OBSERVED IMPACT OF TRAFFIC AND WEATHER ON CONTINUOUS DESCENT AND CONTINUOUS CLIMB OPERATIONS

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Abstract

This paper presents an assessment of the impact of traffic and weather on the likelihood of executing continuous descent operations (CDO) and continuous climb operations (CCO) in a busy multi-airport system. Our analysis of empirical data available for the Houston Metroplex region indicates that increased traffic levels and the presence of traffic management initiatives related to either congestion or weather tend to decrease the likelihood of flights executing both continuous descent and continuous climb operations. The extent to which arrival or departure procedures were used remained the same between flights executing CDOs (or CCOs) and all other flights. We demonstrate this by the use of scatter plots and logistic regression.

Introduction

Performance based Navigation (PBN) is key to the FAA’s modernization of the National Airspace System (NAS). Over the last few years many PBN Area Navigation (RNAV) Standard Terminal Arrival Routes (STAR) with Optimized Profile Descents (OPD) have been implemented at major airports. While there are no implemented RNAV Standard Instrument Departures (SID) with Optimized Profile Ascents (OPA) in the NAS, most RNAV SIDs have few altitude restrictions and many have at or above altitude restrictions which enable supporting OPAs.

OPAs and OPDs provide fuel efficiency benefits to operators [1] by limiting the number of level-offs below top of climb (TOC) and below top of descent (TOD) respectively, but typically, there is a trade-off between how many such subsequent operations can be executed within a given time period without negatively impacting the overall efficiency of the system. It is generally assumed that factors such as demand, aircraft performance, equipage level, fleet mix and weather will influence the extent to which such operations can be executed, but thus far, very little empirical work has been done to verify this assumption.

While OPDs or OPAs are designed to allow aircraft to descend or climb with a minimum number of level-offs, CDOs and CCOs define operations below TOD or TOC where aircraft descend or climb, without any intermediate level-offs. In the absence of empirical data, many studies have used modeling and simulation to estimate the relationship between CDOs and CCOs and system performance.

Melby et al [1] used radar track data from 34 of the Operational Evolution Partnership (OEP) airports and modeled an approach to assess benefits of CDOs and CCOs, finding operator benefits of $380 million annually along with reduction in CO2 emissions by improving climb and descent operations.

Likewise, Shresta et al [2] evaluated daytime operations and concluded that CDOs provide both fuel and emission savings while avoiding conflicts with other traffic.

According to Roach et al [3], flow direction, RNAV route geometry and arrival streams are the biggest contributors to the duration and frequency of level-offs for departures. They found that 20 percent of DFW departures were affected and the average duration of level-offs was over 100 seconds. Further, they found that the use of continuous descent arrivals lessens the impact arrivals have on departures and facilitates more continuous ascents.

McConnachie et al [4] found that on average 30 percent of departures in the NAS are affected by inefficiencies. They conducted a scoping analysis and found that on average three flights out of ten are affected by at least one level-off, and five percent of the climb time is spent maintaining constant altitude. The majority of level-offs last less than one minute.

Dalmau et al [5] studied a perfect flight trajectory and determined that a continuous cruise phase can yield between one and two percent total trip fuel savings and also result in a reduction in trip time between one and five percent of the total trip time, depending on the trip distance between origin and destination.
Cao et al [6] studied the benefits of CDOs into Hartsfield-Jackson Atlanta International Airport (ATL). They found that separation minima, aircraft weight, aircraft control maneuver, and number of step-downs all influence fuel savings.

