Applications and Benefits of RNP Approaches in the United States National Airspace System

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Some of the busiest airports in the NAS set the pace for the entire system. These busy airports experience frequent delays, cancellations and other inefficiencies, and many of these effects tend to propagate regionally or nationally. At many airports, opportunities exist to mitigate these effects, by improving parallel runway operations, converging runway operations, adjacent airport operations, and single runway access. Through the application of low RNP values and approach and missed-approach paths that are not straight in and straight out, these opportunities for improvement are enabled. Because these RNP approach features apply to certain operators and not to others, their application is limited to those locations where aircraft capabilities exist and where benefits can be realized. These procedures are being developed as special aircraft and aircrew authorization required (SAAAR) as a core OEP activity. Our paper will describe the applications of RNP SAAAR at these busy airports, and at a handful of airports where safety/risk mitigation needs can be addressed as well. Our paper will describe a benefits-driven prioritization scheme for implementation of public RNP SAAAR procedures, with details on certain sites and projects. The analysis and modeling for this work was performed by MITRE/CAASD and coordinated through a designated Working Group chaired by Dr. Hassan Shahidi under the Performance-based operations Aviation Rulemaking Committee.

I. Introduction

The Federal Aviation Administration (FAA) is currently implementing performance based navigation in the National Airspace System (NAS), one aspect of which is required navigational performance (RNP) routes and procedures in the terminal area. As an initial step, “special"[††] RNP instrument approach procedures are being implemented in 2004-2005 to gain experience with advanced operations and to validate criteria and guidance material that will enable the implementation of public RNP procedures in the future. This paper describes the operational concept and applications of RNP SAAAR, focusing on the benefits these procedures are expected to provide both to users of these approaches and to the broader National Airspace System (NAS). It is intended to assist FAA program managers, industry (airframe manufacturers, avionics manufacturers, operators), and procedure designers to identify and prioritize sites for implementation of RNP SAAAR procedures.

Targeted levels of performance for benefits-driven RNP approach procedures were identified by industry in 2003 by the Performance-based Operations Aviation Rulemaking Committee (PARC).[‡‡] These objectives are to:

- Increase use of under-utilized runways (parallel, converging or standalone runways).

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[††] "Special" instrument flight procedures for approach operations are approved by the FAA for certain operators but are not published in Title 14 of the Code of Federal Regulations (CFR).
[‡‡] In 2003, the PARC was known as the Terminal Area Operations Aviation Rulemaking Committee (TAOARC).

- Provide lower minima for approach procedures that do not rely on ground based navigational systems, including Instrument Landing System (ILS), to improve airport capacity when ground based systems are out of service.
- Provide better access to runways with terrain or airspace constraints using curved RNAV legs and narrower protected surfaces
- Improve safety by eliminating circling maneuvers, providing laterally and vertically guided approaches not available today through conventional ground-based Navigational Aid (NAVAID) procedures or through existing Area Navigation (RNAV) procedures.

The FAA and industry identified RNP SAAAR approaches as the mechanism for achieving operational capability to fly advanced RNP procedures that meet these objectives. The PARC enumerated the following RNP SAAAR attributes as being demonstrable in the near term using existing equipage and crew training programs:

- Authorized Reduced RNP levels down to RNP-0.1 for any portion of the procedure, including the missed approach
- Obstacle evaluation areas (OEA) without secondary areas
- Curved route segments (i.e., Radius-to-Fix [RF] leg type), even on the missed approach
- Aircraft performance based Vertical Error Budget used as the obstacle clearance surface (OCS) for final approach segment (FAS)
- Missed approach OCS derived from engine out performance of low, medium or high performing aircraft at actual airport elevation and temperature

These RNP features utilize existing aircraft capabilities, revised operational procedures, and newly-developed procedure design criteria.

RNP SAAAR approaches require the use of advanced capabilities that exist on certain aircraft today, such as sophisticated autopilots, ground NAVAID exclusion, track deviation monitoring, and RNP-based alerting. As part of the overall picture, the ability to assess the available infrastructure at a destination (predictive RNP) is necessary to dispatch. In order to fly RNP SAAAR procedures, aircraft capability, operator procedures, training, maintenance and procedure design will need to comply with the specified requirements published in FAA Notice 8000.287 and will require a special authorization.

This paper describes specific procedures that implement RNP SAAAR features to meet the operational objectives. It explains which advanced capabilities are necessary to execute those procedures, identifies areas where further analysis is required to prepare for successful fielding of RNP SAAAR approach procedures, and highlights aspects of these procedures that require crew and controller training and equipment for effective implementation.

II. Improving Runway Utilization

RNP Parallel Approach with Transition (RPAT) is an RNP SAAAR procedure designed to improve arrival capacity of parallel runways with centerline separations between 750 and 4299 feet. RPAT can also be used to increase capacity when the ILS on one of the runways is out. MITRE has performed a benefits analysis, described below, to assemble a list of 12 airports where RPAT may be applied in the near future. Additional RPAT candidate airports may also exist.

RPAT adds an additional arrival stream when the ceiling and visibility are below current Visual Approach minima, but better than RPAT minima (which will depend on specific airport geometry, but will typically be 2000 feet/4 miles). This could be used to add a second runway at airports with closely spaced parallels that go to a single arrival stream in marginal conditions. It may also be useful for utilizing third or fourth runways at larger airports such at Atlanta’s Hartsfield-Jackson or Dallas-Fort Worth.

