NASA Technical Memorandum 103998

IN-04
180802

14P

Flight Evaluation of a Computer Aided Low-Altitude Helicopter Flight Guidance System

Harry N. Swenson, Raymond D. Jones,
and Raymond Clark

January 1993

Quick Release – This Technical Memorandum is an unedited report. It is being released in this format to quickly provide the research community with important information.

NASA
National Aeronautics and
Space Administration

NASA Technical Memorandum 103998

Flight Evaluation of a Computer Aided Low-Altitude Helicopter Flight Guidance System

Harry N. Swenson, Ames Research Center, Moffett Field, California
Raymond D. Jones and Raymond Clark, U.S. Army Avionics R&D Activity,
Ft. Monmouth, New Jersey

January 1993

NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

SUMMARY

The Flight Systems Development branch of the U.S. Army's Avionics Research and Development Activity (AVRADA) and NASA Ames Research Center have developed for flight testing a Computer Aided Low-Altitude Helicopter Flight (CALAHF) guidance system. The system includes a trajectory-generation algorithm which uses dynamic programming and a helmet-mounted display (HMD) presentation of a pathway-in-the-sky, a phantom aircraft, and flight-path vector/predictor guidance symbology. The trajectory-generation algorithm uses knowledge of the global mission requirements, a digital terrain map, aircraft performance capabilities and precision navigation information to determine a trajectory between mission waypoints that seeks valleys to minimize threat exposure. This system has been developed and evaluated through extensive use of piloted simulation and has demonstrated a "pilot centered" concept of automated and integrated navigation and terrain mission planning flight guidance. This system has shown a significant improvement in pilot situational awareness, and mission effectiveness as well as a decrease in training and proficiency time required for a near terrain, nighttime, adverse weather system.

AVRADA's NUH-60A STAR (Systems Testbed for Avionics Research) helicopter has been specially modified, in house, for the flight evaluation of the CALAHF system. The near-terrain trajectory generation algorithm runs on a multi-processor flight computer. Global Positioning System (GPS) data are integrated with Inertial Navigation Unit (INU) data in the flight computer to provide a precise navigation solution. The near-terrain trajectory and the aircraft state information are passed to a Silicon Graphics computer to provide the graphical "pilot centered" guidance, presented on a Honeywell Integrated Helmet And Display Sighting System (IHADSS). This paper presents the system design, piloted simulation, and initial flight test results.

INTRODUCTION

The complexity of rotorcraft missions involving operations close to the ground in nap-of-the-earth (NOE) flight for long periods of time result in high pilot workload. This is especially true for single-pilot vehicles, such as was originally intended for RAH-66 Comanche. In order to allow a pilot more time to perform mission-oriented tasks, some type of automated system capable of performing guidance, navigation, and control functions is needed. Automating NOE flight is extremely challenging due to the advances necessary in several technology areas such as terrain flight guidance, obstacle detection, and obstacle avoidance. NASA's Ames Research Center and the U.S. Army's Avionics Research and Development Activity (AVRADA) have joined to develop these technologies and flight test systems and concepts that have the greatest potential for improved low-altitude and NOE rotorcraft flight operations [1].

Currently, rotorcraft operating in threat areas achieve low-level, maneuvering penetration capability during nighttime and adverse weather conditions through the use of a combination of technologies such as terrain-following (TF) radar systems, forward looking infrared sensors and night vision goggles [2]. TF systems were initially developed for fixed-wing tactical and strategic aircraft and provide vertical commands which can be displayed on a flight director for manual flight or fed to the flight control system for automatic flight. The extension of TF capability to include lateral maneuvering by taking advantage of on-board digital terrain data is commonly referred to in the literature as Terrain Following/Terrain Avoidance (TF/TA) [3]. Within the last few years TF/TA algorithms have been modified to suit the requirements of rotorcraft [4,5]. Research at NASA Ames has concentrated on incorporating these algorithms into an operationally acceptable system, referred to as the Computer Aiding for Low-Altitude Helicopter Flight (CALAHF) guidance system [6]. Several piloted simulations of the CALAHF guidance system have been conducted to develop the system and pilot interface and to evaluate pilot tracking performance and situational awareness under various flight and environmental conditions. Based on the system performance and pilot acceptance demonstrated during the third simulation the CALAHF concept was believed ready for flight evaluation, both as a first step in initiating NASA's automated NOE flight research and as a standalone capability to meet the operational military requirements for covert low-altitude penetration. This resulted in an agreement between NASA-Ames and the U.S. Army AVRADA for a joint flight experiment in the AVRADA NUH-60A STAR (Systems Testbed for Avionics Research) helicopter. Validation of the NASA-developed CALAHF system is being carried out on the NUH-60A STAR helicopter. This paper reviews the system concept, simulation effort, test aircraft integration, and the initial series of flight tests.

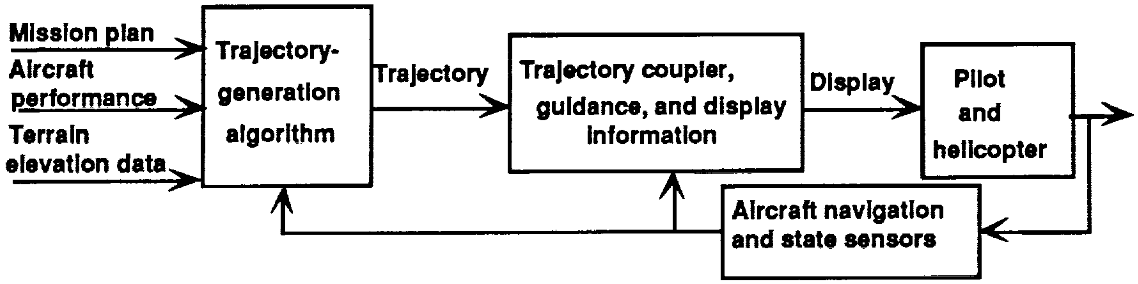

Figure 1 CALAHF system block diagram

CALAHF SYSTEM DESCRIPTION

A functional block diagram of the CALAHF flight system is shown in Fig. 1. The three major components: (1) the trajectory-generation algorithm, (2) trajectory coupler, and (3) displayed information are discussed below.

