Flight Crew Fatigue III: North Sea Helicopter Air Transport Operations

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We studied 32 helicopter pilots before, during, and after 4–5 d trips from Aberdeen, Scotland, to service North Sea oil rigs. On duty days, subjects awoke 1.5 h earlier than pretrip or posttrip, after having slept nearly an hour less. Subjective fatigue was greater posttrip than pretrip. By the end of trip days, fatigue was greater and mood more negative than by the end of pretrip days. During trips, daily caffeine consumption increased 42%, reports of headache doubled, reports of back pain increased 12-fold, and reports of burning eyes quadrupled. In the cockpits studied, thermal discomfort and high vibration levels were common. Subjective workload during preflight, taxi, climb, and cruise was related to the crewmembers' ratings of the quality of the aircraft systems. During descent and approach, workload was affected by weather at the landing site. During landing, it was influenced by the quality of the landing site and air traffic control. Beginning duty later, and greater attention to aircraft comfort and maintenance, should reduce fatigue in these operations.

IN THE MID-1980's, the Fatigue Countermeasures Program at NASA-Ames Research Center and the Medical Department of the United Kingdom Civil Aviation Authority undertook a field study of fatigue in helicopter crews flying support operations from Aberdeen, Scotland, to the North Sea oil fields. These operations began on August 1, 1967. By the time the fatigue study took place, Aberdeen Airport had handled more than half a million helicopter flights and there were four support companies operating about 50 helicopters, making it one of the largest helicopter operations ever undertaken. Activities include lifting, shuttling, and the carrying goods and personnel between Aberdeen and the rigs.

This environment, like the short-haul fixed-wing operations described in the previous paper (10), involved daytime flying with no time zone crossings. It was therefore expected to cause minimal disruption to the circadian clock. Like the fixed-wing operations, it included multiple flight segments in a duty day, and two-person flight crews. However, the North Sea helicopter operations involved additional factors which were seen as potential causes of fatigue. Some of the flights were of extended duration, for example, to the North Shetland Basin (**Fig. 1**), which represented a round trip of about 560 mi or 5 h flying time. The quality of landing sites was very variable, often with few alternates available, and weather conditions in the North Sea are notoriously poor. The helicopter flightdeck was a more physically stressful working environment, where poor ventilation and high levels of vibration were common (12). The large transparent areas surrounding the flight deck exposed crews to solar heating. Cold sea temperatures and severe weather often necessitated the wearing of immersion suits, and it was not uncommon for crewmembers to become uncomfortably hot (11). The helicopters also required more active control and had less sophisticated supporting automation than the fixed-wing aircraft studied.

Four commercial companies participated in the field study of fatigue in helicopter operations, which looked at the most challenging 4–5 d trips being flown out of Aberdeen. The Medical Department of the CAA also sponsored studies addressing the vibration levels in the cockpit (12), the thermal environment and its effects on body temperature (11), and workload associated with paperwork in these operations (13). The same crews and aircraft were studied, but not on the same flights.

METHODS

The 32 male pilots who volunteered to participate were flying Aerospatiale Super Puma, Aerospatiale Tiger, Bell 214 ST, or Boeing Vertol BV234 helicopters. They were monitored before, during, and after the trips* summarized in **Fig. 2**. At the end of each duty day, crews returned home to Aberdeen. There was one exception (the first day of trip three) when a hydraulic failure forced the crew to remain overnight on a rig. Data were collected during February to May 1986 (winter/spring) and

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*For consistency with the other fatigue studies, the 4–5 d duty periods will be referred to as trips, even although the crews returned home every night.

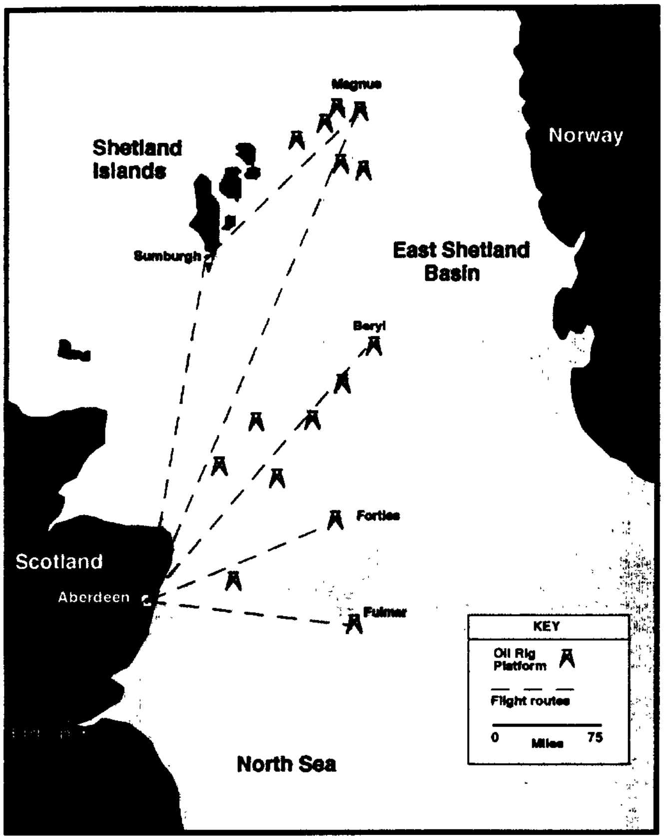


Fig. 1. The Shetland Basin, where the operations took place.

during the following July to September (summer/autumn). All times were recorded on Greenwich Mean Time (GMT). Local time was GMT in the winter and GMT + 1 in the summer. Characteristics of the trips are summarized in **Table I**. Data for duty times and layover durations were taken from the daily logbooks kept by crewmembers. Data for flight hours, number of segments, and segment duration were from the cockpit observer logs (9).

