ATD-2 Benefits Mechanism

ATD-2 team

Abstract

NASA has been developing and demonstrating a suite of decision support capabilities for integrated arrival, departure, and surface (IADS) operations in a metroplex environment. The effort is being made in three phases, under NASA's Airspace Technology Demonstration 2 (ATD-2) sub-project, through a close partnership with the Federal Aviation Administration (FAA), air carriers, airport, and general aviation community. The Phase 1 Baseline IADS capabilities provide enhanced operational efficiency and predictability of flight operations through data exchange and integration, tactical surface metering, and automated coordination of release time of controlled flights for overhead stream insertion. The Phase 2 Fused IADS capabilities include the fusion of strategic and tactical surface metering, Atlanta Center airspace tactical scheduling, Electronic Flight Data (EFD) integration, Terminal Flight Data Manager (TFDM) Terminal Publication (TTP) prototype, and Mobile App for General Aviation (GA) community. In the Phase 2 field evaluation, strategic surface metering provides advance notice of metering and additional stability to the assigned gate holds. The users of the IADS system in Phases 1 and 2 include the personnel at Charlotte Douglas International Airport (CLT) air traffic control tower, American Airlines ramp tower, CLT terminal radar approach control (TRACON), and Washington and Atlanta Center.

This document describes the ATD-2 benefits mechanism used to assess the Phases 1 and 2 IADS capabilities and field evaluation conducted at CLT since September 2017. The ATD-2 benefits mechanism mainly consists of surface metering and overhead stream insertion. This document provides detailed calculation methods of major benefit metrics, such as fuel savings, gas emissions savings, and engine runtime reduction, which can be obtained through surface metering, gate hold of Approval Request (APREQ) flights prior to pushback, and the renegotiation of release time while taxiing. As of April 30, 2020, it is estimated that 5,097,173 pounds of fuel savings and 15,699,292 pounds of CO2 emission reduction have been achieved so far, with a reduction of 3,831 hours in total engine runtime. The amount of CO2 savings is estimated to be equivalent to planting 116,739 urban trees. The pre- and post-metering comparison results using FAA's Aviation System Performance Metrics (ASPM) data have also shown that the surface metering had no negative impact on the on-time arrival performance of both outbound and inbound flights at CLT.

Revision History

Rev	Date	Sections Affected	Description of Change	Who
v1	8 Apr 2020	All	Initial draft	Hanbong Lee
v2	27 May 2020	Abstract, 2.1, 3.1.7, 3.2, 3.3.1, 3.3.2, 3.3.3	Updated benefits results and figures using April 2020 data, removed GS hours from total engine runtime	Divya Bhadoria

Table of Contents

1 Introduction

1.1 Identification

Under the Airspace Technology Demonstration 2 (ATD-2) sub-project, NASA has been developing and demonstrating a suite of decision support capabilities for integrated arrival, departure, and surface (IADS) in three phases. The Phase 1 Baseline IADS capabilities include data exchange and integration, tactical surface metering, and electronic negotiation of release time of controlled flights for overhead stream insertion. The Phase 2 Fused IADS capabilities include the fusion of strategic and tactical surface metering, Atlanta Center airspace tactical scheduling, Electronic Flight Data (EFD) integration, Terminal Flight Data Manager (TFDM) Terminal Publication (TTP) prototype, and Mobile App for General Aviation (GA) community. The users of the IADS system in Phases 1 and 2 include the personnel at Charlotte Douglas International Airport (CLT) air traffic control tower, American Airlines ramp tower, CLT terminal radar approach control (TRACON), and Washington and Atlanta Air Route Traffic Control Center (ARTCC or Center). The Phase 3 field evaluation is about the scheduling of departures in a metroplex environment, where departures from multiple airports in a terminal airspace operate under various restrictions over terminal boundary at the Dallas-Ft. Worth TRACON (D10) metroplex environment [Ref. 1-4].

1.2 Background

As part of the Phases 1 and 2 field evaluation at CLT, the ATD-2 team has developed a methodology to assess the benefits of IADS capabilities and calculated the quantitative benefit metrics using actual flight operations data since the IADS system was deployed at CLT in late 2017. While demonstrating the ATD-2 IADS capabilities in the field, these benefit metrics have been periodically updated with the latest data and shared with the field users.

1.3 Document Purpose and Scope

The purpose of this document is to describe the foundational mechanisms of ATD-2 benefits and explain the calculation methodology for the reported benefit metrics. The benefits discussed in this document are for the Phases 1 and 2 capabilities at CLT. Phase 3 benefits at North Texas metroplex terminal airspace are not covered here.

1.4 Document Organization

The intended audience for this document includes:

- ATD-2 internal researchers, who will use this document to review, maintain, and update ATD-2 benefits metrics, to improve the benefit calculation methods, and to perform the relevant data analyses using actual flight operations data.
- External field users, who are receiving the updated ATD-2 benefits reports. This document is expected to help them understand how the reported benefit metrics are calculated.

This document is organized as follows:

Section 1 provides the background and purposes of this document.

Section 2 of the document describes the overview of the ATD-2 benefits mechanism.

Section 3 presents the detailed calculation methods of the ATD-2 benefit metrics.

Section 4 provides the on-time performance changes before and after the ATD-2 system deployment.

Section 5 contains references cited and documents consulted.

2 ATD-2 Benefits Mechanism Overview

This section discusses the overview of ATD-2 benefits mechanism. The ATD-2 benefits mainly come from two categories: surface metering and overhead stream insertion. These benefits mechanisms are described in the following subsections.

2.1 Benefits from Surface Metering

The goal of surface metering is to reduce excess taxi-out time of departures by shifting some of the taxi time from departure queue to gates while engines are turned off, resulting in a reduction in fuel burn and gas emissions on the airport surface. The surface scheduler in ATD-2 IADS system generates Target Off-Block Times (TOBTs) for departures and provides them as pushback advisories to ramp controllers on Ramp Traffic Console (RTC) display. Detailed information about the scheduler can be found in [Ref. 3, 4].

