Project

Calculating Aircraft Utilization

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Abstract

Purpose – This project introduces the equation for calculating aircraft utilization and describes the parameters in the equation. Aim is also to point out differences in the notation used in the literature.

Methodology – Aircraft utilization is explained based on the chapter "Design Evaluation / DOC" from the lecture notes "Aircraft Design" by Scholz (2015). Parameters that are kept generic in this reference, are mapped to reality with definitions from Thorbeck's DOC method from TU Berlin. Statistics of these parameters are obtained from a literature review.

Findings – Aircraft utilization depends on two parameters. The block time supplement (taxi time plus turnaround time) and the annual operation time (annual potential operation time minus annual downtime). Downtime is caused by scheduled maintenance (A, B, C, D checks), unscheduled maintenance (repairs), and night curfew. Practical values are given. Taxi time (in and out) is together about 20 minutes.

Research Limitations – Turnaround time can vary widely (both among aircraft types and airline philosophies). Delays can change turnaround and taxi time. Maintenance programs are structured differently among airlines, and night flying regulations are much different at different airports. Fixed values do not exist for these parameters.

Practical Implications – It is essential for airlines to keep utilization high. The project shows how this can be achieved.

Social Implications – Public and airline interests clash when discussing night curfew. Noise versus profit. Utilization is the parameter in question.

Originality – A comparable report with a review of aircraft utilization was not found.

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Calculating Aircraft Utilization

Task for a *Project*

Background

Aircraft utilization is defined as the hours an aircraft is airborne during the year. It is the productivity of an aircraft and the basis for its economic success. Utilization is part of Direct Operating Costs (DOC) calculation. As such, utilization is already calculated during aircraft design, which uses DOC as the objective function. Passenger aircraft are bought based on DOC. Utilization is key to airline profitability. An aircraft on ground (AOG) incident is the worst that can happen, because it ruins utilization. Some DOC methods (e.g. from American Airlines, Association of European Airlines, or Airbus) contain the same equation to calculate aircraft utilization, but apply different values for two parameters in the equation: The block time supplement (taxi time plus turnaround time) and the annual operation time (annual potential operation time minus annual downtime). Downtime is caused by scheduled maintenance (A, B, C, D checks), unscheduled maintenance (repairs), and night curfew.

Task

Task of this project is to study the equation that calculates aircraft utilization and to analyze its parameters. The subtasks are:

- Introduction to the equation for aircraft utilization as given by Scholz 2015.
- Introduction to the equation for aircraft utilization as given by Thorbeck 2013.
- Discussion of the parameters of this equation and comparing the different notations.
- Calculation of block time supplement from taxi time and turnaround time.
- Calculation of annual operation time from downtime.
- Investigation of real values for taxi time, turnaround time, aircraft checks, and night curfew.
- Illustration of aircraft utilization with example calculations.

The report has to be written in English based on German or international standards on report writing.

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List of Symbols

d	Distance
n	Number of flights
R	Stage length
RF	Refueling
t	Time
U	Utilization
v	Cruse speed

Indices

a	Annual
av	Average
B	Block
boa	Boarding
BS	Block supplement
$Check$	Aircraft check
$Curfew$	Night curfew at the airport
D	Down
d	Daily
deb	Deboarding
eff	Effective
f	Flight
h	Hourly
OPS	Operation/Operating
pax	Passengers
PB	Pushback
PO	Potential operation
RL	Rigid letter
$Repair$	Aircraft repair
ST	Single task-oriented
T	Taxi
t	Trip
T_in	Taxi-in
T_out	Taxi-out
TA	Turnaround

Design Evaluation / DOC Script Symbols

f	Flight
k_{U1}	Constant parameter
k_{U2}	Constant parameter
$k_{U,A}$	Constant parameter
$k_{U,B}$	Constant parameter
$k_{U,C}$	Constant parameter
t_f	Flight time
t_{GND}	Ground time (Block time supplement per flight)
$t_{OPS,a}$	Annual Operation Time
$U_{a,f}$	Annual Utilization

Thorbeck's DOC Method Symbols

FC	Flight Cycles
FT	Flight Time
$OT_{p.a.}$	Operation Time per Year
BT	Block Time Supplement
$POT_{p.a.}$	Potential Annual Operating Time
$DT_{p.a.}$	Annual Downtime
$FH_{p.a.}$	Annual Flight Hours (Annual Utilization)

Abbreviations

A	Airbus
A/C	Aircraft
AA	American Airlines
AEA	Association of European Airlines
AFT	Aftward
AI	Airbus Industry
ATA	Air Transport Association of America
ATR	Avions de Transport Régional
B	Boeing
BS	Block Supplement
CAMO	Continuing Airworthiness Management Organization
CODA	Central Office for Delay Analysis
DLH	Deutsche Lufthansa
DOC	Direct Operation Cost
EU	European Union
FAA	Federal Aviation Administration
FH	Flight Hour
FWD	Forward
ICAO	International Civil Aviation Organization
MPD	Maintenance Planning Document/Data
NASA	National Aeronautics and Space Administration
QC	Quota Count
TUB	Technical University of Berlin
USA	United States of America

Definitions

Fleet type

"Fleet type is a specific aircraft model with the same cockpit configuration, capacity, crew qualification and maintenance requirements. For example, Boeing B767-300 is a fleet type." (Sherali 2005)

Gate assignments

"The purpose of flight to gate assignments is to assign a flight to a suitable gate where airlines provide passenger boarding or disembarking services." (Ching-Hui 2013)

Routing system

"A routing system is a sequence of flight covered by a single airplane." (Parmentier 2013)

Hub-and-spoke route

"In the hub-and-spoke route system, traffic between origins and destinations is routed through a central hub." (Rasch 2017)

Short-haul, medium-haul, and long-haul flight

"Route category lengths tend to define short-haul routes as being shorter than 600–800 nmi (1,100–1,500 km), long-haul as being longer than 2,200–2,600 nmi (4,100–4,800 km), and medium-haul as being in between." (Wikipedia 2021)

Charter flight

"A charter flight does not follow a schedule set by the air carrier. Essentially a charter is when a person or a company rents an entire aircraft for a very particular purpose." (Airco 2019)

Scheduled Flight

"A scheduled flight means the air carrier sells single seats to individuals until the aircraft is full." (Airco 2019)

Quota Count

"Quota Count is a system used in the UK by London's Heathrow, Gatwick, and Stansted airports to limit the amount of noise generated by aircraft movements at nighttime." (Wikipedia 2022)

Rigid letter check system

"A, B, C, and D check based on aircraft maintenance documentation."

Single task-oriented maintenance system
"Performing the maintenance not only during scheduled periodic checks but also whenever the aircraft is on the ground for any reason." (Ozkol 2017)

Stage length
"The range between the departure and destination airport." (Scholz 2015)

Point-To-Point route
"Direct flight from the origin city to destination without a stopover." (Rasch 2017)

Direct Operation Cost (DOC)
"Direct Operating Costs (DOC) include the entire operating costs of the aircraft." (Scholz 2015)

1 Introduction

1.1 Motivation

Competition between airlines is arduous and faces many challenges. If an airline wants to remain and succeed in this competition, it must manage its operations and resources to satisfy their customers and generate sufficient profit. This requires a realistic calculation of operating costs. Besides the calculation on cost, an airline needs to know the number of hours their aircraft can fly in a year, a month, or a day. Some DOC methods, such as those provided by Air Transport Association of America (ATA), American airlines (AA), Lufthansa (DLH), Association of European Airlines (AEA), and Thorbeck's DOC method (TUB-DOC) allow operators to calculate the utilization of their aircraft. These calculations are necessary for the airlines to determine the ticket price.

1.2 Title Terminology

Calculating
According to Cambridge Dictionary calculating means: "To judge the number or amount of something by using the information that you already have, and adding, taking away, multiplying, or dividing numbers."

Aircraft Utilization
The utilization of an aircraft is the way to define its productivity. It can be expressed as number of flight hours in a specific period such as annual, daily, or hourly (relative) utilization (Scholz 2015).

1.3 Objective

The aim is to find the annual aircraft utilization using the equation presented in the Design Evaluation / DOC lecture notes by Scholz (2015) and compare it to the Thorbeck's DOC method by Thorbeck (2013). This will help defining the constant parameters introduced in Design Evaluation script as k_{U1} and k_{U2}. On the other hand, the variable parameters of this equation will be determined so that readers will be able to calculate different scenarios for the utilization of different aircraft and different airlines. Besides determining the parameters that affect aircraft utilization, such as turnaround time, taxi time, maintenance time, and night curfew, estimating typical values for these parameters for some common aircraft and large airports is part of this project. These values are necessary for calculating the annual operating time and effective flight time, which in turn determine the number of flight cycles per year. With the number of annual flight cycles and the average flight time per cycle, the annual aircraft utilization is obtained.

1.4 Literature

This project is based on the Design Evaluation / DOC script by Scholz (2015), which reviews different DOC methods. In addition to determining and calculating the DOC elements, the general equation for calculating aircraft utilization is provided in section 14.3.10 of this script. In this equation the parameter k_{U1} represents the operating time and k_{U2} represents the block time supplement per flight cycle. Based on AEA (1989a), AEA (1989b), AI (1989), and AA (1980), the values for these parameters are different and are given as constant amounts in a table. Using these values, the results are plotted in graphs as the relationship between flight time and relative aircraft utilization.

While Scholz (2015) presents k_{U1} and k_{U2} as abstract parameters, Thorbeck (2013) gives definitions in the form of equations for these parameters. Note that in the Thorbeck's DOC method the parameters such as operating time, flight time, and block time supplement have a notation that is different from the notation used in Design Evaluation / DOC script, but some hints show how to obtain the values for these parameters.

