ARMY RESEARCH LABORATORY

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Abstract

The purpose of the research project was to understand the future crew environments for developing unmanned aerial vehicle (UAV) systems. A variety of human engineering tools (job assessment software system [JASS], enhanced computer-aided testing [ECAT], and MicroSaint™) were used to address crew issues related to the utility of having rated aviators as crew members, supplementing current crews with imagery and intelligence specialists, and the use of automation to improve systems efficiency. Data from 70 soldiers and experts from Fort Huachuca, Arizona, Fort Hood, Texas, and Hondo, Texas, were collected as part of this effort. The general finding was that the use of cognitive methods and computerized tool sets to understand future crew environments proved to be cost effective and useful. Specifically, no evidence was found to support a requirement for rated aviators in future Army missions, but the use of cognitively oriented embedded training simulators was suggested to aid novices in developing the cognitive skills evinced by experts. The efficacy of adding imagery specialists to 96U crews was discussed, and specific recommendations related to automation were derived from the workload modeling.

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INTRODUCTION

Future battle spaces will be exploited by a variety of aerial and ground platforms to help U.S. forces achieve information dominance. The unmanned aerial vehicle (UAV) family of platforms will increase the range, survivability, and effectiveness of this effort. The purpose of this ongoing research is to understand the crew environment and soldier performance issues related to future UAV systems. Specifically, three major issues were addressed: (a) the importance of using rated aviators for piloting positions for the UAV, (b) the use of imagery specialists and intelligence analysts (96D and 96B military occupational specialty [MOS]) as adjunct crew members, and (c) the potential use of automation to assist in future crew functions. The variety of questions asked required the use of numerous human engineering and human performance data collection methods.

A secondary motivation was to investigate the effectiveness of available tool sets and methodologies to understand human job and mission environments for developing systems. The best way to test the mettle of these approaches was by attacking important problems of developing systems rather than by investigating laboratory problems of dubious validity. The UAV was an ideal candidate because of its crew-intensive mission profiles (Barnes & Matz, 1998) and the need to investigate the crew issues perceived by the Training and Doctrine System Manager (TSM). The TSM's cooperation was absolutely essential in completing this study; in providing direction, expertise, and a sense of priorities; and because a significant investment of the TSM personnel's own time and effort was required during the data collection and analysis portions. The overall study was extensive, including the efforts of more than 70 participants representing expertise from the aviation, intelligence, and UAV communities of Fort Huachuca, Arizona, Fort Hood, Texas, and the contractors in Hondo, Texas, who engineered the Outrider UAV.

RATED AVIATORS

The use of rated aviators as part of the UAV crew was deemed the most crucial issue addressed. The problem is complicated because of the safety, training, and selection issues involved. In the UAV crew, two flight positions were examined: the internal pilot (designated air vehicle operator [AVO]) and the external pilot (EP). The AVO for current Hunter UAV configuration resides in the ground control station (GCS) seated next to the mission payload operator (MPO). The AVO coordinates with the mission commander to do mission planning, assumes flight control of the air vehicle after take-off, and sets the course to the various way points. The AVO must be able to read flight instruments and understand the current flight status but does not usually fly the air vehicle in the sense that a fixed or rotary wing aviator does. Instead, the AVO directs the UAV to a target location and upon arrival, coordinates with the MPO who executes the best search pattern over the target area. The AVO also responds to flight emergencies and makes course changes for tactical or safety reasons. However, most of the initial "hands-on" control of the air vehicle is done by the EP who flies the UAV during take-off and landing using a control device similar to that used for radio-controlled model airplanes. It is important to note that most flight safety problems occur during the EP's watch; this is not a result of any characteristic of the EP; rather, it reflects the dangers associated with take-off and landing for any air vehicle.

Method

Procedure

Four analyses were performed to determine the important cognitive skills required for the AVO and EP positions and to relate them to safety-of-flight issues. Although data were collected for all flight functions for both categories, the main focus was on flight functions clearly related to air vehicle accidents and incidents.

Using the job assessment software system (JASS), the authors collected ratings from UAV AVOs and EPs regarding the importance of an array of cognitive skills to their jobs and tasks. Data were collected from flight-rated U.S. Army aviators to contrast the cognitive skills they reported as particularly important with skills reported by the UAV EPs.

Subsequent analysis indicated that JASS data painted an incomplete picture; it became obvious that more was needed to be known about the relationship between reported cognitive skill levels and actual mishaps. One source of information concerning the relationship of performance and skill level was the training experiences at the UAV Flight School at Fort Huachuca. JASS data were supplemented with enhanced computer-aided testing (ECAT) data from a pilot study collected by Hopson (1995). This study correlated the ECAT scores on one- and two-handed tracking scores with failure rate for the EP training course. In addition, the UAV flight incident report results were compared to the JASS flight tasks, which permitted us to focus our analysis on critical flight functions (TSM, 1998).

Finally, data interpretation proved to be a difficult problem. Besides the relationship of tasks to skill levels, there were operational, programmatic, and experiential issues as well as similar investigations by other services to consider in attempting to forge a position on rated aviators from the raw data. To address these issues, a subject matter expert (SME) working session was convened on 15 October 1998 at Fort Huachuca in order to help interpret the data (see list of participants in Appendix A).

Participants

For the JASS data collection, a total of 30 96U soldiers or Hunter-trained contractors was tested during the exercise. There were 21 MPO and AVO designations, 11 of whom provided JASS data from a primarily AVO task structure and 10 from a primarily MPO task structure for this part of the data analysis. The AVO task list consisted of AVO tasks associated with flight and navigation functions, excluding tasks involved with take-off and landing. In addition, nine certified EPs were tested using the external pilot task structure for the JASS testing. Further, because of the difference in EP experience levels, those with a year or less of experience were considered the low experience group (4) and those with more than 1 year of experience (5) were designated the high experience group. The EP task list consisted of functions related to take-off and landing an air vehicle. This same list of EP functions was administered to 16 currently rated U.S. Army aviators. The aviators characterized themselves as primarily fixed wing (10) or rotary wing (6) when they answered JASS.

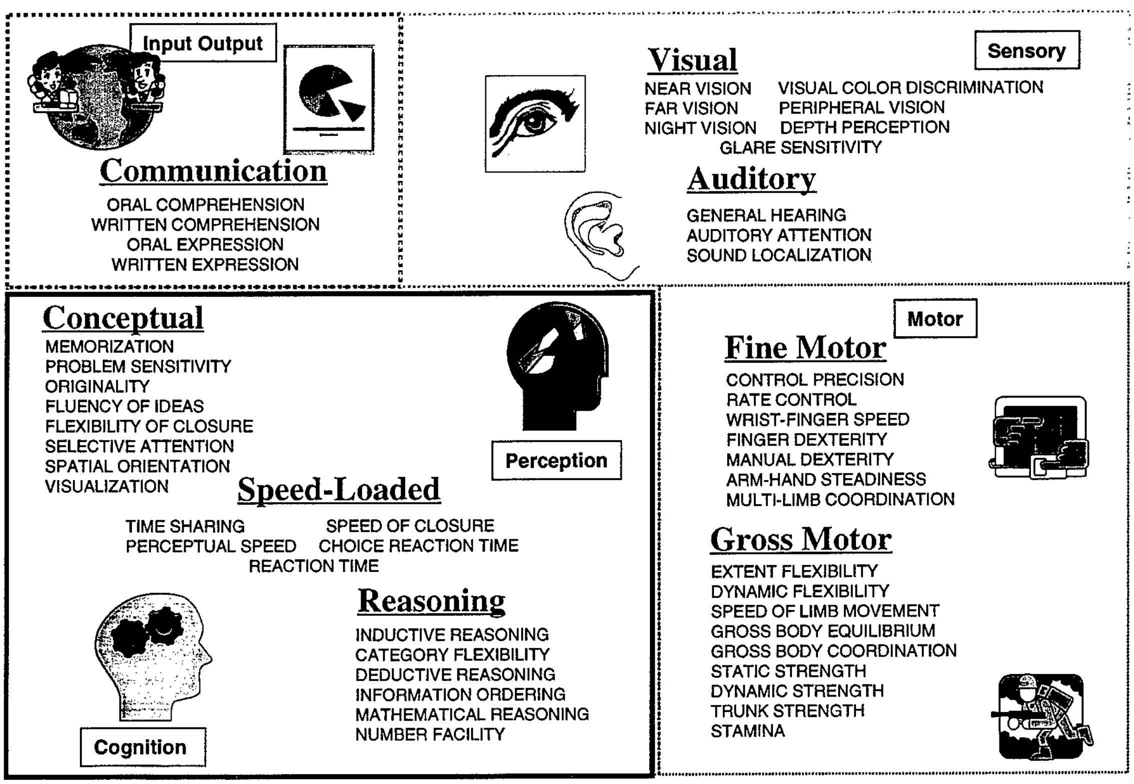
Data from the ECAT selection test battery were used in this analysis as well. The two sub-tests used were the one- and the two-handed tracking tasks. This test was administered in 1995 and used a sample of 28 students from both the Pioneer and Hunter external pilot classes held at Fort Huachuca, including six participants who failed the external pilot course. Finally, a

SME group consisting of 12 members was used to help interpret the data. The group was comprised of military, contractor, and civilian personnel with operational and human engineering backgrounds related to the UAV crew issues.

Test Instruments

Job Assessment Software System (JASS)

JASS is a test instrument developed to elicit from soldiers the relative importance of 50 skills and abilities for specific task functions defining various MOSs. The computerized test is designed to allow the soldiers to rate each skill designation on a seven-point scale for each specified military task. The itemized skills and abilities are illustrated in Figure 1, broken into functional areas: communication, speed-loaded, reasoning, visual, auditory, and psychomotor (fine and gross motor skills). The test is based on validated psychometric investigations performed by Fleishman and his colleagues (Fleishman & Quaintance, 1984) and broken into the underlying cognitive, perceptual, and psychomotor skills that would constitute any human work activity.



Fleishman, E. A. & Quaintance, M. K. (1984). Taxonomies of human performance: The description of human tasks. Orlando: Academic Press.

Figure 1. Job assessment software system – 50 skills and abilities.

This version of JASS was tailored for military applications and was developed using a number of MOS test cases to validate further the basic concepts in an operational context (Knapp & Tillman, 1998). The JASS software was administered to the soldier participants on a laptop computer and required approximately an hour of each soldier's time. Test administrators were present to answer queries about test or procedural matters related to JASS.

Enhanced Computer-Aided Testing (ECAT)

The ECAT battery was developed jointly by the U.S. Army Research Institute and the U.S. Naval Personnel Research and Development Center. It consists of nine sub-tests that were designed to supplement the Armed Services Vocational Aptitude Battery (ASVAB) now used by the Department of Defense for initial selection and training purposes. For this effort, data were collected using only two of the nine sub-tests. These particular tests measured one- and two-handed tracking performance, respectively. The tests were computer administered and lasted approximately 20 minutes each.

Results

The AVO JASS data were investigated to determine whether the requirement for high levels of cognitive skills was pertinent to the flight issues discussed. Figure 2 summarizes the results and indicates that the AVO raters did not consider their flight-related functions (except for communications) to be overly demanding for any of the skill clusters. The complete skill profiles are presented in Appendix B and basically show the same trend. These data are supported by both the accident reports reported next and the feedback from SMEs; the AVO cognitive skill level requirements do not seem to be related to flight issues.

The EP data were more complicated, and both anecdotal and empirical information suggest an important relationship between the EP's skill levels and safety (the data summary is given in Appendix C). Figure 3 is a bar graph plot of the skill categories as a function of skill rating. When the EP's job is compared with the AVO data, it can be seen that this job is rated as requiring higher skill and ability levels across all eight skill clusters.

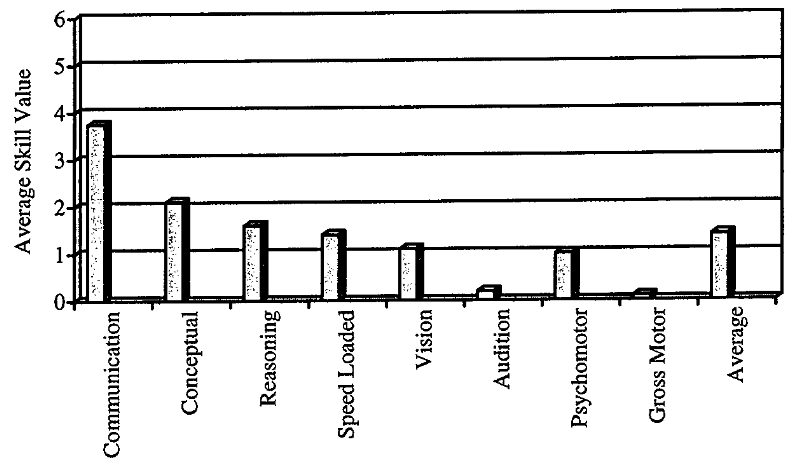


Figure 2. Skill cluster ratings for air vehicle operators.