Trajectory Generation Algorithm

The primary guidance is provided by a valley-seeking, trajectory generating algorithm based on a forward-chaining dynamic-programming technique originally developed for the U.S. Air Force [8]. Significant modifications were made to the original guidance algorithm to adapt it for manual rotorcraft operations. These modifications are discussed in extensive detail in references [4,9], thus the algorithm is described only briefly here. The algorithm uses mission dependent information, i.e mission waypoints, and Defense Mapping Agency digital terrain elevation data combined with aircraft performance parameters and state information, e.g., maximum bank angle, maximum climb and dive angles, maximum pull up and push over load factor, and set-clearance altitude (desired trajectory altitude above the ground) to compute an optimal path between mission waypoints.

The trajectory generation algorithm uses a decoupled procedure in which the lateral and vertical trajectory solutions are determined independently to obtain an optimal trajectory. In this decoupled procedure, the lateral ground track is first determined by assuming that the aircraft can maintain the vertical set-clearance altitude. The vertical trajectory is then calculated using aircraft normal load factor and flight path angle as maneuver constraints to maintain the aircraft at or slightly above the vertical set clearance as determined from the digital terrain map and the lateral ground track.

The lateral path is calculated using a tree structure of possible two-dimensional trajectories by using discrete values of aircraft bank angle. Assuming constant speed and coordinated flight (zero sideslip), each discrete bank angle produces a possible path which in combination forms a tree of possible paths (Fig. 2). In this implementation, the bank angle control has five discrete values that are used for the trajectory calculation (0, ± 1/3 maximum bank angle, ± maximum bank angle). The number of possible paths is reduced to a reasonable level by pruning. Pruning the tree after three to four levels of branching gives the best mix of branch generation and computational speed based upon results from non-real-time computer simulations.

After the tree structure of possible paths has been propagated through the entire patch length, the cumulative cost (J) of all surviving branches are compared, and the path with the lowest cost is selected as the optimal trajectory. The cost function J used to determine the optimal trajectory is

$$J = \sum_{i=1,30} H_i^2 + f(D_i)\omega D_i^2 + \alpha(\Delta\Psi_i)^2 \qquad (1)$$

where H_i is the altitude above sea level at node i, D_i is the lateral distance from reference path (as defined by a straight line between waypoints) at node i, ω is the TF/TA ratio, f(D) is a dead band on the lateral deviation cost, $\Delta\Psi_i$ is the error between reference and command heading at node i and α is the heading weight.

The main parameters in this performance measure are the terms representing altitude H and reference-path deviation D. The cost-functional, when driven by these two terms, allows lateral maneuvering to seek lower altitude terrain by the cost reduction from H; excessive deviation from the reference path is controlled by increasing cost due to D. The TF/TA ratio ω allows blending of these two terms to obtain a desired balance between vertical and horizontal maneuvering. The f(D) and $\alpha(\Delta\Psi_i)^2$ terms were added to reduce undesirable oscillations in the trajectory about the nominal path that are caused by the bank-angle quantization. The f(D) eliminates the need for precise following of the reference path and the $\alpha(\Delta\Psi_i)^2$ term provides a penalty for changing the heading from that given by the reference path. These two terms were added as a result of experience gained in piloted simulations to make the trajectory-generation algorithm emulate pilot control strategies for low-altitude maneuvering flight. The

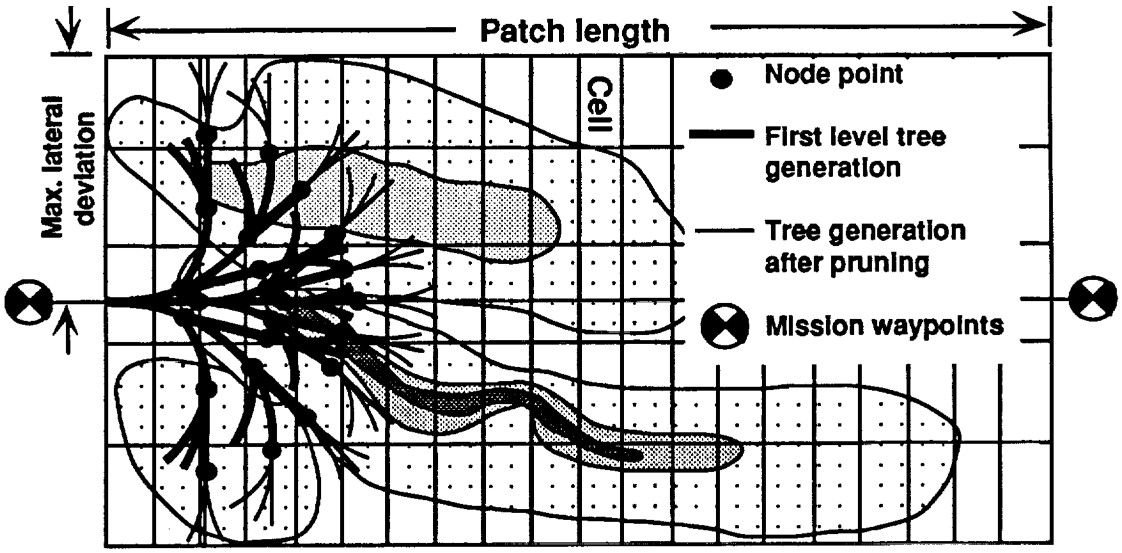

Figure 2 Trajectory Tree generation

trajectory-generation algorithm, as defined above, is designed to compute guidance for a patch which is the area in front of the aircraft's present location. The patch width is the maximum lateral deviation allowed by the algorithm, and the length is the flight preview distance. The algorithm is computationally intensive; for a representative patch length of 30 sec and maximum lateral deviation of 1 km the computational cycle is approximately 4 to 5 sec for a modern (1 to 2 MIP) flight computer. Although the trajectory is updated every cycle time, the updates are blended in such a way that a pilot sees a continuous path and the updates are imperceptible to him The optimal trajectory is passed to the trajectory coupler. The trajectory is represented by 30 discrete instances of commanded aircraft-inertial state (position, velocity and acceleration) as well as commanded bank, heading and vertical flight-path angles at 1-sec intervals.