In a typical RPAT approach procedure, represented schematically in Figure 1, one aircraft flies the usual straight-in ILS approach while a second (RPAT) aircraft flies an offset approach to maintain Instrument Flight Rules (IFR) separation. The aircraft on the ILS approach course is constrained within the normal operating zone (NOZ) which is 1150 feet wide to either side of the extended runway centerline. Next to the ILS course is a non-transgression zone

(NTZ), which is 2000 feet wide. Then the RPAT course is separated from the NTZ by two times the procedure's designated RNP value. Therefore, in an RNP-0.3 RPAT procedure, the distance between the ILS and offset courses is 5000 feet (1850 feet between the offset course and the NTZ). This distance is reduced to 3750 feet if RNP-0.1 is required of the RPAT aircraft.

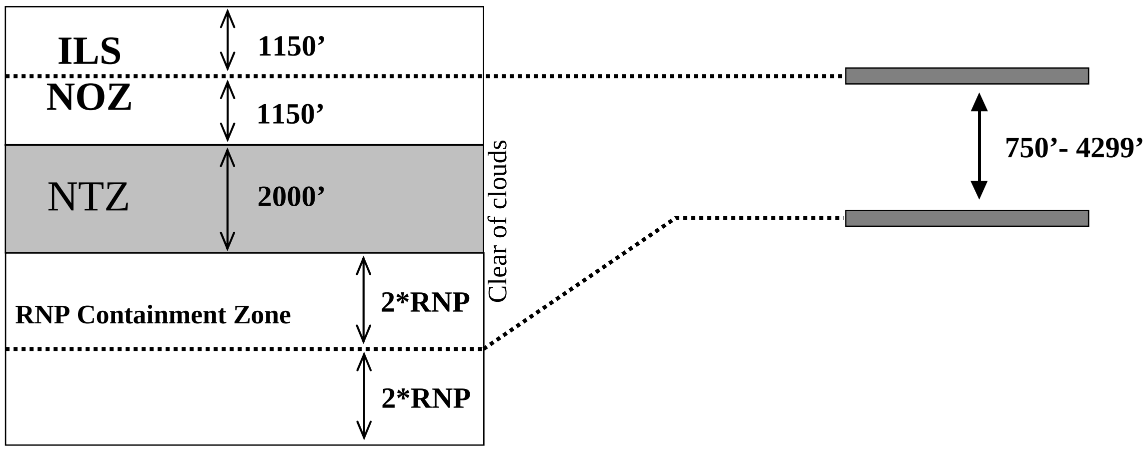

Figure 1: Diagram of basic RPAT procedure concept. (Not to scale)

When two aircraft are setup on the RPAT procedure, the ILS aircraft is given a small lead to enable the RPAT aircraft to have it in sight when the RPAT aircraft reaches the clear of clouds point. Both aircraft begin the procedure using instrument flight rules, descending at a constant rate until they are clear of clouds at or above 2000 feet. The pilot of the RPAT aircraft then acquires the ILS aircraft visually and initiates (or monitors) a guided S-turn to line up with the runway. Visual separation is maintained throughout this transition maneuver, although the Flight Management System (FMS) will provide 3-D guidance to the runway. Since the final approach is made under visual conditions, the RPAT procedure may be applied to runways spaced as close as 750 feet.

There are 49 parallel runway pairs in the NAS with separations between 4299 and 750 feet. These runways may be RPAT candidates. MITRE performed a benefits analysis to determine a short list of airports for RPAT implementation. The analysis was simplified by excluding 15 airports that are not covered by the Aviation System Performance Metrics (ASPM) database. The list of candidate airports was reduced further by removing airports where RPAT would provide no benefit over existing procedures or where one of the runways is too short for general use in marginal weather. This left 12 candidates: Atlanta (ATL), Boston (BOS), Cleveland (CLE), Detroit (DTW), Newark (EWR), New York Kennedy (JFK), Las Vegas (LAS), Portland (PDX), Philadelphia (PHL), Seattle-Tacoma (SEA), San Francisco (SFO) and St. Louis (STL).

To test the RPAT concept, the FAA and industry have made tentative plans to implement trial RPAT procedures at CLE, SEA and SFO in 2005. Other airports are also promising RPAT candidates.

The following analysis was performed to estimate the benefit RPAT would provide if implemented at 12 candidate airports identified above. New RPAT arrival capacities for each airport were modeled, taking into account current wake vortex separation requirements and each airport's specific weight class mix. Capacity increases over single runway operations (dual runway operations in the case of ATL, DTW, and STL) ranged from 16% to 59%. These capacity increases were then combined with ASPM demand and weather data to estimate the reduction in arrival delay if RPAT were used whenever the weather allowed. The effect on departure capacity was ignored. The calculated airborne delay savings were multiplied by the average airline direct operating cost for each airport to arrive at a dollar figure. The results, which assume that all arriving flights are capable of flying the RPAT procedure, are summarized in Table 1. Mixed equipage issues are discussed below.

Future benefits were calculated by inflating the ASPM demand to match the number of operations forecast by the 2003 Terminal Area Forecast (TAF). Other planned improvements, such as new runways, were ignored for this analysis. Atlanta, Seattle-Tacoma, Detroit, San Francisco and Newark show the highest benefit from RPAT.

