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Report SAM-TR- 82-21

ESTIMATING AIRCREW FATIGUE: A TECHNIQUE WITH APPLICATION TO AIRLIFT OPERATIONS

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December 1982

Final Report for Period October 1980 — September 1981

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NOTICES

This final report was submitted by personnel of the Biomathematics Modeling Branch, Data Sciences Division, and the Crew Performance Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7930-15-04.

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

Field	Entry
1. REPORT NUMBER	SAM-TR-82-21
2. GOVT ACCESSION NO.	AD-A125319
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle)	ESTIMATING AIRCREW FATIGUE: A TECHNIQUE WITH APPLICATION TO AIRLIFT OPERATIONS
5. TYPE OF REPORT & PERIOD COVERED	Final Report Oct 1980 - Sep 1981
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	Sherwood W. Samn, Ph.D. Layne P. Perelli, Major, USAF
8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	USAF School of Aerospace Medicine (BR, VN) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	62202F 7930-15-04
11. CONTROLLING OFFICE NAME AND ADDRESS	USAF School of Aerospace Medicine (VN) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235
12. REPORT DATE	December 1982
13. NUMBER OF PAGES	26
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	
15. SECURITY CLASS. (of this report)	Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fatigue
Algorithm
Airlift
Aircrew
Simulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report proposes a method of assessing aircrew fatigue based on work/rest profiles. Possible circadian desynchronization and cumulative fatigue an aircrew may have experienced are considered. The method was used to assess aircrew fatigue during computer-simulated airlift operations. It shows quantitatively how flying-hour limitations can affect average aircrew fatigue and system performance.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ESTIMATING AIRCREW FATIGUE: A TECHNIQUE WITH APPLICATION TO AIRLIFT OPERATIONS

INTRODUCTION

Continued improvement of the U.S. Air Force airlift capability is a high national priority, as evidenced by the recent development of the Rapid Deployment Force concept to deal with military contingency operations in Europe and the Mid-East. Successful operation of USAF airlift operations requires proper resource management of C-141 and C-5 aircraft, equipment, and manpower. The Air Force has been using computer simulations (3,6,7,9) and mathematical programming (4,14) techniques to optimize scheduling and staging procedures in order to estimate aircraft utilization rates based on hypothetical crew ratios. The Airlift Simulation Model (ASM), which was developed at the USAF School of Aerospace Medicine (USAFSAM) and is being repeatedly upgraded, can simulate the major operational attributes of a typical Military Airlift Command (MAC) squadron of jet transports and aircrews (3,10). Recently ASM was upgraded to simulate the airlift activities of multiple squadrons during mobilization, in which resources and requirements undergo abrupt changes. The output of ASM is a massive data file containing detailed information about each and every aircraft and crewmember during the entire simulation period. From this data file, available statistics range from system measures (e.g., aircraft utilization rate or work-month-hours) to individual measures (e.g., average flying hours per crewmember per month or average time away from home by month). In essence, any logistic information about crewmembers and aircraft can be obtained, because the output data file from ASM captures everything that happened during the simulated period. This approach has led to a better understanding of the nature of airlift operations and permits detailed examination of any given mission scenario. Typical missions analyzed have lasted up to 180 days; such scenarios would be entirely too costly and time consuming to evaluate if actual aircraft had to be used. The valuable insight and information gained from these simulations have greatly aided operational planners in best placing aircraft and crews in the system.

One shortcoming of ASM (and for that matter all other airlift simulation models) is its lack of directly interpretable biomedical information concerning the aircrews involved in the missions. Although the ASM output data file provides a wealth of statistics on the working pattern of the crewmembers, these statistics can be difficult to translate, especially by the untrained eye, into meaningful statements about crew performance level on which mission accomplishment may depend. An exaggerated example would be a statistic which reveals that a particular crewmember has worked only 72 hours in a 30-day period. This may not be considered stressful at all at first sight, but if the 72 hours were contiguous, it would be disastrous! The point here is that simple statistics about a variable such as duty length do not capture the temporal or spatial aspects of that variable, and it is these aspects that are important in performance assessment.

The purpose of this paper is to describe efforts to develop an algorithm that will predict fatigue levels of aircrew if they fly the simulated missions. Even though computer simulation optimizes aircraft utilization, routes, and staging locations to move maximum cargo in the shortest time, whether the resulting missions have unacceptable detrimental effects on crew performance and mission success must still be determined. One main source of pilot performance decrement in the airlift mission is the buildup of fatigue due to long flights and duty days, loss of or poor quality sleep, and circadian rhythm disruption resulting from transiting multiple time zones. From experience gained in laboratory studies and field data collection during MAC operations, a technique has been developed and incorporated into ASM to provide a continuous fatigue estimate for each aircrew as it progresses through the mission scenario. This effort is in its initial developmental stage, and the computer-generated output can as yet only be considered as crude estimates of crew fatigue. However, this approach provides a basic structure for future modification and will suggest areas where future research is necessary.

Many benefits could be derived from the capability to predict fatigue effects of operational missions and thus the corresponding loss in aircrew performance. First, it would provide a means for evaluating various work-rest schedules and the present flight-hour limitations as stated in AFR 60-1 (1). Scenarios could be constructed limiting the amount of flying time of any crew during any 30- or 90-day period, as in the current airlift simulations. The same scenarios could then be repeated with the restrictions lifted, and the resultant increase in predicted fatigue could be evaluated. Second, choices could be made among airlift schedules that move the same amount of cargo in approximately the same amount of time and achieve approximately the same aircraft utilization rate, favoring schedules that minimize crew fatigue. Also, some aircraft schedules that planners propose to use in the event of a national emergency, but that have never been tested operationally, may be found to contain work-rest patterns that will create such fatigue levels in the aircrews that the operation cannot be sustained as anticipated. Third, models to predict crew performance and recovery requirements might eventually be developed for use by field commanders to direct maximum-effort airlift operations as they actually occur. These models would be especially useful if real-world data were collected throughout the operation and used to update the computer model. These types of models could be adapted to tactical fighter operations to predict probability-of-kill ratios based on the number of days the operations have lasted, and to predict the number of sorties per day that could be sustained for a given length of time.

PREVIOUS FATIGUE STUDIES OF MAC OPERATIONS

The USAFSAM Crew Performance Branch has been involved with field research of MAC operations for several years. Studies have included both C-141 (5,13) and C-5 (8,15,16) aircraft. The mission profiles studied have included both demanding routine-scheduled airlifts (13,16) and experimental missions designed to examine the limits of aircrew performance (5,8,15). Fatigue data were collected at regular intervals during these missions, using the Subjective Fatigue Checkcard, SAM Form 136 (11). This checkcard has been validated repeatedly and used in a variety of operational settings and laboratory experiments (12). The fatigue reports have been systematically related to work-rest cycles, sleep duration, physiological parameters, circadian rhythms, and environmental stressors. The Subjective Fatigue Checkcard results in scores ranging from 0 to 20 (arbitrary units): the lower the scores, the higher the fatigue level being reported. A copy of the form is provided in Appendix A. The crewmember is required to check whether he feels "better than," "same as," or "worse than" for each of ten fatigue descriptors. Administration time is about 30 seconds.

Recently, the Crew Status Check, SAM Form 202, has been developed at USAFSAM to reduce the time required for crews in a field research setting to report fatigue data (13,16). Minimal time for data-card completion is highly desirable; the less the card interferes with a crewmember's ongoing activities, the more acceptable it is to him, thus generating better cooperation with the researchers. This checkcard (see Appendix A) consists of two 7-point, forced-choice fatigue and workload scales. (Only the fatigue scale is pertinent to the present discussion.) The crewmember only has to select the one statement (of seven) that most closely corresponds to how tired he feels at the time of checkcard administration. On this scale, the higher the number, the greater the subjective feeling of fatigue being reported. The 7-point scale appears to provide slightly greater sensitivity and reliability than the format used in the Subjective Fatigue Checkcard (12).

In field studies where both forms have been used, very high correlations have been obtained between the two measures. This indicates that the two scales are measuring the same underlying factor in a similar manner, and future studies may be able to use only the Crew Status Check and derive the benefit of its shorter administration time. In discussions with crewmembers, most reported preferences for this checkcard; they felt it was easier to use and seemed to reflect more accurately their feelings of fatigue.