Pilot Display Guidance

The guidance and control information is given to the pilot on a helmet mounted display (HMD) in the format shown in Fig. 3. The HMD format is a mixture of screen, body, and inertially referenced symbols. The screen referenced symbols include: a heading tape (023°), engine torque (45%), airspeed (63 kts), radar altitude (105 ft), and ball and slip indicator and are fixed to a location on the HMD display. The body referenced symbols are the aircraft nose (> <), and the flight-path vector/predictor which move in relation to the pilots head position relative to the nose and aircraft's flight path vector. All remaining symbols are inertially referenced and are positioned on the display symbolically in the exact position and orientation as dictated by their world coordinates. The primary situational information is presented to the pilot with an inertially stabilized flight-path vector/predictor symbol predicting the rotorcraft location 4 seconds ahead, and is represented by the circular aircraft icon with attached airspeed flight director tape. The situational information presented on the HMD in Fig. 3 indicates the pilot is turning right with a slight descent as indicated by the flight-path vector/predictor below the horizon, and is looking approximately along the longitudinal axis of the aircraft as indicated by the position of the aircraft nose symbol.

The trajectory information is displayed on the HMD using a pathway-in-the-sky and a phantom aircraft. The pathway symbols represent a three-dimensional perspective of the inertial position and heading of the discretized trajectory. The phantom aircraft, displayed as a delta-winged aircraft represents the instantaneous position along the trajectory that is 4 seconds ahead of the pilot's aircraft. By positioning the flight-path vector symbol on the phantom aircraft, the pilot will track the desired trajectory. In Fig. 3, the HMD symbols are presenting a climbing right turn. The pathway is 30 meters (roughly two rotor diameters) wide at the bottom and parallel to the horizon with vertical projections that are canted at a 45° angle; the width at the top is 60 meters. The depth of the path is 15 meters below the intended trajectory; thus when flying a level straight-line commanded path, the pilots used the analogy of traveling in a full irrigation canal for describing the pathway symbols. Fig. 3 shows a pathway configuration of 7 lines.

Now, we refer to the guidance presented in this fashion as "pilot centered" for the following reasons. First, the presentation allows the pilot to choose the accuracy to which he wishes to track guidance. For example, a pilot can track the phantom aircraft with an intentional vertical bias much like he does when flying formation in near-terrain flight, using pilotage techniques he learned from his

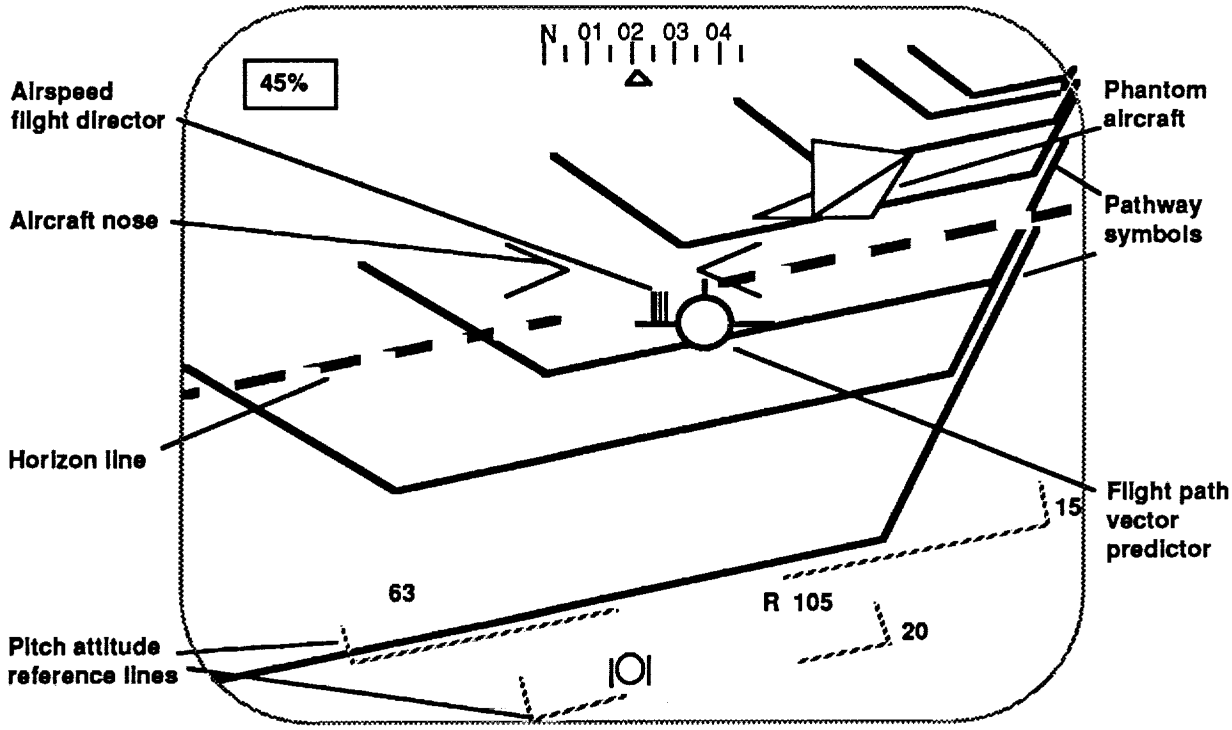

Figure 3 Helmet Mounted display format

first multi-aircraft terrain flight mission. Another reason is the pathway symbology allows the pilot to predict well in advance the maneuvers of the phantom aircraft and determine the pilotage technique most comfortable. This display presentation philosophy is different than traditional "flight director" guidance where the pilot is required to null needles acting as a human autopilot reacting to error signals. Using flight directors pilots often refer to themselves as "meat-servos" and have to trust that the system is operating properly. With the "pilot centered" guidance the pilot no longer has to completely trust the system and can use more of his own judgement in the pilotage of his aircraft.

