Welbees

Scientific evaluation of the long-term impacts of working conditions on cabin crew's health

Final report

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CONTENT

1. Introduction

1.1. Context and objectives

Pension reforms are currently a major concern worldwide. Demographic changes, the global economic crisis and a shift in the labour market dynamics result in a great deal of debate in many countries about the end of active life and the specific conditions for retirement. Particularly, the mandatory retirement age has recently increased for many professional categories in Europe, including aviation cabin crews. Yet, arduous working conditions may have significant impact on workers' health and has been demonstrated to be one determinant factor in explaining life expectancy discrepancies among socio-professional categories.
More specifically for cabin crews, many factors of the work environment may produce long-term effects on cabin crews' health and justify a debate about early retirement for these professionals. The rationale for such special pension schemes is that arduous work increases mortality (i.e. shorter life expectancy) or morbidity (incidence of work-related diseases) for these workers, thus reducing the time retirement benefits can be enjoyed. Hence, earlier access to pension benefits would compensate for a shorter life expectancy without disability.

In this context, EurECCA wishes to review the latest scientific evidence regarding the relationships between working conditions and health, in order to inform the debate on early retirement age for cabin crews and initiate the social negotiations with the aviation authorities.

1.2. Methodology

The present report aims at examining the arduous nature of the cabin crew occupation by identifying the main work-related risk factors which may produce long-term effects on cabin crews' health and affect life expectancy without disabilities. Hence, the primary goal of this report is to provide a synthesis of available scientific evidence on the relationships between exposure to arduous work conditions and long-term consequences on health.

An international expert in the field of aviation medicine and aircrews' physical aptitude, Professor Henri Marotte, has been consulted as part of the project. Following this interview, the main risk factors for the cabin crews have been identified, which was useful to refine the scope of the project and identify the first key elements to be addressed. Serge Volkoff, a renowned expert in epidemiological occupational health was also consulted on the specific issue of pension schemes, including early retirement.

Various sources of information (epidemiologic, ergonomic, sociologic and occupational health) have been analysed. The main scientific databases (such as Science Direct and PubMed) have been used to gather the relevant papers on work-related risk factors and their consequences on health. Studies focusing specifically on cabin crews have been identified and analysed. A number of research reports addressing the issue of arduous work and early retirement age in the European Union have also been reviewed in order to feed into the overall reflexion on retirement age and provide EurECCA with the key elements in their negotiations with the national authority.

The report reviews the long-term effects of a number of risk factors, with a focus on cabin crews' specific risk factors and work conditions. It is important to understand that this report does not intend to define an age above which cabin crews should be allowed to retire. Although the issue needs a thorough scientific understanding, defining retirement age for the cabin crews remains a political decision and should involve social negotiations between the trade unions and the relevant national authority.

Hence, the report aims at reviewing the existing evidence which may justify the cabin crew occupation to qualify as arduous work. The report also suggests possible ways to integrate these scientific elements into the argumentation for a special pension scheme.
A summary of the main scientific evidence and their potential relationships with early retirement is presented in the following sections. A more detailed review of all scientific data has been conducted and is provided in Appendix 1.

2. Arduous work and early retirement

2.1. What is arduous work?

The simple question of what qualifies as arduous work is not straightforward and does not lend itself to an easy definition. Despite the absence of a common definition at the European level, there is actually clear evidence of arduous occupations. Pragmatically, each country has attempted to define its own list of arduous jobs, with significant differences from one country to another. For example, a journalist in one country might be in a risky occupation, whereas his counterpart in another may not be.
Achieving an appropriate and consistent definition of arduous work is a difficult task because it refers to a number of issues with different stakes. The following definition has been used in a research project on behalf of several European trade unions, which has compared special pension schemes due to arduous work in Europe [100]:

"Occupations involving the exposure of the worker over a period of time to one or several factors leading to professional situations susceptible to leave long-lasting and irreversible effects on his/her health; these factors are related to physical constraints, psychosocial risks, an aggressive physical environment, working organisation and working rhythms, including shift work".

Several studies have demonstrated that arduous working conditions and work organisations can directly or indirectly affect workers' health at the end of active life and beyond ([87], [90], [91]).

2.2. Intensification of work demands

Occupational risks prevention policy as well as technological, economic, and social progress have resulted in some particularly arduous activities being reduced or to disappear (e.g. miners). The boom in service activities (tertiary sector) and the emergence of modern technology should have resulted in an overall improvement of working conditions across the past decades. However, these benefits have been superseded by the negative consequences of the recent intensification of work demands over the last decade.

Although activities involving physical workload and long duty length have progressively decreased, a significant change in work rhythms and organisations have occurred in the last decade with more shift work (e.g. night work) and the intensification of constraints on work rhythms. The aviation industry is no exception and flexible rostering involving irregular hours of work may be necessary to cope with the demand. The industry had therefore to adapt its work organisation, with a subsequent increase in mental workload whereas physical workload remains significant for the cabin crews. This temporal pressure reduces leeway in the execution of work and weakens even more older cabin crews who have less ability to adapt.

Arduous work is therefore a current issue although its nature has changed over the last decade. Scientific knowledge should be gathered in order to allow for a social debate on retirement age. Further reflections on the necessary prevention measures to be implemented in the workplace also need to be addressed.

2.3. Exposure to arduous work during the working life

Another issue when attempting to address the issue of arduous jobs and early retirement is that cabin crews are not necessarily exposed to arduous work during their entire working life. This means that a special pension scheme should take into account the periods during which the individual was actually exposed to arduous work and potentially consider a reduction in retirement age in proportion to this time spent working in the arduous occupation [102]. Furthermore, the notion of "job" may be too broad to be able to clearly identify the arduous nature of each particular activity carried out within the "job". Depending on local prevention measures and work organisation, the same "job" may not present the same level of arduousness.

It is also very difficult to determine an exposure threshold to arduous work above which the effect on health may become irreversible. The relationship between work-related risk factors and health is complex and work constraints often cumulate with other non-work-related factors. It is also not clear how work-related factors may cumulate during the entire working life to produce long-term effects on health.

2.4. Measuring the consequences of arduous work

As mentioned earlier, working conditions have been demonstrated to impact on the health of workers. In these studies, various measures have been used to evaluate the consequences on health. Life expectancy is one interesting measure which can be determined with a relatively good degree of accuracy. If cabin crews have a risk of premature mortality, this may justify an earlier access to retirement to compensate for a shorter-than-average life expectancy. Other measures relate to cancer or cardiovascular diseases occurrences, premature aging or deterioration of life quality at old age etc.

Arduous work environment may actually result in two different situations [100]:

- a deterioration of health, which may not become apparent at the time of exposure, leading to chronic diseases;
    - working careers may be reduced due to work-related disability or sickness
    - premature mortality (diminished life expectancy)
- a difficulty for the worker to continue to carry out the same job or remain in the same occupation: the job cannot be performed anymore as the worker gets older.

In one hand, arduous work has negative consequences on health, hence resulting in work-related disabilities and premature mortality. On the other hand, the arduous job becomes too difficult for the older worker who cannot perform the job anymore, although no long-term consequence on health is reported. These two situations need to be investigated considering the specific case of the cabin crew occupation, as they may both be eligible to early retirement schemes.

In the first situation, scientific evidence related to morbidity and life expectancy need to be analysed whereas in the second situation, the nature of the arduous occupation and its sensitivity to older age is to be evaluated.

3. Review of scientific literature

Studies which have analysed the relationship between arduous work and early retirement usually distinguish different types of arduous working conditions. More specifically, four working conditions have been identified as particularly likely to produce long-term risks on health:

- Exposure to toxic agents (e.g. chemicals agents)
- Cosmic radiation
- Physical work (including postural constraints and work pace)
- Shift work (irregular work hours)

These risk factors have been investigated for the specific case of cabin crews. Other risk factors pertaining to the aircraft environment (noise, vibration, pressurisation etc.) have also been evaluated with regard to long-term risks on cabin crews' health, with the aim to single out potential avenues of reflection for a special pension scheme.

The risk factors reviewed in the next section have the potential to produce irreversible effects on cabin crews' health and therefore lead to disabilities and/or shorter life expectancy. It should be noted that health deterioration may become apparent several years or decades after exposure and therefore, the associated risk factor may not be experienced as arduous at the time of exposure (e.g. exposure to chemical agents).

3.1. Toxic agents

Toxic particles might be present in the aircraft cabin in the case where unfiltered air is provided from the engine through the air supply system (the so-called "bleed air"), originating from possible oil leakages in the engine. Bleed air could also be contaminated by hydraulic and deicing fluids. The risk of aerotoxic syndrome has received increasing attention in the past years within the aviation community, as a potential risk for cabin crews' health.

Following a contamination event, inhalation of toxic particles may lead to a series of symptoms including cardiovascular trouble (e.g. palpitations), respiratory anomalies (e.g. chest ache, lung irritation), and neurological symptoms (e.g. headache, trouble speaking, balance and vision problems, loss of consciousness). These symptoms may last several weeks after the contamination event. However, there is currently a lack of studies with regard to the effects of such contamination events on cabin crews' health in the long term.

Volatile Organic Compounds (VOC) also constitute a potential health risk in the aircraft cabin. They include several chemical agents originating from multiple sources. On the basis of actual VOC measurements on several flights, the risk for sensory irritations (eyes and upper airways) in an aircraft cabin has been estimated at 84%. Adverse effects on health of VOC include irritating symptoms (nose, throat, eyes), general fatigue, cognitive effects such as concentration difficulties, and toxic reactions. However, further studies are needed to determine the long-term effects of exposure to VOC in the cabin crew population.

It is currently not possible to ascertain whether exposure to toxic particles in the aircraft cabin may result in chronic health conditions. In all cases, consequences on health arising from acute contamination events may be reduced by the means of appropriate prevention measures and monitoring of cabin air quality. However, as explained more in details in the Annex section (page 27), portable air sampling devices exist (patented in US and EU) that allow for continuous sampling of inflight cabin air and that can be used by non-technical personnel. Thus, cabin air quality assessment could be performed autonomously within an airline, and cumulative exposure also controlled.

3.2. Cosmic radiation

Cosmic radiation from outside the solar system is almost absent on the earth's surface while it increases as altitude and latitude increase. Cabin crews are among exposed professionals for which appropriate exposure limits have been set. While the negative effects for high doses of radiation on cellular DNA (provoking cellular death) are acknowledged, the effects of moderate exposure on health are still debated. In particular, protection measures must be taken during pregnancy. It has been demonstrated that cosmic radiation during a solar particle event (e.g. a flare) can increase significantly (even within a single flight) so that exposure limits per year may be exceeded. Thus, a pregnant cabin crew who would be exposed to such a solar particle event may exceed the recommended yearly limitation. It is also known that high doses of radiation cause birth defects in a developing fetus. This is why special prevention measures for pregnant cabin crews are recommended in relation to radiation exposure.

In all the reviewed studies, measured annual radiation exposition rates amount to 2-4mSv for long-haul crews and 1-2mSv for short-haul crews. These values correspond to 1/5 and 1/10 of international standard recommendation dose limits, respectively. Based on calculated (and actual) values of radiation exposure, it has been estimated that the risk of developing a radiation-exposure induced cancer for an aircrew member over 20 years of service is very low, i.e. 0.4% (0.6% over 30 years). Furthermore, mortality rates for many cancer- and non-cancer related causes (for example leukaemia), are not significantly different from the general population.

The review of scientific data does not show higher risk of mortality due to radiation exposure than in the general population. Hence, the impact of ionizing cosmic radiation on chronic health is currently considered as not substantial.

3.2. Physical factors

3.4. Noise

Noisy work environments have been demonstrated to impact subjective state, objective performance, and health. International and European norms exist which allows to predict hearing impairment as a function of age, noise levels and exposure time during the professional life [101]. Hence, it is possible to determine the exact contribution of past exposure to noise during the working life, and separate the effects of aging [93].

Particularly, noise level in an aircraft cabin is significantly associated with higher perceptions of symptoms such as headache, tiredness, swollen feet, and pain in the back [12]. Furthermore, sensitivity to environmental factors (including noise) increases with age, thus decreasing tolerance to chronic exposure. As a conclusion, prolonged exposure to noise should be considered a risk factor for chronic acoustic health conditions, Non-acoustic long-term effects of noise, e.g. a higher risk for breast cancer in female chronically exposed to noise with respect to non-exposed females, are under study and need further evidence to be confirmed,

3.5. Cabin pressurisation

Effects of altitude are associated with cabin pressurisation, whose prescriptive limits are expressed in terms of altitude (between 1524 and 2438m). With increasing altitude, compensation mechanisms are triggered by the human body, due to reduced oxygen concentration in the air (hypoxia). The efficiency of such mechanisms depends on several factors (e.g. altitude at which a person lives, climb rate, final altitude, and most importantly general health state). Huge individual differences can be observed.

Other symptoms resulting from high altitude originate from gas expansion. Physiological adaptations in the ear and thorax/abdomen normally occur, with potential difficulties in case of some specific health conditions (recent surgical intervention, bowel obstruction).

It has been demonstrated through objective pressurisation measurements that cabin altitude legal limits might be exceeded during cruise, probably as a consequence of aircraft fuselage's air leaks which may develop after years of operations. Anyhow, these exceedances can be considered as minor and associated physiological adaptations would remain limited.

Although many individual differences exist in relation to tolerance to altitude's changes (and to symptoms' occurrence), available knowledge about long-lasting exposure to altitude changes and chronic effects on health is still insufficient to establish an exposure limit.

3.6. Humidity rate

Cabin humidity level is normally low, for safety and health reasons (bacteria proliferation). Objective measures have shown that relative humidity is systematically below the recommended range for aircraft cabin, especially during cruise. This may result in dry eye syndrome with consequences ranging from light to major visual impairment.
Scientific data about the effects on health of long term exposure to low relative humidity is still insufficient to conclude: it is currently not possible to establish a relationship between humidity and health consequences. However, as tolerance to work environment characteristics decreases with age, it is likely that dryness symptoms have higher impact on older cabin crews.

3.7. Physical workload

Physical workload gathers a number of factors which may result in musculoskeletal disorders: repetitive movements of the upper limbs, postural constraints, mechanical vibrations which are transmitted to the whole body, and load handling. These factors are all relevant to the cabin crew occupation which involves repetitive movements when serving the passengers, handling heavy trolleys and being exposed to the vibrations of the aircraft. This physical workload may greatly vary from one company to another depending on the type of aircraft, trolleys, local operating procedures, workforce management, and available countermeasures currently in place to alleviate the issue.

Health problems due to vibration among cabin attendants often relates to neck, shoulder, and lower-back injuries and pains. The highest rate of vibrations has been measured in the rear seats of the cabin, especially during landing. Meteorological conditions may also increase vibration doses and their amplitude. The reviewed studies reported measured vibrations within the regulatory limits. However, there is no clear threshold beyond which exposure to vibrations may have long-term effects on health.

Cabin crews also have to deal with significant physical workload during shifts, especially in relation to pushing and pulling trolleys on an inclined cabin floor. In some field observations, the adoption of ergonomically unfavourable postures may result in musculoskeletal disorders, especially among female flight attendants [85]. The occurrence of musculoskeletal disorders in relation to physical workload may be frequent during a cabin crew's working life, with potential incapacitation states which may remove temporarily the cabin crew from duty. However, physical workload may also have irreversible impact on health. Older workers may suffer long-term disabilities due to premature wear of their body associated with physical workload ([87], [96], [97], [92]). The hypothesis of a premature wear due to physical workload may be difficult to emphasise in the studies because of the health selection process which removes these workers from duty. However, several studies have highlighted the dose-response relationship between physical workload and musculoskeletal disorders. When several physical factors combined, an increase in musculoskeletal disorders was observed.

Physical factors have been demonstrated as impacting workers' health in the short and long terms, sometimes irreversibly. The dose-response effects of these factors have been clearly shown in several studies. However, it is very difficult to define clear thresholds since the effects of physical factors are not systematically irreversible and are very variable depending on the aircraft, the local work procedures and the mitigation measures implemented by the airline. Nonetheless, these physical factors combine with each other and contribute to the overall arduousness of the work carried out. They may result in musculoskeletal disorders.

In the context of early retirement scheme, simple criteria may be retained to evaluate arduousness of the activity. Typically, accumulation of several physical factors producing potential premature wear and musculoskeletal conditions over several years may be considered as an indicator of arduousness (e.g. repetitive movements, standing position etc.), although it is not possible to determine precisely, considering the current scientific knowledge, an exposure duration threshold beyond which the risk becomes significantly higher.

3.3. Shiftwork

Following the worldwide intensification of work rhythms across the last decade, the need to carry out 24/7 activities has emerged. As a consequence, the number of workers exposed to shift work has sharply increased with growing concerns on the long-term effects of irregular hours of work.

Circadian disruptions may occur as a result of shiftwork. Yet, people have been shown to become less tolerant to circadian desynchronizations and jet lag with age. Long term effects of shiftwork actually combine with those of aging, and it is often difficult to disentangle the effects of aging from those of exposure to shiftwork. Consequently, the risk of suffering from chronic fatigue and several other health conditions increases for older people exposed to shiftwork.

Recent studies have highlighted the relationship between nightshift and some forms of cancer. In particular, important modifications in the hormone production cycle occur when the individual is awake during night: melatonin's production is stopped while it is normally released during the night. Melatonin is an important regulator of other hormones, with an oncostatic effect (decrease risk of cancer) for a variety of tumours. As a consequence, some hormones are overproduced during nightshift, leading to the development of hormone-sensitive tumours. It has been reported that the risk for female cabin crews exposed to nightshift to develop a breast cancer is 48% higher than in the general population. Lack of melatonin secretion during a nightshift has been demonstrated as the main contributing factor to breast cancer in female cabin crews. Circadian disruption has also been demonstrated as the main contributing factor of prostate-cancer, which also is a hormone-dependent cancer. The risk for prostate-cancer development in male cabin crews has been reported as 40% higher than in the general population.

Hence, exposure to shiftwork (and especially nightwork) increases the risk of developing some specific hormone-dependent cancers for the cabin crew population. The increase in hormone dependent cancers have long been associated with exposure to cosmic radiations while it actually is a direct consequence of shift work.

The risks associated with shift work are therefore delayed in time and may become apparent only years after exposure, often beyond the working life. However, it is very difficult to establish a cumulative exposure duration threshold associated with a significant increase in morbidity. Criteria used to evaluate exposure to shift work and level of arduousness experienced throughout the working life generally consider exposure duration to shift work above 15 years. Several studies have also highlighted the difficulties to carry on night work more than 10 years (Volkoff & Molinie, 1995).