From experience obtained by observing fatigue scores and the performance of pilots and laboratory subjects during highly fatiguing work-rest cycles, researchers at USAFSAM have developed subjective estimates of the degree of performance degradation associated with fatigue scores. In general, scores on the Subjective Fatigue Checkcard of 12 or higher can be interpreted to mean fatigue is not affecting crew performance; 8 to 11, mild feelings of fatigue; 4 to 7, severe feelings of fatigue (it is hypothesized that scores in this range may indicate significant performance impairment caused by fatigue); 3 or lower, performance on certain complex, demanding tasks has probably been degraded by fatigue effects. (Many but not all flying tasks would be complex and demanding.) Table 1 summarizes the estimated effects of fatigue on performance for both the 20-point and 7-point scales. The hypothesized relationship between performance and reported fatigue provides a means for interpreting the output of the ASM in terms of operational consequences. To facilitate the development of this algorithm, the fatigue scales were compressed to yield the four classes shown in Table 2. Because of its extensive data base and greater range of scores, the 20-point scale was used as a basis in our present effort.

STRUCTURE AND FUNCTION OF THE AIRLIFT FATIGUE ESTIMATOR

A FORTRAN computer program (FATIGUE) based on the fatigue-level performance assessment algorithm was developed to complement the USAFSAM airlift simulation model. Based on the geographical location and start time of the

TABLE 1. HYPOTHESIZED RELATIONSHIP BETWEEN CREWMEMBER'S OPERATIONAL PERFORMANCE CAPABILITY AND SUBJECTIVE REPORT OF FATIGUE

Subjective Fatigue Checkcard (SAM Form 136)	Crew Status Check (SAM Form 202)	Predicted Effect of Fatigue Level on Performance
20 - 18	1	Unusually wide awake. Possible performance enhancement.
17 - 15	2	Very alert, wide awake. No performance impairment due to fatigue.
14 - 12	3	Normal level of alertness, typically well rested. No performance impairment due to fatigue.
11 - 8	4	Mild fatigue perceived. Performance impairment possible but not a significant factor.
7 - 6	5	Moderate fatigue. Performance impairment possible. Flying duty permissible but not recommended unless urgent.
5 - 4	6	Severe fatigue. Performance impairment probable. Flying duty not recommended.
3 - 0	7	Severe fatigue. Performance definitely impaired. Flying duty not recommended. Safety of flight in jeopardy.

duty day, a sleep duration is assigned to each crewmember in the simulation. This estimate of sleep duration is then related to the initial fatigue score a crewmember would be expected to report having just received that amount of sleep. In FATIGUE, the crewmember's circadian rhythm phase, not the duration of prior wakefulness, is used to influence sleep duration. This is in keeping with recent research on sleep-length determinants (2). Prior duty-day lengths are used to determine the rate at which fatigue will build up in subsequent duty days. All factors in FATIGUE are based primarily on the judgment of USAFSAM investigators, from prior research data and their own experience with Air Force operations. Many of these judgments, while appearing reasonable now, may be replaced with empirically determined data bases and relationships (e.g., mathematical models) in the near future.

The following definitions will be used in the upcoming discussion.

Crew duty day: The time (hours) from the crew's alert call until the aircraft blocks into its parking spot after landing at the crew's final destination and before the crew goes into crew rest. The maximum duty day for a C-141/C-5 crew is normally limited to 16 hours for a basic crew or 24 hours for an augmented crew, unless waived by higher headquarters (1).

TABLE 2. HYPOTHESIS OF RELATIONSHIP BETWEEN SUBJECTIVE FATIGUE REPORT AND OPERATIONAL PERFORMANCE CAPABILITY

Fatigue Class	Subjective Fatigue Checkcard (SAM Form 136)	Crew Status Check (SAM Form 202)	Predicted Effect of Fatigue on Performance
IV	20 - 12	1 - 3	Sufficiently alert. No performance impairment due to fatigue.
III	11 - 8	4	Mild fatigue. Performance impairment possible but not significant. Treat as class IV.
II	7 - 4	5 - 6	Moderate to severe fatigue. Some performance impairment probably occurring. Flying duty permissible but not recommended.
I	3 - 0	7	Severe fatigue. Performance definitely impaired. Flying duty not recommended. Safety of flight in jeopardy.

Crew rest period: The time (hours) from when the aircraft blocks into its parking spot at the crew's final destination until the crew receives its alerting call for the next flight. A minimum 12-hour rest must be provided prior to any crew duty day; the amount of sleep required is not specified (1).

Airlift mission: A set of consecutive flying-duty days that are separated by less than 60 hours of crew rest at home or less than 72 hours of crew rest while on temporary duty away from home (TDY).

The specific operation of the algorithm is as follows:

Step 1. Randomly select an initial sleep duration for each crewmember. Two different distributions are used, based on whether sleep is at home station (mean, 7.5 hours; range, 5-9 hours) or at a TDY location (mean, 6.5 hours; range, 4-8 hours). On the average, the TDY distribution estimates approximately 1 hour less sleep duration. This is to take into account the fact that 1) people generally obtain poorer quality sleep in unfamiliar surroundings, and 2) time required to obtain food and lodging often reduces the time available for sleep.

Step 2. Determine sleep-loss penalty when the crewmember must go to sleep at a time other than normal. For these purposes, 2230 is considered a standard bedtime. The reason for this penalty is that it is hypothesized that the quality of sleep is reduced when a person goes to bed at a time out of phase with the local population; i.e., sleeps during daylight hours. In his home time zone, a crewmember trying to sleep during daylight is out of phase with his own circadian rhythm and thus experiences both social and biological desynchronization. In a different time zone, away from home, the sleep-loss penalty always reflects social desynchronization but may or may not involve body-clock desynchronization. For example, going to bed at 1430 in a time zone 8 hours behind one's home station is "out of phase" with society but "in phase" with the body clock (assuming no time-zone readjustment has occurred, which for purposes of this model is assumed to take at least 1 day for each time zone traversed). Thus, an occasional reduction of the sleep-loss penalty when the crew is away from home may seem appropriate. However, we decided not to make this adjustment because of the following assumption: on the average, sleep at home is always more restful than that away from home. Because specific information concerning the types and frequencies of operational sleep patterns and circadian rhythm disruption and their associated effects on sleep quality is not available, we thought it preferable not to develop too complex a structure for the initial model.

Sleep-start time is determined by subtracting the initial sleep duration from the start of the duty day. The sleep-start time is subtracted from 2230, and the absolute difference is assessed a penalty (SP1) according to the rules in Table 3. For example, if the sleep duration is 7 hours and the start of the duty day is 2000, the sleep onset is assumed to be 1300. This deviates from the standard bedtime (2230) by 9.5 hours. Using 9.5 as the value of D in Table 3, we find the sleep penalty to be 1.5 hours.

TABLE 3. SLEEP-LOSS PENALTY FOR NONSTANDARD SLEEP-START TIMES

Difference (D) in Hours between Sleep-Start Time and Standard Bedtime (2230 hours)	Penalty SP1 (hours)
$D \geq 0$ but < 2	0.0
$D \geq 2$ but < 4	0.5
$D \geq 4$ but < 6	1.0
$D \geq 6$ but < 10	1.5
$D \geq 10$ but < 12	2.0

The typical alert time for C-5 crews is 4 hours before scheduled takeoff. In this model, the crews are assumed to adjust their sleep schedule so that they get most of their sleep just prior to receiving their alert call. This procedure minimizes fatigue during the upcoming duty period. Crews, however, do not always follow this procedure, especially when the work-rest cycle is conducive to a "split-sleep" schedule. This typically occurs after a lengthy, tiring mission. Immediately after landing the crews go to sleep for a short time, awaken for a meal and recreation, and return to sleep for the balance of their crew-rest period. We feel that the reduced sleep quality in a split-sleep schedule should receive at least the same penalty as that for going to sleep at a time other than the local population does and obtaining all sleep at the end of the crew-rest period. Thus, a conservative single approach to calculating SP1 was deemed sufficient and, if anything, would overestimate sleep quality for all other conditions.

