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A Resurvey of Shift Work-Related Fatigue in MQ-1 Predator Unmanned Aircraft System Crewmembers

by

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13. ABSTRACT (maximum 200 words)

A previous study showed shift working crewmembers in a MQ-1 Predator unmanned aircraft system (UAS) squadron had significantly increased fatigue, emotional exhaustion, and burnout relative to traditional aircrew from another "high-demand, low density" weapon system. This study presents the results of a follow-up survey of this population of UAS crewmembers who were supporting "reachback" teleoperations using a modified rotational shift work schedule. Specifically, shift work-related increases in fatigue, sleepiness, and risk for performance decrements were examined. Shift system features and individual and situational differences associated with fatigue were also explored. Finally, shift system features of several types of schedules were assessed through modeling and simulation. The study found no significant reduction in reported fatigue despite prior modifications to the shift work schedule. It also demonstrated the potential for inadequate staffing levels to magnify the adverse effects of shift work.

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EXECUTIVE SUMMARY

Purpose: Quantitatively reassess fatigue levels in MQ-1 Predator unmanned aircraft system (UAS) crewmembers supporting reachback teleoperations using rotational shift work.

Background: A previous study showed that shift-working crewmembers in a Predator UAS squadron had significantly increased fatigue, emotional exhaustion, and burnout relative to traditional aircrew from another "high-demand, low-density" weapon system. The squadron work schedule was redesigned, but preferred shift work practices were not fully implemented because of manpower constraints and crewmember preferences.

Key Study Areas:

1. Effect of the changes in the squadron's shift work schedule on cumulative fatigue.
2. Correlations between fatigue and demographic factors.

Methodology: A cross-sectional survey of 66 Predator pilots and sensor operators was conducted in December 2006 to assess shift work-related increases in fatigue, sleepiness, and risk for performance decrements. Additionally, shift system features of several types of schedules were assessed through modeling and simulation (M&S).

Overall Assessment: Based on the data collected, the investigators noted the following:

- Survey results were essentially unchanged compared to one year ago and indicated a pervasive problem with chronic fatigue.
- Nearly 50% of surveyed crewmembers met the diagnostic threshold for levels of daily sleepiness which can be expected to adversely impact job performance and safety.
- Duration of being a shift worker, decreasing sleep quality, and impaired domestic relationships were all associated with increased fatigue.
- M&S did not identify an alternative shift schedule which would result in improved work effectiveness over that predicted for the current schedule.
- The root problem for this population was not the shift system features themselves, but rather a lack of adequate manpower to provide sufficient recovery opportunities.

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I. INTRODUCTION

The advent of unmanned aircraft systems (UAS) has created a host of new human factors challenges arising primarily because the aircraft and the operator are no longer necessarily colocated (Gawron, 1998; McCarley & Wickens, 2004). The most recent Department of Defense UAS roadmap touted this separation of aircraft and operator as a significant advantage of UAS, concluding that “crew duty periods are now irrelevant to aircraft endurance since crew changes can be made on cycles based on optimum periods of sustained human performance and attention” (Office of the Secretary of Defense, 2005, p. 73). However, Walters, Huber, French, and Barnes (2002) noted operational requirements for UAS crewmembers “may include extended duty days, reduced crew size, and varying shift schedules,” which “are likely to reduce operator effectiveness because of fatigue” (p. 13). In fact, the introduction of long-endurance UAS, such as the MQ-1 Predator and MQ-9 Reaper, has necessitated the routine implementation of shift work for United States Air Force (USAF) UAS crewmembers in order to provide the necessary around-the-clock staffing of ground control stations (GCS). As noted by Jansen, van Amelsvoort, Kristensen, van den Brandt, and Kant (2003) in a large 32-month prospective study of fatigue and work schedules, substantially higher fatigue levels (24-29%) are observed in shift workers compared to day workers (18%) or irregular shift workers (19%). Shift worker fatigue has been described as a function of shift timing, length, frequency, and regularity as well as intrashift and intershift recovery opportunities (Jansen et al., 2003; Rosa, 2001; Smith, Macdonald, Folkard, & Tucker, 1998). Due to the chronic and periodic nature of UAS operations, it is likely they are more fatigue-prone than long-haul flight operations.

Beyond the issue of fatigue, serious public health concerns have been raised regarding the association between the documented effects of shift work and the resulting degraded work performance with an increased risk for errors and accidents (Folkard & Tucker, 2003; Mitler, Dinges, & Dement, 1994; Office of Technology Assessment, 1991). Barton et al. (1995) proposed a model explaining this association (Figure 1) in which shift workers experience a wide range of problems from acute disturbances of circadian rhythms and sleep to diminished family and social lives. These disturbances result in acute decrements in mood and performance, which, in turn, may exacerbate the antecedent disturbances as well as directly influencing physical health and safety. Greater disruptions may be produced by certain types of shift systems, features of systems, or work context issues, and thus may have a greater detrimental effect. On the other hand, certain individual and situational factors can moderate shift-work effects. Individual coping strategies may mitigate or exacerbate shift-work impact on long-term mental health, physical health, and safety.

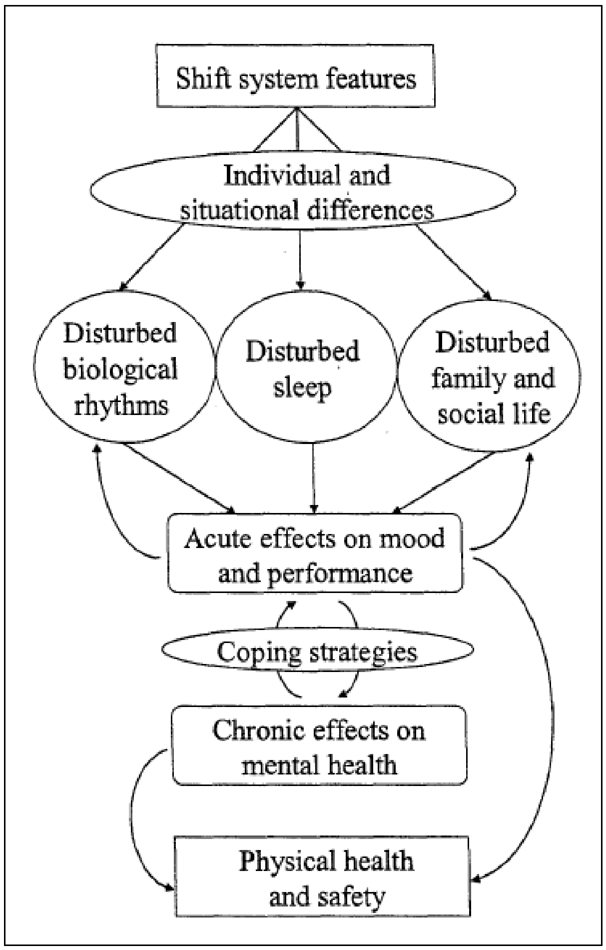


Figure 1. Theoretical model of the effects of work schedules on health and safety (Barton et al., 1995).

Despite these myriad of concerns, only limited research has been conducted on the impact of shift work on UAS operator error or operational efficiency. A modeling and simulation study (Walters et al., 2002) analyzing the effects of fatigue, crew size, and rotation schedule on Army UAS crewmembers' workload and performance predicted that almost three times as many mishaps could occur when the crew was fatigued as compared to rested. Although the results of this simulation were not validated with empirical data, a small study (Barnes & Matz, 1998) of Army UAS crewmembers found target detection and recognition performance, as well as crewmember reaction times, were significantly degraded during nocturnal operations. Similarly, an observational field study (Tvaryanas et al., 2006) of USAF UAS crewmembers involved in rotational shift work noted decrements in mood, cognitive and piloting performance, and alertness associated with the acute fatigue of a single shift. An ongoing study is examining the potential health and safety implications of these findings (G. MacPherson, personal communication, November 30, 2007).

Balancing operational requirements and the documented negative effects of shift work is a significant challenge for supervisors and leaders working in unmanned aviation, especially given the fact there is no single optimum shift work schedule (Miller, 2006). In addition, there is a general absence of good shift work scheduling practices in the USAF (Air Force Inspection Agency, 2004; Miller, Fisher, & Cardenas, 2005). The latter issue was observed in a recent study (Tvaryanas & Thompson, 2006) of crewmembers in a MQ-1 Predator UAS squadron that found significantly increased fatigue, emotional exhaustion, and burnout relative to traditional aircrew from another "high-demand, low-density" weapon system. At the time of the study, squadron pilots were using a 5W:1F:5W:3F*, 3-shift, weekly, clockwise rotating schedule and sensor operators were using a 3-month rotating schedule. Numerous subjective and objective assessment measures were collected that identified a tendency for the adverse effects of shift work to be more pronounced on day and night shifts relative to the evening shift and for those on the rapid versus slow shift rotation schedule (Tvaryanas et al., 2006). The squadron work schedule was redesigned, but preferred shift work practices were not fully implemented because of manpower constraints and crewmember preferences. In the end, the squadron elected for a 6W:3F, 3-shift, monthly, clockwise rotating schedule. The risks and benefits of this shift work schedule were discussed and it was decided to resurvey the

*In describing shift work schedules, the shift plan is defined as a ratio of days worked to days free (i.e., off)—nW:nF.

squadron after a period of one year. The purpose of the present study was to quantitatively reassess fatigue levels in these MQ-1 Predator UAS crewmembers supporting reachback teleoperations using rotational shift work. Key study areas of interest included the effect of the changes in the squadron's shift work schedule on cumulative fatigue and correlations between fatigue and demographic factors.