PILOTED SIMULATION

There have been five piloted simulations dedicated to the development and evaluation of the computer aiding for low-altitude helicopter flight guidance concepts [5,6,7]. The simulations were conducted at NASA Ames Research Center on the six-degree-of-freedom Vertical Motion Simulator (VMS). The VMS provides extensive cockpit motion for use in evaluating handling qualities associated with advanced guidance and control concepts for existing and proposed aircraft. The first three simulations were dedicated to concept development of the CALAHF system [5,6]. The final two simulations were conducted in direct support of the joint NASA/ U.S. Army flight test program [7]. In the fifth simulation, 5 NASA and Army project pilots flew over 300 simulation data runs evaluating and defining the system throughout the proposed flight test envelope. Eighteen guest and evaluation pilots from NASA, DOD and U.S. industry flew the system, giving highly favorable feedback on the system development. The evaluation pilots were able to manually track the HMD guidance through various combinations of terrain, speeds, and weather representative of system use. The guidance can be followed with low pilot workload without detracting from his awareness of the outside world. The pilot was able to combine the guidance with his visual senses to optimize the mission success in varying weather/threat conditions.

AIRCRAFT SYSTEM DESCRIPTION

The U.S. Army and NASA Ames Research Center have started an extensive flight test program of the CALAHF system. The aircraft that is being used for the program is the Army's NUH-60A (STAR) helicopter, Fig. 4. The STAR has been extensively modified to serve as a research aircraft for the U.S. Army [10] and provides digital control and display of all cockpit functions through five multifunction displays (MFD) via a 1553B network. The system is referred to as the Army Digital Avionics System (ADAS). Integrated into the ADAS MFD's is the capability to monitor and control the engines, avionics, circuit breakers, and flight information. ADAS also provides automated secondary systems, checklists, caution/advisory information, and emergency notification and procedure. Due to this unique architecture, the NUH-60 STAR lent itself very well to the integration of the CALAHF system.


Figure 4 NUH-60A STAR helicopter


Figure 6 NUH-60A STAR cockpit configuration & pilot with IHADSS

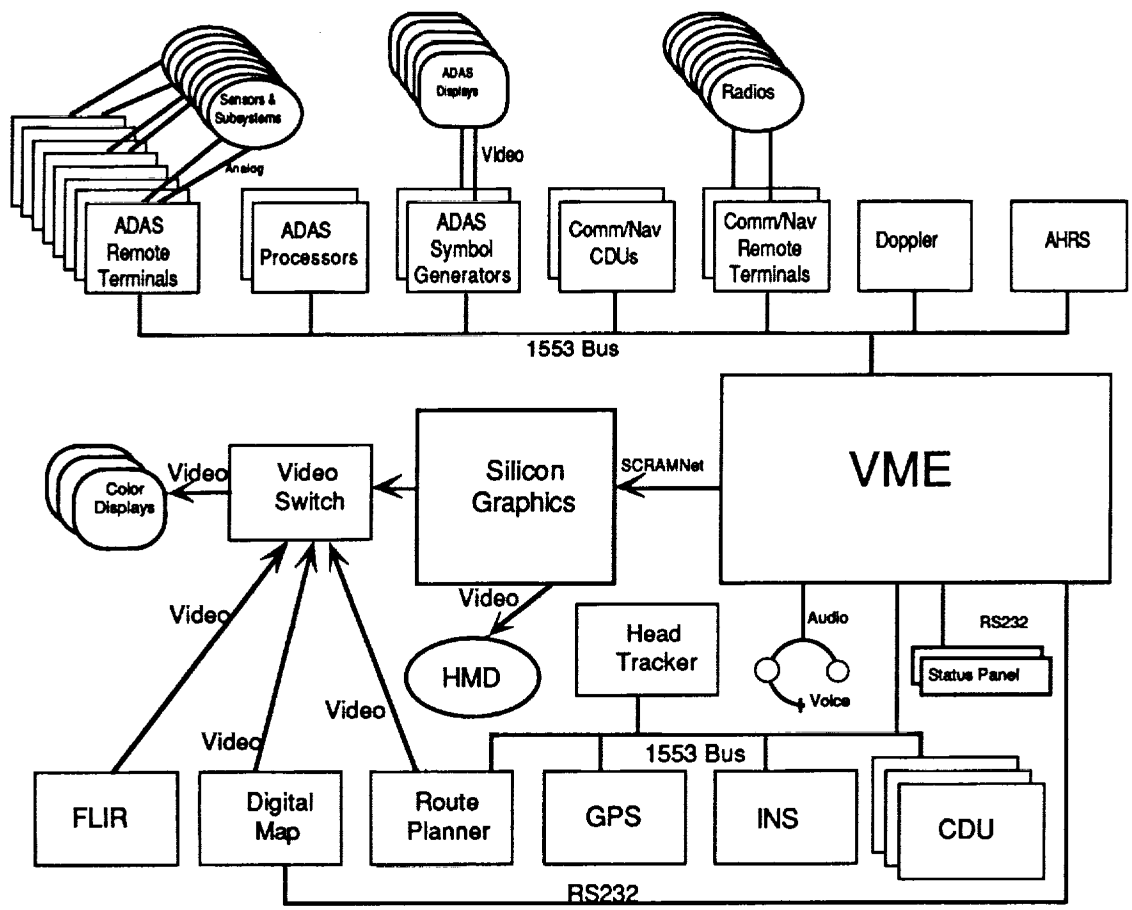

Figure 5 NUH-60A STAR systems diagram

Figure 5 is a block diagram the CALAHF system, as implemented in the STAR. The heart of the system is a general purpose Motorola 68020 based multiprocessor Versa Module Eurocard (VME) computer running a "real-time" operating system. The CALAHF software was rewritten at Ames to include all of the conceptual changes and to be compatible with the VME computer. Connected to the VME on a 1553B network are a Collins RCVR-OH Global Positioning System (GPS) receiver, a Litton LN-39 Inertial Navigation Unit (INU), a Honeywell Integrated Helmet Mounted Display and Sighting System (IHADSS), 3 programmable Collins Control and Display Units (CDU), and an IBM PS2 computer. Also connected to the VME is a Silicon Graphics 4D/120 via a fiber optic SCRAMNet network, and an 386 AT personal computer via a serial line. The VME is also connected to the ADAS system as a remote terminal on its 1553B network. This allows access to airdata, engine performance data, and radar altimeter data.

The VME computer runs the guidance algorithm, integrated navigation, mission plan storage, network control, and overall system software. The VME provides the aircraft state, mission plan, digital terrain elevation data (DTED), and guidance algorithm control data to generate the trajectory output. The VME then stores the trajectory and passes it as well as the current aircraft state information to the Silicon Graphics at a synchronous 20 Hz rate through the SCRAMNet interface for pilot display. Control of the CALAHF system is through the CDUs located both in the pilots console and engineers station. The CDUs allow mode control, selection of CALAHF flight and display parameters, and mission plan editing.

