Pilot Fatigue Risk Analysis: Conceptual Study at Flight Operation of Garuda Indonesia’s Boeing 737 Pilots

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Abstract. Fatigue in aviation is a critical field, since it will influence many passengers’ safety. Garuda Indonesia is a Flag Carrier of the largest archipelago national, which cover three different time zones. This study aims at analyzing the airline pilot’s fatigue contributors at Boeing 737 fleet, the short to medium haul flight operation workhorse of Garuda Indonesia, which fly domestic and regional flights. While in the aviation industry, most of the human factors related fatigue research focused on long-haul pilots, since the exposure of their duties towards jet-lag. However, short-haul pilots experience of flight operation of less than 8 hours flight time per flight sector, multiple flight sectors a day, with the set of two pilots for each rotation pattern causes their elevated levels of fatigue. Classification of fatigue are; physical decline, mental decline, and rest defects. Fatigue of Garuda Indonesia’s Boeing 737 pilot is affected by; duty assignment, personal lifestyle, work environment, rest environment, unresolved stress, and illness. Finding the variables and the phenomenon can also contribute to pilot fatigue management.

1. Introduction
From 1959 to 2015, the number of commercial aircraft of departures (713 million), and more significantly, the number of flight hours (1,321 million) increased[1]. The accidents may be reduced; hence, the fatalities are considerably high compares to the number of aircraft accidents[1][2].

Referring to the non-stop flight time, flight operations are categorized as short-haul flight (<8hrs) and long-haul flight (≥8 hours) [3]. The specific characteristic of long-haul flight operation includes more than three time-zone crossing per flight sector. early-morning arrival, and low work tempo. While on short-haul flight operation, the characteristic includes, multiple flights per duty day, highly dynamic environment, and constant high tempo workload [4]. As a result more take-offs and landings, the most dangerous stages of flight which involves the most significant workload, than long-haul pilots, per duty period[3].

Over the last 20 years, human factors are identified as one of the potentials to compromise the safe operation of the flight, while fatigue has been identified as a causal factor [3]. To manage and improve safety, human factors is believed as the critical determinants [5]. The “Swiss cheese” model of human error, by James Reason, describes four levels of human failure, each influencing the next[6]. Nearly 80% of all aviation accidents linked directly to the unsafe acts of pilots, while substandard conditions of the pilots, including adverse mental/ physiological states, and physical/ mental limitation developed...
as one of the principal subdivisions for unsafe aircrew conditions [6]. Fatigue, subjective or physiological, consider as a substandard condition, which degrades the ability of a person to stay alert and awake, while attentive to their vehicle safe controlling demands; also, fatigue impairs our ability to judge just how fatigued we are [7].

Pilots commonly associate their fatigue with night flights, jet lag, early wake-ups, time pressure, multiple flight legs, consecutive duty periods and long duty days without sufficient recovery breaks, weather, turbulence, and time zone transitions[8].

Availability of fatigue countermeasures is critical to help manage the often overwhelming osleep disruption effects caused by duty schedule’s frequent changes, including early morning flights, successive early wake-up, late night arrivals, multiple daily flight, overnight flight, alternating day-night transitions, long consecutive duty days, extended duty period, and transit time [9–12], smoking, caffeine consumption, sleep/ wake-up habit [8,13–16], bumpy flights, vibration, air pressure change, oxygen level, humidity, air temperature, noise [17–20], stress, personal problems [16,21], rest environment[9], and illness [16,22].

Operating a modern airliner are susceptible to fatigue related impairment, hence, requires the pilot’s technical and non-technical competencies [23]. Therefore, an item of “Reduce Accidents and Incidents Caused by Human Fatigue in the Aviation Industry” has included as an action area by the US National Transportation Safety Board (NTSB), an independent Federal agency which in charged for determining the probable cause of transportation accidents and promoting transportation safety, in their aviation safety “Most Wanted List” [7].

Majority of airline operator in Indonesia are short-haul fight operator, and this research aims to contribute more conceptual research towards short-haul operations. As significant fatigue effects on safety and operational continuity of an airline, this research aims to answer these problems:

1. Recognize and determine the contributing factors of pilot fatigue which existed in Garuda Indonesia’s Boeing 737 fleet flight operations.
2. Determine which contributing factors the significant impact on pilot fatigue in Garuda Indonesia’s Boeing 737 fleet flight operations.
3. To introduce the pilot fatigue risk contributor on short-haul flight operation for supporting flight operations and planning efficiency and effectivity improvement.

