MEASURING THE EFFECTS OF ABORTED TAKEOFFS AND LANDINGS ON TRAFFIC FLOW AT JFK

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A. Disclaimer

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B. Abstract

The FAA Office of Accident Investigation and Prevention (AVP) supports research, analysis and demonstration of quantitative air traffic analyses to estimate safety performance and benefits of the Next Generation Air Transportation System (NextGen). This paper describes research for AVP, developing a unique capability to support safety cases for NextGen Operational Improvements (OIs) across FAA lines of business, by the U.S. DOT Volpe Center and government contractors: The Boeing Company (Boeing), and Saab Sensis Corporation (Saab Sensis). Analysis of eight weeks Airport Surface Detection Equipment – Model X (ASDE-X) surveillance of KFJK terminal area traffic that characterized missed departures and missed arrivals is described first. The paper concludes with simulation studies of these events' impact on traffic flow.

C. Introduction

NextGen is a set of technologies and related actions that will transform National Airspace System (NAS) operations. Implementing NextGen will require a thorough understanding of the safety impact to NAS traffic flow from NextGen technologies. AVP is: developing methods to identify emergent risk at the NAS level, creating tools to estimate the impact selected NextGen OIs will have on system risk, and integrating these tools into the NextGen risk assessment and risk management process [1].

Airport capacity management provides one instance of the necessity to link safety with capacity. Each large U.S. airport broadcasts hourly its available capacity as a 'call rate'. This call rate implicitly represents the fraction by which its capacity must be adjusted to ensure safe operations. The implication for safety risk analysis is significant, because the potential NextGen impacts on airport call rates require an evaluation of safety risk in terms of not only the actual number of operations delivered, but also the number enabled. In other words, NextGen risk management methods must consider the nominal capacity of the NAS when safety risk appears to increase, as well as the actual number of NAS operations delivered when unsafe events occur. The ability to forecast the relationship between safety and capacity will be critical to NAS managers [2].

For this purpose, FAA AVP, the Volpe Center, Saab Sensis and Boeing collaborated on analyses estimating the impact on traffic flow at the John F. Kennedy International Airport (KJFK) from unplanned, potentially higher-risk aborted takeoffs and landings. Eight weeks of flight paths in the KJFK terminal area provided evidence of the events. Traffic flow was simulated for one day in 2009 specifically chosen, because that day KJFK operated under visual meteorological conditions (VMC), that day's traffic was amongst the highest of the year, and yet combined flight delays were relatively low.

First the paper describes techniques that categorized aborted takeoffs (missed departures) and aborted landings (missed arrivals), and quantifies impacts on KJFK capacity from them as parameters suitable for a NAS traffic simulation study. The paper then describes those simulation studies estimating flight delays due to missed departures and missed arrivals.

D. KJFK Traffic Flow

A historical record of Airport Surface Detection Equipment – Model X (ASDE-X) surveillance data collected at KJFK by Saab Sensis provided evidence of missed departures and missed arrivals. ASDE-X is an airport traffic management system for air traffic controllers that constantly locates and identifies aircraft on the airport surface and within approach areas out to five nautical miles. The system uses a combination of surface movement radar and transponder multilateration sensors to display aircraft position labeled with flight call-signs on a control tower display. Saab Sensis designed algorithms based on patterns of events and features and their deviations from typical traffic flow patterns to detect aircraft executing missed arrival and missed departure maneuvers.

A missed departure occurs when an aircraft enters a runway with the intention to take off, but instead exits the runway before doing so. This includes both high acceleration rejected takeoffs and low acceleration events where the aircraft simply taxis off the runway.

A missed arrival occurs when an aircraft begins its final approach to a runway with the intention to land, but instead exits final approach without landing. The flight path may fly over the runway, first crossing its threshold. A flight path that does this and also descends to within 50 meters of the runway is called a 'touch and go'. Otherwise, the missed arrival is a 'go around'. Its flight path either never descends to within 50 meters of the runway, or its flight path exits the approach corridor before reaching the runway threshold. The approach corridor is a wedge-like zone extending outward from a runway threshold for approximately 4000 meters (derived from ASDE-X surveillance of successful arrivals).

KFJK aircraft and surface traffic flow was described by eight weeks of ASDE-X positional data, extracted from four different two-week periods (fourteen consecutive days) from different times of the year: December, February, May and August. The data thus captured various seasonal, local weather, and traffic conditions surrounding KJFK.

