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HUMAN-FACTORS EVALUATION OF C-141 FUEL SAVINGS ADVISORY SYSTEM.(U)

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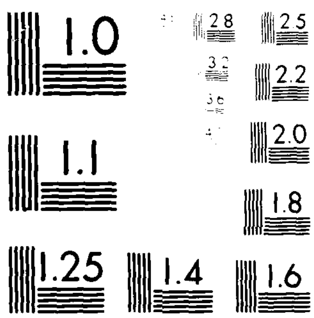

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Report SAM-TR-81-37

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HUMAN-FACTORS EVALUATION OF C-141 FUEL SAVINGS ADVISORY SYSTEM

Layne P. Perelli, Major, USAF

December 1981

Final Report for Period December 1979 - February 1981

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

This final report was submitted by personnel of the Crew Performance Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7930-10-28.

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The operational personnel who participated in this study were fully briefed on all procedures prior to participation in the study.

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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The Air Force installed a Fuel Savings Advisory System (FSAS) in three C-141 aircraft and performed an operational test and evaluation. At the request of the USAF Airlift Center, observers from the USAF School of Aerospace Medicine evaluated human-engineering, workload, and fatigue aspects of FSAS during three long-duration missions. Pilots' subjective fatigue/workload reports, interviews with crewmen, and human-engineering analyses indicated that the FSAS was satisfactory for use in MAC airlift operations. Human-engineering solutions are provided, also suggestions for future improvement of the FSAS.

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PREFACE

I would like to thank Dr. James C. Miller and Dr. William F. Storm for their assistance in collecting the subjective fatigue and workload data under demanding field research conditions. Outstanding data reduction support was provided by A1C Vabian L. Paden, who processed the data, and by A1C Murray Durant, who constructed the graphs.

Special thanks are extended to the crewmen of the 437th Military Airlift Wing, Charleston AFB, South Carolina, who participated in these missions. Their enthusiastic support and cooperation in this field research program contributed significantly to the operational validity of the findings.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

HUMAN-FACTORS EVALUATION OF C-141 FUEL SAVINGS ADVISORY SYSTEM

INTRODUCTION

Due to rapidly escalating fuel costs, the Air Force has been focusing particluar attention on fuel conservation measures in flying operations. Reduced fuel resources are making it difficult for Military Airlift Command (MAC) to adequately train crews, conduct operational proficiency flights, move cargo, and manage large-scale deployments. To maintain military preparedness and combat effectiveness, new methods must be developed to reduce fuel usage.

During climb, cruise, and descent portions of flight, fuel could be saved by optimizing engine pressure ratios (EPR) and attitude settings based on multiple parameters such as gross weight, altitude, and outside temperature. With the constantly changing conditions of flight, however, aircrews cannot manually interpolate and extract flight manual data and continually modify power settings with the speed and accuracy necessary to obtain the small but significant fuel savings that could occur by such optimization. Recently, electronics companies have developed state-of-the-art avionics systems using microcomputers to make the necessary calculations for power settings. These systems are coupled to the autothrottles to continuously adjust power setting. Commercial airline tests of the equipment have demonstrated substantial fuel savings.

In November 1978, Headquarters USAF/RD directed a joint Air Force Systems Command/Air Logistics Command effort to develop, flight test, and employ Fuel Savings Advisory Systems (FSAS) for selected Strategic Air Command (B-52) and MAC (C-141) aircraft. HQ MAC directed the USAF Airlift Center (USAFALCENT) to conduct an operational test and evaluation of three C-141 aircraft equipped with one brand of commercially available FSAS hardware that allowed throttle coupling. All test flights were conducted by the 437th Military Airlift Wing (MAW) at Charleston AFB, South Carolina, using 15 FSAS-trained crews.

The USAFALCENT Project Plan 27-6-79 (6) requested the Crew Performance Branch of the USAF School of Aerospace Medicine (USAFSAM/VNE) to conduct a human-factors evaluation of the FSAS in terms of the system's display/control adequacy and workload/fatigue impacts on crewmembers during operational missions. The present report is the outcome of this effort. Aeronautical Systems Division will use the results of these tests to determine the most cost-effective FSAS concept and develop specifications for an FSAS for the B-52, C-141, C-5, and KC-135 aircraft.

The commercial FSAS chosen for the MAC test consists of a computer (FMCU), a control display unit (CDU), and associated circuitry to interface with the engines, a tactical air navigation system (TACAN), an inertial navigation system (INS), the central air data computers (CADC), and various aircraft sensors. After computing the optimum flight profile, the FSAS provides control outputs to the INS, flight director, autothrottle, and autopilot.

The FSAS improves INS navigational capability by providing storage of up to 40 waypoints instead of only 9 in the INS and has the latitude/longitude and station parameters for 160 TACAN stations permanently stored in the FMCU for immediate recall. The CDU has a 3-line by 24-character alphanumeric LED display. Character height is .15 inch (3.8 mm) formed by a 5 x 7 dot matrix. In addition to displaying flight parameters such as altitude, EPR, MACH/indicated airspeed, and recommended settings for fuel savings, the CDU also provides all INS data, Greenwich Mean Time (GMT), fuel on board, aircraft gross weight, and associated planning information.

To assure system integrity, several internal self-checks are performed by the FMCU and the CDU. The crew can select from several climb, cruise, and descent options to most effectively achieve the desired mission objectives with minimum fuel use. The particular system used in this test can be flown in either an advisory mode, in which the recommended settings are provided for use at the pilot's discretion, or in a fully coupled mode, in which the FSAS provides commands directly to the autopilot/autothrottle system.

PROCEDURES

USAFSAM investigators participated in three FSAS test missions and one control mission. All flights originated from the 437th MAW at Charleston AFB in August, October, and November 1980. Data collected consisted of systematic subjective fatigue and workload reports and sleep log data from each crewmember, individual interviews with each pilot and flight engineer involved in the flights, and personal observation by USAFSAM personnel of the inflight operation of the FSAS.

At the beginning of each mission leg, usually just before starting the preflight check, each crewmember completed a Crew Status Check (SAM Form 202) and a Subjective Fatigue Checkcard (SAM Form 136). Examples are provided in Appendix A. Normally the crew completed the checkcards again just before starting the enroute descent (predescent). On long legs, the crewmen completed additional cards at appropriately spaced intervals during the cruise portion, approximately every 2 hours. If crewmen were asleep during a scheduled data collection period, they were not awakened for checkcard administration. On very short legs (usually less than 2 hours total), no inflight data were collected. Within the hour following each landing, all crewmen again completed both checkcards. Occasionally, when minimal ground time occurred between landing and takeoff, the postlanding data point was also used for the pretakeoff data point.

The Subjective Fatigue Checkcard (7) has been used successfully to evaluate crew fatigue in various USAF operational situations and laboratory experiments (3-5,8-10). The fatigue reports have been systematically related to work-rest cycles, sleep duration, physiological parameters, circadian rhythms, and environmental stressors. The Subjective Fatigue Checkcard scores range from 0-20 (arbitrary units): the lower the score, the higher the fatigue level being reported.

