LOW BACK PAIN AND LOW LEVEL FLYING

Coverphoto : F-16 and a graphic figure of low level vibration.

This examination has been carried out with the Royal Netherlands Air Force.

LOW BACK PAIN AND LOW LEVEL FLYING

(LAGE RUGPIJN EN LAAGVLIEGEN)

PROEFSCHRIFT

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To: Henny
Frans
Nanette
Our parents.

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CHAPTER ONE

LOW BACK PAIN : A COMMON PROBLEM ?

1.1 INTRODUCTION

There is a lot of interest in low back pain (LBP). An enormous amount of papers has been published in the medical, epidemiological and ergonomical literature. Quite rightly so, for we know that 50 % of the population suffers from LBP at least once in a lifetime (Valkenburg en Haanen, 1982). The yearly incidence is calculated at approximately 1 % (Haanen, 1984). In some populations the incidence is even higher. Hildebrandt (1984) proved that 80 % of all plasterers are suffering or have been suffering from LBP. This is very expensive. In the Netherlands Vermeer (1983) computed the cost of LBP at fl 700,000 per working-hour starting from an eight hours working-day and 260 working-days per annum. In 1976, Wood found that each year 1.1 million patients over the age of fifteen went to their family practitioner for LBP in England. He also found that 13.2 million working-days were lost as a result of this syndrome.

Wijhe (1976) stated that LBP is the most common cause of occupational disabilities in industrial societies. Furthermore LBP and headache are the most frequent varieties of pain with which the general practitioner has to contend. According to Anderson (1976) 63 % of absenteeism by handworkers was caused by LBP, which meant the loss of 15 million working-days in Great-Britain. In the United States of America it has been calculated that 7 million people are absent each year as the result of LBP (Fish, 1977).
In the Netherlands Ten Broeke (1979) stated that musculoskeletal disorders, 40% of which is LBP, rank first in working-days lost due to sickness; moreover LBP is ranked number one in new and accepted cases of disability in Social Insurance claims. Willems (1987) showed that company doctors and insurance company medical officers consider disorders of the locomotive system to be most frequent occupational disease.
But, is there really something new in the wind ? Finneson (1975) claimed that, referring to some papyrus rolls, some 5,000 years ago the ancient Egyptians suffered greatly from LBP. It is also been said (Larkin, 1974 and Snook, 1978) that the major concern of Bernardino Ramazzini, the founder of occupational medicine in the late 16th century, was LBP.

1.2 DEFINITION

In this study we shall use the definition of LBP by Nachemson

(1976) : " low back pain is an acute, subacute or chronic pain, which is characterised by either a slowly or a suddenly occuring rather sharp pain with or without radiation over the buttocks or slightly down the leg and concommittant restriction of motion".

Chronic pain is defined as lasting longer than four weeks.

1.3 PROGRESS

LBP is not only a disease of the young adults. Although Fielding (1978) says that significant LBP begins at 35 years of age and that 35 % of the patients will have episodes of LBP, with the pain being recurrent in 90% of the cases, Haanen (1984) stated " it is very remarkable that LBP starts at a young age, between 25 and 35 years of age and then according to many researchers is falling off above 65 years of age,again".
LBP occurs with about the same frequency in people with sedentary occupations as in those during heavy labour (Nachemson, 1976).

LBP may be considered a mainly self limiting disease. Dixon (1976) found that 45 % of the patients suffering from LBP were cured within one week, 86 % within one month and 92 % within two months. McKinzie (1981) regards LBP as a self limiting disease,as well, for he found 90 % recovery within 8 weeks without any therapy. Snook (1978) even found that 80 % of the LBP patients could return to their job within three weeks. In 1969, White already published that 90 % of the LBP patients could return to their working places within three weeks.
With the aid of the statistics on morbidity at the British National Health Insurance (1969 - 1970), Wood (1976) found that an acute LBP attack lasted only 18 - 21 days.
In the Netherlands the benefit period of the GAK and the Social Security Bank lasted less than about four weeks for 82 % of the LBP patients in 1982.

1.4 AETIOLOGY

1.4.1 PREDISPOSING FACTORS

Analysis by Merriam (1983) and Chaffin (1984) confirmed previous reports that people prone to pain in the back have a greater standing height than people who are not.
Vaellfors (1985) stated that LBP may more frequently be a disease for patients suffering from psychiatric illness, for alcoholics and for early retirees.
More than 20 diseases were listed by Moskowitz (1981) as being a possible cause for LBP, but Bywaters (1982), who listed 10 diseases causing LBP, proved that 90 % of the LBP cases were ideopathic.
Snook (1980) found high incidences among truckdrivers and shopworkers, (2-3 %), but also workers in the brick-manufacturing, wood-, paper- and steelindustries showed high incidences (1,6 - 2,2 %). Already, in 1978, Snook had found that the combination of lifting, twisting and bending could be an important cause of LBP.
In a study among physical therapists Molumphy (1985) found that "lifting with sudden maximal effort" and "bending and twisting" were frequent mechanisms of injury.
McKinzie (1981) distinguishes three predisposing factors :

a. sitting posture, mainly in flexion which makes the intradiscal pressure increasing,
b. loss of extension range of the spine and
c. frequency of flexion.

Stanish (1987) stated that LBP in athletes is exceedingly common and he thinks that LBP might be caused by overexertion.
Svensson and Andersson (1983) found correlations between LBP and overtime work, monotonous work and a high degree of lifting. Nachemson stated in 1970 that LBP occurs with about the same frequency in people with sedentary occupations as those with heavy labour occupations, although the latter have a higher incidence of absence from work because they are unable to work with their complaints.
McKinzie (1979) and Magora (1972) came to the conclusion that poor sitting posture may produce LBP in itself without any additional strains of living. Pope (1984), White (1985) and Troup (1986) concluded that sitting is a risk factor as is heavy manual handling and lifting especially during rotation.
Bremmer (1968) and Wickstroem (1978) both suggest that vibrations occuring in modern machinery may be associated with LBP.

So in an overview of the literature a list of predisposing factors is found:

a. an anthropometric factor: height,

b. diseases: psychiatric illness, alcohol abuse,

c. job related factors: jobs with frequent twisting, bending and lifting, overexertion, posture and vibration.

In the population of this study, all pilots meet the same physical and psychological criteria entering the RNlAF. Differences may be expected in physical condition. Posture and the contribution of vibration are unknown parameters. So this study is focusing on posture and vibration as a factor in developing LBP.

1.4.2 POSTURE

Andersson (1985) stated that posture essentially determines the total compressive load on the spine, as well as the load-distribution within the spine. Studies of intradiscal pressure have shown that the load on the lumbar spine is strongly influenced by posture. The intradiscal pressure while standing is about 40% higher than while lying supine and increases a further 40% while sitting.

Kazarian (1972) found that people loose height during the day due to loss of intradiscal fluid caused by the increased intradiscal pressure. This phenomenon is called "creep".

Sitting intradiscal pressures can be reduced considerably by an appropriately inclined backrest, by a support for the lumbar spine and by the use of armrests (Snijders, 1984) e.g. a 130° inclination of the backrest will reduce the intradiscal pressure by some 50%. Lumbar support pushing the lumbar spine into a lordosis of 4 cm gives a 30% reduction of the intradiscal pressure and the support of armrests about another 20%.

Pressure measurements at different angles of forward flexion show a linear increase in pressure with increasing forward flexion. Rotation of the trunk (twisting) increases the pressure further at a given angle of flexion.

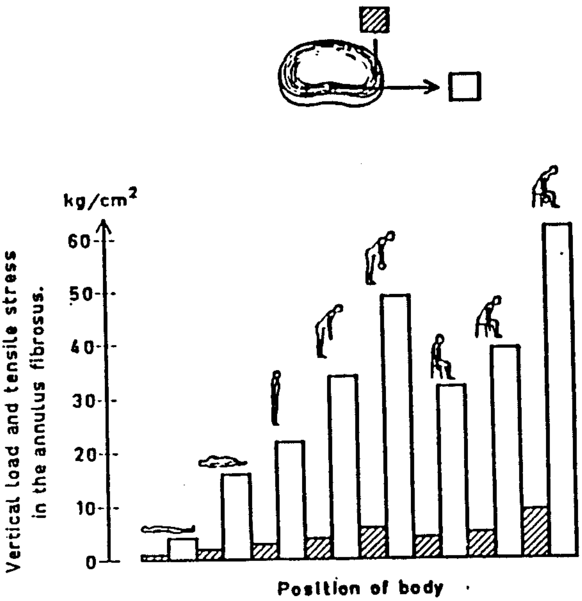
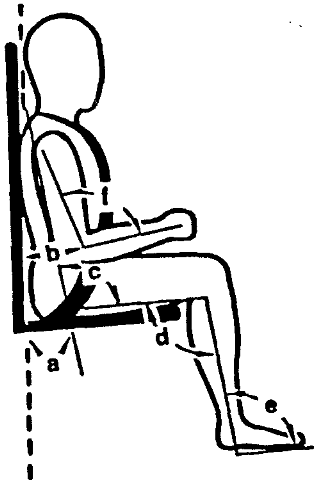


Fig 1. Vertical load per unit of area on the annulus fibrosus and tangential tensile stress in the dorsal part of the annulus fibrosus in the L-3 disk in a subject weighing 70 Kg and assuming the positions schematically shown. (Nachemson, 1960).

Electromyographic and discometric studies of posture showed low activity of the back muscles when the backrest had an inclination of more than 30° and when kyphosis of the lumbar spine could be avoided e.g. by a sufficient lumbar support and again, additional armrests were shown to be very helpful for both the shoulder and the arm muscles, (White ,1985 and Troup,1986). Therefore it is not amazing that Diakow (1984) found a 35.5% prevalence of LBP in dentists, who usually work in a very bad posture. Grandjean (1984) found 57% LBP under secretaries and clerks. And Molumphy (1985) reported that 29% work related LBP of physical therapists was caused by "lifting with sudden maximal effort" and "bending and twisting". Optimal postures have been defined by Schobert (1962) and Rebiffe (1969). These authors have defined comfort angles for most of the joints while sitting.



1. Angle trunk - perpendicular	20° - 30°
2. Elbow angle	80° - 120°
3. Hip angle	95° - 120°
4. Knee angle	95° - 135°
5. Angle upperarm - perpendicular	10° - 45°
6. Ankle angle	90° - 110°

Fig 2. Comfort angles for sitting posture.
(Rebiffe, 1969)

After conscientiously studying 16 manuals on ergonomics and epidemiology Dul and Hildebrandt (1987) have concluded sitting is the main risk factor for LBP. McKinzie (1981) considers posture to be the most obvious predisposing factor, too. Postural fatigue, being the first sign of LBP, is defined as fatigue in specific muscles whose continuous activity is required to maintain posture , De Gaudemaris et al (1986) consider postural fatigue and consequently bad posture to be one of the prevalent occupational factors of LBP. Bowden (1986) even moves one step further, stating that pure muscle fatigue is a limiting factor. On the other hand Nouwen and Bush (1984) came to the conclusion that there is no consistant evidence that LBP-patients have elevated paraspinal EMG-recordings or that its reduction is likely to be an active ingredient in biofeedback therapy. And Nouwen (1983) showed in a study on bilateral paraspinal and abdominal wall EMG-recordings of a group of 20 LBP patients no significant right versus left differences between

LBP patients and pain free controls.
It might be concluded that posture could be an important factor in developing LBP.

1.4.3. VIBRATION

Vibration is generally defined as the motion of objects relative to a reference position that is usually the object at rest. Specificly, vibration is a series of oscillations of velocity, an action that necessarily involves displacement and acceleration. Acceleration is typically used as the fundamental measure of vibration environments and is expressed as multiples of gravitational acceleration of the earth, "G" ($G = 9.8\ m.sec^{-2}$). Vibration is described relative to its effects on man in terms of frequency, intensity (amplitude), direction (with regard to the anatomic axes of the human body and duration of exposure (Von Gierke and Nixon, 1985).

The frequency of periodic motion is the number of complete cycles of motion taking place in 1 second, expressed in the international standard unit Hz. Nonperiodic vibratory motion is adequately described in terms of frequency spectra.

The amplitude of vibration is defined as the maximum displacement about a position at rest. The intensity of non periodic vibrations is a computed time averaged or root-mean-square (rms) value.
Vibration can have three linear and three rotational degrees of freedom. The directions of vibration have been standardized relative to the anatomic axis as illustrated in Fig 3.

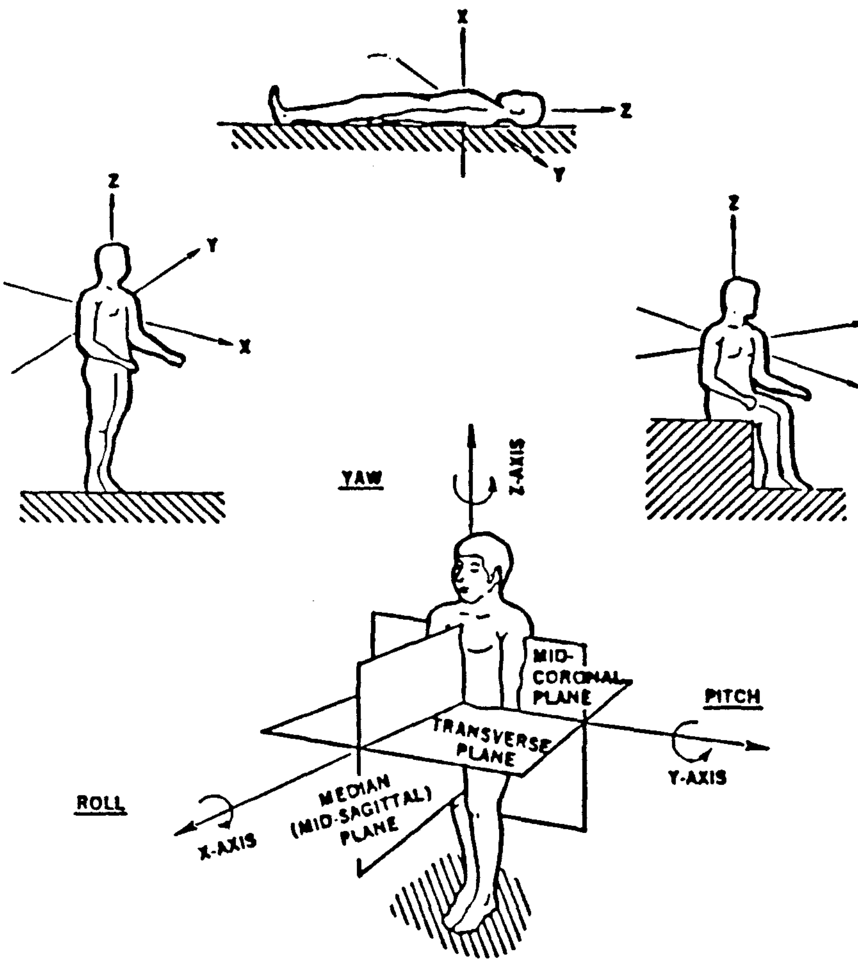


Fig 3. Directions of coordinate system used in biodynamics for mechanical vibrations influencing humans. (Von Gierke, 1985).

In general, human tolerance to continuous vibration declines with increasing duration of exposure. Long term vibration sometimes denotes exposures exceeding 1 hour, whereas short term vibration usually identifies exposures lasting 1 minute to 1

hour. Vibration lasting only a few seconds or a few cycles of motion can usually be treated as transient vibration, shock motion or sometimes as impact.
Each of these variables, suitably weighted, has been incorporated into the general standard for whole body vibration, ISO 2631 (1978). However, the way in which exposure time is taken into account in this standard has been critized by several researchers (Kjellberg, 1985 and Miwa, 1973). At present, it remains unclear to what extent whole body vibration does constitute a health hazard and it is still less clear how the possible risks are related to the duration of the daily exposure.
Whole body vibration may cause both physiological and biomechanical reactions of the human body, as it may affect man's capacities e.g. performance.

Concerning physiological effects on circulatory and respiratory functions a great number of variables have been studied. These studies (Christ and Dupuis, 1966 and Seidel et al , 1980) have revealed either a raised activity at the beginning of exposure followed by a regression towards resting values or a constant level close to or slightly above the resting level. These studies suggest that individuals get used to exposure to whole body vibration. Nevertheless, hyperventilation may occur. It is suggested that this is an effect of the mechanical influence of vibration on the diaphragm and the chest (Seidel,1975).

The effects on muscular and nervous systems have been studied more frequently. EMG's have shown that muscles may be activated during exposure to whole body vibration. During random vibration, stochastic EMG signals occur (Kjellberg, 1985). It is suggested by Hagbarth and Eklund (1965) that this muscle activity is a combination of control movements to stabilize the body and so called tonic reflexes generated by passive movements. Vigorous active muscle contractions seem to accompany shocks and very low frequency vibrations which have high intensity lateral components. Under these circumstances, symptoms of stress may occur which in themselves may lead to a further increase in muscle activity: a close loop system leading to fatigue. Vibrational effects on nervous functions have primarily been studied in relation to balance.

Low frequency vibration affects the vestibular system by otolith overstimulation and the duration of exposure again augments this phenomenon (Reason, 1976, Seidel and Bastek, 1980). The result is motion sickness, a desease of young people, too and F-16 pilots may be very susceptible for this mismatch of receptors.

Epidemiological studies suggest that long term exposure to whole body vibration may influence the gastrointestinal system (Seidel, 1980).
Neurophysiological measures have also been used as indicators of mental load. Ullsperger (1980) suggested that the increased flow of afferent nerve impulses from the sense organs of the joints, muscles, skin, tendons etc. during exposure leads to diminished attention to other stimuli. This hypothesis was supported by the fact that auditory-evoked potentials were reduced during exposure to vibration and that this reduction increased with duration of exposure.
Furthermore, heart rate variability may increase during exposure as the peripheral blood flow is reduced.

Epidemiological investigations have also led to suspicions that whole body vibration above all constitutes a risk for development of injuries and functional disorders of the skeleton and the joints (Seidel, 1980). With the help of biomechanical measurements a very obvious effect of vibrations can be studied in man. Relative movements between different parts of the body, organs or tissue may occur and it is assumed that these relative movements are closely related to injurious effects (Heide, 1978 Guignard, 1970). For the body as a whole, sensitivity for both impedance and transmission is at its peak in the range 4 - 8 Hz in the "Z"-direction. Christ and Dupuis first described in 1966 the resonance frequency of 4 Hz for the spinal column. Von Gierke (1976) stated that the human vertebral column behaves like a vibration system, Hagana et al (1986) showed that the human spine has three defined areas of resonance: 4 - 5 Hz corresponds with the entire body; the area between 7 - 10 Hz represents the spinal column. The resonance at about 18 Hz can be representative for the head. The absorption of the spinal column causes a decrease at the head up to 40%. Seidel and co-workers (1980) studied impedance and transmission from seat to head for a 4 Hz and an 8 Hz sinusoidal vibration in the "Z"- direction. They found that the transmission factor was reduced for the 4 Hz and increased for the 8 Hz with exposure duration. The impedance, however, was not affected. So the body seems to become stiffer with increasing exposure duration. Clarke (1979) showed in a study of train and hovercraft passengers that they

do not change their ideas on comfort, at least for rides up to 2 1/2 hours.
Kazarian (1976) stated that "creep" is accelerated under additionally imposed vibratory load. This phenomenon is named "vibrocreep".

The effects of whole body vibration on performance have been studied in tasks requiring visual acuity and tracking. The vibration effect in these tests is a result of mechanical interference in the functions of the eye and the hand-arm systems. Griffin (1986) concluded that there is no empirical support for the notion that performance deteriorates over time as an effect of vibration. Gray (1976) showed no deficiency in vigilance tasks, visual tasks and tracking tasks in a 3-hour exposure to vibration.
Ribot et al (1986) showed that subjects might switch from a visual and arm- afferent and efferent control in no vibration to a visual control only under vibration conditions and he states that vibration systematically impaired performance in target recentering tasks.
No effects could be found in reaction time, problem solving and other tasks dependent primarily on central nervous system functions. Recently Moseley and Griffin (1987) published a study concerning two experiments on vibration and its effect on visual performance. They showed that it might be possible to model the effects of vibration on visual performance as a spatial filter process and they showed that head vibration influenced contrast thresholds.

Of course, whole body vibration produces discomfort, especially when the vibration is impulsive. Motions with higher peak levels cause greater discomfort, even though they have the same rms level as motions with the lower peaks. Griffin (1985) found that the degree of discomfort produced by whole body vibration is greatly dependent on the direction of the vibration exposure. Contrary to some other studies, he found that the time dependency appears to be present at all durations up to about 30 seconds, growth in discomfort may vary with frequency. He also found no evidence to support the concept of an integration time of the order of 1 second for human response to vibration.
In a literature study on whole body vibration, Hulshof and Veldhuizen van Zanten (1987) found some spinal disorders that could be caused by exposure to whole body vibration, like early degeneration, herniated lumbar discs and low back pain cq

stiffness of the back. They did not find any exposure response relationships in a single manual or study. Nevertheless, because most studies showed a strong tendency in a similar direction, they concluded that long term exposure to whole body vibration is harmful to the spinal system.

1.4.4. FLYING

LBP of pilots may be caused by ejections (only for jetpilots) or by posture and vibrations. Although the first publication on low back pain, flying and vibration was already published in 1936 (according Delahaye), for about a quarter-century the medical authorities of the armed services only described the phenomenon of pain in the lower back among helicopter aircrew. Delahaye and co-authors (1982) wrote the most comprehensive review of this problem :

> "Chronic lumbar pain is the most common complaint. The picture is of a low-grade, tiring, heavy ache localized in the lumbar region, or sometimes lower (lumbo - sacral pain). It extends laterally, often predominantly to one side, and may radiate to the buttocks, the iliac crests or, more rarely, the groin. This discomfort is brought on by flight, aggravated by lifting effort or by long car journeys, and relieved by lying down and by physiotherapy.
> At a higher level of intensity, this discomfort becomes a pain which makes flying very gruelling so that, despite the constraints upon the position of his limbs, the pilot seeks to change his posture. The pain increases in intensity during the last flight at the end of the day, and reaches a maximum when the pilot lands the aircraft. Although it persists during the evening, it tends to diminish, but reappears on standing. It disappears after a night's rest."

