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USE OF A COMMERCIALLY AVAILABLE FLIGHT SIMULATOR DURING AIRCREW PERFORMANCE TESTING

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Investigations of aircrew sustained operations (SUSOPS) have been criticized for employing tasks with no apparent external validity. Because measures obtained directly from aviators flying high-performance aircraft are difficult to obtain, a laboratory compromise is needed. High-fidelity flight simulators used for aircrew training offer the most realistic simulation, but their availability is limited. Personal computer-based flight simulators may provide adequate simulation in the laboratory at a reasonable cost. This report describes a representative research protocol using a commercially available flight simulator during a simulated aircrew SUSOP.

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CONTENTS

SUMMARY PAGE

OVERVIEW

Investigations of aircrew sustained operations (SUSOPS) have been criticized for employing tasks with no apparent external validity. Because measures obtained directly from aviators flying high-performance aircraft are difficult to obtain, a laboratory compromise is needed. High-fidelity flight simulators used for aircrew training offer the most realistic simulation, but their availability is limited. Personal computer-based flight simulators may provide adequate simulation in the laboratory at a reasonable cost. This report describes a representative research protocol using a commercially available flight simulator during a simulated aircrew SUSOP.

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INTRODUCTION

Modern technology has prolonged the ability of an aircraft to remain airborne well beyond the limits of its human operator. This capacity for longer flights, coupled with a tendency for short-duration (4-7 day) third-world combat scenarios, has brought aircrew sustained operations (SUSOPS) to the forefront within the Department of Defense (DOD). The focus of most investigations in this area involves the search for countermeasures to aircrew fatigue and performance decrement associated with SUSOPS. Ideally, data would be collected directly from aircrew during flight operations. For the U.S. Navy, this means collecting data from pilots and naval flight officers while they are engaged in all aspects of flight, including air combat maneuvering and aircraft carrier landings. Although this form of field data collection maximizes external validity and is therefore easily generalized to the operational community, it lacks the practicality and experimental controls common to most laboratory research.

The traditional approach used when investigating SUSOPS has been to employ cognitive test batteries (e.g., the Unified Tri-service Cognitive Performance Assessment Battery (1) and the Walter Reed Performance Assessment Battery (2)) when assessing aircrew performance in the laboratory. The major assumption underlying the use of these batteries is that complex operations can be broken down into smaller component tasks. Because component tasks are more amenable to laboratory testing and statistical analysis, more objective information regarding performance can be ascertained.

Even so, what the component task approach gains in experimental control it lacks in external validity. Many critics have argued that simply examining such dependent measures as reaction time or accuracy in component tasks bears little or no resemblance to the multitasking common in virtually all aspects of flying. More recent efforts have attempted to investigate this multitasking by using high-fidelity simulators combined with more traditional cognitive tasks (3-7) thereby combining the external validity of a flight simulator with the control of a laboratory study. One problem with this approach is that high-fidelity simulators are often inaccessible and extremely expensive, making their use in most research settings impractical.

Personal computer technology has made extremely fast, high-resolution graphics available at a modest cost to the scientist. Coupled with the development of sophisticated flight simulators designed for the personal computer (PC), an inexpensive means of incorporating some of the skills required of a pilot into the research setting is now available. The purpos f this memorandum is to describe our efforts to incorporate one such flight simulator into a representative research protocol.

PERSONAL COMPUTER FLIGHT SIMULATOR

This section provides a description of one example of the incorporation of a PC-based flight simulator into an aircrew SUSOPS research protocol. We have attempted to provide enough detail to allow the readers to reproduce or modify the example for their particular laboratory situation. The description includes 1) a list of specifications, 2) a flight simulator selection, and 3) a representative experimental protocol including simulated missions and a quantitative means of scoring subject performance on the simulator.

SPECIFICATIONS

Flight simulator specifications were aimed at increasing the similarity of the commercially available simulator with flying fixed-wing aircraft in the U.S. Navy. The specifications were divided into three areas: 1) hardware and software compatibility, 2) cockpit instrumentation, and 3) mission flexibility.

The compatibility of the existing laboratory hardware and software with the commercial flight simulators was a chief concern. The flight simulator had to be compatible with a DOD standard Zenith 248 PC series computer and capable of accessing CGA (4-color) or EGA (16-color) graphics. The software program also had to be capable of running from a standard Winchester hard disk drive to minimize access time and improve the real-time display of the simulation. Simulator flight controls should be handled by joystick inputs to increase generalization to real-world situations. All other operations could be keyboard operated.

To increase the external validity of the flight simulator, several avionics instrument displays were required. Most modern fixed-wing fighter and attack aircraft use head-up-displays (HUD) to present flight information. Therefore, a HUD was required of the flight simulator with the following instrumentation included: 1) heading/bearing indicator, 2) nose-attitude indicator, 3) airspeed indicator (digital and analog), 4) altimeter (digital and analog), 5) vertical-velocity indicator (VVI), and 6) instrument landing system (ILS). An angle-of-bank (AoB) indicator was preferred but not required because AoB can be inferred from the horizon as it appears on the cockpit windscreen in most cases. Several additional instruments were required in the cockpit: 1) a fuel-quantity indicator, 2) a low-fuel indicator, 3) a throttle-position indicator, and 4) a landing-gear-position indicator.

The ideal commercial flight simulator must allow for maximum mission flexibility and be capable of simulating Navy missions. In particular, the simulator must be capable of: 1) several real-world mission scenarios, 2) both day and night missions, 3) in-flight refueling, and most important for a Navy simulation 4) aircraft carrier landings. In addition, the ability to vary the difficulty of landings, enemy targets, and enemy air defenses, was desired.

Finally, the commercially available flight simulator should be moderately difficult to fly, yet easy enough to brief that subjects could be trained on its use in a short period of time. For our research purposes, the simulator could not require more than 10-15 h of training for a subject (pilot) to become proficient in its use.