1.5 Structure of the Work

- Chapter 2 defines aircraft utilization and its parameters as well as terminology. We will look at which equations can be used to calculate aircraft flight time and annual utilization. To do this, we will define all the parameters that are used in the general equations of calculation of aircraft utilization. In this chapter, block time and flight time are defined, as well as taxi time and turnaround time. The next definition covered in this chapter is downtime and its parameters, such as aircraft maintenance and checks and nighttime curfews. Moreover, typical values are given for each of these parameters. In Section 2.6, the two calculation equations for aircraft utilization from the Thorbeck's DOC method and the Design Evaluation / DOC script are presented and the different notation in the two papers is compared.

- Chapter 3 introduces two examples to see the progress in calculating aircraft utilization.

- Chapter 4 discusses the results of aircraft utilization equation.

2 Calculation of Aircraft Utilization

2.1 Aircraft Utilization Equation

The utilization of an aircraft is the measure of its productivity. That can be defined as the number of flight hours in a specific period for a specific fleet. Aircraft utilization calculations allow airlines and operators to know how many hours their aircraft can fly in a certain period, such as a year or a day. For this purpose, some of the DOC methods are provided with an equation. Scholz (2015) presents the general equation for calculating aircraft utilization based on AA (1980), NASA (1977), AEA (1989a) and AEA (1989b), and AI (1989). In another reference, Thorbeck (2013), an equation with the same structure, is introduced. Using these two references, we will first introduce the general equation for calculating aircraft utilization.

According to Scholz (2015), the number of flight hours is usually expressed in an annual period called annual aircraft utilization (unit: hours per year). Aircraft utilization can also be specified in other periods such as daily (unit: hours per day) or even hourly. Annual and daily utilization are terms that are commonly used in practice.

Both flight time and block time can be used in calculating annual aircraft utilization. If the flight time is used for calculating aircraft utilization, it will be defined by multiplying the number of flights per year by the average flight time for each flight.

$$U_{a,f} = n_{t,a} \cdot t_f \qquad (2.1)$$

In this equation, $U_{a,f}$ stands for the annual aircraft utilization, $n_{t,a}$ for the number of flights (trips) per year, and t_f for the flight time.

Otherwise, if the block time is used, it is defined as the product of the number of flights per year by the average block time for each flight

$$U_{a,B} = n_{t,a} \cdot t_B \quad , \qquad (2.2)$$

where the annual aircraft utilization is represented by $U_{a,B}$, average block time per flight by t_B, and the number of flights per year by $n_{t,a}$. In this project, the equation used for calculating aircraft utilization is based on the flight time.

Furthermore, the number of flights per year $n_{t,a}$ can be calculated by dividing the annual operation time t_{OPS} by the effective flight time t_{f-eff}

$$n_{t,a} = \frac{t_{OPS}}{t_{f-eff}} \quad . \qquad (2.3)$$

The effective flight time is the result of the flight time t_f plus the block time supplement t_{BS}. With the definition of $n_{t,a}$, Equation (2.1) can be rewritten in (2.4) as a general equation for calculating annual aircraft utilization.

$$U_{a,f} = t_f \frac{t_{OPS}}{t_f + t_{BS}} \tag{2.4}$$

In addition to annual utilization, aircraft utilization can also be expressed in terms of daily utilization. Daily aircraft utilization $U_{d,f}$ is therefore the average flight time t_f multiplied by the number of flights per day $n_{t,d}$.

$$U_{d,f} = n_{t,d} \cdot t_f \tag{2.5}$$

By dividing the annual number of flights $n_{t,a}$ by 365, one gets the number of flights per day.

$$n_{t,d} = \frac{n_{t,a}}{365} \tag{2.6}$$

Aircraft utilization can also be calculated particularly easily with dimensionless hourly aircraft utilization (relative aircraft utilization) with

$$U_{h,f} = n_{t,h} \cdot t_f \quad , \tag{2.7}$$

where $U_{h,f}$ is the hourly aircraft utilization, $n_{t,h}$ the number of flights in one hour, and t_f the average flight time per trip. The number of flight hours in one hour is obtained by dividing the daily number of flights by 24 according to

$$n_{t,h} = \frac{n_{t,d}}{24} \quad . \tag{2.8}$$

In the following, all these factors such as flight time, block time, block time supplement, operation time, and their parameters are discussed in detail.

2.2 Block Time

Block time (block hours) is the time during which a commercial aircraft is in operation outside the gate, including turnaround time, the time for taxi-out to the runway, the actual flight duration, and the time for taxi-in to the arrival gate.

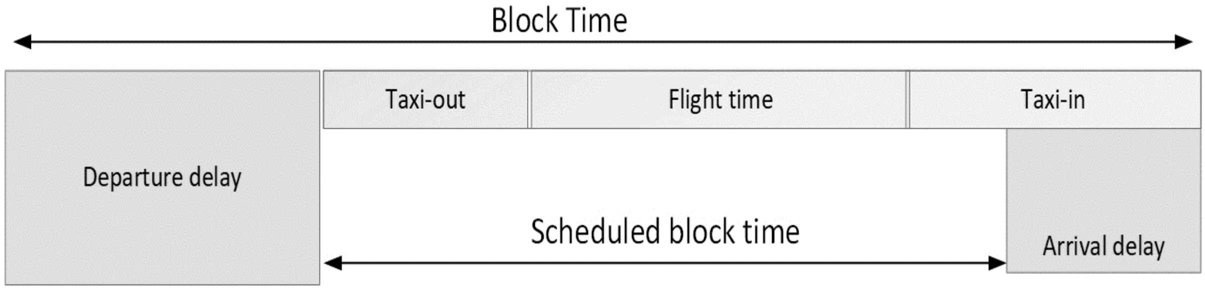


Figure 2.1 Block time

Among the various definitions for block time, Figure 2.1 illustrates a simple definition. Here, the flight time and the taxi time including the taxi-in and taxi-out time are part of the block time. It should be noted that due to delays, the actual block time will almost always differ from the scheduled block time. Delays are considered here in this project as part of the taxi and turnaround time and not separately.

Different references use various definitions for block time. For example, FAA defines block time as the time that begins when an aircraft is moving on its own power for flight and ends when the aircraft comes to rest after landing (Cirium 2015). Moreover, based on AEA (1989b), block time includes start-up and taxi-out, take-off and flight time, and taxi-in after landing (Scholz 2015).

2.3 Flight Time

As with block time, there are various definitions of the flight time in different references and models. According to Scholz (2015), the flight time is the time from takeoff to touchdown. This can also be referred to as flying time or airtime. This definition is shown in Figure 2.1.

In the general equation of aircraft utilization, Equation (2.4), the flight time is given as t_f and can be defined as

$$t_f = \frac{R_{av}}{v_{av}} \quad , \tag{2.9}$$

where R_{av} is the average stage length per trip and v_{av} the average cruise speed (Thorbeck 2013). Therefore, the equation of utilization can be rewritten as

$$U_{a,f} = \frac{t_{OPS}}{1 + \frac{v_{av}}{R_{av}} \cdot t_{BS}} \quad . \tag{2.10}$$

The identifier t_{BS} stands for block time supplement, and t_{OPS} is the annual operation time which will be discussed in the following sections.

2.4 Block Time Supplement per Flight

As mentioned before, the number of flights per year $n_{t,a}$ is the division of the annual operating time to effective flight time per cycle. However, the effective flight time t_{f-eff} is not only the time an aircraft flies from takeoff to landing. To find the effective flight time, the time for turning around, taxi and delays must be added to the airtime. These contributions to the effective flight time, besides the airtime, are the block time supplement t_{BS}. Hence, the effective flight time t_{f-eff} can be calculated by the amount of flight time t_f plus the block time supplement t_{BS}.

When delays are considered as a part of taxi and turnaround time, the value of the block time supplement t_{BS} can be obtained by

$$t_{BS} = t_T + t_{TA} \quad . \tag{2.11}$$

The identifier t_{TA} is the turnaround time and t_T is the taxi time. Taxi time includes taxi-out time t_{T_out} and taxi-in time t_{T_in}. In conclusion, the formula can be rewritten into (2.12).

$$t_{BS} = t_{T\_out} + t_{TA} + t_{T\_in} \tag{2.12}$$

2.4.1 Taxi Time

Taxi time is the total time an aircraft spends moving from a hangar or terminal to the runway until it is cleared for takeoff, and from leaving the runway back to the hangar or terminal (Paramount 2022). Taxi time can be divided into taxi-out and taxi-in. Taxi-out is the average time an aircraft spends leaving the gate to the runway. Taxi-in is the average time it takes for an aircraft to get to the gate after landing.

Shorter taxi time means potentially increased annual utilization, lower fuel costs, and more benefits for airlines. Taxi time may depend on the pilot and many other factors, including fleet type and local weather conditions. However, the type of airport and the volume of traffic have the greatest impact on taxi time. (Wang 2021) (Goldberg 2012)

Using the taxi time data collected by the 'European Organization for the Safety of Air Navigation' (EUROCONTROL) at more than 370 airports during the winter of 2020-2021 shows an average taxi-in time of 5.1 minutes and a taxi-out time of 10.6 minutes. The sum of these times gives the average taxi time of 15.7 minutes (EUROCONTROL 2021).