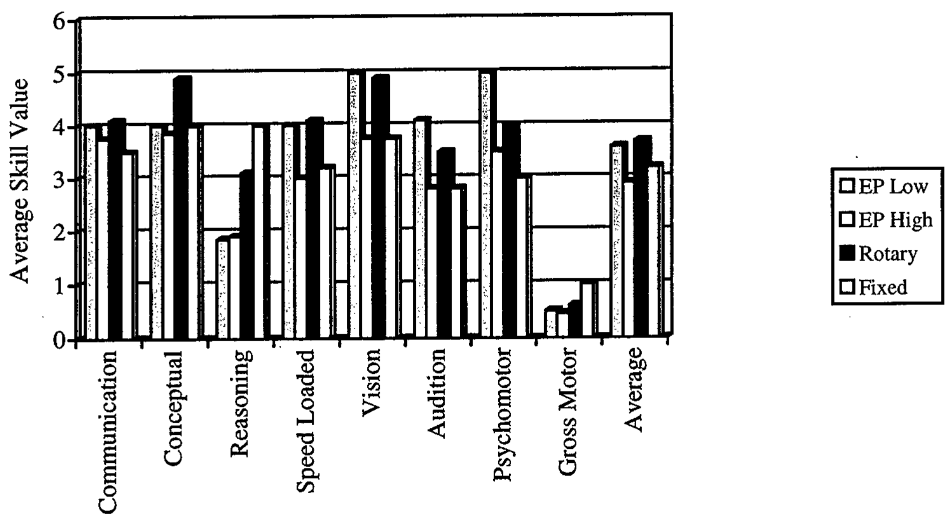


Figure 3. Skill cluster ratings of external pilots (both high and low experience levels) and rated aviators (both rotary and fixed wing).

The data are decomposed further into four job categories: EP low experience, EP high experience, rotary wing aviators, and fixed wing aviators. The main difference was in the reasoning factor, with both aviator groups showing slightly increased importance attached to reasoning skills, compared to the EP groups. There is evidence of relatively heavy loadings on conceptual, vision, and psychomotor components for all groups. The EP low experience group seems to give high ratings to the vision, audition, and psychomotor skill clusters. This suggests that the initial training may have been particularly weighted toward developing these skills.

The ECAT results obtained in a previous study support the particular importance of psychomotor skills during training. As Table 1 indicates, the one- and two-handed tracking scores were nearly perfect indicators of failure rate during the EP training at Fort Huachuca. Five of the six students who failed the course had scores on both the tracking tasks near the bottom of the performance scores of the sampled students. The EP designated "x" who also failed had a severely impaired hand, making his failure to complete the course difficult to interpret.

The data were further analyzed to understand precisely the relationship between flight safety and skill clusters for the four job categories. First, only the task data related to emergency conditions were examined (emergency landings, etc.). Next, identification was made of which of the 50 skills (see Figure 1 for the full listing) were ranked in the top 10 for each of the emergency condition tasks. Finally, determination was made as to how many of these skills were in each skill cluster, and these data were plotted as a function of what percentage of each cluster was represented in the top 10. Based on previous research, it was felt that the importance rankings were a better indicator of the usefulness of each skill cluster in performing crucial task functions vice using simple average skill values (Knapp & Tillman, 1998). The results are plotted in Figure 4, which shows a very different relationship between experience level and the type of skills required in emergency conditions. The experienced EP used mostly conceptual skills in emergency situations, whereas the inexperienced EP reported relying heavily on visual and psychomotor skills during these conditions. These findings are consistent with the results of the ECAT tracking tasks reported (which indicated how important the student's perceptual and motor skills were in passing the EP portion of the UAV training regimen). A surprising finding was that the aviators used speed-loaded skills for emergencies, whereas speed-loaded skills were rated as relatively unimportant by both EP groups.

The UAV accident and air safety report (TSM, 1998) indicated that both the Pioneer and the Hunter UAVs historically had high accident rates of an average of one incident per every 269 and 158 operational hours, respectively. Not surprisingly, almost all of the incidents involved EPs because take-off and landing are the most dangerous parts of the mission for flight safety. However, since 1996, the Hunter EP incident rate has fallen dramatically to 1,201 hours per incident, which compares favorably to the Predator (current Air Force UAV) rate of 1,247 hours per incident. One possibility for this improvement is the maturing of the Hunter EP cadre. Data discussed later support this hypothesis.

Table 1

Ranking of 28 Students on the One-Handed Tracking Test Portions of the ECAT Inventory

System or branch of service	EP	Two-handed tracking	One-handed tracking
Hunter-Army	b	2729	2212
Pioneer-USMC	r	4067	2348
Hunter-Army	d	2829	2353
Pioneer-USN	n	3537	2407
Hunter-USMC	f	3738	2488
Pioneer-USMC	t	3696	2491
Hunter-USMC	e	3512	2545
Pioneer-USMC	q	3208	2605
Pioneer-USMC	v	3271	2632
Hunter-USMC	a	2852	2652
Pioneer-USMC	z	3892	2674
Hunter-USMC	g	3634	2730
Pioneer-USN	u	3123	2796
Pioneer-USMC	I	3656	2800
Pioneer-USN	l	3880	2837
Pioneer-USMC	w	3953	2837
Pioneer-USN	x	3969	2846
Pioneer-USMC	j	3786	2853
Pioneer-Army	p	3902	2923
Pioneer-USN	s	3560	2961
Pioneer-USN	y	3705	2993
Pioneer-USN	k	3782	3002
Pioneer-USN	o	4045	3068
Pioneer-USN	aa	4304	3183
Pioneer-USN	m	4111	3229
Pioneer-USN	ab	4282	3297
Hunter-Army	c	4209	3462
Hunter-Army	h	4895	3756

Shaded area indicates student did not finish course.

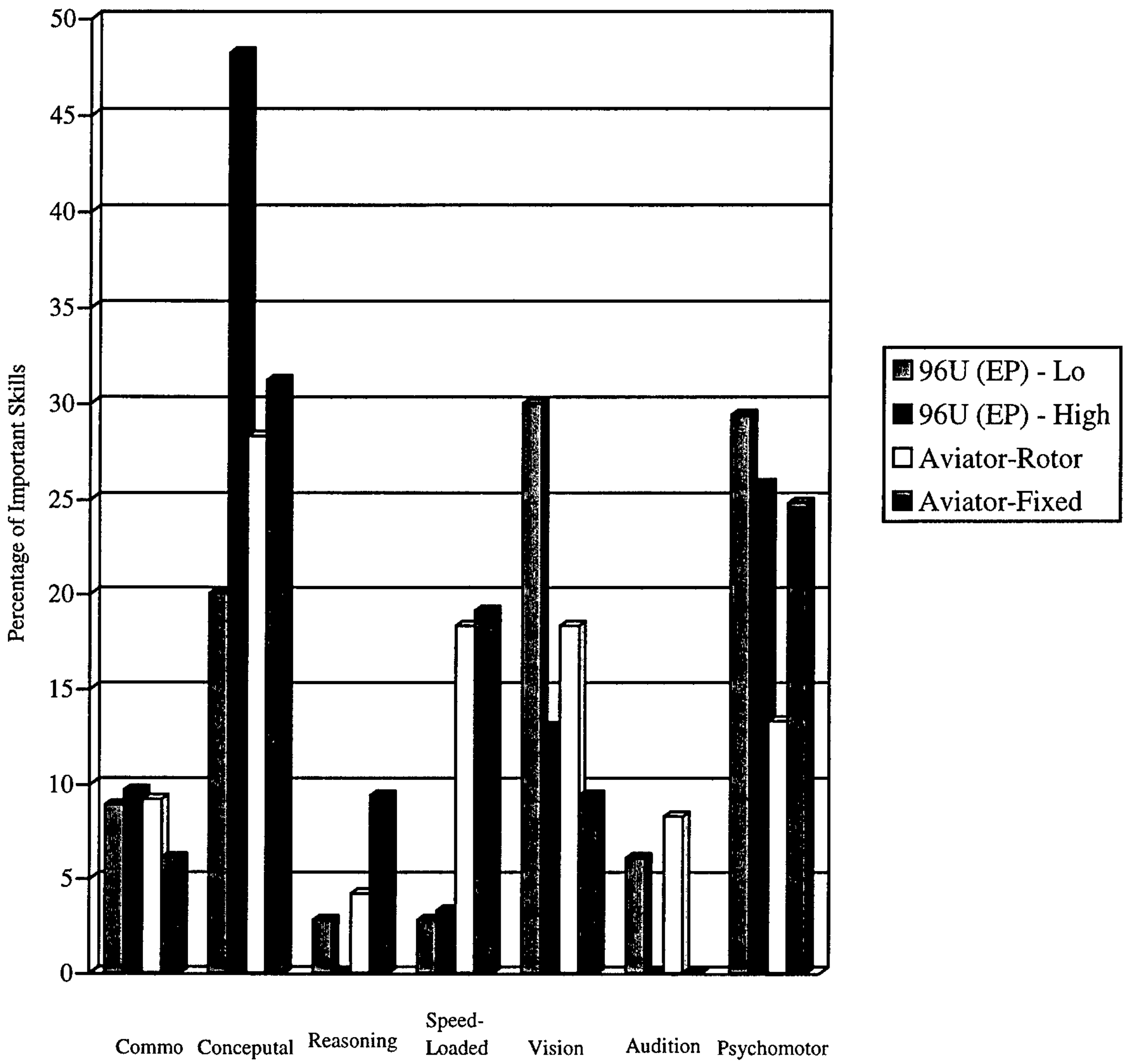


Figure 4. Percentage of important skills used during emergencies, shown by job category.

Discussion

Scant evidence was found for the need of rated aviator skills for the AVO. The JASS list of critical skills, accident data, and the consensus of the SME deliberations suggest that the current skill level of the AVO community is sufficient for piloting responsibilities. The EP situation is more complex. There was a marked difference between experienced and inexperienced EPs in the inventory of skills the two groups used during emergency situations. Apparently, the experienced EPs were able to visualize and anticipate problems before they occurred; an experienced UAV operator described the process as "getting ahead of the air vehicle." With experience, the operator is able to devote his or her attentional resources to future problems while attending to the immediate perceptual and motor tasks in an automatic mode. In effect, the operator crosses a cognitive threshold as expertise increases and the problem domain becomes more cognitive and less psychomotor intensive. This agrees with the psychological literature regarding both automatic processing (Shiffrin & Schneider, 1977) and the development of expertise (Rasmussen, 1983). If this interpretation is correct, using rated aviators would have little effect on the accident rate during landing and take-off. Expertise tends to be task specific. Therefore, the specific motor skills needed to control the radio-controlled UAV would have to be learned by aviators independently of the motor skills learned in flying an aircraft. In particular, the somatic and visual cues that pilots use during aircraft landings would not be useful (and perhaps even counter-productive) for the different skill sets and perceptual viewpoint necessary for radio-controlled landings. This is not to say that there would not be some transfer of training, only that the transfer would be transitory, and the more cost-effective solution would be to develop expertise in the EP corps.

The improvement in the Hunter accident rate gives at least some preliminary assurance that the EP performance record will improve with the maturing of the operator population. This does not address the question of how to turn novices into experts. Fortunately, innovative research funded by the Israeli Air Force offers some promise in addressing this issue. Gopher, Weil, and Bareket (1994) developed a computer game to help train Israeli Air Force cadets before flight training. The computer game simulation was not high fidelity and did not stress motor skills; instead, the game emphasized the higher level conceptual skills (such as the ones identified in the JASS for the experienced EPs) necessary to anticipate and plan in a combat aviation environment. The simulation group was able to generalize these skill sets to actual training. Students practicing the computer game were twice as likely to graduate from advanced flight training as the no-game control groups. The Israeli Air Force has since adopted the computer game as part of their training program. The UAV program would very likely benefit from a similar computer training project. The software would be cost effective because air vehicle fidelity is not an issue; the simulation would need to emphasize attentional and visualization skills. These skills could be developed in parallel to the psychomotor and other flight skills currently being developed in the training program.

A number of related issues were discussed with the SMEs during the consensus exercise held at Fort Huachuca. The greater use of speed-loaded skills by the aviators at first seemed counter-intuitive to the SME group. However, further discussion suggested that the underlying cause was related to the demands of the different aircraft flown by the two communities. The controls and displays that both fixed and rotor wing aviators use are extremely complex, especially compared to the relatively simple EP interface. Thus, the EPs could concentrate on future aircraft states, whereas the aviators had to respond to the more complex interface environment as well as anticipate future problems.