II. METHODS

A. STUDY DESIGN AND POPULATION

The study protocol was approved by the Brooks City-Base Institutional Review Board in accordance with 32 Code of Federal Regulations (CFR) 219 and Air Force Instruction (AFI) 40-402. The target population for this cross-sectional survey of fatigue was all MQ-1 Predator UAS personnel assigned to the Nellis Air Force Base site and supporting Operations ENDURING FREEDOM (Afghanistan) and IRAQI FREEDOM (Iraq) in December 2006. Inclusion criteria were permanently assigned, full-time personnel involved in shift work for at least one month. Squadron-wide solicitation of volunteers was conducted through site electronic communications. In early December 2006, the squadron leadership sent an informational e-mail message to squadron members explaining the general nature of the study, the voluntary nature of participation, and identifying the Universal Resource Locator to access the Web page for the electronic study questionnaire. Each squadron member who wished to participate completed the study questionnaire at their convenience. The opening Web page preceding the actual questionnaire informed study participants that the purpose of the study was a follow-up to a prior fatigue survey and reiterated that participation was voluntary and anonymous. The questionnaire consisted of 51 items and required 10-15 minutes to complete. The Web site was maintained for a 30-day period, although all squadron members who completed the survey did so within the initial ten days. The data from this questionnaire was subsequently combined with prior survey data collected on Predator UAS and E-3B Sentry Airborne Warning and Control System (AWACS) crewmembers in 2005 (Tvaryanas & Thompson, 2006). For purposes of this paper, only data associated with participants who were pilots and sensor operators was utilized in order to avoid confounding by flight status and applicable hours of service rules when making comparisons between the present and prior studies.

B. FATIGUE EVALUATIONS

The study questionnaire, which is available in Appendix A, collected data on age, gender, rank, career field, months involved in shift work, shift currently working, average daily hours of sleep, and an ordinal rating of quality of sleep. Rank was divided into five categories: junior enlisted, noncommissioned officer, senior noncommissioned officer, company grade officer, and field grade officer. Career field was divided into four categories: pilot, sensor operator, intelligence, and other. Current shift was divided into three categories: day shift (morning starts), mid shift (afternoon starts), and night shift (evening starts). Sleep quality was divided into three categories: excellent, moderate, and poor. The questionnaire also asked whether the current shift schedule caused inadequate time with spouse/partner, children, friends and relatives, or for recreational activities.

Since some view fatigue as a multidimensional construct (Gawron, French, & Funk, 2001; Smets, Garssen, Bonke, & Haes, 1995), this study used a composite fatigue survey (CFS) arranged on a Likert-type scale and composed of items from five validated fatigue questionnaires. They were the fatigue scale (FS), checklist individual strength concentration subscale (CISCON), fatigue assessment scale (FAS), World Health Organization quality of life assessment energy and fatigue subscale (EF-WHOQOL), and Maslach burnout inventory emotional exhaustion subscale (MBI-EE). The 11-item FS distinguishes mental fatigue (four items) and physical fatigue (seven items) in addition to yielding a total fatigue score. This scale is purported to be intended for detection of fatigue cases in epidemiological studies (Chalder et al., 1993). The CIS-CON consists of five items and provides a score for the reduced concentration component of fatigue. The CIS-CON has been shown to discriminate between groups with expected differences in fatigue (Beurskens et al., 2000). The 10-item FAS is a unidimensional fatigue scale developed to assess chronic fatigue (Michielsen, De Vries, & Heck, 2003). The 4-item EFWHOQOL and 5-item MBI-EE measure the emotional exhaustion component of burnout—the end stage of fatigue experienced over a relatively long period of time (Barnett, Brennan, & Gareis, 1999; World Health Organization [WHO], n.d.). In this study, the CFS was augmented with the Epworth Sleepiness Scale (ESS); an 8-item scale commonly used to diagnose sleep disorders and considered a valid and reliable self-report of sleepiness (Johns, 1991). Based on concerns identified in a prior study (Tvaryanas et al., 2006), an additional, nonvalidated question eliciting the likelihood of falling asleep during a period of high boredom in the GCS was added among the ESS items, but was scored separately. Finally, two questions assessed the use of naps during or at the end of duty periods and one question evaluated the tendency to maintain workweek wake and sleep times on days off (i.e., circadian adaptation).

C. FATIGUE MODELING

In addition to the fatigue questionnaire, shift work schedules were analyzed using the Fatigue Avoidance Scheduling Tool (FAST) version 1.0.09 (NTI, Inc., Fairborn, OH). FAST allows easy data entry of work and sleep schedules and generates graphical predictions of performance along with tables of estimated effectiveness scores based on the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE™) model (Hursh et al., 2004). The SAFTE™ model projects the combined effects of time of day and sleep history as contributing factors on performance at a specified time. Model predictions have been validated against laboratory data. FAST operates on a standard Windows™-based desktop computer.

D. STATISTICAL ANALYSIS

1. Survey Data

Data were analyzed using Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL) version 11.5. Kolmogorov-Smirnov and Shapiro-Wilk tests were used to assess normalcy. A multivariate analysis of variance (MANOVA) was used to test whether the mean scores of groups differed across the five fatigue questionnaires simultaneously. Box's M and Levene's tests were used to assure the multivariate assumptions of equality of covariance matrices and equality of error variances across groups were not violated. The model was unbalanced and type III sum of squares was utilized. Univariate ANOVAs with Tukey posthoc tests were used to test for between group differences on each scale in the CFS. Binary logistic regression analyses were used to calculate odds ratios and 95% confidence intervals (CIs) for the association between variables assessed in the study questionnaire and the outcome of occupationally significant fatigue, defined as an ESS score greater than ten. Spearman's rank correlation was used to explore associations between variables and CFS scores. Linear regression analyses were then used to quantitatively assess the association of variables and CFS scores. Categorical variables such as gender, rank, and crew position were dummy coded and included, along with continuous variables such as age and months of shift work, in the regression analyses. Residual plots were evaluated to assess the fit of the regression models, determine the influence of outliers, and assure regression assumptions were not violated. Condition indices were used to evaluate collinearity between independent variables (Field, 2003; Statistical Package for the Social Sciences [SPSS], n.d.).

2. Fatigue Modeling

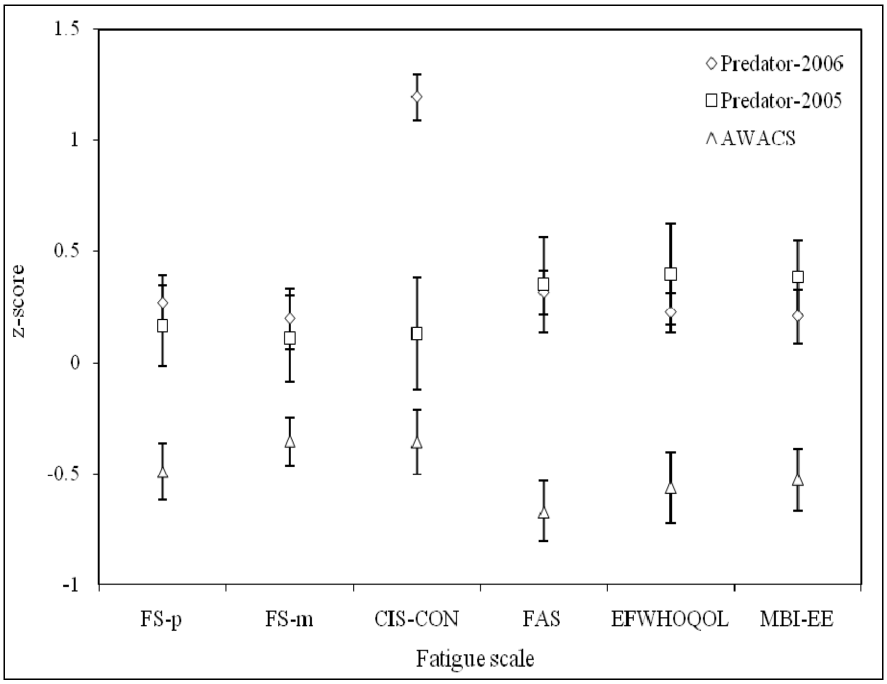
Data on daily predicted work effectiveness was obtained from FAST simulations of four shift work schedules run over 180-day periods: 6W:3F, 3-shift, slow, (i.e., monthly) clockwise rotating schedule; 6W:3F, 3-shift, rapid, (i.e., DDMMNN)† clockwise rotating schedule; 6W:3F, 3-shift, fixed schedule with crewmembers maintaining work/sleep times on days off (i.e., fixed shift – compliant); and 6W:3F, 3-shift, fixed schedules with crewmembers returning to typical day shift sleep times on days off (i.e., fixed shift – noncompliant). Estimates for daily wake/sleep times and sleep quality were obtained from self-reported and actigraphy data gathered in a prior study of this population (Tvaryanas et al., 2006). Data was extracted from the FAST summary tables and analyzed using SPSS. Univariate ANOVAs with Tukey posthoc tests were used to test for between group differences on each shift work schedule.

