CAPACITY EHANCEMENTS IN IMC FOR CONVERGING CONFIGURATIONS WITH DOWN-LINK OF AIRCRAFT EXPECTED FINAL APPROACH SPEEDS

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Abstract

This paper describes procedures for facilitating increased airport capacity in instrument meteorological conditions for airports with converging and triple converging runway configurations. The concept utilizes existing standards and procedures authorized for dependent converging approaches. It proposes control of the relative approach spacing on two and three runway converging configurations and facilitates safe runway approaches, including missed approaches, by utilizing the down-link of aircraft expected final approach speeds. ADS-B (automatic dependent surveillance broadcast) or CPDLC (controller pilot data link communications) may be capable of facilitating such down-link of required data. The paper presents potential throughput gains, discusses potential controller tools for implementation in the near term, discusses potential certification and authorization requirements, and summarizes required further work to determine the feasibility of the concept and the development required for operational deployment.

KEYWORDS: airport capacity, converging approaches, ADS-B, CPDLC, CRDA, DCIA

Introduction

A procedure called Dependent Converging Instrument Approaches (DCIA) was authorized in the U.S. in 1992 in the FAA Air Traffic Order 7110.110. It authorizes the use of approaches to converging or intersecting runways in instrument meteorological conditions (IMC) and establishes the conditions that must be satisfied for conducting such operations. One key requirement that makes this operation possible is the staggering of arrivals on the converging approaches by specific minimum values. These values are specified in the order by groups of runway geometries. They are designed such that even in certain worst conditions, even if both aircraft on the converging approaches missed at the same time, full safety is maintained without any controller intervention or any special pilot techniques. The DCIA procedure is currently in use at a few airports, notably at St. Louis Lambert International (STL) since 1992. It enables STL to provide a rate of about 44 aircraft per hour in IMC, compared with a single stream arrival rate of 36. Before the introduction of DCIAs, STL was forced to operate the airport on a single stream arrival basis in IMC, causing its hubbing airline to regularly cancel flights.

In principle, any airport with a converging or intersecting geometry is eligible for an application of DCIAs. However, the capacity benefit that the DCIA operation provides depends on the minimum stagger values required for its eligible runway configurations. The minimum stagger requirements are governed primarily by the lengths of the runway or their extended centerlines to the point of intersection (called the common point). The longer these runway lengths to this point of intersection, greater the stagger required to provide adequate safety. When an aircraft with a low final approach speed is followed by one with a high final approach speed, the speed differential requires larger staggers. The greater the distance to the common

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point, the greater the distance the fast trailing aircraft can make up, and therefore the larger the required stagger. When the stagger value exceeds 2.5 nmi, most airports derive no significant capacity benefit from the DCIA operation, except perhaps the benefit of providing an option in conducting traffic over different runways.

The minimum staggers required by Order 7110.110 protects against simultaneous dual missed approaches of the aircraft on the converging approaches regardless of their approach speeds. Suppose the minimum stagger value required for the case of a slow aircraft on one runway followed by a fast aircraft on the converging runway is 2 nmi. The minimum stagger value required for the reverse case, i.e., for a fast aircraft followed by a slow aircraft on the same converging runway may only be 0.5 nmi to provide the same degree of safety. The current DCIA order requires *all* aircraft pairs to be staggered by at least 2.0 nmi. This is reasonable in the current system, since the final approach speeds of the aircraft are generally not known by the controller.

With the introduction of technology such as ADS-B (Automatic Dependent Surveillance Broadcast) or CPDLC (Controller Pilot Data Link Communications) it is possible to consider the down-linking of expected final approach speeds of aircraft to the ground automation system. This paper shows that if the expected final approach speeds of aircraft were known, reduced stagger values could be used to achieve significant capacity gains over the capacities implied by the current DCIA stagger values.

This capacity gain is based on the fact that the stagger required for most pairs of aircraft is less than that for the most unfavorable case. However, it also implies that the stagger required for each pair of converging aircraft is somewhat different. It would be unreasonable to expect controllers to deliver different stagger values for each pair depending on the particular combination of aircraft without control aids. This paper describes potential control aids where such variability may be made transparent to controllers.

The concepts proposed in this paper will require considerable validation for operational feasibility through simulations and analyses. They will also need considerable validation of the required system capabilities and interfaces. The research and development required for such validation is outlined at the end of the paper.

Concept for Converging Approaches with Down-Link of Expected Final Approach Speeds

Dependent Converging Instrument Approaches (DCIA) and their ATC Basis

Figure 1 shows the basic DCIA concept. Aircraft AC1 and AC2 are approaching converging runways rwy1 and rwy2, with final approach speeds Fas1 and Fas2 respectively. For the geometry shown, if both aircraft land normally, there is no safety issue. However, suppose both aircraft conduct a missed approach. Then, if conditions are IMC, safety must be guaranteed without recourse to visual separation. The DCIA procedure guarantees safety procedurally. It requires both aircraft to conduct a straight out missed approach (MAPath1 and MAPath2). It also requires that controllers deliver at least a minimum stagger s=a-b. The value of s is derived such that under specified maximum allowable wind conditions, a minimum of 1 nmi would be guaranteed at point P, the point of intersection of the extended centerlines, or the common point. After aircraft pass this point, they would be on diverging courses. Separation is therefore no longer a concern as long as the paths continue to diverge. The DCIA procedure requires that the missed approach paths continue to diverge, and that after the point of intersection, diverge by at least 45 degrees.

The full ATC basis for the procedure is described by Smith, et al., 1992.

