**OFFICE OF THE UNDER SECRETARY OF DEFENSE**
**4000 DEFENSE PENTAGON**
**WASHINGTON, D.C. 20301-4000**

**PERSONNEL AND READINESS**

The Honorable James M. Inhofe
Chairman
Committee on Armed Services
United States Senate
Washington, DC 20510

FEB - 8 2019

Dear Mr. Chairman:

The enclosed report responds to section 750 of the National Defense Authorization Act for Fiscal Year 2017 (Public Law 114-328), which requires the Secretary of Defense to conduct a study of career helicopter and tiltrotor pilots, and assess potential links between the operation of helicopter and tiltrotor aircraft and acute and chronic medical conditions experienced by such pilots. A 14 member working group, consisting of representatives from Department of Defense aeromedical research organizations and the Armed Forces Health Surveillance Branch, conducted the study.

The working group approached the study in three phases: review of the published scientific and technical literature addressing potential health effects of piloting helicopter or tiltrotor aircraft (Phase I); epidemiological study to compare the health of career helicopter and tiltrotor pilots to a control population (Phase II); and integration of the epidemiology study results and literature review findings to formulate conclusions and recommendations (Phase III). The results showed that the career military helicopter and tiltrotor pilots are healthier than military non-pilot officers, for the health conditions assessed in the epidemiological study.

Thank you for your interest in the health and well-being of our Service members, veterans, and their families. A similar letter is being sent to the Chairman of the House Armed Services Committee.

James N. Stewart
Assistant Secretary of Defense for Manpower and Reserve Affairs, Performing the Duties of the Under Secretary of Defense for Personnel and Readiness

Enclosure:
As stated

cc:
The Honorable Jack Reed
Ranking Member

**OFFICE OF THE UNDER SECRETARY OF DEFENSE**
**4000 DEFENSE PENTAGON**
**WASHINGTON, D.C. 20301-4000**

**PERSONNEL AND READINESS**

FEB - 8 2019

The Honorable Adam Smith
Chairman
Committee on Armed Services
U.S. House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

The enclosed report responds to section 750 of the National Defense Authorization Act for Fiscal Year 2017 (Public Law 114-328), which requires the Secretary of Defense to conduct a study of career helicopter and tiltrotor pilots, and assess potential links between the operation of helicopter and tiltrotor aircraft and acute and chronic medical conditions experienced by such pilots. A 14 member working group, consisting of representatives from Department of Defense aeromedical research organizations and the Armed Forces Health Surveillance Branch, conducted the study.

The working group approached the study in three phases: review of the published scientific and technical literature addressing potential health effects of piloting helicopter or tiltrotor aircraft (Phase I); epidemiological study to compare the health of career helicopter and tiltrotor pilots to a control population (Phase II); and integration of the epidemiology study results and literature review findings to formulate conclusions and recommendations (Phase III). The results showed that the career military helicopter and tiltrotor pilots are healthier than military non-pilot officers, for the health conditions assessed in the epidemiological study.

Thank you for your interest in the health and well-being of our Service members, veterans, and their families. A similar letter is being sent to the Chairman of the Senate Armed Services Committee.

James N. Stewart
Assistant Secretary of Defense for Manpower and Reserve Affairs, Performing the Duties of the Under Secretary of Defense for Personnel and Readiness

Enclosure:
As stated

cc:
The Honorable William M. "Mac" Thornberry
Ranking Member

**REPORT TO ARMED SERVICES COMMITTEES OF THE SENATE AND HOUSE OF REPRESENTATIVES**

# Study on Health of Helicopter and Tiltrotor Pilots:

# Literature Review and Epidemiology Study

**In Response to the Study Required by Section 750 of the**

**National Defense Authorization Act for Fiscal Year 2017 (Public Law 114-328)**

**The estimated cost of this report or study for the Department of Defense (DoD) is approximately $66,000.00 in Fiscal Years 2017 - 2018. This includes $32,000.00 in expenses and $34,000.00 in DoD labor.**

**February 2019**

# TABLE OF CONTENTS

# 1 EXECUTIVE SUMMARY

**Background**

This report is in response to section 750 ("Study on Health of Helicopter and Tiltrotor Pilots") of the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2017 (Public Law 114-328). It presents the findings of a working group established to study career helicopter and tiltrotor pilots to assess potential links between the operation of helicopter and tiltrotor aircraft and the acute and chronic medical conditions experienced by such pilots.

In 2017, representatives of three Military Services' aeromedical research organizations and the Defense Health Agency (DHA) met to craft a plan of action responsive to the tasking. As a result, a section 750 of the NDAA for FY 2017 working group was formed, consisting of 14 representatives from aeromedical research organizations and the Armed Forces Health Surveillance Branch (AFHSB), with oversight provided by the U.S. Army Medical Research and Materiel Command and the DHA.

**Approach**

A three-phase study strategy was formulated: Phase I involved a review of published scientific and technical literature addressing potential health effects of piloting helicopter or tiltrotor aircraft (led by the U.S. Army Aeromedical Research Laboratory (USAARL)); Phase II consisted of an epidemiological study to compare the health of career helicopter pilots and tiltrotor pilots to a suitable control population (led by the AFHSB); and Phase III integrated and discussed the results of the epidemiology study with respect to the literature review, and formulated conclusions.

**Results**

The aeromedical literature review of indications for acute and chronic medical conditions highlighted the dominance of musculoskeletal health concerns in the rotary-wing aircrew community. The literature most frequently cites the relationship between the helicopter pilot occupation and neck and back pain, which are exacerbated by increased head-supported mass, and aircraft vibration and aviator posture, respectively. The other significant finding is the lack of information in the published literature regarding any medical issues related to currently flying tiltrotor aircraft (i.e., the V-22).

The retrospective cohort study conducted as part of the section 750 of the NDAA for FY 2017 tasking evaluated 31 acute and chronic medical conditions, including injuries, mental health, and metabolic, neurologic, orthopedic and respiratory conditions. The study found the following:

(1) Based on the 31 conditions evaluated, highly-screened and monitored military helicopter pilots had fewer medical conditions than non-pilot officers.

(2) Helicopter/tiltrotor pilots (exposed cohort) had a 26 percent higher risk of low back pain compared to the fixed-wing control cohort.

(3) In a sub-analysis, the risk of a neck pain diagnosis (i.e., sprains and strains) was 27 percent higher among U.S. Air Force (USAF) helicopter/tiltrotor pilots than USAF fixed-wing pilots.

(4) In comparison to fixed-wing pilots, helicopter/tiltrotor pilots had an increased risk of metabolic syndrome and hyperlipidemia. This was likely related to heightened screening of this population during the study period.

(5) Helicopter/tiltrotor pilots had an 11 percent lower risk of hearing loss than the non-pilot control group. There was no difference between the exposed cohort and the fixed-wing pilot cohort.

**Conclusions**

Career military helicopter and tiltrotor pilots are healthier than the military non-pilot officer control population, at least considering the 31 health conditions assessed in the present epidemiological study. The study found that helicopter and tiltrotor pilots are at increased risk of metabolic syndrome and hyperlipidemia; however, this is likely related to the increased screening of this population during the study period.

Compelling evidence exists that career helicopter pilots are at increased occupational risk for low back pain and neck strain/sprain. This is based on a review of the published aeromedical literature, combined with the new epidemiological study presented in this report.

There was insufficient evidence in the medical literature to assess whether career tiltrotor pilots experience adverse health effects due to operating tiltrotor aircraft. Virtually no information regarding health effects or human factor concerns related to operational tiltrotor aircraft has been published in either the open or government technical literature.

The epidemiological study found that non-pilot officers had a higher risk of hearing loss than the helicopter and tiltrotor pilots.

In drawing these conclusions, the authors are mindful of the study limitations. In particular, the varied occupational composition of the U.S. Army portion of the non-pilot officer control group (including signal, intelligence, transportation, automotive maintenance, and quartermaster corps officers) may have contributed to study limitations because of differences between the helicopter pilots and the Army control population.

# 2 PURPOSE

Section 750 of the NDAA for FY 2017, contains the following tasking:

**SEC. 750. STUDY ON HEALTH OF HELICOPTER AND TILTROTOR PILOTS.**

(a) STUDY REQUIRED. —The Secretary of Defense shall carry out a study of career helicopter and tiltrotor pilots to assess potential links between the operation of helicopter and tiltrotor aircraft and acute and chronic medical conditions experienced by such pilots.

(b) ELEMENTS. —The study under subsection (a) shall include the following:

(1) A study of career helicopter and tiltrotor pilots compared to a control population that—

(A) takes into account the amount of time such pilots operated aircraft;

(B) examines the severity and rates of acute and chronic injuries experienced by such pilots; and

(C) determines whether such pilots experience a higher degree of acute and chronic medical conditions than the control population.

(2) If a higher degree of acute and chronic medical conditions is observed among such pilots, an explanation of—

(A) the specific causes of the conditions (such as whole body vibration, seat and cockpit ergonomics, landing loads, hard impacts, and pilot-worn gear); and

(B) any costs associated with treating the conditions if the causes are not mitigated.

(3) A review of relevant scientific literature and prior research.

(4) Such other information as the Secretary determines to be appropriate.

(c) DURATION. —The duration of the study under subsection (a) shall be not more than two (2) years.

(d) REPORT. —Not later than 30 days after the completion of the study under subsection (a), the Secretary shall submit to the Committees on Armed Services of the Senate and the House of Representatives a report on the study.

## 2.1 DEPARTMENT OF DEFENSE RESPONSE

Accordingly, a working group was assembled to conduct the study under DHA oversight. Representatives of the TriService aviation medicine research community complemented technical staff engaged from appropriate Service organizations, which maintain flying hour databases needed for the study. After the initial formative meeting, AFHSB representatives joined the study working group.

## 2.2 STUDY STRATEGY

To answer the questions posed by the section 750 of the NDAA for FY 2017 requirement, a three-phase study strategy was formulated:

- Phase 1: Review the published scientific and technical literature addressing potential health effects of piloting helicopters or tiltrotor aircraft (led by the USAARL, assisted by the USAF School of Aerospace Medicine and the Naval Medical Research Unit – Dayton (NAMRU-D)).

- Phase 2:  Conduct an epidemiology study to compare the health of career helicopter and tiltrotor pilots to a suitable control population (led by the AFHSB, and assisted by the Army, USAF, and U.S. Navy (USN) flying hour database organizations).

- Phase 3:  Interpret and discuss the combined literature review with the results of the new epidemiology study, drawing conclusions where possible and making recommendations as appropriate, in a report to the Committees on Armed Services of the Senate and the House of Representatives.

# 3 LITERATURE REVIEW ON THE HEALTH OF HELICOPTER PILOTS AND TILTROTOR PILOTS

## 3.1 INTRODUCTION

Helicopters and tiltrotors are two varieties of aircraft designed for specific missions that are impossible for conventional fixed-wing aircraft to accomplish. Both designs utilize blades or rotors to generate lift/propulsion; the helicopter rotor blades are fixed horizontally on the top of the aircraft (Figure 1), while the tiltrotor discs can be rotated to a vertical position for forward flight (Figure 2). Since helicopters have been used for over 75 years and tiltrotor aircraft have been used for approximately 10 years (and far fewer have been produced in comparison to helicopters), much more has been published about aeromedical aspects and health effects of helicopters than tiltrotors. This review relies primarily on the published peer-reviewed literature; however, this report notes areas wherein technical reports can help provide answers to the section 750 of the NDAA for FY 2017 tasking.


Figure 1. Helicopter (UH-60) (U.S. Army photo)

## 3.2 CHALLENGES IN ATTRIBUTING DISEASE TO THE AVIATION OCCUPATION

The study required by section 750 of the NDAA for FY 2017 is a timely and useful look at health trends in a segment of the military aviation community. However, epidemiological studies of special populations have inherent limitations and must be interpreted carefully. Cross-sectional epidemiological studies are useful for determining correlations, but do not prove causation; even the strongest association cannot be used to prove causation in an individual case (i.e., a patient) (Rothman, 1986). For example, the musculoskeletal conditions typically associated with career helicopter pilots also occur with some frequency in the non-aviator population, making it important to determine the background disease rate and any age effect to help separate any contributory role of the aviation environment. Finally, as the aviator population is initially pre-screened, undergoes periodic physical examinations, and receives ongoing surveillance by the unit flight surgeon, the selection of a comparable control group is important.

## 3.3 Platform-independent aviation exposures and aircrew health

### 3.3.1 Performance effects vs. health effects; acute vs chronic effects

Many aspects of the aviation environment can affect aircrew performance in the short term, including acceleration, disorientation, and hypoxia. These factors may affect "health" and their effects can be long-lasting, especially if protective gear is not worn or an accident/impact occurred (e.g., hard landing with secondary spinal fracture, or decompression sickness involving the central nervous system). These factors are reviewed extensively in the aeromedical literature (Davis, Johnson, Stepanek, & Fogarty, 2008; Gradwell & Rainford, 2016), and will only be discussed herein with respect to chronic health effects resulting from the helicopter or tiltrotor aircraft environments.