The navigation integration includes a P-Code GPS to provide high accuracy positional data, and an INU to provide high rate aircraft state information. The navigation software filters and smooths the GPS and INU data providing a continuous output for pilot display. The navigation software on the VME receives the aircraft state data from the GPS at 1 Hz and the INU at 32 Hz via the 1553B. The filters difference the 1 Hz positional information from the GPS and the corresponding INU information to determine latitude, longitude and altitude corrections. The corrections are then ramped back into the INU at 8 Hz rate. Thus the navigation solution for the INU has the accuracy of P-Code GPS in near continuous time (32 Hz).

The helmet mounted display system includes the IHADSS and the Silicon Graphics computer. The IHADSS provides the actual helmet display device and the head positioning data, Fig 6. The Silicon Graphics workstation is the symbol generator containing the software that generates the display symbology shown previously in Fig. 3. The Silicon Graphics computer provides display symbology to the IHADSS via an RS-170 video interface.

A color digitized paper map of the flight test area is generated by an 386 AT PC and presented in the cockpit on a sunlight readable color monitor manufactured by Smith Industries. Superimposed on the map is the current mission plan, helicopter position and the guidance trajectory. The map allows the pilot to maintain a global mission perspective. An automated mission planning and replanning capability is provided by an IBM PS2 computer[11].

The NUH-60A STAR helicopter has a self contained data recording capability. Aircraft state sensor information such as latitude, longitude, altitude, pitch, roll, yaw, airspeed, radar altitude, pilot control inputs, and ground speed are recorded on a VME battery backed-up memory board. Which is transferred to digital tape upon mission completion. The computed trajectory information as well as pilot tracking performance are also recorded. This digital information is recorded at the 20 Hz system rate. Video information from an aircraft nose mounted FLIR Systems, FLIR 2000 Forward Looking Infrared (FLIR) system with superimposed HMD symbology is recorded on a video tape recorder (VTR). Aircraft communications are also recorded on the VTR.

FLIGHT EVALUATION

A flight test evaluation of the CALAHF system has just initiated its data collection phase with the first data collection flight on July 22, 1992, conducted in a rugged, mountainous, uninhabited region just south of Carlisle, Pennsylvania, USA. A DMA data base for the area, covering 77°45' to 77°00' West longitude by 39°45' to 40°15' North latitude was obtained for the evaluation. The terrain is fairly rugged with hills ranging from 150 to 760 meters throughout the test range. A series of waypoints connected by straight lines were selected as the flight test course. Fig. 7 shows the predesignated route of flight superimposed with an actual trajectory flown by the test aircraft over a contour map of the test area.

Five pilots representing the U.S. Army from AVRADA and NASA at Ames Research Center were selected for the flight test. Each of the pilots participated in the simulation program and has a wide range of flight experience in conventional, research and tactical flight regimes. For the flight test, the project pilot was seated in the left seat and a safety pilot was in the right seat of the aircraft. The project pilot's sole function was to fly the aircraft using IHADSS and the CALAHF symbology. The safety pilot was responsible for overall aircraft control, communications, and any other necessary cockpit function. The flight engineer, seated aft, was responsible for data collection and overall project control.

The two primary objectives of this initial flight test phase were: 1) establish the functionality of the CALAHF system in terms of its accuracy in tracking a vertical terrain profile and horizontal viability of its flight path trajectory, and 2) evaluate the test pilots ability to track the CALAHF symbology. Each of the 5 pilots flew the baseline flight test matrix shown in Table 1, providing a wide array of tracking performance data. The the runs were started with the trajectory guidance information displayed on the IHADSS along the first leg of the reference course. The task was to track, precisely and safely, the flight path vector/predictor and phantom aircraft. Pilot and system tracking performance in the vertical and horizontal axis were measured by comparison of the trajectory generated by the guidance algorithm with the actual trajectory flown by the pilots. A typical run was approximately 20 to 30 minutes long. The test pilot flew no more than three consecutive runs, thus eliminating variations in flight performance due to fatigue. The data collected during the flight test were compared with the piloted simulation data discussed earlier.

RESULTS AND DISCUSSION

The system has flown a limited subset of the full test matrix. The results presented here will focus on the functional aspects of the CALAHF system.

Shown in Fig. 7 is a contour map of the flight test area south of Carlisle, Pennsylvania, USA. The mission waypoints, nominal reference path and a sample flight test profile are shown on the map. It can be seen that the CALAHF system followed the mission plan but utilized terrain features to maintain a lower altitude profile whenever possible.

Fig. 8 shows a typical flight in the vertical axis. Both aircraft altitude (commanded and actual) as well as terrain (predicted and actual) are presented. The predicted terrain is determined by the aircraft's precision navigation system and the digital terrain database, and the actual terrain as determined by the aircraft's radar altimeter and its GPS derived mean sea level position. The CALAHF system tracked the predicted terrain reasonably well, however, there are sections where the predicted terrain and actual terrain differ on the order of 60-90 meters. The database accuracy is a major issue with any database-derived guidance system. The effect of terrain discrepancies can be reduced in three possible ways. The first is to fly the system at an altitude greater than 90 meters above the ground. A second approach is feedback radar altimeter information into the vertical trajectory to compute a vertical bias. This approach is thoroughly discussed in [12] where a Kalman filtered was used to integrate radar

