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Effectiveness of Flight Time Limitation (FTL 2.0)

DELIVERABLE 1.1: DEFINITION OF BASELINE

An Agency of the European Union

Disclaimer

DELIVERABLE NUMBER AND TITLE: **FTL D1.1 Definition of baseline – Literature review** (final)
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SUMMARY

The research study FTL 2.0 aims to perform a review of the effectiveness of the provisions concerning flight and duty time limitations and rest requirements contained in Annexes II and III of Commission Regulation (EU) No 965/2012. More specifically, the main purpose is to add to, and subsequently wrap up, the work performed during the first phase of the “Effectiveness of Flight Time Limitation” evaluation (MOVE/C2/2016-360).

The main objective of this first task was to perform a review of the state of the art to define a detailed baseline for the activities to be performed in the FTL 2.0 research study, including lessons learned gathered from experts in aircrew fatigue. The systematic literature search led to the inclusion of 46 studies. The collected state of the art was subsequently mapped using the extracted study data and synthesising the findings of the medium and high relevance studies.

No relevant studies were identified for the FDP ‘Duties of more than 13 hours at the most favourable time of the day’, revealing a profound lack of studies for this FDP, particularly in 2-pilot crews. The findings generally indicate that flight duration (for which effects are modulated by sleep-homeostatic components) and flight timing (for which effects are modulated by the circadian clock) interact on fatigue, sleepiness, and cognitive performance, suggesting that any assessment of long flight durations must take into account the timing of flights (i.e., during the WOCL).

Five highly relevant studies were identified for the FDP ‘Duties of more than 11 hours for crew members in an unknown state of acclimatisation’. Yet, only one study allowed to directly compare the exposure FDP with the primary control FDP, and none explicitly aimed to examine FDPs of different durations flown in an unknown state of acclimatisation. There is therefore a great need for additional high-quality research data in aircrew with the explicit aim to compare unknown state of state acclimatisation FDPs of durations more vs. less than 11h.

Three highly relevant studies were identified for the FDP ‘Duties including a high level of sectors (more than 6)’ but only one study investigated FDPs with more than 6 sectors. The findings emphasise the need to carefully balance FDP length and number of sectors, to avoid potential confounding effects between these two factors. Furthermore, the studies showed the importance of adjusting for potential sleep loss, and of taking into account the specific working conditions (e.g. workload) at the airline conducting the multiple sector operation.

No relevant studies were identified for the FDP ‘On-call duties such as standby or reserve followed by flight duties’, revealing a profound lack of research into on-call duties in aircrew. Furthermore, the studies conducted in non-aircrew populations mostly did not differentiate between on-call duties with and without calls, emphasising the need to study on-call duties with a specific focus on actually ‘being called’.

One highly relevant study was identified for ‘Controlled rest’. Generally, the identified studies supported ‘controlled rest’ as a successful mitigation strategy for unexpected fatigue. The exact CR procedures, however, vary across airlines and need to further investigated. In addition, the effects of sleep inertia are scarcely discussed and need to be considered for the purposes of the current study.

The lessons learned gathered from interviews held with experts on aircrew fatigue emphasised gaining trust and increasing motivation of the participants, enlisting the help of management and unions. Furthermore, potential differences in recruiting strategies for cockpit vs. cabin crew as well as ways to increase sample size while maintaining data quality were emphasized.

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
CR	Controlled Rest
DLR	German Aerospace Centre
EASA	European Aviation Safety Agency
EU	European Union
FDP	Flight Duty Period
FTL	Flight Time Limitation
HRV	Heart Rate Variability
KSS	Karolinska Sleepiness Scale
LH	Long-Haul
NLR	Royal NLR - Netherlands Aerospace Centre
ORO	Organisation Requirements for Air Operations
PVT	Psychomotor Vigilance Test
SH	Short-haul
SP	Samn-Perelli Fatigue Scale
TOC	Top-of-Climb
TOD	Top-of-Descent
ULR	Ultra-Long Range
WOCL	Window Of Circadian Low

1. Introduction to the research study

1.1 Background

During the adoption of a next generation of EU Flight Time Limitation (FTL) requirements for scheduled and charter airline operations, the European Parliament and the Commission instructed EASA to perform a continuous review of the effectiveness of those requirements. This instruction is enshrined in paragraph 9a of Commission Regulation (EU)
No 965/2012[1], which stipulates that the review shall include an assessment of the impact on aircrew alertness of the following Flight Duty Periods (FDPs):

1. Duties of more than 13 hours at the most favourable time of the day;
2. Duties of more than 10 hours at the less favourable time of the day;
3. Duties of more than 11 hours for crew members in an unknown state of acclimatisation;
4. Duties including a high level of sectors (more than 6);
5. On-call duties such as standby or reserve followed by flight duties; and
6. Disruptive schedules.

The review process started in 2017 with the commissioning of a scientific study. In view of the large scope of the task, it was decided to split the set of six FDPs into two groups. The commissioned study started by ranking the six FDPs according to their potential to induce fatigue, identifying 'duties of more than 10 hours at the less favourable time of the day' (2.) and 'disruptive schedules' (6.) as the most fatiguing FDPs, leaving the remaining four FDPs (1., 3., 4., 5.) for evaluation in the current study.

1.2 Main objective and scope of the research study

On 18 February 2019, EASA issued a comprehensive report on the results of the research directly related to the two top-ranking FDPs. In its findings, the report highlighted a considerable frequency of in-flight naps that were observed during the data collection. On this issue, the Scientific Committee (a group of independent scientific experts set up by EASA to award, steer, and assess the outcome of the work) indicated that regulators, operators, and researchers need to better understand the impact of such in-flight naps. The assessment of the effect of short naps in the cockpit – the so-called 'controlled rest' (CR) – was therefore added to the assessment of the remaining four FDPs.