## 3.4 Defining occupational environments of interest

### 3.4.1 Military helicopters

After many years of attempts and skepticism, helicopters began to be accepted in the mid-1940s. This was too late to impact World War II, but in time to see considerable use in the Korean War for troop deployment, resupply, observation, and patient transport (Figure 3) (Adams, 2016). Helicopters rapidly became popular due to their ability to deliver in low altitude, low speed, and obstacle-rich environments that lack improved landing areas. Extensive use of helicopters in the Vietnam conflict further cemented their role in modern aviation. The UH-60 Black Hawk (Figure 1) was the first helicopter designed with crashworthiness and occupant survival as top priorities; it remains one of the safest helicopters available. The AH-64 Apache attack helicopter, introduced in the late 1980s (Figure 4), was the first aircraft, fixed-wing or rotary-wing, to provide complete pilotage capability via a helmet-mounted display (HMD) (Rash, Verona, & Crowley, 1990).

Figure 3. USAF H-5F departs with wounded, c.1950, Korea (Sikorsky photo)

Figure 4. U.S. Army AH-64 Apache attack helicopter (U.S. Army photo)

Helicopter piloting has primarily been a contact (Visual Flight Rules) visual task, (although many helicopters and pilots were, and are, instrument-rated), as typical missions required flight around obstacles, wires, at night, etc. As military operations increased in the deserts of the Middle East, the problem of "brown out," in which a hovering helicopter generates an enveloping and blinding dust cloud (Figure 5), became more frequent and severe. As a result, numerous technologies and countermeasures are under development to cope with degraded visual environment. These technologies may increase operator workload or pose a health risk to pilots (e.g., neck injury due to extra weight on the helmet from night vision goggles (NVG)).

Figure 5. Army UH-60 Black Hawk helicopter in enveloping dust cloud (brown-out) (U.S. Army photo)

### 3.4.2 Military tiltrotor aircraft

As agile and flexible as helicopters can be, there has been a longstanding operational requirement for a faster aircraft with longer range that retained a helicopter's vertical take-off and landing capability. As early as the 1950s, the U.S. Army and USAF teamed with industry and produced the XV-3 tiltrotor testbed (Figure 6). The National Aeronautics and Space Administration and the Department of Defense (DoD) opened the Tilt Rotor Research Aircraft Project Office in 1972, a collaboration that led to the eventual funding and acquisition of the V-22 Osprey (Figure 7), currently fielded and operated by the U.S. Marine Corps (USMC) and USAF (Maisel, Giulianetti, and Dugan, 2000).

Fig 6. XV-3 tiltrotor testbed, c.1950 (Bell Photo)

Fig 7. MV-22 tiltrotor aircraft (NAMRU-D Photo)

### 3.4.3 Occupational exposures

Specific aspects of helicopter and tiltrotor aircraft operations potentially linked to adverse health effects include: a) environmental – altitude, temperature, and disorientation; b) airframe –

vibration and acceleration; c) ergonomics – anthropometry and workload; and d) mission – fatigue and psychological (Davis, Johnson, Stepanek, & Fogarty, 2008; Robson, 2011; Gradwell & Rainford, 2016). Some exposures have been mapped to health effects (e.g., noise), while others have not (e.g., workload). In many cases, adverse health effects are observed, but the specific etiological agent is unclear (e.g., neck pain). Evidence for any linkages to adverse health effects will be discussed in the next section.

## 3.5 RECENT HEALTH TRENDS IDENTIFIED FOR MILITARY HELICOPTER AND TILTROTOR AIRCREW

### 3.5.1 Army helicopter aviator diagnoses and waivers (unpublished data)

#### *3.5.1.1 Background*

In 2016, the USAARL began a research program on helicopter aviator health and risk modeling.[1] As part of that program, a review of current Army Aviator medical issues was undertaken in 2017. The study investigators provided unpublished data, summarized below, to the section 750 of the NDAA for FY 2017 working group to help focus the epidemiological study (reported later) (Curry & Kelley, in review).

#### *3.5.1.2 Summary of Results*

The U.S. Army Aeromedical Electronic Resource Office was accessed to obtain medical diagnostic International Classification of Diseases, 9th revision (ICD-9) codes for Army aircrew diagnoses from 2005 to 2015 (Table 1), which were then combined into descriptive diagnostic categories (Table 2).

**Table 1. Top 5 ICD-9 Diagnoses in Army Aircrew 2005-2015**

| Rank | Disorder | Percent of all Diagnoses |
|---|---|---|
| **1** | Lumbago | 4.7 |
| **2** | Hypertension | 4.4 |
| **3** | Hearing loss | 4.0 |
| **4** | Hyperlipidemia | 3.9 |
| **5** | Metabolic syndrome | 3.4 |

**Table 2. Top 5 Diagnoses (by Category) in Army Aircrew 2005-2015**

| Rank | Disorder | Percent of all Diagnoses |
|---|---|---|
| **1** | Spinal | 15.2 |
| **2** | Orthopedic | 12.9 |
| **3** | Disorders of blood fats | 10.5 |
| **4** | Gastrointestinal tract | 10.3 |
| **5** | Ear, nose and throat | 10.3 |

[1] Work Unit E, "Operator Health and Performance in Complex Systems," Military Operational Medicine Research Program, U.S. Army Medical Research and Materiel Command, Fort Detrick, MD.

### 3.5.2 Anecdotes from V-22 crews

As mentioned previously, the experiences of V-22 crews have been unreported in the scientific or open technical literature to date. Unpublished V-22 crews' anecdotes highlight concerns with health and human performance linked to the tiltrotor flight envelope, particularly among rear crew (e.g., crew chief, loadmaster). However, these anecdotes are unsurprising; aircrew flying other military aircraft and tiltrotor aircrew face occupational health risks alike. These are worthy of further study.

## 3.6 Evidence linking aircraft exposures with clinical outcomes

This section discusses available evidence supporting an association between aviation environmental exposures and clinical outcomes. The review necessarily focuses on helicopter pilot health stressors and outcomes.

### 3.6.1 Musculoskeletal Conditions

#### *3.6.1.1 Neck Pain*

Neck problems are relatively new among helicopter aircrew, who are known to have low back pain problems variously attributed to helicopter-unique factors, such as vibration and posture. Reports of neck pain reports emerged in the 1990s, coincidentally as the use of helmet-mounted devices increased in military rotary-wing aviation.

Ang & Harms-Ringdahl (2006) studied 127 Swedish helicopter pilots, finding a 57 percent three-month prevalence of neck pain, with 32 percent reporting frequent pain. In the United Kingdom (U.K.) Royal Air Force, 57 percent of 188 helicopter pilots admitted to flight-related neck pain, which was significantly correlated with accumulated flight hours (Greaves & Wickes, 2008). Sharma & Agarwal (2008) surveyed 55 Indian military helicopter pilots who flew the Mi-8 (n=31) or the Mi-17 (n=24), and found 19 percent and 22 percent complaining of neck pain, respectively.

In a survey of 66 deployed U.S. Army aircrew, Hiatt & Rash (2011) found that 62 percent admitted to 'occasional' neck pain at minimum and 30 percent described neck pain 'frequently' or 'always' during flight, which was commonly attributed to heavy use of NVGs. Another survey found 58 percent of Army aircrew reporting neck pain while flying; respondents with smaller sitting height, fewer flying hours, and heavier NVG counterbalance weight reported less neck pain (Walters, Cox, Clayborne, & Hathaway, 2012).

Grossman, et al. (2012) found utility helicopter pilots have a higher rate of neck pain (47.3 percent), compared to attack helicopter pilots (36.4 percent). A significant proportion of subjects suffered from pain in multiple regions, particularly among utility helicopter pilots (32.74 percent). Severity of pain was graded higher in all three regions (cervical, mid, and lower back) among utility helicopter pilots, who also had more prevalent and more severe back pain than pilots of other platforms.

U.K. Apache attack helicopter pilots were followed over a 10-year period as part of a joint U.S.-U.K. study primarily aimed at detecting possible effects of the Apache's monocular display on vision. Questionnaire data collected during this study revealed that the percentage of aircrew experiencing in-flight neck pain increased over the course of the study, from 30 percent to approximately 57 percent in both the Apache study group and the non-Apache control helicopter group (Walters, Gaydos, Kelley, & Grandizio, 2013).

Orsello, et al. (2013c) used data from a 2011 survey of 458 USN helicopter aircrew (81 percent of whom were H-60 pilots) to determine predictors and risk factors for neck pain. 58 percent of respondents reported significant in-flight neck pain, of which the strongest predictor was low back pain during flight. Pilots who reported experiencing low back pain during at least 50 percent of the flight duration were seven times more likely to suffer from significant neck pain during flight. Other factors, including height, body mass index, and total flight hours, did not predict in-flight neck pain.

Van den Oord (2013) collected survey and physiological data from Royal Netherlands Air Force helicopter crew and found a 20 percent 1-year prevalence of regular or continuous neck pain, which was slightly lower than previous reports. Muscular strength, range-of-motion, and neck position sense were not correlated with a history of neck pain.

A multinational survey of helicopter aircrew neck symptoms conducted by researchers from the U.K., U.S. Army, USN, and Canada, found that 45 percent of aircrew reported neck pain during flight, while 85 percent reported at least one episode of neck pain during flight (Fraser, Crowley, Shender, & Lee, 2015).

Aydoq, et al. (2004) analyzed conventional x-rays for 732 Turkish pilots, including 159 helicopter pilots, 19 percent of whom had cervical changes—higher than the other pilot groups or the control group. Age was the most important variable related to spondylarthritic (arthritic conditions that affect the spine) or spondylitic changes.

Landau, et al. (2006) compared cervical magnetic resonance imaging findings among fast jet, helicopter, and transport aircraft pilots, and found that spinal degenerative changes seemed to be linked more to age than the flight platform. Since the groups were very small (10 pilots each), and age was not controlled, the effects of age and platform could not be analyzed.

Byeon, et al. (2013) studied 186 Korean helicopter pilots and a clerical control group with radiographs, interviews, and questionnaires, and found that degenerative changes were significantly more prevalent in the helicopter pilot group. In a multivariate model, ‘accumulated flight hours’ was associated with degenerative changes.

A number of relatively controlled observational studies cite the contribution of NVGs or other HMDs to neck pain. Ang & Harms-Ringdahl (2006) found an insignificant association between history of NVG use and neck pain. Greaves & Wickes (2008) reported that U.K. helicopter crews with neck pain had flown significantly more hours than helicopter crews without pain, especially with increased NVG flying hours. Additionally, helicopter front aircrew who had flown over 700 hours with NVGs had more than an 80 percent likelihood of developing flight-related neck pain. Approximately 50 percent of surveyed U.S. Army helicopter pilots with neck pain attributed their symptoms to the heavy use of NVGs in the deployed setting (Hiatt & Rash, 2011). Recent aircrew surveys continue to underscore NVG exposure as a primary source of neck pain risk (Chafe & Farrell, 2016). A 2015 analysis of recent international survey data (Fraser, et al., 2015) found that 45 percent of aircrew reported neck pain during flight, which significantly correlated with the total number of NVG flight hours and the average number of NVG hours per mission; the latter was also predictive of pain persisting after the flight. These survey data also suggest that neck pain tended to appear after two hours of NVG flight, emphasizing the risk of long NVG missions.

Tiltrotor/V-22 experience: There have been no reports of neck pain specifically among V-22 crew; however, given the higher-than-helicopter levels of +Gz[2] and frequent use of NVG, it is likely that this population experiences a high rate of neck pain and injury. This should be investigated.

#### *3.6.1.2 Low Back Pain*

Thomae, et al. (1998) surveyed 131 Australian military helicopter pilots and found 64 percent reported back pain, with 28 percent experiencing the pain during flight. More than half of the pilots indicated that the pain had interfered with their safe control of the helicopter. In a logistic regression model, prior history of back injury was the most signifcant predictor of back pain among helicopter pilots.

Bridger, et al. (2002) found that 80 percent of British Royal Navy helicopter pilots who operated helicopter controls and flew the aircraft exerienced back pain; this rate dropped to 24 percent among non-flying pilot aircrew. In addition, Polish military helicopter pilots were found to have a back pain prevalence of 70 percent, based on a survey of 112 aircrew (Truszczynska, et al., 2012).

In a comprehensive review of back pain among helicopter pilots, Gaydos (2012) found that the prevalence of the most common pain syndromes ranges from 50-92 percent and cited frequent reports of back pain affecting aviation safety. Gaydos described the ‘prototypical’ rotary-wing pilot’s back pain as beginning during flight or within hours of flight, mostly targeted in the low back/lumbar region and/or buttocks, transient, and commonly described as dull and achy. It often resolves post-flight or within hours after flight (though this period is described variably in the literature), and the aviator remains relatively asymptomatic until re-exposure to flight conditions. Shanahan (1984) makes the case that this differs from ‘routine’ episodes of low back pain experienced by the general adult population, whereby incident episodes are rarer, marked by extended asymptomatic periods, and are more unpredictable in recurrence. Orsello, et al. (2013b) found that height was a strong predictor of low back pain among USN helicopter pilots.

Most recently, Knox, et al. (2018) analyzed the U.S. Defense Medical Epidemiology Database (DMED) for cases of lumbar disc herniation among military helicopter pilots from 2006 to 2015, and found its incidence rate to be significantly higher than that of a control group composed of all U.S. military non-helicopter pilot officers. This effect was particularly strong among Army helicopter pilots, who had an incidence rate almost three times more than that of USN and

[2] +Gz represents the gravitational force acting on an aircrew member in a “head-to-toe” or “eyeballs-down” direction, which is increased most frequently in maneuvering aircraft while climbing or in a tight turn. Increased +Gz while wearing heavy HMDs or NVGs is thought to contribute to aircrew neck pain.