NASA deployed the ATD-2 IADS system in CLT facilities for operational field evaluation in late September 2017. Tactical surface metering was initially enabled during the second bank of CLT operations (Bank 2, typically starting around 9am local time) since November 29, 2017. Then, the metering was extended to Bank 3 (typically starting around 11am local time) since February 19, 2018. The surface metering has been extended beyond Bank 2 and 3 since October 2018 and is currently enabled for all banks. It is also noted that airline schedule changes made in September 2019 resulted in an increase in the number of flights assigned a metering hold, as shown in Figure 1.

In Phase 2, the ATD-2 automation was expanded to predict when the tactical metering triggers will be needed and inform local stakeholders of upcoming Surface Metering Programs (SMPs). Users at CLT are given the option to affirm or reject the upcoming SMP and have chosen to auto-affirm upcoming SMPs. The ATD-2 automation computes the assigned TOBTs in advance and freezes them when the TOBT falls within a configurable look ahead time called the Static Time Horizon. The SMP start time is also frozen when it falls within the Static Time Horizon. These capabilities provide stability and predictability. If the runway demand is predicted to drop during an SMP within the Static Time Horizon, ATD-2 will compress flights within the Static Time Horizon to mitigate the risk of starving the runway. Based on these strategic surface metering capabilities, the time-based metering has been turned on by default since January 2020.

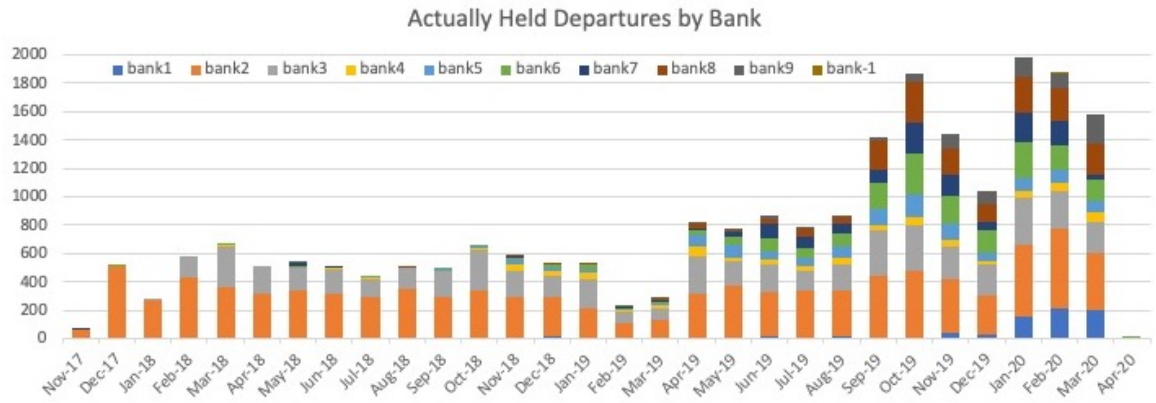


Figure 1 – Total number of departures actually held at gates subject to surface metering per month.

2.2 Benefits from Overhead Stream Insertion (IADS capabilities)

ATD-2 departure scheduling enables non-verbal coordination of release times at CLT through the interface embedded in STBO Client's timeline. Prior to pushback from gate, the surface scheduler estimates the Earliest Feasible Takeoff Times (EFTTs) of APREQ flights by which the aircraft will reach the runway with a high level of confidence. These times are displayed on the timeline of Tower TMC. When the APREQ aircraft is selected on the timeline, the Integrated Departure Arrival Capability (IDAC) in the Time Based Flow Management System (TBFM) searches for the window(s) of release time that would allow the aircraft to be inserted in the available slots in the overhead stream over the constrained meter point. The TBFM/IDAC calculates a runway release time based on the flight's EFTT and returns it to the Tower. If the 'Select Slot on Timeline' option is chosen, the Center sends a release time that is either the same time as requested or a different time depending on slot availability. Detailed information regarding ATD-2's automated APREQ coordination procedures can be found in [Ref. 5, 6].

The improved prediction accuracy of takeoff times by the ATD-2 surface scheduler enables Tower TMC to coordinate release times with the Center while aircraft are still at the gate with engines off. The surface scheduler calculates target pushback time (TOBT) from the negotiated release time. This would allow the aircraft to be held at the gate until its TOBT, but reach the runway and take off within the compliance window (i.e., from two minutes earlier to one minute later than the release time). The gate holding due to scheduling prior to pushback saves fuel burn that would otherwise have been spent on the airport surface.

Also, the electronic coordination procedure makes the re-negotiation process easier and faster in cases when STBO Client timeline indicates that the aircraft is predicted to arrive at the runway earlier or later than the release time. The renegotiation of the APREQ time, even while taxiing after pushback, would allow the aircraft to take an earlier slot in the overhead stream, thus resulting in an earlier runway release time and taxi time reduction.

Below is the brief APREQ renegotiation procedure.

- Step 1: APREQ flight has a release time, but is able to take off earlier.
- Step 2: FAA Tower TMC uses the IDAC green space / red space to identify and request an earlier slot in the overhead stream.
- Step 3: Aircraft receives earlier release time, and the difference between the release times is the reduction in taxi-out time.

3 Benefits Calculation Methods

For the ATD-2 benefits calculations, python scripts were developed and run with the latest version of KCLT full flight summary files. Details of the calculation methods and assumptions for major benefit metrics are described below.

3.1 Collaborative Surface Metering Benefits

3.1.1 Assumptions

The fundamental assumptions made in the ATD-2 benefit calculations are as follows:

- All the actual gate hold times translate to taxi time savings. Therefore, the benefits in fuel and emissions savings are dependent upon taxi time savings, as well as aircraft engine model.
- For calculating fuel burn and emission savings, the engine thrust level during taxi operations is assumed to be the same as in the idle condition. Also, there are no variations in the engine thrust throughout taxiing from gate to runway.
- Departure flights in the same carrier and aircraft model group follow the given single engine taxi percentage averaged from the historical data.

