CAPACITY ENHANCEMENTS IN IMC FOR AIRPORTS WITH CONVERGING CONFIGURATIONS WITH KNOWLEDGE OF AIRCRAFT’S EXPECTED FINAL APPROACH SPEEDS: A CASE STUDY


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Abstract

This paper documents current results from the analysis of a method for increasing the capacity of airports with converging runway configurations in instrument meteorological conditions by using knowledge of expected aircraft landing speeds. The concept builds on existing standards and procedures authorized for dependent converging approaches. Taking Chicago’s O’Hare airport as an example, the paper documents potential benefits of the proposed procedure with expected levels of inaccuracies in predicted final approach speeds and the level of required airline participation in order to realize these benefits. The paper discusses factors affecting the planning and prediction of aircraft final approach speeds, and provides results of a pilot survey regarding these factors. Results of the survey include pilot estimates of the accuracy with which they actually land compared to what they plan. The paper identifies potential methods for determining expected approach speeds and goes on to discuss data link options for making this information available to the terminal automation for integration into required controller tools. Finally, the paper describes efforts currently underway in determining the ATC feasibility of the procedure and potential transition to these capabilities.

KEYWORDS: airport capacity, converging approaches, final approach speed, CRDA, DCIA, ADS-B, CPDLC, ACARS

Introduction

At an airport such as Chicago O’Hare, the arrival rate in visual conditions can be greater than 100 aircraft per hour by using three runways for arrivals. In non-visual conditions, the current operations revert to a pair of parallel runways with an arrival rate of 70 per hour. The purpose of this paper is to show how three runways could still be used in non-visual conditions to recover some of the lost capacity. The basis of such an operation would be the FAA’s Dependent Converging Instrument Approach (DCIA) procedure.

The DCIA procedure was authorized in the U.S. in 1992 in the FAA Air Traffic Order 7110.110A. [1] The order 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. The key requirement that makes this operation possible in IMC is the staggering of arrivals on the converging approaches by specific minimum values. These values are specified in that FAA order. The staggerers are designed such that even in certain worst conditions, even if both aircraft on the converging approaches execute simultaneous missed approaches, full safety is maintained without any controller intervention or any special pilot techniques. The DCIA procedure is currently in use at several airports, notably at St. Louis Lambert International (STL) since 1992.

The capacity benefit that the DCIA operation provides depends on the minimum stagger values required for 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. For airports such as Chicago’s O’Hare, these distances are so long that the current order results in stagger values of 3 nmi or greater. When stagger value exceeds 2.5 nmi, such airports derive no significant capacity benefit from the DCIA operation.

The minimum stagger values required by FAA Order 7110.110A protects against simultaneous dual missed approaches for the worst possible combinations of approach speeds of the converging pair. Mundra and Smith [2] show that if the final approach speeds of aircraft were known, reduced stagger values could be used to achieve capacity gains over the capacities implied by the current DCIA stagger values. The knowledge of expected final approach speeds will always involve some degree of error. This paper reports on an analysis of the factors affecting prediction of expected final approach speeds, and reports on the results of a pilot survey regarding these factors including pilot estimates of the accuracy of the expected final approach speed. The paper also presents the degree of benefit that could be expected given these accuracy estimates and a...
realistic degree of aircraft participation. Once an estimate of the expected final approach speed is made, it needs to be transmitted to the ATC automation system so that the controller aid supporting the modified DCIA procedure can be adjusted accordingly. The paper discusses several options for delivering the final approach speeds to the ATC automation.

**Dependent Converging Instrument Approaches (DCIA)**

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 either one or 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\(^1\). 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 \(s=a-b\) when the leading aircraft crosses the threshold. The value of \(s\) is derived such that under the specified maximum allowable wind conditions, a minimum of 1 nmi separation would be guaranteed at point P, the point of intersection of the missed approach paths, even under the worst missed approach performance conditions for the two aircraft. After aircraft pass this point, they would be on diverging courses, and separation thereafter is guaranteed since the paths continue to diverge. The value of stagger \(s\) is chosen such that the required safe separation is guaranteed for any combination of approach speeds. The full ATC basis for the procedure is described by Smith et al [3] and Smith and Mundra [4].

**Potential Enhancement from Downlink of Aircraft Final Approach Speeds: Example of Chicago O’Hare**

Figure 2 shows the runway configuration 32L/27R/27L, called Plan A, at Chicago’s O’Hare 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 arrival runway configuration can no longer be used.

In instrument conditions the configuration used is parallel runways 27L and 27R, supporting an arrival rate of only about 70 arrivals per hour.