The Crew Status Check was developed at USAFSAM to reduce the time required for crewmen to report both fatigue and workload data in field research. Minimal time to complete the data cards is desired; it interferes less with the crewman's ongoing activities and is thus more acceptable to him. The Crew Status Check consists of two 7-point forced-choice rating scales, one for workload, the other for fatigue. The 7-point scale format appears to be more sensitive to fatigue than does the Subjective Fatigue Checkcard approach (8). The Crew Status Fatigue scale requires the crewman to identify which of seven statements most closely corresponds to how he feels at the time of checkcard administration: on this scale, the higher the number, the greater the feeling of fatigue reported. (Note: This is opposite the scoring procedure for the Subjective Fatigue Checkcard.) Collecting data with both the well-established Subjective Fatigue Checkcard and the Crew Status Check provided a means to validate the newer checkcard by examining the correlation between the two instruments.

In general, scores on the Subjective Fatigue Checkcard of 12 or higher can be interpreted to mean fatigue is not affecting crew performance. Scores of 8 to 11 indicate moderate feelings of fatigue; 7 to 4, severe feelings of fatigue (it is hypothesized that scores in this range 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 are complex and demanding). For the Crew Status Check, fatigue scores of 5 and 6 indicate possible performance impairment and 7 indicates probable impairment due to fatigue. We cannot yet accurately quantify the severity of the impairment or the exact operational consequences of these fatigue levels (8).

The Crew Status workload scale requires the crewman to identify which of seven statements best describes the maximum workload he has experienced during the past hour. The higher the score reported, the greater the subjective experience of recent workload. Consistent scores of 6 to 7 indicate that the crewman is experiencing a higher than desirable workload.

Daily logs of total time each crewmember slept were recorded on SAM Sleep Survey Form 154 throughout each mission. A copy of the form is provided in Appendix A. The purpose of recording sleep data was to determine if the fatigue scores were due primarily to lack of a crewmember's ability to obtain sleep during a crew-rest period. Sleep data are often helpful in explaining extreme fatigue scores when there is no apparent reason for the high fatigue level. On the other hand, if subjects reporting high fatigue levels are receiving expected levels of sleep, the fatigue can probably be attributed to the type and length of duty being performed.

Summaries of the scheduled itineraries and mission logs for each of the four missions observed by USAFSAM personnel are presented in Appendix B. Missions 1, 2, and 4 were the test missions flown with FSAS-equipped aircraft. During test missions, legs were flown alternating between advisory mode and coupling mode. Mission 3 was a control flight using a C-141 not equipped with FSAS; standard MAC policy was followed concerning fuel conservation. The purpose of the control flight was to familiarize the researchers with workload and procedures associated with aircraft not equipped with FSAS and to establish a baseline for comparison to FSAS operations.

No major disruption of scheduled mission itineraries occurred except for an overnight delay caused by severe weather on the last day of Mission 2.

However, several minor delays resulted from maintenance problems, cargo handling, passenger processing, and lack of ground transportation support, which typically occurred on each mission.

To approximate a "worst case" operational environment, USAFSAM investigators chose to evaluate the longest duration, most fatiguing missions available to observe FSAS operation. These conditions were assumed to be more apt to (1) expose problems the pilots might have had in using the system, (2) emphasize the potential for error, and (3) indicate if any situations existed where workload was too high. In preliminary discussions with MAC crewmembers, missions 1, 3, and 4 were selected as some of the most fatiguing regularly scheduled missions in the MAC system. Mission 2 was selected because, even though it might not generate the most fatigue, the several short legs involved might create multiple periods of potentially high workload when using the FSAS for ascent and then almost immediate descent.

All aircraft commanders on USAFSAM-observation missions had received the basic contractor-furnished FSAS training program and had flown with the system on several occasions prior to the test flights. Most copilots had similar experience with the FSAS; however, one copilot augmentee had not seen FSAS in inflight operation prior to the test mission.

Most pilots, especially the copilots, had relatively little Air Force and MAC flying experience. From this standpoint, the USAFSAM test missions were somewhat conservative. That is, if the FSAS created excessive workload or disrupted crew coordination, these problems were more likely to be amplified in crews with few numbers of flight hours in the C-141. To insure that a new system will be operable by personnel with the lowest experience levels available, most operational test programs should not use only the most highly experienced and qualified operators as subjects. Flying time and age for all pilots involved in the USAFSAM missions are presented in Table 1.

TABLE 1. USAFSAM FSAS EVALUATION: PILOTS' FLYING TIME AND AGE

Mission	Crew position[a]	Age	Total AF flying time (h)	MAC C-141 flying time (h)
1. Test	AC	28	2,600	2,330
	CP	23	289	168
	CP	40	4,300	1,200
2. Test	AC	27	2,400	2,200
	CP	25	900	600
3. Control	AC	28	2,000	1,700
	CP	24	680	463
	CP	25	1,000	825
4. Test	AC	29	2,200	2,000
	CP	28	470	220
	CP	29	1,950	750

[a]AC = aircraft commander; CP = copilot.

RESULTS

Subjective Fatigue

The subjective fatigue scores for pilots were averaged for each mission and are presented graphically in Appendix C. Data from the Subjective Fatigue Checkcard and the Crew Status Check are presented separately on each figure. In general, the fatigue levels increased throughout each mission and decreased after crew-rest periods, in patterns similar to those previously observed during other USAFSAM and MAC studies of long-range airlift operations (3-5, 9,10). However, the fatigue levels did not appear to be as severe as in past studies whose purpose was to explore maximum limits of long-duration missions (3,4,9).

To determine the severity of fatigue experienced, subjective fatigue scores which were either high (Form 136 scores between 7 and 4; Form 202 score of 6) or very high (Form 136 scores between 3 and 0; Form 202 score of 7) were tallied for all missions. The results are presented in Table 2. No high or very high fatigue was reported on the Crew Status Check. On the Subjective Fatigue Checkcard, nine high fatigue scores were reported on test missions 1 and 4, and two on control mission 3; no very high fatigue scores were reported on any mission. Of the eleven high fatigue scores reported, eight were from the three aircraft commanders on these missions and only three from the six copilots, indicating possibly a greater stress due to crew position responsibility. In only one instance did two crewmembers report high fatigue scores at the same time. This was at the conclusion of Mission 1, after landing.