3.1.2 Single engine taxi operations

In real operations, it is known that many departing flights taxi with a single engine turned on to save fuel before takeoff and reduce gas emissions on the surface. For more accurate estimates of the benefit metrics, the percentage of Single Engine Taxi (SET) operations is taken into account. The historical and current day operational SET percentage data collected in 2018, provided by airline partners, were incorporated in the benefits calculations. Those SET percentage data are categorized by carrier (e.g., mainline, regional), aircraft model and aircraft body type (e.g., narrow-body, wide-body) at the target airport (CLT) during taxi-out operations.

Given the SET ratio value, ranging from 0 to 1, the effective number of engines for each flight can be computed by the following equation:

$$\text{Effective Engine Count} = \text{SET} * 1 + (1-\text{SET}) * \text{Engine Count}$$

When the single engine taxi operation is not applied during taxi phase (SET = 0), Effective Engine Count is equal to actual Engine Count. On the other hand, if all the aircraft taxi under the single engine taxi policy (SET = 1 or 100%), Effective Engine Count would be one. As another example, if the SET rate for B737 aircraft having two engines is 20%, Effective Engine Count can be computed as follows:

$$\text{Effective Engine Count}_{\text{B737}} = 0.2 * 1 + (1 - 0.2) * 2 = 1.8$$

Note that most aircraft operated at CLT have two engines and that the aircraft having three or four engines are very rare at this airport.

3.1.3 Aircraft type and engine model

There are various aircraft types and engine models operated in the US, and each aircraft engine model has different fuel consumption and gas emissions characteristics. In order to obtain the corresponding fuel flow and emission factors to a specific flight, the aircraft and engine model information is required. This information can be found in FAA's aircraft registry service [Ref. 7], using aircraft registration number (tail number starting with a letter 'N'). The aircraft registration number of the individual flight operated at CLT is available in ATD-2 Fuser database and full flight summary files.

3.1.4 Fuel flow rate and emission index coefficients

Once the aircraft engine model is identified for a flight held at its gate, the corresponding fuel flow rate and emission indices can be found in the Aircraft Engine Emissions Databank provided by International Civil Aviation Organization (ICAO) [Ref. 8]. The ICAO Databank includes the values of fuel flow (i.e., the amount of fuel burnt per second for various jet and turbofan commercial engines) obtained from full-scale engine tests. These values were taken at four different engine operating conditions: Take off (100% engine thrust), Climb Out (85%), Approach (30%), and Idle (7%). The ICAO database also provides the Emission Index (EI) values for hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx), which were obtained by conducting engine tests at each condition for each engine model.

For the fuel and emissions saving calculations, it is assumed that the aircraft moves on the ground at 7% engine thrust level constantly. Therefore, the estimated fuel flow during taxi phase follows the given values in an idle condition. All the emission index values (g of pollutant emitted per kg of fuel burnt) also come from the same idle condition. Because it is difficult to obtain the detailed information about the number of stops and turns, as well as their duration, while taxiing for individual flights, the stop, acceleration, and turning states occurred during taxiing processes are ignored in the benefits calculations. Since the ICAO data is given under standard atmospheric conditions, it is also assumed that the atmospheric conditions for all the flights taxiing on the airport surface at CLT are the same as the standard conditions.

According to the U.S. Energy Information Administration, the carbon dioxide (CO2) emissions coefficient for Jet Fuel is 9.57 kg CO2 / gallon [Ref. 9]. The density of Jet Fuel (Jet A type for US) is 6.84 [lb/gallon] (= 3.103 [kg/gallon]) at 59°F. Therefore, the amount of CO2 emissions when the aircraft consumes 1 kg of Jet Fuel is EI_{CO2} = 9.57 [kg CO2/gallon] / 3.103 [kg Jet Fuel/gallon] = 3.08 [kg CO2 / kg Jet Fuel].

3.1.5 Backup database

Note that for most flights, it is possible to extract aircraft specific engine model from the recorded or public databases like the FAA aircraft registry service. In case that such data is not available, however, we have a backup table for the most frequently used engine models and the corresponding emission factors for the most popular aircraft models at the target airport. This backup table is generated using historical data collected at the field, as well as other data sources from FAA aircraft registry service and ICAO's aircraft engine emissions databank. In the rare instances where aircraft engine model information is not available for a specific flight, or fuel and emission indices for a specific engine model are not found in the ICAO's engine emissions databank, we use statistical averages of the fuel and emission factors from similar aircraft models in the historical data, which is extracted and stored in the fuel and emission table for the given airport.

3.1.6 Fuel and emissions saving calculation

For an individual flight held at gate via pushback hold advisories provided by ATD-2 systems under surface metering, fuel burn and gas emissions savings are calculated by the following equations:

Fuel Saving [kg] = Actual Gate Hold [sec] * Fuel Flow [kg/sec] * Effective Engine Count

CO2 Saving [kg] = Fuel Saving [kg Jet Fuel] * EI_{CO2} [kg CO2 / kg Jet Fuel]

CO Saving [g] = Fuel Saving [kg Jet Fuel] * EI_{CO} [g CO / kg Jet Fuel]

HC Saving [g] = Fuel Saving [kg Jet Fuel] * EI_{HC} [g HC / kg Jet Fuel]

NOx Saving [g] = Fuel Saving [kg Jet Fuel] * EI_{NOx} [g NOx / kg Jet Fuel]

3.1.6.1 Example

Here is an example to show how to calculate the amounts of fuel and emission savings for an individual flight when it is held at gate subject to surface metering. Suppose that a B737-800 aircraft with two turbo-fan jet engines (engine model CFM56-7B24E) was held at gate for 5 minutes, instead of waiting in departure queue before takeoff. From ICAO aircraft engine emissions databank, the fuel flow and emission factors are Fuel Flow = 0.103 [kg/sec], EI_{CO} = 34.71, EI_{HC} = 2.3, EI_{NOx} = 4.09. Assuming that the average single engine taxi-out percentage for B737-800s of this carrier is 20%, Effective Engine $Count_{B737}$ is equal to 1.8. Based on the formula above, the fuel and emissions savings are computed as follows:

Fuel Saving [kg] = 300 [sec] * 0.103 [kg/sec] * 1.8 = 55.62 [kg]

CO2 Saving [kg] = 55.62 [kg Jet Fuel] * 3.08 = 171.31 [kg]

