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Modeling Circle Runway to Increase Runway Capacity

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***Abstract*—Runway is a runway for airplanes to land (landing) or to fly (takeoff). Runway is a major component in an airport, it is necessary to plan a good runway. The runway at Juanda Airport uses a conventional system where the runway is rectangular. In this final project the author plans a runway with a circular runway model. The circular runway is a radical new runway design with a circular shape. With a circular runway, airport operators can operate the runway regardless of the wind direction and for all types of aircraft. Airports with circular runways have a smaller footprint than airports with conventional runways. With the existence of a circular runway, it is expected to increase runway capacity compared to conventional runway capacity. Circular runways can also allow airports to continue operating without interference from crosswinds. From the calculation results, it is found that the runway has a circumference of 9864 m. The ARFL length obtained for a circular runway with a Boeing 747-400 aircraft as a reference is 3795 m. The width of the circular runway is determined to be 140 m wide. The slope of the runway starts at an angle of 0° and then increases gradually to 20°. While the force felt by the aircraft when landing on a circular runway is 0.43 g. Juanda's conventional runway capacity is 32 operations per hour. Where the circular runway capacity is 64 operations per hour, this capacity may increase depending on the type of aircraft served.**

***Keywords* — Circular Runway, Crosswind, Runway Capacity.**

I. INTRODUCTION

A. Background

An airport or airport is a facility where airplanes can take off and land. While the simplest airports have at least one runway, but large airports are usually equipped with various other facilities, both for flight service operators and for their users. According to ICAO (International Civil Aviation Organization) an airport is a certain area on land or water (including buildings, installations and equipment) that is intended either in whole or in part for the arrival, departure and movement of aircraft.

The majority of airports have a conventional runway in the form of a rectangular runway. But the use of conventional runways has some problems such as crosswind. Takeoff and landing on conventional runways are strongly influenced by crosswind, if wind conditions are not conducive then airport authorities must close certain runways and redirect air traffic, this can cause disruption in airport operations and cause delays in flights. This of course can cause problems at airports which have very busy activities.

According to the Netherlands Aerospace Research Center Netherlands. The use of a circular runway is theoretically capable of making aircraft take off and land in the most advantageous direction without being affected by crosswind. The circular runway allows the aircraft to always have headwind during takeoff and landing. Another advantage is that more than one aircraft can use the runway at the same time. This can increase air traffic volume and increase time efficiency.

In this plan, it will be known whether the circular runway can be operated in the statue that has the dominant wind direction. You will also get the number of planes that can work simultaneously if the crosswind has no effect. As a case study, data from Juanda Airport is used, which has a dominant wind direction from West to East.

B. Problem Formulation

In general, from the above background there are several issues that must be discussed:

1. What is the magnitude and direction of the crosswind on a circular runway?
2. How many touchdown points are possible on a circular runway?
3. Does the circular runway meet passenger comfort and safety standards?
4. What is the capacity of a circular runway compared to a conventional runway?

C. Objectives

The purpose of planning is to determine the possibility of implementing a circular runway to increase flight capacity and to be able to determine the effect of crosswind on aircraft movement and to compare the capacity of a conventional runway with a circular runway.