Step 3. Determine the crewmember's sleep-loss penalty for going to sleep in a time zone different from his home time zone. The ASM keeps track of when the crewmember goes to sleep in the local time zone (away from home) and compares it to his home time zone. The difference is assessed a penalty (SP2) according to the rules in Table 4. The sleep-loss penalty for time-zone

TABLE 4. SLEEP-LOSS PENALTY FOR TIME-ZONE TRANSITION

Difference (D) in Hours between Home Time Zone and Local Sleep Time Zone	Penalty SP2 (hours)
$D \geq 0$ but < 1	0.0
$D \geq 1$ but < 3	0.5
$D \geq 3$ but < 6	1.0
$D \geq 6$ but < 12	1.5

difference is an additional penalty for circadian rhythm disruption; i.e., trying to work, eat, and sleep at times to which one's body is not accustomed.

Step 4. Determine the crewmember's fatigue score at the start of each duty day. The two sleep penalties (SP1 and SP2) are subtracted from the initial sleep duraton (SD) to determine the effective sleep (SEF) received by the crewmember:

$$SEF = SD - SP1 - SP2$$

A basic assumption in the computer program FATIGUE is that the duration and quality of the sleep received by a crewmember will determine his starting fatigue score. Fundamental factors that affect the quality of sleep (familiarity of environment, sleep-start time, and time-zone transition) have been used to numerically reduce the duration of sleep. Thus, for example, if on random occasions a pilot spends 8 hours in bed receiving poor quality sleep due to sleeping in strange quarters in a different time zone, the program would translate this into 6 hours of effective sleep. Depending on the effective sleep received, the starting fatigue score is selected from one of the four distributions presented in Table 5. These distributions are not symmetric: The two related to longer effective sleep are skewed toward higher starting fatigue (lower scores), and the two for shorter effective sleep are skewed toward lower starting fatigue (higher scores). This conservative approach reflects what is generally observed in real-world operations.

TABLE 5. DISTRIBUTION OF STARTING FATIGUE SCORES AS A FUNCTION OF TOTAL EFFECTIVE SLEEP RECEIVED

Total Effective Sleep (SEF) (hours)	Fatigue Distribution (mean)	(range)
$SEF \geq 0$ but < 3.5	6	4-7
$SEF \geq 3.5$ but < 5.5	10.5	8-11
$SEF \geq 5.5$ but < 7.0	13	12-15
$SEF \geq 7.0$	17	16-20

No starting fatigue score can be lower than 4. As presented for SAM Form 136 in Table 2, scores lower than 4 indicate severe fatigue; also, no matter how poor the quality of sleep received during the crew-rest period, the 12-hour minimum rest period would usually have sufficient restorative power to eliminate severe fatigue. In rare cases when the starting fatigue is more severe during actual operations, the crewmember might be expected to voluntarily remove himself from flight duty until adequate rest was obtained.

Step 5. Determine the rate of fatigue decrement for the rest of the crew duty day, based on the crewmember's combined previous duty-day lengths. The use of duty hours instead of flying hours does not mean that nonflying duty is as fatiguing as flying duty, but it is an attempt to credit proper fatigue levels from other situations; e.g., a crewmember may have flown only 1 or 2 hours because of maintenance problems but put in a 16-hour duty day and thus experienced a significant amount of fatigue due to "ramp-pounding." There are three classes of decrement rate: class A, -.25 point per hour; class B, -.375 point per hour; and class C, -.5 point per hour. For the start of a new mission, the class A rate is used. A new mission is defined as one after no flying duty during the last 60 hours while at home station or 72 hours while on TDY. Either time period is believed sufficient to dissipate the fatigue effects from the prior flying duty, which is assumed to be an airlift mission involving TDY periods of more than 48 hours. The decrement-rate class is based on both the total number of prior consecutive duty days and the lengths of these days, as indicated in Table 6. The program is designed so that the fatigue score never becomes a negative number. If the duty day lasts long enough for the fatigue score to reach zero, it remains at zero for the remainder of the duty day. This prevents an unusually fatiguing mission from unduly influencing the overall mean score obtained. If the crew duty day lasts more than 16 hours, the crew is assumed to be augmented and thus the crewmembers could get some rest inflight. For this reason, when flights in the simulation are identified as augmented, the fatigue decrement rate is maintained at class A for that flight.

TABLE 6. FATIGUE DECREMENT RATES

NM	AUG	XDH	CDD	NXDH	Class	Decrement Rate per Hour
1	-	-	-	-	A	0.25
-	2	-	-	-	A	0.25
-	-	<10	≤5	-	A	0.25
-	-	<14	≤4	-	A	0.25
-	-	<16	≤3	-	A	0.25
0	1	<10	>5	-	B	0.375
0	1	<14	>4	-	B	0.375
0	1	<16	>3	-	B	0.375
0	1	<24	<3	-	B	0.375
0	1	<24	≥3	=1	B	0.375
0	1	≥24	=1	-	B	0.50
	All other cases				C	

NM = Mission indicator: 1 if new; 0 if continued.
AUG = Crew type: 1 if basic; 2 if augmented.
XDH = Prior maximum duty day (hours).
CDD = Prior consecutive duty days.
NXDH = Number of prior duty days > 16 hours.
- = Any value

Table 7 shows the effects of the fatigue decrement rates on starting fatigue scores of 12, 10, 8, and 6. This table can be used to get a general impression of how long a crew could be expected to perform satisfactorily, depending on starting fatigue score and decrement rate. With a starting fatigue score of 12 and a class A decrement rate, a crew would be predicted to complete a 16- to 20-hour duty day without serious performance decrement (fatigue score of 8 to 7); but with a starting score of 6, the crew would be considered seriously impaired after only 12 hours of duty (fatigue score of 3). With a starting fatigue score of 12 and a class C decrement rate, the crew would be seriously impaired at 16 hours of duty; with a starting score of 6, the crew would be impaired after only about 4 hours of duty.

TABLE 7. EFFECTS OF FATIGUE DECREMENT RATES ON VARIOUS STARTING FATIGUE SCORES

Fatigue Decrement Rate	Starting Fatigue Scores	Hours after Start Time							
		4	8	12	16	20	24	28	32
Class A (-1.0 every 4 hrs)	12	11	10	9	8	7	6	5	4
	10	9	8	7	6	5	4	3	2
	8	7	6	5	4	3	2	1	0
	6	5	4	3	2	1	0	0	0
Class B (-1.5 every 4 hrs)	12	10.5	9	7.5	6	4.5	3	1.5	0
	10	8.5	7	5.5	4	2.5	1	0	0
	8	6.5	5	3.5	2	.5	0	0	0
	6	4.5	3	1.5	0	0	0	0	0
Class C (-2.0 every 4 hrs)	12	10	8	6	4	2	0	0	0
	10	8	6	4	2	0	0	0	0
	8	6	4	2	0	0	0	0	0
	6	4	2	0	0	0	0	0	0

IMPLEMENTATION OF FATIGUE PROGRAM

The procedure described for the fatigue algorithm is summarized in the flow diagrams in Appendix B. The input needed for this algorithm is the ASM's output data file (only file records related to aircrews are used). The information needed from each record is 1) time the record was created, 2) crewmember's identifier, 3) crewmember's location (longitude and latitude), 4) crew status just completed, and 5) time this status started. The time of record creation is also the time the status in question ended. A crewmember can assume any of 16 statuses (Table 8).

TABLE 8. CREW STATUSES

Status	Meaning	Status	Meaning
1	-- Preflight	10	-- Home resting
2	-- Ramp (long maintenance)	11	-- Rested (enroute), waiting alert call
3	-- Inflight	12	-- Time off
4	-- Postflight	13	-- Ramp (no plane)
5	-- Scheduled leave (unpostponable)	14	-- Scheduled leave (postponable)
6	-- Idle at home	15	-- Deadhead
7	-- Unscheduled leave	16	-- Rested (home), waiting alert call
8	-- Enroute resting		
9	-- Alerted		

In implementation of the algorithm, several distributions have to be sampled. The mean and range specified for each distribution are not enough to uniquely determine the distributions, so the following convention was adopted in their construction. Let the distribution sought be $F(x)$, its desired mean be M, and its range be from A to B. Hence $A < M < B$. Then the actual distribution $F(x)$ implemented is obtained by truncating the normal distribution whose mean M and standard deviation $(S) = (B-A)/N$, where N is a positive integer to be chosen. The truncations occur at $x = B$ and $x = A$. This distribution can be shown to have a median at M and a mean m given by

$$m = B - S * \{G((B-M)/S) - G((A-M)/S)\},$$

where $G(x)$ is the standard normal distribution. It can also be shown that

$$m - M = S * \{G((A-M)/S) - G((M-B)/S)\}$$

and that m approaches M as S goes to 0 or as N approaches infinity. In short, we can make the mean m of the truncated normal distribution $F(x)$ come arbitrarily close to the desired mean M by picking N sufficiently large. In the implementation, we have picked N to be 6.0. The comparisons of the actual means (m) and the desired means (M) are given in Table 9.