E. KJFK Missed Arrivals

For aircraft airborne for at least fifteen seconds, two sets of methods screening for missed arrivals were run independently. The first set isolated aircraft flying over a runway, that first fly over a threshold. The Saab Sensis algorithms test for aircraft (x,y) positions located inside the runway beginning with the position crossing the runway threshold, then check (x,y) positions for an airborne runway exit. Further algorithms filter data by surveillance quality, altitude relative to the runway, and airspeed.

The second set of filters identified aircraft entering a runway's arrival corridor with the intent to land, but leaving the corridor before its (x,y) position crosses the runway threshold. Positional data of known successful approaches to each runway were analyzed to geometrically define the wedge that represents the runway approach corridor. A typical approach path was estimated as the average position among successful arrivals computed every 100 meters, starting from the runway threshold and working backwards along an approach path out to 4000 meters from the runway. At the runway threshold, the approach corridor width is twice the runway width. Every 100 meters, the corridor expands on either side of the typical approach path by the larger of 3 degrees or 3 times the standard deviation of the average successful approach position. Figure 1 depicts approach corridors for KJFK created using this method.

Once the arrival corridors were built, ASDE-X surveillance tracks were screened for airborne entry, surveillance quality, and having neither origin nor immediate exit position on or over a runway. Minimum corridor occupancy time and progress towards the runway threshold were used as the features to estimate intent to land.

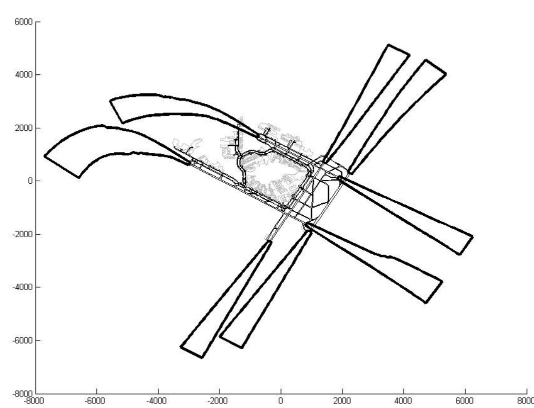

Figure 1. KJFK approach corridors

For the eight-week KJFK data set, Table 1 counts successful and missed arrivals, divided into three categories. Added to the ‘touch and go’ and ‘go around’ categories is a relatively rare type of missed approach labeled ‘flight check’. Flight Checks are apparent test flights, pre-planned missed approaches executed by aircraft registered to the FAA. In the eight-week KJFK data set, ‘flight check’ flights always flew the exact same missed approach twice in succession and never landed at KJFK.

Table 1. Missed arrival frequencies

Arrival Type	**Count**	**% of Total**	**Daily Rate**
Successful	31,380	99.77	560.4
Touch and Go	12	0.04	0.21
Go Around	55	0.17	0.98
Flight Check	6	0.02	0.11
Total Arrivals	31.453	100.0	561.7

F. KJFK Missed Departures

Saab Sensis algorithms detected missed departures from criteria applied to the ASDE-X tracks that aircraft followed during taxi between KJFK departure gates and runways. To determine if an aircraft executed a missed departure, each track was screened for quality, runway entry and exit during taxi, and the track’s proximity to the runway threshold, and further filtered for recent arrivals. Remaining flight tracks were screened for travel down the runway, and sorted by maximum acceleration during runway travel, producing the set of low- and high-acceleration missed departures. Earlier criteria eliminated tracks which were not missed departures. Later criteria categorized missed departures by the aircraft acceleration and the behavior of surrounding aircraft while the target aircraft is on the runway. For the eight-week KJFK data set, Table 2 counts successful departures and two categories of missed departures.

Table 2. Missed departure frequencies

Departure Type	**Count**	**% of Total**	**Daily Rate**
Successful	30,336	99.39	541.7
Missed at high acceleration	12	0.04	0.21
Missed at low acceleration	175	0.57	3.13
Total Departures	30,523	100.0	545.1

Of the 175 low acceleration missed departures, 62 involved aircraft lined up for takeoff on the runway. Of those, 26 had to clear the runway for an arriving aircraft, then reentered the departure queue. One of the 12 high acceleration missed departures was a takeoff rejection due to a runway incursion.