D. Problem Scope

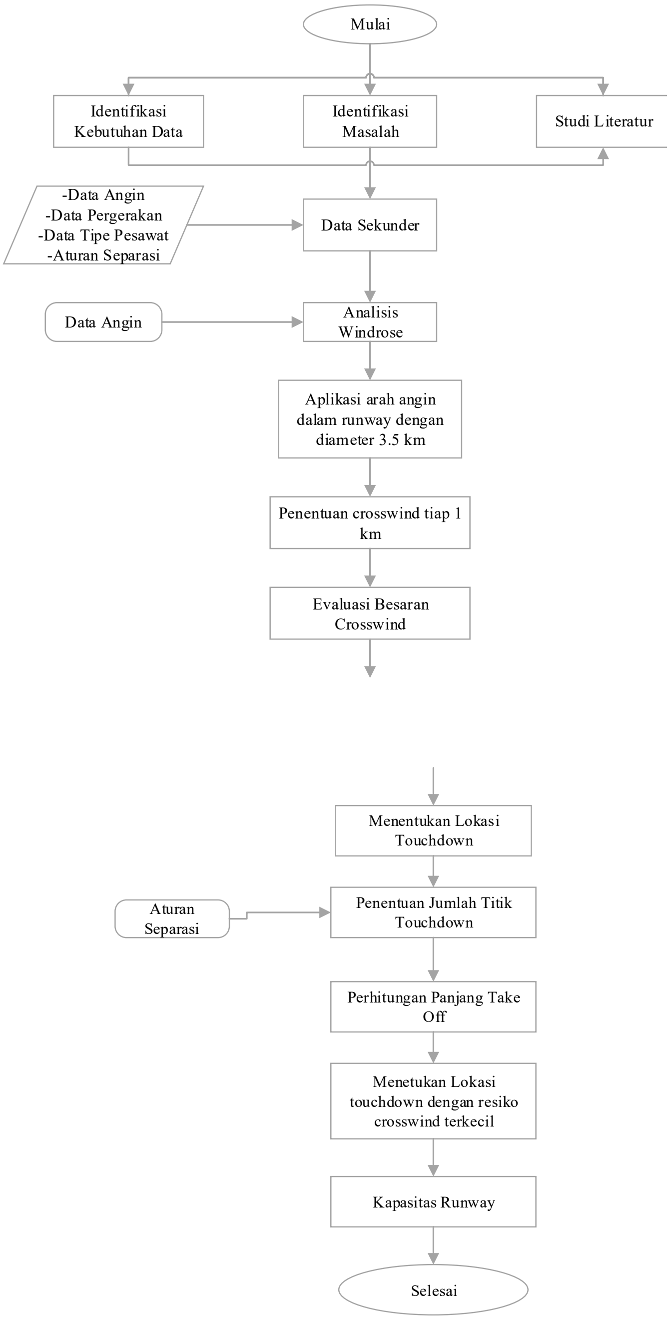
In this final project, the problem is limited to the following discussion points:

1. Issues that are reviewed are only runway planning (runway slope, runway radius and length and minimal separation).
2. Data using data from FAA and flightstats.
3. Not planning the land side of Juanda Airport.

4. Does not take into account the runway pavement.
5. Does not take into account the costs required to build a runway.

II. RESEARCH DESCRIPTION

The methodology used in this study begins with the collection of aircraft movement data and Juanda Airport wind data. The data obtained are used to design a circular runway. Wind data is processed using WRPLOT and Windrose Pro 3 programs to produce crosswind analysis and aircraft movement data is used to calculate circular runway capacity.



III. FINDINGS AND ANALYSIS

A. Circular Runway Length

The calculation results are as follows:

$Lc = 2\pi * 1570$

$Lc = 9864\ m$

B. Runway Length Requirement

The longest runway length based on manufacturing calculations (Lr_0) is the runway for takeoff with a Boeing 747 aircraft type with a runway length of 3300 meters.

The length of the runway after correction is usually referred to as the Airplane Reference Field Length or abbreviated as ARFL.

-Elevation Correction

According to ICAO, the length of the runway increases by 7% for every 300 m increase calculated from the height above sea level. So the formula is:

$F_e = 1 + [0.007 * \left(\frac{h}{300}\right)]$

$F_e = 1 + [0.007 * \left(\frac{2.74}{300}\right)]$

$F_e = 1.0000639$

-Temperature Correction

At higher temperatures, a longer runway is needed, because at high temperatures the air density level will be low, resulting in a low aircraft thrust output. As the temperature standard, the temperature above sea level is 59˚ F = 15˚ C, with the following calculations:

$F_t = 1 + \left[0.01 * \left(T - \left(15 - (0.0065 * h)\right)\right)\right]$

Hitungan koreksi temperatur adalah :

$F_t = 1 + \left[0.01 * \left(34 - \left(15 - (0.0065 * 2.74)\right)\right)\right]$

$F_t = 1.1498219$

-Platform Slope

An upward slope requires a longer runway than a flat or descending base.

$F_s = 1 + (0.1 * S)$

Since there is no change in vertical height on a circular runway, the calculation of runway slope correction can be ignored.

The minimum runway length using the ARFL method is calculated by the following equation:

ARFL = (Lro × Fe × Ft × Fs)

ARFL =(3300 × 1.000639 × 1.1341781 × 1.00125)

ARFL = 3794.65 m

ARFL = 3795 m

The circular runway which has a circumference of 9864 m can accommodate Boeing 747-400 class aircraft.

C. Runway Width

Since the width of the runway does not have a large effect on the takeoff distance, the runway width is set at 140 m to limit the size of the circular runway. Smaller width is not recommended as it will cause greater lateral acceleration.

