# Human-In-The-Loop (HITL) Simulation and Analysis of Optimized Profile Descent (OPD) Operations at Atlanta

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**The MITRE Corporation's Center for Advanced Aviation System Development (CAASD), under the sponsorship of the Federal Aviation Administration's Air Traffic Organization (ATO), conducted a Human-in-the-Loop (HITL) simulation of Optimized Profile Descent (OPD) operations on the proposed DIRTY Area Navigation (RNAV) Standard Terminal Arrival (STAR) procedure into Atlanta's Hartsfield-Jackson International Airport (ATL). The simulation, conducted at the Atlanta Terminal Radar Approach Control (TRACON) facility, assessed the workability of several alternatives for utilizing OPD operations on the DIRTY STAR. As a result of the evaluation, CAASD identified issues which would limit the use of the DIRTY STAR specifically, as well as OPDs more generally. In addition, CAASD was able to identify mitigating strategies and resolutions for many of the issues identified.**

## I. Introduction

As the participation in Performance-Based Navigation (PBN) capabilities, such as use of Area Navigation (RNAV) procedures, becomes increasingly prevalent in the National Airspace System (NAS), new concepts have emerged to further enhance operator and environmental benefits. Increased user operating costs and environmental impact concerns are driving aviation research in 'green' operations. One concept, described by the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) program[1], seeks to reduce fuel costs, greenhouse emissions, and noise by designing RNAV Standard Terminal Arrival (STAR) procedures which allow aircraft to fly Optimized Profile Descents (OPD). The AIRE program was established as a cooperative agreement between the Federal Aviation Administration (FAA) and the European Commission (EC) to accelerate environmental improvements in aviation and to validate proposed improvements through flight trials and demonstrations. OPD operations have been identified as a method for minimizing aviation's impact on the environment by providing a more efficient descent trajectory, with less time spent in level flight, which can result in reduced fuel burn, noise, and carbon emissions.[2] However, before OPD arrival procedures can be implemented at airports throughout the NAS, the impacts associated with managing these flights, from an Air Traffic Control (ATC) perspective, especially in busy terminal environments, needs to be clearly understood. The development of published OPD STAR procedures is also generally considered to be a key step in the modernization of air traffic operations.

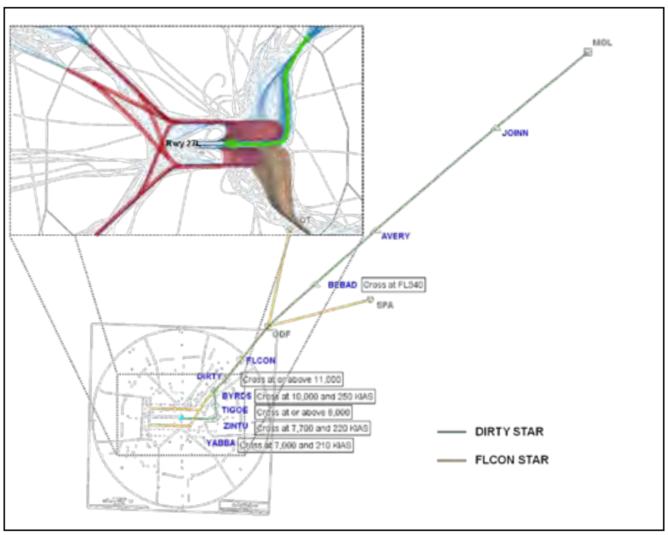


**Figure 1. Lateral Path of DIRTY RNAV STAR**

### A. Background

In May of 2008, AIRE sponsored Continuous Descent Arrival (CDA) demonstration flights at Atlanta's Hartsfield-Jackson International Airport (ATL). The demonstration flights at ATL were conducted using a particular RNAV STAR, the DIRTY STAR (see Fig. 1), designed specifically to reduce level-offs during descent, also taking into consideration the constraints of the metroplex. The

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DIRTY STAR was designed over the northeast corner post of Atlanta's Terminal Radar Approach Control (TRACON) airspace – the arrival corridor for all European arrivals destined for ATL – to allow European aircraft to participate in the AIRE demonstration flights. The lateral path of the DIRTY STAR is essentially the same as the lateral path of the existing Montebello (MOL) en route transition of the FLCON RNAV STAR, with a transition from the BYRDS waypoint for landing on runway 27L. The DIRTY STAR was only designed for a landing west operation, since the descent profile for that direction fit very well within existing airspace constraints.

The AIRE demonstration flights flying the DIRTY STAR procedure into ATL occurred during daytime, off-peak traffic periods, where impacts resulting from surrounding traffic and non-OPD flights could be minimized. The airspace around OPD flights was sterilized, meaning non-OPD flights were kept away from the airspace area through extensive vectoring. Substantial benefits from OPD operations can only be realized if a significant proportion of flights are able to participate, and if non-OPD flights do not experience a sizeable disbenefit in being kept clear of OPD flights. Ideally, this would mean utilizing OPD operations during peak (or near-peak) traffic periods while also ensuring that non-OPD flights are minimally affected. The feasibility of this goal could not be ascertained during demonstration flights alone. Therefore, a Human-in-the-Loop (HITL) simulation was proposed as a mechanism to evaluate OPDs during busy, daytime operations to help identify issues associated with the use of OPD operations and explore possible mitigation strategies.

### B. HITL Simulation Purpose and Goals

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD), under the sponsorship of the FAA's Air Traffic Organization (ATO-P) as part of the AIRE program, was tasked to evaluate, via HITL simulation, OPD operations along the DIRTY RNAV STAR procedure. The simulation was conducted at the Atlanta TRACON facility (A80) in October 2008. This evaluation focused on assessing the operational acceptability of several variations of OPD operations along the DIRTY RNAV STAR procedure, during high-volume traffic periods, from both a TRACON and Air Route Traffic Control Center (ARTCC) radar position perspective. Operational acceptability is intended to measure a level of perceived control that must be met (or exceeded) in order for the controller to feel that the safe control of traffic can be maintained. It is used as an indicator for how manageable a given traffic situation is. Additionally, the evaluation aimed at identifying issues that could specifically limit the use of the DIRTY STAR, if published, as well as more general issues that would apply to potential OPD operations elsewhere. Identification of these issues prior to procedure publication will enable appropriate resolutions to be considered, such as automation enhancements or ATC procedural changes, in order to ensure these operations remain manageable and within Air Traffic Management (ATM) objectives. This in turn will help to accelerate the successful NAS-wide deployment of OPD operations, as well as the operator and environmental benefits that these operations provide.