TABLE 9. MEANS OF TRUNCATED NORMALS

Range A	to B	Desired Mean (M)	Actual Mean (M)
5.0	9.0	7.5	7.497
4.0	8.0	6.5	6.497
16.0	20.0	17.0	17.019
12.0	15.0	13.0	13.004
8.0	11.0	10.5	10.458
4.0	7.0	6.0	5.995

RESULTS

To evaluate the effectiveness of this approach, we used the performance assessment program (FATIGUE) on two C-5 airlift simulations. The scenarios in both simulations were the same except that the flying-hour limitations of 125 hours in 30 days and 330 hours in 90 days were enforced in the first simulation (S1) but waived in the second (S2). The simulated periods were 183 days: the first 90 days were "peacetime" (low aircraft utilization) and the last 93 were "wartime" (high aircraft utilization). The results are shown in Tables 10-15.

Table 10 summarizes the system (nonhuman) performance in terms of aircraft utilization rates; i.e., the average number of flying hours per aircraft per day. As expected, the aircraft utilization rates in scenario S2 (no flying-hour limitations) were higher than those in scenario S1. Table 10 shows the breakdown of aircraft utilization rates by 15-day periods. Differences in aircraft utilization rates between the two scenarios are especially apparent in the later periods, when the crew's flying hours started to "catch up" with them. In these simulations we did not attempt to optimize scheduling or staging policies to achieve maximum aircraft utilization rates; these rates could conceivably be slightly improved in both scenarios, but the resulting contrasts in fatigue effects would probably remain approximately the same. However, this will be analyzed in the future.

TABLE 10. AIRCRAFT UTILIZATION RATES

Period	UR (S1)	UR (S2)	Period	UR (S1)	UR (S2)
0 - 15	.07	.07	91 - 105	9.68	9.85
16 - 30	1.61	1.61	106 - 120	9.64	12.40
31 - 45	1.71	1.71	121 - 135	10.04	11.91
46 - 60	2.34	2.34	136 - 150	9.54	12.14
61 - 75	2.07	2.07	151 - 165	9.23	11.79
76 - 90	1.73	1.73	166 - 180	9.43	12.36

UR = average flying hours per A/C per day in period
S1 = with 30-day 125-flying-hour and 90-day 330 flying-hour limits
S2 = without flying-hour limitations

Tables 11 and 12 summarize individual crewmember's fatigue measures. Table 11 shows a typical output of the FATIGUE program for one crewmember. Each line contains statistics associated to one crew-duty day. The abbreviations used are explained in a list at the end of this report.

TABLE 11. FATIGUE SCORE BREAKDOWN FOR MAN NO. 2

LBL	LSTST	REST-LEN	S.TIME	SD	SP1	SP2	SEF	SCORE1	WORK-LEN	E.TIME	XH	NXH	CDD	AUG	CLASS	SCORE2
4	4	412.32	17.18	6.52	.15	.00	6.37	12.99	21.60	18.08	.00	0.	0.	2	1.	7.59
6	4	68.64	20.94	7.66	1.04	.50	6.12	12.66	7.68	21.26	21.60	1.	1.	2	1.	10.74
8	4	26.88	22.38	7.67	.13	.00	7.54	16.66	24.00	23.38	21.60	1.	2.	2	1.	10.66
10	4	12.00	23.88	7.07	1.14	.50	5.43	9.89	6.72	24.16	24.00	2.	3.	2	1.	8.21
12	12	1579.92	89.99	6.15	.72	.00	5.43	10.66	6.00	90.24	.00	0.	0.	2	1.	9.16
14	12	37.44	91.80	9.00	2.00	.00	7.00	14.43	8.16	92.14	6.00	0.	1.	2	1.	12.39
16	12	26.16	93.23	6.42	.00	.00	6.42	11.53	21.12	94.11	8.16	0.	2.	2	1.	6.25
18	12	28.32	95.29	7.42	.22	.50	6.70	12.56	9.36	95.68	21.12	1.	3.	2	1.	10.22
20	12	20.16	96.52	9.00	.47	.00	8.53	19.02	22.56	97.46	21.12	1.	4.	2	1.	13.38
22	12	31.20	98.76	5.50	1.31	.50	3.69	10.55	9.36	99.15	22.56	2.	5.	2	1.	8.21
24	12	15.60	99.80	6.82	2.00	.00	4.82	10.74	23.28	100.77	22.56	2.	6.	2	1.	4.92
26	12	12.00	101.27	6.97	.22	.50	6.25	13.73	7.92	101.60	23.28	3.	7.	2	1.	11.75
28	12	30.00	102.85	7.79	2.00	.00	5.79	12.83	8.40	103.20	23.28	3.	8.	2	1.	10.73
30	12	17.52	103.93	9.00	2.00	.00	7.00	14.52	8.40	104.28	23.28	3.	9.	2	1.	12.42
32	12	12.00	104.78	8.58	2.00	.00	6.58	13.10	24.72	105.81	23.28	3.	10.	2	1.	6.92
34	12	14.40	106.41	6.63	1.00	.50	5.13	11.36	5.04	106.62	24.72	4.	11.	2	1.	10.10
36	36	305.76	119.36	5.91	.56	.00	5.35	10.19	6.24	119.62	.00	0.	0.	1	1.	8.63
38	36	24.96	120.66	8.25	1.24	.00	7.01	17.17	10.08	121.08	6.24	0.	1.	1	1.	14.65
40	36	12.00	121.58	5.19	2.00	1.00	2.19	4.41	13.68	122.15	10.08	0.	2.	1	1.	.99
42	36	20.40	123.00	6.21	.06	1.00	5.15	11.10	16.08	123.67	13.68	0.	3.	1	1.	7.08
44	36	24.24	124.68	7.09	1.49	1.00	4.61	10.13	13.44	125.24	16.08	1.	4.	1	2.	5.09
46	36	12.00	125.74	5.52	1.11	1.00	3.41	7.50	10.32	126.17	16.08	1.	5.	1	2.	3.63
48	36	24.24	127.18	8.51	.48	.00	8.04	17.32	11.28	127.65	16.08	1.	6.	1	2.	13.09
50	36	13.44	128.21	6.80	.07	.00	6.72	13.02	16.80	128.91	16.08	1.	7.	1	2.	6.72
52	36	15.12	129.54	6.75	2.00	1.50	3.25	5.52	17.76	130.28	16.80	2.	8.	1	3.	.00
54	36	12.00	130.78	6.94	2.00	.00	4.94	9.50	13.44	131.34	17.76	3.	9.	1	3.	2.78
56	36	12.72	131.87	6.31	.64	1.00	4.67	11.50	18.48	132.64	17.76	3.	10.	1	3.	2.26
58	36	42.96	134.43	7.14	1.26	1.00	4.88	9.26	16.80	135.13	18.48	4.	11.	1	3.	.86
60	36	24.48	136.15	5.62	.31	1.00	4.31	10.33	12.48	136.67	18.48	5.	12.	1	3.	4.09
62	36	19.20	137.47	6.32	.82	.00	5.50	12.77	13.20	138.02	18.48	5.	13.	1	3.	6.17
64	36	13.44	138.58	7.70	2.00	1.00	4.70	9.40	14.64	139.19	18.48	5.	14.	1	3.	2.08
66	36	12.00	139.69	7.11	1.14	1.50	4.47	11.50	8.40	140.04	18.48	5.	15.	1	3.	7.30
68	36	12.00	140.54	5.58	2.00	1.00	2.58	5.96	9.84	140.95	18.48	5.	16.	1	3.	1.04
70	70	213.36	149.84	6.98	2.00	.00	4.98	7.98	12.72	150.37	.00	0.	0.	1	1.	4.80
72	70	26.88	151.49	7.88	2.00	1.50	4.38	10.90	17.76	152.23	12.72	0.	1.	1	1.	6.46
74	70	28.08	153.40	7.80	.19	.00	7.61	17.06	15.36	154.04	17.76	1.	2.	1	2.	11.30
76	70	12.24	154.55	4.67	2.00	1.00	1.67	5.80	14.88	155.17	17.76	1.	3.	1	3.	.00
78	70	23.76	156.16	7.02	.56	1.50	4.97	11.50	10.56	156.60	17.76	1.	4.	1	2.	7.54
80	70	21.12	157.48	7.08	1.15	.50	5.42	8.92	12.96	158.02	17.76	1.	5.	1	2.	4.06
82	70	12.00	158.52	6.26	2.00	1.50	2.76	6.52	10.32	158.95	17.76	1.	6.	1	2.	2.65
84	70	16.08	159.62	6.46	2.00	.50	3.96	10.08	3.60	159.77	17.76	1.	7.	1	2.	8.73
86	70	15.12	160.40	6.41	1.00	.50	4.91	10.19	9.60	160.80	17.76	1.	8.	1	2.	6.59
88	70	17.76	161.54	7.70	.49	.00	7.21	18.87	10.56	161.98	17.76	1.	9.	1	2.	14.91
90	70	27.36	163.12	7.79	.19	.50	7.10	16.93	9.60	163.52	17.76	1.	10.	1	2.	13.33
92	70	17.52	164.25	7.06	.23	.00	6.83	13.19	5.04	164.46	17.76	1.	11.	1	2.	11.30
94	70	12.00	164.96	4.84	1.14	.00	3.70	8.67	11.52	165.44	17.76	1.	12.	1	2.	4.35
96	70	23.28	166.41	6.40	1.03	.50	4.87	10.21	8.64	166.77	17.76	1.	13.	1	2.	6.97
98	70	18.00	167.52	5.83	.83	.00	5.00	10.50	16.56	168.21	17.76	1.	14.	1	2.	4.29
100	70	12.24	168.72	6.83	1.09	1.50	4.24	10.68	5.04	168.93	17.76	2.	15.	1	3.	8.16
102	70	12.24	169.44	8.00	1.42	1.50	5.08	11.38	16.08	170.11	17.76	2.	16.	1	3.	3.34
104	70	12.00	170.61	8.78	1.02	.00	7.75	16.57	12.00	171.11	17.76	3.	17.	1	3.	10.57