Back pain in the civilian population is usually reported to medical professionals by patients who have suffered chronic pain for many days. Although there are some patients in whom a rapid onset of pain is associated with a particular activity, such as bending or lifting, there are many patients who cannot remember the occasion of the onset of their pain (Bowden, 1984). In contrast, the helicopter pilot's back pain is closely

associated with actual flight duty. Shanahan (1984) says that the pilot's low back pain is a typically discomfort pain: a dull ache and radiation into the lower extremities is rare. The pain is not relieved by changing positions.
Fritzgerald and Crotty (1972), in a general survey of groundcrew and aircrew in the UK Royal Air Force, found that over half of the 300 pilots who experienced frequent in-flight backache never suffered from backache on the ground. Schulte-Wintrop and Knoche (1986) reported following a survey of 145 helicopter aircrew that 40% complained of back pain during flight and 51% of back pain immediately after flight. In only 39% of the cases, the back pain was described as a long lasting one. Shanahan (1986) reported on a survey of 802 USArmy aviators which showed that 73% experienced back pain while on flight duty, while only 14.5% had symptoms persisted longer than 48 hours. Singh (1983) reported that all of a group of 21 Chetak pilots in the Indian Air Force experienced back pain in flight, but this was relieved in all cases by rest.
Reader (1986) found that pilots suffered twice as often from LBP as groundcrew. 13% of the RAF pilots experienced backache every time they flew, 22% suffered from LBP once a week when flying, whilst 40% developed back pain at least once a month. Shanahan (1984) found in his study that 16% of the USArmy helicopter pilots experienced LBP in more than 75% of their flights, 26% in more than 50% of the missions and 48% in more than 25% of the completed missions. The average duration of flight required to produce back symptoms for this group was 88 minutes. The onset of back symptoms in a particular individual is a threshold phenomenon that requires a certain minimum duration of exposure to flight, therefore, is the conclusion of Shanahan.
Burmeister (1986) conducted a study in a collective of 88 pilots and weapon system operators (WSO's), consisting of 57 jetpilots or WSO's, 20 prop- pilots and 11 pilots flying jet as well as prop aircraft. 52% stated that they suffered from back pain. In prop-pilots this percentage was somewhat higher than in jetpilots. The majority of the complaints began gradually and the pain is only present part of the time. While in proppilots there also was a certain percentage of prolonged pain, some of the jetpilots indicated a rather intermittent course. Dragging pain was more often found in prop-pilots, while jet pilots showed a tendency for stabbing pain. The difference may be attributed to the different operational profile between jet and prop. Both groups stated that the complaints have a predominantly dull character.

Froom and co-workers (1986) reported that the prevalence of a history of LBP, unassociated with flight was nearly identical in fighter, transport and helicopter pilots. Fighter pilots however, had nearly twice the prevalence of chronic pain, pain requiring bed rest and pain radiating to the leg, in comparison to transport and helicopter pilots. Froom (1986) found that fighter pilots with LBP had significantly more narrowed disc spaces than the asymptomatic transport pilots, and fighter pilots without LBP had an intermediate proportion of narrowed disc spaces. He concluded that disc generation may be accelerated by repeated G_z forces experienced by pilots of fighter aircraft.

It is well documented in the aeromedical literature that most helicopters subject their occupants to vibration that coincides with the resonant frequency of the human spinal system (Delahaye, 1982, Gearhart, 1978, Shanahan, 1984 and Wilder, 1982). Repeated exposures to such conditions have been speculated to cause microtrauma to the spinal system that eventually leads to LBP. That a large proportion of pilots experience backpain within the first few hours of flying helicopters tends to argue against this theory. Furthermore, work by Shanahan and Reading (1986), using helicopter cockpit mockups on vibration tables, has shown the presence or absence of helicopter similar vibration had no influence on the time of onset of pain or on pain intensity for subjects exposed to these conditions. Subjects complained of LBP during a two hour "flight" regardless of whether vibration was present or not. In a similar study, Pope and co-workers (1984) found that all their subjects reported back pain when exposed to a two hour "flight" in a helicopter mockup and the subjects actually reported even less pain when exposed to the helicopter similar vibration than when subjected to the static condition. Moreover, the subjects used were students who had neither reported previous episodes of back pain nor had they ever flown helicopters. Consequently, it appears that vibration plays a very small role in the ethiology of the acute and transient back pain in helicopter pilots. Theiler (1986) assailed the judgement of the Court for Social Insurance in Celle, FRG, which was ruled that vibrations give more spinal column disorders in helicopter pilots. He concluded that vibrations in helicopters are like the vibrations of trucks and buses, moreover the exposition to vibration in total is less because the missions last only 2 hours and the annual flying time is reduced to 180 hours.

In Burmeister's questionnaire (1986) prop pilots classified vibrational stress significantly lower than the jet-pilots. Evidently turbulences encountered in jet aircraft play a greater role than vibrations due to prop propulsion. Aghina (1984) found in a study of jet pilots that 52% were complaining of back problems.

The more likely ethiological factor in LBP related to flying is posture. Magora (1972) found that occupations that force workers to sit for prolonged periods, show a high incidence of LBP and Keegan (1983) pointed out that the sitting position without adequate lumbar support and a trunk - thigh angle of less than 105 degrees causes a considerable flattening of the normal lumbar lordosis. This flattening creates stresses which probably cause pain, he postulated.
In 1986, Osinga and Schuffel of the Institute of Sense Organ Physiology at Soesterberg, the Netherlands, wrote a report on posture of pilots in the Bolkow 105-C helicopter. They analysed the factors that are affecting posture, like position and range of controls, the seat fixations, demands for outside view, view obstructions, and available cockpit space. These factors were listed against data of the static and functional anthropometry, resulting in a specification of the desired sitting posture. They concluded that in the design of the cockpit geometry the existing criteria do not appear to meet the requirements. These were based on a maximum stretch of shoulder and arm muscles. A comparison of the desirable sitting posture of young dutch adults meeting the RNlAF selection criteria in the Bolkow 105-C showed large differences, which couldn't even be compensated by modifications of the chair only.
Pope (1986) considers the predominant cause of back discomfort and fatigue to be the Bell helicopter, type UH-1-H specific seated posture (rather than the specific vibrational environment). Froom and co-workers (1987) carried out a study of the Bell helicopter, type AH-1-S helicopter crews. The pilots of this helicopter maintain a vertical position in the gunner's position (front seat), whereas in the pilot's seat (rear), they lean forward and to the left in order to be able to operate the controls. In a cross over study with pilots flying alternately in the front and rear positions he found an increased prevalence of LB pain: 72% versus 55.5%; the onset of the pain was quicker than experienced in the gunner's position and the intensity was greater. Froom concluded that posture is an important component of the low back pain experienced by helicopter pilots during flight. Shanahan (1986) reported that increased lumbar support for helicopter pilots gave an immediate improvement of the low back pain after flight. Reader (1986) used a curved pad in order to improve the lumbar curve of

helicopter pilots. He found a 50% improvement and 32% of the LBP's resolved completely.
Aghina proved in 1984 that 49% of the RNlAF Lockeed F-104 pilots had had episodes of back complaints and 66% of the General Dynamic F-16 pilots. Here, too, the difference may be caused by the totally different sitting position. In a recent study Tielemans (1988) showed that according body sizes of the RNlAF pilots at least 8% of them did not properly fit in the F-16 cockpit.
Shanahan (1984) concluded that although poor posture alone can produce pain in the lumbar region, this postural condition may be aggravated over the long term by the concommittant exposure to vibration that coincides with the resonant frequency of the spinal column.

1.4.5. SUMMARY

LBP is a very common disease. 50% of the people have had the experience at least once in their life. It is mainly the disease for young people over 25 years of age. Considered to be contributing or predisposing factors are:

a. sitting posture, especially in flexion without lumbar support
b. frequent flexion and twisting
c. lifting
d. vibrations with frequencies of 4-8 Hz.

The pilot's LBP may be caused, apart from the "normal" factors, by ejections and mainly by the combination of bad posture and vibrations. About 50% of the flying population is suffering from LBP, equally divided over transport-, helicopter- and jetpilots. However, jetpilots seemed to have more prolonged periodes of LBP and more narrowed disc spaces. This might be caused by repeted high G_z-loads.
Posture in helicopters is a wellknown example of bad cockpit design, but in modern high performance jet aircraft poor posture may produce pain in the lumbar region, as well.

1.5. OBJECTIVES

1.5.1. INTRODUCTION

Although the sitting posture in the F-16 fighter aircraft is considered to be the best ever and pilots do not complain very often about it, it is obvious, taking a glance of the pilot in the aircraft, that this position is far from ideal. The fixed Head Up Display (HUD) and the 30° back angle of the ejection seat force the pilot to bend forward his cervical spine and head, and sometimes even to sit erect without any lumbar support. Because of the ideal outlook through the canopy the pilot rotates and twists in order to check his "six" (the air space behind the aircraft), even under high "G"-loads.

Moreover the pilots always consider this aircraft to be the best flying, with the finest aerodynamic characteristics and equipments. However, during the low level flying training periods, carried out in Happy Valley Goose Bay, Labrador, Canada, the pilots seemed to have a lot of problems with low level turbulances and consequently they seemed to suffer more from LBP in comparison with flying in the Western European Theatre. In 1987, in two cases, they even suffered from herniated discs.

It was suggested that LBP in Canada could be developed by a contribution of aircraft vibrations, shocks, G_z-forces, high air speeds and posture. The substantial damage to aircraft structures sustained during low level flying was considered to be a very good reason to analyse the effects on the human being in the cockpit as well.

The question adressed in this study can be split into a number of parts:

a. Are F-16 pilots suffering from LBP more than other pilots and workers?
b. Are F-16 pilots suffering from LBP more while flying low level missions at high speed?
c. What kind of vibrations do occur in the F-16? What are the frequencies and the magnitudes?
d. Are vibrations during low level missions different from the vibrations that occur at higher level and what is the contribution of the airspeed?
e. Is the F-16 ejection seat a good support of the back and how well designed is the seat-cockpit combination?

f. If LBP in the pilot's population really is a problem, are there any solutions in order to prevent LBP?

1.5.2. PROCEDURE

In order to collect epidemiological data a questionnaire on low back pain was developed, using both the questionnaire the author used and validated with the help of cluster analysis and other statistical techniques in cooperation with the University of Nimwegen and the questionnaire that was used by Groenhout and Valken (1987) in their study controlled by the Coronel Laboratory in Amsterdam. The questionnaires were composed in close cooperation with the methodologists and statisticians of the RNlAF Behavioural Science Division. This questionnaire (Q"G") was introduced to the F-16 pilots on the squadrons by the investigator and had to be completed classically; the author being present in order to be able to answer possible problems in completing.The completed forms were handed to the flight surgeon. The questionnaire consisted of 69 questions on flying experience, vibrations, posture, LBP and related diseases. (Appendix A)
A second questionnaire (Q"N"= Appendix B) was developed in order to collect data of missions flown in Western Europe again using forms of the 1984 study of the investigator. This questionnaire "the Netherlands" consisted of 23 questions on mission data, vibration, posture and LBP. This questionnaire was completed by the pilot after a mission in the Netherlands, received by squadron operations and transferred to the flight surgeon.
The third questionnaire, questionnaire "Canada" (Q"C" = Appendix C), consisted of 22 questions on mainly low level operations, posture and LBP, comparable with Q"N". Also this questionnaire was completed by the pilot, received by squadron operations and transferred to the flight surgeon. Completion of the questionnaires "N" and "C" was closely monitored by the author on the squadrons, too.
In order to discover the vibration magnitudes as well as frequencies, an instrumentation to measure the relevant data at the seat was installed in the F-16 aircraft. After a pilot study to check the reliability of the technical set-up, the instrumentation was transported to Canada and installed again. Twelve different missions were flown and registered. The analysis of the data collected was done by Netherlands Aerospace Laboratory in close cooperation with the investigator.

Posture data were collected as well, with the aid of the questionnaires, pictures, and measurements, and last but not least during this study a lot of low level missions was flown by the investigator in order to collect data of the pilot's posture during flight by questionning them and to be able to compare them with the description of the pilots in the questionnaires.
With statistical aids the hypotheses were then tested.

1.5.3. SUMMARY

The main questions:

a. Do pilots suffer from LBP more frequently after low level missions than after missions at medium or high level?
b. Are posture and vibrations during low level injurious to the health of the F-16 pilot?,

were answered with the help of three questionnaires, an investigation on vibrations of the pilot's seat and a study of the pilot's posture during flight.

CHAPTER TWO

F-16 PILOTS AND LOW BACK PAIN

2.1. INTRODUCTION

Materials and methods.

In order to obtain more insight into the total number of F-16 pilots suffering from low back pain and the relation to low level flying operations, three questionnaires were developped:

- questionnaire "General" on the prevalence of low back pain and the relation to flying experience and job satisfaction
- questionnaire "The Netherlands" in order to collect data in normal daily flight routine in the Netherlands.
- questionnaire "Canada" to be completed after a low level mission during low level training exercise at CFB Goose Bay, Canada.

The questionnaire "G" was based on the questionnaire the investigator used in his 1984 study on cervical complaints. Part of the questionnaire "G" is derived from the questionnaire used by Groenhout and Valken (1987) in their study on backpain in dutch helicoptercrews. The questionnaires "N" and "C" are the same as used in the author's 1984 study. Because no other questionnaire on LBP and flying exists, this questionnaire was developed. The results showed in this study should be interpreted with care due to the questionnaires used.
All questionnaires were completed by pilots of the Royal Netherlands Air Force flying F-16; assigned to all the F-16 flying squadrons after an introduction on the squadrons by the author, who remained stand-by during completion for answering questions or unclearnesses. All the forms held the family names and service numbers of the pilots. The reseacher then changed the names into anonymous at random numbers and the service numbers into ages. The forms were transformed to computer concept cards and stored in the main computer of the Duyverman Computer Center of the Department of Defense. The data were analysed with the help of the "Statistical Package for Sociological Sciences" (SPSS), using the chi-square test.

In this study the folowing definitions are used :

a. air to air mission: a type of mission flown against an opposing aircraft.
b. air to ground mission: a type of mission flown against a ground threat or ground target.
c. low level mission: a mission flown at an altitude of 150 feet; in Western Europe 250 feet.
d. routine flight: a mixture of air to air and air to ground missions, according the annual training schedule.

2.2. GENERAL QUESTIONNAIRE.

Results.

After a comprehensive briefing on the squadrons, the questionnaires were completed by the pilots. In total, 113 forms were completed by 112 pilots and 1 flight surgeon assigned to all the F-16 flying squadrons. The squadron distribution showed that about all the squadron flyers contributed. The ages ranged from 21 to 52 years of age, averaged 31.4 years and had a mean value of 28 years.

AGE	NUMBER	PERCENTAGE
< 26	14	12.3
26 - 30	51	45.1
31 - 35	20	17.7
36 - 40	15	13.2
> 40	13	11.5
Total	113	

Table 1. Age distribution.

Flying experience expressed in grand total flying hours and F-16 experience showed a normal distribution. The average total flying hours ranged between 1,000 and 2,000 hours and the mean F-16 flying hours ranged between 500 and 1,000 hours. The pilots flew in average of 11.8 years in total and the average F-16 experience was 3.0 years. The pilots flew an average of 15 to 20

hours a month, during 3.3 days a week, with 1.87 missions on a flying day. Rest between the consecutive flights on one day was 2 to 3 hours.
64% of all the pilots had low level flying experience at Goose Bay.
Answers to the questions on posture showed some differences (Table 2).

POSTURE	ROUTINE	LOW LEVEL	
RELAXED	1.56	1.46	4 points scale
TORSION*	2.40	2.18	5 points scale
PRONE+	2.08	2.23	5 points scale

Table 2. Difference in posture in routine and low level flight.(*= significant $p< 0.001$).
(+= significant $p< 0.01$), Chi-square test.

Very interesting is the finding that 74.3% of the F-16 pilots consider their job to be a stressfull one and as many as 79.6% were physically fatigued after a routine working day . It is also very interesting that most of the pilots don't believe there is a relationship between sitting position in the F-16 and fatigue. 54% answered no to question that asked for a relation between possible back pains and the pilot's daily work. However, it turned out that pilots who used to lean back more than half of the time, tended to have less stress.

stress	yes	no
lean back < 1/2	75.5%	24.5%
lean back > 1/2	63.6%	36.4%

Table 3. Sitting position in parts of the flying time in relation to stress.

The stressed pilots seemed to be the physically fatigued, too, as the non-stressed are the non-fatigued.

In order to develop and strenghthen muscle groups that are of importance in high performance flying, pilots have available on their squadron "Hydra fitness" training equipment.With the help of this equipment the muscles of the upper part of the body as well as the total aerobic capacity are trained. 46% of the pilots say they never use this equipment, whereas 71% are not training at least twice a week according to the instructions. One hour of sports a week seems to be the average physical preparation. Pilots are considered not to play sports that effort a high aerobic capacity, because then the "G"-tolerance may be reduced. No relation could be proven between non-participation in the sports program for pilots and being physically fatigued after a mission , as well as there seemed to be no relation between physical fatigue and total hours of sports carried out in a week.

FATIGUE		YES	NO
SPORTS	< 1 hour	34%	30%
	1 - 3 hours	51%	56%
	> 3 hours	15%	13%

Table 4. Fatique after flying in relation to sports hours a week.

FATIGUE		YES	NO
SPORTSPROGRAM	< 1x	46%	48%
	1x	24%	26%
	2x	23%	17%
	3x	7%	4%
	> 3x	-	4%

Table 5. Fatigue after a mission in relation to the times the pilot's sportsprogram is carried out in a week.

And, pilots who used to play sports outside the airbase more than 3 hours a week are overrepresented in the group that is performing pilot's muscle training according the schedule.

sports	< 3 hrs	> 3 hrs
pilot's training < 2x	75.3%	43.7%
pilot's training > 2x	24.7%	56.3%
total	100.0%	100.0%

Table 6. Sports hours a week outside the airbase in relation to the pilot's training program.

The investigation found that vibrations do not seriously hamper the operations, only 6.2% of the pilots had complaints, nobody ever had problems reading his instruments, nobody had ever been desoriented by vibrations and just 2.7% supposed vibrations to produce low back pain.
Shocks is a more common experience, with 28.3% being acquainted with this phenemenon. 10.6% of the pilots found it impossible to read their instruments under shocks,and 4.4% matched shocks and low back pain.

Low back pain is a common problem for 28.3% of the F-16 pilots. They suffer from LBP for 4.07 years on average (range 0 to 14 years). Pilots flying more than 8 years show a LBP/no LBP ratio of 0.45, whereas the pilots flying less than 8 years have a ratio of 0.25.
In the group with LBP, 13.1% suffer from this symptom continuously. On average the F-16 pilot has 5 complaints a year about his total spinal column. The pain is hardly ever longlasting; it disappears within some hours . Only 15.9% of the LBP problems last for more than 2 weeks.
Only 9.6% of all the pilots ever suffered from LBP after a training flight in Goose Bay.(which corresponds with 15% of the pilots who had experience in low level flying operations).
The pilots suffer from low back pain in 2/3 of the cases of back pain, the other 1/3 are complaints of the cervical region.
Radiation to the legs is seldom seen: it appears in 4.4% of all the LBP-cases. Two of the group have been treated for a herniated disc. All the pilots who are suffering from LBP also complain of the shocks and only a minority of vibration. And 97% of this group of pilots fatigued from flying.
Futhermore, LBP seemed to be found among pilots with less than 1,000 flying hours and more than 2,000 flying hours grand total, particularly.

Flying experience	<500	500-1000	1000-2000	>2000	total
LBP +	100%	37.5%	21.3%	34.3%	28.3%
LBP -	0%	62.5%	78.7%	65.7%	71.7%

Table 7. Flying experience (in hours) in relation to LBP.

The same results were seen in an investigation of F-16 flying hours.

F-16 experience	<250	250-500	500-1000	>1000	total
LBP +	42.1%	30.6%	18.7%	40.0%	28.3%
LBP -	57.9%	69.4%	81.3%	60.0%	71.7%

Table 8. F-16 experience (in hours) in relation to LBP.

18.6% of the pilots have not been fit for flying duties at least one time due to LBP and 3.5% were not able to return to flying status within 30 days.
To the question of whether they had any irregularities on the total spine X-ray that is made before they were trained to fly the F-16, 23.9% of the pilots answered affirmatively (Total spine X-rays are made every five years by the dutch Central Military Hospital "Dr A. Matthijssen", Utrecht, the Netherlands, reviewed by the radiologists Van Dalen and Blom, who consult the orthopedic surgeons Van Den Berg and Van Akkerveken in the more severe cases). 8% were flying with a dispensation for a more serious back disorder,like narrow intervertebral spaces and Schmorlls' impressions of the lumbar spine. Pilots who had flown a grand total of more than 2000 hours showed irregularities on the total spine X-ray (significance $p < 0.01$), as well as F-16 pilots with over 500 hours. Pilots who started their career before 1979 ($p < 0.01$) and have been flying the F-16 at least since 1984 showed very high numbers of X-rays with variations. All the pilots flying with dispensations had a serious X-ray variation, another 66% of the pilots with minor X-ray variations didn't have a dispensation.

X-RAY VARIATIONS

MINOR: dischondrosis
scoliosis
moderatè narrowed disc space lumbar region
listhesis/ lysis.

MAJOR : more than one narrowed disc spaces lumbar
cervical canal smaller than 14 mm
twosided lysis.

Table 9. X-ray variations classification used by the RNlAF and the Central Military Hospital, Utrecht.

In this group of pilots 8.0% had experience in using the ejection seat. No relation could be proved between LBP and aircraft egress by activating the ejection seat.

A relation between their work as a fighter pilot in a high performance aircraft and the onset of low back problems was assumed by 46.0%. A great variety of possible causes was mentioned:

	times mentioned
- bad designed chairs at the squadron facility	1
- no lumbar support in the parachute harness	1
- backseat flying	7
- air combat training	8
- badly designed ejection seat	8
- turning under high $+G_z$-load	11
- $+G_z$-load	23
- bail out	2
- low level flying	4
- long range flight	2
- cockpit lay-out	2
- desk job	1
- long pilot's career	1
- bad design of F-104 ejection seat	1
- synthetic flying.	2

5.3% of the pilots complained of LBP after each flight , 8.0% said they had LBP after a flight of more than one and a half

hours and 4.4% suffered from LBP after flights with a high level of built-in difficulties.
22.1% of the pilots had episodes of headache, 6.3% episodes of sleeplessness, and only 3.6% had concentration disorders. Furthermore 17.9% complained about their shoulders and another 7.1% about their arms. 19.6% of the pilots experienced urge problems or cramps of the urinary bladder. It seemed that pilots that leaned back had more urge problems.

lean back	<1/4	1/4-1/2	>1/2	total
urge +	17.5%	18.4%	36.4%	19.6%
urge -	82.5%	81.6%	63.6%	80.4%

Table 9. Lean back posture in parts of the flying time in relation to urge of the urinary bladder.