It is interesting to note that the new EASA Flight Time Limitations (FTL) regulation (2016) does not consider exposure duration to irregular work hours and its long-term consequences on aircrews' health. Hence, there is no particular consideration and protection with regard to age and exposure to shift work throughout the working career. Yet, it may be necessary to consider schedule adjustments for these older cabin crews who may experience greater difficulties to adapt to shift work as they get older. This particular issue needs to be addressed within the airline Fatigue Risk Management System (FRMS) in order to improve working conditions for the older cabin crews.

3.4. Psychosocial factors

So far, physical factors and shift work are the two main types of risk factors to be considered within the framework of an early retirement scheme for cabin crews, as they have been demonstrated to have long-term effects on health. However, there is another type of risk factor which also need to be considered in the context of evaluating arduous work. It corresponds to psychosocial factors which are more subjective by nature and which are mainly associated with the cabin crews' perception of their working conditions [101].

Psychosocial factors include any type of psychological tensions and stressful situations in relation with working conditions, which may expose the individual to short or long-term psychiatric decompensation or disorders, sometimes associated with coronary risks. Although the long-term effects on health and life expectancy may not be clearly ascertained, they may result in physical and psychological symptoms which may cause incapacitation during the active life and impact end-of-career choices.

Stress is a typical psychosocial factor which may arise from multiple causes, work-related or not. High job demands, lower perceived availability of resources, lower control over job activities, and scarce social support are among the factors that contribute to chronic stress. Although consequences on health largely depends on stress tolerance mechanism, there are objective evidence of the effects of stress on health: the link between chronic stress and hypertension, gastrointestinal problems, and depression of immune systems has already been demonstrated. While these studies are not specific to the cabin crew population, it is interesting to note that in a study by Sveinsdottir et al. (2007), cabin crews have been found to be more affected by stress than other professionals generally affected by stress issues and burnouts (e.g. nurses). Cabin crews reported occurrences of several symptoms, highlighting how chronic stress should be addressed when considering long term effects on cabin crews' health.

Psychosocial factors may arise from increasing levels of requirement imposed on the cabin crews along with a lower perceived level of autonomy, thus resulting in states of nervousness and fatigue leading to increased risk of muscular contractions and other osteo-articular pains (including neck pain more specifically). Studies have also demonstrated that lower back pains are statistically associated with workers reporting lack of time and resources to achieve quality work [103]. Hence, psychosocial factors may result in various health problems which, if not always associated with serious health disorders, may be difficult to cope with over time. Moreover, stressful work conditions have been shown to cause premature ageing (Conseil d'orientation du travail, 2001). Psychosocial factors have also been demonstrated to play a significant role in musculoskeletal disorders (National Research Council (US) and Institute of Medicine (US) Panel on Musculoskeletal Disorders and the Workplace, 2001).

Work-related psychosocial factors often interact with other psychosocial factors such as anxiety or social isolation [101], thus contributing to "chronic stress" as a consequence of both work and personal issues.

Hence, the contribution of work-related psychosocial factors is difficult to isolate in the context of evaluating their effects on chronic health conditions.

In practice, it may be more appropriate to address work-related psychosocial factors by reducing exposure to these factors at the workplace (change of work procedure or other work assignment for older cabin crews within the company), in order to avoid potential health deterioration into more serious medical conditions in the long term. Improvement of working conditions and management of late career are particularly crucial to address psychosocial factors: such measures should contribute to maintain employability of older cabin crews and prevent any development of psychological and physical disorders arising from psychosocial factors.

4. Discussion

One first observation is that there is no generic justification of a special pension scheme with an early retirement age for cabin crews which has been consistently applied across the European Union. Defining workers who may benefit from preferential treatment in the pension system is a complex issue, mainly because arduous occupations involve multitude of factors which are difficult to disentangle. Nonetheless, arduous work is a reality and may have negative impact either on the mortality rate (in relation to cardiovascular diseases and cancers) or result in long-term disabilities in relation to musculoskeletal disorders and premature aging.

4.1. Main factors contributing to arduousness

The relationship between health and work cannot be limited to a simple causal effect involving one single factor and linear consequences. A specific work condition may have several impacts on health. Equally, an occupational disorder may originate from several work-related causes, to which other non-work-related factors may add to. It should also be noted that exposure to arduous work does not necessarily result in chronic medical conditions and the associated reduced life expectancy without disability.

The most significant risk factor associated with long-term consequences on cabin crews' health is shift work. Particularly, there is a clear relationship between night work and the occurrence of hormone dependent cancers. The long-term effects of shift work may therefore be irreversible and incapacitating. Shift work is recognised as a major health risk for the workers exposed to irregular work hours. Yet, the new EASA FTL regulation does not comment on the chronic effects of exposure to shift work and does not suggest any adjustments for older aircrews. It is therefore essential that the issue of age be specifically addressed within the airline's Fatigue Risk Management System (FRMS).

Physical factors are the second most important risk factor with regard to early retirement pension provisions. They include several different factors, such as physical workload: the cabin crews' duty involves repetitive movements of the upper limbs associated with temporal demand, postural constraints due to the aircraft cabin configuration, and prolonged standing position. Several studies have highlighted the relationship between physical workload as experienced by the cabin crews and the occurrence of musculoskeletal disorders during the later stages of working life and beyond. Furthermore, the whole body is subjected to the aircraft vibrations and noisy environment, with also established effects on chronic health conditions.

Regarding toxic particles, scientific studies are currently not sufficient to establish whether they may have long-term effects on cabin crews' health. It should be noted that there is no scientific evidence of the effects of cosmic radiation on cabin crews' health. Furthermore, available information from scientific studies is still insufficient to conclude on the long-term effects of cabin pressurisation and humidity rate on cabin crews' health.

Although it has been demonstrated that exposure to psychosocial risk factors (tensions at the workplace, stress arising from working conditions) may negatively impact on the health of cabin crews, multiple factors are actually involved and it is, in practice, very difficult to establish the exact contribution of work-related factors. Moreover, these risk factors are most of the time difficult to objectively quantify. Therefore, it is in practice difficult to consider psychosocial factors in the provision of early retirement scheme. Psychosocial factors may actually be more effectively addressed directly by the airline through the implementation of preventive actions at the workplace so as to avoid any long-term consequences on health.

4.2. Life expectancy

Statistics on life expectancy clearly emphasise significant differences among the European countries, ranging from 75.3 years in Serbia to 83 years in Spain and Switzerland (Eurostat, 2017). Large differences are also observed between socio-professional categories. This difference may reach up to 7 years between males belonging to the higher socio-professional categories (managers, general practitioners etc.) and male workers of the lower socio-professional categories [101].
However, these differences cannot be fully attributed to the work environment: chronic health disorders are generally caused by multiple factors and also involve individual characteristics of the worker. It is currently not possible to measure precisely, for a given occupation, the fraction of life expectancy which may be directly attributable to professional exposure. Subsequently, it is even more complex to establish the contribution of one specific risk factor in life expectancy.

An important issue to be considered when studying cabin crews' health conditions is recurrent medical checks normally performed within cabin crew population (twice per year, after 40 years old), which help detect medical conditions compared to the general population. Therefore, when comparing incidence of medical conditions between cabin crews and the general population, the "healthy worker effect" may actually affect the results. Cabin crews often show lower incidence rates of medical conditions, due to the fact that in case of detection of such conditions they are no longer allowed to carry out their duty. As a consequence, they also show higher life expectancy (4 to 5 years) than the general population and are more prone to follow medical advice and to develop healthy lifestyle, thus reducing the risks of developing chronic health conditions.

Several aspects of cabin crews work environment have an impact on cabin crews' health, on both the short and the long terms. While short term effects may be managed by improving local working conditions, some health disorders may become apparent only years after the exposure. On the other hand, some chronic conditions (e.g. allergy) may actually disappear as soon as exposure to the toxic agents stops, with no consequences in the long term on health. This raises another issue as to the difference between life expectancy and life expectancy without disability. If simple life expectancy is considered, all workers exposed to physical arduousness leading to musculoskeletal disorders may not qualify anymore for an early retirement scheme as there are no consequences on life expectancy. However, musculoskeletal disorders significantly impact life quality at old age. This is why life expectancy "without disability" may be rather considered in the debate about earlier retirement age, in order to account for the effects of physical arduousness which do not directly impact life expectancy. Particularly, a relationship between physical arduousness and long-term musculoskeletal disorders have been demonstrated and may constitute relevant evidence of eligibility regarding early retirement scheme.

While life expectancy has been shown to be significantly higher for the cabin crews than the general population, cabin crews nonetheless exhibit higher risk of malignant melanoma (skin cancer), breast cancer for female cabin crews, and prostate cancer for male cabin crews. The causes of the increased incidence of melanoma for cabin crews compared to the general population has still to be explained (Rafnsson et al. (2003) as there is a lack of longitudinal studies. Shift work (especially nightshift) is involved in the two other forms of cancers (breast and prostate cancer).

4.3. Managing older cabin crews

The functional ability of each individual naturally decreases with age. Although the ageing process is specific to each individual, the working conditions may exacerbate the effects of ageing. Hence, repetitive movements may accentuate joint disorders and shift work may increase sleep disorders, which both naturally occur in older age. Without appropriate countermeasures and faced with high time pressure, older cabin crews may be penalised twice over:

- Time constraints may require the older cabin crew to resort to functional abilities which have declined with age
- Time constraints provide less leeway to draw on his/her own operational experience and self-knowledge to adapt their gesture and behaviour to the situation (better anticipation, change of posture etc.).

Older cabin crews are also more affected by irregular hours of work, as they have more difficulties to readapt their circadian rhythms when exposed to shiftwork and/or jet lag. This results in an acute desynchronization because of the misalignment between the body clock and the sleep-wake pattern. Most importantly, chronic desynchronization may contribute to weight gain/obesity, metabolic syndrome/type II diabetes, and cardiovascular disease.

With age, sleep also changes in terms of both quantity and quality. Regarding sleep quantity, the greatest difficulties relate to maintaining sleep, meaning that with age, people have difficulties staying asleep, so that wakeup time occurs earlier. This contributes to an increase in daytime sleepiness. As a result of all hormonal, physiological, and environmental changes, elderly people also sleep less efficiently (time in bed does not correspond to actual sleep time). For example, at 55 and above, 8 hours in bed result on average in 7 hours of actual sleep, the difference corresponding to time to fall asleep and multiple short awakening episodes during the sleep. For a young adult, correspondence between time in bed and sleep time almost perfectly mach. The different sleep stages also change their distribution with age. Deep sleep (restorative sleep from physical fatigue) decreases with age, while the quantity of light sleep increases (8-15% more, on average).

Besides reduced sleep efficiency, other sleep-related consequences of aging include an increased day time sleepiness and need for napping during the day, an advancement in sleep wake cycle (i.e. tendency to wake up earlier in the morning, and to go to bed earlier). All these effects of age are amplified in workers exposed to shiftwork, with further health's consequences associated with nightshift. Importantly, besides the effects of aging on sleep, difficulties in obtaining adequate sleep quantity and quality may also originate from other chronic medical conditions (e.g. gastrointestinal problems, arthritis, etc.) which further contribute to sleep difficulties.

Beyond the provision of early retirement for cabin crews, improving daily work conditions and preventing occupational disorders should be a priority focus. This is especially important as sensitivity to arduous work increases with age. These mitigation measures may include: medical follow-up, changes in work procedures, adaptation of hours of work, training, ergonomic equipment etc.

However, in some specific jobs such as cabin crews, despite efficient mitigation measures, the arduous nature of working conditions cannot be fully prevented as it is "part of the job". Two options may therefore be discussed: either the management of late career for older cabin crews (reappointment to other non-flying activities within the airline) or allowing early retirement to compensate for the risks taken during their career.

Another important consideration in the management of aging within the aviation industry is the benefits of extensive operational experience from older cabin crews. This should be borne in mind as these older workers represent a good asset in terms of both safety risks and management of unexpected situations.

4.4. Special pension schemes

There is no consensus on a common definition of arduous work. Generally, arduous work incorporates both an objective component and a subjective component associated with the workers' perception of their own job. In the context of justifying special retirement scheme for cabin crews, it is important to focus on objective indicators. The following indicators may be used to measure the effects of arduous work on health: indicators of premature aging, indicators of morbidity (symptoms, diseases occurrence, disabilities etc.), or life expectancy. It is important to note that indicators of occupational accidents and recognised professional diseases may only partially represent the issue, as they do not cover the multitude aspects of work-related disorders and may actually under-estimate the prevalence of such disorders (underreporting of occupational disorders).

Whatever the type of indicators used to evaluate arduousness of the job, it is unfortunately impossible to scientifically establish levels and/or duration exposure which may be associated with a significant increase in the level of risks of developing a chronic health condition. Either studies were unable to establish a recognised threshold, or the complexity of work conditions and relationship between health and work requires to take into account too many parameters. In this context, it would seem preferable to define these thresholds through social negotiations. More specifically, arduousness may be evaluated considering the exposure durations to several risk factors which have been demonstrated to produce negative effects on the cabin crews' health (i.e. physical factors, shift work). A combination of these estimated exposures may therefore serve as a basis to grant early retirement.

Early retirement age is not the only mechanism which may be proposed to compensate for exposure to arduous work. Other social policies such as disability benefits, long-term sickness leave, pensions for inability to work may also be used to address the issue of arduous work. The main difference with the early retirement scheme is that they are offered on individualised bases, hence targeting specifically those in need of a special treatment. Thus, only workers with disabilities or reduced work capacity may benefit from these special schemes, especially if they have difficulties in finding a suitable job in later stages of their working lives [102]. These alternative schemes may therefore allow older workers with serious health conditions to stop work before the normal retirement age and benefit from disability pensions on an individual basis. Alternatively, job mobility may be offered to older workers in order to avoid early retirement.

Another interesting perspective on early retirement schemes is how the issue is tackled differently in other European countries or worldwide. In some countries, defining a maximum age may be considered as discriminatory and workers may continue working as long as they are considered fit for duty, without regard for age.

Beside the impact on individuals, the provision of such special retirement schemes also has organisational consequences which should not be neglected from the airline point of view. Hence, early retirement age means early retirement of cabin crews having a great deal of know-how and operational experience.

5. Conclusion

The rationale behind early retirement is to award special pension benefits as an exchange for work-related risks which may negatively impact on life expectancy or reduce the length of one's working life. There are currently no scientific grounds to determine objectively a precise retirement date for a specific job. The main issue is the complexity of measuring objectively exposure to occupational risks and provide an accurate picture of the arduous occupation. Hence, there is no predefined procedure to address the issue of arduous work and its consequences at old age within the context of early retirement pension provisions.

Nonetheless, this report highlights the extent to which the cabin crew occupation involves work which poses significant challenges to the personnel. As the consequences of arduous work increase with age, it may actually shorten the working career. Particularly, physical demands are significantly high in the job and older cabin crews may face serious challenges in continuing duties as they get older. Hence, arduous work also raises the issue of managing later stages of work life and the need to implement transitional measures for these older workers. The improvement of working conditions should be debated within the professional branch in order to avoid exclusion of these workers. Furthermore, the cabin crews also run a higher risk of disability as they experience bodily wear and tear due to physical workload. They are also particularly exposed to hormone dependent cancers due to shift work. Hence, there is evidence that cabin crews' life quality at old age may be impacted by work-related factors. Although not directly shortening life expectancy, they result in poorer health during later stages of working life and beyond. In this context, eligibility of the cabin crew occupation to access compensations in the form of early retirement may be debated.

Beside the debate on early retirement age, it is essential to enforce preventive measures, especially when long-term effects on health have been shown, in order to ensure that the cabin crews reach retirement in overall good health. Targeted conventional social policies should be implemented, for example in terms of medical follow-up, adaptation of hours of work, or ergonomic equipment. As one of the main risk factors, shift work is a major issue with regard to consequences on cabin crews' health and the prevalence of hormone dependent cancers. Prevention measures need to be implemented as part of the airline's Fatigue Risk Management System (FRMS): typically, adjustments of work schedule may be considered for older cabin crews who have difficulties to adapt to disruptive duties. In this context, the airline's FRMS should address both the short-term consequences of shift work (acute fatigue, performance decrement and potential safety issues) as well as the long-term effects on health (chronic fatigue and hormone-dependent cancers).

Yet, such measures may not be sufficient to prevent long-term consequences on health. As arduous work is also known to cause premature aging, compensatory measures in the form of special retirement scheme may therefore be considered for the cabin crews. The objective of such special pension schemes is to adjust the retirement eligibility age to compensate for a shorter life expectancy without disability, in relation to musculoskeletal disorders and prevalence of hormone-dependent cancers.

It is most important that any decision about early retirement age be based on scientific evidence. However, considering the great complexity of the issue, scientific data may only provide food for thought and feed into the reflexion on retirement age by identifying the key elements in terms of risk factors and their consequences on workers' employability and life expectancy without disability. Defining an early retirement age for the cabin crews therefore remains a political decision which should result from social negotiations between the trade unions and the relevant national authority.

6. Appendix 1: Long-term effects of work environment characteristics on cabin crews' health: a scientific review.

6.1. Vibration

Health problems due to vibration (especially during landing) among cabin attendants relates to neck, shoulder, and lower-back injuries and pains. Results from studies on Whole-Body Vibration (WBV) and comfort of aircraft seats (static and dynamic) have also been reviewed.

A first study [2], is a field study based on reports from the European Union. It was observed how some aircraft were frequently associated to vibration-related injuries of neck, shoulders, and lower-back, especially those with a longer tail behind rear wheels (e.g. B737-800). In fact, vibration-related injuries were dealing more with rear cabin positions than to seats in the front part, and to landing rather than to take-off and cruise. Furthermore, exposure to multiple shocks, as for instance during banked turns, generates health issues for flight attendants.

The study implemented objective measurements of vibration by means of a triaxial seat accelerometer under the cabin crew seat's cushion for periods of 20 minutes during three landing sequences. A specific model of aircraft (B737-800) was chosen, as it was the most cited within vibration reports. Table 1 shows mean frequency acceleration, calculated vibration dose values (VDV), crest factor (a measure of how extreme are the vibration peaks within the frequency waveform), and acceleration dose values (ADV). An equivalent daily static compressive stress value on lumbar vertebrae is also provided (S).

Results confirm the specificity of rear cabin seats for vibration issues (more than 50% as compared to front seat) especially in the up-and-down (*z*) dimension, although horizontal vibrations (*x* and *y* dimensions) are not negligible.