2. Background

2.1. Human Factors in Aviation

Accident attribution exclusively to pilot mistake is like a physician telling the customer that he or she is "ill" without examined the causes of the disease further [6]. To understand more about human error, we must be familiar with human factors. Human factors include individuals residing and operating; the way they relate to devices, processes and the surrounding atmosphere; and the way they relate to others. The different components of Human Factors are introduced in 1975 by Frank Hawkins, called SHEL model; the name is derived from the initial letters of its components, Software, Hardware, Environment and Liveware [24]. Liveware is the human being, the critical and versatile element in the scheme, in the middle of the design. There are significant efficiency changes and many constraints for people [24].

Human Factors will impact two broad areas of the system’s effectiveness; safety and efficiency, and the well-being of operational personnel which jointly interrelated overlap and affect each other[24]. The well-being of operation personnel, physical and mental, are affected by fatigue[25].

2.2. Fatigue

Fatigue is acknowledged as a familiar feeling induced by a range of daily operations, but also as one of the important variables which can affect human performance and has been quoted as a cause of injuries and accidents in the transportation sector, including air travel[9].

Sleep is a significant factor that determines fatigue[9]. The appropriate level of alertness and performance is needed by pilots to perform their duties, while it would be difficult when sleep is either
reduced or misalign in relation with their circadian nadir of alertness [26]. Sleep and circadian rhythm disruption contribute the most to waking alertness and human performance[27]. Aviation workplace involves many variables, including personal and family matters, change in time zones, displaced work schedules and extended periods of job, which result in subjective and physiological fatigue, errors induced by cognitive performance decrements, and safety risks [9,28,29].

Fatigue is identified as a subjective experience and classified into physical decline[20][30], mental decline[9,31], and rest defect [9,30,32].

2.3. Pilot Fatigue in Short-Haul Flight Operations
Pilot fatigue in long-haul air transport operations in the aviation industry as drawn more attention by most of the field-based researchers, rather than short-haul operations [33–36].

Short-haul operations related previous studies indicate that short-haul pilots may experience relatively high levels of fatigue, which the major causes are long early start times and duty periods [4,37–39]. Compared to earlier observations from the train industry, pilots were assumed to get less sleep and more tired for service periods that were initiated earlier in the morning compared to those who starts later in the morning [40–42]. Additionally, short- to medium-haul pilots allegedly suffer from pre-hypertension diastolic blood pressure condition of 81-84 mmHg as added risk towards their fitness level [43].

2.4. Fatigue Management in Aviation
In the day-to-day, operation, fatigue is inevitable since the human’s physical and mental capability can only function optimally with unrestricted sleep at night. Therefore, as fatigue cannot be eliminated, it must be managed [44].

Hours of service guidelines alone are not sufficient to minimize fatigue and optimize on the job alertness in safety-sensitive contexts [45]. Consideration must be given to the type of job being performed, the time of day at which the job is being performed, the work environment, the amount/quality of pre/off-duty sleep, the accumulation of chronic sleep debt, the extent of continuous wakefulness, the amount of time on task, and the level of individual fatigue resistance [11].

The industry recognizes two distinct approaches to fatigue management: Prescriptive Approach and Proactive Approach (Fatigue Risk Management System/ FRMS)[46]. Today, the pilot duty time and limitations for airline pilot in Indonesia are regulated in the Civil Aviation Safety Regulation (CASR) part 121. Indonesia’s CASR still uses the prescriptive approach towards pilot duty and rest limitation, but actively develop the FRMS, according to the International Civil Aviation Organization (ICAO) published recommendations, entitled The Manual for the Oversight of Fatigue Management Approaches, Fatigue Management Guide for Airline Operators [44][46].

3. Research Methods and Framework

3.1. Research Subjects

3.1.1. Garuda Indonesia in Brief. Garuda Indonesia right now is the only state-owned airline company in Indonesia and serve to ensure same day connection through air transportation to the corners of the archipelago with the capital city of Jakarta. The flight from Jakarta, Garuda’s pilot home base to Jayapura, Papua, the furthest domestic direct flight (3,778 km), crosses two different time zones. Garuda also operates International flights to countries in Asia, Australia and Europe[46]. One of the aircraft types which becomes the workhorse of Garuda Indonesia is the Boeing 737. Garuda operates their 82 Boeing 737 for around 300 domestic and regional flights sectors per day[46].

3.1.2. The Boeing 737. Boeing has been the premier manufacturer of commercial jetliners for decades. More than 10,000 Boeing-built commercial jetliners are in service worldwide, which is almost half the world fleet [47]. The Boeing 737 is one of the most popular models by the Boeing Commercial Airplanes
Industry, a short to medium range (5000+ km) twinjet narrow-body airliner which can travel at around 0.8 times the speed of sound [48]. Meaning, it can fly from Jakarta to Jayapura in about 6 hours while carrying 160+ of passengers.