2.3. QUESTIONNAIRE "THE NETHERLANDS".

In the Netherlands all the squadrons were presented a form to be completed by the pilot after each mission, either high level or low level, and indepedent of the kind of the mission.
In total, 284 forms were completed by 81 different pilots and handed to the flight surgeon. The age of the pilots of this group ranged from 22 to 50, the average age was 29.8 years with a mean value of 28.

AGE	FREQUENCY	PERCENTAGE
< 26	29	10.2
26 - 30	186	65.4
31 - 35	25	8.8
36 - 40	23	8.0
> 40	21	7.4
Total	284	99.8

Table 10. Age differentiation.

In these missions the mean highest speed is between 480 and 540 knots. The average is 2.44 on the 4 point scale.

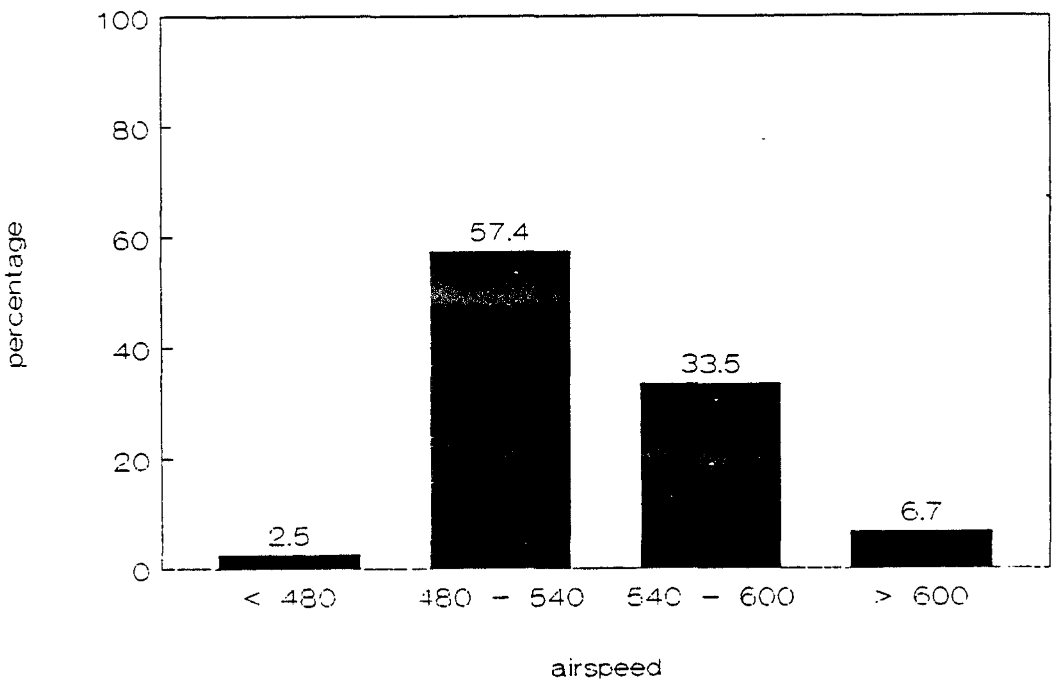


Table 11. Air speed differentation.

In air to air missions the G_z-load is higher than in low level flights.

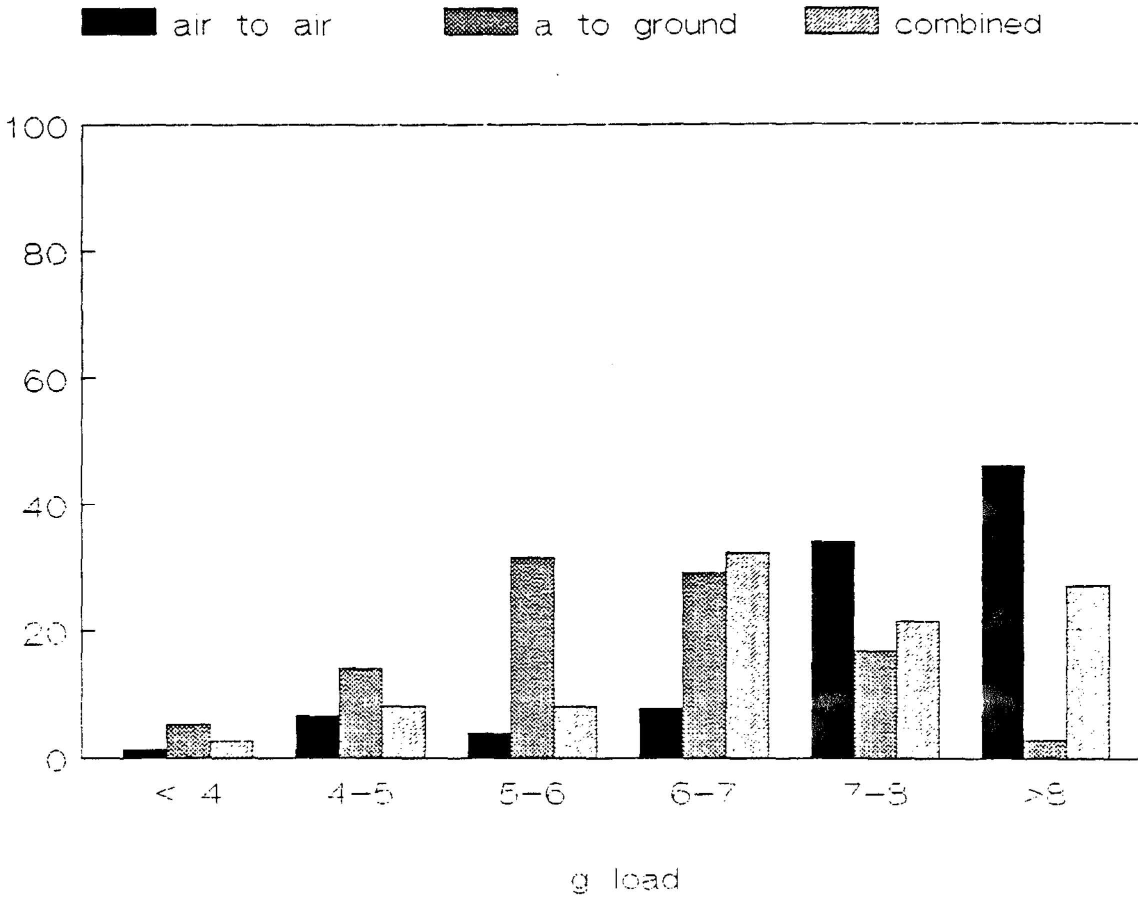


Table 12. G-load in relation to missiontask. (*=p < 0.01).

The mean $+G_z$ peakload was between 6 and 7 $+G_z$, averaged 4.02 on the 6 point scale. The mean flight level was between 500 and 1,500 feet above ground level.

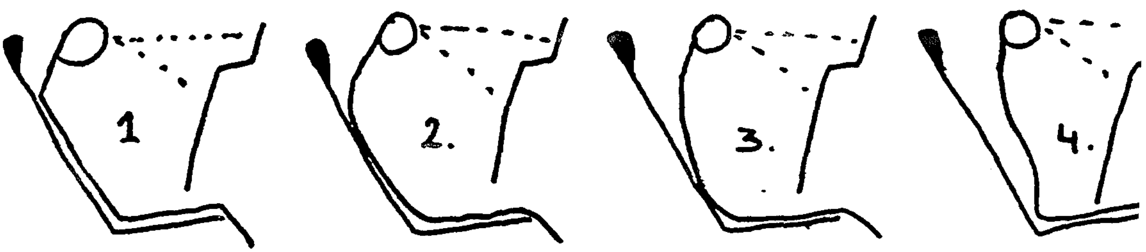


Fig 4. Four possibilities of sitting posture presented in the questionnaires.

(Validated by the author during several flights by interogating the pilots, the sitting posture given in the four drawings turned out to be best possibility to get an impression of the posture in flight. For flying safety reasons and lack of space it is impossible to collect these data on a different way).
The sitting posture had an average score of 2.12 on the 4 point scale and a mean value of 2. The position differed remarkably depending on the air task.

Posture	air to air	%	air to ground	%
1	4	5.3	20	9.6
2	49	64.5	155	74.5
3	22	28.9	31	14.9
4	1	1.3	2	1.9
TOTAL	76	100.0	208	99.9

Table 13. Posture in relation to air task.

In 91.5% of all the missions flown the pilot was content about his sitting position. Air to air pilots were more content than their air to ground collegues: 96.1% versus 90.1%.
In 31 cases instrument reading problems occurred (10.9%).
If torsion of the trunk was matched with air task a remarkable difference was shown.

Torsion	+	-
Air to air	61.8%	38.2%
Air to ground	37.4%	62.6%
Mixed task	29.7%	70.3%

Table 14. Airtask in relation to trunk torsion.

Only 9 missions ended with back problems, (3.2%) . No differences seemed to exist according the airtask, and duration of trunk torsion.

Back pain		yes	no
torsion	yes	3%	97%
	no	2%	98%
airtask	air to air	4%	96%
	air to ground	3%	97%
	routine	3%	97%

Table 15. Relation back pain, torsion of the trunk and airtask.

High G_z-load and cervical and thoracal spine complaints are closely related:

- low back pain < 7 $+G_z$
- higher back pain > 7 $+G_z$.

All the cervical complaints developed above 10.000 feet altitude.
LBP was equally divided over the ages.
Of these back complaints 1.1% concerned the cervical spine (3 out of 9= 33.3%), one was a problem of the thoracal spine (0.4% of the missions cq 11.1% of the back problems) and the rest was low back pain, 5 cases, 1.4% of the missions flown or 55.5% of the cases of reported back pain.
The low back pain had a dull character and no rapid onset; the cervical pain was more smarting, and had a rapid onset, however. Low back pain did not radiate, while cervical pain radiated to the shoulders.
Remarkable is that the pilots contentment with the seating posture increased with a more leaned back (inclined) posture.

Posture	1	2	3	4
Content +	100%	92.3%	84.9%	66.7%
Content -	0%	7.4%	15.1%	33.3%

Table 16. Posture in relation to contentness with posture.

None of the missions was completed prematurely because of the pain.

2.4. QUESTIONNAIRE "CANADA".

742 forms were completed by 50 pilots during the first training period of 1988 in Goose Bay, Labrador Canada. After each flight of the step down low level training program that is carried out in Labrador, the pilots completed a form and handed it to the flight surgeon, being the investigator most of the time.
The group that trained in Labrador during the first period of 1988 consisted of pilots of the three F-16 flying bases. The age differentiation was as follows:

AGE	NUMBER	PERCENTAGE
< 26	34	4.6
26 - 30	338	45.5
31 - 35	174	23.4
36 - 40	80	10.8
> 40	116	15.6
Total	742	

Table 17. Age distribution.

The ages ranged from 25 to 52 years of age, with an average age of 29.7 years.
The thirteen missions that the pilot is supposed to fly during his training have a fixed profile. In this study the missions were equally presented, strictly spoken mission number 13 is an extra one that is flown after a good weather period. Slight variances are possible. They are caused by the number of backseats flown by non dutch pilots.

MISSION NUMBER	FREQUENCY	PERCENT
1	67	9.0
2	74	10.0
3	66	8.9
4	67	9.0
5	61	8.2
6	53	7.1
7	52	7.0
8	58	7.8
9	49	6.6
10	53	7.1
11	60	8.1
12	60	8.1
13	22	3.0
TOTAL	742	100.0

Table 18. Differentiation of missions .

The mean highest airspeed during the exercises was 540 knots. The mean $+G_z$ was 6 to 7. The average $+G_z$ has been 3.70 on the six point scale.

In total 21.2% of the missions have been air to air, 4% combined air to air and air to ground and the rest, being 74.8% real air to ground.

For sitting posture the same four possibilities were shown as in the questionnaire "Netherlands" (Fig 4.)

The mean sitting position was number 2, the average 2.03 on the 4 point scale, but the difference between the posture of the air to air pilots and that of the air to ground force was considerable.

POSTURE	air to air	%	air to ground	%
1	37	23.6	79	13.5
2	102	65.0	383	65.4
3	18	11.5	122	20.8
4	0		1	0.2
TOTAL	157	100.1	585	99,9

Table 19. Posture in relation to air task.
Posture numbers are related to fig 4.

Interesting is the shift in posture shown over the consecutive missions.

Posture	1	2	3	4
Mission 1	16.4%	64.2%	19.4%	0%
2	16.2%	62.2%	21.6%	0%
3	9.1%	68.2%	22.7%	0%
4	7.5%	76.1%	14.9%	1.5%
5	8.2%	76.2%	24.6%	0%
6	7.5%	73.6%	18.9%	0%
7	7.7%	71.2%	21.2%	0%
8	10.3%	70.3%	19.0%	0%
9	6.1%	69.4%	24.5%	0%
10	11.3%	67.9%	20.8%	0%
11	48.3%	41.7%	10.0%	0%
12	38.3%	51.7%	10.0%	0%
13	9.1%	72.7%	18.2%	0%

Table 20. Relation between posture and mission number.

Given the fact that mission number 1 and number 2 are the two familiarization flights and that the missions 11 and 12 are cap- (air to air) missions at high or medium altitude, it is clear that low level flying forces the pilot in a more active and erect position.

Pilots who pull a lot of $+G_z$ probably the more aggressive fighter jockeys, tend to sit more erect,too.

Posture	1	2	3	4
< 4 +Gz	6.0	1.6	9.0	
4-5 +Gz	32.8	10.5	9.3	100
5-6 +Gz	29.3	29.7	37.1	
6-7 +Gz	20.7	29.5	22.9	
7-8 +Gz	6.9	17.9	23.6	
> 8 +Gz	4.3	10.7	7.1	
Total	100.0	99.9	100.0	100

Table 21. +Gz-load in relation to posture.

Table 22 shows the relation air task to posture. During air to air missions more pilots tend to lean back than while flying air to ground.

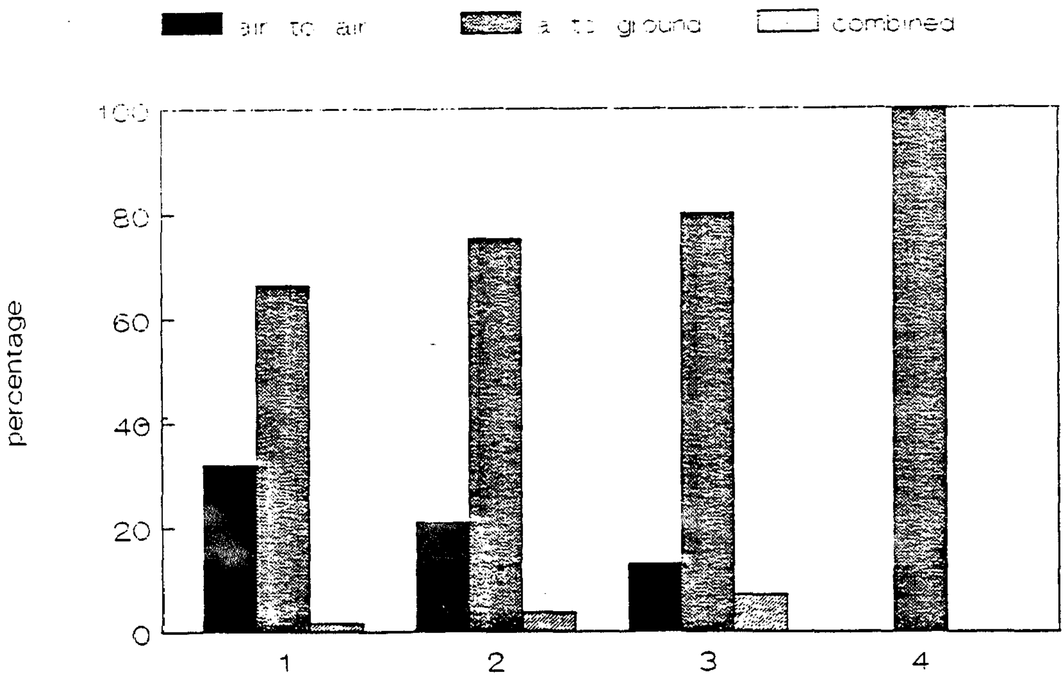


Table 22. Relation between posture and airtask.

During the mission 89.5% of the pilots were satisfied with the sitting position.
In 1.8% of the missions, the pilots had problems reading their instruments in a proper way.

Back pain occured in 42 missions, 5.8% of the missions flown. In 5 cases (11.9%) cervical complaints arose, in 2 cases (4.7%) the complaints were at the thoracal level and 35 missions (83.3 %) ended with a low back pain, this is 4.7% of all the missions flown in Goose Bay. Only two air to air missions ended with a back pain involving the cervical spine (4.7%). The other 95.4% of the back pains developed in air to ground missions. There is a tendency that the more leaned back positioned the pilot is flying, less LBP might develop.

Posture	1	2	3	4
LBP +	1.7%	5.2%	11.4%	0%
LBP -	98.3%	94.8%	88.6%	100%

Table 23. Posture in relation to LBP after mission. Posture numbers are related to figure 4.

No relation seemed to exist to the +Gz pulled. All the LBP problems were caused at altitudes lower than 250 feet and 80% at speeds exceeding 540 knots.
Older pilots suffered from LBP more than the younger ones. 60.4% of the complaints concerned pilots over 30 years (52.3% of this group of pilots).
The difference in character of the pain is considerable; all cases of cervical pain were described as "rapid onset" and "smarting", whereas all cases of low back pain were described as " dull" and "non-radiating".

In total, 25 different pilots had back complaints in this 8 week training period. During that time, 50 pilots were trained , so 50% of them suffered from backache and 36% of the total group of pilots suffered from low back pain.
None of the missions was ended prematurely because of the pain.

2.5. DISCUSSION.

The results of this part of the study should be interpreted with care, because new developed questionnaires were used for want questionnaires on LBP and flying.
The pilots contributing to the three different questionnaires, all belonged to the group of F-16 pilots with the Royal Netherlands Air Force. All these pilots meet the requirements set by the RNlAF in the psychological, medical and physical fields.
The three populations that have completed the three different questionnaires could consist partly or totally of the same pilots and they are well comparable.

	Q"G"	Q"N"	Q"C"
age range	21 - 52	22 - 50	21 - 52
average	31.4	29.8	29.7
mean	28	28	30
flying experience			
total	11.8	11.2	11.6
range	3 - 34	3 - 32	3 - 34
F-16 total	3.0	2.8	3.0

Table 24. Populations of the three questionnaires in relation to age and flying experience.
(in years)
Q"G" = General questionnaire.
Q"N" = questionnaire "the Netherlands".
Q"C" = questionnaire "Canada".

In the general questionnaire (Q"G") 23.9% of the pilots stated that they knew they had minor irregularities on the total spine X-ray. Complaints of LBP is a common problem for 28.3% of the F-16 pilots. This number is much lower than the figures we know for the helicopter, 51 - 100%, according work done by Shanahan (1984) and Singh (1983). It is about half the percentage given by Burmeister (1986) in his study on LBP of jetpilots (52.3%). Moreover it is not in accordance with former work where I showed that about 40% of the F-104 pilots and even 66% of the F-16 pilots had back problems, mainly concerning the cervical spine, however.

Though if you take another view of the figures on LBP of the questionnaires " The Netherlands" and "Canada", the results are more in accordance with the literature. In Q"N" 9 cases of back pain of 8 different pilots occured in a group of 103 pilots. In Q"C" 42 cases of back pain of 25 different pilots occured in a group of 50 pilots.

	Q"G"	Q"N"	Q"C"
back pain	28.3%	12.9%	50.0%
low back pain		5%	36%
cervical pain		4%	10%
thoracal pain		2%	5%

Table 25. Back pain incidences in the three questionnaires.

Since only 64% of the Q"G" had flying experience in the Goose Bay area,we might expect that the percentage of LBP experience of F-16 pilots will increase. Furthermore, it is evident that the 9.6% of the pilots of Q"G" who stated they suffered from LBP after a training flight in Goose Bay, consisted of the group of pilots who remembered the more severe cases.
An investigation of the results of the total spine X-rays (all made and reviewed by the radiologists of the Netherlands Central Military Hospital in Utrecht, the Netherlands: Van Dalen and Blom) demonstrated that of the 113 pilots, 86 pilots didn't show any irregularity (74%). In total 26% of the pilots had a variation on the total spine X-ray, 10 of them had to be considered as major irregularities (8.8%) and 17 (15.0%) as minor ones. All the major variations had received a waiver for flying F-16 by the Head of the Aeromedical Department of the RNlAF Medical Services. It is evident that all the pilots concerned knew they showed a spine disorder on the total spine X-rays and with exception of one pilot all knew about the waiver. The pilots showed to be very well informed about the status of the spine. It is a custom in the RNlAF to inform all the pilots about their total spine X-rays.

	number	X-raypercentage	Q"G"	Q"G"%
no irregular	86	76.1%	86	76.1%
minor irreg	17	15.0%	}	}
major irreg	10	8.8%	}27	}23.9%
waiver	10	8.8%	9	8.0%

Table 26. Total spine X-ray results in relation to pilot's knowledge of the results of these X-rays.

In the Q"N" investigation 9 missions ended with back pain for 8 different pilots. Pilots who developed LBP (N=4, four pilots with 5 cases of LBP) in Q"N" had 3 out of 4 disorders on the total spine X-ray in the lower back region, eg two times a narrowed disc space, and one dischondrosis.
In the Q"C" group 35 missions ended with LBP's for 25 different pilots. 13 of them (52%) showed irregularities on the total spine X-rays. Again mainly narrowed disc spaces , lysis and dischondrosis were the diagnoses.

