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TEST and EVALUATION of the HIGH ACCURACY GUIDANCE (HAG) ALGORITHM

March 13, 2008

USASMDC
P.O. Box 1500
Huntsville, Alabama 35807-3801

ANALYSIS COMMENTS

Not part of the original U.S. Army report

WHAT THIS IS

The original March 13, 2008 USASMDC public-release report. The Army cover is preserved unchanged at left.

PUBLIC-RELEASE STATUS

The source is marked "Distribution A - Approved for Public Release." This gives the analysis a direct Army-authored evidentiary foundation.

READING RULE

Everything in this right-hand panel is analysis/commentary. It is not part of the Army report and should never be quoted as Army language.

CORE QUESTION

What did the Army actually test, what did it actually conclude, and how does that test configuration compare with HAG's intended endgame add-on role?

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WHY THE TABLE OF CONTENTS MATTERS

The Army did not issue a one-paragraph endorsement. It documented objectives, ground rules, the 6-DOF test bed, the HAG interface, threat descriptions, figure of merit, results and conclusions.

ANALYSIS APPROACH

The strongest reading follows the Army report in sequence: test design first, then controls, then threat set, then results, then the conclusion. This avoids cherry-picking a single favorable sentence.

INTENDED HAG ROLE

HAG is described by its developer as a specialized terminal endgame add-on. The existing interceptor guidance brings the missile into the kill zone; HAG then uses seeker-derived information for the final predictive intercept. The approximately three-second interval is the developer's description, not a duration stated in this Army report.

Background

1.1 The U.S. Army Space and Missile Defense Command (USASMDC) conducted a "black box" test of the High Accuracy Guidance (HAG) software which was invented by HAG Technologies, Inc. (HTI). The integration and testing of the HAG software was performed via a Six Degrees of Freedom (6 DOF) nominal interceptor system similulation.

1.2 This report has been produced to satisfy the requirements of the Co-operative Test Agreement, between USASMDC and HAG Technologies, Inc., that specifies that a unclassified, public release report will be provided by USASMDC upon conclusion of the comparative test and evaluation.

1.3 A "black box" test and evaluation of HAG was conducted in 1997, which used synthesized threats and a generic interceptor model. Although other organizations have evaluated HAG as well, this report will not reference those efforts.

Evaluation Objectives

2.1 The objective of this evaluation was to determine if the HAG guidance law merits further interest for application to either current or future Department of Defense (DoD) interceptor systems. Classified tactical and synthesized threats were specifically selected to find the HAG break points and bound the performance envelope.

2.2 The technical approach integrated the HAG guidance algorithms/software into a 6 DOF interceptor system simulation for the purpose of testing, analyzing, and reporting HAG terminal guidance performance relative to the terminal guidance performance of a nominal interceptor guidance law.

Evaluation Ground Rules and Test Approach

3.1 This effort used various threat scenarios representing a cross-section of high- fidelity threats and synthesized threats. The inclusion of synthesized threats established a common reference with the 1997 test and allowed further exploration of the capabilities of HAG. The test premise was that no interceptor hardware or software modifications were required, other than the substitution of HAG terminal guidance algorithms in place of the existing interceptor terminal guidance algorithms. The HAG Test Team was allowed to optimize the HAG configuration for this missile and target set, however the baseline interceptor terminal guidance remained fixed at its nominal configuration.

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BLACK-BOX, 6-DOF TEST

The Army states that USASMDC conducted a "black box" HAG test in a Six Degrees of Freedom nominal interceptor simulation. That means performance could be evaluated without disclosure of the proprietary algorithm.

THE ARMY'S OBJECTIVE

The stated objective was to determine whether HAG merited further interest for current or future DoD interceptor systems, using tactical and synthesized threats selected to probe break points and bound the performance envelope.

KEY TEST-ARCHITECTURE POINT

The report says the only interceptor modification was substitution of HAG terminal-guidance algorithms for the existing terminal-guidance algorithms. This was a terminal-guidance replacement comparison.

IMPORTANT DISTINCTION

HAG's intended operational concept is narrower: an endgame add-on, not a replacement for the interceptor's full guidance architecture. The Army test is therefore highly relevant, but it should not be described as a perfect reproduction of the intended operational handoff concept.