The main objective of this research study (FTL 2.0) is to perform a review of the effectiveness of the provisions concerning flight and duty time limitations and rest requirements contained in Annexes II and III of Commission Regulation (EU) No 965/2012. More specifically, the main purpose is to add to, and subsequently wrap up, the work performed during the first phase of the "Effectiveness of Flight Time Limitation" evaluation (MOVE/C2/2016-360).

[1] https://www.easa.europa.eu/en/document-library/regulations/commission-regulation-eu-no-9652012

1.2.1 Task 1.1: Specific objectives and technical tasks

The main objective of this task is to perform a review of the state of the art collecting the required background information that is relevant for establishing a robust and detailed baseline for the activities to be performed in this research study. The deliverable includes a mapping of the collected state of the art that is perceived as relevant for the work to be carried-out herein with the appropriate bibliographical support, as well as the elaboration of a revised work program that reflects both best scientific/technical approaches available and the 'lessons learned' from previous work.

1.3 Scope of the current deliverable

The deliverable D1.1 describes the process and reports the results of the systematic literature search, including a mapping of the collected state of the art deemed relevant for the study activities to be carried out. The 'lessons learned' were collected from both a scientific and technical point of view, interviewing experts in the field of aviation from research, airline representation, and project management.

2. Review of the state of the art

2.1 Critical assessment of existing references

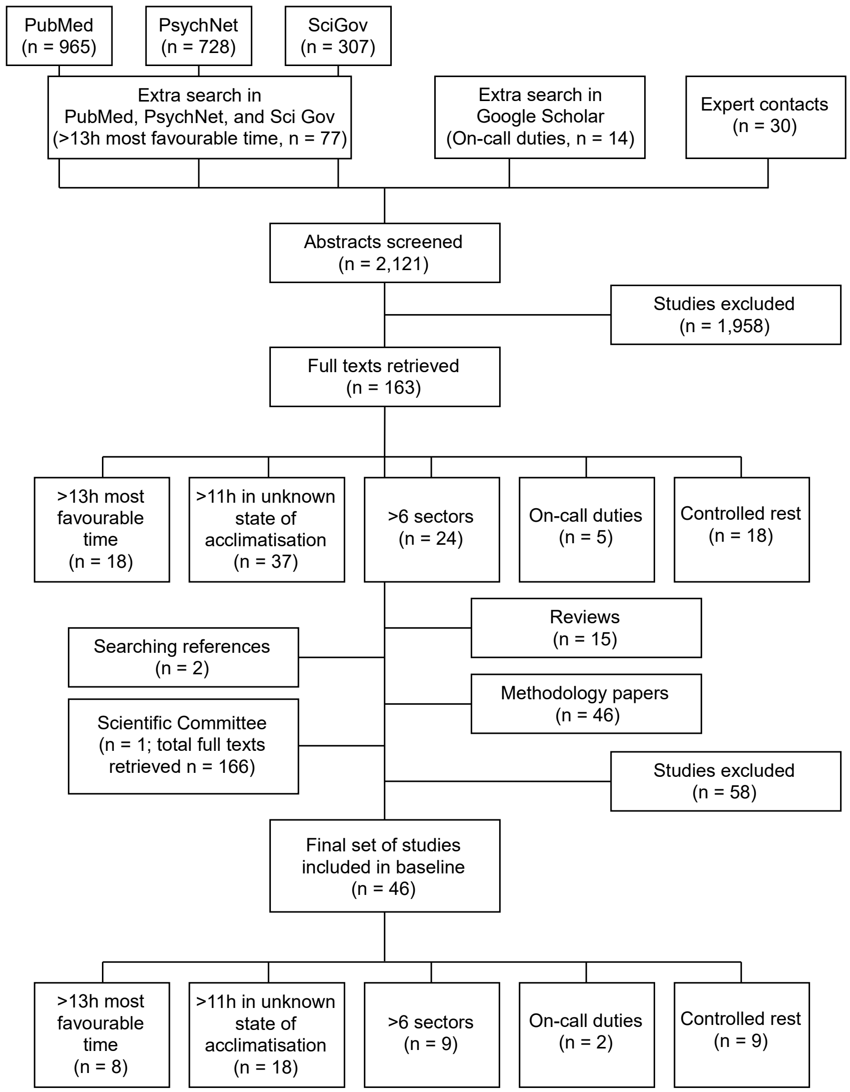
2.1.1 Literature search strategy and process

A systematic search was performed on January 4, 2022, by the NLR library department/information centre in three different search engines (PubMed, PsychNet, and ScienceGov). The search combined search terms relating to the population (i.e., pilots, aircrew, cabin crew) and outcome of interest (i.e., fatigue, alertness), but deliberately did not include search terms regarding the intervention/exposure – the four FDPs and CR –, to minimise the risk of excluding potentially relevant studies. Different combinations of – or variations of – the search terms fatigue, sleep(iness), drowsiness, alertness, vigilance, workload, flight-/aircrew, pilot, and cabin crew, were used. The detailed search strategy is listed in Appendix A. In order to balance mapping the most recent state of the art with including relevant studies, the cut-off for publication date was set to ≥ 1980, and publication language was limited to English, Dutch, and German. Besides field-studies, both survey- and lab-studies were included.

Additional references were identified by manually searching bibliographies of the retrieved publications. Furthermore, scientists from within the project team's network were requested to provide relevant and/or most recent publications on fatigue and alertness studies in aircrew. Two additional searches were performed. One for on-call duties, due to a limited number of references yielded by the engine-based search; the extra search was conducted in Google Scholar using the same search terms as in the engine-based search, i.e., combinations and variations of the search terms on-call, standby, reserve and the above-listed search terms regarding population and outcome. Another additional search was performed for the FDP '>13h duties at the most favourable time of day' in the three search engines with an explicit focus on 2-pilot duties of more than 13 hours; 2-pilot duties of such length are only legal in combination with commander's discretion or operator's extension (allowable twice a week) or with a break on the ground (i.e., split duty). Hence, the extra search added the terms 'basic crew' (for target population) and 'split duty/duties', 'extended duty/duties', and 'commander discretion' (for schedules/exposure).