The DCIA procedure guarantees that at least one mile is provided at the point P of the intersection of the missed approach paths even if:

1. both aircraft conduct missed approaches
2. no visual separation, and no radar or radio contact is available
3. worst possible final approach speed combination will exist for the two aircraft

4. minimum stagger will have been provided by controllers at the point of missed approaches
5. worst possible wind conditions will be encountered (DCIAs require that surface winds be no more than 30 knots with a maximum cross wind of 15 kts and a maximum tail wind of 5 kts.)
6. worst case acceleration performance is encountered for the pair for missed approaches (i.e., leader does not accelerate and trailer does)
7. no credit is taken for vertical separation (some vertical separation will naturally exist because of the different locations of the two aircraft and differences in vertical performance)

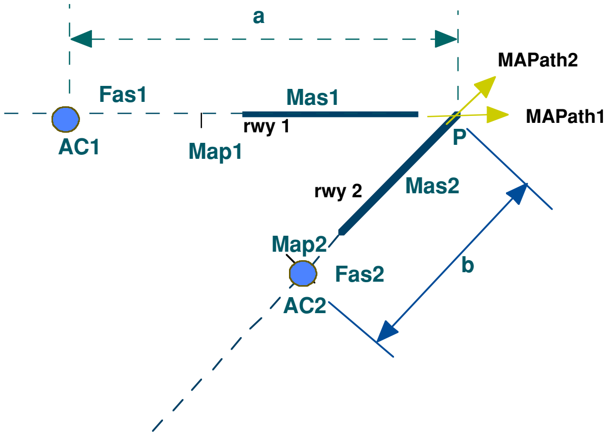

Figure 1. Basic DCIA Concept

Potential Enhancement from Downlink of Aircraft Final Approach Speeds: Example of STL

Figure 2 shows the runway configuration 30R and 24 for STL. Runway 30R is 9003 feet long, and runway 24 is 7602 ft long. The distances of their thresholds from the point of intersection of their extended centerlines are 9167 and 4842 ft., respectively. These latter distances determine the minimum required stagger values for the DCIA procedure. Figure 3 shows the stagger solution surface for this configuration. It shows that depending on the final approach speeds of the aircraft approaching the two runways, a stagger value of somewhere from 0.69 nmi to 1.93 nmi may be required in case of dual missed approaches to assure at least 1 nmi before the aircraft start diverging. If the leading aircraft in the staggered converging pair is approaching runway 30R with a speed of 110 knots and the trailing aircraft on runway 24 is approaching runway threshold at 155 knots, then a stagger of 1.93 nmi will be required. However, if the situation were reversed, i.e., if the leading on runway 30R were approaching its threshold at 155 knots and the trailing aircraft were approaching runway 24 at 110 knots, then a stagger of 0.69 nmi will be required when the leading aircraft reaches its threshold. Similar values can be derived for the situation when the aircraft leading is on runway 24. Because the distance to intersection from the runway threshold 24 is smaller than that of runway 30R, those values are always less than the ones shown in Figure 3. Order 7110.110 takes the largest of these values and rounds it to the next half mile. It therefore requires a minimum stagger value of 2 nmi for conducting DCIAs for runways 30R and 24. It is this value that STL uses for its DCIA operation to runways 30R and 24. In this operation, STL can handle about 44 aircraft per hour. Without DCIAs, STL would be forced to operate on a single stream basis in IMC, and could then support about 36 aircraft per hour.

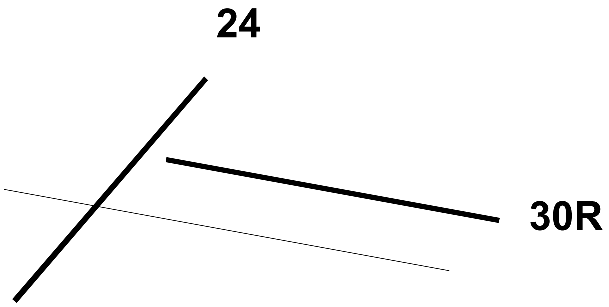

Figure 2. Runways at St. Louis Lambert International Airport

As seen in Figure 3, the stagger required for the safety provided by the DCIA operation depends on the final approach speeds of the two aircraft on the converging runways. If the expected final approach speeds of the two aircraft approaching the converging runways were known, the stagger required could be calculated from Figure 3, and would vary from a minimum of 0.69 nmi to a maximum of 1.93 nmi. If the final approach speeds were equal a stagger of about 1.2 nmi would be required. Figure 4 provides an estimate of the improvements in acceptance rate for runways 30R/24 if stagger values reflecting the values required by the final approach speeds of particular aircraft pairs could be provided.

