Evaluating the Benefits of a Pilot/Controller Collaboration Initiative

Prepared by:

The Global Aviation Information Network
Working Group E:
Flight Ops/ATC Ops Safety Information Sharing

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Table of Contents

1.0 Introduction

2.0 Analysis

3.0 Conclusion

Appendix A: Descriptions of Tools Used

Figures:

Cover Photo: Boeing B737

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Executive Summary

This report was developed by the Global Aviation Information Network (GAIN) Working Group E, Flight Ops/ATC Ops Safety Information Sharing. The report presents an estimation of benefits accrued from a pilot/controller collaboration effort conducted at Charlotte/Douglas International Airport (KCLT). The Working Group hopes that the findings in this report will help spur more such initiatives in the future.

The goal of the initiative was to reduce go-arounds. Four potential benefits were evaluated:

1. Reduced operator cost
2. Reduced controller workload
3. Reduced aircraft delay
4. Reduced collision risk

The analysis was conducted using simplified computer tools and a very small sample of actual data. Thus, the results can only be claimed to be a rough order approximation. The benefits of eliminating a go-around are estimated to be:

Impact (per go-around)	Runway 18R go-around	Runway 23 to 18R go-around
Direct Operating Cost	$208	$440
Controller Workload	0.45 separations	1.46 separations
Aircraft Delay	6.3 minutes of delay	13.7 minutes of delay
Collision Risk	No discernable Impact	Prob. of Collision = 1.0×10^{-8}

All these estimates (with the possible exception of the collision risk) are expected to be conservative. These estimates were based on a traffic load that was about average at the time (June 2003). The results during a high traffic load condition would be much greater.

The initiative reduced go-arounds on Runway 23 by 21 percent. It is estimated that the annual savings would be $70,000 in direct operating cost, $72,000 in delay costs, 232 fewer air traffic control separation actions, and a 21 percent reduction in a very small, but existent, collision risk.

The report goes into detail on how these numbers were developed.

Any increase in aircraft activity would increase all of these benefits disproportionately.

These estimates are very airport-specific and would not apply to other airports. However, it is very likely that the same benefits would accrue, but in different amounts.

1.0 Introduction

1.1 Purpose of Report

This report was developed by the Global Aviation Information Network (GAIN) Working Group E (Flight Ops/ATC Ops Safety Information Sharing). It develops numeric estimates of benefits obtained from a pilot/controller collaboration initiative conducted at Charlotte/Douglas International Airport (KCLT).

Because of the very limited resources available to do this analysis, only a very small sample of data could be analyzed, and simple-to-use, un-validated computer tools are employed. These numerical values are considered to be approximate, conservative estimates.

But the purpose of this report is not the numbers themselves, but to show that these savings do exist, can be estimated, and can be considerable.

1.2 The Global Aviation Information Network (GAIN)

GAIN is an industry-led initiative to promote and facilitate the voluntary collection and sharing of safety information by and among users in the international aviation community to improve safety. GAIN was first proposed by the Federal Aviation Administration (FAA) in 1996, but has now evolved into an international industry-wide endeavor that involves the participation of professionals from airlines, air traffic service providers, employee groups, manufacturers, major airframe and equipment suppliers and vendors, and other aviation organizations.

More information on GAIN can be found on the GAIN web site: www.gainweb.org

1.3 Working Group E (WG E): Flight Ops/ATC Ops Safety Information Sharing

The Working Group has three main focus areas:

1. Promote the development and creation of a Just Culture environment within the Flight Ops and ATC Ops communities.
2. Identify Flight Ops/ATC Ops collaboration initiatives that improve safety and efficiency.
3. Increase awareness of the benefits of pilot/controller collaboration and promote such collaboration in training and education programs.

The working group consists of representatives from airlines, pilot and controller unions, air traffic service providers, government agencies, and other aviation organizations.

1.4 The Charlotte/Douglas International Airport (KCLT) Collaboration Initiative

Safety experts at US Airways noticed at its major East Coast hub at Charlotte, North Carolina, a higher-than average percentage of flights going into KCLT was experiencing steep approach profiles, unstable approaches, and go-arounds on Runway 23. A member of the safety group contacted the KCLT air traffic control tower and set up a meeting with the FAA management and the National Air Traffic Controllers Association (NATCA) to discuss, and hopefully solve, these issues.