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\(^1\) Converging operations are authorized, and utilized routinely, in the U.S. when visual separation can be provided by ATC.
Figure 3 shows the stagger surface (i.e., the minimum stagger requirements) for the runway pair 32L and 27R. It shows that the actual stagger values required for converging operations to runways 32L/27R can vary anywhere from 0.5 to 3.2 nmi, depending on the expected final approach speeds of the two aircraft in the pair. (It is this 3.2 nmi that would be used in the current DCIA order.) If the approach speeds were nearly equal, a stagger of only about 1.5 nmi would be required.

![Stagger Surface for 32L Leading 27R at ORD](image)

**Figure 3. Stagger Surface for 32L Leading 27R at ORD**

Figure 4 provides the arrival rates possible by using such variable stagger values and compares them to other arrival rates for this configuration. The arrival rate values in Figure 4 were computed based on a Monte Carlo simulation that considered a string of 50 Large (as opposed to Heavy or Small) arriving aircraft on each runway. The final approach landing speed of each aircraft was randomly chosen to be between 105 kts and 143 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 2.5 nmi plus a value between 0 and the Trailer Precision value shown in Figure 4. The Trailer Precision value represents the buffer that the controller places on the trailing aircraft to ensure that the minimum separation (2.5 nmi in this case) is not violated. For the converging runway cases, the distance between the aircraft would be the minimum stagger distance plus a value between 0 and the Trailer Precision. The arrival rate was determined to be the cumulative time if takes the 50 aircraft to fly their respective separation distances to the runway divided by the number of aircraft intervals. Five hundred of these 50-aircraft sets were simulated and the average arrival rate is plotted.

Figure 4 has been calibrated for the current operations at ORD. It shows that if the delivery precision were about 2.0 nmi, then in an independent dual runway operation such as 27R/27L, ORD would be able to land about 70 aircraft per hour. In visual conditions when three runways are in use for arrivals, 110 aircraft per hour would be the landing rate. These rates approximately correspond to the current rates that ORD achieves.

If dynamic CRDA were used for this triple runway operation as described below, landing rates on the order of 97 to 115 aircraft per hour might be achieved as shown in Figure 4. (The Trailer Precision for a ghosting operation is expected to be in the 0.5 to 1.0 nmi range corresponding to the laboratory experience discussed in the next section.) The use of Classic ghosting (i.e., the stagger values required by FAA Order 7110.110A) is also shown in Figure 4. Since the required stagger values for the current DCIA order are large, it is not surprising that the arrival rate if the current DCIA operation were used would be well below that which can be achieved with an independent dual runway operation.

**Dynamic CRDA and DCIA: A Preliminary Concept of Operation**

Mundra and Smith [2] describe the potential of enhancing the controller display tool called the Converging Runway Display Aid (CRDA) [5] for the proposed dynamic CRDA/DCIA operation. In its “tie mode” (see Feldman [6]), CRDA can be used for spacing aircraft. “Tie-like ghosts” are placed where the aircraft should be in order to achieve the proper stagger. Operational experience from the use of tie-like ghosts in Philadelphia International and Calgary International 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.” [7]

Based on this operational experience and the data from simulations, it is hypothesized that use of tie-like...
ghosts has promise in implementing the dynamic CRDA concept. In this proposal, stagger requirements would be computed based on the knowledge of expected final approach 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 5 and Table 1 show an example of dynamic tie-like ghosts for stagger values required for pairs of aircraft based on their final approach speeds. Tie ghosts are generated at distances $d_1$, $d_2$, $d_3$ etc based on the expected final approach speeds of the successive aircraft. In computing stagger distances, uncertainty in knowledge of expected approach speeds is applied. In this example, it is assumed that aircraft speeds can be up to 10 knots faster than initially declared. Thus, if an aircraft declares an expected approach speed of 130 kts, a value of $(130 + 10) = 140$ kts is used when it is the trailing aircraft in a pair. When aircraft speeds are not known, the worst possible approach speed is used (e.g., 143 kts for a large when trailing, and 105 kts for a large when leading).

At this point the actual value of uncertainty in estimated landing speed is unknown. It is assumed in this example, that this uncertainty is less than 10 knots for the vast majority of the aircraft; but that there is still a small but finite likelihood that there will be some aircraft for which the difference between actual and expected speeds will be greater. For this reason provision is made to determine outliers through controller-pilot communication as described next.