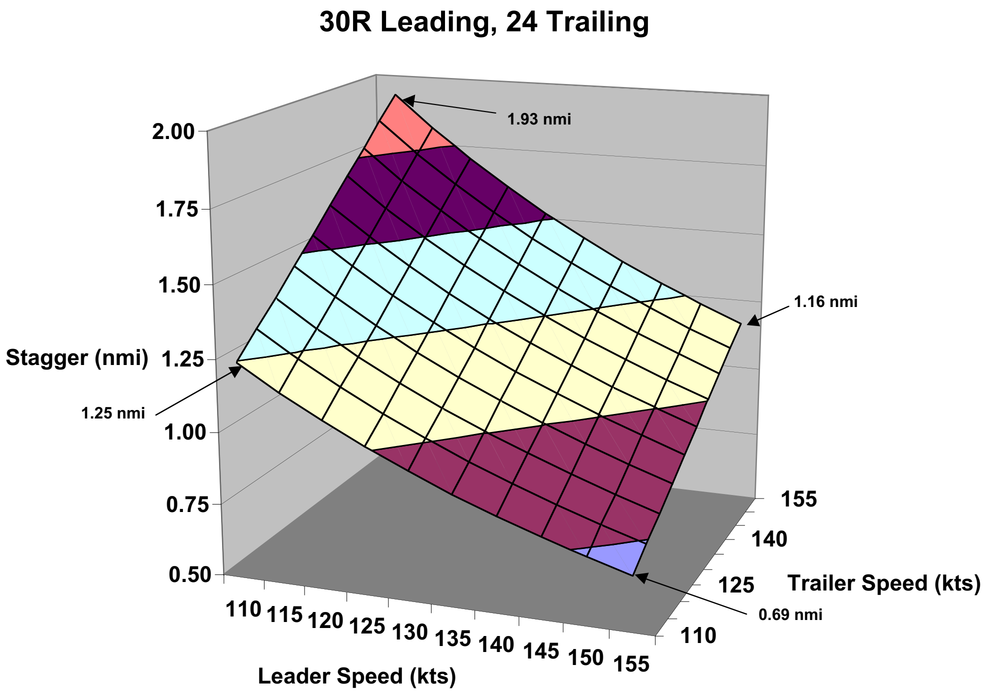

Figure 3. Stagger Surface for 30R Leading 24 at STL

The arrival rate values displayed in Figure 4 were computed based on a monte carlo simulation that considered a string of 20 arriving aircraft. The final approach speed of each aircraft was randomly chosen to have a speed between 125 kts and 145 kts. The distance that each aircraft would be behind another aircraft as the leading aircraft crossed the runway threshold would also be a random value. In the case of the single runway, it would be 3 nmi plus a value between 0 and the Trailer Precision value shown in Figure 4. For the converging runway cases, the distance between the aircraft would be the minimum stagger plus a value between 0 and the Trailer Precision. The arrival rate was determined to be the cumulative time if takes each of the 20 aircraft to fly the separation distances to the runway divided by the number of aircraft intervals. One thousand of these 20-aircraft sets were simulated and the average arrival rate is plotted.

Figure 4 has been calibrated for the current operations at STL. It shows that if the delivery precision were about 2.0 nmi, then in a single runway operation, STL would be able to land about 36 aircraft, and for the 2 nmi stagger operation currently used for runways 30R/24, it could land about 44 aircraft on the two runways. The figure also shows, that if a stagger operation could be run that provides only the minimum stagger value required for a particular pair, then an acceptance rate of about 56 arrivals per hour could be supported.

Clearly controllers could not be expected to provide a different value of stagger depending upon the expected final approach speeds of the approaching aircraft. Controllers also could not be expected to query aircraft regarding their expected final approach speeds and enter those values for use by automation. Such an activity would be too workload intensive. Thus, the potential increase in capacity described above would require at least two additional automation components:

- the down-link of expected aircraft final approach speeds to ground automation

- effective tools for controllers to deliver variable stagger depending on the expected final approach speeds of the particular pair approaching the converging runways

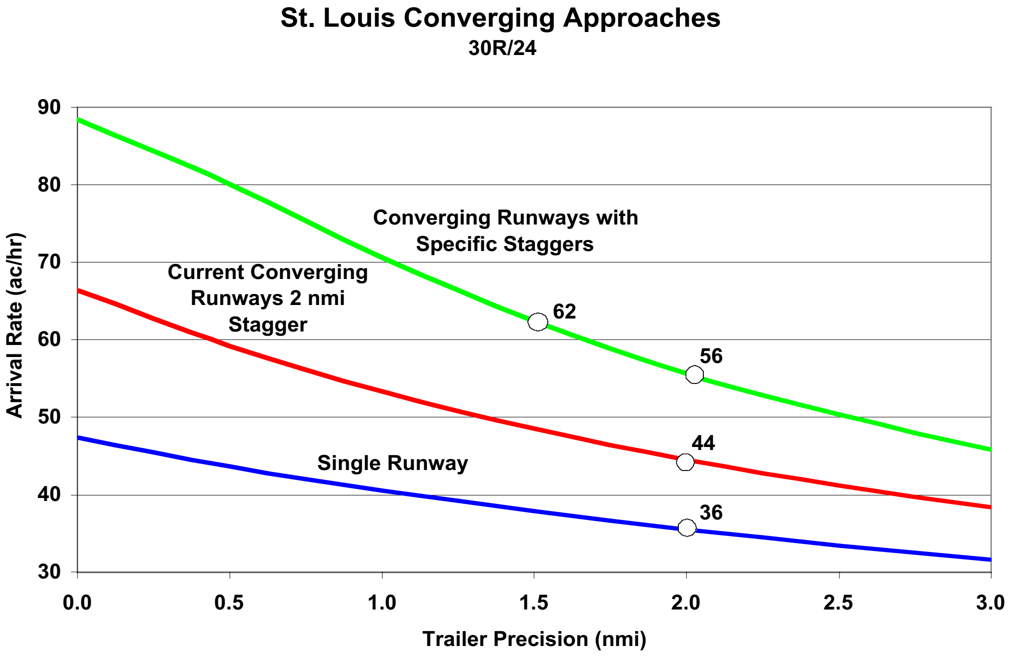

Figure 4. Arrival Rates for STL Runways 30R and 24

Downlinking Expected Aircraft Final Approach Speeds

Pilots of most airframes plan their landing speeds, based on the gross weight of the aircraft, surface winds, and other relevant considerations. Each airline has a set of guidelines regarding how pilots should consider these factors. If an aircraft is Flight Management System (FMS) equipped, the final approach reference speed (Vref) is computed in the FMS, and is usually determined by the crew at about the top of descent. The expected final approach target speed would then be computed as Vref+a standard safety margin+a wind factor. The safety margin may vary by operator and aircraft type; 5 knots is a typical value. The wind factor may also vary from airline to airline. One airline provides the following guidance: wind-factor= steady wind/2+gust, not to exceed 20 knots. If an aircraft is not FMS equipped, the crew refers to paper documentation such as a flight deck approach speed reference table or the airplane manuals.