This meeting led to the realization that there needed to be a significant improvement in education and communication between pilots and air traffic controllers. Beginning in the Fall of 1996, representatives from US Airways, The Air Line Pilots Association, International (ALPA), NATCA, and the staff at KCLT ATCT, began working diligently to enhance their interaction in the area of training and quality assurance. The details of how the initiative evolved is discussed in the WG E report *Pilot/Controller Collaboration Initiatives: Enhancing Safety and Efficiency.*

The major participants in this initiative were:

KCLT Air Traffic Control Tower management and staff
Air Line Pilots Association, International (ALPA)
National Air Traffic Controllers Association (NATCA)
US Airways Safety Group

One thing that greatly facilitated this effort was the presence of the US Airways training facility on the airport and the flight simulator time made available by US Airways.

The initiative produced a better understanding among controllers about the need for reduced approach speeds and approach stabilization on final approach. It also reinforced to the pilots the need for proper phraseology and use of call signs on read-back, and appreciation of the need to provide early notification of the need to deviate from ATC instructions.

The result was a 21 percent decrease in go-arounds (on Runway 23) in the face of an air traffic increased of 10 percent. There are still go-arounds for a variety of reasons.

2.0 Analysis

2.1 Purpose

The purpose of this analysis is to quantify the benefits achieved by this initiative. Because of limited resources, only a small data sample could be analyzed, and only simple, easy-to-use computer models (of questionable accuracy) could be employed. To do a highly-detailed analysis would have required a much greater effort (than a single person over a few months) and, in the end, one could still argue over the adequacy of the data sample and the accuracy of the models. Also, that detailed analysis would only present a picture at a point-in-time. Many things upon which accurate results highly depend are subject to change. While similar results might be achieved by such an initiative elsewhere, the numerical values would be quite different.

All we could do was to be reasonably conservative in the assumptions, and not to claim great accuracy in the results. It is hoped that this will show that these benefits are real, can be quantified, and are considerable.

2.2 Benefits

Four potential benefits of reducing the number of go-arounds are investigated:

1. Cost avoidance for the aircraft operator
2. Reduced controller workload
3. Reduced delay to other aircraft
4. Reduced collision risk

Eliminating the cost in time and money to the aircraft operator is an obvious benefit. There is also a loss of time to the passenger, but this is not considered because, being only a few minutes, it probably will not affect him/her financially (although it might emotionally).

The part of reduced work for the air traffic controllers that will be estimated is the work required to fit the go-around aircraft back into the approach stream. This is a variable. If the arrival load is heavy, there might be a considerable amount of aircraft to work around. If the traffic is light, there might be no aircraft in the way. There is also additional time required to handle the go-around aircraft, but this is not evaluated.

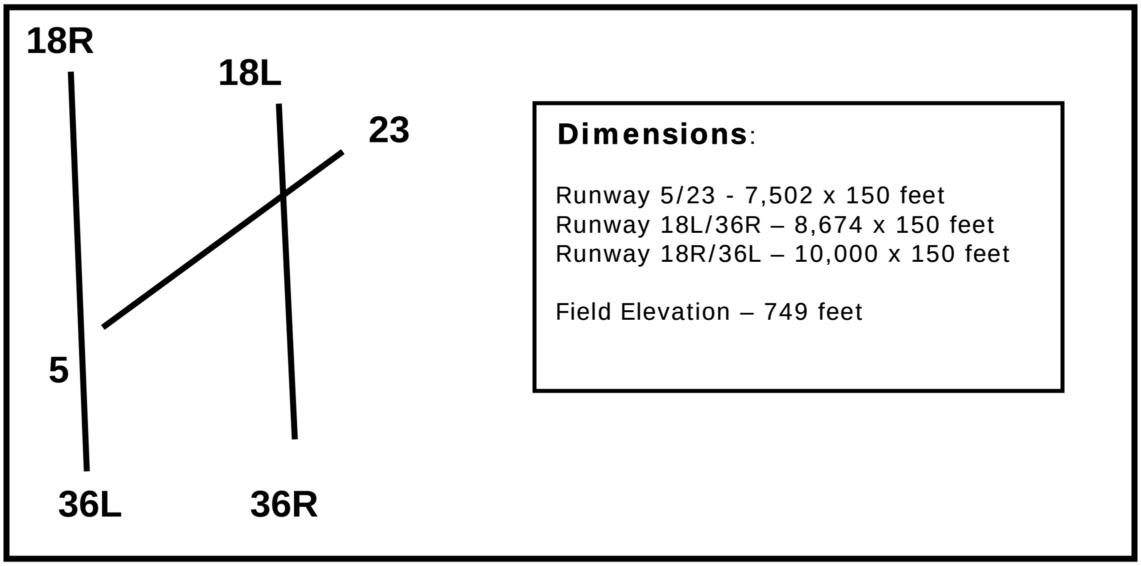
The impact of an additional operation on delay to other aircraft also depends on how busy the airport (particularly the runway used) is when the go-around occurs.

