Flight Route Optimization in Required Navigation Performance (RNP) Approach Flight Procedures Based on Experimental Algorithm

Imam Sonhaji*, Fety Fatonah, Djoko Jatmoko

Politeknik Penerbangan Indonesia, Jl. Raya PLP Curug, Serdang Wetan, Legok, Tangerang, Banten 15820
**Corresponding Author. Email: imam.sonhaji@ppicurug.ac.id*

ABSTRACT
ICAO recommends that capacity and efficiency achievement programs be carried out through the Performance Based Navigation (PBN) implementation model. This research aims to obtain an overview of the optimal formula model that can be implemented into flight paths based on the RNP approach procedure for flight path efficiency and fuel efficiency. This research uses quantitative experimental methods. The results of this research are that the optimization model at minimum speed (V=210 knots) produces route effectiveness of 8% and fuel savings of 1.5% compared to the established current procedure. The conclusion is that for straight paths, route optimization is achieved by applying the maximum speed, but for circular (arc) paths, route optimization is achieved by applying the specified minimum speed.

Keywords: Performance Based Navigation, Required Navigation Performance, Flight Procedure

INTRODUCTION

The International Civil Aviation Organization (ICAO) predicts that domestic and international flights will reach 6 (six) billion by 2030 [1]. Therefore, ICAO requires each member country to continue developing its civil aviation management order towards logging that prioritizes safety, capacity and efficiency, security and facilitation, economic development, and environment protection. Air Navigation Capacity and Efficiency is a concept that will be applied in the next 20 years to ensure harmonization of all member countries globally to innovate in managing the implementation of existing technology optimization while still focusing on safety aspects [2].

ICAO recommends that capacity and efficiency achievement programs be carried out through the Performance Based Navigation (PBN) application model. PBN is an aircraft navigation concept by optimizes the performance of equipment on aircraft with special provisions on the path (ATS route) and landing procedures (Instrument Approach Procedure) or in certain airspace designs [3]. PBN consists of models, namely Area Navigation (RNAV) and Required Navigation Performance (RNP) where both models have differences RNP is equipped with onboard monitoring and alerts, while RNAV is not equipped [4]. Both RNAV and RNP aim to increase fuel capacity and efficiency without compromising safety and environmental aspects [5].

Table 1. Indonesia PBN Implementation.

PBN Procedures	International Airport	Domestic Airport
PBN IAP	30	51
PBN SID/STAR	15	13

The problem found is that the flight procedure design on the RNP approach-based instrument approach procedure (IAP) has never been tested through simple algorithmic calculations through simulator testing to obtain a formula model that can provide alternative fuel efficiency solutions through the efficiency of an aircraft's flying distance. In China, the increase in flights at low levels/altitudes known as general aviation (GA), PBN is key in airspace management (Airspace planning) and increasing efficiency and rationality. [6]. The application of PBN with the concept of dynamic approach and landing procedures directs the aircraft to fly along a path with a design to avoid residential areas around the airport, reduce noise and exhaust emissions, avoid areas with bad weather to prevent incidents and accidents and reduce landing distance by 56% compared to the previous route [1].

The application of the PBN model with the point merge concept to optimize flight procedures can be used to reduce flight time, aircraft fuel consumption, and effects on the environment [7]. The RNP approach procedure is designed by considering safety aspects through flight area protection and height limitation from existing obstructions to produce a fuel-efficient and environmentally friendly flight path [8]. Research [9] results show that although noise and emissions are proportional to fuel use, they can be reduced by making a flight path designed with low idle thrust and the PBN Route concept is a solution to achieving it. Research [10]shows that PBN is a solution related to noise due to flight traffic growth, besides that in the future PBN will focus more on the use of satellites in ground-based navigation equipment such as NDB, VOR, DME, and others to produce a more precise and accurate flight path and aircraft fuel efficiency can be realized.

