NASA Technical Memorandum 100017

USAAVSCOM Technical Report 87-A-9

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ADVANCED HELICOPTER COCKPIT AND CONTROL CONFIGURATIONS FOR HELICOPTER COMBAT MISSION TASKS

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SUMMARY

Two piloted simulations were conducted by the U.S. Army Aeroflightdynamics Directorate to evaluate workload and helicopter-handling qualities requirements for single pilot operation in a combat Nap-of-the-Earth environment. The single-pilot advanced cockpit engineering simulation (SPACES) investigations were performed on the NASA Ames Vertical Motion Simulator, using the Advanced Digital Optical Control System control laws and an advanced concepts glass cockpit. The first simulation (SPACES I) compared single pilot to dual crewmember operation for the same flight tasks to determine differences between dual and single ratings, and to discover which control laws enabled adequate single-pilot helicopter operation. The SPACES II simulation concentrated on single-pilot operations and use of control laws thought to be viable candidates for single pilot operations workload. Measures detected significant differences between dual- and single-pilot operation and between single-pilot task segments. Control system configurations were task dependent, demonstrating the need for an inflight reconfigurable control system to match the optimal control system with the required task.

GLOSSARY

ADOCS advanced digital optical control system

AGL above ground level

ARTI advanced rotorcraft technology integration

ARMCOP Army copter

ASE aircraft survivability equipment

AT/AT attitude command/attitude stabilization (hold)

AT/VH attitude command/velocity hold

CGI computer generated imagery

CRT cathode ray tube

CSRDP crew station research and development program

E&S Evans and Sutherland

FPM flightpath management

HAC helicopter air combat

HQR handling quality rating

HUD head-up-display

KIAS knots indicated air speed

LHX light helicopter family

MM mission management

MMD mission management display

NASA National Aeronautics and Space Administration

NOE nap-of-the-Earth

OGE out of ground effect

RT/AT rate command/attitude stabilization (hold)

SPACES single pilot advanced cockpit engineering simulation

SWAT subjective workload analysis technique

TSD tactical situation display

UH-60 U.S. Army Utility Helicopter - 60 (Blackhawk)

VMS Vertical Motion Simulator

1. INTRODUCTION

The missions, tactics, and crew-task demands of the Army helicopter operations have undergone rapid and extensive change. One such change is the emphasis to fly only a few feet above the terrain and as close as possible to obstacles for maximum protection from perceived air defense threats. Given past technology, both pilot and co-pilot workload is high during NOE flight. For one pilot to perform both flightpath management and mission management, both tasks will have to be simplified or automated to achieve adequate performance.

The overall problem is to define aircraft stability, control, and performance characteristics, that when combined with the appropriate cockpit devices (e.g. integrated CRTs, helmet-mounted displays, touch-pads, voice input/output, moving map displays), allow adequate mission and flight performance. Several efforts have been underway to address these broad advanced rotorcraft issues such as the ARTI program (Ref. 1), the CSRDP (Ref. 2), development of the ADOCS (Ref. 3), and on-going work to rewrite the rotorcraft handling-qualities specification MIL-H-8501 (Ref. 4).

The SPACES experiments grew primarily from the desire to initiate the development of a single-pilot data base for the Army's LHX program. Previous handling-qualities specifications data and pilot compensation data were generated primarily in a two-crew context; that is, the evaluation pilot has been requested to perform only flightpath management tasks. A single-crew LHX pilot would have to simultaneously perform all the flightpath management tasks plus the mission management tasks previously performed by the co-pilot or other crew member, thus affecting performance.

SPACES I experiments were exploratory looking at 20 flight-control configurations in a single-pilot and a dual-pilot mode to help determine which combination(s) were most effective for tasks performed. The results from the first SPACES experiment are reported in Haworth, et al. (Refs. 5 and 6). The dual-pilot evaluations, with mission management tasks removed, served for baseline data collection and for comparison with single-pilot ratings during SPACES I. The SPACES II evaluation concentrated on single-pilot operation using the two best-rated systems from the SPACES I experiment and two additional control-response types. The two additional response types were thought to have potential for single-pilot operation based on flight tests for the proposed N8501 LHX Handling Qualities Specification (Ref. 7).

2. PURPOSE

The primary purpose of the SPACES effort was the investigation of single-pilot performance in the combat low-level and NOE flight environment using advanced rotorcraft cockpit and control law concepts. More specifically, these were investigations of the effects of adding mission management tasks to flightpath management tasks to simulate single-pilot operations in an advanced concepts cockpit.

3. FACILITY

3.1 Vertical Motion Simulator

The SPACES investigations were conducted in the NASA Ames VMS facility shown in Fig. 1. The simulator has a large-amplitude motion system with six degrees of freedom. The VMS is capable of large excursions in translational motion in two of the three axes (Z and either X or Y depending on cab alignment) and limited rotational motion. The pilot cab is mounted on a hexipod which provides the rotational motion and very limited translational motion. The pod is mounted to a carriage which is motorized and travels along the large horizontal beam. A rack and pinion gear system provides X or Y motion; and the large horizontal beam is moved in the Z direction by two large rams mounted under the beam.

3.2 Simulation Visual Model

The visual display consisted of a four-window CGI system (Fig. 2) utilizing the HAC data base (Ref. 8). The HAC data base with supporting CGI models provided moving visual ground and air threats for combat realism and forced task time lines. The primary visual ground threat was a ZSU-23-4 that was programmed to follow up to six paths through the data base. The ZSU-23-4 was also programmed to acquire and fire at the own ship (the piloted simulated helicopter) following acquisition logic when line of sight existed with the own ship. The visual air-to-air threat was a HIND-A helicopter that was modeled to fly multiple low-level flightpath routes.

In addition to threat/targets, special effects were added to the data base. Tracers were simulated when the gun was fired, a missile flash was simulated for missile launch, target hits were displayed, and air defense artillery bursts were simulated for visual indications of enemy fire. Own ship destruction from weapons firing was indicated by graphically drawn cracks on the HUD. Appropriate sound cues were coupled to the visual effects.

Visibility was reduced to 2 kilometers at the surface of the data base with a simulated cloud ceiling at 200 ft above the data-base floor. This simulated adverse weather, and forced low-level air-to-air engagements and operations. Wind and turbulence were also introduced during the simulation helping to demonstrate the usefulness of Earth-referenced stability systems for low-airspeed and hover tasks.

3.3. Advanced Glass Cockpit Hardware

The SPACES glass cockpit was designed to emulate a limited number of fundamental augmentation/automation concepts for advanced rotorcraft. Prior ADOCS experiments on automated/augmented control design and the design of an advanced concepts cockpit based on LHX/ARTI cockpit proposals served as the design framework and transition for the SPACES development. The physical cockpit design (Fig. 3) incorporated two CRTs and a HUD, programmable switches, touchscreens, data-entry device, voice output system, and side-arm flight controllers.

The HUD (an E&S Picture System One) was placed directly in front of the pilot. The HUD visually overlaid 90% of the center CGI CRT allowing the pilot to maintain visual contact outside the aircraft during low-level flight. Navigation, caution indicators, weapon status, and essential flight information were presented on the HUD for single-pilot operation. A line drawing of the aircraft and weapon stores remaining was shown on the lower part of the HUD.