There are at least two technologies currently being developed that provide the potential for the down-link of this information to the ground automation system: ADS-B (Automatic Dependent Surveillance-Broadcast) and CPDLC (Controller Pilot Data Link Communications).

ADS-B provides for the capability to broadcast expected final approach speeds in its on-condition report construct. (see *RTCA 1998*) The specific broadcast message content and report rate are not yet specified, however. (See also *RTCA 2000a*). This capability is not provided in the minimum message format, but can be provided if an operator chooses this option. It is then conceivable that the expected final approach speeds could be transferred from the FMS, over a bus, and then down-linked automatically. Alternately, the crew could input the planned landing speed into a control display unit (CDU), and that input could then be downlinked. An automatic down-link of expected approach speeds from the FMS would impose no additional workload on the crew. However, not all aircraft are FMS equipped; thus for those aircraft not FMS equipped, either the approach speeds would be unavailable, or provision would still have to be made for the manual entry of expected final approach speeds. Even for those equipped with FMS, although the standard safety margin could be predetermined and added to the Vref speed for the downlink message, the wind/gust adjustment would be different for each approach. The speed downlinked from an FMS would thus almost always be different from the landing speed planned by the crew, and some of the capacity benefit would be lost in order to account for this error[1]. Input of planned landing speed by the crew into a CDU would be the most accurate method of knowing expected landing speed. However, this implies an additional task by the crew. It should usually be possible to execute the task well before entry into the approach control airspace[2]. Additional analysis must be conducted to determine which of these methods would be most suitable. Additional analysis would also required to determine specific architectural and other requirements in facilitating such down-link through ADS-B.

CPDLC Build I and IA *(*see *RTCA 2000b),* designed for use in en route operations, are slated for operational deployment in 2002 and 2004 respectively. Build II, contingent on the success of Builds I and IA, may be deployed in the 2006 timeframe[3]. Build II messages have not been finalized; however Build II spiral B is expected to include terminal messages. It is therefore conceivable that an aircraft expected final approach speed message could be included in the build II spiral B message set. At least one airline has made a commitment to equip 28 of its aircraft with CPDLC for the initial operational deployment. If an airline determines that it will equip its fleet with CPDLC, then it may be more cost effective for such an airline to upgrade to build II that includes the downlink of aircraft speed than to equip with ADS-B. The final architecture may therefore require an accommodation of downlink of aircraft landing speeds through both ADS-B and CPDLC[4].

Finally, it must be pointed out that there are differences between airframes in the way the landing speeds are managed. For example, in the A320 aircraft, during approach preparations, the crew enters the arrival airport weather data, including surface wind direction and speed, temperature and altimeter setting. The system calculates the target approach speed and displays it to the crew. During landing, the system manages the speed[5], just as the crew would manage it manually in other airframes.

There will always be some aircraft not downlinking their final approach speeds. This procedure will use the most conservative stagger values for such aircraft, as in the current DCIA operations.

Finally, there will be uncertainty between the speeds downlinked as expected landing speeds, and those actually flown, due to changes in wind values. The procedure must account for such uncertainty.

Controller Tools for Variable Stagger-Spacing

A controller display tool called the Converging Runway Display Aid (CRDA) has been in use in the U.S. since 1992. (see *Mundra,1988, Smith et al 1992)*. It is this tool that is used in performing the staggering required for the converging runway operation at STL. The CRDA tool is available in all ARTS IIIA and ARTSIIIE systems. It has two modes of operation called “stagger” and “tie”. In the stagger mode, a reference target (called the “ghost” target) is displayed at a reference location

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[1] If the aircraft is flown with the auto-throttle engaged, the auto-throttle will compensate for wind shifts. In such an operation, the crew would enter Vref in the mode control panel, and allow for automatic wind compensation of the system. Operators may require the use of auto-throttles under certain conditions, such as high gusts or wind shear. Some operators also require their use on coupled approaches. Clearly, the use of auto-throttles would introduce specific errors between expected and achieved final approach speeds. It would require further analysis to determine the extent of these errors and strategies for mitigating them, including use of larger uncertainty values in gusty conditions.

[2] The input of the expected final approach speeds could usually be accomplished well before entry into the terminal area, although availability of the most current wind information will also dictate its timing.

[3] Build II is also known as Aeronautical Data Link System (ADLS)

[4] Since the input of the expected final approach speeds on the data link will usually not be a time-critical activity, down-link through ACARS (Aircraft Communications Addressing and Reporting System) may be suggested. However it is unlikely that ACARS would be acceptable for the function being proposed here because the application ultimately will involve a separation function. Besides, the ACARS network is being phased out, its functionality being replaced by VDL Mode 2, which will also support CPDLC.

[5] This function can be overridden by the pilot, but it takes a specific action by the crew to do so.

with respect to which controllers must space the real aircraft. (see *Feldman, 1992 and FAA, 1994*). In this mode, controllers space real aircraft from “ghost” aircraft much as they space real aircraft from real aircraft. This is the mode most commonly used at STL.

In the tie-mode, a “ghost” target is displayed at the desired location where the aircraft should be located, and takes into account the stagger spacing required by the operation. Figure 5 shows the operation used at Philadelphia International Airport (PHL). Target ghosts are used to stagger aircraft to the two runways, 27R and 35. This is a VFR operation, and it is desired that there be a 0.75 nmi stagger such that when aircraft 1 passes through the intersection, aircraft 2 is 0.75 nmi from the intersection. This is accomplished by displaying the target ghost at distance d1+0.75 as shown, where d1 is the distance of aircraft 1 from the intersection. The controller controlling traffic to runway 35 simply vectors his aircraft, aircraft 2, such that it is tied to the target ghost when aircraft 2 is on short final.