USMC helicopter pilots.

Tiltrotor/V-22 experience: There have been no reports of back pain specifically among V-22 crews; however, given the comments about higher-than-helicopter levels of +Gz, and the concerns about vibration levels, rapid accelerations, and turbulence, this population likely experiences a high rate of back pain and spine injury. This should be investigated.

### 3.6.2 Ear/Hearing Conditions

High internal helicopter noise levels are well-known, and all aircrew are expected to comply with required levels of hearing protection. Noise surveys and research on the effects of noise on communication and workload apply to helicopter/tiltrotor flight, and across the spectrum of aviation platforms. Some examples documenting the hazard in helicopters include the work of Fitzpatrick (1988), Owen (1996), Orsello, et al. (2013a), and Hansen, et al. (2017).

Tiltrotor/V-22 experience: Although not cleared for public release, noise surveys of the V-22 have been conducted and protection guidance given.

### 3.6.3 Cardiovascular

Tolerance for sustained acceleration is not usually an issue among helicopter pilots, as the level of G-force (G) that can be maintained for more than a few seconds is quite low. However, at the time the AH-64 Apache was introduced more than 30 years ago, its increased maneuverability (up to +3.5Gz) resulted in concern that dehydrated aircrew may potentially encounter G symptoms of gray-out or even black-out; this was ensued by a published educational article (Crowley, Cornum, & Marin, 1990). Such problems either never developed or were managed at the unit level. Additionally, a case report was recently published describing possible G-related symptoms in an Australian Black Hawk helicopter pilot, which highlights the possibility of acceleration symptoms (McMahon & Newman, 2016).

Tiltrotor/V-22 experience: Unlike traditional helicopters, tiltrotor aircraft can sustain G long enough to elicit cardiovascular reflexes and G symptoms, particularly in a pilot weakened by operational stresses. This should be investigated.

### 3.6.4 Psychiatric conditions

The advent of high definition displays, which may show detailed weapons effects on human targets, brings a new concern for the potential onset of mental health issues among attack helicopter crew. Whereas helicopter gunners in previous generations fired at some distant anonymous tree line, now aircrew are inundated with imagery showing potentially disturbing details (Macy, 2008). Aviation crewmembers can, of course, be exposed to very disturbing wartime sights and emotions in other ways (Mills, 1992); however, this area deserves further research to determine if there are latent problems in need of treatment.

Tiltrotor/V-22 experience: There have been no reports, published or anecdotal, of psychiatric conditions incurred by V-22 crews.

## 3.7 LITERATURE SUMMARY

Although the helicopter and tiltrotor aviation environments are replete with environmental and operational hazards that can cause acute performance and health effects, these are almost always transient, barring a catastrophic event (e.g., crash). By far, the helicopter pilot health issues that dominate the medical literature are musculoskeletal—neck pain and back pain. Although strong evidence exists suggesting a causative link between these environments and acute musculoskeletal problems, separating the long-term effects of the helicopter aviation environment from the effects of age and non-aviation causes is very difficult. Well-designed cohort studies are recommended. Additionally, an updated study to assess the effectiveness of hearing conservation programs for helicopter and tiltrotor crewmembers would be useful. There is no literature available describing any health effects among pilots of tiltrotor aircraft.

# 4 REPORT OF 2018 EPIDEMIOLOGY STUDY OF MILITARY HELICOPTER PILOT AND TILTROTOR PILOT HEALTH

## 4.1 BACKGROUND

In response to section 750 of the NDAA for FY 2017, the DHA J-9 Research & Development Directorate was assigned to develop an integrated and coordinated approach to address these specific requirements. The J-9 developed a working group to address this requirement and requested the AFHSB propose and conduct an analysis on the acute and chronic health outcomes among helicopter and tiltrotor pilots.

## 4.2 METHODS

### 4.2.1 Study Design

A retrospective cohort study design was used to investigate the incidence of acute and chronic medical conditions among Active Component helicopter and tiltrotor pilots, and to compare these rates to those among non-pilot officers and fixed-wing pilots. The rationale for the selection of the health outcomes in this study is detailed below. Personnel, demographic, Military Service, and medical diagnostic ICD-9 and ICD-10th revision (ICD-10) encounter data were obtained from the Defense Medical Surveillance System (DMSS). Each Service provided specific pilot cohort data.

### 4.2.2 Subjects

The exposed cohort (helicopter and tiltrotor pilots) was identified using Service-generated rosters of helicopter and tiltrotor pilots with at least 1,000 flight hours in the aircraft of interest. For the purposes of this study, subject matter experts on the working group determined that a minimum of 1,000 flight hours was required for a pilot to be considered a “career pilot.”

Two unexposed cohorts were identified for this study. The first unexposed cohort, consisting of maintenance officers, was selected due to its expected similarity with the exposed cohort in its demographic and exposure characteristics (apart from being a pilot). However, since the Army had very few non-pilot maintenance officers, the Army portion of this unexposed cohort was expanded to encompass a selection of commissioned and warrant officers, including signal, intelligence, transportation, automotive maintenance, and quartermaster corps officers. The remainder of this report will refer to this unexposed cohort as the “non-pilot officer” cohort. This cohort was identified using the primary military occupational specialty (PMOS) codes from the DMSS (USAF: starts with 21; Army: starts with 120A, 125D, 131A, 140A/K/L, 150A, 170A, 255A/N, 270A, 290A, 311A, 350F/G, 351L/M, 352N/S, 353T, 420A/C, 640A, 670A, 740A, 880A, 881A, 882A, 890A, 913A, 914A, 915A, 919A, 920A/B, 921A, 922A, 923A, 948B, 948D, 15C/D, 25A, 35D/E/F/G, 88A/B/C/D, 92A/D; USN: starts with 152, 631-632, 636, 663, 731-733, 736; USMC: 6002, 6004, 6302, 6502).

The second unexposed cohort was composed of fixed-wing pilots. This cohort was selected to provide a comparison group with a similar potential health status as the exposed cohort. This cohort was identified using the DoD occupation codes in DMSS of 220100 (fixed-wing fighter/bomber pilots) or 220200 (other fixed-wing pilots). For the remainder of this report, this unexposed cohort will be referred to as the “fixed-wing pilot” cohort.

All cohorts were restricted to Active Component Service members (due to near complete capture of medical encounters during service), who served at any time between January 1, 1998 and December 31, 2015; were an officer or warrant officer; and were less than 40 years of age when they joined the cohort. Subjects entered the exposed cohort when they became a helicopter/tiltrotor pilot (defined as a DMSS demographic record wherein the indicated grade was either officer or warrant officer, and the DoD occupation code was 220300 (helicopter pilot)). Subjects entered one of the two unexposed cohorts when they started as a non-pilot officer (first DMSS demographic record with a PMOS of interest) or a fixed-wing pilot (first DMSS demographic record with a DoD occupation code of interest).

Subjects were followed from entry into the cohort of interest until they left service; left the Active Component; had an incident diagnosis for the condition of interest (separate censoring for each condition); or until December 31, 2017 (whichever came first). Subjects were excluded from the condition-specific analysis if they had the condition of interest diagnosed prior to entering the cohort. Although an analysis of the impact of flight hours on the risk of onset of specific conditions was requested, this analysis could not be conducted, since the date of reaching 1,000 flight hours was not available from all Military Services. Additionally, data on flight hours over time (longitudinal) were not available from any of the Services.

#### 4.2.3 Outcomes

Thirty-one acute and chronic medical conditions were independently evaluated for the study. Conditions ranged from injuries, mental health and metabolic conditions, to respiratory outcomes. Condition selection was based on data reflecting the 10 most frequent diagnoses, the 10 most frequent medical reasons for waivers, conditions resulting in permanent grounding among helicopter pilots (Tables 1 and 2), and from literature reviews. Appendix B contains a list of the conditions evaluated, ICD-9/ICD-10 codes, and the case definitions used to define each condition. For each condition, the first medical encounter with the diagnosis of interest was considered the incident diagnosis.

#### 4.2.4 Analysis

Analyses were conducted separately for each outcome. Person-time was calculated as the time from entry into the cohort to censoring event. Descriptive statistics and incidence rates were generated for each cohort and for outcome. The incidence rate ratio (IRR) was calculated by comparing the exposed cohort to each of the unexposed cohorts. A Poisson regression analysis was used to generate adjusted IRR estimates and associated 95 percent confidence intervals (95 percent Confidence Interval (CI)). Models were adjusted by sex, age category (i.e., 29 years or less, 30-39 years), and rank (i.e., CWO-2 and above all commissioned officers). All analyses were conducted using SAS 9.4 (Cary, North Carolina).

### 4.3 RESULTS

#### 4.3.1 Cohort Description

The exposed cohort included 3,733 pilots (3,601 helicopter and 132 tiltrotor pilots). The majority of the cohort was 29 years of age or less (77 percent), male (97 percent), warrant officers (64 percent) (although all tiltrotor pilots were officers), and in the Army (76 percent) (Table 3). The first unexposed cohort, non-pilot officers, included 45,566 Service members. Like the exposed cohort, the majority of the first unexposed cohort pilots were 29 years of age or less (62 percent), male (81 percent), and in the Army (76 percent). However, they had a higher proportion of officers (79 percent) than CWO-O2 and above all commissioned officers. The second unexposed cohort, fixed-wing pilots, included 31,341 Service members. This cohort also had a majority of Service members who were 29 years of age or less (86 percent) and male (94 percent), but the majority were officers (99 percent) and in the USAF (55 percent) or USN (36 percent). The median follow-up time was greatest among the exposed cohort (3,440 days), compared to 2,465 days for the non-pilot officers, and 2,922 days for the fixed-wing pilots.

### 4.3.2 Helicopter and Tiltrotor Pilots

The number of tiltrotor pilots was too small to conduct statistical analyses separately from the helicopter pilots. However, case counts and incidence rates were calculated for each group separately (Table 4, Figure 8). Among both helicopter and tiltrotor pilots, the most common outcomes were lumbago, allergic rhinitis, and hearing loss. For all outcomes, except carpal tunnel syndrome, the incidence rate estimate was higher among the helicopter pilots than the tiltrotor pilots. However, most frequent outcomes were similar among the comparison cohorts as well. Among non-pilot officers, the most frequent outcomes were lumbago, allergic rhinitis, and sleep apnea (Table 6). Among the fixed-wing pilots, the most frequent outcomes were allergic rhinitis, lumbago, and hearing loss (Table 7).

**Table 3. Demographics of the Study Cohorts**

| | Cohort | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exposed | | | | | | Unexposed | | | |
| | All | | Helicopter Pilots | | Tiltrotor Pilots | | Non-pilot Officers | | Fixed-wing Pilots | |
| | N | % | N | % | N | % | N | % | N | % |
| **Total N** | 3,733 | 100 | 3,601 | 100 | 132 | 100 | 45,566 | 100 | 31,341 | 100 |
| **Age (years)** | | | | | | | | | | |
| **29 or less** | 2,874 | 77 | 2,753 | 76 | 121 | 92 | 28,148 | 62 | 27,031 | 86 |
| **30-39** | 859 | 23 | 848 | 24 | 11 | 8 | 17,418 | 38 | 4,310 | 14 |
| **Sex** | | | | | | | | | | |
| **Male** | 3,632 | 97 | 3,502 | 97 | 130 | 98 | 36,686 | 81 | 29,437 | 94 |
| **Grade** | | | | | | | | | | |
| **Officer** | 1,360 | 36 | 1,228 | 34 | 132 | 100 | 35,780 | 79 | 30,893 | 99 |
| **Warrant Officer** | 2,373 | 64 | 2,373 | 66 | 0 | 0 | 9,786 | 21 | 448 | 1 |
| **Service** | | | | | | | | | | |
| **Army** | 2,821 | 76 | 2,821 | 78 | 0 | 0 | 36,181 | 79 | 445 | 1 |
| **Navy** | 85 | 2 | 85 | 2 | 0 | 0 | 1,878 | 4 | 11,325 | 36 |
| **Air Force** | 446 | 12 | 415 | 12 | 31 | 23 | 6,422 | 14 | 17,154 | 55 |
| **Marine Corps** | 381 | 10 | 280 | 8 | 101 | 77 | 1,085 | 2 | 2,417 | 8 |
| **Follow up Time (days)** | | | | | | | | | | |
| **Mean** | 3,647 | | 3,653 | | 3,497 | | 2,775 | | 3,247 | |
| **Median** | 3,440 | | 3,440 | | 3,348 | | 2,465 | | 2,922 | |
| **Minimum** | 274 | | 274 | | 1,887 | | 29 | | 28 | |
| **Maximum** | 7,274 | | 7,274 | | 6,728 | | 7,274 | | 7,305 | |

### 4.3.3 Comparison of Risk: Exposed versus Non-Pilot Officers

Compared to the non-pilot officers, the helicopter/tiltrotor pilot cohort had a lower risk for 25 out of the 31 outcomes investigated (Table 6). For these outcomes, after adjusting for differences in the demographics, the reduction in risk among helicopter/tiltrotor pilots ranged from 11 percent less likely to have hearing loss (adjusted IRR 0.89 (95 percent CI: 0.80, 0.99)) to 86 percent less likely to have a major depressive affective disorder, single episode (adjusted IRR 0.14 (95 percent CI: 0.08, 0.24)). There was no difference in the risk for 4 of the 31 outcomes (emphysema, chronic bronchitis, chronic airway obstruction not otherwise classified, and Dupuytren's syndrome). Only one outcome, metabolic syndrome, had a statistically significant higher risk among the exposed cohort than the non-pilot officer cohort. After adjusting for demographic differences, helicopter/tiltrotor pilots were almost six times more likely to acquire a metabolic syndrome than non-pilot officers (adjusted IRR 5.71 (95 percent CI: 2.89, 11.28)) (Table 5). The Service- and grade-stratified analyses did not yield different findings and are therefore not shown.