†D = day shift; M = mid shift; and N = night shift.

III. RESULTS

A. SURVEY DATA

A total of 114 individuals completed the Web-based questionnaire and were included in the master dataset. Data from 66 study participants who met the inclusion criteria were inserted into the study dataset. The data associated with these 66 study participants are summarized in Tables 1 and 2. The mean scores on the five fatigue scales in the CFS from the present study (Predator-2006 group) were compared to results from a prior survey (Tvaryanas & Thompson, 2006) of MQ-1 Predator UAS crewmembers in 2005 (Predator-2005 group) and an external historical control ground (E-3B Sentry crewmembers). The latter was selected to reduce potential issues of confounding by crew composition (e.g., high prevalence of enlisted crewmembers), mission length and profile, and operations tempo. Fatigue scores were normally distributed for the FS, CIS-CON, and MBI-EE scales. There were minor departures from normality for scores on the FAS and EF-WHOQOL. Although MANOVA is robust in the face of most violations of normality if sample size is not small (i.e., less than 20), the authors decided *a priori* to use a nonparametric test (i.e., Kruskal-Wallis test) to screen for differences in group locations with statistically significant differences being further subject to analysis with parametric tests. In this case, significant differences were observed between groups for all five fatigue scales: FAS $\chi^2_{2df} = 28.833$, $p < 0.001$; FS-physical $\chi^2_{2df} = 16.435$, $p < 0.001$; FS-mental $\chi^2_{2df} = 7.543$, $p = 0.023$; CIS-CON$\chi^2_{2df} = 8.740$, $p = 0.013$; EF-WHOQOL$\chi^2_{2df} = 17.695$, $p < 0.001$; and $\chi^2_{2df} = 18.487$, $p < 0.001$. Based on the results of the subsequent MANOVA, mean scores were shown to differ across the five fatigue questionnaires based on group (Wilk's $\lambda = 0.736$, $p < 0.001$). In particular, univariate effects based on group were found for all five fatigue scales: FAS $F_{2,132} = 18.551$, $p < 0.001$; FS-physical $F_{2,132} = 8.994$, $p < 0.001$; FS-mental $F_{2,132} = 4.384$, $p = 0.014$; CIS-CON $F_{2,132} = 4.475$, $p = 0.013$; EF-WHOQOL $F_{2,132} = 12.424$, $p < 0.001$; and MBI-EE $F_{2,132} = 10.720$, $p < 0.001$. Both Predator groups had higher mean scores as compared to the control group on the FAS ($p < 0.001$), FS-physical ($p \leq 0.016$), EF-WHOQOL ($p < 0.001$), and MBI-EE ($p < 0.001$) scales; no difference was observed between Predator groups. Mean scores on the FS-mental and CIS-CON scales were higher for the Predator-2006 group compared to the control group; there were no differences between the Predator groups or between the Predator-2005 and control groups. Figure 2 summarizes the results from the five fatigue questionnaires by group. To aid graphical analysis, raw fatigue scores were normalized for each questionnaire to control for the effects of differences in the number of constituent items in each questionnaire on mean scores.



AWACS – airborne warning and control system; CIS-CON – checklist individual strength concentration subscale; EFWHOQOL – World Health Organization quality of life assessment energy and fatigue subscale; FAS – fatigue assessment scale; FS-p – fatigue scale, physical fatigue subscale; FS-m – fatigue scale, mental fatigue subscale; MBI-EE – Maslach burnout inventory emotional exhaustion subscale.

Error bars are standard error of the mean.

Figure 2. Mean fatigue scores by group.

Table 1. Summary of participant demographics and questionnaire responses.

Variable	Summary Measure
Age, mean (SD)	34.85 (8.69)
Gender, no. (%)	
Male	61 (92.4)
Female	5 (7.6)
Rank, no (%)	
E-1 to E-4	11 (16.7)
E-5 to E-6	8 (12.1)
E-7+	7 (10.6)
O-1 to O-3	13 (19.70)
O-4 to O-6	27 (40.9)
Crew position, no. (%)	
Pilot	37 (56.1)
Sensor operator	29 (43.9)
Months involved in shift work, mean (SD)	12.32 (9.03)
Current shift, no. (%)	
Day (morning starts)	23 (34.8)
Mid (afternoon starts)	23 (34.8)
Night (evening starts)	20 (30.3)
Average daily sleep, mean (SD)	6.40 (1.14)
Sleep quality, no. (%)	
Poor	16 (24.2)
Moderate	42 (63.6)
Excellent	8 (12.1)
CFS scales, mean (SD)	
CIS-CON	18.02 (4.56)
EFWHOQOL	11.91 (2.05)
FAS	27.89 (4.97)
FS-p	22.65 (6.35)
FS-m	10.86 (3.91)
MBI-EE	21.03 (6.99)
Epworth Sleepiness Scale, mean (SD)	10.67 (5.48)

CFS – composite fatigue survey; CIS-CON – checklist individual strength concentration subscale; EFWHOQOL – World Health Organization quality of life assessment energy and fatigue subscale; FAS – fatigue assessment scale; FS-p – fatigue scale, physical fatigue subscale; FS-m – fatigue scale, mental fatigue subscale; MBI-EE – Maslach burnout inventory emotional exhaustion subscale; SD – standard deviation.

Table 2. Summary of participant demographics and questionnaire responses (cont.).

Variable	Summary Measure
Inadequate time for spouse, no. yes (%)	43 (65.2)
Inadequate time for children, no. yes (%)	23 (34.8)
Inadequate time for friends, no. yes (%)	35 (53.0)
Inadequate time for recreation, no. yes (%)	43 (65.2)
Likelihood of falling asleep in GCS, no. (%)	
Never	17 (25.8)
Seldom	22 (33.3)
Moderate	15 (22.7)
High	12 (18.2)
Use napping during duty, no. (%)	
Never	27 (40.9)
Rarely	19 (28.8)
Sometimes	16 (24.2)
Often	4 (6.1)
Use napping prior to driving home, no. (%)	
Never	37 (56.1)
Rarely	15 (22.7)
Sometimes	12 (18.2)
Often	2 (3.0)
Maintain work wake/sleep cycle on days off, no. (%)	
Never	16 (24.2)
Rarely	10 (15.2)
Sometimes	23 (34.8)
Often	17 (25.8)

GCS – ground control station.

Since an ESS rating above 10 out of a possible score of 24 is a concern with respect to acceptable job performance (Miller, 2006), a study participant with an ESS rating greater than 10 was defined as a "fatigue case." A threshold of greater than 10 appeared valid in this study given the odds ratio for being classified as a fatigue case was 5.102 (95% CI 1.731-15.041) for those reporting a moderate or high chance of falling asleep in the GCS, as compared to those reporting a slight or less chance. Unifactorial logistic regression models were used to identify independent variables significantly associated with being classified as a fatigue case (results summarized in Table 3). Significant variables were collected and regressed in a multifactorial logistic model (results summarized in Table 4). Since scores on all five fatigue scales in the CFS were significantly associated with being classified a fatigue case in the unifactorial logistic models, the fatigue scale scores were subject to an exploratory factor analysis with varimax rotation. The factor analysis yielded a single factor with loadings ranging from 0.775 (CIS-CON) to 0.919 (FS-physical). A reliability analysis of the five fatigue scales showed good reliability with a standardized Cronbach's α of 0.908. Given these results, a weighted CFS score was computed using the factor loadings. Results of the factor analysis are summarized in Table 5.

Table 3. Results for unifactorial logistic regression models.

Variable	Odds Ratio	95% CI
Age	0.952	0.898-1.010
Gender	4.133	0.436-39.138
Rank	0.828	0.599-1.146
Crew position	1.015	0.384-2.685
Months involved in shift work	1.079	1.014-1.149*
Current shift	0.873	0.479-1.591
Average daily sleep	0.834	0.537-1.298
Sleep quality	0.406	0.165-0.996*
CFS scales		
CIS-CON	1.266	1.104-1.452‡
EFWHOQOL	1.400	1.070-1.832*
FAS	1.197	1.061-1.351†
FS-p	1.259	1.117-1.419‡
FS-m	1.369	1.153-1.625‡
MBI-EE	1.263	1.122-1.423‡
Weighted CFS score	1.079	1.039-1.120‡
Use napping during duty	2.014	1.139-3.563*
Use napping prior to driving home	1.485	0.834-2.644
Maintain work wake/sleep cycle on days off	0.994	0.644-1.535

*$p \leq 0.050$
†$p \leq 0.010$
‡$p \leq 0.001$

CFS – composite fatigue survey; CIS-CON – checklist individual strength concentration subscale; EFWHOQOL – World Health Organization quality of life assessment energy and fatigue subscale; FAS – fatigue assessment scale; FS-p – fatigue scale, physical fatigue subscale; FS-m – fatigue scale, mental fatigue subscale; MBI-EE – Maslach burnout inventory emotional exhaustion subscale.

Table 4. Results for multifactorial logistic regression model.