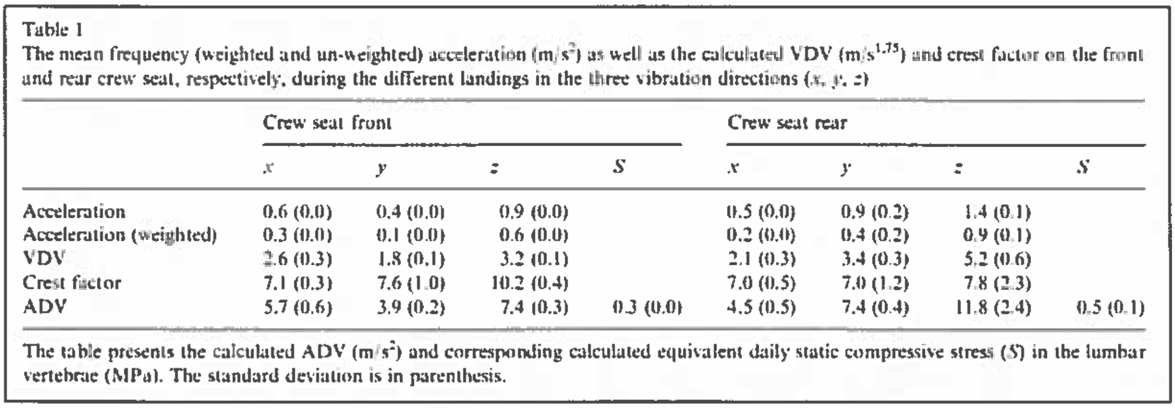


Table 1

The mean frequency (weighted and un-weighted) acceleration (m/s^2) as well as the calculated VDV (m/s$^{1.75}$) and crest factor on the front and rear crew seat, respectively, during the different landings in the three vibration directions (x, y, z)

	Crew seat front				Crew seat rear			
	x	y	z	S	x	y	z	S
Acceleration	0.6 (0.0)	0.4 (0.0)	0.9 (0.0)		0.5 (0.0)	0.9 (0.2)	1.4 (0.1)	
Acceleration (weighted)	0.3 (0.0)	0.1 (0.0)	0.6 (0.0)		0.2 (0.0)	0.4 (0.2)	0.9 (0.1)	
VDV	2.6 (0.3)	1.8 (0.1)	3.2 (0.1)		2.1 (0.3)	3.4 (0.3)	5.2 (0.6)	
Crest factor	7.1 (0.3)	7.6 (1.0)	10.2 (0.4)		7.0 (0.5)	7.0 (1.2)	7.8 (2.3)	
ADV	5.7 (0.6)	3.9 (0.2)	7.4 (0.3)	0.3 (0.0)	4.5 (0.5)	7.4 (0.4)	11.8 (2.4)	0.5 (0.1)

The table presents the calculated ADV (m/s^2) and corresponding calculated equivalent daily static compressive stress (S) in the lumbar vertebrae (MPa). The standard deviation is in parenthesis.

***Table 1-** vibration values as measured during landing phases of a B737-800. Data refer to [2].*

Although results show high values of vibration doses during landing, especially in rear seats, the study concludes that daily exposition to whole-body vibrations for cabin crews is within the limit established by European Directive [69], which reports a VDV limit value of 21m/s^{1,75} for a period of 8h. The directive also envisages the possibility (appropriately justified) of exemptions for cabin attendants of the aviation sector. However, by comparison, a VDV value of 5.2m/s^{1,75} found in the rear seat during aircraft landing (*z* dimension) is higher than that measured under driver's seat of a combine travelling at 20km/h (4.27m/s^{1,75}) [3], for which less than 2 hours of exposition is sufficient to harm body.

The recorded vibration values recorded in [2] show how seat position must not be overlooked when considering impact of vibrations. Other studies have performed the same measurements on passenger's seats installed on a shaker table [1]: obtained values were lower to those plot in Table 1, probably because an "average" vibration signal was used to excite the table, without considering seat's position and aircraft type either. Obtained VDV value was 3.85m/s^{1,75} for an economy class seat.

Finally, as acknowledged in the study, vibration measurements were done during "normal landings". In bad weather conditions vibration doses are likely to increase significantly, due to the more unstable position of aircraft during landing. Therefore, a risk for health due to vibration cannot be excluded for cabin attendants, especially in relation to exposition to multiple shocks (see also the crest factors in Table 1).

To improve the design of the seat is the best mitigation measure together with appropriate training about the best position to be kept during landing. Experiences from road vehicles [3] suggest that seats with air suspension attenuate vibrations (at least those above 4Hz) better than those with mechanical suspension, and increase driver's comfort. Applicability of such design alternatives for cabin seats in commercial aviation should be reviewed in the future.

Knowledge about long term health effects of prolonged exposure to vibrations is insufficient to establish a direct link between vibrations and chronic health conditions, as well as to draw some conclusions about the effects of chronic exposure to vibration as a function of age. All the reviewed studies on cabin crews' environment only limited themselves to report measured vibrations to be within regulatory limits.

6.2. Radiation

Being frequently on air, the quantity of cosmic radiation that hits flight crew members is significantly higher than normal people spending almost their whole life on earth's surface. While the DNA damaging effects of ionizing radiations are scientifically proven and find some applications in medicine (e.g. in radiotherapy), the effect of cosmic radiation on health is still sometimes a matter of debate. Prescriptive limits of exposure are established within the aviation domain, and constant, periodic monitoring is required.

Galactic cosmic radiation comes from outside the solar system and its action is mitigated by the presence of atmosphere, and of earth's and sun's magnetic fields. Dose rates arriving on earth's surface depend on magnetic latitude, altitude, and solar cycle. Like other radiations, cosmic radiation is measured in Sievert or its multiples (the most common in use being the milliSievert, mSv).

International reference standard for maximum exposure to ionizing radiation published in 1991 by the International Commission on Radiological Protection (ICRP) was revised in 2007 [70, 71]. A European directive [72] completes the regulatory frame for the European context. In both reports, the indicated maximum mean exposure limit for human body is 20mSv/yr (averaged over 5 years, with a maximum in any 1 year of 50mSv) [4], as reported in Table 2.

The effects of cosmic radiation are obviously more important for aerospace flights and astronauts than for commercial aviation crews. However, its impact on commercial aviation crews should not be overlooked [7]. For example, it has been observed a significantly higher distribution (double rates) of skin melanoma among airline pilots compared to the general population (cf. section about life expectancy): immune-suppression effects of cosmic radiation are considered as a contributory cause, but further studies on causes are needed [73]. DNA damages (necrosis, apoptosis, or mutations) are the most important consequences of expositions to great doses of ionizing radiation [7]. However, recent results exclude cosmic radiation as possible cause skin melanoma among cabin crew population. As explained later in the text, ultraviolet radiation is more implied than cosmic radiation in melanoma occurrence.

Importantly, the European directive establishes that for professionals likely to be exposed to more than 1 mSv/yr, the employer must provide measurement of actual exposure, consider this exposure during scheduling, appropriately inform workers about exposure's risk, and ensure special protection for female aircrew during pregnancy (for whom the exposure limit is established at 5mSv/yr [8]) in order to enable informed decision making about acceptable risk [4] [7] [8].

	ICRP	EU	FAA
General public	1 mSv yr^{-1}	1 mSv yr^{-1}	1 mSv yr^{-1}
Occupationally exposed	20 mSv yr^{-1}, 5 yr average, but not more than 50 mSv in 1 yr	20 mSv yr^{-1}, 5 yr average, but not more than 50 mSv in 1 yr	20 mSv yr^{-1}, 5 yr average, but not more than 50 mSv in 1 yr
Foetus equivalent dose	1 mSv yr^{-1}	1 mSv for declared term of pregnancy and ALARA	1 mSv maximum, but 0.5 mSv in any month
Control level	N/a	6 mSv	N/a

Table 2 *- Maximum mean effective dose limits, as established in ICRP, EU, and FAA regulations. Table extracted from [4].*

In-flight radiation measurements have allowed validation of computer modelling programs [4]. Simulation algorithms for radiation prediction of specific flights have been developed in recent years [6]. One simulation software freely available from Federal Aviation Administration (FAA) is CARI-6 [cf. webography section]. CARI-6 has been used to calculate radiation exposure for some international routes [74]. For example, in a flight from Lisbon to New York with a duration of almost 7h, the total radiation rate would be 0.0289mSv [8].

As reported through several studies, calculated annual radiation rates for European crews operating at maximum Flight Time Limitations (FTL), are of 2-4mSv for long-haul pilots and crews and 1–2mSv for short-haul. These rates correspond to 1/5 and 1/10 of ICRP recommended dose limit, respectively [4]. Figure 1 shows how many flight hours would be needed for an aircrew member to reach a 6mSv exposition rate in one year, as a function of 2 latitudes and 3 altitudes [75].

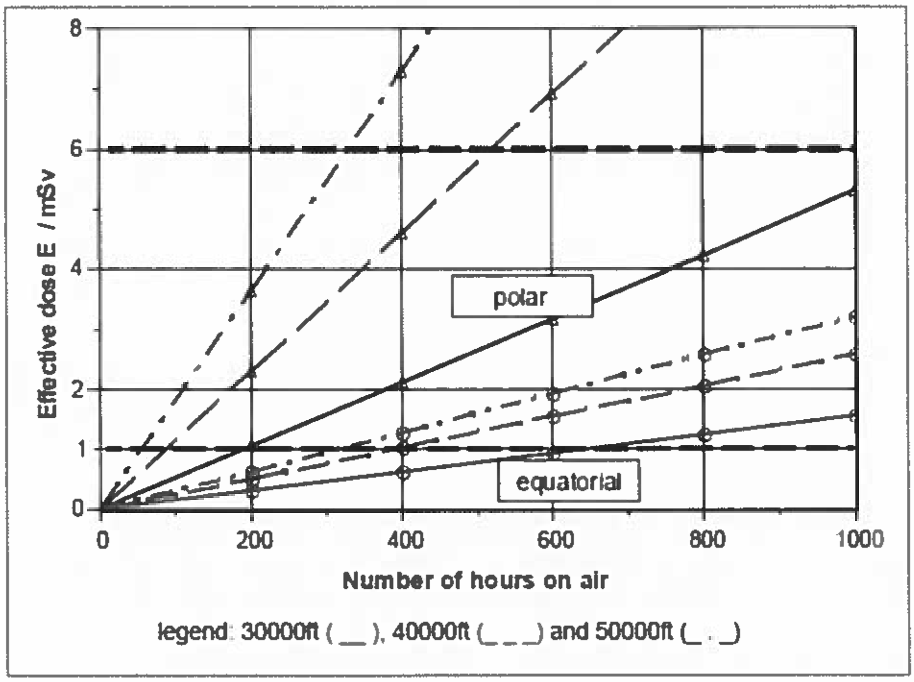


Figure 1 *- Minimum number of flight hours needed to obtain annual dose of 6 mSv in polar and equatorial regions for three flight altitudes. Figure extracted from [75].*

Based on calculated (and actual) values of radiation exposure, it has been estimated that the risk of developing a radiation-exposure-induced cancer for an aircrew member who has accumulated a 5 mSv annual exposure over 20 years of service is very low, i.e. 0.4% (0.6% over 30 years) [4]. As for comparison, the general risk of dying of a cancer in the western population is 23%. Over the same working service span, the risk for a child of inheriting a cancer from an exposed parent (5mSv/yr), is 1/2500 (1/50 is the incidence of genetic abnormalities in the general population). Risks for the fetus during pregnancy deriving from exposition to radiation are also estimated as insignificant. In order to reach the established limit for a pregnant woman of 1mSv, seven New York-Tokyo round trips in one year would be needed [9].

Thus, epidemiological studies on effects of exposure to cosmic radiation do not show any strong relation between cancer occurrence and exposure rates, confirming weak probabilities of effects on health due to radiation exposure for cabin crew (and passenger) [9]. This was also confirmed by an international study in the framework of a European Project (ESCAPE) that involved 8 EU members and that focused on mortality causes, both cancer- and non-cancer-related [10]. The study managed data from a total of more than 44000 cabin crew members, providing large-scale data for computation of mortality rates, as required by previous investigations [11]. More precisely, it was observed how mortality rates among cabin crews were not significantly different from those of the general population. No significant differences for lung cancer, leukemia, and breast cancer, with the latter being slightly higher in women cabin crews but the difference did not reach statistical significance. Mortality due to cerebrovascular, cardiovascular and respiratory diseases was significantly lower among cabin crew members. Analyses on cardiovascular mortality also considered "time since first exposure", meaning time since first employment, confirming a lower cardiovascular mortality for both female and male cabin crew as compared to the general population (60-70% and 30-40%, respectively). Conversely, significant higher mortality rates for male cabin crew as compared to the general population were found for melanoma and non-melanoma skin cancer (while lower in female cabin crew). Table 3 shows the standardized mortality ratios (SMR), i.e. the ratio between observed and expected cases, for male and female cabin crews in the before- and after-jet eras [10]. The most remarkable conclusion of such a wide-scale study was that evidences showed no different rates of cancer-related mortality (and of leukemia, which would be the most evident consequence of excessive cosmic radiation exposure rate), while higher rates were found for some non-cancer-related disease, as AIDS (in male cabin crew), or aircraft accident. The impact of ionizing cosmic radiation on cabin crew mortality was thus estimated as not significant.

Cause of death	Employment period	Observed no. of deaths (O)	Corrected no. of deaths* (O_c)	Expected no. of deaths (E)	SMR† (O_c/E)	95% CI†
			Female cabin crew			
All causes	Before 1971	161	161	187.7	0.86	0.73, 1.00
	Across 1971	120	120	158.7	0.76	0.63, 0.90
	After 1970	160	160	206.9	0.77	0.66, 0.90
All cancer	Before 1971	72	77.6	91.4	0.85	0.67, 1.16
	Across 1971	55	61.6	75.2	0.82	0.60, 1.11
	After 1970	44	51	76.6	0.67	0.46, 0.90
Breast cancer	Before 1971	24	26.4	20.6	1.28	0.81, 2.02
	Across 1971	18	20.4	20.3	1.00	0.57, 1.63
	After 1970	17	19.9	19.1	1.05	0.57, 1.69
All leukemia	Before 1971	5	5.4	2.7	2.04	0.68, 5.34
	Across 1971	3	3.3	2.8	1.16	0.24, 3.79
	After 1970	1	1	4.4	0.23	0.01, 1.43
All cardiovascular disease	Before 1971	7	7.3	25.7	0.29	0.11, 0.64
	Across 1971	2	2.3	14.9	0.16	0.02, 0.62
	After 1970	4	4.7	13.4	0.35	0.09, 0.95
			Male cabin crew			
All causes	Before 1971	132	132	108.2	1.22	1.02, 1.45
	Across 1971	209	209	259.3	0.81	0.7, 0.92
	After 1970	230	230	159.5	1.44	1.26, 1.64
All cancer	Before 1971	38	40.9	31.9	1.28	0.81, 1.88
	Across 1971	51	56.4	80.9	0.70	0.51, 0.95
	After 1970	30	33.2	32.8	1.01	0.67, 1.5
All lymphoma	Before 1971	4	4.1	1.2	3.47	0.95, 9.66
	Across 1971	4	4.4	3.1	1.43	0.38, 3.86
	After 1970	3	3.5	2.2	1.56	0.31, 4.91
All leukemia	Before 1971	1	1	1.0	0.98	0.02, 5.84
	Across 1971	2	2.2	2.7	0.80	0.09, 3.12
	After 1970	4	4.5	2.1	2.13	0.57, 5.78
All cardiovascular disease	Before 1971	24	25.9	33.0	0.79	0.51, 1.24
	Across 1971	33	36.2	63.1	0.57	0.39, 0.85
	After 1970	9	9.9	20.6	0.48	0.22, 0.96
AIDS†	Before 1971	3	3.3	0.2	19.79	4.1, 62.1
	Across 1971	27	31.7	0.8	38.04	23.2, 54.3
	After 1970	88	101.7	6.0	16.97	12.8, 20.9

* Calculated according to the method of Rittgen and Becker (18).

† SMR, standardized mortality ratio; CI, confidence interval; AIDS, acquired immunodeficiency syndrome.

Table 3 - Standardized mortality ratios (SMR) for female and male cabin crew, as a function of period of employment. Table reproduced from [10].

A study of radiation exposure for air force members in Canada [5] performed both radiation exposure calculation of past flights (by means of validated algorithms) as well as inflight measurements, confirming the low exposition rates reported above. The selected period for calculation (30 months) was divided in 2 one-year period and 1 six-months period, with 171, 179, and 128 monitored aircrews, respectively: maximum recorded values were 3.4, 3.4, and 4.2mSv/yr), and only about 10% of monitored flights had associated radiation values of more than 3mSv/yr. Normalized (1 year) mean exposition values for the three periods were 1.2, 1.2, and 1.8mSv.

In summary, objective in-flight measurements and simulation studies (by means of the use of predictive algorithms) have demonstrated how cabin crew expositions to cosmic radiation is well below the established limit in the current regulations, and that such exposure rates are insufficient for generating radiation-related cancers or to increase mortality rates within flight attendants. However, special attention must be always accorded to female cabin crews during pregnancy.

6.3. Noise

Noise level is one important parameter with negative impact on subjective feeling, objective performance, and health, especially for long-haul flights.

A European project (HEACE) measured the effects of sound and noise (among many other parameters) on performance and the medical response of cabin crews in both real and simulated flights [12]. The project focused particularly on long-haul flights, and showed the difference existing between different zones of aircraft in relation to noise measurements. More precisely, it highlights how noise increases going aft within the cabin (a mean difference of 8dB approximately exists between business class and economy class, with mean values of 71dB and 79dB, respectively), and how cabin is more affected by noise than cockpit. Interestingly, the noise values measured in real flights were used to set-up different simulation conditions and to evaluate noise impact on subjective evaluations of several symptoms. The study demonstrates how noise increases subjective sensitivity to environmental context, as the perception of some symptoms (e.g. swollen feet and pain in the back) evaluated by means of questionnaires was significantly higher in noisy conditions. Noise level was found to have significant impact also on the level of distraction, level of annoyance, overall satisfaction, perception of vibration and movement, and further symptoms such as tiredness and headache. The effects increased with flight time.

Some important results have been related in the last years to a new hypothesis about non-acoustic long-term effects of noise. Significant associations have been found between long term exposure to traffic noise and incidence of breast cancer in female population [82]. However, this hypothesis needs further evidences in order to be confirmed.

6.4. Cabin Altitude

Effects of altitude are associated with cabin pressurization. Although there are some prescriptive limits to cabin pressurization, expressed in terms of altitude (e.g. 1524–2438m), individual differences exist in relation to the tolerance to these limits [63]. The effects of pressurization on health (especially on cardio-circulatory system) have been reviewed.