Table 1: RPAT benefit results assuming all aircraft are RPAT-capable

Site	Applicable Runways	Fraction of time RPAT is applicable	Approximate Capacity Increase	Estimated 2003 Benefit	Maximum 2010 Benefit (2003 dollars) (other enhancements excluded)
Atlanta	26R/27L, 8L, 9R (Triples)	17%	40%	$3,700,000	$4,650,000
Boston	4L/R	6%	35%	$390,000	$470,000
Cleveland	24L/R, 6L/R	14%	59%	$460,000	$570,000
Detroit	21L/R, 22L/R, 3L/R, 4L/R (Triples)	18%	25%	$1,200,000	$1,530,000
Newark	4L/R 22L/R (possibly)	11%	45%	$880,000	$1,140,000
JFK	4R/L 22R/L	5%	20%	$170,000	$250,000
Las Vegas	25R/L, 19R/L, 7R/L, 1R/L	3%	43% (limited WX application)	$240,000	$290,000
Portland	10R/L, 28R/L	23%	17%	$110,000	$160,000
Philadelphia	26/27R	7%	16%	$300,000	$360,000
Seattle	16R/L, 34R/L	23%	18%	$1,900,000	$2,480,000
San Francisco	10s, 28s, 1s, 19s	14%	54%	$1,200,000	$1,660,000
St. Louis	12R/L, 30R/L (SOIA today)	16%	24%	$550,000	$430,000

Since special equipment and training will be required to receive authorization to fly RPAT procedures, mixed equipage must be considered when predicting RPAT benefits. Minimum equipage requirements have not been specified, but the current RPAT proposal suggests SAAAR authorization for RPAT will require a Flight Management Computer (FMC) with Global Positioning System (GPS). Such equipment is fairly common, though not universal. Current equipage at the 12 RPAT candidate airports is shown in Table 2. Note that no candidate site's fleet is 100% equipped, so mixed equipage will have to be accommodated.

One option to deal with mixed equipage would be to manage the flights "first come, first served", clearing each authorized flight for the RPAT procedure as it begins its approach. All non-authorized flights would fly the ILS approach. Ideally, equipped flights would be vectored to the RPAT approach as they enter the terminal airspace so that the local controller can make maximal use of the RPAT procedure. This method of sorting aircraft was modeled to estimate the actual RPAT benefit that would be achieved in a mixed-equipage environment. It was found that the benefit scales approximately linearly with equipage until it reaches about 85% at 70% equipage. The benefits increase more slowly as equipage approaches 100%. The expected benefits for current equipage levels are given in Table 2, where the middle column shows the fraction of flights that carried at least one FMC with GPS capability and the right hand column shows the expected fraction of RPAT benefit that would be realized with this equipage level.

Table 2: RPAT equipage rates at 12 RPAT candidate airports.

Airport	May 2004 Arrival Ops with FMC and GPS	Modeled Fraction of Maximum Benefit Realized
Atlanta	39%	49%
Boston	44%	57%
Cleveland	54%	67%
Detroit	29%	38%
Newark	58%	76%
JFK	50%	67%
Las Vegas	28%	34%

Portland	50%	64%
Philadelphia	43%	53%
Seattle	68%	85%
San Francisco	49%	65%
St. Louis	45%	57%

A second method for accommodating mixed equipage would be to hold non-equipped flights to allow RPAT-capable flights to land. This may be advantageous if there are a large number of capable flights during peak periods when throughput must be maximized. Further analysis is needed to determine how best to accommodate mixed equipage at each RPAT site.

III. Future Concepts

While RPAT has great potential to increase arrival capacity of parallel runways spaced as close as 750 feet, it is still limited by relatively high minima (2000 feet and 4 miles) and the need for an ILS approach on one of the runways. Another RNP SAAAR procedure has been proposed that would reduce the ceiling to as little as 250 feet (depending upon obstructions) and would not rely on ground-based navigational aids. This procedure would rely upon the aircrafts' RNP capabilities to maintain separation and provide guidance all the way to the runway threshold.[§§]

This procedure is depicted graphically in Figure 2. Each arrival path is centered within an RNP containment zone whose width is four times the procedure's RNP value. The RNP value therefore determines the minimum centerline spacing to which this procedure can be applied. For RNP-0.1, the RNP containment zone would extend 1200 feet to either side of the extended runway centerline, allowing the procedure to be employed to runways as close as 2400 feet.

If it is operationally feasible, this procedure would likely have a tremendous capacity and efficiency benefit. It would essentially double the IMC capacity of airports with closely spaced parallel runways (RPAT only applies in marginal weather). It could also be used as a substitute for an ILS system where the ILS is out of service due to construction or where an ILS has not been installed due to cost.

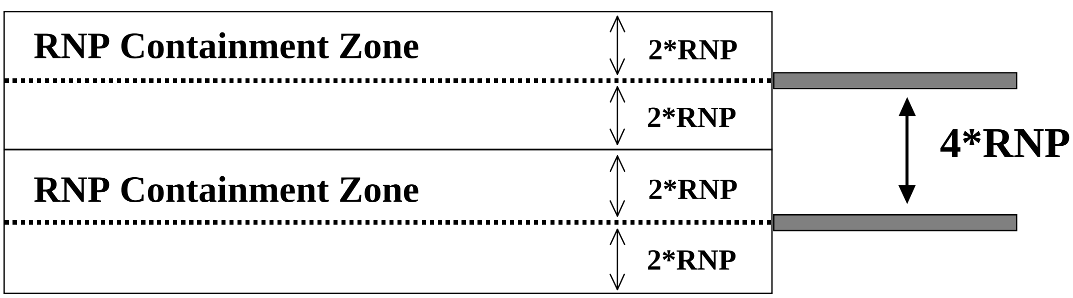

Figure 2: Notional diagram of dual RNP-contained approach procedures [***]

Blunder analysis (i.e., probability and severity) needs to be done before this could be implemented. Current procedures mitigate blunders by relying on a monitor controller to notify pilots who drift toward the NTZ. Without a monitor controller and NTZ, this procedure would have to rely on a reduced blunder scenario to meet the target level of safety. This may be reasonable since the advanced avionics required for RNP-0.1 authorization may greatly reduce blunder severity. Also, the likelihood of wake vortex encounters would have to be studied and mitigation strategies implemented.