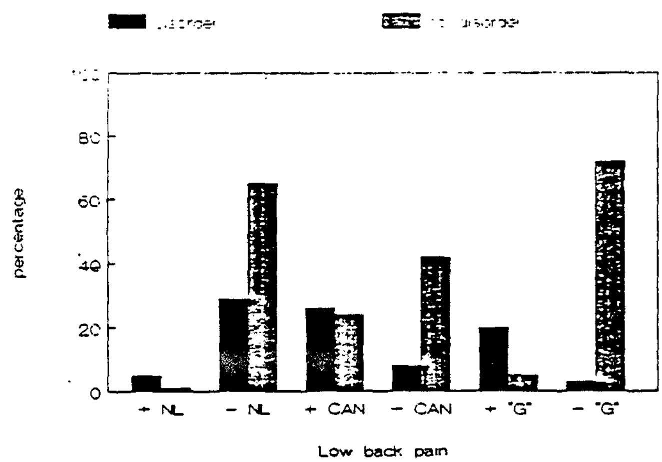


Table 27. Total spine X-ray disorders in relation to LBP during/after the mission.

It is evident and even significant ($p < 0.01$, chi-square test) that pilots with even minor disorders of the lumbar spine are more prone to LBP while flying the F-16.
This finding is not in accordance with the statemant of Phillips

and co-workers (1986) that spinal radiographs have minimal value in predicting LBP complaints. It is also not in accordance with La Rocca (1985) who stated that there is no obvious relationship between degenerative changes shown on X-rays and low back pain. However, Frymoyer and co-workers (1984) and Scavone (1981) found that cases with traction spurs or disc space narrowing or both, especially between L_5 and L_4, showed an increased incidence of LBP, and the findings in this study are in accordance with that statement.
The gravitational forces that were reached in missions in which LBP occured differed in the Q"N" and the Q"C". In the Netherlands the mean +Gz was between 6 and 7, average 4.02 on the six point scale and in Canada the mean $+G_z$ again laid between the 6 and 7, but the average was only 3.70.

	Q"N"	Q"C"	
G_z average	4.02	3.70*	on the six point scale
speed	2.44	2.88*	on the six point scale
altitude > 250 ft	100%	26.7%*	
< 250 ft	0%	73.4%*	

Table 28. Comparison Q"N" and Q"C" for Gz, speed and altitude.
* = significant $p<0.01$ Chi-square test

Table 28 shows the different speed, G's and altitudes in Q"N" and Q"C". They seem to be an explanation for the different lumbar versus cervical back pain ratios. This ratio is for Q"N" 5/4 = 1.2 and for Q"C" 35/7 = 5.0.
In former work (1984) using the same questionnaires the author showed that cervical complaints used to develop at higher $+G_z$-levels than the lower back pain. Furthermore, once again it turned out that cervical complaints appear very sudden and are smarting or burning, while low back pains have a dull character. Moreover low back pain does not radiate while 50% of the cervical pains do radiate to the shoulders and arms. This is in accordance with earlier work of the author on the cervical spine and in accordance with Delahaye (1982).

Remarkable is the difference in the mental and physical experience of the F-16 pilot compared with the 1984 questionnaire. Pilots then seemed to be eager and aggressive; only 7.6% was fatigued after the mission. Nobody felt stressed, irritated or had to go beyond his strength. In this investigation 74.3% of the pilots considered their job to be stressfull and even 79.6% felt physically fatigued after a routine working day. The two groups are not so well comparable: in 1984 the average F-16 flying time was less than 250 hours and in 1988 in average the experience with the Falcon was between 500 and 1000 hours. An explanation could be based on factors such as:

a. starting to fly a new aircraft distracts from the real impression,
b. the big load of tasks to be performed by pilots increased even more since 1984,
c. lack pilots at squadron level,
d. dissatisfaction with the task and career in the air force.

The training program set up for the fighter pilots in order to fit him better to the job was put into action early in 1988, after a short trial, in Leeuwarden AB as well as in Twenthe AB and in Volkel AB. Like the 1984 study, this time too, the pilots did not seem to be athletically inclined. In 1984 42.1% of the pilots didn't play any sports at all; now this is even 46.0%, although each squadron now has its own pilot's training equipment. However, as was proved in 1984, once again it has been found that the benefits of sports seemed to be questionable: pilots who play sports and/or the special set up pilot's sport weight lifting program are as stressed and fatigued after the mission as their collegues who do nothing at all. The only benefit of sports seems to be prolonged $+G_z$ resistance.
Posture is another interesting story. Pilots declare in Q"G" that in routine flight they are more relaxed, more rotated and less erected than in low level flight. This is not confirmed in Q"N". On the other hand it is proved again in Q"C": in an air to ground mission, especially when it is flown at low level, pilots tend to sit more prone or erect, with less support of the backrest.
This posture, almost without any support of the back, combined with vibrations, shocks and static $+G_z$-loads may be the explanation of the threefold LBP occurance to low level flying aviators compared with pilots that fly at higher level.

2.6. SUMMARY

Pilots flying low level missions are pulling less static $+G_z$ than in high level missions. Moreover their posture is less rotated, but more prone and less relaxed: the support of the backrest tends to a minimum.

Furthermore pilots are physically fatigued after a routine working day and backmuscles may become fatigued very fast during flight. The special physical training program for pilots based on weight lifting is not carried out by approximately 50% of the flyers.

The flying speed in Canada is higher in average, and the flying altitude there is lower.

This complex in total can be responsible for a threefold appearance of low back pain during low level missions compared to missions at higher level.

CHAPTER THREE

POSTURE

3.1. INTRODUCTION

The F-16 is a modern fighter aircraft with very unstable flying characteristics by itsself, but with the help of the fly-by-wire technology and the flight control computer this unstable character is changed into a very stable one. The result is a highly manoeuvrable aircraft. The aircraft does not have the regular stick in the middle between the legs with big deflections, but a hardly movable sidestick on the right hand console. On the left hand side the throttle to control the engine thrust is situated. The throttle movements decribe a semicircular path. Finally, there are two connected pedals for braking and suppressing side slips.

Pilots are seated in their jet aircraft approximately 1 to 3 hours a day. On a normal working day of 8 hours they spend most of their time in briefings, mission planning and debriefings. During all these activities pilots tend to sit either leaned backward or forward: never in the best posture possible. While planning, jet pilots use to draw their maps standing bending over the navigation tables. And during the preflight walk around pilots have to use again their back and abdominal muscles crawling under their jet. But, because of the dynamic and static high G_z-loads while flying, posture in the aircraft, especially lumbar support, is highly important.

3.2. METHODS

The measures of the seat and the cockpit lay out are taken directly out the F-16 handbook for pilots, the "dash-one" or were taken by the investigator in the cockpit.
Pictures were taken of the removed seat in order to get a better impression of both the support that the seat supplies to the pilot and the angles which different body parts showed with respect to another.

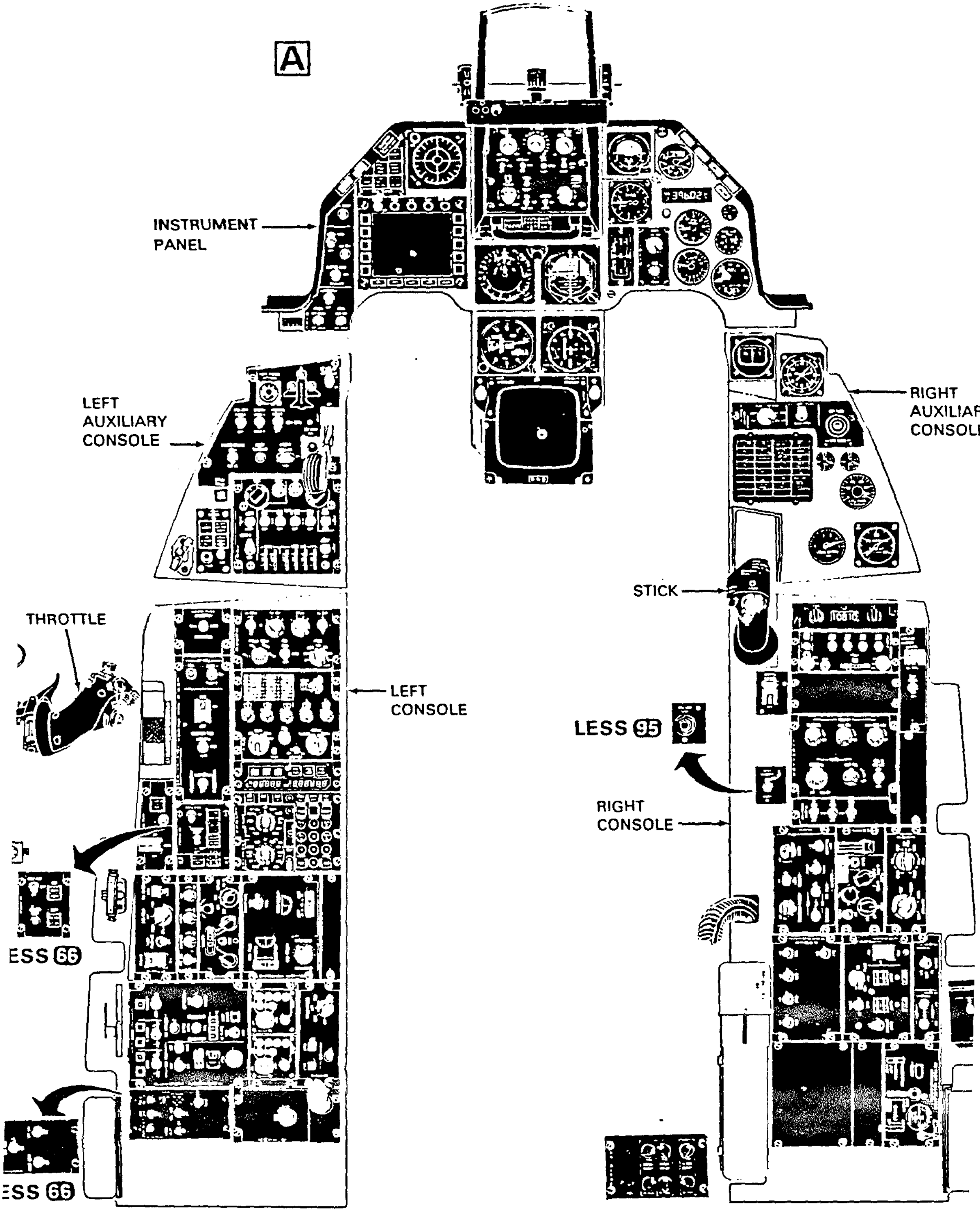


Fig 3. Cockpit lay-out.

Furthermore the questionnaires "N","G" and "C" gave an impression of the pilot's posture in flight.
Finally, pictures were taken during a working day routine, while briefing, planning and during the walk around (fig 4 and 5). Last but not least, the investigator flew a lot of missions both low level and high level either in The Netherlands and Canada in order to validate the answers to the posture question asked in the questionnaires Q"N" and Q"C".

Fig 4. Pilots planningroom.

Fig 5. Walk around.

3.3. RESULTS

Cockpit

The accessibility of the controls in the cockpit is given by the position of the ejection seat, the distance between them and the maximal excursions of the controls. For the individual pilot, adjustment of the mutual distance and position is desired. The ejection seat is adjustable only in the upward direction. The pedals are adjustable only in depth (front - aft). Both the sidestick as well as the throttle are not adjustable.
The pedals are adjustable over a range of 10 inches. The ejection seat is adjustable over a range of 10 inches ,too. The maximal deflection of the controls are :

- sidestick	0,3 inch
- throttle	120° or 7 inches
- pedals	10 inches.

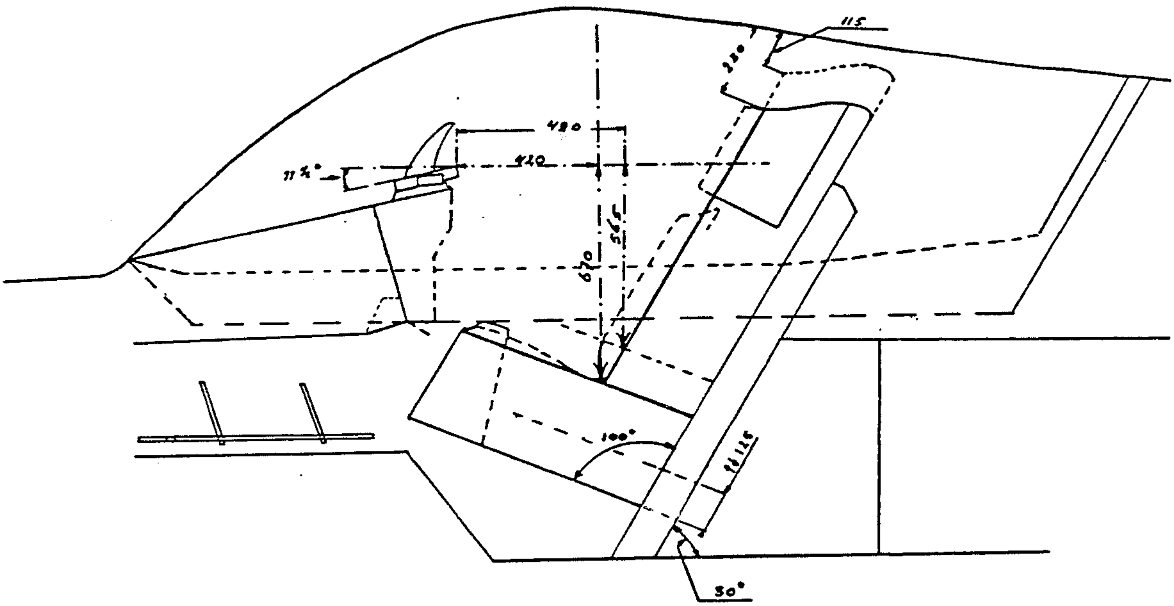


Fig 6. Cockpit layout.

The ejection seat is constructed around a steel frame covered with fiberglass strengthened polyester. The seat cushions and back cushions are secured with straps and velcrotape. The cushions are made of a canvas envelope filled with a 1/2 mm fiberglass woven material fixed on 8 mm of Styropor.
The seat is almost flat and the backrest shows a flat strip in the middle (with a parker srew in the middleline 1/10 inch protruding !), it is 6 inches wide and has some side support in the lumbar region. There is no lumbar support in the centerline. The height of the backrest is 22 inches and it is 13 inches wide. The depth of the seat is 19 inches, to give a support of the upperlegs. The width of the seat is 18 inches, both at the rear and the aft end. The backangle of the ejection seat backrest is 30° on the rail at the back of the seat, but the backangle of the backrest is only 22°.
The backrest - seat angle is about 97°. The seat is adjustable over a rail, continuously for about 10 inches.

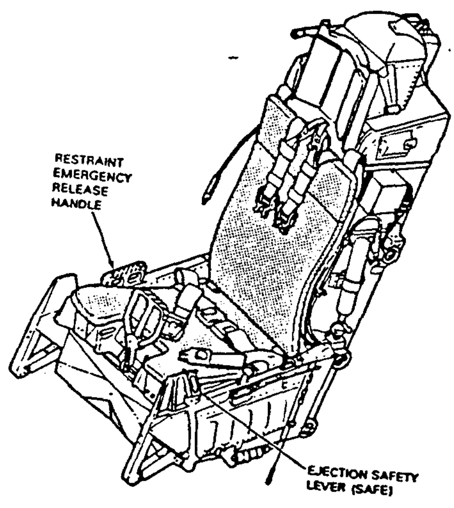


Fig 4. Ejection seat.

The pilot has to look through the head up display (HUD) which shows the information he needs for his task (speed, direction,altitude,weapon systems, G-load,times etc) presented by an optical system on a glass screen and focussed on the far distance. The location of the HUD fixes the pilot's seating position and encourages him to bring the seat down as much as he can. Despite this, the pilot is forced to bend his head and/or cervical spine in order to see through the HUD, especially when he prefers to sit in a rather high position in order to be able to

look over the HUD and still want to use his radar. Cervical flexions of 28° - 41° are seen, using the navigationcomputer. Support of the backrest is reduced to a minimum. The HUD and the high front console and instrument panels force the pilot to bend forward in a more prone position. In Chapter two is described that in low level flying, pilots even tend to increase the prone position. So normally in the middle position (posture 2 in the questionnaires "N' and "C") on the level of vertebra L_1 downward, the back is touching the backrest, and on the level of L_3 in posture 3.
Starting from the maximal range in seat and controls adjustment the figures given in Table 29 can be derived.

	degrees
Angle trunk perpendicular	28 - 41
elbow angle	80 - 150
hip angle	60 - 70
knee angle	100 - 120
angle upperarm - perpendicular	-10 - 50

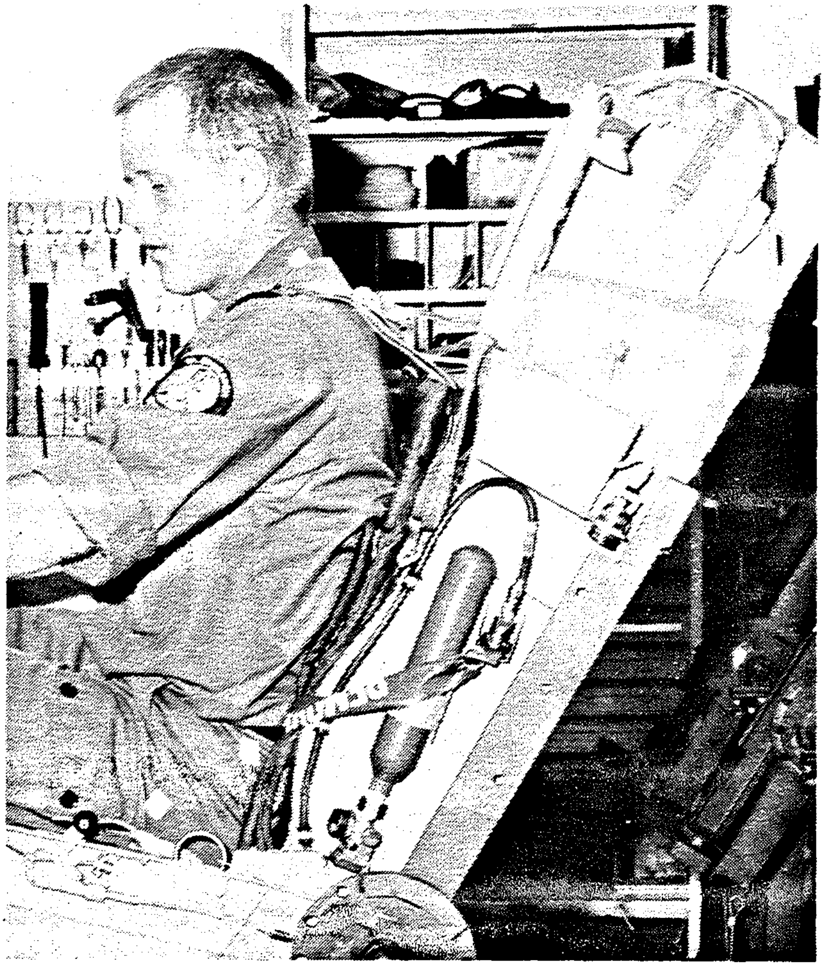
Table 24. Angles between body parts in F-16 seat.

Moreover the pelvis is fixed by the lap belt to the seat. This again increases the lumbar kyphosis.
The right arm is supported by an adjustable arm rest. The left arm remains unsupported.

Working day routine.

Starting from drinking coffee in the early morning in the pilot's bar till the late afternoon or even evening - in case of night flying - pilots always seems to try to maintain a kyphosis. Bended forward on a bar stool, sitting relaxed - backward leaned - during the briefings and bended forward and hanging over the navigation tables planning missions. (See fig 5.).
Even, if they are exercising the pilot's muscles training program, the result of all the different training stations will be, apart from strenghtening the muscles, a flexed attitude due to high flexor muscle tension. This phenomenon is often called the

"Oberkreuz" syndrome.
An extra strain to the muscles could be the rapid cooling of the muscles after a flight, when the pilot perspiring after the mission, leaves the airplane without dressing with an extra windproof jacket and/ or scarf.



3.4. DISCUSSION

The position seated in the F-16 is not a position to be recommanded. Very remarkable is the fact that the famous 30°

backangle of the ACES II ejection seat is not there, but was shown to be 22°.
None or at least insufficient lumbar support gives a kyphosis according Snijders (1984). This phenomenon is further increased by the fixating of the pelvis by the lap belt.
The long straight backrest gives no support at all to the back from L_3 upward. The combination of flexion downward of the cervical spine and no support of the left arm will greatly tire the neck and shoulder muscles. (Snijders, 1985). Moreover these muscles are affected under the static $+G_z$ forces and the weight of the helmet.
Osinga and Schuffel (1986) mentioned the maximal reach of the stretched arm. That will apparently be 66 cm (= 26 inches) for a supported back and maximal 26 plus two times 3.5 inches makes 32 inches, when the arm is totally stretched, the back is not supported and the shoulder can be brought forward. The distance between the ejection seat and the front console is 35 inches, however.
Angles of different body parts (table 24) compared with the figures of Rebiffe show remarkable differences especially concerning trunk perpendicular-, hip- and upperarm perpendicular angles. Pilots though, are not well seated in the ejection seat, according modern ergonomic knowledge.

The fixed position of the HUD and its importance in modern jet flying forces the pilot to lean forward, and in low level flight the result is that the back is not supported till L_3. Tielemans (1988) showed in his very interesting study on F-16 cockpit design and anthropometric data of the dutch young adults (and student pilots) that 21.48% of the male and 25.78% of the female applicant population doesn't fit in the cockpit due to selection criteria. Even if the cockpit lay out data are used while selecting student pilots, still 7.93% of the male and 11.12% of the female student population doesn't properly fit in the cockpit. These figures were simply based on body sizes and not on desired angles of body parts.
However, pilots still are very satisfied and content about the seating position in the F-16 cockpit. In Q"N" as well in Q"C" about 90% of the pilots were totally statisfied. The best explanation may be that in the older or even in the other aircraft the posture is even worse. Furthermore pilots tend to look for a possible plausible cause of LBP more to a dynamic than to a static explanation, such as posture.

A routine pilot's working day has a lot of working routines that are not very friendly for the back; this my strong belief and repeated observation after nine years experience as a flight surgeon. Insufficient relaxing and stretching exercises after the muscle training program tend to increase the disharmony between back and abdominal muscles. Moreover flying fighter aircraft, coping with high $+G_z$ loads, exhausts the abdominal muscles by performing the straining maneuvers needed to maintain a blood flow to the head. The total result will then be a high load on the back muscles again, or (and this is to observe very often) a very severe kyphosis of the total spine, worsening during the day.