Variable	Odds Ratio	95% CI
Months involved in shift work	1.104	1.010-1.207*
Sleep quality	1.130	0.372-3.427
Use napping during duty	3.173	1.384-7.275†
Weighted CFS score	1.080	1.033-1.129‡

$R^2_{(adj)} = 0.558$, Model classification accuracy = 84.8%
*$p \leq 0.050$
†$p \leq 0.010$
‡$p \leq 0.001$

Table 5. Characteristics of the CFS scales.

Scale	Factor Loadings	Interscale Correlation (Range)
CIS-CON	0.775	0.479-0.680
EFWHOQOL	0.689	0.395-0.629
FAS	0.865	0.610-0.761
FS-p	0.919	0.560-0.869
FS-m	0.844	0.395-0.763
MBI-EE	0.867	0.455-0.869

CFS – composite fatigue survey; CIS-CON – checklist individual strength concentration subscale; EFWHOQOL – World Health Organization quality of life assessment energy and fatigue subscale; FAS – fatigue assessment scale; FS-p – fatigue scale, physical fatigue subscale; FS-m – fatigue scale, mental fatigue subscale; MBI-EE – Maslach burnout inventory emotional exhaustion subscale.

While the prior analysis identified the independent variables associated with occupationally significant fatigue (i.e., ESS rate > 10), a linear regression analysis was performed to identify those variables directly associated with fatigue scale scores in order to more thoroughly evaluate the data. Nonparametric correlations were used to identify independent variables significantly associated with the weighted CFS score (results summarized in Table 6). Significant variables were then collected and regressed in a multifactorial linear model (results summarized in Table 7). In a different analytic approach, full-factorial stepwise linear regression models were also explored for each of the CFS scales. With the exception of the FS-mental and MBI-EE scales, the CFS scale linear regression models were similar, if less complete, than the weighted CFS score model. The FS-mental regression model differed in that it included the independent variable crew position and explained more of the variability in the dataset than the weighted CFS score model (see Table 8). This was the only model to suggest the pilot position was associated with more mental fatigue than the sensor operation position. The MBI-EE regression model was unique, being the only model to include gender (see Table 9).

Table 6. Results of nonparametric correlations with weighted CFS score.

Spearman's rho	Weighted CFS Score
Age	N-0.093
Gender	0.215
Rank	N-0.100
Crew position	0.018
Months involved in shift work	0.377†
Current shift	N-0.030
Average daily sleep	N-0.255*
Sleep quality	N-0.475†
Use napping during duty	0.128
Use napping prior to driving home	0.040
Maintain work wake/sleep cycles on days off	N-0.166
Inadequate time for life activities	0.483†

*$p \leq 0.050$
†$p \leq 0.010$

Table 7. Results for the weighted CFS score multifactorial linear regression model.

Variable	Beta	Standard Error
Months involved in shift work	0.508	0.254*
Average daily sleep	N-1.352	2.045
Sleep quality	N-9.592	3.964*
Inadequate time for life activities	23.836	6.044‡

$R^2_{(adj)} = 0.400$; $F_{4,59} = 11.461$, $p < 0.001$
*$p \leq 0.050$
‡$p \leq 0.001$

Table 8. Results for the FS-mental fatigue scale linear regression model.

Variable	Beta	Standard Error
Months involved in shift work	0.169	0.049‡
Sleep quality	N-2.738	0.711‡
Crew position	N-1.738	0.839*

$R^2_{(adj)} = 0.338$; $F_{3,60} = 11.706$, $p < 0.001$
*$p \leq 0.050$
‡$p \leq 0.001$

Table 9. Results for the MBI-EE scale linear regression model.

Variable	Beta	Standard Error
Inadequate time for life activities	9.793	2.022‡
Gender	7.739	2.735‡

$R^2_{(adj)} = 0.312$; $F_{2,61} = 15.272$, $p < 0.001$
‡$p \leq 0.001$

B. FATIGUE MODELING

Examples of the graphical output from the four FAST simulations are provided in Figures 3 through 6. There were departures from normality for the data on predicted work effectiveness obtained from the FAST simulations. Again, a nonparametric test (i.e., Kruskal-Wallis test) was used to screen for differences in group locations with statistically significant differences being further subject to analysis with parametric tests. In this case, significant differences were observed between the schedules (χ^2_{3df} = 168.430, $p < 0.001$). Based on the results of the subsequent ANOVA, mean predicted work effectiveness was shown to differ across the four simulated schedules ($F_{3,428}$ = 48.110, $p < 0.001$) (Figure 7). There was no difference in predicted work effectiveness between the slow and fixed, compliant schedules or the rapid and fixed, noncompliant schedules. However, predicted work effectiveness for both slow and fixed, compliant schedules differed ($p < 0.001$) from that predicted for both rapid and fixed, noncompliant schedules. In other words, the slow and fixed, compliant schedules were equivalent and superior, in terms of predicted work effectiveness, to the rapid and fixed, noncompliant schedules.

A problem with all the schedules analyzed was the number of consecutive night shifts. As a general principle, the number of consecutive night shifts should be minimized, and preferably there should only be a single night shift in a shift plan. In addition, each night shift should be followed by 24 hours off for recovery from the acute fatigue (Miller, 2006). We examined alternatives to the 6W:3F shift structure, but were unable to shorten the ratio of work days to days off because of significant manpower constraints. The squadron manning ratio at the time of the survey was 0.64 and the crew to GCS ratio was 6.8, compared to the Air Combat Command requirement of 12 crews per orbit (i.e., GCS). Thus, there was insufficient manpower to interject more days off and opportunities for recovery into the schedules.

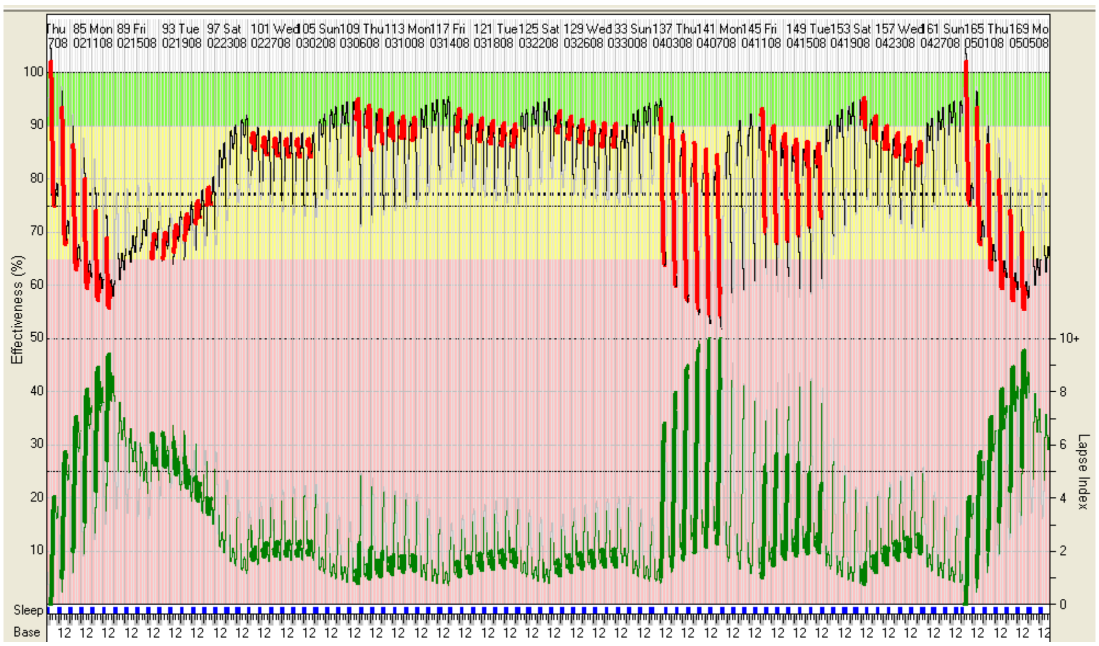


Figure 3. FAST output for a simulated 6W:3F, 3-shift, slow (monthly) clockwise rotation schedule.