[§§] It has also been asserted that aircraft-to-aircraft self-separation concepts and equipment would help mitigate the risk of loss of separation. Radar surveillance would not have a role.

[***] Source: "Concept for Implementing A Performance-Based National Airspace System," Jerry Davis and Bill Syblon, AMTI, 2003

Equipage will be another limiting factor in implementing these closely-spaced procedures. Since RNP containment will be required for simultaneous arrivals, non-equipped flights will have to be accommodated by using a single runway procedure (ILS approach, for example). Sites with a significant portion of unequipped aircraft will realize little benefit from this procedure.

The RPAT candidate airports with runway spacing greater than 2400 feet are listed in Table 3. These sites may benefit from dual RNP parallel approach procedures.

Table 3: RPAT candidate airports with runways that are spaced between 2400 and 4299 feet.

Airport Name	Runway Pairs	Approximate Centerline Spacing	Service Begin Date
Atlanta Hartsfield-Jackson	9R/10	4,200	6/8/2006
Detroit	22R/22L; 21R/21L	3,800; 2,700	In Use
New York-Kennedy	4L/4R	3,000	In Use
Portland	10L/10R	3,100	In Use
Seattle-Tacoma	16L/16R	2,500	11/20/2008
St. Louis	12R/12	2,500	2006

IV. Converging Runway Applications

Another application for RNP SAAAR is converging runways, where we considered runways having an angle of between 15 and 100 degrees between their intersections or projected intersections. Four airports in the NAS use what is known as Simultaneous Converging Instrument Approaches (SCIA), a procedure designed for converging runways which enables greater capacity versus a single runway. However, due to potential conflicts of the missed approach surfaces and a requirement that missed approach points (MAPs) be 3 nautical miles apart (the Instrument Flight Rules [IFR] radar separation minimum for terminal operations) as outlined in FAA order 7110.98a, the minima for these SCIA procedures is significantly higher than standard single runway ILS procedure. When the weather falls below these high minima, alternate runway configurations are necessary to ensure safety, resulting in a reduction in capacity. A graphic of a current SCIA approach is shown in Figure 3, with the incoming ILS approach from the final approach fix (FAF) proceeding to the missed approach point (MAP), followed by the runway and missed approach segment. The amount of protected airspace for these missed approach segments, determined from terminal procedures (TERPS) and thus called a TERPS surface, may be quite large and can play a major role in determining the minima of an SCIA procedure, since TERPS surfaces are not allowed to overlap, for obvious safety reasons. The positive course guidance of an RNP missed approach may allow for a slight relaxation of the 3 nautical mile separation requirement between MAPs, which is a reduction of separation standards for converging runway operations. The 3-nmi distance between MAPs is what governs the minimum in the scenario depicted in Figure 3, since the TERPS are not touching.

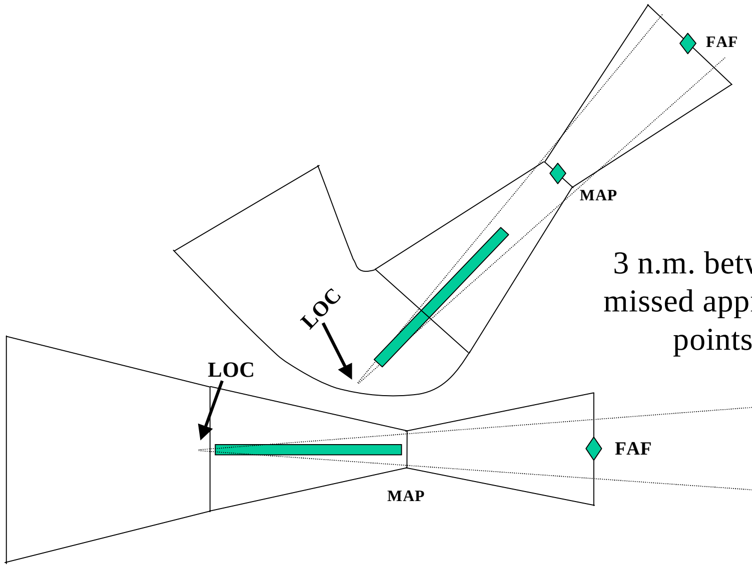

Figure 3: Current SCIA approach configuration†††

RNP SAAAR would apply to these converging runway approaches and also in the missed approach domain, providing positive course guidance and narrow lateral TERPS surfaces, possibly with constant-radius turns (known as "RF legs") in the case of curved missed approaches. The near term concept of this would be to design an RNP SAAAR approach to one runway, taking advantage of the narrow lateral and vertical containment of RNP SAAAR there, while the other runway would retain the existing ILS approach. Under this paradigm, the missed approach segments may be decoupled and the minima for SCIA may be lowered, allowing for continued use of SCIA in weather conditions which are unfavorable for SCIA today. This is depicted in Figure 4.