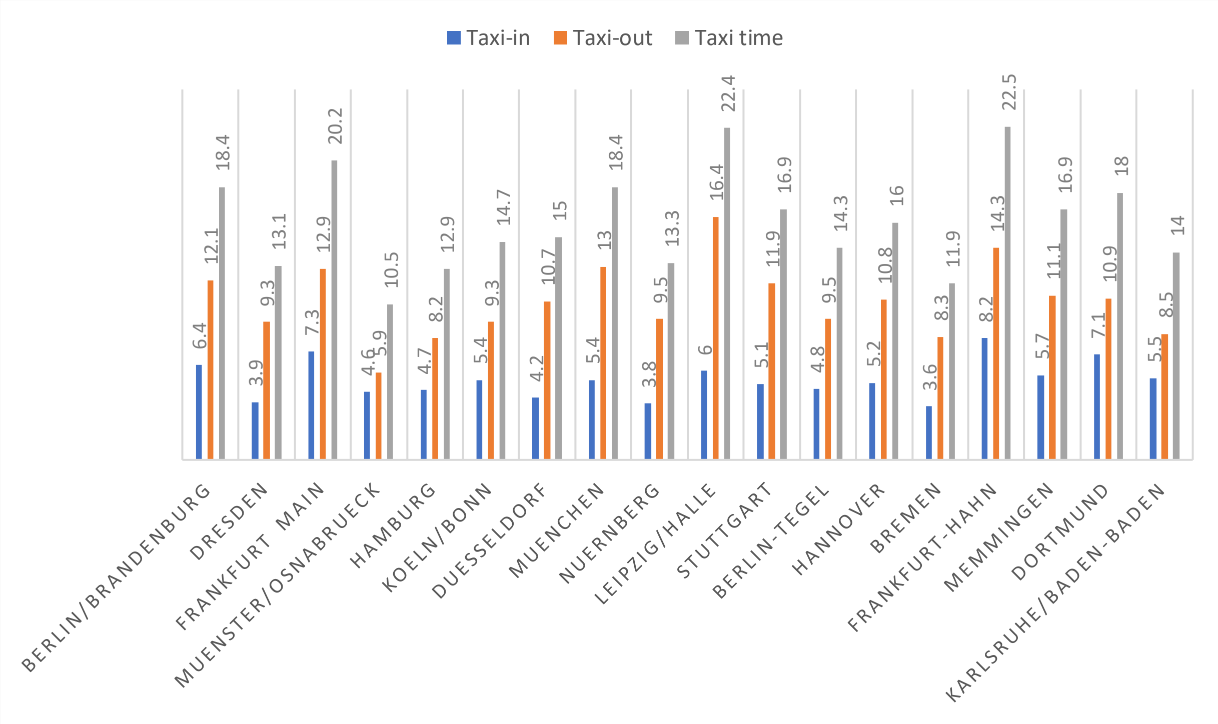


Figure 2.2 Average taxi time at German airports (EUROCONTROL 2021)

Taxi time varies in different airports and different seasons. Figure 2.2 shows the average taxi time at 18 airports of Germany in the winter of 2020-2021 as an example. The data in Table 2.1 shows that taxi times at large airports are generally longer than at medium and small airports due to the higher traffic volume. These figures in the Table 2.1 are an excerpt from EUROCONTROL (2020) for the years 2015 to 2019.

Table 2.1 Average taxi time for different airport types from 2015 to 2019 (EUROCONTROL 2020)

	2015	2016	2017	2018	2019
All airports					
Taxi-in	5.9	6.0	6.1	6.2	6.2
Taxi-out	12.5	12.8	12.9	13.8	13.4
Taxi time	18.4	18.8	19.0	20	19.6
Large to very large airports					
Taxi-in	6.8	6.8	6.8	6.8	7.1
Taxi-out	14.2	14.6	14.4	14.9	15.2
Taxi time	21	21.4	21.2	21.7	22.3
Medium to small airports					
Taxi-in	5.1	5.2	5.5	5.6	5.4
Taxi-out	11	11.3	11.8	12.1	11.7
Taxi time	16.1	16.5	17.3	17.7	17.1

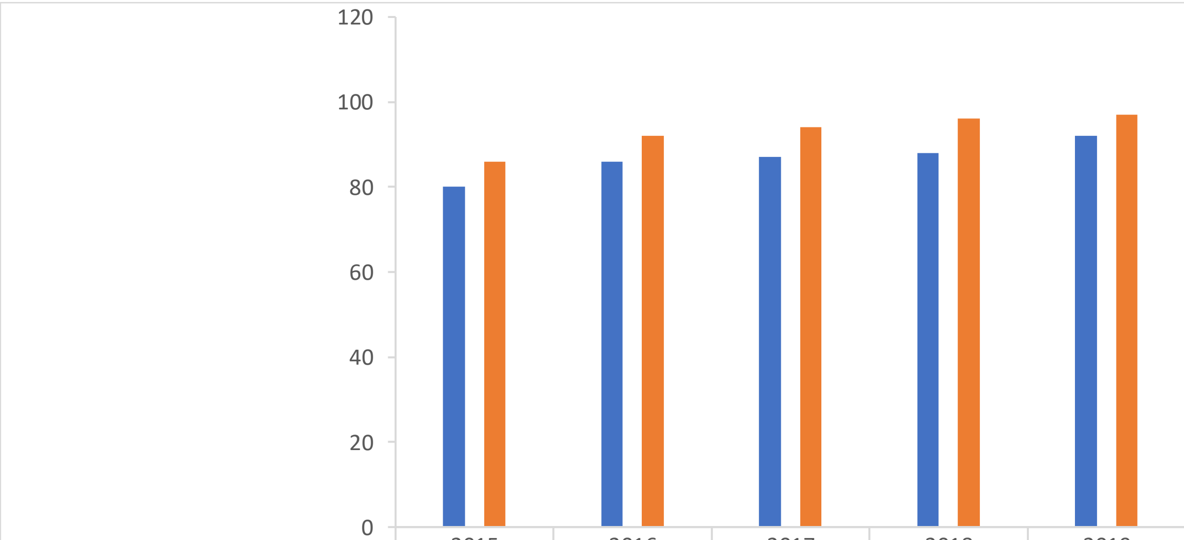
In addition, AEA (1989a) assumes a taxi time of 15 minutes for short- and medium-haul flights. This time includes 10 minutes for taxi-out and 5 minutes for taxi-in. In the AEA (1989b) a taxi time of 25 minutes for long-haul flights is used, which comprises 20 minutes for taxi-out and 5 minutes for taxi-in. It should be noted that this time includes taxi time and time on the ground waiting for clearance and pushing the aircraft back (Scholz 2015).

2.4.2 Turnaround Time

Aircraft turnaround is the preparation of an arriving aircraft at an airport for the next departing flight. Activities related to the exchange of passengers, crews, catering, cargo, and baggage belong to the turnaround. During this period, the lavatory and cabin must be serviced, the aircraft must be refueled, and food and beverages need to be reloaded. To reduce the time required to turn the aircraft, these activities should be performed efficiently and simultaneously without interfering with each other. (Ciesluk 2020) (Makhloof 2012)

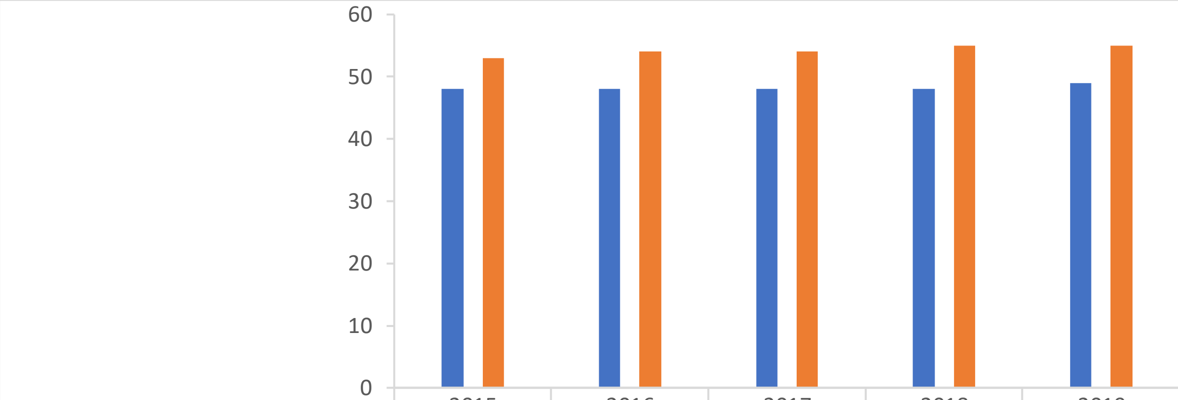
To calculate aircraft utilization, airlines must estimate the turnaround time of their long-haul and short-haul aircraft. Besides the type of aircraft and flight (short-haul, medium-haul, or long-haul), the specific airport and type of service (charter, scheduled) also affect the turnaround time. Note that due to delays, the scheduled turnaround time may openly differ from the actual turnaround time. Based on the data provided by CODA members, EUROCONTROL (2020) recommends the amounts for average turnaround time shown in the following two tables. Table 2.2 shows the average turnaround time for heavy aircraft and Table 2.3 for medium aircraft.

Table 2.2 Turnaround time [minutes] for heavy aircraft (EUROCONTROL 2020)



	2015	2016	2017	2018	2019
Mean scheduled turnaround time	80	86	87	88	92
Mean actual turnaround time	86	92	94	96	97

Table 2.3 Turnaround time [minutes] for medium aircraft (EUROCONTROL 2020)



	2015	2016	2017	2018	2019
Mean scheduled turnaround time	48	48	48	48	49
Mean actual turnaround time	53	54	54	55	55

The processes involved in turnaround, such as disembarking, refueling, services, embarking and pushback and their time are shown in Figure 2.3 as a derived Gantt chart. Krammer (2010) considers different ground handling scenarios for conventional and low-cost airlines. This figure shows the time for ground handling processes for conventional airlines with 67 % passenger load factor and two catering trucks. The parking position is at terminal.