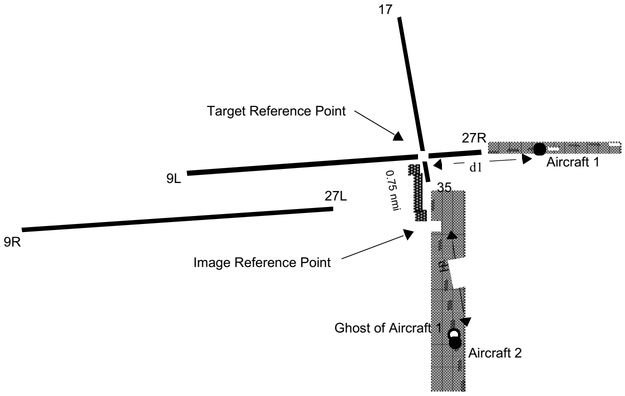

Figure 5. Runway 27R/35 Ghosting Operation at PHL

NavCanada has considerably enhanced the human interface characteristics of the “ghosting” concept, providing their controllers with a great deal of flexibility in implementing the capability. *(*see *Burnett et al, 2000)* The Edmonton approach control facility and the Calgary tower use the tie-like ghosting capability extensively, using it for all their VFR and IFR staggering operations as well as certain single stream spacing operations. The tie-like ghosts are also used for tactical coordination between the Calgary tower and approach control. For example, if the tower does not need the normal stagger spacing behind certain targets, the tower coordinates with approach control to skip the generation of certain “ghosts”. The tie-like “ghost” stream is thus somewhat variable, and such variation is quite acceptable to radar controllers in the approach control facility. Operational experience from the use of tie-like ghosts in PHL and Calgary thus indicates that controllers are able to use tie-like ghosts for spacing with ease and a precision appropriate for their operation. Simulations conducted at MITRE in 1995 indicated a precision of 11 seconds in approach spacing delivery with tie-like ghosts. (*Harding, et al., 1996*)

Based on this operational experience and the data from simulations, it is hypothesized that use of tie-like ghosts has promise in implementing the variable stagger concept proposed above. In this proposal, stagger requirements would be computed based on the down-link of aircraft speeds of the converging pair. Tie-like ghosts would then be generated by the automation system at a location reflecting the appropriate stagger requirements for the particular pair.

Figure 6 shows the use of variable stagger spacing for STL runways 30R and 24. Aircraft 1,3 and 5 are approaching runway 30R and 2,4 are approaching runway 24, with expected final approach speeds as indicated. Table 1 shows the stagger values required for each pair.

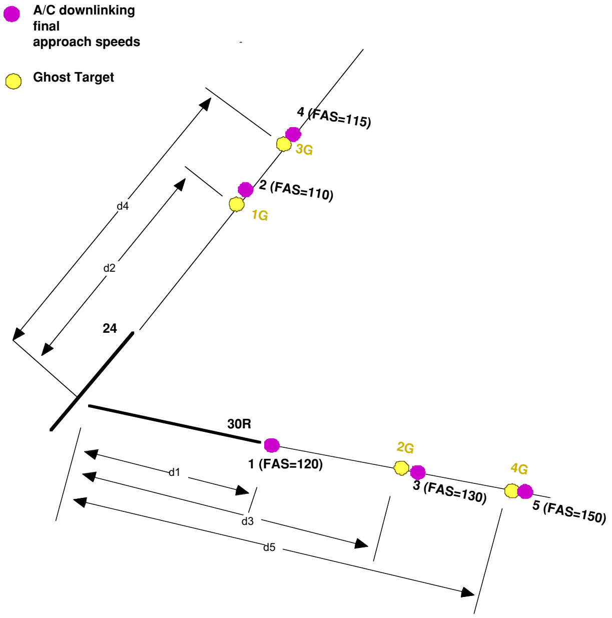

Figure 6. An Example of Variable Ghosting at STL

Table 1. Speed Specific Stagger Values for STL Example

Aircraft Pair	Speeds (kts)	Stagger Value Required (nmi)	Ghost Target Generated by Automation	Controller Task
1-2	120-110	d2-d1 = 1.08	1G	tie a/c 2 to ghost target 1G when a/c 1 crosses its threshold
2-3	110-130	d3-d2 = 1.36	2G	tie a/c 3 to ghost target 2G when a/c 2 crosses its threshold
3-4	130-115	d4-d3 =1.01	3G	tie a/c 4 to ghost target 3G when a/c 3 crosses its threshold
4-5	115-150	d5-d4 = 1.39	4G	tie a/c 5 to ghost target 4G when a/c 4 crosses its threshold

Ghost targets are so generated that both the stagger requirements between the converging pair and the in-trail requirements on the same approach are satisfied. Table 2 shows the resulting in-trail separation for each final approach.

Table 2. In Trail Separation in nmi for STL example

In Trail Separation between aircraft no.	On 30R	On 24
1-3	3	
3-5	3	
2-4		3

In this example, the in-trail separation was dominated by the minimum in-trail radar separation, 3 nmi, in each instance. Preliminary analysis shows that when pair-specific staggering is used, the actual in-trail spacing on each approach for runways 30R/24 may vary from 3.0 to 3.2 nmi[6]. Thus, in this example, the target ghosts generated for each approach would not be regularly spaced, but will be spaced at some value between 3.0 and 3.2 nmi. Simulations would have to be conducted to determine whether it would be operationally acceptable to provide such a target ghost stream when the spacing will change somewhat based on the particular aircraft being paired.