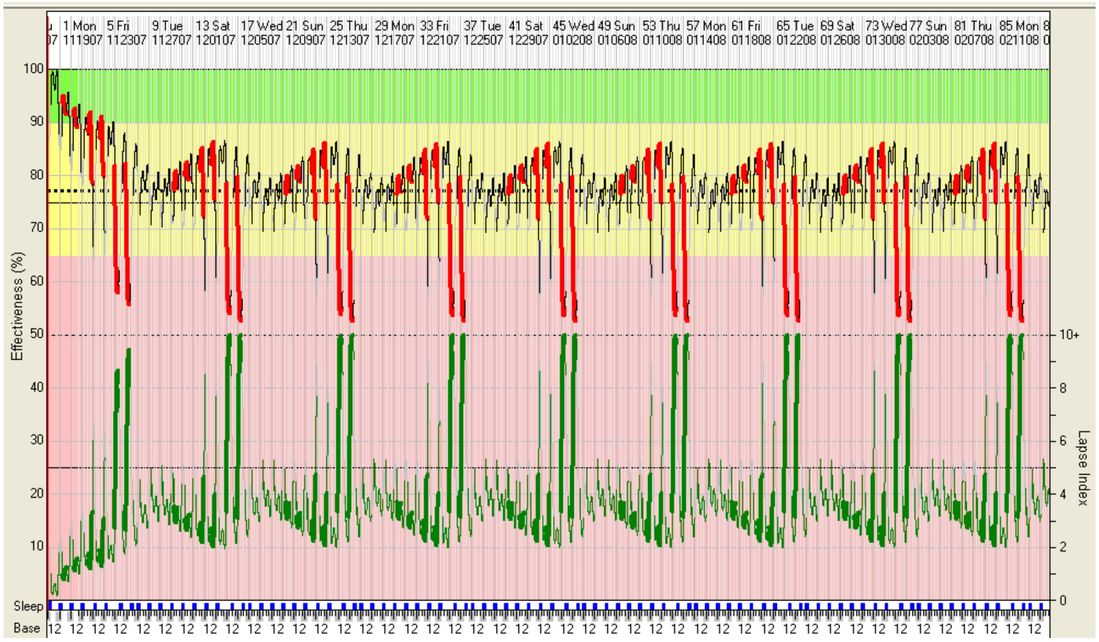


Figure 4. FAST output for a simulated 6W:3F, 3-shift, rapid (DDMMNN) clockwise rotation schedule.

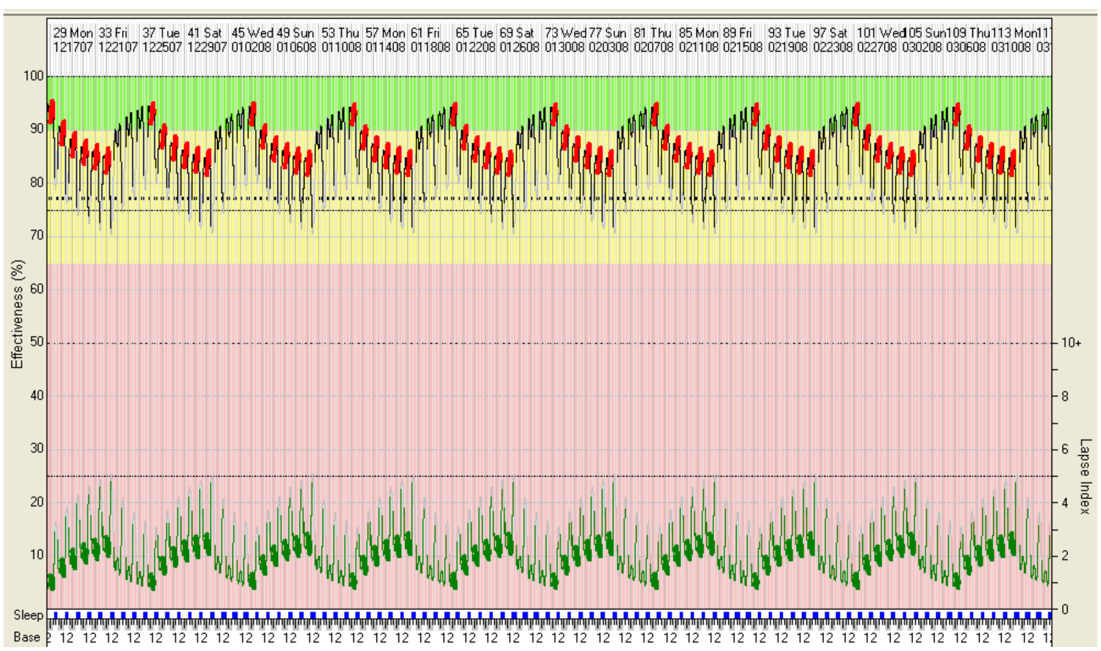


Figure 5. FAST output for a simulated 6W:3F, 3-shift, fixed (night) shift schedule, crewmember maintaining night shift sleep/wake times during off days (i.e., compliant with recommendations).

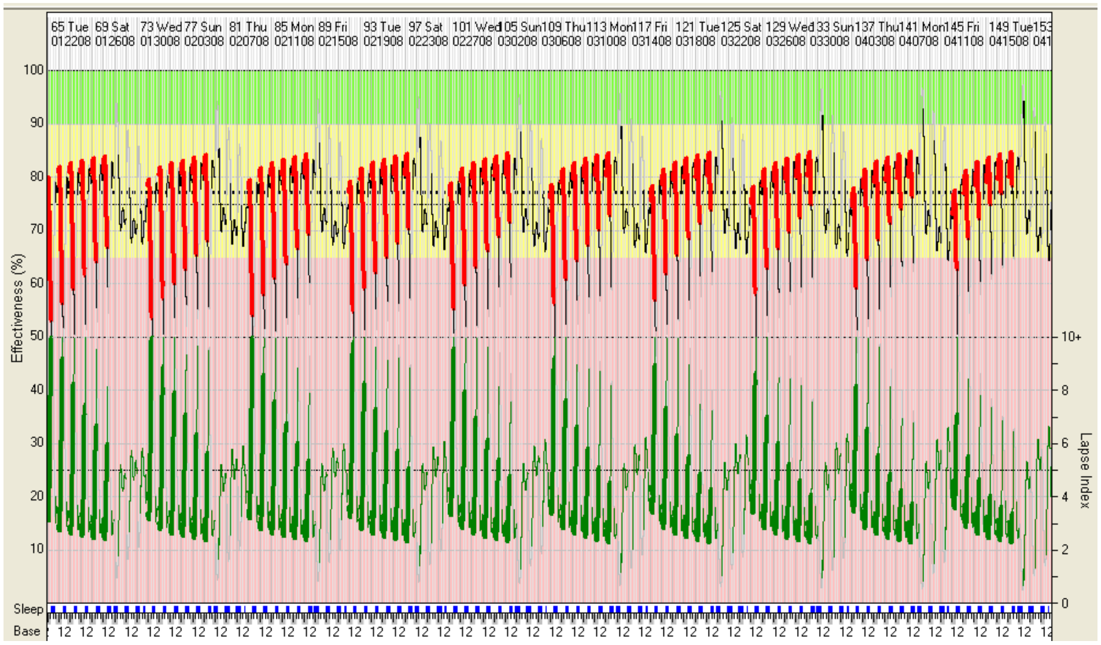
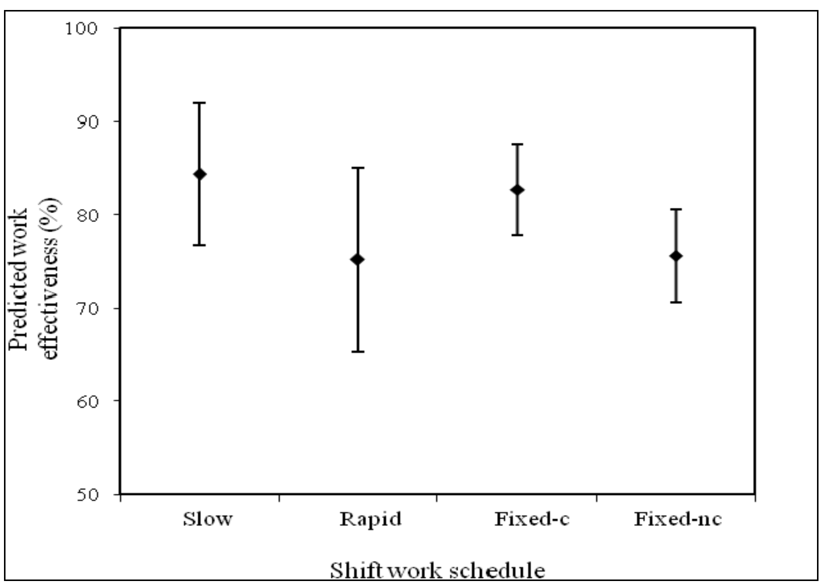


Figure 6. FAST output for a simulated 6W:3F, 3-shift, fixed (night) shift schedule, crewmember reverting to day shift sleep/wake times during off days (i.e., noncompliant with recommendations).



Fixed-c = fixed shift, compliant with off-day sleep time recommendations.
Fixed-nc = fixed shift, noncompliant with off-day sleep time recommendations.

Error bars are ± one standard deviation.

Figure 7. Mean predicted work effectiveness from the FAST simulations of four shift-work schedules.

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IV. DISCUSSION

This study sought to update the initial assessment of shift worker fatigue in USAF MQ-1 Predator UAS crewmembers by resurveying squadron personnel one year after modifying their shift scheduling practices. The *a priori* expectation was for decreased subjective fatigue since the pilots were transitioned from a weekly rotation schedule, which tends to perpetuate disturbed circadian rhythms, to a monthly rotation schedule. In addition, the number of consecutive days off was increased from two to three in order to provide greater opportunity for recovery sleep. However, study results differed markedly from this expectation. Mean fatigue scores were unchanged compared to one year before with the exception of the CIS-CON scale, a measure of mental fatigue, for which scores were significantly higher compared to the prior year. It is difficult to interpret this finding as there was no corresponding increase in scores on the FS-mental scale, another measure of mental fatigue. Collectively, the results from the six assessment instruments in the CFS were indicative of chronic fatigue. Compared to the control group, the study sample had higher scores on the FAS, which is specifically purported to be a measure of chronic fatigue (Michielsen, De Vries, Van Heck, Van de Vijver, & Sijtsma, 2004). Additionally, chronic fatigue is known to predispose workers to chronic job stress and burnout, most commonly manifesting as emotional exhaustion (Michielsen et al., 2003). This effect was observed in the study sample, which had higher scores than the control group on the two assessments of emotional exhaustion and burnout, the EF-WHOQOL and MBI-EE. Since workers in shift systems require more time to recover than those working only day shifts, the observed chronic fatigue is likely reflective of continued inadequate opportunity for restorative sleep.