The goals of the HITL simulation included:

- Assess the design of the DIRTY RNAV STAR procedure given a fleet mix consistent with current operations.
- Determine the interactions and issues associated with managing OPD flights during busy traffic levels.
- Identify the factors that influence the ability of aircraft to remain on the OPD procedure (i.e., without intervention by ATC) all the way to the runway.
- Assess design modifications to the DIRTY RNAV STAR procedure for improving the efficiency and workability of operations.
- Identify the inter-facility coordination necessary between TRACON and ARTCC controllers to successfully manage OPD flights.

## II. HITL Simulation Setup

### A. Simulation Environment

The simulation was conducted using CAASD's portable traffic simulation platform, using the Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS) software tool. For this evaluation, ATC workstations consisted of a laptop computer connected to a 19" Liquid Crystal Display (LCD). A QWERTY keyboard and a track-ball mouse were available to serve as input devices. Four different ATC positions were simulated; two en route positions and two terminal positions. The Computer Human Interface (CHI) was configured to replicate the en route [HOST Computer System (HCS)] or terminal [Common Automated Radar Tracking System (CARTS)] automation, respectively. Four additional laptops served as simulation pilot stations, where simulation pilots entered aircraft instructions issued by controller participants[2]. All of these laptops were connected to a common local network, which allowed the simulations to model a continuous air traffic operation across en route airspace and TRACON airspace. Over-The-Shoulder (OTS) communications were used in this simulation; therefore, controllers were situated adjacent to their corresponding simulation pilot. A photograph of the HITL simulation layout is shown in Fig. 2.

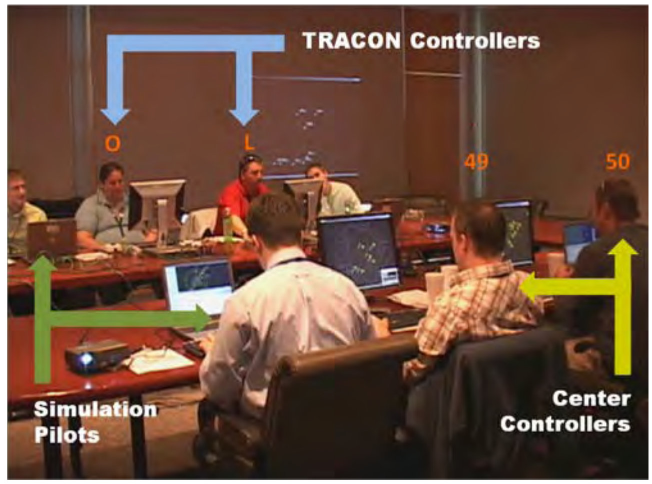


**Figure 2. TARGETS Simulation Set-up**

### B. Participants and Airspace

Two Atlanta ARTCC (ZTL) radar controllers and two A80 front-line managers participated in the simulation. The ZTL controllers worked the Lanier Sector (50) and the Logen Sector (49). The A80 controllers worked the feeder position (L) and the center final position (O). An overview of the modeled airspace, as well as the relevant arrival procedures used during the experiment, is depicted in Fig. 3. The constraints of the DIRTY arrival procedure are provided in Table 1.

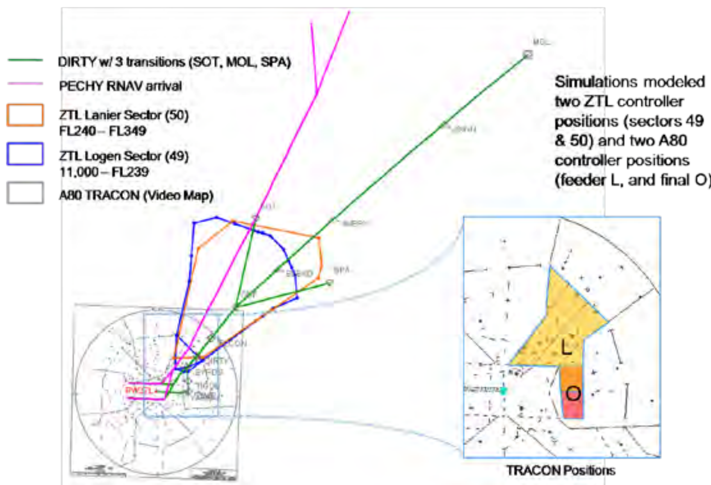


**Figure 3. Modeled Airspaces**

**Table 1. DIRTY STAR Constraints**

| Waypoint | Constraint |
|---|---|
| MOL | - |
| JOINN | - |
| AVERY | - |
| BEBAD | Cross at 34,000 ft |
| ODF | - |
| FLCON | - |
| DIRTY | Cross at or above 11,000 ft |
| BYRDS | Cross at 10,000 ft , 250 kts |
| TIGOE | Cross at or above 8,000 ft |
| ZINTU | Cross at 7,700 ft, 220 kts |
| YABBA | Cross at 7,000 ft, 210 kts |

Although the original DIRTY STAR procedure was designed only for flights filing FLCON along the MOL transition, controllers indicated that if they were to use this procedure during busy, daytime operations, the other two FLCON en route transitions, Snowbird (SOT) and Spartanburg (SPA), should also be eligible for the OPD. Otherwise, too much coordination and workload would be involved in maintaining the distinction between the OPD flights and non-OPD flights arriving from the different transitions. As such, flights coming from all three en route transitions were eligible to be cleared for the OPD in all OPD-simulated scenarios.

### C. Scenario Characteristics

Several scenarios were developed to achieve the simulation objectives previously stated. Each scenario was designed to run for approximately 45 minutes. During this time, controllers issued instructions to aircraft within their airspace and simulation pilots entered the corresponding action into the automation. Standard ATC phraseology for communications between controller and simulation pilot was employed as much as possible. The scenarios examined several variations on the use of OPD procedures and were classified into one of the following scenario types:

- **Baseline (A):** This scenario type captures current ZTL/A80 ATC operations, without OPD operations. These scenarios help validate the suitability of traffic files (i.e., levels) used for the evaluation and also

[2] For simplicity, controller participants are referred to as “controllers”.

establish a baseline for making scenario comparisons. Baseline scenarios were designated by the letter "A".

