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Calculation Of Aircraft Emission Reduction During The Taxi-Out Phase With The Implementation Of Single Engine Operation At Kertajati Airport

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Abstract. The aviation sector is estimated to contribute about 2% of total CO2 emissions due to human activities. Increased aviation activity at Kertajati Airport has the potential to increase aircraft gas emissions, making the evaluation of emission reduction strategies very important. The main focus of this research is to analyze the effectiveness of single-engine taxi operations during the taxi-out phase in reducing emissions. Using a hybrid approach that combines Advanced Approach and Sophisticated Approach, this quantitative study examines emissions of Hydrocarbons (HC), Carbon Monoxide (CO), and Nitrogen Oxides (NOx). The analysis compares normal operations with single-engine taxi operations during the taxi-out phase. Research results show that in normal operations, total emissions during the taxi-out phase are HC: 22,328.55 grams, CO: 961,184.10 grams, and NOx: 193,381.07 grams. The implementation of single-engine taxi strategy significantly reduces emissions to HC: 6,841.11 grams, CO: 326,101.67 grams, and NOx: 63,002.80 grams. Key findings indicate substantial emission reductions: 69% for HC, 66% for CO, and 67% for NOx. These results demonstrate the effectiveness of single-engine taxi operations in mitigating the environmental impact of aircraft operations at Kertajati Airport. This study provides valuable insights for airport managers and aviation industry stakeholders in developing more environmentally friendly operational practices. The implementation of this strategy has the potential to significantly contribute to efforts in reducing the carbon footprint of the aviation sector, aligning with global commitments to mitigate climate change.

Keywords : Aircraft emissions, Single-engine taxi, Taxi-out, Kertajati Airport, Ecofriendly aviation

Sektor penerbangan diperkirakan menyumbang sekitar 2% dari total emisi CO2 akibat aktivitas manusia. Peningkatan aktivitas penerbangan di Bandara Kertajati berpotensi meningkatkan emisi gas pesawat, sehingga evaluasi strategi pengurangan emisi menjadi sangat penting. Fokus utama dari penelitian ini adalah untuk menganalisis efektivitas operasi taksi bermesin tunggal selama fase taxi out dalam mengurangi emisi. Dengan menggunakan pendekatan hibrida yang menggabungkan Pendekatan Lanjutan dan Pendekatan Canggih, penelitian kuantitatif ini meneliti emisi Hidrokarbon (HC), Karbon Monoksida (CO), dan Nitrogen Oksida (NOx). Analisis ini membandingkan operasi normal dengan operasi taksi bermesin tunggal selama fase taxi-out. Hasil penelitian menunjukkan bahwa pada operasi normal, total emisi pada fase taxi out adalah HC: 22.328,55 gram, CO: 961.184,10 gram, dan NOx: 193.381,07 gram. Penerapan strategi taksi bermesin tunggal secara signifikan mengurangi emisi menjadi HC: 6.841,11 gram, CO: 326.101,67 gram, dan NOx: 63.002,80 gram. Temuan utama menunjukkan pengurangan emisi yang substansial: 69% untuk HC, 66% untuk CO, dan 67% untuk NOx. Hasil ini menunjukkan efektivitas operasi taksi bermesin tunggal dalam memitigasi dampak lingkungan dari operasi pesawat di Bandara Kertajati. Studi ini

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memberikan wawasan yang berharga bagi para pengelola bandara dan pemangku kepentingan industri penerbangan dalam mengembangkan praktik operasional yang lebih ramah lingkungan. Penerapan strategi ini berpotensi memberikan kontribusi yang signifikan terhadap upaya pengurangan jejak karbon di sektor penerbangan, sejalan dengan komitmen global untuk mengurangi perubahan iklim.

Kata Kunci : Emisi pesawat, Taksi bermesin tunggal, Taksi, Bandara Kertajati, Penerbangan ramah lingkungan

1. Introduction

The transfer of flight operations from Husein Sastranegara Airport to Kertajati Airport was officially implemented on October 29, 2023. This policy is implemented with the primary aim of improving safety and security standards in the aviation sector. West Java International Airport (BIJB) located in Kertajati, Majalengka, is currently fully operational, serving both domestic and international flight routes. Kertajati Airport has significant potential to accommodate hajj and umrah flights, considering that West Java Province is the region with the highest population of hajj pilgrims in Indonesia.

Along with the increase in operational capacity of Kertajati Airport, which can now handle up to 16 flights per day and 4,680 passengers per day, the potential increase in aircraft gas emissions is also becoming greater. (*Angkasa Pura 2*, n.d.)). This emphasizes the urgency of research on emission savings, particularly during the taxi-out phase with the implementation of single-engine taxiing. This study is not only relevant for controlling the environmental impact of increased flight activities but also has the potential to make a significant contribution to Kertajati Airport's efforts in implementing more environmentally friendly aviation practices from the outset of its operation as the main airport in West Java.(Mauleon-Mendez et al., 2018; Qian et al., 2018)

Ultimately, global warming contributes to climate change, which leads to an increase in extreme weather disturbances that impact flight activities (Aritenang, 2019)

In the ICAO 9889 document, there are various air pollutants in the form of gas and particulate emissions from aviation activities that have the potential to impact human health and the environment. In general, the pollutants considered as the main components of those emissions include (International Civil Aviation Organization, 2019) :

a. Nitrogen Oxides (NOx), including Nitrogen Dioxide (NO2) and Nitric Oxide (NO);
b. Volatile Organic Compounds (VOC), including Non-Methane Hydrocarbons (NMHC);
c. Carbon Monoxide (CO);
d. Particulate Matter (PM);
e. Size fractions PM 2.5 and PM10;
f. Sulfur Oxides (SOx).