Aircraft expected approach speeds could be derived from the cockpit or the airlines operations center approximately twenty minutes prior to touch down\(^2\) and communicated by an appropriate data link, and displayed in the aircraft data block. If an aircraft is not participating, i.e., if its expected final approach speed is not known, the data block would make an appropriate indication, and the worst possible speed would be used by the algorithm. About 10 minutes prior to landing (parameter to be determined through simulations), the controller would advise the pilot the value of the speed

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\(^2\) This is about the time that the pilot plans for the final approach speed. The speed could be transmitted later than this or subsequently updated as long as the speed estimate reaches the ATC automation prior to the point when the aircraft is 15 to 20 nmi from the runway. The required timing of events and their effect on the automation, the data link architecture, and controller actions need to be investigated.
expected across the threshold as displayed in the data block. The pilot would respond with the speed the pilot expects to use across the threshold. If the value the pilot provides is no more than 10 knots greater than the value displayed in the data block, the controller would punch a quick-action key to accept the displayed value. Otherwise the controller would punch another quick-action key to reject the displayed value. If the value is rejected, the worst possible speed is used by the dynamic CRDA algorithms. If it is accepted, the value displayed in the data clock is used by the algorithm.

Whether such an increase in communication and workload would be acceptable to controllers and pilots...

must be determined through appropriate studies including real time simulations. However, if shown acceptable, this method will also provide a full safety back-up for potential errors introduced by the communication channel. It is conceivable that after an adequate data collection effort, reliable limits to the speed uncertainty may be established. In that case, and if a robust communication channel is provided, then a voice check of this nature may not be needed.

It has been found from operational experience that “ghost” targets must be available to controllers about 15-20 nmi before threshold for a feasible CRDA operation. It is assumed therefore that dynamic ghosts would be available at least 10 minutes before landing. Thus, the expected final approach speed must be computed and transmitted to the terminal automation at least 10 minutes prior to touch down.

The degree of benefit possible by utilizing expected approach speeds depends on the accuracy with which approach speeds could be estimated and the number of aircraft participating in the procedure. This paper now discusses the factors that affect the determination of expected final approach speed, and the means by which they could be determined and communicated.

### Approach Speed Prediction

#### Factors Affecting the Target Speed

The flight crew of a transport category aircraft operating under Part 121 of the Federal Air Regulations must determine a safe final approach airspeed for each approach and landing. This speed will be referred to below as Vtgt. Speed planning generally occurs twenty to thirty minutes before arrival, near top of descent, in conjunction with the approach briefing. This may also be a suitable time for the crew to send the anticipated approach speed to the TRACON CRDA automation if it is determined that this information should be obtained from the crew.

The factors affecting approach target speed are well known, and include aircraft type, landing weight, landing flap setting, weather conditions (especially wind), use of automation, and company policy. Individual pilot experience and judgment also affect the selection of target speed. Figure 6 below shows how the factors are related (read left to right) to produce a Vtgt speed and eventually the actual speed over the threshold.

Target speed selection begins with determination of the Vref speed, which is the slowest safe speed for a...
given landing weight and flap configuration. All speed adjustments are made in reference to Vref. Flight crews refer to printed documentation or the flight management system to determine the Vref speed for each arrival.

An adjustment for surface wind conditions is typically made either heuristically, according to the carrier’s wind adjustment policy or by the aircraft automation as in the case of many Airbus aircraft. Pilot judgment or other factors (e.g., airframe icing) are then applied to define the final target speed. Of course no matter how good the pilot or speed control automation, there will exist some flight technical error applied to the planned Vtgt resulting in an actual speed at threshold.

**Sources of prediction and error**

Two sources for generating the anticipated approach speed are considered:

1. Flight Crew
2. Airlines Operations Center (AOC)

In general the flight crew has access to all the factors that could affect Vtgt. Airline Operations Control (AOC) centers also have access to most of the required information. The accuracy of the estimate is a function of the source data and the occurrence of unplanned events which would cause the estimated values to be in error. The following paragraphs compare the effect of relevant factors for these two methods.

**Landing Weight**

For a particular aircraft type, landing weight and landing flap setting determine the Vref speed. Examination of the landing data tables for a sample of aircraft indicates that the variation of Vref speed with landing weight is on the order of one knot per 1000 lb. and even less for widebody aircraft. Therefore the prediction of target speed will not be affected substantially by small errors in estimates of landing weight, whether done by the pilot or by AOC. However, if the AOC is estimating the weight, larger and more significant errors may occur as a result of an unplanned airborne hold or a significant flight plan deviation due to weather. Holding is generally coordinated with the AOC, but weather deviations are not.

**Wind Adjustments—Airbus and “Other” Types**

In normal operations the actual IAS to be used by the crew is adjusted upward from the base Vref based on prevailing wind conditions to arrive at a target speed. The magnitude of the speed adjustment varies by aircraft type and the flight operations policy of individual air carriers. A typical adjustment for gusty wind conditions is to add one half the steady wind velocity plus all the gust increment, to the Vref for the current weight/flap combination, not to exceed 20 kts.

Recent Airbus aircraft (A318-A321, A330, A340) are a special case, and use a proprietary algorithm, which automatically computes the target speed when the crew enters the surface wind data. The system adds approximately 1/3 the headwind component, with gusts disregarded, to the Airbus equivalent of Vref, not to exceed 20 kts. This target speed can be accessed from a Flight Management Guidance Computer (FMGC) page.