- **Unconstrained (B):** This scenario type includes OPD operations involving variable vertical profiles and top-of-descents (ToDs), based on aircraft type category. Operations are simulated to replicate Flight Management Computer (FMC)-calculated profiles, or in other words, aircraft fly the DIRTY STAR as designed from cruise altitude. Unconstrained scenarios were designated by the letter "B".
- **Lower and Closer (C):** In this scenario, clearances for OPD operations are issued lower and closer to the airport[3]. Instead of beginning at cruise altitudes, the OPD begins at FL240 and closer to the airport at Foothills (ODF), with all restrictions after ODF being the same as those in the original DIRTY STAR. This scenario type was designated by the letter "C".
- **Customized (D):** This scenario type incorporates suggested procedure modifications to the DIRTY RNAV STAR based on feedback received from the controllers during the evaluation week. This scenario type was more exploratory; to test improvements to efficiency and workability of OPD operations. Customized scenarios were designated by the letter "D".

### D. Traffic Generation

Three separate traffic files were developed, based on actual recorded traffic data, to provide a variety of traffic volumes and flight interactions for assessing the manageability of OPD operations. Existing RNAV procedures at ATL are designated for turbojet aircraft only, which was also the case for the proposed DIRTY STAR during the simulation. While turboprop aircraft were included in the simulation, these aircraft were not eligible participants for the OPD since they do not file the FLCON STAR, a prerequisite for clearance to the DIRTY STAR[4]. Details for the three traffic files used are provided in Table 2.

**Table 2. Details of the Simulated Traffic**

| | Date Derived From | Time | Traffic Volume Representation |
|---|---|---|---|
| **Traffic File #1** | July 11, 2008 | 1645 – 1745Z (1145-1245 local time) | Moderate traffic volume |
| **Traffic File #2** | June 15, 2008 | 2200 – 0000Z (1700-1900 local time) | Higher traffic volume |
| **Traffic File #3** | June 3, 2008 | 2030 – 2130Z (1530-1630 local time) | Moderate traffic volume |

**Table 3. Scenario Distribution by Traffic File and Scenario Type.** *A checkmark indicates that a scenario of the indicated traffic file #X and type (letter) was conducted. The (#) adjacent to the checkmark indicates the order that scenarios were conducted.*

| | Traffic File #1 | Traffic File #2 | Traffic File #3 |
|---|---|---|---|
| Baseline (A) | ✓ (1) | ✓ (2) | Practice |
| Unconstrained (B) | | ✓ (3) | |
| Lower & Closer (C) | | ✓ (4) | |
| Customized (D) | ✓ (6) | ✓ (5) | |

Over the course of the evaluation, six scenarios were conducted using a combination of traffic files and scenario types. Scenario combinations, and the order in which the scenarios were conducted, are presented in Table 3.

### E. Modeling Enhancements Implemented

Given that OPD operations involve a range of different vertical profile descents (and ToD locations) to meet the constraints defined by the procedure, it was essential to properly emulate aircraft performance. This variability was anticipated to largely affect traffic manageability. Therefore, enhancements were made to ensure aircraft descent behavior appropriately reflected the variability observed in real-world operations. The enhancements involved more accurate modeling of OPD trajectories in terms of ToD locations and descent gradients.

#### *1. Top-of-Descent Modeling*

Aircraft categorization data, which exists within TARGETS, was leveraged to determine more accurate ToD locations. Aircraft categorization data maps aircraft types (e.g., Boeing 737, Cessna 172) to more generalized aircraft performance classes (e.g., Large Jet, Small Piston). The TARGETS trajectory modeler uses attributes of the performance classes (e.g., aircraft weight, climb/descent rates, and turn rates) to model expected performance behavior for similarly sized and equipped aircraft. An analysis was conducted to determine whether ranges of expected ToD points were distinct, based on aircraft category. The Monte Carlo Flight Management System

[3] Similar to the design of the conventional RIIVR2 STAR into Los Angeles International Airport (LAX).
[4] Turboprop arrivals from the northeast file the WHINZ conventional (non-RNAV) arrival procedure.

(FMS)/Aircraft Simulation Tool (MFAST) was used to generate 1,000 vertical profiles along the DIRTY STAR procedure from the MOL transition, using a historical fleet mix from May 2008 for the FLCON STAR[5].

Other input parameters for the model included:

- Wind = None
- Temperature = Standard 15 degrees C at surface
- Cruise Mach = 0.78
- Descent Speed = 295 KIAS
- Aircraft Weight = varied between "empty operational weight" and "max landing weight"

The results were grouped into two aircraft category types: Heavy Aircraft and Large Aircraft[6]. As shown in Fig. 4 and Fig. 5, distinct distributions for the ToD points were evident for the two aircraft categories analyzed. This information was used to define OPD profiles within TARGETS for the HITL simulation. To account for the SOT and SPA transitions, results of the MOL transition analysis were extrapolated.

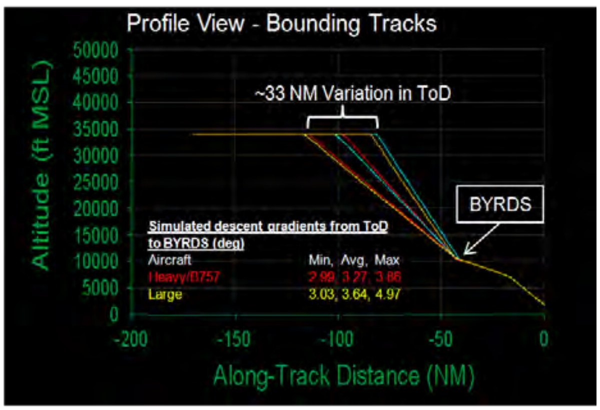


**Figure 5. Simulated Top-of-Descent Range by Aircraft Category - Profile View**

*2. Descent Gradients*

To address OPD trajectory accuracy, vertical profiles of five flights (all B767's) from the May 2008 DIRTY AIRE operational demonstrations, which began ToD after the BEBAD waypoint, were used as a basis for generating realistic descent gradients for Heavy aircraft in TARGETS. The vertical profiles of the demonstration flights are shown in Fig. 6.