SIMULATOR SELECTION

The search for a commercially available PC-based flight simulator was *not* exhaustive. In fact, since the initial selection in 1989, several simulators capable of fulfilling the specifications are now available. We chose the F-19 Stealth Fighter, developed and marketed by Microprose Software Incorporated, Hunt Valley, Maryland. Our selection serves only as an example of the utility of commercially available PC-based flight simulators in the experimental setting; other commercially available simulators could be adapted for research in a similar manner.

EXAMPLE EXPERIMENTAL PROTOCOL

Simulator Training

The flight simulator training described here was based on concepts used by the U.S. Navy to train student pilots. In this example, the experimental subjects (pilots) are first briefed on the principles of flight, basic navigation, and aerodynamics as they apply to the flight simulator. Following the initial brief, a series of orientation flights are flown by the pilots to introduce them to the operation and control of the flight simulator. By the end of initial simulator training (total training time 1.5 h), the pilot should be comfortable with these concepts and be capable of flying the simulator. Following initial training and orientation, the pilots are briefed on carrier landings and will successfully complete 10 arrested landings (total training time 7 h) during both day and night carrier qualifications (CQ). Only after successful CQ are pilots authorized for further missions. A more detailed description of the training protocol used in this example follows.

<u>The Flight Simulator and its Instruments</u>. The F-19 Stealth Fighter is designed to sacrifice speed and agility for stealth against enemy radar. Pilots should understand that to fly this simulator successfully, they must fly low (below 400 ft) and slow (less than 250 knots indicated air speed (kias)), otherwise, enemy detection is highly probable. The mission in this example is to avoid radar detection and engagement by the enemy.

Before the familiarization flight, a preflight briefing is conducted to orient the pilot with the basic flight instruments and controls as they apply to the simulator. All of the information necessary to fly the simulator successfully is located within the HUD positioned on the upper two-thirds of the monitor as shown in Fig. 1. The HUD includes basic instrumentation: 1) a radar altimeter (both analog and digital) located on the right side, 2) an airspeed indicator (both analog and digital) opposite the altimeter on the left side, and 3) a heading indicator located across the top. In addition to the basic instrumentation, a stall-speed indicator, a nose-attitude indicator, a flight-path indicator, a (VVI), and an (ILS) are available to the pilot. The stall-speed indicator is positioned with the airspeed indicator on the left. Stall speed is indicated by a vertical line adjacent to the *<u>analog</u>* airspeed indicator. When the stall line is level with the *<u>digital</u>* airspeed indicator, a stall is imminent. The nose-attitude indicator and the flight-path indicator are always illuminated and serve as flight path aids to the pilot. The VVI is located adjacent to the *<u>analog</u>* altimeter indicating the rate of descent of the aircraft. The VVI is particularly useful during the landing sequence. The ILS is used as a navigation aid by the pilot during the landing sequence. When activated, it is located with the nose-attitude indicator and the flight-path indicator in the middle of the HUD.

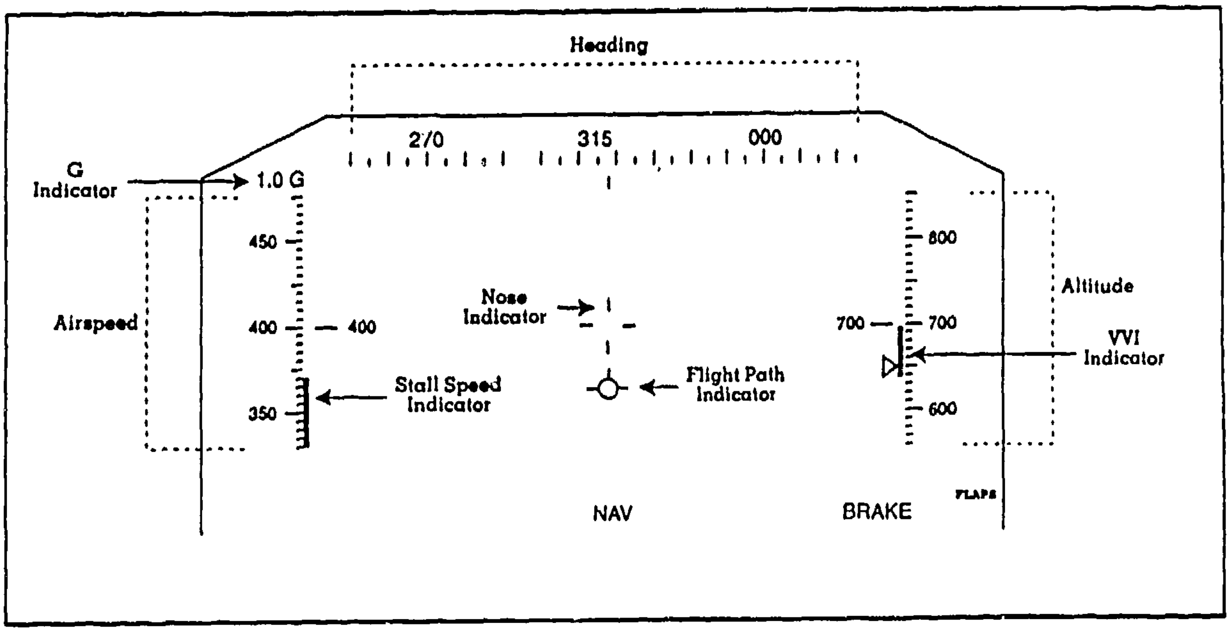

Figure 1. The cockpit head-up display (HUD) as it appears to the pilot during flight. The ILS is not depicted here, but would appear with the nose attitude and flight path indicator in the center of the HUD when activated during the landing sequence.