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5 An automated method of delivery, such as a direct downlink from the FMS, may also be possible. However, an FMS-derived approach speed would be subject to specific limitations regarding pilot factors, would be expensive to implement, would extend over a longer implementation time frame, and would be more susceptible to equipage concerns. This option is not considered further in this paper.
Many airlines instruct their crews to fly a small increment above Vref as a lower limit of target speed, usually Vref + 5 kts (also included in Airbus automation). This adjustment is made to guarantee a safe and smooth transition from the glidepath through the landing flare to touchdown. Therefore the total range of adjustment for wind could be up to 15 kts, and thus appears to be the dominant factor in approach speed prediction. While Airbus and other aircraft are subject to somewhat similar wind adjustments, the Airbus aircraft will apply smaller adjustments since the automation only adds 1/3 the headwind component, as compared to the non-Airbus aircraft which add half the total wind and all the gust factor, regardless of direction.

Unique to the Airbus is the use of a target minimum groundspeed (MiniGS) when flying an approach in Managed Speed mode. The Managed Speed mode combined with MiniGS is intended to provide protection from a sudden airspeed loss to unsafe levels during windshear conditions. For the Airbus aircraft flown in managed speed mode, the threshold speed is computed from the surface wind values (from ATIS) entered into the FMGC and thus would be no less predictable than for other aircraft. This speed can be accessed from a page in the FMGC. Thus the differences in speed management between Airbus and Other aircraft will not affect the ability to predict threshold speed.

While pilots have access to wind data from the Automated Terminal Information Service (ATIS), it may also be possible to develop an AOC prediction algorithm which uses the same information from ground based data sources such as the NOAA observation database. Since the carrier wind adjustment policy is known, the standard adjustments for wind could then be applied by the AOC algorithm to generate a predicted target speed. In either case, changes in winds after a prediction has been made will result in an error in the predicted value since pilots (or the Airbus aircraft automation) will respond to these changes. In fact, effects of such last minute changes may be large enough that an operating limitation suspending dynamic CRDA operations under certain wind conditions may be required.

Additional Factors

During the flight crew approach briefing the crew reviews any additional factors that may require speed adjustment as determined by the crew according to their judgment and experience. For example, runway contamination may suggest the use of a non-standard, larger flap setting with a lower Vref speed as a means offsetting reduced braking effectiveness. Airframe icing encountered on the approach may require an increment of speed to be added to Vigt. Some pilots may even apply their own idiosyncratic adjustments (e.g. “...140 kts always works well for this airplane”).

Pilot judgment factors are necessarily applied as circumstances require, and therefore cannot be predicted by an external agent such as the AOC. Speed variation due to flap setting and pilot judgment can only be accounted for by making pilots the source of the speed prediction.

AOC vs. Pilot Prediction

In summary, pilots are in the best position to determine the target speed. They have access to the full range of information required to make the prediction. Non-airbus aircraft are operationally required to determine the target speed, whereas recent Airbus aircraft are required to ensure that aircraft automation has the necessary data to compute it. (These Airbus pilots, would, however, have to access the target speed information from a page in the FMGC).

The AOC could predict the final approach target speed, but subject to limitations. AOC does not know the flap setting used for a particular approach, nor does it know the specific “other factors”, including individual pilot technique that may affect the selection of Vtgt. Estimated landing weight errors may be present due to weather or altitude deviations from flight plan that are not coordinated with AOC.

For both pilot-derived or AOC-computed values, the dominant source of prediction error, however, appears to be changes to actual surface wind after the initial estimate has been made. This would affect both “Other” and Airbus aircraft. Operations in rapidly changing wind environments, such as may exist during frontal passage or in the vicinity of convective weather, may not be suitable for the application of dynamic CRDA.

Data Collection to Determine Predictive Accuracy

A data collection effort is being planned to gather data on the accuracy of predicted final approach speed for use in the CRDA automation. Since the positioning of the dynamic “ghost” targets is a safety critical function, the accuracy with which final approach speed can be predicted must be known for the required safety analyses to be completed. Predictions from both candidate sources, pilots and AOC, will be included.

Pilot prediction data could be collected via an ACARS free text message. A specific routing address could be created to capture this data. AOC prediction
will require developing an algorithm that would use predicted landing gross weight, ATIS wind information at the estimated time of arrival minus twenty minutes\(^6\), and the application of the air carrier wind adjustment heuristic to generate the planned final approach speed. Separately, a source of “truth” data would be developed to determine the error in the prediction. Ideally, the air carrier Flight Operations Quality Assurance (FOQA) database would be tapped for the actual indicated airspeed at the threshold. Alternatively, a more cumbersome method would use recorded ARTS data, and arrival wind data to calculate the IAS at the last radar position update. This would be less accurate than the higher quality FOQA data.