Combining the ToD location data with the descent gradient data, OPD vertical profiles in TARGETS were generated (Fig. 7) to more accurately represent expected OPD trajectories during the HITL simulation.

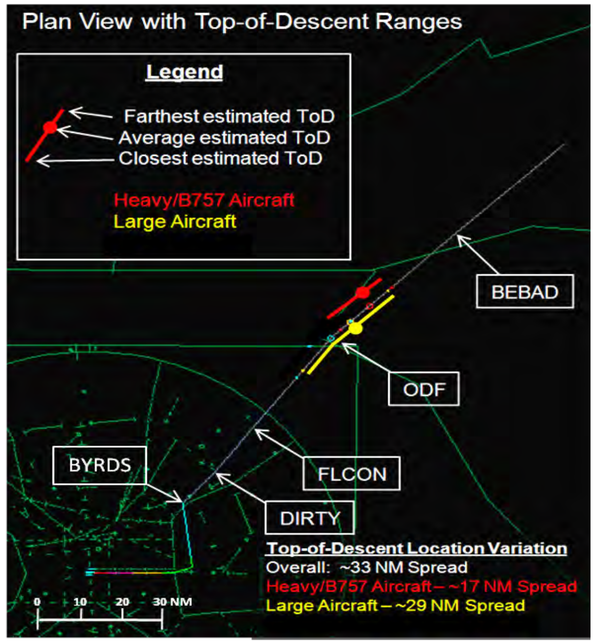


**Figure 4. Simulated Top-of-Descent Range by Aircraft Category – Plan View**

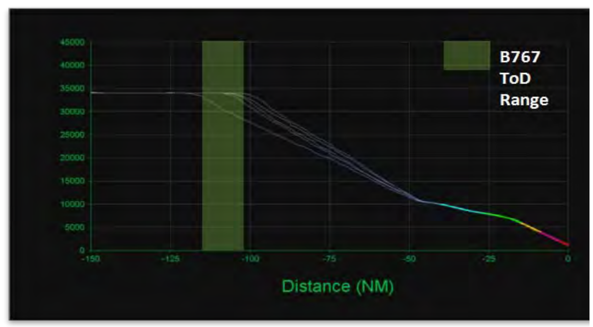


**Figure 6. OPD Demo Flight Profiles, May 2008**

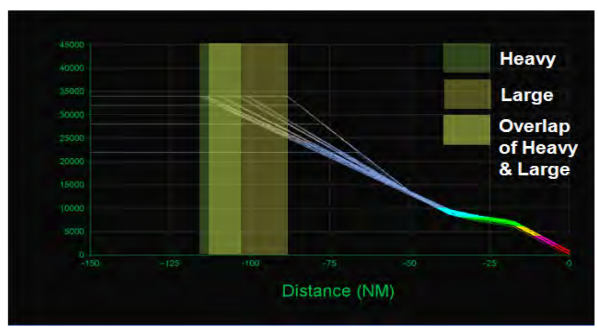


**Figure 7. OPD Flight Profiles used in TARGETS HITL Simulation**

[5] The constraint of FL340 at BEBAD was ignored in this analysis to prevent the generation of a geometric profile (fixed, straight-line vertical path) from BEBAD to DIRTY, which would cause all flights to begin their ToD at BEBAD. While this was not the design intent of the procedure, this behavior was seen in several of the initial demonstration flights. Including this constraint would have provided very little ToD variability and would have made it difficult to generalize the results to the other two transitions, since a BEBAD-like waypoint does not currently exist on those transitions. The second set of AIRE demonstrations along the DIRTY RNAV procedure also removed this constraint.

[6] Regional jets were included within the Large Aircraft category.

## III. Issue Identification and Potential Resolutions

### A. Uncertainty of Aircraft Performance

Controller concerns related to OPD operations were primarily centered on aircraft performance variability. An unrestricted descent profile can vary widely from one aircraft to another due to differences in aircraft type, flight management systems, operator preferences (e.g., cost indices), and pilot technique. From a controller's standpoint, the management of OPD operations becomes more difficult due to this variability since it introduces uncertainty that can limit the ability to maintain a high level of situational awareness (specifically, projecting future position based on current state). As a result, controllers resort to reserving large volumes of airspace to accommodate OPD flights in order to account for all possible ways that an aircraft could descend through their airspace. Restricting large portions of airspace can negatively impact non-OPD flights that also traverse that airspace. An analysis of track data from the simulation, seen in Fig. 8, indicated that non-OPD flights were typically vectored or re-routed to avoid OPD flights and the airspace reserved for OPD flights.