CO Saving [g] = 55.62 [kg Jet Fuel] * 34.71 = 1,930.57 [g]

HC Saving [g] = 55.62 [kg Jet Fuel] * 2.3 = 127.93 [g]

NOx Saving [g] = 55.62 [kg Jet Fuel] * 4.09 = 227.49 [g]

3.1.7 Benefits metrics

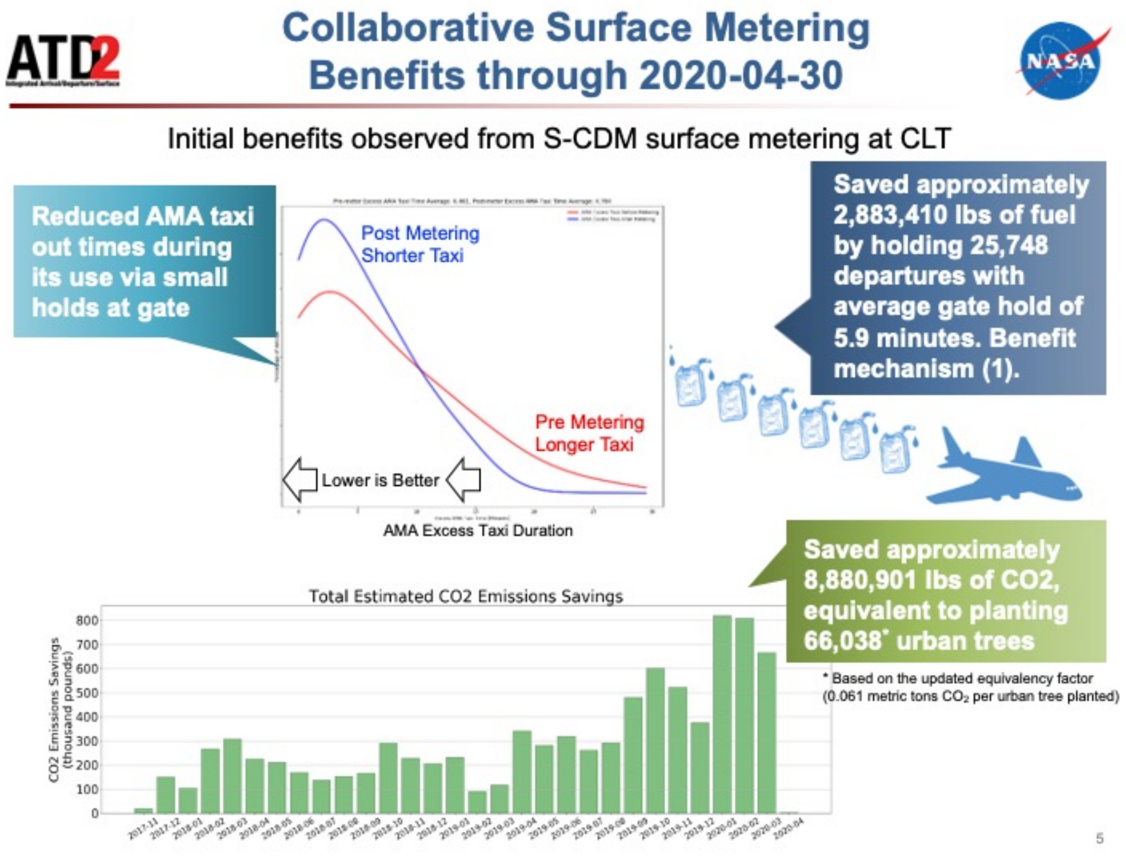
In the ATD-2 benefits summary reports, several major benefits metrics, including the total fuel savings, the corresponding CO2 reduction, and the total number of departures held at gates from collaborative surface metering, are provided.

The total fuel savings are calculated by summing up the estimated fuel savings of individual flights held at gates subject to surface metering in pound unit. A departure flight is considered as an actually held flight, if it satisfies the following conditions: its

Target Off-Block Time (TOBT) is provided to ramp controller via Ramp Traffic Console (RTC), it is not a controlled flight, and the actual gate hold time is greater than 0. The actual gate hold time is defined as the difference between Actual Off-Block Time (AOBT) and flight ready time entered through the ATD-2 system. We have counted how many flights are actually held at their gates and accumulated the numbers since the first surface metering implementation at CLT in November 2017. The average gate hold time of these flights can be obtained by dividing the sum of gate hold times by the total number of actually held flights.

The monthly bar chart for the total amount of estimated CO2 savings is also reported. There are some variations in the monthly CO2 savings, depending on the number of metered flights and the surface congestion level. The total amount of CO2 savings can be transformed to the equivalent number of urban trees planted. According to US Environmental Protection Agency (EPA), the emission factor is 0.0605 metric tons CO2 per urban tree planted. That is, one medium growth tree planted in an urban environment and grown for 10 years can sequester 60.5 kg of CO2 [Ref. 10].

Note that on December 17, 2018, the EPA updated this emission factor from 0.039 metric tons CO2 per urban tree planted, which only had captured coniferous trees, to 0.060 based on a weighted average of coniferous and deciduous trees in an urban area. Due to the rounding while performing the calculations given in the equations, the computation



Collaborative Surface Metering Benefits through 2020-04-30

Initial benefits observed from S-CDM surface metering at CLT

Reduced AMA taxi out times during its use via small holds at gate

Saved approximately 2,883,410 lbs of fuel by holding 25,748 departures with average gate hold of 5.9 minutes. Benefit mechanism (1).

Saved approximately 8,880,901 lbs of CO2, equivalent to planting 66,038* urban trees

* Based on the updated equivalency factor (0.061 metric tons CO_2 per urban tree planted)

Figure 2 – Collaborative surface metering benefits through April 30, 2020.

results may have a tolerance. In the urban tree benefit calculations, the emission factor of 0.061, instead of 0.060, is used as a conservative approach.

As shown in Figure 2, through collaborative surface metering at CLT, ATD-2 system has saved approximately 2,883,410 pounds of fuel and about 8,880,901 pounds of CO2, which is equivalent to planting 66,038 urban trees until April 30, 2020.