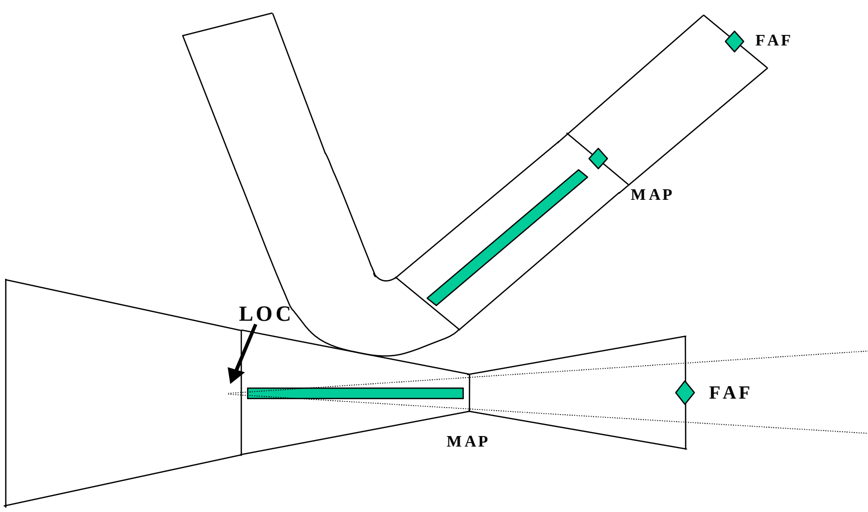

Figure 4: Future SCIA procedure using RNP SAAAR to reduce the size of the curved missed-approach and bring the MAPs closer together

Here we see the 3 nautical mile rule relaxed and narrow RNP missed approach TERPS surface in the approach at the top of the diagram, while the bottom runway retains the standard ILS final and missed approach segments. In addition, the TERPS surfaces are tangent, enabling lower minima. In general, depending on airport geometry, the driving factor in reducing minima is either de-conflicting the TERPS surfaces or the 3 nautical mile restriction for distance between MAPs. Analysis of this question at several sites follows in the next section.

††† Source for Figures 3 and 4: "Concept for Implementing A Performance-Based National Airspace System," Jerry Davis and Bill Syblon, AMTI, 2003

There are several additional factors that need consideration if RNP SAAAR missed approaches are to be implemented. Order 7110.98A states: "The ATM shall designate a primary and secondary runway for SCIA runway configurations including separation responsibilities and *procedures to be applied in the event a missed approach is initiated inside the MAP.*" (emphasis added). Balked landings are an issue of critical importance when considering independent converging approaches, as there is no stagger to compensate for two potentially simultaneous balked landings. This issue would have to be resolved at each site implementing SCIA with an RNP SAAAR missed approach segment. In addition, the concept of RNP SAAAR missed approaches derives most of its benefit from early guided turns on the missed approach. The current version of the SAAAR criteria, FAA notice 8000.287, requires that all turns for RNP guided missed approaches occur after the departure end of the runway (the far end of the runway, as seen by the arriving pilot). How this impacts RNP SAAAR missed approaches must be explored further on a site by site basis.

An initial analysis was performed on four sites that currently use SCIA today, as evidenced by existing instrument approach plates: Dallas-Fort Worth, Washington Dulles, Philadelphia and Pittsburgh. In addition, analysis was performed on three sites (Charlotte, Chicago's O'Hare, and Minneapolis) that either currently or in the future may use converging runways simultaneously, but only in VMC. The initial analysis was a parametric study of benefits (without analysis of any particular approach or runway design) assuming minima could be lowered by anywhere from 100 to 400 ft. While RNP SAAAR approaches are not intended to achieve ILS minima, a 400 ft reduction in minima may be possible for some approaches with particularly high minima. MITRE modeled the benefits of these gradual step-downs in minima using a similar method to the parallel approach analysis, taking into account demand, airport capacity and fleet mix to obtain an airborne delay savings cost at these sites. Results of that analysis are presented in Table 3, highlighting in bold the most likely minimum reduction for three of the sites explained in more detail in the following section.

Table 3: Delay benefits due to SCIA with lowered minima using RNP SAAAR procedures

				$ Airborne Savings per year			
Site	Current SCIA Minimum (ft)	Proposed SAAAR Runway	Capacity Increase Over IMC Baseline	Minima reduced by 100 ft	Minima reduced by 200 ft	Minima reduced by 300 ft	Minima reduced by 400 ft
CLT	1000	23	0.1%[‡‡‡]	$0	$1,200	$1,919	$2,159
DFW	1000	13R/31R	33%	$223,000	$385,000	$586,000	$833,000
IAD	1000	12	50%	$51,000	$53,000	$73,000	$86,000
MSP[§§§]	1000	35	28%	$628,014	$664,392	$717,972	$750,684
ORD	1000	4R	14%	$1,017,297	**$1,342,723**	$2,839,866	$3,361,181
PHL	700	9R	30%	$761,000	**$910,000**	$1,000,000	$1,174,000
PIT	900	32	11%	**$16,000**	$20,000	$25,000	$27,000

As stated earlier, the primary factor in choosing these sites for analysis is that they currently use SCIA or are considering the use in the near future. This provides an opportunity to leverage RNP SAAAR with existing procedures to increase efficiency and safety. Other airports may have runways that are not used together currently, but are suitable for SCIA. The potential for RNP SAAAR missed approaches may exist at some of these sites, which include Albuquerque, Boston, Miami and others. Since implementing SCIA at these sites would require a change in current operations, it was not possible to properly baseline these sites for analysis, but further research will be conducted on their suitability for RNP SAAAR. In addition, sites with intersecting runways may be able to use SCIA to minima of 700 foot ceiling and 2 miles visibility, if combined with Land and Hold Short operations (although it is known that this procedure is not accepted by all pilots, an issue that needs to be addressed).