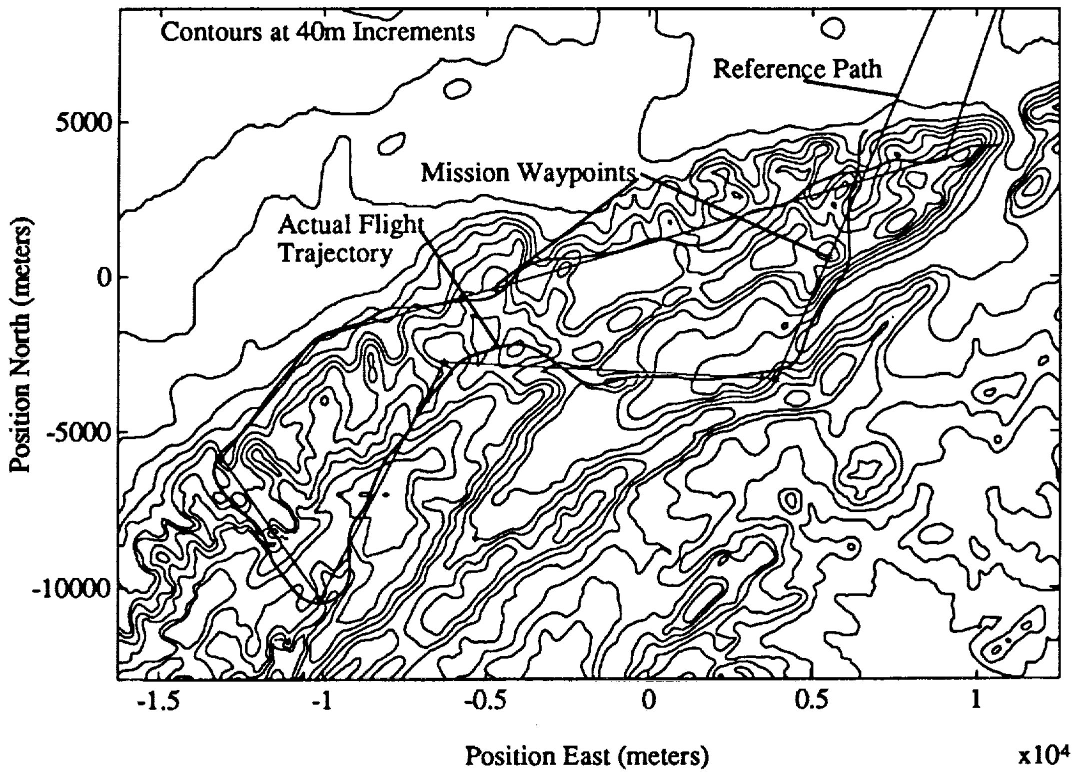

Figure 7 Contour map with mission plan and flight trajectory

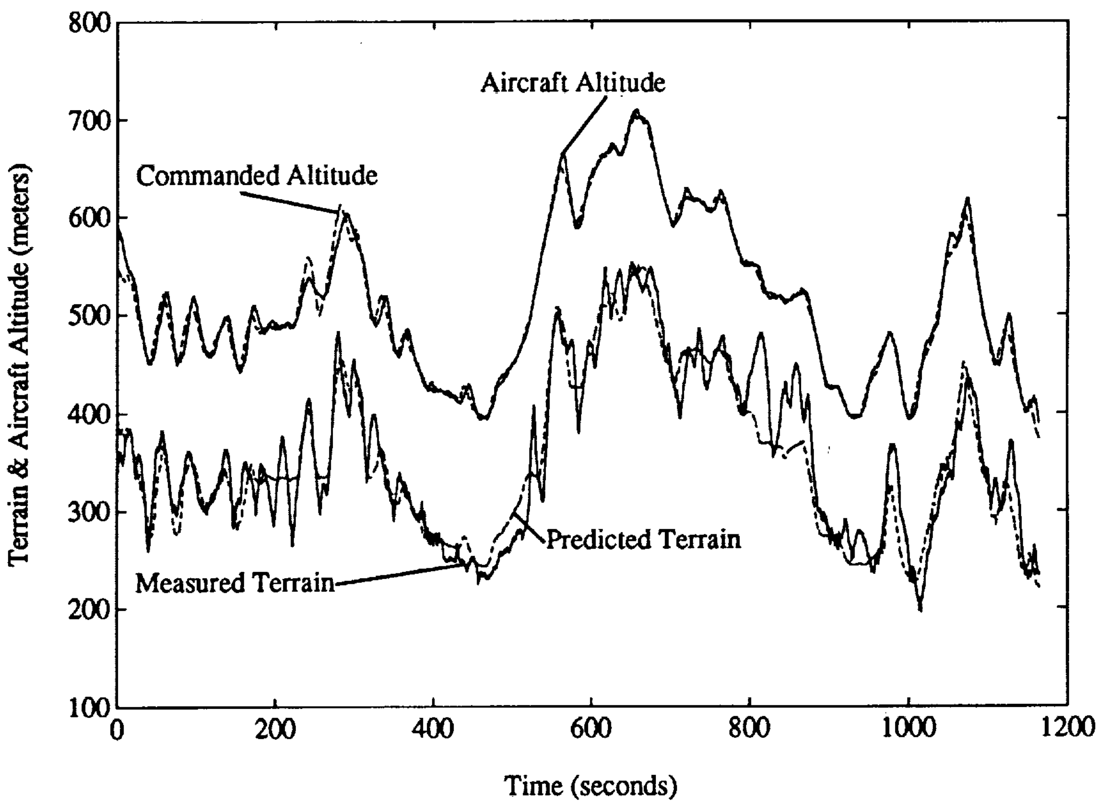

Figure 8 Example vertical trajectory and terrain profile

Table 1 Engineering Evaluation Test Matrix

Flight Plan	Airspeed (knots)	Set-Clear Altitude (ft AGL)	Max Bank (deg)	MaxClimb (deg)	Lead A/C Time (sec)	Pathway 10 lines Pac-Man	TFTA Ratio
Carlisle	80	300	20	6	4	10 lines	TF
Carlisle	80	300	20	6	4	10 lines	TFTA .1
Carlisle	40	300	20	6	4	10 lines	TFTA .1
Carlisle	110	300	20	6	4	10 lines	TFTA .1
Carlisle	80	300	30	6	4	10 lines	TFTA .1
Carlisle	80	300	20	9	4	10 lines	TFTA .1
Carlisle	80	300	20	6	3	10 lines	TFTA .1
Carlisle	80	300	20	6	5	10 lines	TFTA .1
Carlisle	80	300	20	6	4	Pac-Man	TFTA .1
Carlisle	80	300	20	6	4	10 lines	TFTA0.5
Carlisle	80	150 RAE*	20	6	4	10 lines	TFTA .1
Carlisle	80	100 RAE*	20	6	4	10 lines	TFTA .1

*RAE is Radar Altimeter Enhanced based upon reference [12]

altimeter, precision navigation and digital terrain data for improved vertical performance. The algorithm presented in [12] was validated with actual flight data in an off-line analysis and the results suggest a 15 meters set clearance may be used subject to obstacle avoidance limitations. The final improvement would be to obtain a more accurate terrain database. For the initial test, the set clearance was limited to 90 meters, the radar altimeter feedback system will be integrated in the near future, and the U.S. Army in cooperation with the U.S. Air Force are currently mapping the test area to produce a higher accuracy terrain database.