Compensation mechanisms are triggered by our body under the effects of altitude. Those mechanisms have the function of reducing effects of hypoxia (diminished concentration of oxygen in the air, due to lower air pressure) and to produce hypocapnia (reduction of carbon dioxide in the blood) [13]. While at sea level (0m altitude) the oxygen concentration in the air is about 20.9%, at 2400m (i.e. 8000ft), concentration lowers at 15%.

The efficiency of compensatory mechanisms depends on several factors, like the normal altitude at which a person lives, the climb rate, the final altitude of an ascent, and the general health state of the subject.

As observed in experiments with hypobaric chambers, hypoxia effects can be already present at altitudes of 2400m (the maximum altitude limit reproduced in pressurized aircraft cabins, often referred to as "cabin altitude"), with symptoms related to visual impairment, namely a reduced visual acuity (contrast detection) and a reduced color sensitivity [15]. These effects are explained on the basis of different sensitivity to blood oxygen concentration level of cones and rods (the two types of light-sensitive cells within the retina). The partial oxygen pressure in the blood changes from 95mmHg to 60mmHg at the cabin altitude's limit of 2400m, meaning a considerable reduction in oxyhemoglobin saturation, from 95-100% at sea level to 90% at cabin altitude [14], as shown in Figure 2.

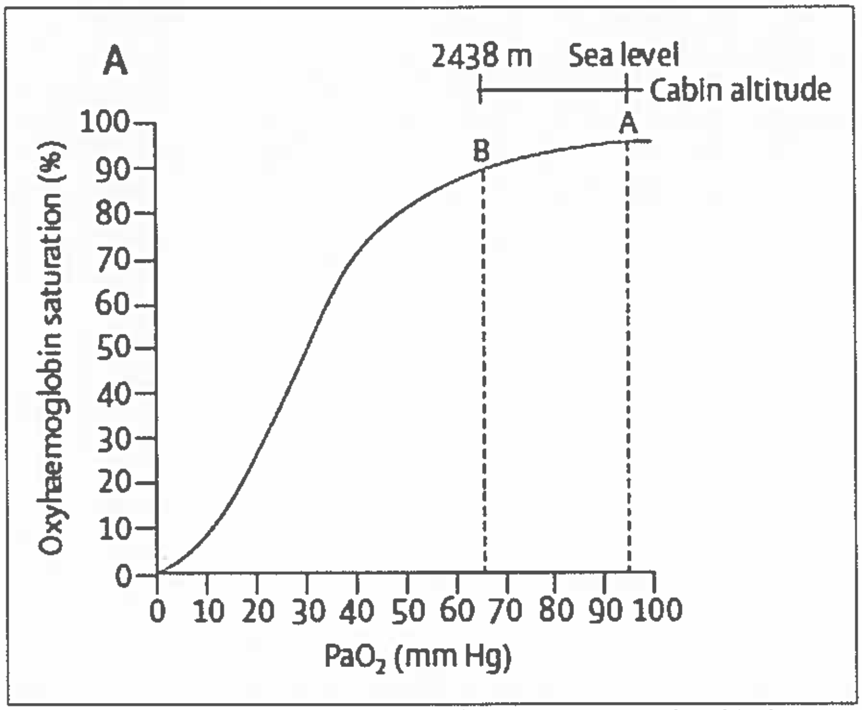


Figure 2 - Effect of cabin altitude on oxyhemoglobin saturation. At cabin altitude, oxygen pression is approximately 65mmHg (while being 90mmHg at sea level) determining an oxyhemoglobin saturation level of 90% (95-100% at sea level).

More important effects of hypoxia are cognitive-related and occur at higher altitudes, with total cognitive impairment, loss of consciousness (and, eventually, death) beyond altitudes of 6000m (about 20000ft). Therefore, effects of hypoxia and altitude for cabin crews should be minimal in pressurized cabins. However, it has been demonstrated how commercial aircrafts often cross the threshold of 2400m, leaving room for possible visual impairments in cabin crews and passenger. A study conducted in United States in 2013 measured the peak cabin altitude on a series of domestic flights and on several aircraft types. Results showed that 10% of measured flights ($N = 200$) exceeded the 2400m (8000ft) limit during cruise. Importantly, the study also demonstrated how peak cabin altitude has grown throughout time, as the values obtained in a previous study in 1988 (by means of the same measuring method) were significantly lower.

In any case, the physiological reaction for a change in altitude from 8000ft to 8500ft would be very little, with a minimal change in the oxygen partial pressure.

Another effect of altitude and pressure variation on the body is body gas expansion. The law of Boyle establishes that the volume occupied by a gas is inversely proportional to the surrounding pressure. The expansion during a flight is estimated at 30%. For a healthy subject, this expansion would mean minor abdominal cramping and adaptation mechanism in the middle-ear. Differently, if some medical conditions exist (e.g. recent surgical interventions, bowel obstructions, diverticulitis). Some recent activities may also provoke difficulties in adaptation to gas expansion (e.g. recent scuba dive), barotrauma could be more important.

As a conclusion, it must be acknowledged that the effects of altitude and pressurization (cabin altitude) are still to be investigated in depth, although is well known that under 2400m (8000ft) compensation mechanisms (e.g. hyperventilation) are not necessary, and that small excesses beyond this limit generate minimal physiological stress.

It must be remembered that, although long-lasting effects of cabin altitude on health were not found within reviewed literature, cabin altitude might become a health issue with aging. Although knowledge about cabin altitude effects is insufficient to establish an age limit for cabin crew, it is well known that elder people show diminished tolerance to change, including altitude's changes.

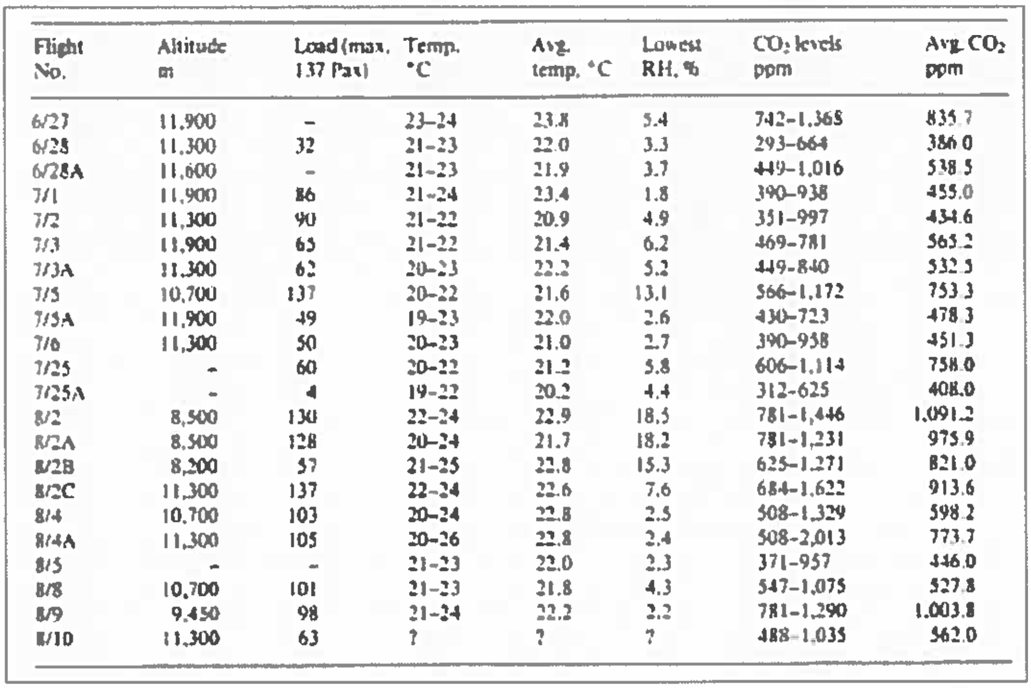
6.5. Temperature and Thermal comfort

As many surveys have pointed out, temperature is often reported by passengers and cabin crew as element of discomfort. In order to consider temperature's effects on health, other parameters might be related to temperature, the most important being relative humidity (RH). For instance, low humidity rates might be easily tolerated, unless temperature becomes too extreme. Considerations on temperature have been made in conjunction with hygrometry effects.

Cabin humidity is normally regulated at very low level in aircraft, with the aim of preventing corrosion of metallic components, and of avoiding microorganism proliferation [35]. This low relative humidity is often at the base of "dryness-induced" discomfort (and stress) among passengers and flight attendants [19].

In 2013 the updated version of "Thermal Environmental Conditions for Human Occupancy" was published (superseding older version of 2004 and 1992) by "The American Society of Heating, Refrigerating and Air-Conditioning Engineers" (ASHRAE, 2013). Other international standards are ISO 7730-2005 [80] and Chinese national standard [81].

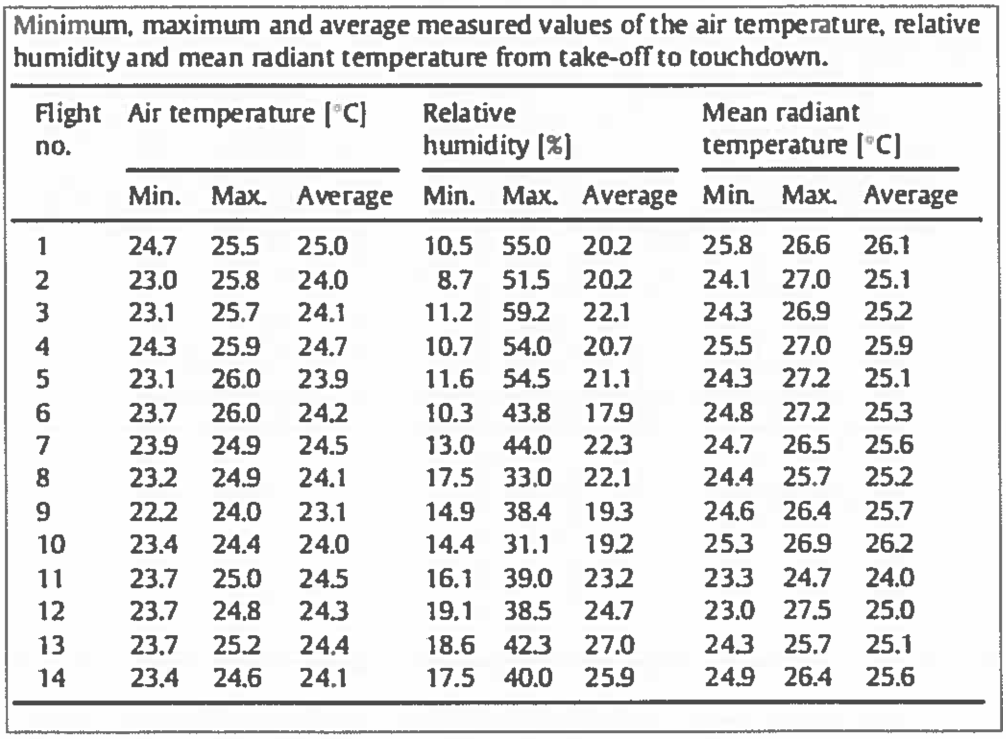
As reported in [19], many studies had compared temperature and relative humidity levels recorded during several flights (real or simulated) to optimal levels included in the standards, finding that recorded values were considerably below recommended values (20.2-24.7°C in winter, 24.0-27.4°C in summer, with RH of 50%. For example, temperature, RH, and comfort were measured on different types of aircraft [59]. Results related to Airbus A320 are reported in Table 4.



Flight No.	Altitude m	Load (max. 137 Pax)	Temp. °C	Avg. temp. °C	Lowest RH, %	CO_2 levels ppm	Avg. CO_2 ppm
6/27	11,900	–	23–24	23.8	5.4	742–1,365	835.7
6/28	11,300	32	21–23	22.0	3.3	293–664	386.0
6/28A	11,600	–	21–23	21.9	3.7	449–1,016	538.5
7/1	11,900	86	21–24	23.4	1.8	390–938	455.0
7/2	11,300	90	21–22	20.9	4.9	351–997	434.6
7/3	11,900	65	21–22	21.4	6.2	469–781	565.2
7/3A	11,300	62	20–23	22.2	5.2	449–840	532.5
7/5	10,700	137	20–22	21.6	13.1	566–1,172	753.3
7/5A	11,900	49	19–23	22.0	2.6	430–723	478.3
7/6	11,300	50	20–23	21.0	2.7	390–958	451.3
7/25	–	60	20–22	21.2	5.8	606–1,114	758.0
7/25A	–	4	19–22	20.2	4.4	312–625	408.0
8/2	8,500	130	22–24	22.9	18.5	781–1,446	1,091.2
8/2A	8,500	128	20–24	21.7	18.2	781–1,231	975.9
8/2B	8,200	57	21–25	22.8	15.3	625–1,271	821.0
8/2C	11,300	137	22–24	22.6	7.6	684–1,622	913.6
8/4	10,700	103	20–24	22.8	2.5	508–1,329	598.2
8/4A	11,300	105	20–26	22.8	2.4	508–2,013	773.7
8/5	–	–	21–23	22.0	2.3	371–957	446.0
8/8	10,700	101	21–23	21.8	4.3	547–1,075	527.8
8/9	9,450	98	21–24	22.2	2.2	781–1,290	1,003.8
8/10	11,300	63	?	?	?	488–1,035	562.0

Table 4 - Measurement of temperature, lowest RH, and CO2 on 22 A320 flights. Data from [59].

As it can be observed, temperature was rarely comprised within the recommended range (especially the summer one), while RH was always well below recommended values. This was confirmed by measurements performed on 14 commercial flights connecting Italian cities [19], as reported in Table 5.



Minimum, maximum and average measured values of the air temperature, relative humidity and mean radiant temperature from take-off to touchdown.

Flight no.	Air temperature [°C]			Relative humidity [%]			Mean radiant temperature [°C]		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
1	24.7	25.5	25.0	10.5	55.0	20.2	25.8	26.6	26.1
2	23.0	25.8	24.0	8.7	51.5	20.2	24.1	27.0	25.1
3	23.1	25.7	24.1	11.2	59.2	22.1	24.3	26.9	25.2
4	24.3	25.9	24.7	10.7	54.0	20.7	25.5	27.0	25.9
5	23.1	26.0	23.9	11.6	54.5	21.1	24.3	27.2	25.1
6	23.7	26.0	24.2	10.3	43.8	17.9	24.8	27.2	25.3
7	23.9	24.9	24.5	13.0	44.0	22.3	24.7	26.5	25.6
8	23.2	24.9	24.1	17.5	33.0	22.1	24.4	25.7	25.2
9	22.2	24.0	23.1	14.9	38.4	19.3	24.6	26.4	25.7
10	23.4	24.4	24.0	14.4	31.1	19.2	25.3	26.9	26.2
11	23.7	25.0	24.5	16.1	39.0	23.2	23.3	24.7	24.0
12	23.7	24.8	24.3	19.1	38.5	24.7	23.0	27.5	25.0
13	23.7	25.2	24.4	18.6	42.3	27.0	24.3	25.7	25.1
14	23.4	24.6	24.1	17.5	40.0	25.9	24.9	26.4	25.6

Table 5 - Recorded temperature and RH in 14 commercial flights. From [19].

As it can be observed, RH ranged from 8.7% to 59.2%, with average flight values ranging from 17.9% to 27.0%. Therefore, passenger experienced low values of RH during their flights. However, there was no significant impact on subjective evaluations of thermal comfort. In any case, it is well known that main effects of prolonged "dryness" exposure are related to possible irritation of eyes, nose, and throat, rather than to thermal comfort. Consequences of the dry eye syndrome can vary from subtle but constant irritations of the eye to significant inflammation and even scarring of the front surface of the eye. Furthermore, it must be remembered that the minimum RH values are always recorded during cruising, i.e. the flight phase in which airliners spend most of the flying time.

In fact, dynamic phases (i.e. climb and descent) are of particular interest, since these are the phases where human body is experiencing the highest RH variations. For short-haul flight, climb and descent time can reach half the duration of the whole flight. As demonstrated by simulations in a climate chamber [20] the changes of RH during climb and descent have an impact on human comfort, which is higher at the highest values of temperature and RH used in the study (28°C and 80%, respectively). Thermal sensation, thermal comfort, humidity comfort, humidity acceptability, and air quality acceptability were collected throughout the simulations by means of subjective rating scales. The study demonstrates how subjects were very sensitive to the change in RH, especially for the big changes (i.e. from 80% to 20%). However, the sensation of discomfort at low RH levels was not reported, probably because time exposure to low RH in the study were quite short (30 minutes) and insufficient to produce thermal discomfort and, more importantly, physiological effects on eyes, nose, and throat.

In summary, it is acknowledged how exposures to low RH levels are at the basis of thermal discomfort with possible health effects (dry eye syndrome) for cabin crews, due to the high experience of RH changes (climb and descent phases). Symptoms of dryness were reported in all exposure conditions (the range being 9.1%-43.9%) by participants in a study within simulated flight environments [36]. However, the control that cabin crews can have over RH in cabin environment remains limited for safety issues. Thermal and humidity comfort levels can be reached theoretically only by acting on temperature, which is the only parameter over which cabin crews have the possibility of setting desired values. Methodologies have been developed in the last years [21] [22], for predicting cabin temperature for thermal comfort. Basically, they are based on a correction of the Predicted Mean Vote (PMV), i.e. an objective parameter for assessing thermal comfort and on the climate of departure city. These methodologies are presented as a possible tool for helping cabin crews in avoiding overheating or undercooling situations (thermal discomfort), typical of some flights (especially short-haul continental flights).

Although many studies have shown how low RH is the major cause of thermal discomfort, long term effects on health of low humidity environment remain unknown, since scientific literature on this issue is in practice inexistent. However, since elder people show a generalized increase of sensitivity (and decrease in tolerance) to several environmental aspects (like noise, lighting, vibration, etc.), it is reasonable to think that low RH and consequent dryness symptoms could represent a health issue for older cabin crews.

6.6. Air Quality

Toxic particles might be present in the cabin in case unfiltered air is provided from engine through air supply system (the so-called "bleed" air). Impact of aerotoxic syndrome among flight attendants have been assessed through literature. Bleed air coming from the engines is normally supplied to the cabin after having been properly cooled and its humidity lowered. In case of engine oil leaks, some toxic particles would enter the air circuit and would be released in cabin environment, with considerable risk for respiratory systems of cabin occupants, as these synthetic lubricants become extremely toxic as temperature increases (i.e. when they are pyrolyzed) [40]. Aldehydes are toxic compounds whose concentration in the air sensibly increase with oil pyrolysis. Bleed air from engine could also be contaminated by hydraulic and deicing fluids. Consequently, the risk of aerotoxic syndrome has received increasing attention through the years.