### 4.3.4 Comparison of Risk: Exposed versus Fixed-Wing Pilots

The helicopter/tiltrotor pilot cohort had a similar risk as the fixed-wing pilots for 26 of the 30 outcomes investigated (Table 7). After adjusting for demographic differences, the exposed cohort had a 27 percent lower risk of allergic rhinitis (adjusted IRR 0.73 (95 percent CI: 0.66-0.82)) than the fixed-wing pilot cohort. However, when compared to the fixed-wing pilot cohort, the helicopter/tiltrotor pilot cohort had a 26 percent higher risk for lumbago (adjusted IRR 1.26 (95 percent CI: 1.15, 1.39)); a 21 percent higher risk of hyperlipidemia (adjusted IRR 1.21 (95 percent CI: 1.04, 1.44)); and over 7 times greater risk of metabolic syndrome (adjusted IRR 7.46 (95 percent CI: 1.73, 32.20)). The majority of the results of the Service- and grade-stratified analyses were similar to the overall findings. However, when the analysis was restricted to each Service, USAF helicopter/tiltrotor pilots had a 27 percent higher risk of neck sprains/strains (adjusted IRR 1.27 (95 percent CI: 1.06, 1.53)), compared to USAF fixed-wing pilots (Table 5).

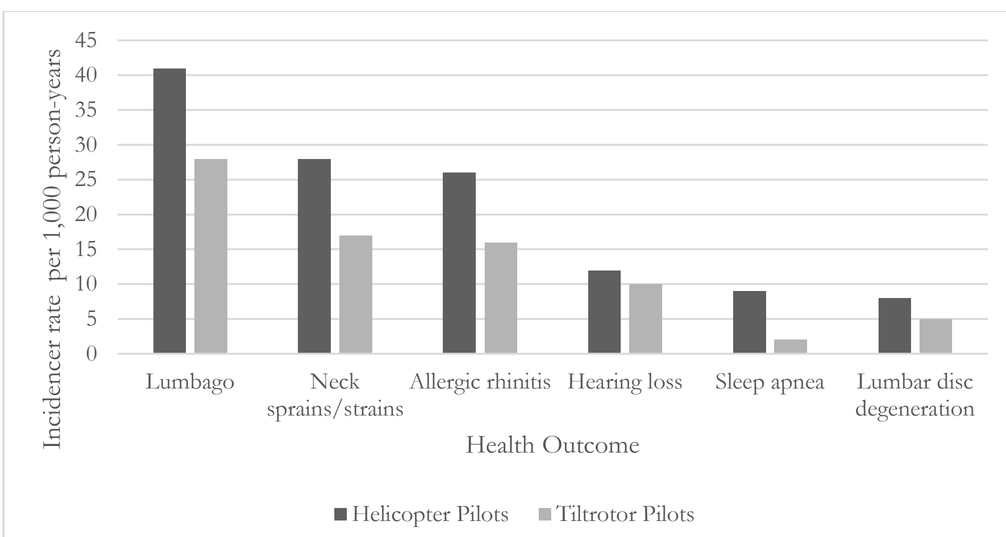


Figure 8. Incidence rates for top six health outcomes in helicopter and tiltrotor pilots

**Table 4. Incidence Counts and Rates for Helicopter and Tiltrotor Pilots**

| | Helicopter Pilots | | | Tiltrotor Pilots | | |
|---|---|---|---|---|---|---|
| **Outcome** | **Person-years** | **N** | **Incidence Rate** | **Person-years** | **N** | **Incidence Rate** |
| **Lumbago** | 25,780 | 1,064 | 41.27 | 1,084 | 30 | 27.66 |
| **Hypertension** | 35,358 | 117 | 3.31 | 1,261 | 1 | 0.79 |
| **Hearing loss** | 31,155 | 388 | 12.45 | 1,193 | 12 | 10.06 |
| **Hyperlipidemia** | 35,057 | 145 | 4.14 | 1,231 | 2 | 1.63 |
| **Metabolic Syndrome** | 35,972 | 16 | 0.45 | 1,264 | 0 | 0.00 |
| **Pure Hyperglyceridemia** | 35,961 | 6 | 0.17 | 1,264 | 0 | 0.00 |
| **Esophageal Reflux** | 34,445 | 195 | 5.66 | 1,206 | 6 | 4.98 |
| **Allergic Rhinitis** | 28,181 | 722 | 25.62 | 1,020 | 16 | 15.69 |
| **Displacement lumbar disc** | 34,500 | 249 | 7.22 | 1,240 | 6 | 4.84 |
| **Sleep Apnea** | 35,254 | 303 | 8.60 | 1,261 | 2 | 1.59 |
| **Degeneration lumbar disc** | 34,565 | 294 | 8.51 | 1,229 | 6 | 4.88 |
| **Hypothyroidism** | 35,919 | 15 | 0.42 | 1,264 | 0 | 0.00 |
| **Testicular dysfunction** | 35,624 | 89 | 2.50 | 1,247 | 2 | 1.60 |
| **Cervical disc displacement** | 35,439 | 160 | 4.52 | 1,261 | 1 | 0.79 |
| **PTSD** | 35,973 | 34 | 0.95 | 1,264 | 0 | 0.00 |
| **Displacement lumbar intervertebral disc without myelopathy** | 34,356 | 378 | 11.00 | 1,238 | 7 | 5.65 |
| **Anxiety state unspecified** | 35,597 | 87 | 2.44 | 1,262 | 1 | 0.79 |
| **Migraine** | 35,447 | 66 | 1.86 | 1,249 | 2 | 1.60 |
| **Degeneration of lumbar or lumbosacral intervertebral disc** | 34,584 | 271 | 7.84 | 1,227 | 7 | 5.70 |
| **Major depressive affective disorder single episode unspecified classification** | 35,927 | 14 | 0.39 | 1,264 | 0 | 0.00 |
| **Obstructive sleep apnea** | 35,271 | 291 | 8.25 | 1,261 | 2 | 1.59 |
| **Chronic Airway Obstructive Pulmonary Disease** | 35,548 | 38 | 1.07 | 1,264 | 0 | 0.00 |
| **Emphysema** | 36,001 | 1 | 0.03 | 1,264 | 0 | 0.00 |
| **Chronic bronchitis** | 35,969 | 2 | 0.06 | 1,264 | 0 | 0.00 |
| **Asthma** | 35,606 | 34 | 0.96 | 1,264 | 0 | 0.00 |
| **Chronic airway obstructions, not otherwise classified** | 35,981 | 2 | 0.06 | 1,264 | 0 | 0.00 |
| **Raynaud's Syndrome** | 35,994 | 2 | 0.06 | 1,264 | 0 | 0.00 |
| **Dupuytren's Syndrome** | 35,996 | 3 | 0.08 | 1,264 | 0 | 0.00 |
| **Carpal Tunnel Syndrome** | 35,894 | 35 | 0.98 | 1,253 | 2 | 1.60 |
| **Tarsal Tunnel Syndrome** | 35,989 | 3 | 0.08 | 1,264 | 0 | 0.00 |
| **Neck Strains/Sprains** | 29,854 | 825 | 27.97 | 1,104 | 19 | 17.22 |

**Incidence rates per 1,000 person-years**

Table 5. Outcomes with Statistically Significant Higher Risk (Incidence Rate Ratios) Among Helicopter/Tiltrotor Pilots Compared to Non-Pilot Officers or Fixed-Wing Pilots

| Outcome | Person years | N | Incidence Rate | Person years | N | Incidence Rate | IRR | 95% lower | 95% upper | IRR | 95% lower | 95% upper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Helicopter/Tiltrotor Pilots** | | | **Non Pilot Officers** | | | **(Statistically significant outcome from Table 7)** | | | | | |
| **Metabolic Syndrome** | 37,235 | 16 | 0.43 | 346,033 | 32 | 0.09 | 4.65 | 2.55 | 8.47 | 5.71 | 2.89 | 11.28 |
| | **Helicopter/Tiltrotor Pilots** | | | **Fixed Wing Pilots** | | | **(Statistically significant outcomes from Table 8)** | | | | | |
| **Metabolic Syndrome** | 37,235 | 16 | 0.43 | 278,540 | 6 | 0.02 | 19.95 | 7.81 | 50.98 | 7.46 | 1.73 | 32.20 |
| **Hyperlipidemia** | 36,287 | 147 | 4.05 | 273,571 | 885 | 3.24 | 1.25 | 1.05 | 1.49 | 1.21 | 1.02 | 1.44 |
| **Lumbago** | 26,865 | 1,094 | 40.72 | 231,320 | 6,193 | 26.77 | 1.52 | 1.43 | 1.62 | 1.26 | 1.15 | 1.39 |
| **Neck Sprains/Strains (USAF Only)** | 3,791 | 120 | 31.66 | 131,191 | 3,264 | 24.88 | 1.27 | 1.06 | 1.53 | 1.27 | 1.06 | 1.53 |

**Note: This table contains extracted results that reached statistical significance from the more detailed Tables 6 and 7.**
**Incidence rates per 1,000 person-years**
**IRR = Incidence rate ratio; CI = Confidence interval**
**Poisson model adjusted for sex, age category (i.e., 29 years or less, 30-39 years), and rank (i.e., officer, warrant officer)**

Table 6. Detailed Comparisons Between Helicopter/Tiltrotor Pilots and Non-Pilot Officers

| | Helicopter/Tiltrotor Pilots | | | Non Pilot Officers | | | Crude | | | Adjusted | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outcome | Person years | N | Incidence Rate | Person years | N | Incidence Rate | IRR | 95% lower | 95% upper | IRR | 95% lower | 95% upper |
| **Lumbago** | 26,865 | 1,094 | 40.72 | 233,723 | 11,674 | 49.95 | 0.82^ | 0.77 | 0.87 | 0.78^ | 0.73 | 0.83 |
| **Hypertension** | 36,619 | 118 | 3.22 | 333,223 | 2,269 | 6.81 | 0.47^ | 0.39 | 0.57 | 0.44^ | 0.36 | 0.53 |
| **Hearing loss** | 32,349 | 400 | 12.37 | 312,514 | 4,428 | 14.17 | 0.87^ | 0.79 | 0.97 | 0.89^ | 0.80 | 0.99 |
| **Hyperlipidemia** | 36,287 | 147 | 4.05 | 332,841 | 2,508 | 7.54 | 0.54^ | 0.46 | 0.63 | 0.55^ | 0.46 | 0.65 |
| **Metabolic Syndrome** | 37,235 | 16 | 0.43 | 346,033 | 32 | 0.09 | 4.65* | 2.55 | 8.47 | 5.71* | 2.89 | 11.28 |
| **Pure Hyperglyceridemia** | 37,225 | 6 | 0.16 | 345,437 | 147 | 0.43 | 0.38^ | 0.17 | 0.86 | 0.38^ | 0.17 | 0.88 |
| **Esophageal Reflux** | 35,651 | 201 | 5.64 | 323,434 | 3,452 | 10.67 | 0.53^ | 0.46 | 0.61 | 0.53^ | 0.46 | 0.61 |
| **Allergic Rhinitis** | 29,201 | 738 | 25.27 | 252,171 | 9,883 | 39.19 | 0.64^ | 0.60 | 0.69 | 0.71^ | 0.66 | 0.77 |
| **Displacement lumbar disc** | 35,741 | 255 | 7.14 | 327,719 | 3,502 | 10.69 | 0.67^ | 0.59 | 0.76 | 0.62^ | 0.54 | 0.71 |
| **Sleep Apnea** | 36,514 | 305 | 8.35 | 330,664 | 6,790 | 20.53 | 0.41^ | 0.36 | 0.46 | 0.35^ | 0.31 | 0.39 |
| **Degeneration lumbar disc** | 35,794 | 300 | 8.38 | 327,936 | 4,121 | 12.57 | 0.67^ | 0.59 | 0.75 | 0.63^ | 0.56 | 0.71 |
| **Hypothyroidism** | 37,182 | 15 | 0.40 | 342,748 | 627 | 1.83 | 0.22^ | 0.13 | 0.37 | 0.32^ | 0.19 | 0.54 |
| **Testicular dysfunction** | 36,871 | 91 | 2.47 | 341,666 | 1,065 | 3.12 | 0.79^ | 0.64 | 0.98 | 0.69^ | 0.55 | 0.86 |
| **Cervical disc displacement** | 36,700 | 161 | 4.39 | 339,115 | 1,910 | 5.63 | 0.78^ | 0.66 | 0.91 | 0.84^ | 0.71 | 0.99 |
| **PTSD** | 37,237 | 34 | 0.91 | 344,644 | 1,420 | 4.12 | 0.22^ | 0.16 | 0.31 | 0.19^ | 0.13 | 0.27 |
| **Displacement lumbar intervertebral disc without myelopathy** | 35,595 | 385 | 10.82 | 326,699 | 4,476 | 13.70 | 0.79^ | 0.71 | 0.88 | 0.74^ | 0.66 | 0.83 |
| **Anxiety state unspecified** | 36,859 | 88 | 2.39 | 333,230 | 3,947 | 11.85 | 0.30^ | 0.16 | 0.25 | 0.18^ | 0.14 | 0.22 |
| **Migraine** | 36,696 | 68 | 1.85 | 327,248 | 3,012 | 9.20 | 0.20^ | 0.16 | 0.26 | 0.23^ | 0.18 | 0.29 |
| **Degeneration of lumbar or lumbosacral intervertebral disc** | 35,811 | 278 | 7.76 | 328,286 | 3,787 | 11.54 | 0.67^ | 0.60 | 0.76 | 0.64^ | 0.56 | 0.72 |
| **Major depressive affective disorder single episode unspecified classification** | 37,191 | 14 | 0.38 | 342,935 | 990 | 2.89 | 0.13^ | 0.08 | 0.22 | 0.14^ | 0.08 | 0.24 |