The question of using rated aviators in either the AVO or EP positions was specifically addressed by the group after the data were presented. The group consensus was that UAV operators do not need to be rated aviators for Army applications. In particular, neither the Air Force nor the Navy representatives believed that the EP or AVO should necessarily be aviator rated. The Navy's solution was to have the equivalent of the mission commander be aviator rated when possible. This solution had the advantage of freeing the AVO and EP to concentrate on UAV-related issues, while the mission commander handled the mission planning and air space coordination, giving the crew the benefit of his or her aviation expertise in a supervisory role. The Air Force representative pointed out that the Predator (a current Air Force UAV) was a different air vehicle than those employed by the Army. The Predator was designed to be flown like a standard aircraft and as such, the transfer of skills from the aviator to the UAV community was a natural solution. According to this representative, no firm decision had been made concerning the use of rated aviators for future Air Force UAVs such as Dark Star.

In summary, there was no evidence that would lead to the conclusion that either the AVO or the EP should be rated aviators. In particular, the EPs' landing and take-off functions require motor and cognitive skills that are unique to their mission profiles and job environment. However, the greater use of cognitive skills by the experienced EPs suggests that greater emphasis should be placed on developing these skills during training. The use of computer games was offered as an innovative and cost-effective solution to accomplish this end. Finally, the utility of having military aviators or personnel with equivalent experience as part of the decision chain for UAV crews seems to be both a cost-efficient and a tactically effective method to introduce aviator skill sets into the UAV program.

IMAGERY AND INTELLIGENCE SPECIALISTS AS COMPONENTS OF THE UAV CREW

As mentioned, two 96U operators reside in the GCS during a typical mission. The MPO works with the AVO to search the target area and make preliminary recognition and detection decisions regarding potential targets in the locations designated by the intelligence staff as named areas of interest (NAI). However, MPOs are not imagery or intelligence analysts, and their reporting requirements in this regard are minimal. In light of the specialized skills of the UAV crews, the possibility of adding operators from MOSs with skills and abilities that complement the MPOs' skill set was the focus of this portion of the study. The two MOSs investigated were the 96B, Intelligence Analyst, and the 96D, Imagery Analyst.

Method

Procedure

The JASS computer-based job assessment system was used as in the rated aviator section work. Data analysis proved to be fairly complicated because 96B and 96D MOSs have distinctly different task structures and would therefore bring different skill sets to the 96U crew. In order to assess the commonalities as well as the differences among the three jobs, separate task structures had to be derived for each of the MOS positions. From the task lists, it was then possible to derive an overall ranking of the importance of the JASS skill sets for each task structure.

The actual comparison was done in three steps: (a) the top 20 JASS skills (see Figure 1) for each of the 16 tasks that the MPO performed were rank ordered; (b) the top 20 skills for both the 96B and 96D distinct skill sets were ranked separately; and (c) the resulting ranks of the JASS skills from the 96B and the 96D were compared to the ranks of the JASS skills for the 96U operators for each of the 16 tasks evaluated in the initial step. Kendall's rank order correlation test was used to evaluate rank concordance.

Participants

The comparison was made for the tasks to which the 21 96Us responded on the JASS inventory. Scores from nine 96B analysts and eight 96D imagery specialists were collected on the JASS in order to compare the skill sets of these two MOSs to those of the UAV GCS operators. All soldiers were stationed at Fort Huachuca.

Results and Discussion

Table 2 matches the UAV crew task duties to the skill rankings for the 96B and 96D operators. Kendall's rank order correlation test was used to assess the commonalities among the JASS results. The columns in Table 2 labeled "MOS" indicate the degree of correlation between the 96D and 96B skill rankings and the rankings on each of the duties listed in the first column. The 96D skill rankings were significantly correlated to two of the UAV crew duties ($p < .05$). In contrast, the 96B showed a significant Kendall rank correlation to 14 of the 16 duties the UAV crew engaged in during their missions (again, $p < .05$). Interpretation of the data was that the 96D was a possible candidate to complement the skill profiles of the UAV crews because of the difference in the skill sets used by these two MOS groups. In terms of information theory, the lack of redundancy between the two MOSs implies a higher information transmission rate. The authors' interpretation was given credibility by the SME discussions that indicated the importance of enhancing the imagery interpretation skills of the MPO in particular. It was felt, especially by the 96U operator participants, that the 96D skills would be a very useful addition to the UAV crew. This does not imply that MPO requires the in-depth imagery understanding of the 96D; the 96D skills could be employed remotely at the brigade or division tactical operations center (TOC). For many or perhaps even most missions, the detection and recognition reporting skills of the MPO would suffice to meet the commander's goals. The 96D skills would be necessary for particularly difficult interpretations or specialized missions when in-depth target analyses are required. Another possibility would be to incorporate the 96D skills into the mission command module by enhancing the skill set of the data exploitation operator (DEO) with additional imagery training. The DEO resides in the command module and performs the function of a senior analyst but is not currently required to have 96D training. In summary, the principal conclusion is that additional imagery support using 96D specialists should enhance the overall operational versatility and capabilities of the UAV crews. On the other hand, the role of the 96B as now configured seems to be a satisfactory adjunct to the UAV crews' intelligence-gathering function.

Table 2

Statistical Comparison of Skill Commonalities Using the Kendall Rank Order Correlation Test

96U duties	96D highest overall skills	96B highest overall skills
Create air vehicle mission plan on display		**
Perform air reconnaissance		**
Perform air vehicle navigation		**
Prepare air vehicle mission plan		**
Detect targets of military significance		**
Identify target type and number		**
Operate remote video terminal		**
Perform mission payload terminal		**
Recognize targets; place in context		**
Transfer control of air vehicle		
Prepare intelligence reports		**
Disseminate mission results	**	**
Coordinate airspace requirements		**
Coordinate with higher headquarters		**
Coordinate with support and external elements	**	**
Conduct launch and recovery operations		

**Significance level: $p < .05$

AUTOMATION AND WORKLOAD MODELING FOR FUTURE UAV PLATFORMS

An important consideration in designing the future crew interfaces is the degree and type of automation required in future UAV applications. The UAV operator has to perform multiple functions, often simultaneously during a typical mission profile (Barnes & Matz, 1998). In order to understand automation requirements in this environment, the MicroSaint™ modeling environment was used to investigate the workload for one potential future UAV platform, the Outrider. The Outrider was a good candidate to investigate incipient crew workload issues (i.e., high workload may suggest a need to automate tasks) because the Outrider was in the process of completing an advanced combat technology development (ACTD) during these data collection efforts. MicroSaint™ was chosen because it is a relatively mature instrument and has been used successfully in a number of human engineering applications. (A detailed description of MicroSaint™ is given in Appendix D.) However, the general findings of this report should generalize to a larger class of PC workload modeling environments; in particular, the underlying workload model residing in MicroSaint™ is shared with other test instruments such as the Improved Performance Research Integration Tool (IMPRINT).

Method

Procedure

First, a model of the Hunter UAV system was developed by using MicroSaint™ and a database that contained most of the GCS operator tasks and functions related to the Hunter system, which range from setting up the equipment, route planing, internal flight procedures, and intelligence gathering to actually landing the UAV. The Hunter model was based mainly on a Hardman III workload task analysis[1] done for the Joint Tactical UAV Program Office as part of a previous project. In addition to task time data and the task sequence logic, the database contained the visual, auditory, cognitive, and psychomotor workload values for each task. This model served as a foundation for the design of the Outrider model.

The Hunter model was then modified according to information from SMEs and data collected during an observation of the Outrider training simulator. The scenario chosen to be used in the model included four stationary targets, no malfunctions, and no in-flight modifications. After the model was executed, two sets of data were produced: the workload values for each operator throughout the scenario and the number of steps required to perform each task.

Participants

The number of SMEs available to assist in building the Outrider model was small; however, the scarcity of the subject pool was mitigated by drawing upon an existing network model of the Hunter UAV, which had been validated during a number of simulation exercises (Barnes & Matz, 1998). The first iteration of knowledge elicitation was done at Fort Huachuca with two experienced UAV operators who were familiar with the Outrider and a human factors specialist familiar with the previous workload model developed for the Hunter in the 1993-1995 time frame. The next iteration was completed at Fort Hood using two 96U soldiers who had

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[1]Test battery developed by ARI

been trained the month before in the Outrider training simulator in Hondo, Texas. The last iteration took place in Hondo with two SMEs whose job was to develop lesson plans for the training simulator and to teach 96U operators to use the Outrider simulator. Both operators had been flight-qualified Hunter operators before being employed in their current positions.

Workload Scales

The visual, auditory, cognitive, and perceptual (VACP) workload theory implemented in this work is discussed in detail in an Army Research Institute report (McCracken & Aldrich, 1984).

Workload theory is based upon the idea that every task a human performs requires some effort or work. Usually, a task is composed of several different types of work, such as visual or cognitive. For example, consider a task such as steering a car. This task will have some visual work (watch where you are going), some cognitive work (decide if you are turning enough), and some psychomotor work (rotate the steering wheel). The workload theory implemented in this effort assigns values representing the amount of effort that must be expended in each channel in order to perform the task. Table 3 scales are taken directly from Bierbaum, Szabo, and Aldrich (1989).

This theory also hypothesizes that when two tasks are performed at once, the workload levels are additive within channels, across tasks. For example, if two tasks are being done at once, one with a psychomotor load of 2.6 and one with a psychomotor load of 4.6, then a psychomotor score of 7.2 (2.6 + 4.6) would be recorded for the time that the two tasks were being performed together.

Results

Four different categories of data were collected to help determine which tasks should be candidates for automation. These categories were based on the model output and data taken from interviews with the SMEs. Besides the two model-based data sources, the SMEs provided a list of tasks that were critical to the mission, and they indicated which additional tasks they would like to see automated.

Table 3

Workload Scale Values

Scale	Scale value	Descriptor
		Auditory scale
	0.0	No auditory activity
	1.0	Detect or register sound (detect occurrence of sound)
	2.0	Orient to sound (general orientation or attention)
	4.2	Orient to sound (selective orientation or attention)
Auditory workload	4.3	Verify auditory feedback (detect occurrence of anticipated sound)
	4.9	Interpret semantic content (speech)
	6.6	Discriminate sound characteristics (detect auditory differences)
	7.0	Interpret sound patterns (purse rates, etc.)
		Cognitive scale
	0.0	No cognitive activity
	1.0	Automatic (simple association)
	1.2	Alternative selection
Cognitive workload	3.7	Sign or signal recognition
	4.6	Evaluation or Judgment (consider single aspect)
	5.3	Encoding or decoding, recall
	6.8	Evaluation or judgment (consider several aspects)
	7.0	Estimation, calculation, conversion
		Psychomotor scale
	0.0	No psychomotor activity
	1.0	Speech
	2.2	Discrete actuation (button, toggle, trigger)
	2.6	Continuous adjustive (flight control, sensor control)
	4.6	Manipulative
Psychomotor workload	5.8	Discrete adjustive (rotary, vertical thumb wheel, lever position)
	6.5	Symbolic production (writing)
	7.0	Serial discrete manipulation (keyboard entries)
		Visual scale
	0.0	No visual activity
	1.0	Visually register or detect (detect occurrence of image)
	3.7	Visually discriminate (detect visual differences)
Visual workload	4.0	Visually inspect or check (discrete inspection or static condition)
	5.0	Visually locate or align (selective orientation)
	5.4	Visually track or follow (maintain orientation)
	5.9	Visually read (symbol)
	7.0	Visually scan, search, or monitor (continuous or serial inspection, multiple conditions)

Automation is generally suggested for tasks (a) that have high workload, (b) that require multiple operator actions, (c) that are mission critical or life threatening, and (d) the operator feels are auxiliary or bookkeeping, which could be automated easily. The four categories of data (workload, steps per task, critical tasks, and operator suggestions) were analyzed to identify which tasks might be automated. Tasks that appear in multiple categories were then reviewed for a final recommendation about the requirement for automation.

Workload

Each task within the Outrider model has corresponding visual, auditory, cognitive, and psychomotor workload values. Tasks that have workload values of 5.2 or higher in at least two of the workload components were viewed as high workload tasks and are listed next:

- Enter way points
- Verify system settings
- Monitor video, telemetry, and systems
- Check AV and navigation systems
- Enter way points and prepare flight plan

Steps Per Task

Each task within the Outrider model is performed in one or more steps. The tasks with three or more steps involved are

- Set up equipment
- Perform off-line mission planning
- Enter way points
- Analyze and modify mission planning
- Verify system settings
- Perform engine start procedures
- Perform verifications
- Monitor video, telemetry, and systems
- Check AV and navigation systems
- Monitor flight and search parameters
- Enter way points and prepare flight plan
- Monitor landing
- Modify landing

- Perform checks after landing

Critical Tasks

The functions that must be performed in order for the mission to be completed are

- Set up equipment
- Set up map system
- Create mission plan
- Preflight
- Verify indicators
- Start engine
- Perform take-off procedures
- Fly to way points
- Perform area search
- Recover AV

Tasks that operators suggested are

- Analyze and modify mission plan
- Perform pre-flight functions

The tasks that appear in two or three of the categories are listed next. No tasks appeared in all four categories. Tasks from the function "set up equipment" were removed because they cannot be automated. Tasks from the function "perform off-line mission planning" were also removed because it is a non-critical function that is usually performed only during training and because the UAV operators already perform mission planning "on line".