3.5. SUMMARY

The famous 30° back angle backrest of the ACES II ejection seat turned out to have an inclination of 22°. In the normal flying position the back rest does not give much support. Furthermore it forces the cervical spine to bend over 30°. The seating position may be described as semicircular: great cervical kyphosis and no lumbar lordosis.
The cockpit lay out is not according the anthropometric standards and the HUD forces the pilot to maintain a certain position.
Nevertheless the pilots are still happy with the seat and the cockpit design, apart from some minor details.
All different duties of the working day routine load the total spine. Without any possibility to relax or to stretch, the result is an aggravation of the kyphosis.

CHAPTER FOUR

AIRCRAFT VIBRATION

4.1 INTRODUCTION

Vibration in jet aircraft may be caused by the engine rotation, unbalances in pumps and plane-air contacts of which air turbulances and the groundeffect are more specific manifestations. Specific aircraft vibration characteristics are due to the aircraft design, especially the shape of the wing and its total surface and the flight control system. Vibrations are transmitted to the pilot through the seat and partly through the side stick, the throttle and the pedals and frequencies may differ dependent on the location.
For this investigation a triaxial in rubber embedded vibration transducer, installed on the seat of the pilot, measured the seat vibrations in three axes. For further analysis of the data, as measured by the seat transducer, it was necessary to know the flight conditions at the time of the measurements. This was done by simultaneously recording the following parameters:

pressure altitude,
airspeed,
normal acceleration,
lateral acceleration,
engine rotations.

4.2. METHODS AND OBJECTIVES.

The additional instrumentation elements onboard the aircraft consisted of a small data acquisition unit, installed in the aft avionic compartment and a triaxial vibration transducer, mounted on the ejection seat in the cockpit. The acquisition unit consisted of two low pass filters (to prevent aliasing errors during the digitizing process). An 8-channel differential input multiplexer, a sample and hold amplifier and a 12 bits analog to digital converter (ADC). A control module generated a programmed input switching and sampling sequence. The ADC converted the sampled and binary coded input signals into a serial bitstream. These data were recorded on the free audio channel of the aircraft's video recorder. A schematic diagram of the instrumentation onboard the aircraft is given in fig 9.

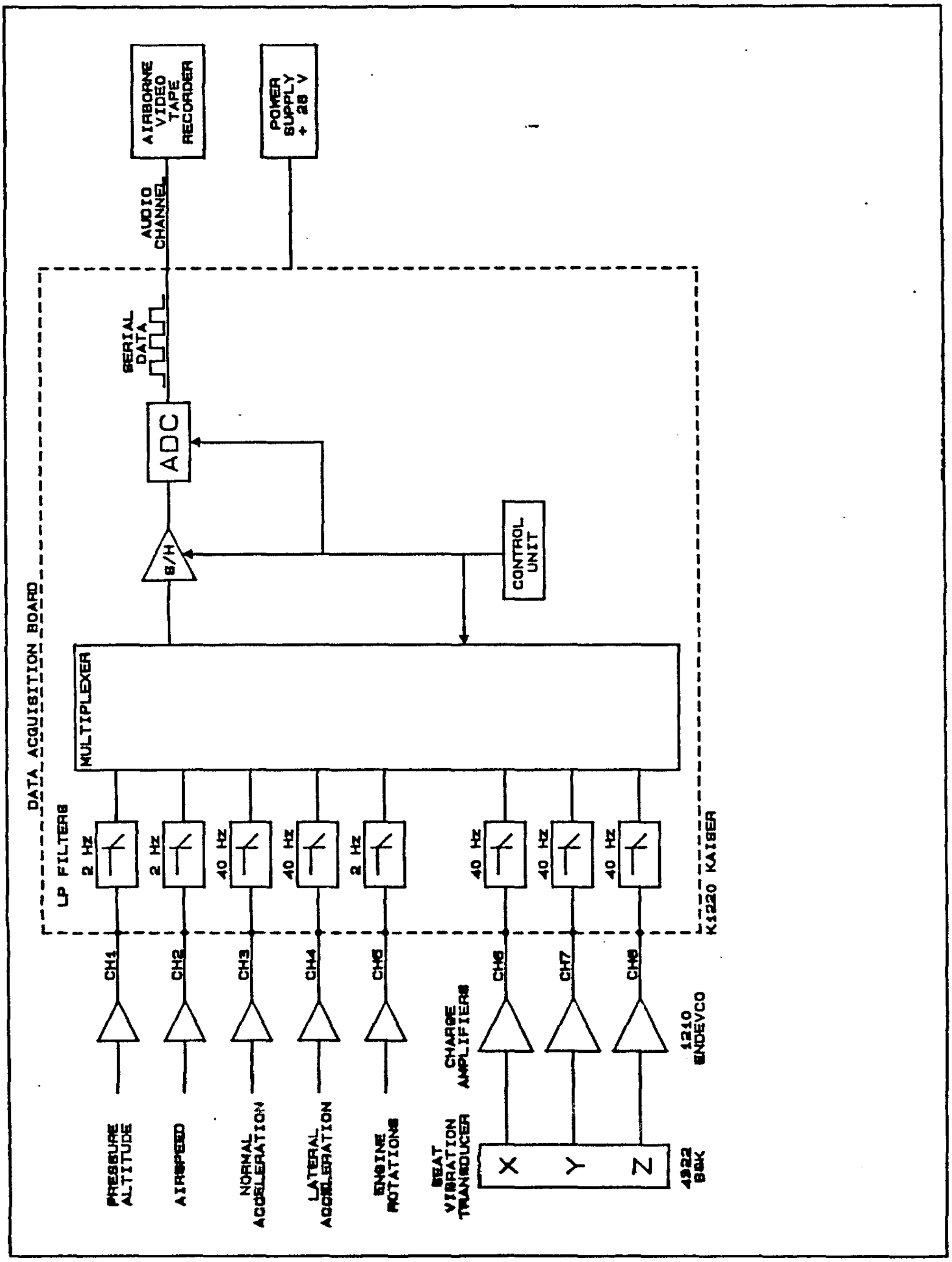


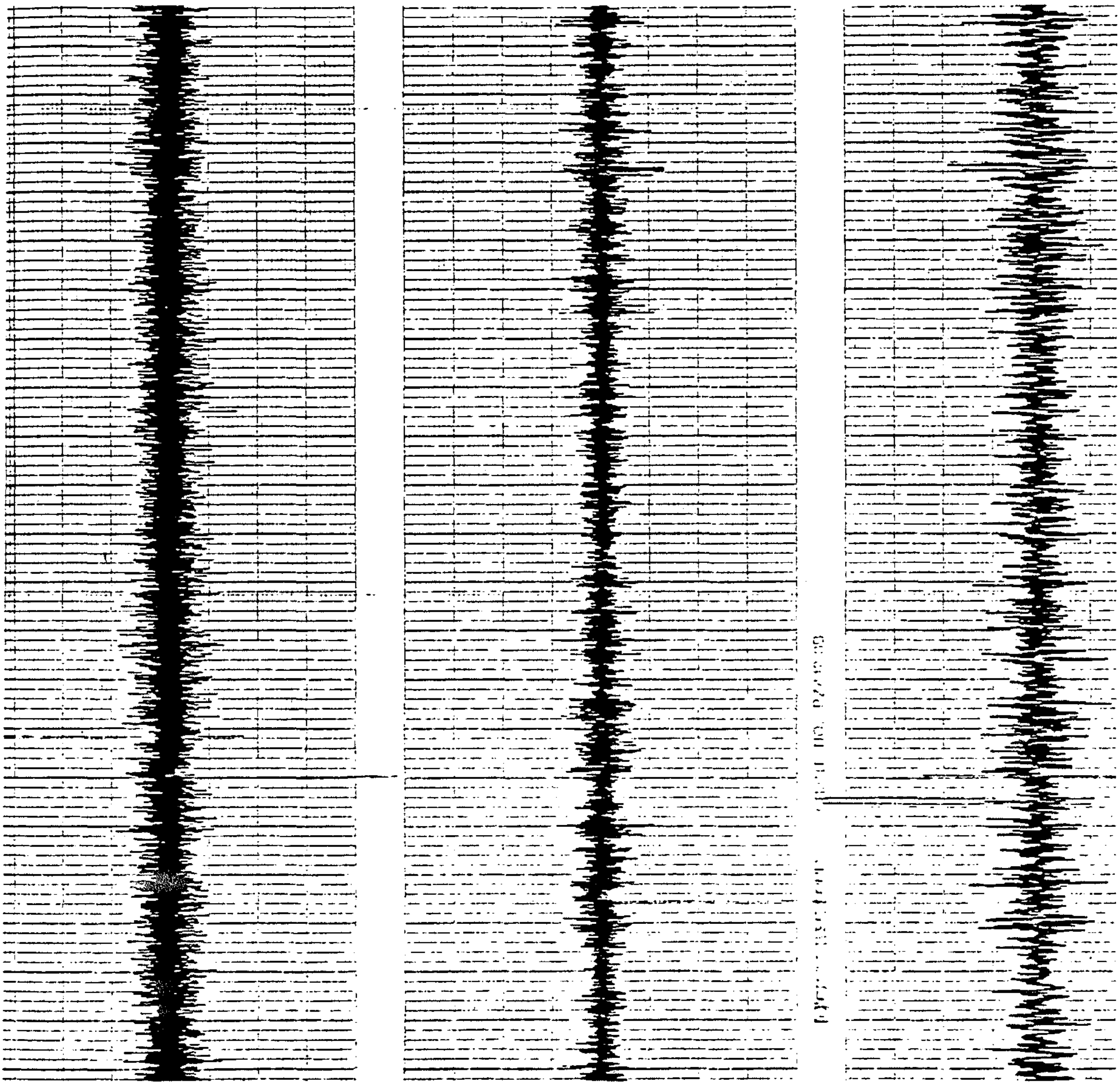
Fig 9. Instrumentation schedule onboard F-16.

Since the frequencies of the signals were expected to be in the range 4 - 16 Hz, the sample rate was set at 128 samples per second. The low pass filter cut off frequency for the vibration and acceleration channels was then set at approximately 40 Hz, being $2\frac{1}{2}$ times the highest frequency to be expected.
For the remaining three channels containing aircraft information (speed, altitude and engine speed), the cut off frequency was set at 2 Hz.
The seat vibration transducer was a triaxial in rubber embedded piezoelectric vibration transducer, (Bruel and Kjaer, type 4322).
The transducers were connected to amplifiers using the original cables, properly fixed with the aircraft. Through charge amplifiers, (ENDEVCO, model 1210 Air Borne), the charges were converted into electrical potentials and the latter were applied to the data acquisition system (Kaiser, model K 1220).
The aircraft parameters were available as buffered electrical signals on a connector to the Flight Load Recording system and could be easily tapped. The supply voltage (+28 Volts) for the data acquisition was available through the power connector for the Flight Load Recorder. It should be mentioned that the Flight Load Recording equipment was not installed on this aircraft.
Since the dimensions of the data acquisition system used, were slightly smaller than the signal data mux/converter of the Flight Load Recorder system, it was possible to install the acquisition unit, using the same bracket, directly beside the video recorder in the aft avionic compartment.
To record the digital encoded data on the second audio channel of the video tape recorder(Type Teac ABVTR, frequency range 400 - 10,000 Hz) a small modification to the existing wiring was necessary.
For the amplification of the seat transducer signals the amplifier module with the 3 charge amplifiers was installed in the LH (left horizontal) console on the place of the ECM (electronic counter measures) control box, by removing that box.
Transfer of the signals from the amplifier module in the cockpit to the aft avionic compartment was accomplished through the use of the wiring from the ECM control box to the bulkhead disconnect. By means of an additional cable assembly from this bulkhead connector to the data acquisition unit the signals were passed.
The seat transducer was connected to the amplifier module through the standard connector assembly. However to avoid interference with the functioning of the seat ejection system, both connectors were held together by means of tape instead of the screw connection.
Prior to the installation of the equipment, a safety of flight study was performed. Through the similarity of the input cicuits

with the standard instrumentation system, the data acquisition system could be used without any further precautions. A fuse in the system protected the aircraft wiring against shortcircuiting in the power supply of the acquisition unit.
Installation of the seat transducer and the cable routing on the seat were carried out by the Netherlands Aerospace Laboratory in close cooperation with the egress specialists of both the armament shop of Volkel AFB and the Dutch Exercise Detachement at CFB Goose Bay, Canada.
At the ground station the PCM data stream was reproduced using a suitable Sony video player. The decoding of the PCM signal was done by a PCM decoder unit. This unit (Kaiser PCM decoder and Loral ADS-100) is compatible to the encoder unit and therefore contains the corresponding programming of sampling sequence and number of the channels. The decoded data was in 8 bits (parallel-word) format available on an expansion connector of this unit and could applied through a buffer/conversion board to a personal computer system (Zenith) equipped with a digital input board. A simple software program passed the data to a storage device such as floppy drive or hard disk for later conversion to engineering units and further data processing. Selected parameter data could be converted into an analog signal and through a low pass filter applied to a fast fourier analyzer.
With "Asystant" a data analysis package, the data collected were made visible again, weighted for the factors given by ISO 2631.

4.3. RESULTS.

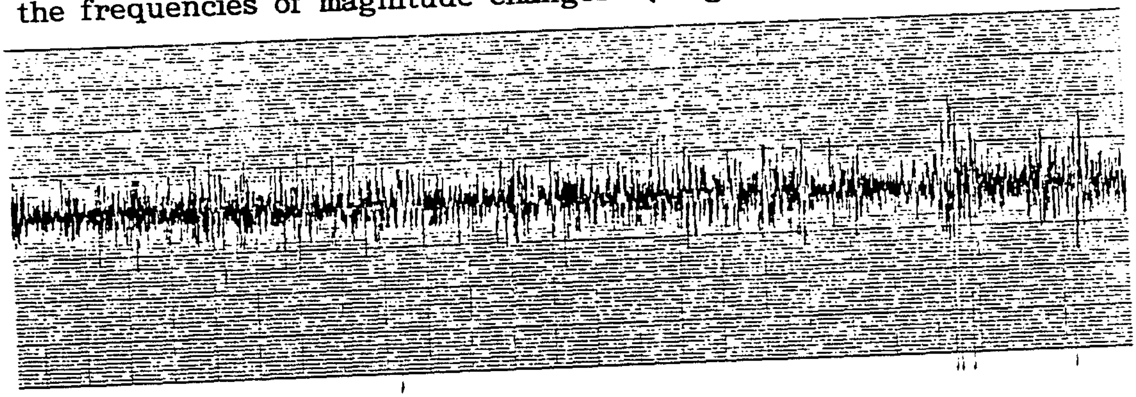
In all possible directions (x, y and z) a continuously changing nonsinusoidal acceleration with peaking magnitudes was seen (Fig 10.).



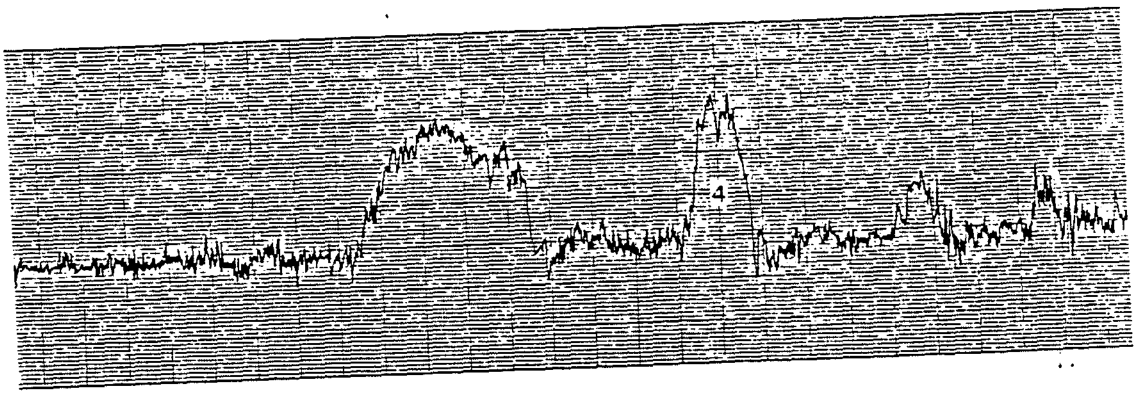
x-direction y-direction z-direction

Fig 10. Aircraft vibration in three axis.
2 cm = 1 mV = 1 G

If a strong $+G_z$ load is added to the airframe, eg in curves, the magnitudes of the dynamic, vibrational load will decrease as do the frequencies of magnitude changes (Fig 11.).



aircraft vibration in z-direction (dynamic load)



aircraft static G_z-load in curve.

Fig 11. Aircraft vibration dimmed under static load.
2 cm = 1 mV = 1 G.

Analysis of the acquired data, magnitude expressed as a rms (root-mean-square) value, according ISO 2631 showed some constant peak frequencies apart from engine speed, flying level and/or airspeed.
For the "z"-axis peaks were found at 1.25 - 1.5 Hz and mainly at 4 - 5 Hz at lower level flight. For the "x"-axis peaks were seen at 1.5 Hz and at approximately 10 Hz. The "y"-axis showed variable values (Fig 12.).

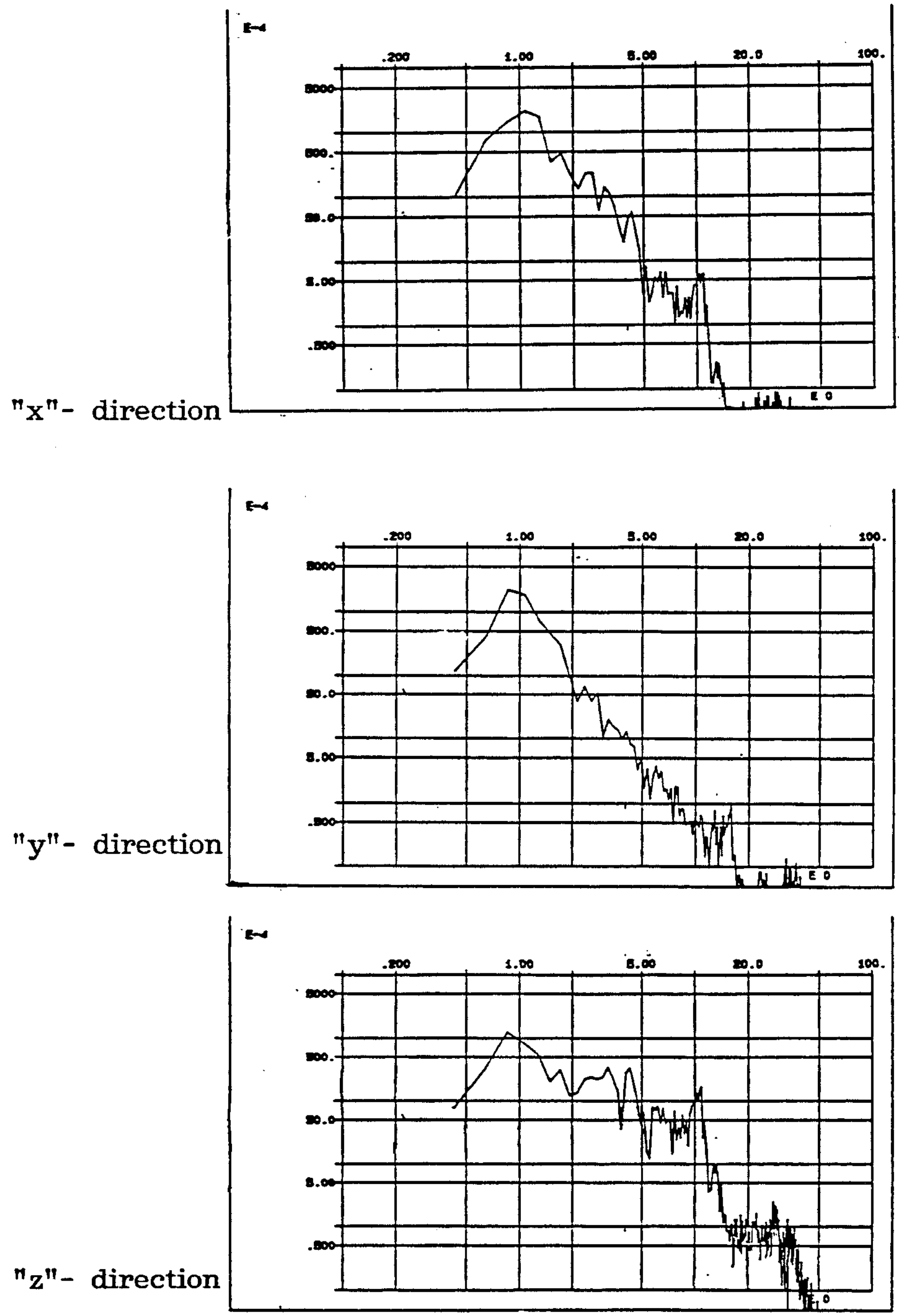


Fig 12. Vibration frequencies and magnitudes in three axes.
(a,rms) (m.sec^{-2})^{2}.10^{-5}

Flying altitude and airspeed showed to have a relation with the magnitude of the vibrations that occured.
Flying at 1000 feet above ground level with different air speeds showed remarkable differences at 300 knots (Fig 13.) and at 450 knots (Fig 14.).