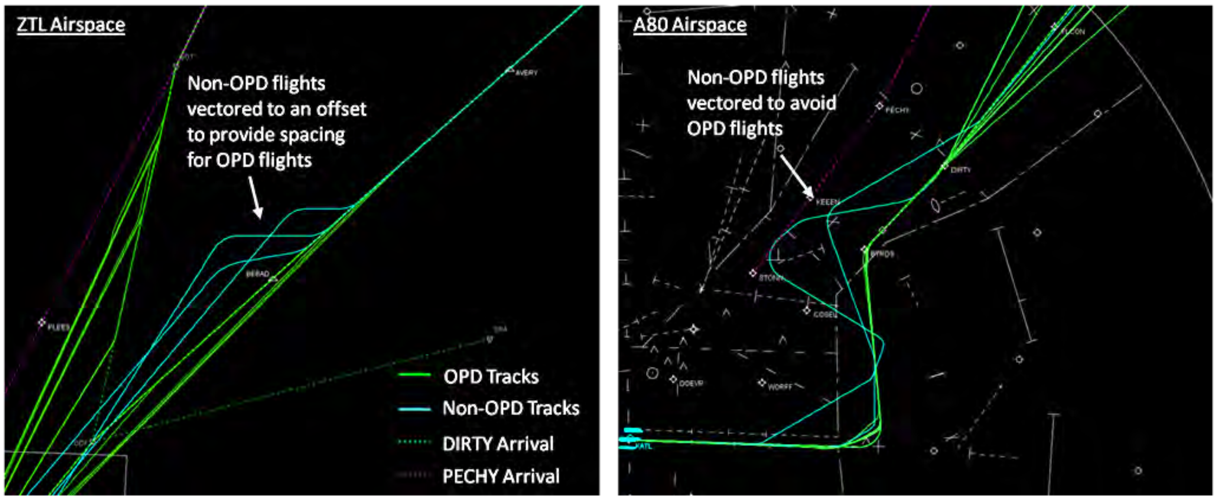


**Figure 8. Impact to Non-OPD Flights**

One potential resolution examined during the HITL simulation to reduce the variability associated with these factors (and the need for controllers to reserve large amounts of airspace) is to initiate OPD operations from lower altitudes and closer to the destination airport. At lower altitudes, the differences in aircraft performance, such as speeds and descent gradients, begin to narrow, resulting in more aircraft flying similar profiles regardless of aircraft type. With aircraft flying similar profiles, the predictability of OPD operations is likely to increase, resulting in less airspace needing to be reserved and a more manageable situation for air traffic controllers. Controllers would likely issue OPD clearances to more aircraft if predictability of the descent trajectory was increased. Benefits would then be available to a larger percentage of eligible participants. It should be noted that the magnitude of efficiency benefits may be reduced if improved predictability is the result of a highly constrained OPD procedure that restricts aircraft from flying an optimal descent trajectory. In the case of lower and closer OPD operations into ATL, issuing the OPD clearance at or around FL240 and near the Foothills navigational aid (ODF), which is approximately 100 nautical miles from ATL along the lateral path of the DIRTY STAR, would reduce the range of potential ToD locations significantly and reduce descent profile variability. Beginning the OPD lower and closer also retains most of the benefits that OPD operations provide. Research has shown that approximately 85% of the fuel and emission benefits associated with OPD operations can be obtained at altitudes below FL200.[3]

While TARGETS is capable of simulating many types of operations, the fidelity of aircraft performance is not at a level capable of precisely modeling the performance characteristics of every aircraft type descending along an OPD procedure, down to the individual series of airframe models (e.g., B737-200 vs. B737-300). For this particular HITL simulation, aircraft performance was generalized to broader aircraft weight categories, despite the fact that aircraft of the same weight category may in fact fly the same OPD procedure differently. While the significance of those differences is not known, it is generally thought to be reasonably similar for most aircraft. More accurate aircraft performance data would be needed to better assess how well different aircraft types would work together in a mixed OPD environment. Controllers indicated that aircraft type, and the expected performance for a particular aircraft type along the OPD, may factor into their decision to clear particular aircraft for an OPD procedure, based on the sequence and aircraft types of traffic in the vicinity.

**B. Merging and Spacing**

Controller participants clearly stated that merging and spacing of OPD flights with surrounding traffic is a major issue, especially during busy traffic periods. Concerns regarding airspace flexibility, speed control, and increased awareness of spacing issues for converging flows were all cited. A description of each of these areas is provided.

*1. Retaining Airspace Flexibility*

In current operations, Lanier and Logen sector controllers often send FLCON arrivals direct to the DIRTY waypoint. This shortcut creates the desired sequencing and spacing of arrivals before transferring them to TRACON airspace. However, if OPD flights strictly follow the lateral path of the FLCON STAR without shortcuts to the DIRTY waypoint, they must be separated and sequenced prior to the Foothills (ODF) navigational aid. Compared to current operations, this eliminates 40 nautical miles of airspace for sequencing and spacing (see Fig. 9a). For the DIRTY STAR, as currently designed, this does not present an issue because the first altitude restriction is at the DIRTY waypoint, which should allow controllers to issue the OPD clearance even while the aircraft is on a shortcut direct to DIRTY (see Fig. 9b). However, if altitude restrictions are added at the ODF navigation aid or the FLCON waypoint, these restrictions will be ignored by aircraft that are given a shortcut to the DIRTY waypoint because the shortcut requires that the pilot remove these waypoints, and the altitude constraints at those waypoints, from the active FMS path.

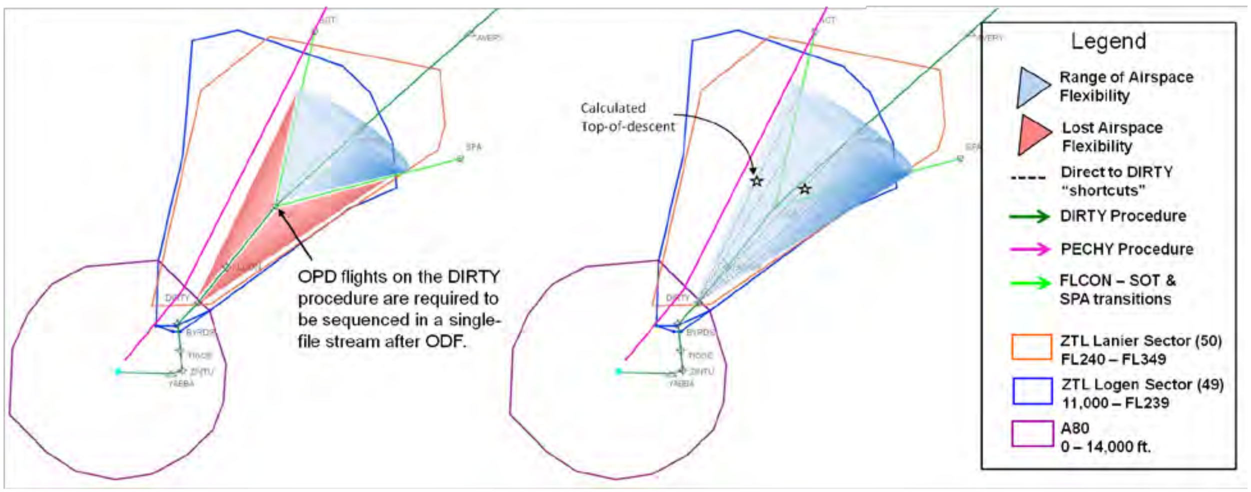


**Figure 9. Impacts to Airspace Flexibility.** *Part a) depicts the loss of airspace flexibility when OPD flights are required to be sequenced in a single stream after Foothills (ODF). Part b) depicts a potential solution that would help retain airspace flexibility by incorporating "direct to" shortcuts to the DIRTY arrival fix for OPD flights.*

If the DIRTY arrival is busy at ODF, aircraft are offloaded to the PECHY STAR to allow some aircraft to continue the OPD procedure. This situation was observed during simulation and is illustrated in Fig. 10 using track data.