3.2 Overhead Stream Operational Integration Benefits

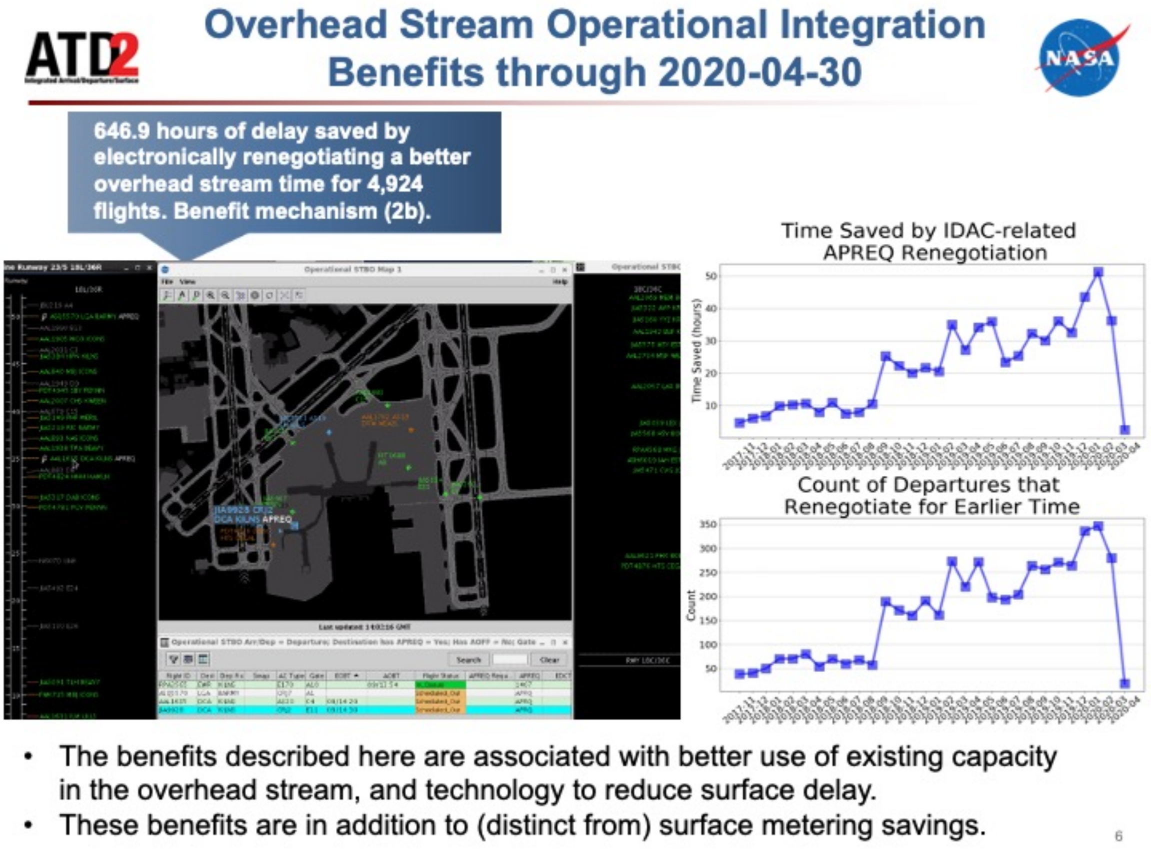
The benefits from ATD-2 departure scheduling into overhead stream are measured in two parts: (2a) the amount of fuel and emissions savings due to gate hold that would otherwise have been spent taxiing if the coordination of release time had happened after pushback, which was the case before deploying the ATD-2 systems, and (2b) the amount of fuel and emissions savings due to re-negotiation of release times to earlier times while aircraft are taxiing.

In the former case (2a), the amount of fuel savings can be easily calculated using the actual gate hold time of flights with APREQ negotiated at gate prior to pushback, based on the same method introduced in the previous subsection. The fuel savings from this case will be included in the calculation of the total fuel savings in the next subsection, along with the other flights held at gates as advised by the ATD-2 system.

In the latter case (2b), the difference between old and revised release times is regarded as taxi-time savings and translated into fuel and emissions savings. That is, for the flights that have multiple APREQs, all negotiated via IDAC, when the final APREQ time is earlier than its initial APREQ time, the APREQ time saving can be computed as follows.

$$\text{IDAC-related APREQ saving [sec]} = \text{initial APREQ time} - \text{final APREQ time}$$

We have counted the number of APREQ flights that renegotiated for earlier release time via TBFM/IDAC capability, as well as the time savings. As of April 30, 2020, about 646.9 hours of delay in total has been saved by electronically renegotiating a better overhead stream time for 4,924 APREQ flights. The plots on the right-hand side in the figure below show these values by month. Note that ATD-2 system is providing the release time re-negotiation capability for APREQ flights leaving for ATL, ORD, LGA, and EWR airports, which cover approximately 67% out of all APREQ flights at CLT.



Overhead Stream Operational Integration Benefits through 2020-04-30

646.9 hours of delay saved by electronically renegotiating a better overhead stream time for 4,924 flights. Benefit mechanism (2b).

- The benefits described here are associated with better use of existing capacity in the overhead stream, and technology to reduce surface delay.
- These benefits are in addition to (distinct from) surface metering savings.

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Figure 3 – Overhead stream operational integration benefits through April 30, 2020.

3.3 Total benefits in the field from multiple benefits mechanisms

ATD-2 team reports the total benefits in the field based on the multiple benefits mechanisms described in the previous subsections. These benefits metrics include total fuel savings, CO2 savings, equivalent urban trees planted, surface delay savings from APREQ time renegotiation with the corresponding passenger value and flight crew cost, and total engine runtime reduction from gate holding.

3.3.1 Total fuel savings

Through the surface metering capability provided by the ATD-2 system, the excess taxi-out time of departures can be reduced by holding them at gates. In addition to general surface metering for the non-controlled flights, the gate holds of APREQ flights prior to pushback and the renegotiation of release time while taxiing also reduce excess taxi time. All these taxi-out time reductions can translate into fuel savings. The total fuel savings from the three benefits mechanisms can be obtained by summing up the amount of fuel saved by surface metering gate holds, APREQ gate holds before pushback, and IDAC-related APREQ time negotiation after pushback. Note that the fuel savings from gate holds of the flights with Expect Departure Clearance Time (EDCT) or Ground Stop (GS) restrictions are not included in this calculation.