"x"- directic

"Y"-direction

"Z"-direction

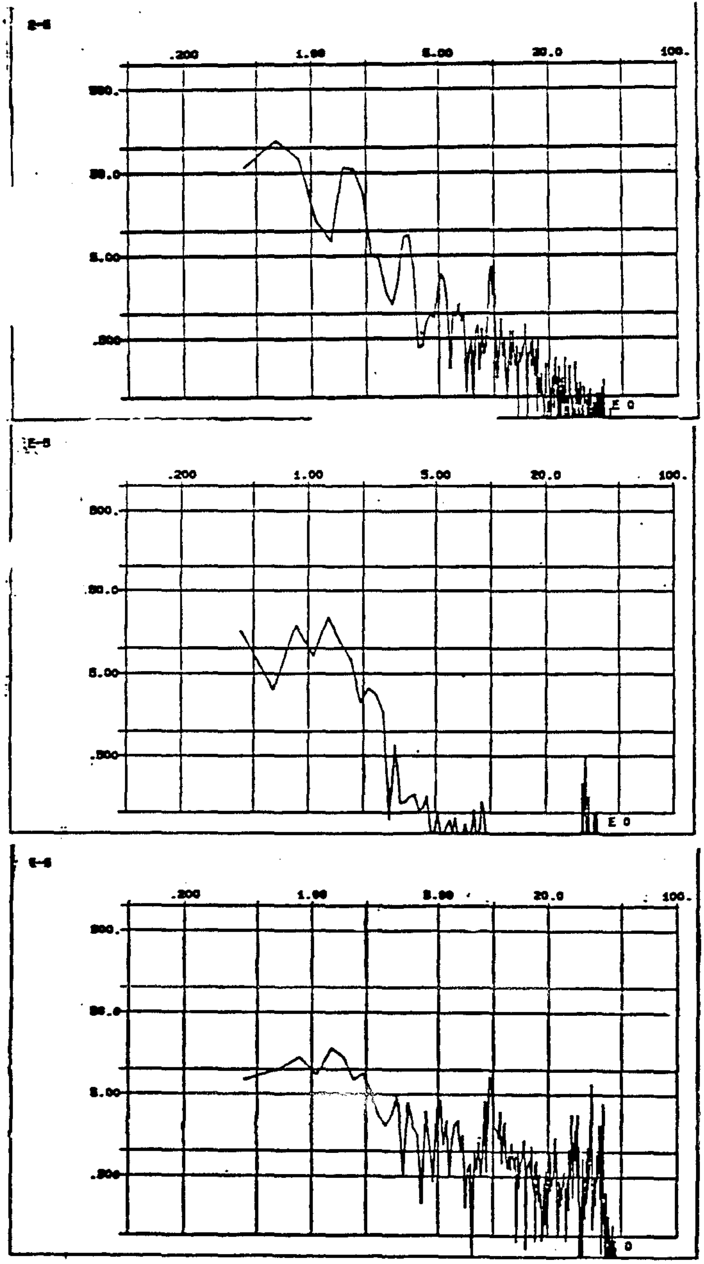
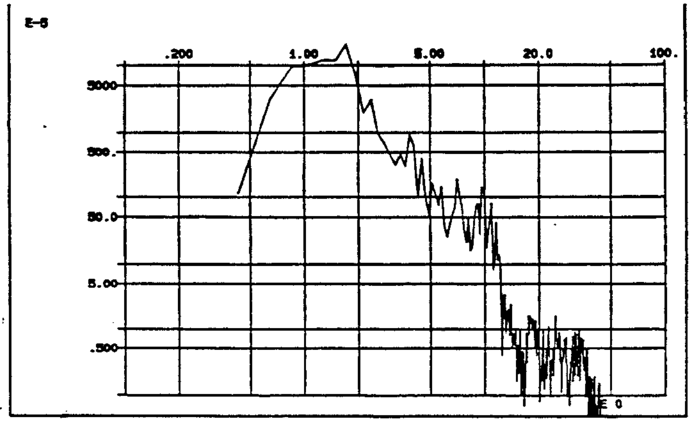
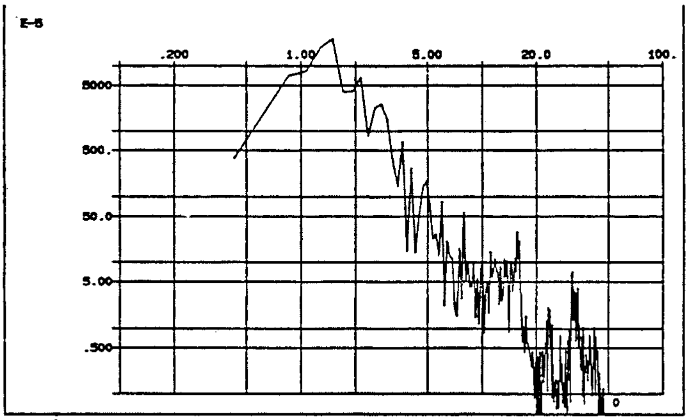


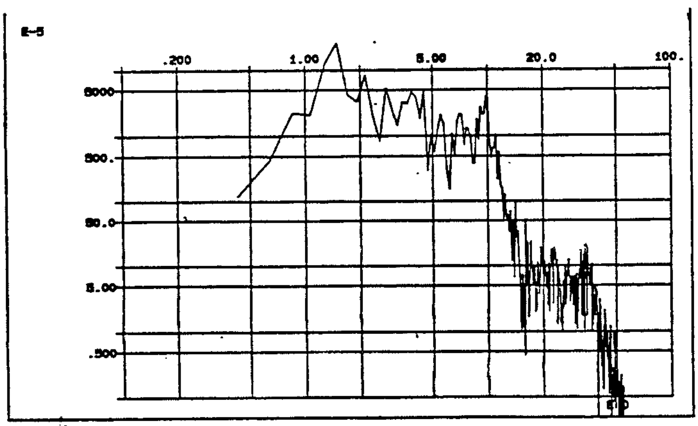
Fig 13. Vibration frequencies and magnitudes at 300 knots airspeed and 1,000 feet above ground level in three axes.In a,rms $(m.sec^{-2})^{2}.10^{-5}$.



"X"- direction



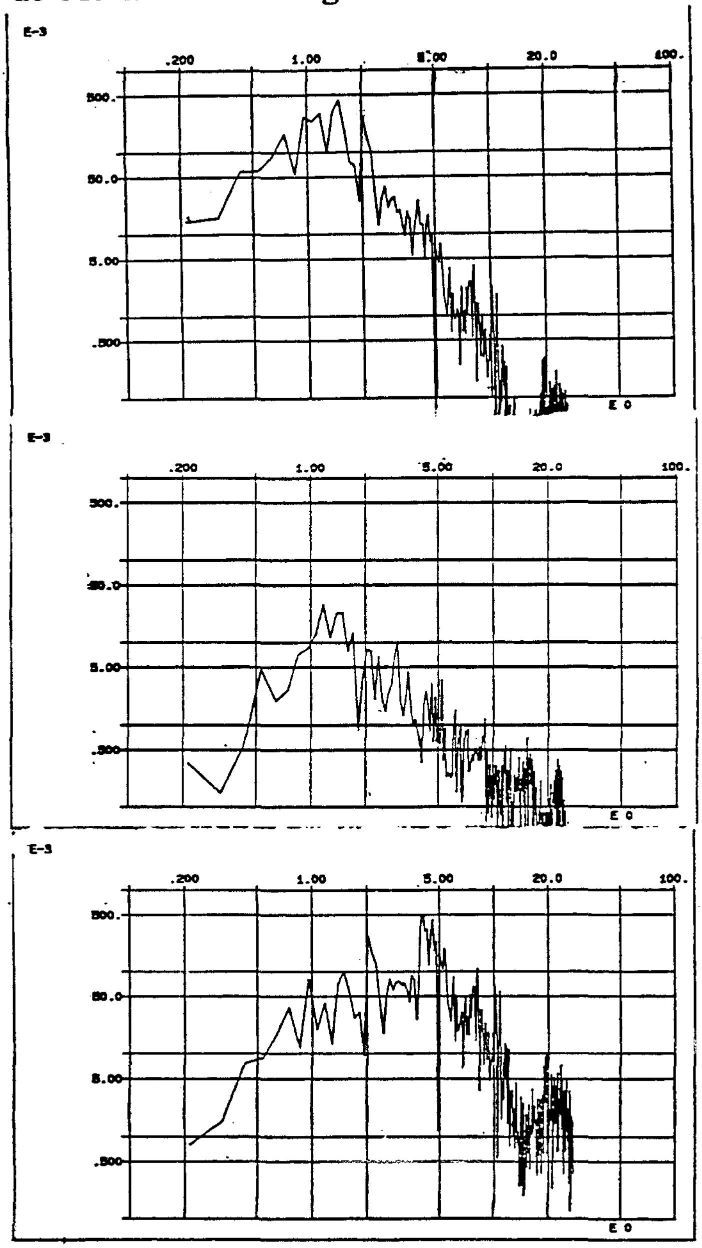
"Y"- direction



"Z"- direction

Fig 14. Vibration frequencies and magnitudes at 450 knots airspeed and 1000 feet above grond level in three axes.
in a,rms $(m.sec^{-2})^2.10^{-5}$

Flying 150 feet above ground level with different air speeds again showed highly remarkable differences eg Fig. 15 at 450 knots, Fig. 16 at 540 knots and Fig. 17 at 600 knots.

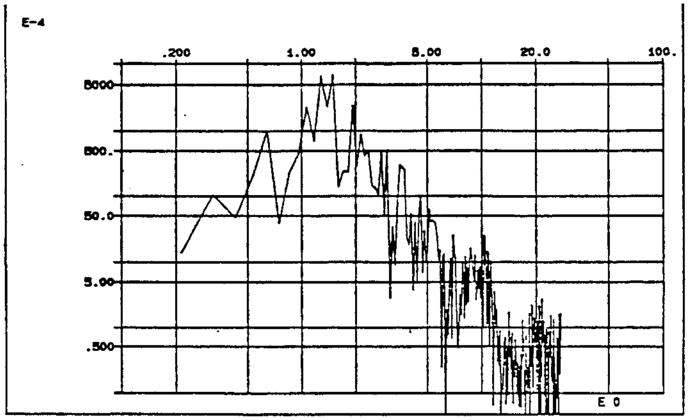


"X"- direction

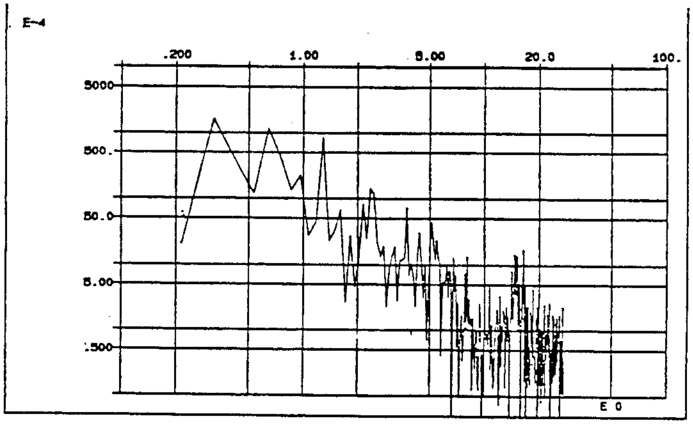
"Y"- direction

"Z"- direction

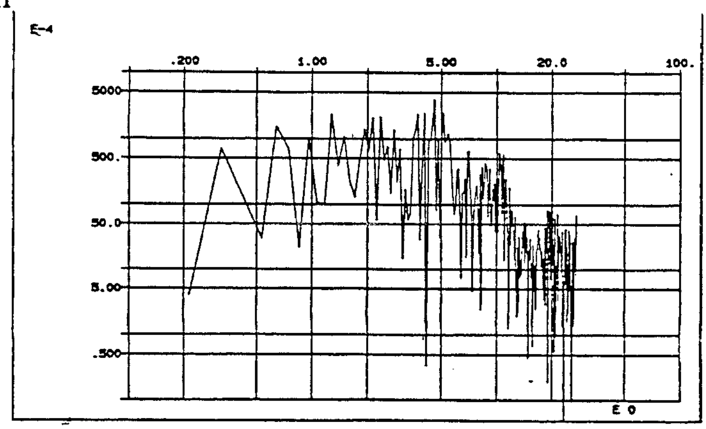
Fig 15. Vibration frequencies and magnitudes at 150 feet above ground level and 450 knots airspeed in three axes. In a, rms $(m.sec^{-2})^2.10^{-5}$



"X"- direction



"Y"- direction



"Z"-direction.

Fig 16. Vibration frequencies and magnitudes 150 feet above ground level at 540 knots airspeed in three different axes.
In a,rms $(m.sec^{-2})^2.10^{-5}$.

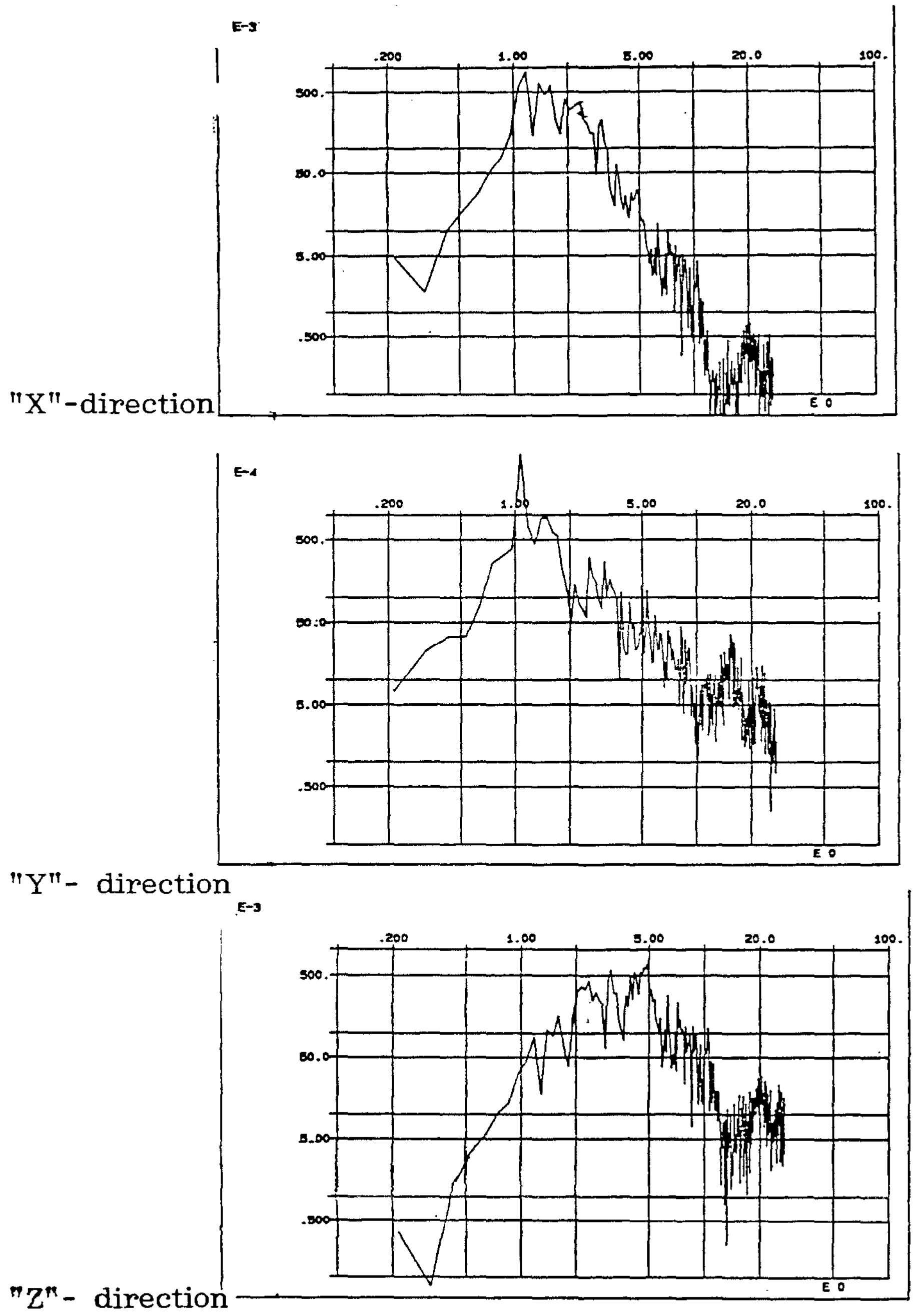
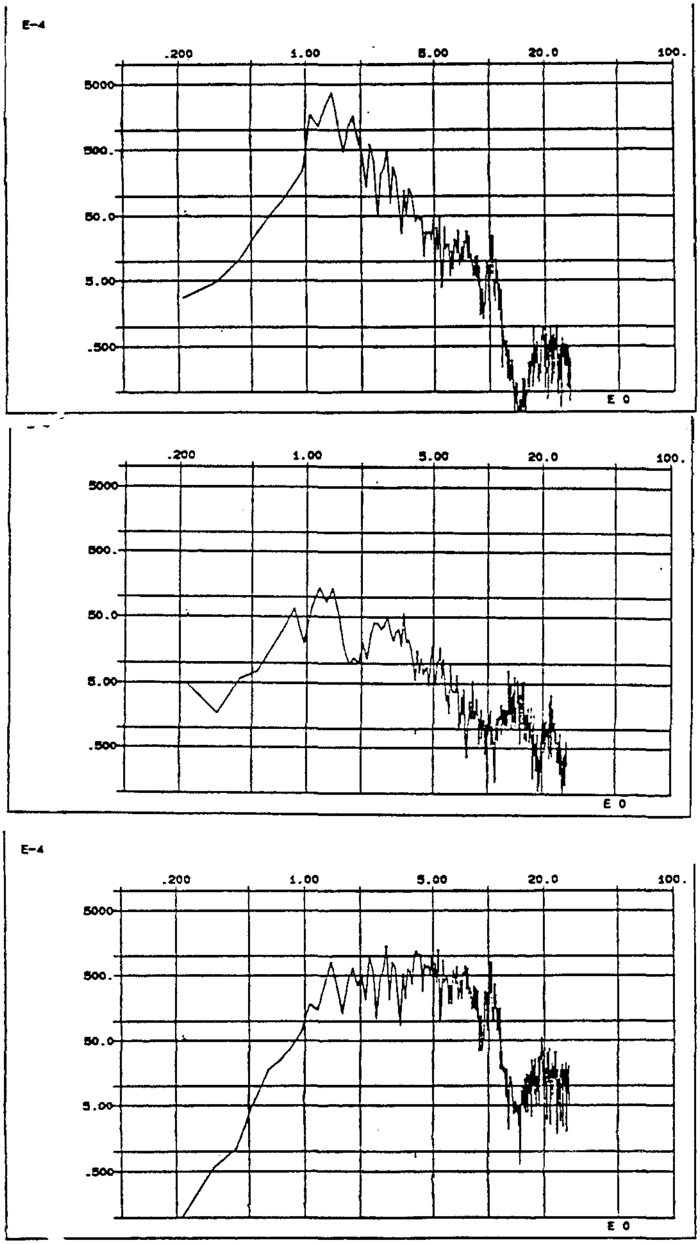


Fig 17. Vibration frequencies and magnitudes 150 feet above ground level at 600 knots airspeed, in three different axes. In a,rms $(m.sec^{-2})^2.10^{-5}$.

If the accelerometer was placed under the seat cushions, the results show the same values. The seat cushions seemed not to demp the vibrations.



"X"- direction

"Y"- direction

"Z"- direction

Fig 18. Vibration frequencies and magnitudes taken under the seat cushions, 150 feet above ground level at 500 knots airspeed, in three different axes. In a,rms $(m.sec^{-2})^2.10^{-5}$.

Tables 30, 31 and 32 show comparisons of the most important magnitudes for "x"-, "y"- and "z"-vibrations.

Airspeed	300	450	480	540	600
Flying level					
1000	2	200	---	---	---
150	---	---	200	400	3000

Table 30. Comparison of magnitude rms at different air speeds and flying level for "x"-axis vibration.

air speed in knots/hour
flying level in feet above ground level
magnitudes at 4-5 Hz in rms $(m.sec^{-2})^2.10^{-5}$.

Airspeed	300	450	480	540	600
Flying level					
1000	3	100	---	---	---
150	---	---	100	200	500

Table 31. Comparison of magnitude rms at different air speeds and flying level for "y"-axis vibration.

air speed in knots/hour
flying level in feet above ground level
magnitudes at 4-5 Hz in rms $(m.sec^{-2})^2.10^{-5}$.

Air speed	300	450	480	540	600
Flying level					
1000	4	2500	---	---	---
150	---	---	7000	40000	60000

Table 32. Comparison of magnitude rms at different air speeds and flying level for "z"-axis vibration.

air speed in knots/hour
flying level in feet above ground level
magnitudes at 4-5 Hz in $rms(m.sec^{-2})^2.10^{-5}$.

Even while taxiing the vibration on the pilots seat is quite considerable.

	magnitude
"x"-axis	4000
"y"-axis	30
"z"-axis	20000

Table 26. Magnitudes in three different axis while taxiing at 4-5Hz.

magnitudes in $rms(m.sec^{-2})^2.10^{-5}$.
taxispeed approx. 20 knots/hour.

4.4. DISCUSSION

In the F-16 aircraft vibrations in all three axis are existing. The biggest magnitudes are found in the "Z"-axis. Peak magnitudes arose at frequencies of 1 Hz and of 4-5 Hz, the later being one third of the octave band and being the first resonance frequency of the spinal column, described by Christ and Dupuis (1966). In helicopters the peak amplitudes arose at 15 - 23 Hz (Delahaye et al, 1982). Groenhout and Valken (1987) found in their study on vibrations in helicopters used in the Netherlands, peak magnitudes in the "Z"-axis at 16 -25 Hz.

The magnitudes that are found are not extraordinary high, compared with other vehicles and aircraft. During taxiing on the concrete taxi-ways the F-16 reached magnitudes of 0.29 (w,rms)m.sec^{-2}, while Oostman-Gerlings et al (1985) proved in their study that only trams and light vans, unloaded and driving on a highway paved with bitumen, could reach the same values. The magnitudes flying are relatively small, too. However, interesting is the result of this study that amplitudes increase with increasing airspeed and decreasing flying level above the ground.
The vectorial weighted acceleration of the three axes, also named vectorially added acceleration, according to the formula

$$A = V\ (a_z)^2 + (\ 1.4\ a_y)^2 + (\ 1.4\ a_x)^2$$

brings more information, if compared with Alouette III and UH-1-H, both helicopters.

F-16	knots	300	450	480	540	600
	altitude	1000	1000	150	150	150
	A(w,rms)	140	3550	9900	56500	85000

A III	cruising	62000
	contour	71000
Boelkow-105	cruising	38000
	contour	58000
UH-1-H	cruising	61000
	contour	83000

Table 27. A (w,rms) of different aircraft.
Speed in knots per hour
Altitude in feet above ground level.

Contour flying in helicopters is comparable with low level terrain following missions in jet aircraft. The A(w,rms) in the F-16 low level flight has about the same values or even exceeds the weighted accelerations of the helicopters. The accelerations still are relatively small, but the 4-5 Hz of the F-16 coincides with the first resonant frequency of the spinal system of a seated human subject. Therefore, many authors have speculated that chronic exposure to aircraft vibration is detrimental to the spinal system.