D. Runway Slope

Starting from the inside of the circle which has a flat surface the slope will increase gradually towards the outside of the circle. Because of the centrifugal force, the aircraft will start from the center of the runway and move to the outside of the runway until it takes off. The slope starts from an angle of 0° to 20°.

E. Wind Analysis

For wind data obtained from Iowa State University Environmental Mesonet. Below is the wind data on January 1, 2016 for complete wind data can be seen in the appendix. In this plan, wind data was taken during January 2016.

Furthermore, the data obtained is entered into the WRPLOT application to be processed into a windrose diagram. From the results of the WRPLOT analysis, the following results are obtained:

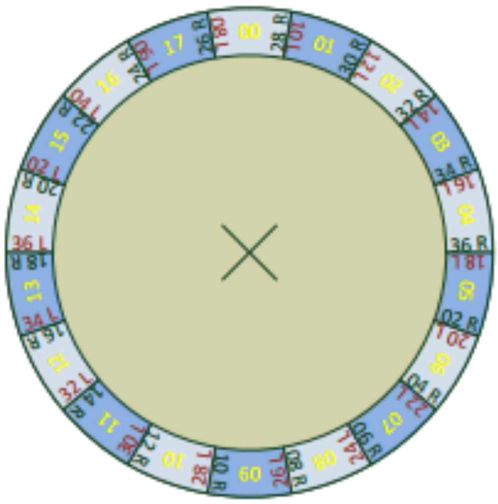


Figure. 2. Circular Runway Numbering System

From the results of the WRPLOT analysis, it was found that the wind at Juanda Airport mostly blows from west to east with a maximum speed of 21.9 knots from an angle of 200°. The results of the analysis also prove that the wind conditions at Juanda Airport are relatively stable and calm.

Table 1.
WRPLOT Wind Analysis Results

	Directions / Wind Classes (Knots)	0.97 - 4.08	4.08 - 7.00	7.00 - 11.08	11.08 - 17.11	17.11 - 21.58	>= 21.58	Total (%)
1	355 - 5	0.40377	0.13459	0	0	0	0	0.53836
2	5-15	0.13459	0.53836	0	0	0	0	0.67295
3	15 - 25	0.13459	0.53836	0	0	0	0	0.67295
4	25 - 35	0.26918	0.26918	0	0	0	0	0.53836
5	35 - 45	0	0	0	0	0	0	0
6	45 - 55	0	0.26918	0.40377	0.13459	0	0	0.80754
7	55 - 65	0.13459	0.26918	0.26918	0	0	0	0.67295
8	65 - 75	0	0.13459	0.13459	0	0	0	0.26918
9	75 - 85	0	0.13459	0.53836	0	0	0	0.67295
10	85 - 95	0	0.13459	0.26918	0	0	0	0.40377
11	95 - 105	0	0	0	0	0	0	0
12	105 - 115	0	0.26918	0	0	0	0	0.26918
13	115 - 125	0.13459	0.26918	0	0	0	0	0.40377
14	125 - 135	0	0.13459	0.26918	0	0	0	0.40377
15	135 - 145	0	0.67295	0	0.13459	0	0	0.80754

F. Runway Numbering

In a conventional runway the numbering is based on the cardinal direction where the runway is facing. The wind direction starts from 0° to 359°. On circular runways the naming cannot be used so a new numbering scheme is needed for circular runways.

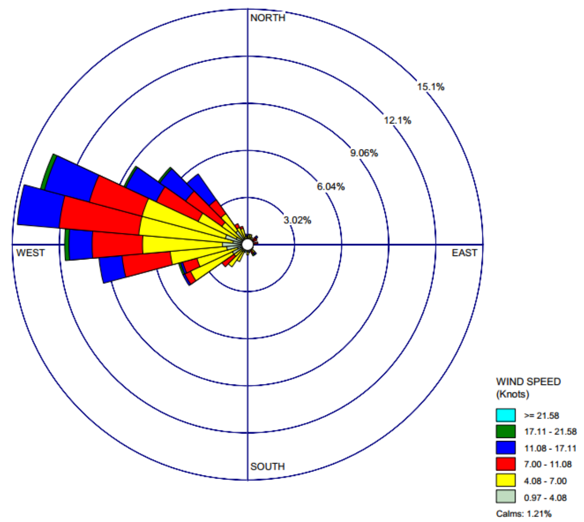
To facilitate the naming of the runway is divided into 18 segments with each segment. Each segment has a length of 548 m. Circular runway numbering is based on the conventional runway numbering system for easy switching.