Many studies have focused on the concentration of several substances in the air supplied to aircraft cabin, e.g. the tricresyl phosphate (TCP, an additive to lubricant oil) found in 25%-100% of aircraft air samples, tributyl phosphates (TBPs, a constituent of hydraulic fluids) found in 73% of sampled flights, and in low concentrations in 100% of urine samples, based on [58]. Diagnosed symptoms of aerotoxic syndrome are described with precision in [23], and they are put in relation with cabin crew reports (see Figure 3, data related to pilots). For example, the 13% of the sample died or experienced long-lasting consequences (i.e. unfit to fly anymore) after having repeatedly breathed toxic aircraft cabin.

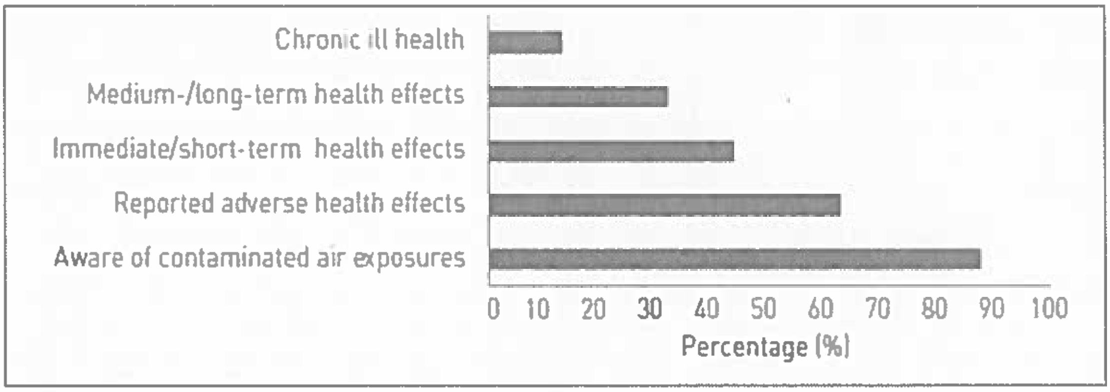
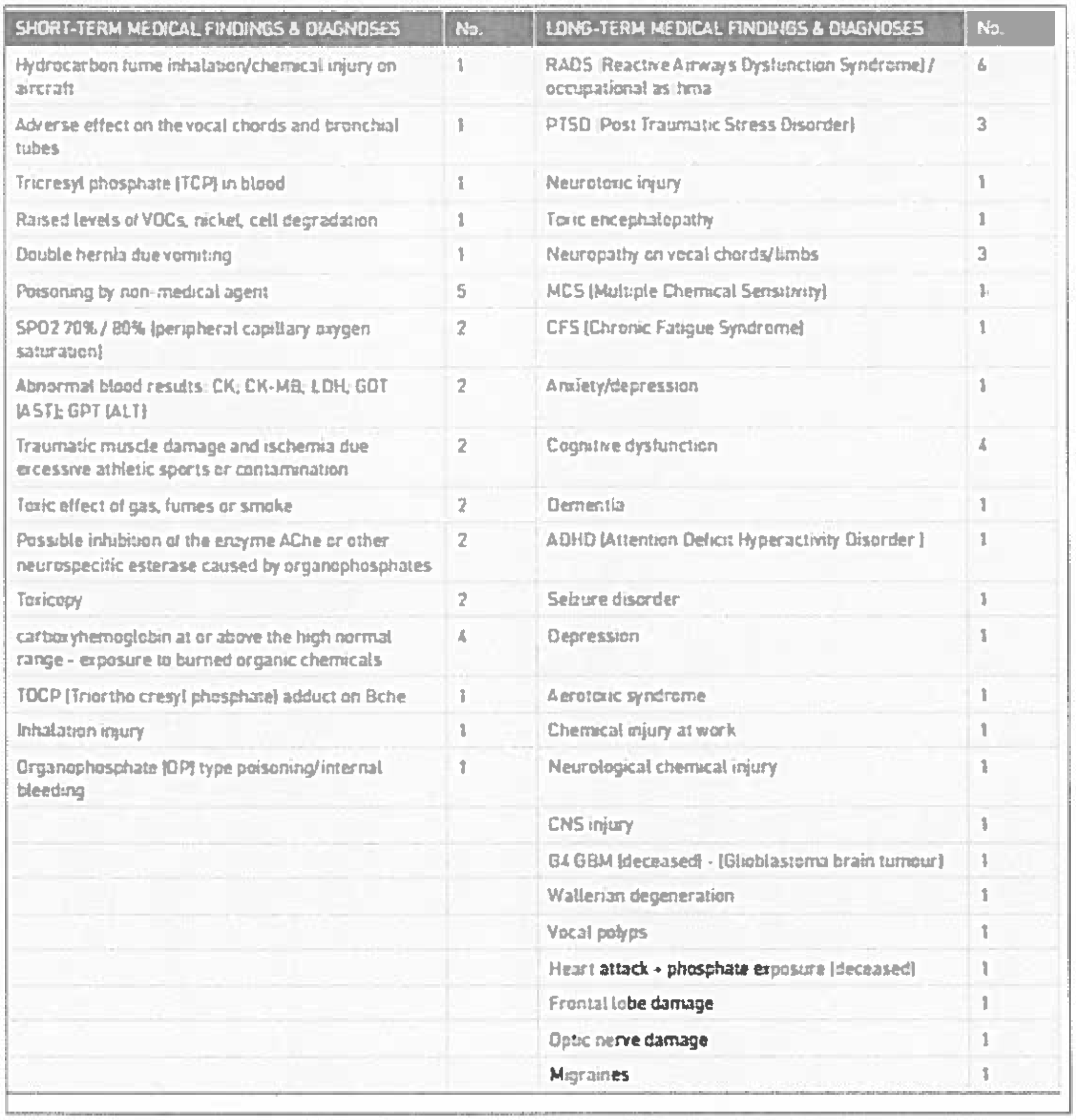


Figure 3 - Percentages of pilots that reported having experienced disturbances due to toxic substances in the cabin air, as a function of duration of consequences (N = 274). Data from [23].

A collection of typical symptoms of toxic particles respiration is provided in Figure 4, based on the analysis of 15 incidents selected in [23]. Effects can be cardiovascular (Chest pain/ tightness/variable heart rate/palpitations/BP), neurobehavioral, neurological (headache, trouble speaking, balance and vision problems, loss of consciousness) and respiratory (chest ache, lung irritation), including also chronic fatigue, multiple chemical sensitivity, cancer, and soft tissue damage. While some symptoms will disappear as soon as exposure is over, some others have been reported to last for days, even weeks [56], like headaches, neuropsychological symptoms (and cognitive ones, like recall impairment), or even respiratory symptoms [30].

A syndrome is a collection of symptoms, and since the listed symptoms are rarely present individually, there is sufficient evidence for talking about aerotoxic syndrome. Furthermore, increasing attention is being paid in the last years to the consequences of low, continuous exposure, since it might be responsible of the difference in vulnerability of cabin crews with respect to passengers. Although no medical organization have already acknowledged the existence of aerotoxic syndrome officially [25], it has been proposed that protocols for better managing the related health risks should be envisaged in the next future [23], since there has always been substantial agreement among respondents when reporting symptoms after exposure to contaminated cabin air [56]. Importantly, exposure does not only relate to flying phases, but also to ground operations, as for instance engines' warm up.



SHORT-TERM MEDICAL FINDINGS & DIAGNOSES	No.	LONG-TERM MEDICAL FINDINGS & DIAGNOSES	No.
Hydrocarbon fume inhalation/chemical injury on aircraft	1	RADS (Reactive Airways Dysfunction Syndrome) / occupational asthma	6
Adverse effect on the vocal chords and bronchial tubes	1	PTSD (Post Traumatic Stress Disorder)	3
Tricresyl phosphate (TCP) in blood	1	Neurotoxic injury	1
Raised levels of VOCs, nickel, cell degradation	1	Toxic encephalopathy	1
Double hernia due vomiting	1	Neuropathy on vocal chords/limbs	3
Poisoning by non-medical agent	5	MCS (Multiple Chemical Sensitivity)	1
SPO2 70% / 80% (peripheral capillary oxygen saturation)	2	CFS (Chronic Fatigue Syndrome)	1
Abnormal blood results: CK; CK-MB; LDH; GOT (AST); GPT (ALT)	2	Anxiety/depression	1
Traumatic muscle damage and ischemia due excessive athletic sports or contamination	2	Cognitive dysfunction	4
Toxic effect of gas, fumes or smoke	2	Dementia	1
Possible inhibition of the enzyme AChe or other neurospecific esterase caused by organophosphates	2	ADHD (Attention Deficit Hyperactivity Disorder)	1
Toxicopy	2	Seizure disorder	1
carboxyhemoglobin at or above the high normal range - exposure to burned organic chemicals	4	Depression	1
TOCP (Triortho cresyl phosphate) adduct on Bche	1	Aerotoxic syndrome	1
Inhalation injury	1	Chemical injury at work	1
Organophosphate (OP) type poisoning/internal bleeding	1	Neurological chemical injury	1
		CNS injury	1
		G4 GBM (deceased) - (Glioblastoma brain tumour)	1
		Wallerian degeneration	1
		Vocal polyps	1
		Heart attack + phosphate exposure (deceased)	1
		Frontal lobe damage	1
		Optic nerve damage	1
		Migraines	1

Figure 4 - Symptoms diagnosed by medical staff in the analysis of 15 selected accidents. Data from [23].

The bleed air system for cabin air supply exists since the 1950s. However, it is only in recent years that it has been recognized a general health problem with bleed air, as it has been demonstrated that oil leakages are quite frequent during flights (although at low contamination levels), that TCP concentration in used engine oil is significantly greater than in fresh oil [24], especially during engines' power variations, and that causation links exist between oil leakages and acute and chronic symptoms.

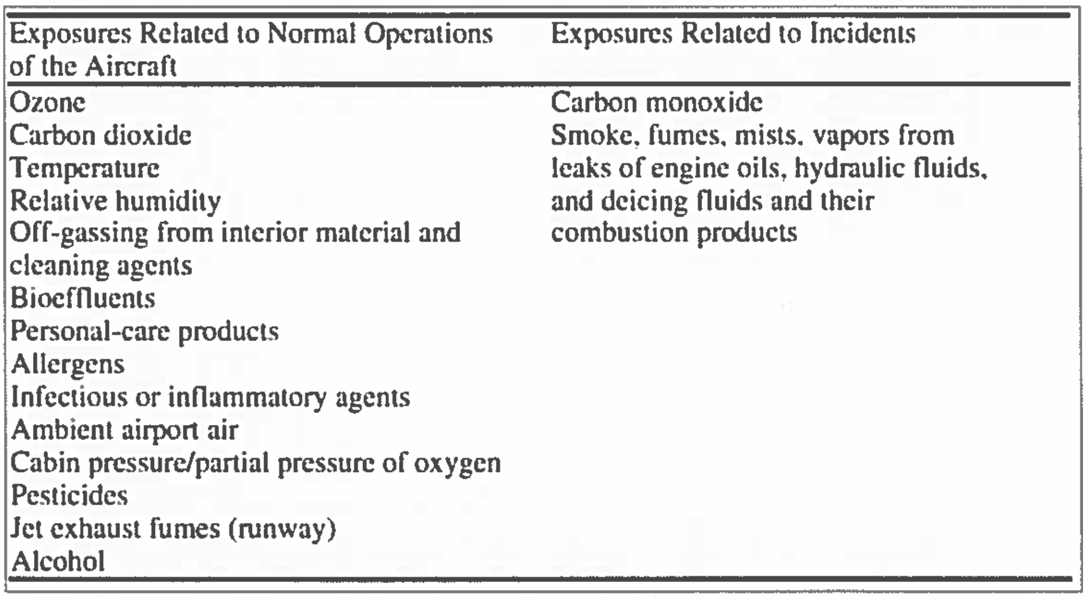
As explained in [26], the rate of contamination accidents is rather low but the rate of contamination events (and consequent symptoms) is relatively high, estimated in 0.09~0.388 per thousand flights. Notwithstanding this, legislation still seems to ignore some scientific and pragmatic evidences, like for instance the indication by European Chemical Agency (ECHA) that oil additives had never been tested in aircraft environment, and that reliance on currently defined safety limits and exposure limits would be responsible of a considerable underestimation of actual exposure and inhalation episodes. The open letters of Global Cabin Air Quality Executive to EASA synthetize this situation [see webography].

The underestimation of toxic events onboard is also explained by the underreporting, and sometimes aircrew reluctance to report, due to fear related to job security. The actual frequency of toxic and fumes events in the cabin remains matter of debate, as different statistics are released depending on the organization that is running the epidemiological study: for instance, CAA, Pilot Unions (BALPA), and airlines in UK have often provided quite different frequencies [27]. In summary, the objective measurement of cabin contaminated air and the causal link with health problems is still an open issue, due to methodological difficulties that still must be overcome, e.g. focus on a limited set of toxic compounds, small samples of flights, and failure to consider cumulative effects of even small exposure to toxic chemicals. Research in the next future will necessarily have to consider these methodological issues, and set up reliable measurements both in the medium and the large terms, so that actual exposure can be considered in a large sample of flights. The fact that little leakage's episodes occurs in normal flight (e.g. with visible fume events) requires more attention on appropriate biomarkers that could inform about actual exposure, and about the use of reliable measurement methodology, for example by increasing sensor accuracy using distributed sensors measuring set up [28].

Small personal air sampling devices have been tested in the last decade [32]. Such devices could be used by non-technical people, they could guarantee continuous sampling, and it would allow assessment of cumulative exposure effects. The tests demonstrated an exposure to TCP concentration between 31nanograms/m3 and 83nanograms/m3, and a sensitivity to concentrations above 4.5nanograms/m3. The device has been patented in the US (#8,945,127 B2) and in Europe (# 01973929.1).

Among other chemicals that can contaminate cabin air, brominated flame retardants (BFR) have also received some attention, due to their acknowledged neurotoxicity. BFR contained in cabin air and dust have been found in significant higher concentration in serum samples of cabin attendants' (and even more of pilots' and aircraft maintainers) than of control group [29].

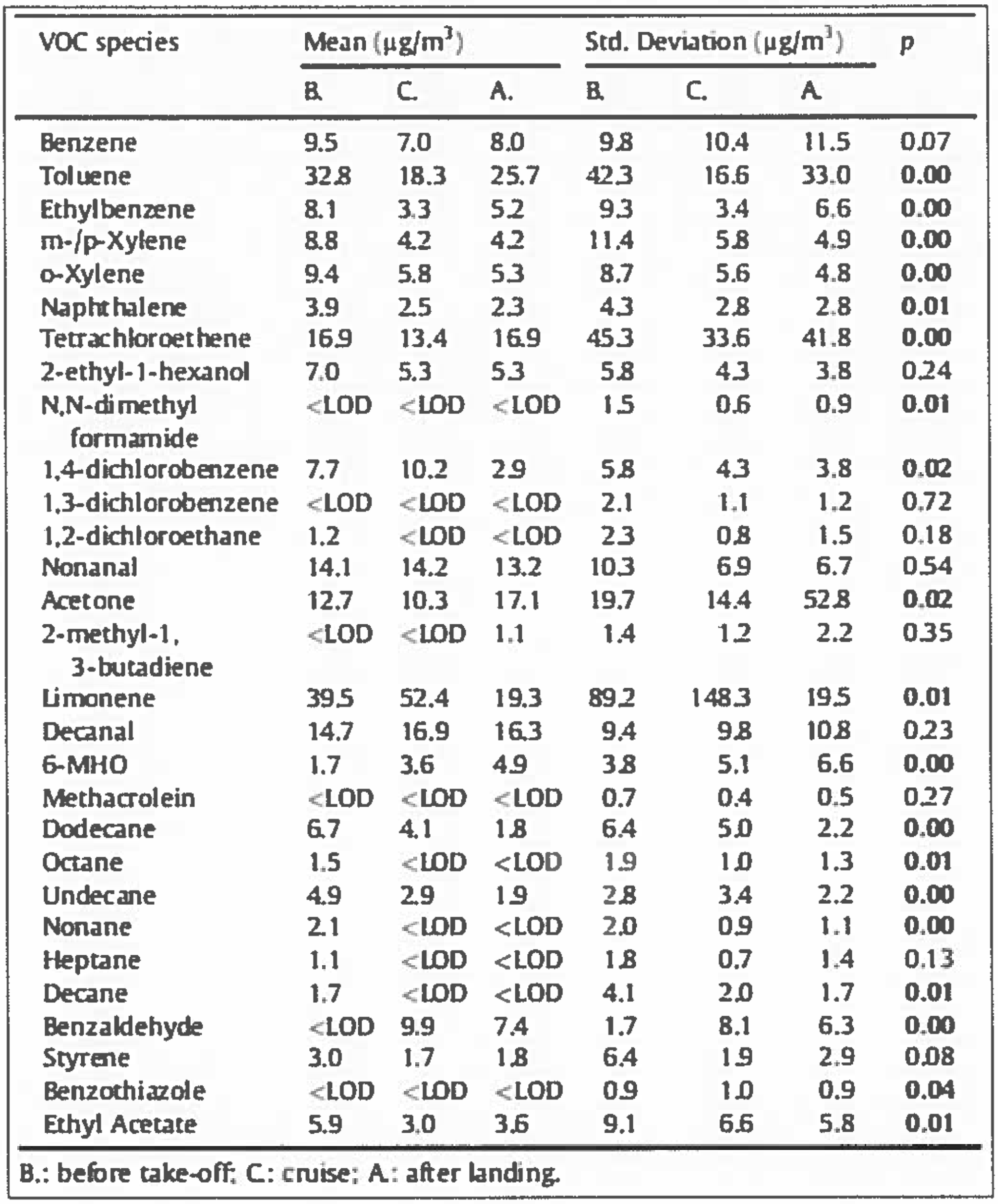
A list of possible exposure sources relative to cabin air quality is provided in Figure 5 [30].