### Survey of Pilot Procedures Associated with Final Approach Speed

Considering that there are so many procedural factors that determine final approach speed for a given type of aircraft, a survey was created to gather information about how pilots plan and adjust their final approach speeds. This is the first step in the larger data collection effort, in that this information will help develop a comprehensive data collection plan that addresses all expected factors affecting approach speed planning and execution. The survey consisted of seventeen questions along with some demographic data. There were both open-ended and multiple-choice questions. This paper describes a subset of the questions with the remainder presented in future work. The survey was presented as an online web page. The respondents were volunteers who filled out the survey online. The Air Line Pilots Association (ALPA) supported the survey effort by including a link to the survey in their weekly electronic newsletter. The Air Line Pilots Association is a union representing 66,000 airline pilots at 43 U.S. and Canadian airlines.\(^7\)

As shown in Table 2 there were 502 respondents over the course of approximately three weeks and 72 percent of them indicated that they had greater than 1,000 hours of flying experience with their current aircraft type. Due to the differences in approach speed planning and execution between Boeing and Airbus aircraft, the results were separated into three groups (Boeing, Airbus, and Other). The results are presented for each of the three groups including the actual question and a breakdown of the responses.

“How often during the last month have you used a landing flap setting other than the standard setting?” The results reported in Table 3 indicate that 85 percent of the pilots used a standard flap setting during the previous month. In order to calculate a ground-based speed estimate, an algorithm would need to know the landing flaps. This information suggests that it may be possible to use standard flaps when calculating a ground-based landing speed prediction.

### Table 2. Number of Pilots by Type and Position

<table>
<thead>
<tr>
<th></th>
<th>Boeing</th>
<th>Airbus</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captain</td>
<td>144</td>
<td>38</td>
<td>110</td>
<td>292</td>
</tr>
<tr>
<td>First Officer</td>
<td>94</td>
<td>25</td>
<td>86</td>
<td>205</td>
</tr>
<tr>
<td>Second Officer</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>502</strong></td>
<td><strong>100%</strong></td>
<td></td>
<td></td>
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</tbody>
</table>

### Table 3. Frequency of Non-Standard Flaps – Last Month

<table>
<thead>
<tr>
<th></th>
<th>Boeing</th>
<th>Airbus</th>
<th>Other</th>
<th>Total</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>190</td>
<td>58</td>
<td>177</td>
<td>425</td>
<td>84.7%</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>5</td>
<td>12</td>
<td>37</td>
<td>7.4%</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>2.4%</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>0.8%</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1.0%</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>0</td>
<td>3</td>
<td>19</td>
<td>3.8%</td>
</tr>
<tr>
<td>6 or more</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>502</strong></td>
<td><strong>100%</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“How often during the last month have you amended your planned final approach speed after contacting approach control?” The responses in Table 4 indicate that although the majority of pilots had not amended their speed during the last month, 41 percent indicated that they had modified their planned approach speed after contacting approach control. This indicates that planned approach speed does undergo some revision, and that the concept may need to accommodate such revisions.

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“Given that there are many factors that affect the actual speed over the threshold, how accurate do you believe your initial target speed estimate (the one normally briefed during the Preliminary Landing, or Descent checklists) would be? Based on my experience I estimate that my initial target speed estimate would be within: Plus _______ knots to minus _______ knots.” The results are depicted in Table 5.

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\(^6\) The approximate time when the pilot would be making the final approach speed estimate.

\(^7\) See their web site for more information http://www.alpa.org
Table 4. Frequency of Amended Speed - Last Month

<table>
<thead>
<tr>
<th>Boeing</th>
<th>Airbus</th>
<th>Other</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>127</td>
<td>50</td>
<td>119</td>
<td>296</td>
</tr>
<tr>
<td>1</td>
<td>44</td>
<td>6</td>
<td>34</td>
<td>84</td>
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<tr>
<td>2</td>
<td>32</td>
<td>5</td>
<td>12</td>
<td>49</td>
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<td>3</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>3</td>
<td>18</td>
<td>46</td>
</tr>
<tr>
<td>6 or more</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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</table>

Across all participants 4 percent of pilots indicated that would be more than 10 kts above and another 4% indicated that they would be 5 kts below their planned speed.

The next question asked pilots “On what percentage of approaches would your actual threshold speed be within the range you selected above?” 89 percent of pilots indicated that their speed would be within the above reported bounds at least 90 percent of the time. Table 6 shows the responses by aircraft type.