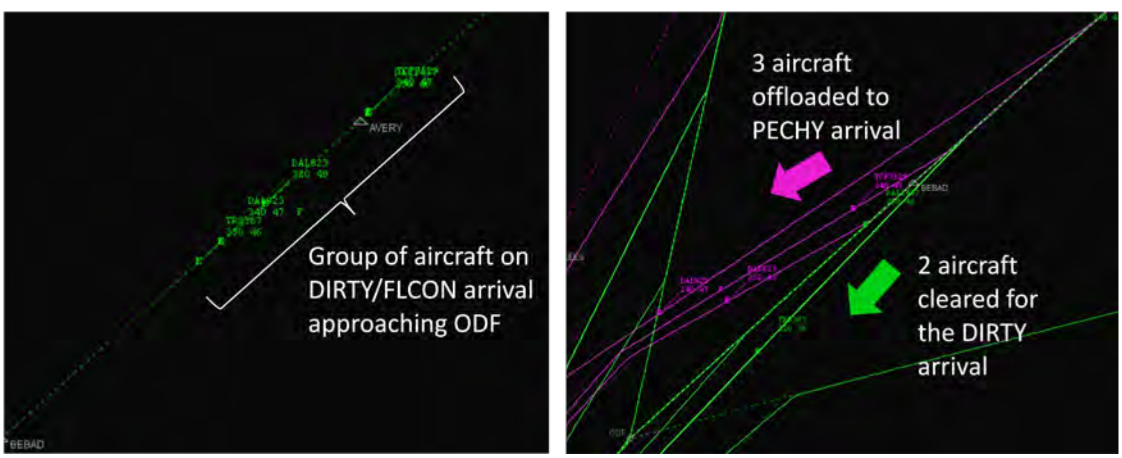


**Figure 10. Aircraft Offloaded to PECHY to Accommodate OPD Flights**

Any additional distance flown by offloaded aircraft may offset some of the cumulative benefits provided to the OPD flights. Also, offloaded aircraft may impose additional workload on the TRACON's feeder position to merge PECHY flights once inside TRACON airspace, if both flows are designated to feed the same arrival runway (see Fig. 11). While not seen during simulation, the merging of PECHY and DIRTY arrival traffic may necessitate vectoring aircraft off of the OPD procedure to manage the merge, reducing the OPD benefit for those flights.

2. *Issuing Speed Clearances to OPD Flights*

If an aircraft is cleared for an OPD while traveling at or near its maximum descent speed, its FMS may calculate a steep descent angle. If the controller issues a speed reduction for spacing, the aircraft may not be able to meet altitude restrictions farther along the OPD procedure, since a slower speed may require the aircraft to perform a shallower descent. To mitigate this issue, a descent profile compatible with the majority of eligible aircraft could be forced by publishing speed restrictions along the OPD procedure. Descent speed clearances could then be issued to flights on the OPD procedure, which should still allow the majority of flights to meet altitude restrictions farther along the OPD procedure.

3. *Early Coordination of Arrivals*

ATL has three arrival runways which are fed by four arrival corner posts; therefore, at least one runway must contain a merge. This merge may occur at the turn to final approach for runway 27L as the FLCON/DIRTY arrivals are merged with CANUK arrivals from the southeast (see Fig. 12). During busy traffic periods, it may be difficult to merge these two flows while keeping DIRTY arrivals on an OPD. This could be alleviated by introducing automation to improve awareness of merging OPD and standard arrival aircraft so that the merge of these flows can be coordinated or accounted for earlier on. Appropriate automation for this task requires additional research, though a "ghosting" application similar to the Converging Runway Display Aid (CRDA) was suggested by controller participants.