Table 6. Detailed Comparisons Between Helicopter/Tiltrotor Pilots and Non-Pilot Officers

| | Helicopter/Tiltrotor Pilots | | | Non Pilot Officers | | | Crude | | | Adjusted | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Outcome** | **Person years** | **N** | **Incidence Rate** | **Person years** | **N** | **Incidence Rate** | **IRR** | **95% lower** | **95% upper** | **IRR** | **95% lower** | **95% upper** |
| **Obstructive sleep apnea** | 36,532 | 293 | 8.02 | 330,991 | 6,562 | 19.83 | 0.40^ | 0.36 | 0.45 | 0.35^ | 0.31 | 0.39 |
| **Chronic Airway Obstructive Pulmonary Disease** | 36,811 | 38 | 1.03 | 333,604 | 1,290 | 3.87 | 0.27^ | 0.19 | 0.37 | 0.31^ | 0.22 | 0.43 |
| **Emphysema** | 37,264 | 1 | 0.03 | 346,054 | 17 | 0.05 | 0.55 | 0.07 | 4.10 | 0.53 | 0.07 | 4.25 |
| **Chronic bronchitis** | 37,233 | 2 | 0.05 | 345,956 | 39 | 0.11 | 0.48 | 0.12 | 1.97 | 0.40 | 0.09 | 1.72 |
| **Asthma** | 36,870 | 34 | 0.92 | 334,015 | 1,218 | 3.65 | 0.25^ | 0.18 | 0.36 | 0.30^ | 0.21 | 0.42 |
| **Chronic airway obstructions, not otherwise classified** | 37,245 | 2 | 0.05 | 345,852 | 62 | 0.18 | 0.30 | 0.07 | 1.22 | 0.28 | 0.07 | 1.16 |
| **Raynaud's Syndrome** | 37,258 | 2 | 0.05 | 345,569 | 106 | 0.31 | 0.18^ | 0.04 | 0.71 | 0.23^ | 0.05 | 0.93 |
| **Dupuytren's Syndrome** | 37,260 | 3 | 0.08 | 345,889 | 58 | 0.17 | 0.48 | 0.15 | 1.53 | 0.42 | 0.13 | 1.38 |
| **Carpal Tunnel Syndrome** | 37,147 | 37 | 1.00 | 341,679 | 852 | 2.49 | 0.40^ | 0.29 | 0.56 | 0.43^ | 0.31 | 0.60 |
| **Tarsal Tunnel Syndrome** | 37,253 | 3 | 0.08 | 345,666 | 97 | 0.28 | 0.29^ | 0.09 | 0.91 | 0.28^ | 0.09 | 0.90 |

**Incidence rates per 1,000 person-years**
**IRR = Incidence rate ratio**
**Poisson model adjusted for sex, age category (i.e., 29 years or less, 30-39 years), and rank (i.e., officer, warrant officer)**
*** indicates a statistically significantly elevated IRR; ^ indicates a statistically significantly reduced IRR**

Table 7. Detailed Comparisons Between Helicopter/Tiltrotor Pilots and Fixed-Wing Pilots

| | Helicopter/Tiltrotor Pilots | | | Fixed wing Pilots | | | Crude | | | Adjusted | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Outcome** | **Person years** | **N** | **Incidence Rate** | **Person years** | **N** | **Incidence Rate** | **IRR** | **95% lower** | **95% upper** | **IRR** | **95% lower** | **95% upper** |
| **Lumbago** | 26,865 | 1,094 | 40.72 | 231,320 | 6,193 | 26.77 | 1.52* | 1.43 | 1.62 | 1.26* | 1.15 | 1.39 |
| **Hypertension** | 36,619 | 118 | 3.22 | 274,969 | 588 | 2.14 | 1.51* | 1.24 | 1.84 | 0.77 | 0.57 | 1.06 |
| **Hearing loss** | 32,349 | 400 | 12.37 | 263,292 | 2,190 | 8.32 | 1.49* | 1.34 | 1.65 | 1.11 | 0.94 | 1.31 |
| **Hyperlipidemia** | 36,287 | 147 | 4.05 | 273,571 | 885 | 3.24 | 1.25* | 1.05 | 1.49 | 1.21* | 1.02 | 1.440. 90 |
| **Metabolic Syndrome** | 37,235 | 16 | 0.43 | 278,540 | 6 | 0.02 | 19.95* | 7.81 | 50.98 | 7.46* | 1.73 | 32.20 |
| **Pure Hyperglyceridemia** | 37,225 | 6 | 0.16 | 278,378 | 35 | 0.13 | 1.28 | 0.54 | 3.05 | 0.50 | 0.13 | 1.94 |
| **Esophageal Reflux** | 35,651 | 201 | 5.64 | 268,384 | 1,528 | 5.69 | 0.99 | 0.85 | 1.15 | 0.84 | 0.68 | 1.04 |
| **Allergic Rhinitis** | 29,201 | 738 | 25.27 | 209,026 | 6,429 | 30.76 | 0.82^ | 0.76 | 0.89 | 0.73^ | 0.66 | 0.82 |
| **Displacement lumbar disc** | 35,741 | 255 | 7.14 | 272,077 | 1,191 | 4.38 | 1.63* | 1.42 | 1.87 | 0.92 | 0.74 | 1.14 |
| **Sleep Apnea** | 36,514 | 305 | 8.35 | 276,770 | 1,068 | 3.86 | 2.16* | 1.91 | 2.46 | 0.99 | 0.81 | 1.21 |
| **Degeneration lumbar disc** | 35,794 | 300 | 8.38 | 273,330 | 1,195 | 4.37 | 1.92* | 1.69 | 2.18 | 1.04 | 0.85 | 1.28 |
| **Hypothyroidism** | 37,182 | 15 | 0.40 | 277,685 | 166 | 0.60 | 0.67 | 0.40 | 1.14 | 0.62 | 0.30 | 1.28 |
| **Testicular dysfunction** | 36,871 | 91 | 2.47 | 276,201 | 406 | 1.47 | 1.68* | 1.34 | 2.11 | 1.06 | 0.74 | 1.52 |
| **Cervical disc displacement** | 36,700 | 161 | 4.39 | 276,014 | 688 | 2.49 | 1.76* | 1.48 | 2.09 | 0.84 | 0.64 | 1.11 |
| **PTSD** | 37,237 | 34 | 0.91 | 278,478 | 67 | 0.24 | 3.80* | 2.51 | 5.73 | 0.91 | 0.47 | 1.78 |
| **Displacement lumbar intervertebral disc without myelopathy** | 35,595 | 385 | 10.82 | 271,789 | 1,467 | 5.40 | 2.00* | 1.79 | 2.24 | 1.10 | 0.91 | 1.32 |
| **Anxiety state unspecified** | 36,859 | 88 | 2.39 | 277,215 | 344 | 1.24 | 1.92* | 1.52 | 2.43 | 0.93 | 0.64 | 1.36 |
| **Migraine** | 36,696 | 68 | 1.85 | 276,124 | 381 | 1.38 | 1.34* | 1.04 | 1.74 | 0.90 | 0.60 | 1.34 |
| **Degeneration of lumbar or lumbosacral intervertebral disc** | 35,811 | 278 | 7.76 | 273,416 | 1,098 | 4.02 | 1.93* | 1.69 | 2.20 | 1.09 | 0.88 | 1.34 |

Table 7. Detailed Comparisons Between Helicopter/Tiltrotor Pilots and Fixed-Wing Pilots

| Outcome | Helicopter/Tiltrotor Pilots | | | Fixed wing Pilots | | | Crude | | | Adjusted | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Person years | N | Incidence Rate | Person years | N | Incidence Rate | IRR | 95% lower | 95% upper | IRR | 95% lower | 95% upper |
| **Major depressive affective disorder single episode unspecified classification** | 37,191 | 14 | 0.38 | 278,170 | 100 | 0.36 | 1.05 | 0.60 | 1.83 | 0.53 | 0.22 | 1.25 |
| **Obstructive sleep apnea** | 36,532 | 293 | 8.02 | 276,837 | 1,027 | 3.71 | 2.16* | 1.90 | 2.46 | 1.00 | 0.81 | 1.22 |
| **Chronic Airway Obstructive Pulmonary Disease** | 36,811 | 38 | 1.03 | 277,289 | 170 | 0.61 | 1.68* | 1.18 | 2.39 | 1.06 | 0.60 | 1.85 |
| **Emphysema** | 37,264 | 1 | 0.03 | 278,513 | 9 | 0.03 | 0.83 | 0.11 | 6.55 | 0.57 | 0.03 | 11.67 |
| **Chronic bronchitis** | 37,233 | 2 | 0.05 | 278,517 | 5 | 0.02 | 2.99 | 0.58 | 15.42 | 1.08 | 0.06 | 19.30 |
| **Asthma** | 36,870 | 34 | 0.92 | 277,426 | 152 | 0.55 | 1.68* | 1.16 | 2.44 | 1.10 | 0.61 | 1.98 |
| **Chronic airway obstructions, not otherwise classified** | 37,245 | 2 | 0.05 | 278,540 | 3 | 0.01 | 4.99 | 0.83 | 29.84 | 2.10 | 0.10 | 46.03 |
| **Raynaud's Syndrome** | 37,258 | 2 | 0.05 | 278,506 | 13 | 0.05 | 1.15 | 0.26 | 5.10 | 0.37 | 0.05 | 2.94 |
| **Dupuytren's Syndrome** | 37,260 | 3 | 0.08 | 278,466 | 25 | 0.09 | 0.90 | 0.27 | 2.97 | 0.74 | 0.13 | 4.06 |
| **Carpal Tunnel Syndrome** | 37,147 | 37 | 1.00 | 277,977 | 121 | 0.44 | 2.29* | 1.58 | 3.31 | 1.05 | 0.57 | 1.91 |
| **Tarsal Tunnel Syndrome** | 37,253 | 3 | 0.08 | 278,493 | 22 | 0.08 | 1.02 | 0.31 | 3.41 | 0.46 | 0.08 | 2.55 |
| **Neck Sprains/Strains (comparison within USAF only)** | 3,791 | 120 | 31.66 | 131,191 | 3,264 | 24.88 | 1.27* | 1.06 | 1.53 | 1.27* | 1.06 | 1.53 |

**Incidence rates per 1,000 person-years**
**IRR = Incidence rate ratio**
**Poisson model adjusted for sex, age category (i.e., 29 years or less, 30-39 years), and rank (i.e., officer, warrant officer)**
*** indicates a statistically significantly elevated IRR; ^ indicates a statistically significantly reduced IRR**

## 4.4 DISCUSSION

Most of the published evidence describing helicopter pilot career health risks consists of case reports or series, surveys, or cross-sectional database studies, which are prone to a wide range of biases. The present study used a retrospective cohort methodology, two separate control groups, and adjusted for sex, age, and rank variables, rendering this study among one of the most rigorous studies of helicopter pilot health trends.

### 4.4.1 Health of tiltrotor pilots

While the intent of section 750 of the NDAA for FY 2017 was to "assess potential links between the operation of helicopter and tiltrotor aircraft and acute and chronic medical conditions experienced by such pilots," it was not statistically feasible to analyze the health trends of tiltrotor pilots separately, due to their small numbers. However, to allow at least some qualitative comparisons with the available data, incidence rates were calculated separately for helicopter pilots and tiltrotor pilots.

In general, the data revealed that incidence rates were higher among helicopter pilots than tiltrotor pilots for 30 of the 31 health outcomes studied (Fig. 8), including lumbago, hypertension, hyperlipidemia, metabolic syndrome, sleep apnea, lumbar disc degeneration, and neck strain/sprain. However, differences exist between the helicopter pilot and tiltrotor pilot groups that could account for some differences in health outcomes. The helicopter pilots were older and most were Army warrant officers, whereas the tiltrotor pilots were younger and all were commissioned officers.

More controlled analyses can account for demographic differences once sufficient numbers of tiltrotor pilots with adequate flight exposure are available. Further assessments of tiltrotor pilot health are not possible in the present epidemiological analysis. Controlled analyses were performed on the combined helicopter pilot/tiltrotor pilot sample (termed the 'exposed' cohort).