The upper 13-in. CRT, called the TSD, shown in Fig. 4, presented a moving map display of the HAC data base and essential situational information. Map information included navigation routes, terrain features, cultural features, grid lines, and threat and friendly positions. An own-ship helicopter symbol was centered on the map and moved as the aircraft changed position and heading. Declutter features allowed the pilot to remove unwanted symbols and grid lines for detailed observations of desired map areas. A zoom feature allowed the pilot to zoom in and out from overhead as necessary for local area viewing. Line-of-sight indication was displayed on the moving map by use of a connecting red line between the threat and the own ship.

The lower 9-in. CRT, termed the MMD, was touch sensitive for pilot interaction. This display presented aircraft and weapon status, system menu items, situation reports, mission updates, and other needed text information. The interactive screen on the MMD was also used by the pilot to update waypoints on the TSD. In a degraded aircraft-system mode, the MMD displayed appropriate checklists for pilot action.

Other cockpit hardware included the programmable switches, voice output system, and data-entry keyboard. Twelve programmable micro-switches were situated around the TSD to supplement the menu selections found on the MMD and allowed for discrete activations of aircraft systems such as the landing gear, weapon systems, and aircraft survivability equipment. A voice recognizer and a personal speech system were planned for use for pilot-voice input/output interaction. Most of the reactive menu items found on the MMD were programmed to be selectable with use of the voice system, but technical difficulties and developmental time prevented use of the input system. Voice output from a Votrax provided voice warnings and caution messages along with checklist confirmation during routine and degraded operations. The data-entry device located near the left flight controller allowed for pilot-entered data-burst transmissions for tactical intelligence and mission updates.

Adjustable side-stick controllers were mounted on both sides of the pilot seat. The controller configuration for SPACES was a 2+1+1 limited-displacement controller setup (Fig. 5), patterned after the ADOCS Phase 2 configuration. The right-hand side-stick force controller was longitudinal and lateral cyclic control, and the left-hand side-stick force controller was collective. The force pedals with small displacement were used for directional control. A trim button was mounted on the top of the right hand controller during SPACES II for use with the attitude stabilization systems. A trigger release for gun firing and missile launch was mounted on the forward part of the right-hand grip. The left-hand controller, in addition to the action bar for collective activation, had two buttons and a proportional control switch on top of the grip. The upper-left button cycled the HUD configurations, the upper-right button was the switch to activate position control laws and the proportional switch was used to slew the missile pod up and down for targeting during SPACES II.

3.4. Mathematical Models

The mathematical model was the ARMCOP 10-degree-of-freedom helicopter model configured as a UH-60 (Refs. 9,10). The rotor model assumed rigid blades with rotor forces and moments radially integrated and summed about the azimuth. The fuselage aerodynamic model used a detailed model representation over a nominal angle of attack and sideslip range of ±15°. A simplified curve fit operated at large angles of attack or sideslip. Parameters from the UH-60 were used in the model along with developed stabilator control laws.

3.5. Advanced Digital Optical Control System

The flight control system used for the SPACES was the ADOCS design with only slight modifications. Basically the control system was a model-following system with feed-forward shaping and feedback. In the ADOCS nomenclature, the systems are referred to as command/stabilization but are thought of as command/hold by the research community. Two basic ADOCS control-response types were selected for SPACES I and four for SPACES II.

The basic control laws for the SPACES I investigation were the ADOCS hybrid control system (Table 1) and the ADOCS AT/AT for both the longitudinal and lateral axes. In addition to the two SCAS, the following selectable modes were available: 1) turn coordination, 2) heading rate command/heading hold, 3) altitude rate command/altitude hold, 4) airspeed hold (hybrid system only), and 5) position hold (hybrid system only). The vertical control system consisted of a vertical-acceleration command/vertical velocity-stabilization system. The yaw axis was a yaw-acceleration command/yaw-rate stabilization system for low-speed and forward flight. The flightpath control configurations for SPACES I are listed in Table 2.

SPACES II added two new concepts to the test matrix. The additions were an RT/AT system patterned after the ADOCS system, but with the hover hold/position hold added and a modification of the AT/AT system. The modified system was AT/AT in longitudinal and RT/AT in roll with hover hold/position hold added. The SPACES II configurations are summarized in Table 3.

4. SUBJECTIVE DATA COLLECTION TECHNIQUES

Three subjective ratings were used during the investigations: 1) The Cooper-Harper HQR scale (Ref. 11), 2) SWAT (Ref. 12), used as a technique to obtain workload ratings during the actual performance of a task, and 3) The Weighted Bipolar Rating Technique developed at the NASA Ames Research Center to record the multidimensional nature of mental workload (Ref. 13).

The SWAT and Bipolar workload data collection was performed to gather additional information that may have not been collected by use of the HQR scale itself. Additionally, the ratings were collected to determine the correlation between the three scales and usefulness of the scales as workload measures.

5. CONDUCT OF THE EXPERIMENT

5.1. General

Army engineering test pilots participated in the SPACES experiments. The pilots flew identical control configurations and performed the same flightpath management tasks in both the dual- and single-pilot role for SPACES I. An experienced Army aviator in the simulation control room montoring the cockpit and CGI visual, acted as the second crew member and conducted mission management functions (co-pilot duties) for the dual pilot setting for SPACES I. The simulator pilot in the dual-pilot context operated as the flightpath manager maintaining flightpath control of the simulated vehicle similar to traditional handling qualities investigations.

Only the single-pilot operation was investigated in SPACES II. For single-pilot operation in both investigations, the simulation pilot was required to perform both flight path management and mission management tasks. This included flight maneuvering plus concurrent operation on a tactical communications network (Fig. 6), navigation, threat avoidance and countermeasures, selection of firing points, planning of engagement tactics, and weapons selection and firing.

5.2. Scenario

The basic mission scenario (Fig. 7) was to depart a forward refueling point and fly a series of way-points (while evading threat detection and engagement) to arrive at a firing position, and then perform reconnaissance and subsequent air-to-ground attack tasks. After the ground engagement and damage assessment, the pilot was informed of a threat helicopter penetration which led to an air-to-air engagement with the threat helicopter. During these activities, the crew was also occupied with communications, navigation, reconnaissance, targeting, aircraft survivability equipment (ASE) and other related mission management tasks.

Operation in the total scenario was approximately 20 minutes in length. Way points, threat aircraft routes, communications, and the threat laydown were varied at the end of each run to reduce learned responses for single pilot operation.

5.3. Data Collection

Data collection was divided into four scenario phases: 1) NOE low-level flight, 2) hovering reconnaissance, 3) air-to-ground attack, and 4) air-to-air engagement. The phases were designed to coincide with specific flight tasks maneuvers such as precision hover, bob-up and bob-down. Cooper-Harper HQRs and SWAT ratings were obtained from the pilot for the specified maneuvers at the completion of each scenario phase. Bipolar workload ratings were collected after all daily scenario phases were completed. Each of

the above scales are designed to measure pilot compensation and workload. Specific statistical information was obtained at the end of each scenario run.