A flowchart depicting an overview of the search process is shown in Figure 1. A total of 2,121 abstracts were identified through databases and contacting peer-scientists. The abstracts were screened on relevance by two independent reviewers, yielding an overall agreement rate of 96%. Disagreements were resolved by inclusion of the respective publications. The full texts of 163 studies were retrieved, with the highest number retrieved for '>11h duties in an unknown state of acclimatisation' (n = 37), followed by 'duties with >6 sectors' (n = 24), 'controlled rest' (n = 18), and '>13h duties at the most favourable time of day' (n = 18) (taking into account the additional search in PubMed, PsychNet, and SciGov), and the lowest number retrieved for 'on-call duties' (n = 5) (taking into account the additional search in Google Scholar). Additionally, 15 reviews were identified yielding two additional relevant studies as well as one additional study selected through members of the Scientific Committee (raising the total of retrieved full texts to 166). Furthermore, 46 potentially relevant methodology papers were identified, describing various approaches and instruments to assess fatigue/sleepiness, performance, alertness, and/or workload in operational settings. The 46 publications concerning methodology will be used as an integral part of Task 2.1, to define the scope and process of the data collection, including selecting the most appropriate set of measures.

Figure 1. Flowchart of the systematic search process. Two additional searches were performed: (i) in PubMed, PsychNet, and SciGov for the FDP '>13 h duties at the most favourable time'; and (ii) in Google Scholar for the FDP 'On-call duties'



Based on assessments of the 166 full texts, a final set of 46 studies was included (28% inclusion rate). Exclusion criteria were: relationship between outcome (i.e., fatigue, alertness) and FDP not studied; no outcome (i.e., stress); no exposure (i.e., # of sectors not reported); not in commercial aircrew (i.e., military, emergency medical services). Of the included 46 studies, a majority of 18 studies (39%) was deemed relevant for the FDP '>11h duties in an unknown state of acclimatisation', followed by 9 studies (19.5%) for 'controlled rest' and 9 studies (19.5%) for the FDP 'duties with >6 sectors', with 8 studies (17.5%) deemed relevant for the FDP '>13h duties at the most favourable time of day' and 2 studies (4.5%) for the FDP 'on-call duties'. The included publications were systematically assessed, extracting the following information:

- Primary FDP;
- Other FDPs (if applicable);
- Flight route/s;

- Country/ies of the operating airline/s (categorised as Europe vs. Non-Europe);
- Study design (e.g., field, survey, simulator);
- Type of operation (e.g., short-haul, long-haul, regional, mixed);
- Sample size and population (e.g., pilots, cabin crew);
- Measured variables, including the type of instrument/scale/test (e.g., Karolinska Sleepiness Scale (KSS), Psychomotor Vigilance Test (PVT));
- Main findings;
- Relevance for the purpose of establishing a baseline (low, medium, high); and
- Other relevant information (FDP-specific, e.g., acclimatisation status).

A high relevance score was assigned when the study included: the FDP of interest, repeated measures, validated measures (i.e., KSS, PVT, Samn-Perelli Fatigue Scale (SP)), and FDP-relevant time points (i.e., on the inbound flight).

The collected state of the art was then mapped using the extracted study data and synthesising the studies' findings by relevance to establish a robust and detailed baseline. In line with the previous contract, we based the collected state-of-the-art on studies with medium to high relevance, excluding low-relevance studies.

2.2 Mapping of collected state of art

2.2.1 Synthesising the results of the literature search

The identified 46 studies were grouped according to FDP/CR assignment and EU vs. Non-EU setting, and further categorised according to their relevance for the current study, regarding background information needed to adequately perform the work required in the current study.

Date of publication of the 46 included studies ranged from 1986 to 2021. Nearly half of the studies were conducted in a European setting (20 studies, 43%) vs. a Non-European setting (22 studies, 48%), with 4 studies (9%) not reporting that information, respectively, reporting a mix of European and Non-European operations (i.e., review papers for the FDP 'on-call duties'). The vast majority of studies were conducted in pilots/cockpit crew (38 studies, 83%), with 6 studies (13%) conducted in cabin crew or a mix of pilots and cabin crew (the remaining 2 papers were reviews for the FDP 'on-call duties'). Virtually all studies included some form of repeated-measures regarding performance, fatigue, alertness, and/or sleepiness data, with 1 study reporting cross-sectional survey data and another 2 studies reporting register data of accidents. Sample sizes ranged from 7 to 6311 participants, with a median number of 50 participants per study. The type of operation was closely related to the type of FDP, with Ultra-Long Range (ULR) operations dominating the FDP '>13h duties at the most favourable time of day', LH operations dominating the FDP '>11h duties in an unknown state of acclimatisation' and 'controlled rest', and Short-haul (SH) dominating the FDP 'duties with >6 sectors'.

The relevance of all included publications for the current study was assessed, using scores of high, medium, and low relevance. In general, the majority of studies was assessed as having minor relevance for the purposes of carrying out the current study: 27 studies (59%) low relevance, 10 studies (22%) medium relevance, and 9 studies (19%) high relevance (across all FDPs and CR). Of the 8 included studies for the FDP '>13h duties at the most favourable time of day', all 8 studies were of low relevance. For the FDP '>11h duties in an unknown state of acclimatisation', the relevance of the 18 included studies was assessed as high/medium/low for 5/3/10 studies. Of 9 included studies for the FDP 'duties with >6 sectors ', 3 studies were of high relevance, followed by 4 and 2 studies of medium and low relevance, respectively. For the FDP 'on-call studies', the two included studies were both of low relevance. Of 9 included studies for 'controlled rest', one study was deemed high relevance, followed by 3 and 5 medium- and low-relevance studies, respectively. Tables 1-3 summarise descriptive characteristics of the studies with medium to high relevance only. A complete list of all included studies is provided in Appendix B.