TABLE 12. SUMMARY OF EFFECTIVE SLEEP AND FATIGUE SCORES (MAN NO. 2; 51 DUTY DAYS)

Effective Sleep Duration			Starting Fatigue			Ending Fatigue		
Hours	FD	AD	Score	FD	AD	Score	FD	AD
.00	0	.00	.00	0	.00	.00	4	7.84
.50	0	.00	1.00	0	.00	1.00	1	9.80
1.00	0	.00	2.00	0	.00	2.00	4	17.65
1.50	1	1.96	3.00	0	.00	3.00	2	21.57
2.00	1	3.92	4.00	1	1.96	4.00	6	33.33
2.50	2	7.84	5.00	3	7.84	5.00	1	35.29
3.00	2	11.76	6.00	1	9.80	6.00	7	49.02
3.50	3	17.65	7.00	2	13.73	7.00	4	56.86
4.00	4	25.49	8.00	2	17.65	8.00	5	66.67
4.50	11	47.06	9.00	4	25.49	9.00	1	68.63
5.00	7	60.78	10.00	12	49.02	10.00	6	80.39
5.50	2	64.71	11.00	7	62.75	11.00	3	86.27
6.00	4	72.55	12.00	5	72.55	12.00	2	90.20
6.50	4	80.39	13.00	4	80.39	13.00	3	96.08
7.00	5	90.20	14.00	2	84.31	14.00	2	100.00
7.50	3	96.08	15.00	0	84.31	15.00	0	100.00
8.00	1	98.04	16.00	3	90.20	16.00	0	100.00
8.50	1	100.00	17.00	3	96.08	17.00	0	100.00
9.00	0	100.00	18.00	1	98.04	18.00	0	100.00
9.50	0	100.00	19.00	1	100.00	19.00	0	100.00
10.00	0	100.00	20.00	0	100.00	20.00	0	100.00

Average effective sleep: 5.35 hours

Average starting fatigue score: 11.56

Average ending fatigue score: 7.24

FD = frequency distribution; AD = accumulative distribution

A summary of the same crewmember's effective sleep, starting fatigue scores, and ending fatigue scores for the mission simulation is given in Table 12. In this example, the crewmember had 51 crew-duty days, with an average ending fatigue score of 7.24. According to Table 2 (Subjective Fatigue Checkcard), this score suggests that on an average duty day, this crewmember may have experienced moderate fatigue with some performance impairment. The 7.24 is only an average; the ending fatigue score for this crewmember was below 7.24 (more severe fatigue) on many duty days. The frequency distribution of the ending fatigue scores (Table 12) indicates that four times this score fell below 1.0. We can refer back to Table 11 and find out what happened in these cases. They occurred on simulation days (S.TIME) 121.58, 129.54, 134.43, and 154.55. The low ending-fatigue scores were either due to low starting-fatigue scores (SCORE1 = 4.41, 5.52, 9.26, and 5.80 respectively), high fatigue-decrement rates (CLASS = 1, 3, 3, and 3 respectively), or long duty days (WORK-LEN = 13.68, 17.76, 16.80, and 14.88 hours respectively). The low starting-fatigue scores were due primarily to unfavorable starting times and large time-zone differences. The high fatigue-decrement rates were due to many consecutive duty days, many of which were long.

Tables 13-14 are summaries of system fatigue measures. In both simulations, two crew types were used: basic (one pilot and one copilot) and augmented (an additional pilot). Since fatigue levels of augmented crews are usually lower than those of basic crews who have had similar duty days, the two crew types were analyzed separately.

Table 13, a typical output of the program FATIGUE, shows an average ending fatigue score of 5.90 for all men who had flown on a basic crew during days 150 to 165. There were 315 duty days (scores) during this period, and the average duty-day length was 12.95 hours. Table 13 also gives the distribution (frequency and accumulative) of the ending fatigue scores (SCORE), duty-day lengths (DUTY LEN), number of duty days per man (DSS/MAN), 30-day flying hours prior to the start of duty day (30-DAY), and 90-day flying hours prior to the start of duty day (90-DAY). In this example the flying-hour limitations were waived, and 39.0% of the ending fatigue scores were less than 5! This indicates that a substantial portion of the aircrew population probably experienced some performance impairment near or at the end of their duty day (possibly during landing). The duty-day lengths are determined by the preassigned route structure in the system and random variations due to aircraft maintenance and weather conditions. The frequency distribution of duty days/man shows that 25 out of 72 men did not have a duty day during this 15-day period. This happened because rested aircrews were at the wrong airbase when they were needed. The proper distribution of aircrews in the system is an extremely difficult operations problem, and research is being conducted to solve it. Improved aircrew distribution will certainly improve the ending fatigue scores, if the system workload remains the same. The 30-day frequency column in Table 13 shows that among the 315 duty days in this 15-day period, at least 25% started with pilots having over 125 flying hours in the 30 preceding days. This explains why scenario S2 had better aircraft utilization rates than did S1 (see Table 10). The 90-day accumulative-distribution column in Table 13 also shows this effect, but to a lesser extent since this period was only about 60 days into intense flying mode (intense flying started at day 90).