6. RESULTS

The ratings obtained during dual-pilot operation signify performance of distinct flightpath management tasks. Ratings from single-pilot operation represent the result of imposing mission management tasks onto the flightpath management tasks. SWAT and bipolar ratings and figures are specifically contained in pilot-workload analysis section of this paper.

6.1. Nap-of-the-Earth/Low-Level Flight

For consistent task-measure comparison, dual-pilot ratings were gathered on a portion of a familiar low-level course where the pilot was instructed to maintain 60 ±5 KIAS and a variable altitude of 50 ft or less AGL. Single-pilot ratings were given for low-level flight routes at 60 ±5 KIAS while the pilot performed mission management tasks such as navigation, navigation update, communications, and use of threat countermeasures. Average single and dual pilot HQRs for selected ADOCS control systems for SPACES I and II are presented in Figs. 8, 9, and 10.

When comparing all dual-pilot and single-pilot HQRs obtained during SPACES I for NOE flight, the single-pilot ratings averaged 2.2 ratings worse than dual-pilot ratings overall, indicating degraded flightpath performance and higher pilot workload. Only configuration HB with AT/VH in pitch and RT/AT in roll received satisfactory handling qualities (HQRs less than 3.5 are considered satisfactory of Level 1) for single-pilot operation in the low-level environment. All 10 of the hybrid configurations flown "dual" received satisfactory ratings. Configuration HB was the best rated ADOCS hybrid system with altitude hold, and turn coordination in forward flight.

Altitude hold appeared to be significant for reducing workload and HQRs during the SPACES I studies. The altitude hold feature was common to the better rated configurations and served to reduce pilot compensation and workload by providing vertical terrain avoidance. It is predicted that terrain/obstacle avoidance in the lateral direction if implemented will most likely result in further reduction of workload.

For the SPACES II simulation, the same configuration as reported in SPACES I with AT/VH in pitch and RT/AT in roll received satisfactory (Level 1) average pilot ratings. For a similar system (AT/AT) without velocity hold in pitch but with RT/AT in roll, the average rating was Level 2, but close to the Level 1 limit. The configurations with RT/AT or AT/AT in both pitch and roll were solidly Level 2. This verifies results obtained in SPACES I that velocity hold is important for single-pilot NOE, low-level constant-airspeed flight modes. The same requirement does not exist for dual-pilot modes with the pilot acting only as the flightpath manager.

6.2. Air-to-Ground Engagement

The air-to-ground engagement occurred in hovering unmasked flight. In the dual-pilot situation, the pilot received and followed instructions from the co-pilot/researcher as to the attack position, target identification, azimuth pointing, selection of weapon, target acquisition, and when to fire. The single pilot performed the above tasks, including communications without the aid of a second crewmember. The specific targeting flight task was to maintain an unmasked hover altitude in line of sight of the ground target, slew in the direction of the target, overlay the HUD sighting reticle on the target within ±1° for 1 sec, and then maintain the target within ±3° of the reticle for an additional 2 sec. HUD symbology changes and audio tones indicated when lock-on and launch parameters were met. If line of sight existed with the ZSU-23-4 ground target for a specified amount of time after unmasking, the ownship was fired upon and hit resulting in forced time lines for target acquisition similar to real-world considerations.

For SPACES I (Fig. 11) the average differential in HQRs between single- and dual-pilot conditions were slightly more than one half of a rating point with the single-pilot condition being higher (degraded). This general trend probably reflected that the targeting task could not be completely off-loaded from the pilot in the dual-pilot situation, and/or that the given display features of the cockpit enabled the pilot to perform the task faster and better without the interference of verbal crewmember input. Three control configurations in SPACES I were rated satisfactory for dual-pilot operation in the air-to-ground attack task as presented in Fig. 11. These were configurations AG, AH, and HB with configuration HB receiving the best average HQR of 2.4. Each of the Level 1 dual-pilot configurations had two features in common: altitude hold and heading hold. Configuration HB was the only configuration that received average Level 1 ratings in both the dual-pilot and single-pilot conditions for the air-to-ground engagement task. The lowered ratings for the HB configuration were probably due in part to the position hold feature which is a element of that configuration. Since the ground-attack task for SPACES I was essentially one of bob-up and stabilizing on the target, the position hold feature was considered an enhancing feature.

The SPACES II air-to-ground attack maneuvers were generally more dynamic than SPACES I. In SPACES I the threat location on the moving map display was constantly updated and the pilot was able to plan firing locations. During SPACES II the threat location was not indicated on the moving map display until line of

sight existed with the threat. Once line of sight existed the pilot dynamically maneuvered to avoid acquisition and lock on while positioning to target the threat.

The results of the ground-attack phase for SPACES II are presented in Fig. 12. Only the RT/AT response-type received Level 1 average ratings. These results suggest that the attitude response-type (especially in combination with velocity hold) causes a degradation in handling qualities for the ground-attack task. Since the task involved precision pointing, the velocity hold function operated to readjust attitude to maintain groundspeed by commanding pitch and roll attitude changes, in direct opposition to the pilot's need for an attitude-stabilized platform. Both the AT/AT and RT/AT response-types produced attitude changes in direct proportion to cyclic commands, with some slight variation due to gust rejection with a good ability for precise pointing. The RT/AT was more attractive than AT/AT probably because of the requirements for larger control inputs to maneuver and the fact that a constant control force is not required to maintain the selected attitude with the RT/AT system.

6.3. Hovering Flight (Reconnaissance)

After the pilot completed the battle-damage reconnaissance of a specified target area he was required, while at a hover to send a data-burst transmission to update the tactical situation. This forced the pilot to maintain hovering flight and to respond to data-entry prompts on the TSD by using the keyboard near the pilot's left hand. During SPACES I only the ADOCS hybrid system with shown options for hover received acceptable or satisfactory ratings as shown in Fig. 13. The overwhelming option for favorable pilot comments was the position hold feature especially with wind and turbulence present.

One major conclusion of the SPACES I simulation was that the AT/AT response-type was unsatisfactory for the hovering task, while the AT/VH response-type, with position hold, was satisfactory (Level 1). There was no evaluation in SPACES I of an AT/AT response-type with position hold. For SPACES II, such a system was developed. In addition, the RT/AT case was evaluated both with and without position hold during SPACES II.

The position hold feature implemented on the ADOCS flight control system and evaluated during SPACES I was slightly modified for SPACES II: the range for engagement was increased from 3 knots to 5 knots groundspeed. In both simulations, position hold disengaged whenever the pilot applied more than one-half pound of force on the cyclic. When the pilot released the stick after the groundspeed was reduced below 5 knots, the position hold system would reengage. Figure 14 shows the influence of position hold on pilot ratings for the SPACES II hover task. It is evident that all of the response-types were solidly Level 2 when position hold was not available thus verifying the results from SPACES I. For precision hover, position hold is required for Level 1 HQRs in the single-pilot condition when mission tasking is imposed.