The total CO2 savings can be obtained directly from the fuel savings with conversion factors, 3.08 [kg CO2 / kg Jet Fuel] and 3.103 [kg/gallon], for Jet A type fuel. The equivalent urban trees planted are also calculated using the same conversion method. As shown in the figure below, the ATD-2 system has saved approximately 5,097,173 pounds of fuel and about 15,699,292 pounds of CO2 (or 745,201 gallon) in total until April 30, 2020, which is equivalent to planting 116,739 trees in urban area.

3.3.2 Monetization from IDAC renegotiation of APREQ flights

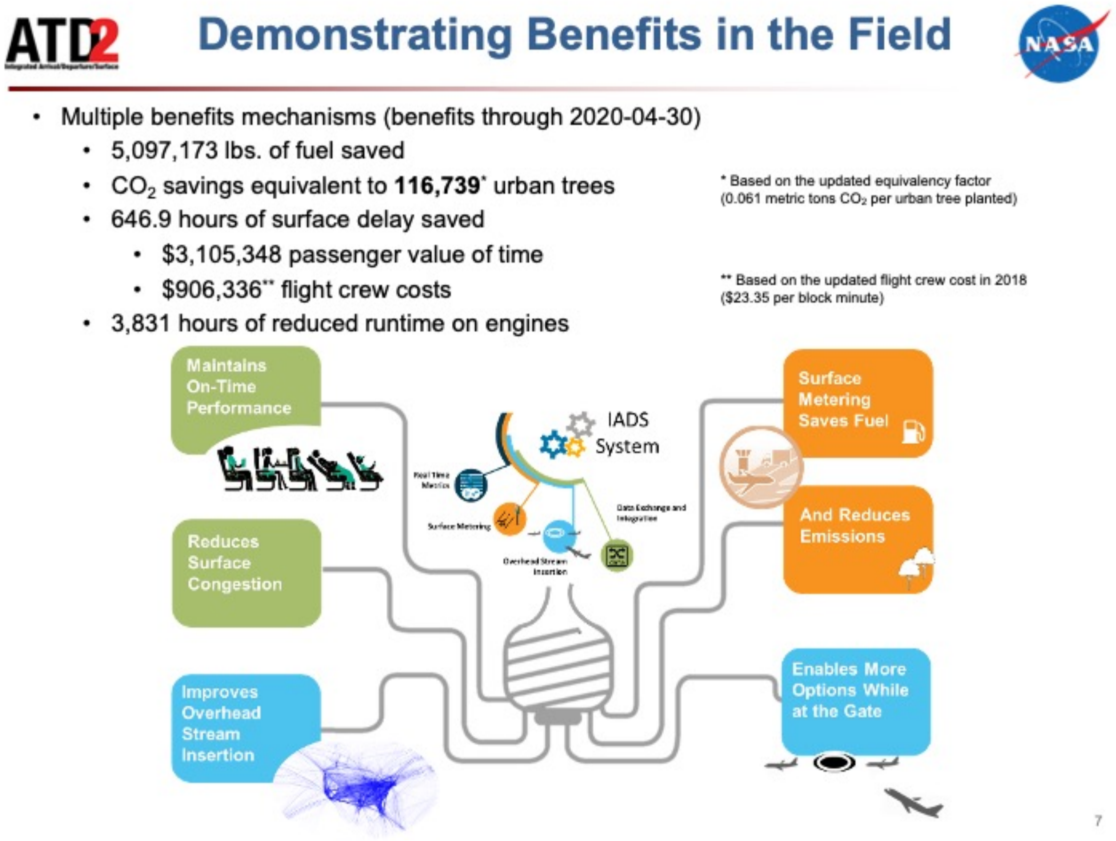
From the APREQ time renegotiation process, we can achieve surface delay. This delay saving can be converted to the passenger time value and flight crew costs.

For the passenger value calculation, it is assumed that the average capacity per APREQ flight aircraft is 123.53 seats and that the average load factor is 82.5%, leading to an average of 101.91 passengers per APREQ flight. According to the US Department of Transportation (DOT) estimates for all purpose travel, an average single passenger value per hour is $47.10 [Ref. 11]. Then, these 101.9 passengers can be translated to $4800.20 as the average passenger value of time savings per hour for APREQ flights. For example, when the surface delay savings from IDAC scheduling is 646.9206 hours, the estimated passenger value will be $4800.20 [$/hour] * 646.9206 [hour] = $3,105,348 in total.

For the flight crew saving calculation, we use an estimate flight crew cost in 2018 from [Ref. 12], which estimates crew cost as $23.35 per minute (the second largest line item in flight operating cost) and was increased by 3% from $22.67 of 2017 data. With respect to the amount of surface delay saved by ARPEQ renegotiation, we can obtain the flight crew cost saving up to $23.35 [$/min] * 60 [min/hour] * 646.9206 [hour] = $906,336.

3.3.3 Engine runtime reduction from gate holding

In addition to the surface delay savings from ARPEQ time renegotiation, engine runtime can be reduced by holding the flights that are subject to the surface metering program, APREQ, or EDCT restrictions at gates as advised by the ATD-2 system. The total amount of engine runtime reduction is the sum of surface metering pushback hold, APREQ gate hold, and EDCT gate hold flights in hours. Until April 30, 2020, we have reduced the engine runtime by 3,831 hours in total at CLT.



Demonstrating Benefits in the Field

- Multiple benefits mechanisms (benefits through 2020-04-30)
  - 5,097,173 lbs. of fuel saved
  - CO_2 savings equivalent to **116,739*** urban trees
  - 646.9 hours of surface delay saved
    - $3,105,348 passenger value of time
    - $906,336** flight crew costs
  - 3,831 hours of reduced runtime on engines

* Based on the updated equivalency factor (0.061 metric tons CO_2 per urban tree planted)

** Based on the updated flight crew cost in 2018 ($23.35 per block minute)

Maintains On-Time Performance

Reduces Surface Congestion

Improves Overhead Stream Insertion

Surface Metering Saves Fuel

And Reduces Emissions

Enables More Options While at the Gate

Figure 4 – Multiple ATD-2 benefits in the field through April 30, 2020.