TABLE 2. FREQUENCY COUNTS OF HIGH AND VERY HIGH PILOT-FATIGUE SCORES

Mission		Score Categories: High	Score Categories: Very high	No. Reports
	SAM Form 136, Subjective Fatigue Checkcard--	(7-4)	(3-0)	
1.	Ascension Island, South Atlantic	6	0	42
2.	Guantanamo Bay, Cuba	0	0	30
3.	Johannesburg, South Africa	2	0	79
4.	Amman, Jordan	3	0	71
	SAM Form 202, Crew Status Subjective Fatigue Check--	(6)	(7)	
1.	Ascension Island, South Atlantic	0	0	42
2.	Guantanamo Bay, Cuba	0	0	30
3.	Johannesburg, South Africa	0	0	79
4.	Amman, Jordan	0	0	71

The MAC missions studied are all flown routinely each month. The fatigue data indicated that these are tiring missions due to duty-day length and time-zone crossings. The data indicated that inflight fatigue did not reach levels to jeopardize mission success. Missions 1, 3, and 4 were flown with augmented crews. Crewmembers were adequately rested prior to departure and were usually able to obtain inflight crew rest. The missions themselves posed no fatigue hazard.

Although no statistical analysis was performed, nc differences were apparent between the fatigue levels obtained on the test missions and on the control mission. Thus, use of the FSAS did not appear to increase crewmember's fatigue levels to any appreciable extent.

The joint graphic presentations of Figures C-1 through C-4 (Appendix C) show that the Crew Status Check fatigue data and the Subjective Fatigue Checkcard data curves are very similar to each other. Witnin-subject Pearson product moment correlations (r) between the two scales for the 11 pilots studied over the four missions are presented in Table 3. The high, statistically significant correlations obtained suggest that the scales were measuring the same underlying factor in a similar manner. These data indicate that only the Crew Status Check may need to be used to obtain fatigue scores in future studies; its faster administration time would be beneficial. All crewmembers but one preferred the Crew Status Check. They said it was easier to use and seemed to more accurately reflect their true feelings of fatigue.

TABLE 3. WITHIN-SUBJECT PEARSON PRODUCT MOMENT CORRELATIONS BETWEEN CREW STATUS CHECK AND THE SUBJECTIVE FATIGUE CHECKCARD RESPONSES

Mission	Crew position	r - value*	No. Reports
1. Test	AC	- .832	15
	CP	- .915	15
	CP	- .674	15
2. Test	AC	- .882	15
	CP	- .919	15
3. Control	AC	- .908	26
	CP	- .870	27
	CP	- .706	26
4. Test	AC	- .862	24
	CP	- .794	23
	CP	- .859	24
Four missions pooled using Fisher's Z transformation		- .851	

*All correlations are significantly different from zero beyond the .01 level.

Sleep Data

The total average hours slept during each crew-rest period by the pilot were as follows: Mission 1, 7.08 hours; Mission 2, 7.20 hours; Mission 3, 7.92 hours; Mission 4, 7.17 hours. No pilot received less than 5.5 hours of sleep during any crew-rest period. From analysis of the sleep logs we can safely assume that each pilot received expected amounts of sleep throughout each mission. Thus, fatigue score decrements probably resulted from mission effects rather than from sleep loss.

Workload

The workload scores for pilots were also averaged for each mission and are presented in Appendix C. Examination of the graphs did not reveal any periods of intense inflight workload. In general, workload was, as would be expected, higher during takeoff and landing. A frequency count of high (5: extremely busy; barely able to keep up), very high (6: too much to do, overload, postponing some tasks), and dangerously high (7: unmanageable; potentially dangerous; unacceptable) workload scores recorded on the Crew Status Check are presented in Table 4. No incidents of very high workload were reported. Only one instance of dangerously high workload was reported on any of the missions. This incident occurred during the landing of the first leg of Mission 4. The air traffic controller directed the pilot to a short final approach with other aircraft in the pattern, and there was momentary confusion as to the intended landing sequence. The FSAS was not being used at this time and had no impact on this event. The three reports of high workload (Mission 4) were also associated with landings and did not involve the FSAS.

TABLE 4. FREQUENCY COUNTS OF HIGH TO DANGEROUSLY HIGH PILOT-WORKLOAD SCORES

SAM Form 202, Crew Status Workload Check

	Score Categories			
	High (5)	Very high (6)	Dangerously high (7)	No. Reports
1. Ascension Island, South Atlantic	0	0	0	42
2. Guantanamo Bay, Cuba	0	0	0	30
3. Johannesburg, South Africa	0	0	0	79
4. Amman, Jordan	3	0	1	71

The checkcards gave no indication that overall inflight cockpit workload was significantly increased due to the FSAS. In some instances, workload was slightly reduced by (1) improving navigational capability because of easier INS/TACAN update procedures, (2) use of the autothrottles, and (3) increased waypoint storage. One reason that FSAS did not usually increase inflight workload was that its use was somewhat optional. In several instances where workload started to increase due to demanding departures or approaches or conflicts between other duties and use of FSAS, the FSAS was either decoupled or ignored to reduce workload to a manageable level.

However, when 40 waypoints had to be loaded and verified, time required for preflight was significantly increased. (Time could be saved if waypoints could be loaded into FSAS while the INS was in "Align" mode instead of having to load while in "Standby" mode.) If time was available, pilots usually chose to load all 40 prior to takeoff. On occasion, however, crews loaded as many as they had time for before takeoff and deferred the balance until after leveloff. Then, to insure proper navigation, the pilot had to remember to insert the remaining waypoints before reaching the last waypoint previously loaded. No specific guidance, routine procedures, or alerting features were available to assist the pilot. This updating problem also existed when using only the INS in aircraft that were not equipped with FSAS.

From individual interviews with crewmen, pilot acceptance of FSAS appeared to be good, despite their complaints of receiving inadequate initial training on the system. However, some did feel that these types of systems are being installed without an overall concern for system integration.

Flight engineers were required to manually record FSAS data as part of the USAFALCENT test procedures. This function significantly increased their inflight workload but would not be required for standard FSAS operations. Other than this temporary increase in workload, flight engineers had no major complaints about FSAS.

Training and Procedural Problems

The test crews received minimal training on the FSAS but were able to quickly learn its operation without any serious problem. FSAS operating procedures were generally simple and easily learned. However, the minimal training received should <u>not</u> be considered sufficient if the FSAS is accepted for fleetwide installation. While the system operation itself (e.g., loading data and coupling to the autopilot/autothrottles) is relatively straightforward, for some issues the MAC crews need specific procedures and guidance. In the interest of fuel conservation, the FSAS should be flown in the coupled mode as much as possible, especially during climb and descent. Additional training appears to be necessary to teach crews how to maximize FSAS use when on climbout, descent, and under the direction of an air traffic controller.

Waypoint verification techniques also need to be improved and documented. Crews now use basically the same approach as for the INS. But with the possible 40 waypoints of the FSAS to load instead of the nine of the INS, much more time during preflight is consumed. Pressure to meet block times may cause crews to rush, increasing the chance for overlooking verification procedures and causing errors. On one test mission a crew had begun to taxi for takeoff when a USAFSAM observer discovered that the latitude loaded in Waypoint No. 2 was 10 degrees off. This crew had been trying to follow the verification practices currently in effect; no specifically documented verification procedures existed. A potential for serious navigational errors exists without an improved verification technique.