Mora and Yusmar (2014) state that during a flight phase from the departure airport to the destination airport, an aircraft goes through several stages, including flight preparation, taxi-out from the apron, take-off, climb, cruise, descent, approach, and taxi-in at the destination airport. In addition to these phases, the aircraft will also go through a holding phase before landing for specific reasons (Mora & Yusmar, 2014).

Furthermore, the research by Kameníková et al. (2022) refers to Pillirone's explanation of the single engine taxi procedure. According to Pillirone, single engine taxi is a special taxiing procedure that uses only one power unit for twin-engine commercial aircraft. This procedure can also be applied to three or four-engine aircraft by not using one or two power units. Single engine taxi is divided into two types, namely (Kameníková et al., 2022):

a. Single engine taxi-out: taxi before departure;

b. Single engine taxi-in: taxi after landing.

Based on ICAO document 9988 regarding the Landing and Take-Off (LTO) cycle, the taxi time is established to be approximately 26 minutes. After subtracting 6 minutes (3 minutes for engine warm-up and 3 minutes for cool-down), there remains around 20 minutes for taxi time. When conditions permit, the single-engine taxi procedure can be implemented to enhance fuel efficiency (ICAO 2019, n.d.)

Table 1 Reference Emissions for the Landing and Take-Off (LTO) Cycle

Operational Phase	Operating Time (minutes)
Take-off	0.7
Climb	2.2
Approach	4.0
Taxi/ground idle	26.0

The single-engine taxi procedure is only implemented if the taxi time exceeds 6 minutes, which includes 5 minutes for engine warm-up and an additional 1 minute. This extra minute is based on safety considerations. Although the time could potentially be more than 1 minute, this minimum figure is used due to data limitations to estimate the maximum potential emission reductions that can be achieved.

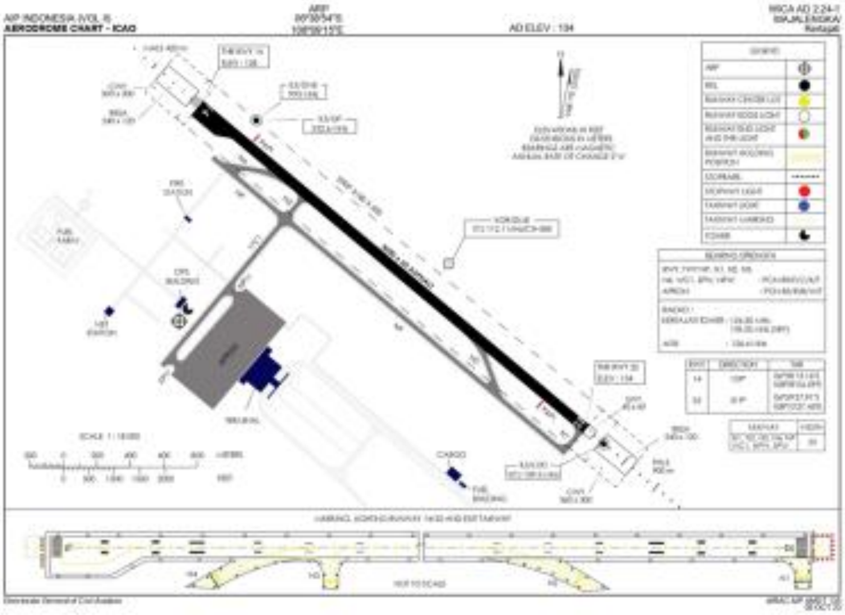
2. Research method

Research methods are essentially scientific ways to obtain data with specific purposes and uses. Based on this, there are four key terms that need to be considered: scientific methods, data, purpose, and use (Sugiyono, 2013, n.d.). In this research, the method adopted is a quantitative approach that concentrates on measuring emissions during the single-engine taxi phase, employing a hybrid method that integrates the Advanced Approach and Sophisticated Approach. This approach uses specific data, including the fuel flow coefficient, emission index, and taxi-out time at Kertajati Airport. By applying this method, emissions of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx) are assessed for both normal operations and the single-engine taxi strategy.

This evaluation yields a quantitative insight into the emission reductions achieved through more efficient and environmentally friendly operational practices.(EUROCONTROL, 2009)..

3. Results and Discussion

Kertajati Airport, also known as West Java International Airport (BIJB), is located in Majalengka Regency, West Java Province. With IATA code: KJT and ICAO code: WICA. Kertajati Airport is built on an area of 1,800 hectares and can serve up to 5.6 million passengers per year. This airport is equipped with an apron that can accommodate 22 wide-body aircraft (*Angkasa Pura 2*, n.d.).



Source: (Directorate General of Civil Aviation, 2023)

Figure 1 Layout of Kertajati Airport

With a wide layout and potentially high traffic volume, taxi-out management at Kertajati Airport becomes a crucial aspect in emission control efforts. The long taxi-out distance can increase fuel consumption and the resulting emissions. Therefore, the optimization of taxi-out procedures and the implementation of environmentally friendly practices such as single engine taxiing are becoming increasingly relevant.