3.2. Pilot Interview
Based on the literature review, preliminary interview conducted towards seven SMEs consists of five active Garuda Indonesia Pilots and two of Garuda Indonesia’s in-house Flight Surgeon Medical Doctors to elicit practical experiences and opinions.

3.3. Research Model
Research model as depicted in Figure 1 is constructed based on the literature review analysis and further modified from the model created by Lee and Kim (2018), by not including the flight direction, since due to the nature of short-haul flight operations, merge the crew scheduling and partnership in one variable of duty assignment [12], maintain the variable of working environment, and add two variables, which are unresolved stress, which includes differences of values between working partners, household tension, preoccupation and personal problems; and illness, which includes managed allergies and perceived unfit condition [16][49], and change the variable name, instead of hotel environment becomes rest environment to accommodate other than hotel rest accommodation.

![Figure 1. Research Model.](image)

3.4. Hypotheses

3.4.1. Duty Assignment. Long working days, early departures, late entries and non-standard working hours include night duties and schedule changes are constant for the pilots [28]. Duty assignments are known to affect sleep and subsequent alertness, although already within regulated time limits [48]. Multiple departures and arrivals per day create significant stress levels; owing to late arrival, sleep can either be postponed, or may be resulted as an unwanted early wake up [49]. The amount of sectors and duty length were the most critical influence in short-haul activities [39][50].

_Hypotheses 1._ The Duty Assignment has a positive effect on pilot fatigue.

3.4.2. Personal Lifestyle. Clinicians are undoubted of the effects of lifestyle on health. People with sleep problems often have poor lifestyles including obesity, absence of physical activity, hard work and cigarette smoking[14]. Cigarette smokers are more likely than non-smokers to report going to sleep difficulties and problems staying asleep [8]. The excessive use of caffeine may exacerbate an anxiety disorder [8]. Hence, the side effects can include increased heart rate, nervousness, anxiety, restlessness, nausea and increased frequency of urination, as well as reductions in fine motor control [13]. The lifestyle of practicing heavy physical exercise considered as strenuous activity, which also contributes
towards fatigue [16]. The moment an individual is asleep may influence the sleep cycle framework. Disrupting the quality and amount of restful sleep subsequently poses a potential safety hazard on the flight deck [8].

Hypotheses 2. Imbalance Personal lifestyle has a positive effect on pilot fatigue.

3.4.3. Undesired Working Environment. Pilot’s working environment, with the maximum permissible cabin altitude of routine commercial flight at high altitude of 8000 feet, when exposed for several hours may result in noticeable fatigue and potentially more significant medical problems, probably caused by the mixture of moderate hypoxia, abdominal gas extension, absence of motion and sitting position [52]. Pilots also exposed to various stresses from continuously pay attention to automatic digital instruments [53]. In the same time, vibration interfere with neuromuscular control and lead to fatigue[53], and noise, defined mainly as unwanted sound, affects communication and may damage the hearing mechanism, the result is increased levels of stress and fatigue [52].

Hypotheses 3. Undesired working environments have a positive effect on pilot fatigue.

3.4.4. Unresolved Stress. It has been said that the eternal hanging of an incomplete task is the most fatiguing. Personal problems which not resolved drains the body of energy and also associated with depression, and have a particular contribution towards fatigue [16].

Hypotheses 4. Unresolved stress has a positive effect on pilot fatigue.

3.4.5. Rest environment. The uneasy or unknown setting; sound, light, warmth and cold, impairs relaxation, as does the bed which is seen as too difficult or too smooth, the cushion which does not correctly promote the head and neck, may distort sleeping tranquillization [8,55]. In this case, the rest environment includes the room condition, distance from activity places, and neighborhood [44,56].

Hypotheses 5. An improper rest environment has a positive effect on pilot fatigue.

3.4.6. Illness. Some pilots may perceive some illness as prevalent, such as common cold, and also well-managed asthma, allergies or a sleep-disturbing pathological condition which also contribute to fatigue significantly when relapse [16]. Several other medical conditions include blocked sleep apnoea, restless leg syndrome, medicines, anxiety, sleeplessness, and acute suffering [53]. Sedation or drowsiness is the side effect when the body fights illness through its metabolic defenses, the fatiguing effects of the illness itself impaired alertness [16][53].

Hypotheses 6. Illness has a positive effect on pilot fatigue.