To be included in the analyses, crewmembers had to have provided logbook data for at least one pretrip day, all trip days, and at least one posttrip day. There were 22 crewmembers who provided sufficient data, including 17 who flew 4-d trips and 5 who flew 5-d trips. Their average age was 34.3 yr (SD ± 6.7 yr), and they reported an average of 8.6 yr (SD ± 4.4 yr) of flying experience, taken as the largest value from among the categories: years with the present airline; years of military experience; years of airline experience; years of general aviation experience; and other. This value probably underestimates the total years of helicopter flying experience, since half the crewmembers had some years of military experience before going into commercial aviation. Calculating experience as the sum of military and the highest other category suggested an average helicopter flight experience of 10.7 yr. Of the 22 crewmembers, 3 provided incomplete data on duty times and were therefore excluded from the statistics in Table I. Unless otherwise stated, all analyses of variance were within subjects. For *t*-tests, where a Levene's test revealed unequal variances, the separate *t*-test value was taken. Otherwise, the pooled value was taken.

In addition to the standard measures collected in the NASA fatigue studies (9), the helicopter pilots were asked to rate their workload during each phase of flight as soon as possible after the completion of that phase. The subjective measure of workload used was a modified Bedford Scale (14). This gives an assessment of the overall workload (on a scale from 1–10) without attempting to differentiate between mental, physical, and temporal loads. Pilots also rated, on a scale from one (very favorable) to five (very unfavorable), the following aspects of each flight segment: the weather conditions for landing; the particular airport, platform, or rig where the landing occurred; and (where applicable) the letdown aids and air traffic control. The functioning of the aircraft systems was rated for every segment on a scale from one (perfect) to five (useless). **Fig. 3** shows an example of the rating cards used.

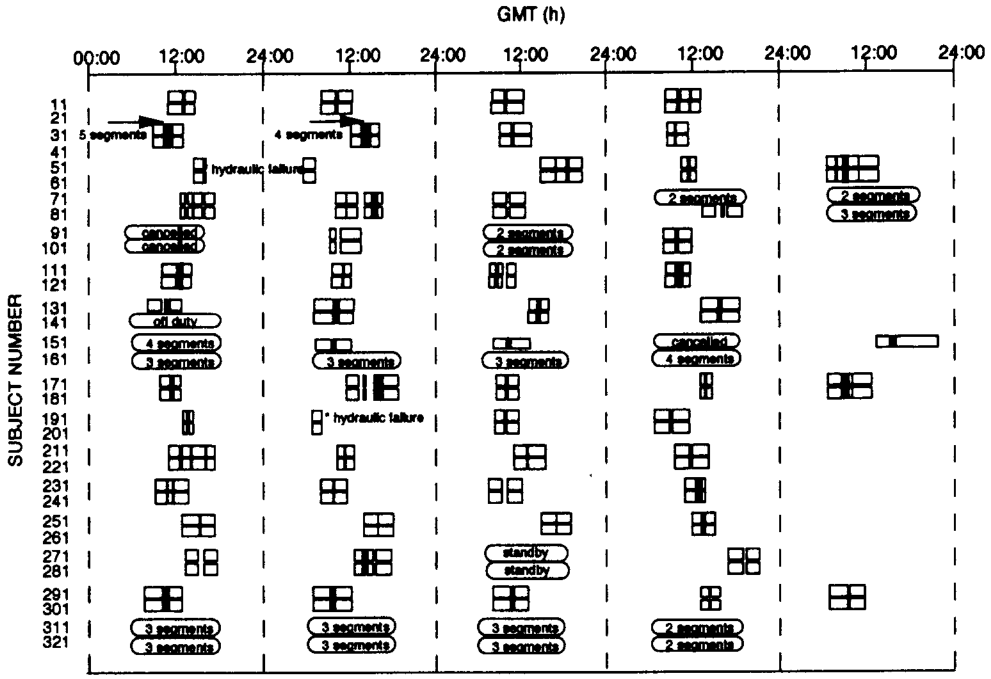
RESULTS

Sleep

Table II compares the sleep measures on pretrip, trip, and posttrip nights. Sleep latency was calculated as the difference between the reported times of going to bed and falling asleep. Scores on the four sleep quality questions, rated from 1 (least) to 5 (most), have been converted so that higher values indicate better sleep, and combined to give the overall sleep rating. Heart rate, temperature, and activity data during each sleep episode have been trimmed to include values from 20 min after the reported sleep onset time until 10 min before the reported wakeup time (9). Physiological data during sleep were available for 20 subjects (63%). The probabilities in Table II indicate values for the pretrip/trip/posttrip comparisons in one-way analyses of variance (ANOVA), with subjects treated as a random variable. Where the ANOVAs indicated significant differences, post hoc *t*-tests were used to compare pretrip, trip, and posttrip values. All the comparisons discussed were significant at least at $p < 0.05$.

On trip days, subjects fell asleep earlier and woke up earlier than either pretrip or posttrip. The nighttime sleep episode was shorter, and the total sleep per 24 h (i.e., including naps) was less than either pretrip or posttrip. Sleep latencies were shorter pretrip than during trips or posttrip.

The percentage of subjects who reported sleeping or napping more than once per 24 h was relatively low on trip days (pretrip 13%, trip 21%, posttrip 35%). One reason for this is that CAA regulations prohibit napping in two-person cockpits. Since the total sleep per 24 h on trip days averaged 0.81 h less than during pretrip, crewmembers accumulated a sleep debt across trips **(Fig. 4)**. Comparing trip days to pretrip days, 50% of crewmembers averaged more than 1 h of sleep loss per 24 h, and 14% averaged more than 2 h of sleep loss. The hours of sleep lost during the trips were not regained after 2 nights of posttrip sleep. However, this is not unexpected since recovery sleep after sleep loss does not make up the number of hours of sleep lost, but is deeper than normal sleep (1,5). The cumulative sleep loss at the end of 4-d trips was not significantly differ-



Note: ⬭ indicates days when no flight time data were collected

Fig. 2. Time lines of the trips studied. Open bars indicate flight segments. Shaded bars indicate multiple very short flight segments. Flight time data were unavailable for the segments in the rounded frames.

ent from that at the end of 5-d trips (2-group t-test; $t = -1.65$, $p = 0.12$).