The F-19 Stealth Fighter is also equipped with a satellite/navigation map (lower left of the cockpit display) and a tracking camera (lower right of the cockpit display). Both arrays are always visible to the pilot (see Fig. 2 for the general layout). The satellite/navigational map gives the pilot a two-dimensional representation of the geographical features surrounding the aircraft. It is used to assist in locating the carrier battle group during the final leg of each mission. The tracking camera is used to visually identify a contact and track its movement. The camera has three modes (navigation, air-to-air, and air-to-ground) and can be directed in any of four directions (left, right, fore, and aft). The current mode indicator is located in the lower center of the HUD. When a contact is detected, it will appear on this screen. The relative bearing of the contact with respect to the plane is shown in the lower right corner of the tracking camera display. Contact distance (range) is located in the lower left corner of the display. The camera is very useful during the approach pattern flown prior to landing on the carrier.

Several other instruments are available in the cockpit as indicated in Fig. 2. A throttle position indicator is located in the lower left of the cockpit. Just above the throttle position indicator are the landing gear and autopilot indicators (the autopilot will not be used in this simulation). Located between the navigational map and the tracking camera display is the electromagnetic visibility (EMV) scale, the enemy tracking warning light, and the low-fuel indicator. The EMV scale indicates the strength of enemy ground and aircraft radar signals as well as the electromagnetic visibility of the F-19 Stealth Fighter. The EMV scale is essential to the mission of this aircraft because the aircraft's defenses rely heavily on stealth technology. Located directly above the EMV scale is the enemy tracking warning light, which is illuminated whenever an enemy ground installation or air threat has made a positive identification of the F-19 Stealth Fighter and is tracking it with radar. Located directly below the EMV scale is the low-fuel indicator, which functions as an additional warning of low-fuel status.

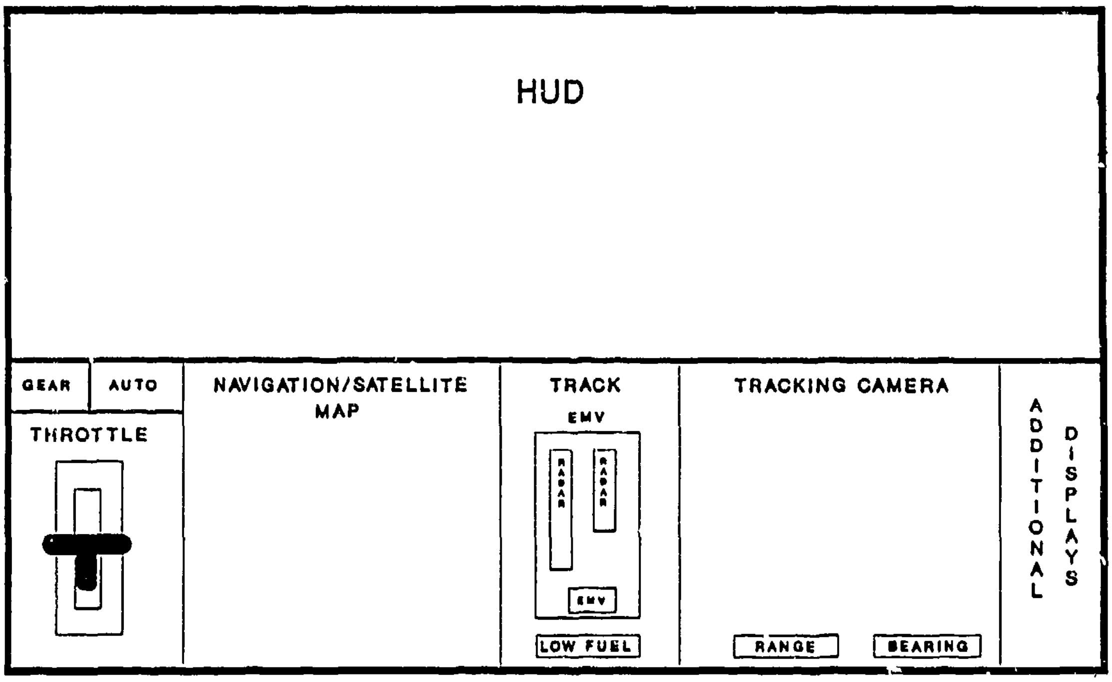

Figure 2. The entire instrument array as it appears to the pilot during flight.

The simulator is controlled by both keyboard and joystick inputs. The keyboard functions are illustrated in Fig. 3. To reduce confusion to the subjects, all important keys were marked, and the rest were blackened out. All U.S. military aircraft are designed to receive control surface input by the right hand positioned on the stick. Therefore, the joystick was positioned to the right of the keyboard for right-handed operation by all subjects. As in the actual aircraft, joystick inputs controlled the pitch and roll of the aircraft.

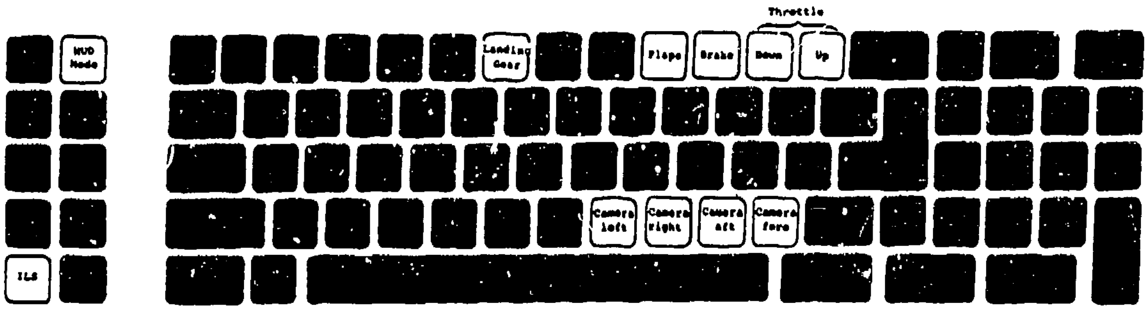

Figure 3. The flight simulator keyboard controls. All nonessential keys have been blackened out to aid the pilot during simulator operation.