Table 2.
WRPLOT Wind Analysis Results

	Directions / Wind Classes (Knots)	0.97 - 4.08	4.08 - 7.00	7.00 - 11.08	11.08 - 17.11	17.11 - 21.58	>= 21.58	Total (%)
16	145 - 155	0.13459	0.26918	0.26918	0	0.13459	0	0.80754
17	155 - 165	0.13459	0	0	0	0	0	0.13459
18	165 - 175	0	0.26918	0	0.26918	0	0	0.53836
19	175 - 185	0.40377	0.26918	0	0	0	0	0.67295
20	185 - 195	0	0.40377	0	0	0	0	0.40377
21	195 - 205	0	0.26918	0.13459	0	0	0.13459	0.53836
22	205 - 215	0.26918	0.94213	0	0	0	0	1.21131
23	215 - 225	0.53836	1.21131	0	0	0	0	1.74966
24	225 - 235	0.13459	0.94213	0.94213	0	0	0	2.01884
25	235 - 245	1.07672	2.96097	0.40377	0.13459	0	0	4.57604
26	245 - 255	0.67295	2.69179	0.94213	0.13459	0.13459	0	4.57604
27	255 - 265	1.3459	3.63392	3.09556	1.48048	0	0	9.55585
28	265 - 275	1.61507	5.1144	3.23015	1.48048	0.26918	0	11.7093
29	275 - 285	0.94213	6.05653	5.1144	2.69179	0	0	14.8048
30	285 - 295	1.48048	5.51817	3.49933	2.96097	0.26918	0	13.7281

Table 3.
WRPLOT Wind Analysis Results

	Directions / Wind Classes (Knots)	0.97 - 4.08	4.08 - 7.00	7.00 - 11.08	11.08 - 17.11	17.11 - 21.58	>= 21.58	Total (%)
31	295 - 305	0.80754	2.69179	2.96097	2.15343	0.13459	0	8.74832
32	305 - 315	0.26918	1.74966	2.82638	2.01884	0.13459	0	6.99865
33	315 - 325	1.07672	1.3459	1.07672	2.01884	0	0	5.51817
34	325 - 335	0.26918	0.94213	0.26918	0	0	0	1.48048
35	335 - 345	0.26918	0.80754	0.13459	0	0	0	1.21131
36	345 - 355	0	0.53836	0	0.13459	0	0	0.67295
	Sub-Total	12.6514	42.3957	26.7833	15.747	1.07672	0.13459	98.7887
	Calms							1.21131
	Missing/Incomplete							0
	Total							100



Gambar. 1. Windrose Bandara Juanda

Both directions of the circular runway can be used in accordance with the instructions from the ATC (Air Traffic Controller).

Runway numbering is in accordance with the conventional numbering system where the numbering is based on the heading of the aircraft taking off or landing. When the segment operates clockwise then the "L" code is used and when the segment operates counterclockwise then the "R" code is used.

Based on this numbering system, the runway can operate in 2 different modes, namely clockwise or counterclockwise.

G. Analysis Gaya

In the design of a circular runway, the runway is tilted inward. This is called superelevation which functions to counter the centrifugal force so that the aircraft can continue to run normally without bouncing off the runway.

A force calculation is required to determine whether a circular runway is feasible. Because humans have limits where the body can bear the g force. G force that is too large can cause loss of consciousness and even death. The following are the forces acting on an airplane on a circular runway:

$$N\cos\theta = mg + f\sin\theta$$
$$N\cos\theta = \mu N\sin\theta = mg$$
$$N(\cos\theta - \mu\sin\theta) = mg$$
$$N = \frac{mg}{\cos\theta - \mu\sin\theta}$$

$$F_{net} = N\sin\theta + f\cos\theta = N\sin\theta + \mu N\cos\theta$$
$$F_{net} = N(\sin\theta + \mu\cos\theta)$$
$$= \left(\frac{mg}{\cos\theta - \mu\sin\theta}\right)(\sin\theta + \mu\cos\theta)$$
$$F_{net} = \frac{\sin\theta + \mu\cos\theta}{\cos\theta - \mu\sin\theta}mg = \frac{\tan\theta + \mu}{1 - \mu\tan\theta}mg$$