Table 1. Included studies for the FDP 'Duties of more than 11 hours for crew members in an unknown state of acclimatisation' (medium to high relevance).

Authors	Year	Group	Region	Population	Variables	Number of participants	Type of operation	Relevance
Samel et al.	1997	EU	Germany	Pilots	SP, sleep log, PSG, NASA-TLX	N = 50	LH	High
Sallinen et al.	2021	EU	Finland	Pilots	KSS, sleep log, actigraphy	N = 86	LH	Medium
Samel & Wegmann	1987	EU	Germany	Cockpit crew	Circadian (body temperature, heart rate, cortisol)	N = 12	LH	Medium
Wegmann et al.	1986	EU	Germany	Cockpit crew	Sleepiness, sleep log, PSG	N = 12	LH	Medium
van den Berg et al.	2015	Non-EU	South Africa	Cabin crew	PVT, KSS, SP, sleep log, actigraphy	N = 55	ULR	High
Roach et al.	2012	Non-EU	Australia	Pilots	PVT, SP, sleep log, actigraphy	N = 19	LH	High
Powell et al.	2010	Non-EU	New Zealand	Pilots	Performance, KSS, SP	N = 105	LH	High
Petrilli et al.	2006	Non-EU	Australia	Pilots	PVT, SP, sleep log, actigraphy	N = 19	LH	High

Table 2. Included studies for the FDP 'Duties including a high level of sectors (more than 6)' (medium to high relevance).

Authors	Year	Group	Region	Population	Variables	Number of participants	Type of operation	Relevance
Åkerstedt et al.	2021	EU	Norway	Pilots, cabin crew	KSS, sleep log	N = 106	Ultra-SH	High
Sallinen et al.	2020	EU	Mixed	Pilots, cabin crew	KSS, sleep log, actigraphy	N = 392	Mixed	Medium
Goffeng et al.	2019	EU	Norway	Pilots, cabin crew	SP, diverse neuropsych. tests	N = 59	SH	Medium

Authors	Year	Group	Region	Population	Variables	Number of participants	Type of operation	Relevance
van Drongelen et al.	2013	EU	Netherlands	Cabin crew	Accidents	N = 6311	SH	Medium
Honn et al.	2016	Non-EU	US	Pilots	PVT, KSS, SP	N = 24	SH	Medium
Powell et al.	2008	Non-EU	New Zealand	Pilots	Alertness, SP	N/A (4206 obs)	SH	High
Powell et al.	2007	Non-EU	New Zealand	Pilots	Alertness, SP	N/A (2034 obs)	SH	High

Table 3. Included studies for 'Controlled rest' (medium to high relevance).

Authors	Year	Group	Region	Population	Variables	Number of participants	Type of operation	Relevance
Hilditch et al.	2020	EU	Mixed	Pilots	Sleep log, actigraphy	N = 44	LH	Medium
Eriksen et al.	2006	EU	Scandinavia	Pilots	KSS, sleep log, actigraphy	N = 20	LH	Medium
Rosekind et al.	1994	Non-EU	US	Pilots	PVT, KSS, sleep log, PSG, actigraphy	N = 21	LH	High
Gander et al.	1991	Non-EU	US	Pilots	Sleep log, circadian (body temperature)	N = 29	LH	Medium

The collected state of art was mapped based on the studies with the highest relevance (medium to high), since they offer the most useful background information to establish a robust and detailed baseline and to subsequently carry out the activities of the current study.

'Duties of more than 13 hours at the most favourable time of the day'. Of the final 46 selected studies, 8 (17.5%) were included for this FDP. Of these 8 studies, all were deemed low relevant. The **8 low-relevance studies** reported FDPs of more than 13h, yet in many cases they occurred during the night (i.e., least favourable time of day) and none of the studies were done in basic crews (i.e., 2-pilot crews). Findings suggested that ultra-long haul (> 16 h) were not inherently more fatiguing than long-haul (8-16 h) flights despite the longer duty times during ULR operations (Gander et al., 2013; Signal et al., 2014; Wu, 2013). One study (Gander et al., 2014) suggested that flight timing (arrival/departure times) may be more important than flight duration for fatigue and cognitive performance at Top of Descent (TOD). Another study (Lamond et al., 2006) evaluated the impact of different layover periods on cognitive performance during inbound flights of comparable duration (mean 14.3h ± 0.6h), showing slower PVT responses for short layovers prior to the inbound flight, irrespective of flight duration.