Unlike these studies, the focus of this research is entirely on empirical data. In May 2014, the FAA’s Houston Metroplex project was implemented with a focus on the two major airports: Houston George Bush Intercontinental Airport (IAH), and Houston Hobby Airport (HOU). In addition, the changes to the Houston airspace included 61 new or revised procedures, airspace boundary adjustments and integration of Time Based Flow Management (TBFM). The project implemented 12 RNAV STARs with OPDs into IAH and five new RNAV STARs into HOU, with altitude windows that enable most aircraft to fly without level-offs. Ten new RNAV SIDs each were implemented at IAH and HOU, with six of these shared between the two airports. The RNAV SIDs were designed with “at or above” restrictions. The new arrival and departure procedures are designed to support CDO and CCO into and out of the two major airports while deconflicting arrival and departure flows into these two airports as well as 16 satellite airports within the region.

A comprehensive post implementation analysis of the Houston Metroplex was conducted by the NextGen Operations Analysis Division (ANG B72) and the results of those analyses will be published at the end of FY 2015 [7]. Unlike that effort, in this research, we focus on operational changes and performance trade-offs in the Houston Metroplex area. In particular we investigate impacts of increasing traffic and the presence of severe weather or holding events on the execution of CDOs and CCOs into and out of the two major airports. The RNAV SIDs were designed with “at or above” restrictions. The new arrival and departure procedures are designed to support CDO and CCO into and out of the two major airports while deconflicting arrival and departure flows into these two airports as well as 16 satellite airports within the region.

Approach
There are several challenges involved in identifying flights that execute CDOs and CCOs. Because there is no readily available empirical data that captures the execution of such operations, it is necessary to use complex algorithms to evaluate flown trajectories. We first estimate TOD and TOC, and then determine if any level segments were flown below TOD and TOC in order to identify flights that executed CDOs and CCOs.

**CDO and CCO Determination**

TOD is the point at which an aircraft transitions from cruise to the descent phase of flight while TOC is the point at which an aircraft transitions from ascent to the cruise phase of flight. Unfortunately, neither is empirically reported, and has to be estimated using surveillance data.

In order to identify flights executing CDOs and CCOs, we developed complex algorithms to process surveillance data collected by the FAA’s Performance Data Analysis and Reporting System (PDARS) within the Fort Worth (ZFW) and Houston (ZHU) Air Route Traffic Control Centers (ARTCC). This dataset distinguishes flight plan and positional information reported by individual flights, which we used to evaluate characteristics of their lateral and vertical profiles, and corresponding flight efficiency. We used vertical flight efficiency indicators such as time and distance in level flight to determine if a flight was able to maintain a continuous descent profile below its TOD until approximately 30 nm from the destination airport for arrivals and below TOC for departures. Due to the close proximity of the two airports which necessitates the use of altitude restrictions to separate approaches and take-offs, subject matter experts from the Houston Terminal Radar Approach Control (I90) and ZHU believed it would be unreasonable to expect continuous descent profiles all the way to touchdown. Since most of the Initial Approach Fixes are located around 30 nm of the two airports, we assumed that a flight executed continuous descent if it had no level-segments between TOD and a 30 nm ring around the destination airport for arrivals.

Consistent with other PBN analyses, we evaluated both TOD and TOC within 200nm from IAH and HOU as the end and the start of the level segment on the highest altitude in descent and ascent phases, respectively. Also, an aircraft is considered to be in level-flight if it remains within 200ft of the same altitude for 50 seconds or longer.

**Procedure Utilization**
We also evaluated procedure utilization to gain an understanding of how the RNAV SIDs and STARs were being used, and their relationship, if
any, to CCOs and CDOs. Empirical data capturing actual utilization of available procedures is currently archived for only voice recordings, which cannot be effectively processed for long periods of time. Therefore, we developed a complex in-house tool to estimate procedure utilization by analyzing conformance of the flown trajectories to the published procedures.

For a flight, we determine conformance as the extent to which its trajectory overlaps with the procedure specified in the last flight plan or amendment that was recorded prior to it joining the procedure. We do not check for conformance against the whole procedure, but only between an arrivals’ joining waypoint that was specified in the flight plan and the first waypoint on its approach path. For departures, we determine conformance between a departure procedure’s first waypoint on the transition and the exit fix, if specified, or the last waypoint on the transition as specified in the flights’ filed flight plan.