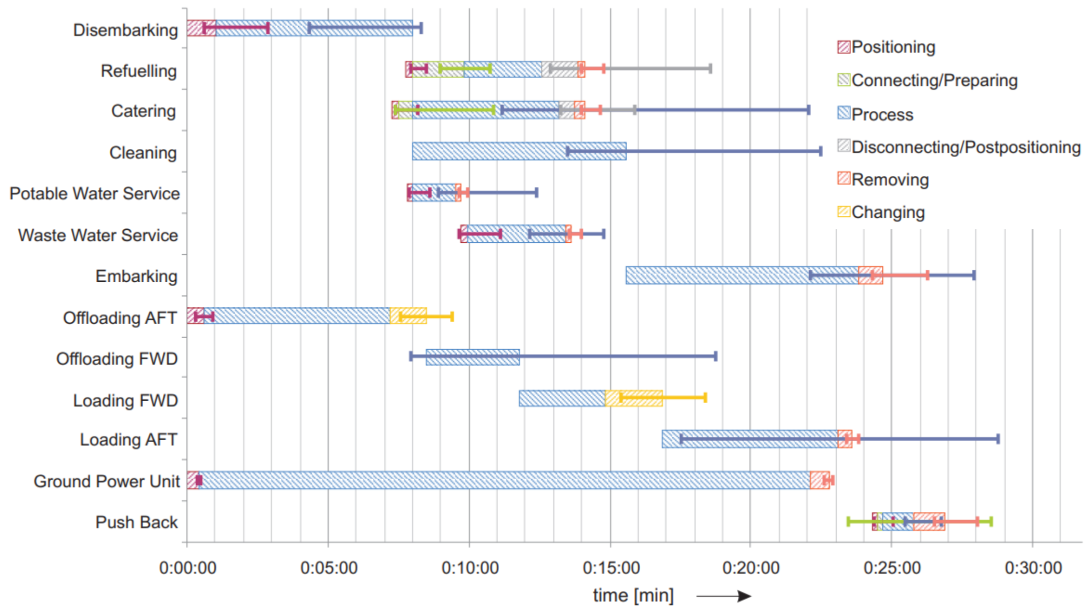


Figure 2.3 Turnaround Gantt chart (Krammer 2010)

The length of each process is given based on the realistic turnaround data in relation to the standard deviation of each turnaround process (Krammer 2010).

In his thesis, Sanchez (2009) categorized turnaround processes as passenger deboarding and boarding, refueling, cargo (unloading and loading), and services such as catering, cleaning, portable water service, and wastewater service. Note that many of these activities occur simultaneously. Table 2.4 shows the time required for these activities for some common commercial aircraft such as A319, A320, B737-700, and B737-800 according to Sanchez (2009).

Table 2.4 Turnaround activities and time for four commercial aircraft (Sanchez 2009)

	Typical time for different Aircraft type			
Turnaround activities	**A319**	**A320**	**B737-700**	**B737-800**
Deboarding	9,1	9,4	8	10
Boarding	11,4	15	12	15
Cleaning	13,4	16,8	14	15
Refueling	15,6	13	13	13
Unloading and Loading	29,5	39	26	29
Portable Water Service	6,5	6,5	6	6
Wastewater Service	6,5	6,5	14	14
Turnaround time	30	40	32	38

In addition, the turnaround time can be defined as the sum of the times for positioning the stairs, deboarding, refueling, boarding, removing stairs, and pushback. To estimate these, Sanchez (2009) presents equations and amounts in his master's thesis, which are reviewed below.

- Time for positioning and removing airstairs: This time depends on the vehicle speed, the distance, and the time for opening (closing) the door. Based on Sanchez (2009), the time for positioning the air stairs can be considered as 52 s and the time for removing the air stairs can be 31 s. Note that he assumed a constant speed for the vehicle as well as the same distance between the door of the aircraft and the starting position of the ladder in all cases.

- Deboarding time: This time depends on the number of passengers and the luggage they have. If $n_{pax,\mathrm{out}}$ is considered as the number of passengers leaving the aircraft, the deboarding time $t_{pax,deb}$ is obtained with

$$t_{pax,deb} = \frac{n_{pax,out}}{0.0986 \cdot n_{pax,out} + 19.747} \quad . \tag{2.13}$$

  Note that Sanchez (2009) estimates that an average of 34 passengers leave the aircraft every minute.

- Refueling: Considering initial refueling speed [l/min] as RF_{Speed} and loaded fuel volume [l] as V_{Fuel}, one can calculate the refueling time t_{RF} [min] with

$$t_{RF} = \frac{1}{-0.036} \cdot Ln\left(1 + \frac{V_{Fuel} \cdot (-0.036)}{RF_{Speed}}\right) \quad . \tag{2.14}$$

- Boarding time: Assuming that 20 passengers can enter the aircraft per minute, the boarding time $t_{pax,boa}$ is calculated with

$$t_{pax,boa} = \frac{n_{pax,in}}{0.0839 \cdot n_{pax,in} + 9.324} \quad , \tag{2.15}$$

where $n_{pax,in}$ represents the number of passengers going on board.

- Pushback time: The time required to pushing back the aircraft can be estimated as a function of tractor speed and distance traveled,

$$t_{PB} = \frac{d_{PB}}{v_{PB} \cdot 60} \quad . \tag{2.16}$$

  Here t_{PB} stands for pushback tractor time [min], v_{PB} for pushback tractor speed [m/s] and d_{PB} is distance covered by pushback tractor [m].

Based on Gomez (2009), shorter turnaround times allow low-cost airlines to achieve higher annual utilization than airlines focused on business travelers. Gomez (2009) describes new methods to reduce turnaround time for low-cost airlines for short- and medium-haul aircraft. A brief overview of the main points of these methods is given below:

- Enabling taxi-in and taxi-out without ground equipment and avoiding delays caused by pushback operations by parking on the apron in front of the terminal and parallel to the terminal building.
- Passenger boarding by stairs and using a second stair for the rear door.
- Parking aircraft within walking distance of the gate to avoid transporting passengers by bus between the gate and the aircraft.
- Removing catering service to eliminate time spent loading the catering-trolleys and reducing cleaning time.
- Reducing the cargo transport to the transport of luggage.
- Carrying enough fuel so that refueling is not required for each flight for short stage lengths.

2.4.3 Values for Block Time Supplement

Taxi time, including taxi-in time t_{T_in} and taxi-out time t_{T_out}, and turnaround time t_{TA} result in the block time supplement t_{BS} as shown in Equation (2.12). For example, AEA (1989b) assumes a t_{T_in} of 5 minutes, a t_{TA} of 90 minutes, and a t_{T_out} of 20 minutes for long-haul flights. Putting these amounts into (2.12) gives the block time supplement as

$$t_{BS} = 20 + 90 + 5 = 105 \text{ min} \quad . \tag{2.17}$$

According to Scholz (2015), Table 2.5 contains further values used in four different DOC methods as block time supplement.

Table 2.5 Values for block time supplement (Scholz 2015)

DOC method	t_{BS} [h]
AA (1980)	0.327
NASA (1977)	0.327
AEA (1989a)	0.750
AEA (1989b)	0.420
AI (1989)	
R < 1000 nm	0.754
1000 ≤ R ≤ 2000 nm	1.650
2000nm < R	3.302

2.5 Operation Time and Downtime

As one can see in Equation (2.4), where we calculate annual aircraft utilization, we need to know how many hours an aircraft can fly in a year. This number of hours is the annual operating time t_{OPS}. To determine the operating time, we first need to calculate the time when an aircraft cannot or is not allowed to fly.

In theory, an aircraft can fly 365 days per year, which means that the potential operation time in a year is $t_{PO} = 365 \cdot 24\text{ h} = 8760\text{ h}$.

Of course, this will never be the case due to forced downtime t_D, such as repair and aircraft checks. The following equation determines the estimated annual operation time t_{OPS}.

$$t_{OPS} = t_{PO} - t_D \tag{2.18}$$

For determining the downtime t_D, the time for maintenance, repair, and checks of the aircraft must be considered, as well as airport restrictions such as night curfew and any other situations that limit an aircraft's flight time. These factors change the value of the downtime t_D and consequently the operation time t_{OPS}. With (2.19) one can calculate the forced downtime.

$$t_D = t_{Checks,a} + t_{Repair,a} + t_{Curfew,a} \tag{2.19}$$

Annual time for aircraft check is shown as $t_{Cheks,a}$, which includes the yearly time for A, B, C and D check. The time required to repair the aircraft in one year is represented as $t_{Repair,a}$, and night curfew as $t_{Curfew,a}$.

These factors causing forced downtime are considered and defined in the following.

2.5.1 Aircraft Maintenance and Checks

One of the most important parameters for flight scheduling and estimating downtime is to consider the time the aircraft is grounded for repairs, maintenance, and periodic checks. The Aircraft maintenance schedule is dictated by aircraft manufacturers. Airbus, for example, provides for its customers a maintenance planning document and Boeing a maintenance planning data, known as MPD. These documents explain the maintenance tasks required for each aircraft. They also state how and when the maintenance tasks such as A, B, C, and D checks must take place. MPD must be approved by the authorities EASA and the FAA. The reversed documents with the additional information will be monitored by the CAMO (Continuing Airworthiness Management Organization), which is responsible for controlling the required regular maintenance by airlines or maintenance operators (Cook 2004).

MPD regulations are different for different types of fleets. Typical aircraft maintenance tasks are listed in Table 2.6.