'Duties of more than 11 hours for crew members in an unknown state of acclimatisation'. Of the final 46 selected studies, 18 (39%) were included for this FDP. Of these 18 studies, 8 (44.5%) were deemed medium to high relevant. The 8 studies all allowed to determine a state of acclimatisation on the inbound flights, reporting number of time zones crossed, flight and/or FDP duration, and layover period (as defined by ORO.FTL.105 Table 1). In general, studies reported consistent findings of higher fatigue scores on the inbound (home/return) than outbound flight and higher fatigue scores at the end than the beginning of flights, irrespective of the state of acclimatisation. Of the **3 medium-relevance studies**, 2 studies provided good-quality data on circadian adaptation and sleep-wake behaviour on transatlantic routes (Samel & Wegmann, 1987; Wegmann et al., 1986), including the exposure FDP of aircrew being in an unknown state of acclimatisation (X-state) and FDP duration of more than 11h. The third study (Sallinen et al., 2021) assessed on-duty sleepiness in commercial airline pilots, finding high levels of sleepiness (KSS ≥ 7) in (i) B-state (known state of acclimatisation: layover <48h) and X-state inbound flights departing in the early morning; and (ii) X-state inbound flights during the night. They did not, however, study the relationship with FDP duration. The **5 high-relevance studies** all assessed performance and/or fatigue/sleepiness measures at several time points before, during, and after the flight. One study (Samel et al., 1997) included the primary control FDP of aircrew being in an unknown state of acclimatisation (X-state) and FDP duration of less than 11h; the other 4 studies included the exposure FDP of aircrew being in an unknown state of acclimatisation (X-state) and FDP duration of more than 11h. One of these 4 studies (Petrilli et al., 2006) included both, the control and exposure FDP for a direct comparison. They assessed pilot fatigue (7-point SP) during an international pattern, involving the four flight legs Australia-Asia, Asia-Europe, Europe-Asia, and Asia-Australia in the same crew. The last two legs (3^{rd} and 4^{th} leg) were flown in an unknown state of acclimatisation, yet with different durations (3^{rd} leg = exposure FDP (>11h) vs. 4^{th} leg = control FDP (<11h)). Average fatigue scores were lower for the exposure than control FDP; yet, the order of flight legs within the international pattern may have confounded the direct comparison, such that time into the trip may have increased fatigue on the 4^{th} leg (control FDP) beyond the effects of FDP duration. Another study (D. Powell et al., 2010) examined the impact of an additional day's layover period on fatigue (7-point SP) on a flight rotation between New Zealand and the US West Coast. The difference in layover period (1 day vs. 2 days) changed the state of acclimatisation from known (B) to unknown (X) on flights that were otherwise similar (i.e., same route, same duration), allowing to compare the exposure FDP (X-state and >11h FDP) with a secondary control FDP (B-state and >11h FDP). While the authors observed a generally beneficial effect of an additional layover day on pilot fatigue, there was no difference between the FDPs flown in states B and X, suggesting that the switch from a known state to an unknown state of acclimatisation may have outweighed the positive effect of a longer recovery period at the destination.

'Duties including a high level of sectors (more than 6)'. Of the final 46 selected studies, 9 (19.5%) were included for this FDP. Of these 9 studies, 7 (78%) were deemed medium to high relevance. All 7 studies found moderate effects of the number of sectors on fatigue, sleepiness, and/or cognitive performance. The **4 medium-relevance studies** included a flight simulator study (Honn et al., 2016) that compared 9h-duties with one take-off and landing vs. five take-offs and landings. Results showed a greater build-up of fatigue in the multi-segment duty day than in the single-segment duty day, directly attributable to the number of flight sectors flown. A study using register data on occupational accidents found that cumulative exposure to short-haul flights (i.e., sector-equivalent) was associated with an increased risk of occupational accidents among cabin crewmembers (van Drongelen et al., 2013). These findings however, reflect cumulative exposure during multiple years, and no conclusions regarding the effect of the number of sectors per duty can be drawn. A field study among European airline crew found that PVT reaction times slowed by five milliseconds with each additional flight sector over the work period of four consecutive daytime duties (Goffeng et al., 2019). The average number across the four workdays was 15.3 sectors. A recent study by Sallinen et al. (2020) using data from the previous contract (FTL 1.0) found that number of sectors (along with morning flights and FDP length) contributed only marginally to fatigue, whereas night flights encroaching the Window Of Circadian Low (WOCL) (02:00-05:59) constituted the major cause of high fatigue. Of the **3 high-relevance studies**, Powell et al. (2007) found that number of sectors and FDP length were the strongest influences on fatigue, with SP scores increasing by 2.8 points for every sector (range: 1-5 sectors). Their results, however, may be somewhat confounded by sleep loss, which was not measured in the study. In another study, Powell et al. (2008) confirmed their findings for fatigue in 2-pilot crews in mixed SH and LH operations, yet the number of sectors was limited to 1-2 sectors. In a most recent study, Åkerstedt et al. (2021) found that the number of sectors predicted fatigue in a simple regression analysis, but the significant effect disappeared in the multi-variable analysis, mainly due to FDP length. The range of sectors (1-8) in this study was the largest of all included studies (average number of 4.3 ± 2.6 sectors), making it the only study that examined fatigue for FDPs with more than 6 sectors.

'On-call duties such as standby or reserve followed by flight duties'. Of the final 46 selected studies, 2 (4.5%) were included for this FDP. Of these 2 studies, none was deemed medium to high relevance. Both publications were review papers summarising findings in non-aircrew populations (e.g., physicians, medical residents, engineers (train, ship), gas and electricity company workers). Nonetheless, they had some informative value, showing that working on-call from home appears to adversely affect mental health, personal life, and sleep patterns (e.g., quantity, and in most cases, sleep quality). Most studies did not differentiate between on-call nights from home with and without calls.