This research is expected to be able to provide an overview of the optimal formula model that can be implemented into the flight path based on the RNP approach Procedure so that it can contribute to flight path efficiency, fuel efficiency, and environmental protection caused by both noise and carbon emissions

METHOD

Literature Studies

The future challenge in airspace management of Air traffic Management (ATM) is the transformation and adaptation of aircraft navigation systems into a Performance Navigation (PBN)-based management model (Yang et al., 2020). PBN is known for 2 (two) models of navigation specification (nav spec), namely Area Navigation (RNAV) and Required Navigation Performance (RNP), and both have the advantages of shorter paths, fuel efficiency, and environmentally friendly and can increase airspace capacity [11].

Required Navigation Performance (RNP) is an aircraft navigation system that provides flexibility to fly from one point to another with guaranteed accuracy so that safety and efficiency aspects are still achieved [12].

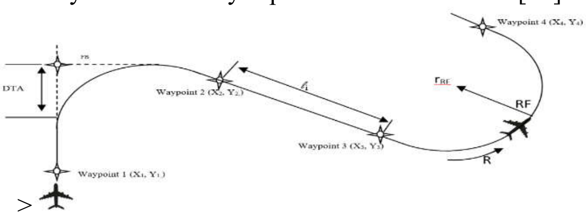

Figure 1. RNP Route Structure

In the RNP procedure, the route is composed of waypoints and legs. Leg is a component that connects 2 (two) waypoints through 2 (two) models, namely Track to Fix (TF) and Radius to Fix (RF) [12]. The application of RNP-based routes is also implemented in the Instrument Approach Procedure (IAP). IAP is a series of predefined maneuvers for aircraft that operate regularly from the beginning of the approach phase to the point from which the landing can be visually performed [13]. Waypoints are geometric-specific points used to form Area Navigation (RNAV) routes or to form aircraft flight paths [14]. The types are divided into 2, namely fly-by and fly-over.

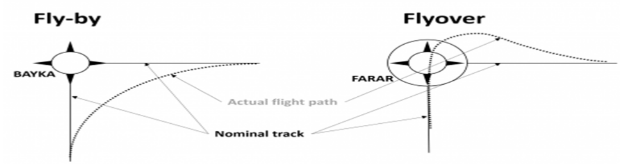

Figure 2. Fly Over and Fly By

Figure 2 illustrates the difference between a fly-by waypoint and a flyover waypoint, a fly-by waypoint is a waypoint that requires anticipated turns to allow interception to the next segment or procedure route, while a flyover waypoint is a waypoint that is initiated to join the next segment or procedure.

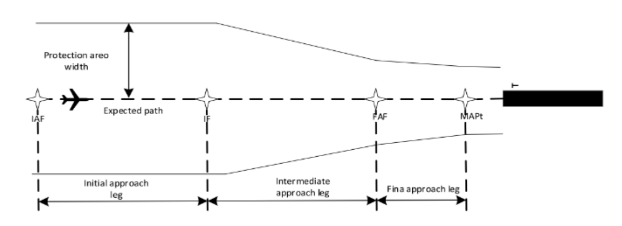

Figure 3. RNP Approach Leg

Figure 3 explains that the RNP-based instrument approach procedure (IAP) has several segments, namely [14]:

1. Initial Approach (IA) Leg. This segment is the initial segment in IAP;
2. Intermediate Approach (I) Leg. An advanced segment of IA leg;
3. Final Approach (FA) Leg. The final segment before executing the landing procedure.

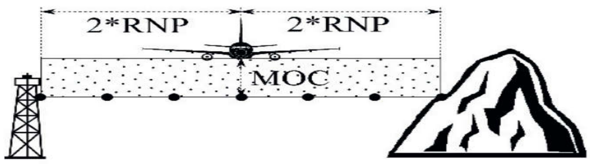

Figure 4. Minimum Obstacle Clearence (MOC)

The flight path is designed by considering the height of obstacles in the area to be passed (ICAO, 2018). Each flight path is the height of the obstacle plus the minimum distance called the minimum obstacle clearance (MOC) with the aim that every aircraft passing through its path is protected as shown in Figure 4.

$$H_{path} - MOC - H_{terrain} > 0 \quad (1)$$

Equation (1) shows that the altitude of the aircraft on the flight path must be greater than the terrain altitude and the specified Minimum Obstacle Clearance (MOC). (ICAO, 2018).