### 4.4.2 Health of the exposed cohort

Differences in health outcomes emerged between the exposed cohort and the two control groups, after adjusting for demographic dissimilarities. The exposed cohort was notably healthier than the non-pilot officer cohort (regarding the 31 outcomes under study), while comparisons with the fixed-wing pilots revealed more similar health outcomes. Similarities between the intensive health screening and surveillance imposed on the exposed cohort and the fixed-wing pilot cohort are undoubtedly responsible for the health outcome patterns seen in the results of the present epidemiological study. It is not surprising that aircrew are healthier than non-aviation personnel, even within the military, since they undergo frequent screenings, compared to the general population.

Differences in health outcomes between the exposed cohort and the fixed-wing pilot cohort may therefore most likely be due to aspects of the rotary-wing environment (the tiltrotor data are a minute fraction of the exposed cohort data).

#### *4.4.2.1 Musculoskeletal health outcomes*

The exposed cohort was found to have a 26 percent higher incidence of lumbago (low back pain) compared to the fixed-wing pilot cohort, and a 22 percent lower risk of low back pain than the non-pilot officer cohort. The risk of neck problems was not elevated in the overall analysis, but within the USAF, helicopter pilots and tiltrotor pilots had a 27 percent higher risk of neck sprains/strains.

#### *4.4.2.2 Metabolic health outcomes*

The exposed cohort was found to have an increased risk of metabolic syndrome when compared to either the non-pilot officer cohort or the fixed-wing pilot cohort. Specifically, the exposed cohort had almost six times greater risk of metabolic syndrome than non-pilot officers, and over seven times greater risk than the fixed-wing pilot cohort. In addition, the analysis showed a 27 percent higher risk of hyperlipidemia among helicopter/tiltrotor pilots compared to fixed-wing pilots.

These results are surprising, given the aforementioned healthier nature of the aircrew in the exposed cohort, compared to the non-pilot officer cohort. The finding across both control groups suggests something unique about the exposed cohort that deserves further investigation. One factor that could dominate the analysis is a dramatically heightened search within Army aviation for cardiac risk factors, such as elevated serum lipids and body weight, which apparently occurred during the study period (Personal communication, J. McGhee, May 2018). As U.S. Army helicopter pilots comprise 75 percent of the exposed cohort, an aggressive Army policy to discover and diagnose elements of metabolic syndrome could affect the results of the analysis. This enhanced detection due to increased screening is a well-known source of error in epidemiological studies. These findings will be discussed further in the context of the previous aeromedical research in the published literature.

#### *4.4.2.3 Hearing loss outcomes*

The exposed cohort was found to have an 11 percent lower risk of hearing loss than the non-pilot officer cohort, which could reflect an elevated risk in the non-pilot officer cohort, or a lower risk in the exposed cohort. Since no difference was found between the exposed cohort and the fixed-wing pilot cohort, this finding may indicate a need for increased attention to hearing conservation among the military occupations included in the non-pilot officer cohort.

### 4.4.3 Study limitations

This epidemiological study is vulnerable to the same potential biases as all retrospective database studies. Despite the efforts taken to limit the analysis to datasets containing a sufficient number of records and to control for known correlates of health outcomes (e.g., age, rank), these results should be interpreted cautiously. While the selection of both control groups was done with care, comparisons must be limited to military populations. Temporal and Service-specific differences in case-finding may have exaggerated the risk of specific health outcomes (e.g., metabolic syndrome). Additionally, the inclusion of non-maintenance commissioned and warrant officers into the Army unexposed non-pilot officer cohort may limit the baseline comparability of this unexposed cohort to the exposed cohort for the Army. The PMOS categories selected for this

Army non-pilot officer cohort rendered the Army portion of this cohort more of a sampling of the general officer population than a more comparable aviation maintenance officer control group (as selected for the other Services). This control group consisted of 36,181 (79.4 percent) of the 45,566 officers in the whole control group. Since the Army had the largest numbers in both the exposed and this unexposed cohort, the Army's rates had the largest impact on the overall rates. However, the occupational exposures of non-flying maintenance officers and other non-flying officers in the Army are similar in many respects (e.g., noise, repetitive trauma, accidental injury). These exposures do not include known unique aspects of the rotary-wing or tiltrotor environments.

# 5 SUMMARY DISCUSSION OF REVIEWED LITERATURE AND 2018 EPIDEMIOLOGY STUDY

Section 750 of the NDAA for FY 2017 requests a "study of career helicopter and tiltrotor pilots to assess potential links between the operation of helicopter and tiltrotor aircraft and acute and chronic medical conditions experienced by such pilots". The NDAA for FY 2017 language further requests a literature review and specified that the study include a control population, consider flight time, and determine rates of medical conditions as compared to control population(s). The tasking also requested an explanation of the causes of any elevated risks found in the epidemiology study, and the costs of treating the attributable medical conditions.

The three-phase approach taken to answer section 750 of the NDAA for FY2017 has been responsive to the intent of the tasking; produced findings of interest; and highlighted gaps in knowledge that deserve the attention of the DoD aeromedical research community.

The assembled working group reflected the interest and commitment of the TriService aeromedical community, and the leadership provided by the DHA facilitated the participation of the AFHSB in the epidemiological study.

## 5.1 LITERATURE REVIEW

The review of the aeromedical literature for indications of acute and chronic medical conditions highlighted: a) the complete dearth of information in the published literature regarding any medical issues related to flying tiltrotor aircraft (i.e., currently, the V-22); and b) the dominance of musculoskeletal health concerns in the rotary-wing aircrew community. Neck and back pain are most frequently cited in the literature as related to the helicopter pilot occupation, exacerbated by increased head-supported mass, and aircraft vibration and aviator posture, respectively.

While the literature contains no data on health concerns related to tiltrotor aircraft, a review of the widely known capabilities of current (and future) tiltrotor aircraft provides several areas of concern in need of further study. Health effects from altitude, sustained G-forces, vibration, and head-supported mass are of particular concern.

## 5.2 EPIDEMIOLOGICAL STUDY

The retrospective cohort study conducted as part of section 750 of the NDAA for FY 2017 tasking incorporated two carefully selected control groups and accurate histories of pilot aircraft types, while controlling for known correlates of common aviation-related medical problems.

The study found that highly-screened and monitored military helicopter pilots are healthier than non-pilot officers, but documented a 26 percent higher risk of low back pain in the exposed cohort, compared to the fixed-wing control cohort. In a sub-analysis, the risk of a neck pain diagnosis (i.e., sprains and strains) was found to be 27 percent higher for USAF helicopter/tiltrotor pilots than USAF fixed-wing pilots. These findings support numerous anecdotes and a large body of published aeromedical literature attributing low back pain and neck pain to the helicopter pilot occupation.

Other findings of the epidemiological study include an apparent excess risk of metabolic syndrome and hyperlipidemia in the helicopter/tiltrotor pilot cohort. These findings mirror the results of Curry & Kelley (in review), which surveyed U.S. Army aircrew diagnoses and waivers during a similar period (between 2005 and 2015, in comparison to 1998 and 2015 in the present study). These findings are counter-intuitive, as discussed above (section 4.4.2.2), and may relate to increased screening during the study period (Delgado-Rodriguez & Llorca, 2004); a study of more recent diagnostic patterns in Army aircrew could help clarify this puzzling finding.

While the number of available tiltrotor pilots for the epidemiological study was insufficient to allow rigorous statistical analysis, qualitative comparison of simple incidence rates indicates that helicopter pilots had a higher risk than tiltrotor pilots for 30 of the 31 health outcomes under study. While these findings may not survive rigorously controlled analyses in the future, they do support the attribution of most of the adverse health outcomes in the exposed cohort to the much larger helicopter pilot component.

# 6 ETIOLOGY OF LINKED MEDICAL OUTCOMES

As outlined earlier in this report, there are numerous hazards of the flight environment that can produce transient medical problems (e.g., disorientation, hypoxia, G-forces); as long as these well-known flight-related conditions do not interfere with safe flight and result in a crash, they present no health risks that are likely to persist post-flight. This section will focus on elucidating the causes of the two lingering medical conditions for which there is convincing evidence from the literature and from the present epidemiological study: neck sprain/strain, and low back pain.

## 6.1 NECK SPRAIN/STRAIN

Neck pain is a relatively recent problem in helicopter aviation, which is classically associated with low back pain problems (discussed below). Neck pain reports began to appear in the 1990s, coincidentally as the use of helmet-mounted devices increased in military rotary-wing aviation.

Neck injuries that occur in the high +Gz environment tend to be more acute and are frequently linked to a specific injurious event, whereas the typical helicopter pilot's neck pain is gradual in onset and chronic, more like a musculoskeletal overuse injury. As fixed-wing helmets have become more technology-laden and helicopters more agile, these patterns blur.

Many reports in the literature attempt to determine the causal factors for neck pain among helicopter aircrew. Increased head-supported weight is widely believed to contribute to aircrew neck pain, particularly when associated with center-of-gravity (CG) shifts (usually forward, as with NVGs or HMDs) (Rash, 2001). Ang & Harms-Ringdahl (2006) found that a history of NVG use was insignificantly associated with neck pain. Greaves & Wickes (2008) reported that U.K. helicopter crews with neck pain had flown significantly more hours than helicopter crews without pain, especially with increased NVG flying hours. In 2008, Gallagher, et al. found that heavier balanced helmets were tolerated better than lighter helmets with a forward CG shift. Barker & Albery (2010) studied 17 volunteers wearing helmet-supported weights ranging from 2.25 to 6.05 pounds for four hours at 1G. Neck fatigue and discomfort were greater in all the helmet wear configurations; wear time was correlated with neck-related symptoms. Recent helicopter aircrew surveys continue underscore NVG exposure as a primary source of neck pain risk (Chafe & Farrell, 2016; Fraser, et al., 2015).

Anthropometry is another potential contributor to aircrew neck pain. Harrison, et al. (2012) analyzed questionnaire data from 40 Canadian helicopter aircrew and developed a simple logistic regression equation that predicted the occurrence of neck pain based on two variables: the longest single NVG mission and aircrew member height. However, Orsello, et al. (2013b) found no correlation between USN aircrew height and in-flight neck pain. Chafe & Farrell (2016) found no significant differences in height between 52 aircrew with no neck trouble and 161 aircrew with self-reported lifetime prevalence of neck pain. In a study of 88 U.S. Army aircrew, Walters, et al. (2012) found an association between higher sitting height and neck pain. Further study is needed to determine the relationship between neck pain, anthropometry, and ergonomics.

Other factors cited as potential causes of neck (and back) pain among helicopter pilots include sitting height clearance and display design and location (Chafe & Farrell, 2016), while ergonomic considerations for rear crew (gunners, crew chiefs, flight engineers, etc.) include crew seat design, particularly the backrest and leg spaces (Grant, 2002). Van den Oord, et al. (2012) has shown the benefit of an optimized helmet fit on neck pain among Royal Netherlands Air Force helicopter crew. Additional factors contributing to neck pain that are inherent in aircraft fundamental design may be more difficult to engineer out, such as vibration.

Finally, there is evidence to support the intuitive belief that neck pain and back pain are linked: Orsello, et al. (2013b) found that the strongest predictor of in-flight neck pain among 458 USN helicopter aircrew was having low back pain during flight.

## 6.2 LUMBAGO (LOW BACK PAIN)

The main competing back pain etiologic theories are based on the adverse effects of sustained posture or exacerbating vibration—both of which are prominent in flying helicopters. Postural mechanisms and resulting ischemia have been favored by Pope, et al. (1985), Bridger, et al. (2002), Rodriguez, et al. (2018) and others, while vibration has been emphasized by Boshuizen, et al. (1989) and de Oliveira & Nadal (2005). Bongers & Hulshof (1990) determined that transient pain was associated with the number of flight hours per day, while chronic pain was more associated with total hours of flight time. This pattern of chronic pain favors an effect of accumulative vibration dose and posture. Lings & Leboeuf-Yde (2000) reviewed the vibration and low back pain literature and found weak evidence supporting a causative link between vibration and low back pain; nonetheless, whole body vibration exposure should be reduced to the greatest extent possible. Lings & Leboeuf-Yde (2000) further recommended that research in this area be curtailed, as the problem is waning due to "technical prophylactic developments…already in progress."

Reviewing the competing etiological theories for low back pain among helicopter pilots, Gaydos (2012) concluded that the postural mechanisms have stronger support than the vibration theories, but agreed with Kasin, et al. (2011) that it is most likely that multiple factors combine to cause a range of musculoskeletal symptoms among aircrew.

The present analysis did not confirm the recent results of Knox, Deal, & Knox, (2018), which reflect an increased incidence of lumbar disc hernation among helicopter aircrew, particularly among Army helicopter pilots. Methodological differences between the two studies may account for the following inconsistencies: different definition of exposed cohort (Knox, et al. did not use confirmed rosters or restrict to career pilots); different age groups (Knox, et al. included aircrew over 40 years of age); different time period (Knox, et al. studied 2006-2015); different control groups (Knox, et al. included all non-helicopter pilot officers); and different diagnostic codes (Knox, et al. included only ICD-9 codes). The databases used were related. Knox, et al. queried the DMED, a subset of DMSS; however, DMED has a limited ability to restrict outcomes to incident encounters only. DMED can neither combine inpatient and outpatient medical encounters, nor apply incident restirctions to multiple codes, which can lead to inaccurate counting of incident cases. These methodological differences may have uncovered a different pattern of helicopter pilot-related health outcomes worthy of consideration.