Fatigue and Mood Ratings

Every 2 h while they were awake, subjects rated their fatigue level on a 10 cm line from "most alert" to "most drowsy." They also rated their current mood from 0 (not at all) to 4 (extremely) on 26 adjectives which have been shown to load on three orthogonal factors: positive affect, negative affect and activation (8). Within-subjects two-way ANOVAs (pretrip/trip/posttrip by time-of-day) were performed to see if duty demands had a measurable effect on fatigue and mood ratings **(Table III)**. There were 16 crewmembers who provided sufficient data for these analyses, with the ratings grouped in 4 h time-bins.

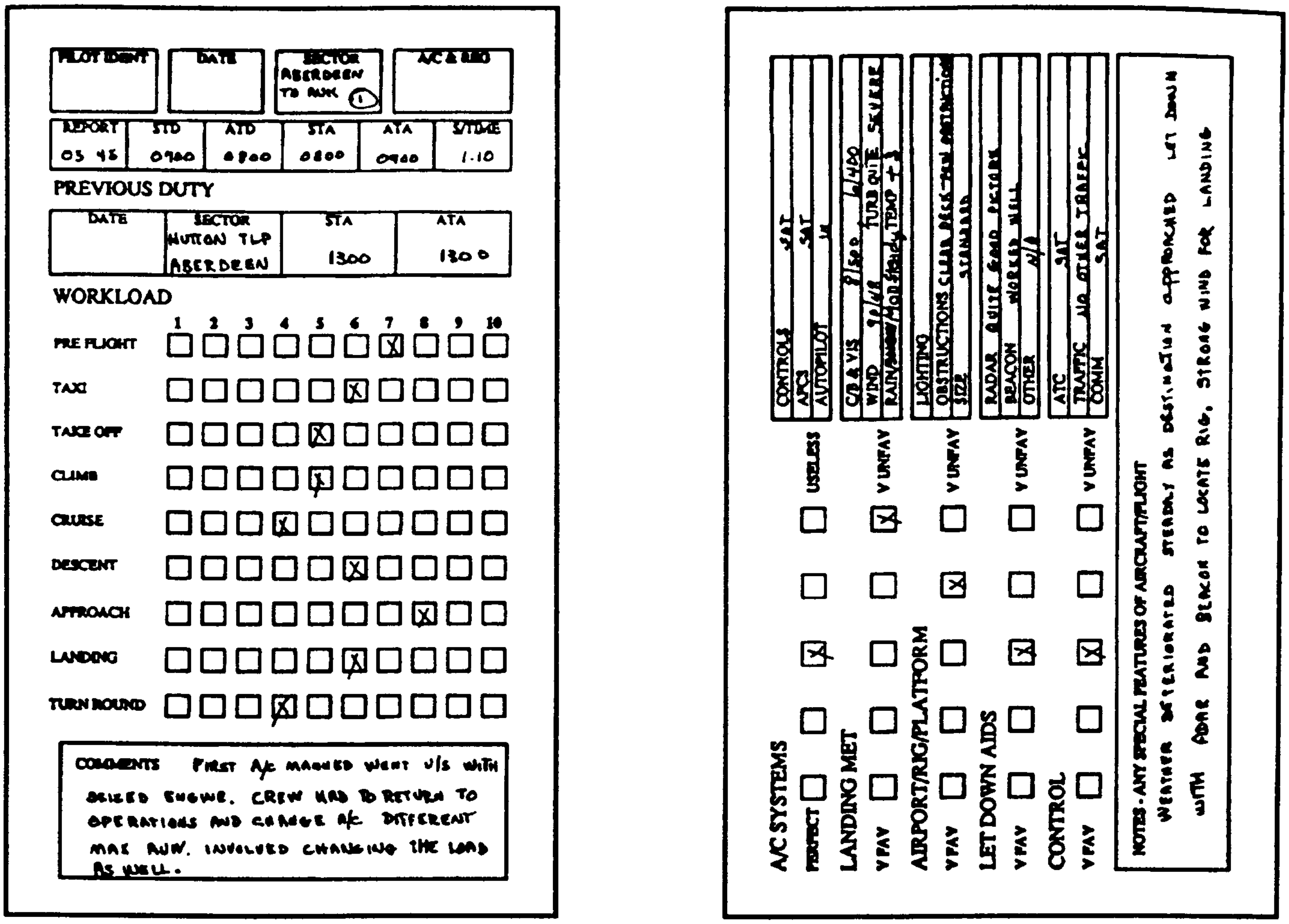
Fatigue ratings were higher posttrip (mean = 48.79) than pretrip (mean = 44.49, $t = -1.93$, $p = 0.05$). Fatigue, negative affect, and activation showed significant time-of-day variation. The significant interactions (time-of-day by pre/trip/post) suggest that the time-of-day variation in fatigue and mood ratings was different across pretrip, trip, and posttrip days. This is illustrated in **Fig. 5**, and is further examined in **Table IV**, which compares the pretrip, trip, and posttrip values in each 4 h time-bin (one-way ANOVAs with subjects treated as a random variable). Where the ANOVAs indicated significant differences, post hoc t-tests were used to compare pretrip, trip, and posttrip ratings for the respective 4-h time bins. All the comparisons discussed were significant at least at $p < 0.05$.

At 0900 hours, fatigue was lower on trip days than either pretrip or posttrip. At 1700 hours, fatigue was higher on trip days than pretrip. At 2100 hours, fatigue was higher on trip days and on posttrip days than it was on pretrip days. At 1700 hours, negative affect was higher on trip days than either pretrip or posttrip. At 2100 hours, negative affect was higher on trip days than

TABLE I. TRIP STATISTICS.