The analysis of taxi-out time has been conducted based on flight operational data at Kertajati Airport in May 2024. Taxi-out time is defined as the difference between pushback time and take-off time for each flight. This study includes a total of 148 flights with various types of aircraft. The analysis results show that the average taxi-out time at Kertajati Airport is 13 minutes. The data indicates that the taxi-out time varies from 7 minutes to 54 minutes. This variation can be caused by various factors, such as the type of aircraft. Wide-body aircraft, such as the B77W type, tend to have longer taxi-out times, often exceeding 15 minutes. This is due to the larger size of the aircraft and the more complex maneuvering requirements. In addition, several aircraft tail numbers that appear repeatedly in the data tend to show consistent taxi-out times.

Table 2 Analysis of Taxi Out Time in May at Kertajati Airport

No	Aircarft Tail Number	Aircraft Type	Pushback Time	Take Off Time	Taxi Out Time (Minutes)
1	9MRAC	A320	03:32	03:44	12
2	PKGLV	A320	02:59	03:11	11
3	PKSTU	A320	08:51	09:02	11
4	PKSJO	A320	07:43	07:51	8
5	PKSTR	A320	07:48	03:01	13
6	PKSTR	A320	12:03	13:35	11
7	PKAZG	A320	12:14	12:44	10
8	PKGLV	A320	06:31	06:42	11
9	PKSAK	A320	02:49	02:59	10
10	PKSAK	A320	03:47	04:06	11
11	PKAXE	B738	07:38	07:48	10
12	9MMLP	B738	07:31	07:43	12
13	PKSAO	A320	08:38	08:49	11
14	PKSAO	A320	02:50	03:00	10
15	PKGLV	A320	11:44	12:01	10
16	PKSJV	A320	02:46	02:57	11
17	PKSJV	A320	07:59	08:08	9
18	PKAZE	A320	13:41	13:52	11
19	9MRAB	A320	03:25	03:38	12
20	PKGQE	A320	11:21	11:32	11
21	PKSTP	A320	09:03	09:14	11
22	PKSJV	A320	03:00	03:12	12
23	PKSJV	A320	08:05	08:28	23
24	9MMMX	B738	02:03	02:15	12
25	PKSTP	A320	08:39	08:49	10
26	PKSAU	A320	07:07	07:21	14
27	PKSGD	A320	02:52	03:01	9
28	PKGLV	A320	06:41	06:53	12
29	PKSGD	A320	03:00	03:09	9
30	PKSGD	A320	09:09	09:21	12
31	PKAXR	A320	13:28	13:39	11
32	9MDAE	A320	03:30	03:40	10
33	PKGLX	A320	06:55	07:08	13
34	PKSTP	A320	08:39	08:50	11
35	PKSGD	A320	02:54	03:04	10
36	PKBBN	B738	08:22	08:32	10
37	PKGTI	A20N	06:58	07:11	13

No	Aircarft Tail Number	Aircraft Type	Pushback Time	Take Off Time	Taxi Out Time (Minutes)
38	PKSAI	A320	06:31	06:40	9
39	PKSGD	A320	03:02	03:12	10
40	PKSGD	A320	07:44	07:52	8
41	PKAZE	A320	13:58	14:11	13
42	PKSTP	A320	08:48	09:00	12
43	PKSAQ	A320	02:46	02:58	12
44	PKAZE	A320	13:36	13:48	12
45	PKGTI	A20N	06:22	06:32	10
46	PKSAQ	A320	02:51	03:02	11
47	PKSAF	A320	08:05	08:16	11
48	PKAZK	A320	13:52	14:05	13
49	9MDAE	A320	03:44	03:55	11
50	PKSTP	A320	08:46	08:56	10
51	PKSAF	A320	07:03	07:13	10
52	PKSAO	A320	02:43	02:52	9
				Average taxi-out time	13

Source: AirNav Indonesia Branch Kertajati Airport

The data processing results with a total of 148 flights during May 2024 show the diversity of the fleet serving flights at Kertajati Airport. The main findings of this analysis indicate the presence of five different types of aircraft and nine variations of aircraft engine types operating takeoffs from Kertajati Airport. The five types of aircraft consist of A20N, A320, B738, B739, and B77W. Meanwhile, the nine identified types of engines include CFMI CFM56-5B4/3, CFMI CFM56-5B4/P, CFMI CFM56-5B6/3, CFMI CFM56-5B6/P, CFMI CFM56-7B26, CFMI CFM56-7B26E, CFMI LEAP-1A26, GE GE90-115B, and IAE V2527-A.

One consistent characteristic among all types of aircraft in operation is the use of a twin-engine configuration. This indicates a uniformity in certain aspects of the fleet serving Kertajati Airport, despite variations in the types of aircraft and engines used.

Table 3 Aircraft Engine Types Based on Aircraft Tail Number

No	Aircarft Tail Number	Aircraft Type	Engine Type
1	9MRAC	A320	CFMI CFM56-5B6/3
2	PKGLV	A320	CFMI CFM56-5B4/3
3	PKSTU	A320	IAE V2527-A5
4	PKSJO	A320	IAE V2527-A5
5	PKSTR	A320	IAE V2527-A5
6	PKSTR	A320	IAE V2527-A5
7	PKAZG	A320	CFMI CFM56-5B6/3