- Enter way points
- Analyze and modify mission plan
- Perform pre-flight procedures
- Verify system settings
- Perform engine start procedures

- Monitor video, telemetry, and systems
- Check AV and navigation systems
- Enter way points and prepare flight plan
- Monitor landing
- Modify landing
- Perform checks after landing

Discussion

The results indicate that the candidates for automation include pre- and post-flight procedures and checks, verification of system settings, and computer checks for the mission plans. This corresponds with the suggestions provided by the SMEs who stated that although the Outrider system does provide some error messages, it does not check to see if the mission plan or system settings are within range or engineering limits. In addition, the results indicate that monitoring is another task that could be automated. However, monitoring the aircraft is one reason why human operators are involved in the "loop". Still, this task can be partially automated (e.g., warnings or voice commands can be given by the system when certain parameters are no longer within specified values). In particular, when system safety is involved, having both the human and the system computer monitor for possible safety issues is essential. The task "modify landing" addresses the issue of unsafe landings and would entail extensive analyses to determine the optimal mixture of human and computer control during dangerous landing situations. In general, the operators were not asking for fully automated systems; instead, they preferred the decision making to remain with the operator and the workload reduction to be accomplished by making the computer interface faster and more efficient as well as having the computer become another set of "eyes" to check for safety problems.

It is also important to determine how operators react when the system behaves unexpectedly and which corrective tasks should be automated or computer aided. Areas for future work include expanding the model to simulate more scenarios, such as instances of dynamic targets and system malfunctions, and to collect human performance to extend the model's capabilities to predict mission and task outcomes. Further investigation is also needed to examine the human cognitive profile related to search tasks and to assess the utility of automated search and target detection algorithms. Finally, the model should be improved so that it is possible to examine how fatigue and possibly stress factors affect operator performance and overall mission safety in future UAV operational tempos.

GENERAL DISCUSSION

The use of a variety of human engineering tools has helped in our understanding of future crew environments. Most of the results were generic and can be used to help guide the design process for any UAV configurations involved in tactical Army missions. For example, the MicroSaint™ model generated a number of hypothetical task structures for possible automation, which should generalize to most future tactical UAV environments. These tasks can be narrowed further by design considerations, and realistic soldier-in-the-loop simulation experiments can then be designed to focus on a small set of pre-selected tasks. The results of the JASS study for the rated pilots were supplemented by performance data from both training and accident data that indicated the ability of these techniques to combine easily with empirical methods. Another feature of the analyses was the reliance on the SME team for interpretation. This is probably inevitable in a developing system because no one person could possibly understand the tactical, programmatic, and engineering issues of a system that is yet to be developed. The backgrounds of the SMEs involved were broad enough to cover many of these facets, thus laying a firm foundation for further analyses. Also, the combination of modeling techniques and expert input helped to curtail the shortcomings of both approaches by constraining the experts' tendency to tell "war stories" and by giving the results of the modeling efforts face validity and an operational context.

The preliminary suggestions for the UAV program, which were derived across the three sets of analyses, are

1. It is not cost efficient to require flight certification for either the AVO or EP operator positions.

2. Computerized training (especially embedded training) should be an effective means for developing operator flight skills. These efforts should concentrate on the cognitive components of the flight tasks.

3. Aviator-rated personnel (or personnel with equivalent expertise) should be involved in the decision chain to aid the UAV crew in mission planning, air space coordination, and general liaison with the other services.

4. Imagery interpretation skills drawn from the 96D training program would be a useful addition to the UAV targeting and reporting process. These skills do not have to be present in UAV ground control stations.

5. Automation requirements for the UAV operator should focus on computer assistance (e.g., quickly change way points) and system monitoring rather than on acquiring fully automated sub-systems. (Note. The utility of automated landing and take-off was not addressed in this study because the status of this feature on the Outrider was not clear at the time the workload data were collected.)

6. Future modeling efforts should include human performance (particularly in the search domain) and fatigue and stress data to predict mission performance during future UAV operational tempos more effectively.

The basic premise of this effort is that by using a variety of human engineering methods, a set of tools and methods could be created, which will mutually reinforce each other. The authors deliberately chose to investigate methods that were both cost and time efficient, thus avoiding methods that required large-scale simulations or field exercises. MicroSaint™ was chosen in part because it is available on personal computers and its software is relatively inexpensive and easy to use. The overall goal is to improve the human engineering design process by introducing methods (particularly computerized ones) that encourage early human system integration (HSI) analysis before the traditional materiel acquisition process begins. Too often, especially early in the acquisition process, the amount of HSI analysis is determined by cost and timeliness considerations. Tools such as JASS, ECAT, IMPRINT, and MicroSaint™ are being continually refined and validated to be more efficient and scientifically valid. The strategy adapted here is to combine these methods for a synergistic approach that can be used to investigate a complex and changing HSI environment early in the design process.

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APPENDIX A

PARTICIPANTS IN SUBJECT MATTER EXPERT WORKING GROUP

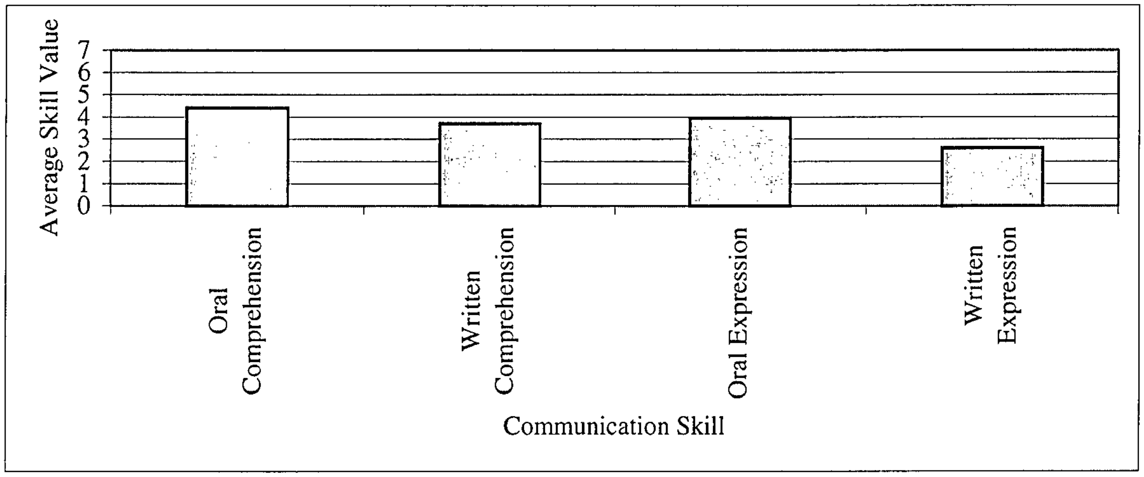
PARTICIPANTS IN SUBJECT MATTER EXPERT WORKING GROUP

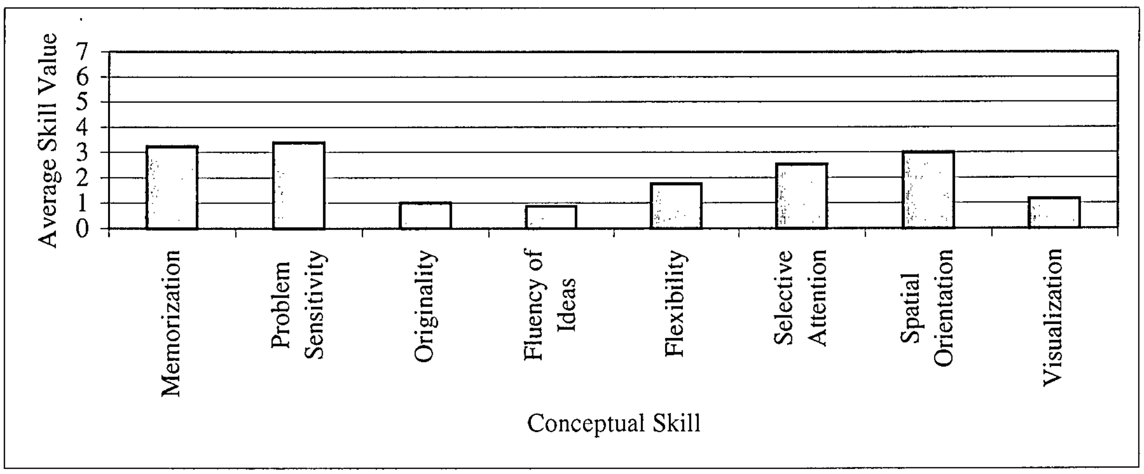
Michael J. Barnes	Army Research Laboratory (ARL)
Dr. Beverly G. Knapp	ARL
Brian Schreiber	Lockheed Martin
LT Henry Williams	Navy Aero-Medical Laboratory
Dr. Joseph L. Weeks	Air Force Research Laboratory
Barbara Karbens	Joint Tactical Program Office
Brett Walters	Micro Analysis & Design
SFC Ronald Miller	Joint Program Office Coordinator
SFC Edward Bradley	Fort Huachuca
SFC Allen Ruggles	Fort Huachuca
SSG Perry Coleman	Fort Huachuca
SSG Daryl Gorff	Fort Huachuca