	Mean (SD)	Minimum	Maximum	n
On-duty (GMT)	7.42 (2.02)	4.33	12.50	19 subjects
Off-duty (GMT)	14.62 (2.55)	7.75	22.0	19 subjects
Duty hours/day	7.13 (1.67)	3.00	11.83	19 subjects
Nighttime layover (h)	16.97 (3.08)	10.00	23.00	19 subjects
Flight hours/day	3.40 (1.19)	1.13	5.61	10 trips
# Segments/day	2.90 (1.37)	1.00	7.00	10 trips
Segment duration (h)	1.31 (0.55)	0.03	2.55	10 trips
# Segments/trip	11.60 (3.03)	7.00	17.00	10 trips

Note: There were no time zone crossings.



PILOT IDENT	DATE	SECTOR	A/C & REG
		ABERDEEN TO MUK ①	

REPORT	STD	ATD	STA	ATA	S/TIME
03 45	0700	0800	0800	0900	1.10

PREVIOUS DUTY

DATE	SECTOR	STA	ATA
	HUTTON TLP ABERDEEN	1300	1300

WORKLOAD

	1	2	3	4	5	6	7	8	9	10
PRE FLIGHT	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐
TAXI	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐
TAKE OFF	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐
CLIMB	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐
CRUISE	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐
DESCENT	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐
APPROACH	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐
LANDING	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐
TURN ROUND	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐

COMMENTS FIRST A/C MANNED WENT U/S WITH SEIZED ENGINE. CREW HAD TO RETURN TO OPERATIONS AND CHANGE A/C DIFFERENT MAX RUW. INVOLVED CHANGING THE LOAD AS WELL.

Side A

A/C SYSTEMS

PERFECT ☐ ☐ ☒ ☐ ☐ USELESS

CONTROLS	SAT
AFCS	SAT
AUTOPILOT	U/S

LANDING MET

V FAV ☐ ☐ ☐ ☐ ☒ V UNFAV

C/B & VIS	8/500 6/400
WIND	90/48 TURB QUITE SEVERE
RAIN/SNOW	MOD Steady TEMP +3

AIRPORT/RIG/PLATFORM

V FAV ☐ ☐ ☐ ☒ ☐ V UNFAV

LIGHTING	
OBSTRUCTIONS	CLEAR DECK—NO OBSTRUCTIONS
SIZE	STANDARD

LET DOWN AIDS

V FAV ☐ ☐ ☒ ☐ ☐ V UNFAV

RADAR	QUITE GOOD PICTURE
BEACON	WORKED WELL
OTHER	N/A

CONTROL

V FAV ☐ ☐ ☒ ☐ ☐ V UNFAV

ATC	SAT
TRAFFIC	NO OTHER TRAFFIC
COMM	SAT

NOTES - ANY SPECIAL FEATURES OF AIRCRAFT/FLIGHT WEATHER DETERIORATED STEADILY AS DESTINATION APPROACHED LET DOWN WITH RADAR AND BEACON TO LOCATE RIG, STRONG WIND FOR LANDING

Side B

Fig. 3. Example of a workload rating card. Side A, modified Bedford Scale. Side B, ratings of environmental factors. One card was completed by each subject for each segment flown.

pretrip. At 0900 hours, activation was higher on trip days than either pretrip or posttrip. At 2100 hours, activation was lower on trip days than pretrip.

Caffeine Consumption, Meals and Snacks

Coffee was available in Aberdeen but not in flight on the majority of aircraft. Pilots could also request coffee on the rigs. The number of cups of caffeinated beverages, and the time of day at which they were consumed, were recorded in the daily logbook. All 22 of the crewmembers included in the sleep analyses consumed caffeine at some time during the study. To test if duty demands had an effect on caffeine consumption, a one-way ANOVA (pretrip/trip/posttrip) was performed, with subjects treated as a random variable (**Table V**).

Post hoc *t*-tests indicated that caffeine consumption was higher on trip days than either pretrip ($0.001 > p > 0.0001$) or posttrip ($0.05 > p > 0.01$).

Food was available in Aberdeen and on the rigs, but not in flight. The time of eating and the classification of meals (breakfast, lunch, dinner, snack) was recorded in the daily logbook. To test whether duty demands had an effect on the number of meals or snacks eaten per day, one-way ANOVAs were performed, with subjects treated as a random variable (Table V). Post hoc *t*-tests revealed that fewer snacks were eaten per day posttrip than either pretrip ($0.05 > p > 0.01$), or on trips ($0.05 > p > 0.01$).

Physical Symptoms

The logbook also contained a table for each day for noting physical symptoms (9). Of the 22 subjects, 18 included in the analyses (82%) reported symptoms at some time during the study. The three most common symptoms were: headaches (34% of all reports; reported by 73% of subjects at some time during the study); back pain (18% of all reports; reported by 32% of subjects at some time during the study); and burning eyes (10% of all reports; reported by 18% of subjects at some time during the study). The frequency of reports of each of these symptoms on pretrip, trip, and posttrip days is shown in **Table VI**.

Complaints of headache were twice as common on trip days by comparison with pretrip and posttrip, while reports of back pain increased 12-fold on trips and reports of burning eyes increased 4-fold.

TABLE II. COMPARISONS OF SLEEP MEASURES BEFORE, DURING, AND AFTER TRIPS.

	Pretrip	Trip	Posttrip	p(F)
Sleep onset (GMT)	23.63	22.75	23.42	**
Wakeup (GMT)	7.17	5.58	7.27	***
Sleep latency (h)	0.19	0.49	0.58	***
Sleep duration (h)	7.30	6.43	7.39	**
Total sleep/24 h	7.55	6.71	7.49	**
Difficulty falling asleep?	4.17	3.93	4.33	
How deep was your sleep?	3.25	3.42	3.67	*
Difficulty rising?	3.40	3.32	3.57	
How rested do you feel?	2.97	2.93	3.04	
Sleep rating	13.71	13.64	14.61	*
# awakenings	1.16	1.22	1.14	
Mean heart rate (bpm)	60.39	58.20	59.03	
SD heart rate	4.52	4.39	4.92	
Mean activity (counts/min)	2.34	1.32	1.35	
SD activity	5.79	5.38	4.14	
Mean temperature (°C)	36.01	36.08	36.16	
SD temperature	0.14	0.12	0.15	

* 0.05 > p > 0.01; ** 0.01 > p > 0.001; *** p < 0.001.