Both the aircraft commander and the copilot had a tendency to attend to the FSAS display and its operation for long periods of time. This tendency led to increased "head in the cockpit" time and occasionally created a situation in which neither crewmember was flying the aircraft. The training program should stress the hazard involved in this situation and provide guidance as to how to avoid it. An improved training program would both enhance fuel conservation and increase safety of flight.

An additional area of concern is related to the system documentation and detailed checklists. Care must be taken to properly integrate the FSAS into the INS technical orders. A new checklist should be developed to contain (1) all necessary information for joint FSAS/INS operation, (2) details of possible failure modes, (3) inflight updating procedures, and (4) specific guidance on fuel-savings techniques.

Human-Engineering Deficiencies and Possible Solutions

As a result of the observations, interviews with MAC crewmembers, and analyses performed by USAFSAM personnel, I judged the FSAS to be acceptable from a human-engineering point of view. However, several deficiencies were discovered and should be corrected at the earliest possible cost-effective opportunity. If the system is redesigned as part of development of a new aircraft, such as the CX, consideration should be given to correcting these deficiencies and retrofitting the C-141.

1. The most universal complaint of the FSAS was that the LED display on the CDU could not be read in bright sunlight. During each test mission, complete washout occurred at least once. The reduced readability and manual shading by pilots increase display read time, increase "head down" time, cause significant channelized attention, and may on occasion cause misreading of the display. The FSAS is useful for obtaining ground speed and wind data on final approach; for this, an easily readable display is highly desirable. Either relocating the display unit, providing a nonobstructing sun screen, or procuring a display that will not wash out in sunlight should solve the problem.

2. During the flight, keyboard brightness was turned to a low level to protect night vision. At this illumination level, the pushbutton indicating which function had been selected was not bright enough to distinguish from the others. The illumination contrast should be increased. Keyboard illumination is uneven across keys and should be equalized.

3. During night flight, the alarm (ALR), status (STS), and warning (WRN) annunciators were very bright, compromising night vision. Illumination levels should be made adjustable.

4. A better indication is needed to warn the pilot that an FSAS failure has occurred. The system should be tied to the master caution light, and an appropriate annunciator panel light installed. The warning annunciator on the CDU did not have sufficient attention value. Also, the warning light couldn't be cleared without affecting the operation of the system. A warning-light reset is necessary.

5. The location of the CDU on the center console was a major problem with the FSAS. Since FSAS/INS information is becoming more important in the instrument crosscheck, a display should be provided in each pilot's primary

field of view. A similar problem was previously identified for the INS location in the C-5A (9). With the increased information available from FSAS and the pilots' increased attention to the center console, the "head in the cockpit" time is increasing dramatically. This increase is accompanied by some unquantifiable loss in the margin of flight safety. Thus, should this system be procured, MAC should continue to monitor its impact on aircrew procedures.

DISCUSSION

The USAFSAM evaluations revealed no human-factors problems that would prohibit use of the FSAS in MAC airlift operations. However, significant improvements could be made. The FSAS is introducing new types of cognitive tasks into the cockpit, which are susceptible to disruption from the high fatigue levels occasionally encountered in MAC operations. Manual keyboard entry of long sequences of numbers and recall of multiple steps in proper sequence for computer operation will take longer to perform and will have increased chance of error. Time available for other tasks, such as instrument scanning and collision avoidance, will be reduced. For these reasons, no modifications that increase the complexity of FSAS operation should be permitted without a thorough analysis of flight deck workload. In a limited test such as this, not all failures or flight situations with a potential for jeopardizing flight safety can be observed or uncovered, thus MAC should continue to monitor the aircrew interaction with FSAS if the system is procured.

Several possible improvements to the FSAS were identified. In some cases, these modifications would require only a software change; in others, new hardware may be required.

1. With the advent of C-141B refueling capability, 40 waypoints will not always be sufficient to hold an entire computer flight plan. Increased computer memory would permit sufficient waypoints to cover all possible computer flight plans. Additional waypoint storage capability would also permit storing alternate destinations and frequently used flight plans or routes.

2. In some cases the return route uses the same waypoints as the outbound route. A "route reversal" feature would permit the FSAS to invert the order of the waypoints without requiring them to be reloaded and reverified, thus reducing the chance for error.

3. A clearance altitude higher than permitted by the aircraft gross weight cannot be loaded into the FSAS during preflight, even though the crew plans to reach that altitude only after a given amount of fuel burnoff. The FSAS could be designed to take into account projected fuel burnoff, calculate where in the flight profile the planned clearance altitude can be achieved, and accept the clearance altitude if it is reasonable.

4. To obtain data between present position and an alternate waypoint, at least six steps are required. Since this is a frequent system query, simplification of this procedure would reduce crew workload. Use of a "0" waypoint for present position (similar to the INS) may be a solution.

5. Increasing the number of TACAN station parameters permanently stored in the FMCU would be useful. The ability to call up TACAN stations reduces manual data input requirements; a desirable feature for the pilots.

6. FMCU calculation of "along track offsets" for specified course deviations (for example, around thunderstorms or traffic) would help.

7. With additional programming and increased memory size, much of the flight manual data could be stored in the FMCU; and many calculations usually performed by the flight engineer concerning takeoff, landing, and fuel data could be calculated by the FSAS, continually updated, and available to the pilot. The FMCU could be queried to provide inflight information concerning the maximum achievable ceiling and associated stall speed, or to determine how much flight time and fuel burnoff would be required before a given altitude or alternate could be reached.

8. During these missions a problem was uncovered where fuel-savings procedures (although not due to FSAS) are indirectly increasing crew fatigue. Normally on a long, fatiguing mission, pilots will make informal arrangements among themselves for inflight crew rest in which one of the pilots (or two if an augmented crew) will try to retire to a crew bunk to sleep, leaving only one pilot at the controls. This is an approved procedure and contributes significantly to fatigue reduction. However, AFR 60-16 (1) stipulates that if the aircraft is above 35,000 feet (10.7 km), the pilot remaining at the controls must wear the quick-don oxygen mask (MBU-10/P) to provide a margin of safety in the event of a rapid decompression. Depending on the rate of decompression, the time of useful consciousness without the mask may be as short as 10 seconds at 40,000 feet (12.2 km) (2).

a. Because fuel consumption is inversely related to cruise altitude, flight above 35,000 feet is being mandated more and more on computer flight plans. The problem for the crewmember is that the quick-don mask is extremely uncomfortable to wear, for even short periods of time. This makes a pilot reluctant to leave his seat for inflight crew rest and thus force the remaining pilot to wear the mask. Therefore both pilots remain in their seats, with one trying to sleep there. Most pilots have difficulty sleeping in the seat; but even if they do sleep there, it is violating at least the spirit of the oxygen-mask regulation. The result is that many crewmembers are receiving less and poorer quality inflight crew rest than if they were to use the crew bunks, or some crews may not adequately protect themselves from the rapid decompression hazard.