[‡‡‡] Insufficient delay during times procedure would apply
[§§§] MSP does not currently run SCIA, but runway 35, a new runway, will enable SCIA

V. Airspace Redesign Applications

In densely populated areas, often times more than one airport is necessary to adequately serve the needs of the entire metropolitan area. Examples of this are Chicago, New York/New Jersey, Washington D.C., Dallas, and Seattle. As more traffic develops within the NAS, much of this traffic is routed through major cities causing congestion around the airports. Since some of these cities have multiple airports, certain operational procedures are created to help mitigate any overlapping airspace. During Visual Meteorological Conditions (VMC), these mitigation procedures have been proven very effective. However, in IMC, airspace conflicts[****] can severely reduce capacity at one or more neighboring airports. This analysis focuses on the benefits of implementing curved approach paths to mitigate conflicts in IMC.

An analysis was performed to determine the extent to which airspace conflicts cause excess delay or cancellations in Chicago and New York. We identified the time periods when airspace conflicts were likely by using configuration and weather information in ASPM airport data. We then calculated the total minutes of arrival and departure delay and the number of cancelled flights for those time periods. Next we determined the delay and cancellations for each airport during similar calendar and schedule time periods where the airspace conflicts did not occur (i.e. same day of the week, same month and same time period). We then compared the results to determine if there was an increase in minutes of delay or an increase in number of cancellations during times of conflict. Finally we determined the airline direct operating costs of the excess delay and cancellations due to conflicts. A correlation was assumed between the increased operating costs and the airports operating in conflicting configurations. Where appropriate, we also determined the amount of savings incurred by lowering the minima at 100 foot increments from the current minima to a theoretical minimum of 200 feet.

Table 4: Additional Cost Due to Confliction (MDW and ORD)

	Departure Delay (minutes)	Arrival Delay (minutes)	Canceled Departures	Canceled Arrivals	ADOC
MDW	6744	3597	5	1	$275,000
ORD	53988	61449	149	84	$4,365,000

Table 5: Additional Cost Due to Confliction (JFK and LGA)

	Departure Delay	Arrival Delay	Canceled Departures	Canceled Arrivals	ADOC
JFK	5105	1953	34	46	$751,100
LGA	10925	10051	153	151	$2,268,100

VI. Airport Access Applications

RNP SAAAR approaches may improve access to some airports where current approach procedures are limited due to obstacles near the ILS approach or curved approach paths preclude the use of ILS guidance. FAA Order 8000.287 authorizes RNP SAAAR approaches without secondary TERPS surfaces at RNP levels less than 0.3 nautical miles. It also authorizes RF RNAV leg types for approaches. Together, narrower TERPS and guided curves may help to avoid obstacles in the initial or intermediate approach at some airports, lowering minima. Furthermore, current visual-only approaches may be augmented by fully guided instrument procedures. This will provide a great benefit in safety, capacity and efficiency.

Modeling of approaches was performed to determine the number of airports in the NAS that might see lower minima using RNP SAAAR approaches. Approaches based on FAA Order 8260.48 “Area Navigation (RNAV)

[****] The term “airspace conflict” is used here to denote a period of time when a traffic flow at one airport precludes the use of a favorable flow at a nearby airport. It should not be taken to indicate any actual or potential loss of separation between aircraft.

Approach Construction", or more commonly known as Lateral Navigation (LNAV)/Vertical Navigation (VNAV) RNAV approaches, were used as a baseline for comparison against RNP SAAAR criteria to assess improved access to runways. An improvement was noted when the height above touchdown (HAT) for an RNP SAAAR approach was estimated to be lower than the existing LNAV/VNAV approach by at least 60 feet. A description of how this analysis was conducted follows.

The criteria published in FAA Order 8260.51 for RNP Approaches and FAA Notice 8000.287 for RNP SAAAR were used as a reference for modeling RNP approaches (portions of the Notice criteria used were the removal of the secondary surfaces and low RNP values).

Figures 9 through 11 contrast the modeling of obstruction clearance using the 8260.51 criteria with a model which implements RNP SAAAR attributes. The 8260.51 model requires a corridor that is two times RNP (0.3x2 = 0.6 nm) wide in the primary surfaces and one times RNP (0.3) wide in the secondary surfaces, for a total of 0.9 nautical miles to the left or right of the final approach course (FAC). The modeling process methodology is summarized by the hypothetical example depicted in Figures 9-11. Here, the hypothetical controlling obstruction (filled in gray) is 500' tall and stands in the secondary surface. Using the 8260.51 criteria, the lowest minima achievable is 250' plus the controlling obstruction in the secondary or approximately 750 feet (depending on where the obstacle is located within the secondary surface). If the RNP SAAAR attribute of RNP less than 0.3 with no secondary surfaces is applied, the controlling obstacle is removed. The resulting surface is shown in Figure 10. The new controlling obstacle is only 300 feet tall, allowing a minimum height above threshold of 550 feet. Now if an RF leg is used to construct a curved approach, as in Figure 11, it bypasses the 300 foot obstacle. The highest remaining obstacle is 100 feet tall and allows a minimum height above threshold of 350 feet.