Exposures Related to Normal Operations of the Aircraft	Exposures Related to Incidents
Ozone	Carbon monoxide
Carbon dioxide	Smoke, fumes, mists, vapors from leaks of engine oils, hydraulic fluids, and deicing fluids and their combustion products
Temperature	
Relative humidity	
Off-gassing from interior material and cleaning agents	
Bioeffluents	
Personal-care products	
Allergens	
Infectious or inflammatory agents	
Ambient airport air	
Cabin pressure/partial pressure of oxygen	
Pesticides	
Jet exhaust fumes (runway)	
Alcohol	

***Figure 5** - Exposure Sources Relevant to Aircraft Cabin Air Quality [30].*

Volatile organic compounds (VOCs) also are a cabin air quality issue. In-flight measurements on 107 commercial flights were conducted during a 2 years periods [37] and on average, 59 VOCs were detected in each flight, out of a total of 346 detected VOCs. VOCs include hydrocarbons, e.g. alkanes and alkenes, esters, alcohols, ketones, aldehydes, halides, and aromatics. Importantly, it has been demonstrated how their concentration can depend on factors like air route, aircraft model, and seasonal variations. Also phase of flight has an effect on VOCs concentration: alcohols and other aromatics are higher during meal services than during climb or descent. However, peak values for the most part of detected VOCs were produced during "before take-off" and "cruise" phases. Adverse health effects of VOCs include irritating effects (nose, throat, eyes), general effects like fatigue, cognitive effects like difficulty in concentrating and maintaining attention, toxic effects, and even carcinogenicity (benzenes). A list of 29 VOCs has been proposed as target compounds related to cabin air quality, on the basis of their significant concentration variations during different flight phases [38]. The list and statistical tests on concentration levels are reported in **Table 6**.



VOC species	Mean (µg/m³)			Std. Deviation (µg/m³)			*p*
	B.	C.	A.	B.	C.	A.	
Benzene	9.5	7.0	8.0	9.8	10.4	11.5	0.07
Toluene	32.8	18.3	25.7	42.3	16.6	33.0	0.00
Ethylbenzene	8.1	3.3	5.2	9.3	3.4	6.6	0.00
m-/p-Xylene	8.8	4.2	4.2	11.4	5.8	4.9	0.00
o-Xylene	9.4	5.8	5.3	8.7	5.6	4.8	0.00
Naphthalene	3.9	2.5	2.3	4.3	2.8	2.8	0.01
Tetrachloroethene	16.9	13.4	16.9	45.3	33.6	41.8	0.00
2-ethyl-1-hexanol	7.0	5.3	5.3	5.8	4.3	3.8	0.24
N,N-dimethyl formamide	<LOD	<LOD	<LOD	1.5	0.6	0.9	0.01
1,4-dichlorobenzene	7.7	10.2	2.9	5.8	4.3	3.8	0.02
1,3-dichlorobenzene	<LOD	<LOD	<LOD	2.1	1.1	1.2	0.72
1,2-dichloroethane	1.2	<LOD	<LOD	2.3	0.8	1.5	0.18
Nonanal	14.1	14.2	13.2	10.3	6.9	6.7	0.54
Acetone	12.7	10.3	17.1	19.7	14.4	52.8	0.02
2-methyl-1, 3-butadiene	<LOD	<LOD	1.1	1.4	1.2	2.2	0.35
Limonene	39.5	52.4	19.3	89.2	148.3	19.5	0.01
Decanal	14.7	16.9	16.3	9.4	9.8	10.8	0.23
6-MHO	1.7	3.6	4.9	3.8	5.1	6.6	0.00
Methacrolein	<LOD	<LOD	<LOD	0.7	0.4	0.5	0.27
Dodecane	6.7	4.1	1.8	6.4	5.0	2.2	0.00
Octane	1.5	<LOD	<LOD	1.9	1.0	1.3	0.01
Undecane	4.9	2.9	1.9	2.8	3.4	2.2	0.00
Nonane	2.1	<LOD	<LOD	2.0	0.9	1.1	0.00
Heptane	1.1	<LOD	<LOD	1.8	0.7	1.4	0.13
Decane	1.7	<LOD	<LOD	4.1	2.0	1.7	0.01
Benzaldehyde	<LOD	9.9	7.4	1.7	8.1	6.3	0.00
Styrene	3.0	1.7	1.8	6.4	1.9	2.9	0.08
Benzothiazole	<LOD	<LOD	<LOD	0.9	1.0	0.9	0.04
Ethyl Acetate	5.9	3.0	3.6	9.1	6.6	5.8	0.01

B.: before take-off; C: cruise; A: after landing.

Table 6: Statistical comparison of VOC levels at different flight phases. Data from [38].

Correlational analyses have also been performed in order to better define what VOCs mixtures are present in cabin air, and to better identify potential VOCs sources [43]. Results showed very few strong correlations at $p<.001$, suggesting the existence of multiple VOCs sources in aircraft cabin. However, a precise mapping between a specific VOC and its source within aircraft cabin is still missing (study [43] envisaged further studies in order to obtain such results).

A compilation of recorded concentrations of non-reactive VOCs in aircraft cabins is provided in [42] and reported in Table 7. The reviewed study used maximum recorded concentration of VOCs to simulate multiple simultaneous exposure to VOCs, and combined them in a formula for calculating a Hazard Index (HI) for sensory irritation (eyes and upper airways), which finally resulted 84% for aircraft cabin.

In summary, there has been an increasing interest in the last years about aerotoxic syndrome, due to many studies focused on in-flight measurements of toxic particles' concentration that revealed the presence of multiple toxic agents that could produce contamination events. However, there is insufficient knowledge to establish a direct link between toxic particles and exposure's period. Toxic agents can produce health damages independently of age. Therefore, in order to limit toxic particles and improve aircraft cabin quality, constant monitoring and prevention (limit all personnel's exposure) seem to be the best preventive measure.

Compound Study/number of flights/types Sampling duration	Acetaldehyde	Methylene chloride	2-propanol	2-butanone	Propanal	Hexanal	Heptanal	Octanal	Nonanal	Decanal	Benzaldehyde	Trichlorethylene	Tetrachlorethylene	TCP	TBP	ToCP	C_{11-12}	Benzene	Toluene	Ethylbenzene	Xylene[d]	HI %
Crump et al., 2011/ 100/5 5 min (Table 4)	nm											20	nm	38	22	23	87	nm	170	nm	52	
Denola et al., 2011 46/3 15 min to 10 hours	nm														nd		nm					
Houtzager et al., 2013 20/Boeing 737 ½–2 hours	nm													0.2[e]	nd		nm					
Rosenberger et al., 2013 26/2 ½–5 hours	nm													0.07	nd		nm					
Van Netten, 2009 2/1 55 min	nm													0.1	nm		nm					
Nagda and Rector, 2003[b]/ 71/18 No information	46	122	93	18	5	nm							13	nm			nm	7	87	nm	15	
Spengler et al., 2012[b]/ 86/6 No information	nm											41	10	nm			nm	62	133	13	61	
Solbu et al., 2011 40/6 2–10 hours	nm													nd	4	nd	nm					
Wang et al., 2014[c]/ 14/1 5 min	nm							17	36	57	32	nm	13	nm			39	145	237	45	74	
Weisel et al., 2013/ 52/4 2½–8½ hours	nm					8	4	5	14	12	nm	nm										
NOAEL value[f], mg/m³ TDI, ng/kg bwd	7		17[g]	33	6	6	6	6	6	6	2					50	>1.4[h]		75	20	7.5	
Sensory effects: HQ % = $\frac{\text{Max conc}}{\text{guideline}}$ Neurotoxic effects: HQ % = $\frac{\text{daily intake (8 hrs)}}{\text{TDI}}$	0.7	–[i]	0.6	0.05	0.1	0.1	0.1	0.3	0.6	1	2	–[i]	–[i]			4600	0.6	–[i]	0.2[a]	0.2	0.1	7 4600

Table 7 - Maximum concentrations (µg/m3) of common non-reactive VOCs and carbonyls in aircraft cabin cabins, NOAEL values, hazard quotients (HQ), and hazard index (HI).

NOTES: nm=not measured. nd=below Level of Detection (LOD). aAveraged maximum values based on several studies. bMaximum concentration taken from Table B-3. cFourth quartiles (Table 2). dSum of ortho, meta and para isomers. eSum of four tricresyl phosphate isomers, but not ToCP. fNOAEL values for sensory irritation (Wolkoff, 2013). gEstimated as LOAEL/5 value (van Thriel et al., 2003). hEstimated as LOAEL/5 for decane (Kjærgaard et al., 1989). iNot considered a sensory irritant. LOAL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect. TDI = Tolerable Daily Intake.

6.7. Chemical Products

Insecticides, bactericides, and other chemical products used for aircraft cleaning and maintenance might increase the risk of disease for cabin crew, due to their exposition to areas cleaned with those substances.

Disinsection is the use of insecticides to kill insects present on aircrafts and that are transported to zones where they were not present, but in which they can rapidly become endemic (especially disease-transmitting insects, like mosquitos). The use of insecticides, especially pyrethroid insecticides onboard cause flight attendants being exposed to such substances, increasing the neurotoxicity risk level. Exposure to pyrethroids can cause malfunctioning of sodium and calcium voltage-sensitive cellular channels, with negative effects on immune system, and chronic symptoms as headache, gastrointestinal disturbances, and respiratory difficulties, among others. It has been demonstrated how urinary pyrethroids metabolites levels are significantly higher in flight's attendants working on disinsected aircrafts as compared to non disinsected aircrafts, with time between disinsection and flight being a significant predictor of urinary pyrethroids concentrations [44].

Similar to what concluded in relation to air quality of aircraft cabin, there is no specific knowledge about long term-effects of exposure to chemical products used for aircraft disinsection. However, considered the typical effects of age on health (i.e. diminished tolerance to environmental factors), it is reasonable to think that in case of contamination events, elder cabin crews would show worse consequences on health as compared to younger colleagues.

6.8. Stress

Effects of stress are different whether the short-term or the long-term is considered. Whereas "situational stress" (also referred to as acute stress) produces normally reversible changes in specific body functions, long term changes due to prolonged stress reactions (also referred to as chronic stress) alter sometimes irreversibly body homeostasis and allostasis (i.e. the capacity of maintaining homeostasis of physiological functions through physiological and behavioral change).

Long-term stress might generate chronic body reactions that can become unsustainable and evolve in serious health problems, as in burnout reactions. Excessive stress can be generated by job demands and the bad adaptation to situation requirements, and by emotional labor, i.e. by the need of regulating emotional reactions and expressions in front of public or customers, while displaying emotional states that are in accord with organizational objectives. The need for continuous emotional regulation can be considered a further stress source (i.e. stressor) for flight attendants with respect to other professions in which there is no such a constraint.

In terms of the job demands-control model (JD-C) proposed by Karasek in 1979 [77] and of its revised version called job demands-resources model (JD-R) proposed in [78], burnout is the result of prolonged situations of great job demands, low control over job activities, low perceived availability of resources to satisfy job demands, and low social support within job context (i.e. high isolation). It has been evidenced how isolation and solitude highly contribute to cabin crew stress levels [15] [79]. The isolation situation is originated by the fact that a flight attendant works with a group (the crew) that is disbanded after service, and that has a high change rate. Temporariness of social relations lowers familiarity with colleagues.

The measurement of isolation, together with other constructs that could suggest high burnout risk, has been performed in Taiwan [15] [18] by means of a wide-scale questionnaire. The items that composed the questionnaire were intended to collect a measure of job demands (JD), job resources (JR), exhaustion (EX), cynicism (CY), colleague isolation (IS), health problems (HP), and job performance (JP). By means of structural equation modelling, relationships between constructs were assessed. It was confirmed that job demands and job resources are antecedents of burnout, while (decreased) job performance and health problems are the most important consequents of burnout. The model also showed isolation as construct linking job resources and job performance: the more available resources, the less the experienced isolation, and the better job performance. Other contributors to burnout have been identified in the model, as for example work interference into family life and lack of career advancement. Therefore, organizational policies for career advancement and a better balance between family and worktime are important defenses against the incidence of burnout and stress in general. Training programs focused on resources like colleagues' support could contribute to reduce flight attendants' isolation feeling.

Another study aimed to measure stress incidence in flight attendants, teachers, and nurses [16], in Iceland. A questionnaire including items on socio-demography, working environment, and a symptoms' list was used for data collection. Results showed that cabin crew reported higher rate of gastrointestinal, sound perception, and common cold symptoms than nurses and teachers. Furthermore, cabin crews (and teachers) reported more frequent stress symptoms than nurses. Again, cabin crews reported higher monotony and physical effort, together with lower job security than the other job categories. The study highlighted how cabin crews described their physical environment as particularly stress-generating and more demanding, with specific attention on the accountability for whatever event can originate in a flight (violent passengers, a fire, or a medical emergency). Consequently, cabin crews assessed their health as worse as compared to the other job categories. However, more objective studies need to be conducted to better disentangle the impact of specific work environment issues on cabin crew's health.

It must be kept in mind that the consequences of stress (the physiological response) on health depend essentially on the personal mechanisms of adaptation and on individual coping strategies. The perceived level of stress is the result of personal evaluations of the impact that a stressor will have on one's own capacity to maintain satisfactory performance levels, and on a longer term, physical and mental wellbeing. Therefore, the influence of physical work environment on stress will be mediated by personal experience, individual differences, and cognitive attribution styles. There is no one-size-fits-all countermeasure for stress management.

Psychological models of stress consider stress as the product of exogenous (or even endogenous) stressors' influence on body and mind (i.e. on cognition and decision making), mediated by personal experience, familiarity, and current state [17]. Consequently, when dealing with stress, the main focus of investigation are the interpretation mechanisms adopted by professionals and their strategies to cope with perceived stress. This does not mean that the consequences of stress are totally subjective and impossible to measure objectively. The link between long-term stress and effects on health like hypertension [17], gastrointestinal disorders (e.g. ulcers), and depression of immune system are proved. In order to evaluate the impact of stress within a group of professionals, it would be appropriate to carry out an extensive qualitative work and take into consideration individual differences that would emerge, both in terms of causes of stress and coping strategies. A stressful working environment is one major driver for developing chronic hypertension and high blood pressure, due to predominant activation of sympathetic autonomous nervous system [17]. In fact, the parasympathetic (also referred to as vagal) component of autonomous nervous system is inhibited by stress reaction, while its activity normally increases under the influence of sport activity, and even meditation (e.g. yoga, or mindfulness sessions). However, working environment is one strong driver for chronic stress together with others that are not easily measurable in an objective fashion, as for example family, social context, and lifestyle, which are difficult to be monitored within job context, if not impossible. Family dynamics are likely to have an influence also on daily work activities, but their management essentially relies (for the moment) on professionals' capacity to reappraise their influence. In summary, lifestyle and personal coping strategies are important as well as working environment in the etiology of stress, and they should be targeted when promoting a campaign on health at workplace.

Interestingly, cabin crews have been found in some local contexts more affected by stress than other professionals, "classically" affected by stress issues (and by burnout situations), like for example nurses. The fact that cabin crews report major incidence of several stress symptoms confirm that (chronic) stress incidence should not be overlooked when considering long term cabin crews' health.

6.9. Shiftwork, Nightshift and Chronodisruption

6.10. Effects of shiftwork on sleep

Shiftwork requires people to continuously adapt their familiar commitments and social life to work schedule, being obliged to sleep at different periods. Consequently, their biological rhythms must readapt rapidly in order to avoid (or at least limit) sleep debt and fatigue. It is acknowledged that people become less tolerant to shift work (and to phenomena that desynchronize body rhythms with light-darkness cycle, like jet lag) as they age, as well as more subject to chronic fatigue.

People older than 60 years have less regular circadian rhythms: their temperature and melatonin rhythms show lower amplitude and tend to advance (i.e. to reach their minimum earlier and earlier in the first part of the morning) as compared to younger people. For example, older people have greater difficulty in coping with jet lag [64], especially after eastward flights. Thus, re-adaptation of body rhythms (e.g. due to shiftwork) is more difficult, as their sleep habits become more rigid. Chronic "jet lag" (desynchronization) is also related to cortisol levels higher than normal, causing a reduction of temporal lobe's volume in the brain and deficits in spatial learning and memory. Five years of exposure to high levels of cortisol are sufficient to produce such modifications [68].

Independently of how much we sleep and when, our circadian rhythms will show quite stable patterns and slow adaptations to a new sleep-wake cycle. This means that we will experience a circadian minimum in the very first part of the morning (i.e. between 3:00am and 6:00am) and to a lesser extent, in the first part of the afternoon (i.e. between 2:00pm and 4:00pm). The former period could be described as "the best period for sleep", or the "primary sleep gate", meaning that best sleep quality will be normally experienced during this period. Consequently, the most important sleep disruptions and effects on performance will occur while being alert in this period. It has been observed how the worse feeling of impaired performance (and corresponding low levels of objective performance) are more frequent during nightshift for elder people, while during morning shift for younger people.

Circadian disruption caused by shiftwork produces an array of jet-lag-like symptoms in the short-term, like difficulty to adapt sleep rhythms, while it may contribute to weight gain/obesity, metabolic syndrome/type II diabetes, and cardiovascular disease in the long-run [67]. As explained later in the text, shiftwork has also important effects on cancer's incidence.

For example, sleep quality and quantity are particularly sensitive to the number of consecutive nightshift, with a considerable impact on elder people. Number of consecutive nightshift is one of the most important criteria to be considered when planning rosters within several industrial domains [65]. Recent neuroimaging studies show how brain structures devoted to sleep-wake modulation might show subtle structural changes (i.e. grey matter volume reduction) in people exposed to shiftwork as compared to day workers [66].

A longitudinal study [84] on aging, health, and work, evidenced both inter- and intra-individual changes in workers' health as effect of age. Although it was difficult to separate "pure" effects of age from those due to prolonged exposure to specific professional risks like shiftwork, it was anyway possible to see how some sleep difficulty symptoms were more work-related than age-related, as they disappeared after retirement, once exposure to shiftwork was over.

Age-related effects include sleep quality impairments that are noticeable since the thirties. A slowdown of these impairments has sometimes been observed after the sixties, and even the fifties, normally interpreted in terms of benefic effects of retirement. This has been related to the benefit of retirement (a work-related effect), namely a reduction of overall stress. In any case, a strict distinction between age-related effects and work-related effects cannot be sustained, because age and work effects are intermixed and combine each other. Furthermore, it might of low interest to distinguish between pure effects of aging and shiftwork, since cabin crews are exposed to both. Therefore, it might more important to know the "normal" effects of aging (for instance on sleep and on body rhythms adaptation), without forgetting that they are amplified by exposure to shiftwork (especially nightshift).

6.11. Effects of age on sleep

Aging is a normal process of physical, psychological, and social change. Age has effects on basic sleep physiology, sleep patterns, habits and quality of sleep. With age, we become more sensitive to hormonal changes, physiological conditions, environmental conditions (light, noise, temperature).

In addition, important associations exist between sleep and health (and disease), so that some sleep disorders become more prevalent as we age. Some practical tips can help to address sleep problems in order to get a good night's sleep. However, some changes in sleep patterns and quality due to the normal process of aging are quite inevitable and irreversible, independently of work activity and schedules.

Consequently, the effects of shiftwork discussed in the above section, would result amplified by normal aging processes, so that young people (in terms of both years of service and chronological age) would be less affected by shiftwork than elder people.