Preflight Checklist and Take-off. For our example, after starting-up the flight simulator, pilots will select their mission with the following parameters:

Region of the world:	Libya
Level of conflict:	Limited war
Type of mission:	Strike training
Opponent quality:	Green opponents
Flight performance:	Realistic landings

(Note: the F-19 Stealth Fighter has multiple combat scenarios available to the user. Details regarding its use can be found in the F-19 Stealth Fighter user's manual.)

Following mission selection, pilots are instructed to skip the simulators "Intelligence briefing" and proceed directly to "Arm your plane." One of the unique features of the F-19 flight simulator is the wide variety of ordnance from which to select. In addition to ordnance, additional fuel can be selected in the form of 1900 lb fuel containers. During this example, combat engagements are avoided because combat missions and enemy forces are not consistent from one flight to the next. Therefore, pilots are instructed to select four additional 1900 lb containers of fuel for the surveillance mission described below.

With the selection of the Libyan mission scenario and the four additional fuel containers, the pilots are ready to begin their mission. At the beginning of each mission in this example, the pilots are seated in the cockpit of their F-19 Stealth Fighter on the flight deck of the USS AMERICA (CV-66). While the pilots are still on the carrier deck awaiting the catapult launch, they are oriented with the basic flight instruments and controls. Following orientation, but before take-off, pilots will complete a preflight checklist:

1. Switch the tracking camera to the air-to-ground mode.
2. Move the tracking camera view to the rear of the aircraft.
3. Zoom the satellite/navigational map until the carrier battle group is in view.
4. Apply the brake (this will lock aircraft into bow catapult).
5. Extend the flaps.

Catapult Launch and Familiarization Flight. To initiate the catapult launch, the pilot must first apply maximum thrust. Only after the engines have come to full power should the brakes be released and the aircraft launched. The plane will quickly depart from the aircraft carrier, increase airspeed, and accelerate past stall speed. Once stall speed is surpassed, pilots will initiate a 10-degree, nose-up attitude and begin the initial climb out. After stable flight is achieved, the landing gear and flaps are retracted, and the throttle reduced. The wing commander (experimenter) will then instruct the pilot to fly a prescribed course, altitude, and airspeed.

During the familiarization phase of flight, pilots are instructed to practice level flight skills and constant AoB turns. During level flight, pilots should attempt to keep the nose attitude indicator and the flight path indicator in the HUD horizon. Wings should be level, and aircraft buffeting should be kept at a minimum. Several different AoB turns should be attempted until the pilot feels comfortable at all prescribed AoBs. Pilots should remember that their aircraft will lose altitude while going through a turn, and they should compensate with slight backward pressure on the joystick. An AoB of more than 60-70° should be avoided as accelerated stalls are likely at airspeeds below 250 kias.

An introduction to navigation using the tracking camera and proper procedures when entering the landing racetrack pattern is also given during this phase of training. This initial simulator training takes approximately 60-90 min.

Aircraft Carrier Landings and Carrier Qualifications

Landing aboard an aircraft carrier is one of the most demanding tasks that a naval aviator performs. Not only does the landing occur at the end of a flight when fatigue is maximum, but they are frequently made at night and during less than ideal weather conditions when visual cues are limited. These factors are further complicated by the fatigue associated with a SUSOP. For this reason, any simulation used with naval aviators should include aircraft carrier landings.

Like all aspects of naval aviation, the approach, landing pattern, and arrested landing are all conducted according to procedure. Within the limits of the F-19 simulator, a set of procedures similar to those used in the U.S. Navy have been adopted for this example. Once given authorization by the wing commander, the landing sequence will commence. When the aircraft carrier is within site (approx. 20 km) the pilot must compute a heading that will enable the aircraft to pass several (2-4) km astern the carrier and proceed in that direction. Because the aircraft carrier is always heading 180°, once astern of the ship, the pilot is instructed to come to course 180° and pass directly overhead. From this point in the approach, no additional commands are given by the wing commander. The approach and racetrack landing pattern are shown in Fig. 4.

Pilots enter the racetrack pattern at point A (2-4 km astern the aircraft carrier, heading 180°, 200-250 kias, altitude 1200 ft, 0 ft/s rate of descent). This enables the pilot to fly safely over the carrier. When the aircraft reaches point B (7.5 km ahead of the carrier, heading 180°, altitude 1200 ft, 200-250 kias, 0 ft/s rate of descent), the pilot executes a 40-45° AoB left turn while maintaining altitude. The pilot will continue in a constant AoB turn until point C (heading 355°) when level flight is resumed. When point D is reached, (heading of the aircraft carrier from the plane = 270°), a slow descent is begun (500 ft/min rate of descent), the flaps and landing gear are lowered, and airspeed is reduced to 180-210 kias. At point E, where the carrier bears 230° from the plane, the slow descent is continued, and a 45-50° AoB left turn is executed. Any necessary adjustments for final approach are made during this turn. The pilot should level the plane off at point F on heading 175° (pilots will land on the angle deck heading 175°) with the carrier approximately 2-4 km directly ahead. At this point, the plane should still be gradually descending through an altitude of 500 ft. Final speed and altitude adjustments are made here, and a recheck of the flaps and landing gear should be performed. The aircraft should touch down on the carrier deck (point G) at an altitude of 125 ft and less than 210 kias. If an arresting wire is caught, the pilot will immediately cut all power and apply the brakes. On the other hand, if an arresting wire is not caught by the aircraft, the plane will not stop. Under these circumstances, the pilot should apply full power and take off again. Time permitting, the pilot will reestablish the aircraft in the racetrack pattern at point B, climbing to 1200 ft and attempt another arrested landing.