TABLE III. FATIGUE AND MOOD RATINGS ACROSS PRETRIP, TRIP, AND POSTTRIP DAYS.

	F Ratio Pre/Trip/Post	F Ratio Time-of-Day	F Ratio Interaction
Fatigue	4.16*	26.33***	5.93***
Positive affect	1.11	1.31	1.07
Negative affect	1.42	9.49***	4.79***
Activation	0.45	39.87***	8.97***

* 0.05 > p > 0.01; *** p < 0.001.

Analysis of Workload

As expected, average workload ratings varied in different phases of flight (Table VI).

For about 10% of flights, a reduction in workload during take-off and landing would have been desirable. The ratings (out of 5) for the environmental factors for each segment are summarized in **Table VII**.

Segments were also categorized by their position in the daily flight schedule (first, second, third, etc. segment flown) and by season (winter/spring vs. summer/autumn). For each phase of flight, an analysis of variance was performed to examine the effects of the seven environmental factors (five ratings plus segment number and season) on workload **(Table VIII)**. There were significant differences among subjects for workload ratings during every phase of flight.

The quality of aircraft systems influenced workload ratings from preflight through cruise, with the exception of during takeoff. Weather at the landing site affected workload during preflight, descent, and approach. The quality of the landing site ("airport" in Table VIII) influenced workload during preflight and landing. There were seasonal differences in the workload associated with turnarounds. Since ratings on the five environmental factors were not independent, for each phase of flight smaller ANOVAs were performed which included different subsets of factors. These additional analyses are described in detail elsewhere (7). The ANOVA models with subsets of factors suggested the following relationships, in addition to those identified in the ANOVAs with all seven factors (Table VIII). Segment number had

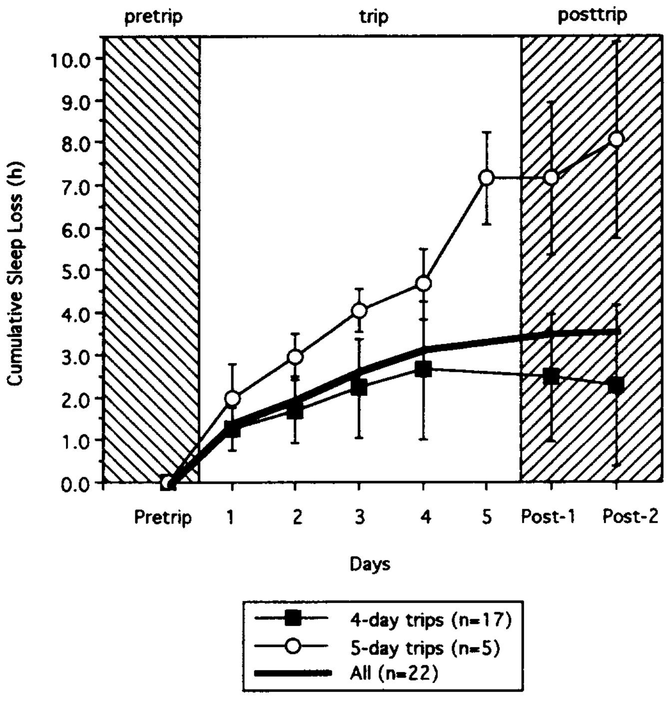


Fig. 4. Average day-by-day cumulative sleep loss with respect to baseline sleep. For each subject, his total sleep per 24 h on each trip day was subtracted from his average total sleep per 24 h on pretrip days, to give a daily measure of sleep loss. Average daily sleep loss was then calculated, and the values added across the consecutive trip days and posttrip days. Vertical lines indicate standard errors. Sleep loss by the end of 5-d trips was not significantly different from sleep loss by the end of 4-d trips.

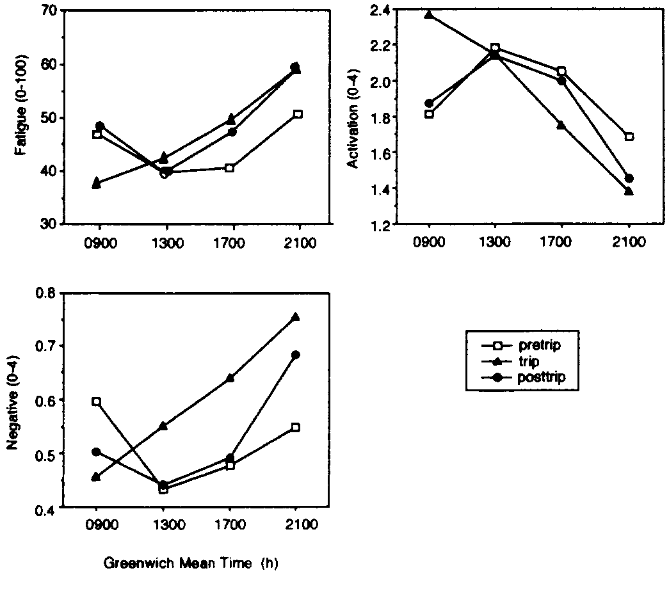


Fig. 5. Average fatigue and mood ratings at different times of day, comparing pretrip, trip, and posttrip days.

TABLE IV. FATIGUE AND MOOD RATINGS AT DIFFERENT TIMES OF DAY COMPARING PRETRIP, TRIP, AND POSTTRIP DAYS.

	F Ratio 0900 Hours Time-Bin	F Ratio 1300 Hours Time-Bin	F Ratio 1700 Hours Time-Bin	F Ratio 2100 Hours Time-Bin
Fatigue	7.43**	0.69	4.03*	13.06***
Negative affect	1.65	2.03	3.68*	4.05*
Activation	10.66***	0.16	2.86	6.05**

* $0.05 > p(F) > 0.01$; ** $0.01 > p(F) > 0.001$; *** $p(F) < 0.001$.

a significant effect on preflight workload ratings. Depending on which subset of variables was included, season or segment number had a significant effect on workload ratings during taxi. For workload during landing, there was a significant interaction between the quality of the landing site and the quality of air traffic control.