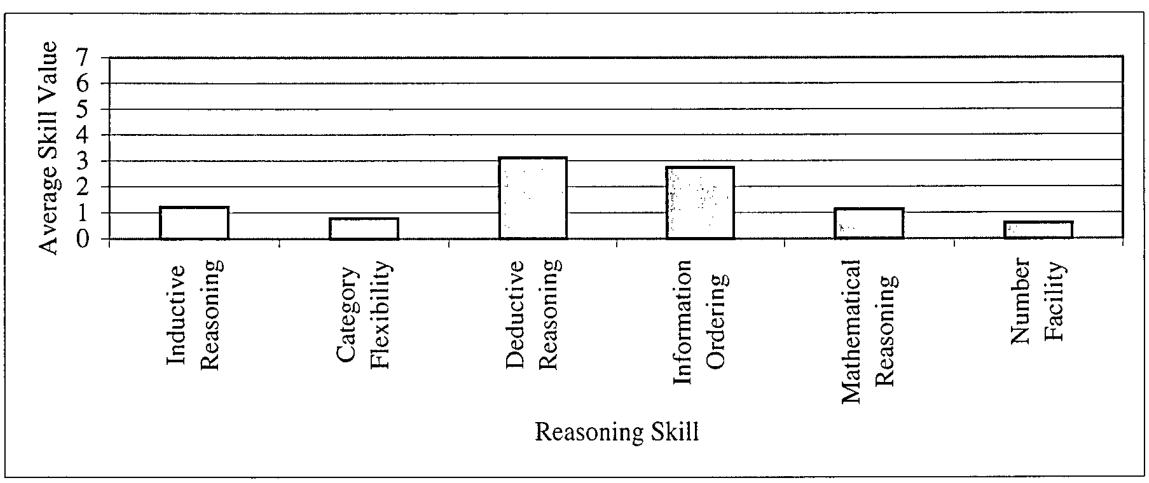
APPENDIX B

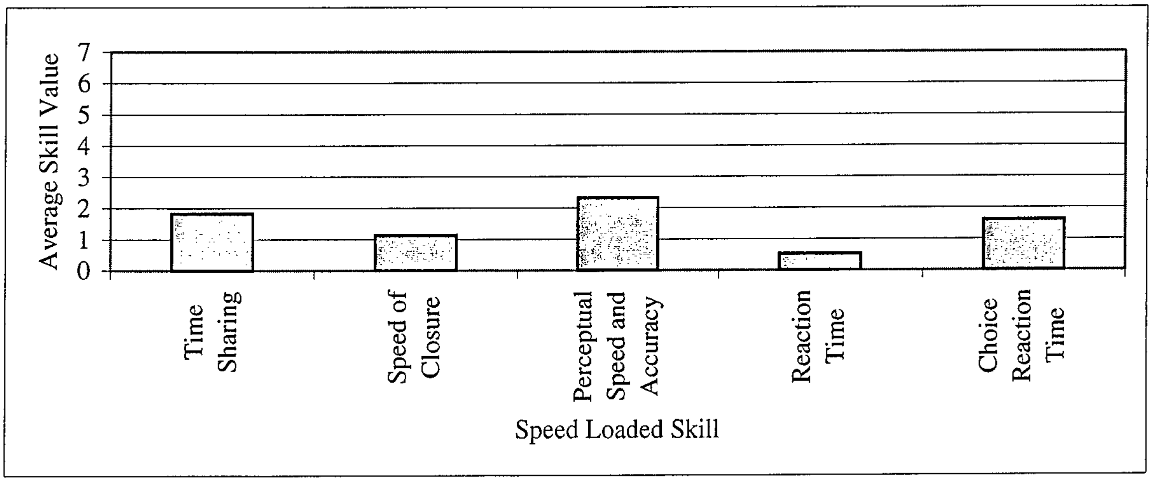
JASS AVERAGES FOR AVO POSITION ACROSS DUTIES

JASS AVERAGES FOR AVO POSITION ACROSS DUTIES








Average Skill Value
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6
5
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3
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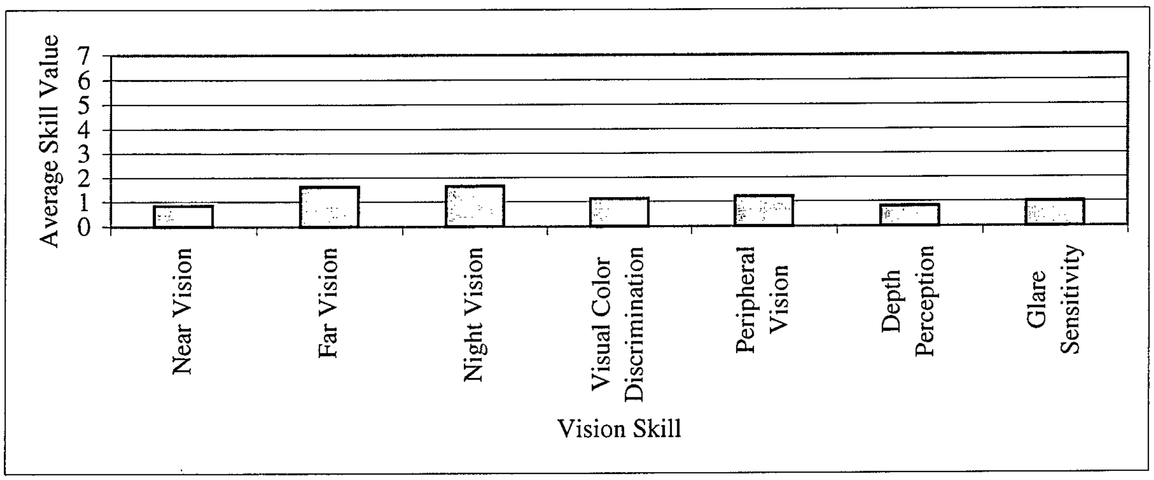
Time Sharing
Speed of Closure
Perceptual Speed and Accuracy
Reaction Time
Choice Reaction Time
Speed Loaded Skill


Average Skill Value
7
6
5
4
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2
1
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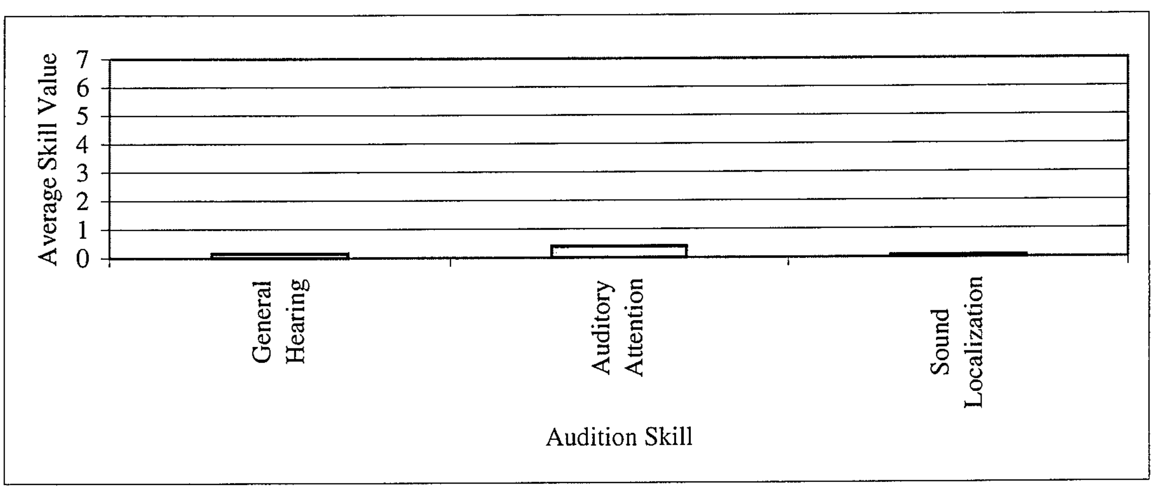
Near Vision
Far Vision
Night Vision
Visual Color Discrimination
Peripheral Vision
Depth Perception
Glare Sensitivity
Vision Skill


Average Skill Value
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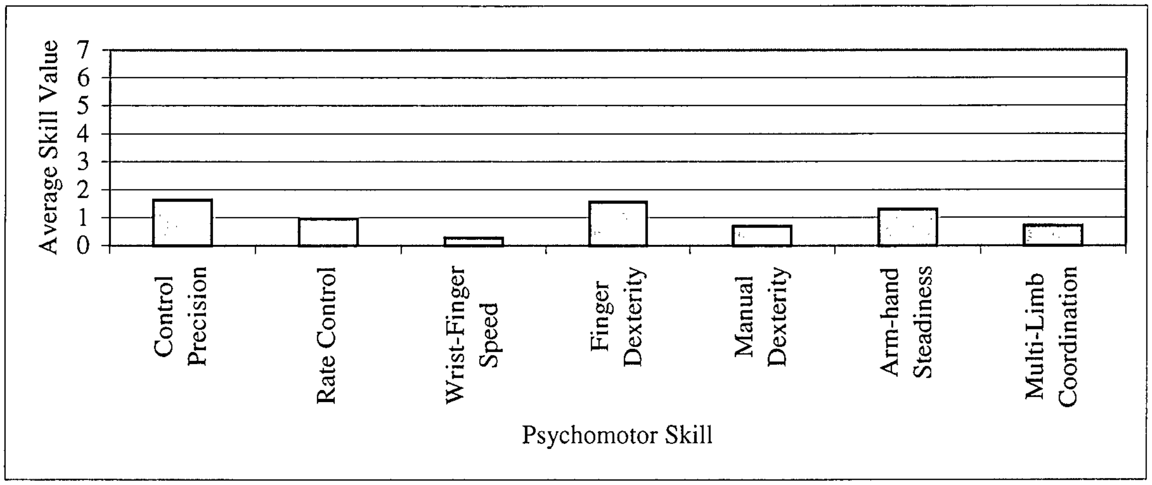
6
5
4
3
2
1
0
General Hearing
Auditory Attention
Sound Localization
Audition Skill


Average Skill Value
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6
5
4
3
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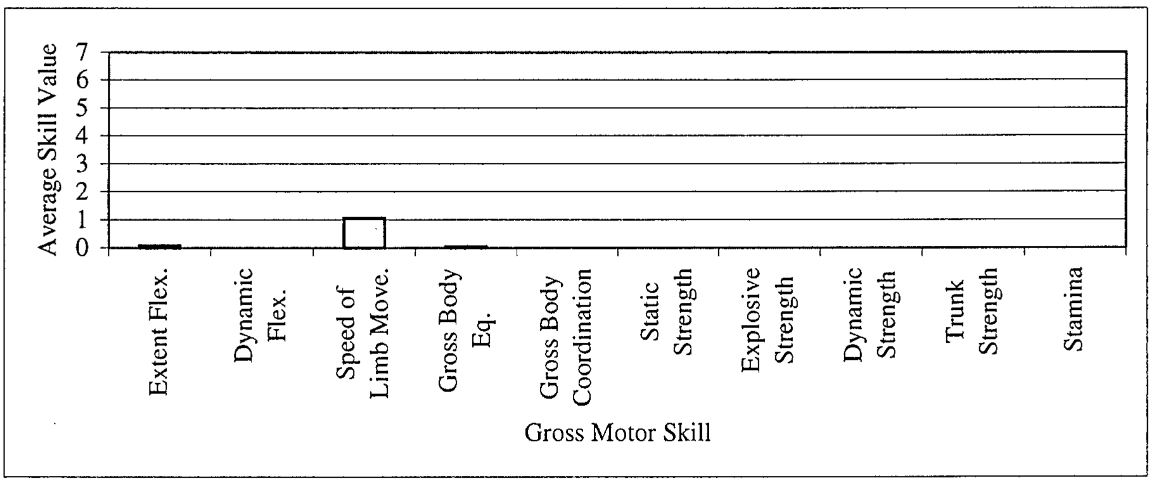
Control Precision
Rate Control
Wrist-Finger Speed
Finger Dexterity
Manual Dexterity
Arm-hand Steadiness
Multi-Limb Coordination
Psychomotor Skill


Average Skill Value
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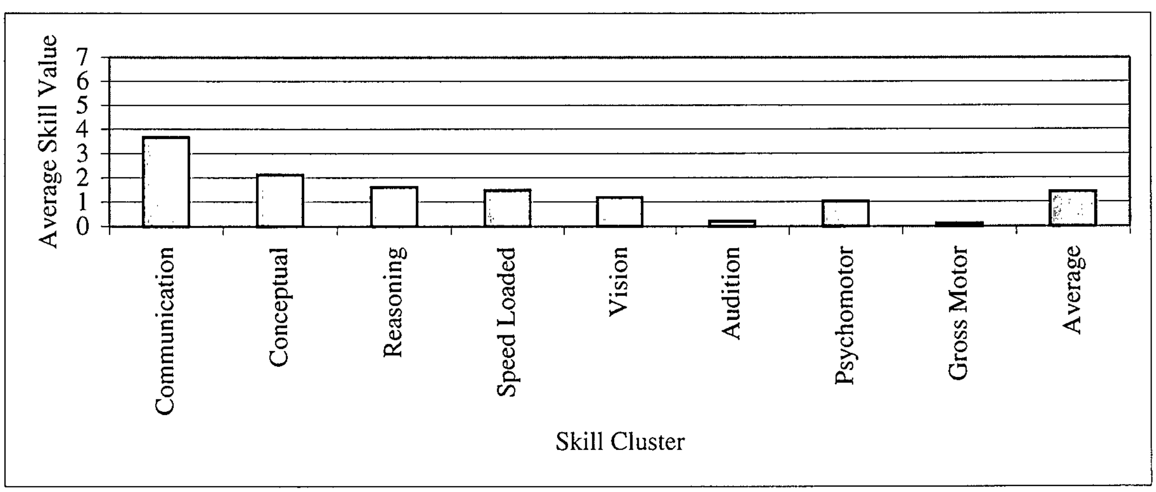
6
5
4
3
2
1
0
Extent Flex.
Dynamic Flex.
Speed of Limb Move.
Gross Body Eq.
Gross Body Coordination
Static Strength
Explosive Strength
Dynamic Strength
Trunk Strength
Stamina
Gross Motor Skill


Average Skill Value
7
6
5
4
3
2
1
0
Communication
Conceptual
Reasoning
Speed Loaded
Vision
Audition
Psychomotor
Gross Motor
Average
Skill Cluster

Average score within each skill cluster across 16 duties for the AVO

Communication	**AVO**
Oral Comprehension	4.41
Written Comprehension	3.72
Oral Expression	3.96
Written Expression	2.61
AVERAGE	3.68

Conceptual	**AVO**
Memorization	3.24
Problem Sensitivity	3.40
Originality	1.02
Fluency of Ideas	0.89
Flexibility	1.78
Selective Attention	2.53
Spatial Orientation	3.00
Visualization	1.18
AVERAGE	2.13

Reasoning	**AVO**
Inductive Reasoning	1.23
Category Flexibility	0.79
Deductive Reasoning	3.13
Information Ordering	2.75
Mathematical Reasoning	1.14
Number Facility	0.62
AVERAGE	1.61

Speed-loaded	**AVO**
Time Sharing	1.84
Speed of Closure	1.14
Perceptual Speed and Accuracy	2.33
Reaction Time	0.53
Choice Reaction Time	1.62
AVERAGE	1.49

Vision	AVO
Near Vision	0.87
Far Vision	1.64
Night Vision	1.66
Visual Color Discrimination	1.13
Peripheral Vision	1.23
Depth Perception	0.82
Glare Sensitivity	1.02
AVERAGE	1.20

Audition	AVO
General Hearing	0.16
Auditory Attention	0.40
Sound Localization	0.07
AVERAGE	0.21