# 7 COST OF LINKED MEDICAL OUTCOMES

The costs of medical treatment are difficult to estimate—disease causes are multifactorial, individual treatment needs are different, and many factors contribute to the costs (van Dongen, et al., 2016). Low back pain is cited as the world's most disabling condition, with annual treatment costs estimated at $90 billion (B) dollars (Samartzis, et al., 2018). In the United States, the costs of neck and back pain, acute and chronic, are immense. In 2005, total estimated associated medical costs were $86B dollars per year (Boyles, 2008).

The sources of 'cost' to aircrew of a medical condition are broad and include potential career cost, while estimating cost requires estimation of treatment patterns. Adding to the challenges of such a cost analysis are the difficulties in estimating the cost of medical treatment in the military health care system. A business case analysis sponsored by the Deputy Under Secretary of Defense for Installations and Environment concluded that avoidable costs associated with back and neck pain among DoD helicopter aircrew totaled over $239 million (M) each year, with a significant cost per year in Department of Veterans Affairs payments for flying-related disabilities (Hamon, 2012).

The importance of pain management in the military, including cost, has been recognized and is the focus of a major task force (Rhodes, 2017). Besides direct costs of treatment, musculoskeletal pain and disorders have implications on mission success and overall defense cost—for example, military personnel evacuated from combat zones in Iraq and Afghanistan due to low back pain have only a 13.3 percent probability of returning to their units (Neale, 2009).

## 7.1 NECK PAIN

As with other musculoskeletal injuries, it is difficult to calculate a cost of treatment because few treatments are effective, and some medications are overprescribed (Boseley, 2017). Particularly for neck strain/sprain among helicopter aircrew, where the cause is most probably the occupational burden of additional head-supported mass for prolonged period, the alternatives are either rest and conservative treatment or continued symptoms. The indirect costs to the individual (in terms of well-being), aviation safety (distraction, reduced range of motion), and the military (cost of training, grounding, and reduced mission effectiveness) are also enormous (Harrison, Coffey, Albert, & Fischer, 2015).

## 7.2 LOW BACK PAIN

Childs, et al. (2015) provided a recent reference for low back pain costs to the military in an analysis of physical therapy as a potential cost-saving measure. In that study, the mean two-year direct cost of low back pain ranged from $1,914.00 to $3,456.00, depending on the study treatment group. Hospitalization cost (if required) ranged from $10,510.00 to $13,075.00.

## 7.3 CAVEAT TO CALCULATED COST DATA

While the section 750 of the NDAA for FY 2017 tasking requests "costs associated with treating" medical conditions linked to helicopter or tiltrotor aircraft, it must be noted that this information is incomplete and potentially misleading. First, the direct cost calculation does not account for a) unreported musculoskeletal problems, which are very common according to the literature reviewed for this report, or b) outpatient visits beyond the initial encounter – either of these factors could multiply the direct cost figures many times over. Second, the indirect cost of these musculoskeletal medical conditions dwarfs the direct costs, including time lost due to grounded aviators, the immense cost of even a few permanently grounded trained aircrew (at $600,000.00-$2M each), and the certain effect of pain on aircrew performance and combat effectiveness (Gaydos, 2012).

# 8 CONCLUSIONS

- Career military helicopter and tiltrotor pilots are healthier than the military non-pilot officer control population, at least considering the 31 health conditions assessed in the present epidemiological study.
    - This may be due to differences in occupational exposures and/or the heightened screening and medical surveillance of military aircrew.
    - Statistically significant differences included an elevated risk of hearing loss among the non-pilot officer control group; this may reflect a greater noise hazard or a need for enhanced hearing conservation in this population.
- There is compelling evidence that career military helicopter pilots are at increased occupational risk of: a) low back pain (lumbago); and b) neck strain/sprain.
    - This conclusion is based on the large body of supporting operational aircrew studies (e.g., surveys, case series, and epidemiological studies in the aeromedical literature; and on the results of the carefully-controlled AFHSB epidemiological study presented in this report, which compared career military helicopter pilots to military fixed-wing aviation and ground occupational control groups.
- There was insufficient evidence to assess whether career tiltrotor pilots experience adverse health effects from operating tiltrotor aircraft.
    - Virtually no information regarding health effects or human factor concerns related to operational tiltrotor aircraft has been published in either the open or government technical literature.
    - Nonetheless, anecdotes and the available literature regarding the operating envelope and environmental characteristics of operational tiltrotor aircraft (i.e., V-22 Osprey) suggest that aircrew could be at significant risk for occupational injury/illness. These risks may be higher or lower than the risks posed by other military aircraft, all of which carry inherent operational hazards.
    - Documentation of any health risks posed by current tiltrotor aircraft is essential to
        - Develop prevention and treatment strategies for affected Service members, and
        - Better understand potential risks to crews of future tiltrotor aircraft (e.g., the Army's Future Vertical Lift aircraft).
- The exposed cohort, mostly composed of Army helicopter pilots, had a significantly elevated risk of metabolic syndrome (and related health outcomes).
    - This finding is probably related to increased screening during the study period, but should be investigated using more recent aircrew health data.

# 9 REFERENCES

Adams, M. (2016). Rotary wing operation by land and sea. In D. P. Gradwell, & D. J. Rainford, *Ernsting's Aviation and Space Medicine* (5th ed., pp. 805-813). Boca Raton, FL: CRC Press.

Ang, B., & Harms-Ringdahl, K. (2006). Neck pain and related disability in helicopter pilots: a survey of prevalence and risk factors. *Aviat Space Environ Med, 77*, 713-19.

Associated Press. (2015, May 19). *Marines: Osprey aircraft has good safety record.* Retrieved from www.usatoday.com: https://www.usatoday.com/story/news/nation/2015/05/19/osprey-safety-record/27568521/

Atherton, K. (2015, March 10). *Soon You'll Be Able To Buy A Tiltrotor Aircraft*. Retrieved April 2, 2018, from Popular Science: https://www.popsci.com/soon-youll-be-able-buy-tiltrotor-aircraft

Aydoq, S. T., Turbedar, E., Demirel, A. H., Tetik, O., Akin, A., & Doral, M. N. (2004). Cervical and lumbar spinal changes diagnosed in four-view radiographs of 732 military pilots. *Aviat Space Environ Med, 75*, 154-7.

Barker, D. J., & Albery, C. (2010). Neck fatigue and comfort effects due to the extended wear of law enforcement representative head-borne personal protective equipment. 1-109.

Bongers, P. M., Hulshof, C. T., Dljkstra, L., Boshuizen, H. C., Groenhout, H. J., & Valken, E. (1990). Back pain and exposure to whole body vibration in helicopter pilots. *Ergonomics, 33*, 1007-26.

Boseley, S. (2017, Feb 10). *Epidemic of untreatable back and neck pain costs billions, study finds.* Retrieved from theguardian.com: https://www.google.com/amp/s/amp.theguardian.com/society/2017/feb/10/epidemic-of-untreatable-back-and-neck-pain-costs-billions-study-finds

Boshuizen, H. C., Bongers, P. M., & Hulshof, C. T. (1989). Back disorders and occupational exposure to whole-body vibration. *Vienna: International Symposium on the Research Section of the ISSA on Vibration at Work. Int J Indust Ergonomics.*

Boyles, S. (2008, Feb 12). *$86 billion spent on back, neck pain.* Retrieved July 20, 2018, from WebMD: www.webme.com/back-pain/news/20080212/86-billion-spent-on-back-neck-pain#1

Bridger, R. S. (2002). Back pain in Royal Navy helicopter pilots: Part 1. General findings. *Contemp Ergonomics, 73*, 805-811.

Bridger, R. S., Groom, M. R., Jones, H., Pethybridge, R. J., & Pullinger, N. (2002). *Aviat Space Environ Med, 73*, 805-811.

Bridger, R. S., Groom, M. R., Pethybridge, R. J., Pullinger, N. C., & Paddan, G. S. (2009). Back pan in Royal Navy helicopter pilots: Part Il general findings. *Scand J Clin Lab Invest*.

Byeon, J. H., Kim, J. W., Jeong, H., Sim, Y. J., Kim, D. K., Choi, J. K., & Kim, G. C. (2013). Degenerative changes of spine in helicopter pilots. *Ann Rehab Med, 37*, 706-12.

Byeon, J. H., Kim, J. W., Jeong, H., Sim, Y. J., Kim, D. K., Choi, J. K., . . . Kim, G. C. (2013). Degenerative changes of spine in helicopter pilots. *Ann Rehab Med, 37*, 706-12.

Chafe, G. S., & Farrell, P. S. (2016). *Royal Canadian Air Force CH-146 Griffon aircrew 2014 spinal musculoskeletal trouble survey*. DRDC-RDDC. Toronto: Defence Research and Development Canada.

Chafe, G. S., & Farrell, P. S. (2016). *Royal Canadian Air Force CH-146 Griffon aircrew spinal musculoskeletal trouble survey*. DRDC-RDDC. Toronto: Defence Research and Development Canada.

Childs, J. D., Fritz, J. M., Wu, S. S., Flynn, T. W., Wainner, R. S., Robertson, E. K., . . . George, S. Z. (2015). Implications of early and guideline adherent physical therapy for low back pain on utilization and costs. *BMC Health Services Research, 15*, 150.

Crowley, J. S., Cornum, R., & Marin, R. (1990). Aeromedical aspects of helicopter air-to-air combat. *Aviation Digest*(1-90-1), 2-10.

Curry, I., & Kelley, A. (n.d.). US Army Aircrew Morbidity 2005-2015. *(in review)*.

Davis, J. R., Johnson, R., Stepanek, J., & Fogarty, J. A. (2008). *Fundamentals of aerospace medicine* (4th ed.). Philadelphia: Wolters Kluwer.

de Oliveira, C. G., & Nadal, J. (2005). Transmissibility of helicopter vibration in the sines of pilots in flight. *Aviat Space Environ Med, 76*, 576-580.

de Oliveira, C. G., & Nadal, J. (2005). Transmissibility of helicopter vibration in the spines of pilots in flight. *Aviat Space Environ Med, 76*, 576-580.

Delgado-Rodriguez, M., & Llorca, J. (2004). Bias. *J. Epidemiology and Community Health, 58*, 635-641.

Dille, J. R., & Mohler, S. R. (2008). The beginnings: past and present. In J. R. Davis, R. Johnson, J. Stepanek, & J. A. Fogarty, *Fundamentals of aerospace medicine* (pp. 1-19). Philadelphia: Wolters Kluwer.

Eveland, E., Goodyear, C., Shouse, C., & Esken, B. (2008). Human performance with helmet-mounted systems: the role of helmet configuration and mission duration. *Aviat Space Environ Med, 79*, 223-224.

Fitzpatrick, D. (1988). An analysis of noise-induced hearing loss in Army helicopter pilots. *Aviat Space Environ Med, 59*, 937-941.

Fraser, W. D., Crowley, J. S., Shender, B. S., & Lee, V. M. (2015). *Multinational survey of neck pain in rotor-wing aircrew*. The Technical Cooperation Program.

Gaydos, S. J. (2012). Low back pain: considerations for rotary-wing aircrew. *Aviat Space Environ Med, 83*, 879-889.

Gertler, J. (2017, June 28). *Report to Congress: Out of Breath – Military Aircraft Oxygen Issues*. Retrieved April 1, 2018, from U.S. Naval Institute: https://news.usni.org/2017/06/28/report-congress-breath-military-aircraft-oxygen-issues

Gradwell, D. P., & Rainford, D. J. (2016). *Ernsting's Aviation and Space Medicine* (5th ed.). Boca Raton, FL: CRC Press.

Grant, K. (2002). Ergonomic assessment of a helicopter seat: the HH-60G flight engineer position. *Aviat Space Environ Med, 73*, 913-918.

Greaves, J., & Wickes, S. (2008). Review of the United Kingdom national work programme on the long term effects of sustained high G on teh cervical spine. *NATO RTO Review of national work programmes on the long term effects of sustained high G on the cervical spine*. Neuilly sur Seine: NATO.

Grossman, A., Nakdimon, I., Chapnik, L., & Levy, Y. (2012). Back symptoms in aviators flying different aircraft. *Aviat Space Environ Med, 83*, 702-705.

Harrison, M. F., Coffey, B., Albert, W. J., & Fischer, S. L. (2015). Night vision goggle-induced neck pain in military helicopter aircrew: a literature review. *Aviat Space Environ Med*, *86*, 46-55.

Harrison, M. F., Forde, K. A., Albert, W. J., Croll, J. C., & Neary, J. P. (2016). Position and helmet load influences on neck muscle activation. *Aerosp Med Hum Perf, 87*, 48-53.

Harrison, M. F., Neary, J. P., Albert, W., & Croll, W. J. (2011). Neck pain and muscle function in a population of CH-146 helicopter aircrew. *Aviat Space Environ Med, 82*, 1125-1130.

Hiatt, K., & Rash, C. E. (2011). The reported incidence of man-machine interface issues in Army aviators using the Aviator's Night Vision System (ANVIS) in a combat theatre. *Proceedings of SPIE - The International Society for Optical Engineering*.

Jonsson, E., Olafsson, G., Fritzell, P., Hagg, O., & Borgstrom, F. (2017). A profile of low back pain: Treatment and costs associated with patients referred to orthopedic specialists in Sweden. *Spine, 42*, 1302-1310.

Kasin, J. I., Mansfield, N., & Wagstaff, A. (2011). Whole body vibration in helicopters: risk assessment in relation to low back pain. *Aviat Space Environ Med, 82*, 790-6.