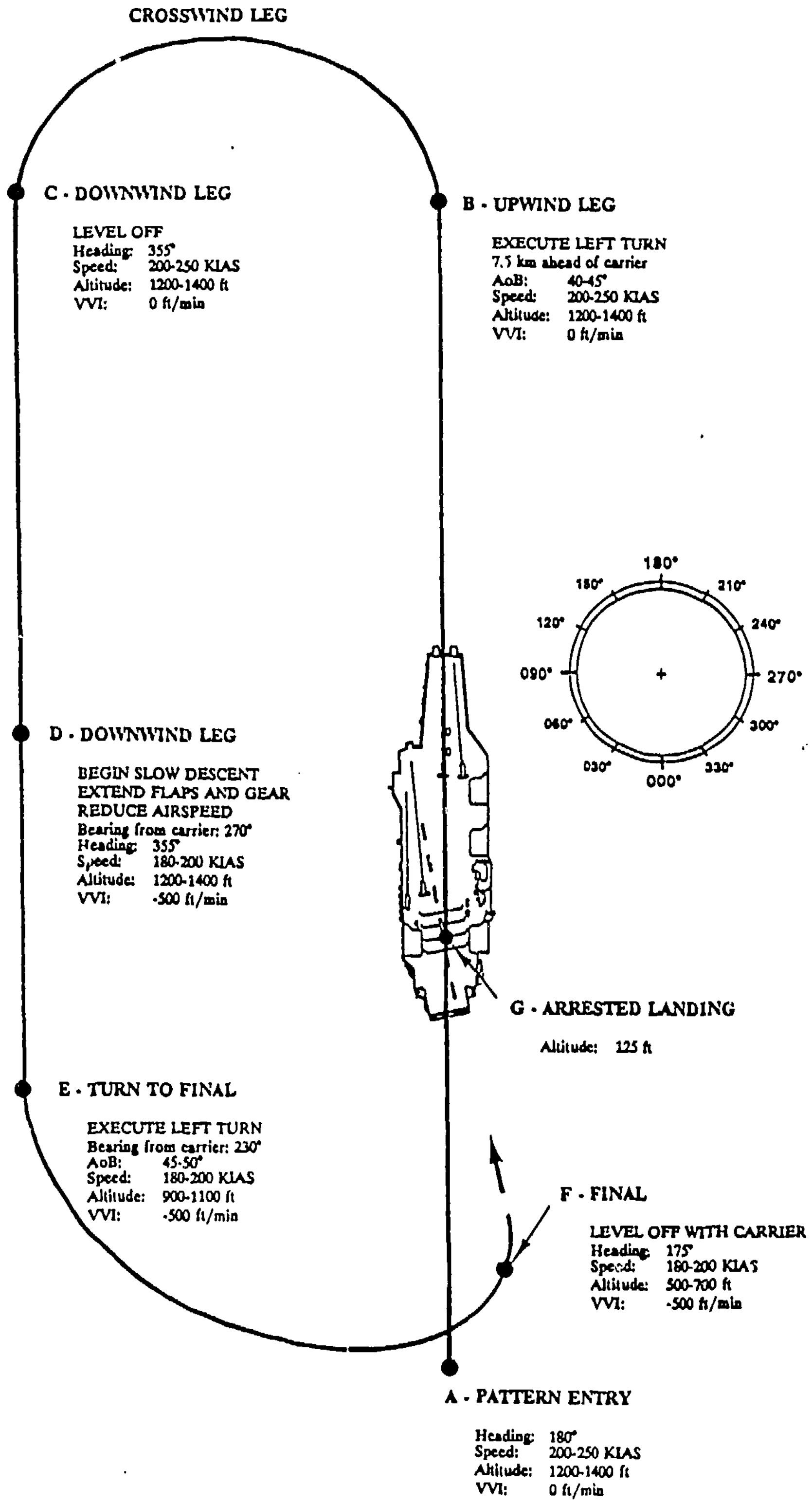

Figure 4. The military 360° aircraft carrier landing pattern.(over the Mediterranean Sea). Thus, all pilots are exposed to the same threat, and the individual experiences of the pilots are held relatively constant.

During the CQ phase of training the pilot will simulate a typical U.S. Navy CQ by making several arrested landings aboard the USS AMERICA. The initial preflight and launch are the same as the familiarization flight above. Immediately upon take-off the pilot will enter the racetrack pattern and make his first arrested landing. If the landing sequence is successful, the pilot should cut power and apply the brake. When the engines have shut down completely, the pilot will immediately simulate another catapult launch by going through the launch sequence again (apply full throttle and release the brake) and become reestablished in the racetrack pattern. If the landing was not successful but no crash ensued, the pilot should reestablish the aircraft in the racetrack pattern and attempt another arrested landing. If the plane crashes on landing, the pilot should immediately go through the mission start-up sequence, preflight, and launch sequence to continue CQ.

One of the unique features of this simulator is the ability to select day or night missions. The primary difference when selecting night over day missions is the color contrast between the ground and sky and the available detail of the picture. In both instances, visual discriminations are more difficult during the night missions. To ensure that the pilots are proficient at landing on the carrier during the day and night, CQ should include both mission types. A minimum of 10 successful arrested landings (5 day, 5 night) should be accomplished. At the end of this phase of training, the subject should feel confident with landing the F-19 Stealth Fighter aboard an aircraft carrier during the day or night and be completely experienced in the proper procedures.

<u>Simulated Missions</u>

As stated earlier, an important specification for the simulator was the flexibility to fly several different missions on request. Although the F-19 Stealth Fighter can engage enemy aircraft and ground elements, the enemy's composition and defense capability are not consistent from one mission to the next. Without the ability to hold the enemy threat constant between missions, all flights during this example are flown in minimal threat areas

During the mission phase of this example, pilots will take off from the USS AMERICA cruising off the coast of Libya. By varying the assigned heading, several different missions are possible. Table 1 presents 10 representative 4-leg missions, each requiring approximately 24 min to complete, excluding the landing sequence. By flying these missions during the day and night, a total of 20 different missions are possible.