6.4. Air-to-Air Engagements

Air-to-air engagements were started from an OGE hover "ambush point." The air-to-air target was a threat helicopter that flew varying-programmed low-level routes, maneuvers, and airspeeds. The initial engagement was normally attempted with the simulated air-to-air missile. As the range to the air threat decreased, the pilot was allowed to select the fixed-gun system because of the increased maneuvering activity. The change over to the fixed gun system occurred when the pilot felt he could no longer obtain the necessary missile launch constraints (same as air-to-ground engagement). For dual-pilot simulations, the experimenter/co-pilot gave the pilot specific locations and tracking information for the threat helicopter until the air-to-air engagement became dynamic enough that the co-pilot was unable to aid the pilot. During single-pilot engagements, the pilot was only given the general location of the helicopter threat via ground and air communications, requiring the pilot to acquire the air target without the aid of a co-pilot.

During the SPACES I simulation, the average range for successful missile engagement was 2328 feet with average range for successful gun engagement approximately one half of that distance. Air-to-air engagements normally lasted less than 20 sec after establishing pilot line-of-sight with the target. Attitude command/attitude stabilization, configuration AH with heading hold and altitude hold (Fig. 15), was rated satisfactory for missile and gun engagements for both dual- and single-pilot conditions. When the hybrid configuration HA system was simulated, all pilots successfully engaged the threat helicopter with air-to-air missile system without reverting to the fixed gun even though this configuration received level 2 rating for the single-pilot condition. The average difference in HQRs, between single pilot and dual pilot, showed the single-pilot handling qualities being only slightly degraded. The air-to-air engagement task was primarily a single-pilot task, because of the required maneuver dynamics, targeting information presented on the pilot displays and short target-acquisition times. Once the air-to-air threat was presented, all other mission tasking was ignored while the pilots in both the dual- and single-pilot conditions concentrated on the target and HUD. For the SPACES II simulation, the results (Fig. 16) show that the RT/AT response-type was preferred by pilots over the attitude systems for the same reasons stated in the air-to-ground section of this paper.

6.5. Pilot Workload Analysis

Both SWAT and the NASA bipolar workload techniques revealed a higher level of pilot workload for the single-pilot configuration than the dual-pilot configurations as shown in Fig. 17. The techniques also distinguished between control configurations and showed differences between segments in the single-pilot

configuration. However, neither technique showed significant differences between segment tasks in the two-pilot arrangement. This indicated that the addition of a second crew member served to smooth out workload peaks and thereby reduced the differences between the workload of the flight segments. In reviewing the results and similarity between the SWAT and Bipolar subjective workload techniques, the correlation between the two is significant at $R = 0.67$. As expected both techniques were significantly correlated to the Cooper-Harper HQRs at $R = 0.75$ and $R = 0.79$, respectively for the Bipolar and SWAT.

Differences between dual- and single-pilot ratings on all scales were relatively small for both the air-to-air and air-to-ground engagements as found with the HQRs. The above tasks, although aided by the co-pilot/experimenter in the dual-pilot condition, were essentially single-pilot tasks because of the short time line for crew coordination, nature of the targeting task, and advanced cockpit informational presentation that supplied visual targeting indications to the pilot.

7. CONCLUSIONS

7.1. General

As predicted, superimposing mission management tasks on flightpath management tasks result in degraded pilot HQRs and higher pilot compensation and workload. Because of the close proximity of obstructions in the low-level and NOE flight environment, constant flightpath supervision is required. The addition of mission management tasks further increases pilot attentional demands, contributing to operator overload and reduced flightpath performance. Handling quality rating, SWAT, and bipolar measures were sensitive to differences in pilot compensation and performance between the single-pilot and dual-pilot conditions and between single-pilot task segments. Significant differences did not exist between task segments in the dual-pilot condition since the addition of the second crewmember smoothed out workload peaks.

7.2. Nap-of-the-Earth/Low-Level Flight

1) Airspeed hold was preferred over attitude hold in NOE/low-level flight. However, this probably reflected the task constraint requiring the pilots to maintain a constant airspeed for consistent task measure comparison. Holding constant airspeed is more reflective of low-level flight than of NOE dynamic maneuvering in which airspeed is constantly varied.

2) Altitude hold was also significant in reducing pilot compensation during NOE low-level flight. Altitude hold allowed the use of the pilot's left hand for mission tasks and provided limited vertical terrain avoidance, especially when the pilot was unable to constantly monitor altitude as a consequence of mission tasks. It is predicted that the addition of lateral terrain/obstacle avoidance system would further produce a reduction in piloting workload for NOE flight traveling.

3) The use of a rate command/attitude hold control response-type should be further investigated for use in the NOE maneuver environment where the pilot is not constrained by holding constant airspeed. Observations made during SPACES II indicated that rate command/attitude hold may be a preferable system for the NOE dynamic flight when combined with limited displacement side-arm flight controllers.

4) Attitude command/velocity hold in pitch, combined with rate command/attitude hold in roll for bank-angle hold was considered satisfactory for single-pilot low-level flight under the conditions tested.

5) Turn Coordination in forward flight at 60 knots was also considered enhancing especially when combined with the rate command/attitude hold in roll.

7.3. Air-to-Air and Air-to-Ground Engagements

1) For both air-to-air and air-to-ground engagements, the differences between dual- and single-pilot HQR, SWAT, and Bipolar ratings were relatively small, with single-pilot ratings slightly higher. Time lines were forced because the ground threat could destroy the own ship and because of the active presentation of the air threat. This caused the pilot to primarily pilot the vehicle and shed non-essential mission tasking to concentrate on destroying the threat.

2) Rate command/attitude hold was preferable over attitude command/attitude hold for low-speed precision pointing tasks for air-to-air and air-to-ground attack.

3) The air-to-air engagement was dynamic, lasting on the average of 20 sec. One of the greatest piloting challenges was to maintain aircraft alignment with the target to meet the constraints for missile launch. In the simulated low-level terrain environment targets were difficult to acquire at the longer ranges desired for missile launch. Missile engagements were further hampered when the pilot was required to identify the aircraft as friend or foe.

7.4. Hovering Flight

For precision hover, hover hold with position hold, which includes altitude and heading hold, is required for Level 1 single-pilot handling qualities. Addition of a second crew member has a similar effect as recorded during SPACES I. As in NOE flight, the close proximity of objects in the immediate environment drives the need for a precision hover capability. When the single pilot is required to

accomplish more than flightpath tasks the ability to maintain precision hover decreases, thus increasing the need for hovering flight stabilization.

7.5. Workload Analysis

The workload analysis showed that single-pilot workload was higher than dual pilot at the conditions tested. The SWAT and Bipolar workload techniques also distinguished between control configurations and showed significant differences between segments for the single-pilot case. The correlation between the two workload techniques was significant at $R = 0.67$. Both workload techniques were significantly correlated to the Cooper-Harper HQRs at $R = 0.75$ and 0.79, respectively, for bipolar and SWAT indicating the sensitivity of the handling qualities scale for measuring decreased task performance with increased workload.

A number of factors must be considered in weighing the importance of these conclusions:

1) The data comes from a moving, ground-based simulation. It is important that the results be verified in a flight-test program.