The collision risk will be small because the go-around aircraft will be given intense air traffic control attention, but there is always some risk when aircraft are operating in close proximity and pilots are busy.

2.3 KCLT Operations

The KLCT runways are shown in Figure 1. There are three runways: 5/23, 18R/36L, and 18L/36R. Figure 2 shows aircraft tracks recorded over four hours on 6/5/2003. The chart shows clearly that all three runways were used for both arrivals and departures during this period. Traffic other than KCLT arrivals and departures is also shown in this figure. Figure 2 and these data were obtained from the FAA's Sector Design and Analysis Tool (SDAT). The radar data were obtained through the FAA's National Offload Program (NOP) which provides a direct feed from the terminal radar processor. SDAT eliminates selected radar data returns for efficient storage. This could make rounded turns appear as sharp corners.

The selected data form the basis of the analysis. This sample was selected because South operations (where runway 23 was used for arrivals) were in effect and the traffic density was above average, but not peak. Otherwise, the selection was quite arbitrary.

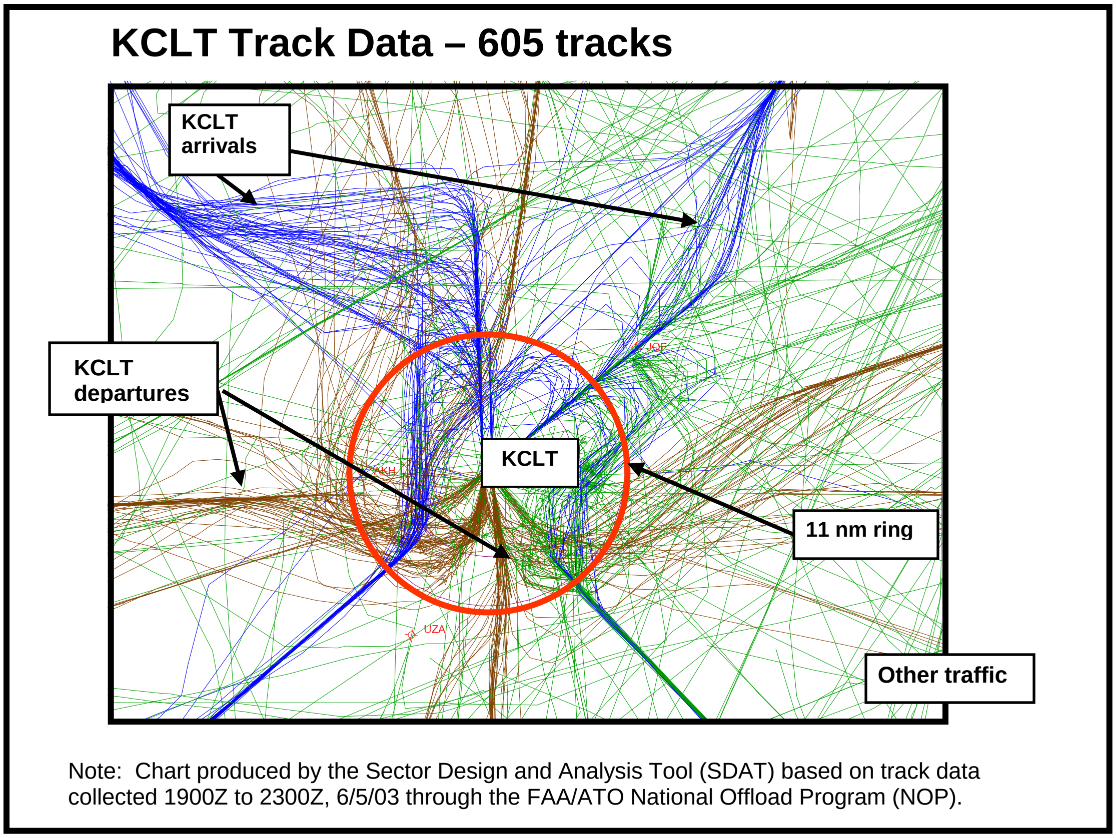


Dimensions:

Runway 5/23 - 7,502 x 150 feet
Runway 18L/36R – 8,674 x 150 feet
Runway 18R/36L – 10,000 x 150 feet

Field Elevation – 749 feet

Figure 1. KCLT Runways (approximate)


KCLT Track Data – 605 tracks

Note: Chart produced by the Sector Design and Analysis Tool (SDAT) based on track data collected 1900Z to 2300Z, 6/5/03 through the FAA/ATO National Offload Program (NOP).