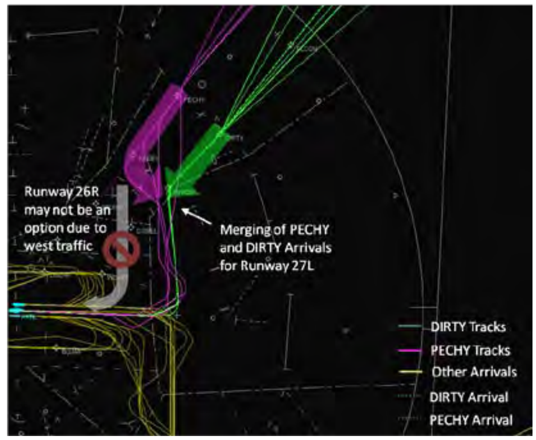


**Figure 11. Merging of PECHY and DIRTY Arrivals for Runway 27L**

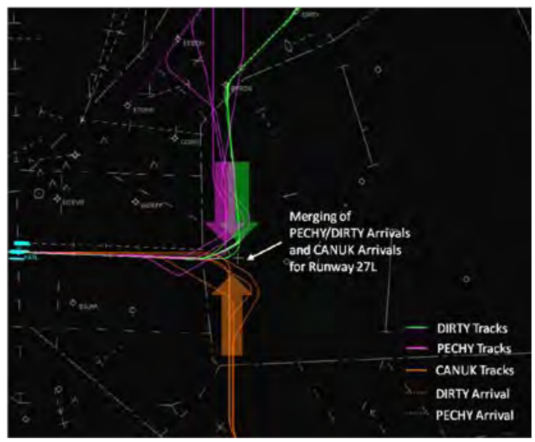


**Figure 12. Merging of PECHY, DIRTY, and CANUK Arrivals for Runway 27L**

## C. Managing Hand-offs and Coordination

When simulating OPD operations from cruise altitude (as described for scenario type B), a number of issues were revealed. Controllers raised concerns about the transfer of control of OPD aircraft between sectors, and that OPD operations could lead to a higher occurrence of technical violations of airspace. In today's arrival operations, controllers will typically level descending aircraft at the bottom of their airspace area of control boundary to initiate a hand-off to a subsequent controller working the airspace sector below them. This ensures the subsequent controller is aware of the aircraft and is ready and willing to accept control responsibility for it before it crosses into that controller's airspace. Once accepted by the subsequent controller, the aircraft is generally issued a clearance to resume its descent. A technical violation occurs if an aircraft crosses from one controller's airspace into another controller's airspace, prior to the subsequent controller accepting the hand-off. When aircraft are transferred at level altitudes, the occurrence of a technical violation is low. However, in the case of OPD operations, an OPD clearance essentially clears a pilot to descend the aircraft at their discretion (given the constraints of the STAR procedure) to the runway, passing through multiple en route and TRACON sectors along the way. An OPD aircraft's descent trajectory is more difficult for a controller to predict because of the variability of when and where that aircraft will cross from one sector to another. This could lead to situations where a controller working a lower altitude sector fails to notice and/or acknowledge (in a timely manner) the hand-off of a descending OPD aircraft from a controller working the upstream sector. With the Lanier sector controller issuing OPD clearances, concerns were raised by controllers that this could lead to a technical violation since the Lanier controller would no longer have positive control of an aircraft to keep it out of the Logen sector's airspace prior to the hand-off being completed. This situation occurs again as the aircraft enters TRACON airspace, and again when transferred from feeder (L) position to final (O) position. While this is understood to be the nature of OPD operations, it may require changes to current Standard Operating Procedures (SOP) to allow this exception, without it resulting in a technical violation. One resolution at the en route level, which would not require modifications to ZTL's SOP, is for Lanier sector controller to descend the aircraft to FL240 and hand-off to the Logen sector controller. The Logen sector controller would then issue the OPD clearance (similar to the lower and closer scenario simulated).

To easily identify OPD flights during the simulation trials, en route controllers entered the characters 'OPD' in the fourth line of the data block. Although the information in the fourth line of the data block could transfer to the terminal datablock scratchpad in the simulated environment, the HCS cannot transfer such data to Common Automated Radar Tracking System (CARTS) or STARS automation. Controllers agreed that this sort of electronic coordination would be preferable to manual coordination (and in most cases necessary) to reduce additional workload associated with identifying flights cleared for the OPD across facilities. It is unknown whether the initial release of the En Route Automation Modernization (ERAM) automation would be capable of supporting this functionality. If not, it may be beneficial to explore the possibility of incorporating this requirement into a future ERAM release.

### D. OPD Operations and the User Request Evaluation Tool (URET)

En route controllers rely on tools available today, such as URET for conflict probing and situational awareness of incoming flights. Since unrestricted, FMS-calculated descent trajectories are unknown to controllers or automation without the downlink of intent information, it is not clear if the current URET conflict probe would adequately support OPD operations. Additional adaptation may be required to properly handle OPD operations.

En route controllers were also concerned that electronic flight strips for incoming flights are sometimes delayed until right before completion of aircraft hand-off to the receiving sector. The participants expressed that having little advanced warning of potential crossing traffic would reduce their confidence in being able to successfully issue an OPD clearance without later discontinuing it to avoid crossing or merging traffic situations. Flight strip data availability may be needed earlier in advance in order to increase OPD clearances. It should be noted that the implications of doing so upon other aspects of ATC is not known.

### E. Traffic Management Unit Coordination

The data from the evaluation and discussions indicate that successful OPD clearances would be limited to such times where controllers feel as though they can manage the OPD flights without affecting surrounding traffic (either in-trail or crossing). The opinion of the en route controllers was that the ARTCC Traffic Management Unit (TMU) would play a significant role in enabling this success. The TMU manages traffic demand according to sector capacity by coordinating the release aircraft from nearby airports. If this balance is effectively managed, there will be fewer conflicts with OPD flights. With proper training and situation awareness, the TMU can improve the likelihood that each OPD clearance will be executed as intended.

## IV. HITL Traffic Observations

Table 4 provides a summary of OPD flight statistics that were observed during the HITL simulation. The difference in the number of eligible aircraft within the same traffic file is a result of a variation in simulation run-time. Eligible aircraft are defined as aircraft that file the FLCON3 STAR procedure and enter the airspace as defined by each scenario type where OPD clearances are issued before the end of the simulation[7]. Aircraft were counted as OPD attempts if they were issued an OPD clearance during the simulation.

[7] Because controllers continued to clear aircraft to the OPD procedure throughout the simulation, some aircraft were not able to fly the full length of the procedure before the simulation ended (i.e., some aircraft do not have completed tracks). As such, the number of aircraft that required vectoring may have been higher than noted in the table.

**Table 4: Summary of OPD Flight Statistics**

| Scenario | Description | Eligible Aircraft | OPD Attempts | % OPD Attempts per Eligible Aircraft | Vectored Off |
|---|---|---|---|---|---|
| 2B | OPD from cruise Lanier (50) issuing | 23 | 13 | 56.5% | 2 |
| 2C | OPD lower & closer Logen (49) issuing | 20 | 10 | 50.0% | 1 |
| 2D | OPD with shortcuts Lanier (50) issuing | 39 | 20 | 51.3% | 3 |
| 1D | OPD with shortcuts, lower & closer Logen (49) issuing | 36 | 25 | 69.4% | 6 |

Of the twelve aircraft vectored off of the OPD, ten were vectored for sequencing and spacing in TRACON airspace. Any additional vectoring alters the distance an aircraft must fly before landing. Because the distance from ToD to the runway is considered when computing the descent profile, any aircraft that received additional commands before reaching the runway was considered as being vectored off the OPD (and counted as such). The two other aircraft were instructed by an en route controller to join the PECHY STAR, thereby discontinuing the OPD. Some eligible aircraft were instructed to fly the PECHY STAR procedure almost immediately in order to ensure adequate separation for aircraft flying the FLCON/DIRTY STAR procedure. In the two 'D' scenarios, which allowed controllers to shortcut flights to the DIRTY waypoint, and then issue the OPD clearance, a higher number of attempts to allow OPD flights were observed.

## V. Summary of OPD Traffic Workability

While all scenarios were deemed operationally acceptable by controllers for the simulated traffic levels, certain tradeoffs were made by ATC regarding the extent to which OPD operations were used and how long a flight progressed without controller intervention. Those tradeoff decisions, which impact system-wide efficiency, were a result of several issues that manifested with the use of OPD operations in the traffic environment simulated.