The maximum safe speed that can be carried out by the aircraft when on a circular runway must first be calculated:

$$F_{net} = F_{centripetal}$$
$$\frac{\tan\theta + \mu}{1 - \mu\tan\theta}mg = \frac{mv^2}{r}$$
$$\frac{\tan\theta + \mu}{1 - \mu\tan\theta}g = \frac{v^2}{r}$$

where :
m = Mass of the aircraft
g = Earth's gravity (9.81 m/s^2)
μ = Asphalt friction coefficient (0.67)
θ = Circular runway slope angle (20°)
v = Velocity
then :

$$\frac{\tan(20) + 0.67}{1 - \mu\tan(20)}(9.81) = \frac{v^2}{1570}$$
$$v^2 = 21060.78313$$
$$v = \sqrt{21060.78313}$$
$$v = 145.123 \approx 145\ m/s = 522\ km/h$$

From the calculation results, it can be concluded that the circular runway is able to safely carry an aircraft with a takeoff speed of 522 km/h, namely a Boeing 747-400 class aircraft which has a takeoff speed of 290 km/h.

After obtaining the maximum safe speed, it is continued with the calculation of the lateral acceleration experienced by the aircraft. Lateral acceleration can be calculated using the following formula:

Table 4.
Category of Aircraft by Speed According to FAA

Kategori	Kecepatan Mendarat
A	< 90 knots
B	91 knots - 120 knots
C	121 knots - 140 knots
D	141 knots - 165 knots

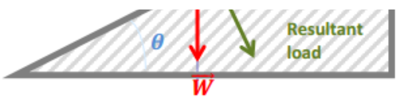


Figure. 3. Style Diagram on Circular Runway

$$a = \frac{v^2}{r}$$

where:
a = Lateral Acceleration
v = Aircraft Speed (290 km/h = 81 m/s)
r = Circular runway radius
then :

$$a = \frac{81^2}{1570} = 4.18 m/s^2 \approx 0.43g$$

From the calculation results, it can be seen that the force experienced by the aircraft and passengers is 0.43 g.

In 1992 NASA (National Aeronautics and Space Administration) conducted a study on human tolerance to g force with the title *Issues on Human Acceleration Tolerance After Long Duration Space Flights.*

From the results of the study, it was found that humans in general can receive a lateral acceleration force of 5 g but there are also those who are able to receive a force of more than 5 g. For complete research results can be seen in the image below.

This proves that the circular runway does not interfere with the comfort or safety of passengers because the lateral acceleration force that occurs is relatively small. As a reference, commercial aircraft generally receive a force of 0.4 g.

H. Evaluation of Circular Runway Performance

-Calculation of Existing Runway Capacity

Calculation of runway capacity for existing conditions was taken in December 2016. The busiest day in normal conditions occurred on December 3, 2016.

From the data, it can be seen that the peak hour occurs at 07:00 – 07:59 with 25 aircraft movements. Aircraft categories are classified based on landing speed. For more details on the classification of aircraft based on Federal Aviation Administration (FAA) regulations, see the table below

Category A aircraft are propeller-engined aircraft such as the C-172/182 and aircraft of the same characteristics. Category B aircraft are turbo-prop engined aircraft such as DHC-7/8, ATR-42/72, L-410, PC-9 and aircraft of similar characteristics. Category C and D aircraft are jet-engined aircraft such as the A-320, F-100, MD-80, CRJ, B-737 and aircraft of similar characteristics.

-Arrival Only

The first step that must be taken is to calculate the runway capacity by assuming that the runway will only serve arriving aircraft (arrivals only).

Error Free State [M_{ij}]

It is known that the minimum separation between aircraft required in space near the runway (δ_{ij}) is 3 nmi and the entrance path to the runway is 6 nmi on average.

- **The docking state**, where the speed of the aircraft in front (leading, V_i) is slower than the aircraft behind (trailing, V_j).

  Formula : $T_{ij} = T_j - T_i = \frac{\delta_{ij}}{V_j}$

  If V_C = 120 knots and V_D = 140 knots, then:

  $$T_{CD} = \frac{3}{140}(3600) = 77.143\ detik$$

  If V_B = 97 knots and V_C = 120 knots, then :

$$T_{BC} = \frac{3}{120}(3600) = 90\ detik$$

If V_B = 97 knots and V_D = 140 knots, then :

$$T_{BD} = \frac{3}{140}(3600) = 77.143\ detik$$

- **Stretch State**, where the speed of the aircraft in front (leading, V_i) is faster than the speed of the aircraft behind (trailing, V_j).