b. There is no easy solution to this problem at the present time. The requirements for saving fuel will continue, and this will cause flights above 35,000 feet to become more commonplace. Redesign of the oxygen mask to provide acceptable comfort would be costly and take a long time. This may be the only viable long-term solution. However, the FSAS system could possibly be integrated with the cabin altitude sensor and the aircraft spoiler system and be programmed to reduce airspeed automatically, with aircraft descent to a preprogrammed altitude and level-off, in the event of a rapid decompression. This would allow the pilot at the controls to immediately don the oxygen mask without worrying about aircraft control. The rapid decompression hazard is real and will not go away simply by waiving the regulation. At the same time, crews should not be denied inflight crew rest because of mask discomfort. MAC Headquarters should further investigate this situation to determine the extent of the problem. In any future aircraft design, such as the CX, this problem should be alleviated, and possibly the solution could be retrofitted to the C-141 and C-5.

9. As witnessed in other USAFSAM evaluations of operational tests, crewmembers were subjected to many unnecessary irritants that contributed to increased crew fatigue and morale problems (10). Crew rest started at the time the aircraft blocked in. However, delays in obtaining transportation, checking into the billeting office, and traveling to off-base quarters occurred frequently and substantially reduced the effectiveness of the crew-rest period. Crews were often required to double-up in their sleeping quarters, which generated both complaints and sleep disruption due to variations in sleeping habits. Appetizing meals were often unavailable to crews at times and locations to support their flight schedules; the quality of box lunches and flight snacks was poor. As new systems such as FSAS increase complexity and workload, proper crew rest and nutrition become increasingly important for maintenance of adequate aircrew performance.

Support problems can be minimized with a concerted effort by all levels of command. With reduced crew resources, increasing mission complexity, and the growing importance of tactical and strategic airlift, the Air Force must continually strive to enhance aircrew performance. Steps in this direction can be made by significantly improving the quality of the factors contributing to crew rest and recuperation.

CONCLUSIONS AND RECOMMENDATIONS

1. Many improvements could be made on the FSAS as it is implemented; but from a human-engineering point of view, I judged the initial system to be acceptable. No identified deficiencies were classified as critical or to have quantifiably impacted the safety of flight. However, it is difficult to estimate the negative effect of increased "head in the cockpit" time and distraction from the primary task of flying the airplane, accruing due to FSAS use. MAC should set up a process to continue monitoring aircrew interaction with FSAS to insure that no potential catastrophic failure modes are hidden in the system. If the FSAS is redesigned as part of development of a new aircraft, such as the CX, consideration should be given to correcting the identified deficiencies and retrofitting the improvements to the C-141.

2. The subjective fatigue and workload data collected during the missions did not indicate that these factors had significantly increased due to the FSAS. The only noticeable increases in workload occurred when many waypoints were loaded during preflight. Due to the pressure on the pilot to make block times, the present verification system did not provide a sufficient crosscheck to detect miskeying. Formal, standardized procedures must be developed to prevent navigational errors.

3. Use of the FSAS did not appear to significantly increase fatigue; but the types of operations required by FSAS (such as manual entry of long sequences of numbers and recall of multiple steps for waypoint change and

computer operation) appeared to be susceptible to the high fatigue levels occasionally encountered in MAC operations. No further increase in the complexity of operating this system is warranted without a systematic analysis of the total C-141 cockpit workload.

4. An improved training program along with detailed technical orders must be developed before the system is placed in routine operations. Standardized procedures and complete checklists must be developed for using the FSAS for operations such as waypoint verification, inflight computer updating, and decisions of when to fly in the coupled mode. These actions are necessary not only to achieve maximum fuel savings but also to improve flight safety. This training program should stress to all crewmembers that both pilots should not attend to the FSAS at the same time; one of them should always be in control of the aircraft.

5. Because of the growing importance of including FSAS data in the pilot's instrument crosscheck and to prevent excessive "head in the cockpit" time, having the FSAS data displayed on the forward instrument panel, in each pilot's primary field of view, is strongly recommended.

6. Recent USAFSAM observers have noted that MAC crews are exposed to unnecessary irritants that contribute significantly to crew stress and fatigue and decreased morale. A concentrated effort should be made at all levels of command to improve crew-rest facilities; availability of high quality, nutritious meals, box lunches, and flight snacks at all terminals servicing MAC crews; and movement of crews between aircraft and quarters. The addition of new equipment, such as FSAS, and increasing mission complexity demand that the Air Force strive to obtain maximum performance from its crewmembers.

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APPENDIX A

DATA COLLECTION FORMS

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 SEP 76 136 SUBJECTIVE FATIGUE CHECKCARD

Figure A-1. USAF School of Aerospace Medicine 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. Each crewmember filled out the fatigue checkcard during preflight, immediately after leveloff, just prior to top of descent, and immediately after landing. Occasionally, portions of the inflight data collection schedule were omitted when the mission legs were less than 2 hours; on long mission legs additional data points were obtained between leveloff and top of descent.

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. USAF School of Aerospace Medicine Crew Status Check, SAM Form 202. This checkcard was filled out every time the Form 136 was accomplished.

SLEEP SURVEY

NAME (Last, First, MI)	GRADE	DATE/TIME

1. On the chart below, mark an X in each half hour interval you slept yesterday and today.

YESTERDAY

MID-NIGHT 0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 MID-NIGHT

TODAY

MID-NIGHT 0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 MID-NIGHT

2. HOW MUCH TROUBLE DID YOU HAVE GOING TO SLEEP LAST NIGHT?

☐ NONE ☐ SLIGHT ☐ MODERATE ☐ CONSIDERABLE

3. HOW RESTED DO YOU FEEL?

☐ WELL RESTED
☐ MODERATELY RESTED ☐ SLIGHTLY RESTED ☐ NOT AT ALL

4. DO YOU FEEL LIKE YOU COULD HAVE USED SOME MORE SLEEP?

☐ YES ☐ NO

SAM FORM SEP 76 154 PREVIOUS EDITION WILL BE USED REMARKS ON REVERSE

Figure A-3. USAF School of Aerospace Medicine Sleep Survey, SAM Form 154. This form was filled out by each crewmember at the end of each crew-rest period throughout the mission.