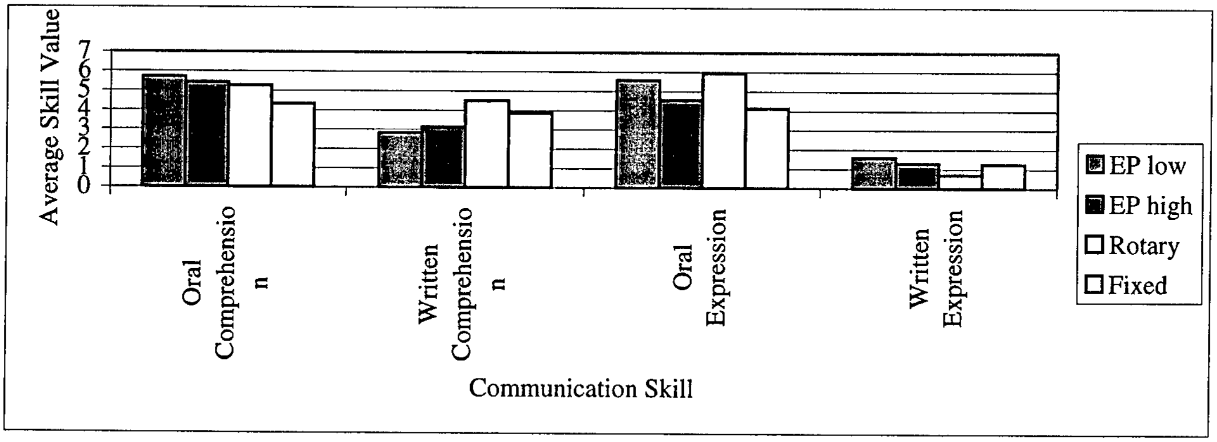
Psychomotor	AVO
Control Precision	1.65
Rate Control	0.97
Wrist-Finger Speed	0.29
Finger Dexterity	1.58
Manual Dexterity	0.71
Arm-hand Steadiness	1.31
Multi-Limb Coordination	0.72
AVERAGE	1.03

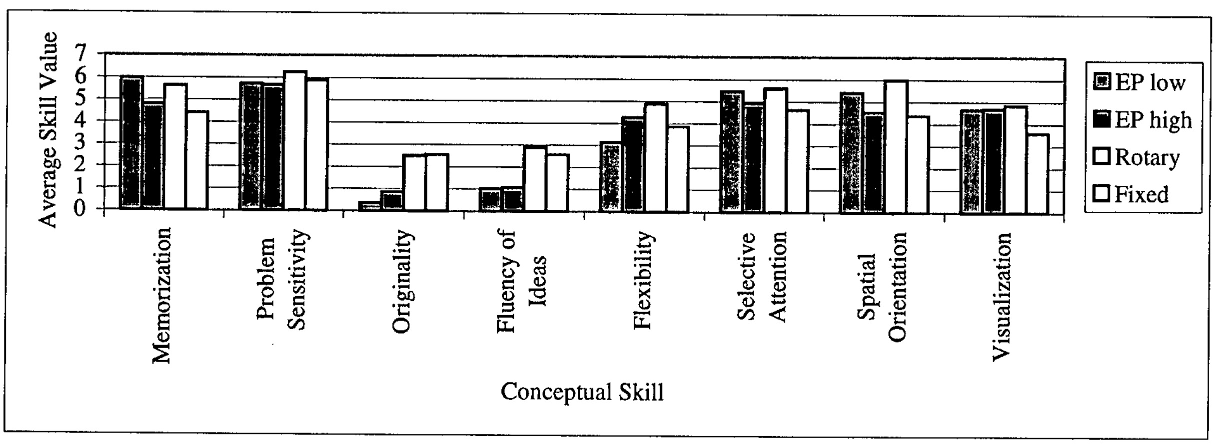
Gross Motor	AVO
Extent Flexibility	0.08
Dynamic Flexibility	0.00
Speed of Limb Movement	1.06
Gross Body Equilibrium	0.05
Gross Body Coordination	0.00
Static Strength	0.00
Explosive Strength	0.00
Dynamic Strength	0.00
Trunk Strength	0.00
Stamina	0.00
AVERAGE	0.12

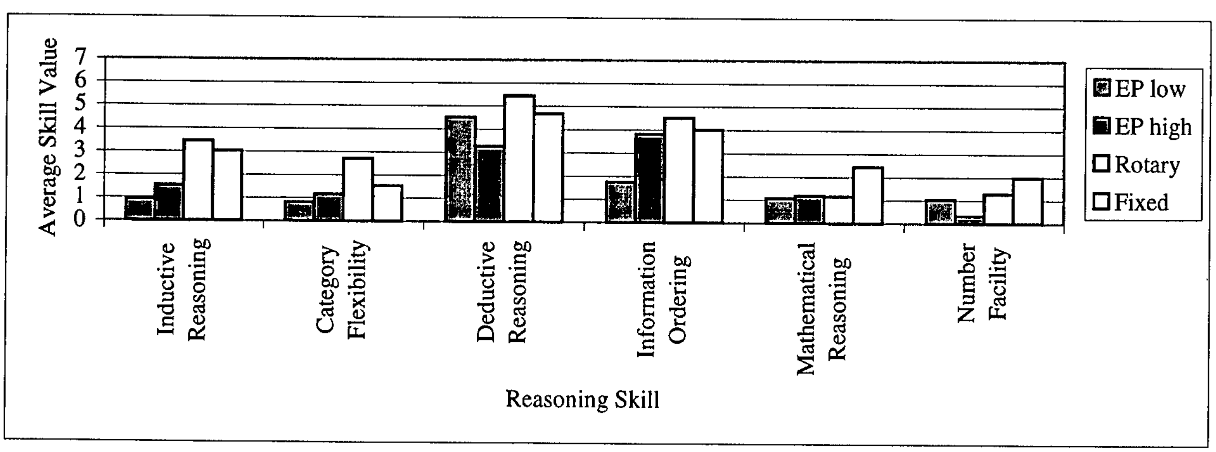
APPENDIX C

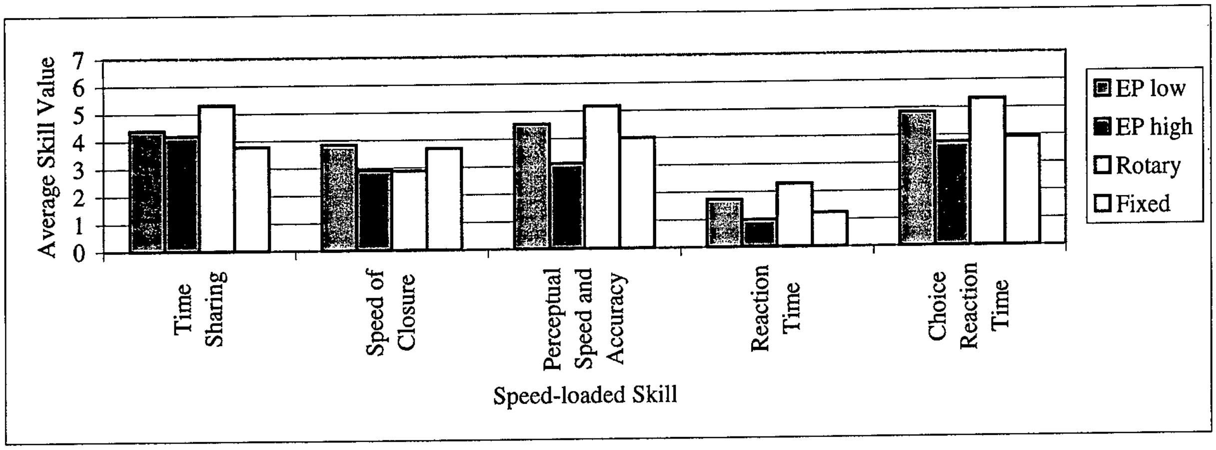
JASS DATA AVERAGES FOR EP (LOW AND HIGH EXPERIENCE) AND FIXED AND ROTARY WING AVIATORS' POSITION ACROSS DUTIES

JASS DATA AVERAGES FOR EP (LOW AND HIGH EXPERIENCE) AND FIXED AND ROTARY WING AVIATORS' POSITION ACROSS DUTIES









Average Skill Value
7
6
5
4
3
2
1
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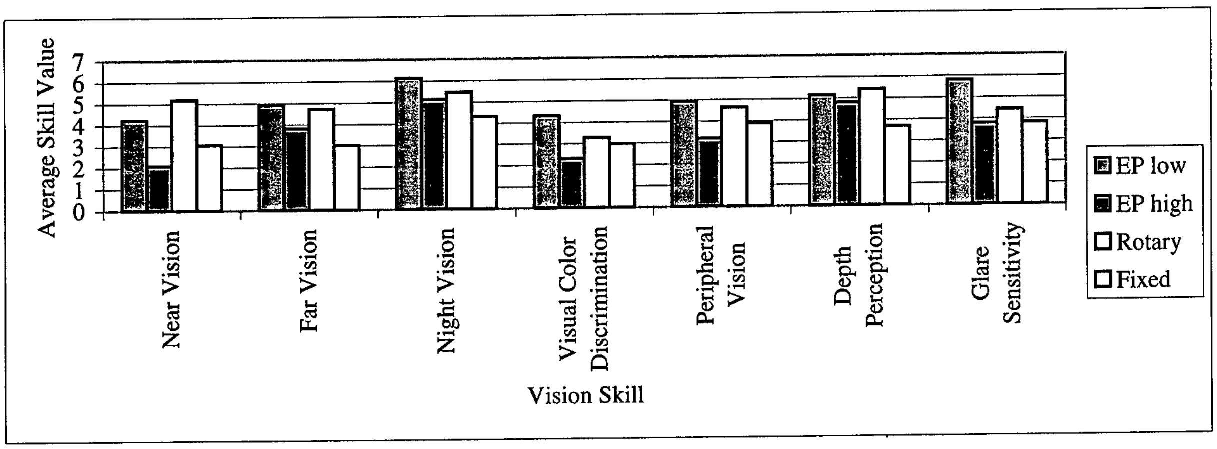
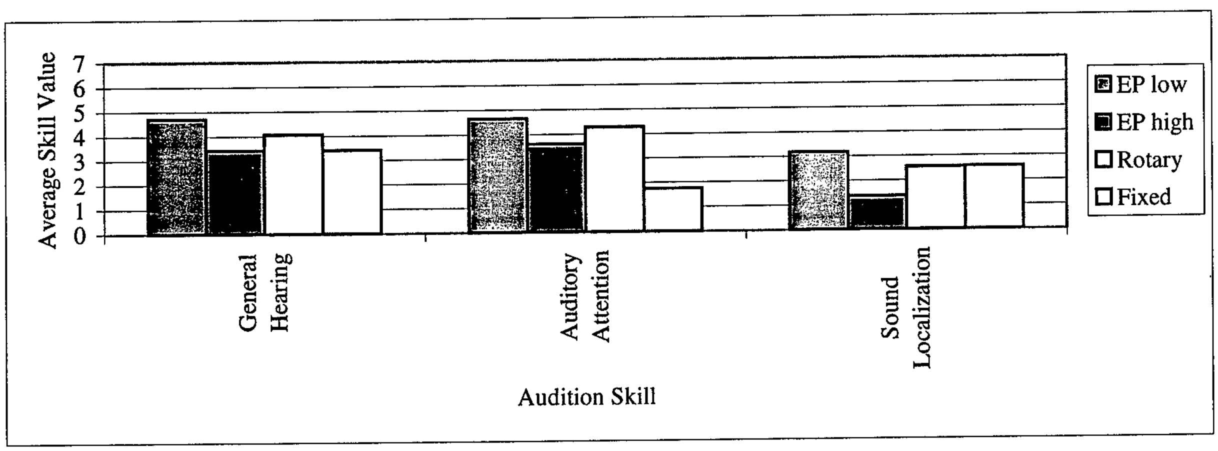
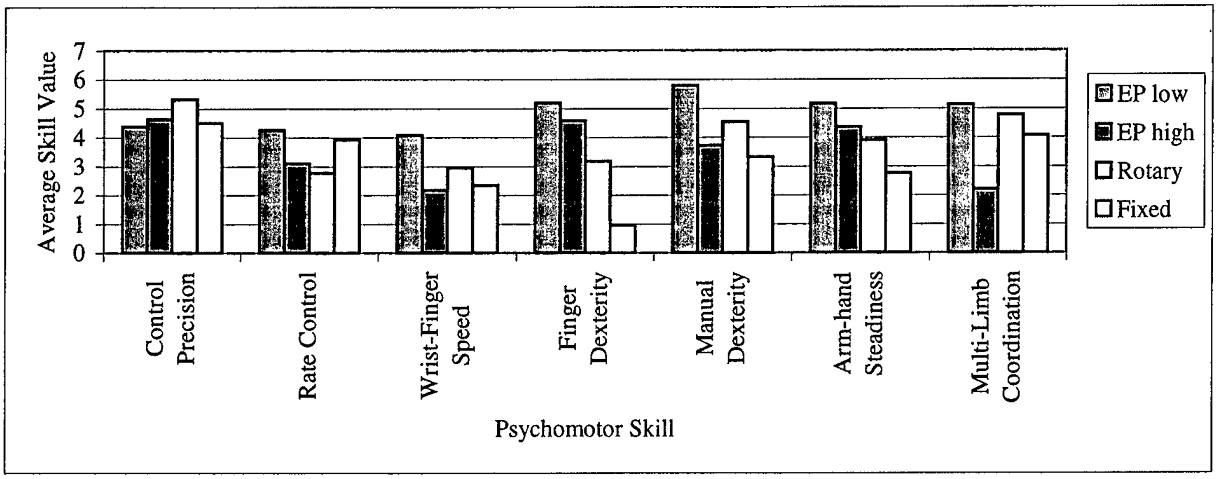
Time Sharing
Speed of Closure
Perceptual Speed and Accuracy
Reaction Time
Choice Reaction Time
Speed-loaded Skill
EP low
EP high
Rotary
Fixed



