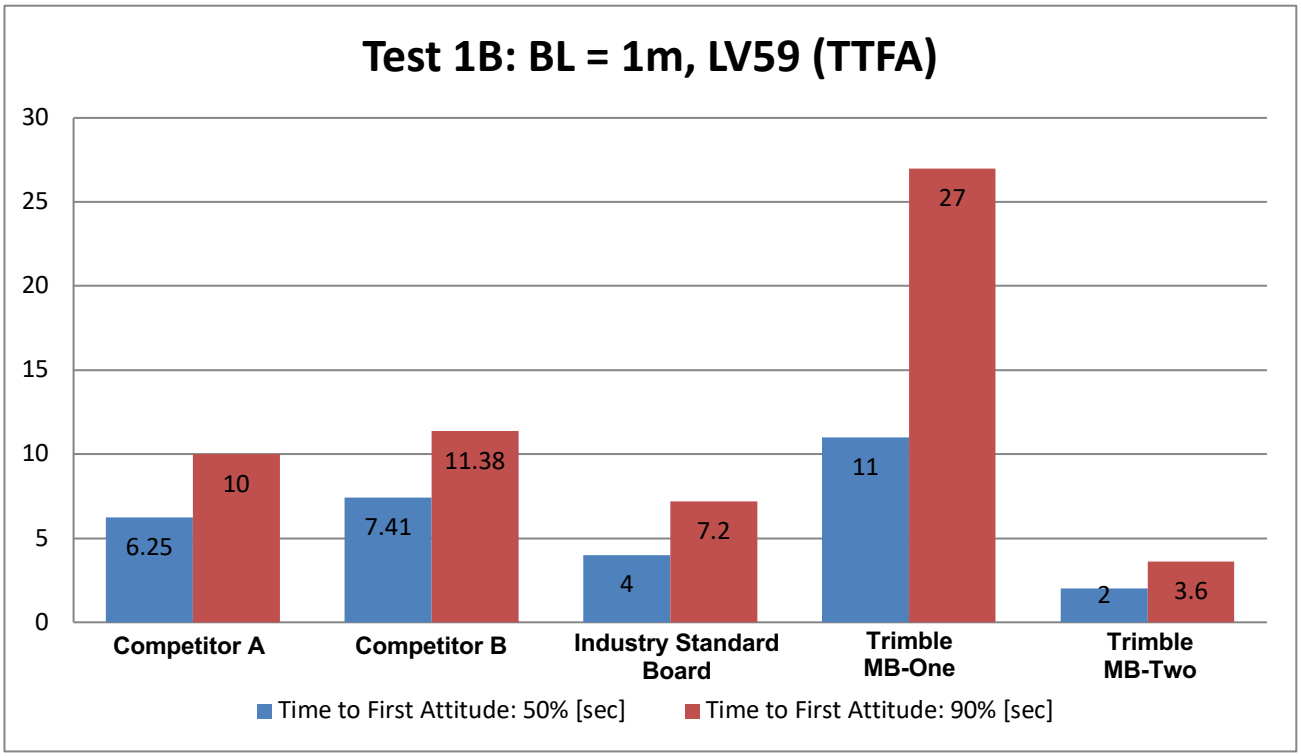
Group 1 (B) Baseline = 1m, Antennas – LV59 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 07:04:44.00 - 15:23:56.00 29952.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	28,053	28,040	28,244	27,884	28,290
Availability (%)	93.66	93.62	94.3	93.1	94.45
Mean Heading (deg)	130.21	130.21	130.17	130.19	130.24
Mean Pitch (deg)	0.03	0.12	0.06	0.13	0.11
Heading RMS (deg)	0.13	0.15	0.17	0.15	0.16
Pitch RMS (deg)	0.22	0.37	0.33	0.27	0.3
Heading Outliers (epochs)	0	0	0	2	0
Heading Outliers (%)	0	0	0	0.01	0
Heading Reliability (%)	100	100	100	99.99	100
Pitch Outliers (epochs)	0	0	0	0	0
Pitch Outliers (%)	0	0	0	0	0
Pitch Reliability (%)	100	100	100	100	100
Number of TTFH observations	40	40	40	40	40
Time to First Attitude: 50 %	6.25	7.41	4	11	2
Time to First Attitude: 90 %	10	11.38	7.2	27	3.6
Time to First Attitude: Max (s)	10	12	8	42	4
Time to Last Attitude: 50 %	0.5	0.5	0.5	0.5	0.5
Time to Last Attitude: 90 %	0.9	0.9	0.9	0.9	0.9
Time to Last Attitude: Max (s)	1	1	1	1	1

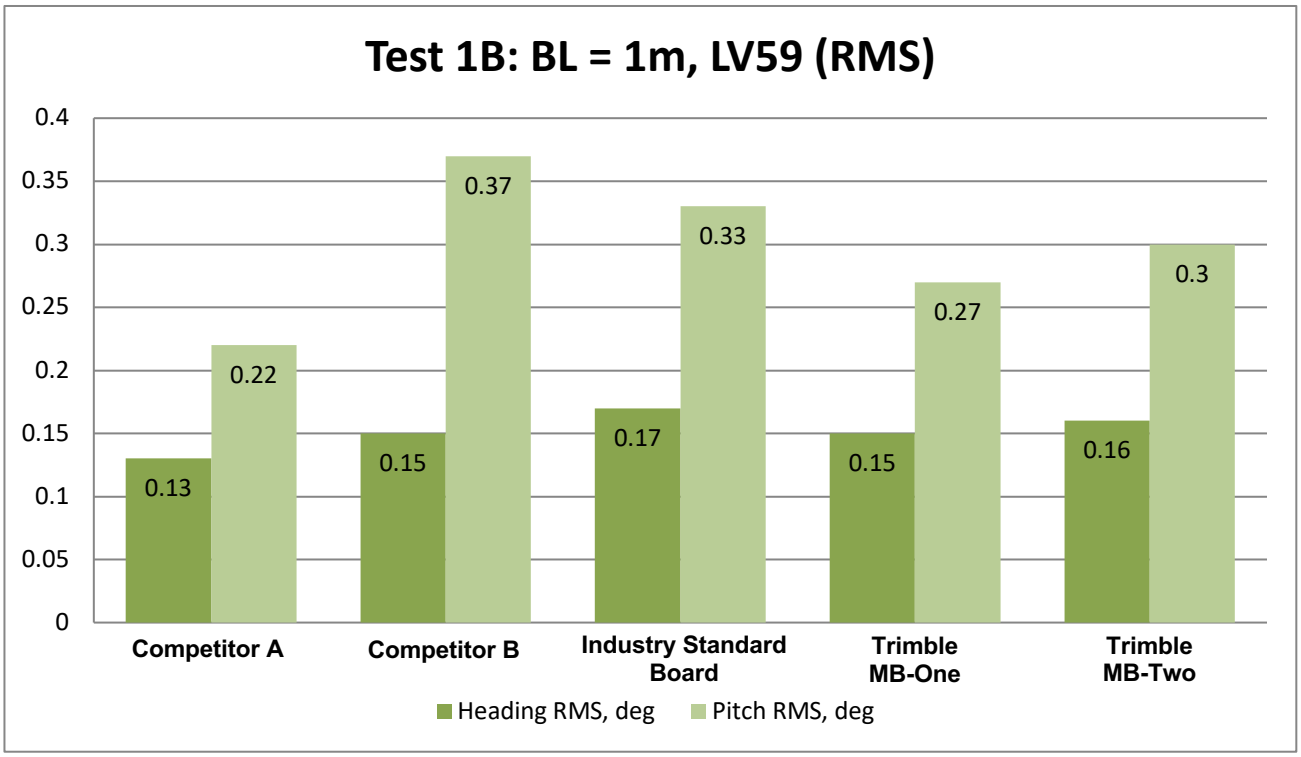
Group 1 (B) Availability / Reliability Plot:



Group 1 (B) TTFA Plot:



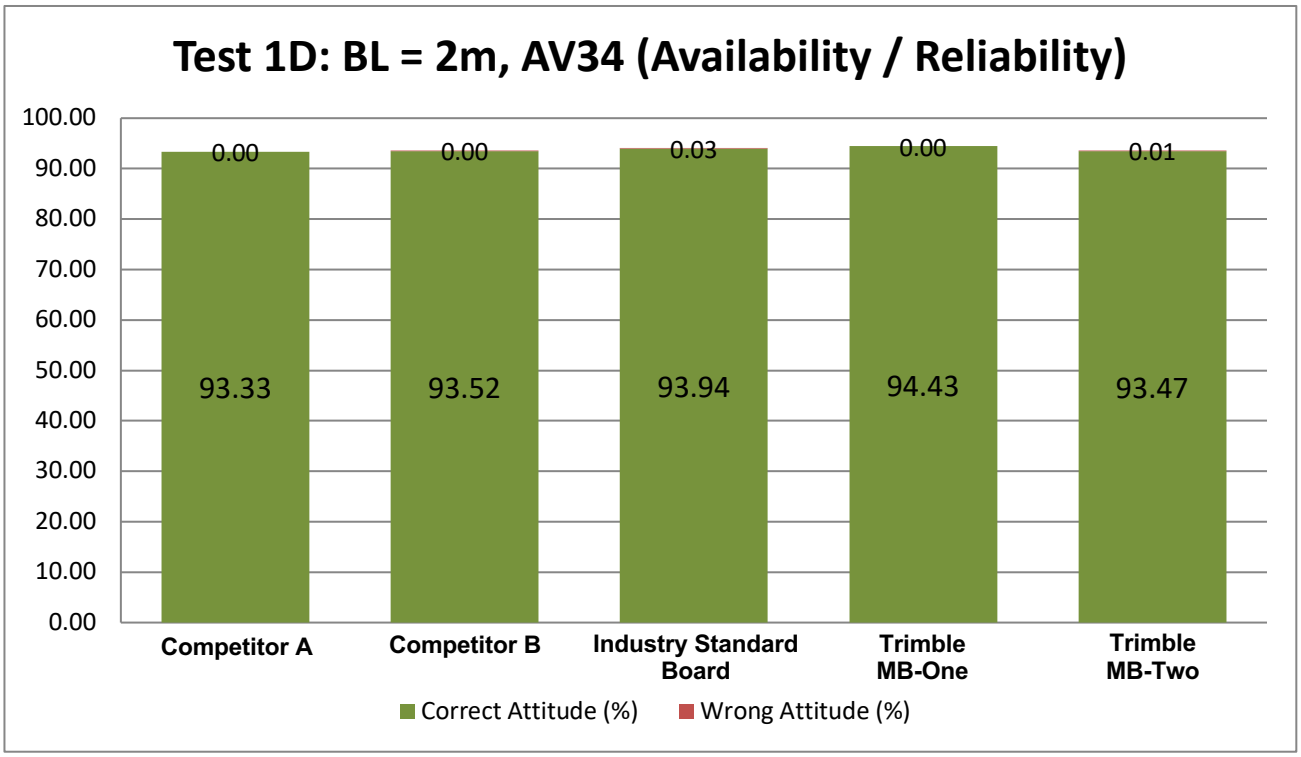
Group 1 (B) RMS Plot:



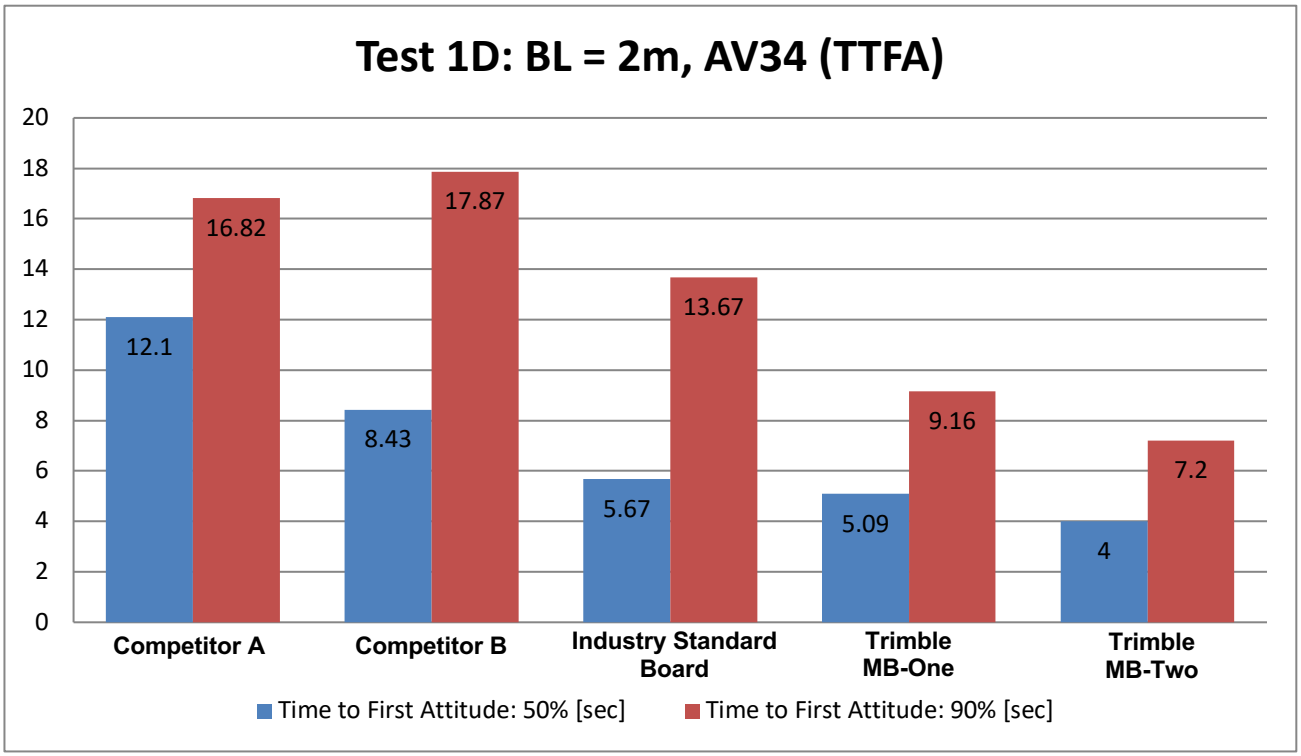
Group 1 (D) Baseline = 2m, Antennas – AV34 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 09:05:26.00 - 21:20:00.00 44074.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	41,133	41,219	41,414	41,617	41,198
Availability (%)	93.33	93.52	93.96	94.43	93.47
Mean Heading (deg)	187.71	187.7	187.71	187.7	187.71
Mean Pitch (deg)	0.63	0.64	0.63	0.67	0.74
Heading RMS (deg)	0.07	0.11	0.1	0.08	0.1
Pitch RMS (deg)	0.14	0.27	0.23	0.16	0.2
Heading Outliers (epochs)	0	1	13	0	3
Heading Outliers (%)	0	0	0.03	0	0.01
Heading Reliability (%)	100	100	99.97	100	99.99
Pitch Outliers (epochs)	0	0	13	0	2
Pitch Outliers (%)	0	0	0.03	0	0
Pitch Reliability (%)	100	100	99.97	100	100
Number of TTFH observations	59	59	59	59	59
Time to First Attitude: 50 %	12.1	8.43	5.67	5.09	4
Time to First Attitude: 90 %	16.82	17.87	13.67	9.16	7.2
Time to First Attitude: Max (s)	18	25	50	14	8
Time to Last Attitude: 50 %	0.5	0.5	0.5	0.5	0.5
Time to Last Attitude: 90 %	0.9	0.9	0.9	0.9	0.9
Time to Last Attitude: Max (s)	1	1	1	1	1

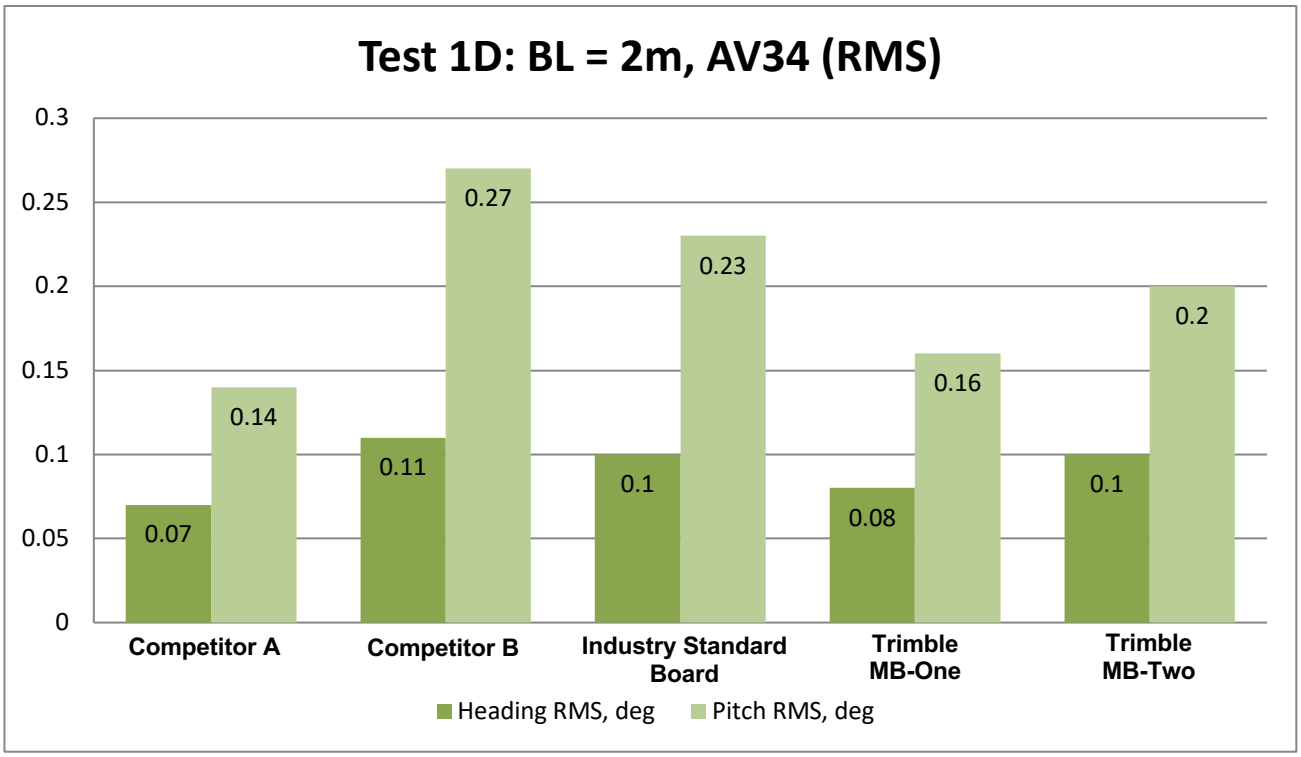
Group 1 (D) Availability / Reliability Plot:



Group 1 (D) TTFA Plot:



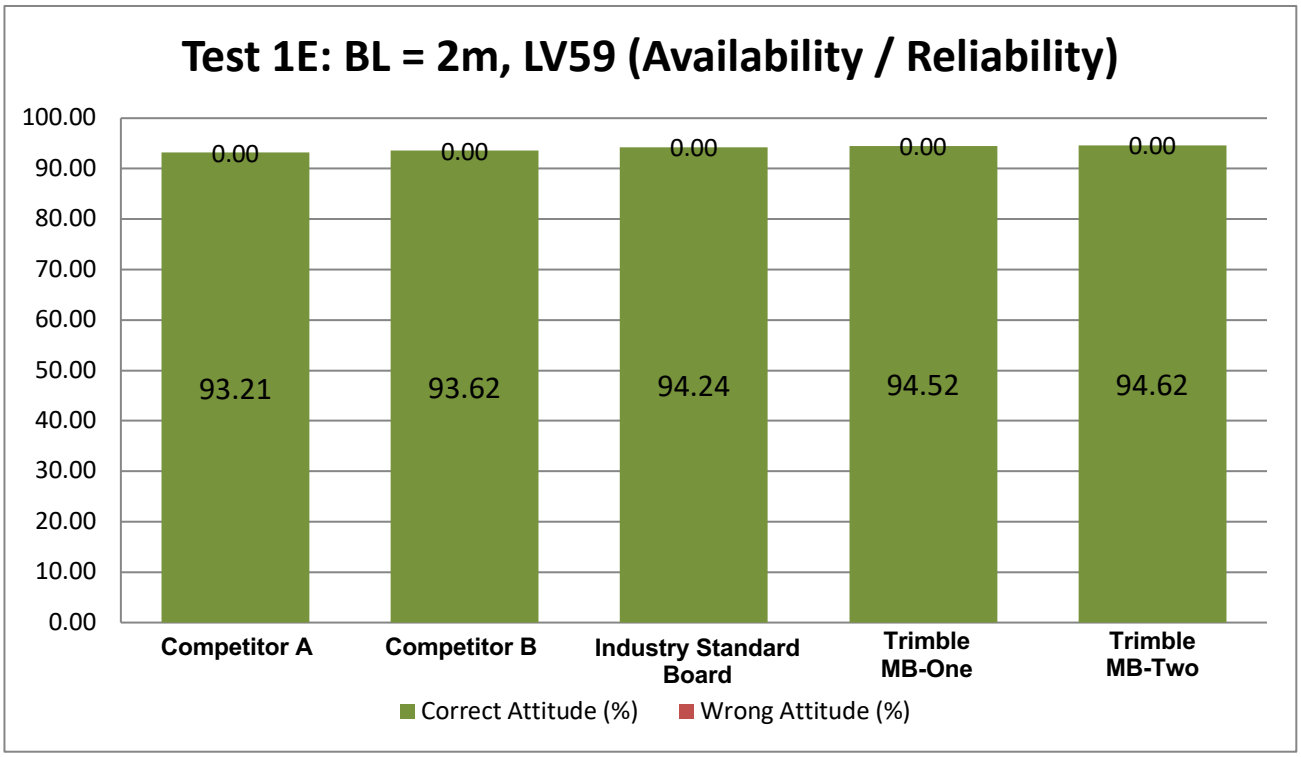
Group 1 (D) RMS Plot:



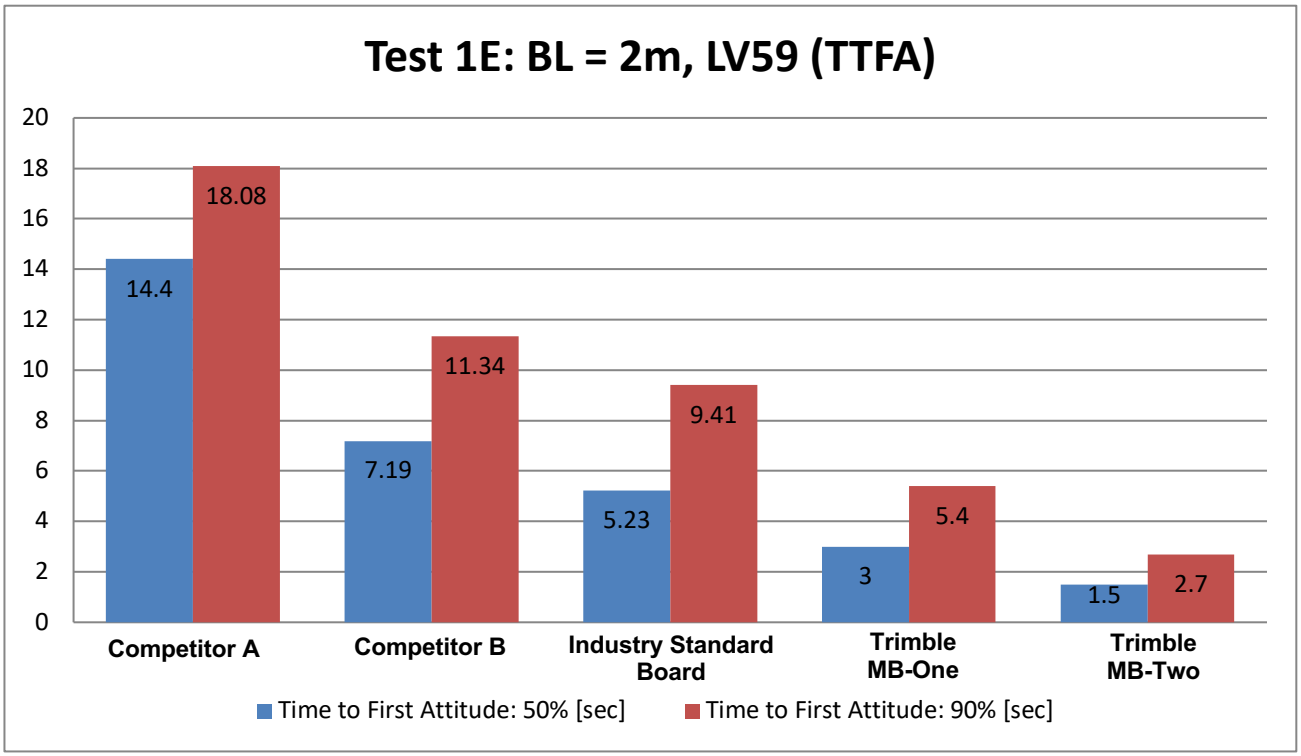
Group 1 (E) Baseline = 2m, Antennas – LV59 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 06:48:49.00 - 16:20:54.00 34325.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	31,993	32,133	32,346	32,443	32,476
Availability (%)	93.21	93.61	94.23	94.52	94.61
Mean Heading (deg)	187.71	187.73	187.73	187.71	187.71
Mean Pitch (deg)	0.54	0.53	0.55	0.59	0.58
Heading RMS (deg)	0.05	0.06	0.07	0.07	0.07
Pitch RMS (deg)	0.09	0.14	0.14	0.13	0.12
Heading Outliers (epochs)	0	0	0	0	0
Heading Outliers (%)	0	0	0	0	0
Heading Reliability (%)	100	100	100	100	100
Pitch Outliers (epochs)	0	0	0	0	0
Pitch Outliers (%)	0	0	0	0	0
Pitch Reliability (%)	100	100	100	100	100
Number of TTFH observations	46	46	46	46	46
Time to First Attitude: 50 %	14.4	7.19	5.23	3	1.5
Time to First Attitude: 90 %	18.08	11.34	9.41	5.4	2.7
Time to First Attitude: Max (s)	19	12	28	6	3
Time to Last Attitude: 50 %	0.5	0.5	0.5	0	0
Time to Last Attitude: 90 %	0.9	0.9	0.9	0	0
Time to Last Attitude: Max (s)	1	1	1	0	0

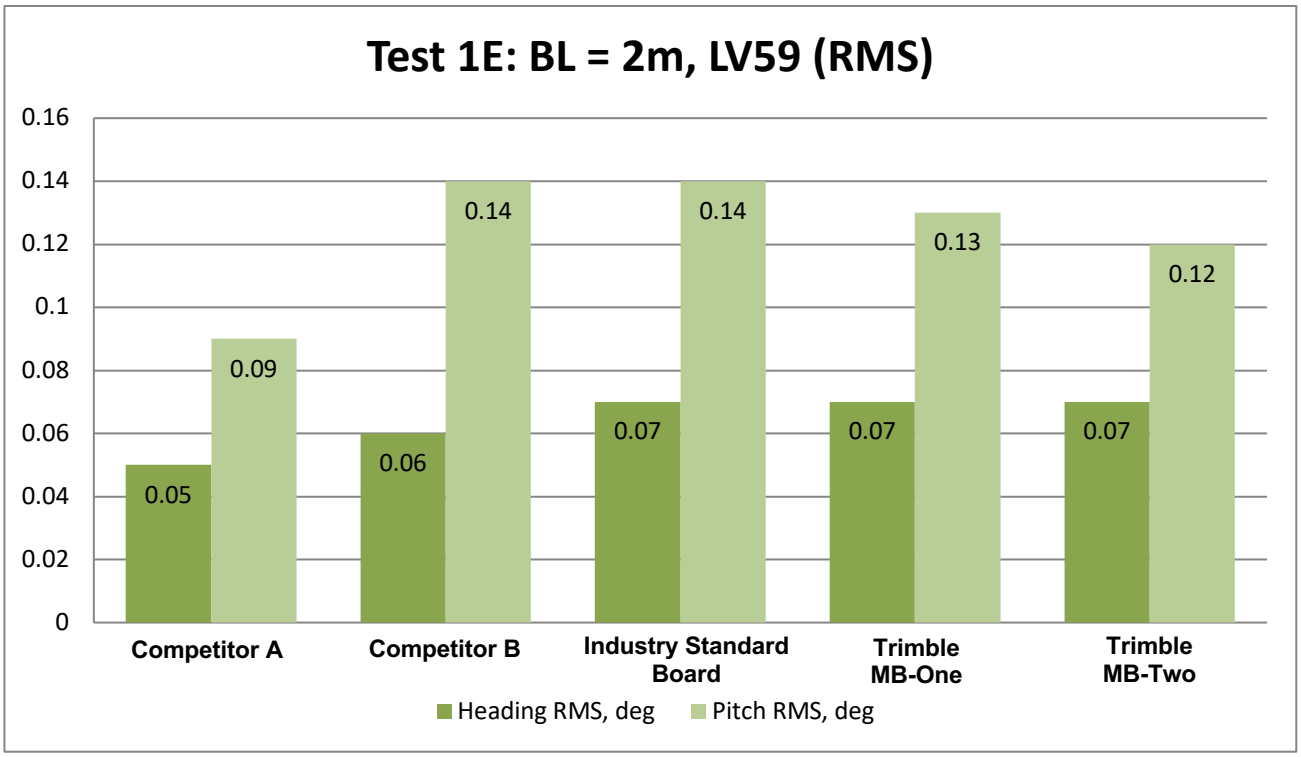
Group 1 (E) Availability / Reliability Plot:



Group 1 (E) TTFA Plot:



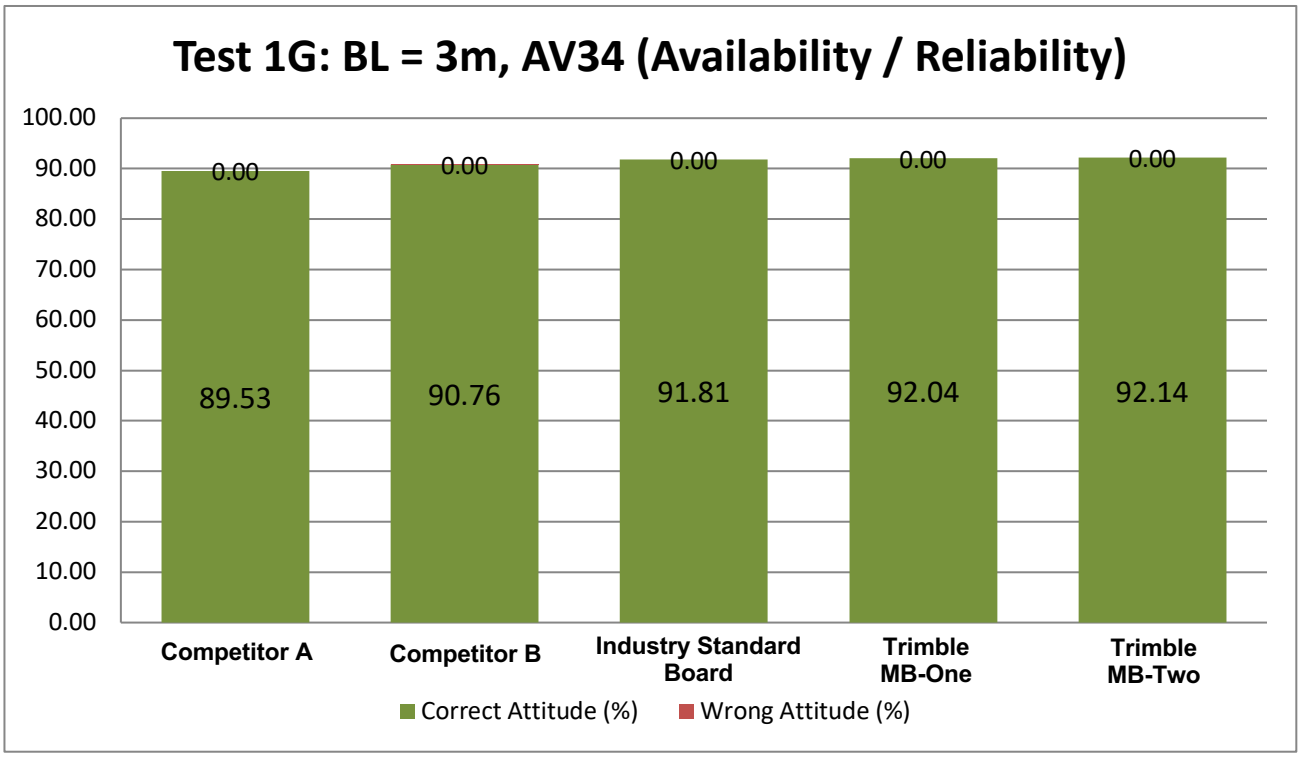
Group 1 (E) RMS Plot:



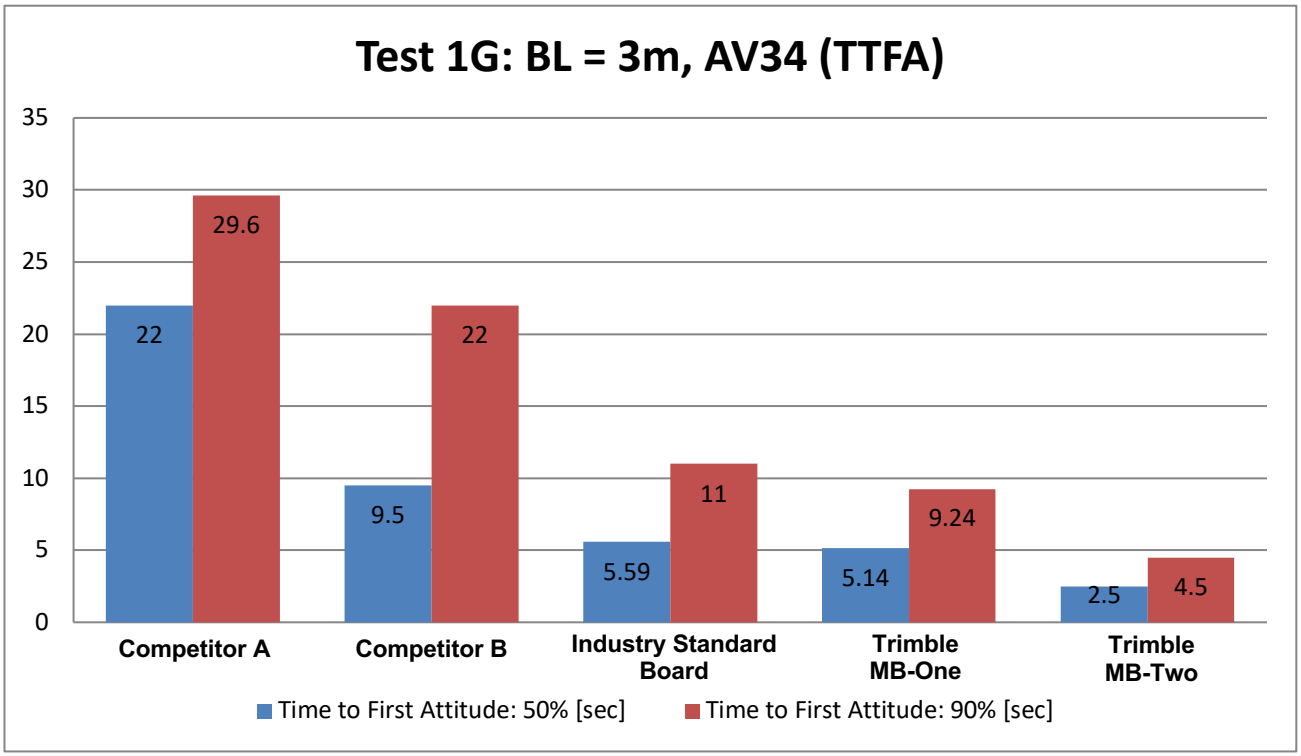
Group 1 (G) Baseline = 3m, Antennas – AV34 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 08:49:07.00 - 16:39:41.00 28234.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	25,278	25,626	25,923	25,986	26,015
Availability (%)	89.53	90.76	91.81	92.04	92.14
Mean Heading (deg)	234.59	234.58	234.58	234.59	234.61
Mean Pitch (deg)	-0.04	-0.06	-0.03	0	0
Heading RMS (deg)	0.06	0.09	0.09	0.06	0.08
Pitch RMS (deg)	0.09	0.16	0.17	0.12	0.14
Heading Outliers (epochs)	0	1	0	0	0
Heading Outliers (%)	0	0	0	0	0
Heading Reliability (%)	100	100	100	100	100
Pitch Outliers (epochs)	0	0	0	0	0
Pitch Outliers (%)	0	0	0	0	0
Pitch Reliability (%)	100	100	100	100	100
Number of TTFH observations	38	38	38	38	38
Time to First Attitude: 50 %	22	9.5	5.59	5.14	2.5
Time to First Attitude: 90 %	29.6	22	11	9.24	4.5
Time to First Attitude: Max (s)	32	59	26	16	5
Time to Last Attitude: 50 %	0.5	0.5	0.5	0.5	0.5
Time to Last Attitude: 90 %	0.9	0.9	0.9	0.9	0.9
Time to Last Attitude: Max (s)	1	1	1	1	1