Table 2. RNP and MOC Value

App Segment	RNP Value (NM)	MOC (m)
Initial	1	300
Intermediate	1	150
Final	0.3	0

Table *2*. RNP and MOC Value is the basis for determining the altitude of the flight path designed so that aircraft crossing the path are protected from obstacles or terrain [15].

Table 3. Speed Restriction

Approach Segment	*Category C*	*Category C (minimum)*	*Category D*	*Category D (minimum)*
Initial	240 knots	210 knots	250 knots	210 knots
Intermediate	240 knots	180 knots	250 knots	180 knots
Final	160 knots	140 knots	185 knots	165 knots

Table 3 shows the speed limit of aircraft when carrying out IAP in Category C (Medium) and Category D (Heavy) so that speed regulation can be done earlier by a pilot during IAP.

Simulation Studies

This study uses secondary data on the instrument approach procedure (IAP) based on Required Navigation Performance (RNP) at Husein Sastra Negara International Airport Bandung. This research uses a simple general algorithm that is used as parameters that are inputted into the ATC simulator (Micronav Sim). Waypoint data, latitude, and longitude position data will be inputted into the ATC simulator (Micronav Sim) with several parameters as follows:

$$\mathbf{X} = (x_1, y_1, v_1, ..., x_{(n-1)}, y_{(n-1)}, v_{(n-1)}) \quad (1)$$

where X is the position of the aircraft when passing through the waypoint. X1 is the latitude position of Waypoint 1, Y1 is the position of Longitude Waypoint 1, and V1 is the speed of the aircraft at Waypoint 1.

$$R \leq 3^0 \text{ per second} \quad (2)$$

R is the rate turn which is standard 360 degrees within 2 minutes or equivalent to 30 per second.

$$\varphi \leq 20^0 \quad (3)$$

φ is the bank angle of the aircraft when performing a circular maneuver

$$\theta_{FB} \leq 90^0 \quad (4)$$

θ FB is the angle formed from the intersection of the maneuver rotating the aircraft concerning the next track.

$$r_{RF} \leq (V + V_{wind\ speed}) / (20 \times \pi \times R) \quad (5)$$

R is the radius of the curved/twisted track, while V is the speed of the aircraft when curving / rotating maneuvers, Vwind speed is the wind speed

The calculation of fuel consumption in the descent phase is carried out by following the calculation [16]

$$F_{min} = C_{f3} (1 - h/C_{f4}) \quad (6)$$

Fmin is the minimum fuel consumption calculated, while Cf3 is the 1st descent fuel flow coefficient (kg/min) Cf4 is the 2nd descent fuel flow coefficient (feet), and h is the altitude of the aircraft (feet).

Table 4. Fuel Consumption Aircraft Category C

Level (feet)	Fuel (Kg/Minute)	Rate Of Descend (feet/minute)
500	97.2	760
1000	96.1	780
1500	95.0	800
2000	94.0	850
3000	31.0	1020
4000	25.0	1360
6000	24.5	1380
8000	23.3	1410
10.000	22.1	1550
12.000	20.9	1590

Table 4 shows data that can be used for the calculation of aircraft fuel consumption when conducting IAP Runway 11. During observation, the time value of the aircraft when descending passes a certain level.

RESULTS AND DISCUSSION

The concept of aircraft navigation with a performance-based navigation (PBN) model can be applied with the RNP Arc type. The RNP Arc is designed by relying on the aircraft's ability to keep the aircraft's flight position accurate on course even if the course is winding or circling.