TABLE 13. SUMMARY DATA FROM PROGRAM FATIGUE FOR A BASIC CREW
(FOR PERIOD BETWEEN DAYS 150 AND 165)

Ending Fatigue			Duty Day Length			Duty Days/Man			Flying Last 30 Days			Flying Last 90 Days		
Score	FD	AD	Hours	FD	AD	Days	FD	AD	Hours	FD	AD	Hours	FD	AD
0	24	7.6	0	0	.0	0	25	34.7	0	5	1.6	0	0	.0
1	16	12.7	2	0	.0	1	1	36.1	10	6	3.5	30	6	.0
2	27	21.3	4	2	.6	2	6	44.4	20	6	5.4	60	0	.0
3	21	27.9	6	15	5.4	3	3	48.6	30	6	7.3	90	0	.0
4	35	39.0	8	50	21.3	4	2	51.4	40	8	9.8	120	0	.0
5	40	51.7	10	75	45.1	5	2	54.2	50	11	13.3	150	0	.0
6	38	63.8	12	57	63.2	6	4	59.7	60	17	18.7	180	56	17.8
7	36	75.2	14	31	73.0	7	9	72.2	70	22	25.7	210	128	58.4
8	24	82.9	16	60	92.1	8	6	80.6	80	24	33.3	240	67	79.7
9	22	89.8	18	25	100.0	9	4	86.1	90	21	40.0	270	26	87.9
10	11	93.3	20	0	100.0	10	7	95.8	100	34	50.8	300	19	94.0
11	9	96.2	22	0	100.0	11	2	98.6	110	25	58.7	330	11	97.5
12	3	97.1	24	0	100.0	12	1	100.0	120	21	65.4	360	6	99.4
13	5	98.7	26	0	100.0	13	0	100.0	130	31	75.2	390	2	100.0
14	2	99.4	28	0	100.0	14	0	100.0	140	14	79.7	420	0	100.0
15	0	99.4	30	0	100.0	15	0	100.0	150	12	83.5	450	0	100.0
15	2	100.0	32	0	100.0	16	0	100.0	160	18	89.2	480	0	100.0
17	0	100.0	34	0	100.0	17	0	100.0	170	19	95.2	510	0	100.0
18	0	100.0	36	0	100.0	18	0	100.0	180	7	97.5	540	0	100.0
19	0	100.0	38	0	100.0	19	0	100.0	190	8	100.0	570	0	100.0
20	0	100.0	40	0	100.0	20	0	100.0	200	0	100.0	600	0	100.0

Average: 5.8945 Average: 12.9531 Average: 315 days

AVERAGE FATIGUE SCORE = 5.8945
AVERAGE DUTY-DAY LENGTH = 12.9531
NUMBER OF DUTY DAYS = 315.0000

FD - frequency distribution; AD = accumulative distribution

Table 14 shows the correlation coefficients and their 95% confidence intervals for 1) ending fatigue scores and duty-day lengths and 2) ending fatigue scores and 30-day flying hours for both scenarios. The negative correlation between ending fatigue scores and duty-day lengths is not unexpected because the ending fatigue score is a function of duty-day length. That they are not more negatively correlated testifies to the fact that duty-day length is not the sole factor in determining ending fatigue score.

TABLE 14. CORRELATION COEFFICIENTS OF (1) ENDING FATIGUE SCORES AND DUTY-DAY LENGTHS AND (2) ENDING FATIGUE SCORES AND 30-DAY FLYING HOURS FOR 15-DAY PERIODS, FOR SCENARIOS 1 AND 2

		SCORE VS DUTY LENGTH		SCORE VS 30-DAY HOURS	
Period		S1	S2	S1	S2
Days 76-90:	CC	-.25	-.28	-.28	-.31
	CI	(-.48,-.01)	(-.50,-.03)	(-.50,-.03)	(-.52,-.06)
	NS	59	60	59	60
91-105:	CC	-.41	-.39	-.33	-.28
	CI	(-.51,-.31)	(-.48,-.29)	(-.43,-.22)	(-.38,-.17)
	NS	278	295	278	295
106-120:	CC	-.50	-.45	-.34	-.31
	CI	(-.59,-.40)	(-.53,-.36)	(-.45,-.23)	(-.40,-.21)
	NS	257	341	257	341
121-135:	CC	-.45	-.50	-.17	-.22
	CI	(-.57,-.39)	(-.57,-.41)	(-.29,-.06)	(-.32,-.11)
	NS	276	326	276	326
136-150:	CC	-.51	-.56	-.26	-.25
	CI	(-.59,-.41)	(-.63,-.49)	(-.37,-.14)	(-.35,-.15)
	NS	254	341	254	341
151-165:	CC	-.47	-.49	-.30	-.24
	CI	(-.56,-.37)	(-.57,-.40)	(-.41,-.18)	(-.34,-.14)
	NS	255	315	255	315
166-180:	CC	-.52	-.51	-.18	-.21
	CI	(-.61,-.42)	(-.59,-.43)	(-.30,-.06)	(-.31,-.10)
	NS	237	322	237	322

CC = Correlation coefficient
CI = 95% confidence interval
NS = Number of samples

Even though the ending fatigue score is not an explicit function of 30-day flying hours, the negative correlations between these two variables, as shown in Table 14, are also not unexpected; the fatigue decrement rate is a function of the number of consecutive duty days, which in turn is correlated with 30-day flying hours.

Tables 15 and 16 display the differences between scenarios S1 and S2 in terms of the average ending fatigue scores and the percentages of ending fatigue scores below 5, respectively, by periods of 15 days. Slight but obvious differences between the average ending fatigue scores in S1 and S2 are seen in Table 15. The scores in S2 are generally lower, as expected. The differences in S1 and S2 in terms of the percentages of ending scores below 5 are more apparent (Table 16). This is true especially in the periods after day 120, since the 30-day flying-hour limit for all practical purposes is effective only after day 120.

TABLE 15. AVERAGE ENDING FATIGUE SCORES

Period (15 days)	No. Samples	S1*	No. Samples	S2**
Days 76- 90	59	7.91	60	7.73
91-105	278	7.25	295	7.12
106-120	257	6.74	341	6.22
121-135	276	6.45	326	6.15
136-150	254	6.47	341	6.30
151-165	255	6.84	315	5.89
166-180	237	6.63	322	5.97

*Scenario with flying-hour limitations enforced
**Scenario with no flying-hour limitations

TABLE 16. PERCENTAGE OF ENDING FATIGUE SCORES BELOW 5 (SEVERE FATIGUE)

Period (15 days)	No. Samples	S1*	No. Samples	S2**
Days 76- 90	59	16.9%	60	16.7%
91-105	278	28.4%	295	24.4%
106-120	257	31.5%	341	34.0%
121-135	276	34.4%	326	39.0%
136-150	254	32.2%	341	34.0%
151-165	255	31.0%	315	39.0%
166-180	237	28.7%	322	38.2%

*Scenario with flying-hour limitations enforced
**Scenario with no flying-hour limitations

Finally, an interesting observation on these data is summarized in Table 17. Here we have calculated 1) for S1, the percent increase of the percentage of ending fatigue scores below 5 when the flying-hour limits are waived and 2) for S2, the percent of duty days in which the pilots had over 130 flying hours in the 30 days prior to the start of these duty days. (Data for 125 hours was not calculated in these runs, so we used 130 instead.) The two sets of numbers in Table 17 suggest there may be some relationship between them. In fact, they seem to suggest that the percentage of duty days started with pilots who had violated the 125 hours/30 days flying-limitation rule is of the same order as the percent increase in the percentage of fatigue scores below 5 when flying-limitation rules were waived. This is only a conjecture, and more simulations and careful statistical analysis are needed. Since the main purpose of this paper was to investigate the feasibility of using the FATIGUE program to study the effects of various flying-limitation rules on aircrew performance, additional simulations (consequently, a detailed statistical analysis) were not performed. This will be done in following studies.

TABLE 17. PERCENT DUTY DAYS WITH FLYING-HOUR LIMITATION EXCEEDED COMPARED WITH PERCENT INCREASE IN PERCENTAGE OF SEVERE-FATIGUE SCORES

Period (15 days)	Percent DD with More than 130 FH/30 Days	Percent Increase in % Ending Fatigue Scores Below 5
Days 121-135	7.9	13.37
136-150	30.7	5.59
151-165	34.6	25.8
166-180	33.5	33.1

CONCLUSIONS AND FUTURE RESEARCH

Typical output of an airlift simulation gives only operational measures of system performance, such as aircraft utilization rates, number of missions cancelled, or average flying hours per crewmember per month. These statistics do not tell a decision maker, especially if he is untrained in the area of human factors, how well the aircrews in the system fared or how vulnerable they were to catastrophic performance failure. In this paper, we have made a bold attempt to bridge this gap. We have proposed an algorithm to estimate fatigue (as would have been reported by aircrews on long-duration flights). The algorithm is based on many years of experience in observing and collecting data on aircrews by human-factor scientists at the Crew Technology Division at USAFSAM. This is the first attempt to predict aircrew fatigue and performance levels, and many refinements to this algorithm will be made in the future. For example, the concept of home time should be clarified. It is not apparent what home time is when a crewmember is flying away from home for several days and does not stay at any one place long enough to restabilize his circadian rhythms, yet is no longer in phase with his home-base time. This problem is currently an area of active research. However, it is still at an elementary stage (most investigations are being done in controlled environments because of imprecise measurement technology and vast differences in human response to time-zone desynchronization). Future improvements to the FATIGUE program as applied to airlift simulation should also concentrate on determining the proper graphic and tabular data to be presented at the conclusion of each simulation run. A tremendous amount of data can be obtained and examined from various points of view, so a judicious compression of the data will be needed to make the output useful to potential simulation users.