Boundaries of daily exposure to vibration are described in ISO 2631. The F-16 flying low level at 600 knots, producing vibration accelerations in the z-direction of 0.6 $m.sec^{-2}$, could be flown at that level and speed for about 3 hours before the "fatigue-decreased proficiency boundary" is passed. The "exposure limits boundary" is passed after about six hours. But, these figures are applicable for sinusoidal vibrations and all different discrete frequencies should be evaluated separately with reference to the appropiate limit at that frequency, according a note in ISO 2631. Moreover, more stringent limits may have to be applied when the task to be performed is of a particularly demanding perceptual nature or calls for an exercise of fine manual skill, like for instance low level flying.
Since the for man most sensitive frequency ranges are 4 to 8 Hz for longitudinal (a_z) vibration, in this study the middle of the 1/3 octave band 4-5 Hz is considered to describe the effect of the total octave band.
The flying task, normally not exceding one hour and 10 minutes and flown at different altitudes and with changing speeds can easily be carried out according ISO 2631. However, the limits given in this standard are applicable in the "one G_z"-environment.

4.5. SUMMARY

Vibrations in the F-16 mainly occur at 1Hz and 4-5 Hz, the first resonant frequency of the spinal system. The amplitude of the vibration is increased with increasing airspeed and is also increased with decreasing flying level. At decreasing flight level a shift to 4 - 5 Hz is shown. The highest amplitude found, 0.6 $m.sec^{-2}$ in the "z"-axis permits, according ISO 2631, a flying time of 6 hours before the "exposure limit" is passed.
The seat cushion of the ejection seat does not damp the vibration transmitted on the pilot.

CHAPTER FIVE

FINAL CONCLUSION

Pilots flying F-16 suffer less from LBP than the averaged young adult, however pilots are a very selected population. In this study was found that 28% of the F-16 pilots suffered from LBP in their Air Force carreer. Fielding (1979) showed that 35% of people younger than 35 years of age have a history of LBP. Groenhout and Valken (1987) showed in their recent study among helicopter pilots that 19% of the Dutch helicopter pilots' population suffered from LBP within the last 12 months before the questionnaire.

Groenhout and Valken (1987) also found that 12% of the helicopter pilots complained of LBP or stiffness of the lower back after each flight. This study showed that only 3.5% of the F-16 pilots say to complain of LBP after each flight. But, it was also shown that flying in the Netherlands only 1.4% of the missions ended with LBP and that in Canada flying low level missions 6% of the missions ended with LBP; however 36% of the pilots flying at low level in Canada showed to suffer from LBP at least one time in 12 missions flown!
So the conclusion is justified that the low level flight training missions caused more LBP than the profiles usually flown in Western Europe. Furthermore, F-16 pilots flying low level exercises suffer from LBP in an extend comparable with helicopterpilots, a wellknown, wellstudied and frequently described population.

Back pain in the civilian population is usually reported to medical professionals by patients who have suffered from chronic pain for many days. Although there are some patients in which a rapid onset of pain associated with a particular activity, such as bending or lifting, there are many patients who cannot remember the occasion of onset of their pain (Shanahan and Reading,1984).

In contrast, pilot's back pain is closely associated with actual flight duty. Fritzgerald and Cotty (1971), found that over half of the 300 pilots who experienced frequent in-flight backache never suffered from backache on the ground. And Schulte-Wintrop and Knoche (1986) found that 39% of the post flight backache was described as a lasting one for more than 12 hours. In this study backpain did not last longer than 12 hours.

Shanahan (1984) suggests that there are two groups of pilots who suffer from back pain, a majority that suffers a temporary pain which is felt only during and immediately after flight, and a minority that suffers from chronic pain, which resembles the problem known as ideopathic low back pain in the civilian world. Shanahan suggests that repeated exposures to the temporary pains of flight may lead to persistent pain in time. Furthermore, temporary pain may bring a pilot to modify flight plans or distract him from his mission.

"Static" gravitational forces in the "Z"-axis could be an important contributing factor in developing LBP. In a half an hour recording carried out in this study it was shown that the mean $+G_z$-force was 1.7 $m.sec^{-2}$. However, it was shown that while flying low level less $+G_z$'s were pulled than when was flown at higher altitudes; peak values are also lower at lower flying level. Though, at low level significantly more LBP developed.

In this study, amplitudes of vibrations,especially at 4-5 Hz showed to increase with increasing air speed and decreasing flight level, most likely caused by a combination of low level turbulance, lift surface of wings and fuselage and the direct hit flight control computer. Magnitudes reached as such are not high enough to expect structural dammage to the pilot's back within a short period of time, even when he is flying two missions a day. But, in this study shocks were not taken into account and ISO 2631 and further literature do not give a multiplying factor to stringent the limits given in case of demanding tasks and or fine manual skills.

Although many authors have speculated that chronic exposure to aircraft vibration is detrimental to the spinal system, it still remains uncertain what the pathological effects of chronic, intermittent exposure to 4-5 Hz frequency, low amplitude vibration may be over the short and long term. Most studies suggesting a higher prevalence of back pain in occupations that expose workers to vibration are purely associative studies. That vibration is, in fact, causative, cannot be inferred from these studies since they fail to provide for control of many other factors that may also contribute to a high prevalence of back pain in the particular population studied. Possible contributing factors include seating position, opportunity for changing position and the multiplicity of variables that fall under the general category of lifestyle. Moreover, no guidelines or tables exist to combine static $G_{x,y,z}$-forces and dynamic x,y,z-axis vibrations. This study showed that the contribution of vibration does not exceed the boundaries given by ISO 2631.

Since Shanahan, Mastroianni and Reading (1986) proved that the helicopter pilots seated in a normal helicopter mockup showed the identical back pain with or without (simulated) vibration and even that there was no significant difference in time of onset or intensity of pain for the vibration and no vibration test conditions, posture is generally considered (Shanahan et al 1986, Troup,1986, Schulte Wintrop et al 1986, Pope,1986 and Osinga 1986) to be the most contributing factor in developing LBP.
Interesting in this study is that LBP in Canada mainly developed during air to ground low level missions carried out at very high speeds and the tendency that more LBP occured in a less relaxed sitting position or in this case, in more erect, less supported backs. This etiological factor may be aggravated by the superimposition of low frequency vibration in the range of the resonant frequency of the spinal system and the averaged pulled or peak G_z-forces.
To estimate roughly the back muscle force and load on L_3 in upright sitting posture as observed in F-16 low level flight, the model of Fig 19 is introduced. In static posture the following forces and geometry determine an equilibrium of forces and moments in the free body diagram of the part of the body situated above the cross section on the level of L_3 :

F_{gz} = force in the "z"- direction acting on mass center of gravity,

F_{gx} = force in the "x"- direction acting on mass center of gravity,

F_m = back muscle force,

F_s = shoulder harness force,

F_{rgz} = reaction force on L_3 being the result of F_{gz},

F_{rgx} = reaction force on L_3 being the result of F_{gx},

F_{rm} = reaction force on L_3 being the result of F_m,

F_{rs} = reaction force on L_3 being the result of F_s,

m_b =	body mass above L_3,
m_h =	helmet mass,
m_{sh} =	shoulder harness mass,
m_t =	total mass above L_3,
a =	lever arm between F_{gz} and the middle of L_3,
b =	lever arm between the back muscles and the middle of L_3,
c =	lever arm between F_{gx} and the cross section at L_3,
d =	lever arm between F_s and the cross section at L_3.

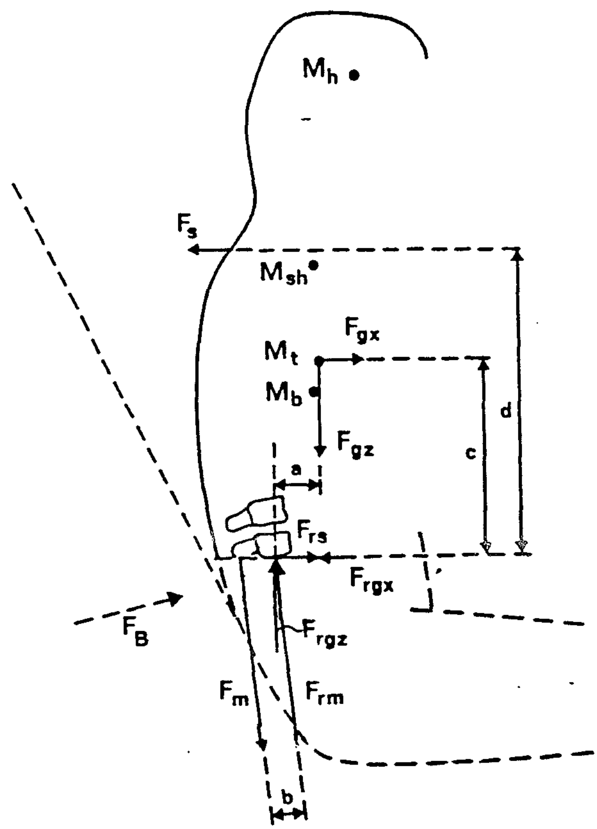


Fig 19. Biomechanical model of the upper body.

In the model the backrest force (F_b) influences the equilibrium of the pelvis, but does not act on the free body diagram in Fig 19., because its point of application is approximately on-or below the level of L_3.
Equilibrium exists when the sum of the forces is zero in all directions and the sum of moments of force is zero in all planes.
In the model a restriction is made to equilibrium in the sagittal plane.
Equilibrium of forces is assumed to be obtained by reaction forces acting in the middle of the vertebra L_3.
Equilibrium of moments is given by the following equation:

$$F_{gz} . a + F_{gx} . c = F_m . b + F_s . d$$

With the use of the tables by Chaffin (1984) and Chandler et al (1975) and assuming a total body mass of 75 kg, we obtain:

$a = 5.5$ cm,
$b = 5$ cm,
$c = 30$ cm,
$d = 50$ cm and
$m_b = 0.5 . 50\%$ trunk + 10% arms + 8% head and neck of 75 kg body weight = 43% of 75 kg = ca 32 kg.

With a helmet mass of 2 kg and a shoulder harness mass of 5 kg, the total mass becomes:

$$m_t = m_b + m_h + m_{sh} = 32 + 2 + 5 = 39 \text{ kg}.$$

Measurement of the force on the shoulder harness gave

$$F_s = 10 \text{ N}.$$

Based on the equilibrium of moments the back muscle force can be calculated :

$$F_m = (F_{gz} . a + F_{gx} . c - F_s . d) / b.$$

With a vertical acceleration of 1.7 g + 0.6 g= 2.3 g and a horizontal acceleration of 0.4 g we obtain:

$$F_m = (m_t . 2.3g . a + m_t . 0.4g . c - F_s . d) / b$$
$$= (39 . 2.3 . 9.80665 . 0.055 + 39 . 0.4 . 9.80665 . 0.3 - 10 . 0.5) /$$

$$0.05 \qquad (g= 9.80665, \text{ according ISO R31 })$$
$$= (48 + 46 - 5)/0.05$$
$$= 1780 \text{ N}$$

With a vertical acceleration of 1.6 g and a horizontal acceleration of 0.3g, representing a low level level one g flight, we obtain:

$$F_m = (m_t.\ 1.6g.\ a + m_t.\ 0.3g.\ c - F_s.\ d)/b$$
$$= (39.\ 1.6.\ 9.80665.\ 0.055 + 39.\ 0.3.\ 9.80665.\ 0.3 - 10\ .0.5)/$$
$$0.05$$
$$= (34 + 34 - 5)/\ 0.05$$
$$= 1260 \text{ N}$$

Without a shoulder harness force we get under normal g conditions :

$$F_m = 21/\ 0.05$$
$$= 420 \text{ N}$$

The total load on L_3 can be derived by vectorial summation of the reaction forces acting in the cross section. In the case of a vertical acceleration of 2.3g and a horizontal acceleration of 0.4g the vertical component of the total load on L_3 is dominated by the muscle force and becomes approximately 2160 N.
Under normal gravity load and with F_{gx} and F_s are zero, the total load on L_3 becomes ca 800 N.

The meaning of the model and the estimated numbers can be found in the comparison of different situations and the expectation that in low level flying considerable loads are acting on the back muscles.
The load can be decreased by decreasing the lever arm a. A lumbar support filling the space between back and backrest in Fig 19. may realize this by straightening the spine. The latter will also reduce the intradiscal pressure which is higher when the spine shows a lumbar kyphosis as Fig 19.

The very high force to be produced by sustained muscular contraction leads to postural fatigue, a condition which always arises when an awkward posture is maintained for a long time. The blood circulation may be reduced, preventing a proper supply of nutrients to the muscles and removal of muscle activity by-products, leading to a rapid fatigue and pain. Postural fatigue has to be distincted from muscle fatigue induced by strong contractions in that:

a. the muscles involved are active at levels which are a small fraction of the maximum voluntary contraction force,

b. the evidence of fatigue is muscle pain, rather than the dimunition of force, and

c. the fatigue takes a much longer time to occur than is usually the case in studies of sustained contractions.

After long series of ischaemic contractions "low frequency fatigue" may be induced, that recovers very slowly due to damage to the internal tubule system of the muscle. Other studies suggest temporary pain to be associated with accumulation of lactic acid or other products of muscle metabolism. The development of fatigue in sustained muscular contractions is described by Bowden; there is still some disagreement about the effect of contractions which are a small fraction (less than 10%) of the maximum voluntary contraction. The critical forces differ from 8% to 15% of the maximum voluntary contraction force, below which an exertion can be held for an indefinite time.

The estimated forces based on figure 19 are 1280 - 1780 N, being approximately 26 - 37% of the maximum voluntary muscle contraction force in torso extension of the 50%ile of the male population of 4680 N (Chaffin,1984). Moreover, a twisted posture has been shown to require extra muscular activity in the lower back! And pilots answered in the "general questionnaire" that 25% of the flying time they are seated rotated.
The development of muscle fatigue in the back will be accelerated if the pilot is exposed to a high workload. Activity of back muscles increases during concentration at work (Reason, 1978).
Again an acceleration will be seen if the seated person is unable to move back and legs.

Andersson described the force on the lumbar disc sitting leaned forward: 700 N, instead of 350 N, in the more erect position. Under a $+G_z$-load of 2.3 g the force on the disc of the pilot fitted with helmet and harness increases to 2160 N. A contineous high pressure of the disc may lead to herniation, according Andersson and others.

In previous chapters the daily routine of the pilots was described. All their activity tends to put a load on the back muscles, even the muscle trainings program. No "total" relaxation will be given to the muscles, nor an equilibrium will be reached between abdominal and back muscles.
Daily flight routine, low level flying especially, tends to train a special item during the whole mission. If low level flying could be alternated with air to air tasks or a phase in which the altitude is changed, a real relieve for the back muscles could be created. Limitations to one flying hour a day and a balanced sports program, with a substantial training part on general physical condition, is again a possibility to create relief.
X-rays taken of the total spine bring some information that could be used to select student pilots or pilots who convert to a new aircraft. This study showed that especially backs with slightly narrowed disc spaces and dischondrosis suffered from LBP. Knowing this now, and this finding is not in accordance with the meaning that spinal radiographs have minimal value in predicting LBP, the total spine X-ray should further be used in pilot examinations, may be in a different way, an anterior-posterior and an oblique photograph will be all you need to decide whether a pilot meets the criteria or not.

However, it may be concluded that posture (and the forward shift in posture during low level flight in particular) and not vibration, speed or the pilots constitution is the most contributing factor in developing LBP under F-16 pilots, and the solution to this LBP will be then to avoid unnecessary stresses to the backmuscles and, if possible, relaxing to the back muscles and a more balanced training of general physical condition and special muscle groups. If postural fatigue can be avoided the pilot will be enthusiastic again to fly his wonderfull airplane. Furthermore, without postural fatique, it will be possible to execute the pilot's task and appointed mission at a higher level.

Results of the study

The first question to be answered was whether F-16 pilots

suffered more from LBP than other flyers and workers. This study found that pilots of both helicopters, transport aircraft and jets suffer from LBP to the same extend.
F-16 pilots are indeed suffering more from LBP flying low level missions at high speed compared with flying at higher level.
The vibrations that occured during flight mainly consisted of 1 Hz and 4-5 Hz frequencies, the latter being the first resonance frequency of the spinal column . The amplitudes reached values about equal to helicopters. A relation appeared to exist between airspeed, the flying level and the magnitudes of the vibration.
The magnitudes increased with increasing airspeed and decreasing flying level.
The seat did not support the lower back sufficiently and the cockpit-seat combination is not a very ergonomical design.
However, some simple recommandations may improve the working places of the pilot and may prevent them from developing LBP.

CHAPTER SIX

RECOMMANDATIONS.

Since posture is the main factor in developing LBP for F-16 pilots, no major adjustments to the aircraft are necessary to reduce vibrations. However, a better more vibration demping seat cushion always may bring some relieve. An active demping system, a seat suspention system, decribed by van Vliet et al (1985) is not necessary.

X-rays, now taken of the total spine, in anterio-posterior, lateral and 3/4 positions, are very valuable, but can be limited to ap's and lateral radiographs.

In order to avoid stresses and strains on the back or unfavourable influences to the back muscles, a whole range of recommandations are possible:

a. a lumbar support, individually manufactured and fitted to the pilot's harness. Not thicker than 3 centimeters and made of a hard padding and exactly fitted to the pilot's back at L_3-L_4 level.

b. a muscle training program or even better a balanced sport and relaxation program that brings an equilibrium between back and abdominal muscles and leads to an improved physical condition. Possibly together with a reintroduction of physical condition tests for pilots.

c. limitation of the missions flown to one mission a day.

d. an armrest at the throttle position in order to avoid unnecessary, unbalanced neck and backmucle forces.

e. a movable, height adjustable HUD or a helmet mounted HUD to avoid a posture during flight, forced by the HUD position.

f. warm and windproof clothing clothing in order to prevent cooling of the back muscles after the mission.

g. a navigation table, not horizontally placed, but erected like the drawing tables of architects and a stool that is adjustable and supports the sitting/standing pilot.

h. a videotape recorder, used in briefings and debriefings mounted at a proper altitude and easily to operate sitting in a chair that gives proper lumbar support.

i. a briefing/ debriefing room fitted with well designed chairs.

CHAPTER SEVEN

SUMMARY.

Low level flying is a very good tactical possibility to carry out a mission unseen by a hostile radarsystem. Nowadays, Western Europe in general and the Federal Republic of Germany in particular, decreased the permissions to low level flying in assigned regions. That's why the Royal Netherlands Air Force is flying a part of the low level flying training in Goose Bay, Labrador, Canada. Twelve to thrirteen missions per pilot are flown within 12 days in a uninhabited region, threefold the size of the Netherlands, according a schedule in which the flying altitude decreases, the airspeed increases and the airtask intensifies.

Caused by the high G-loads on the airframe, a lot of structural dammage of the aircraft is found, eg. dammage of the ventral vins and the tail; but also the flyer appeared to show more and different complaints than during and after flying in the Netherlands.

Less facts in literature can be found about jet pilots and aproximately none about the specific F-16 pilot, relating to the influences of airspeed, flying altitude, vibrations and posture. In this study literature is collected, analysed and amplified with new specific data. Furthermore, vibrations at low level are analysed and accelerating forces are related to a biomechanic model.

In **chapter one** literature is presented concerning low back pain related to posture, vibrations and flying. 50% of the male population is suffering from low back pain every now and then, especially young adults. The most contributing factors in developing low back pain are: posture, frequent bending and rotating of the trunk, lifting and vibrations. 50% of the the pilots, too, are suffering from low back pain, both transport-, helicopter- and jetpilots. However, jetpilots seem to suffer more prolonged, most likely caused by the high G-forces they experience flying the jets. Pilot's posture in aircraft are wellknown examples of unsuccesfull applied ergonomy.

The main questions of this study are:

- Do pilots flying at low level, more frequently suffer from low back pain than those who fly at higher altitude?

- Are posture and vibrations during low level injurious to the health of the F-16 pilot?

In **chapter two** three questionnaires are analysed. The "general" questionnaire gives insight in population of the Dutch F-16 pilots : a group of males ranging from 21 to 52 years of age, medium-age of 31, flying three years this type of aircraft. They are fatigued after flying, unsatisfied with their position with the Royal Netherlands Air Force, playing less sports and 30% of them has some experience with low back pain after flying. The questionnaires "the Netherlands" and "Canada" give more insight in the flying operations, posture and the possibly developed low back pain. Pilots appear to pull less "G"-s at low level than at higher altitude; furthermore they are sitting less rotated, more supine and less relaxed. The backrest of the ejection seat gives about no support.

In **chapter three** the posture of the F-16 pilots is analysed. The ejection seat, having a tilt backangle of 22° and the position of the cockpit instruments, forces the pilot to a semicircular position: a cervical kyphosis and no lumbar lordosis. Apart from the posture during flying, the remaining work activities of the pilots are very unfriendly to the low back; both the visual inspection of the aircraft, preparing the mission, briefing and debriefing and the pilot's sportprogram load the back partially. Without any possibility to relax or to stretch the muscles the result will be a kyphosis.

Chapter four describes the study of vibrations on the ejection seat of the F-16 during different air speeds and altitudes. The most important magnitude of the vibrations in x-,y-, and z-axis are found at 4-5 Hz. The amplitude increases with increasing speed and decreases with higher flying levels. The seat cushion of the ejection seat shows about no demping.

In **chapter five** posture and accelerating forces are joined into one model. The calculated forces on L_3 can reach values, being 26-37% of the maximum voluntary muscle contraction force in torso extension in man.

In **chapter seven** a number of recommandations are suggested in order to avoid dammage to the low back of the F-16 pilot, while, however, the assigned task can be executed and without major transformation to the cockpit or the flight control system of the aircraft.

CHAPTER EIGHT

SAMENVATTING

Vliegen op lage hoogte is een goede taktische mogelijkheid om ongezien door vijandelijke radar een vliegopdracht uit te kunnen voeren. Nu West-Europa in het algemeen en de Bondsrepubliek in het bijzonder, het laag vliegen in speciaal aangewezen gebieden wat minder toelaat, vliegt de Koninklijke Luchtmacht sinds 1987 een deel van de laagvliegtraining in Goose Bay, Labrador, Canada. In een onbewoond trainingsgebied ter grootte van driemaal Nederland worden 12 tot 13 missies per vlieger gevlogen binnen 12 dagen tijd; volgens een schema, waarbij de vlieghoogte afneemt, de snelheid wordt opgevoerd en de taak geintensiveerd. Door de grote krachten, die op het vliegtuig worden uitgeoefend komt er nogal wat structurele schade voor aan het vliegtuig, zoals bv aan de buikvinnen en de staart; maar ook de vlieger bleek meer en andere klachten te vertonen dan tijdens en na het vliegen in Nederland.
Over de invloed van snelheid, hoogte, vibraties en zitpositie op de vlieger zijn weinig gegevens voorhanden in de literatuur met betrekking tot straaljager-vliegers en zeker niet specifiek betreffende de groep F-16 vliegers.
In dit proefschrift zijn literatuurgegevens verzameld en met nieuwe specifieke gegevens aangevuld. Daarnaast worden de vibraties tijdens het laagvliegen geanalyseerd en worden versnellingskrachten in een biomechanisch houdingsmodel aangegeven.