8	PKGLV	A320	CFMI CFM56-5B4/3
9	PKSAK	A320	IAE V2527-A5
10	PKSAK	A320	IAE V2527-A5
11	PKAXE	B738	CFMI CFM56-5B6/3
12	9MMLP	B738	CFMI CFM56-7B26E
13	PKSAO	A320	IAE V2527-A5
14	PKSAO	A320	IAE V2527-A5
15	PKGLV	A320	CFMI CFM56-5B4/3
16	PKSJV	A320	IAE V2527-A5
17	PKSJV	A320	IAE V2527-A5
18	PKAZE	A320	CFMI CFM56-5B6/3
19	9MRAB	A320	CFMI LEAP-1A26
20	PKGQE	A320	CFMI CFM56-5B4/3
21	PKSTP	A320	IAE V2527-A5
22	PKSJV	A320	IAE V2527-A5
23	PKSJV	A320	IAE V2527-A5
24	9MMMX	B738	CFMI CFM56-7B26E
25	PKSTP	A320	IAE V2527-A5
26	PKSAU	A320	IAE V2527-A5
27	PKSGD	A320	IAE V2527-A5
28	PKGLV	A320	CFMI CFM56-5B4/3
29	PKSGD	A320	IAE V2527-A5
30	PKSGD	A320	IAE V2527-A5
31	PKAXR	A320	CFMI CFM56-5B6/P
32	9MDAE	A320	CFMI CFM56-5B6/P
33	PKGLX	A320	CFMI CFM56-5B4/3
34	PKSTP	A320	IAE V2527-A5
35	PKSGD	A320	IAE V2527-A5
36	PKBBN	B738	CFMI CFM56-7B26
37	PKGTI	A20N	CFMI LEAP-1A26
38	PKSAI	A320	IAE V2527-A5
39	PKSGD	A320	IAE V2527-A5
40	PKSGD	A320	IAE V2527-A5

Source: (*Planespotters.Net*, n.d.)

Based on the aircraft engine type for a total of 148 flights (departures) in May 2024, the fuel flow coefficient data (in kg/s) and emission index (EI) (in g/kg of fuel) were obtained from the ICAO Engine Emission Database. This data can be seen in Table 4.3 below.

Table 4 Fuel Flow Coefficient dan Emission Index

No	Engine Type	Fuel Flow Coefficient (kg/s)	Emission Index (EI) g/kg of fuel HC	CO	Nox
1	CFMI CFM56-5B6/3	0,095	2,93	38,39	3,94
2	CFMI CFM56-5B4/3	0,102	1,92	32,07	4,22
3	IAE V2527-A5	0,134	0,14	1,96	5,19
4	IAE V2527-A5	0,134	0,14	1,96	5,19
5	IAE V2527-A5	0,134	0,14	1,96	5,19
6	IAE V2527-A5	0,134	0,14	11,96	5,19
7	CFMI CFM56-5B6/3	0,095	2,93	38,39	3,94
8	CFMI CFM56-5B4/3	0,102	1,92	32,07	4,22
9	IAE V2527-A5	0,134	0,14	11,96	5,19
10	IAE V2527-A5	0,134	0,14	11,96	5,19
11	CFMI CFM56-5B6/3	0,095	2,93	38,39	3,94
12	CFMI CFM56-7B26E	0,108	1,75	30,94	4,27
13	IAE V2527-A5	0,134	0,14	11,96	5,19
14	IAE V2527-A5	0,134	0,14	11,96	5,19
15	CFMI CFM56-5B4/3	0,102	1,92	32,07	4,22
16	IAE V2527-A5	0,134	0,14	11,96	5,19
17	IAE V2527-A5	0,134	0,14	11,96	5,19
18	CFMI CFM56-5B6/3	0,095	2,93	38,39	3,94
19	CFMI LEAP-1A26	0,091	0,29	21,63	4,61
20	CFMI CFM56-5B4/3	0,102	1,92	32,07	4,22
21	IAE V2527-A5	0,134	0,14	11,96	5,19
22	IAE V2527-A5	0,134	0,14	11,96	5,19
23	IAE V2527-A5	0,134	0,14	11,96	5,19
24	CFMI CFM56-7B26E	0,108	1,75	30,94	4,27
25	IAE V2527-A5	0,134	0,14	11,96	5,19
26	IAE V2527-A5	0,134	0,14	11,96	5,19
27	IAE V2527-A5	0,134	0,14	11,96	5,19

Source : ((*ICAO Aircraft Engine Emissions Databank 2024*, n.d.))

Formulation 1

In formulation 1, the operation during the taxi-out phase is conducted under normal conditions (all engines running) and repeated for each flight. The process of calculating the formula using Microsoft Excel starts with the variable TIMij, which is converted from minutes to seconds. The result of this conversion is then multiplied by the fuel flow coefficient and the Emission Index. Finally, this calculation is multiplied by the number of engines for each flight.

$Eij = TIMij \times FFcoefficient \times EIij \times Ni$................................(1)

The formula is :

Eij	=	total pollutant emissions (i) on each flight (j) in grams (g)
TIMij	=	total time required (i) on each flight (j) in seconds
$FF_{coefficient}$	=	fuel flow data in kilograms per second of fuel (kg/s of fuel)
EIij	=	pollutant emission index (i) on each flight (j) in g/kg
Ni	=	number of engines used on each flight (i)