It has been seen from operational experience as well as simulations that for a successful ghosting operation, the final controllers must receive stable ghost targets for at least a 15-20 nmi final approach course. Since the specific stagger values depend on the particular aircraft pair and their *sequence* within the pair, it follows that the overall sequence to the two runways must also be determined and entered into the automation system prior to aircraft turning on to 15 to 20 nmi final. It will remain to be determined in simulations what the specific requirements on this sequence capability will be; however, it is expected that no particular optimization of the sequence will be required. In particular it is expected that no *automatic* optimization will be required. It may be a task that either the feeder or the final controller(s) may be able to perform. It is also conceivable that a coordinator may need to determine and input the sequence. The specific requirements and their feasibility would have to be determined through simulations.

In computing required stagger values, appropriate buffers will have to be provided for the uncertainty in the expected final approach speed information. Where final approach speed

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[6] A similar analysis for triple approaches to Chicago shows that the in-trail separation on one approach may vary from 3 nmi to 3.9 nmi.

information is not available, worst case stagger values will be assumed as they are in the current implementation. Thus, there will probably be a cut-over point in the level of equipage when enough benefit is accrued from this enhancement. There should be no need for controllers to know which aircraft are transmitting the approach speed information and which aircraft are not. In other words, it appears that this operation would be largely transparent to controllers.

Controller Pilot Roles and Responsibilities

Whether the aircraft expected approach speeds are provided through ADS-B or CPDLC, *there is no change in the roles of controllers and pilots with respect to separation responsibility*. The DCIA operation is currently authorized and used in the U.S.. It is based solely on controllers providing the required separation. The DCIA operation is completely transparent to pilots.

However, in this proposed procedure pilots may be required to input their expected final approach speeds into a CDU.

If proven feasible, the procedure will be largely transparent to controllers over the currently used CRDA/DCIA operation. However, one additional task may be required of an as yet to be determined position in approach control: to declare the sequence of aircraft to the converging approaches.

Certification and Authorization Considerations

The proposed procedure is based on the DCIA procedure. The DCIA procedure is currently authorized and operational in the U.S. The proposed procedure complies fully with the safety and procedural requirements of DCIA. These bases are fully documented in FAA documents leading to the order that authorized DCIAs.

The proposed procedure may require the use of a feature of CRDA, called tie-like ghosting, as a controller tool for spacing. Some enhancements to the CRDA functionality currently implemented in the U.S. will be required. The use of tie-like ghosts for spacing has been authorized for DCIAs.

The procedure *will* require the downlink of expected approach speeds. The procedures and systems involved in such downlink, including their input into the operational system and the resulting computations, will have to be certified and authorized for operational use.

The procedure may require pilot input of expected final approach speeds. If so, these procedures will have to be developed and approved.

Application of the Proposed Procedure to Triple Approaches: Example of Chicago O'Hare

This section applies the foregoing procedure to Chicago's O'Hare airport, and shows that the procedure may enable triple approaches in IMC and facilitate specific capacity improvements.

Figure 7 shows the runway configuration 9L/9R/4R at Chicago's O'Hare airport. This is one of the three preferred configurations for the airport. During visual meteorological conditions (VMC), this configuration can be used to support over 100 arrival operations per hour. When weather conditions fall below VMC, the triple runway configuration can no more be used, because protection must be provided in case of simultaneous missed approaches on the converging runway and one of the parallel runways. Below VMC, therefore, the facility reverts to a two runway operation. Runways 9L and 4R may be used down to a ceiling and visibility of 700 and 2, with a rate of almost 80 arrivals per hour. However, below 700 & 2, the only available configuration is the parallel runway one, in this case runways 9L and 9R. When such a simultaneous parallel runway operation is used, the facility can support an arrival rate of about 68. It also requires the use of two more controllers that must be used as monitor controllers.

Order 7110.110 (see *FAA, 1995*) could be applied to this triple runway configuration to derive required stagger values such that adequate protection would be available in IMC in case of simultaneous missed approaches on the converging runways. Order 7110.110 would have to be applied to both configurations 9R/4R and 9L/4R, since adequate protection must be guaranteed for both sets of potential simultaneous missed approaches.

In addition, certain missed approach path requirements would also have to be satisfied.

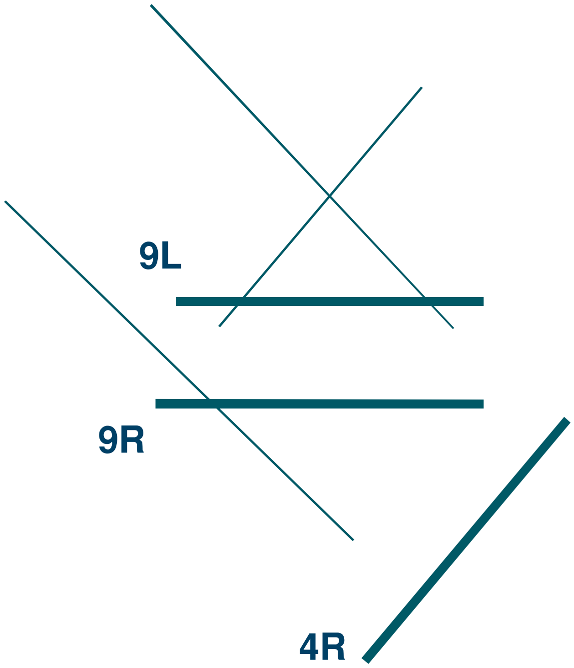

Figure 7. Chicago O'Hare Runways 9L, 9R and 4R

The thresholds of the runway pair 9R/4R are 10,790 and 7,630 feet respectively from the point of intersection. This implies a stagger value of 3 nmi in Order 7110.110. The thresholds of both runways in the pair 9L/4R are 14,460 feet from the intersection. This latter geometry places it "off the charts" in Order 7110.110. This longer intersection distance requires a stagger value above 3 nmi, and would provide no capacity benefit over a single runway operation; therefore this runway length was not included in Order 7110.110. However, if ORD had requested stagger values for these runways, they could have been calculated, and would have exceeded 3 nmi. It is this larger stagger value which would dominate the triple stagger operation. Thus, applying Order 7110.110 to configuration 9R/9L/4R at ORD would require stagger values in excess of 3 nmi and would provide no capacity benefit.