Comparisons With Short-Haul Fixed-Wing Operations

Table IX compares (by 2-group t-tests) demographic and personality measures between the helicopter crewmembers and the short-haul fixed-wing crewmembers described in the second paper of this series (8,10). The fixed-wing statistics are for the subset of 44 subjects included in the sleep analyses in ref. 10.

Including military and other experience increased the average years of experience for the helicopter crewmembers to 10.68, but this was still significantly less than that of the short-haul fixed-wing crewmembers (2-group $t = -3.84$, $0.001 > p > 0.0001$). Helicopter pilots were 9 yr younger, weighed less (perhaps because of the age difference) and scored slightly lower on the expressivity scale of the Personal Attributes Questionnaire.

Table X compares (by 2-group t-tests) the duty characteristics of the helicopter operations with those of the short-haul fixed-wing operations (for the trips flown by the 44 subjects included in the sleep analyses in ref. 10)

The helicopter crewmembers began work about an hour earlier, but had duty days more than 3 h shorter, and nighttime layovers more than 4 h longer, than their short-haul fixed-wing counterparts. Their duty days averaged about an hour less flight time and two flight segments fewer. Recall also that the helicopter crews returned home each night, whereas the short-haul crews slept in en route layover hotels during trips.

Table XI compares (by 2-group t-tests) changes in sleep from pretrip nights to trip nights, for helicopter and short-haul fixed-wing operations. The later data includes 33 pilots who gave pretrip baseline data. There were no significant differences between the groups on these measures.

TABLE V. CONSUMPTION OF CAFFEINE MEALS AND SNACKS BEFORE, DURING, AND AFTER TRIPS.

	Pretrip	Trip	Posttrip	F
Caffeine, servings/day	3.14	4.73	3.46	10.55***
Number of meals/day	2.27	2.58	2.25	2.53
Number of snacks/day	1.20	1.26	0.83	5.71**

*** $p < 0.001$.

Both groups increased their daily caffeine consumption on trips by about 50% over pretrip levels (10). Headaches were the most commonly reported physical symptom in both studies. They were reported by 73% of helicopter pilots at some time during the study, compared with 27% of fixed-wing pilots. Back pain was the second most common symptom reported by helicopter pilots (32%), and was the third most common symptom reported by fixed-wing pilots (11%). The second most common symptom reported by fixed-wing pilots was congested nose (20%). The third most common symptom reported by helicopter pilots was burning eyes (18%).

DISCUSSION

Helicopter servicing of the North Sea oil fields is a large and very challenging operation. There are many factors in this environment which can contribute to flight crew fatigue. Some are impossible to modify directly, for example, extreme weather conditions. Others cannot be modified, at least in the short term, because of technological or financial constraints. These include: limited automation of aircraft systems; operating aircraft near the limit of their range and performance capabilities; and difficult landing sites. Given these constraints, it is particularly important to identify those aspects of the operations which can be modified to reduce the likelihood of fatigue impairing flight crew performance.

Crewmembers averaged about 50 min less sleep on trip nights than pretrip, primarily due to the fact that they had to wake up about 1.5 h early to report for duty. Multiple regression analyses reported elsewhere (7) indicated that the time of going on duty the next morning accounted for 41% of the variability in sleep duration. Comparing the total sleep per 24 h (including naps) on trip days vs. pretrip days, 50% of crewmembers averaged more than 1 h of sleep loss on trip days and 14% averaged more than 2 h of sleep loss. In the laboratory, 1 h of sleep loss per night produces a cumulative increase in sleepiness (2). Reducing nighttime sleep in the laboratory by more than 2 h can impair performance and cause

TABLE VI. FREQUENCY OF REPORTS AND COMMON PHYSICAL SYMPTOMS.

Symptom	% Pretrip	% Trip	% Posttrip
Headache	33	52	15
Back pain	7	86	7
Burning eyes	17	66	17

TABLE VII. AVERAGE WORKLOAD RATINGS DURING DIFFERENT PHASES OF FLIGHT.

Phase of Flight	Mean (SD)	% Acceptable (1–3)	% Acceptable For Limited Time (4–6)	% Unacceptable (7–10)*
Preflight	3.56 (1.50)	59	35	5
Taxi	3.62 (1.64)	54	40	7
Takeoff	4.53 (1.58)	29	59	11
Climb	4.02 (1.42)	41	54	5
Cruise	3.38 (1.24)	60	38	2
Descent	3.61 (1.16)	51	47	2
Approach	4.21 (1.35)	32	61	6
Landing	4.60 (1.52)	28	62	10
Turnaround	3.40 (1.51)	59	34	6

* Scores 6–7 indicate that a reduction in workload is desirable, scores 8–10 indicate an increasing potential for overload.

changes in sleep architecture that indicate insufficient sleep (3). On the other hand, 32% of crewmembers reported averaging more sleep on trip nights than pretrip. On trip nights, crewmembers succeeded in falling asleep somewhat earlier (average 48 min) but took longer to fall asleep (average 18 min). This stands in contrast to the shorter sleep latencies observed in the laboratory with increasing sleep debt (3). There are several physiological factors which make it difficult to fall asleep earlier than usual. Sleep onset is less likely at certain phases of the circadian cycle (the so-called "wake maintenance zones"), one of which occurs shortly before the habitual bedtime (15,16). Because the "biological day" dictated by the circadian clock tends to be longer than 24 h, it is easier to go to sleep later than to go to sleep earlier. Going to sleep later also means staying awake longer, which allows more time for the homeostatic "sleep pressure" to build up (1,5).

Crewmembers rated their sleep as better overall on posttrip nights than on trip nights, and deeper on posttrip nights than pretrip. This is consistent with the polygraphically confirmed observation in the laboratory that recovery sleep after sleep restriction is deeper (3).