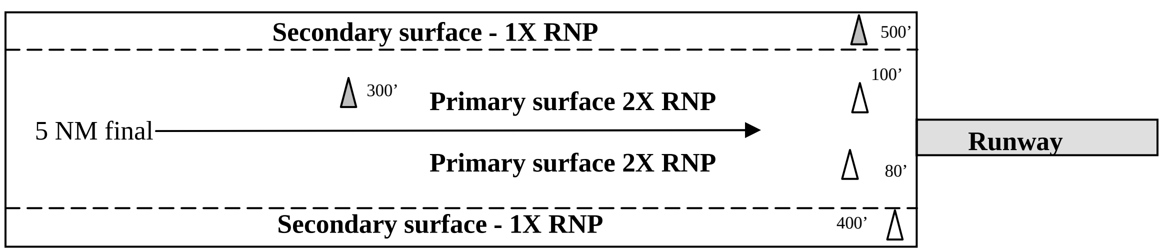

Figure 9: Diagram of hypothetical airport environment where obstacle penetrates secondary surface.

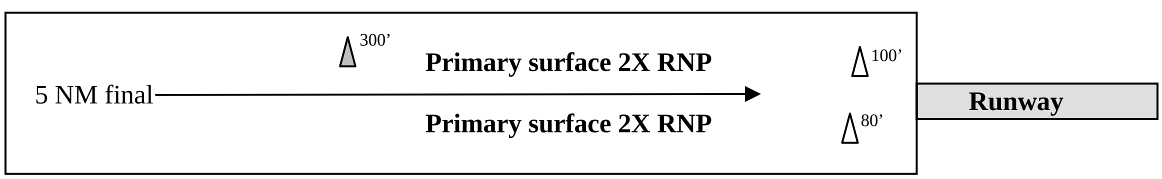

Figure 10: Hypothetical environment after removing secondary surface to avoid tallest obstacle.

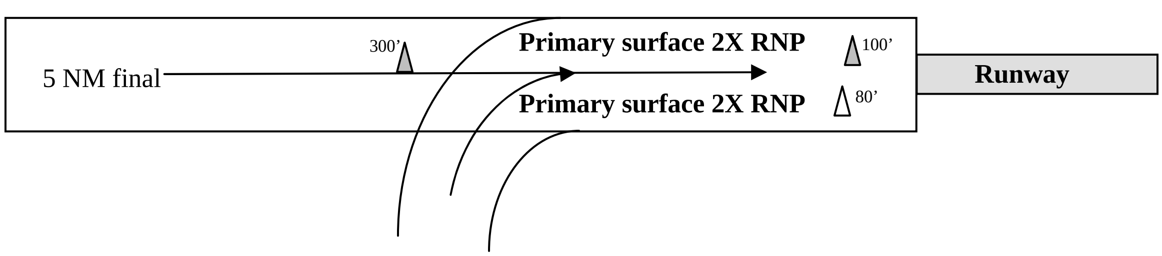

Figure 11: Hypothetical environment using RF leg on approach

In this manner, a comparative analysis was carried out for approximately 170 airports which included 717 runway ends. Included in the airport list were the Operational Evolution Plan (OEP) Top 35; the Top 100 from the ACE Plan; 35 airports where CFR 121.445 Special Pilot Qualification is required; and others that were suggested by operators taking part in the PARC's RNP SAAAR deliberations. Of the 717 runway ends, 287 showed possible benefit using the two RNP SAAAR attributes listed above. Fifty of the 287 benefit from the curved approach attribute and 237 benefit using RNP less than 0.3 with no secondary surfaces. A runway end was determined to benefit if its minima was reduced by at least 60 feet using RNP SAAAR.

Only obstacles in the final segment were assessed in this modeling. To further refine the results, additional criteria such as missed approach obstacles, runway lighting and runway marking would need to be addressed. A detailed site-by-site analysis will also be necessary to ensure that no other obstacles are present to preclude using a curved final approach procedure.

Using the curved approach model, 50 runway ends were identified as potential candidates; however, after further examination 37 of these were eliminated as candidates due to Glidepath Qualification Surface (GQS) violations, which make them ineligible for SAAAR approaches. These 37 runway ends had to be eliminated due to obstructions exceeding the height of GQS containment surface.

The 13 potential candidates were then modeled against actual published LNAV/VNAV RNP approaches. It was found that six of them have published approach procedures indicating that they are being used and may likely benefit from SAAAR approaches. The other seven do not have published procedures and will require further study. An example of one good candidate for using the curved approach model is Runway 25 Eagle Colorado (EGE) which shows a potential ceiling reduction of 1804 feet. The existing EGE approaches “RNAV (GPS)-D” and “LOC DME-C” have HATs of 2365’ and 2605’, respectively. The modeling data used in this example showed a possible HAT of 561 feet by mitigating the obstacles that fell between 5 NM and 1.5NM on the final approach course.