Table 5 Emissions Generated by Aircraft with Normal Operations

No	TIMij (minutes)	TIMij (Seconds)	Fuel Flow Coefficient (kg/s)	Emission Index (EI) g/kg of fuel			Number of Engines	Total Pollutant Emissions (g)		
				HC	CO	Nox		HC	CO	NOx
1	12	720	0,095	2,93	38,39	3,94	2	400,82	5251,75	538,99
2	17	1020	0,102	1,92	32,07	4,22	2	399,51	6673,13	878,10
3	11	660	0,134	0,14	1,96	5,19	2	24,76	2115,48	918,01
4	13	780	0,134	0,14	1,96	5,19	2	29,27	2500,12	1084,92
5	13	780	0,134	0,14	1,96	5,19	2	29,27	2500,12	1084,92
6	13	780	0,134	0,14	11,96	5,19	2	29,27	2500,12	1084,92
7	12	720	0,095	2,93	38,39	3,94	2	400,82	5251,75	538,99
8	11	660	0,102	1,92	32,07	4,22	2	258,51	4317,90	568,18
9	10	600	0,134	0,14	11,96	5,19	2	22,51	1923,17	834,55
10	10	600	0,134	0,14	11,96	5,19	2	22,51	1923,17	834,55
11	11	660	0,095	2,93	38,39	3,94	2	367,42	4814,11	494,08
12	15	900	0,108	1,75	30,94	4,27	2	340,20	6014,74	830,09
13	11	660	0,134	0,14	11,96	5,19	2	24,76	2115,48	918,01
14	10	600	0,134	0,14	11,96	5,19	2	22,51	1923,17	834,55
15	14	840	0,102	1,92	32,07	4,22	2	367,42	4814,11	494,08
16	11	660	0,134	0,14	11,96	5,19	2	24,76	2115,48	918,01
17	9	540	0,134	0,14	11,96	5,19	2	20,26	1730,85	751,10
18	11	660	0,095	2,93	38,39	3,94	2	367,42	4814,11	494,08
19	13	780	0,091	0,29	21,63	4,61	2	41,17	3070,59	654,44
20	11	660	0,102	1,92	32,07	4,22	2	258,51	4317,90	568,18
21	11	660	0,134	0,14	11,96	5,19	2	24,76	2115,48	918,01
22	12	720	0,134	0,14	11,96	5,19	2	27,01	2307,80	1001,46
23	23	1380	0,134	0,14	11,96	5,19	2	51,78	4423,29	1919,47
24	12	720	0,108	1,75	30,94	4,27	2	272,16	4811,79	664,07
25	10	600	0,134	0,14	11,96	5,19	2	22,51	1923,17	834,55
26	14	840	0,134	0,14	11,96	5,19	2	31,52	2692,44	1168,37
27	9	540	0,134	0,14	11,96	5,19	2	20,26	1730,85	751,10
28	12	720	0,102	1,92	32,07	4,22	2	282,01	4710,44	619,83
29	9	540	0,134	0,14	11,96	5,19	2	20,26	1730,85	751,10
30	12	720	0,134	0,14	11,96	5,19	2	27,01	2307,80	1001,46
31	11	660	0,097	5,50	27,70	4,00	2	704,22	3546,71	512,16
32	10	600	0,097	5,50	27,70	4,00	2	640,20	3224,28	465,60
33	13	780	0,102	1,92	32,07	4,22	2	305,51	5102,98	671,49
34	11	660	0,134	0,14	11,96	5,19	2	24,76	2115,48	918,01
35	10	600	0,134	0,14	11,96	5,19	2	22,51	1923,17	834,55
36	10	600	0,113	1,90	18,80	4,70	2	22,51	1923,17	834,55
37	13	780	0,091	0,29	21,63	4,61	2	257,64	2549,28	637,32
38	9	540	0,134	0,14	11,96	5,19	2	41,17	3070,59	654,44
39	10	600	0,134	0,14	11,96	5,19	2	22,51	1923,17	834,55
40	8	480	0,134	0,14	11,96	5,19	2	18,01	1538,53	667,64
41	13	780	0,095	2,93	38,39	3,94	2	434,23	5689,40	583,91
42	12	720	0,134	0,14	11,96	5,19	2	27,01	2307,80	1001,46
							Total Emissions	22328,55	961184,10	193381,07

Source: Research Analysis, 2024

Based on the calculations using formulation 1 for 148 flights, it can be seen in table 4.4 that the total emissions produced during the taxi-out phase are:
a. Hydrocarbons (HC): 22,328.55 grams
b. Carbon Monoxide (CO): 961,184.10 grams
c. Nitrogen Oxides (NOx): 193,381.07 grams

As illustrated in Table 5there is a clear correlation between taxi-out time and the amount of emissions. On flight 95 with the lowest taxi-out time (7 minutes), it produced emissions of HC: 15.76 g, CO: 1,346.22 g, NOx: 584.19 g. Meanwhile, on flight 119 with the highest taxi-out time (54 minutes), it produced emissions of HC: 640.81 g, CO: 76,410.73 g, NOx: 12,175.34 g. This comparison shows that the increase in taxi-out time from 7 minutes to 54 minutes resulted in a significant increase in emissions. This difference in increase also indicates that other factors, such as the type of aircraft reflected in the variation of fuel flow coefficient and emission index, also affect the amount of emissions produced.