In **hoofdstuk een** worden literatuurgegevens gepresenteerd betreffende lage rugpijn in relatie tot zitten, vibraties en vliegen. Lage rugpijn komt bij 50% van de mannelijke bevolking voor, voornamelijk bij jonge volwassenen. De factoren die het meeste bijdragen tot het ontstaan van lage rugpijn zijn: zithouding, veelvuldig buigen en draaien met het bovenlichaam, tillen en vibraties. Eveneens 50% van de vliegers lijdt regelmatig aan lage rugpijn, zowel transport-, heli- als straaljagerpiloten. Echter, jetvliegers blijken langduriger last te hebben, mogelijk veroorzaakt door de hoge G-krachten, die ze ondervinden tijdens het vliegen. Zithoudingen in vliegtuigen zijn bekende voorbeelden van een niet geslaagde ergonomie.
De vraagstelling van dit proefschrift is:

- krijgen vliegers die op lage hoogte vliegen frequenter lage rugpijn dan degenen die op grotere hoogte vliegen?

- dragen zithouding en vibraties in negatieve zin bij in het ontstaan van lage rugpijn?

In **hoofdstuk twee** worden drie vragenlijsten geanalyseerd. De vragenlijst "algemeen" geeft inzicht in de Nederlandse F-16 vliegerpopulatie: een groep mannen van 21 tot 52 jaar, gemiddeld 31 jaar, die drie jaar op dit type vliegen. Ze zijn moe na de vlucht, ontevreden met hun positie in de Koninklijke Luchtmacht, sporten weinig en 30% heeft ervaring met lage rugpijn na het vliegen. De vragenlijsten "Nederland" en "Canada" geven meer inzicht in de vliegoperaties, de zithouding en de eventueel ontstane rugklachten. Vliegers blijken op lage hoogte minder "G"-s te trekken dan op grotere hoogte, daarnaast zitten ze minder gedraaid, meer rechtop en minder ontspannen. De stoelleuning steunt nauwelijks.

In **hoofdstuk drie** wordt de houding van de F-16 vlieger geanalyseerd. De schietstoel, die 22° achterover helt en de instrumentatie van de cockpit dwingt de vlieger tot een half-cirkelvormige houding: een forse cervicale kyphose en geen lumbale lordose. Naast de vlieghouding zijn ook de overige werkzaamheden van de vlieger rug-onvriendelijk; zowel de visuele inspectie van het vliegtuig, de vluchtvoorbereiding, de nabeschouwing alsmede het sportprogramma belasten de rug eenzijdig. Zonder ontspanning of rekken van de spieren restert een kyphose.

Hoofdstuk vier beschrijft het onderzoek naar vibraties op de schietstoel van de F-16 tijdens verschillende vliegsnelheden en vlieghoogten. De belangrijkste amplitude van de vibraties in x-, y en z-richting wordt gevonden bij 4-5 Hz. De amplitude neemt toe met toenemende snelheid en af bij grotere vlieghoogte. Het zitkussen van de schietstoel dempt nauwelijks.

In **hoofdstuk vijf** worden zitpositie en versnellingskrachten in een model samengevoegd. De berekende krachten op L_3 kunnen oplopen tot niet waarden, die 26 tot 37% van de maximale spiercontractiekracht bij extensie van het bovenlichaam bij mannen bedragen.

In **hoofdstuk zes** worden een aantal aanbevelingen gedaan om de lage rug van de F-16 vlieger zo veel mogelijk te sparen, terwijl toch het opgedragen vliegprogramma kan worden uitgevoerd en zonder grote ingrepen aan de cockpit of het besturingssysteem van het vliegtuig.

CHAPTER NINE

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GLOSSARY

ACCELERATION
A vector specifying the time rate of change of velocity with respect to an inertial frame of reference. Units: metres per scond per second (m/s^2).

ACCELERATION-AMPLITUDE
The definitive value of a vibratory acceleration (customarily the peak or root mean square value).

ACCELEROMETER
A transducer which concerts input accelerations into electrical outputs proportional to the instantaneous value of the input acceleration.

AIR TO AIR
A type of mission flown against an opposing aircraft.

AIR TO GROUND
A type of mission flown against a ground threat or ground target.

AMPLITUDE
The instantaneous value or, commonly, the maximum or vector value of a harmonic oscillation.

ANALYSER
An instrument for measuring the acceleration level, bandspectral density or some other frequency-dependent attribute of vibration intensity at various frequencies.

ANATOMICAL AXES
A coordinate system of three orthogonal axes deemed to pass through the human body with the head and trunk in the normal anatomical position.

BUFFETING
Heavy vibration of the empennage or, by extension, other parts of the airframe induced aerodynamically.

COMPLEX VIBRATION
Vibration at more than one frequency, not harmonically related, at the same time; or a mixture of periodic and non-periodic vibrations.

CREST FACTOR
The ratio between the peak value and the root mean square value of an oscillating quantity.

DAMPING
Diminution of an oscillation by thermodynamically irreversible energy dissipation.

DECREMENT
The decrease in amplitude of a damped transient vibration.

DIRECTION OF VIBRATION
The direction of a vibration vector with respect to a specified coordinate system.

FATIQUE-DECREASED PROFICIENCY BOUNDARY
A standardised level of vibration above which whole body vibration is deemed likely to lead to an ompairment of human performance or working efficiency.

FILTER
A device for separating oscillations on the basis of frequency, by electrical or mechanical means.

FLAILING
Uncontrolled passive displacement or oscillation of major parts of the body induced by severe aerodynamic forces, vibration or impact.

FLIGHT SURGEON
A medical officer in the air force specializing in aviation medicine.

FOOT
A measure of length, equal to 12 inches or 0.3048 metres.

FOURIER ANALYSIS
Analysis of a complex function into discrete frequency components related harmonically to one other.

FREQUENCY
The reciprocal of the period: the number of complete cycles per unit time. Units: the Hertz (Hz).

"G"-FORCE
The acceleration produced by the force of gravity at the surface of the earth. It varies slightly with locality, elevation and latitude, but by international agreement the value 980.665 cm per second squared has been adopted as the standard value.

HARMONIC
A sinusoidal function whose frequency is an integral multiple of some fundamental frequency.

HEAD-UP DISPLAY
A device by which visual information is collimated and projected in the line of regard when the viewer is looking straight ahead, as at the horizon in straight and level flight.

IMPEDANCE
The complex ratio or voltage (or some analogous quantity) to current (or its analogue). Units: Ohms

KNOT
Unit of speed of one nautical mile (6,076.12 feet = 1852 metres) an hour.

LOW LEVEL
A flying altitude of 150 feet or less.

MAGNITUDE
The instantaneous value of a variable quantity.

PERFORMANCE
The degree to which skill is exercised succesfully upon a specified task; or the capacity at any time to carry out tasks in general.

PIEZO-ELECTRIC
Capable of generating an electrical signal in response to an impressed mechanical force.

POWER SPECTRAL DENSITY
The mean square value of that part of a time-varying quantity passed by a narrow band filter, expressed as a function of frequency, per unit bandwidth, in the limit as the bandwidth nears zero and the averaging time becomes infinite.

REDUCED COMFORT BOUNDARY
A standardised limit of comfort or threshold of discomfort due to vibration, expressed as the root mean square acceleration-amplitude of acceptable vibration as a function of frequency and exposure time.

RESONANCE
The condition in which any change in the frequency of excitation causes a decrease in the response of a vibrating system.

RESONANCE FREQUENCY
The frequency at which resonance occurs (= natural frequency).

ROOT MEAN SQUARE (rms) VALUE
The square root of the average of the squared values of any set of numbers.

SHOCK
A sudden force or displacement causing transient vibration or shock motion of a mechanical system.

SINUSOIDE
The graphic representation of the sine ratio.

"THIRD-OCTAVE"
The interval between two frquencies having a frequency ratio of $2^{1/3}$ (1.2599),ie , one third of an octave.

TRANSMISSION
The passage of waves or forces through space or a body between a transmitting station and a receiver.

VIBRATION
Mechanical oscillation.

WEIGHTING
The selective modification of the values of a complex signal or function for the purposes of analysis or evaluation, according to prescribed rules or formulae.

WHOLE BODY VIBRATION
Vibration of man or animals applied through one or more principal supporting surfaces against the impedance of the body as a whole.

X-AXIS VIBRATION
Vibration acting along the anteroposterior axis of the human body.

Y-AXIS VIBRATION
Vibration acting sideways upon the human body.

Z-AXIS VIBRATION
Vibration acting along the longitudinal (cephalocaudal) axis of the human body (=vertical vibration).

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
AB	Air Base
AFB	Air Force Base
CAP	Combat Air Patrol
CFB	Canadian Forces Base
ECM	Electronic Counter Measures
F-	Fighter aircraft
G-load	Gravitational load (x times. 9.8 $m.sec^{-2}$)
HUD	Head-up display
LBP	Low Back Pain
PCM	Pulse Code Modulation
Q"C"	Questionnaire "Canada"
Q"G"	Questionnaire "General"
Q"N"	Questionnaire "the Netherlands"
RNlAF	Royal Netherlands Air Force

CURRICULUM VITAE

The author of this thesis was born in The Hague, the Netherlands in 1950. After completing HBS-B (Dutch High School) at St. John's College in The Hague he studied medicine at the Faculty of Medicine of the State University of Leyden, where he was graduated in 1974.
He joined the Royal Netherlands Air Force Medical Services as a general practitioner and was posted in Soesterberg, Rheine (FRG), Bramsche (FRG) and Volkel AB. The two last assignments he served as the Chief Base Medical Services.
He studied aerospace medicine at the Institute for Aerospace Medicine of the Federal German Air Force in Fuerstenfeldbruck, FRG.
He studied occupational medicine at the Faculty of Medicine of the Catholic University of Nijmegen, the Netherlands. He was graduated in occupational health in 1984.
He resigned from the Royal Netherlands Air Force in December 1988, then he became Head of the Occupational Health Division of Hoogovens Co.

Appendix A

QUESTIONNAIRE RELATION LOW BACK PAIN AND LOW LEVEL FLYING

o This questionnaire will be revised by the investigator anonymously. Your name and service number are required in order to link the total spine X-ray and the forms completed after the missions flown.

o No one will ever have notice of this completed form, exept the investigator.

o Please mark the appropiate answers.

o Complete the open questions on the lines.

PERSONAL DATA

Name :	....	
Servicenumber :	....	
Squadron :	306	1
	311	2
	312	3
	313	4
	315	5
	316	6
	322	7
	323	8
Pilot's experience	total < 500 hrs	1
	500 - 1000 hrs	2
	1000 - 2000 hrs	3
	> 2000 hrs	4
F-16 experience	total < 250 hrs	1
	250 - 500 hrs	2
	500 - 1000 hrs	3
	> 1000 hrs	4

Since wenn do you fly? 19..

Since wenn do you fly F-16? 19..

How many hours do you fly per month? ....

How many hours do you fly per week? ....

How many days do you fly per week? ....

How many hours do you fly per flying day?	< 1 hr	1
	1 - 2 hrs	2
	2 - 3 hrs	3
	> 3 hrs	4

How many hours of rest do you have between the consequetive flights?	< 2 hrs	1
	2 - 3 hrs	2
	3 - 4 hrs	3
	> 4 hrs	4

FLYING ROUTINE

What part of the mission time do you lean back relaxed?	< 1/4	1
	1/4 - 1/2	2
	> 1/2	3

What part of the mission time are you sitting rotated?	< 1/10	1
	1/10 - 2/10	2
	2/10 - 3/10	3
	3/10 - 4/10	4
	> 4/10	5

What part of the mission time are you sitting bended?	< 1/10	1
	1/10 - 2/10	2
	2/10 - 3/10	3
	3/10 - 4/10	4
	> 4/10	5

LOW LEVEL FLYING (< 250 ft)

What part of the mission time do you lean back relaxed?	< 1/4	1
	1/4 - 1/2	2
	> 1/2	3

What part of the mission time are you sitting rotated?	< 1/10	1
	1/10 - 2/10	2
	2/10 - 3/10	3
	3/10 - 4/10	4
	> 4/10	5

What part of the mission time are you sitting bended?	< 1/10	1
	1/10 - 2/10	2
	2/10 - 3/10	3
	3/10 - 4/10	4
	> 4/10	5

Do you have any flying experience in Goose Bay, Canada?	yes	1
	no	2

GENERAL QUESTIONS

Do you think your job is mentally demanding?	yes	1
	no	2

Are you physically tired of your job?	yes	1
	no	2

How often do you excercise the pilots's training program?	< 1x	1
	1x	2
	2x	3
	3x	4
	> 3x	5

How many hours do you play sports per week?	< 1 hour	1
	1 - 3 hrs	2
	> 3 hrs	3

VIBRATIONS

Do vibrations hamper you performing task in the F-16?	yes	1
	no	2

Do vibrations hamper you reading your instruments?	yes no	1 2
Do vibrations contribute in desorientation?	yes no	1 2
Do vibrations contribute in acquiring low back pain?	yes no	1 2

SHOCKS

Do you feel hampered by shocks caused by air turbulence and jet wash?	yes no	1 2
Do shocks hamper you reading your instruments?	yes no	1 2
Do shocks contribute in acquiring low back pain?	yes no	1 2

HEALTH

BACK

Do you suffer from low back pain or stiffness directly after flying?	yes no	1 2
Since wenn do you suffer from low back pain?		19..
Do you suffer from low back pain every day?	yes no now and then	1 2 3
How often do you suffer from low back pain per year?		.. times

How long does the pain last?	minutes	1
	hours	2
	days	3
	weeks	4

Did you suffer from low back pain longer than two weeks during the last twelve months?	yes	1
	no	2

Did you ever suffer from low back pain directly after low level flying?	yes	1
	no	2

Where is your back pain located?	nowhere	1
	neck	2
	middle	3
	low back	4
	total back	5

Does the pain radiate to the legs?	yes	1
	no	2

Did you ever suffered from ischialgia?	yes	1
	no	2

Did ever suffered from a slipped disc?	yes	1
	no	2
if yes, treated?	yes	1
	no	2
if yes, how?	operation	1
	bedrest	2
	physiother	3
	chiropract	4
	others	5

Have you ever been treated for other low back deseases than slipped discs?	yes	1
	no	2

Have you ever been prohibited to fly due to low back pain?	yes no	1 2
if yes, longer than 30 days?	yes no	1 2
Does your total spine X-ray show any irregularities?	yes no	1 2
Do you fly with a dispensation or restriction due to low back pain?	yes no	1 2
Did you ever had to activate your ejection seat?	yes no	1 2
Do you think your low back pain is caused by your job?	yes no	1 2

if yes, which part? ....
....
....

Do you suffer from low back pain in any of the following situations?

- during or after each mission?	yes no	1 2
- missions longer than 1 1/2 hours?	yes no	1 2
- missions in which you need to be highly concentrated?	yes no	1 2

Do you try to help your back by:

- flying with a lumbar support?	yes no	1 2
- moving on your seat?	yes no	1 2

- others? ....
....

OTHER DESEASES

Did you ever suffered from haemorrhoids?	yes	1
	no	2
if yes, during or after flying?	yes	1
	no	2
Do you ever experience headache directly after flying?	yes	1
	no	2
Do you suffer from intestinal cramps after flying?	yes	1
	no	2
Do you suffer from cramps of the urinary bladder after flying?	yes	1
	no	2
Do you suffer from shoulderpain?	yes	1
	no	2
elbow?	yes	1
	no	2
Do you suffer from insomnia?	yes	1
	no	2
Do you experience any lack of concentration?	yes	1
	no	2

Thank you very much for completing this questionnaire.
Please hand this form to the flight surgeon.

Appendix B

QUESTIONNAIRE RELATION LOW BACK PAIN AND LOW LEVEL FLYING

POST MISSION QUESTIONNAIRE "THE NETHERLANDS"

o This questionnaire will be revised by the investigator anonymously. Your name and service number are required in order to link the total spine X-ray and the forms completed after the missions flown.

o No one will ever have notice of this completed form, exept the investigator.

o Please mark the appropiate answers.

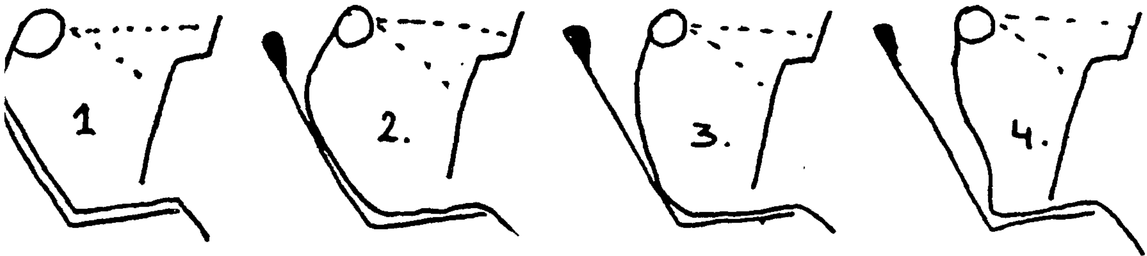
o Complete the open questions on the lines.

Name	....	
Service number	....	
Air speed	< 480 kts	1
	480 - 540 kts	2
	540 - 600 kts	3
	> 600 kts	4
Mean flying level	250 - 500 ft	1
	500 - 1000 ft	2
	1500 - 10000 ft	3
	> 10000 ft	4
Highest + Gz	< 4 G	1
	4 - 5 G	2
	5 - 6 G	3
	6 - 7 G	4
	7 - 8 G	5
	> 8 G	6

Type flown	F-16 A	1
	F-16 B front	2
	F-16 B rear	3

Mission task	air to air	1
	air to ground	2
	combined task	3

What has been your posture ?



Did you sit rotated during the bigger part of this mission?	yes	1
	no	2
Are you satisfied about your posture?	yes	1
	no	2
Did you experience any problem reading your instruments?	yes	1
	no	2
Did you suffer from any low back pain?	yes	1
	no	2
Did you experience other medical or flight physiological problems?	yes	1
	no	2

if yes, which ones? ....
....
....

If you do not suffer from low back pain after this mission, you now have completed this questionnaire. Thanks for your help. If you do suffer from low back pain, please continue.

What is the location of the pain?	neck	1
	middle part	2
	low back	3
	total back	4
Did the pain come fast or slowly?	fast	1
	slowly	2
What was the character of the pain?	dull	1
	smarting	2
	burning	3
	crunchy	4
Did the pain radiate to ...?	shoulder	1
	arm	2
	leg	3
	abdomen	4
	none	5
Did you complete your mission?	yes	1
	no	2
Do you want to go to the flight surgeon or physiotherapist?	yes	1
	no	2
Do you still suffer from LBP?	yes	1
	no	2

Thanks for completing this form and you know where to find your flight surgeon!!!!

Appendix C

QUESTIONNAIRE RELATION LOW BACK PAIN AND LOW LEVEL FLYING

POST MISSION QUESTIONNAIRE 'CANADA'

o This questionnaire will be revised by the investigator anonymously. Your name and servicenumber are required in order to link the total spine X-ray and the forms completed after the missions flown.

o No one will ever have notice of this completed form, exept the investigator.

o Please mark the appropiate answers.

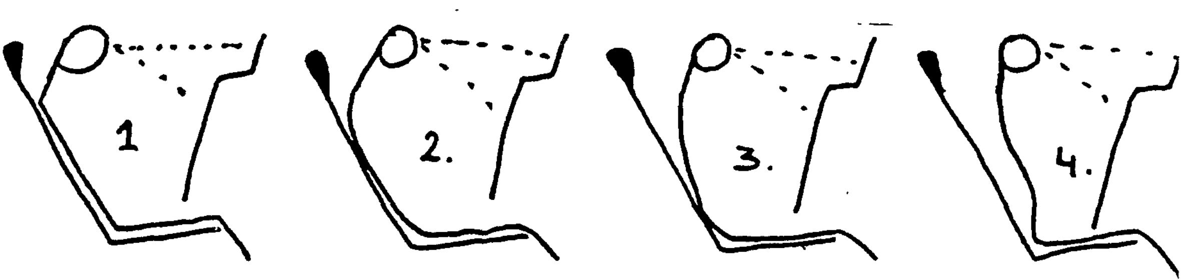
o Complete the open questions on the lines.

Name	....	
Service number	....	
Mission number	1 2 3 4 5 6 7 8 9 10 11 12 13	
Air speed	< 480 kt	1
	480 - 540 kts	2
	540 - 600 kts	3
	> 600 kts	4
Flying level	> 250 ft	1
	150 - 250 ft	2
	< 150 ft	3
Highest +Gz	< 4 G	1
	4 - 5 G	2
	5 - 6 G	3
	6 - 7 G	4
	7 - 8 G	5
	> 8 G	6

Type flown	F-16 A	1
	F-16 B front	2
	F-16 B rear	3

Mission task	air to air	1
	air to ground	2
	combined task	3

What was your posture?



Are you satisfied with your posture?	yes	1
	no	2

Did you experience any problems reading your instruments?	yes	1
	no	2

Did you suffer from low back pain during or after this mission?	yes	1
	no	2

Did you experience any other medical or flight physiological problems?	yes	1
	no	2

if yes, which ones? ....
....
....

If you do not suffer from low back pain, your questionnaire is now completed. Thanks for you help.
If you do suffer from low back pain, please continue.

What is the location of the pain ?	neck	1
	middle part	2
	low back	3
	total back	4
Did the pain come fast or slowly?	fast	1
	slowly	2
What was the character of the pain?	dull	1
	smarting	2
	burning	3
	crunchy	4
Did the pain radiate to ..?	shoulder	1
	arm	2
	leg	3
	abdomen	4
	none	5
Did you complete your task?	yes	1
	no	2
Do you want to see the flight surgeon or the physiotherapist?	yes	1
	no	2
Do you still suffer from low back pain?	yes	1
	no	2

Thank you for completing this form, and you know where to find your flight surgeon!!!