  Formula : $T_{ij} = T_j - T_i = \frac{\delta_{ij}}{V_i} + \gamma\ (\frac{1}{V_j} - \frac{1}{V_i})$

  If V_D = 140 knots and V_C = 120 knots, then :

  $T_{DC} = T_C - T_D = \frac{\delta_{DC}}{V_D} + \gamma\ (\frac{1}{V_C} - \frac{1}{V_D})(3600)$

  $T_{DC} = \frac{3\ (3600)}{140} + 9\ (\frac{1}{120} - \frac{1}{140})(3600)$

  T_{DC} = 115.714 seconds

  If V_D = 140 knots and V_B = 97 knots, then :

  $T_{DB} = T_B - T_D = \frac{\delta_{DB}}{V_D} + \gamma\ (\frac{1}{V_B} - \frac{1}{V_D})(3600)$

  $T_{DB} = \frac{3\ (3600)}{140} + 9\ (\frac{1}{97} - \frac{1}{140})(3600)$

  T_{DB} = 179.735 seconds

  If V_C = 120 knots and V_B = 97 knots, then :

  $T_{CB} = T_B - T_C = \frac{\delta_{CB}}{V_C} + \gamma\ (\frac{1}{V_B} - \frac{1}{V_C})(3600)$

  $T_{CB} = \frac{3\ (3600)}{140} + 9\ (\frac{1}{97} - \frac{1}{120})(3600)$

  T_{CB} = 141.163 detik

- **The situation is equal**, where the speed of the aircraft in front (leading, V_i) and behind (trailing, V_j) is the same.

  Formula : $T_{ij} = T_j - T_i = \frac{\delta_{ij}}{V_j}$

  If V_i = Vj = 97 knots, then :

  $$T_{BB'} = \frac{3}{97}(3600) = 111.34\ detik$$

  If V_i = Vj = 120 knots, then :

  $$T_{CC'} = \frac{3}{120}(3600) = 90\ detik$$

  If V_i = Vj = 140 knots, then :

  $$T_{DD'} = \frac{3}{140}(3600) = 77.143\ detik$$

Because the runway usage time, R_i on average is smaller than the separation time in the air, it will be used in the calculation of the capacity, namely the separation time in the air (T_{ij}).

When the results are tabulated in an error-free matrix [M_{ij}], a minimum time separation at the runway threshold will be obtained for all of the following situations:

		Leading		
		140	120	97
trailing	140	77.143	77.143	77.143
	120	115.714	90	90
	97	179.735	141.163	111.34

Meanwhile, the percentage of combination [P_{ij}] that occurs in the mixture can be seen in the percentage matrix below. The amount of the mixed percentage is obtained from the arrival schedule.

		Leading		
		140	120	97
trailing	140	25	21	4
	120	21	18	3
	97	4	3	1

E[T_{ij}] = Σ $p_{ij}M_{ij}$ = Σ $p_{ij}T_{ij}$

E[T_{ij}] = 94.31 seconds

Thus the capacity of the runway system to serve arrivals only is :

$C = \frac{1}{E(T_{ij})}\ (3600)$

$C = \frac{1}{94.31}\ (3600)$ = 38 operation/hr

Position Error State

Assuming that there is a position error (σ_0) on the flight schedule of 20 seconds distributed normally, and the probability of violating the minimum separation rule for the allowable arrival distance is 10 percent, the runway capacity for this situation can be calculated. With a probability of violation of 10 percent, the value of qv can be found from statistical tables which is 1.28.

- The docked state, the size of the support does not depend on the speed.

  Formula :

  $B_{ij} = \sigma_0\ q_v$

  B_{ij} = 20 (1.28) = 25.6 seconds

- Stretch state, where the aircraft in front (leading, V_i) is faster than the one behind it (trailing, V_j).