The aircrew fatigue scores predicted by the FATIGUE program appeared to correspond to scores obtained during actual operations requiring intense periods of long-duration flight. However, USAFSAM researchers have never had the opportunity to study C-5 flight operations lasting over 100 days, so no data base exists for a complete comparison with model outputs. Our ending fatigue scores may be conservative, even though they indicate some mild performance impairment, because the FATIGUE program did not attempt to account for fatigue effects accumulating over a several-month period of intense flying. Both simulations examined involved extremely heavy workloads, and more severe fatigue could probably be expected.

We believe the assumptions made in constructing this performance assessment model have been reasonable and sensible, also the predicted fatigue levels in the two simulations. This effort has helped to focus our attention on the types of experiments and research needed in the future to refine and validate the model. This effort has demonstrated the feasibility of modeling the course of aircrew fatigue during long-duration airlift missions; if further refined, such modeling will bring about a significant new capability in airlift management.

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APPENDIX A

FORMS FOR SUBJECTIVE REPORTING OF FATIGUE

NAME AND GRADE	TIME/DATE

INSTRUCTIONS: Make one and only one (✓) for each of the ten items. Think carefully about how you feel RIGHT NOW.

STATEMENT	BETTER THAN	SAME AS	WORSE THAN
1. VERY LIVELY			
2. EXTREMELY TIRED			
3. QUITE FRESH			
4. SLIGHTLY POOPED			
5. EXTREMELY PEPPY			
6. SOMEWHAT FRESH			
7. PETERED OUT			
8. VERY REFRESHED			
9. FAIRLY WELL POOPED			
10. READY TO DROP			

PREVIOUS EDITION WILL BE USED

SAM FORM 136
SEP 76

SUBJECTIVE FATIGUE CHECKCARD

Figure A-1. Subjective Fatigue Checkcard, SAM Form 136. The card is scored by adding two points for every check in the "better than" column, one point for every check in the "same as" column. Checks in the "worse than" column are not counted.

NAME | DATE AND TIME

SUBJECTIVE FATIGUE

(Circle the number of the statement which describes how you feel RIGHT NOW.)

1	Fully Alert; Wide Awake; Extremely Peppy
2	Very Lively; Responsive, But Not At Peak
3	Okay; Somewhat Fresh
4	A Little Tired; Less Than Fresh
5	Moderately Tired; Let Down
6	Extremely Tired; Very Difficult to Concentrate
7	Completely Exhausted; Unable to Function Effectively; Ready to Drop

COMMENTS

WORKLOAD ESTIMATE

(Circle the number of the statement which best describes the MAXIMUM workload you experienced during the PAST HOUR. Estimate and record the number of MINUTES during the past hour you spent at this workload level.)

		MINUTES
1	Nothing to do; No System Demands	
2	Little to do; Minimum System Demands	
3	Active Involvement Required, But Easy to Keep Up	
4	Challenging, But Manageable	
5	Extremely Busy; Barely Able to Keep Up	
6	Too Much to do; Overloaded; Postponing Some Tasks	
7	Unmanageable; Potentially Dangerous; Unacceptable	

COMMENTS

SAM FORM JUL 80 202 CREW STATUS CHECK

Figure A-2. Crew Status Check, SAM Form 202.

APPENDIX B

FLOW CHARTS FOR FATIGUE PROGRAM

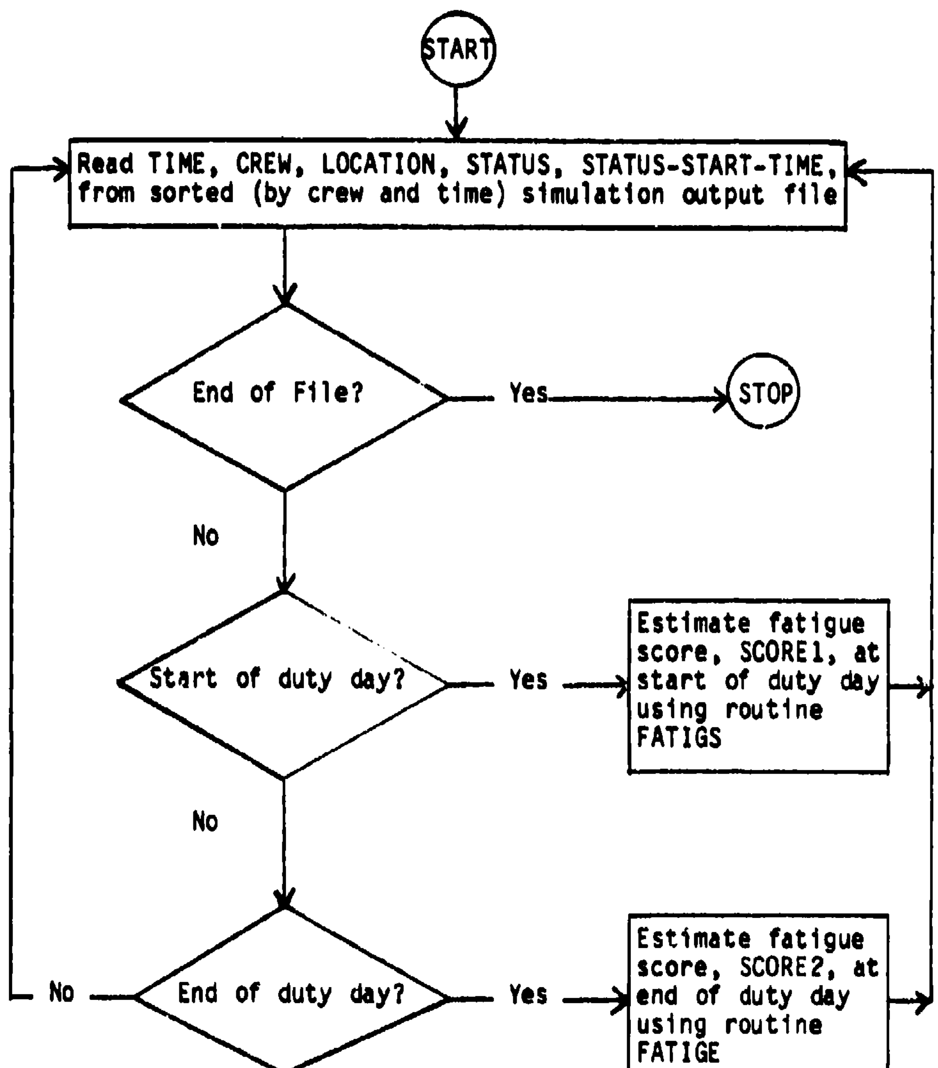

Figure B-1. General flow diagram of FATIGUE program.