APPENDIX B

SCHEDULED ITINERARIES AND MISSION LOGS

TABLE B-1. USAFSAM FSAS MISSION #1, 11-13 AUGUST 1980
(Augmented Test Mission AQA 483)

Scheduled Itinerary

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				11/1330Z[a]
Patrick AFB FL	1 + 10	11/1440	3 + 20	11/1800
Antigua (Caribbean)	3 + 15	11/2115	2 + 15	11/2330
Ascension Island	7 + 30	12/0700	20 + 00	13/0300
Antigua (Caribbean)	8 + 05	13/1105	2 + 15	13/1320
Patrick AFB FL	3 + 25	13/1645	2 + 15	13/1900
Charleston AFB SC	1 + 10	13/2010		

Mission Log

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				11/1325
Patrick AFB FL	1 + 10	11/1435	3 + 30	11/1805
Antigua (Caribbean)	3 + 20	11/2125	2 + 40	12/0005
Ascension Island	7 + 40	12/0745	18 + 45	13/0230
Antigua (Caribbean)	7 + 30	13/1000	2 + 00	13/1200
Patrick AFB FL	3 + 15	13/1515	1 + 20	13/1635
Charleston AFB SC	1 + 10	13/1745		

[a]All times Greenwich mean time

TABLE B-2. USAFSAM FSAS MISSION #2, 14-16 AUGUST 1980
(Unaugmented Test Mission AJA 471A)

Scheduled Itinerary

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				14/1230Z[a]
Norfolk NAS VA	1 + 10	14/1340	3 + 20	14/1700
Guantanamo Bay, Cuba	3 + 15	14/2015	17 + 15	15/1330
Kingston, Jamaica	0 + 50	15/1420	1 + 30	15/1550
Guantanamo Bay, Cuba	0 + 45	15/1635	2 + 15	15/1850
Norfolk NAS VA	3 + 10	15/2200	2 + 15	16/0015
Charleston AFB SC	1 + 10	16/0125		

Mission Log

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				14/1210
Norfolk NAS VA	1 + 05	14/1315	3 + 25	14/1640
Guantanamo Bay, Cuba	3 + 20	14/2000	17 + 40	15/1340
Kingston, Jamaica	0 + 50	15/1430	1 + 20	15/1550
Guantanamo Bay, Cuba	0 + 50	15/1640	1 + 45	15/1825
Norfolk NAS VA	3 + 30	15/2155	16 + 15[b]	16/1410
Charleston AFB SC	0 + 55	16/1505		

[a]All times GMT
[b]Severe thunderstorms forced crew to remain overnight.

TABLE B-3. USAFSAM FSAS MISSION #3, 20-24 OCTOBER 1980
(Augmented Control Mission AQA 487)

Scheduled Itinerary

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				20/1330Z[a]
Patrick AFB FL	1 + 10	20/1440	3 + 20	20/1800
Antigua (Caribbean)	3 + 15	20/2115	2 + 15	20/2330
Ascension Island	7 + 30	21/0700	20 + 45	22/0345
Johannesburg, S. Africa	6 + 15	22/1000	24 + 25	23/1025
Ascension Island	7 + 00	23/1725	17 + 15	24/1040
Antigua (Caribbean)	8 + 05	24/1845	2 + 15	24/2100
Patrick AFB FL	3 + 30	25/0030	2 + 15	25/0245
Charleston AFB SC	1 + 10	25/0355		

Mission Log

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				20/1315
Patrick AFB FL	1 + 00	20/1415	3 + 55	20/1810
Antigua (Caribbean)	3 + 10	20/2120	1 + 55	20/2315
Ascension Island	7 + 45	21/0700	20 + 00	22/0300
Johannesburg, S. Africa	6 + 00	22/0900	25 + 15	23/1015
Ascension Island	7 + 40	23/1755	15 + 55	24/0950
Antigua (Caribbean)	-	Bypassed[b]	-	-
Patrick AFB FL	-	Bypassed[b]	-	-
Charleston AFB SC	11 + 35	24/2125		

[a]All times GMT
[b]No cargo requirement at either station.

TABLE B-4. USAFSAM FSAS MISSION #4, 9-13 NOVEMBER 1980
(Augmented Test Mission AJA 4J1)

Scheduled Itinerary

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				9/1700Z[a]
Dover AFB DE	1 + 45	9/1845	3 + 15	9/2200
Ramstein AFB GE	7 + 50	10/0550	17 + 35	10/2325
Amman, Jordan	7 + 05	11/0630	3 + 00	11/0930
Ramstein AFB GE	7 + 45	11/1715	18 + 15	12/1130
McGuire AFB NJ	9 + 20	12/2050	2 + 15	12/2305
Charleston AFB SC	1 + 45	13/0050		

Mission Log

Station	Airborne (h+min)	Arrive	Ground (h+min)	Depart
Charleston AFB SC				9/1705
Dover AFB DE	1 + 05	9/1810	3 + 30	9/2140
Ramstein AFB GE	8 + 15	10/0555	17 + 35	10/2330
Amman, Jordan	6 + 40	11/0610	2 + 05	11/0815
Ramstein AFB GE	7 + 40	11/1555	20 + 30	12/1225
McGuire AFB NJ	8 + 50	12/2115	2 + 15	12/2330
Charleston AFB SC	1 + 25	13/0055		