Fatigue was rated as significantly higher posttrip than pretrip, possibly indicating an accumulated effect of duty demands and sleep loss. In the first rating on trip mornings, fatigue was lower and activation higher than either pretrip or posttrip. This is somewhat surprising given the early wakeup times and shortened sleep on trips. It may reflect increased motivation associated with going on duty. By the end of trip days, fatigue and negative affect were higher, and activation was lower than by the end of pretrip days, suggesting an impact of duty-related activities on these measures. Multiple regression analyses (7) indicated that the later crewmembers stayed on duty, the higher their fatigue ratings by the end of the day. Similarly, the longer they remained on duty, the more negative their mood became. Going on duty earlier resulted in a lower activation rating by the end of the day, possibly because of the associated sleep loss. Fatigue, activation, and negative affect ratings showed significant time-of-day variation, as was found for short-haul fixed-wing crewmembers (10). Neither group showed significant time-of-day variation in positive affect.

Caffeine consumption increased by 42% on trip days by comparison with pretrip and posttrip days. Most of this extra consumption occurred shortly after wakeup (which was earlier on trips) and around the time of the mid-afternoon peak in physiological sleepiness (7). Since caffeine was not usually available in flight, the afternoon increase in caffeine consumption presumably occurred after duty (see Table I). The urge to fall asleep in the afternoon would be expected to increase progressively with the sleep loss accumulating across trip days (2). Headaches affected 73% of subjects at some time during the study, while back pain affected 32% and burning eyes 18%. On trips, the incidence of headaches doubled, back pain increased 12-fold, and burning eyes quadrupled, by comparison with home.

Comparing these operations to the short-haul fixed-wing operations examined in the first NASA fatigue field study (8,10), helicopter crews worked shorter duty days (by an average of 3.4 h) with fewer flight segments (by an average of 2.1) and fewer flight hours (by an average of 0.9 h). They also had longer nighttime layovers (by an average of 4.2 h). A 2-group *t*-test did not indicate a significant difference between the helicopter and short-haul fixed-wing groups in their sleep loss on trip nights, by comparison with pretrip nights. However, fewer helicopter crewmembers averaged more than 1 h of sleep loss per day on trips (50% vs. 67% of fixed-wing crew-

TABLE VIII. AVERAGE SCORES FOR THE FIVE ENVIRONMENTAL FACTORS.

Environmental Factors	Mean (SD)	% Favorable (1–2)	% Neither (3)	% Unfavorable (4–5)
Aircraft systems	1.79 (0.91)	83	11	6
Landing weather	1.93 (1.00)	74	16	9
Airport	1.94 (0.88)	75	21	4
Letdown aids	1.98 (1.05)	69	24	7
Air traffic control	1.88 (0.87)	77	19	4

TABLE IX. EFFECTS OF ENVIRONMENTAL FACTORS ON WORKLOAD DURING DIFFERENT PHASES OF FLIGHT.

Phase of Flight	F Ratio Season	F Ratio Segment Number	F Ratio Aircraft Systems	F Ratio Landing Weather	F Ratio Airport	F Ratio Letdown Aids	F Ratio Air Traffic Control
Preflight	0.63	1.73	4.75**	4.43**	3.85*	0.86	0.61
Taxi	3.06	3.02*	3.02*	2.03	0.23	1.31	2.00
Takeoff	4.72	1.95	1.43	0.56	0.60	1.25	0.60
Climb	1.44	2.15	4.27**	0.47	0.10	0.57	1.67
Cruise	1.60	1.51	2.79*	1.22	0.93	0.28	0.38
Descent	2.20	0.46	2.48	5.65**	1.93	0.34	0.67
Approach	2.18	1.30	1.21	7.90***	0.56	0.37	0.82
Landing	3.45	0.65	2.57	0.53	6.33**	0.78	0.32
Turnaround	5.88*	0.64	0.68	0.65	0.31	0.28	1.16

* $0.05 > p > 0.01$; ** $0.01 > p > 0.001$; *** $p < 0.001$.

members), and more helicopter crewmembers slept more per 24 h on trips than pretrip (32% vs. 12% of fixed-wing crewmembers). This comparison suggests that sleep loss was less severe during the helicopter operations. However, the estimates of sleep loss for the fixed-wing operations may have been exaggerated by the practice of crewmembers napping strategically on the day before the trip. This inflated their total pretrip baseline sleep, against which sleep loss was calculated (10). It is noteworthy that providing helicopter crews with 4.2 h more layover time did not prevent them from losing sleep. This highlights the importance of the timing of the layover. The helicopter crews finished work much earlier than the fixed-wing crews, but they also had to report for duty earlier (by 1.2 h on average). They were not able to advance their sleep sufficiently to compensate for these early wakeups, i.e., the additional layover time in the afternoon did not serve as additional time for sleep, at least in part because of the physiological constraints on sleep timing outlined above. In contrast to their fixed-wing counterparts, the helicopter crewmembers did not report consistently poorer sleep quality on trip nights compared with pretrip or posttrip. Two factors may have contributed to this. First, the helicopter crewmembers were younger (by an average of 9 yr). Second, they returned home each night, whereas the fixed-wing crews slept in en route layover hotels while on trips.

Helicopter crewmembers showed duty-related changes in fatigue and mood ratings, reporting greater fatigue, lower activation, and more negative mood by the end of trip days than by the end of pretrip or posttrip days. Comparable changes were not reported by the fixed-wing crewmembers, after allowing for the time-of-day variation in these measures (10). Complaints of headache and back pain were three times more common among helicopter crewmembers than among fixed-wing crewmembers. These differences may be related to the more physically stressful working environment of the helicopter cockpits. A study on the thermal environment in these cockpits (11) indicated that core temperatures of pilots remained below the level where any performance decrement due to heat stress might be expected. However, 40–50% (depending on the season) of the skin temperature readings fell outside the range of thermal comfort (33–34.5°C). Poor ventilation and airflow on many flightdecks probably accentuated sensations of physical discomfort (Barnes RM. Unpublished observations). A study on vibration exposures in these cockpits (12) found that all the helicopters exceeded the "reduced comfort" boundary defined by the International Standards Organi-

TABLE X. PILOT CHARACTERISTICS, HELICOPTER VS. SHORT-HAUL FIXED-WING OPERATIONS.