Table 2.6 Typical aircraft checks, their elements, and duration (Cook 2004)

Check	Time required	Items
Transit	1 hour	• Visual inspection • Fluid levels • Tires and brakes • Emergency equipment
A	10 hours	• Routine light maintenance • Engine inspection
B	10 to 24 hours	• Detailed visual inspection and lubrication of all moving parts
C	3 to 7 days	• Structural inspection of the airframe • Opening access panels • Routine and non-routine maintenance • Run-in tests
D	Over 30 days	• Major structural inspection of airframe after paint removal • Engines, landing gear, and flaps removed • Instruments, electronic and electrical equipment removed • Interior fittings (seats and panels) removed • Hydraulic and pneumatic components removed

To estimate the downtime caused by aircraft maintenance we must consider the fleet type. As mentioned above, different manufacturers have different rules for the maintenance of a specific type of aircraft. Table 2.7 shows the time intervals for maintenance checks for some of the aircraft produced by major aircraft manufacturers such as Airbus, Boeing, and ATR.

Table 2.7 Maintenance checks for some different types of aircraft (Cook 2004)

Aircraft	The time interval for Checks			
	A	**B**	**C**	**D**
B737-300	275 FH	825 FH	18 months	48 months
B737-400	275 FH	825 FH	18 months	48 months
B737-500	275 FH	825 FH	18 months	48 months
B737-800	500 FH	-	4000 to 6000 FH	96 to 144 months
B757-200	500 to 600 FH	-	18 months or 6000 FH	72 months
B767-300	600 FH	-	18 months or 6000 FH	72 months
B747-400	600 FH	-	18 months or 7500 FH	72 months
A319	600 FH	-	18 to 20 months or 600 FH	72 months
A320	600 FH	-	18 to 20 months or 6000 FH	72 months
A321	600 FH	-	18 to 20 months or 6000 FH	72 months
ATR42-300	300 to 500 FH	-	3000 to 4000 FH	96 months
ATR72-200	300 to 500 FH	-	3000 to 4000 FH	96 months

2.5.2 Night Flying Restrictions

To avoid the effects of noise pollution on residents living near airfields, airports in many parts of the world have regulations that prohibit the takeoff and landing of aircraft during the night (ICAO 2013). Nighttime aircraft noise can cause significant health problems for people living near airports, including increased blood pressure, heart problems, and even early death. For example, Greiser (2010) studied the residents near Cologne-Bonn Airport and showed an increased risk of coronary heart disease, stroke, and cancer from nocturnal aircraft noise (Korteland 2011).

In 2012, there were approximately 250 airports worldwide, 161 of which were international airports, which had some form of nighttime operating restrictions. But not all airports adhere to a nighttime curfew, and it varies widely in different parts of the world. Twelve percent of European airports had a nighttime curfew in 2012. This number is only four percent of airports in the Middle East, five percent in North America, and only one percent of airports in Africa, Asia Pacific, Latin America, and the Caribbean. Table 2.8 shows the distribution of commercial airports with night curfew around the world (ICAO 2013).

Table 2.8 Number of airports with night flight restrictions in different regions (ICAO 2013)

Region	Number of the airports with night curfew
Europe	126
Africa	5
Middle East	6
Asia-Pacific	15
North America	81
Latin America and the Caribbean	8

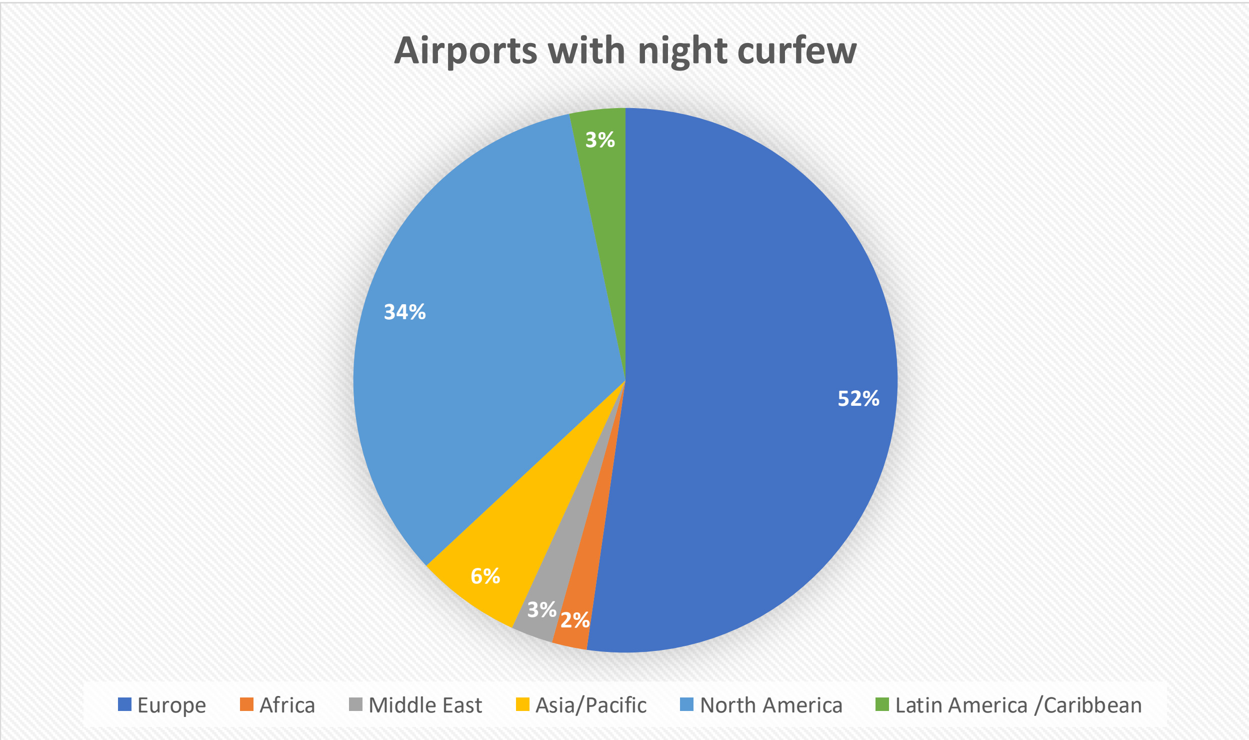


Figure 2.4 Distribution of airports with night flight restrictions (ICAO 2013)

Figure 2.4 shows the distribution of airports with night flight restrictions in 2013. It shows that most airports with night flight restrictions are in Europe and North America. In Europe, different rules applied to night flight restrictions at different airports. The difference is in the definition of nighttime (core night), the number of prohibited flights, and the type of aircraft, based mainly on their noise impact. The night restrictions in some of the major airports in Europe such as Charles de Gaulle, Frankfurt, Schiphol, and Heathrow will be named below as examples.

There are various definitions for the term "night". The core night in Schiphol airport is defined between 23:00 and 06:00, in Frankfurt 23:00 till 05:00, in Heathrow 23:30 till 06:00, and Charles de Gaulle between 23:00 and 06:00. (Faber 2012)

The difference is not only in the definition of the night period but also in the type of restrictions, which can vary from airport to airport. Most airports in Europe have regulations regarding aircraft noise. Some classifications define which aircraft are allowed to fly during the nighttime hours. At Heathrow Airport, for example, the aircraft are classified based on their noise performance known as Quota Count (QC). The noisiest aircraft types, classified as QC/8 or QC/16, generate a noise level of more than 99 dB and QC/4 a noise level between 96 dB and 98.9 dB. These aircraft types (QC/4, QC/8, and QC/16) cannot take off or land between 23:30 and 07:00 at Heathrow (Faber 2012).

Table 2.9 shows the defined nighttime in these four airports and the number of scheduled flights, which can operate during nighttime.

Table 2.9 Number of allowed flights at four airports in Europe (Faber 2012)

Airport	Nighttime	Flight restrictions
Heathrow	23:30-06:00	16 flights
Schiphol	23:00-07:00	maximum of 88 flights
Frankfurt	23:00-05:00	No flights
Charles de Gaulle	00:00-04:59	maximum of 55 flights

2.5.3 Values for the Operation Time

To obtain the annual operation time t_{OPS}, we subtract the amount of annual downtime from the potential operation time t_{PO}, see Equation (2.18). Based on Thorbeck (2013), for instance, a reservation of 3.2 days per year (4 days per 15 month) for C check, 5.6 days per year (4 weeks per 5 years) for D check and 2.6 days per year for repairs results in 353.6 operating days per year. The other constraint considered is the night flight curfew, which is an average of 7 hours per day (23:00 to 6:00) (Thorbeck 2013).

When the time for the aircraft checks and repairs as well as the night curfew are taken into account, the forced downtime t_D can be calculated with (2.20).

$$t_D = t_{C-check,a} + t_{D-check,a} + t_{Repair,a} + t_{Curfew,a}$$
$$t_D = (11.4 \cdot 24\ \text{h}) + (353.6 \cdot 7\ \text{h}) = 2748.8\ \text{h} \tag{2.20}$$

Using this value for t_D, annual operation time in hours is

$$t_{OPS} = 8760\ \text{h} - 2748.8\ \text{h} = 6011.2\ \text{h} \quad . \tag{2.21}$$

The following values in Table 2.10 are used as practical values for t_{OPS} in the other DOC Methods based on AEA (1989a), AEA (1989b), AA (1980), AI (1989), and NASA (1977).

Table 2.10 Values for operation time (Scholz 2015)

DOC method	t_{OPS} [h]
AA (1980)	3205
NASA (1977)	3205
AEA (1989a)	3750
AEA (1989b)	4800
AI (1989)	
R < 1000 nm	3994
1000 ≤ R ≤ 2000 nm	5158
2000nm < R	6566

2.6 Comparing the Methods for Calculating Aircraft Utilization

To calculate annual aircraft utilization, some DOC methods have established equations. For example, the DOC methods of the Air Transport Association of America (ATA), the American Airlines (AA), Lufthansa (DLH), the Association of European Airlines (AEA) and the Thorbeck's DOC method provide equations for calculating the aircraft utilization. The structure of these equations is the same in all methods and is shown in Equation (2.4). The differences between these methods are different notations and different values for the operating time t_{OPS} and the block time supplement t_{BS}.