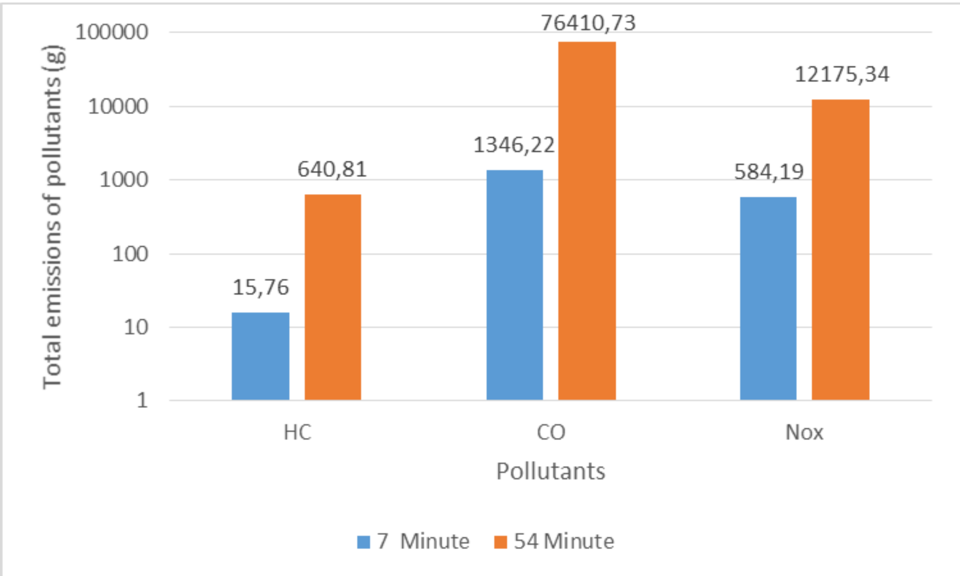


Figure 2 Correlation of Taxi-Out Time for Flights 95 and 119

Source: Research Analysis, 2024

Formulation 2

In formulation 2, operations during the taxi-out phase are conducted with the assumption that all engines must be started at least 5 minutes before takeoff and repeated for each flight. The process of calculating the formula using Microsoft Excel starts with the variable TIMij in seconds. This value is multiplied by the number of machines reduced by one. From the result of the multiplication, subtract 300 seconds.). Next, the result of this subtraction is multiplied by the fuel flow coefficient and the emission index. (Emission Index).

$$Eij = ([TIMij \times (Ni - 1)]\min\{TIMij, 300\})FFcoefficient \times EIij \text{.........}(2)$$

The formula is :

Eij	=	total pollutant emissions (i) for each flight (j) in grams (g)
TIMij	=	total time required (i) for each flight (j) in seconds
$FF_{coefficient}$	=	fuel flow data in kilograms per second of fuel (kg/s of fuel)
EIij	=	pollutant emission index (i) for each flight (j) in g/kg
Ni	=	number of engines used for each flight (i)

Based on the calculations using formulation 2 for 148 flights, it can be seen in table 4.5 that the total emissions produced during the taxi-out phase with the application of single-engine operation are as follows:

a. Hydrocarbons (HC): 6,841.11 grams
b. Carbon Monoxide (CO): 326,101.67 grams
c. Nitrogen Oxides (NOx): 63,002.80 grams

Table 6 Emissions Generated by Aircraft with Single Engine Taxi Operations

No	TIMij (Sseconds	Ni-1	TIMij, 300	Fuel Flow Coefficient (kg/s)	Emission Index (EI) g/kg of fuel			Total Pollutant Emissions (g)		
					HC	CO	Nox	HC	CO	NOx
1	720	1	300	0,095	2,93	38,39	3,94	116,91	1531,76	157,21
2	1020	1	300	0,102	1,92	32,07	4,22	141,00	2355,22	309,92
3	660	1	300	0,134	0,14	1,96	5,19	6,75	576,95	250,37
4	780	1	300	0,134	0,14	1,96	5,19	9,00	333,82	769,27
5	780	1	300	0,134	0,14	1,96	5,19	9,00	333,82	769,27
6	780	1	300	0,134	0,14	11,96	5,19	9,00	333,82	769,27
7	720	1	300	0,095	2,93	38,39	3,94	116,91	1531,76	157,21
8	660	1	300	0,102	1,92	32,07	4,22	70,50	1177,61	154,96
9	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	208,64
10	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	208,64
11	660	1	300	0,095	2,93	38,39	3,94	100,21	1312,94	134,75
12	900	1	300	0,108	1,75	30,94	4,27	113,40	2004,91	276,70
13	660	1	300	0,134	0,14	11,96	5,19	6,75	576,95	250,37
14	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	208,64
15	840	1	300	0,102	1,92	32,07	4,22	105,75	1766,42	232,44
16	660	1	300	0,134	0,14	11,96	5,19	6,75	576,95	250,37
17	540	1	300	0,134	0,14	11,96	5,19	4,50	384,63	166,91
18	660	1	300	0,095	2,93	38,39	3,94	100,21	1312,94	134,75
19	780	1	300	0,091	0,29	21,63	4,61	12,67	944,80	201,36
20	660	1	300	0,102	1,92	32,07	4,22	70,50	1177,61	154,96
21	660	1	300	0,134	0,14	11,96	5,19	6,75	576,95	250,37
22	720	1	300	0,134	0,14	11,96	5,19	7,88	673,11	292,09
23	1380	1	300	0,134	0,14	11,96	5,19	20,26	1730,85	751,10
24	720	1	300	0,108	1,75	30,94	4,27	79,38	1403,44	193,69
25	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	208,64
26	840	1	300	0,134	0,14	11,96	5,19	10,13	865,43	375,55
27	540	1	300	0,134	0,14	11,96	5,19	4,50	384,63	166,91
28	720	1	300	0,102	1,92	32,07	4,22	82,25	1373,88	4180,78
29	540	1	300	0,134	0,14	11,96	5,19	4,50	384,63	166,91