3.5. Pilot Survey
Survey to Garuda Indonesia’s B737 pilots conduct afterward, and the result analyses to find out which factor contributes a more significant effect than the other. The above contributing factors may be perceived differently in the flight operation’s workload, which makes short-haul flight operation fatigue perception is different compared to long-haul flight operation.

3.6. Sample Size
This research use probability samples for unbiased inferences about the population of interest [55].

The formula used for calculating sample size is:

$$n = (p (100-p) z^2) / E^2$$

Where: $n$ is the required sample size, $p$ is the percentage occurrence, $E$ is the percentage maximum error required, and $Z$ is the value corresponding to the level of confidence required.

In management and social research, the confidence level of 95% ($Z=1.96$) considered as typical, 5% considered as acceptable margin of error, and $p$ estimate of 50% considered as suggested for maximization of variance and produce maximum sample size. From this calculation, with a population of 600 personnel, the minimum sample would be 234 respondents.
References
[1] Boeing 2016 Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operation 1959-2015 available at www.boeing.com/news/techissues/pdf/statsum.pdf
[2] Flight Safety Foundation 2018 Fatal Accidents per year 1946-2017 Available at https://www.aviation-safety.net/graphics/infographics/Fatal-Accidents-Per-Year-1946-2017.jpg
[3] Roach GD, Sargent C, Darwent D and Dawson D 2012 Accid. Anal. Prev 45 22–6
[4] Gander PH, Gregory KB and Graeber RC 1998 Aviat. Sp. Env. Med. 69 B8–15
[5] National Aeronautics and Space Administration (NASA) 1999 An Analysis of Part 121/135 Duty Schedule-related Fatigue Incidents (NASA Aviation Safety Reporting System)
[6] Shappell SA, Wiegmann DA 2000 The Human Factors Analysis and Classification System – HFACS. DOT/FAA/AM-00/7 Off. 2000;DOT/FAA/AM:15.
[7] National Transportation Safety Board (NTSB) 2016 Most Wanted Transportation Safety Improvement: Reduce Fatigue-related accidents available at: www.ntsb.gov/mostwanted
[8] Caldwell JA 2016 Ernsting’s Aviation and Space Medicine (Boca Raton: CRC Press)583–600
[9] Lee S and Kim JK 2018 J. Air. Transp. Manag. 67 197–207
[10] Hartzler BM 2013 Accid. Anal. Prev 62 309–18.
[11] Federal Aviation Administration (FAA) 2012 available at http://www.faa.gov/
[12] Goode JH 2003 J. Safety. Res. 34 309-13
[13] Goodman IS and Gilman A Goodman & Gilman’s The Pharmacological Basis of Therapeutics ed.3 1966 (New York: Macmillan)
[14] Phillips BA and Danner FJ 1995 Cigarette Smoking and Sleep Disturbance. Addict Disord their Treat 17 40–8.
[15] Farhoomand A, Joshi H and Tsang S 2009 Nintendo’s Disruptive Strategy: Implications for the Video game industry (Asia Case Research Center: The University of Hongkong)
[16] Reinhart RO 2007 Basic Flight Physiology. 3rd ed (New York: McGraw-Hill) 311
[17] Vink P, Bazley C, Kamp I and Blok M 2012 Appl. Ergon. 43 354-9
[18] Ciloglu H, Alziadeh M, Mohany A and Kishawy H 2015 Int. J. Ind. Ergon. 45 116-23
[19] Maier J and Marggraf-Michele C 2015 Build. Environ. 84 214-20
[20] Dawson D and McCulloch K 2005 Sleep. Med. Rev. 9 365–80
[21] Civil Aviation Authority (CAA) 2014 Flight-crew human factors handbook. (Sussex: Civil Aviation Authority) 242
[22] Davies G. Respiratory Disease 2016 In: Gradwell DP, editor Ernsting’s Aviation and Space Medicine. 5th ed. Boca Raton: CRC Press 427–40.
[23] International Civil Aviation Organization (ICAO) 2013 1st. ed. (Montreal: International Civil Aviation Organization)162