In moderate to low traffic levels, such as those seen in Traffic File #1, controllers felt the OPD operations could be managed safely and orderly, but not always expeditiously due to a projected reduction in efficiency (arrival throughput) associated with OPD operations. Since data was not collected for the baseline scenarios, this assertion could not be confirmed. Efficiency reductions were mostly attributed to a controller's tendency to provide additional spacing between aircraft flying the OPD procedure, in order to account for uncertainties in ToD points and descent speed profiles among different aircraft, or vectoring non-OPD participants off of their routes to accommodate OPD flights. During typical busy operations without OPD operations, controllers indicated that they periodically space aircraft tightly, approaching the minimum separation standards of five miles-in-trail for en route airspace. For OPD operations, controllers felt ten miles-in-trail may be necessary to account for variability in ToD points and speed profiles. In simulations involving moderately busy traffic levels, such as those simulated using Traffic File #2, issues associated with managing OPD operations became more apparent. As a result, controllers felt OPD operations during the busiest traffic periods would not be feasible at ATL, since too much efficiency would be lost to accommodate a high traffic demand. Fewer flights would be issued the OPD clearance and flights would likely need to be removed from OPD procedures in order to manage the demand, which would offset some of the benefits associated with OPD operations. Modeling has shown that at least 15% of the total benefit would still be achievable for OPD's that are terminated early.[3]

Both ZTL and A80 controllers expressed the need for electronic coordination between ARTCC and TRACON facilities for easier coordination and management of flights across facility boundaries. Without automated electronic coordination, ZTL controllers would need to coordinate each OPD flight with A80 via voice communication channels. This would dramatically increase the workload associated with managing OPD operations, and according to feedback received from the controllers, would likely result in fewer flights being cleared for an OPD.

Merge points in TRACON airspace can be problematic for OPD operations, particularly if ZTL has offloaded many flights onto the PECHY STAR. As a parallel arrival procedure to the DIRTY/FLCON STAR, the PECHY STAR serves as an option for offloading non-OPD flights to increase available space between in-trail OPD flights. During this simulation, it was noted by the TRACON feeder controller that flights offloaded to the PECHY would need to be merged back into the same flow as the OPD flights for landing on runway 27L. This would be necessary when arrival demand from the other corner posts is heavy; rerouting flights on the PECHY STAR to one of the remaining arrival runways, 26R or 28, is not a suitable option. While merging a small number of PECHY STAR flights (2-3) appeared to be manageable, merging a large number of PECHY STAR flights would likely result in some OPD flights being vectored off of the OPD procedure. A merging and spacing tool applied in TRACON airspace could assist the controller with attaining an early understanding of aircraft spacing relative to one another at a merge point. If intervention is required, an earlier understanding of the merge conflict may allow controllers to resolve it by issuing speed commands, instead of removing aircraft from their cleared procedure.

Traffic manageability seemed to improve when the low altitude en route sector (Logen) issued the OPD clearance instead of the high altitude sector (Lanier), despite little change in the percent of OPDs attempted between the two scenarios. The Lanier sector controller was able to use early speed control to begin setting up OPD flight sequencing prior to the hand-off to the Logen sector controller. Impacts associated with crossing traffic were reduced, since OPD-eligible flights were first stepped down to FL240, maneuvering them below the typical crossing traffic flows. This also reduced concerns of the Lanier sector controller regarding potential technical violations of airspace. Under current rules specified in FAA Order 7110.65, the Lanier sector controller cannot issue a clearance that authorizes a descent into the Logen sector's airspace without acknowledgement from the Logen sector controller.

In order to maintain efficiency while managing OPD operations, OPD procedures should be designed so they do not overly restrict the airspace that controllers work. In current ZTL operations, RNAV arrivals are often instructed to shortcut direct to the DIRTY waypoint, rather than continuing along the published lateral path towards the ODF navigational aid. Controllers use this shortcut as a tool to improve efficiency, provide a shorter flight path, and to set up appropriate spacing and sequencing for the hand-off to the TRACON. Confining OPD flights to the lateral path of the DIRTY STAR (and the SOT and SPA transitions), without the use of shortcuts, requires flights to be in a single-file flow at ODF, instead of further downstream at the DIRTY waypoint. This severely limits the Lanier/Logan sector controller's ability to adequately space and sequence aircraft for delivery to TRACON airspace, since these tasks must be accomplished much earlier. Controllers felt that if OPD-eligible flights could be given a direct to DIRTY clearance first, followed by an OPD clearance, OPD participation could be increased. Simulation results revealed little change in the percentage of OPDs attempted when shortcuts were allowed versus when they were not allowed, using the busiest traffic level (Traffic File #2). A higher percentage of OPD attempts were observed when shortcuts were used during a moderate traffic level scenario (Traffic File #1).

## VI. Conclusion

The HITL simulation identified several issues related to the management of OPD flights that could preclude the widespread use of OPD operations during busy traffic periods at Atlanta, as well as other large airports, if the issues are not addressed. The results of this analysis are intended to be a first step in the process for accelerating the implementation and use of OPD operations throughout the NAS. While the focus of this evaluation was centered on the air traffic controller perspective, other perspectives, such as those of pilots and operators, should also be considered before drawing any final conclusions on the overall use of OPD operations in busy terminal environments.

Finally, this HITL simulation and subsequent discussions raised some additional questions about OPD operations. The following activities address the management of OPD operations; their impact can be explored through additional simulation:

- Use of descent speed assignments issued on a per aircraft basis.
- Published descent speed assignments and (window altitudes) on OPDs.
- Use of merging and spacing automation for early coordination of merging OPD operations.[4]
- Use of additional lateral path options (shortcuts) along OPD procedures.
- Issuing OPD clearances at lower altitudes (after initial descent) and closer to the airport, perhaps within TRACON airspace only.
- Metering to successfully enable OPD operations.

Other questions can be answered through data analysis and discussions with airline operators. They are as follows:

- How do descent speed assignments impact the FMC-calculated descent trajectories?
- What coordination tools are available or easily implemented which would support TRACON/ARTCC coordination of OPD flights?
- What is the impact of window constraints on reducing vertical path variability?

- What is the trade-off between operator benefits and airport capacity?
- In what situations are lateral path options (shortcuts) along OPD trajectories supported by the aircraft FMC?

CAASD will continue to pursue these research areas, in addition to others, to achieve an optimal balance between NAS system-wide efficiency benefits and individual user efficiency benefits.

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