  Formula : $B_{ij} = \sigma_0\ q_v - \delta_{ij}\ (\frac{1}{V_j} - \frac{1}{V_i})$

  If V_D = 140 knots dan V_C = 120 knots, then :

  $B_{DC} = \sigma_0\ q_v - \delta_{DC}\ (\frac{1}{V_C} - \frac{1}{V_D})\ (3600)$

  $B_{DC} = 20\ (1.28) - 3\ (\frac{1}{120} - \frac{1}{140})\ (3600)$

  B_{DC} = 12.743 seconds

  If V_D = 140 knots and V_B = 97 knots, then :

  $B_{DB} = \sigma_0\ q_v - \delta_{DB}\ (\frac{1}{V_B} - \frac{1}{V_D})\ (3600)$

  $B_{DB} = 20\ (1.28) - 3\ (\frac{1}{97} - \frac{1}{140})\ (3600)$

  B_{DB} = -8.5973 seconds

  If V_C = 120 knots and V_B = 97 knots, then :

  $B_{CB} = \sigma_0\ q_v - \delta_{CB}\ (\frac{1}{V_B} - \frac{1}{V_C})\ (3600)$

  $B_{DC} = 20\ (1.28) - 3\ (\frac{1}{97} - \frac{1}{120})\ (3600)$

  B_{CB} = 4.2598 seconds

- The situation is equal, where the speed of the aircraft in front (leading, V_i) and behind (trailing, V_j) is the same. From the calculation results, the same result will be obtained, namely 25.6 seconds.

  The rebuttal values are then summarized into a rebuttal value matrix [B_{ij}] as follows.

		Leading		
		140	120	97
trailing	140	25.6	25.60	25.60
	120	12.74	25.60	25.60
	97	-8.60	4.26	25.60

By combining the error-free matrix [M_{ij}] and the counter-value matrix [B_{ij}], the actual time interval between arrivals at the runway threshold is obtained:

		Leading		
		140	120	97
trailing	140	102.743	102.743	77.143

120	128.454	115.60	90
97	171.135	145.423	136.94

When this is combined with the mixed aircraft percentage [P_{ij}], the average interarrival time is

$E[T_{ij}] = \Sigma\ p_{ij}M_{ij} = \Sigma\ p_{ij}T_{ij}$

$E[T_{ij}] = 113.76$ detik

Thus, the capacity of the runway system to serve arrivals in the event of a position error is:

$C = \frac{1}{E(T_{ij})}\ (3600)$

$C = \frac{1}{113.76}\ (3600)$ = 31 operation/hr

-Departure Only

The next step is to assume that the runway will only serve departing aircraft (departures only).

The minimum separation distance between departures is 120 seconds (ATC Tower Juanda International Airport Surabaya). The percentage matrix of the combination [P_{ij}] that occurs in the mixture can be seen in the percentage matrix below.

	Leading			
		140	120	97
trailing	140	5.3	15.9	1.8
	120	15.9	47.6	5.5
	97	1.8	5.5	0.6

The amount of service time between departures on the threshold of runway $E(t_d)$ is as follows:

$E(t_d) = \Sigma\ (p_{ij})(M_{ij})$

$E(t_d) = 120$ seconds

Runway capacity that only serves departures is obtained from the formula:

$C = \frac{1}{E(T_{ij})}\ (3600)$

$C = \frac{1}{120}\ (3600)$ = 30 operation/hr

-Mixed Operation

The final step in determining the runway capacity is to find the possibility of a departure operation between two arrivals.

Average runway usage time, which is the multiplication of the percentage of the aircraft category with the runway usage time for each category of aircraft.

$E[R_i] = 0{,}08(62) + 0{,}42(67{,}4) + 0{,}50(64{,}5) = 65{,}50$ seconds

The expected time for the arriving aircraft to cover the last 2 miles to the runway threshold is:

$E(\frac{\delta d}{Vj}) = [0{,}08(\frac{2}{97}) + 0{,}42(\frac{2}{120}) + 0{,}50(\frac{2}{140})]3600 = 56{,}90$ seconds

$E(t_d) = 120$ seconds

$E(B_{ij}) = 20\ (1{,}28) = 26$ seconds

To calculate the probability that a departure operation can be performed between two arrival operations, we can use the following formula:

$E[T_{ij}] \geq E[Ri] + E[\frac{\delta_d}{V_j}] + E\ (B_{ij}) + (n\text{-}1)\ E\ (t_d)$

$E[T_{ij}] \geq 65{,}50 + 56{,}90 + 26 + (n\text{-}1)\ 120$

$\geq 148{,}40 + 120\ (n\text{-}1)$

From the time matrix between arrivals, it can be seen that the probability of one departure that can be made between two arrivals is 4 percent, and cannot make more than one departure between two arrivals. The runway capacity for these conditions can be calculated based on the following formula:

$C_m = \frac{1}{E(\Delta T_{ij})}(1 + \sum n_{d\ p_{nd}})$

$C_m = \frac{1\ (3600)}{114}(1 + 1(0.04))$ = 32 operation/hr

Since the value in the interarrival time matrix [Mij] is at least 148.40 seconds, values smaller than that will be changed to 148.40 seconds so that one departure can be made between two arrivals.