Most of the high-acceleration missed departures (7 out of 12) returned to gate, perhaps due to mechanical need. This compares with only about one fifth (13 out of 62) of low-acceleration missed departures that returned to gate.

G. Impact Analysis

The traffic simulation methodology leverages a tool suite comprising Boeing’s National Flow Model (NFM) for NAS-wide simulation [3], and Boeing’s Airport Capacity Constraints Model (ACCM) that supplies the NFM with airport capacity estimates under the operating conditions being simulated [4]. This paper extends the results from a prior study [5] that simulated a single day of NAS traffic in 2009 to estimate the impacts from missed departures and missed arrivals on KJFK traffic flow.

Saab Sensis missed departure and missed arrival frequency estimates, their effects on slot usage (i.e., airport capacity), and departing flights’ taxi times were carried forward by the Boeing simulation studies. Saab Sensis concluded that the only flight to lose a slot was the one experiencing a missed departure. Consistent with this, Boeing processed each KJFK departing flight on the study day iteratively and independently. The process estimated the local KJFK traffic flow impacts from missed departures by assuming that each missed departure returns to the back of the departure queue (as opposed to the gate for an unpredictable period of time). The process did not assess how impacts might propagate across the NAS. This iterative process was designed to simulate more than one lost slot, and so the following description assumes that the missed departure also causes one other flight in the departure queue to lose its slot.

Suppose for instance that a KJFK flight scheduled for 09:35 am runway departure a) experiences a missed departure, b) has to return to the back of the departure queue, and c) causes one additional departure slot, in addition to its own, to be lost. If KJFK departures during the 09:00 hour were 60 per hour, then the second lost slot translates into another minute with no departing flights. Every flight in the departure queue behind the 09:35 missed departure will experience one minute of delay. Because the flight (*f*) missing its 09:35 departure goes to the back of the queue, it experiences a total added delay of: 2 minutes + 1 minute*[length of queue behind *f*]. For the example shown in Figure 2, if three flights are in the queue behind the 09:35 departure, the total extra delay experienced by the four flights is: 2 + 1*(3) + 1 + 1 + 1 = 8 minutes. Note that the potential for even greater delay exists as additional flights enter the queue behind the flight that misses its scheduled departure.

During simulations, an extra five minute 'transit penalty' was imposed on the flight that experienced the missed departure or arrival. For departures, this penalty estimated the time taken for the aircraft to exit the runway where the rejection occurred and then return to the back of the departure queue. For arrivals the transit penalty estimated the time needed to leave the approach path and then return to the back of the landing queue.

A missed departure or arrival can occur at any time, yet the impact the event has on traffic flow depends a great deal on the time of day. A missed departure (arrival) invariably has greater impact during a peak time for KJFK departures (arrivals) than at other times of day. Consequently, the entire day's traffic, not a random sample of it, was analyzed. Each KJFK flight was analyzed individually with the computed metrics providing a range of potential impacts in terms of flight delays.

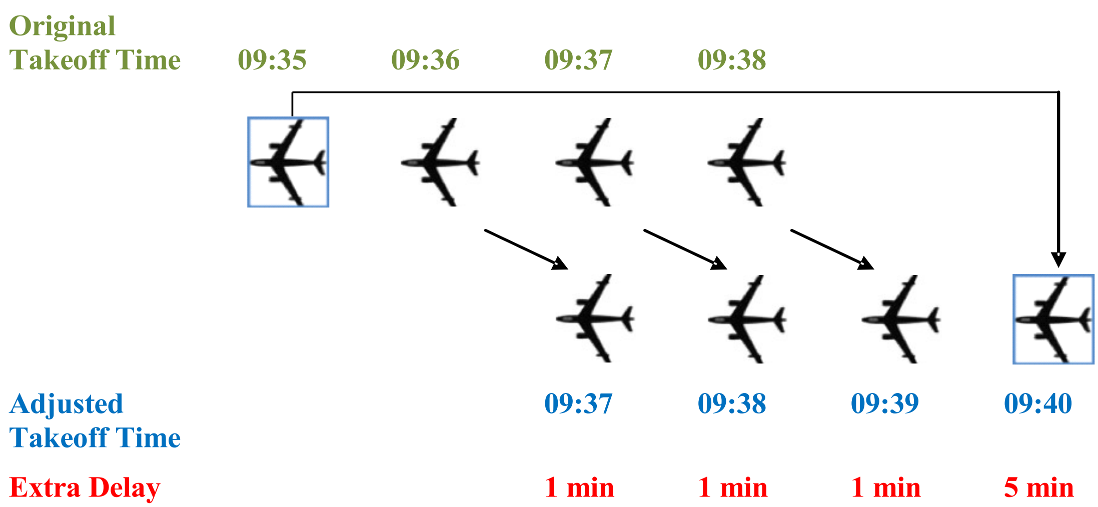

Figure 2. Modeling missed departure takeoff delay

Several metrics describing KJFK missed departures were computed by the iterative process:

Extra takeoff delay for missed departure flight – the time between the scheduled takeoff time and the simulated takeoff time for the flight experiencing the missed departure;

Total extra takeoff delay – the time between the scheduled and simulated takeoff times created by the missed departure, summed over all affected flights;

Departing flights affected – count of flights affected by the missed departure;

Extra takeoff delay per affected flight – (Total extra takeoff delay) / (Number of departing flights affected);

Departure recovery time – elapsed time after the simulated missed departure until KJFK flights again depart on schedule.

Table 3 reports missed departure metrics once the iterative process was applied to each KJFK departing flight on the study day.

Table 3. Missed departure metrics

Departure Metric	Mean	Min	Max
Extra takeoff delay for missed departure flight (min)	9.7	5.0	36.7
Total extra takeoff delay (min)	28.1	5.0	161.8
Extra takeoff delay per affected flight (min)	3.7	0.4	18.3
Departure recovery time (min)	31.8	5.0	162.4
Departing flights affected	15.8	1.0	75.0

The maximum total extra delay due to a missed departure (162 minutes) occurred at a moment during the last departure push of the day when the most aircraft of the day were affected (75). At that moment total delay peaked, yet the average extra delay (2.2 minutes) per affected flight at that time was actually less than the average for the day (3.7 minutes).

A missed departure impacted approximately 16 flights on average. However, 35% of the time the only affected flight was the missed departure itself. Because every missed departure receives a 5 minute transit penalty, these cases inflated the extra takeoff delay per affected flight.

Arrival flights and missed arrivals at KFJK were analyzed by a similar process. Saab Sensis also concluded that exactly one slot is lost during a missed arrival, the slot corresponding to the missed arrival flight. The metrics computed for missed arrivals were similar to those for missed departures:

Extra landing delay for missed arrival flight – the time between the scheduled landing time and simulated landing time for the flight experiencing the missed arrival;

Total extra landing delay – the time between the scheduled and simulated landing times created by the missed arrival, summed over all affected flights;

Arriving flights affected – count of flights affected by the missed arrival;

Extra landing delay per affected flight – (Total extra landing delay) / (Number of arriving flights affected);

Arrival recovery time – elapsed time after the simulated missed arrival until KJFK flights arrive on schedule.

Table 4 reports missed arrival metrics once the iterative process was applied to each KJFK arriving flight on the study day.

Table 4. Missed arrival metrics

Arrival Metric	Mean	Min	Max
Extra landing delay for missed departure flight (min)	6.7	5.0	16.7
Total extra landing delay (min)	16.8	5.0	105.7
Extra landing delay per affected flight (min)	3.5	0.1	13.3
Arrival recovery time (min)	21.3	5.0	135.1
Arriving flights affected	10.1	1.0	77.0

The maximum total extra landing delay due to a missed arrival (106 minutes) affected 68 flights and so delay peaked at a different time than when the most flights (77) were affected by a missed arrival. During peak landing delay, extra delay per affected flight was approximately 1.6 minutes, less than the overall average per flight (3.5 minutes). Once again the overall average extra landing delay per flight was inflated because 46% of simulated missed arrivals affected only one flight. The preceding metrics, combined with the predicted frequencies of missed departures and missed arrivals, provide an estimated range of impacts of these events on KJFK traffic flow.

The simulation study results that produced Tables 3 and 4 are presented in two sets of four charts. The first four describe the traffic flow impacts from missed departures. For the missed departure metrics, each data point in a chart represents the effect of simulating a missed departure event for a flight at that time. The second four charts similarly describe traffic flow impacts from simulating missed arrival events.

A missed departure can have a significant impact on total extra takeoff delay with the greatest impact associated with a departure push (Figure 3). At approximately 21:30, just one KJFK missed departure led to 162 minutes of total delay spread among 75 flights (2 minutes 12 seconds per affected flight). That missed departure experienced about six minutes of extra delay. During another departure push at 17:15, a missed departure also affected 74 flights after it, but the total extra takeoff delay was relatively small, just 46 minutes (36 seconds per affected flight).