Data

We processed six months of surveillance data after the implementation of Houston Metroplex, including arrivals and departures from IAH and HOU between July and December 2014, and categorized each flight as having executed a CDO or CCO based on its performance below TOD or TOC.

In an effort to focus the analysis on operations that were most directly affected by Metroplex improvements, we excluded night-time operations, and operations conducted by military, helicopter and piston aircraft. Further, the dataset used in this analysis was limited to only Aviation System Performance Metrics (ASPM) carriers with Airline Service Quality Performance (ASQP) reporting requirement. The final dataset used in the regression analysis is summarized in Table 1.

<table>
<thead>
<tr>
<th>Airport</th>
<th>Arrivals</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAH</td>
<td>54,542</td>
<td>65,998</td>
</tr>
<tr>
<td>HOU</td>
<td>15,574</td>
<td>19,208</td>
</tr>
</tbody>
</table>

Based on preliminary analysis, we identified key parameters that we believed would affect the extent to which CDOs and CCOs are executed: the ratio of airport arrival and departure demand to hourly capacity, the amount of airborne holding, and the presence of severe weather.

The airport demand to capacity ratio provides insight on how volume and congestion influence the execution of continuous operations. It is defined as the number of arrivals or departures within each 60 minute time bin, divided by the number of aircraft that tower controllers report they are able to handle in that same time period, which is known as the “called rate.” Note that poor weather conditions or low visibility can lower the called rate during a given time period. A demand to capacity ratio of close to 1.0 implies that the airport is running close to its current capacity. We would expect that in this condition it might be more difficult for a pilot to execute a continuous climb or descent.

Holding events, especially non-weather related holding, provide insights into how overall system performance impacts the use of continuous descents or climbs. We evaluated holding events for arrivals into IAH and HOU using information available from PDARs holding reports generated for Houston Center (ZHU).

Due to the difficulty in identifying discrete time periods of extreme weather occurring in the Metroplex area and the ripple effects thereof, we used National Traffic Management Log (NTML) restrictions to IAH to identify periods when weather was impacting operations at these two airports. Rather than use discrete time-periods, we classified the whole day when the airport was experiencing any weather based restrictions as being impacted by weather.

Analysis and Results

The operations at IAH and HOU differ considerably in terms of fleet mix, type of operations such as commercial, air taxi and general aviation operations and demand.

Simple trend analysis shows that as arrival demand to capacity ratio increases, the percent of flights executing CDOs decreases. The departure demand to capacity ratio has a much smaller influence on the execution of CDOs (Figure 1.)
Similarly, as shown in Figure 2, arrival demand to capacity ratio has far greater influence on CCOs compared to departure demand to capacity ratio. This is to be expected, as arrivals typically have precedence over departures; for workload, safety and traffic flow management purposes, departing aircraft are often separated from arriving aircraft by enforcing level-offs at lower altitudes.

The impacts of weather based restrictions on CDOs and CCOs is shown in Figure 3 which shows how these restrictions lower the percent of CDOs and CCOs for any given demand to capacity ratio.
Figure 3 also shows that weather based restrictions have greater influence on CDOs than CCOs, reducing them by about 10 percent, whereas CCOs are only reduced by about one percent.

A comparison of holding events during days with and without weather restrictions is shown in Figure 4. Almost all holding events occurred on weather restricted days, indicating that weather is one of the major contributors to inefficiencies for arrival flights. Further, holding events are not influenced by the execution of CDOs as shown in Figure 4b.