As well as overall system performance, such as mission completion and terrain usage, consideration needs to be made for the pilots ability to track the system. The lateral, vertical, and terrain tracking performance for a few representative test configurations are shown in Fig. 9. The figure shows the mean and 1-sigma tracking error for four of the configurations tested to date. Also shown in the figure are corresponding results from piloted simulations using the CALAHF system. Flight test and simulation results are consistent in lateral tracking performance with less than ±10 meters 1-sigma deviation from the commanded trajectory as shown in Fig. 9(a). The notable exception is the flight at 60 knots. At 60 knots the test aircraft's flight control system transitions between heading hold and turn coordination requiring more pilot compensation. Even at 60 knots the pilots tracked the system within 20 meters (or approximately 1 rotor diameter) 1-sigma of the desired trajectory.

For the initial flight test runs vertical pilot tracking performance was much worse than simulator performance. This is attributed to two factors. The small over shoots at terrain peak crossings (Fig. 8) were attributed (by the pilots) to a coupling effect of airspeed, power, and altitude during climb up one hill side and reduction of power to descend down the backside. The pilots felt that on these initial flight tests, they were not able to track these reversals fast enough. The second factor is that the pilots may still be on the learning curve for the flight system as opposed to the simulation results. Even with these two factors the vertical tracking performance is within ±15 meters 1 sigma from the desired flight path as seen in Fig. 9(b).

Fig. 9(c) is the statistical variation of the difference between radar altitude and set clearance over a particular test run. Some variation is expected as seen from the simulation data. Also, the CALAHF system does not require the pilot to match every bump in the terrain and a climb performance limitation is imposed on the system. These factors though are overwhelmed by the terrain errors discussed earlier causing a three fold increase in terrain tracking variation as compared to simulation data in the rugged flight test area.

CONCLUSIONS

A low-altitude, covert terrain following/terrain avoidance guidance algorithm for helicopter operations has been developed and flight tested on a NUH-60A helicopter. Initial evaluation of the data reflect that the guidance system could be used reasonably well to track a predesignated course using the terrain for masking in the horizontal and vertical axis. However, the inaccuracy in the DMA database (compared to the actual terrain) mandated a clearance altitude of at least 90 meters in rugged terrain. As DMA data become more accurate and radar altimeter information is fully utilized, the present clearance altitude may be lowered to 15 meters. The pilots were able to follow the computer-aided flight guidance symbology with relative ease and precision.