Figure 4 charts slot availability. The peak levels of affected flights and total extra takeoff delay from a missed departure (Figure 3) correspond closely to times of day when the departure slots are all filled (Figure 4). Figure 4 helps to explain why the total extra takeoff delay spiked twice between 17:00 and 18:00. In the last quarter hour there was an open departure slot, and some of the delay experienced by flights joining the departure queue after the missed departure could be absorbed. But, if the missed departure occurred close to 18:00, the open departure slot was no longer available and the propagated delay was more severe, causing the second spike within that hour. Since the extra takeoff delay for a missed departure depended on the departure queue length at that time, that metric did not necessarily follow the saw tooth pattern of the other two.

Figure 5 depicts a close correlation between queue length and extra takeoff delay, as one would expect. From the KJFK traffic models, the only flights to contribute to extra takeoff delay were the missed departure flight and flights that joined the departure queue after the missed departure had reentered it. The extra delay attached to each flight can be modest, but during high-volume departure pushes it could impact so many flights that it might take quite some time for delay to dissipate.

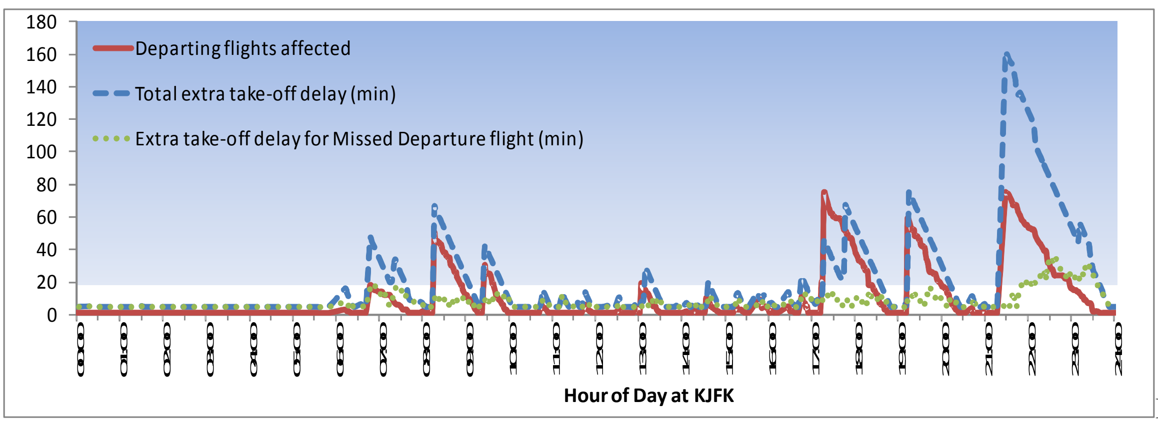

Figure 3. Extra delays from missed departures

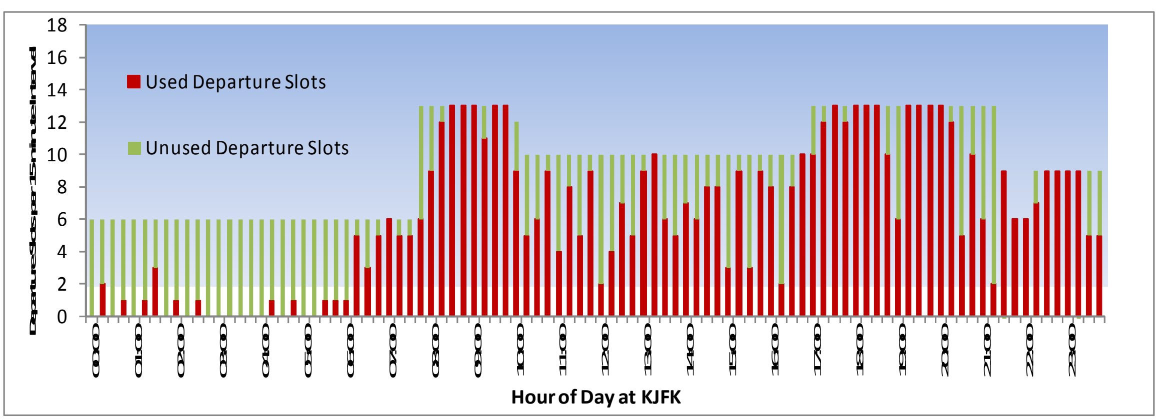

Figure 4. Hourly KJFK departure slots

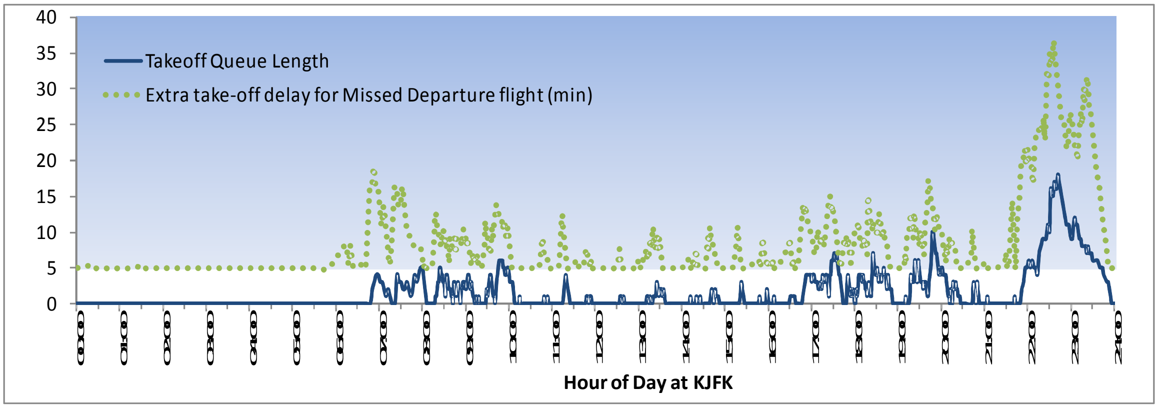

Figure 5. Hourly KJFK departure queues