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[a]All times GMT

APPENDIX C

MEAN SUBJECTIVE FATIGUE AND WORKLOAD RESPONSES

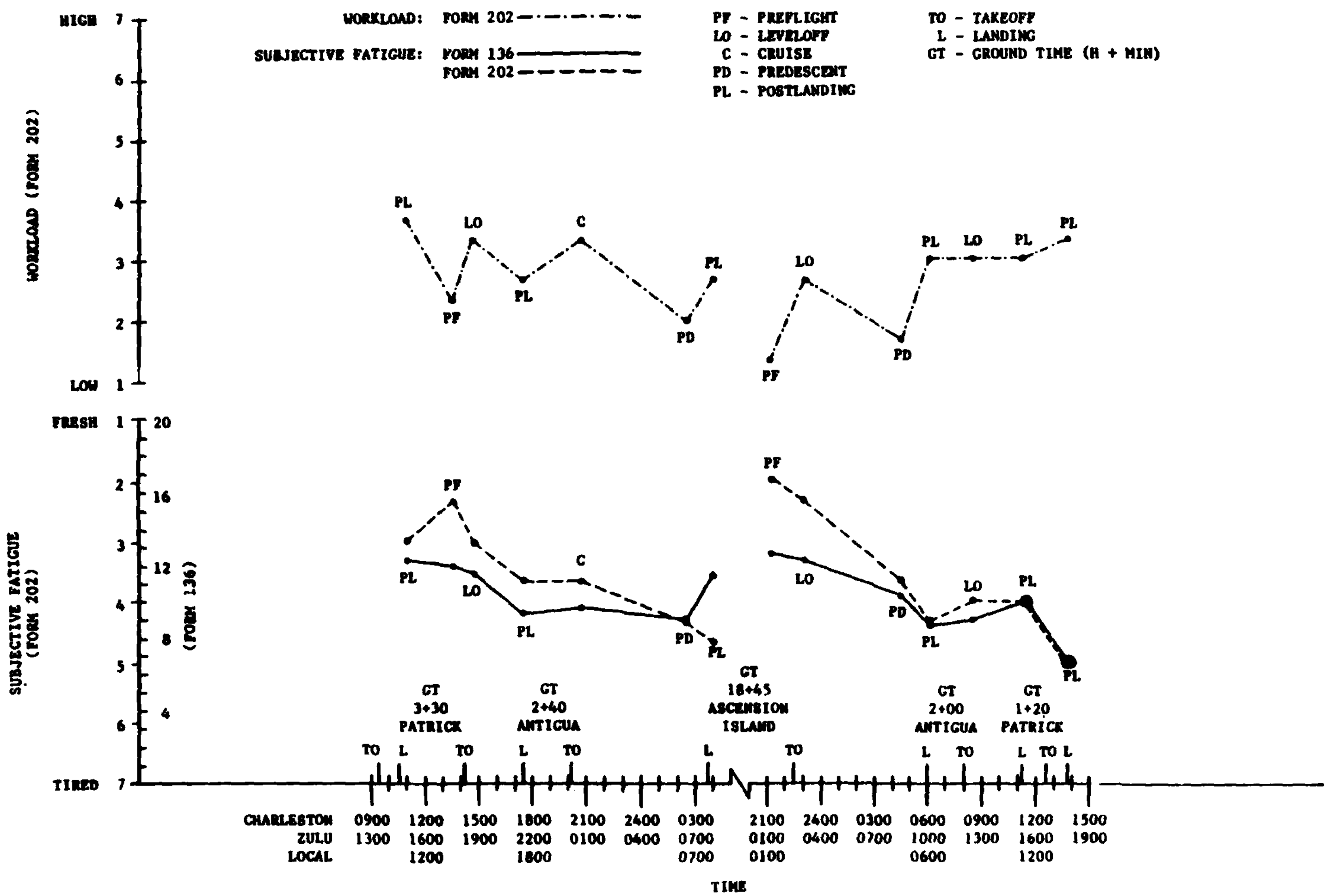

Figure C-1. Mean subjective fatigue and workload responses of the three pilots on Mission 1.

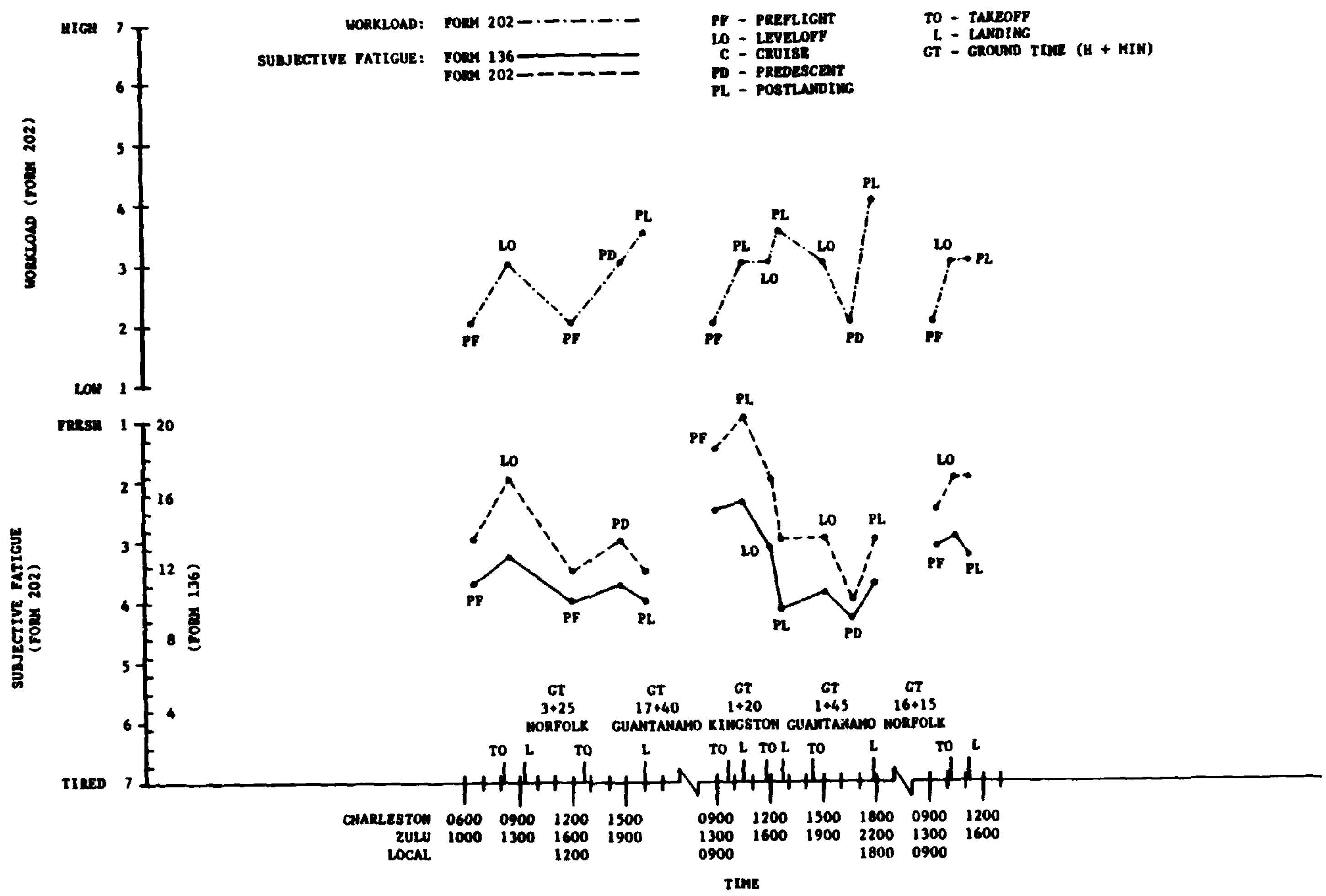

Figure C-2. Mean subjective fatigue and workload responses of the two pilots on Mission 2.