Using the RNP less than 0.3 with no secondary surfaces approach model, 237 runways were identified as potential candidates. However, after further examination 28 of these were eliminated, again due to GQS violations. The 209 remaining potential candidates were then modeled against published LNAV/VNAV RNP approaches if one was available. Of these, 137 have published approach procedures indicating that they are being used and may likely benefit from SAAAR approaches. 44 do not have published procedures and will require further study. One example candidate for using the RNP less than 0.3 with no secondary surfaces approach model is Pittsburgh Runway 10L which shows a potential ceiling reduction of 79 feet. The PIT runway 10L LNAV/VNAV RNAV approach has a HAT of 416’. The modeling data used in this example showed a possible HAT of 337’ by mitigating the obstacles that fell in the secondary surfaces using an RNP value of 0.11.

Figure 12 shows the result of comparing the HATs for 93 runways using LNAV/VNAV RNAV approaches with the HATs that might be obtained using RNP SAAAR procedures. The figure plots the LNAV/VNAV approach HATs in ascending order, along with the corresponding RNP SAAAR estimated HATs. It is interesting to note that the RNP SAAAR HATs are consistently lower than the LNAV/VNAV HATs but vary in the amount of reduction. It can be seen in Figure 12 that the RNP SAAAR HAT estimates are never less than 250 feet, in compliance with the Notice.

This analysis demonstrates that many runway ends might benefit from SAAAR approaches. However, it did not include all possible obstructions and was based only on a portion of the TERPS criteria for RNP SAAAR. These initial results enable further study at selected sites to refine results and take into account additional criteria, including missed approach obstacles, runway lighting, runway marking and vertical error budget.

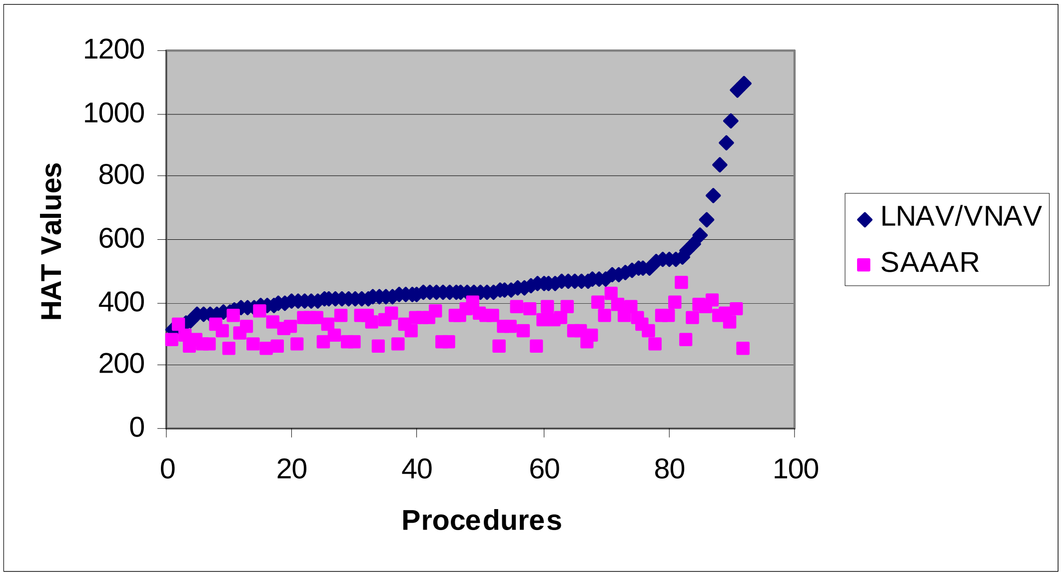

Figure 12: A snapshot of 93 published LNAV/VNAV RNAV HATs compared to corresponding projected HATs based on SAAAR.

VII. Prioritization of Airports

The benefits driven approach to analyzing airport candidacy for RNP procedures worked well for airports with well defined operations. However, it is important to look at other forms of candidacy to determine appropriate airports for RNP procedures that were not mentioned above. An analysis was performed to determine the relative rankings of airports in terms of benefits and candidacy. The benefits ranking considers solely the expected improvement for the airport with respect to RNP SAAAR procedure implementation as discussed earlier. The candidacy ranking represents the measured need of an airport to receive capacity enhancement, regardless of the method. The candidacy ranking considers the airports future socioeconomic needs via the Future Airport Capacity Task (FACT). The FACT report was developed to determine which airports will need capacity enhancements in 2013 and in 2020 based upon current growth assumptions. The candidacy ranking also incorporates a ranking based upon CAASD modeling of the NAS wide effect of capacity enhancements at the airport. The candidacy ranking also determined current operating costs for an airport that a RNP procedure would affect. These operating costs included arrival delay, departure delay, and departure cancellations these metrics were normalized into a dollar amount using calculated airline direct operating costs. The overall ranking incorporates the candidacy rankings and the benefits rankings, as well as the current equipage levels at the airport.

VIII. Conclusion

Development and implementation of performance based navigation is ongoing in the U.S. NAS. As RNAV and RNP equipage becomes more universal, RNP and RNP SAAAR procedures will improve capacity, safety, and efficiency in all phases of flight. In particular, terminal RNP SAAAR procedures have the potential to improve the operation of many kinds of airports, from small regional facilities to large international hubs. The FAA is committed to implementing public RNP SAAAR procedures where they would be beneficial and where operators are eligible to participate. Lead operators are currently contributing to the development of trial procedures at up to five major airports in the U.S. and more terminal areas will be added as additional procedures are developed.

IX. Disclaimer

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