Along with the body and brain changes that occur as we age, sleep also changes as part of the normal aging process. From a physiological point of view, the quantity of deep sleep (namely, stage 3 and 4 in a polysomnogram, i.e. the recording of brain electrical activity during sleep) sensibly diminishes in a normal aging process, thus diminishing the restorative benefits of deep sleep in the recovery from physical fatigue. In parallel, there may be longer periods of stage 1 and stage 2 sleep (light sleep), as much as 8-15%. Most studies also demonstrate an overall decline in REM sleep, which is the sleep stage in which dreams occur, and most importantly that restores brain from experienced mental fatigue.

As we age, the secretion of hormones is altered. We release less growth hormone, which normally is secreted during deep sleep and is particularly important to our muscles and tissue. The release of cortisol, that normally helps us become alert in the morning hours, increases in the evening around the 5th decade of life. Around or during menopause, women's estrogen levels decrease and hot flashes occur. As a result, skin temperature rises and women may experience increased heart rates and sweating that disrupts sleep.

A key sleep-promoting hormone, melatonin, is often released in the evening during darkness. As we age, we may not produce as much melatonin, and this makes it more difficult to fall asleep. Importantly, reduced melatonin production is linked to nightshift [60] [61], and to the reduced benefits of this hormone in hormone-regulation. Melatonin production's suppression (due to both aging and nightshift) has been indicated as the main cause of higher incidence rates among cabin crews of specific hormone-sensitive cancers (breast, prostate).

As said, the change in sleep architecture that occurs is associated with the normal aging process, but important disruptions in sleep can occur, due to the impact of specific medical conditions. It is acknowledged that the better the health of older adults, the more likely they are to sleep well. For instance, the physical changes associated with chronic medical conditions such as arthritis and other musculoskeletal problems, gastrointestinal problems such as heartburn and any pain add to the litany of sleep disruptions that can occur as we age. Medications taken for the symptoms of these conditions may also lead to difficulties sleeping. Older people are also more sensitive to environmental factors, particularly if they have more light sleep. While noise, light and temperature may have minimally affected us as young adults, these factors have a greater impact on our sleep, causing arousals and further disruptions as we age. Such fragmented sleep means less continuous, efficient and deep sleep resulting in daytime sleepiness and an inability to perform well during the day and experience a quality of life.

As a result of all of these physiological, hormonal, and environmental changes, older persons tend to sleep less efficiently. While they may be in bed 8 hours, at 55 years of age and older, both men and women may be in actual sleep for just 7 hours or less.

In summary, most important consequences of age on sleep are: increased napping throughout the day; increased sleep latency; increased number of awakenings (especially in the morning); decreased stage 3 and 4 sleep (slow wave sleep, or deep sleep); increased stage 1 sleep (light sleep); decreased REM sleep; equal distribution of REM sleep through sleep cycles (i.e. no increase in REM at the end of the sleep period as for younger people and adults); reduced sleep efficiency, i.e. increased difference between time in bed and actual sleep time; phase advancement (i.e. tendency to wake up earlier in the morning due to reduced sleep) and to go bed earlier due to increased daytime sleepiness, corresponding to more rigid sleep habits (and to a change in the chronotype); decrease of rhythm amplitude, which is a sign of inadaptation; decreased melatonin levels; increased feelings of nonrestorative sleep.

Effects of shiftwork on sleep are the most evident, by they are not the unique. Shiftwork can produce a number of perturbations in several body functions besides sleep, for example hormones' regulation, with possible important consequences on (potential) cancer occurrences.

Night work has been indicated as potential contributing factor, if not a cause, of higher breast cancer risk in female cabin crew as well as in other professions (e.g. nurses, cleaning services, etc.) due to melatonin suppression during night shift. A review and meta-analysis released in 2005 [47], considered the relationship between night work and breast cancer in terms of Relative Risk (RR) and 95% Confidence Interval (CI) or of Standardized Incidence Ratio (SIR). RR compares the probability of an event occurring (e.g. developing a cancer) in a group exposed to a specific factor to a group non-exposed to the same factor (e.g. smokers vs. non-smokers, nightshift workers vs. regular shift workers). SIR compares the probability of occurrence of an event in a specific group and in the general population. Two longitudinal studies with nurses checked the incidence of long-term night shift (e.g. 30 years and more), and controlled for known risk factors of breast cancer. The first study reported a RR = 1.36 (95% CI, 1.04–1.78) for breast cancer when night rotating shift were sustained for 30 years or more, with increased RR for increasing number of years in nights shift work [55]. The second study reported a RR = 1.79 (95% CI, 1.06–3.01) for breast cancer risk in women with at least 20 years history of night shift [57] [62].

In the same review [47] a total of seven studies that focused exclusively on female cabin crews are also considered [33, 34, 39, 41, 49, 53, 54]. In all these studies the risk for breast cancer of flight attendants was compared with the general population, and SIR used for risk quantification. All the values were combined in the meta-analysis for cabin crews only, and for all female exposed to night shifts. The obtained overall values were (SIR 1.44; 95% CI, 1.26–1.65) and (RR, 1.51; 95% CI, 1.36–1.68), respectively, with a combined overall value for the 13 studies of 1.48 (95% CI, 1.36–1.61) as reported in Figure 6. This means that females night shift workers have a 48% of increased risk to develop breast cancer more than the normal population. When separating cabin crew personnel form other professions results remain substantially unvaried.

Similarly, a review that included a total of 17 studies [52] reported a significantly higher SIR (1.04–5.24, 95% CI 1.00–17.38) for breast cancer among female cabin crews. Mortality rates showed no significant differences between cabin crews and general population [Standardized Mortality Ratio, (SMR) 1.0–1.28, 95% CI 0.54–3.7].

All these results have been connected to evidences of the effects of melatonin as oncostatic for a variety of tumors. Consequently, being alert during night (thus suppressing the normal melatonin's production process) causes an increase in hormone productions that may lead to hormone-sensitive tumors at breast level.

This explanation considers cosmic radiation exposition as uninfluential in breast cancer's incidence (as it has been believed for years), and directly relates cancer incidence with night shift. Separated statistical analysis for cabin crews only and for other professions confirmed this interpretation, giving similar results.

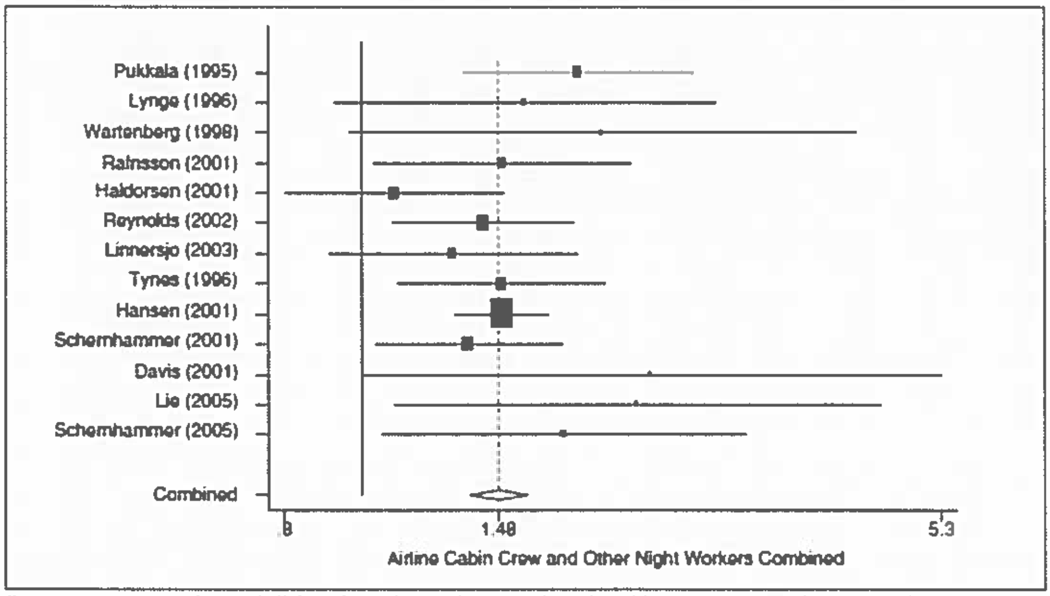
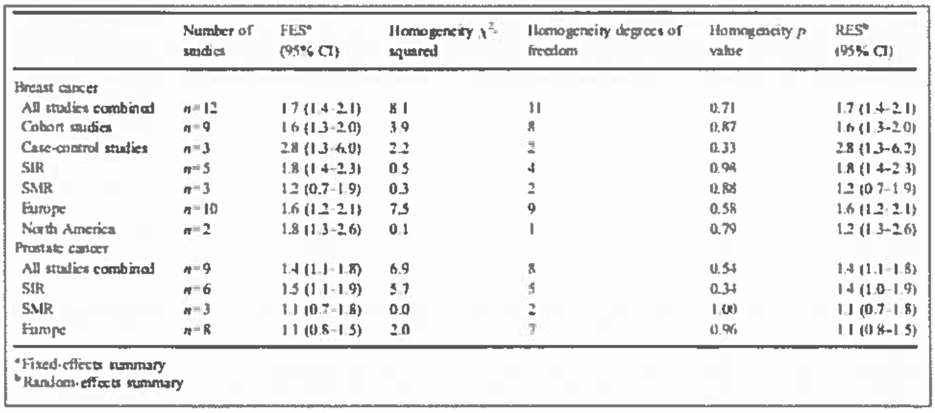


Figure 6: Meta-analysis of all female night workers combined and breast cancer risk in 13 studies [47].

NOTE: The dashed vertical line represents the combined estimate, and the diamond-shaped box represents the confidence interval from the random-effects model. The estimates are plotted with boxes; the area of each box is inversely proportional to the estimated effect's variance in the study, hence giving more visual prominence to studies where the effect is more precisely estimated.

Chronodisruption (CD) and cancer have been analyzed also in [48]. CD is a set of disturbances related to physiological, endocrinological, metabolic, and behavioral daily cycles. This review corrects the estimated risk of breast cancer at 70% for flight personnel and at 40% for shift workers. However, as the authors acknowledge, effective control of covariates might have been insufficient, thus overestimating these indices. For instance, almost all the studies controlled for the effect of the age, while only one considered women's age at first childbirth, number of children, or number of fertile years. Importantly, the review connects CD to prostate cancer (hormone-sensitive cancer), and thus to an increased relative risk for male flight attendants. The meta-analysis was conducted on a total of 21 studies, part of which were the same meta-analyzed in [47]. All the studies dealt with flight personnel and with prostate (*n* = 9*)* and/or breast cancer (*n* = 12). Additionally, 9 studies dealing with shift workers were also considered. Results for flight personnel are reported in Table 8. The combined risk index was 70% for breast cancer and 40% for prostate cancer.



	Number of studies	FES[a] (95% CI)	Homogeneity χ^2 squared	Homogeneity degrees of freedom	Homogeneity *p* value	RES[b] (95% CI)
Breast cancer						
All studies combined	*n* = 12	1.7 (1.4-2.1)	8.1	11	0.71	1.7 (1.4-2.1)
Cohort studies	*n* = 9	1.6 (1.3-2.0)	3.9	8	0.87	1.6 (1.3-2.0)
Case-control studies	*n* = 3	2.8 (1.3-6.0)	2.2	2	0.33	2.8 (1.3-6.2)
SIR	*n* = 5	1.8 (1.4-2.3)	0.5	4	0.98	1.8 (1.4-2.3)
SMR	*n* = 3	1.2 (0.7-1.9)	0.3	2	0.88	1.2 (0.7-1.9)
Europe	*n* = 10	1.6 (1.2-2.1)	7.5	9	0.58	1.6 (1.2-2.1)
North America	*n* = 2	1.8 (1.3-2.6)	0.1	1	0.79	1.2 (1.3-2.6)
Prostate cancer						
All studies combined	*n* = 9	1.4 (1.1-1.8)	6.9	8	0.54	1.4 (1.1-1.8)
SIR	*n* = 6	1.5 (1.1-1.9)	5.7	5	0.34	1.4 (1.0-1.9)
SMR	*n* = 3	1.1 (0.7-1.8)	0.0	2	1.00	1.1 (0.7-1.8)
Europe	*n* = 8	1.1 (0.8-1.5)	2.0	7	0.96	1.1 (0.8-1.5)

[a] Fixed-effects summary
[b] Random-effects summary

Table 8: Results of meta-analysis for flight personnel on incidence on breast and/or prostate cancer) [48].

Although significant lower incidence of some cancers and noncancer causes of mortality have been reported within the scientific literature, this does not mean that cabin crews population shows better general health. A study [83] gives an overview of cabin crews' health, as reported by means of a subjective survey. It has resulted that cabin crews show higher rates of some specific diseases than the general population. These diseases relate to chronic bronchitis (checked for smoking habits), cardiac diseases in female flight attendants, sleep disorders, depression, and fatigue. Most importantly, some of them showed higher incidence as a function of job tenure, meaning that the risk for such diseases is higher for cabin crews with more operational experience. Even if conclusions might be affected by recall bias, results provide important insights on health's issues to be further investigated in the next future.

6.10. Life Expectancy

A review of 65 publications (since 1990) about cancer's incidence and noncancer mortality among cabin crew personnel has been proposed in [45]: cancer's mortality was in general lower than in the general population. A reduced standardized mortality ratio (SMR) of 0.65 was found for cancer mortality as well as all-cause mortality, corresponding to (estimated) 4-5 years higher life expectancy. Conversely, a significantly higher risk was found for breast cancer in female cabin crews, and for (malignant) melanoma in both female and male cabin crews. As already shown in other studies, cosmic radiation is considered as uninfluential on melanoma (due to exposure rates that are insufficient for carcinogenesis), while higher exposure to ultraviolet (UV) radiations is likely to be more related to higher melanoma risks. Another epidemiological study [46] drawn the same conclusions about melanoma and breast cancer incidence in cabin crew populations. Meta-analysis on the risk of melanoma within pilots and cabin crews was performed on a total of 19 published studies [50]. Overall standardized incidence ratio (SIR) was 2.21 (95%CI, 1.76-2.77), meaning that pilots and cabin crews have twice the incidence of melanoma as compared to the general population. The separate SIRs were 2.09 (95% CI, 1.67-2.62) for cabin crews and 2.22 (95%CI, 1.67-2.93) for pilots. The major incidence of melanoma within pilot and cabin crew populations in comparison to the general population could be intimately related to UV radiation that a 9000m of altitude (a common flight altitude) is double as compared to ground level. The cancerogenic effect of UV radiation is known, as it can cause DNA modifications in skin's cells. Occupational exposure to sunlight seems therefore more involved than "non-professional" exposure, i.e. the personal characteristics and habits in relation to sun exposure. This conclusion was drawn in a study that focused on potential risk factors for melanoma in cabin crews and pilots [31], in which there were no substantial differences with the general population with respect to a series of potential confounding variables, namely hair color, eye color, freckles, number of naevi, family history of skin cancer and naevi, skin type, history of sunburn, sunbed, all sunscreen use, and number of sunny vacations. The study concluded that these factors were not responsible for major incidence of melanoma among cabin crews and pilots than in the general population. Occupational-related cumulative exposure could be more responsible for such results.

7. References

1. Ciloglu, H., Alziadeh, M., Mohany, A., & Kishawy, H. (2015). Assessment of the whole-body vibration exposure and the dynamic seat comfort in passenger aircraft. *International Journal of Industrial Ergonomics*, *45*, 116-123.
2. Burström, L., Lindberg, L., & Lindgren, T. (2006). Cabin attendants' exposure to vibration and shocks during landing. *Journal of sound and vibration*, *298*(3), 601-605.
3. Hostens, I., & Ramon, H. (2003). Descriptive analysis of combine cabin vibrations and their effect on the human body. *Journal of sound and vibration*, *266*(3), 453-464.
4. Bagshaw, M. (2008). Cosmic radiation in commercial aviation. *Travel medicine and infectious disease*, *6*(3), 125-127.
5. Bennett, L. G. I., Lewis, B. J., Bennett, B. H., McCall, M. J., Bean, M., Doré, L., & Getley, I. L. (2013). Cosmic radiation exposure survey of an air force transport squadron. *Radiation Measurements, 48*, 35-42.
6. Pinilla, S., Asorey, H., & Núñez, L. A. (2015). Cosmic Rays Induced Background Radiation on Board of Commercial Flights. *Nuclear and Particle Physics Proceedings, 267*, 418-420.
7. A.A. Goodarzi, A. Anikin and D.D. Pearson, *Chapter 33 - Environmental Sources of Ionizing Radiation and Their Health Consequences*, In Genome Stability, edited by Igor Kovalchuk and Olga Kovalchuk, Academic Press, Boston, 2016, Pages 569-581
8. Barish, R. J., & Dilchert, S. (2010). Human resource responsibilities: Frequent flyer radiation exposure. *Employee Responsibilities and Rights Journal, 22*(4), 361-369.
9. Barish, R. J. (2014). In-Flight Radiation: Addressing Patients' Concerns. *Journal of Radiology Nursing, 33*(2), 46-52.
10. Zeeb, H., Blettner, M., Langner, I., Hammer, G. P., Ballard, T. J., Santaquilani, M., ... & Hammar, N. (2003). Mortality from cancer and other causes among airline cabin attendants in Europe: a collaborative cohort study in eight countries. *American journal of epidemiology, 158*(1), 35-46.
11. De Angelis, G., Caldora, M., Santaquilani, M., Scipione, R., & Verdecchia, A. (2002). Radiation-induced health effects on atmospheric flight crew members: clues for a radiation-related risk analysis. *Advances in Space Research, 30*(4), 1017-1020.
12. Mellert, V., Baumann, I., Freese, N., & Weber, R. (2008). Impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots. *Aerospace Science and Technology, 12*(1), 18-25.
13. Andrew B Lumb, *Chapter 15 - High Altitude and Flying*, In Nunn's Applied Respiratory Physiology (Eighth Edition), Elsevier, 2017, Pages 245-258.
14. Silverman, D., & Gendreau, M. (2009). Medical issues associated with commercial flights. *The Lancet*, *373*(9680), 2067-2077.
15. Chen, C. F., & Kao, Y. L. (2012). Investigating the antecedents and consequences of burnout and isolation among flight attendants. *Tourism Management*, *33*(4), 868-874.
16. Sveinsdottir, H., Gunnarsdóttir, H., & Friðriksdóttir, H. (2007). Self-assessed occupational health and working environment of female nurses, cabin crew and teachers. *Scandinavian journal of caring sciences*, *21*(2), 262-273.
17. Rosenthal, T., & Alter, A. (2012). Occupational stress and hypertension. *Journal of the American Society of Hypertension*, *6*(1), 2-22.
18. Chen, C. F., & Kao, Y. L. (2011). The antecedents and consequences of job stress of flight attendants–Evidence from Taiwan. *Journal of Air Transport Management, 17*(4), 253-255.
19. Giaconia, C., Orioli, A., & Di Gangi, A. (2015). A correlation linking the predicted mean vote and the mean thermal vote based on an investigation on the human thermal comfort in short-haul domestic flights. *Applied ergonomics, 48*, 202-213.
20. Li, C., Liu, H., Li, B., Cheng, Y., Du, C., & Sheng, A. (2017). Human responses to the air relative humidity ramps: A chamber study. *Building and Environment*, *123*, 458-468.