Table 5. Knots Above and Below Planned Speed

<table>
<thead>
<tr>
<th>Knots Above Planned</th>
<th>Boeing</th>
<th>Airbus</th>
<th>Other</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 knots</td>
<td>3%</td>
<td>13%</td>
<td>2%</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>1 knots</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>2 knots</td>
<td>8%</td>
<td>6%</td>
<td>5%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>3 knots</td>
<td>5%</td>
<td>4%</td>
<td>5%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>4 knots</td>
<td>1%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>5 knots</td>
<td>47%</td>
<td>47%</td>
<td>54%</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>7 knots</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>8 knots</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>10 knots</td>
<td>30%</td>
<td>23%</td>
<td>26%</td>
<td>28%</td>
<td></td>
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<tr>
<td>12 knots</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>15 knots</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
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</tr>
<tr>
<td>20 knots</td>
<td>0%</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>25 knots</td>
<td>1%</td>
<td>1%</td>
<td>0%</td>
<td>1%</td>
<td></td>
</tr>
</tbody>
</table>

There is a significant interest by at least one airline in using the existing ACARS data link to downlink the expected final approach speed information. The survey included questions regarding whether pilot workload would permit sending such an ACARS message, and whether they would do so. Overall 65 percent of the pilots indicated that their workload would permit sending such a message. Interestingly, only 63 percent indicated that they would be willing to do so. This indicates that

Table 6. Percentage Within Above Reported Bounds

<table>
<thead>
<tr>
<th>Percentage Within Above Reported Bounds</th>
<th>Boeing</th>
<th>Airbus</th>
<th>Other</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>37</td>
<td>24</td>
<td>37</td>
<td>98</td>
<td>19.5%</td>
</tr>
<tr>
<td>95%</td>
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<td>90%</td>
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<td>20.8%</td>
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<td>19</td>
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<tr>
<td>80%</td>
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<td>1</td>
<td>7</td>
<td>17</td>
<td>3.4%</td>
</tr>
<tr>
<td>75%</td>
<td>10</td>
<td>2</td>
<td>6</td>
<td>18</td>
<td>3.6%</td>
</tr>
<tr>
<td>&lt;75%</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</table>

Even if the airlines determined that they would like to participate in such a procedure, that they would have to negotiate with the pilots to gain their acceptance in downlinking such information.

In summary, the results of the survey indicate that 92 percent of the pilots estimate that the speed they actually fly over the threshold is no more than 10 knots faster and no less than 5 knots slower than what they plan in their initial briefing. The pilots also indicated that they use non-standard flap settings about 15 percent of the time which may indicate some potential for an acceptable estimate by the airline operations center.

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Data Link

This section describes conceptual options for delivering the planned approach speed of arriving aircraft to the terminal automation system. Possible connectivity options from both the cockpit and from airline computer systems to Air Traffic Control systems are presented and analyzed. Assumptions made in the following description would need to be validated through a safety assessment process addressing airborne and ground system perspectives consistent with the guidelines established in RTCA DO-264.

Perhaps the two most obvious options for downlinking planned final approach speeds from the cockpit are Automatic Dependent Surveillance-Broadcast (ADS-B) or ADS-B-like methods, and Controller-Pilot Data Link Communications (CPDLC).

ADS-B

The ADS-B MASPS [8] provide for an on-condition message for planned approach speed. RTCA DO-260, Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance-

8 Some other options, including Future Air Navigation System (FANS), are also possible, but are not discussed here for brevity.
Broadcast (ADS-B) [9] includes a “Runway Threshold Speed” subfield in the Aircraft Operational Coordination Messages. The architectural framework for the downlink of ADS-B information and its integration into a terminal automation system have been demonstrated successfully in the Safe Flight 21 program and is being migrated into the Common-ARTS and the Standard Terminal Automation Replacement System (STARS) in the lower 48 states. The integration of ADS-B messages into the terminal automation systems has thus established the integrity of the ADS-B link for ATC purposes. A major challenge in this method would be aircraft equipping. In this option, current Mode-S systems would have to be upgraded to become capable of down-linking planned approach speed information. It is also likely that implementing only the capability to downlink expected final approach speed may be less expensive than implementing a full ADS-B capability, and may be considered by the airlines short of a full ADS-B implementation. Alternatively, pending initiatives such as the implementation of Reduced Vertical Separation Minima (RVSM) in domestic U.S. airspace may provide an opportunity to implement full or partial ADS-B capability as part of the necessary transponder upgrade that the RVSM initiative will require. If so, the planned final approach speed information could be incorporated into such an implementation.

**CPDLC**

A second option could utilize Controller-Pilot Data Link Communications (CPDLC)[11]. The FAA is currently examining the dependencies between the CPDLC, and En Route Automation Modernization (eRAM) programs. It is likely that CPDLC will be implemented in a series of releases with increasing functionality and integration with eRAM. In the CPDLC architecture, the aircraft avionics will be connected to the Aeronautical Telecommunication Network (ATN) infrastructure. It is this infrastructure that would be used to transmit the data to the terminal automation. Current airborne and ground system implementations of ATN CPDLC are based on ATN Baseline 1 [12] and would not support this concept. Implementations beyond ATN Baseline 1 could support this concept if the appropriate ATN CPDLC message elements were supported.