Figure 6 compares two metrics, departure recovery time and total extra takeoff delay. The two were closely related, diverging only at approximately 07:00 and 17:15. Departure recovery time was significantly longer than the total extra takeoff delay at both times due to the availability of a single available departure slot among a sequence of consecutive occupied slots. How that open slot was utilized depended on the timing of the missed departure occupying that open slot when it rejoined the departure queue. Over a significant length of time, flights joining the queue behind the affected flight were each delayed slightly. At 17:15 there were 75 affected flights, delayed 45 minutes in total, only 37 seconds per flight on average. But it took 96 minutes before there were enough available departure slots for the departure queue to return to a state in which all flights took off as originally scheduled. Simulated departure recovery times were upper bounds because the models did not include actions air traffic controller might use to mitigate small extra takeoff delays per flight.

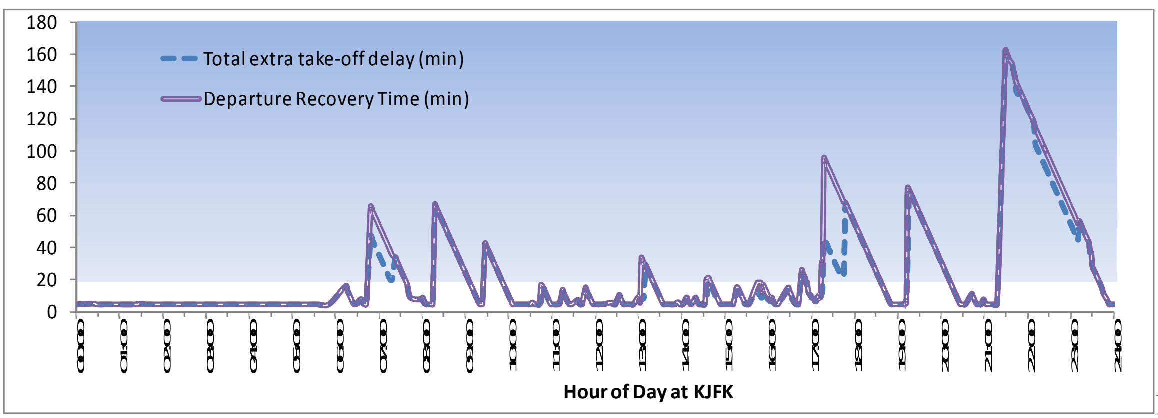

Figure 6. KJFK departure recovery times

Figures 7 through 9 present the same set of results for missed arrival metrics. Total extra landing delay (Figure 7) never rose as dramatically as the departure delay, with only one large peak at around 19:30 exceeding 100 minutes. This is explained by very brief periods of saturated arrival slots (Figure 8) which translate into KJFK landing queues that never exceeded seven aircraft (Figure 9). The exception was the ninety minutes between 19:15 until 20:45 when total extra landing delay could exceed one hour. The smaller build-up of KJFK arrivals means that missed arrivals did not create nearly as much delay to other flights as the missed departures.