WHAT THE REPORT DOES SUPPORT

The Army confined HAG to terminal guidance. It did not ask HAG to replace initial-turn or midcourse guidance. That boundary becomes explicit again in the final results section.

evaluating the guidance function. The autopilot function and the fuzing function were not used.

3.3 The interceptor seeker hardware and software test bed utilized, for insertion of the guidance laws, provided the most accurate and noise-free target state estimates possible. In this evaluation, both the nominal interceptor guidance law and HAG's guidance law benefit from these highly refined target state estimates. Once integrated into interceptor simulation, the HAG algorithms replace the guidance law that is currently used during terminal guidance.

3.4 The HAG design was treated as a "black box" for this test. Detailed engineering descriptions of the HAG design were not available to the test teams. Access to the HAG source code was available only to the HAG test team, however this option was not exercised. The relative merits of the HAG design was solely determined by simulation results comparison to the nominal interceptor performance

3.5 The HAG Test Team optimized the HAG parameters during the integration phase by performing simulation tests with the nominal interceptor and the threats used for this evaluation. Once the HAG Test Team verified that the HAG software was fully integrated, optimized, and ready for final runs, the HAG configuration and parameter settings were locked down. No changes were allowed during the final runs-for-record.

Simulation Test Bed

4.1 The simulation selected as the test bed for this evaluation is a DoD 6DOF high- fidelity classified interceptor system simulation.

4.2 The major advantage of the interceptor simulation chosen is that it produces a high confidence of absolute interceptor to target miss distance. Disadvantages of using this model include: the difficult task of integrating HAG with a complex simulation, and the long run times associated with a complex simulation.

4.3 All of the simulation results for this evaluation were generated using a PC-based Windows XP platform. Compilers utilized for this simulation include Compaq Visual Fortran version 6.6B and GNAT Ada 95 version 3.13. All interceptor base line guidance cases and HAG cases were executed on an equal footing using the same platform, the same compilers and the same initial seeds. The only difference in the simulation was that baseline interceptor guidance code was used to compute terminal guidance commands for the nominal cases, and HAG code was used to compute terminal guidance commands for the HAG cases.

DoD interceptor baseline/HAG Interface Description

Interface variables between the 6 DOF model and the HAG system software were

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FAIR COMPARISON

Both the nominal guidance law and HAG benefited from the same highly refined target-state estimates. The Army compared the relative merits from simulation results rather than from access to HAG's internal design.

BLACK-BOX INTEGRITY

The report says detailed HAG engineering descriptions were unavailable to the test teams and the source-code access option was not exercised.

CONFIGURATION LOCK

After integration and optimization, the HAG configuration and parameters were locked. No changes were allowed during the final runs-for-record. This is one of the strongest test-integrity facts in the public report.

EQUAL FOOTING

Baseline and HAG cases used the same platform, compilers and initial seeds. The stated difference was the terminal-guidance code used to compute commands.

INTERPRETATION

These controls make the test useful as a comparative experiment. A modern endgame-add-on test should preserve the same discipline while adding an explicit handoff point from nominal guidance to HAG.

of the engagement. This interface was developed and refined during the HAG evaluation effort, but was completed and held constant during execution of runs-for-record.

Threat Descriptions

6.1 The TBM threats selected, for the HAG evaluation, represent a broad spectrum of ranges and velocities. This evaluation included 6 tactical threats. These threats are characterized by high-confidence tabular trajectories and, also, complex RF (radio frequency) signature models. These threats are all inbound and traveling anti-parallel to the interceptor launcher downrange axis. Two (2) variations were included with additional spiraling characteristics

6.2 The 15 synthesized threats selected for HAG evaluation represent a broad spectrum of ranges and velocities. The scenarios evaluated included maneuvering, evasive and air-breathing threats.

6.3 In summary, 23 scenarios were evaluated.

Figure Of Merit

For this evaluation, the main criteria for determining the relative merit of HAG compared to the nominal baseline guidance is Probability of Hit (PHit, % of miss distances within allowable limits) for each of the various threat scenarios tested. This criteria is selected because it is the best indicator of successful intercept, and is applicable to all of the scenarios included in this evaluation. Also, other simulation results are used to provide additional insight into the relative merits of HAG guidance as compared to the baseline guidance.