At an appropriate point in the evolution of CPDLC a message element from the CPDLC message set could be used to define and downlink planned aircraft final approach speed. The planned aircraft approach speed message could be downlinked either in response to a ground system request (e.g., during a request to transfer communication from the en route to the terminal airspace) or it could be initiated from the cockpit. Depending on the implementation options that appear most appropriate, the planned aircraft approach speed would either be downlinked to the en route system and forwarded to the terminal automation or be downlinked directly to the terminal automation.

**ACARS**

Although either Mode-S or CPDLC appear to be ideal vehicles for implementing this downlink capability, both of these are somewhat longer term solutions, and there is considerable interest from airlines in using the existing Aircraft Communications Addressing and Reporting System (ACARS) for near term implementation.

The main challenge in using ACARS for communicating planned final approach speed to terminal automation is that ACARS avionics and its supporting infrastructure is a level D system and therefore has no built-in safeguards against introduction of errors that could cause safety-critical issues. If ACARS is considered for this application, the following issues must be satisfactorily addressed:

- Mitigation of hazards in the operational concept by conducting Operational Safety Assessment
- Use of ACARS to transfer operational ATC data.
- Input of non-ATC controlled data into terminal ATC operational systems.
- Adequacy of the performance of ACARS for this application
- Acceptability of the additional pilot and controller workload in verifying planned aircraft approach speed by voice.
- For AOC derived messages, potential airline concerns regarding the use of airline automation systems to provide ATC real time operational data.

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9 Although the message itself is being deleted from DO-260A, provision to re-insert the message is being made.
10 Of course, whether pilot entered data will be acceptable is another matter, and must be addressed separately.
11 This capability is not currently planned, but it could be considered as an add-on toward the second half of the decade, some time after 2007.
12 The appropriate message elements for this exchange are uplink message 134 [REPORT (speedtype) (speedtype) SPEED] and downlink message 113 [(speedtype) (speedtype) SPEED (speed)] where (speedtype) is defined as the (approach) parameter.
RTCA Special Committee 201 is addressing mitigation of major hazards for undetected misleading data transmitted over ACARS (for example, for take off data), and may provide a basis for transmitting expected final approach speeds over ACARS.

In this concept, the pilot could determine and enter the planned approach speed into the Control/Display Unit (CDU) of the Aircraft Communications Addressing and Reporting System (ACARS). The planned approach speed data would then be downlinked via ACARS to the Airline Operational Center (AOC). After that, there are three possible data paths from the AOC to the terminal automation system.

The first data path could utilize the existing connection between Enhanced Traffic Management System (ETMS) hub at Volpe National Transportation Systems Center (VNTSC) and major terminal systems; the second data path could utilize the National Airspace Data Interchange Network (NADIN) connectivity between en route and terminal automation system; and the third data path could utilize the ARINC network by installing a new node at each terminal automation system. An analysis of the three options indicates that the preferred mode would probably be AOC connectivity to the terminal automation through the ETMS hub. Figure 7 illustrates this option.

VNTSC is connected to participating Airlines’ Operations centers (AOCs) through the Collaborative Decision-Making (CDM) net. Six major TRACONS equipped with ARTS IIIIs have a direct feed to Enhanced Traffic Management System (ETMS) Hub (VNTSC) site. (Other ARTS systems feed position data to ETMS through their associated ARTCC’s host computers.) The ETMS hub is connected to the TRACONS through the bandwidth manager. In this concept the airlines operations center would generate an expected final approach speed message (or a pilot generated planned final approach speed message downlinked from ACARS) and forward it to the ETMS hub through airline routers to the AOC/CDM net. VNTSC would convert this message to a NAS application message format (based on an existing control message called CT) and forward it to the local TMU file server at the ARTS IIIIE or STARS. The TMU file server at the TRACON would then forward the message to the ARTS IIIIE gateway. The key new item here is that there would be an exchange of an applications message between the TMU and ARTSIIIE (or STARS) where currently there is only a control message exchange.

**Implications for Potential Benefits**

With knowledge that the estimate of the final approach speed will be inaccurate, some compensation must be made in computing the position of the “ghost” target. As suggested by the pilot survey and discussed in the operational concept, 10 kts of speed would be added to the estimated approach speed of the trailing aircraft and 5 kts of speed would be subtracted from the estimated approach speed of the leading aircraft. This will maintain the overriding concept of accounting for a wide range of possible errors. Of course 10 kts and 5 kts are only best guesses at this point. With such an algorithm, one could re-simulate the results shown in Figure 4 to arrive at Figure 8.