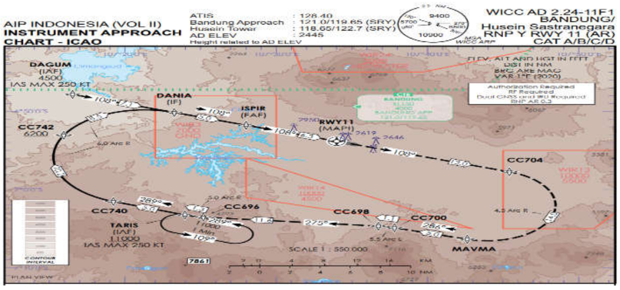

Figure 5. IAP Runway 11

Figure 5 above is the RNP Arc flying procedure applied to RWY 11 Instrument Approach Procedure (IAP). This procedure starts from the point "Taris" as the Initial Approach Fix (IAF) and continues to the point "Dania" as the Intermediate Approach Fix (IF) and to the point "ISPIR" as the Final Approach Fix (FAF).

										MAG VAR 0.4°E(2020)	
SERIAL NR	PATH DESCRIPTOR	WPT IDENTIFIER	RF ARC CENTER	FLY-OVER	COURSE °M(°T)	DIST (NM)	TURN DIRECTION	ALT (FT)	SPEED LIMIT (KT)	VPA/ TCH	NAV SPEC
TARIS TRANSITION											
010	IF	TARIS (IAF)	-	-	-	-	-	+11000	-250	-	RNP 1.0
020	TF	CC740	-	-	289(290.0)	8.0	-	-	-	-	RNP 0.3
030	RF	CC742	CCCS9	-	6.0 Arc	10.2	R	+6200	-	-	RNP 0.3
040	RF	DANIA (IF)	CCCS9	-	6.0 Arc	8.5	R	-	-	-	RNP 0.3
APPROACH AND MISSED APPROACH											
010	IF	DANIA (IF)	-	-	-	-	-	-	-	-	RNP 0.3
020	TF	ISPIR (FAF)	-	-	108(108.9)	5.0	-	@4500	-	-	RNP 0.3
030	TF	RWY11 (MAPt)	-	Y	108(108.9)	4.3	-	2495	-	-3.0/50	RNP 0.3
040	TF	CC704	-	-	108(108.9)	12.0	-	-	-	-	RNP 0.3
050	RF	MAVMA	CCC64	-	4.5 Arc	14.0	R	-	-	-	RNP 0.3
060	TF	CC700	-	-	284(284.9)	5.0	-	-	-	-	RNP 0.3
070	RF	CC698	CCC67	-	3.3 Arc	1.1	L	-	-	-	RNP 0.3
080	TF	CC69A	-	-	273(273.7)	11.4	-	-	-	-	RNP 0.3
090	RF	TARIS (IAF)	CCC68	-	3.0 Arc	1.3	R	-	-	-	RNP 1.0

Figure 6. Code of RNP Y Runway 11

Figure *6* above is the waypoint data in IAP RWY 11 along with the altitude specified, for this procedure, the aircraft altitude starts from the level of 11,000 feet at the "TARIS" point. Then the aircraft began to descend to the "ISPIR" point at a height of 4,500 feet.

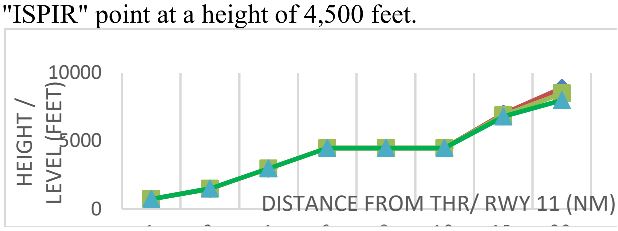

Figure 7. Flight Profile (Level)

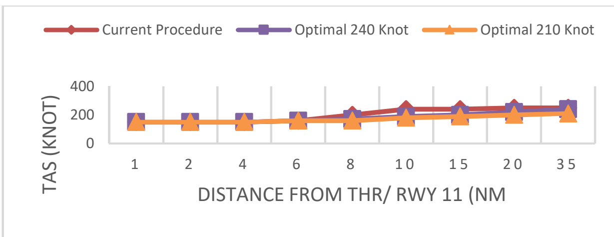

Figure 8. Flight Profile (Speed)

Figure *7* Figure *8* Comparison of aircraft speed to distance to runway, the value of aircraft speed will always adjust the distance traveled from each waypoint traversed. On a detour route, the aircraft requires a bank angle value according to the turn radius at a certain altitude [12]. In the experiment, the large bank angle was made with attention to comfort, which is no more than 20^0, while the turn radius is set through standard provisions of 3^0 / second.