2) Hover hold as simulated was probably more accurate than current technology allows.

3) Pilot learning and transfer effects were predicted because of the complexity and unique tasking nature of the simulation. To counter the learning and transfer effect, a randomized block design was used. Randomization of conditions will increase data scatter; however, the measures of central tendency will remain valid. Since cognitive load tasking also influences the pilot ratings especially in the single-pilot situation, the pilot was not allowed to practice the same run several times prior to data collection. This caused the data as predicted to have more scatter when compared to typical handling-quality evaluations in which the same task configuration is practiced several times before a rating is obtained. The obtained performance rating in the SPACES conditions may be more typical of actual world performance and pilot compensation since the pilot has not recently practiced the same task.

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TABLE 1

ADOCS HYBRID CONTROL SYSTEM — SPACES I

LONGITUDINAL	PITCH ATTITUDE COMMAND/GROUNDSPEED STABILIZATION FOR LOW SPEED AND PITCH ATTITUDE COMMAND/AIRSPEED STABILIZATION AT HIGH SPEED. (AT/LV – AT/AS)
LATERAL	ROLL ATTITUDE COMMAND/GROUND SPEED STABILIZATION FOR LOW SPEED AND ROLL RATE COMMAND/ROLL ATTITUDE STABILIZATION AT HIGH SPEED. (AT/LV – RT/AT)
VERTICAL	VERTICAL ACCELERATION COMMAND/VERTICAL VELOCITY STABILIZATION FOR LOW SPEED AND FOR FORWARD FLIGHT.
YAW	YAW ACCELERATION COMMAND/YAW RATE STABILIZATION FOR LOW SPEED AND YAW ACCELERATION/YAW RATE FOR FORWARD FLIGHT.

TABLE 2

FLIGHT PATH CONTROL CONFIGURATIONS — SPACES I

CONFIGURATION	PITCH/ROLL		SELECTABLE SCAS MODES				
			B	C	D	E	F
	HYBRID	AT/AT	TURN COORD.	HEADING HOLD	ALTITUDE HOLD	AIRSPEED HOLD	POSITION HOLD
AA		X	X	X			
AB		X		X			
AC		X	X				
AD		X					
AE		X	X		X		
AF		X			X		
AG		X		X	X		
AH		X	X	X	X		
HA	X			X	X		
HB	X		X	X	X	X	X
HC	X		X		X	X	X
HD	X		X		X		
HE	X				X	X	X
HF	X			X			
HG	X			X		X	X
HH	X		X	X		X	X
HI	X		X			X	X
HJ	X						

TABLE 3

FLIGHT PATH CONTROL CONFIGURATIONS — SPACES II

VERTICAL SCAS
- RATE COMMAND/ALTITUDE HOLD

YAW SCAS
- YAW RATE COMMAND/HEADING HOLD

LONGITUDINAL AND LATERAL CONTROL SCAS

PITCH	ROLL	SELECTABLE SCAS MODES				
		TURN COORD.	HEADING HOLD	ALTITUDE HOLD	POSITION HOLD	AIRSPEED HOLD
HYBRID		X	X	X	X	X
AT/AT		X	X	X	O	O
AT/AT	RT/AT	X	X	X	X	O
RT/AT		X	X	X	X	O
*HYBRID - 1		–	O	X	w/o HH	–
*HYBRID - 2		–	X	X	O	–

*HOVER AND LOW SPEED ONLY

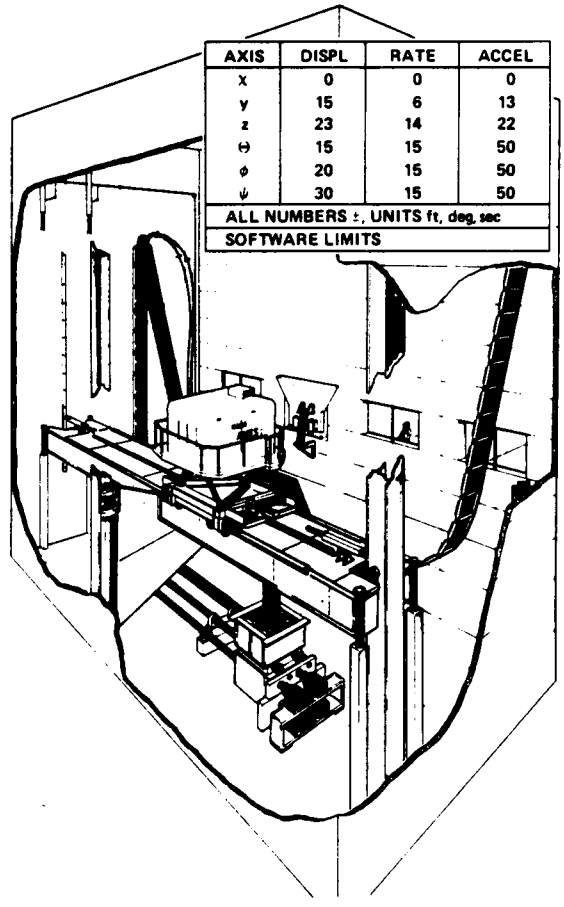

Fig. 1 Vertical motion simulator.

Fig. 2 Computer-generated image.

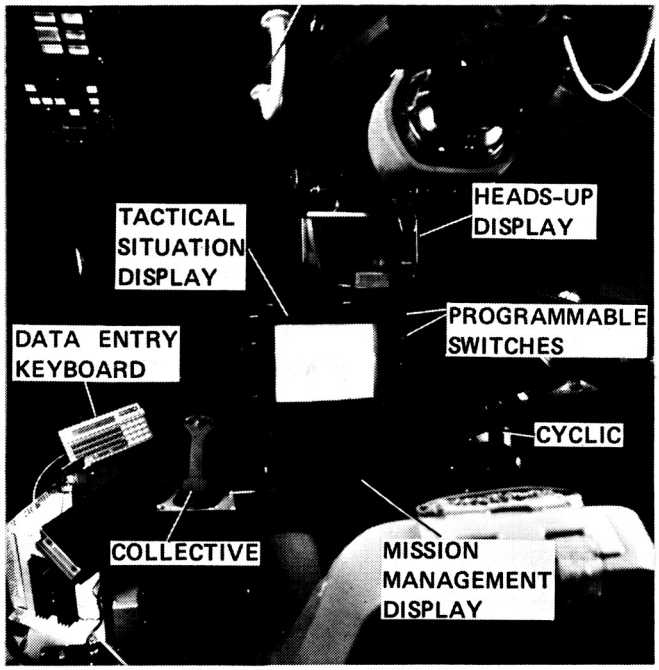

Fig. 3 SPACES cab.