Table 2.11 is to illustrate the differences in the notation of Design Evaluation / DOC script by Scholz (2015), and the Thorbeck's DOC model by Thorbeck (2013).

Table 2.11 Comparison of the notations of different equations

	Thorbeck-DOC	**Design Evaluation / DOC**	**This project**
	$FH_{p.a.} = FC \cdot FT$	$U_{a,f} = n_{t,a} \cdot t_f$	$U_{a,f} = n_{t,a} \cdot t_f$
	$FC = \frac{POT_{p.a.} - DT_{p.a.}}{FT + BT}$	$n_{t,a} = \frac{k_{U1}}{t_f + k_{U2}}$	$n_{t,a} = \frac{t_{OPS}}{t_f + t_{BS}}$
Annual aircraft utilization	$FH_{p.a.}$	$U_{a,f}$	$U_{a,f}$
Annual number of flight cycles	FC	$n_{t,a}$	$n_{t,a}$
Annual operating time	$OT_{p.a.}$	k_{U1}	t_{OPS}
Annual potential operating time	$POT_{p.a.}$	-	t_{PO}
Annual forced downtime	$DT_{p.a.}$	-	t_D
Block time supplement per flight	BT	k_{U2}	t_{BS}
Average flight time per trip	FT	t_f	t_f

The two equations for calculating aircraft utilization presented by the Thorbeck's DOC method and AEA and other DOC methods are described below.

2.6.1 Thorbeck's DOC Method

According to Thorbeck (2013), the following equation is used to calculate the number of annual flight cycles FC

$$FC = \frac{OT_{p.a.}}{FT + BT} \ , \tag{2.22}$$

where $OT_{p.a.}$ represents the annual operating time, BT the block time supplement per flight and FT the flight time. In turn, FT can be obtained by dividing average stage length R by cruise speed v:

$$FT = \frac{R}{v} \ . \tag{2.23}$$

The annual operating time $OT_{p.a.}$ is the annual potential operating time $POT_{p.a.}$ minus the annual forced downtime $DT_{p.a.}$.

$$OT_{p.a.} = POT_{p.a.} - DT_{p.a.} \tag{2.24}$$

Using Equations (2.23) and (2.24), Equation (2.22) for the number of annual flight cycles can be rewritten as

$$FC = \frac{POT_{p.a.} - DT_{p.a.}}{\left(\frac{R}{v} + BT\right)} \ . \tag{2.25}$$

Based on the Thorbeck's DOC method, the annual forced downtime is 2748.8 hours. This includes C check (3.2 days), D check (5.6 days), and repair time (2.6 days) resulting in 353 operating days. The nighttime flight curfew is set at an average of 7 hours per day (23:00 to 6:00). This reduces the operating hours to 6011.2 hours per year. With an annual operating time of 6011.2 hours and an average block time supplement of 1.83 hours, the number of annual flight cycles is shown as

$$FC = \frac{6011{,}2}{\left(\frac{R}{v} + 1.83\right)} \ . \tag{2.26}$$

It should be noted that the time for the block time supplement per flight is considered as the sum of the turnaround time and the taxi time. Based on AEA (1989a), for example, this time is 0.75 hours. Considering the data in Table 2.1 for the taxi time and the values for the turnaround time according to Gomez (2009) and Sanchez (2009), the average block time supplement of 1.83 hours is too high.

Figure 2.5 shows the result of this equation as the ratio between flight cycle and stage length. According to this model, shorter flight distances result in more flight cycles per year at the same cruising speed.

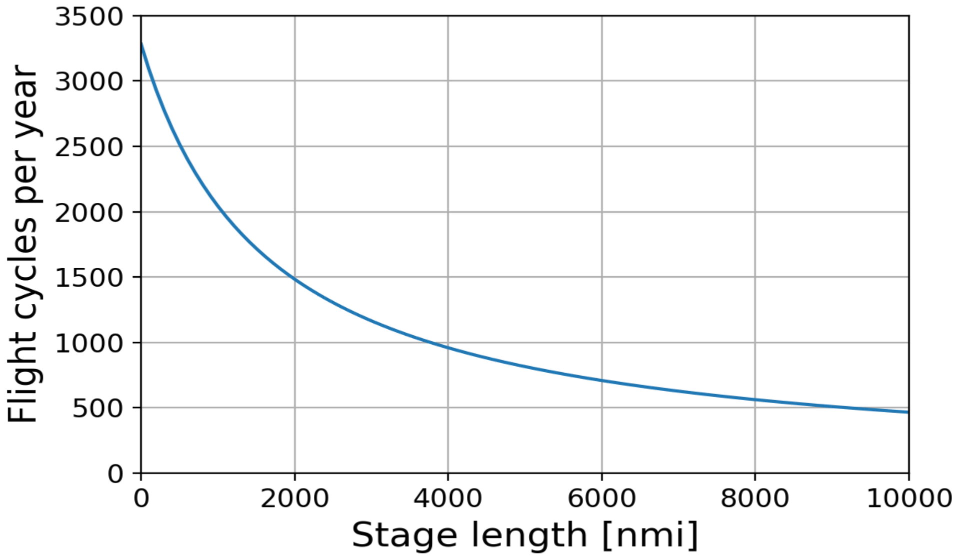


Figure 2.5 Annual number of flight cycles at various stage lengths (Thorbeck 2013)

In this method, annual aircraft utilization is referred to as $FH_{p.a.}$ and is determined with

$$FH_{p.a.} = FC \cdot FT \quad , \tag{2.27}$$

where FC is the number of annual flight cycles and FT the average flight time per cycle.

According to this model, increasing R (stage length) will result in a higher annual flight time, as shown in Figure 2.6.

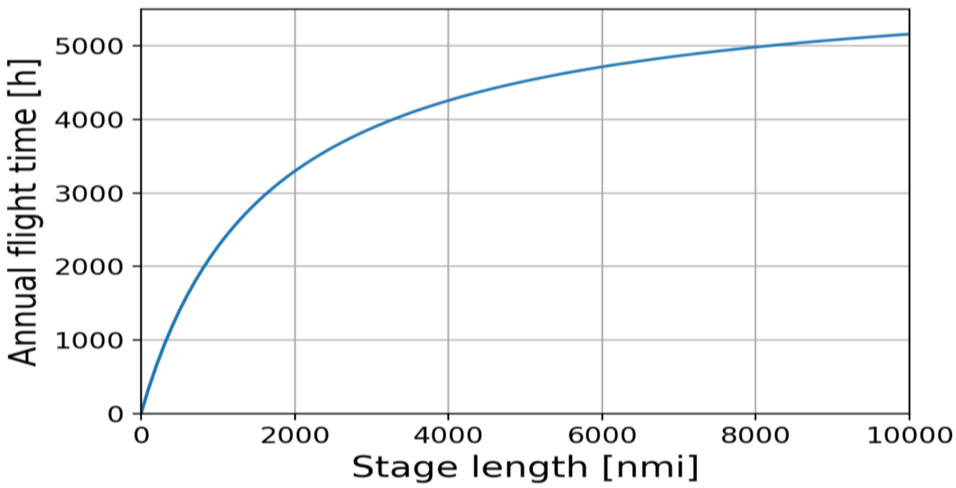


Figure 2.6 Annual flight time at various stage lengths (Thorbeck 2013)

2.6.2 AEA and Other DOC Methods

Design Evaluation / DOC script by Scholz (2015) describes the DOC methods based on the Association of European Airlines (AEA). The models of Air Transport Association of America (ATA), the American Airlines (AA), and the NASA method are the other DOC methods that are considered in this script. Scholz (2015) defines the general equation for calculating aircraft utilization in Design Evaluation / DOC script as

$$U_{a,f} = t_f \frac{k_{U1}}{t_f + k_{U2}} \quad , \tag{2.28}$$

where $U_{a,f}$ is the annual aircraft utilization and t_f is the average flight time per cycle.

Unlike the Thorbeck's DOC method, in Design Evaluation / DOC the parameters for annual operating time and block time supplement are notated as constant parameters k_{U1} and k_{U2}. In this model, k_{U1} is the annual operating time which is named by Thorbeck (2013) as $OT_{p.a.}$ and in this project as t_{OPS}. On the other hand, k_{U2} is the block time supplement which is notated in by Thorbeck (2013) as BT and in this work as t_{BS}. For different DOC methods, values for k_{U1} are shown in Table 2.10 and values for k_{U2} in Table 2.5.

It should be noted that the parameters k_{U1} and k_{U2} and thus the equation for calculating the aircraft utilization were named differently in the demonstration version of the Design Evaluation / DOC script. Scholz (2015) first considers $t_{OPS,a}$ as the annual operating time and t_{GND} (ground time) as the block time supplement. This means that (2.28) can be rewritten as

$$U_{a,f} = t_f \frac{t_{OPS,a}}{t_f + t_{GND}} \quad . \tag{2.29}$$

The following plots are obtained using (2.28) with the values for k_{U1} from Table 2.10 and k_{U2} from Table 2.5. Figure 2.7 shows relative aircraft utilization in relation to flight time per cycle. Based on AA (1980), NASA (1977), AEA (1989a), and AEA (1989b) methods, as shown in Figure 2.7, a higher relative utilization can be achieved for a longer flight time per cycle.