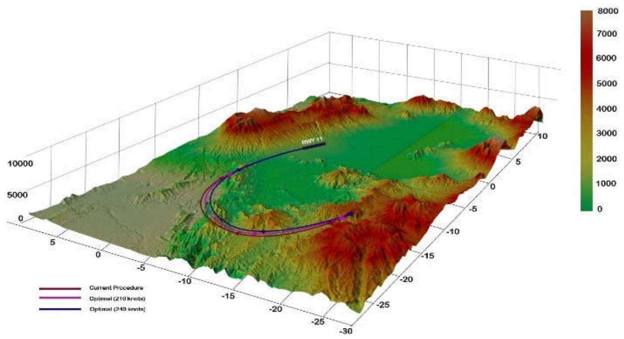

Figure 9. Flight Illustration

Figure *9* is an illustration made after all data is inputted into the simulator and run to provide a comprehensive picture of aircraft maneuvers when using existing procedures and optimization procedures with speed (V = 240 Knots) and (V = 210 Knots). There is a difference in the flight radius of the aircraft with the application of these speeds, so the impact of the optimization is seen on shorter flight routes.

Table 5. Flight Optimization

Instrument Approach Procedures (IAP)	Flight Time (sec)	Fuel Consumption (lb)	Flight Distance (NM)
IAP (Initial V = 250 Knot)	560	502.84	35
IAP (Initial V = 240 Knot)	557	500.75	33.8
IAP (Initial V = 210 Knot)	548	495.26	30.9

Table *5* above shows that route optimization in the Instrument Approach Procedure (IAP) can be done on a straight segment path with a higher flight speed (V), the flight distance will be short, but on a winding or twisted flight route (arc segment), the minimum speed makes the flight route shorter. The speed of the aircraft at the initial approach fix (IAF) at the point "Taris" using a minimum speed of 210 knots at an altitude of 11,000 feet will result in a shorter flight distance and more efficient fuel consumption because fuel consumption will be greater on aircraft flying at high speed but at low altitude because it requires greater power [17]. This optimization model (V=240 knots) results in a flight efficiency of 2.8% and a fuel economy of 0.4% while this optimization model (V=210 knots) results in a flight efficiency of 8% and fuel economy of 1.5% compared to the current procedure, this can continue to be developed for the next phase of flight.

ICAO continues to echo in the aspect of environment protection, one of which is by implementing PBN-based routes to save fuel consumption because higher fuel efficiency improvements can significantly reduce carbon emissions produced [18]. PBN-based routes applied to departure procedures are also used to provide fuel use efficiencies, such as lower climb speed targets for initial acceleration and constant climb speed to provide more aircraft power efficiency so that it is more fuel efficient and can reduce aircraft engine noise [19]. Saving fuel consumption on aircraft will contribute greatly to reducing flight operational costs, and this will have a major impact on aircraft operators or airlines [20], this fact shows the role of air traffic management in supporting increased profits from aircraft operators or airlines.

CONCLUSION

This study concludes that the application of RNP Arc-based flight procedures is very suitable in areas with mountainous contours because it has high accuracy so that winding or circuiting routes become more precise. The flight route of the aircraft in the RNP arc procedure can be optimized by using a minimum speed at IAP V = 210 Knots (Aircraft Category = C) of 8% and can save aircraft fuel use by 1.5%.

REFERENCES

[1] U. Kale, I. Jankovics, A. Nagy, dan D. Rohács, “Towards sustainability in air traffic management,” *Sustain.*, vol. 13, no. 10, hal. 1–18, 2021, doi: 10.3390/su13105451.

[2] International Civil Aviation Organization (ICAO), “Air Navigation Capacity and Efficiency,” *https://www.icao.int/airnavigation/Pages/default.aspx*, 2022.

[3] ICAO, *Performance-based Navigation (PBN) Manual*. 2008.