Average Skill Value
7
6
5
4
3
2
1
0
Near Vision
Far Vision
Night Vision
Visual Color Discrimination
Peripheral Vision
Depth Perception
Glare Sensitivity
Vision Skill
EP low
EP high
Rotary
Fixed



Average Skill Value
7
6
5
4
3
2
1
0
General Hearing
Auditory Attention
Sound Localization
Audition Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
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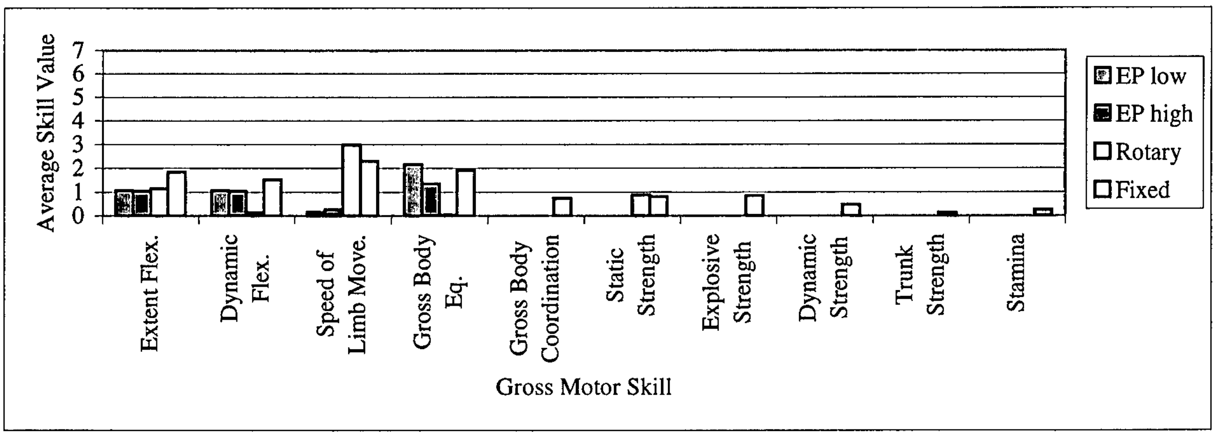
6
5
4
3
2
1
0
Control Precision
Rate Control
Wrist-Finger Speed
Finger Dexterity
Manual Dexterity
Arm-hand Steadiness
Multi-Limb Coordination
Psychomotor Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
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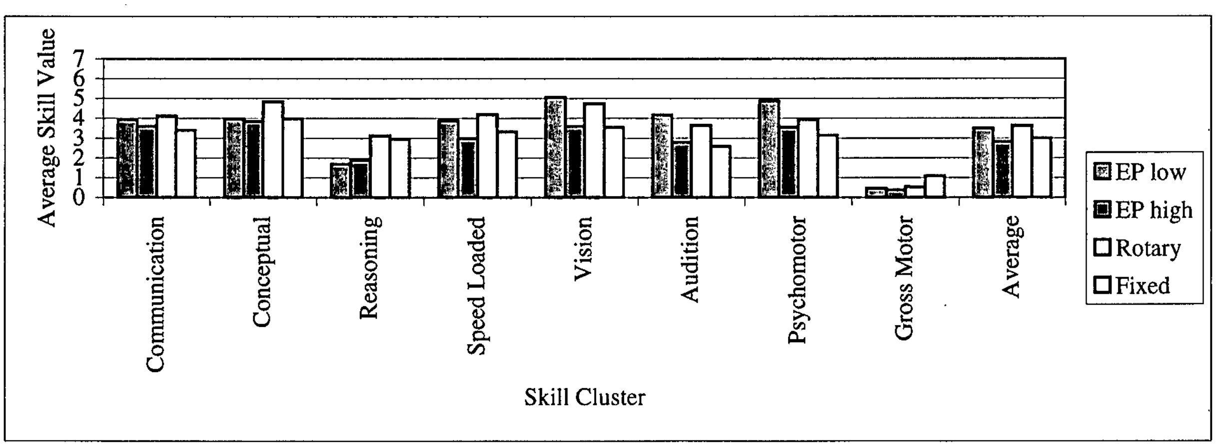
6
5
4
3
2
1
0
Extent Flex.
Dynamic Flex.
Speed of Limb Move.
Gross Body Eq.
Gross Body Coordination
Static Strength
Explosive Strength
Dynamic Strength
Trunk Strength
Stamina
Gross Motor Skill
EP low
EP high
Rotary
Fixed


Average Skill Value
7
6
5
4
3
2
1
0
Communication
Conceptual
Reasoning
Speed Loaded
Vision
Audition
Psychomotor
Gross Motor
Average
Skill Cluster
EP low
EP high
Rotary
Fixed

Average score within each skill cluster across nine duties

Communication	Group			
	EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
Oral Comprehension	5.69	5.41	5.25	4.31
Written Comprehension	2.83	3.12	4.49	3.86
Oral Expression	5.57	4.54	5.95	4.12
Written Expression	1.59	1.30	0.71	1.25
AVERAGE	3.92	3.59	4.10	3.39

Conceptual	Group			
	EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
Memorization	5.97	4.81	5.62	4.40
Problem Sensitivity	5.72	5.67	6.23	5.88
Originality	0.36	0.87	2.50	2.55
Fluency of Ideas	1.00	1.06	2.89	2.56
Flexibility	3.13	4.26	4.88	3.86
Selective Attention	5.46	4.93	5.60	4.63
Spatial Orientation	5.42	4.54	5.98	4.38
Visualization	4.65	4.69	4.84	3.60
AVERAGE	3.96	3.85	4.82	3.98

Reasoning	Group			
	EP inexperienced (low)	EP experienced (high)	Rotary	Fixed
Inductive Reasoning	0.92	1.52	3.44	3.03
Category Flexibility	0.81	1.15	2.71	1.52
Deductive Reasoning	4.51	3.26	5.45	4.67
Information Ordering	1.75	3.82	4.53	4.01
Mathematical Reasoning	1.07	1.19	1.16	2.44
Number Facility	1.03	0.33	1.28	1.98
AVERAGE	1.68	1.88	3.10	2.94

	Group			
Speed-loaded	**EP inexperienced (low)**	**EP experienced (high)**	**Rotary**	**Fixed**
Time Sharing	4.39	4.19	5.30	3.77
Speed of Closure	3.83	2.91	2.88	3.68
Perceptual Speed and Accuracy	4.53	3.09	5.16	4.00
Reaction Time	1.72	0.98	2.29	1.23
Choice Reaction Time	4.83	3.74	5.30	3.90
AVERAGE	3.86	2.98	4.19	3.32

	Group			
Vision	**EP inexperienced (low)**	**EP experienced (high)**	**Rotary**	**Fixed**
Near Vision	4.23	2.09	5.17	3.07
Far Vision	4.90	3.82	4.72	3.02
Night Vision	6.13	5.13	5.46	4.33
Visual Color Discrimination	4.31	2.31	3.28	2.98
Peripheral Vision	4.92	3.19	4.62	3.87
Depth Perception	5.14	4.80	5.42	3.68
Glare Sensitivity	5.81	3.78	4.42	3.81
AVERAGE	5.06	3.59	4.73	3.54

	Group			
Audition	**EP inexperienced (low)**	**EP experienced (high)**	**Rotary**	**Fixed**
General Hearing	4.70	3.42	4.06	3.42
Auditory Attention	4.64	3.59	4.28	1.75
Sound Localization	3.17	1.36	2.54	2.57
AVERAGE	4.17	2.79	3.63	2.58

	Group			
Psychomotor	**EP inexperienced (low)**	**EP experienced (high)**	**Rotary**	**Fixed**
Control Precision	4.38	4.64	5.32	4.51
Rate Control	4.26	3.11	2.77	3.93
Wrist-Finger Speed	4.08	2.18	2.95	2.35
Finger Dexterity	5.20	4.59	3.18	0.96
Manual Dexterity	5.79	3.72	4.54	3.32
Arm-hand Steadiness	5.17	4.36	3.90	2.76
Multi-Limb Coordination	5.13	2.20	4.77	4.07
AVERAGE	4.86	3.54	3.92	3.13

	Group			
Gross Motor	**EP inexperienced (low)**	**EP experienced (high)**	**Rotary**	**Fixed**
Extent Flexibility	1.07	1.04	1.15	1.84
Dynamic Flexibility	1.07	1.04	0.14	1.52
Speed of Limb Movement	0.15	0.26	2.97	2.30
Gross Body Equilibrium	2.16	1.35	0.04	1.91
Gross Body Coordination	0.00	0.00	0.00	0.73
Static Strength	0.00	0.00	0.87	0.81
Explosive Strength	0.00	0.00	0.00	0.85
Dynamic Strength	0.00	0.00	0.00	0.47
Trunk Strength	0.00	0.00	0.00	0.12
Stamina	0.00	0.00	0.00	0.24
AVERAGE	0.45	0.37	0.52	1.08

APPENDIX D

DISCRETE EVENT SIMULATION USING MICROSAINT™

DISCRETE EVENT SIMULATION USING MICROSAINT™

Discrete event simulations (DES) use a computer model to describe a process that can be expressed as a sequence of events, each with a distinct beginning and end. Events can be any part of the process, such as scheduled activities or tasks that represent the flow of the process. The tasks are displayed schematically on a diagram called the task network diagram, which is the basis of the model.

MicroSaint™ is a simulation software package for constructing models that simulate real-life processes. In this section, the basic DES components that comprise the MicroSaint™ software tool are described. Models can be relatively simple or complex. A simple, functional model can be built just by creating a network diagram and entering task timing information for each task in the network. More complex models can be built, which include dynamically changing variables, probabilistic and tactical branching logic, conditional task execution, and extensive model data collection—all of which can be specified by choosing menu commands or providing expressions for MicroSaint™ to execute during specific circumstances.

Whether the model is simple or complex, the process of executing a MicroSaint™ model and generating statistics and graphs from the collected data is mostly automatic. The software uses random numbers to generate specific task times from a pre-established distribution and routing choices specific to the current execution. After the model has been run, statistic charts, scatter plots, line or step graphs, bar charts, and frequency distributions can be used to analyze the data collected during model execution. In addition, the results files can be opened in spreadsheets or statistical packages for further analysis.

This section is designed to provide sufficient information about MicroSaint™ so that the Outrider UAV modeling presented in this report can be understood. This is not meant to provide a complete understanding of how MicroSaint™ can be used for modeling in general. For questions and a more detailed understanding of MicroSaint™, refer to the MicroSaint™ 3.0 manual.

User Interface

MicroSaint™ uses a standard Windows™-style graphical interface. The standard point-and-click method is used to select MicroSaint™ tools and to define and move objects. Double-clicking an object with the mouse opens a description dialog box where information specific to the object can be entered. Figure D-1 shows the task network diagram window of MicroSaint™. The window contains a sample network diagram of four nodes labeled 1 through 4, with a probabilistic decision node after Node 2.