All missions are flown at an altitude below 400 ft (note: the aircraft is very unstable at this altitude due to downdrafts and wind currents making flight significantly more challenging), with airspeed between 200-250 kias. Pilots should expect regular deviations in the plane's heading, altitude, and speed. Continuous pilot correction is essential to hold the plane within its mission parameters; thus, a constant scan of the HUD must be performed throughout each mission. Each mission outlined in Table 1 will require coordinated turns (coordinated in this instance refers to all pilots (subjects) participating in the experiment turning simultaneously). The command to turn to a new heading is given by the wing commander (experimenter) 30 s before the beginning of the next leg. On the fourth leg of each mission, the tracking camera (TRACAM), set in the air-to-ground mode, is used to locate the aircraft carrier in preparation for landing.

If a pilot crashes during any leg of the mission several contingencies have been made to resume the flight with the remaining pilots. In all cases, if a pilot crashes during the flight, the simulator will be reset, and the flight will resume as described in Table 2. Because it is desirable to land all pilots on the aircraft carrier at about the same time, the crash missions have been designed to coincide with the remaining legs of the original mission. For example, if a pilot crashes during leg 2 of the mission, he will be launched again from the aircraft carrier, while the remaining pilots are turning to the new heading assigned to leg 3. The *crash* pilot will be assigned a heading of 180° (Table 2). When the remaining pilots change course for their final heading on leg 4, the *crash* pilot will turn to a new heading of 000°. This will enable all pilots to arrive at the aircraft carrier in close proximity to each other.

Table 1. Representative Flight Missions.

Mission number	Mission leg	Assigned heading	Time (min)	Mission number	Mission leg	Assigned heading	Time (min)
1	1	225	6	2	1	180	6
1	2	135	6	2	2	090	6
1	3	045	6	2	3	000	6
1	4	315	6	2	4	270	6
3	1	135	6	4	1	315	6
3	2	225	6	4	2	225	6
3	3	315	6	4	3	135	6
3	4	045	6	4	4	045	6
5	1	045	6	6	1	000	6
5	2	135	6	6	2	090	6
5	3	225	6	6	3	180	6
5	4	315	6	6	4	270	6
7	1	225	6	8	1	135	6
7	2	315	6	8	2	045	6
7	3	045	6	8	3	315	6
7	4	135	6	8	4	225	6
9	1	315	6	10	1	045	6
9	2	045	6	10	2	315	6
9	3	135	6	10	3	225	6
9	4	225	6	10	4	135	6

Scoring

If the simulator is to be used as a research tool, a quantitative means of scoring the flight is desirable. In this example, the wing commanders are responsible for grading each mission flown. An example grading sheet is provided in Fig. 5.

The grading is divided into two phases: mission and landing. During the mission phase, only the number of crashes are recorded. Crash data are collected on all four legs of the missions. Likewise, the total number of crashes per mission is recorded.

Table 2. Representative Crash Missions.

Crash leg	Remaining legs	Assigned heading	Time (min)
1	2	180	6
1	3	300	6
1	4	060	6
2	3	180	6
2	4	000	6
3	4[a]	180	3
3	4[a]	000	3

[a] A crash on leg 3 will result in two 3-min legs on leg 4 rather than one 6-min leg.

The aircraft carrier landing is the most difficult task a pilot must perform during this simulation. As such, landings are graded in much more detail than the missions themselves. Wing commanders serve as landing signal officers (LSOs), and assign a score ranging from 0-4 for each landing. The grading scale is as follows:

4 - Good pass
3 - Fair pass
2 - Bolter
1 - Technique Wave-off
0 - Crash

This grading scale differs slightly from the system used in actual aircraft carrier landings. The differences lie in the scores assigned to the top three grades. In the U.S. Navy, LSOs assign a score of 4 to a good pass, 3 to a fair pass, and 2.5 to a bolter. This scoring protocol has been modified here to accommodate crash landings (rarely observed in the fleet) and to provide sufficient range to observe any notable variation in landing performance as a function of experimental variables.

A good pass grade is given to those pilots who execute a good approach, line up well with the carrier, maintain a constant rate of descent, avoid violent last-minute corrections, and execute a safe landing. A fair pass is given to those who do not meet the standards for a good pass but still land the plane safely. For example, excessive speed (greater than 210 kias) when landing is cause enough to receive only a fair pass. A bolter is given when the pilot brings the plane in and touches the deck but does not catch an arresting wire. A technique wave-off occurs when either the wing commander orders the pilot to abort the landing (unsafe approach), or the pilot elects to discontinue the landing and fails to bring his aircraft down onto the carrier. A crash score is given for the landing if the pilot crashes anytime after entering the racetrack approach pattern (Fig. 1, point A).

Unlike the real-world scenario aboard a fleet aircraft carrier, the F-19 simulator is not capable of identifying which of the four arresting wires the aircraft engaged. Therefore, no arresting wire score is recorded.

SUBJECT ID:						
MISSION NUMBER	LEG 1 CRASH	LEG 2 CRASH	LEG 3 CRASH	LEG 4 CRASH	TOTAL CRASHES	LANDING SCORE
1						
2						
3						
4						
5						
6						
7						
8						
9						
.						
.						
.						
∞						

Figure 5. Mission Grade Sheet

DISCUSSION

Our example details how a commercially available flight simulator can be used in an experimental protocol. Such simulations, although not capable of introducing all the variables associated with flying a high- performance aircraft, are certainly capable of reproducing some of the fundamental tasks. Even so, naval aviation involves more than simply flying the aircraft. Naval aviators are involved frequently with additional tasks (e.g., computations involving heading, fuel consumption, and speed/altitude relationships, as well as a constant stream of radio communications) while simultaneously flying high-performance aircraft. For this reason, aircrew investigations that utilize discrete component tasks, in a single task mode, have been subjected to intense scrutiny by the operational community.