[24] International Civil Aviation Organization (ICAO) 1998 Human Factors Training Manual (Montreal: International Civil Aviation Organization)
[25] Dumitru IM and Boscoiuia M 2015 Int. Conf. of Scientific Paper AFASES 2015 (Brasov) 22–4
[26] Sallinen M, Sihvola M, Puttonen S, Ketola K, Tuori A, Härmä M, et al. 2017 Accid. Anal. Prev. 98 320–9
[27] Van Dongen H and Dinges D 2000 Princ. Pract. Sleep. Med. 3 391-9
[28] Caldwell JA 2005 Travel. Med. Infect. Dis. 3 85–96
[29] Mallis MM, Mejdal S, Nguyen TT and Dinges DF 2004 Aviat. Space Environ. Med. 75 A4-14
[30] Dinges DF, Graeber RC, Rosekind MR and Samel A 1996 Flight. Saf. Dig. 16
[31] Marcora SM, Staiano W and Manning V 2008 J. Appl. Physiol. 106 857–64
[32] Van Cauter E, Holmbeck U, Knutson K, Leproult R, Miller A, and Nedeltcheva A 2007 Horm. Res. Paediatr. 67 2-9.
[33] Darwent D, Dawson D and Roach GD 2010 Sleep 33 185-95
[34] Petrilli RM, Roach GD, Dawson D and Lamond N 2006 Chronobiol. Int 23 1357-62
[35] Signal TL, Gale J and Gander PH 2005 Aviat. Space Environ. Med. 76 1058-63
[36] Spencer MB, Stone BM, Rogers AS and Nicholson AN 1991 Aviat. Space Environ. Med. 62 3-13
[37] Bourgeois-bougrine S, Cabon P, Mollard R, Coblentz A, and Speyer J 2003 Hum. factors. Aerosp. Saf. 3 177–87
[38] Jackson CA and Earl L 2006 Occup. Med. 56 263-8
[39] Powell DMC, Spencer MB, Holland D, Broadbent E and Petrie KJ 2007 Aviat. Sp. Environ. Med. 8 698–701
[40] Ingre M, Kecklund G, Åkerstedt T, Söderström M and Kecklund L 2008 Biol. Rhythm Res. 25 349-58
[41] Sallinen M, Härmä M, Mutanen P, Ranta R, Virkkala J and Müller K 2005 Ind. Health 43 114-22
[42] Roach GD, Reid KJ, Dawson D 2003 Occup. Environ. Med 60 e17
[43] Yuliawati I, Yuliana, Ningsih KU, Wahdah N, Ariani S and Khrisnapandit I 2018 Hasil Kajian Balai Kesehatan Penerbangan tentang Fatigue Risk Management System: Pengaruh faktor resiko kelelahan terhadap obesitas pada personil penerbangan di Indonesia. Balai Kesehatan Penerbangan 48.
[44] International Civil Aviation Organization (ICAO) 2017 Doc 9966 Manual for the Oversight of Fatigue Management Approaches. 2nd ed. (Montreal: International Civil Aviation Organization) 202
[45] Lerman SE, Eskin E, Flower DJ, George EC, Gerson B and Hartenbaum N 2012 J. Occup. Environ. Med. 54 231-58
[46] PT Garuda Indonesia (Persero) Tbk. Company Profile 2018 available at https://www.garuda-indonesia.com/id/en/corporate-partners/company-profile/index.page?
[47] Boeing. Boeing in Brief 2018 General Information available at http://www.boeing.com/company/general-info/index.page/#/overview
[48] Thomas LC, Gast C, Grube R and Craig K 2015 Procedia Manuf. 3 2357-64
[49] Bourgeois-Bougrine S, Carbon P, Gounelle C, Mollard R and Coblentz A 2003 Aviat. Sp. Environ. Med. 74 1072–7
[50] Yuliawati I, Barus SB, Aryani S, Taryanto M, Mariska I, and Haryati ER 2015 Hasil Penelitian Balai Kesehatan Penerbangan tentang Faktor resiko kelelahan pada personil penerbangan sipil dalam rangkapenerapan Fatigue Risk Management System di Indonesia (Balai Kesehatan Penerbangan) 103
[51] Gradwell D and Rainford D, editors 2016 Ernsting’s Aviation and Space Medicine 5 (CRC Press)
[52] Rood GM and James SH. Noise 2016 In: Gradwell DP, editor. Ernsting’s Aviation and Space Medicine. 5th ed (Boca Raton: CRC Press) 747–67.
[53] Salazar GJ and Caldwell JA 2010 Travel. Med. Infect. Dis 3 85–96
[54] Rudari L, Johnson M, Geske R and Sperlak L 2016 Int. J. Aviat. Aeronaut. Aerosp 3
[55] Levine DM, Stephan DF, Krehbiel TC and Berenson ML 2008 Statistics for Managers using Microsoft Excel. 5th ed. Nakosteen R, editor. (Boston: Prentice Hall) 562
[56] Kotlik JW and Higgins CC 2001 ITLPJ 19 43
[57] Taherdoost H 2016 Int. J. Acad. Res. Manag. 5 18–27