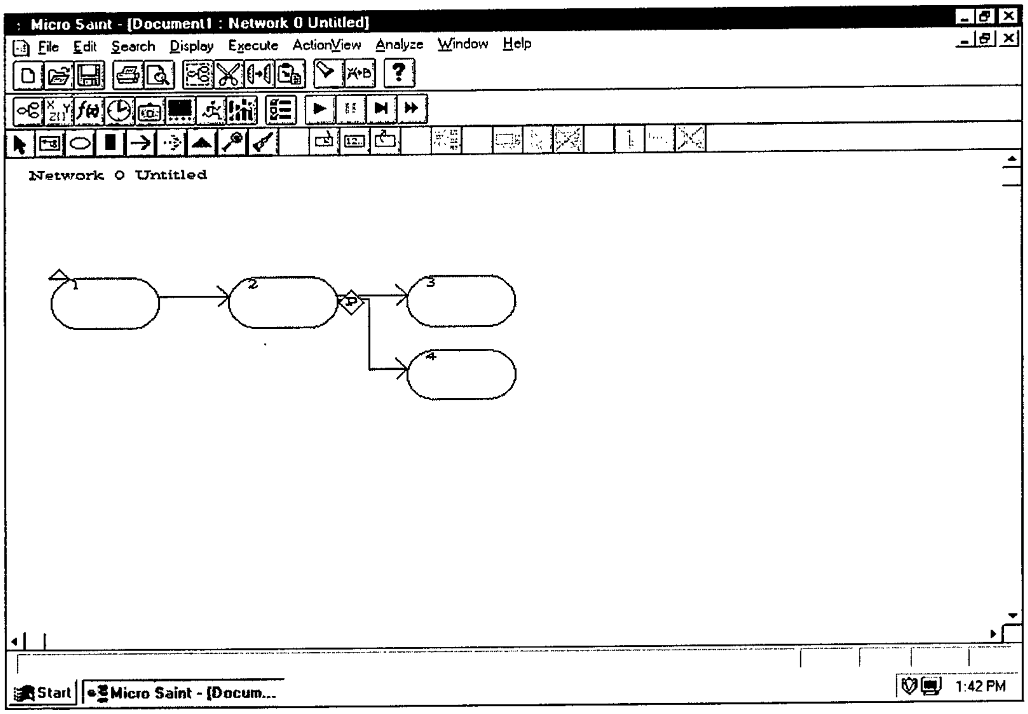


Figure D-1. The MicroSaint™ user interface and an example of a task network diagram.

Task Network Diagram

The task network is a graphical representation of the process that is being modeled. Tasks are represented in a diagram that shows the order of task execution within the process. A task network diagram is composed of nodes representing tasks that are connected by arrows. A rounded rectangle or oval shape represents each task. Sub-networks are represented by a rectangle. The arrows between the nodes indicate the possible sequences in which the tasks can be performed. Figure D-1 is an example of a task network. The "P" in the diamond-shaped node represents the type of decision (probabilistic) that is used to determine which path is taken.

Task and network nodes are created in MicroSaint™ with the task and network tools. Users click on the network diagram with one of the tools to place a task or network and then continue clicking to place subsequent tasks (or networks). The path tool is used to draw a path from each task or network to any other task or network that can follow it, and it indicates the direction of task execution. MicroSaint™ also uses symbolic animation during execution. When a particular task in the network has been reached, the rounded rectangle for that task is highlighted. The animation shows entities (items, people, etc.) as they move through the network. This type of animation is particularly useful in debugging a model and when verifying a model with SMEs.

Task Description

Tasks are the lowest level in a model network hierarchy and are described by specific parameters such as task timing information, release condition, and beginning and ending effect, which relate the task to other system activities. An example of the task description dialog box is displayed in Figure D-2. The description is for Task Number 1 (this number is inside the MicroSaint™ software and does not affect or reference the process being modeled); a name for the task can be entered into the name field. Expressions for each of the task parameters can be entered in the labeled fields.

Task Timing Information

Task timing information consists of the mean time for the task, the standard deviation, and a type of time distribution. In Figure D-2, the task mean time is 10 time units (hours, minutes, seconds, etc.), the standard deviation is one time unit, and the time distribution is normal.

The mean time is the average time required to complete a task. For example, if the task represents an activity such as "enter way points," then the mean time to execute the task is the average time that it takes an operator to enter the way points. The mean time is used in conjunction with the standard deviation and time distribution to determine the simulated task execution time for each execution of the task. The standard deviation is used in conjunction with the time distribution and controls the spread of a distribution

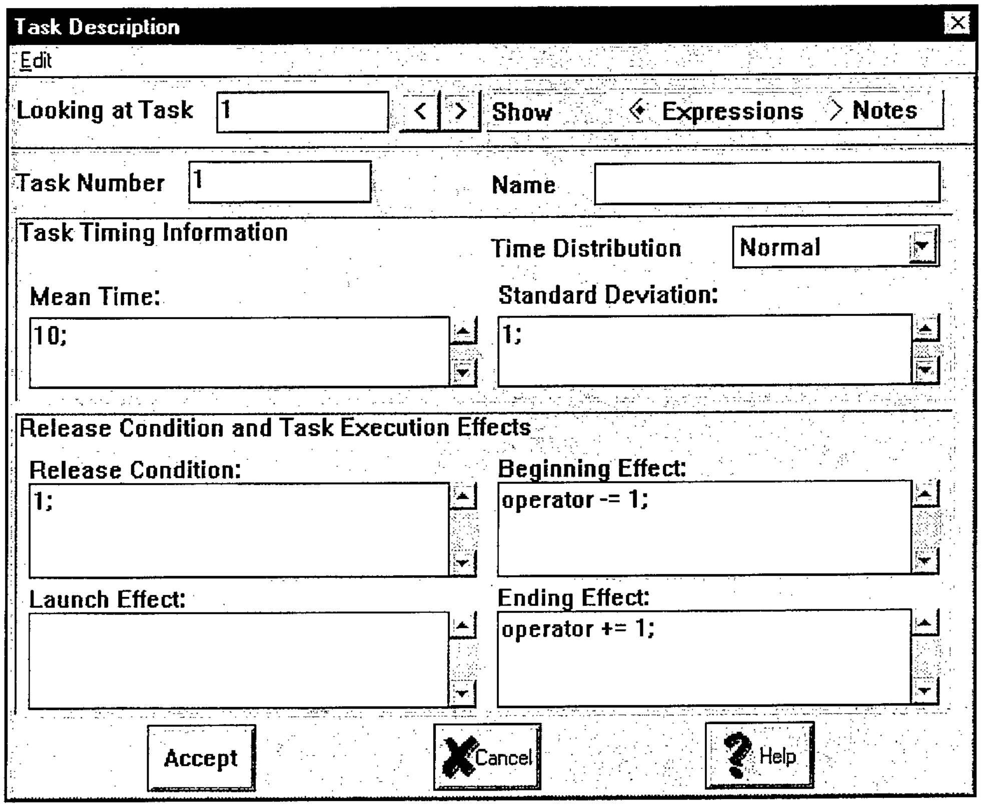


Figure D-2. Task description dialogue box.

The time distribution indicates the function used by MicroSaint™ to randomly generate execution times for a task. The mean time and standard deviation are used in conjunction with the probability distribution to determine the task execution time. In most cases, the execution time is not constant, but instead, the execution time is variable within a range of values that can be represented by a probability distribution. MicroSaint™ supports more than 21 probability distribution types, including normal, rectangular, exponential, gamma, Wiebull, Poisson, triangular, and others.

Release Conditions

Situations often occur when a task cannot begin executing until certain conditions are met. A task can have resource requirements such as availability of an operator or other constraints such as time of day or availability of part type that controls when the task can begin. In MicroSaint™, the expression in the "release condition" field can prevent a task from executing until certain conditions in the model are met (e.g., the availability of a resource, the completion of another task). The release condition expression can be as simple as the value 1 for tasks that execute as soon as the previous task completes, or it may be a complicated expression in which several conditions are evaluated. Entities moving through the network cannot be released into a task for processing until the release conditions for the task are met.

Task Execution Effects

An execution effect defines how the task performance affects other aspects of the system. For instance, the current state of the system may change when a task begins and then change again when the task ends. These changes are made using expressions in the beginning and ending effects of a task description. In the example in Figure D-2, the expression in the beginning effect of the task reduces the number of available operators by one. The expression in ending effect increases the number of available operators by one.

Controlling Process Logic

The arrows that are displayed between nodes define the basic order in which tasks are executed. Alternatives are indicated when more than one path is displayed, which originated from a single node. Task sequences can also be affected by conditions outside the network diagram. For example, a task can be started as a function of time. A diamond-shaped "decision node" automatically displays on the network diagram when more than one path follows a task. These decision points can be used to represent real-world decisions or to control aspects of how the model works, which may have little to do with the process being modeled.

The conditions that control the branching must be entered as expressions. MicroSaint™ provides the following decision types to ensure that real-world situations can be represented in the model:

1. In a probabilistic decision type, the next task to execute is determined by the relative probabilities of all tasks listed. Probabilistic decisions allow only one of the following tasks to execute.

2. In a multiple decision type, all the tasks with conditions that evaluate to non-zero will execute. This allows for one or more tasks to begin execution, based on rules that determine execution tasks.

3. In a tactical decision type, the next task to execute is the task with the condition that evaluates to the highest value. This allows for rule-based decisions. A tactical decision type differs from the multiple type in that only one following task is executed.

Variables and algebraic expressions can be used in the branching logic, and the value of the variables can be changed by conditions in the model. This allows complete control and manipulation of the network flow.

Simulation Clock

The simulation clock tracks the simulated time as the model executes. Time can be advanced in the simulation either in *fixed* or *variable* time intervals. In a *fixed* interval simulation, the simulation clock is advanced in fixed time intervals; the simulation is referred to as clock driven. Examples of clock-driven simulations are chemical processes and weather models. In a *variable* interval simulation, events are used to advance the clock in initial value and type (integer, real, array of integers, array of real numbers).

Expressions

An expression can be a calculation, formula, function, or statement that supplies a value or performs an operation. Expressions are used to supply numerical values such as mean times or true or false values such as those used in release conditions. They are used to make changes in the state of the model, such as beginning effects and ending effects. Each expression in MicroSaint™ must end with a semi-colon and can include any of the following elements:

- Constants
- Variables
- Functions (groups of expressions that can be referred to or called)
- Comments

- Mathematical operators (+, -, *, /, ^, %, ( ))
- Assignment operator (:=)
- Adjustment operators (+=, -=, *=, /=)
- Logical operators (>, >=, <, <=, &, ==, |, <>)
- If-then-else and while-do statements

Scenario Event

A scenario event is scheduled to occur at a specific time (in simulation time) during model execution. Scenario events are also used to change variable values, thereby changing the state of the model. These can be one-time events or they can repeat at regular intervals. An example of a one-time event would be setting a variable at simulation time zero, indicating the number of alarms that will sound during a nuclear plant disturbance. Scenario events are defined by supplying the following information for each event in the event description dialog box:

1. Time of occurrence.
2. Whether the event should repeat and at what interval.
3. Time when you want the event to stop repeating, if applicable.
4. The expressions you want executed at the specified time(s).

Model Execution

When the model execution is started, an entity begins at the first task node in the model. If the release condition for that task is evaluated to "true," then the task executes. The effect(s) that the task has on the system are evaluated, based on the expressions defining the task description. The changes are expressed in variables that can be used in other tasks in the model. Once the task is completed, the entity proceeds to the next task in the network diagram. When more than one path is available, the branching logic is used to determine the path the entity will follow. In general, the entire network diagram is traversed by the entity and the model is completed when the entity reaches the end of the last task in the network. Models can have conditions that send entities through the network until a specified simulation time or until a pre-determined number has completed the simulation.

Data Collection During Model Execution

The output data for a simulation are specific values of model variables recorded at specific times during the execution of the model. The data recorded are used to answer the questions about the system being modeled. The output is similar to the results of an experiment. Data output can include measures of system effectiveness or can be used for system diagnostics. Some examples of useful output are resource use, cost, and errors initiated.

Data are collected during the execution of a MicroSaint™ model using a feature called "snapshots". Snapshots provide a way to collect values of variables at specified points during model execution. They can be programmed to occur at specific clock times, when a task begins or ends, or when a model execution ends. Snapshots are defined by providing the following information in the snapshot description dialog box:

1. A name for the document where the data are stored.
2. The "trigger types" for the snapshot (end of run, clock, begin task, end task).
3. The number of the triggering task, if applicable.
4. The start time, stop time, and repeat interval, as applicable, if the snapshot has a clock trigger.
5. The names of the variables for which you want to record values.

Once the snapshots have been defined, they can be set to "on" or "off" during model execution. When they are turned "on," the variable values are stored in a results file with the extension "**.res**". After the file is opened, the analyze commands in MicroSaint™ can be used to generate statistics and create graphs from the data. The data can also be imported into other statistical analysis packages.

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The purpose of the research project was to understand the future crew environments for developing unmanned aerial vehicle (UAV) systems. A variety of human engineering tools (job assessment software system [JASS], enhanced computer-aided testing [ECAT], and MicroSaint™) were used to address crew issues related to the utility of having rated aviators as crew members, supplementing current crews with imagery and intelligence specialists, and the use of automation to improve systems efficiency. Data from 70 soldiers and experts from Fort Huachuca, Arizona, Fort Hood, Texas, and Hondo, Texas, were collected as part of this effort. The general finding was that the use of cognitive methods and computerized tool sets to understand future crew environments proved to be cost effective and useful. Specifically, no evidence was found to support a requirement for rated aviators in future Army missions, but the use of cognitively oriented embedded training simulators was suggested to aid novices in developing the cognitive skills evinced by experts. The efficacy of adding imagery specialists to 96U crews was discussed, and specific recommendations related to automation were derived from the workload modeling.

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