'Controlled rest'. Of the final 46 selected studies, 9 (19.5%) were included for CR. Of these 9 studies, 4 (44.5%) were deemed medium to high relevance. In general, the findings of all 4 studies supported the use of controlled rest/en-route napping as a successful strategy in mitigating unexpected fatigue during the flight. Of the **3 medium-relevance studies**, Hilditch et al. (2020) found that controlled rest was taken on 46% of a total of 239 flights, with 80% of all CR attempts estimated by actigraphy to have successfully achieved sleep. CR was more frequent on (i) 2-pilot (69%) vs. >2-pilot flights (23%); (ii) return (60%) vs. outbound flights (33%); (iii) night (55%) vs. day flights (34%); and <10h (63%) vs. >10h flight duration (27%). In the specific airline used in this study, CR was most commonly used on flights with 2-pilot crews of <10 h duration and inbound night time flights. Another study combined self-reports of en-route napping with measures of body temperature to estimate circadian phase (Gander et al., 1991).Their findings suggest that naps taken early during the flight are likely due to accumulated sleep debt and/or adverse circadian phase (low body temperature), whereas naps taken later during the flight are more likely attributable to longer time awake. The third medium-relevance study compared fatigue and controlled rest between 2-pilot vs. 3-pilot crews (Eriksen et al., 2006). In 2-pilot crews, pilots were allowed to take an unplanned controlled rest in their seat one at a time for a period of 45-min, whereas the 3-pilot crews could use the bunk rest for >1h. The 2-pilot crew had higher levels of sleepiness during much of the flight, in particular 2–4h after TOC. The findings suggest that controlled rest can be successfully used to combat fatigue in 2-pilot crews but does not lead to the same levels of alertness as 3-pilot crews using in-flight rest. The only **high-relevance study** found (Rosekind et al., 1994) randomly assigned pilots to a Rest vs. No-Rest group. Pilots in the Rest group were allowed 40-min (excluding 3min preparation and 20min recovery) to nap in their seats during the cruise phase of flights between the US and Asia, whereas pilots in the No-Rest group had no sleep opportunity and continued with their normal assignments during the corresponding 40-min time frame. As a result of the controlled rest procedure, pilots in the Rest group demonstrated significantly faster PVT response times as well as significantly fewer lapses in attention during the final approach of the flight. Subjective alertness ratings were not affected, however.

2.3 Lessons learned

Four interviews were held to gather 'lessons learned' on aircrew fatigue/alertness field studies from experts in research, airline representatives, and project management. The interviewees were fatigue experts that had recently worked on large-scale studies in operational aviation environments. The representatives included two project partners (NLR, Jeppesen) and two experts from outside the consortium, i.e., an airline representative/pilot and an academic researcher/former cabin crew member. The interviews were held online, lasted approximately one hour, and were semi-structured, i.e., interview questions had been prepared and were then adapted to the specific expertise of the interviewee. The interview questions were grouped along three main themes: **organizational** (e.g., how to make sure that subjects remain motivated to avoid drop-outs), **technical** (e.g., how to ensure high-quality data), and **scientific** aspects (e.g., which data collection methods to use).

2.3.1 Organizational aspects

How to approach the airlines / recruit participants?

All interview partners emphasised that involving management and unions of both pilots and cabin crew early on is of key importance. Methods of approaching airlines/participants included: having management/unions send out to all their members a letter with information about the study, serving as a heads-up to potential participants; using EASA for the introduction (e.g., via a letter to the airlines); and investing in a relationship with the contacted airlines (e.g., visits, exchanges, conversations about goals and mutual benefits). Response rate and number of enrolled participants were seen as strongly dependent on the rosters that airlines fly; in one case, drop-out rate was quite high, yet not due to lack of participant interest but due to limited availability of the specific flight rosters that were required for study enrollment (e.g., crucial to know beforehand what schedules airlines/pilots/cabin crew are flying). Getting the data to make meaningful assumptions may also be more a matter of data quality than sample size, such that motivated participants deliver high-quality data, which can in turn compensate for a smaller sample size.

What (if any) incentives should be used to increase motivation? How to maximise adherence / minimise drop-outs?

Interviewees stressed the need to gain trust and maximise motivation of participants. Ways to increase motivation included providing personal feedback to participants and a hands-on approach with informing them that their data was correctly received, giving positive feedback and reaching out to all participants, not only if there are data issues. In addition, motivation could be increased by clarifying the importance of the study, its objectives and what will be done with the results ("what's in it for them"). Furthermore, monetary incentives were named to reduce participant bias when recruiting aircrew, i.e., financially compensating participants may be a way to increase sample size without compromising data quality and detail (multiple measures at multiple time points over several days/weeks), although this was not seen without controversy. Advertising data protection and confidentiality was also emphasised, to make sure that participants do not fear employer interrogation or retribution (e.g., for being fatigued at work). Outsourcing training/instruction of participants to administrative personnel at the airlines was not recommended, respectively, viewed with reservations, but assessed as sometimes necessary if time and/or budget constraints did not allow the Principal Investigators (PIs) to do it themselves. It is recommended to be there in person, if possible.

2.3.2 Technical aspects

Preferred / recommended measurements (both objective and subjective)?

By some interviewees, the PVT was not seen as adding more value to subjective assessments of fatigue, such as using KSS or SP. In general, KSS was slightly preferred over SP, citing the higher granularity of KSS scores, but assessment of both was usually recommended. Neurobehavioral tests and physiological measures (e.g., 2-electrode device to measure HRV) were judged as cumbersome and not feasible (due to, e.g., battery life), especially for in-flight measures. Moreover, using actiwatches in addition to sleep diaries to derive sleep-wake states was viewed as possibly redundant but might be required in case of light recordings. The maximum period for (continuous) measurements likely depends on the incentives for the participants as well as the study design (e.g., within-subject vs. between-subject design) but should be kept to a minimum (e.g., 2-4 weeks in one expert's opinion). Monitoring the incoming data in (near) real-time is desirable, to determine whether sufficient data of sufficient quality has been collected (meaning the participant can stop the data collection).

How to ensure data confidentiality?

Reliability of sleep-wake measurements were seen as key to gain participants' trust in data protection and confidentiality. In addition, involving the unions and investing in a good relationship with both the Scientific Committee and the Mirror Group early on, allowing them to give input/feedback, was named as highly important for the project's success.

2.3.3 Scientific aspects

Differences between cabin vs flight crew to take into account?

No differences were seen with regards to measurement time points, citing that the critical phases are similar for both cockpit and cabin crew. Workload was evaluated as being of a more physical nature for cabin crew, i.e., cabin crew is usually 'busier' throughout the flight, so including an instrument/scale that measures several dimensions of workload was seen as important. With regards to recruitment, it was recommended to target cockpit and cabin crew differently, e.g., perhaps focusing more on physical fatigue/workload for cabin crew.