One solution to this multitasking dilemma is to incorporate some of the more reliable discrete measures as secondary tasks while pilots operate a flight simulator. Several tasks are available as secondary tasks with the flight simulator. A few tasks that are particularly promising are the dichotic listening, two-dimensional compensatory tracking, mathematical processing, and the Sternberg memory search tasks. The dichotic listening task (DLT) is a divided-attention task that requires subjects to attend to information to one ear while being presented information simultaneously to both ears. Subjects must filter out distracting information from the unattended ear while focusing their attention on the task-relevant information in the target ear. The DLT is comparable to the continuous filtering of radio transmissions by the pilot during flight. The original version of this divided-attention task was specifically developed to predict pilot training success in the Israel Air Force (8). The original version has since been adapted for use as a predictor of military pilot success in both the U.S. and Israel (9-12).

Two-dimensional compensatory tracking tasks and other psychomotor tasks are appealing as secondary tasks due to their high degree of external validity. All forms of aircraft (fixed and rotary wing) require some degree of stick and rudder inputs for controlled flight. The ability to track in one, two, and three dimensions is therefore critical to pilot success. The one-dimensional tracking task that we recommend has been approved by the Advisory Group for Aeromedical Research and Development (AGARD) and is available as part of the AGARD Standardized Tests for Research with Environmental Stressors (STRES) Battery (13).

Although several different mathematical processing tasks are available, we use the mathematical task included as part of the AGARD STRES Battery (13). It was designed to place demands on cognitive resources associated with working memory. Specifically, subjects must a) retrieve information from long-term memory, b) update information in working memory, c) execute arithmetical operations sequentially, and d) perform numerous numerical comparisons. This process is similar to the many mathematical calculations that a pilot must perform in the cockpit. For example, pilots must calculate heading, fuel-consumption rate, and target- acquisition rates, as well as make many other mathematical comparisons.

The Sternberg memory search task (14-16) has been used extensively to determine cognitive workload. Although there appears to be no direct correlate in the cockpit, its inclusion serves to determine the amount of effort employed in flying the simulator (17). The task requires subjects to memorize a set of letters (memory set). Following memorization, the subject is asked to compare a series of sequentially presented letters (probes) to the items in the memory set. Subjects respond as to whether or not the probe was a member of the memory set. Both accuracy and reaction time have been shown to vary with cognitive workload.

The mission profile described earlier is well suited for cognitive dual-tasking procedures. For example, by modifying the presentation length so that no task exceeds 4 min in length, the DLT, two-dimensional tracking, mathematical processing, and Sternberg memory search tasks are easily inserted as secondary tasks into any 6-min leg of the mission described above. Figure 6 illustrates one way of incorporating these tasks into the four-leg missions described above.

Visual presentation of the cognitive tasks, simultaneously with the flight simulator, requires an additional personal computer, monitor, and in some instances a response input board (e.g., the Mini-modulus III). Our particular setup is illustrated in Fig. 7. With slight program modifications (i.e., increasing font size and right justifying the text presentation during all secondary tasks), confounding variables due to the physical setup can be kept at a minimum.

In summary, we are currently collecting data in our laboratory using these four tasks with the F-19 Stealth Fighter flight simulator. We believe that the addition of personal computer flight simulation in aircrew SUSOP research protocols serves to enhance the external validity of research findings.