As described by Barton et al. (1995) in their shift work model (Figure 1), the three major factors likely to cause the myriad of problems in shift workers involve disturbances in circadian rhythms, sleep, and domestic relationships. Our study also identified these same factors as being associated with composite fatigue scores. In particular, the regression analysis showed that increasing duration of shift work, decreasing sleep quality, and impaired domestic relationships were all associated with increased fatigue.

Problems of circadian origin stem from an individual's inability to adjust their internal biological clock to the changes in daily routine required in a shift worker's schedule. As such, circadian issues would be expected to grow with increasing exposure to shift work. While sleep duration was found to be inversely associated with fatigue, this association was not significant after including the other aforementioned factors in the analysis. Thus, it may be possible that diminished quality of sleep may be more important than the quantity of sleep in explaining the excessive fatigue observed in this study. For example, Åkerstedt, Kecklund, and Knutsson (1991) reported reduced stage two, rapid-eye-movement, and slow wave (stages 3-4) sleep in connection with morning and night shifts. However, the average six hours of self-reported daily sleep in this study suggests the problem is more likely a combination of partial sleep deprivation and the influences of disrupted homeostatic and circadian systems.

Barton et al.'s shift work model also suggests there are other individual and situational differences that need to be considered when examining shift worker adaptation. We were able to elicit some of these individual and situational factors in the multiregression analysis of the individual fatigue scales used in the CFS. In particular, pilots were found to have higher mental fatigue scores than sensor operators, suggesting a possible task-related contribution to their fatigue. This is plausible since pilots perform prolonged vigilance work and such vigilance work is known to invoke subjective feelings of boredom and monotony and invariably induce decreased levels of physiologic arousal (Kass, Vodanovich, Stanny, & Taylor, 2001; Sawin & Scerbo, 1995). However, when coupled with the need to maintain high levels of alertness, vigilance tasks can be perceived as quite stressful (Krueger, 1991; Thackray, 1980) and this stress predisposes one to fatigue (Schroeder, Touchstone, Stern, Stoliarov, & Thackray, 1994). Another individual difference observed in this study was gender; females were observed to have higher levels of emotional exhaustion as measured on the MBI-EE. This is consistent with other studies, which have found that women often need to overcome more domestic challenges and, as a consequence, appear to have more difficulty coping with shift work (Hossain et al., 2004). Not surprisingly, inadequate time for life activities was also associated with emotional exhaustion in our study sample.

Finally, Barton et al.'s model implies that both the acute and chronic effects of shift work can adversely impact physical health and safety. While this study was not designed to address the former, the current iteration of the survey instrument did assess the latter issue. Approximately 40% of the study sample reported a moderate to high likelihood of falling asleep in the GCS while operating a weaponized, remotely piloted aircraft. This is not surprising given the mean score on the ESS was above the threshold generally considered concerning with respect to acceptable job performance (Miller, 2006). The factors identified as predictive of a crewmember being a potential safety risk included duration of shift working, increasing fatigue levels as assessed by the composite fatigue score, and the use of napping during duty hours. Interestingly, the last factor was the strongest predictor and is likely a reflection of the degree of fatigue being experienced by the individual rather than an indication of a direct hazard linked to napping. Nevertheless, consideration should be given to including the first two factors into squadron preflight risk assessment tools. In addition, these same safety concerns logically extend to crewmembers driving home from work, especially since nearly 70% of the study sample reported rarely or never taking a nap prior to departing from work.

Everything discussed up to this point clearly indicates problems with features of the squadron's shift system, another component of Barton et al.'s shift work model. Rather than recommending further changes to the shift work schedule and waiting months to reassess the effect, modeling and simulation was utilized to explore potential outcomes of four scheduling scenarios. Using predicted work effectiveness as a metric of a schedule's merit, there did not appear to be an alternative to the present schedule that offered any significant advantage. The rapid rotation schedule was predicted to result in a lower mean work effectiveness than the slow rotation schedule. While the slow rotation and fixed shift schedules did not differ in terms of predicted work effectiveness, the fixed shift schedule appeared to have less overall variability and fewer excursions below the model's criterion line.‡ However, a disadvantage of the fixed shift schedule is its dependence on individuals complying with the recommendation to maintain

‡The criterion line in FAST corresponds to a predicted work effectiveness of 77.5 percent and is a guide for using countermeasures to enhance performance. Performance in below the criterion line represents the performance of a person during the day following loss of an entire night's sleep (NTI, 2005).

work-related wake/sleep routines on days off (i.e., compliant), otherwise it degrades into a weekly rotating schedule with the potential for significant circadian disturbances. In our study sample, 40% of individuals reported rarely or never maintaining work-related wake/sleep routines on days off, but this factor was not found to be associated with fatigue in any of the regression models. The other concern is that the SAFTE™ model does not account for the effects of environmental variables such as light (Mallis, Mejdal, Nguyen, & Dinges, 2004). Given early morning light often makes complete shifting of a night worker's circadian cycle impossible, most night workers maintain at least a partial day orientation with resulting shift lag (Åkerstedt, 2003). Thus, the SAFTE™ model likely overestimates the advantage of the fixed shift schedule.

Overall, this study found no improvement in the pervasive shift work fatigue noted in a survey of the same squadron the year prior. Since shift work is known to have adverse consequences on health and safety (Barton et al., 1995; Folkard & Tucker, 2003; Mitler, Dinges, & Dement, 1994), this situation can and should be viewed through the lens of human performance, and thus the model of human systems integration (Booher, 2003). Fatigue and stress are survivability domain issues (Figure 8), which when unmitigated, can spill over into the occupational health and safety domain (Barton et al., 1995). As our modeling and simulation demonstrated, the root problem for this population was not the shift system features themselves, but rather a lack of adequate manpower (another HSI domain) to provide sufficient recovery opportunities. Thus, at best, all that can be recommended are preventive and compensatory measures. While it is desirable to minimize the number of consecutive night shifts, it is a reasonable alternative to continue the present schedule with multiple night shifts in succession and provide exposure to bright light during the night shift. While this will require modification of the GCS work environment (i.e., human factors engineering and habitability domains) and may not be immediately feasible, this feature should be considered in all future GCS design iterations. Other recommendations include educating supervisors and crewmembers as well as their spouses (i.e., training domain) on circadian rhythms, sleep disorders, the impact of shift work on family and social life, alertness strategies, safe driving, nutrition, physical activity, and coping with stress. Supporting medical personnel should ensure they have up-to-date knowledge of sleep disorders and shift maladaptation syndrome (i.e., training domain) and provide tailored medical surveillance of shift workers (i.e., occupational health domain). Finally, supervisors should implement methods to mitigate the danger of post-shift fatigue on driving safety by providing organizationally-sponsored car pools and offering work locations for post-shift naps prior to driving home (i.e., safety and habitability domains) (Knauth & Hornberger, 2003; Miller, 2006).