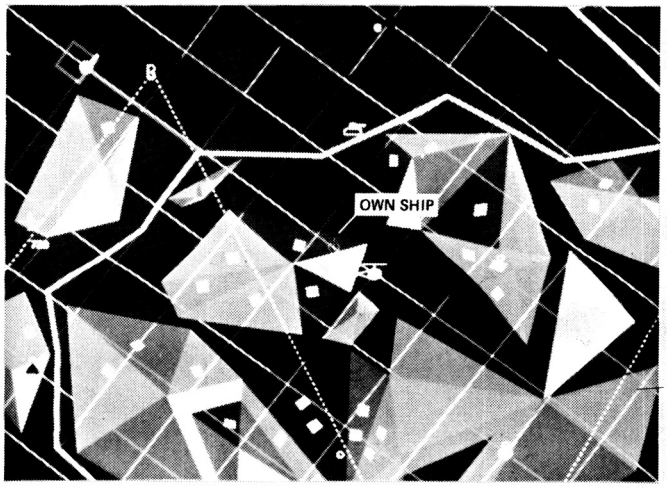

Fig. 4 Moving map display.

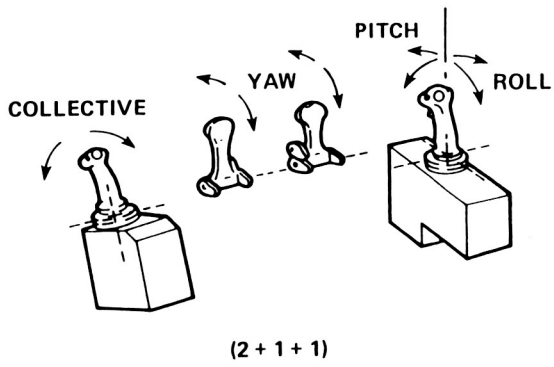

Fig. 5 Control configuration.

VOICE/COMM SCENARIO

PLAYER	CALL SIGN	VOICE	RADIO	FREQUENCIES
AIR BATTLE CAPTAIN	VN644A	1	VHF/UHF	122.9 243.5
BLUE 1	VN644A1	2	VHF/UHF	122.9 243.5
BLUE 2	VN644A2	–	VHF/UHF	122.9 243.5
OPERATIONS	VN644N	3	FM	33.7
GROUND COMMANDER	AN76B	4	FM	36.6
ARTILLERY UNIT	EB53D	5	FM	41.2
FAC	TA59C	6	VHF/UHF	135.3 246.8

SIMULATED COMMAND NET INTERFACE

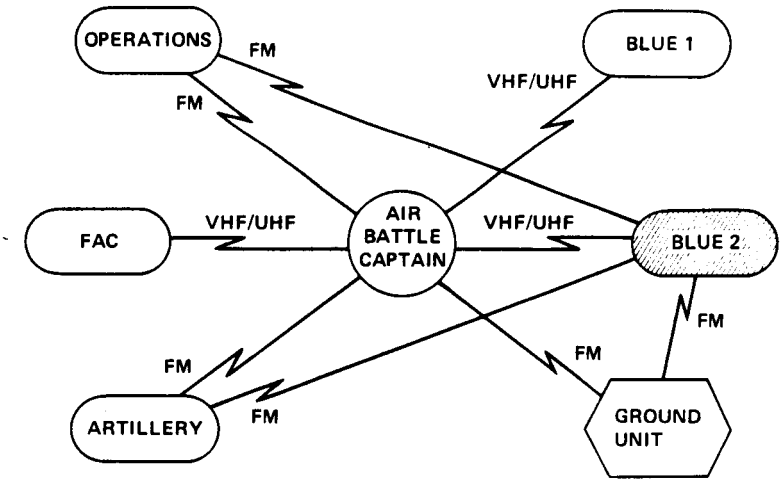

Fig. 6 Simulated command net interface and voice/command sceanrio.

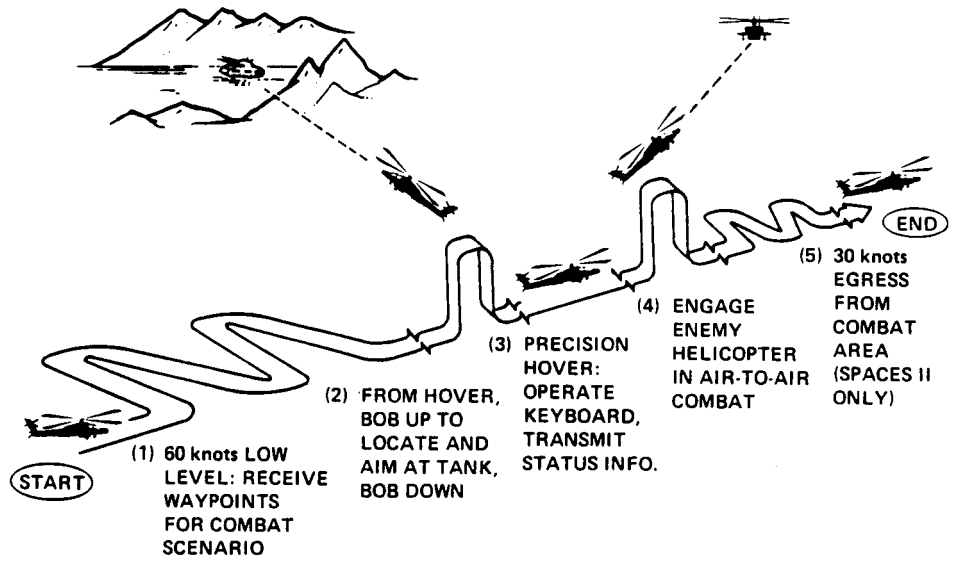

Fig. 7 Scenario and tasks for simulations. Breaks indicate pauses in simulation for Cooper-Harper and pilot workload ratings, and comments.

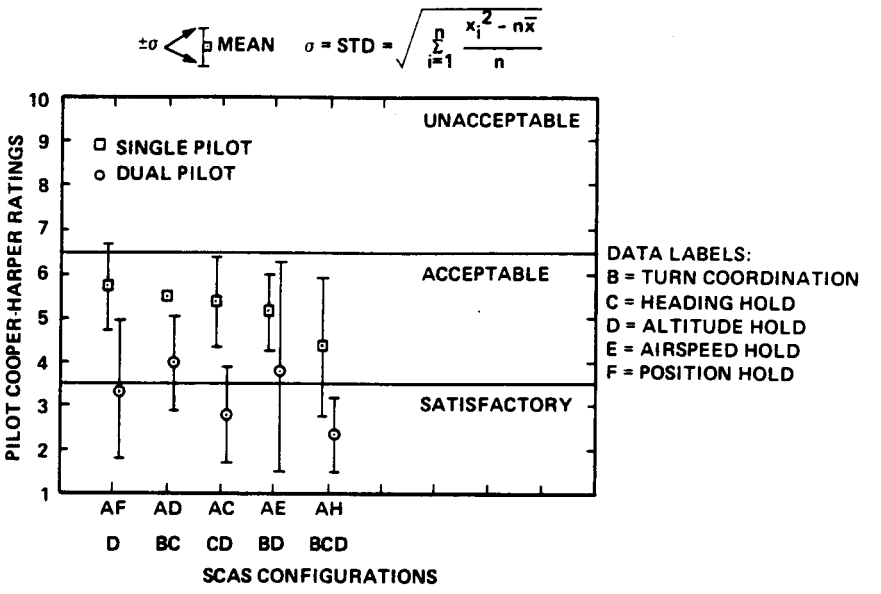

Fig. 8 SPACES I--NOE flight task at 60 KIAS: AT/AT control system.