[4] D. A. Pamplona, A. G. De Barros, dan C. J. P. Alves, “Fast-Time Simulation,” hal. 1–18, 2021.

[5] W. Schuster dan W. Ochieng, “Performance requirements of future Trajectory Prediction and Conflict Detection and Resolution tools within SESAR and NextGen: Framework for the derivation and discussion,” *J. Air Transp. Manag.*, vol. 35, hal. 92–101, 2014, doi: 10.1016/j.jairtraman.2013.11.005.

[6] J. Mu, “Base on PBN’s General Aviation Airspace Planning Research,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 538, no. 1, hal. 1–5, 2019, doi: 10.1088/1757-899X/538/1/012060.

[7] Y. Tian, D. Xing, L. Wan, dan B. Ye, “Study on the Optimization Method of Point Merge Procedure Based on Benefit in the Terminal Area,” *Math. Probl. Eng.*, vol. 2020, 2020, doi: 10.1155/2020/5757948.

[8] L. Zhu, J. Wang, Y. Wang, Y. Ji, dan J. Ren, “DRL-RNP: Deep Reinforcement Learning-Based Optimized RNP Flight Procedure Execution,” *Sensors*, vol. 22, no. 17, 2022, doi: 10.3390/s22176475.

[9] E. Otero, U. Tengzelius, dan B. Moberg, “Flight Procedure Analysis for a Combined Environmental Impact Reduction: An Optimal Trade-Off Strategy,” *Aerospace*, vol. 9, no. 11, hal. 683, 2022, doi 10.3390/aerospace9110683.

[10] M. E. Eagan dan R. Gundry, “Airport noise and performance-based navigation: A force for good or evil?” *J. Airpt. Manag.*, vol. 12, no. 4, hal. 359–369, 2018.

[11] M. W. Sawyer, K. A. Berry, A. Henderson, R. Rohde, dan D. Liskey, “A Proactive Assessment of the Changing Non-conformance Risk Profile for Arrival and Departure Procedures in NextGen,” *Procedia Manuf.*, vol. 3, no. Ahfe, hal. 2967–2973, 2015, doi: 10.1016/j.promfg.2015.07.836.

[12] T. Hasegawa, T. Tsuchiya, dan R. Mori, “Optimization of Approach Trajectory Considering the Constraints Imposed on Flight Procedure Design,” *Procedia Eng.*, vol. 99, hal. 259–267, 2015, doi: 10.1016/j.proeng.2014.12.534.

[13] T. J. Nichols, “Approaches Operating Under Title 14 of the Code of Federal Regulations,” 2017.

[14] ICAO, *Doc 8168*, vol. I, no. November. 2018.

[15] International Civil Aviation Organisation, “Required Navigation Performance Authorization Required (RNP AR) Procedure Design Manual - Doc 9905.” hal. 94, 2021.

[16] EUROCONTROL EXPERIMENTAL CENTRE, *The Base of Aircraft Data (Bada)*, no. 10. 2004.

[17] R. Sáez dan X. Prats, “Time-based-fuel-efficient aircraft descents: Thrust-idle descents along re-negotiated routes vs. powered descents along published routes,” *Transp. Res. Part D Transp. Environ.*, vol. 114, no. September 2022, hal. 1–19, 2023, doi: 10.1016/j.trd.2022.103563.

[18] W. Liao, Y. Fan, dan C. Wang, “Exploring the equity in allocating carbon offsetting responsibility for international aviation,” *Transp. Res. Part D Transp. Environ.*, vol. 114, no. September 2022, hal. 103566, 2023, doi: 10.1016/j.trd.2022.103566.

[19] M. Zhang, A. Filippone, dan N. Bojdo, “Multi-objective optimization of aircraft departure trajectories,” *Aerosp. Sci. Technol.*, vol. 79, no. x, hal. 37–47, 2018, doi: 10.1016/j.ast.2018.05.032.

[20] S. Dožić dan M. Kalić, “An AHP approach to the aircraft selection process,” *Transp. Res. Procedia*, vol. 3, no. July, hal. 165–174, 2014, doi: 10.1016/j.trpro.2014.10.102