4 On-Time Performance

Although the objective of surface metering is to reduce the departure runway queue length during busy periods by holding aircraft at their gates, the runway throughput should not be negatively affected by metering, nor the arrival on-time performance of departures at their destination airports. These are important metrics that must be examined, in addition to the key surface metering performance and benefits metrics.

The comparison of on-time performance between pre- and post-metering is challenging because it requires sufficient data under similar operational conditions, such as traffic demand, weather, and TMI restrictions, in both periods. Instead, ATD-2 on-time performance analysis used FAA's Aviation System Performance Metrics (ASPM) database [Ref. 13], which is widely used by the aviation community for this type of analysis.

ASPM's arrival times of CLT departures at their destination airports were extracted for the period from January to December in 2017 (pre-metering, except for December 2017) and the same period in 2018 (post-metering). The industry standard on-time performance metrics, so called A0 (i.e., the flight has arrived at the gate on or earlier than its scheduled arrival time), were compared. In Figure 5 below, the upper graph shows the comparison of A0 metric across all banks, and the lower plot shows the comparison in banks 2 and 3, during which the surface metering was tested in 2018. In both views, the results do not indicate any noticeable differences.

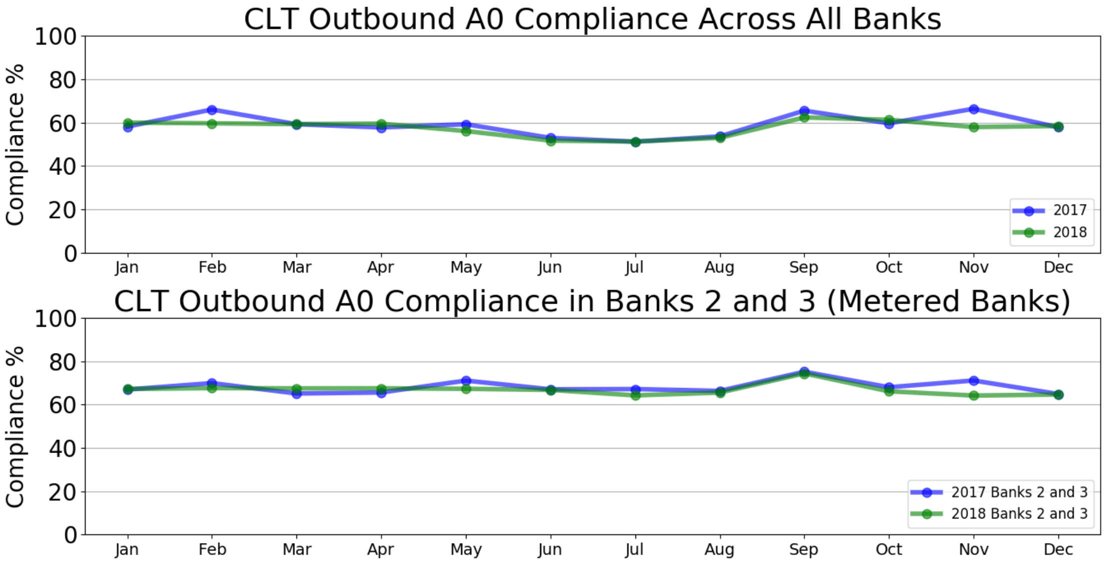


Figure 5 – Outbound A0 compliance by month in 2017 and 2018 across all banks (upper) and in banks 2 and 3 only (lower) at CLT.

Table 1 shows the comparison of the same on-time performance metric for the outbound flights from CLT. The average compliance data across all banks shows a 1.3% of year-over-year (YoY) reduction during the post-metering period in 2018, and the average compliance in banks 2 and 3 only shows the same change. This comparison result suggests that surface metering did not adversely affect the arrival on-time performance of outbound flights.

Table 1 CLT outbound A0 on-time performance

	2017 Compliance	2018 Compliance	YoY Change
All Banks	58.8%	57.5%	-1.3%
Banks 2 and 3	68.1%	66.8%	-1.3%

In a similar way, the A0 metrics of inbound aircraft arriving at CLT were also compared for the same periods in order to assess whether the gate hold of departures due to surface metering would adversely affect arrival flights' on-time performance. As shown in Figure 6 and Table 2, the results show that surface metering had no negative impact on the on-time performance of inbound arrival flights at CLT. The average A0 compliance during banks 2 and 3 in 2018 (post-metering) shows a slight improvement (+3.3%) over the same period in the previous year (pre-metering) that surpasses the change in the year-to-year average across all banks (+2.3%).