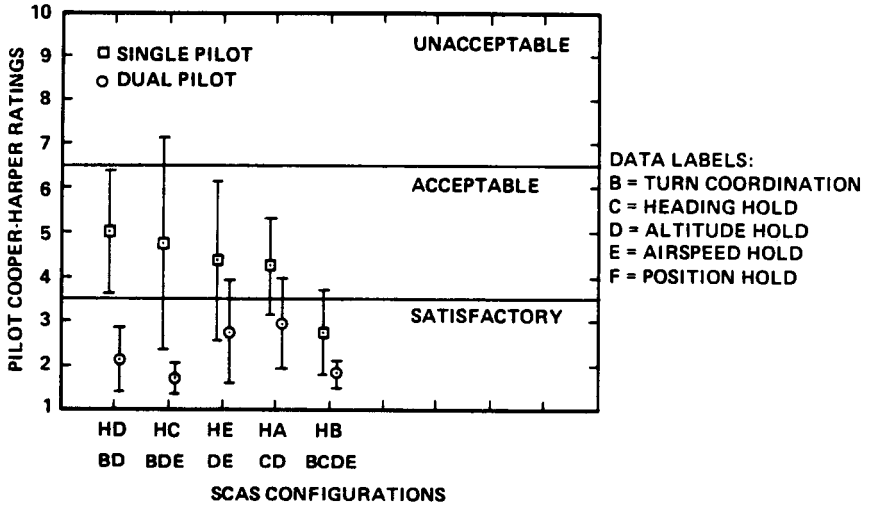

Fig. 9 SPACES I--NOE flight task at 60 KIAS: hybrid control system.

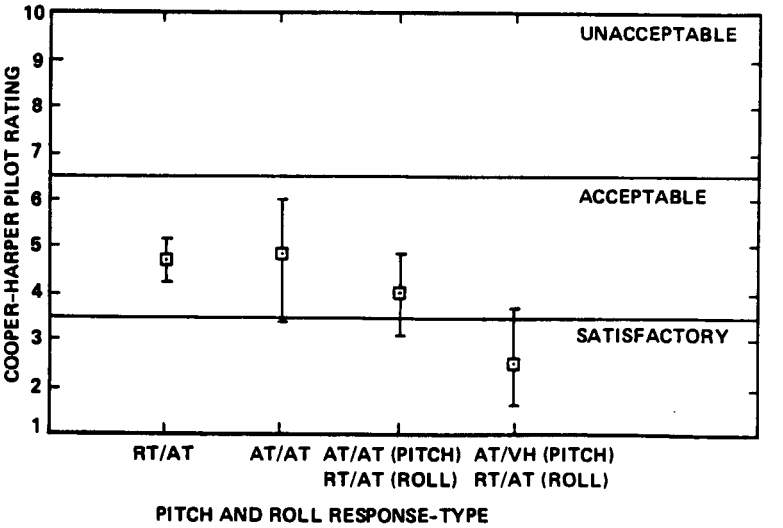

Fig. 10 SPACES II--NOE flight at 60 knots.

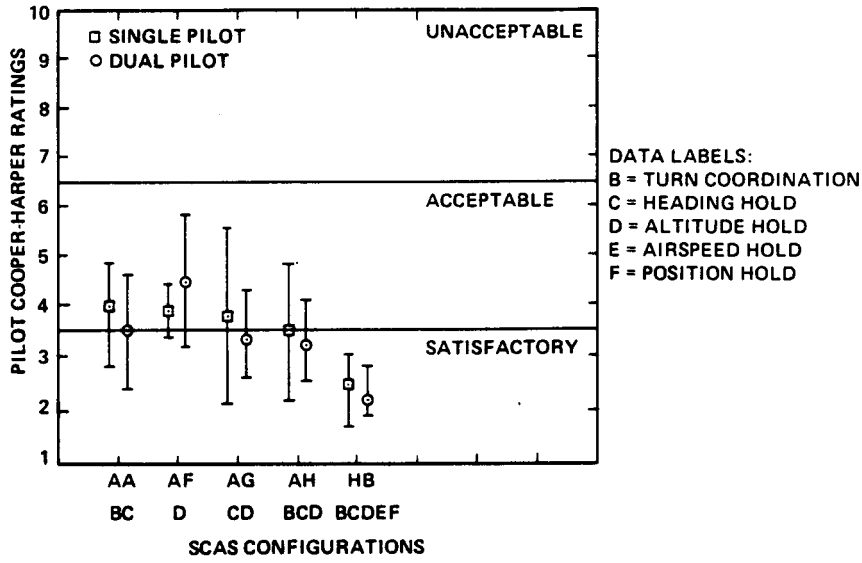

Fig. 11 SPACES I--Air-to-ground attack.

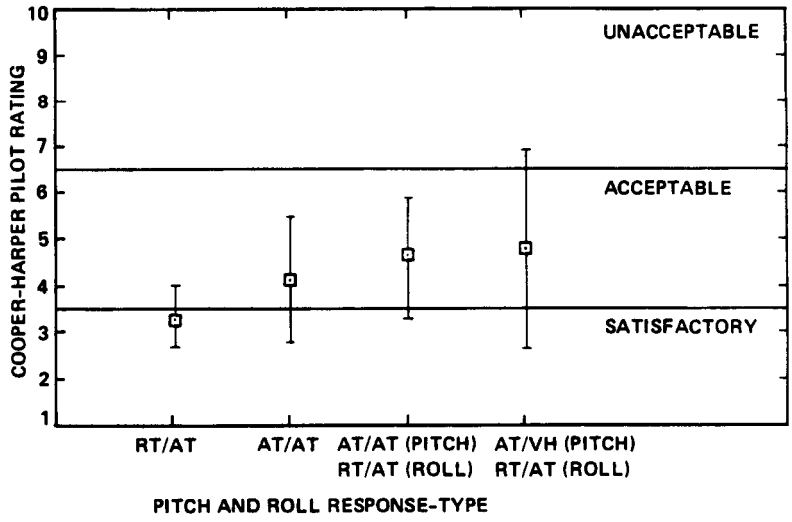

Fig. 12 SPACES II--Air-to-ground attack.

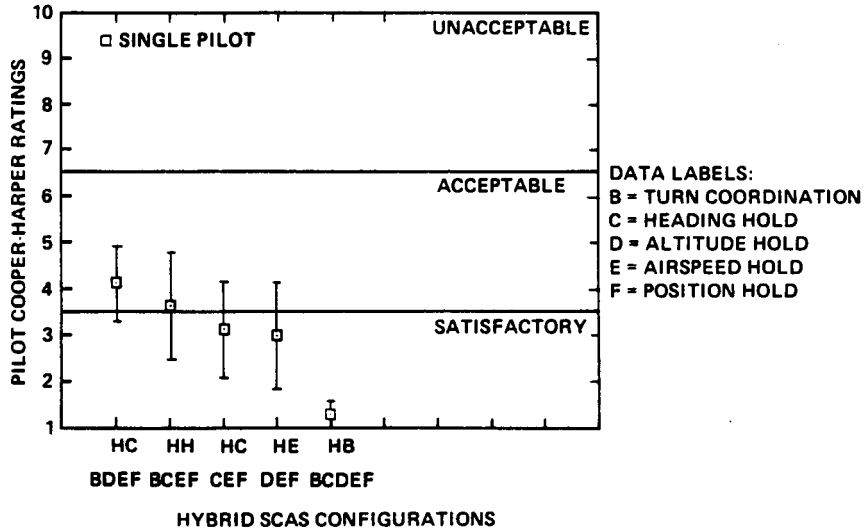

Fig. 13 SPACES I--Hover task with single pilot.