	Mean (SD) Helicopter	Mean (SD) Fixed-Wing	*t*
Age (yr)	34.32 (6.66)	43.02 (7.65)	4.54***
Experience (yr)	8.64 (4.35)	17.07 (6.56)	6.22***
Height (in)	70.73 (2.66)	70.59 (1.86)	0.24
Weight (lb)	164.80 (4.10)	174.84 (2.15)	2.15*
Personal Attributes Questionnaire			
Instrumentality	21.36 (3.71)	23.27 (3.94)	1.89
Expressivity	19.55 (3.84)	22.34 (4.40)	2.53*
I + E	2.41 (1.10)	2.84 (1.01)	1.59
Work and Family Orientation			
Mastery	21.32 (3.55)	19.95 (4.10)	1.33
Competitiveness	12.27 (3.93)	12.57 (3.49)	0.31
Work	17.68 (2.06)	17.66 (2.09)	0.04
Eysenck Personality Inventory			
Neuroticism	8.15 (4.73)	6.58 (4.51)	1.27
Extraversion	9.52 (3.72)	10.91 (3.46)	1.46
Lie Scale	3.27 (2.00)	3.41 (1.92)	0.27
Morning/Eveningness	59.82 (8.27)	63.41 (9.47)	1.51

* $0.05 > p > 0.01$; *** $p < 0.001$.

TABLE XI. DUTY CHARACTERISTICS, HELICOPTER VS. SHORT-HAUL FIXED-WING OPERATIONS.

	Mean (SD) Helicopter	Mean (SD) Fixed-Wing	t
On-duty (local time)	7.47 (2.20)	8.71 (3.14)	3.62***
Off-duty (local time)	14.77 (2.53)	19.06 (3.54)	11.05***
Duty hours/day	7.30 (2.53)	10.66 (2.41)	12.81***
Nighttime layover duration (h)	16.77 (3.05)	12.52 (2.52)	10.14***
Flight hours/day	3.58 (1.11)	4.50 (1.39)	5.08***
Flight segments/day	3.02 (1.46)	5.12 (1.34)	8.82***
Flight hours/month	61.48 (18.69)	70.21 (9.92)	1.95

*** $p < 0.001$.

zation (ISO 263), and several approached or exceeded the "fatigue decreased proficiency" boundary. This is the limit beyond which exposure to vibration can be regarded as carrying a significant risk of impaired working efficiency. Improved seat design, and improved isolation of the seat from floor vibration were recommended as countermeasures. The 12-fold increase in reports of back pain during trips reinforces the importance of this recommendation.

The workload ratings in this study tended to be higher than those during the flight test evaluation of workload in a shorthaul fixed-wing aircraft (Barnes RM. Unpublished observations). Preflight workload ratings were influenced by segment number, landing weather, the landing site, and the quality of the aircraft systems. This is consistent with the fact that the aircraft were often operating near the upper limit of their range and in poor weather, with limited alternate landing sites. Paperwork was also cited by pilots as an important source of workload during preflight. Efforts to reduce and standardize paperwork have since been undertaken (13). Workload ratings during taxi were affected by the quality of aircraft systems, the flight segment number, and the season, depending on which variables were included in the ANOVA model. Pilots also cited weather and traffic conditions at peak times as important contributing factors to their perceived workload during taxi.

None of the environmental factors tested had a significant effect on workload ratings during takeoff. During climb and cruise, the only significant factor found was the quality of the aircraft systems. However, the cockpit observers noted that the high workload associated with climb can be exacerbated by heavy ATC demands in the presence of other traffic. Although the present analyses did not identify landing weather as factor affecting workload during cruise, the cockpit observers noted that, in poor weather, the non-flying pilot could spend a considerable amount of time obtaining weather information from various rigs.

TABLE XII. CHANGES IN SLEEP FROM PRETRIP TO TRIP NIGHTS: COMPARING HELICOPTER AND SHORT-HAUL FIXED WING CREWS.

	Helicopter	Short-Haul Fixed-Wing	t
Sleep onset time (h)	−0.88	−0.31	1.32
Sleep latency (min)	18.22	25.55	1.35
Wakeup time (h)	−1.59	−1.53	0.16
Sleep duration (h)	−0.87	−1.37	−1.53

During descent and approach, the landing weather had a major effect on the subjective workload ratings. This is consistent with the fact that weather conditions in the North Sea oil fields often present a hostile environment for helicopter operations, including high winds, reduced visibility due to fog banks and low cloud, icing, turbulence over the rigs, and, at low levels, salt spray. Subjective ratings of workload during landing were associated with the quality of the landing site and the air traffic control. Traffic control, at sites other than airfields, is usually procedural in the terminal areas, requiring a high level of alertness. Turbulence over the rig, obstructions, and the size of the landing area may also increase workload. Landings on platforms on tankers at fixed moorings often require fine judgment because of the additional problems of heave and sway.

A number of recommendations about ways to reduce fatigue can be made on the basis of these findings. First, the scheduling practice of requiring early duty report times effectively reduces the time available for sleep, even during long layovers. This is because physiological factors tend to oppose falling asleep earlier than the usual bedtime. Delaying on-duty times (by 1.5–2.0 h on average) would be expected to produce a significant improvement in the amount of sleep that crewmembers are able to obtain.

Second, the challenging physical environment of the helicopter flightdeck, combined with high workload, might be expected to contribute to the high incidence of headaches and back pain reported, and to the increase in subjective fatigue and negative mood across duty days. Improvements in seat design, in the isolation of the seat from floor vibration (12), and in ventilation on the flightdeck, could be beneficial.

Third, the quality of aircraft systems was perceived by crewmembers to have an important effect on workload during preflight, taxi, climb, and cruise. This suggests that workload reduction during these phases might be achieved by improving aircraft maintenance. The data also support the idea that the impact of adverse weather on subjective workload during descent and approach can be reduced by improving the quality of the letdown aids and the landing site.

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