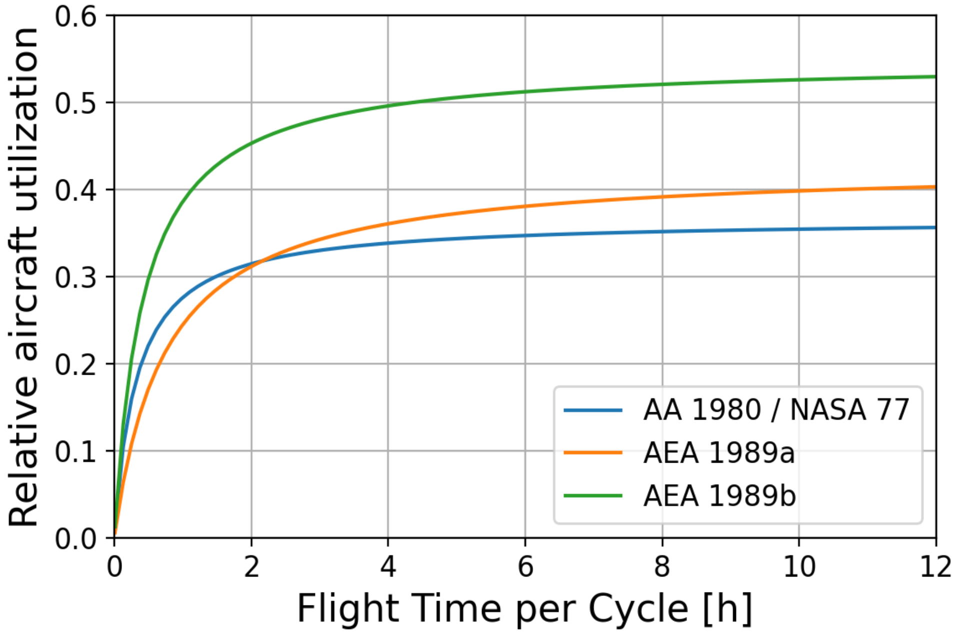


Figure 2.7 Relative aircraft utilization based on AA (1980), AEA (1989a) and AEA (1989b) (Scholz 2015)

The relation between the flight time per cycle and the relative aircraft utilization based on AI (1989) is shown in Figure 2.8. In this model, the values for k_{U1} and k_{U2} are depending on the stage length R. This leads to three different diagrams which are shown in the following figure. In this case, higher relative utilization is expected with longer flight time and longer stage length.

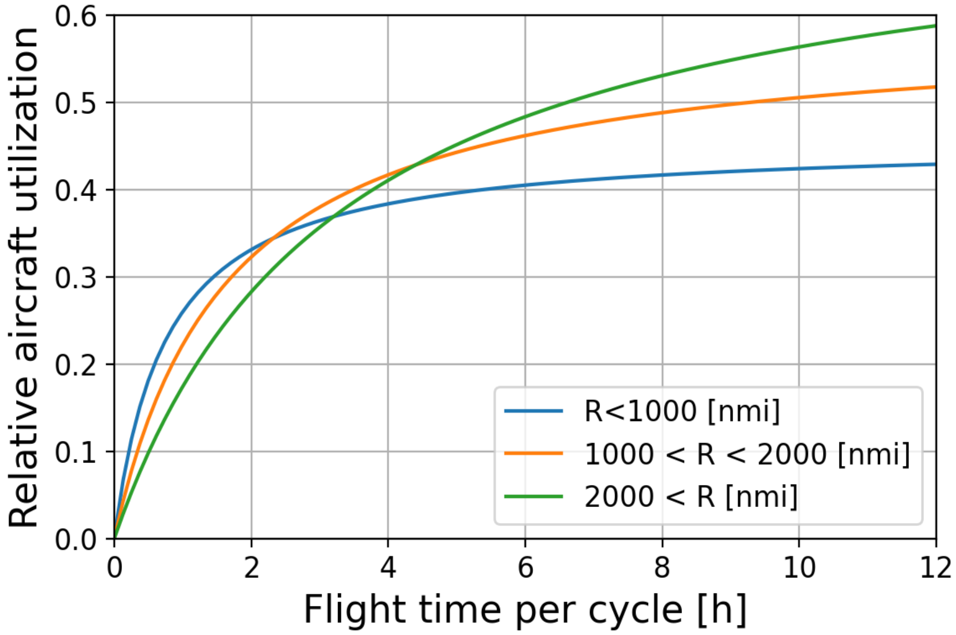


Figure 2.8 Relative aircraft utilization based on the AI (1989) (Scholz 2015)

A further important equation introduced in the script by Scholz (2015), which is based on data from Airbus, calculates aircraft utilization for long-haul aircraft, such as the Airbus 340. A problem with Equation (2.28) is that it is not applicable for long-haul flights because the aircraft utilization increases the longer a flight is, which is not always correct in practice. Preparing the aircraft for the next long-haul flight is difficult to plan and usually not financially profitable (Pournima 2015). In this case, the aircraft may be available for another long-haul flight the next day (Scholz 2015), resulting in a decreasing annual utilization for flights longer than 8 hours. Therefore, an alternative equation structure for calculating aircraft utilization for long-haul aircraft is defined as

$$U_{a,f} = k_{U,A} \cdot (t_f - k_{U,B})^2 + k_{U,C} \quad , \qquad (2.30)$$

with $k_{U,A} = -0.00796\ 1/\text{h}^2$, $k_{U,B} = 8.124\ \text{h}$ and $k_{U,C} = 0.525$.

The result of this relationship is plotted Figure 2.9. According to this model, the relative aircraft utilization has its maximum at a flight time of 8 hours per cycle and falls afterwards.

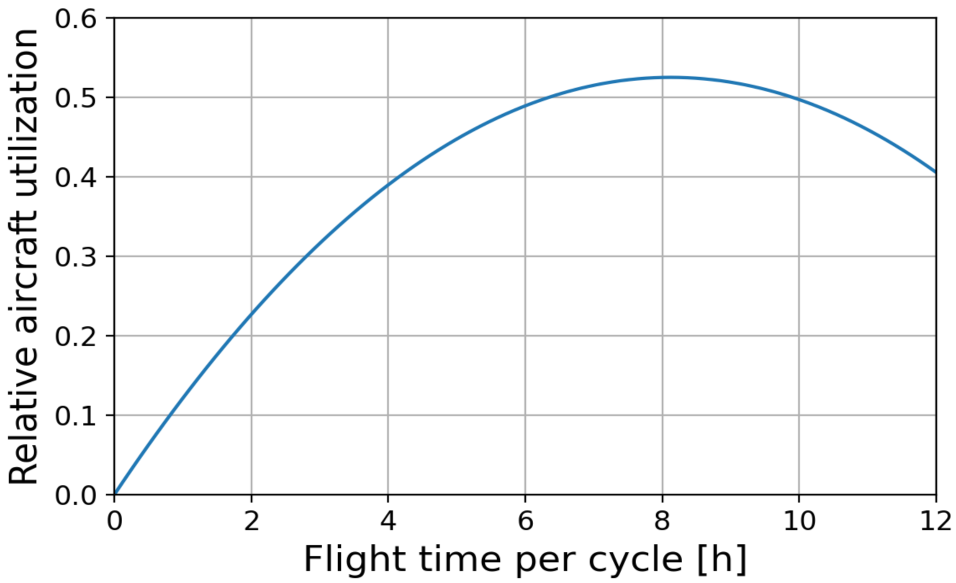


Figure 2.9 Relative aircraft utilization for long-haul flights (Scholz 2015)

3 Case Study

3.1 A320 Based in Frankfurt

In this section, the utilization is calculated for a specific aircraft, A320, whose flight base is assumed to be Frankfurt. A particular aircraft provides specific data on average flight speed v_{av} , and the type of aircraft (heavy, medium, or light) can be used for determining turnaround time and maintenance downtime. A specific airport, on the other hand, can provide an estimate of the average taxi time and defines the night flight regulations. In turn, the average taxi time and turnaround time are used to calculate the block time supplement t_{BS}. Once the values of the operation time and block time supplement are determined, they can be inserted into the general equation for aircraft utilization.

To get the operating time t_{OPS}, the downtime t_D must be calculated and inserted into Equation (2.18). To estimate the downtime for this aircraft, based on the data from Tables 2.6 and 2.7, the following amounts can be reserved for the aircraft checks.

- A/B check: 60 h = 2.5 days
- C check: 80 h = 3.3 days
- D check: 120 h = 5 days

Therefore, the aircraft remains on the ground for regular checks for an average of 10.8 days per year, which results in 354.2 operating days in one year. It should be noted that only the regular checks are considered here. Depending on the age of the aircraft, further repairs may be required, which extend the maintenance downtime.

The night curfew in Frankfurt, where this aircraft is presumably based, is from 23:00 to 05:00. These estimations of maintenance downtime and consideration of airport night curfew lead to the following calculation of the operation time t_{OPS}:

$$t_{OPS} = t_{PO} - t_D$$
$$t_{OPS} = (354.2 \cdot 24\,h) - (354.2 \cdot 6\,h) = 6370.8\,h \tag{3.1}$$

In the next step, based on the data from Table 2.3, a turnaround time of 55 minutes can be considered for the A320. For the Frankfurt Airport, a taxi-in time of 7.3 minutes and a taxi-out time of 12.9 minutes is considered as shown in Figure 2.2. Putting these values into Equation (2.12) results in a block time supplement t_{BS} as:

$$t_{BS} = 12.9\text{ min} + 55\text{ min} + 7.3\text{ min} = 75.2\text{ min} = 1.25\text{ h} \quad . \tag{3.2}$$

With these values for t_{OPS} and t_{BS} we can specify the annual aircraft utilization.

$$U_{a,f} = \frac{6370.8}{1 + 1.25\,\frac{v_{av}}{R_{av}}} \tag{3.3}$$

The average cruising speed of the A320 is 828 km/h (Modern Airliners 2022) and is identified by v_{av} .