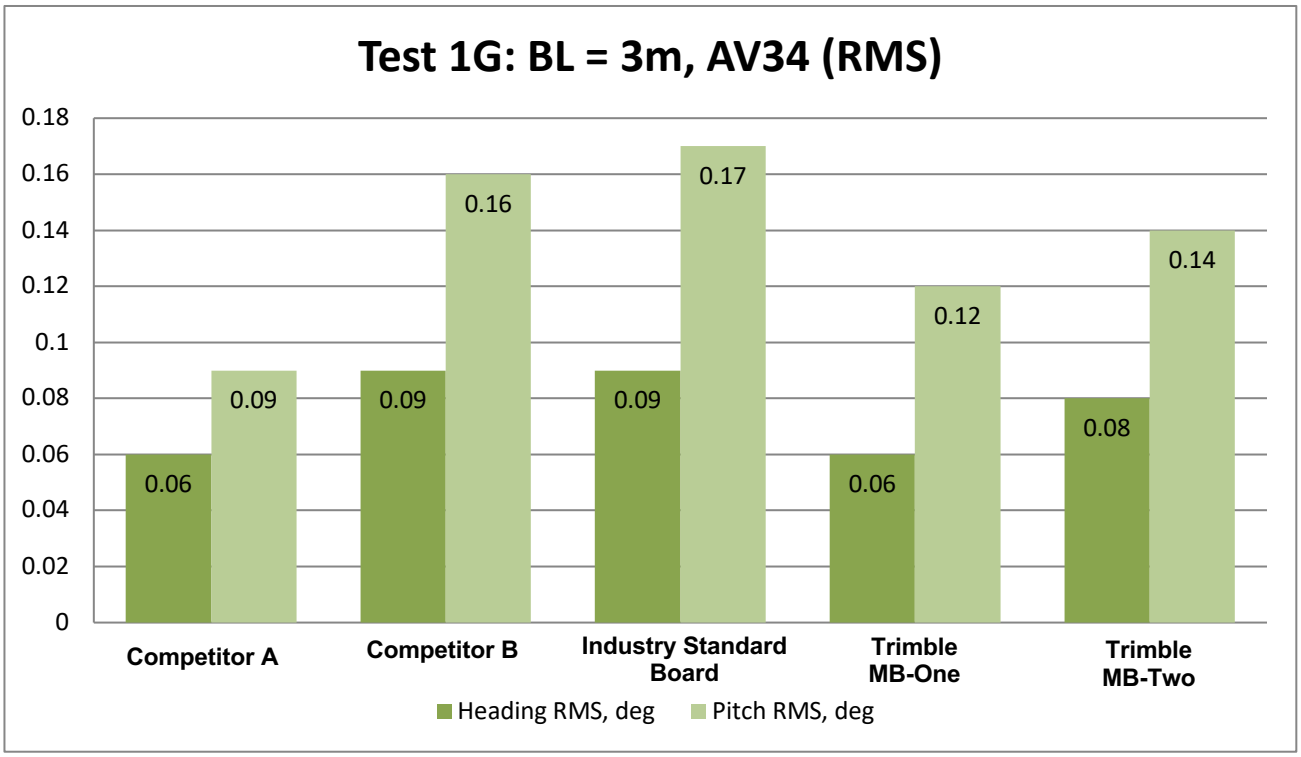
Group 1 (G) Availability / Reliability Plot:



Group 1 (G) TTFA Plot:



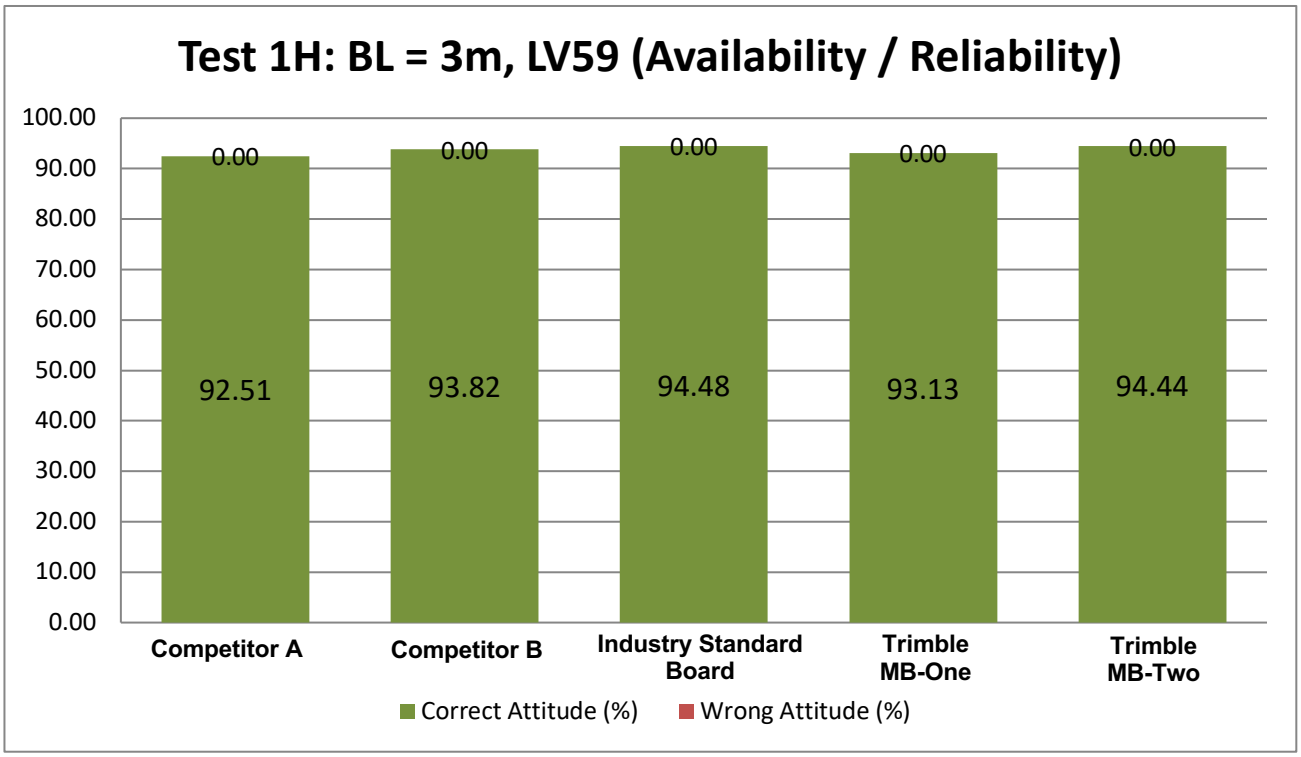
Group 1 (G) RMS Plot:



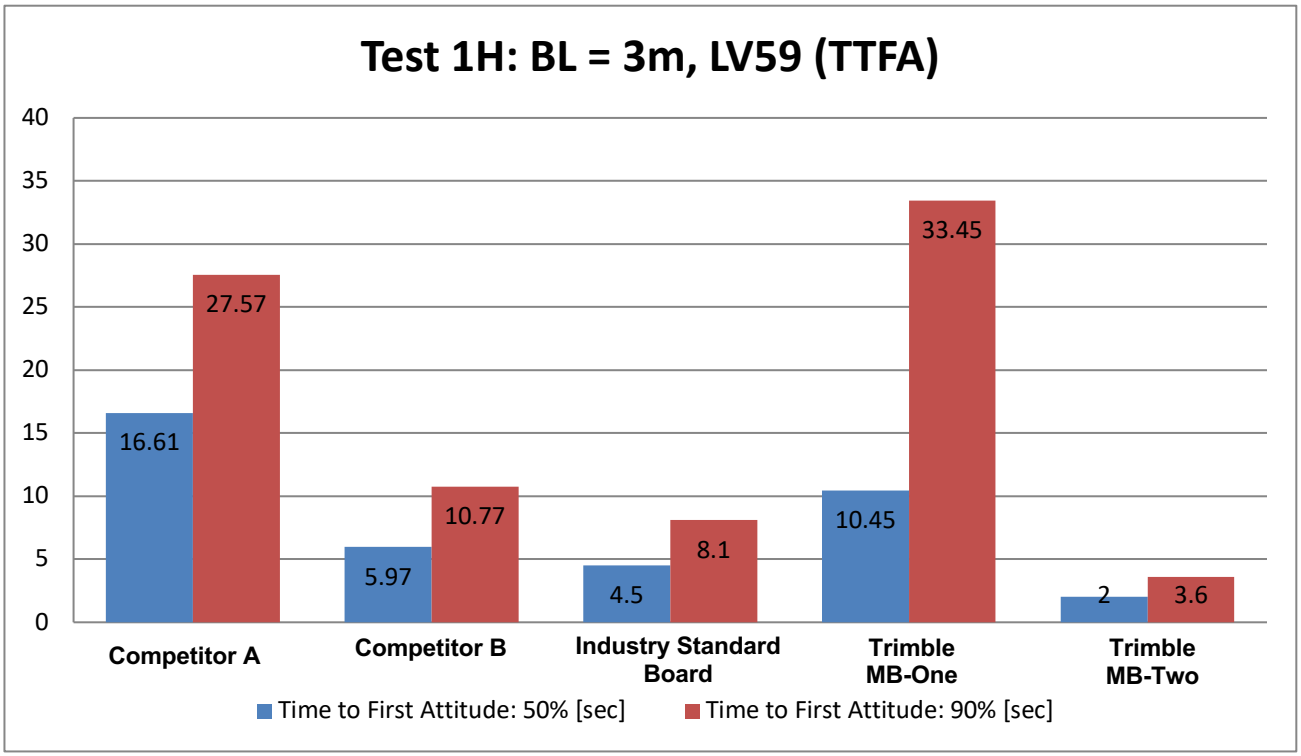
Group 1 (H) Baseline = 3m, Antennas – LV59 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 11:10:47.00 - 19:00:40.00 28193.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	26,080	26,449	26,634	26,254	26,625
Availability (%)	92.51	93.81	94.47	93.12	94.44
Mean Heading (deg)	232.52	232.54	232.53	232.54	232.52
Mean Pitch (deg)	-0.07	-0.07	-0.08	-0.02	-0.02
Heading RMS (deg)	0.04	0.05	0.05	0.05	0.05
Pitch RMS (deg)	0.05	0.09	0.11	0.09	0.09
Heading Outliers (epochs)	0	0	0	0	0
Heading Outliers (%)	0	0	0	0	0
Heading Reliability (%)	100	100	100	100	100
Pitch Outliers (epochs)	0	0	0	0	0
Pitch Outliers (%)	0	0	0	0	0
Pitch Reliability (%)	100	100	100	100	100
Number of TTFH observations	37	37	37	37	37
Time to First Attitude: 50 %	16.61	5.97	4.5	10.45	2
Time to First Attitude: 90 %	27.57	10.77	8.1	33.45	3.6
Time to First Attitude: Max (s)	30	12	9	39	4
Time to Last Attitude: 50 %	0.5	0.5	0.5	0.5	0.5
Time to Last Attitude: 90 %	0.9	0.9	0.9	0.9	0.9
Time to Last Attitude: Max (s)	1	1	1	1	1

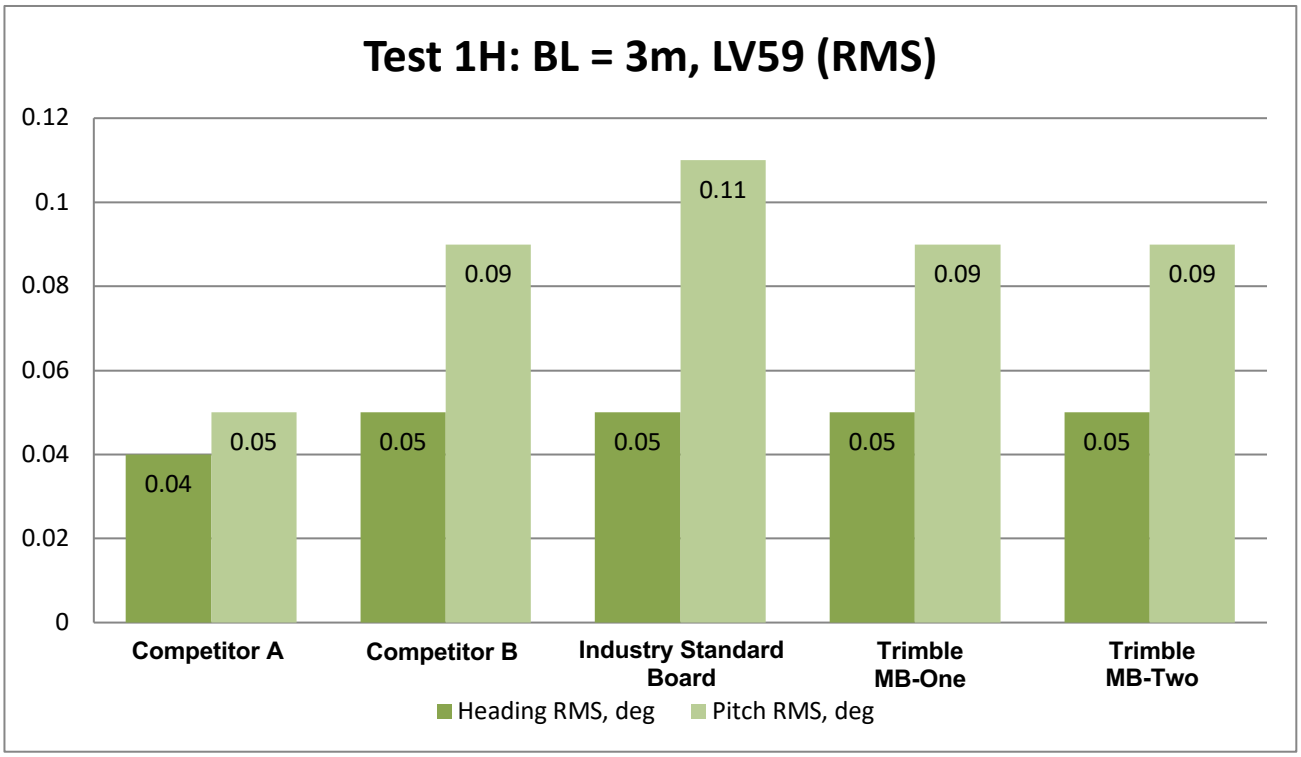
Group 1 (H) Availability / Reliability Plot:



Group 1 (H) RMS Plot:



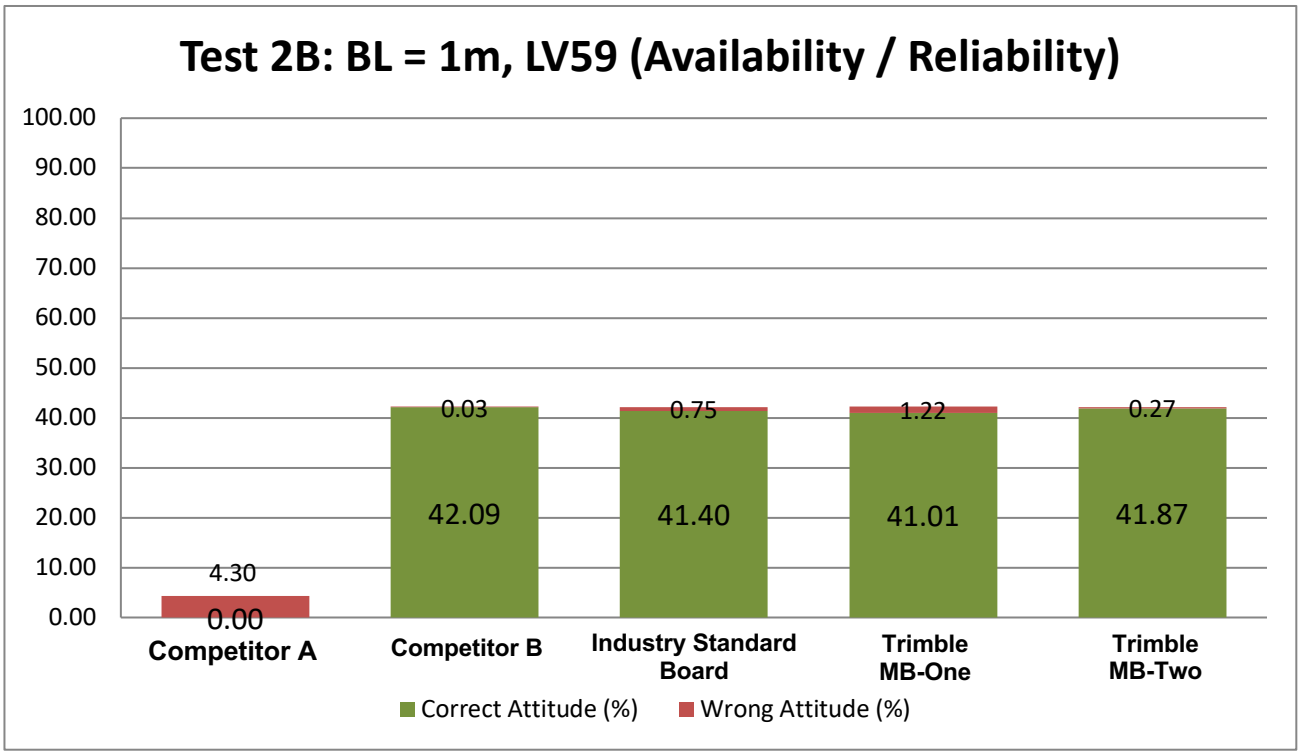
Group 1 (H) RMS Plot:



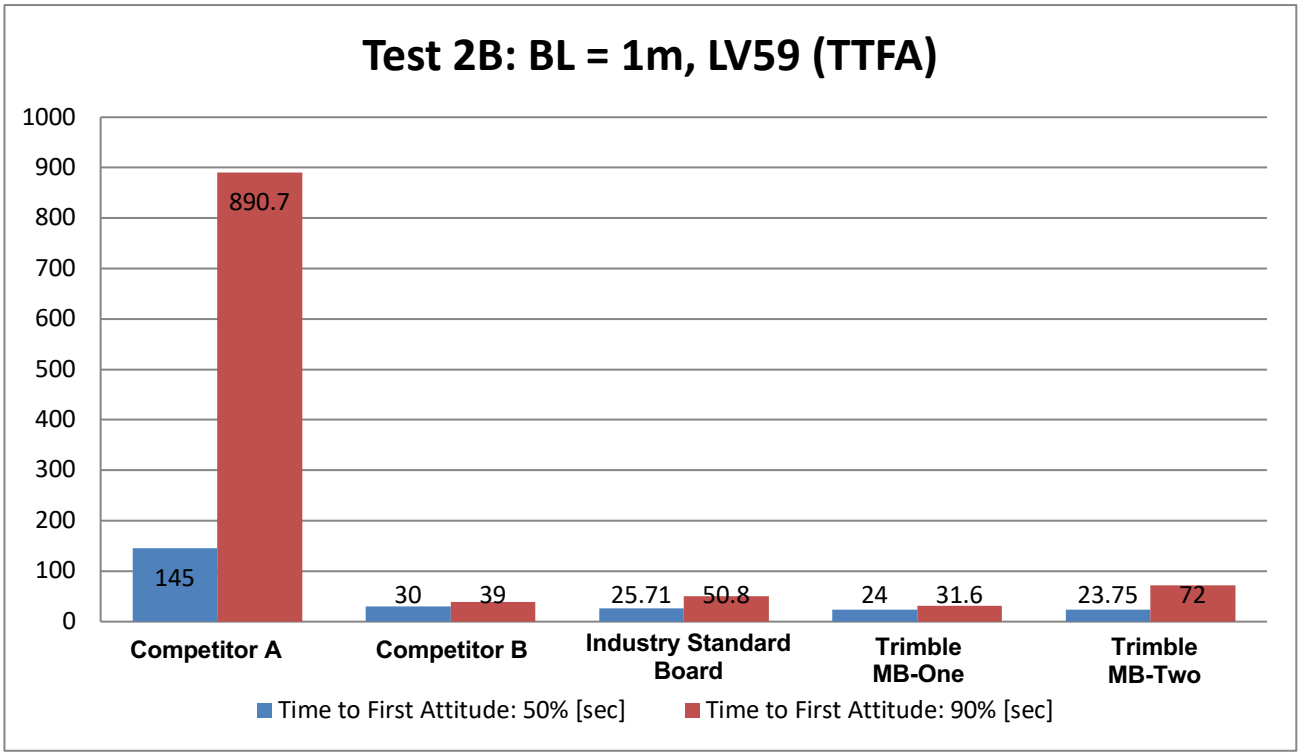
Group 2 (B) Baseline = 1m, Antennas – LV59 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 07:54:15.00 - 17:28:05.00 34430.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	1,481	14,505	14,518	14,543	14,515
Availability (%)	4.3	42.13	42.17	42.24	42.16
Mean Heading (deg)	0	277.24	277.22	277.25	277.22
Mean Pitch (deg)	-0.27	-2.49	-2.57	-2.48	-2.34
Heading RMS (deg)	0	0.36	0.66	0.58	0.58
Pitch RMS (deg)	1.41	0.62	0.87	0.9	0.73
Heading Outliers (epochs)	1,481	10	259	419	93
Heading Outliers (%)	100	0.07	1.78	2.88	0.64
Heading Reliability (%)	0	99.93	98.22	97.12	99.36
Pitch Outliers (epochs)	1,426	2	0	157	0
Pitch Outliers (%)	96.29	0.01	0	1.08	0
Pitch Reliability (%)	3.71	99.99	100	98.92	100
Number of TTFH observations	9	18	18	18	18
Time to First Attitude: 50 %	145	30	25.71	24	23.75
Time to First Attitude: 90 %	890.7	39	50.8	31.6	72
Time to First Attitude: Max (s)	897	53	58	34	84
Time to Last Attitude: 50 %	215	1.5	1.5	0	1.5
Time to Last Attitude: 90 %	800.7	2.7	2.7	0	2.7
Time to Last Attitude: Max (s)	807	3	3	0	3

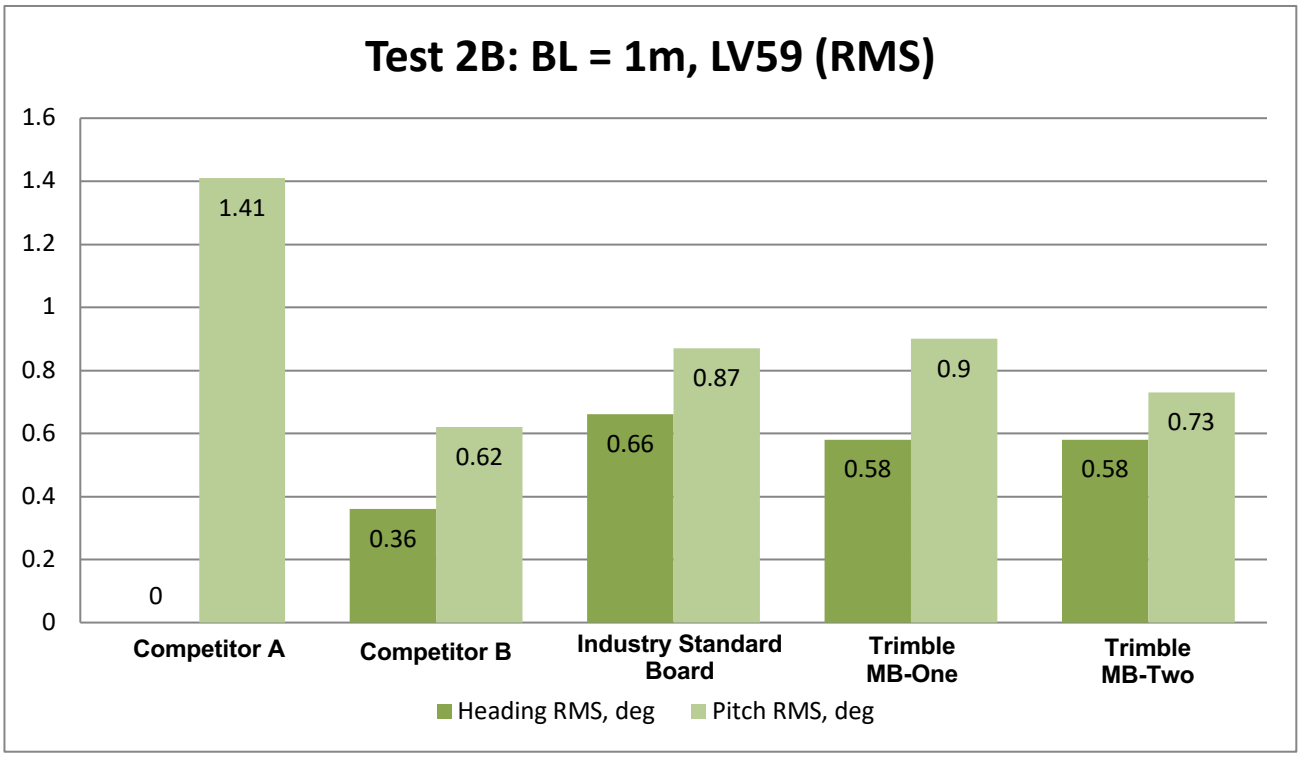
Group 2 (B) Availability / Reliability Plot:



Group 2 (B) TTFA Plot:



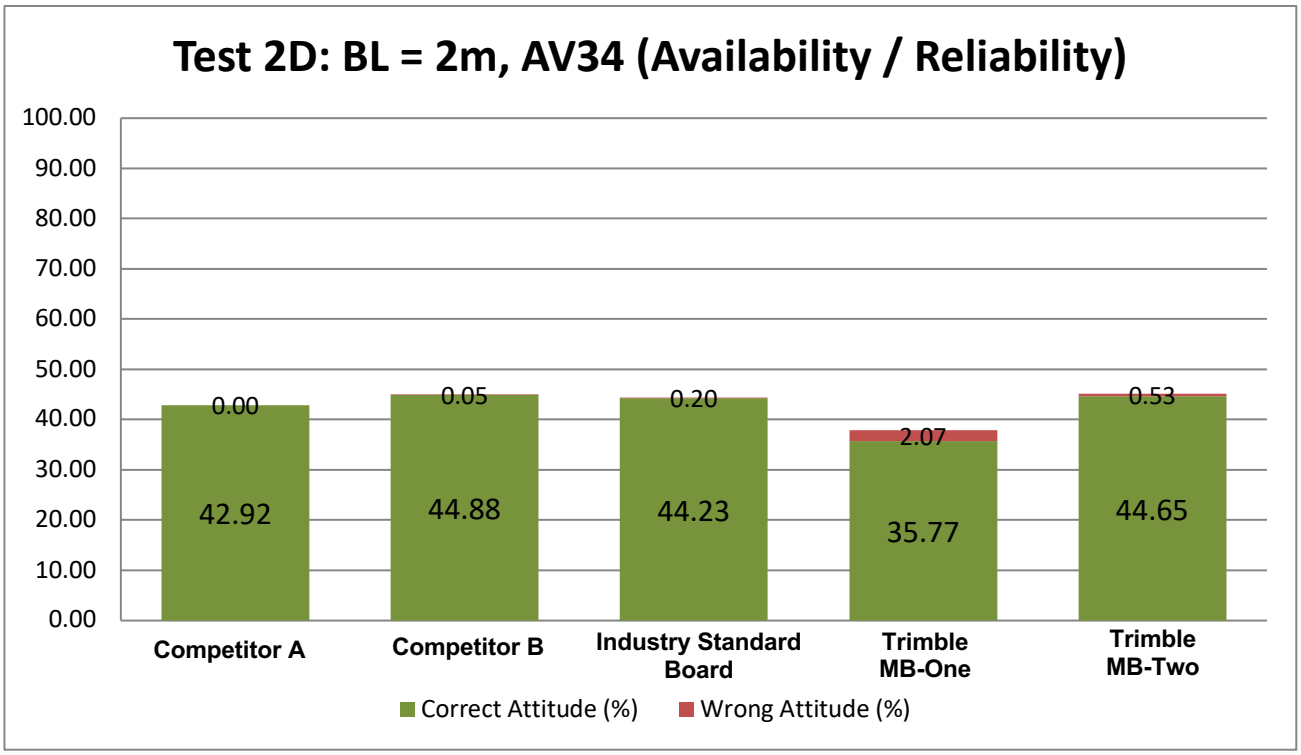
Group 2 (B) RMS Plot:



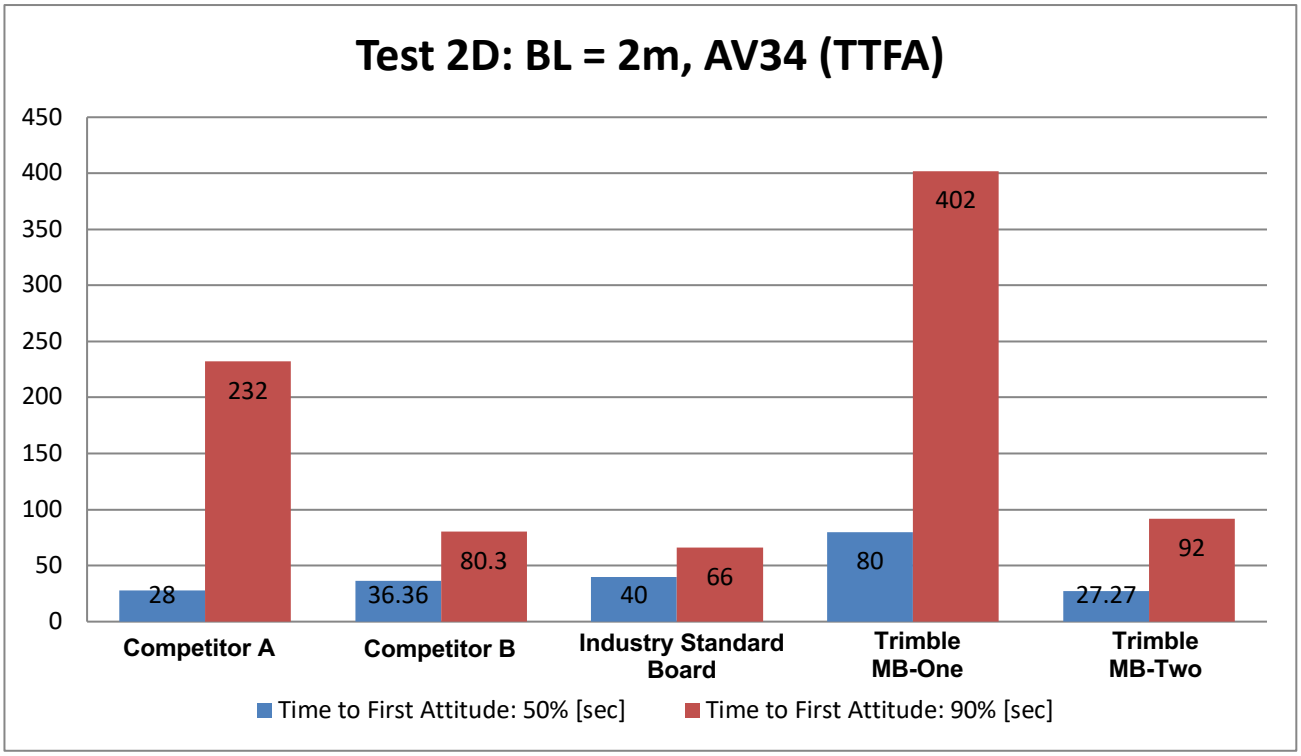
Group 2 (D) Baseline = 2m, Antennas – AV34 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 07:58:30.00 - 17:32:56.00 34466.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	14,793	15,488	15,314	13,043	15,572
Availability (%)	42.92	44.94	44.43	37.84	45.18
Mean Heading (deg)	274.34	274.25	274.39	274.34	274.22
Mean Pitch (deg)	-3.96	-4.14	-3.95	-3.93	-4.11
Heading RMS (deg)	0.35	0.42	0.56	0.5	0.4
Pitch RMS (deg)	0.38	0.72	0.67	0.62	0.49
Heading Outliers (epochs)	0	18	68	713	184
Heading Outliers (%)	0	0.12	0.44	5.47	1.18
Heading Reliability (%)	100	99.88	99.56	94.53	98.82
Pitch Outliers (epochs)	0	0	57	673	0
Pitch Outliers (%)	0	0	0.37	5.16	0
Pitch Reliability (%)	100	100	99.63	94.84	100
Number of TTFH observations	18	18	18	18	18
Time to First Attitude: 50 %	28	36.36	40	80	27.27
Time to First Attitude: 90 %	232	80.3	66	402	92
Time to First Attitude: Max (s)	785	83	300	440	184
Time to Last Attitude: 50 %	1	1	1	0	1
Time to Last Attitude: 90 %	1.8	1.8	1.8	0	1.8
Time to Last Attitude: Max (s)	2	2	2	0	2

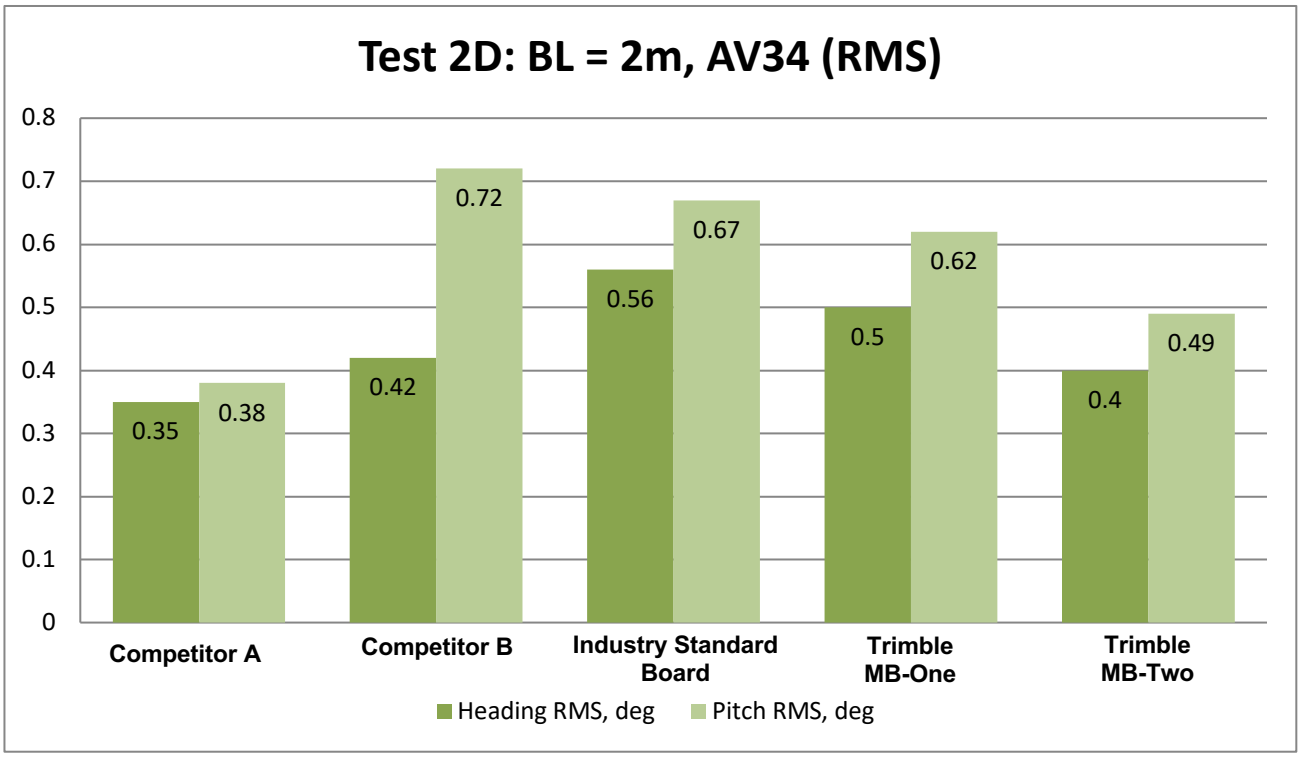
Group 2 (D) Availability / Reliability Plot:



Group 2 (D) TTFA Plot:



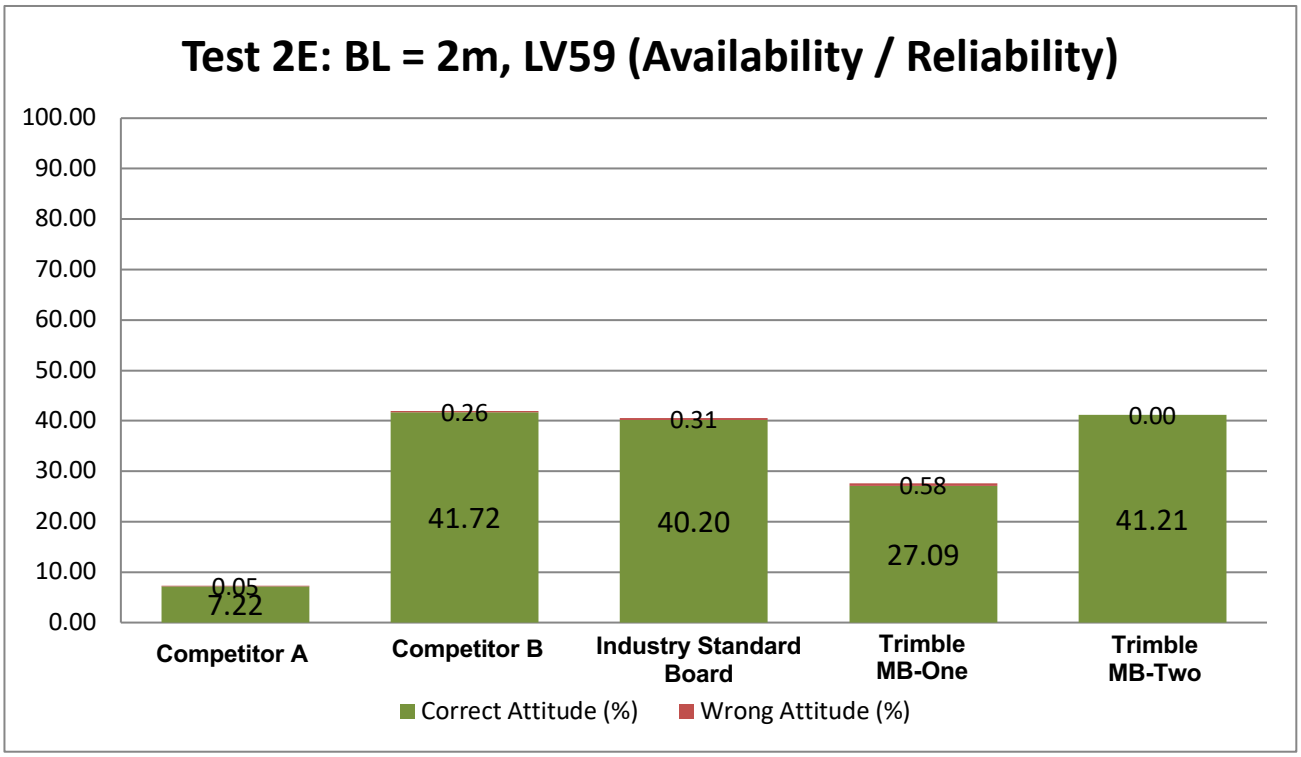
Group 2 (D) RMS Plot:



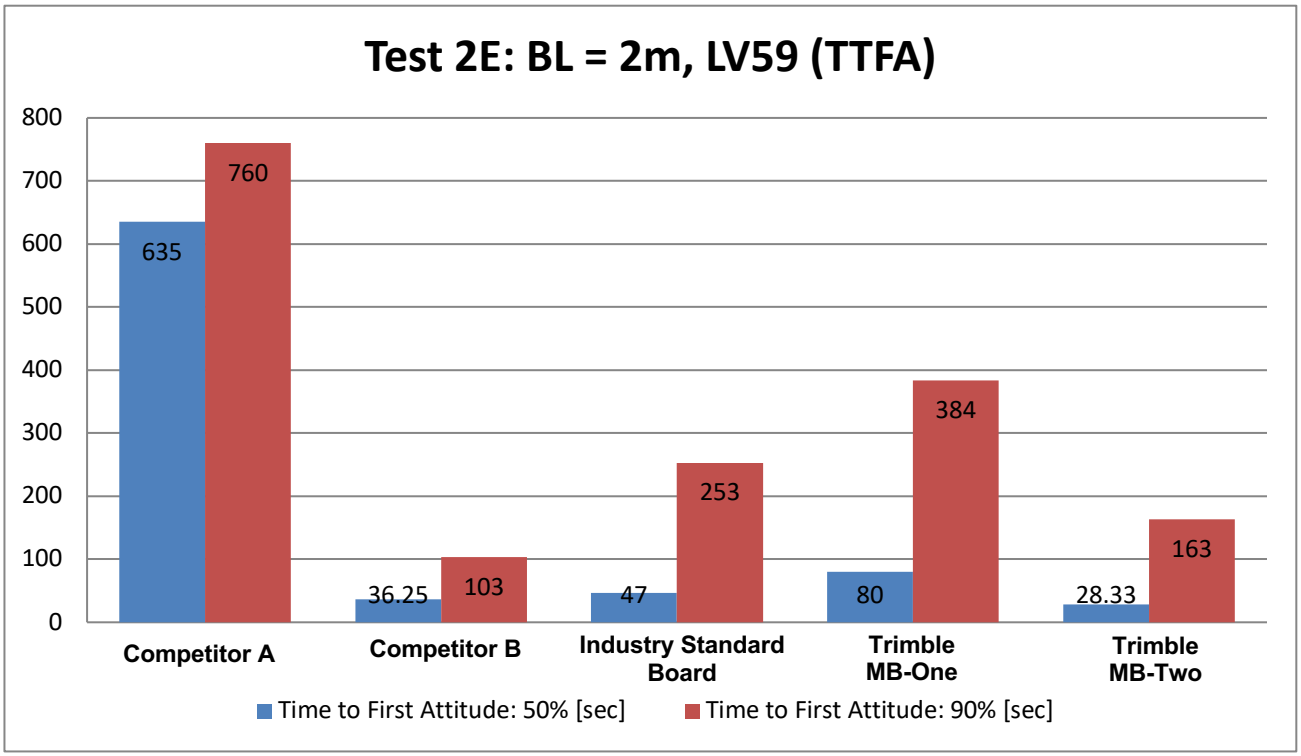
Group 2 (E) Baseline = 2m, Antennas – LV59 Test results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 08:15:09.00 - 17:30:27.00 33318.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	2,420	13,993	13,504	9,223	13,737
Availability (%)	7.26	42	40.53	27.68	41.23
Mean Heading (deg)	92.81	93.13	93.23	92.97	93.13
Mean Pitch (deg)	5.87	5.69	5.56	5.97	5.8
Heading RMS (deg)	0.44	0.54	0.72	0.61	0.6
Pitch RMS (deg)	0.39	0.74	0.79	0.7	0.57
Heading Outliers (epochs)	15	69	104	193	0
Heading Outliers (%)	0.62	0.49	0.77	2.09	0
Heading Reliability (%)	99.38	99.51	99.23	97.91	100
Pitch Outliers (epochs)	15	85	53	149	0
Pitch Outliers (%)	0.62	0.61	0.39	1.62	0
Pitch Reliability (%)	99.38	99.39	99.61	98.38	100
Number of TTFH observations	5	17	17	16	17
Time to First Attitude: 50 %	635	36.25	47	80	28.33
Time to First Attitude: 90 %	760	103	253	384	163
Time to First Attitude: Max (s)	760	381	386	396	441
Time to Last Attitude: 50 %	0.5	0.5	0.5	6.15	0.5
Time to Last Attitude: 90 %	0.9	0.9	0.9	384	0.9
Time to Last Attitude: Max (s)	1	1	1	436	1

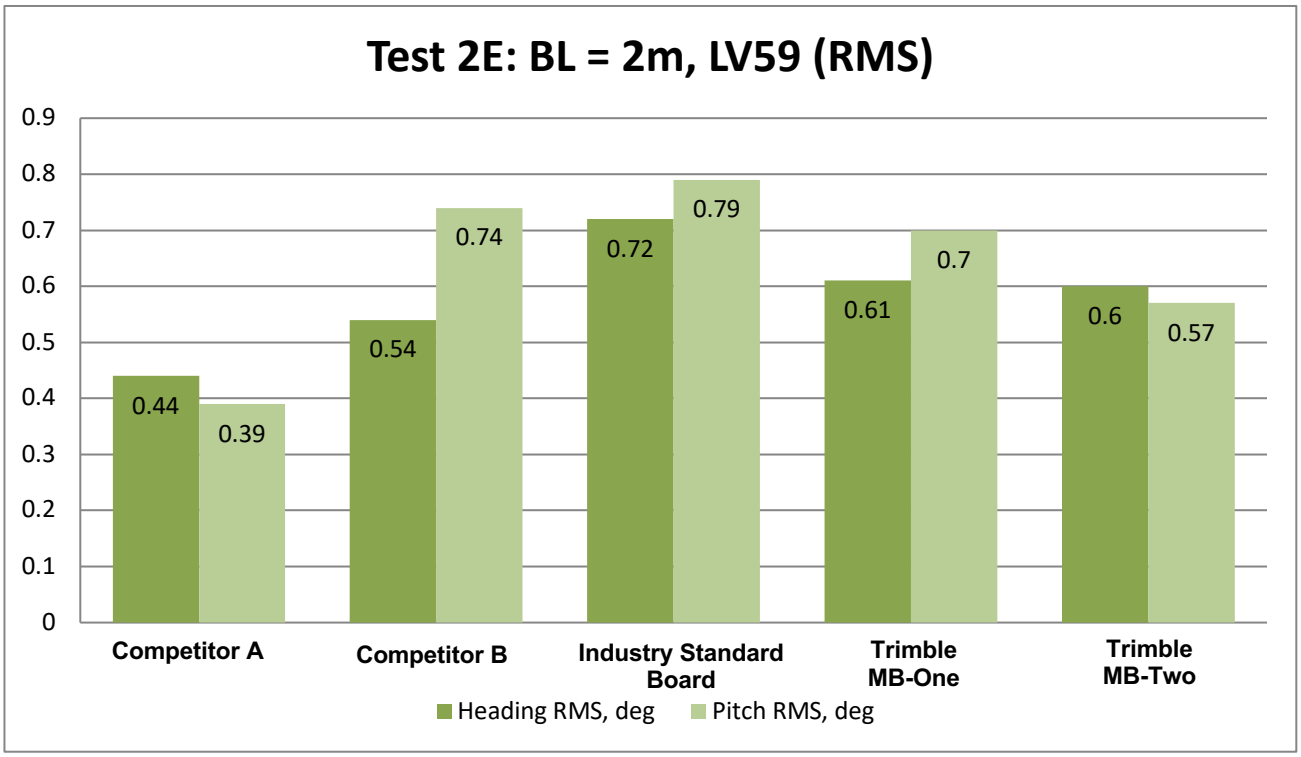
Group 2 (E) Availability / Reliability Plot:



Group 2 (E) TTFA Plot:



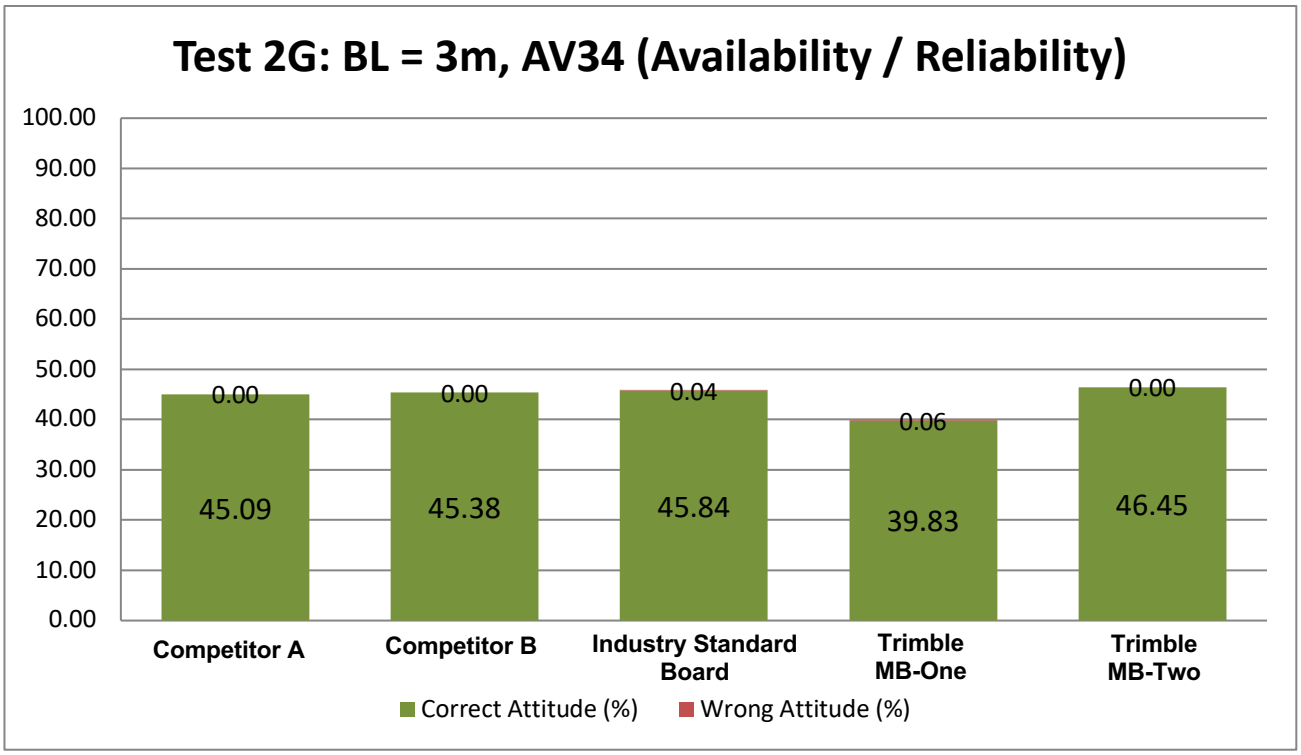
Group 2 (E) RMS Plot:



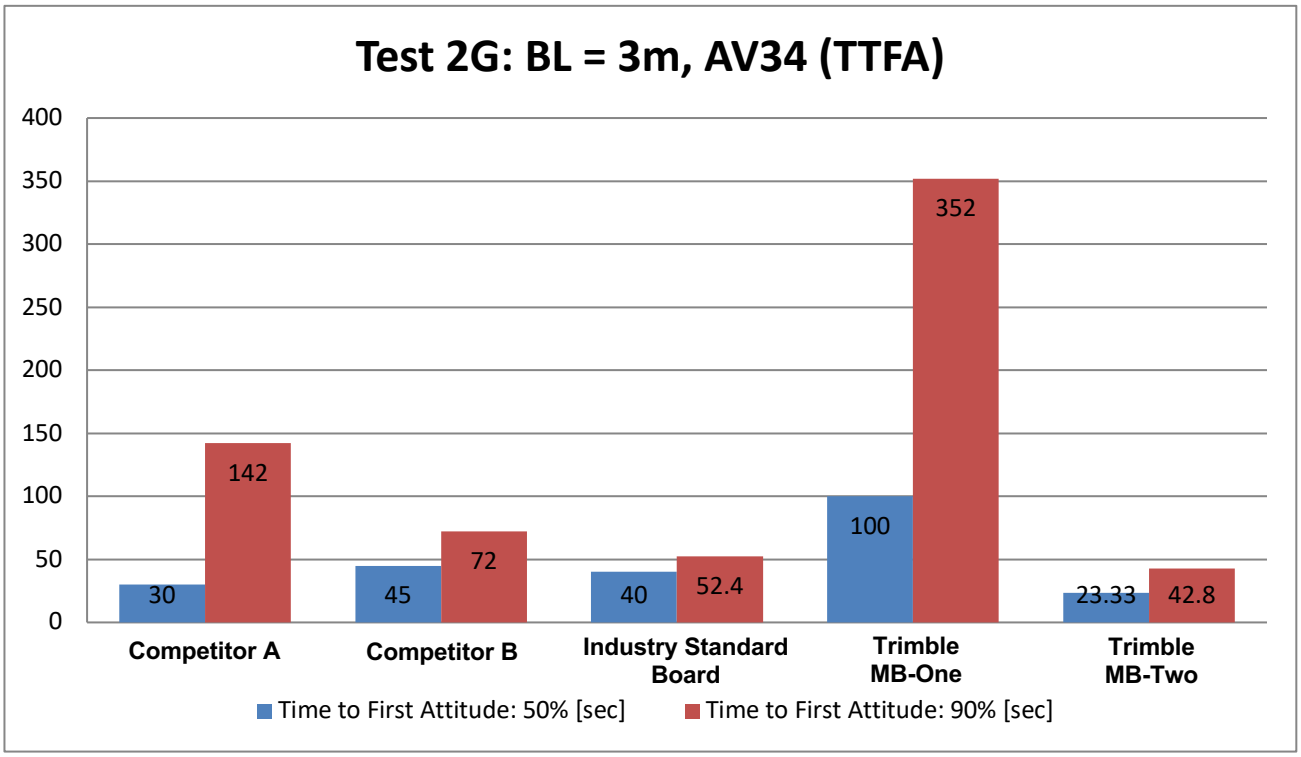
Group 2 (G) Baseline = 3m, Antennas – AV34 Test results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 07:50:06.00 - 17:31:57.00 34911.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	15,741	15,843	16,019	13,927	16,216
Availability (%)	45.09	45.38	45.89	39.89	46.45
Mean Heading (deg)	276.78	276.75	276.77	276.79	276.7
Mean Pitch (deg)	-3.12	-3.13	-3.11	-3.03	-3.3
Heading RMS (deg)	0.2	0.17	0.24	0.28	0.21
Pitch RMS (deg)	0.25	0.33	0.35	0.42	0.31
Heading Outliers (epochs)	0	0	15	22	0
Heading Outliers (%)	0	0	0.09	0.16	0
Heading Reliability (%)	100	100	99.91	99.84	100
Pitch Outliers (epochs)	0	0	10	19	0
Pitch Outliers (%)	0	0	0.06	0.14	0
Pitch Reliability (%)	100	100	99.94	99.86	100
Number of TTFH observations	18	18	18	18	18
Time to First Attitude: 50 %	30	45	40	100	23.33
Time to First Attitude: 90 %	142	72	52.4	352	42.8
Time to First Attitude: Max (s)	285	81	56	521	47
Time to Last Attitude: 50 %	1	1	1	0	0.5
Time to Last Attitude: 90 %	1.8	1.8	1.8	0	0.9
Time to Last Attitude: Max (s)	2	2	2	0	1

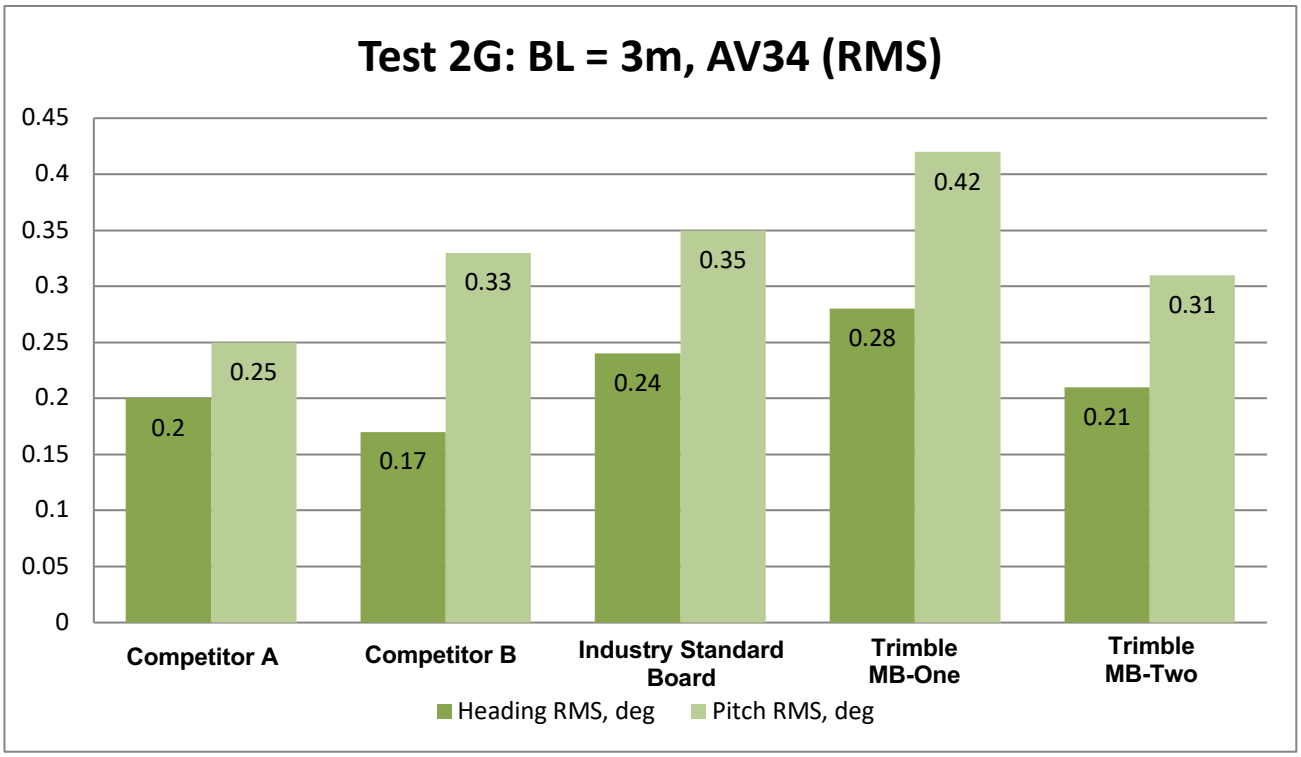
Group 2 (G) Availability / Reliability Plot:



Group 2 (G) TTFA Plot:



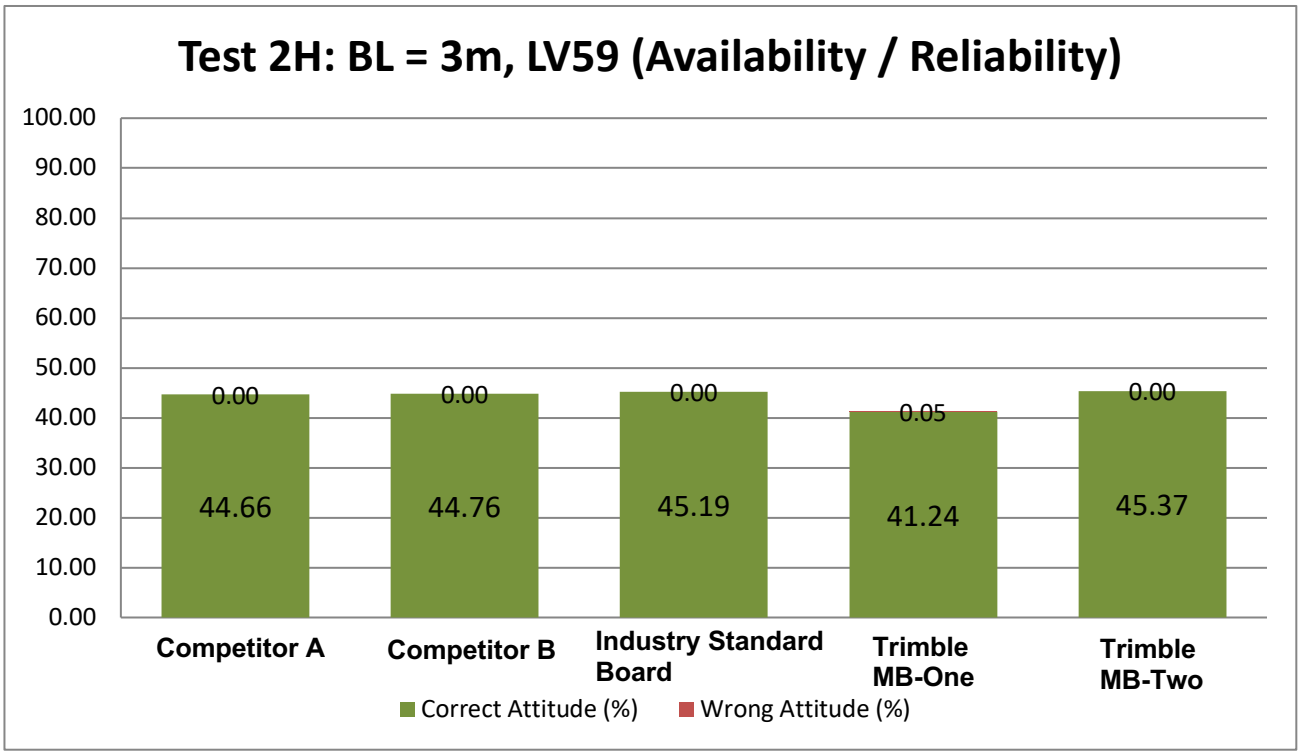
Group 2 (G) RMS Plot:



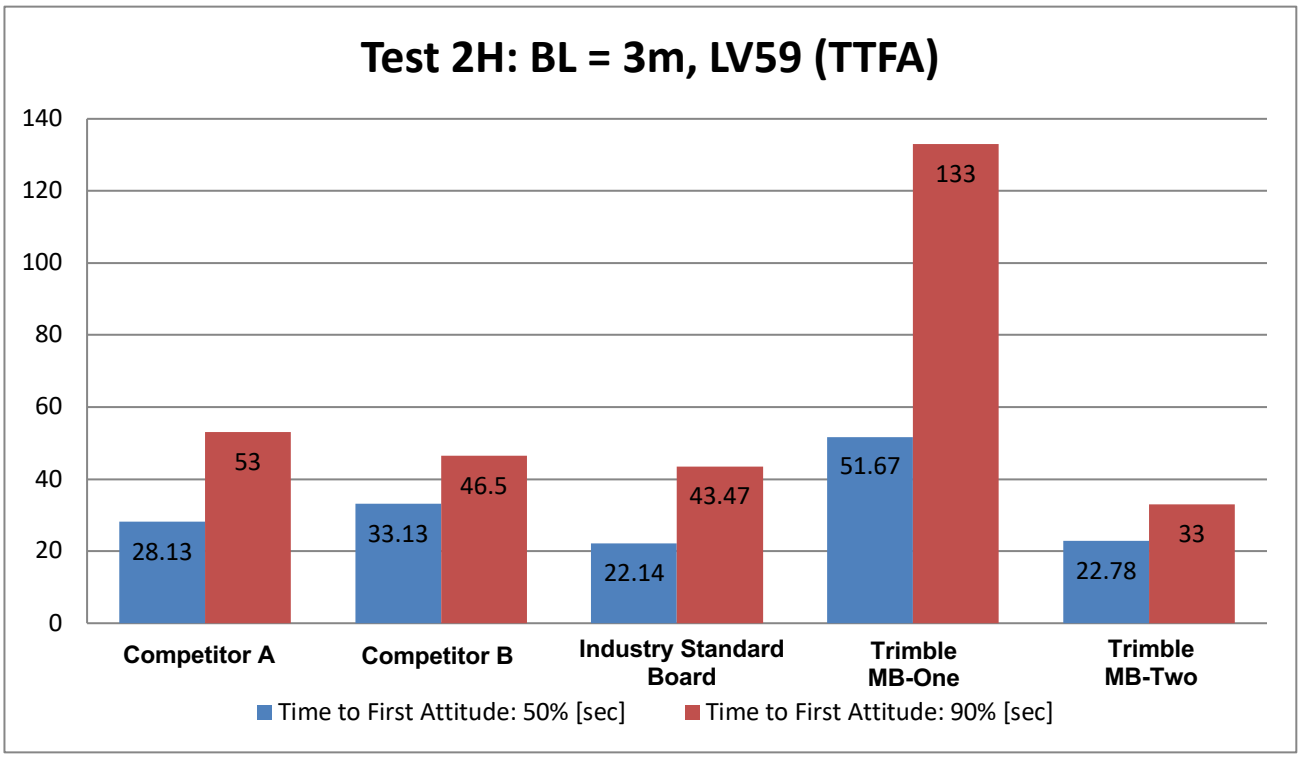
Group 2 (H) Baseline = 3m, Antennas – LV59 Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 08:00:01.00 - 17:02:11.00 32530.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	14,529	14,563	14,702	13,433	14,759
Availability (%)	44.66	44.77	45.2	41.29	45.37
Mean Heading (deg)	96.75	96.73	96.73	96.73	96.73
Mean Pitch (deg)	2.31	2.32	2.32	2.33	2.31
Heading RMS (deg)	0.13	0.11	0.16	0.23	0.16
Pitch RMS (deg)	0.17	0.19	0.22	0.35	0.21
Heading Outliers (epochs)	0	0	0	16	0
Heading Outliers (%)	0	0	0	0.12	0
Heading Reliability (%)	100	100	100	99.88	100
Pitch Outliers (epochs)	0	0	0	11	0
Pitch Outliers (%)	0	0	0	0.08	0
Pitch Reliability (%)	100	100	100	99.92	100
Number of TTFH observations	17	17	17	17	17
Time to First Attitude: 50 %	28.13	33.13	22.14	51.67	22.78
Time to First Attitude: 90 %	53	46.5	43.47	133	33
Time to First Attitude: Max (s)	155	55	48	159	47
Time to Last Attitude: 50 %	1	1	1	0	1
Time to Last Attitude: 90 %	1.8	1.8	1.8	0	1.8
Time to Last Attitude: Max (s)	2	2	2	0	2

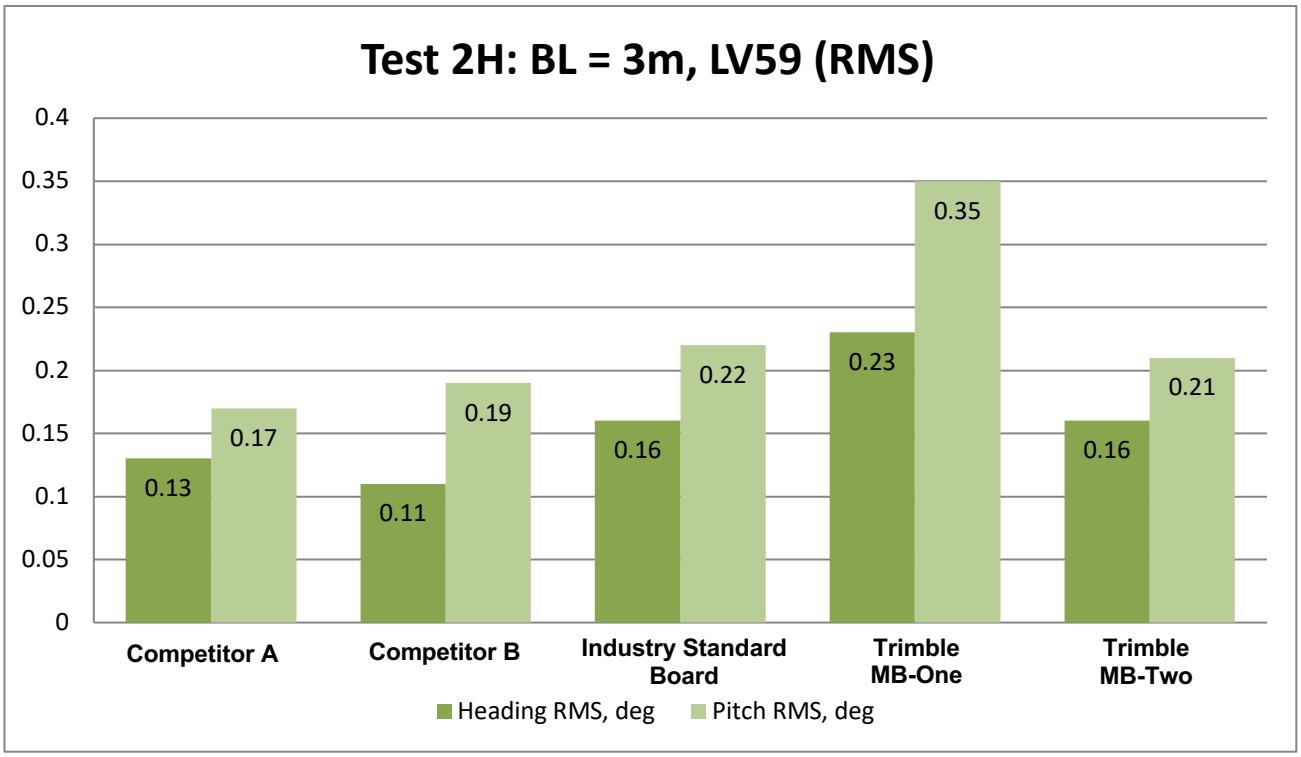
Group 2 (H) Availability / Reliability Plot:



Group 2 (H) TTFA Plot:



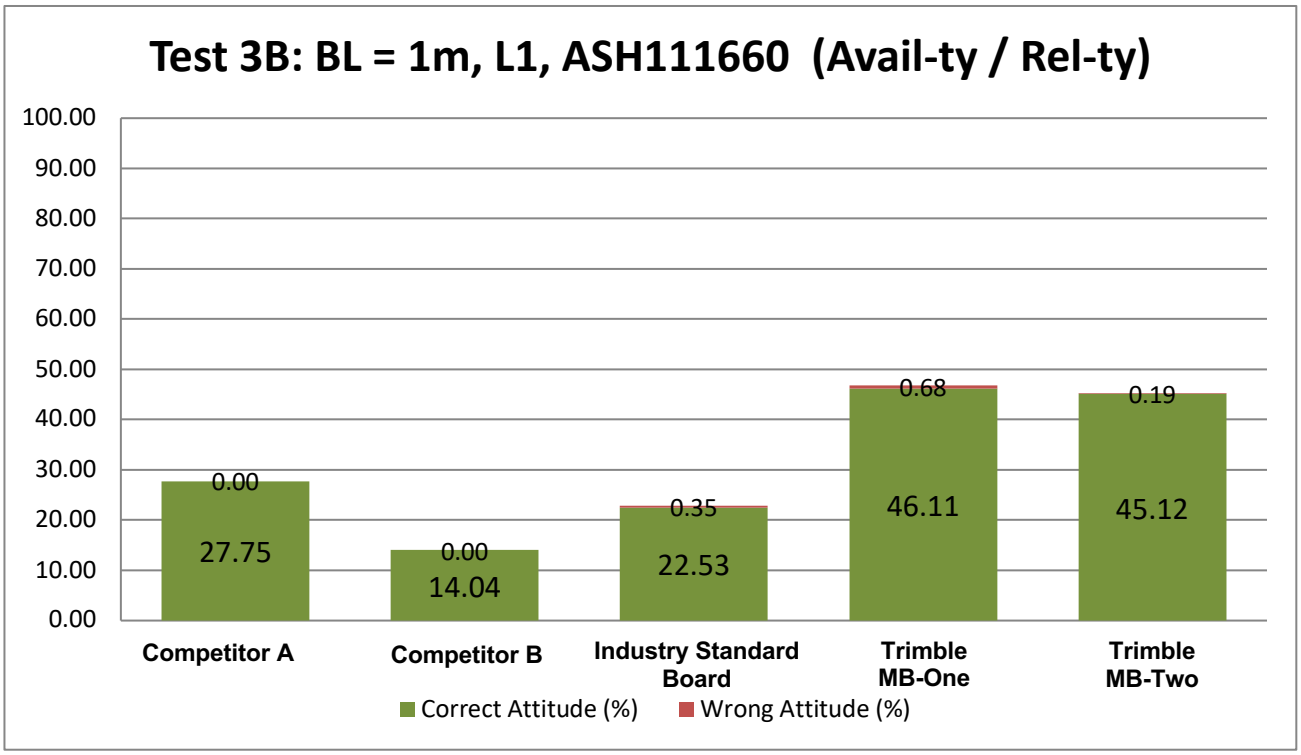
Group 2 (H) RMS Plot:



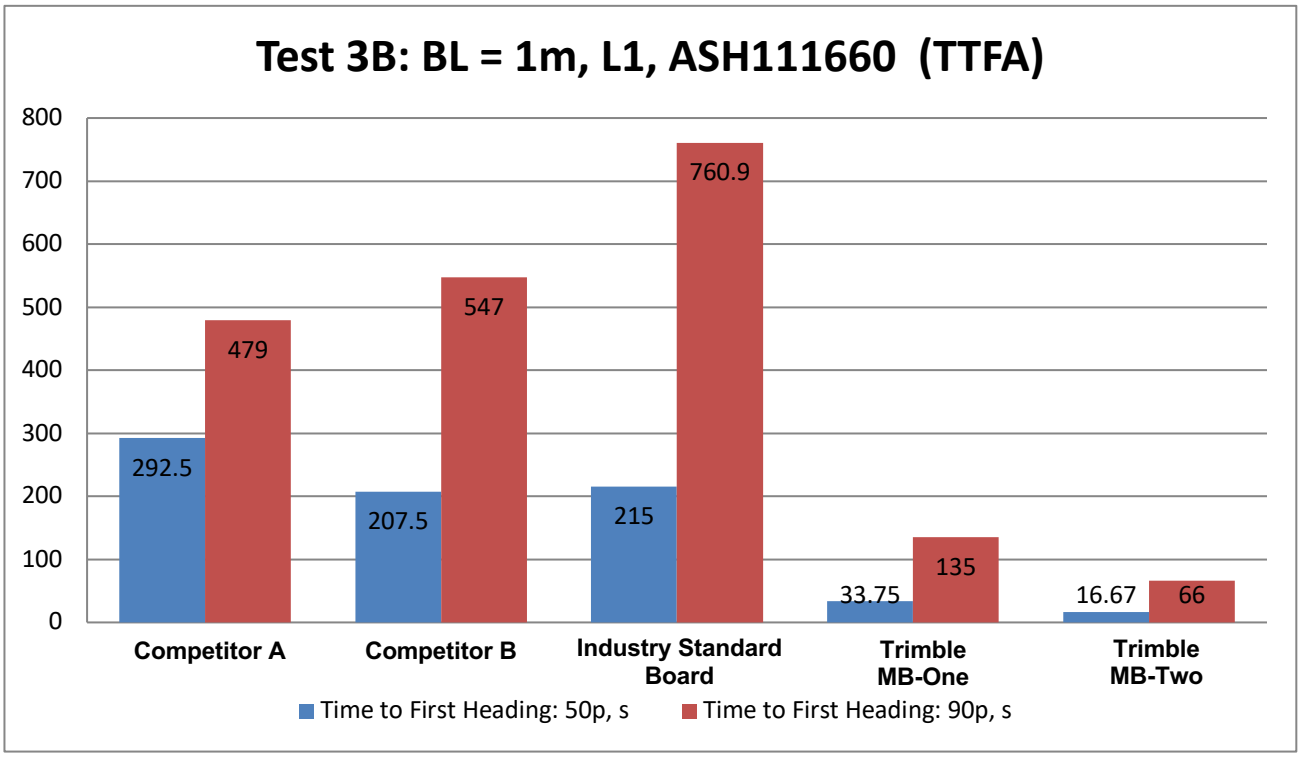
Group 3 (B) Baseline = 1m, L1-only, Antennas – ASH11660 Test results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 08:53:48.00 - 17:02:06.00 29298.00s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	8,130	4,113	6,705	13,709	13,277
Availability (%)	27.75	14.04	22.89	46.79	45.32
Mean Heading (deg)	276.85	276.89	276.97	275.2	276.83
Mean Pitch (deg)	-0.53	-0.47	-0.35	1.85	-0.52
Heading RMS (deg)	0.44	0.42	0.61	0.81	0.52
Pitch RMS (deg)	0.54	0.53	0.64	1.27	0.73
Heading Outliers (epochs)	0	0	104	200	57
Heading Outliers (%)	0	0	1.55	1.46	0.43
Heading Reliability (%)	100	100	98.45	98.54	99.57
Pitch Outliers (epochs)	0	0	0	93	15
Pitch Outliers (%)	0	0	0	0.68	0.11
Pitch Reliability (%)	100	100	100	99.32	99.89
Number of TTFH observations	11	13	9	15	14
Time to First Heading: 50p (s)	292.5	207.5	215	33.75	16.67
Time to First Heading: 90p (s)	479	547	760.9	135	66
Time to First Heading: Max (s)	553	610	769	159	153
Time to Last Heading: 50p (s)	13.75	65	9	5.36	14
Time to Last Heading: 90p (s)	49	367	40.9	9.64	46
Time to Last Heading: Max (s)	55	493	49	33	55