21. Liping, P., Yingjie, W., Meng, L., Helin, Z., & Jun, W. (2013). Method to predicting optimal cabin operative temperature for civil aircraft. *Building and Environment*, *69*, 160-170.
22. Pang, L., Qin, Y., Liu, D., & Liu, M. (2014). Thermal comfort assessment in civil aircraft cabins. *Chinese Journal of Aeronautics*, *27*(2), 210-216.
23. Michaelis, S., Burdon, C., and Vyvyan, H. (2017). Aerotoxic Syndrome: A new occupational disease? Public Health Panorama, 3(2), 198-211.
24. Megson, D., Ortiz, X., Jobst, K. J., Reiner, E. J., Mulder, M. F., & Balouet, J. C. (2016). A comparison of fresh and used aircraft oil for the identification of toxic substances linked to aerotoxic syndrome. Chemosphere, 158, 116-123.
25. Rosenberger, W., Beckmann, B., & Wrbitzky, R. (2016). Airborne aldehydes in cabin-air of commercial aircraft: Measurement by HPLC with UV absorbance detection of 2, 4-dinitrophenylhydrazones. Journal of Chromatography B, 1019, 117-127.
26. Ke, P., Sun, C., & Zhang, S. (2014). Airworthiness requirements and means of compliance about the bleed air contamination. Procedia Engineering, 80, 592-601.
27. Harrison, V., & Mackenzie Ross, S. (2016). An emerging concern: toxic fumes in airplane cabins. Cortex, 74, 297-302.
28. Wang, R., Li, Y., Sun, H., & Chen, Z. (2017). Analyses of integrated aircraft cabin contaminant monitoring network based on Kalman consensus filter. ISA transactions.
29. Strid, A., Smedje, G., Athanassiadis, I., Lindgren, T., Lundgren, H., Jakobsson, K., & Bergman, Å. (2014). Brominated flame retardant exposure of aircraft personnel. Chemosphere, 116, 83-90.
30. Committee on Air Quality in Passenger Cabins of Commercial Aircraft, Board on Environmental Studies and Toxicology Staff, and National Research Council Staff, (2002). Airliner Cabin Environment and the Health of Passengers and Crew. Washington, US: National Academies Press. ProQuest ebrary.
31. Rafnsson, V., Hrafnkelsson, J., Tulinius, H., Sigurgeirsson, B., & Olafsson, J. H. (2003). Risk factors for cutaneous malignant melanoma among aircrews and a random sample of the population. *Occupational and environmental medicine*, *60*(11), 815-820.
32. van Netten, C. (2009). Design of a small personal air monitor and its application in aircraft. Science of the total environment, 407(3), 1206-1210.
33. Pukkala, E., Auvinen, A., Wahlberg G. (1995). Incidence of cancer among Finnish airline cabin attendants. *BMJ., 311*,649–652.
34. Rafnsson, V., Tulinius, H., Jonasson, J.G., et al. (2001). Risk of breast cancer in female flight attendants: a population-based study (Iceland). *Cancer Causes Control, 12*(2), 95–101.
35. Gładyszewska-Fiedoruk, K. (2012). Indoor air quality in the cabin of an airliner. Journal of Air Transport Management, 20, 28-30.
36. Grün, G., Trimmel, M., & Holm, A. (2012). Low humidity in the aircraft cabin environment and its impact on well-being–Results from a laboratory study. Building and Environment, 47, 23-31.
37. Guan, J., Gao, K., Wang, C., Yang, X., Lin, C. H., Lu, C., & Gao, P. (2014). Measurements of volatile organic compounds in aircraft cabins. Part I: methodology and detected VOC species in 107 commercial flights. Building and Environment, 72, 154-161.
38. Guan, J., Wang, C., Gao, K., Yang, X., Lin, C. H., & Lu, C. (2014). Measurements of volatile organic compounds in aircraft cabins. Part II: Target list, concentration levels and possible influencing factors. Building and Environment, 75, 170-175.
39. Reynolds, P., Cone, J., Layefsky, M., et al. (2002). Cancer incidence in California flight attendants (United States). *Cancer Causes Control, 13*(4), 317–324.
40. Michaelis, S. (2016). Oil bearing seals and aircraft cabin air contamination. Sealing Technology, 2016(4), 7-10.
41. Wartenberg, D., Stapleton, C.P., (1998). Risk of breast cancer is also increased among retired US female airline cabin attendants. *Br Med J, 316*(7148), 1902.

42. Wolkoff, P., Crump, D. R., & Harrison, P. T. (2016). Pollutant exposures and health symptoms in aircrew and office workers: Is there a link?. Environment international, 87, 74-84.
43. Wang, C., Yang, X., Guan, J., Gao, K., & Li, Z. (2014). Volatile organic compounds in aircraft cabin: Measurements and correlations between compounds. Building and Environment, 78, 89-94.
44. Wei, B., Mohan, K. R., & Weisel, C. P. (2012). Exposure of flight attendants to pyrethroid insecticides on commercial flights: urinary metabolite levels and implications. *International journal of hygiene and environmental health*, *215*(4), 465-473.
45. Hammer, G. P., Blettner, M., & Zeeb, H. (2009). Epidemiological studies of cancer in aircrew. *Radiation protection dosimetry*, *136*(4), 232-239.
46. Whelan, E. A. (2003). Cancer incidence in airline cabin crew. *Occupational and Environmental Medicine 60*, 805-806.
47. Megdal, S. P., Kroenke, C. H., Laden, F., Pukkala, E., & Schernhammer, E. S. (2005). Night work and breast cancer risk: a systematic review and meta-analysis. *European Journal of Cancer*, *41*(13), 2023-2032.
48. Erren, T. C., Pape, H. G., Reiter, R. J., & Piekarski, C. (2008). Chronodisruption and cancer. *Naturwissenschaften*, *95*(5), 367-382.
49. Haldorsen, T., Reitan, J.B., Tveten, U. (2001). Cancer incidence among Norwegian airline cabin attendants. *Int J Epidemiol, 30*(4), 825–830.
50. Kainz, W., Posch, C., Vujic, I., Johnston, K., Gho, D., Monico, G., ... & Ortiz-Urda, S. (2014). The Risk of Melanoma in Airline Pilots and Cabin Crew A Meta-analysis.
51. Anses, Saisine n° 2011-SA-0088 « horaires atypiques », (2011). Évaluation des risques sanitaires pour les professionnels exposés à des horaires de travail atypiques, notamment de nuit.
52. Gassmann, A. S., Gonzalez, M., & Mathelin, C. (2015). Les hôtesses de l'air sont-elles à risque accru de cancer du sein ? *Gynécologie Obstétrique & Fertilité*, *43*(1), 41-48.
53. Linnersjö, A., Hammar, N., Dammstrom, B.G., et al. (2003). Cancer incidence in airline cabin crew: experience from Sweden. *Occup Environ Med, 60*(11), 810–814.
54. Lynge, E. (1996). Risk of breast cancer is also increased among Danish female airline cabin attendants. *Br Med J, 312*(7025), 253.
55. Schernhammer, E. S., Laden, F., Speizer, F.E., et al., (2001). Rotating night shifts and risk of breast cancer in women participating in the Nurses' Health Study. *J Natl Cancer Inst, 93*(20), 1563–1568.
56. Winder, C., Fonteyn, P., Balouet, J.-C. (2002). Aerotoxic syndrome: a descriptive epidemiological survey of aircrew exposed to in cabin airborne contaminants. *J. Occup. Health Saf., 18*, 321–338.
57. Schernhammer, E., Kroenke, C., Laden, F., et al., (2005). Night work and melatonin levels in women participating in the Nurses' Health Study II: associate with breast cancer risk. *In: 2nd symposium of the Dana–Farber/Harvard cancer center program in breast cancer 2005, Boston.*
58. Michaelis, S. (2010). *Health and Flight Safety Implications from Exposure to Contaminated Air in Aircraft* (Doctoral dissertation, PhD thesis, University of New South Wales).
59. Haghighat, F., Allard, F., Megri, A. C., Blondeau, P., & Shimotakahara, R. (1999). Measurement of thermal comfort and indoor air quality aboard 43 flights on commercial airlines. *Indoor and Built Environment, 8*(1), 58-66.
60. Touitou, Y., Reinberg, A., & Touitou, D. (2017). Association between light at night, melatonin secretion, sleep deprivation, and the internal clock: Health impacts and mechanisms of circadian disruption. *Life sciences.*
61. Touitou, Y., Coste, O., Dispersyn, G., & Pain, L. (2010). Disruption of the circadian system by environmental factors: effects of hypoxia, magnetic fields and general anesthetics agents. *Advanced drug delivery reviews, 62*(9), 928-945.

62. Jia, Y., Lu, Y., Wu, K., Lin, Q., Shen, W., Zhu, M., ... & Chen, J. (2013). Does night work increase the risk of breast cancer? A systematic review and meta-analysis of epidemiological studies. *Cancer epidemiology*, *37*(3), 197-206.
63. Nicholson, A. N. (2009). Intercontinental air travel: the cabin atmosphere and circadian realignment. *Travel medicine and infectious disease*, 7(2), 57-59.
64. Waterhouse, J., Reilly, T., Atkinson, G., & Edwards, B. (2007). Jet lag: trends and coping strategies. *The Lancet*, *369*(9567), 1117-1129.
65. Van den Bergh, J., Beliën, J., De Bruecker, P., Demeulemeester, E., & De Boeck, L. (2013). Personnel scheduling: A literature review. *European Journal of Operational Research*, *226*(3), 367-385.
66. Kim, J. B., & Kim, J. H. (2017). Regional gray matter changes in shift workers: a voxel-based morphometry study. *Sleep Medicine*, *30*, 185-188.
67. Haus, E. L., & Smolensky, M. H. (2013). Shift work and cancer risk: potential mechanistic roles of circadian disruption, light at night, and sleep deprivation. *Sleep medicine reviews*, *17*(4), 273-284.
68. Cho, K. (2001). Chronic 'jet lag' produces temporal lobe atrophy and spatial cognitive deficits. Nature Neuroscience, 4(6), 567-568.
69. European Council, Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks rising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC), *Official Journal of the European Communities L 177* (2002) 13–19.
70. International Commission on Radiological Protection (ICRP), "ICRP Publication 60. 1990 Recommendations of the International Commission on Radiological Protection", Ann. ICRP 21, 1–201 (1991).
71. International Commission on Radiological Protection (ICRP), *"The2007 Recommendations of the International Commission on Radiological Protection.* ICRP Publication 103", Ann. ICRP 37, 1–332 (2007).
72. European Communities. The basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. Luxembourg: Office for Official Publications of the European Communities; Council Directive 96/29/EURATOM of 13 May 1996; *Official Journal of the European Communities 39*:L159; 1996.
73. Sanlorenzo, M., Wehner, M. R., Linos, E., Kornak, J., Kainz, W., Posch, C., ... & McGrath, J. T. (2015). The risk of melanoma in airline pilots and cabin crew: a meta-analysis. *JAMA dermatology*, *151*(1), 51-58.
74. Friedberg, W., & Copeland, K. (2003). *What aircrews should know about their occupational exposure to ionizing radiation* (No. DOT/FAA/AM-03/16). FEDERAL AVIATION ADMINISTRATION OKLAHOMA CITY OK CIVIL AEROMEDICAL INST.
75. European Commission (2009). Radiation Protection No. 156: Evaluation of the implementation of radiation protection measures for aircrew. Luxemburg: Author.
76. Hampson, N. B., Kregenow, D. A., Mahoney, A. M., Kirtland, S. H., Horan, K. L., Holm, J. R., & Gerbino, A. J. (2013). Altitude exposures during commercial flight: a reappraisal. *Aviation, space, and environmental medicine*, *84*(1), 27-31.
77. Karasek Jr, R. A. (1979). Job demands, job decision latitude, and mental strain: Implications for job redesign. *Administrative science quarterly*, 285-308.
78. Demerouti, E., & Nachreiner, F. (2001). The Job Demands—Resources Model of Burnout. *Journal of Applied Psychology*, *86*(3), 499-512.
79. Ballard, T., Corradi, L., Lauria, L., Mazzanti, C., Scaravelli, G., Sgorbissa, F., ... Verdecchia, A. (2004). Integrating qualitative methods into occupational health research: a study of women flight attendants. *Occupational and Environmental Medicine*, *61*(2), 163–166.

80. ISO, ISO 7730: Moderate Thermal Environment-determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort, International Standard Organization, Geneva, 2005.
81. GB/T 50785, Evaluation Standard for Indoor Thermal Environment in Civil Buildings, General Administration of Quality Supervision, Inspection and Quarantine, Beijing, 2012 (in Chinese).
82. Hansen, J. (2017). Environmental noise and breast cancer risk? *Scandinavian Journal of Work, Environment & Health, 43*(6), 505-508.
83. McNeely, E., Gale, S., Tager, I., Kincl, L., Bradley, J., Coull, B., & Hecker, S. (2014). The self-reported health of US flight attendants compared to the general population. *Environmental Health, 13*(1), 13.
84. Marquie, J. C., Ansiau, D., & Rico Duarte, L. (2007, August). Ageing, shiftwork, and sleep disorders: Results from the VISAT longitudinal study. In *18th International Symposium on Shiftwork and Working Time, Yeppoon, QLD Australia* (pp. 28-31).
85. Glitsch, U., Ottersbach, H. J., Ellegast, R., Schaub, K., Franz, G., & Jäger, M. (2007). Physical workload of flight attendants when pushing and pulling trolleys aboard aircraft. *International Journal of Industrial Ergonomics, 37*(11), 845-854.
86. National Research Council (US) and Institute of Medicine (US) Panel on Musculoskeletal Disorders and the Workplace (2001). Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. Washington (DC): *National Academies Press* (US). 4, Epidemiologic Evidence. Available from: https://www.ncbi.nlm.nih.gov/books/NBK222426/
87. Cassou B., *et al.*, Évolution de la santé après la retraite et conditions de travail durant la vie active : à propos d'une cohorte de retraités parisiens suivis 10 ans (2001). In Travail, Santé, Vieillissement - Relations et évolutions, Toulouse, Octarès Ed., Collection Colloques: 115-123.
88. Cassou B., *et al.,* Facteurs prédictifs d'incapacité physique dans une cohorte de retraités parisiens suivis pendant 10 ans (1997). Rev Epidemiol Santé Publique, 45(5): 382-91.
89. Derriennic F., *et al.,* Evolution of osteoarticular disorders as a function of past heavy physical work factors: longitudinal analysis of 627 retired subjects living in the Paris area (1993). Br J Ind Med, 50(9): 851-860.
90. Ollac M. & Volkoff S. (2000). Les conditions de travail. Paris, La Découverte Ed., Collection Repères.
91. Monfort C., *et al.,* Conditions de travail et évolutions des douleurs musculoquelettiques chroniques du cou et des épaules. ESTEV analyse longitudinale 1990-1995 (2001). In Travail, Santé, Vieillissement – Relations et évolutions, Toulouse, Octarès Ed., Collection Colloques: 81-89.
92. Tourranchet A., Derriennic F., De Stampa M. (2001), Rôle de l'âge et des conditions de travail sur l'apparition et la disparition des troubles de la mobilité physique entre 1990 et 1995 dans l'enquête ESTEV, In Travail, Santé, Vieillissement - Relations et évolutions, Toulouse, Octarès Ed., Collection Colloques: 125-133.
93. Molinie AF. & Volkoff S., Départ en retraite : les deux facettes de la "pénibilité" du travail, Centre d'études de l'emploi (2003), Quatre pages (60): 1-4.
94. De Zwart B., *et al.*, Repeated survey on changes in musculoskeletal complaints relative to age and work demands (1997). Occup Environ Med, 54(11): 793-799.
95. De Zwart B., *et al.*, Selection related to musculoskeletal complaints among employees (1997). Occup Environ Med, 54(11): 800-806.
96. De Zwart B., Frings-Dresen M., Van Duivenbooden J., Senior workers in the Dutch construction industry: a search for age-related work and health issues (1999). Exp Aging Res, 25(4): 385-91.
97. Kreutz G., *et al.*, Vieillissement, santé, travail : état des lieux et perspectives de prévention (2004). INRS, *Documents pour le médecin du travail*, 97: 69-75.
98. Volkoff S. & Molinie AF, Éléments pour une démographie du travail, in JC.Marquié, D.Paumès, S.Volkoff, Le travail au fil de l'âge, Toulouse (1995). Octarès Ed., Collection travail: 99-119.

99. Compte rendu du groupe de travail « *Age et travail* » (2001) du Conseil d'orientation du travail, 10 mai 2001.
100. Syndex, Better understanding of arduous occupations within the European Pension Debate (2014). Final report.
101. Lasfargues G., Molinie AF. & Volkoff S., Départs en retraite et travaux pénibles (2005). Centre d'études de l'emploi : Rapport de recherche.
102. Zaidi A. & Whitehouse E., Should pension system recognise "Hazarduous and arduous work"? (2009). OECD social, employment and migration working paper n°91.
103. Struillou Y, Pénibilité et retraite (2003). Rapport remis au Conseil d'orientation des retraites.

Webography

CALI-6 software free download version:
https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6/
[retrieved on 29th September 2017].

CALI-6 software free online version:
http://jag.cami.jccbi.gov/cariprofile.asp *[Retrieved on 29th September 2017].*

EU publications on Radioprotection:
https://ec.europa.eu/energy/en/radiation-protection-publications *[Retrieved on 29th September 2017].*

US publications on Radioprotection:
https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/reports/
[Retrieved on 29th September 2017].

Open letter of 31st from Global Cabin Air Quality Executive (GCAQE) to EASA:
https://gcaqe.org/wp-content/uploads/2017/08/GCAQE-letter-to-Patrick-Ky-EASA_31-July-2017.pdf
[Retrieved on 12th October 2017].

Eurostat – Statistics explained
http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Life_expectancy_at_birth,_1980-2015_(years).png
[Retrieved on 4th December 2017].