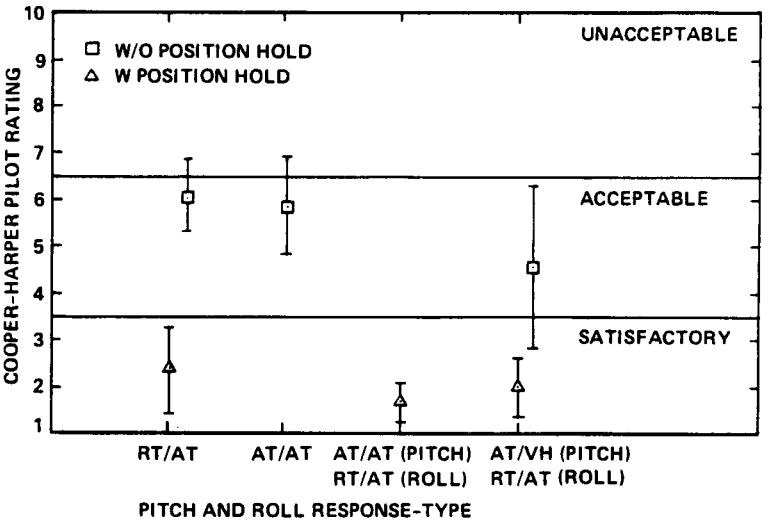

Fig. 14 SPACES II--Hover and transmit status report (single pilot).

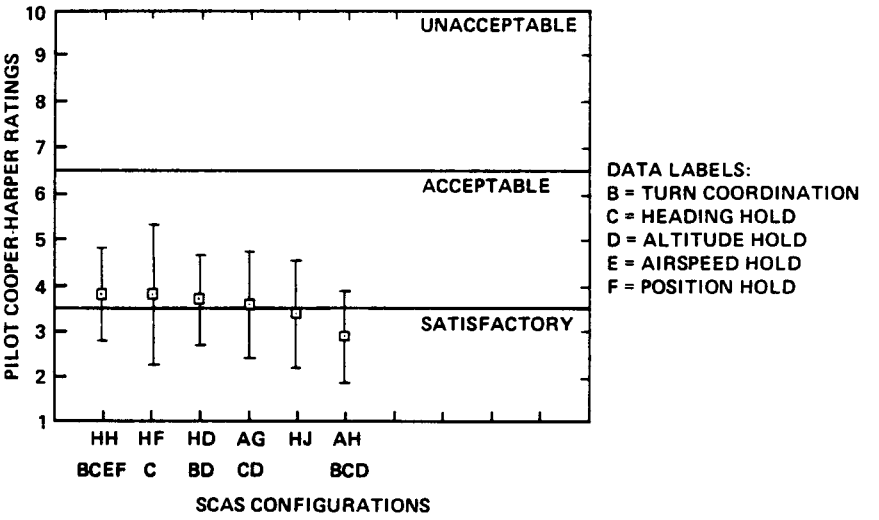

Fig. 15 SPACES I--Air-to-air engagement task.

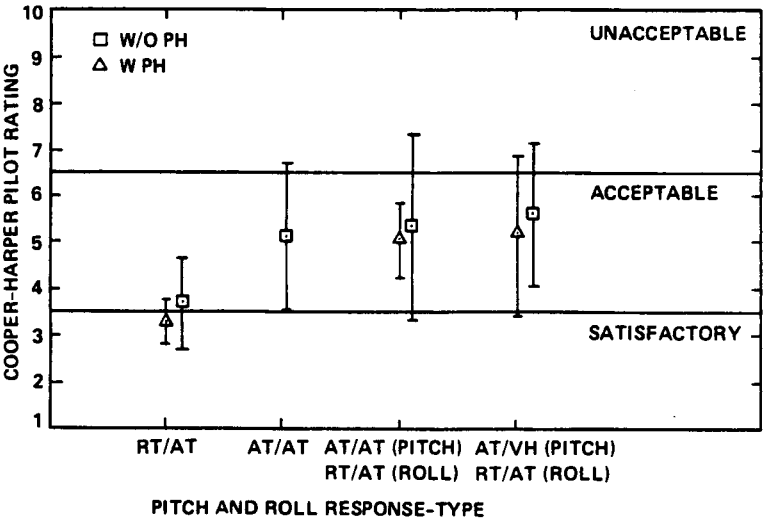

Fig. 16 SPACES II--Air-to-air attack.

NASA National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100017 USAAVSCOM TR 87-A-9		

4. Title and Subtitle

Advanced Helicopter Cockpit and Control Configurations for Helicopter Combat Missions

5. Report Date

December 1987

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.

A-87315

10. Work Unit No.

992-21-0

9. Performing Organization Name and Address

Ames Research Center, Moffett Field, CA 94035 and
*Aeroflightdynamics Directorate, U.S. Army Aviation Research and Technology Activity, Ames Research Center, Moffett Field, CA 94035-1099

11. Contract or Grant No.

13. Type of Report and Period Covered

Technical Memorandum

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, DC 20546 and U.S. Army Aviation Systems Command, St. Louis, MO 63120-1798

14. Sponsoring Agency Code

15. Supplementary Notes

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This paper was presented at the 45th AGARD Guidance and Control Panel Symposium, September 28 - October 2, 1987, in Stuttgart, Germany.

16. Abstract

Two piloted simulations were conducted by the U.S. Army Aeroflightdynamics Directorate to evaluate workload and helicopter-handling qualities requirements for single pilot operation in a combat Nap-of-the-Earth environment. The single-pilot advanced cockpit engineering simulation (SPACES) investigations were performed on the NASA Ames Vertical Motion Simulator, using the Advanced Digital Optical Control System control laws and an advanced concepts glass cockpit. The first simulation (SPACES I) compared single pilot to dual crewmember operation for the same flight tasks to determine differences between dual and single ratings, and to discover which control laws enabled adequate single-pilot helicopter operation. The SPACES II simulation concentrated on single-pilot operations and use of control laws thought to be viable candidates for single pilot operations workload. Measures detected significant differences between dual- and single-pilot operation and between single-pilot task segments. Control system configurations were task dependent, demonstrating the need for an inflight reconfigurable control system to match the optimal control system with the required task.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Stability augmentation program Helicopter Advanced cockpit	Unlimited - Unclassified Subject category - 08

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	20	A02

NASA FORM 1626 OCT 86

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