The procedure proposed in this paper offers the potential for an increased operations rate in IMC for this configuration.

Since it is the stagger requirements to runways 9L/4R that dominate the stagger requirements, Figure 8 shows the stagger surface (i.e., the minimum stagger requirements) for runway pair 9L and 4R. It shows that the stagger requirements for converging operations to runways 9L/4R can vary anywhere from 0.5 to 2.8 nmi, depending on the expected final approach speeds of the two aircraft in the pair. Figure 8 also shows that if the approach speeds are nearly equal, a stagger of only about 1.4 nmi would be required[7].

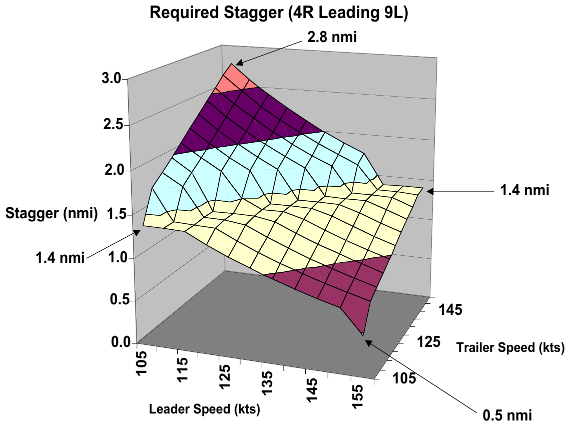

Figure 8. Stagger Surface for 4R Leading 9L at ORD

Figure 9 shows potential capacity values that may be possible with such an operation.

The interpretation of Trailing Precision is the same as in Figure 4. The line labeled "trailer 10 kts faster" provides a buffer of 10 kts in case the aircraft is flown faster on final approach than the pilot initially indicated; i.e., it accounts for a 10 kt error in expected final approach speed values. This figure shows arrival throughput estimates for various configurations of interest. It shows that for operations to an independent pair of runways, assuming a manual spacing accuracy of about 1 to 2

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[7] The maximum stagger value of 2.8 nmi for this configuration is less than that implied in Order 7110.110. This is because Order 7110.110 provides stagger values for groups of runways of different lengths and different included angles. Computation of the stagger required for any particular configuration can result in smaller values, especially when the geometry is favorable. The included angle for ORD's 9L/4R configuration is very favorable. Hence the lower stagger value 2.8 in this chart, compared to >3.0 in 7110.110. The stagger value for configuration 9R/4R is found to be 2.4 nmi. Capacity runs with these particular values, 2.4 and 2.8, show that no significant capacity gain can be achieved with these fixed values for this triple configuration compared to the dual configuration 9L/9R.

nmi, a rate of about 68 ±5 aircraft per hour might be supported. For an independent triplet of runways, an operation conducted only in VMC, an arrival rate of about 100 ±10 aircraft per hour might accrue. For the dependent triple operation being proposed, and assuming a delivery accuracy of 0.5 to 1.0 nmi reported earlier with target ghosting, the figure shows that a rate of somewhere between 80 to 90 may be sustainable in IMC to Cat I minima.

Figure 10 shows the use of target ghosts to facilitate the triple dependent converging approach procedure, similar to that described earlier for STL. The aircraft on 4R would project two ghosts, one on runway 9L and the other on runway 9R. For example, aircraft 1 for runway 4R would project ghosts 1Ga and 1Gb respectively to runways 9R and 9L respectively. The corresponding aircraft on runways 9L and 9R, aircraft 2 and 3, would generate one ghost, 3G, onto approach to 4R. The automation would decide which of the aircraft on 9L or 9R would project the "farthest back" ghost on runway 4R. In all cases, the ghosts projected from the other runway would be compared to the minimum required spacing with respect the aircraft immediately ahead. If that spacing is greater than the ghost spacing, the ghost will be moved back such that all separation standards are accommodated.