No	TIMij (Sseconds	Ni-1	TIMij, 300	Fuel Flow Coefficient (kg/s)			Emission Index (EI) g/kg of fuel		Total Pollutant Emissions (g)	
30	720	1	300	0,134	0,14	11,96	5,19	7,88	5673,11	292,09
31	660	1	300	0,097	5,50	27,70	4,00 8	192,06	967,28	139,68
32	600	1	300	0,097	5,50	27,70	4,00	160,05	806,07	116,40
33	780	1	300	0,102	1,92	32,07	4,22	94,00	1570,15	206,61
34	660	1	300	0,134	0,14	11,96	5,19	6,75	576,95	250,37
35	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	208,64
36	600	1	300	0,113	1,90	18,80	4,70	64,41	637,32	4159,33
37	780	1	300	0,091	0,29	21,63	4,61	12,67	4944,80	201,36
38	540	1	300	0,134	0,14	11,96	5,19	4,50	384,63	166,91
39	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	208,64
40	480	1	300	0,134	0,14	11,96	5,19	3,38	288,48	125,18
41	780	1	300	0,095	2,93	38,39	3,94	133,61	1750,58	3,94 179,66
42	720	1	300	0,134	0,14	11,96	5,19	7,88	673,11	292,09
43	720	1	300	0,134	0,14	11,96	5,19	7,88	673,11	292,09
44	720	1	300	0,095	2,93	38,39	3,94	116,91	1531,76	157,21
45	600	1	300	0,091	0,29	21,63	4,61	7,92	590,50	125,85
46	660	1	300	0,134	0,14	11,96	5,19	6,75	576,95	250,37
47	660	1	300	0,134	0,14	11,96	5,19	6,75	576,95	250,37
48	780	1	300	0,095	2,93	38,39	3,94	133,61	1750,58	179,66
49	660	1	300	0,097	5,50	27,70	4,00	192,06	967,28	139,68
50	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	5208,64
51	600	1	300	0,134	0,14	11,96	5,19	5,63	480,79	5208,64
							Total Emission	6841,11	326101,67	63001,80

Source: Research Analysis, 2024

Based on the analysis that has been conducted, the results shown in Table 6 provide a clear picture of the effectiveness of implementing the single-machine shutdown operation strategy on hydrocarbon (HC) emissions. The data indicate a significant reduction in HC emissions, amounting to 15,487.44 grams, from the total emissions during normal operation, which reached 22,328.55 grams.

The calculation of the percentage reduction in emissions reveals quite impressive results. By comparing HC emissions under normal operating conditions and the single machine shutdown operation conditions, a reduction percentage of 69% was obtained. This figure indicates that more than two-thirds of HC emissions can be reduced through the implementation of this strategy.

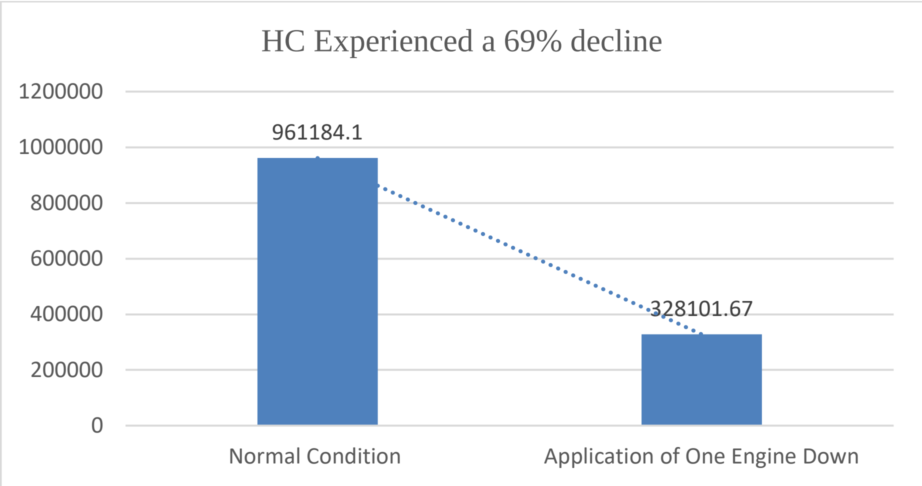


Figure 3 Reduction of Hydrocarbon Emissions (HC).

Source: Research Analysis, 2024

The comparison between these two operating conditions shows a substantial reduction in CO emissions. The difference in emissions between normal operation and single engine operation is 326,101.67 grams. This figure represents a significant reduction in CO emissions. The reduction in hydrocarbon (HC) pollutant emissions between normal operation and single engine operation reaches an impressive figure of 66%. This figure indicates that more than two-thirds of HC emissions can be reduced through the implementation of this strategy.