Evaluation Results

8.1 Testing was conducted in a phased approach with each of the phases building on the success of the previous phase. The first phase integrated the HAG guidance algorithms into the 6 DOF simulation using true IMU and seeker states in the interface to HAG, and then tested against all 23 threats. The results from Phase 1 using the truth interface are not achievable in a realistic setting where actual seeker measurements are used in the guidance algorithms. These results were used to insure that HAG was properly integrated.

8.2 In the second phase of the HAG evaluation, the truth interface was replaced with the final seeker measurement interface. This measurement interface utilizes only data which can be measured, filtered, and made available to the onboard missile guidance function. Again, the baseline guidance law was used to compare performance to the HAG guidance law, against all 23 threats (just one self-defense

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THREAT SET

The Army used 6 tactical ballistic-missile threats, including 2 with additional spiraling characteristics, plus 15 synthesized threats spanning maneuvering, evasive and air-breathing cases - 23 principal scenarios.

WHY SPIRALING MATTERS

Spiraling and evasive motion directly stress the future-intercept problem HAG was designed to solve. These are especially relevant cases for a predictive endgame algorithm.

FIGURE OF MERIT

The principal comparison metric was Probability of Hit (PHit): the percentage of miss distances within allowable limits for each scenario.

PHASE 1

True IMU and seeker states were used only to verify integration. The Army explicitly says those truth-interface results were not achievable in a realistic setting.

PHASE 2 - OPERATIONALLY IMPORTANT

The truth interface was replaced by a seeker-measurement interface using only data that could be measured, filtered and made available to the onboard missile guidance function. This is the closest public-report language to the intended seeker-to-HAG endgame concept.

8.3 In the third and final phase of the HAG evaluation, each of the 23 threats were evaluated at 11 to 27 additional downrange/crossrange/altitude intercept conditions using the same simulation and interface configuration as Phase 2. Phase 2 consists of an initial sampling of the 23 threats. Phase 3 explores more of the battle space by adding 406 additional scenarios for a total of 429 scenarios.

8.4 Finally, the objective of testing against each of these 23 threats was to determine HAG terminal guidance performance relative to the a nominal guidance law over a broad spectrum of threat characteristics, in particular, those threat characteristics described in the threat descriptions section. The scenarios for the HAG guidance law evaluation was checked to verify that seeker acquisition was successful and timely, so that the HAG terminal guidance algorithms had a chance to achieve intercept. The initial turn and midcourse guidance phases of the engagement were unchanged by the integration of the HAG terminal guidance algorithms. HAG test results only effected the terminal guidance phase of each engagement.

8.5 The baseline interceptor PHit performance data generated in this evaluation was compared to the previous analyses for selected tactical threats. The performance observed in this evaluation is consistent with earlier, independent results.

9. Conclusions

9.1 The results showed that no single guidance law performed well against all threats tested. On the other hand, the results demonstrate the synergy of combining guidance laws.

9.2 Integration of the current HAG guidance law with the nominal interceptor guidance law provides performance benefits against the suite of maneuvering air and missile targets considered in this effort. In fact, HAG added performance benefits for 12 of the 23 scenarios tested, and tied the nominal case 4 times.

9.3 With additional development and insight into the HAG algorithms, it is possible that HAG could be used to augment a proportional navigation law.

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SCALE: 429 SCENARIOS

Phase 3 added 406 downrange, crossrange and altitude conditions to the 23 initial scenarios, for a stated total of 429 scenarios. This was a broad battlespace evaluation, not a single demonstration run.

TERMINAL-ONLY BOUNDARY

The Army expressly states that initial-turn and midcourse guidance were unchanged and that HAG affected only the terminal-guidance phase. This is critical when describing what HAG was asked to do.

THE ACTUAL ARMY CONCLUSION

The report says no single guidance law performed well against all threats. HAG added performance benefits in 12 of 23 principal scenarios and tied the nominal case 4 times.

THE MOST IMPORTANT SENTENCE

The Army concluded that the results demonstrated "synergy" from combining guidance laws. That conclusion is highly relevant to HAG's intended role as a complementary endgame capability rather than an all-purpose replacement.

MODERN RETEST THAT MATCHES INTENDED USE

Keep the current interceptor guidance through the earlier engagement. Enter the kill zone. Use the onboard seeker measurements. Then hand terminal control to HAG for its intended final endgame interval and compare that architecture against the current baseline. The approximately three-second interval is a developer description and should be labeled as such unless separately documented.