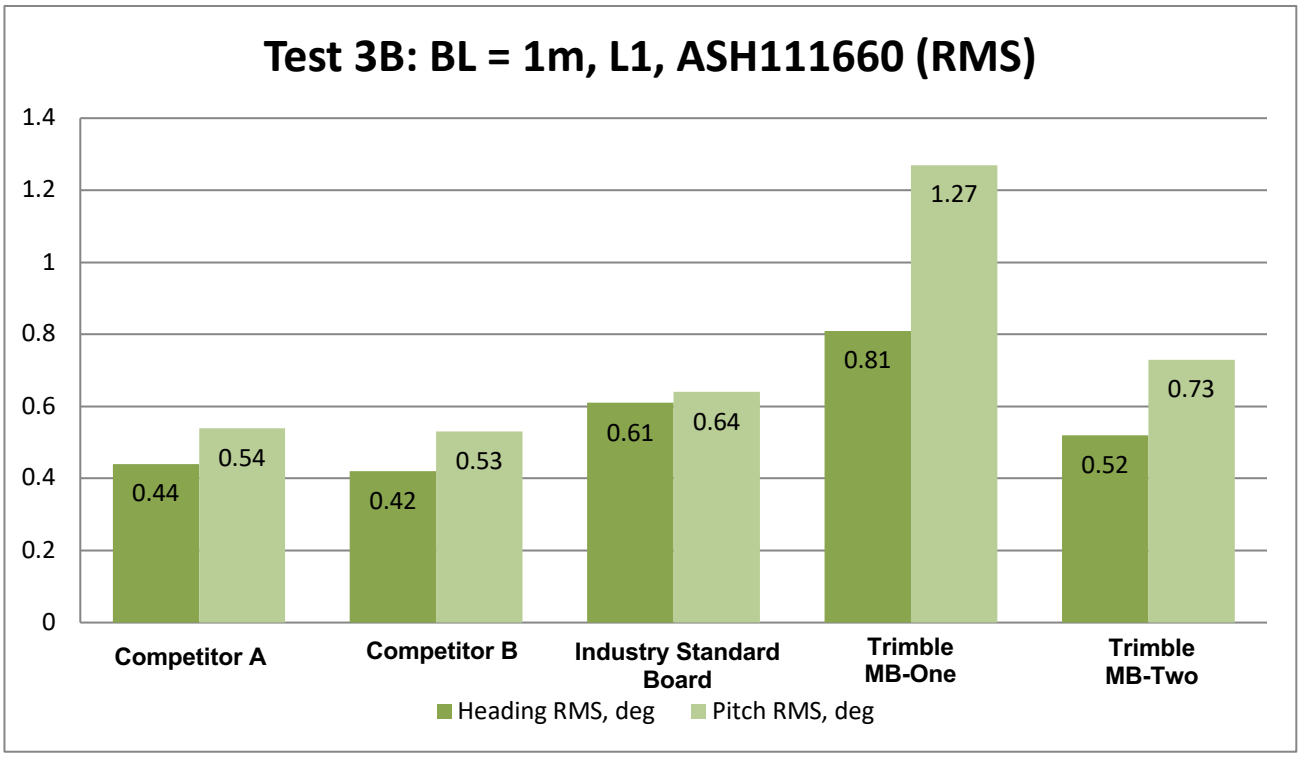
Group 3 (B) Availability / Reliability Plot:



Group 3 (B) TTFA Plot:



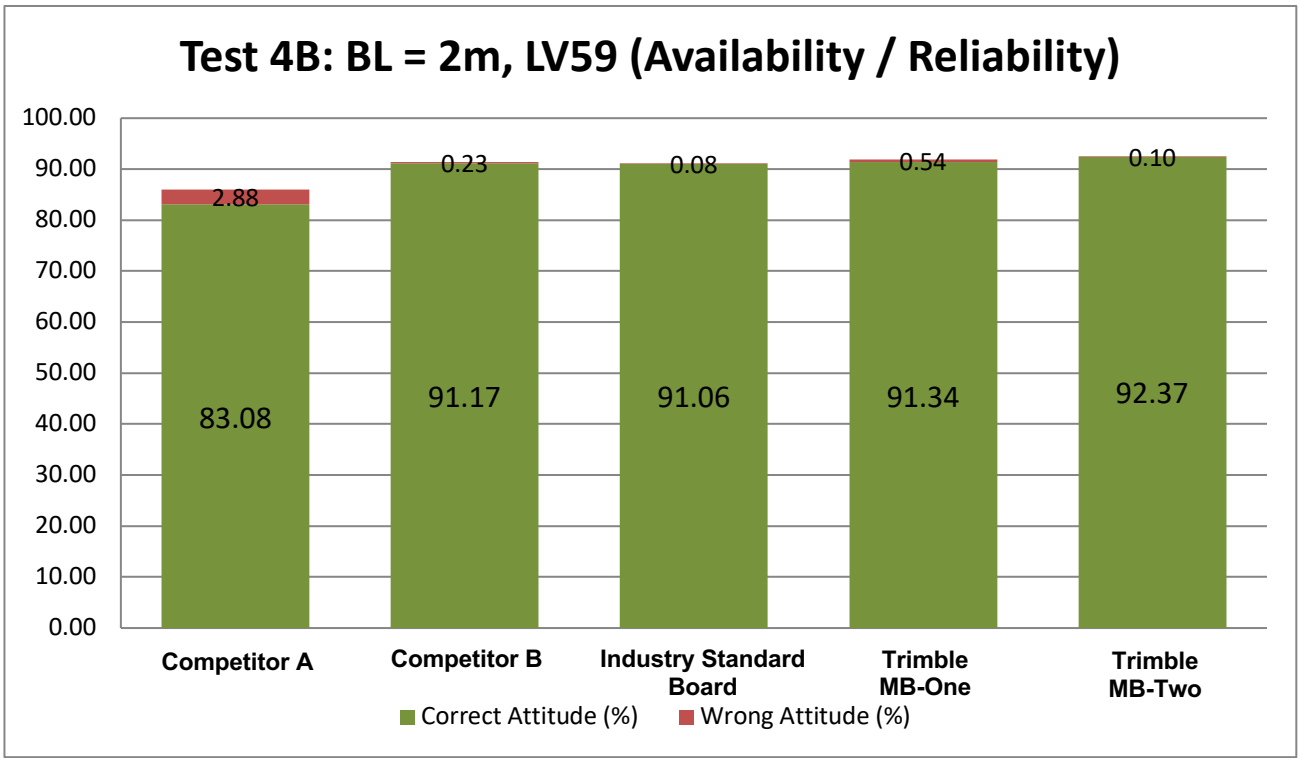
Group 3 (B) RMS Plot:



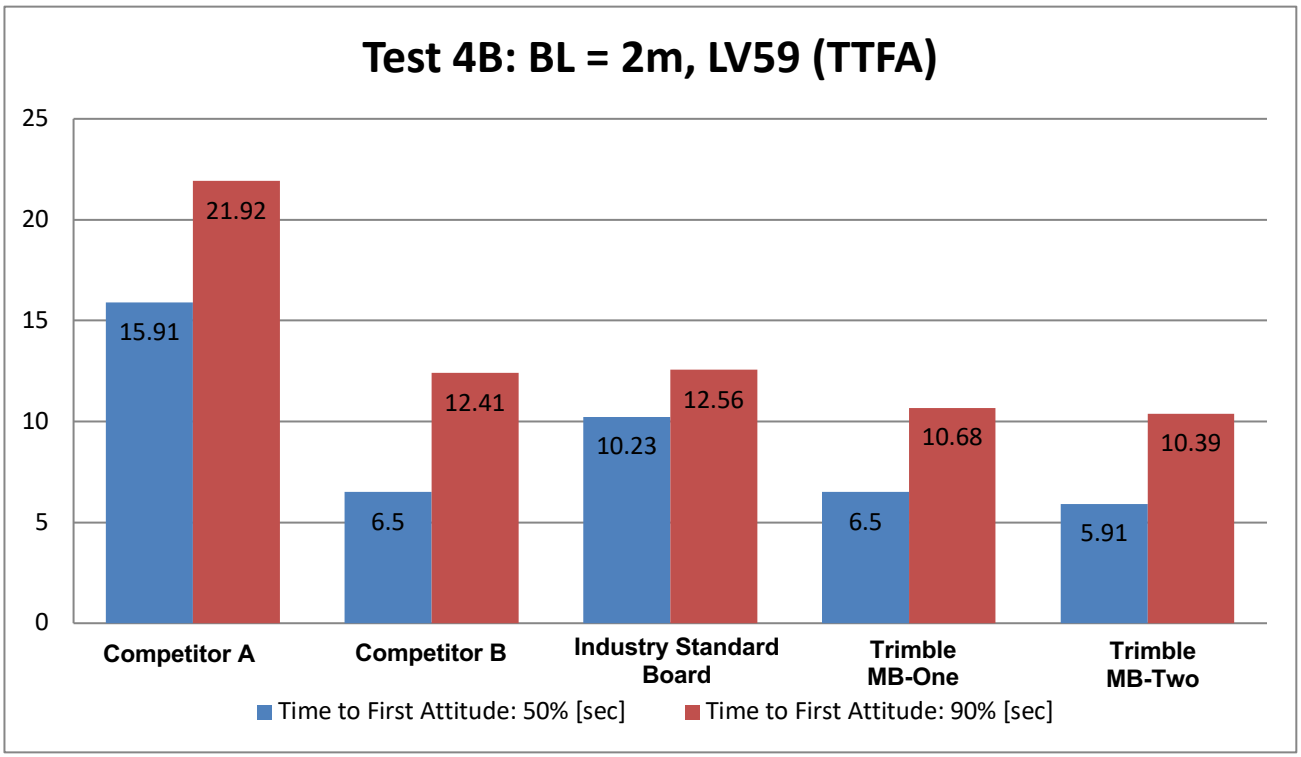
Group 4 (B) Baseline = 2m, Antennas – LV59, L1/L2 GPS + GLONASS Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 13:44:59.35 - 14:41:25.40 3386.05s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	58,215	61,901	61,721	62,222	62,627
Availability (%)	85.96	91.41	91.14	91.88	92.48
Heading RMS (deg)	0.1	0.1	0.13	0.16	0.11
Pitch RMS (deg)	0.26	0.27	0.29	0.38	0.24
Heading Outliers (epochs)	1953	79	51	187	69
Heading Outliers (%)	3.35	0.13	0.08	0.3	0.11
Heading Reliability (%)	96.51	99.67	99.9	99	99.29
Heading No Reference (epochs)	80	125	12	433	375
Heading No Reference (%)	0.12	0.19	0.02	0.64	0.58
Pitch Outliers (epochs)	1,726	158	32	366	36
Pitch Outliers (%)	2.97	0.26	0.05	0.59	0.06
Pitch Reliability (%)	96.78	99.46	99.85	98.65	99.23
Number of TTFH observations	13	13	13	13	13
Time to First Attitude: 50 %	15.91	6.5	10.23	6.5	5.91
Time to First Attitude: 90 %	21.92	12.41	12.56	10.68	10.39
Time to First Attitude: Max (s)	25.5	14.25	13.15	11.2	11.1
Time to Last Attitude: 50 %	4	0.55	0.55	0.43	0.55
Time to Last Attitude: 90 %	7.2	0.99	0.99	0.76	0.99
Time to Last Attitude: Max (s)	8	1.1	1.1	0.85	1.1

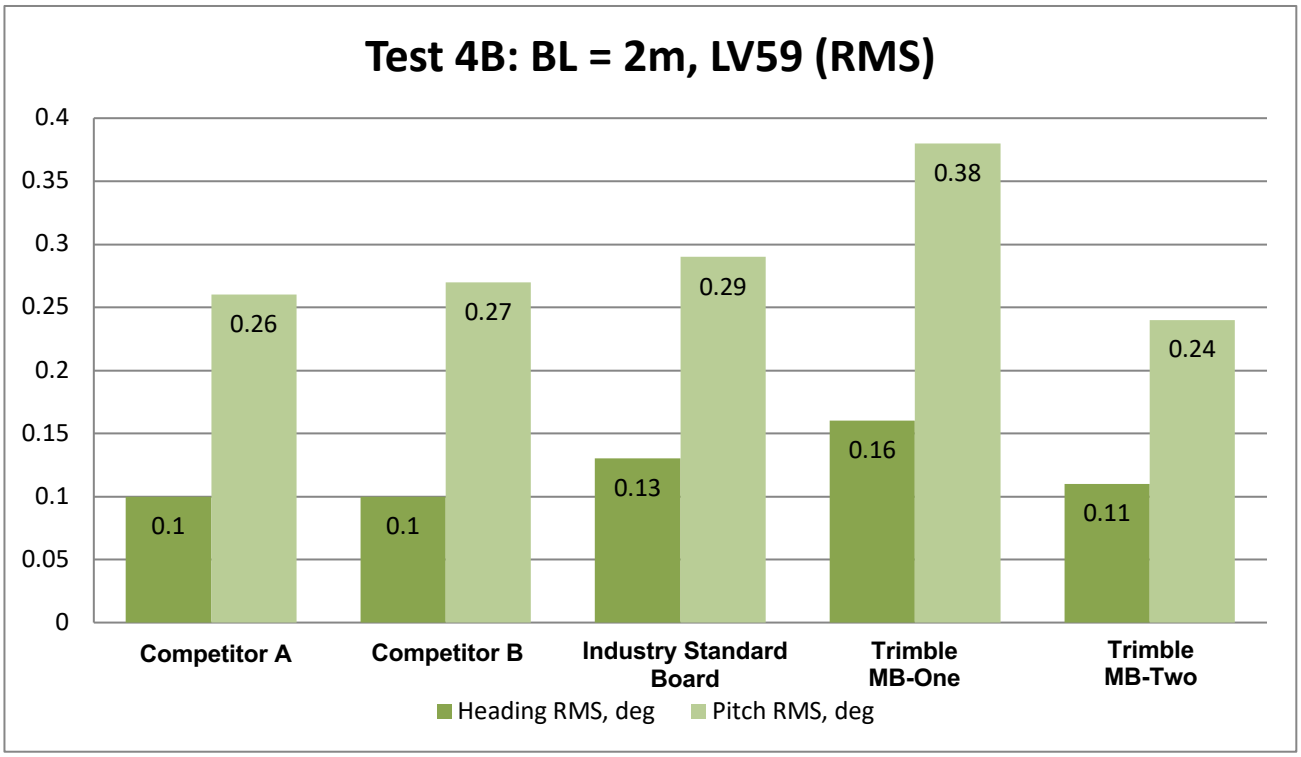
Group 4 (B) Availability / Reliability Plot:



Group 4 (B) TTFA Plot:



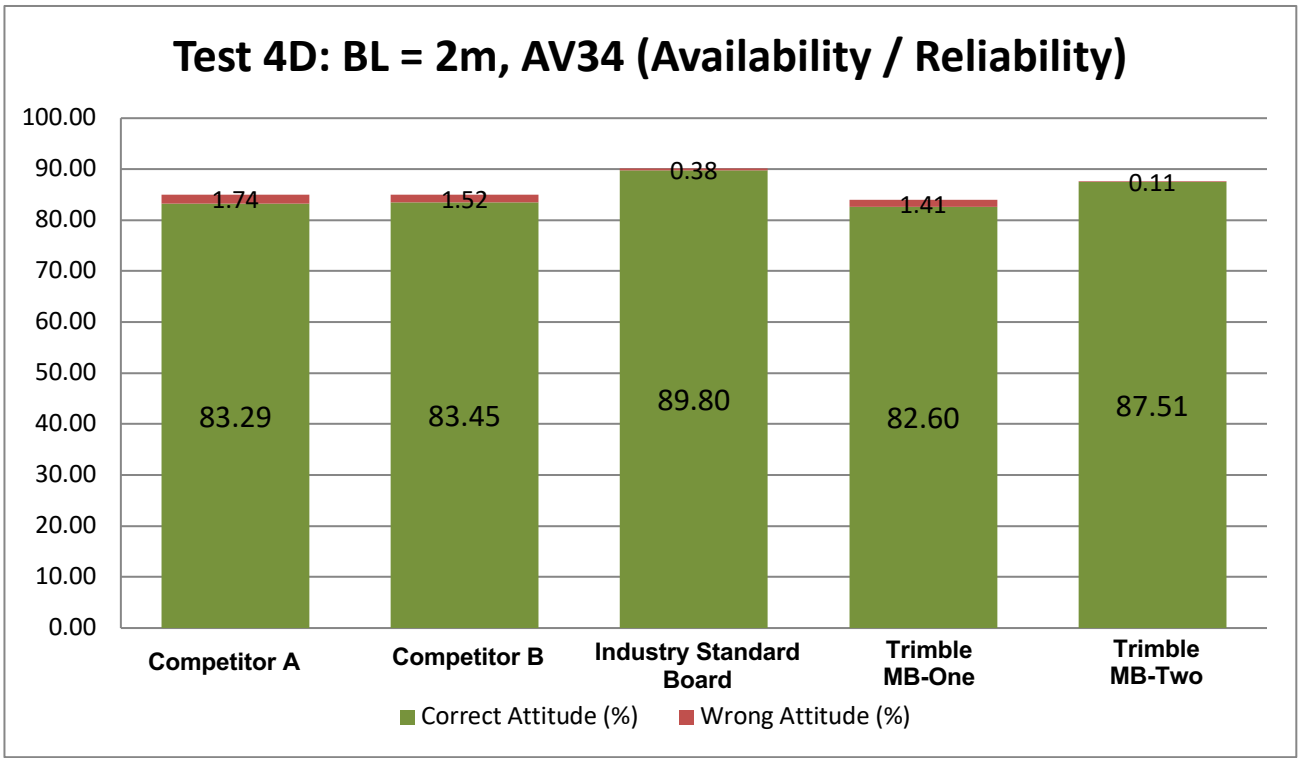
Group 4 (B) RMS Plot:



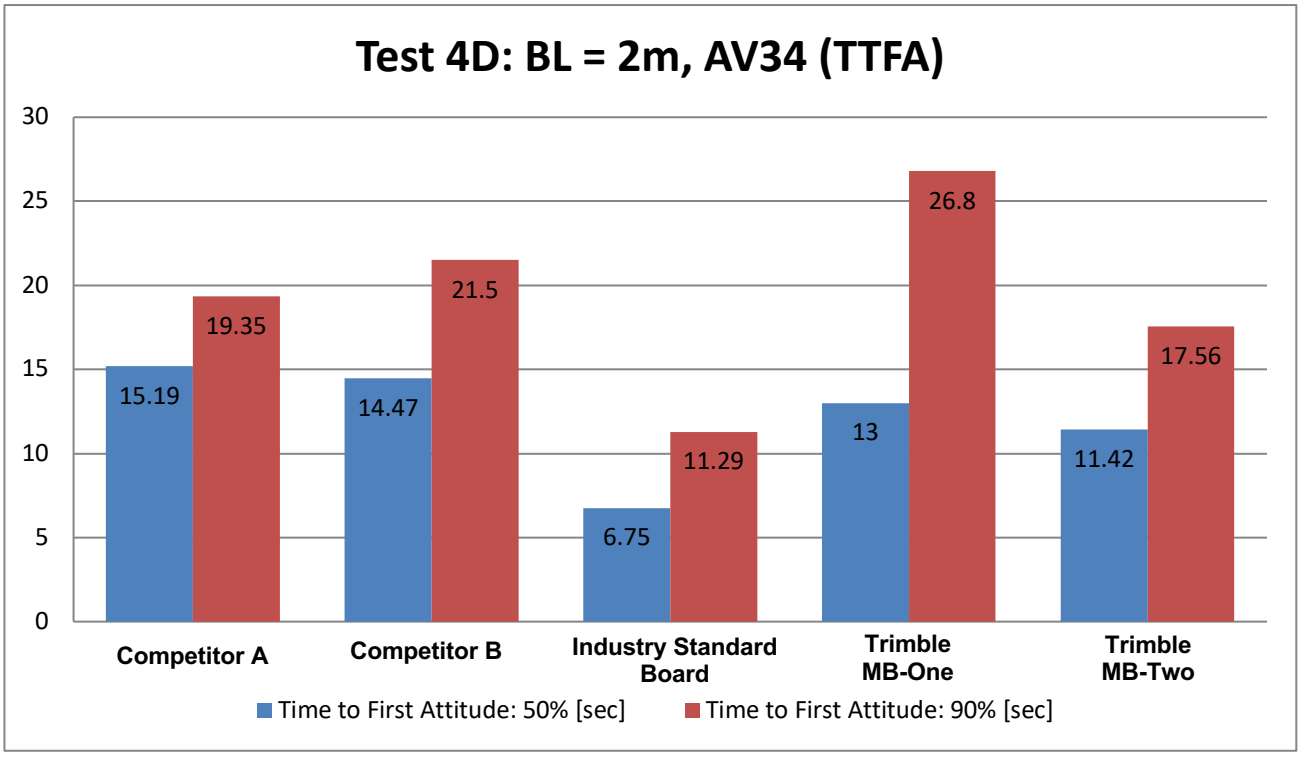
Group 4 (D) Baseline = 2m, Antennas – AV34, L1/L2 GPS + B1/B2 BeiDou Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 09:34:06.20 - 10:39:30.55 3924.35s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	66,735	66,693	70,784	65,936	68,771
Availability (%)	85.03	84.97	90.19	84.01	87.62
Heading RMS (deg)	0.14	0.17	0.15	0.19	0.13
Pitch RMS (deg)	0.38	0.6	0.38	0.53	0.37
Heading Outliers (epochs)	1,365	319	76	566	89
Heading Outliers (%)	2.05	0.48	0.11	0.86	0.13
Heading Reliability (%)	97.12	99.5	98.72	98.28	99.53
Heading No Reference (epochs)	554	16	830	571	236
Heading No Reference (%)	0.71	0.02	1.07	0.73	0.32
Pitch Outliers (epochs)	1,040	1,196	302	1,110	71
Pitch Outliers (%)	1.56	1.79	0.43	1.69	0.1
Pitch Reliability (%)	97.02	97.67	97.89	97	99.09
Number of TTFH observations	27	27	27	26	27
Time to First Attitude: 50 %	15.19	14.47	6.75	13	11.42
Time to First Attitude: 90 %	19.35	21.5	11.29	26.8	17.56
Time to First Attitude: Max (s)	20.45	34.15	12.1	34.1	19.1
Time to Last Attitude: 50 %	1.83	0.57	0.45	0.25	0.5
Time to Last Attitude: 90 %	3.29	1.03	0.81	0.45	0.9
Time to Last Attitude: Max (s)	3.65	1.15	0.9	0.5	1

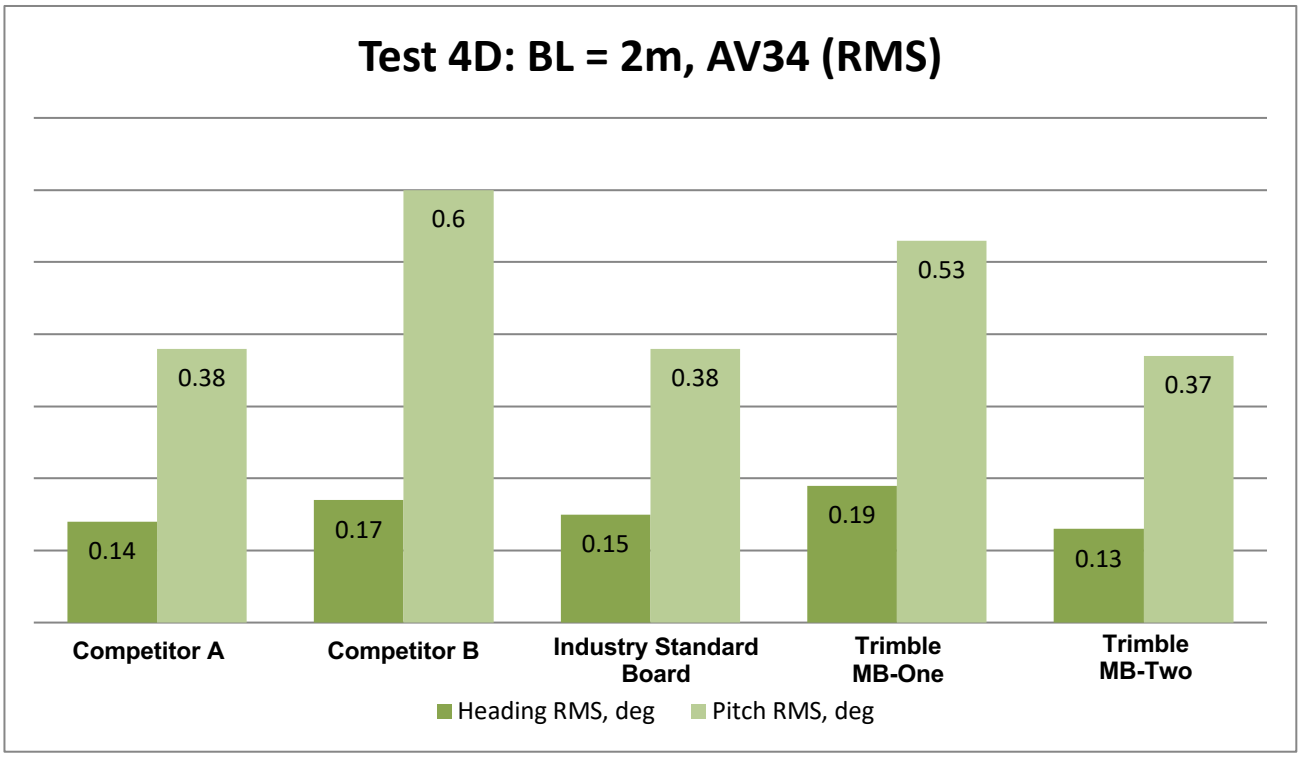
Group 4 (D) Availability / Reliability Plot:



Group 4 (D) TTFA Plot:



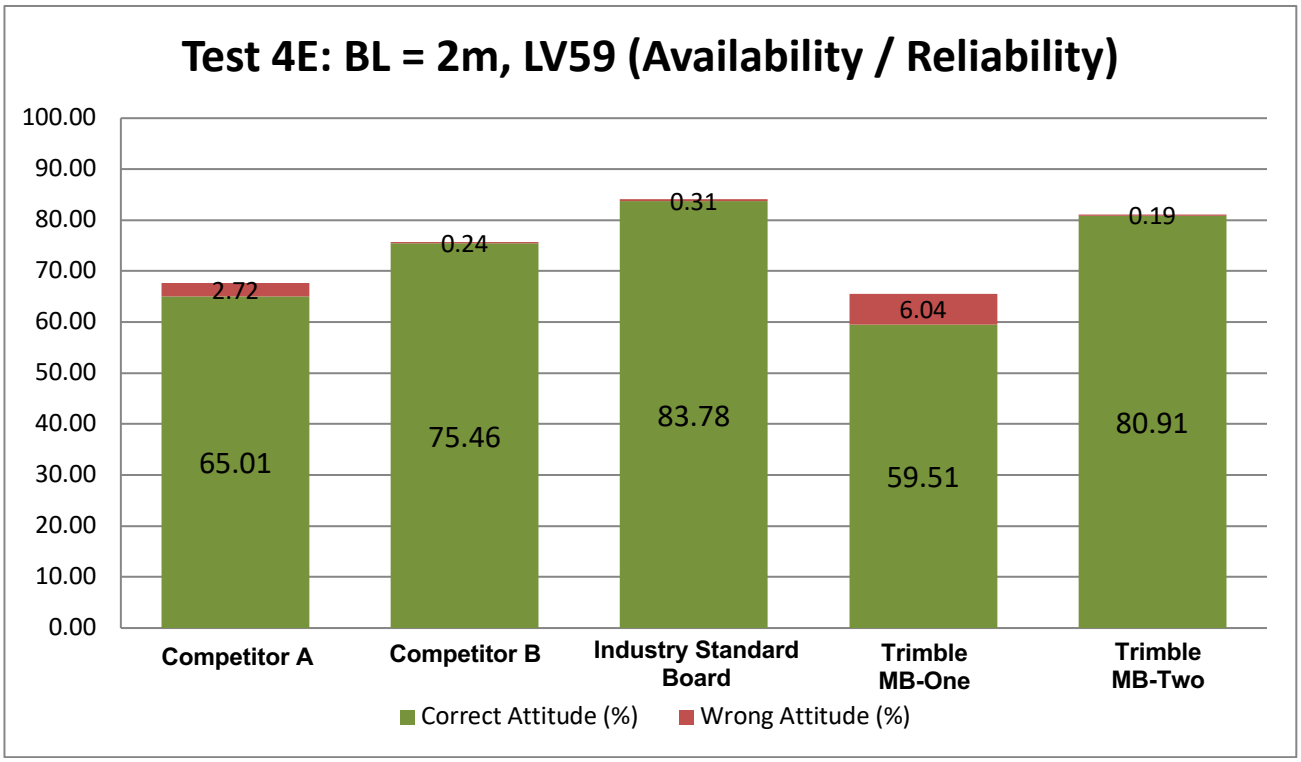
Group 4 (D) RMS Plot:



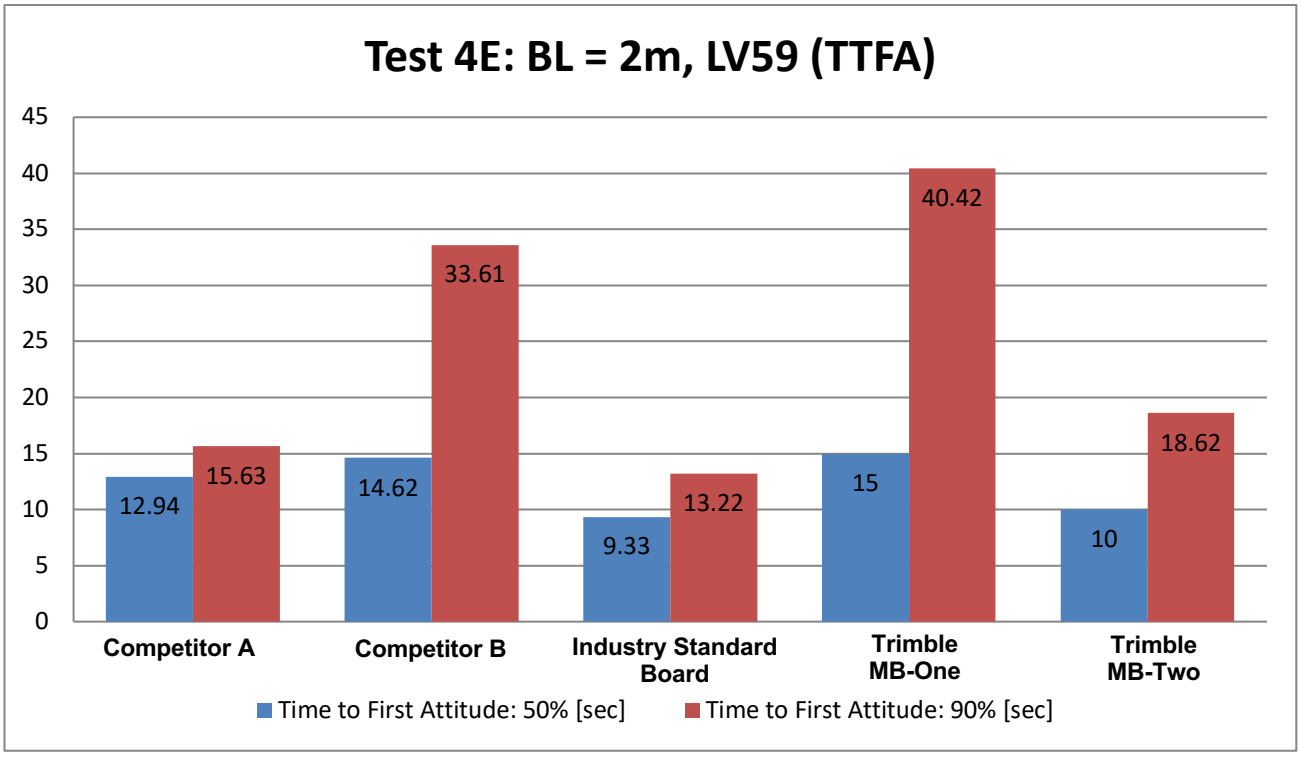
Group 4 (E) Baseline = 2m, Antennas – LV59, L1/L2 GPS + B1/B2 BeiDou Test Results:

	Competitor A	Competitor B	Industry Standard Board	Trimble MB-One	Trimble MB-Two
Time: 14:35:26.65 - 15:43:02.50 4055.85s	File #0	File #1	File #2	File #3	File #4
Availability (epochs)	54,942	61,405	68,212	53,172	65,790
Availability (%)	67.73	75.7	84.09	65.55	81.11
Heading RMS (deg)	0.12	0.12	0.16	0.19	0.13
Pitch RMS (deg)	0.27	0.28	0.27	0.36	0.24
Heading Outliers (epochs)	2,203	73	250	4,896	154
Heading Outliers (%)	4.01	0.12	0.37	9.21	0.23
Heading Reliability (%)	92	99.81	97.75	90.25	98.94
Heading No Reference (epochs)	2,192	46	1,288	288	544
Heading No Reference (%)	2.7	0.06	1.61	0.36	0.72
Pitch Outliers (epochs)	2,016	195	121	4,126	5
Pitch Outliers (%)	3.67	0.32	0.18	7.78	0.01
Pitch Reliability (%)	92.05	99.49	97.72	91.57	99.02
Number of TTFH observations	16	28	28	27	28
Time to First Attitude: 50 %	12.94	14.62	9.33	15	10
Time to First Attitude: 90 %	15.63	33.61	13.22	40.42	18.62
Time to First Attitude: Max (s)	16.3	38.2	14.1	44.25	27.1
Time to Last Attitude: 50 %	2.75	2.72	2.42	2.47	2.47
Time to Last Attitude: 90 %	4.95	4.91	4.36	4.45	4.45
Time to Last Attitude: Max (s)	5.5	5.45	4.85	4.95	4.95

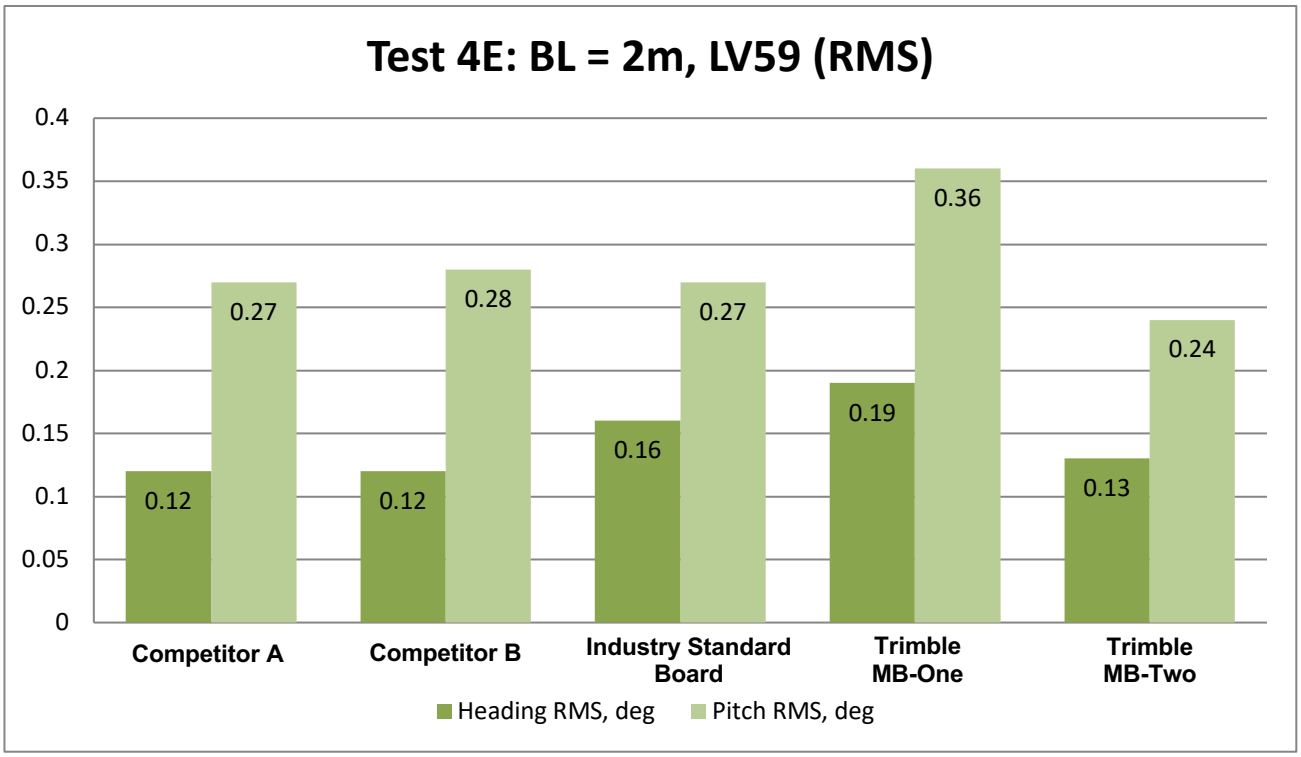
Group 4 (E) Availability / Reliability Plot:



Group 4 (E) TTFA Plot:



Group 4 (E) RMS Plot:



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