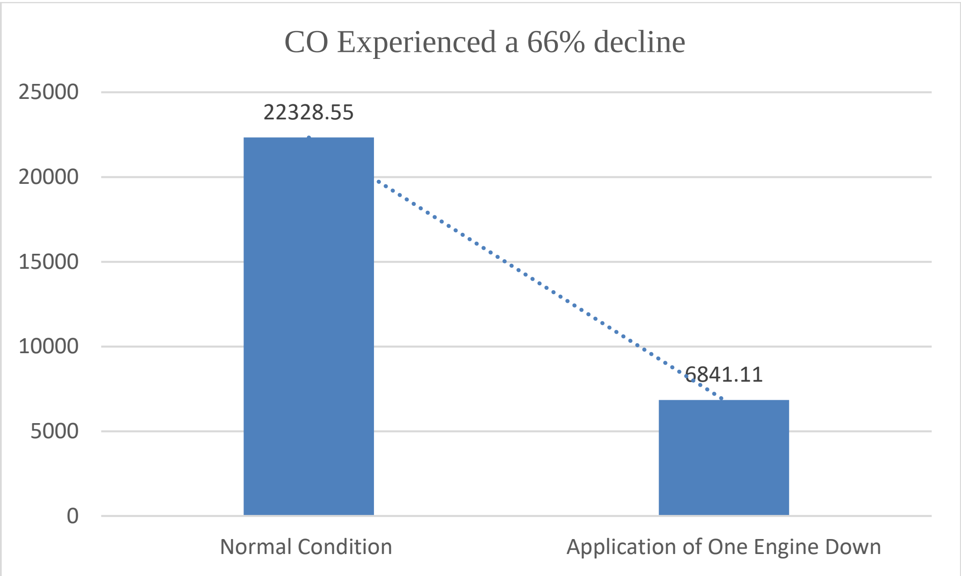


Figure 4 Reduction of Carbon Monoxide (CO) Emissions.

Source: Research Analysis, 2024

In Figure 4, there is a significant reduction in nitrogen oxide (NOx) emissions when the single engine shutdown operation strategy is applied. In normal operating conditions, where all machines are running, NOx emissions are recorded at 63,002.80 grams. However, when the one-engine-off operation strategy is implemented, NOx emissions drastically decrease to 130,378.27 grams. The comparison between these two operating conditions shows a substantial reduction in NOx emissions. The emission difference between normal operation and one-engine-off operation is 67,375.47 grams. This figure represents a significant reduction in NOx emissions. The percentage calculation of the reduction in nitrogen oxide (NOx) emissions between normal operation and one-engine-off operation reaches a quite impressive figure of 67%.

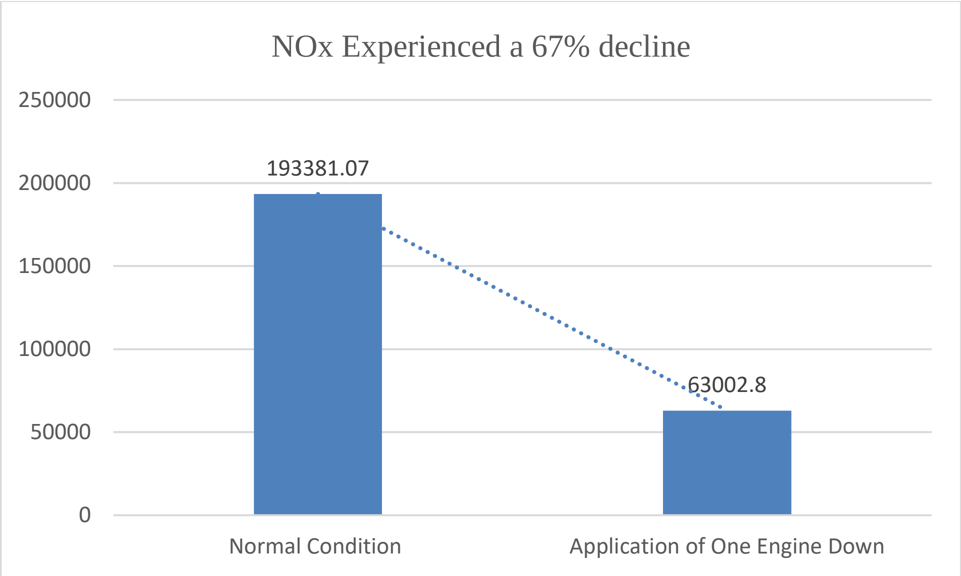


Figure 5 Reduction of Nitrogen Oxide (NOx) Emissions

Source: Research Analyst, 2024

This result shows that the implementation of single-engine taxi operations during the taxi-out phase can have a positive impact on reducing aircraft emissions.

4. Conclusion

This study aims to analyze aircraft exhaust emissions during the taxi-out phase at Kertajati Airport and evaluate the potential for emission reduction through the implementation of a single-engine taxi operation strategy. Based on the analysis of 148 flights, it shows that the implementation of single-engine taxi-out operations can have a significant positive impact on reducing aircraft emissions. Hydrocarbon (HC) emissions decreased by 69%, Carbon Monoxide (CO) emissions decreased by 66%, and Nitrogen Oxide (NOx) emissions decreased by 67%. This research emphasizes the effectiveness of strategies in reducing the environmental impact of aircraft operations. (ICAO, 2018, 2020)

The implications of this research are highly significant. The implementation of a single-engine operation strategy during the taxi-out phase can reduce exhaust emissions by 66%-69%, contributing to global efforts to minimize the environmental impact of the aviation sector. At Kertajati Airport, this strategy can enhance operational efficiency by lowering fuel consumption and airline operational costs, as well as reducing expenditures on carbon credits. The findings of this research can also serve as a foundation for airport operators and regulators to develop policies that support environmentally friendly practices. (Truong et al., 2020)Additionally, this research supports the aviation industry in achieving more sustainable operations, making it an important step toward more environmentally friendly aviation standards on a global scale. This research has limitations in the data collection process, as it only uses data from Kertajati Airport for one month. The results of this research may not be directly applicable to other airports, as each airport has different characteristics in terms of location, infrastructure, and the number of flights.

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