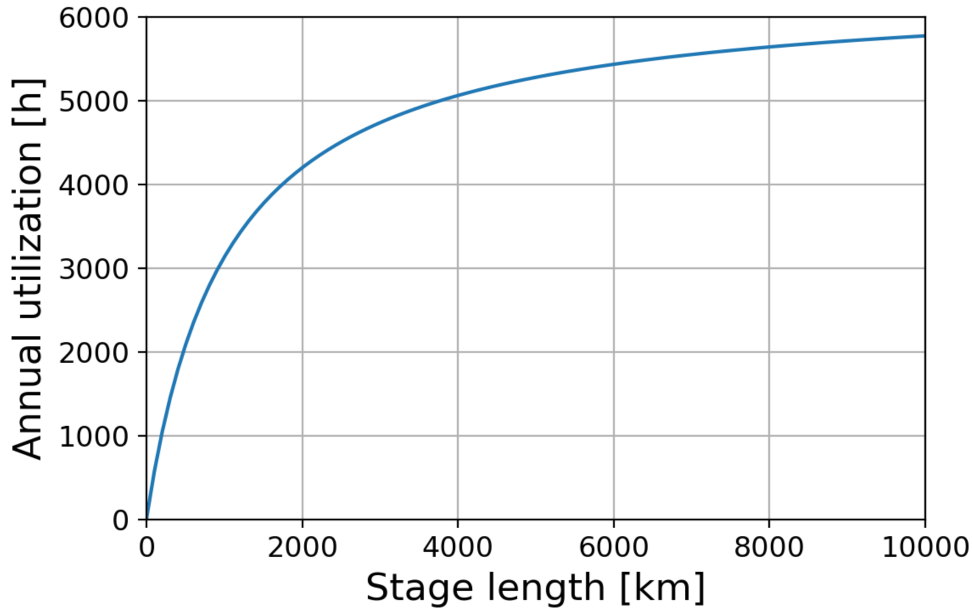


Figure 3.1 Annual utilization for A320 based in Frankfurt airport

Figure 3.1 shows the relationship between the average stage length per flight cycle and the annual aircraft utilization, given by Equation (3.3). Based on this model, a higher annual utilization is assumed for longer flight stages (longer flight time).

3.2 A340 with Different Maintenance Scheduling

Reducing check times through other maintenance programs, such as the task-oriented approach, leads to an increase in operating time per year. This results in a higher annual utilization rate. Based on data collected from one airline for the Airbus A340, Table 3.1 shows the annual inspection days for the A, C, and yearly checks with the classic maintenance concept or rigid letter check system (Kavsaoğlu 2010).

Table 3.1 A340 Annual check downtime using classical maintenance approach (Kavsaoğlu 2010)

Check Type	Ground Downtime for maintenance (days)	Number of checks performed during Overnight checks
A check	4.5	32
C check	3.0	0
Yearly Check	1.2	2
Total	8.7	34

This maintenance time can be reduced with a task-oriented maintenance concept as shown in Table 3.2. This reduction is achieved by performing more inspections during non-operational time, meaning that every moment the aircraft is on the ground for any reason is considered as an opportunity for maintenance. This results in a saving of 72 days over ten years or an average of 7.2 days per year. (Kavsaoğlu 2010).

Table 3.2 A340 Annual check downtime by applying a task-oriented maintenance concept (Kavsaoğlu 2010)

Check Type	Ground Downtime for maintenance (days)	Number of checks performed when the aircraft is on the ground for any reason
A Check	0.0	149
C Check	0.5	79
Yearly Check	1.0	35
Total	1.5	263

Assuming that the A340 is based at the Heathrow airport, the values for the maintenance down-time for two different maintenance approaches are as follows:

- Rigid letter system: 8.7 days
- Single task-oriented system: 1.5 days

Table 2.9 shows that the night curfew at Heathrow for A340 is from 23:30 to 06:00 (6.5 h). These estimates lead to the calculation of the two different operation time t_{OPS_RL} for the rigid letter maintenance system and t_{OPS_ST} for single task-oriented system.

$$
\begin{aligned}
t_{OPS\_RL} &= t_{PO} - t_D = (356.3 \cdot 24\ \text{h}) - (356.3 \cdot 6.5\ \text{h}) = 6235.25\ \text{h} \\
t_{OPS\_ST} &= t_{PO} - t_D = (363.5 \cdot 24\ \text{h}) - (363.5 \cdot 6.5\ \text{h}) = 6361.25\ \text{h}
\end{aligned}
\tag{3.4}
$$

Based on the data from Table 2.2, a turnaround time of 97 minutes is considered for A340 as a heavy aircraft. Using the data in Table 2.1, a taxi time of 22.3 minutes is assumed at Heathrow Airport. Therefore, the t_{BS} can be determined as

$$t_{BS} = 97 + 22.3 = 119.3 \text{ min} = 1.99 \text{ h} \quad . \tag{3.5}$$

With these amounts for t_{OPS_RL} and t_{OPS_ST} and t_{BS}, the effect of the two maintenance models can be compared using the general equation for annual utilization, Equation (2.4). For the annual utilization for the rigid letter maintenance system this will be

$$U_{a,f} = \frac{6235.25}{1 + 1.99 \frac{v_{av}}{R_{av}}} \quad , \tag{3.6}$$

and for single task-oriented maintenance system this will be

$$U_{a,f} = \frac{6361.25}{1 + 1.99 \frac{v_{av}}{R_{av}}} \quad . \tag{3.7}$$

The average cruising speed v_{av} of the A340 is assumed as 871 km/h (Modern Airliners 2022). Figure 3.2 compares the annual flight utilization for these two different maintenance programs.

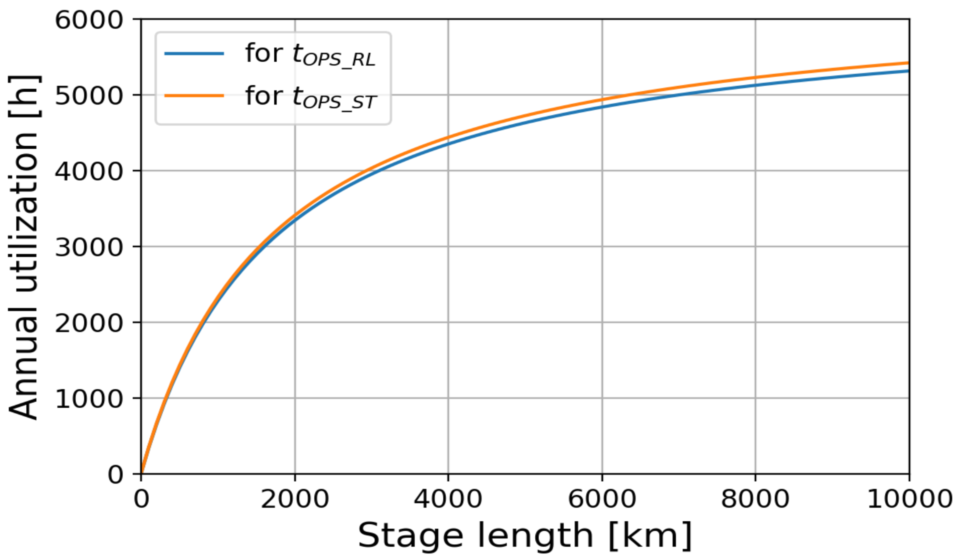


Figure 3.2 Annual flight time with two different maintenance downtimes

Figure 3.2 shows that annual aircraft utilization can be increased by a more effective maintenance program, such as a task-oriented maintenance system.

4 Summary and Conclusions

The utilization of an aircraft is the measure of its productivity and can be represented as annual, daily, or hourly utilization. The general equation for calculating aircraft utilization, Equation (2.4), is presented at the beginning of this project, but to understand this equation we must first know the parameters that can affect aircraft utilization. The parameters can be divided into two categories: first, those that affect the operating time, and second, those that change the block time supplement. Moreover, to obtain the annual operating time, the forced downtime is needed. The aircraft repair and maintenance time and the night curfew are considered here as parameters that cause forced downtime. On the other hand, the calculation of the block time supplement requires an estimation of the taxi time and the turnaround time for each flight. All these parameters are considered in this project and the typical values for each of them are given. With these estimates for the equation parameters, the annual aircraft utilization can be determined.

The equation for aircraft utilization in the Design Evaluation / DOC script by Scholz (2015) gives us a general picture of how we can calculate the annual, daily, or hourly (relative) aircraft utilization. This equation is based on the AA (1980), NASA (1977), AEA (1989a), AEA (1989b) and AI (1989) methods, which all have the same structure. Annual operating time and block time supplement per flight are notated in Design Evaluation lecture notes as constant parameters k_{U1} and k_{U2}. These parameters have different values for different DOC methods mentioned above which are listed by Scholz (2015) in his script.

To clarify how to obtain the values of the parameters k_{U1} and k_{U2}, the Thorbeck's DOC method by Thorbeck (2013) is used in this project. The general equation for calculating annual aircraft utilization has the same structure in both Thorbeck (2013) and Scholz (2015) references, but different notation. To avoid confusion, Section 2.6 refers to all these different notations. In this section, readers can see the equations and their parameters introduced in the Design Evaluation / DOC script, Thorbeck's DOC method, and this project in Table 2.11.

The correlation between flight time and flight stage length resulting from the equation for calculating aircraft utilization is shown in two study cases. The first case study shows that the annual flight time for longer flight stages can be increased due to lower block time supplement for each flight and longer annual operating time.

The second case study shows that lower maintenance downtime leads to higher annual operating time and consequently higher annual aircraft utilization. This example illustrates the importance of reducing forced downtime and helps to understand why airlines, airports and operators are constantly trying to reduce block time supplements and forced downtime.

At this point, it should be noted once again that the general equation of aircraft utilization does not give correct results when it comes to a very long flight (more than 8 hours). For this type of flight, we can use the Equation (2.30). This shows that the aircraft utilization decreases for the extremely long flight.

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