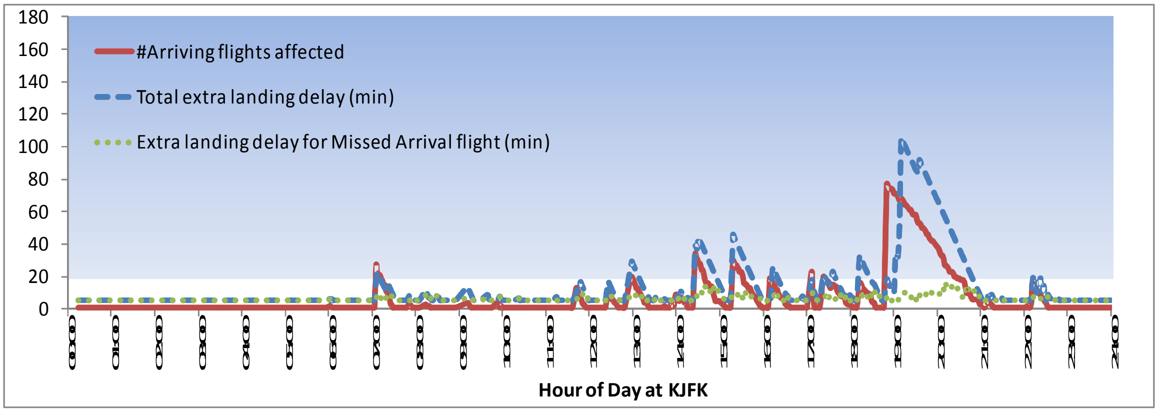

Figure 7. Extra delays from missed arrivals

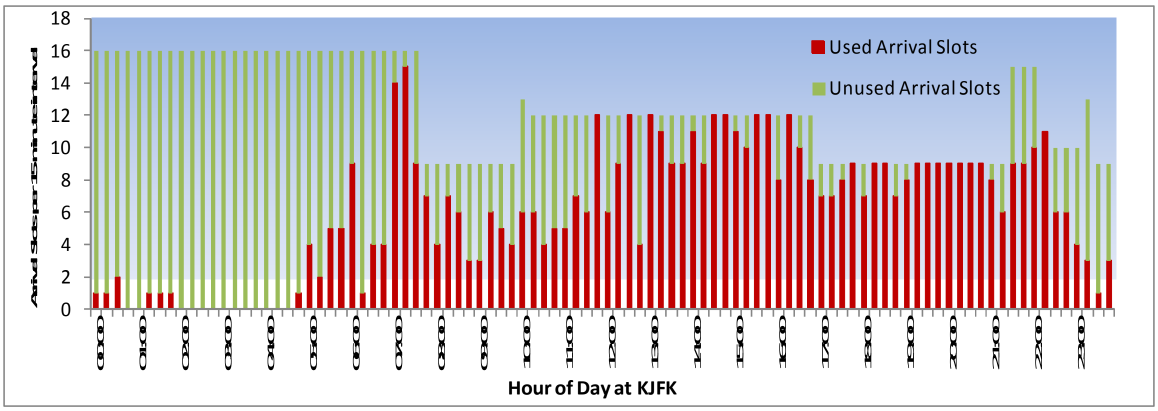

Figure 8. Hourly KJFK arrival slots

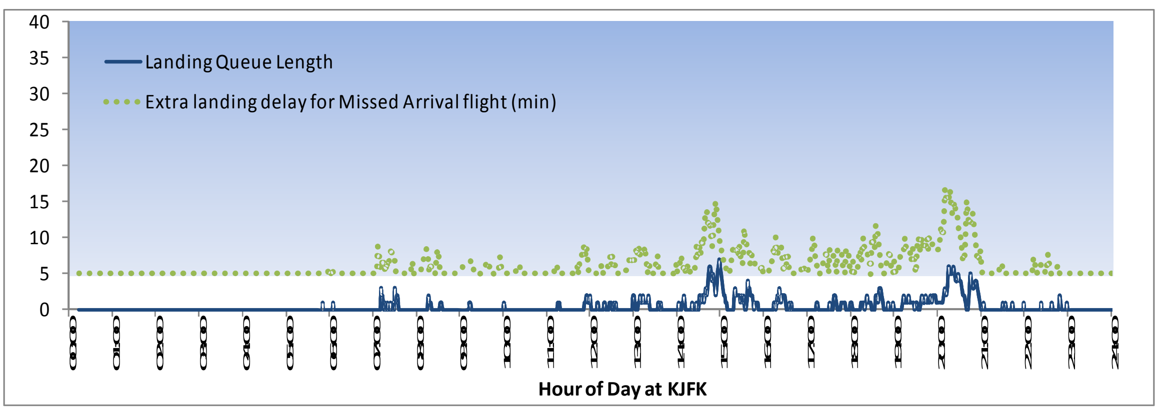

Figure 9. Hourly KJFK arrival queues

Figure 10 compares metrics for arrival recovery time with total extra landing delay. Similar to departures, the two metrics were closely related. Applied to available arrival slots, the same explanation given for departures describes why the two arrival metrics diverge.

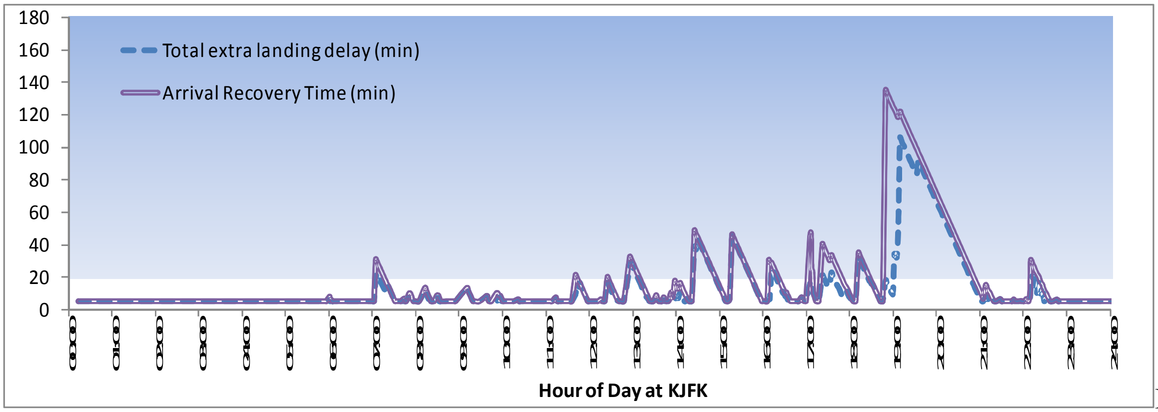

Figure 10. KJFK arrival recovery times

H. Conclusions and Future Work

Simulated KJFK traffic flow impacts from missed departures and missed arrivals by time of day suggest that the typical flight experienced minimal delay. This is based on analysis for a day when KJFK efficiently managed a large amount of traffic while Visual Meteorological Conditions prevailed. Often the only flight affected was the one experiencing the missed departure or missed arrival. Under simulated conditions a missed departure could add on average nearly 4 minutes of takeoff delay to each of 16 flights. There was an 11.3% chance of any one flight experiencing a significant takeoff delay greater than 15 minutes due to a missed departure. An eight-week sample of ASDE-X surveillance suggested approximately 3 missed departures per day at KFJK.

A missed arrival could add on average nearly 2 minutes of landing delay to each of 10 flights. There was a very low probability, 0.3%, of any one flight experiencing more than 15 minutes of delay due to a missed arrival. Delay impacts from missed arrivals were smaller because, for arrivals, the length of time no free slots were available to mitigate delay was smaller than for departures. Analysis of ASDE-X surveillance suggested there was one missed arrival per day at KFJK.

Subsequent studies on behalf of AVP will:

simulate missed arrivals and missed departures at multiple airports;

estimate the delay impacts to individual passenger trips, not just flights;

simulate other operating conditions (e. g, Instrument Meteorological Conditions);

re-examine delay in the presence of specific NextGen Operational Improvements that may reduce missed departures and missed arrivals.

I. References

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