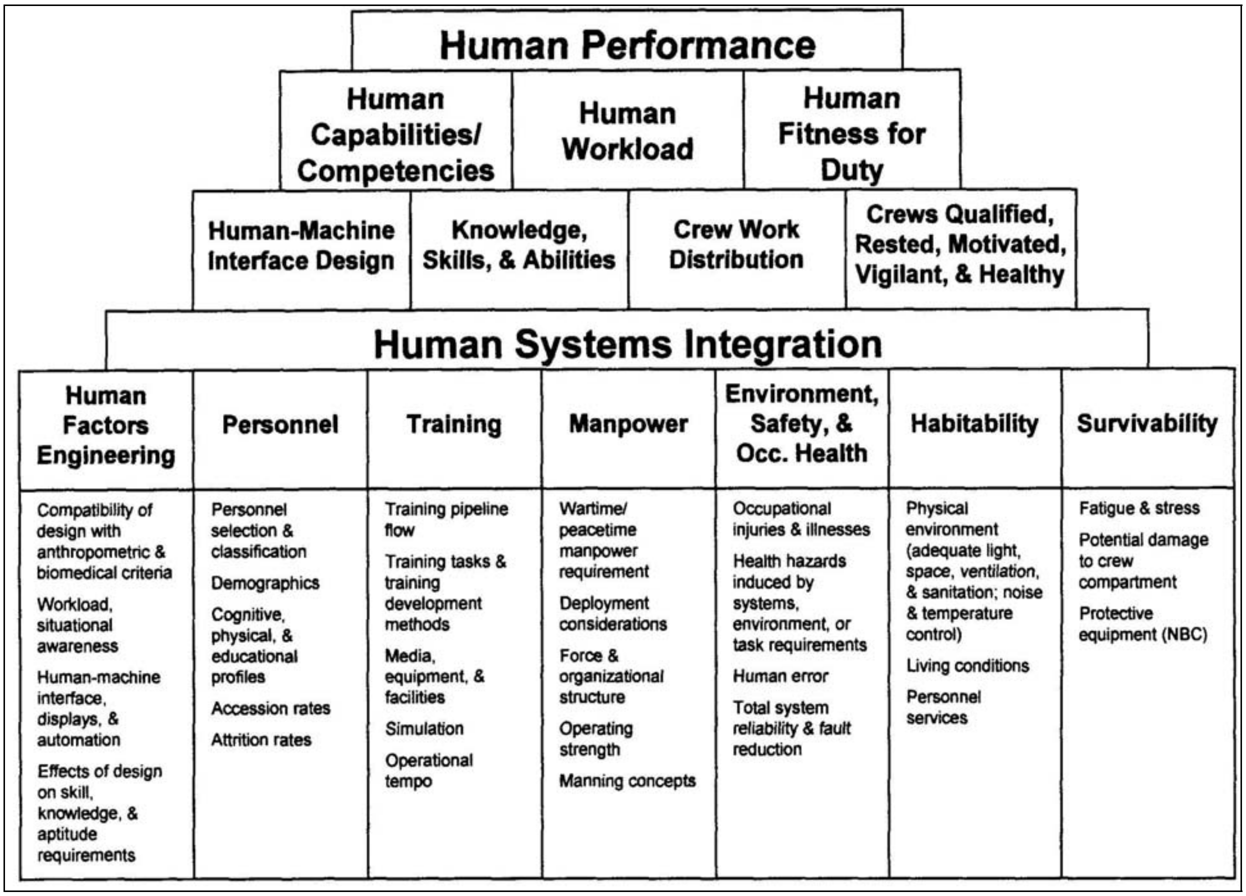

Figure 8. Model for obtaining human performance from the domains of human systems integration (HSI) with examples of HSI elements/areas of concern for each domain (Tvaryanas, 2006).

In summary, this paper discussed the results of a recent follow-up survey of a population of MQ-1 Predator UAS crewmembers supporting "reachback" teleoperations using rotational shift work. Specifically examined were shift work-related increases in fatigue, sleepiness, and risk for performance decrements. Shift system features and individual and situational differences associated with fatigue were also explored. Finally, shift system features of several types of schedules were assessed through modeling and simulation. The use of shift work in the setting of inadequate staffing levels has significant implications with regard to enhancement of the negative effects of shift work. The lessons learned in this paper reflect the inherent human limitations of being able to "do more with less." If implemented correctly, shift system features can minimize the harm to workers, but it is critical for organizational leadership to realize there is no optimally healthy or safe night schedule given basic human physiology.

Conclusions drawn from this study must consider the limitations of the analysis. First, this study used a cross-sectional design, which is a fairly quick and easy method for measuring the current health status of populations, but has the disadvantage of being unable to assess temporal relationships, thereby limiting the ability to infer cause-and-effect relationships. Additionally, a limitation of all fatigue studies is the general lack of a standard way to assess fatigue (Michielsen, De Vries, & van Heck, 2003). This study assessed subjective fatigue to include asking participants to report the duration and quality of their sleep. Although subjective estimates of sleep have been shown to perform similarly to actigraphy, both suffer from a wide variation in accuracy between individuals (i.e., random error) when compared with polysomnography (Signal, Gale, & Gander, 2005). While there are relatively detailed shift work-specific assessment tools (Barton et al., 1995), the CFS used in this study was limited to a few relatively short fatigue questionnaires because of the need to limit the impact on participants' time. Finally, the small group sample sizes increased the risk for false-negative errors, which should be a consideration in drawing major conclusions from this study.

APPENDIX

1. Age:__________

2. Gender:
    ○ Male
    ○ Female

3. Rank:
    ○ E-1 to E-4
    ○ E-5 to E-6
    ○ E-7+
    ○ O-1 to O-3
    ○ O-4 to O-6

4. Crew position:
    ○ Pilot
    ○ Sensor operator
    ○ Intel
    ○ Other, please specify:_____

5. How many <u>months</u> have you been involved in shift work:_____

6. Which best describes your <u>current</u> work schedule:
    ○ Day shift (morning starts)
    ○ Mid shift (afternoon starts) (**Select only one)**
    ○ Night shift (evening starts)

7. Number of hours slept per day during the past <u>2 weeks</u>:_____

8. Quality of sleep during the past <u>2 weeks</u>:
    ○ Poor
    ○ Moderate (**Select only one)**
    ○ Excellent

9. Does your current shift schedule cause you:
    ○ Inadequate time with spouse/partner
    ○ Inadequate time with children (**Select all that apply)**
    ○ Inadequate time with friends and relatives
    ○ Inadequate time for recreational activities

Instructions:
Below are 30 statements. Please rate how often these statements apply to you during the past 2 weeks. For example:

I feel tired

If you feel this statement is not "yes, that is true", but also not "no, that is not true", click the appropriate circle most in accordance with how you have felt. For example, if you felt tired but not very tired, click the circle close to "yes, that is true" like this:

	yes, that is true						no, that is not true
I feel tired	○	○	●	○	○	○	○

There are no right or wrong answers. Please do not skip any statements and mark only 1 circle for each statement.

	yes, that is true						no, that is not true
1. I don't do much during the day	○	○	○	○	○	○	○
2. I have trouble concentrating	○	○	○	○	○	○	○
3. When I am doing something, I can concentrate well	○	○	○	○	○	○	○
4. I feel fatigued when I get up in the morning and have to face another day on the job	○	○	○	○	○	○	○
5. I feel no desire to do anything	○	○	○	○	○	○	○
6. Working with people all day is really a strain for me	○	○	○	○	○	○	○
7. I am bothered by fatigue	○	○	○	○	○	○	○
8. I feel used up at the end of the workday	○	○	○	○	○	○	○
9. I get tired	○	○	○	○	○	○	○

very quickly							
10. I feel sleepy or drowsy	○	○	○	○	○	○	○
11. I make slips of the tongue when speaking	○	○	○	○	○	○	○
12. I'm lacking in energy	○	○	○	○	○	○	○
13. I have less strength in my muscles	○	○	○	○	○	○	○
14. I have enough energy for everyday life	○	○	○	○	○	○	○
15. I can concentrate well	○	○	○	○	○	○	○
16. I am satisfied with the energy I have	○	○	○	○	○	○	○
17. Thinking requires effort	○	○	○	○	○	○	○
18. Mentally, I feel exhausted	○	○	○	○	○	○	○
19. I feel weak	○	○	○	○	○	○	○
20. I have problems with my memory	○	○	○	○	○	○	○
21. I am easily fatigued	○	○	○	○	○	○	○
22. I have problems with tiredness	○	○	○	○	○	○	○
23. I have difficulty concentrating	○	○	○	○	○	○	○
24. I need to rest more	○	○	○	○	○	○	○
25. My thoughts easily wander	○	○	○	○	○	○	○
26. I have problems starting	○	○	○	○	○	○	○

things							
27. Physically, I feel exhausted	○	○	○	○	○	○	○
28. I feel emotionally drained from my work	○	○	○	○	○	○	○
29. I have problems thinking clearly	○	○	○	○	○	○	○
30. I feel burned out from my work	○	○	○	○	○	○	○

Instructions:
Below are 8 statements. Please rate how often these statements apply to you during the past 2 weeks. How likely are you to doze off or fall asleep in the following situations, in contrast to just feeling tired? Even if you have not done these things, estimate their effect on you.

	Would never doze	Slight chance of dozing	Moderate change of dozing	High chance of dozing
1. Sitting and reading	○	○	○	○
2. Watching television	○	○	○	○
3. Sitting inactive in a public place (for example, a theater or meeting)	○	○	○	○
4. As a passenger in a car for an hour without a break	○	○	○	○
5. Lying down to rest when circumstances permit	○	○	○	○
6. Sitting and talking to someone	○	○	○	○
7. Sitting quietly after lunch without alcohol	○	○	○	○
8. In a car while stopped for a few minutes in traffic	○	○	○	○
9. Sitting in the GCS during a period of high boredom	○	○	○	○

Instructions:
Below are 3 statements. Please rate how these statements apply to you during your current monthly shift rotation (e.g., days, mids, or night shifts).

	never	rarely	some-times	often
1. Use napping during the duty period to maintain alertness or reduce fatigue	○	○	○	○
2. Use napping at the end of the duty period to increase alertness or reduce fatigue prior to	○	○	○	○

	driving home				
3.	Maintain your typical work week wake and sleep times during your days off	○	○	○	○

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LIST OF REFERENCES

Air Force Inspection Agency (2004). *Shift worker fatigue eagle look* (Eagle Look Report, PN 04-602). Kirtland Air Force Base, NM: United States Air Force Inspection Agency.

Åkerstedt, T. (2003). Shift work and disturbed sleep/wakefulness. *Occupational Medicine*, *53*, 89-94.

Åkerstedt, T., Kecklund, G., & Knutsson, A. (1991). Spectral analysis of sleep electroencephalography in rotating three-shift work. *Scandinavian Journal of Work*, *Environment*, *and Health*, *17*, 330-336.