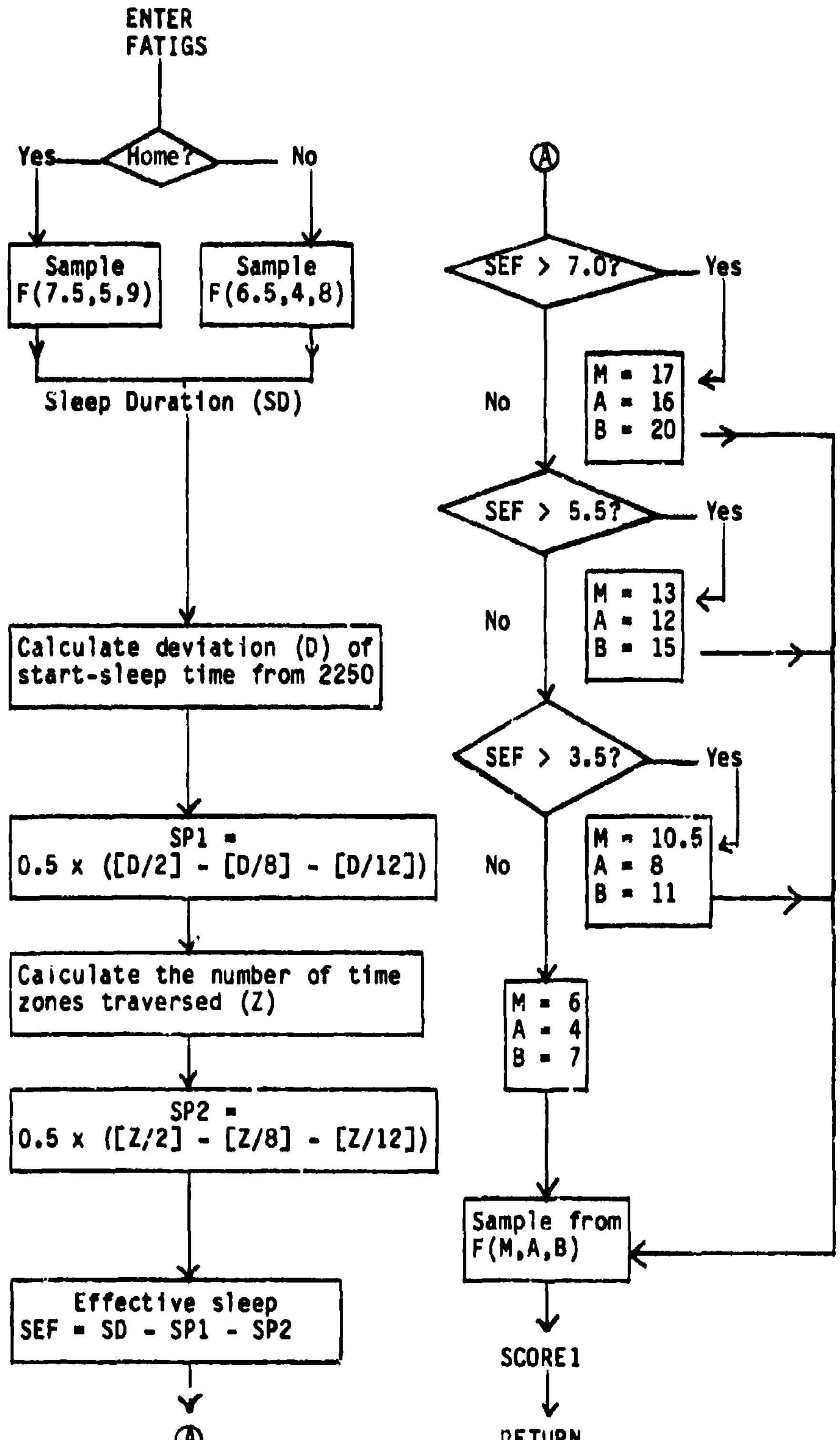

Figure B-2. Flow diagram of FATIGS routine. F(M,A,B) is the truncated normal distribution with median M and truncations at A and B.

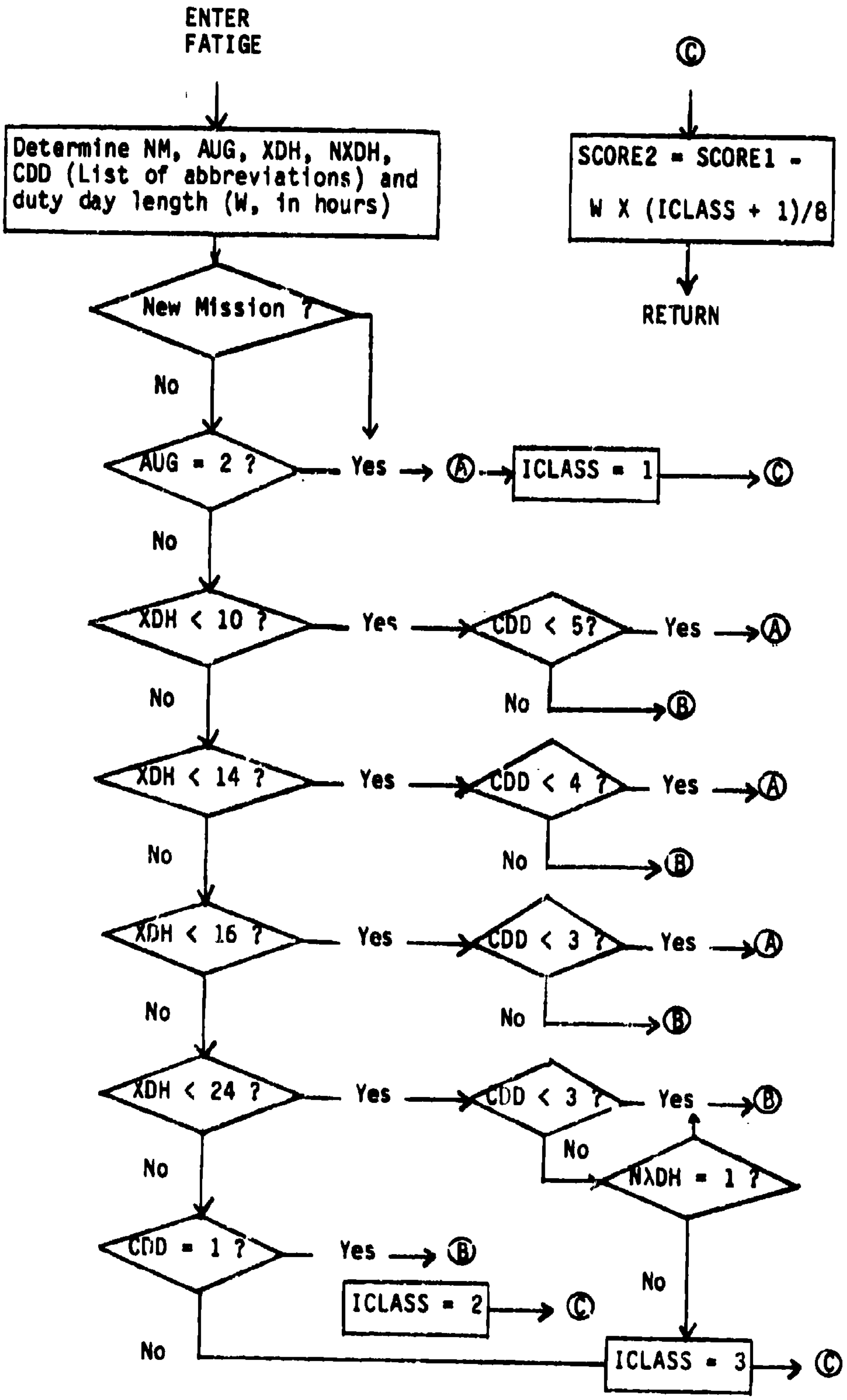

Figure B-3. Flow diagram of FATIGE routine.

LIST OF ABBREVIATIONS

AUG	Crew-type indicator: AUG = 1 if basic and 2 if augmented.
CDD	Number of consecutive duty days prior to current duty day.
CLASS	Fatigue decrement rate: CLASS = 1 if CLASS A and 2 if CLASS B or CLASS C.
E.TIME	Time at which duty day ends.
LBL	Label for duty day in question.
LSTST	Pointer to first duty day for current mission.
MISSION	Set of consecutive duty days that are separated by less than 60 hours of crew rest at home or less than 72 hours of crew rest while TDY (temporary duty away from home).
NM	Mission indicator: 1 if new; 0 if continued.
NXDH	Number of prior duty days that exceeded 16 hours.
REST-LEN	Length (hours) of rest period prior to current duty day.
SCORE	Same as SCORE1
SCORE1	Starting fatigue score, obtained by sampling an appropriate distribution that depends on the estimated effective sleep (SEF).
SCORE2	Ending fatigue score of duty day in question.
SEF	Estimated effective sleep.
SD	Estimated initial sleep duration.
SP1	Sleep penalty due to (possibly poor) sleep starting time.
SP2	Sleep penalty due to possible time-zone difference.
S.TIME	Starting time (in days, with respect to the start of the simulation) of current duty day.
WORK-LEN	Time span from alert to final postflight
XDH	Maximum current-mission duty day (hours) prior to the duty day in question.