Knox, J. B., Deal, J. B., & Knox, J. A. (2018). Lumbar disc herniation in military helicopter pilots vs. Matched Controls. *Aerosp Med Hum Perform, 89*, 442-445.

Landau, D. A., Chapnick, L., Yoffe, N., Azaria, B., Goldstein, L., & Atar, E. (2006). Cervical and lumbar MRI findings in avaitors as a function of aircraft type. *Aviat Space Environ Med, 77*, 1158-61.

Lange, B., Torp-Svendsen, J., & Toft, P. (2011). Neck pain among fighter pilots after the introduction of the JHMCS helmet and NVG in their environment. *Aviat Space Environ Med, 82*, 559-63.

Lings, S., & Leboeuf-Yde, C. (2000). Whole-body vibration and low back pain: a systematic critical review of the epidemiological literature 1992-1999. *Int Arch Occup Environ Health, 73*, 290-297.

Macauley, C. B. (1944). *The helicopters are coming.* New York: McGraw Hill Book Company.

Macy, E. (2008). *Apache: Inside the cockpit of the world's most deadly fighting machine.* New York: Atlantic Monthly Press.

Mathys, R., & Ferguson, S. (2012). Simulation of the effects of different pilot helmets on neck loading during air combat. *J Biomechanics, 45*, 2362-7.

McMahon, T. W., & Newman, D. G. (2016). G-induced visual symptoms in a military helicopter pilot. *Mil Med, 181*.

Mills, H. L. (1992). *Low level hell.* London: Air Life.

Mowry, C., & Ison, D. C. (2015). Assessing computer vision syndrome risk for pilots. *J Aviat/Aerosp Educ and Research, 24*(2), 79-121.

Neale, T. (2009, November 9). *Back pain sidelines many U.S. Soldiers.* Retrieved from MedPage Today: https://www.medpagetoday.com/publichealthpolicy/militarymedicine/16889

Orsello, C. A., Moore, J. E., & Reese, C. (2013). Sensorineural hearing loss incidence among US military aviators between 1997 and 2011. *Aviat Space Environ Med, 84*, 975-9.

Orsello, C. A., Phillips, A. S., & Rice, G. M. (2013). Height and in-flight low back pain association among military helicopter pilots. *Aviat Space Environ Med*, *84*, 32-7.

Orsello, C., Phillips, A., Moore, J., & Rice, G. (2013). In-flight neck pain among U.S. Navy H-60 helicopter pilots: predictors, prevalence, and impact. *Aviat Space Environ Med, 84*, 4.

Owen, J. P. (1996). A survey of hearing loss in Army aircrew. *Occupational Medicine*, *46*, 53-58.

Pope, M. H., Wilder, D. G., Seroussi, R. E., & Donnermeyer, D. D. (1985, Aug). Effects of helicopter vibration on the spinal system. *Orthopedics and Rehab*, 145.

Pousette, M. W., Lo Marrtire, R., Linder, J., Kristofferrsson, M., & Ang, B. O. (2016). Neck muscle strain in Air Force pilots wearing night vision goggles. *Aerosp Med Hum Perf, 87,* 928-932.

Rash, C. (2001). *Helmet-mounted displays: design issues for rotary-wing aircraft.* Bellingham, WA: SPIE Press.

Rash, C. E., Verona, R. W., & Crowley, J. S. (1990). Human factors and safety considerations of night-vision systems flight using thermal imaging systems. *Proc. SPIE 1290, Helmet-Mounted Displays II.* Orlando, FL.

Rhodes, C. (2017, Oct 16). *Addressing chronic pain in the armed forces.* Retrieved July 10, 2018, from Practical Pain Management: https://www.practicalpainmanagement.com/treatments/addressing-chronic-pain-united-states-armed-forces

Robson, S. (2011, May 13). *Survey: Copter pilots seek civilian medical treatments in attempt to save careers.* Retrieved July 20, 2018, from Stars and Stripes: https://www.stripes.com/news/survey-copter-pilots-seek-civilian-medical-treatments-in-attempt-to-save-careers-1.143459

Rodriguez, C. G., De Oliveira, C. G., Da Silva, M. A., & Fereira, J. S. (2018). *Evaluation of orthostatic osture of helicopter pilots: implications of the posture adopted in cockpit and of a work journey.* Retrieved from www.2.com: http://www.celiagrodriguez.xpg.com.br/artigo_final.pdf

Rothman, K. J. (1986). *Modern epidemiology.* Boston: Little, Brown and Company.

Samartzis, D., Alini, M., An, H., Karppinen, J., Rajasekaran, S., Vialle, L., . . . de Kleuver, M. (2018). Precision spine care: A new era of discovery, innovation, and global impact. *Global Spine J, 8*, 321-322.

Shanahan, D. F. (1984). Back pain in helicopter flight operations. *Aeromedical support in military helicopter operations.* Neuilly sur Seine, France: NATO Advisory Group for Aerospace Research and Development (AGARD).

Sharma, S., & Agarwal, A. (2008). Cervicalgia amongst helicopter pilots using helmet-mounted devices. *Indian J Aerosp Med, 52*, 1-7.

Thomae, M. K., Orteus, J. E., Brock, J. R., Allen, G. D., & Heller, R. F. (1998). Back pain in Australian military helicopter pilots: a preliminary study. *Aviat Space Environ Med, 69*, 468-73.

Thomae, M. K., Porteous, J. E., Brock, J. R., Allen, G. D., & Heller, R. F. (1998). Back pain in Australian military helicopter pilots: a preliminary study. *69*, 468-73.

Thoolen, S. J., & van den Oord, M. (2015). Modern air combat developments and their influence on neck and back pain in F-16 pilots. *Aerosp Med and Human Perf, 86*, 936-941.

Truszczynska, A., Lewkowicz, R., Truszczynski, O., Rapala, K., & Wojtkowiak, M. (2012). Back pain in Polish military helicopter pilots. *Int J Occup Med Environ Health*, *25*, 258-264.

Van den Oord, M. (2013). Prevention of flight-related neck pain in military helicopter aircrew: an overview. *Aviat Space Environ Med, 84*, 2292-2293.

van Dongen, J. M., Ketheswaran, J., Tordup, D., Ostelo, R. W., Bertollni, R., & van Tulder, M. W. (2016). Health economic evidence gaps and methodological constraints in low back pain and neck pain: Results of the Research Agenda for health Economic Evaluation (RAHEE) project. *Best Pract & Res Clin Rheum*, *30*, 981-993.

Walters, P. L., Gaydos, S., Kelley, A. M., & Grandizio, C. M. (2013). *Spinal pain and occupational disability: a cohort study of British Apache AH Mk 1 pilots.* Fort Rucker, AL: US Army Aeromedical Research Laboratory.

Walters, P., Cox, J., Clayborne, K., & Hathaway, A. (2012). *Prevalence of neck and back pain amongst aircrew at the extremes of anthropometric measurements.* Fort Rucker, AL: US Army Aeromedical Research Laboratory.

Zim, H. S. (1943). *Man in the air: the effects of flying on the human body*. New York City: Harcourt, Brace and Company.

# Appendix A
# Outcomes Investigated in Epidemiological Study,
# **with ICD-9/10 Codes and Case Definitions**

| Outcome | ICD 9 Codes | ICD 10 Codes | Case Definition |
|---|---|---|---|
| **Esophageal Reflux** | 530.81 | K21 | One hospitalization or outpatient medical encounter with any of the case defining diagnoses in the primary diagnostic position; or one hospitalization or outpatient medical encounter with an esophageal complication or extra esophageal symptom code (ICD-9: 150.x, 151.0, 230.1, 530.1x, 530.2x, 530.3x, 53.8x, 476.xx, 493.xx, 519.1x,521.3x, 784.42, 784.49, 786.2; ICD-10: C15.xx, C16.0, D00.1, K20.xx, K20.xx, K22.1x, K22.2x, K22.8x, J37.xx, J45.xx, J98.0x, K25.3x, R49.0, R49.8, R05.xx ) in the primary diagnostic position AND any case defining diagnosis in any other diagnostic position |
| **Chronic Airway Obstructive Pulmonary Disease** | 491, 492, 493, 494, 496 | J41, J42, J43, J44, J45, or J47 | One hospitalization or two outpatient medical encounters with any of the defining diagnoses in any diagnostic position |
| **Emphysema** | 492 | J43 | |
| **Chronic bronchitis** | 491 | J42, J41 | |
| **Asthma** | 493 | J45 | |
| **Bronchiectasis** | 494 | J47 | |
| **Chronic airway obstructions, not otherwise classified** | 496 | J44 | |
| **PTSD** | 300.09 | F43.1 | One hospitalization with any of the defining diagnoses in the first or second diagnostic position; or two outpatient medical encounters, within 180 days of each other, with any of the defining diagnoses in the first or second diagnostic position; or one outpatient medical encounter in a psychiatric or mental health care specialty setting (MEPRS code BF) with any of the defining diagnoses in the first or second diagnostic position |
| **Anxiety state unspecified** | 300.00 | F41.9 | |
| **Major depressive affective disorder single episode unspecified classification** | 296.20 | F32.9 | |
| **Hypertension** | 401.XX | I10 | One hospitalization with any of the defining diagnoses in the primary diagnostic position; or two outpatient medical encounters, within 90 days of each other, with any of the defining diagnoses in the primary diagnostic position |
| **Migraine** | 346.XX | G43 | One hospitalization with any of the defining diagnoses in the any diagnostic position; or one outpatient medical encounter with any of the defining diagnoses in the primary diagnostic position. |
| **Sleep Apnea** | 327.2x | G47.3 | One hospitalization with any of the defining diagnoses in any diagnostic position; or two outpatient medical |

| | | | |
|---|---|---|---|
| | | | encounters, within 90 days of each other, with any of the defining diagnoses in any diagnostic position |
| **Hyperlipidemia** | 272.2, 272.4 | E78.2, E78.4, E78.5 | One hospitalization with the diagnosis in any diagnostic position; or two or more outpatient encounters within 180 days with at least one encounter having the diagnosis in primary diagnostic position |
| **Metabolic Syndrome** | 277.7x | E88.81 | |
| **Pure Hyperglyceridemia** | 272.1x | E78.1 | |
| **Hypothyroidism** | 244.xx | E03 | |
| **Lumbago** | 724.2x | M54.4 | One hospitalization or outpatient medical encounter with the diagnosis of interest in any diagnostic position |
| **Hearing loss** | 389.XX | H90, H91 | |
| **Displacement lumbar disc** | 722.10 | M51.26 | |
| **Degeneration lumbar disc** | 722.52 | M51.36 | |
| **Testicular dysfunction** | 257.xx | E29 | |
| **Cervical disc displacement** | 722.0x | M50 | |
| **Neck sprains/strains** | 723.1, 847.0, 847.9 | M54.2, S13.9XXA, S13.8XXA, S16.1XXA | |
| **Displacement lumbar intervertebral disc without myelopathy** | 722.10 | M51 except M51.0 | |
| **Degeneration of lumbar or lumbosacral intervertebral disc** | 722.52 | M51.37 | |
| **Allergic Rhinitis** | 477.XX | J30 | One outpatient medical encounter with any of the defining diagnoses in any diagnostic position |
| **Raynaud's Syndrome** | 443.0 | I73.0 | Two outpatient medical encounters with the diagnosis of interest; one of the two encounters must have the diagnosis in the primary diagnostic position |
| **Dupuytren's Syndrome** | 728.6 | M72.0 | |
| **Carpal Tunnel Syndrome** | 354.0 | G56.0 | |
| **Tarsal Tunnel Syndrome** | 355.5 | G57.5 | |
| **MEPRS = Medical Expense and Performance Reporting System** | | | |
| * The clinical definition of metabolic syndrome is a cluster of metabolic risk factors for cardiovascular disease and type 2 diabetes mellitus. The major components of metabolic syndrome include excess abdominal fat; atherogenic dyslipidemia; hypertension; hyperglycemia; insulin resistance; a proinflammatory state; and a prothrombotic (thrombosis) state. (From**:** Clinical Management of Metabolic Syndrome: Report of the American Heart Association/National Heart, Lung, and Blood Institute/American Diabetes Association Conference on Scientific Issues Related to Management. *Circulation* 2004; 109:551-556.) | | | |

# Appendix B
# Acronyms

| | |
|---|---|
| AFHSB | Armed Forces Health Surveillance Branch |
| CI | Confidence Interval |
| CG | Center-of-Gravity |
| DHA | Defense Health Agency |
| DMED | Defense Medical Epidemiology Database |
| DMSS | Defense Medical Surveillance System |
| DoD | Department of Defense |
| FY | Fiscal Year |
| G | G-Force |
| HMD | Helmet-Mounted Display |
| ICD-9 | International Classification of Diseases – 9th Revision |
| ICD-10 | International Classification of Diseases – 10th Revision |
| IRR | Incidence Rate Ratio |
| MEPRS | Medical Expense and Performance Reporting System |
| NAMRU-D | Naval Medical Research Unit – Dayton |
| NDAA | National Defense Authorization Act |
| NVG | Night Vision Goggles |
| PMOS | Primary Military Occupational Specialty |
| PTSD | Posttraumatic Stress Disorder |
| U.K. | United Kingdom |
| USAARL | U.S. Army Aeromedical Research Laboratory |
| USAF | U.S. Air Force |
| USMC | U.S. Marine Corps |
| USN | U.S. Navy |