	Leading			
		140	120	97
trailing	140	148.4	148.4	148.4
	120	148.4	148.4	148.4
	97	171.135	148.4	148.4

Thus,

$E[T_{ij}] =$ 0.25(148.4)+0.21(148.4)+0.04(148.4)+0.21(148.4)+0.18(148.4)+0.03(148.4)+0.04(171.135)+0.03(148.4)+0.01(148.4) = 147.15

Then the runway capacity for mixed operations will be

$C_m = \frac{1\ (3600)}{147}(1 + 1(0.96) + 0.04(2))$ = 49 operation/hr

- Circular Runway Capacity

To determine the capacity of a circular runway, crosswind analysis is needed to determine the takeoff and landing locations. For this analysis, we use the data obtained from Iowa State University and the Windrose Pro 3 software.

From the analysis results, it can be seen that the crosswind greater than 20 knots comes from angles of 360°, 10°, 20°, 30°, and 40°. In the previous discussion, it was stated that the circular runway was divided into 18 segments. By knowing the direction of the dominant crosswind wind can be determined the touchdown and landing positions.

With the results of the analysis, it was determined that the runway segments 00, 01, 02, 09, 10, and 11 could not be used because the crosswind component exceeded 20 knots. Then the segment that has a crosswind component of less than 20 knots is selected, namely segments 04 and 13, which each has a crosswind component of 18 knots and 18 knots.

From the calculations in chapter 4, it is known that the ARFL is 3795 m long, so the runway must have a minimum length of as long as the ARFL. The distance from segment 4 to segment 13 is 4384 m long, and vice versa. Therefore, the circular runway can operate as 2 individual runways. In this design the runway operates in a clockwise direction.

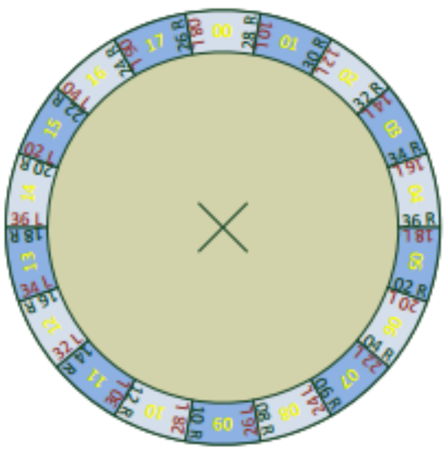
The runway capacity will be doubled if 2 runways move individually. In the previous calculation, it is known that the existing runway capacity for arrival only is 31 operations/hour, departure only 30 operations/hour and mixed operations 49 operations/hour. With a circular runway, the runway capacity will increase to 62 operations/hour for arrival only, 60 operations/hour for departure only and 98 operations/hour for mixed operation.

Since the ARFL used is ARFL for Boeing 747-400 type aircraft, the runway can only accommodate 2 aircraft simultaneously. When the type of aircraft operating is only Boeing 737-300 or Airbus A320, the circular runway can operate into 4 individual runways because the ARFL of the aircraft is shorter than the Boeing 747-400. This increases the capacity to 4 times compared to conventional runways.

IV. CONCLUSION AND SUGGESTIONS

A. Conclusion

From the results of the calculation analysis in this Final



Gambar. 6. Segmen Runway Melingkar

Project, it can be concluded several things as follows:

1. The largest crosswinds are 20.58 knots, 21.9 knots, 21.57 knots, and 20.58 knots.
2. The possible touchdown points on a circular runway with Boeing 747-400 aircraft as the ARFL reference are 2 touchdown points. The number of touchdown points can increase if the ARFL reference used is shorter, such as for Boeing 737 aircraft.
3. The force felt by the aircraft when landing on a circular runway is 0.43 g, which is still within the passenger comfort limit.
4. Juanda'a conventional runway capacity is 32 operations per hour. The circular runway capacity is 64 operations per hour, this capacity can increase depending on the type of aircraft served.

B. Suggestions

The suggestions for planning a circular runway at Juanda International Airport are as follows:

1. Additional planning is needed for the design of terminals, taxiways, aprons, and other supporting facilities.
2. It is necessary to conduct a more detailed research on the capacity of the circular runway.

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