Comparison of flight and simulation data shows good

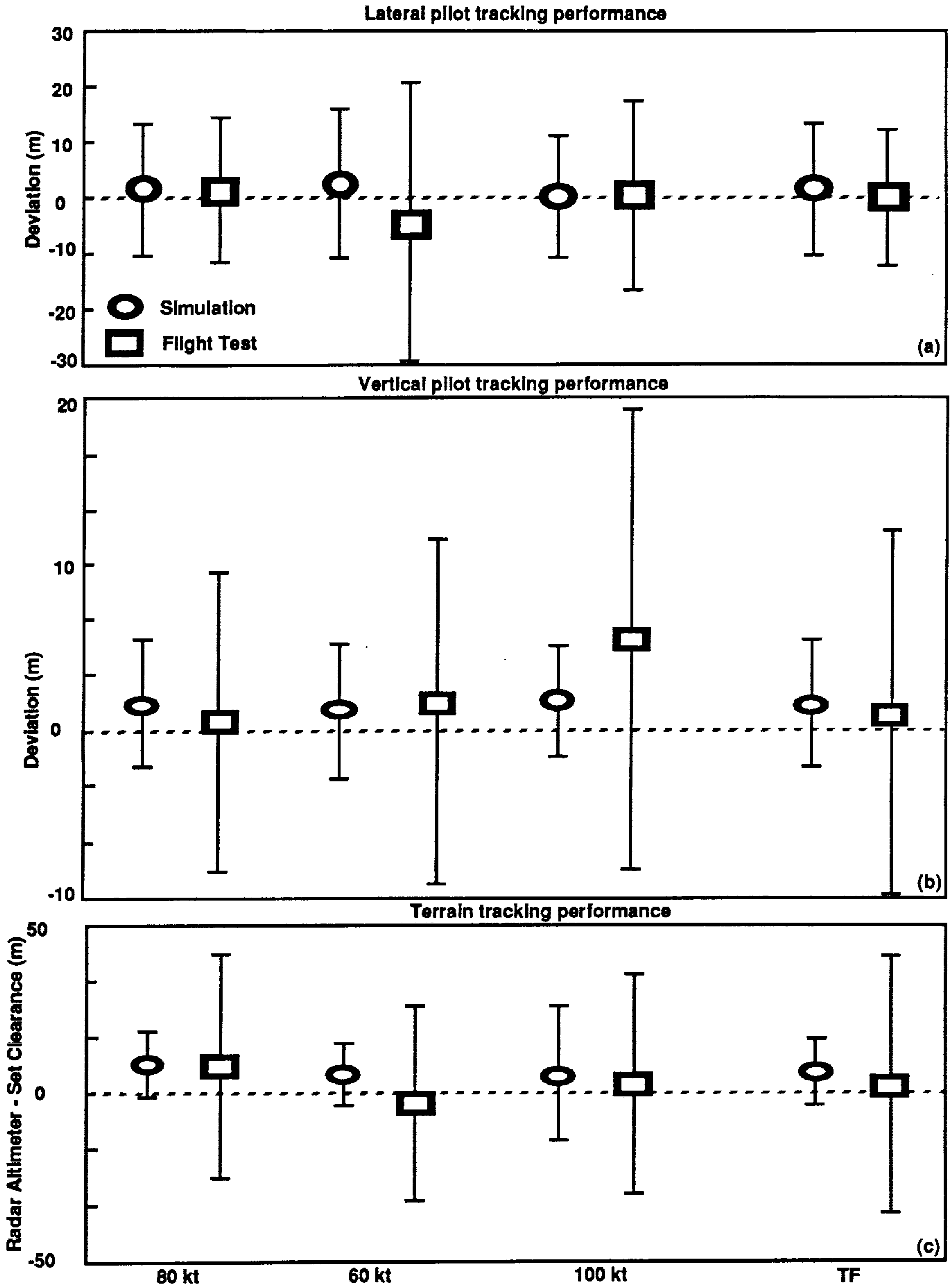

Figure 9 Flight test & simulation statistical comparison

correlation for lateral tracking performance but significant increase in vertical tracking deviations. The major reason for this increase is that airspeed, power and altitude changes seemed to be more highly coupled in the aircraft than during simulation. Another reason is the current analysis is based upon the initial data collected and may not reflect the relative growth in pilot learning as does the simulation data.

Pilot feedback from these initial flights indicates that the guidance system can be followed with low pilot compensation and with minimal distraction from his general situational awareness. This system allows the pilot to combine guidance information with his visual senses to optimize the successful accomplishment of the mission. The Computer-Aiding for Low-Altitude Helicopter Flight System has matured through extensive use of piloted simulation, integration into the NUH-60A STAR helicopter, and recent flight test and evaluation in the rugged terrain of Carlisle Pennsylvania. Future flight tests will include the use of operational pilots from U. S. Army line units using the system in terrain flight missions.

REFERENCES

[1] Sridhar, B., Cheng, V.L., and Swenson, H.N., "Status of Automatic Guidance Systems for Rotorcraft in Low Altitude Flight," AGARD CP-504, Oct. 1991.

[2] Clifford, J.E., "PAVE LOW III A Long Awaited Capability, Lessons Learned and Projections," IEEE National Aerospace and Electronics Conference (NAECON), Dayton OH, May 1979.

[3] Russ, D.E., Houtz, J.E., and Rothstein, S.W., "Evaluations of Alternate TF/TA System Designs Using Pilot In The Loop Simulations," AGARD CP-387, Oct. 1985,

[4] Dorr, D.W., "Rotory Wing Aircraft Terrain Following/ Terrain Avoidance System Development," AIAA Guidance Navigation and Control Conference, Aug. 1986.

[5] Swenson, H.N., Hardy, G. H., and Morris, P. M., "Simulation Evaluation of Helicopter Terrain Following/ Terrain Aviodance Concepts," AIAA/IEEE 8th Digital Avionics Systems Conference, Oct. 1988, San Jose, CA.

[6] Swenson, H.N. "Computer Aiding for Low-Altitude Helicopter Flight," American Helicopter Society's 46th Annual Forum, Phoenix AZ, May 1991.

[7] Swenson, H.N., Zelenka, R.E., Hardy, G.H., and Dearing, M.G., "Simulation Evaluation of a Low-Altitude Helicopter Flight Guidance System Adapted for Helmet-Mounted Display," AIAA/IEEE 10th Digital Avionics System Conference, Los Angles CA, Oct. 1991.

[8] Denton, R. V., Froeberg, P.L., Jones, J. E., and Nikoukhah, R., "Terrain Following/Terrain Avoidance Algorithm Study," AFWAL TR-85-3007, May 1985.

[9] Denton, R. V., Pekelsma, N.J., and Smith, F. W., "Autonomous Flight and Remote Site Landing Guidance Research for Helicopters," NASA CR-177478, May 1987.

[10] Operator's Manual NUH-60A Helicopter, U.S. Army Avionics Research and Development Activities TM-55-1520-237(ADAS)-10, Ft. Monmouth, NJ, jan. 1987.

[11] Male,H., Kurshner, M., Anello, S.F., "Integration of an On-Board Route Planner for Helicopter Applications," IEEE/AIAA 11th Digital Avionics Systems Conference, Seattle WA, Oct. 1992.

[12] Zelenka, R.E., "Integration of Radar Altimeter, Precision Navigation, And Digital Terrain Data for Low-Altitude Flight," AIAA Guidance, Navigation and Control Conference, Hilton Head SC, Aug. 1992.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1993	Technical Memorandum

4. TITLE AND SUBTITLE
Flight Evaluation of a Computer Aided Low-Altitude Helicopter Flight Guidance System

5. FUNDING NUMBERS
505-64-36

6. AUTHOR(S)
Harry N. Swenson, Raymond D. Jones,* and Raymond Clark*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER
A-93033

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-103998

11. SUPPLEMENTARY NOTES
Point of Contact: Harry N. Swenson, Ames Research Center, MS 210-9, Moffett Field, CA 94035-1000, (415) 604-5469
Presented at the AGARD FMP/GCP Symposium on "Combat Automation for Airborne Weapons Systems: Man/Machine Interface Trends and Technologies," Edinburgh, Scotland, UK, Oct. 19-22, 1992. *U.S. Army Avionics R&D Activity, Ft. Monmouth, NJ

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited
Subject Category 04

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Flight Systems Development branch of the U.S. Army's Avionics Research and Development Activity (AVRADA) and NASA Ames Research Center have developed for flight testing a Computer Aided Low-Altitude Helicopter Flight (CALAHF) guidance system. The system includes a trajectory-generation algorithm which uses dynamic programming and a helmet-mounted display (HMD) presentation of a pathway-in-the-sky, a phantom aircraft, and flight-path vector/predictor guidance symbology. The trajectory-generation algorithm uses knowledge of the global mission requirements, a digital terrain map, aircraft performance capabilities and precision navigation information to determine a trajectory between mission waypoints that seeks valleys to minimize threat exposure. This system has been developed and evaluated through extensive use of piloted simulation and has demonstrated a "pilot centered" concept of automated and integrated navigation and terrain mission planning flight guidance. This system has shown a significant improvement in pilot situational awareness, and mission effectiveness as well as a decrease in training and proficiency time required for a near terrain, nighttime, adverse weather system.

14. SUBJECT TERMS
Helicopters, Flight test, Terrain flight guidance, Helmet-mounted displays

15. NUMBER OF PAGES
14

16. PRICE CODE
A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		