The results in Figure 8 show that even accounting for the uncertainty in the estimate of approach speeds as estimated by pilots in the survey reported earlier, the benefit would be 10 to 20 additional arrivals per hour in IMC over that achieved today.

However, the results in Figure 8 apply only when there is 100 percent participation. As it is unlikely that equipage for dynamic DCIA operations will be mandated, there will be less than full participation. This being the case, the Monte Carlo simulation was run again with varying percentages of the traffic marked as nonparticipating. The range of participation was varied from 50 to 100 percent. When a leading aircraft is marked as nonparticipating, its final approach speed was assumed to be at the lower end of the approach speeds for that class of aircraft. When a trailing aircraft is marked as nonparticipating, its final approach speed was assumed to be at the upper end of the approach speeds for that class of aircraft.
Since we also want to understand the affect of the speed uncertainty, the trailer speed uncertainty was varied over a range of 0 to 20 kts.

Figure 9 shows the results from the simulation of the tradeoff between the level of participation and the uncertainty in the speed estimate. To be considered beneficial, the arrival rate would probably have to be at least 5 aircraft per hour more than the independent dual rate of 70 aircraft per hour. At Chicago O’Hare two major airlines comprise 80 percent of the traffic. If those two airline fleets participated, then one could achieve an arrival rate of 80 aircraft per hour in IMC with a 10 kt speed uncertainty. With a 15 kt speed uncertainty one could achieve an arrival rate of 78 aircraft per hour.

Dynamic Ghosting at ORD: A Potential Evolution

Even if expected aircraft speeds were available from the airlines, several additional steps will be required in the development and implementation of dynamic CRDA.

- Verification of the integrity of the planned approach speed data to be used by terminal automation through appropriate safety analyses.
- Development of dynamic CRDA algorithms and their refinements through real time simulations to generate a dynamic CRDA tool acceptable to controllers
- Development and certification of the appropriate interfaces to receive and integrate expected aircraft approach speeds into terminal automation
- Development of an operational concept acceptable to both controllers and pilots

Further, even if dynamic CRDA were shown to be feasible and acceptable, the core application described here would only be used for the few percent of the time that the facility is in IMC and is using the appropriate configurations. It has been observed in the past that the use of CRDA is considerably more robust if the facility uses it frequently, and not just during the infrequent times that it experiences instrument conditions. It is therefore desirable that meaningful VMC applications of CRDA be found for potential airports. Several VMC applications of CRDA at ORD are being explored in real time ATC simulations with controllers from Chicago Approach Control as a necessary stepping stone towards any future dynamic capabilities. These applications aim at improving the current operations to runways 27L, 27R and 22R for arrivals (called Plan W) to eliminate its land
and hold short operation (LAHSO), and enabling another configuration, Plan B, that uses runways 22R, 14L and 14R for arrivals leaving 22L available for departures only. Controllers from Chicago’s Approach Control have expressed considerable optimism in implementing these near term VMC capabilities.

**Figure 9. Tradeoff Between Arrival Rate, Participation and Speed Estimate Uncertainty**

**Summary and Conclusions**

This paper shows that significant capacity gains may be possible by enhancing an existing procedure called Dependent Converging Instrument Approaches (DCIA) for approaches to converging runways in IMC by utilizing planned final approach speeds of aircraft to generate reference targets called “tie-ghosts” to help controllers deliver required safe spacing. The proposed enhanced procedure, called “dynamic DCIA”, is based on enhancing a current controller display capability called the Converging Runway Display Aid (CRDA). The paper takes the case of Chicago’s O’Hare airport and shows that about 10 extra arrivals may be possible in IMC if expected final approach speeds could be determined to within about 10 knots, and if at least 80 percent of aircraft can be expected to participate. The paper discusses factors that affect the accuracy of such prediction, and documents results of a pilot survey in which 92% of the pilots estimated that their actual approach speed would be no faster than 10 knots and no slower than 5 knots of their planned approach speed about 90 percent of the time. The paper discusses potential links by which the planned approach speed information could be communicated to the terminal automation. Although ADS-B or a controller pilot data link are probably the ideal data links for this purpose, a solution using an existing link such as ACARS may also be possible, and its limitations might be overcome by an appropriate operations concept. A comprehensive safety analysis of the communication channel would be necessary, and a comprehensive data collection effort is needed so that the difference between planned and actual approach speeds can be established reliably. The paper briefly addresses issues in operational transition and deployment to a dynamic CRDA capability, shows that a CRDA capability used only in IMC should be supplemented by one used in VMC and briefly describes encouraging efforts underway to identify potential VMC applications of CRDA for Chicago’s O’Hare airport for near term benefits.

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**References**


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