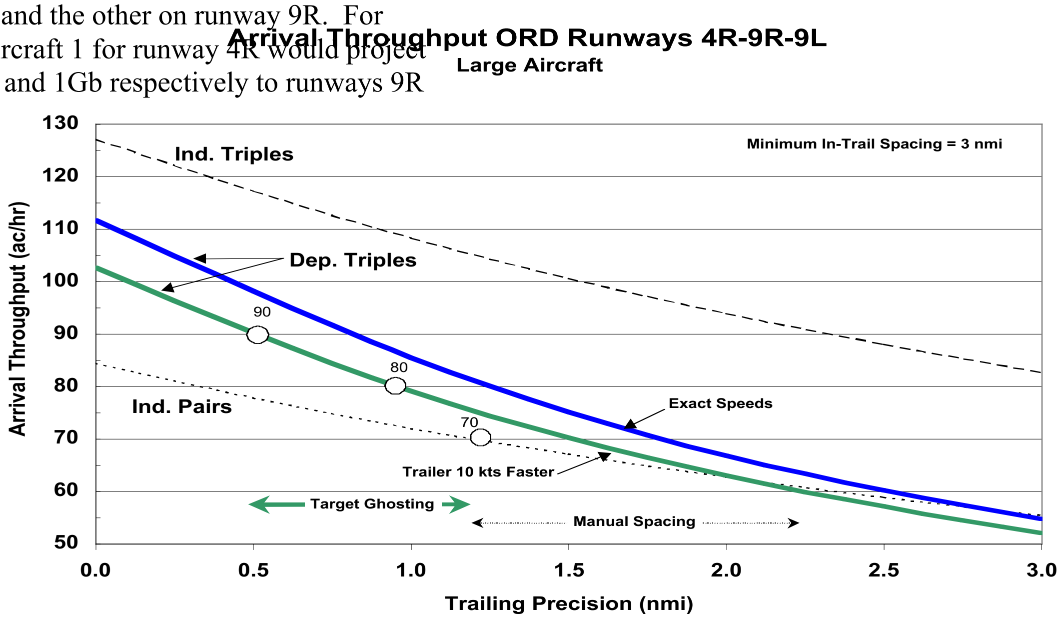

Figure 9. Potential Arrival Rates for ORD Runways 4R, 9R and 9L

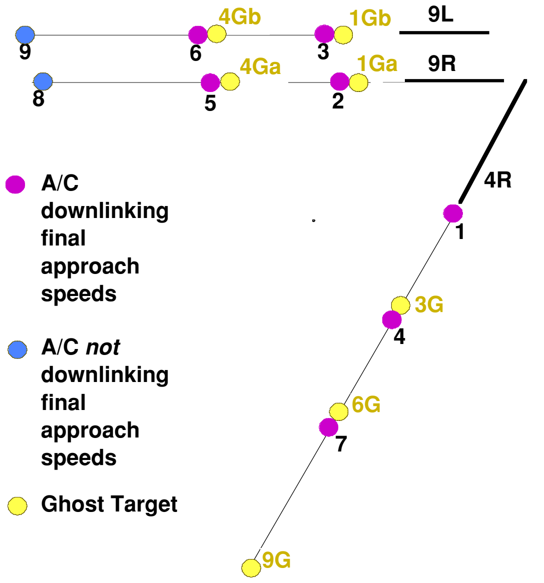

Figure 10. An Example of Potential Ghosting for 9L, 9R, 4R at ORD

Figure 11 provides a notional picture of the missed approach paths required to implement this triple dependent converging approach procedure. This will represent some modifications to the existing missed approach procedures for these runways.

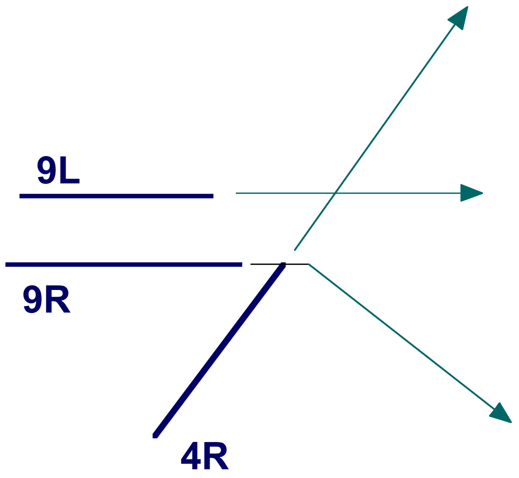

Figure 11. Schematic of Missed Approach Geometry for Dependent Approaches to 9R, 9L, 4R at ORD

Summary and Conclusions

This paper describes a procedure that builds on the existing Dependent Converging Instrument Approach (DCIA) procedure currently authorized and used in the U.S. It shows that significant arrival capacity benefits could be obtained for airports such as Chicago O'Hare if (a) aircraft expected final approach speeds could be down-linked and (b) controllers could be provided tools to provide only the minimum requires stagger to provide the safety required by the DCIA procedure. The paper suggests two specific ways in which aircraft expected approach speeds might be made available to ground automation: ADS-B and/or CPDLC. If proved possible, airline strategic plans may determine if both options should be pursued and combined. The paper also proposes the use of target tie-like ghosts, based on an enhancement of the converging runway display aid (CRDA) currently certified and used in the NAS. The paper shows that the procedure involves no change in current controller pilot responsibilities. It does however require one new task in the approach control facility. It may also require manual input of expected approach speeds by pilots into a CDU. Simulations will be required to determine the feasibility of the proposed procedures. The paper shows that although extending the DCIA procedure and the CRDA tool for authorizing the proposed procedure should be a relatively straight-forward exercise, the process of down-linking expected aircraft approach speeds will require specific system certifications and authorizations.

Recommendations

Real time simulations should be conducted to determine the feasibility of the proposed procedure and controller tools to perform the proposed operation for dual and triple runway configurations.

Analysis should be performed to determine the feasibility of providing the downlink of planned final approach speed information through ADS-B and/or CPDLC and the required architecture if feasible. An analysis should also be conducted of the trade-offs between automatic downlink from the FMS systems vs. downlink of manual entry of expected approach speeds, and wind uncertainty values and their relationship to aircraft operating modes in different weather conditions.

A cost and benefit analysis should be performed to determine the expected benefits from the procedure including the effects of the uncertainty in final approach speed values; the costs to the FAA and the airlines of the different implementation options; and the cut-over point of minimum equipage levels at which benefits would accrue.

Alternate methods of providing the spacing tasks should be explored in case the proposed target ghost tools prove to be infeasible. Both active FAST and CDTI based tools may be considered.

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