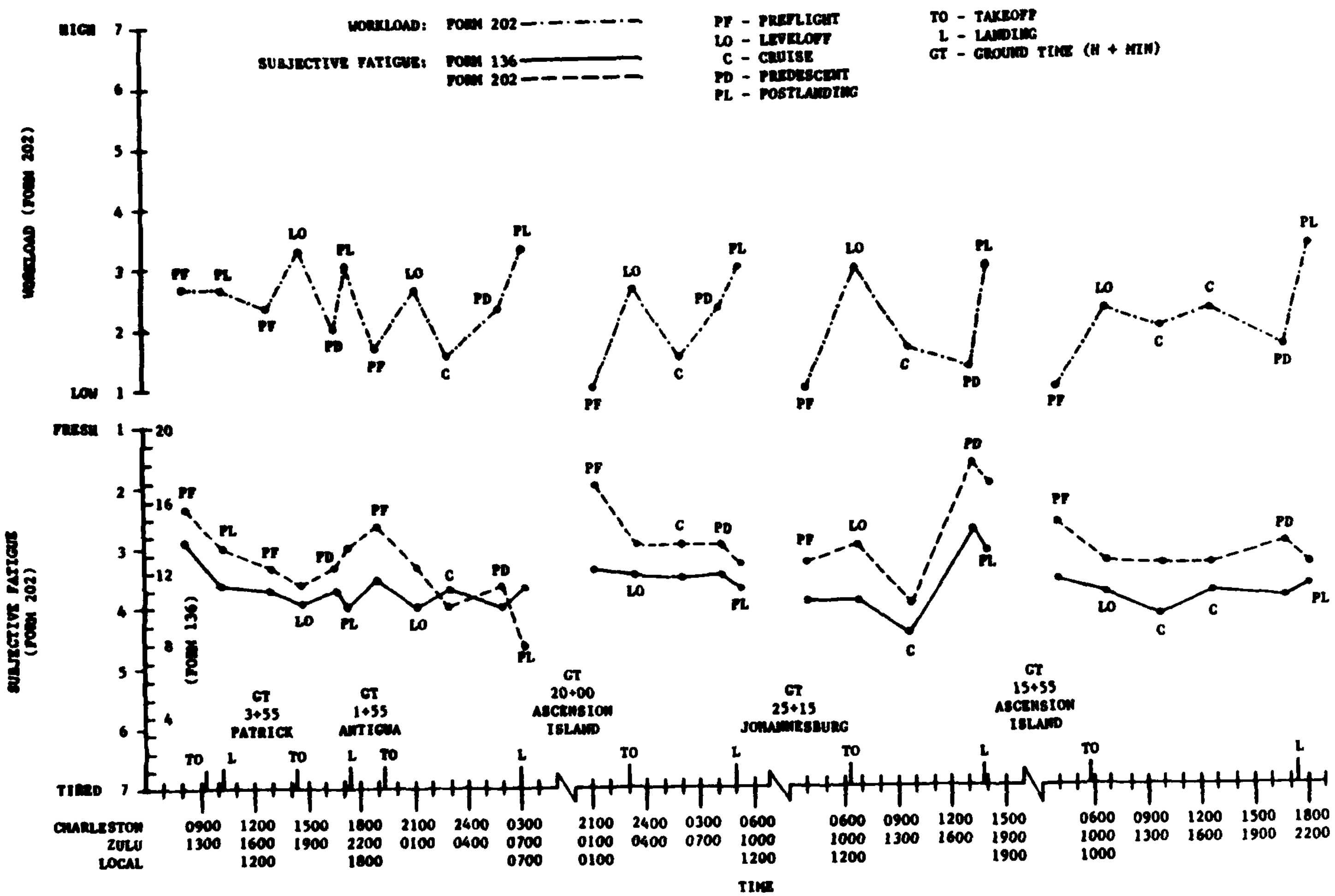

Figure C-3. Mean subjective fatigue and workload responses of the three pilots on Mission 3.

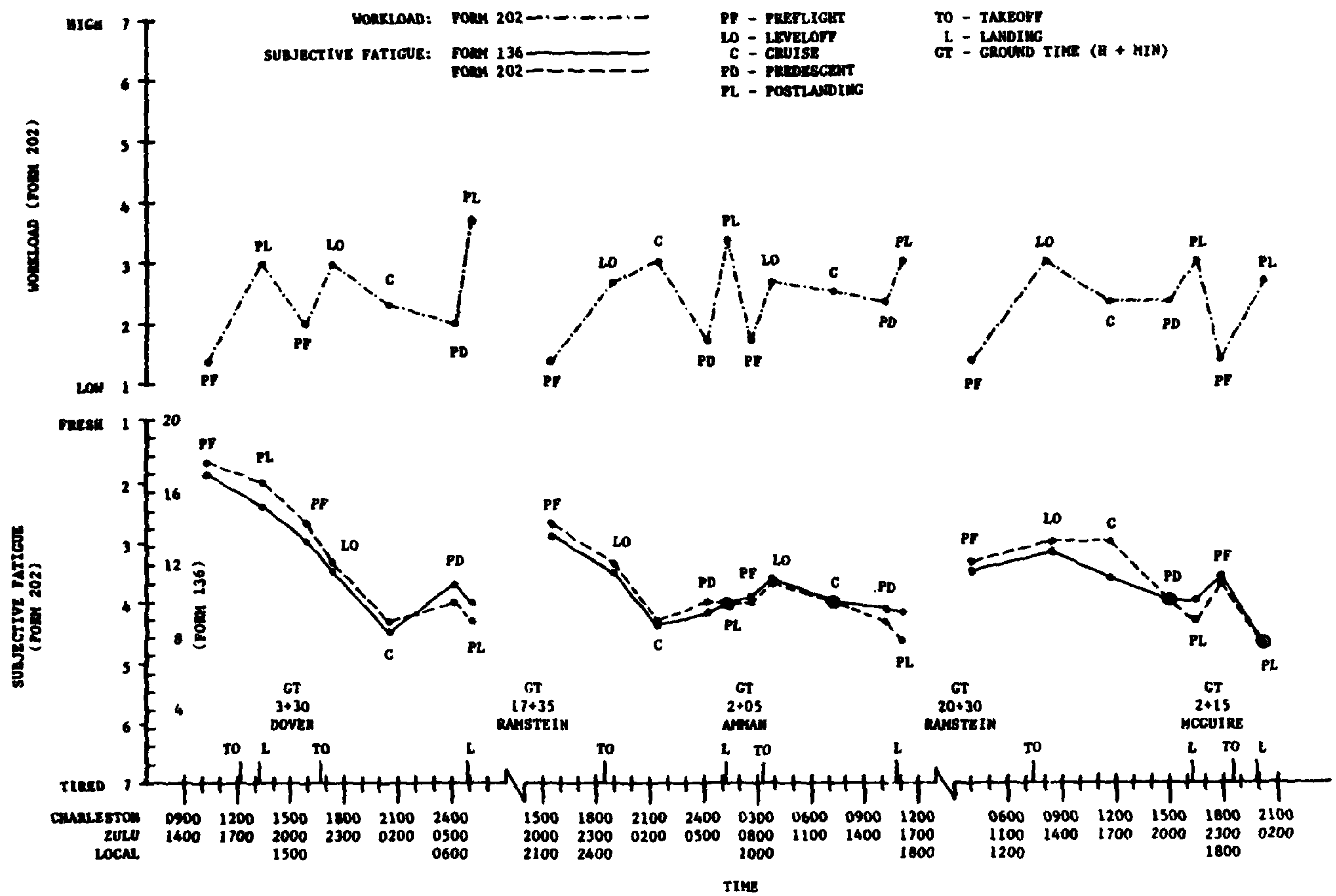

Figure C-4. Mean subjective fatigue and workload responses of the three pilots on Mission 4.

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