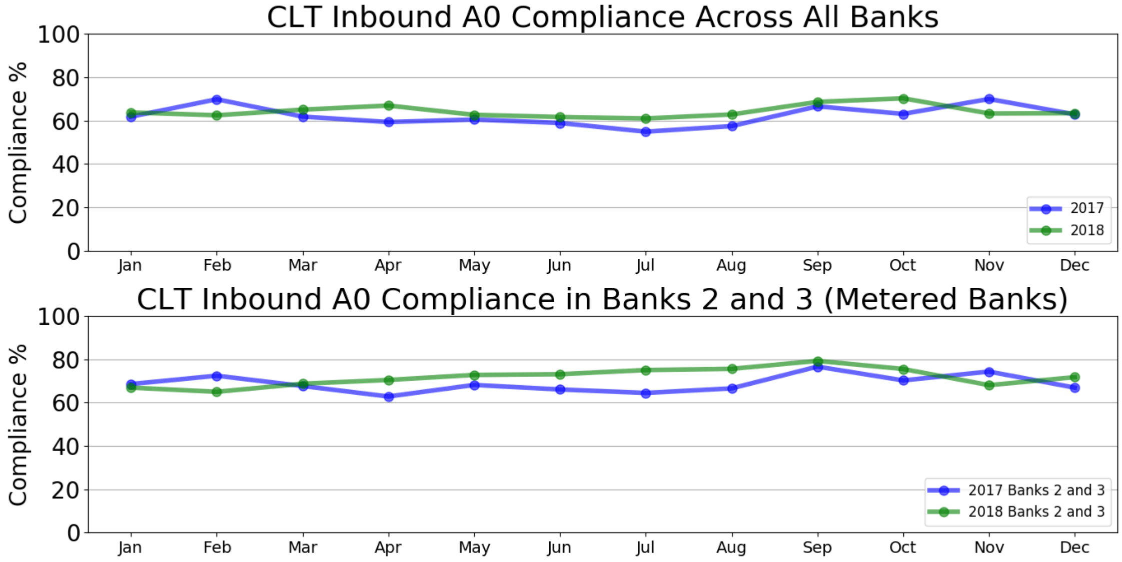


Figure 6 – Inbound A0 compliance by month in 2017 and 2018 across all banks (upper) and in banks 2 and 3 only (lower) at CLT.

Table 2 CLT inbound A0 on-time performance

	2017 Compliance	**2018 Compliance**	**YoY Change**
All Banks	62.1%	64.4%	+2.3%
Banks 2 and 3	68.6%	71.9%	+3.3%

5 References

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Appendix A: Acronyms

This appendix contains acronyms that are used repeatedly throughout this document.

Acronym	Term
4D	Four-Dimensional
AAL	American Airlines
AAR	Airport Arrival Rate
ADR	Airport Departure Rate
ADW	Arrival Departure Window
AEFS	Advanced Electronic Flight Strips
AMA	Airport Movement Area
AMAT	Actual Movement Area entry Time
AOBT	Actual Off-Block Time
APREQ	Approval Request (CFR)
ARMD	Aeronautics Research Mission Directorate (NASA)
ARTCC, or Center	Air Route Traffic Control Center
ASDE-X	Airport Surface Detection Equipment – Model X
ATC	Air Traffic Control
ATCSCC, or Command Center	Air Traffic Control System Command Center
ATCT, or Tower	Airport Traffic Control Tower
ATD-1	ATM Technology Demonstration 1
ATD-2	Airspace Technology Demonstration 2
ATL	Hartsfield-Jackson Atlanta International Airport
ATM	Air Traffic Management
ATOT	Actual Takeoff Time
BOS	General Edward Lawrence Logan International Airport
CD	Clearance Delivery
CDM	Collaborative Decision Making
CFR	Call For Release
CLT	Charlotte-Douglas International Airport
CMS	Controller Managed Spacing
ConOps	Concept of Operations

ConUse	Concept of Use
CTD	Controlled Time of Departure
CTOT	Controlled Takeoff Time
DMP	Departure Metering Program
DRC	Departure Reservoir Coordinator
DRM	Departure Reservoir Management
DSS	Decision Support System
DST	Decision Support Tool
EDC	En route Departure Capability
EDCT	Expect Departure Clearance Time
EFD	Electronic Flight Data
EOBT	Earliest Off-Block Time
ERAM	En Route Automation Modernization
ETA	Estimated Time of Arrival
ETOT	Estimated Takeoff Time
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
FCFS	First-Come-First-Served
FDIO	Flight Data Input/Output
FFC	FutureFlight Central
FO	Flight Operator
GC	Ground Controller
HITL	Human-in-the-Loop
IADS	Integrated Arrival, Departure, Surface
IDAC	Integrated Departure Arrival Capability (TBFM)
IDS	Integrated Display System
IOC	Integrated Operations Center
JFK	John F. Kennedy International Airport
KPPs	Key Performance Parameters
LC	Local Controller
LGA	LaGuardia Airport

MIT	Miles-in-Trail
MOPs	Measures of Performance
MP	Meter Point
N90	New York TRACON
NAC	NextGen Advisory Committee (FAA)
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCT	Northern California TRACON
NextGen	Next Generation Air Transportation System
NTML	National Traffic Management Log
OAG	Official Airline Guide
OAK	Metropolitan Oakland International Airport
OER	Operational Evaluation Report
OFF	Takeoff Time
ORD	Chicago O'Hare International Airport
PCT	Potomac Consolidated TRACON
PDC	Pre-departure Clearance
PDRC	Precision Departure Release Control
PGUI	Planview Graphical User Interface
PHX	Phoenix Sky Harbor International Airport
PIC	Pilot in Command
P-time	Proposed Departure Time
RBS	Ration By Schedule
RDR	Runway Departure Rate
RFRT	Request For a Release Time
RMTC	Ramp Manager Traffic Console
RNAV	Area Navigation
RTC	Ramp Traffic Console
RTOT	Requested Takeoff Time
RTT	Research Transition Team
SARDA	Spot and Runway Departure Advisor

SDT	Scheduled Departure Time
SFO	San Francisco International Airport
SID	Standard Instrument Departure
SJC	Norman Y. Mineta San Jose International Airport
SOBT	Scheduled Off-Block Time
STA	Scheduled Time of Arrival
STARS	Standard Terminal Automation Replacement System
STBO	Surface Trajectory-Based Operations
SWIM	System Wide Information Management
TBFM	Time Based Flow Management System
TFDM	Terminal Flight Data Manager
TFM	Traffic Flow Management
TFMS	Traffic Flow Management System
TGUI	Timeline Graphical User Interface
TMAT	Target Movement Area entry Time
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiative
TMU	Traffic Management Unit
TOBT	Target Off-Block Time
TRACON	Terminal RADAR Approach Control
TS	Trajectory Synthesizer
TSAS	Terminal Sequencing and Spacing (formerly TSS)
TTOT	Target Takeoff Time
TTP	TFDM Terminal Publication
UDB	Unscheduled Demand Buffer
UTOT	Undelayed Takeoff Time
Wake RECAT	Wake Turbulence Recategorization
ZDC	Washington Air Route Traffic Control Center
ZJX	Jacksonville Air Route Traffic Control Center
ZTL	Atlanta Air Route Traffic Control Center