Confounders to take into account?

In addition to those listed on the research proposal, the confounders 'satisfaction with schedule/working arrangement' and 'degree of control over schedules' were mentioned. It was also stated that airlines may apply their own rules beyond the regulatory rules, e.g., preferential bidding (shift assignment based on personal preferences), that can skew towards 'better' results than would be the case with pure regulatory rules (aka positive bias). Taking into account airline-specific regulations might be challenging to do explicitly (such as including airlines that are comparable in number and kind of additional rules or comparing airlines that are close to flying 'purely regulatory') but was seen as important to keep in mind.

3. Conclusions

The main objective of this task was to perform a review of the state of the art to define a detailed baseline for the activities to be performed in the FTL 2.0 research study, including lessons learned gathered from experts in aircrew fatigue. The search strategy procedure led to the inclusion of 46 studies. The collected state of the art was subsequently mapped using the extracted study data and synthesising the medium to high relevance studies' findings.

No relevant studies were identified for the FDP **'Duties of more than 13 hours at the most favourable time of the day'**, revealing a profound lack of studies for this FDP, particularly in 2-pilot crews. While the 8 low-relevance studies reported FDPs of more than 13h, most of these FDPs occurred during the night and none of the studies were conducted with basic crews. The findings generally indicate that flight duration (for which effects are modulated by sleep-homeostatic components) and flight timing (for which effects are modulated by the circadian clock) interact on fatigue, sleepiness, and cognitive performance, suggesting that any assessment of long flight durations must take into account the timing of flights (i.e., during the WOCL).

Five highly relevant studies were identified for the FDP **'Duties of more than 11 hours for crew members in an unknown state of acclimatisation'**. Yet, four of these 5 studies were conducted in a Non-EU setting, and only one study allowed to directly compare the exposure FDP (unknown state X and FDP duration more than 11h) with the primary control FDP (unknown state X and FDP duration less than 11h). None of the studies explicitly aimed to examine FDPs of different durations flown in an unknown state of acclimatisation. There is a great need for high-quality research data in aircrew (i.e., several time points pre-, in-, and post-flight using validated fatigue/performance measures) with the explicit aim to compare unknown state of state acclimatisation FDPs of durations more vs. less than 11h.

Three highly relevant studies were identified for the FDP **'Duties including a high level of sectors (more than 6)'**. Of these, only one study by Åkerstedt et al. (2021) investigated FDPs with more than 6 sectors. The findings emphasise the need to carefully balance FDP length and number of sectors, to avoid potential confounding effects between these two factors. Furthermore, the studies showed the importance of adjusting for potential sleep loss, which can also affect the triangle relationship between fatigue, number of sectors, and FDP duration, and of taking into account the specific working conditions (e.g. workload) at the airline conducting the multiple sector operation.

No relevant studies were identified for the FDP **'On-call duties such as standby or reserve followed by flight duties'**, revealing a profound lack of research into on-call duties in aircrew. Furthermore, the studies conducted in non-aircrew populations mostly did not differentiate between on-call duties with and without calls, emphasising the need to study on-call duties with a specific focus on actually 'being called'.

One highly relevant study was identified for **'Controlled rest'**. In the study, pilots were randomly assigned to a Rest vs. No-Rest group, with only the former were allowed to nap in their seats. Pilots in the Rest group showed a significantly better cognitive performance during the final approach, even though this difference was not apparent in subjective alertness. Generally, the identified studies supported 'controlled rest' as a successful mitigation strategy for unexpected fatigue; the exact CR procedures, however, vary across airlines. Furthermore, effects of *sleep inertia*, which may counteract some of the beneficial effects of in-flight napping, are scarcely discussed and need to be considered for the purposes of the current study.

The lessons learned gathered from interviews held with experts on aircrew fatigue emphasised gaining trust and increasing motivation of the participants, enlisting the help of management and unions. Potential differences in recruiting strategies for cockpit vs. cabin crew as well as ways to increase sample size while maintaining data quality were discussed.

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Appendix A Search Strategy

› Population

Flight crew/airline crew/aircrew/cockpit crew/cabin crew/airline pilot(s)/cat pilot(s)/cargo pilot(s)/pilots of airlines/aircraft pilot(s)/commercial pilot(s)

› Outcome

Fatigue/drowsiness/sleepiness/sleep/attention/alertness/vigilance/workload/measurement/data collection