Barnes, M.J., & Matz, M.F. (1998). Crew simulations for unmanned aerial vehicle (UAV) applications: sustained effects, shift factors, interface issues, and crew size. In *Proceedings of the Human Factors and Ergonomics Society 42nd annual meeting* (pp. 143-147). Santa Monica; Human Factors and Ergonomics Society.

Barnett, R. C., Brennan, R. T., & Gareis, K. C. (1999). A closer look at the measurement of burnout. *Journal of Applied Biobehavioral Research*, *4*(*2*), 65-78.

Barton, J., Spelten, E., Totterdell, P., Smith, L., Folkard, S., & Costa, G. (1995). The standard shiftwork index: A battery of questionnaires for assessing shiftwork-related problems. *Work and Stress*, *9*(*1*), 4-30.

Beurskens, A. J. H. M., Bfiltmann, U., Kant, I., Vercoulen, J. H. M. M., Bleijenberg, G., & Swaen, G. M. H. (2000). Fatigue among working people: Validity of a questionnaire measure. *Occupational and Environmental Medicine*, *57*(*5*), 353-357.

Booher, H. R. (2003). Introduction: Human systems integration. In H. R. Booher (Ed.), *Human Systems Integration Handbook* (Chap. 1, pp. 1-30). Hoboken: Wiley.

Chalder, T., Berelowitz, G., Pawlikowska, T., Watts, L., Wessely, S., Wright, D., & Wallace, E. P. (1993). Development of a fatigue scale. *Journal of Psychosomatic Research*, *37*(*2*), 147-153.

Field, A. (2003). *Multiple regression II*: *Using the model and assessing its validity*. Retrieved May 30, 2005, from http://www.sussex.ac.uk/Users/andyf/teaching/rm2/ lecture04(multipleregression2).pdf

Folkard, S., & Tucker, P. (2003). Shift work, safety, and productivity. *Occupational Medicine*, *53*(*2*), 95-101.

Gawron, V. J. (1998). Human factors issues in the development, evaluation, and operation of uninhabited aerial vehicles. *AUVSI '98: Proceedings of the Association of Unmanned Vehicle Systems International*, 431-438.

Gawron, V. J., French, J., & Funk, D. (2001). An overview of fatigue. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload, and fatigue. Human factors in transportation* (pp. 581-595). Mahwah: Erlbaum.

Hossain, J. L., Reinish, L. W., Heslegrace, R. J., Hall, G. W., Kayumov, L., Chung, S. A., Bhuiya, P., Jovanovic, D., Huterer, N., Volkov, J., & Shapiro, C. M. (2004). Subjective and objective evaluation of sleep and performance in daytime versus nighttime sleep in extended hours shift-workers at an underground mine. *Journal of Occupational and Environmental Medicine*, *46*, 212-226.

Hursh, S. R., Redmond D. P., Johnson, M. L., Thorne, D. R., Belenky, G., Balkin, T. J., et al. (2004). Fatigue models for applied research in warfighting. *Aviation, Space, and Environmental Medicine*, *75*(*3 Suppl*), A44-53.

Jansen, N. W. H., van Amelsvoort, L. G. P. M., Kristensen, T. S., van den Brandt, P. A., & Kant, I. J. (2003). Work schedules and fatigue: A prospective cohort study. *Occupational and Environmental Medicine*, *60*(*Suppl 1*), i47-i53.

Johns, M. W. (1991). A new method for measuring daytime sleepiness: the Epworth Sleepiness Scale. *Sleep*, *14*, 540-5.

Kass, S.J., Vodanovich, S. J., Stanny, C., & Taylor, T. M. (2001). Watching the clock: Boredom and vigilance performance. *Perceptual Motor Skills*, *92*, 969-976.

Knauth, P., & Hornberger, S. (2003). Preventive and compensatory measures for shift workers. *Occupational Medicine*, *53*, 109-116.

Krueger, G. P. (1991). Sustained military performance in continuous operations: Combatant fatigue, rest and sleep needs. In R. Gal & A. D. Mangelsdorff, A. D. (Eds.), *Handbook of Military Psychology* (pp. 255-277). New York: Wiley.

Mallis, M. M., Mejdal, S., Nguyen, T. T., & Dinges, D. F. (2004). Summary of the key features of seven biomathematical models of human fatigue and performance. *Aviation, Space, and Environmental Medicine*, *75*(*3 Suppl*), A4-A14.

McCarley, J. S., & Wickens, C. D. (2004). *Human factors concerns in UAV flight*. Retrieved December 2, 2007, from http://www.hf.faa.gov/docs/508/docs/uavFY04Planrpt.pdf

Michielsen, H. J., De Vries, J., & van Heck, G. L. (2003). Psychometric qualities of a brief self rated fatigue measure: The fatigue assessment scale. *Journal of Psychosomatic Research*, *54*, 345-352.

Michielsen, H. J., De Vries, J., van Heck, G. L., van de Vijver, A. J. R., & Sijtsma, K. (2004). Examination of the dimensionality of fatigue: The construction of the fatigue assessment scale (FAS). *European Journal of Psychological Assessment*, *20*(*1*), 39-48.

Miller, J. C., Fisher, S. D., & Cardenas, C. M. (2005). *Air Force shift worker fatigue survey* (AFRL-HE-BR-TR-2005-0128). Brooks City-Base, TX: Air Force Research Laboratory.

Miller, J. C. (2006). *Fundamentals of shift work scheduling* (AFRL-HE-BR-TR-2006-0011). Brooks City-Base, TX: Air Force Research Laboratory.

Mitler, M. M., Dinges, D. F., & Dement, W. C. (1994). Sleep medicine, public policy, and public health. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and practice of sleep medicine* (2nd ed., Chap. 41, pp. 453-462). Philadelphia: Saunders.

NTI. (2005). *Fast start guide* [Computer software]. Fairborn, OH: NTI, Inc.

Office of the Secretary of Defense. (2005). *Unmanned aircraft systems roadmap 2005-2030*. Retrieved December 2, 2007, from http://www.acq.osd.mil/usd/Roadmap%20Final2.pdf

Office of Technology Assessment. (1991). *Biological rhythms*: *The implications for the worker*. (Committee Report OTA-BA-463). Washington: Government Printing Office.

Rosa, R. R. (2001). Examining work schedules for fatigue: It's not just hours of work. In P. A. Hancock & P. A. Desmond (Eds.), *Stress*, *workload and fatigue* (pp. 513-528). Mahwah: Lawrence Erlbaum Associates.

Sawin, D. A., & Scerbo, M. W. (1995). Effects of instruction type and boredom proneness in vigilance: Implications for boredom and workload. *Human Factors*, *37*, 752-765.

Schroeder, D. J., Touchstone, R. M., Stern, J. A., Stoliarov, N., & Thackray, R. (1994). *Maintaining vigilance on a simulated ATC monitoring task across repeated sessions* (DOT/FAA/AM-94/6). Oklahoma City, OK: Federal Aviation Administration, Civil Aeromedical Institute.

Signal, T. L., Gale, J., & Gander, P. H. (2005). Sleep measurement in flight crew: Comparing actigraphic and subjective estimates to polysomnography. *Aviation*, *Space*, *and Environmental Medicine*, *76*(*11*), 1058-1063.

Smets, E. M. A., Garssen, B., Bonke, B., De Haes, J. C. (1995). The multidimensional fatigue inventory (MFI). Psychometric qualities of an instrument to assess fatigue. *Journal of Psychosomatic Research*, *39*(*3*), 315-325.

Smith, L., Macdonald, I., Folkard, S., & Tucker, P. (1998). Industrial shift systems. *Applied Ergonomics*, *29*, 273-280.

Statistical Package for the Social Sciences (Version 11.5) [Computer software]. Chicago, IL: SPSS.

Thackray, R. I. (1980). *Boredom and monotony as a consequence of automation: A consideration of the evidence relating boredom and monotony to stress* (DOT/FAA/AM-80/1). Oklahoma City, OK: Federal Aviation Administration, Civil Aeromedical Institute.

Tvaryanas, A. P. (2006). Human systems integration in remotely piloted aircraft operations. *Aviation*, *Space*, *and Environmental Medicine*, *77*(*12*), 1278-1282.

Tvaryanas, A. P., Lopez, N., Hickey, P., DaLuz, C., Thompson, W., & Caldwell, J. L. (2006). *Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft* (*OP-REPAIR*) (HSW-PE-BR-TR-2006-0001). Brooks City-Base, TX: 311th Performance Enhancement Directorate, United States Air Force.

Tvaryanas, A. P., & Thompson, W. T. (2006). Fatigue in military aviation shift workers: Survey results for selected occupational groups. *Aviation*, *Space*, *and Environmental Medicine*, *77*(*11*), 1166-1170.

Walters, B. A., Huber, S., French, J., & Barnes, M. J. (2002). *Using simulation models to analyze the effects of crew size and crew fatigue on the control of tactical unmanned aerial vehicles* (*TUAVs*) (ARL-CR-0483). Aberdeen Proving Ground, MD: Army Research Laboratory.

World Health Organization. *Measuring quality of life*. Retrieved January 4, 2005, from http://www.who.int/evidence/assessment-instruments/qol

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