To understand the impact of the newly designed RNAV SIDs and STARs and the execution of CDOs and CCOs, we also compared the extent of the utilization of these procedures by flights executing CDOs and CCOs with all other flights as shown in Figure 5. The key purpose of SIDs and STARs are to safely and expeditiously facilitate transitioning flights between the terminal area and en route phase of the flight and vice versa. Our findings indicate that utilization of the procedures is high and empirical data indicates that CDOs and CCOs are executed when conditions facilitate such operations at both airports.
In general, whether a flight flew a CDO or not, more than 50 percent of the flights requested at least 140 nm or more of the OPD STARs into IAH and more than 50 percent of the departing flights requested at least 120 nm or more of the RNAV SIDs out of IAH. Of the flights requesting OPD STARs, 50 percent of them conformed to 80 percent or higher of the procedure for arriving flights and 30 percent of the departing flights conformed to more than 80 percent of the filed RNAV SIDs.

**Logistic Regression**

To gain an understanding of the impact of these independent variables on the probability that a CDO or CCO would be executed at IAH or HOU, we developed a logistic regression model using CDO (or CCO) as the dependent variable, and arrival demand to capacity ratio, departure demand to capacity ratio, the number of holding events, the presence of weather restrictions, and an airport indicator as the independent variables.

The results of the logistic regression using CDO as the dependent variable is summarized in Table 2 and using CCO as the dependent variable is summarized in Table 3.

Coefficients in logistic regressions are typically hard to interpret without converting them to marginal effects, evaluated at the mean of each variable. This provides an intuitive interpretation which is summarized in Table 4.
Table 4. Summary of Logistic Regression Results

<table>
<thead>
<tr>
<th>Independent Variable (X)</th>
<th>Change in probability of CDO for unit change in X (%)</th>
<th>Change in probability of CCO for unit change in X (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival demand-to-capacity ratio</td>
<td>-0.50%</td>
<td>-0.40%</td>
</tr>
<tr>
<td>Departure demand-to-capacity ratio</td>
<td>-0.07%</td>
<td>-0.10%</td>
</tr>
<tr>
<td>Number of Holding Flights</td>
<td>-3%</td>
<td>-0.50%</td>
</tr>
<tr>
<td>Weather Restrictions</td>
<td>-7%</td>
<td>-2%</td>
</tr>
</tbody>
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First, the results show that, as expected, the demand to capacity ratio negatively impacts both CDOs and CCOs. For the purpose of this regression, the ratio was expressed as 0 to 100, so the interpretation is that each one percent increase in arrival demand to capacity lowers the likelihood of executing a CDO by 0.5%, and lowers the likelihood of a CCO by 0.4%. So, for example, a 20% increase in the arrival demand to capacity ratio would lower the share of CDO’s by about 10% and of CCOs by about 8%.

On the other hand, the departure demand to capacity ratio has a much smaller impact on either CDOs or CCOs. It should be noted that both results mirror what our scatter plots showed in Figures 1 and 2.

Weather and holding both have a negative impact on CDOs and CCOs, although the impact is much greater for CDOs than CCOs which is expected, since during extreme weather conditions departures might be delayed on the ground. For example, each additional holding flight during a given hour, reduced the share of CDOs by 3%. The presence of bad weather reduces the share of CDOs by 7%, all else equal. The impact of weather and holding on the execution of CCOs was lower, as expected.

Finally, as shown by the IAH airport dummy, CDOs are more prevalent into IAH relative to HOU, however it is more likely that a departure out of HOU will execute a continuous climb as opposed to one out of IAH.

Conclusions

We conducted an analysis of Houston Metroplex area airports using empirical data to assess the impact of traffic and weather on the execution of CDOs and CCOs into IAH and HOU. Arrival demand relative to capacity greatly influenced not only CDOs but also CCOs. Weather restrictions and holding had a larger impact on arrivals than departures.

Finally our analysis of procedure conformance showed that utilization of RNAV STARs with OPDs and RNAV SIDs is high irrespective of the execution of CDOs and CCOs. Logistic regression analysis as well as simple scatter plots suggests that execution of CDOs and CCOs is more likely when conditions that facilitate such operations occur, and that pilot execution of such continuous operations is not correlated with conformance to published procedures.

References


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