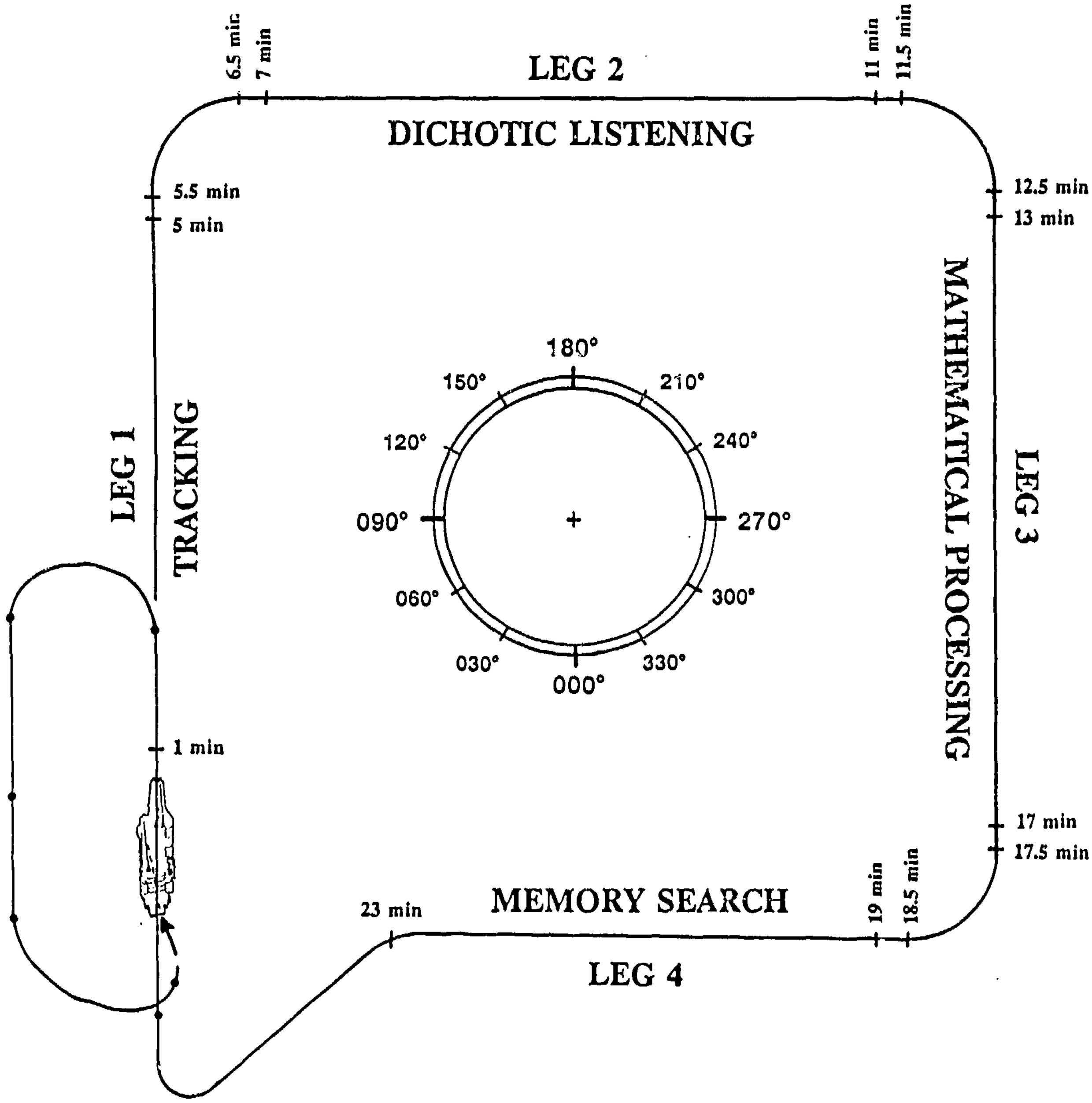

Figure 6. The placement of the cognitive tests within a representative mission profile.

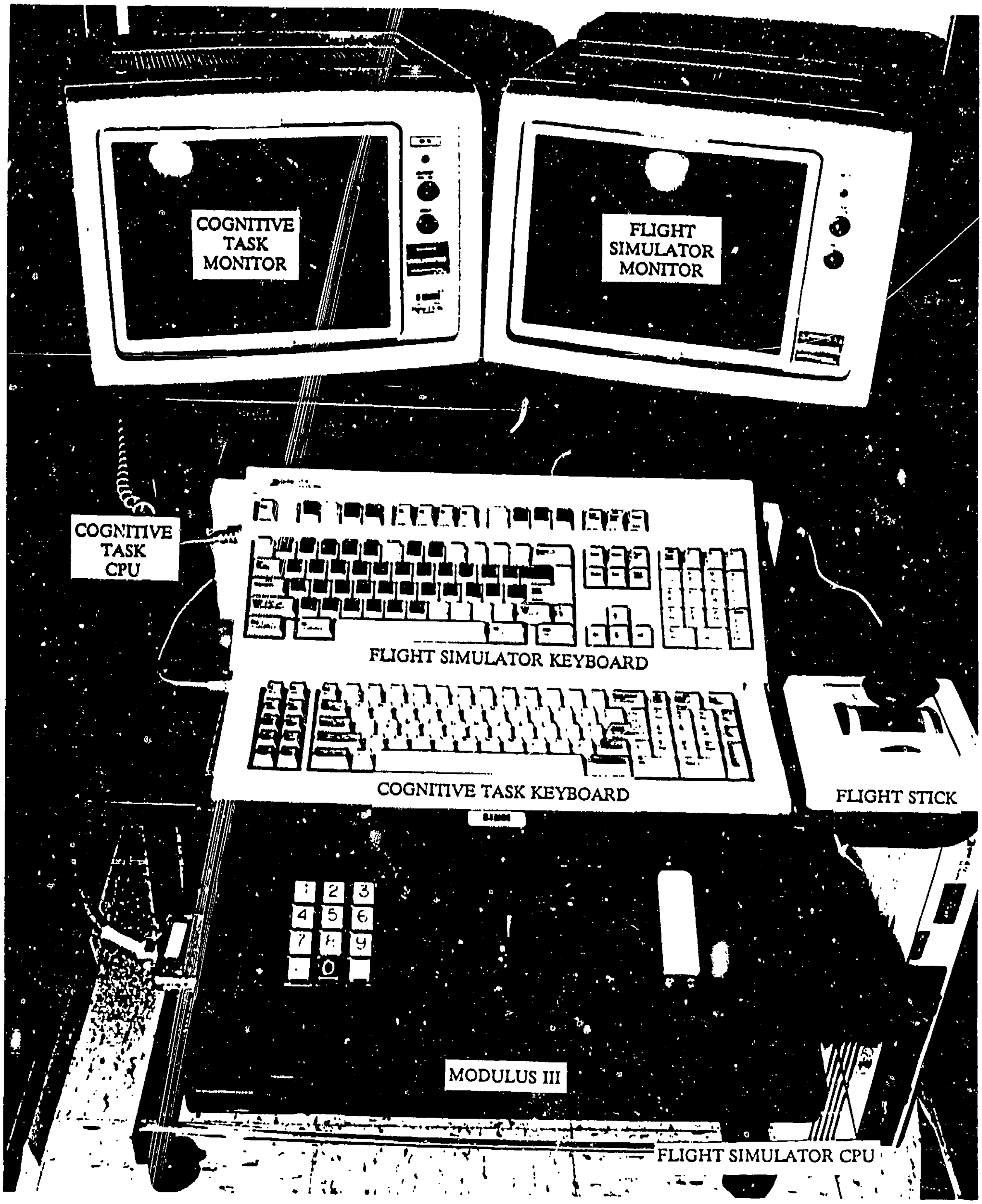

Figure 7. Dual CPU configured subject test station. The simulator keyboard is partially obscuring the front of the cognitive test CPU in this illustration.

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