› Language

English, Dutch or German

› Publication date

1980-present date

› Type of publication

Peer-reviewed only

Appendix B Final set of included studies

Table B1. Final set of included studies

Authors	Year	FDP	Region	Population	Variables	Number of participants	Type of operation	Relevance
Devine et al.	2021	>13h favourable time	Non-EU (China)	Pilots	Sleep log, actigraphy	20	ULR	Low
O'Hagan et al.	2020	>13h favourable time	N/A	Pilots	PVT, SP, diverse performance tests	7	SH	Low
Gander et al.	2014	>13h favourable time	Non-EU (US)	Pilots	PVT, KSS, SP	156	ULR, LH	Low
Signal et al.	2014	>13h favourable time	Non-EU (South Africa)	Pilots	PVT, KSS, SP, sleep log, actigraphy	52	ULR	Low
Gander et al.	2013	>13h favourable time	Non-EU (US)	Pilots	PVT, KSS, SP, sleep log, actigraphy	70	ULR	Low
Wu	2013	>13h favourable time	Non-EU (US)	Pilots	PVT, KSS, SP, sleep log, actigraphy	74	ULR, LH	Low
Lamond et al.	2006	>13h favourable time	Non-EU (Australia)	Pilots	PVT, sleep log, actigraphy	19	LH	Low
Goode	2003	>13h favourable time	N/A	Pilots	Accidents	N/A	Mixed	Low
Samel et al.	1997	>11h unknown state	EU (Germany)	Pilots	SP, sleep log, PSG, NASA-TLX	50	LH	High
Sallinen et al.	2021	>11h unknown state	EU (Finland)	Pilots	KSS, sleep log, actigraphy	86	LH	Medium
Samel & Wegmann	1987	>11h unknown state	EU (Germany)	Cockpit crew	Circadian (body temperature, heart rate, cortisol)	12	LH	Medium
Wegmann et al.	1986	>11h unknown state	EU (Germany)	Cockpit crew	Sleepiness, sleep log, PSG	12	LH	Medium
Eriksen & Akerstedt	2006	>11h unknown state	EU (Sweden)	Pilots	KSS, sleep log, actigraphy	14	LH	Low
Wright & McGown	2004	>11h unknown state	EU (UK)	Pilots	Alertness, sleepiness, sleep log, actigraphy	12	LH	Low
Ariznavarreta et al.	2002	>11h unknown state	EU (Spain)	Pilots	actigraphy, circadian (skin temperature, heart rate)	23	LH	Low
Tresguerres et al.	2001	>11h unknown state	EU (Spain)	Pilots	Actigraphy, circadian (melatonin, cortisol)	23	LH	Low
Lowden et al.	1998	>11h unknown state	EU (Sweden)	Aircrew	Sleepiness, sleep log, actigraphy	42	LH	Low

Spencer et al.	1991	>11h unknown state	EU (UK)	Cockpit crew	Alertness, sleep log, PSG, circadian (body temperature)	12	LH	Low
Van den Berg et al.	2015	>11h unknown state	Non-EU (South Africa)	Cabin crew	PVT, KSS, SP, sleep log, actigraphy	55	ULR	High
Roach et al.	2012	>11h unknown state	Non-EU (Australia)	Pilots	PVT, SP, sleep log, actigraphy	19	LH	High
Powell et al.	2010	>11h unknown state	Non-EU (New Zealand)	Pilots	Performance, KSS, SP	105	LH	High
Petrilli et al.	2006	>11h unknown state	Non-EU (Australia)	Pilots	PVT, SP, sleep log, actigraphy	19	LH	High
Cosgrave et al.	2018	>11h unknown state	Non-EU (US)	Pilots	KSS, SP, sleep log, actigraphy	410	LH	Low
Gander et al.	2016	>11h unknown state	Non-EU (US)	Pilots	PVT, KSS, SP, sleep log, actigraphy, circadian (sleep propensity)	39	LH	Low
Gander et al.	2015	>11h unknown state	Non-EU (Mixed)	Pilots	PVT, KSS, SP, sleep log, actigraphy	237	LH	Low
Gander et al.	2013	>11h unknown state	Non-EU (US)	Pilots	PVT, KSS, SP, sleep log, actigraphy, circadian (sleep propensity)	30	LH	Low
Åkerstedt et al.	2021	>6 sectors	EU (Norway)	Pilots, cabin crew	KSS, sleep log	106	Ultra-SH	High
Sallinen et al.	2020	>6 sectors	EU (Mixed)	Pilots, cabin crew	KSS, sleep log, actigraphy	392	Mixed	Medium
Goffeng et al.	2019	>6 sectors	EU (Norway)	Pilots, cabin crew	SP, diverse neuropsych. tests	59	SH	Medium
Van Drongelen et al.	2013	>6 sectors	EU (Netherlands)	Cabin crew	Accidents	6311	SH	Medium
Bourgeois-Bougrine et al.	2003	>6 sectors	EU (France)	Pilots	Fatigue	739	Mixed	Low
Powell et al.	2008	>6 sectors	Non-EU (New Zealand)	Pilots	Alertness, SP	N/A (4206 obs)	SH	High
Powell et al.	2007	>6 sectors	Non-EU (New Zealand)	Pilots	Alertness, SP	N/A (2034 obs)	SH	High
Honn et al.	2016	>6 sectors	Non-EU (US)	Pilots	PVT, KSS, SP	24	SH	Medium
Arsintescu et al.	2020	>6 sectors	Non-EU (US)	Pilots	PVT, SP, sleep log	90	SH	Low
Nicol & Botterill	2021	On-call	N/A	Non-aircrew	N/A	N/A	N/A	Low
Hall et al.	2017	On-call	N/A	Non-aircrew	N/A	N/A	N/A	Low
Hilditch et al.	2020	Controlled rest	EU (Mixed)	Pilots	Sleep log, actigraphy	44	LH	Medium
Eriksen et al.	2006	Controlled rest	EU (Scandinavia)	Pilots	KSS, sleep log, actigraphy	20	LH	Medium
Sallinen et al.	2018	Controlled rest	EU (Finland)	Pilots	KSS, sleep log, actigraphy	58	Mixed	Low
Sieberichs & Kluge	2018	Controlled rest	EU (Germany)	Pilots	Survey	106	Mixed	Low
Sallinen et al.	2016	Controlled rest	EU (Mixed)	Pilots	KSS, sleep log, actigraphy	90	Mixed	Low
Rosekind et al.	1994	Controlled rest	Non-EU (US)	Pilots	PVT, KSS, sleep log, PSG, actigraphy	21	LH	High

Gander et al. 1991	1991	Controlled rest	Non-EU (US)	Pilots	Sleep log, circadian (body temperature)	29	LH	Medium
Zaslona et al.	2018	Controlled rest	Non-EU (Mixed)	Pilots	Sleep log, questionnaire	123	ULR, LH	Low
Petrie et al.	2014	Controlled rest	Non-EU (New Zealand)	Pilots	Fatigue	253	Mixed	Low

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