Figure 2. KCLT Aircraft Tracks -- Four-hour Sample

Examples of two of the most common (according to KCLT controllers) types of go-arounds happened to be found in the sample data. Both involved B-737 aircraft. Figure 3 shows a go-around (emphasized) on Runway 18R. Figure 4 shows a go-around on Runway 23 (the shortest of the three runways) that was routed to Runway 18R (the longest of the three). It is obvious why this kind of go-around is of much more of a concern than the former. Also, it was said that this kind occurs most frequently.

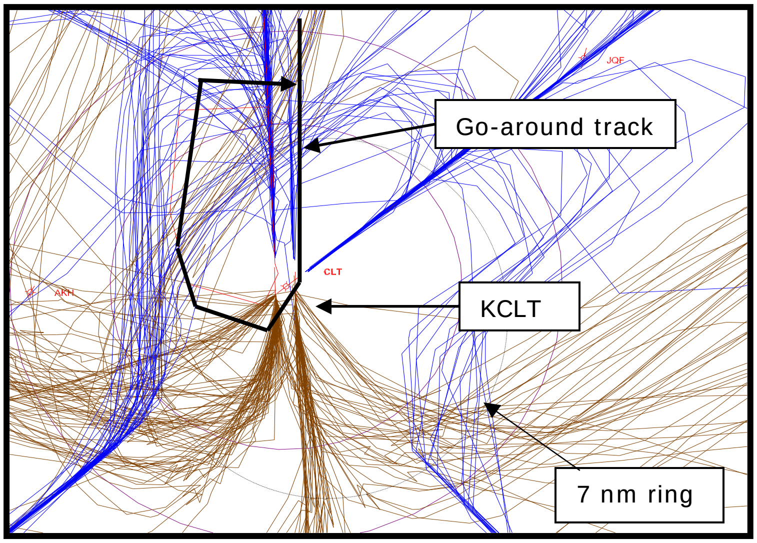


Figure 3. Go-around on Runway 18R

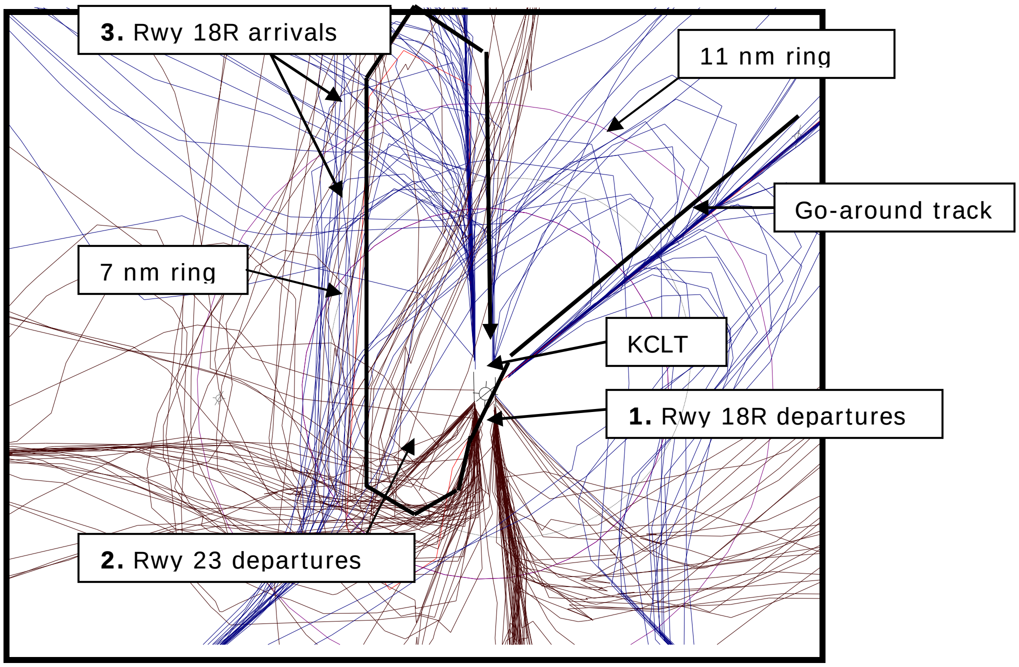
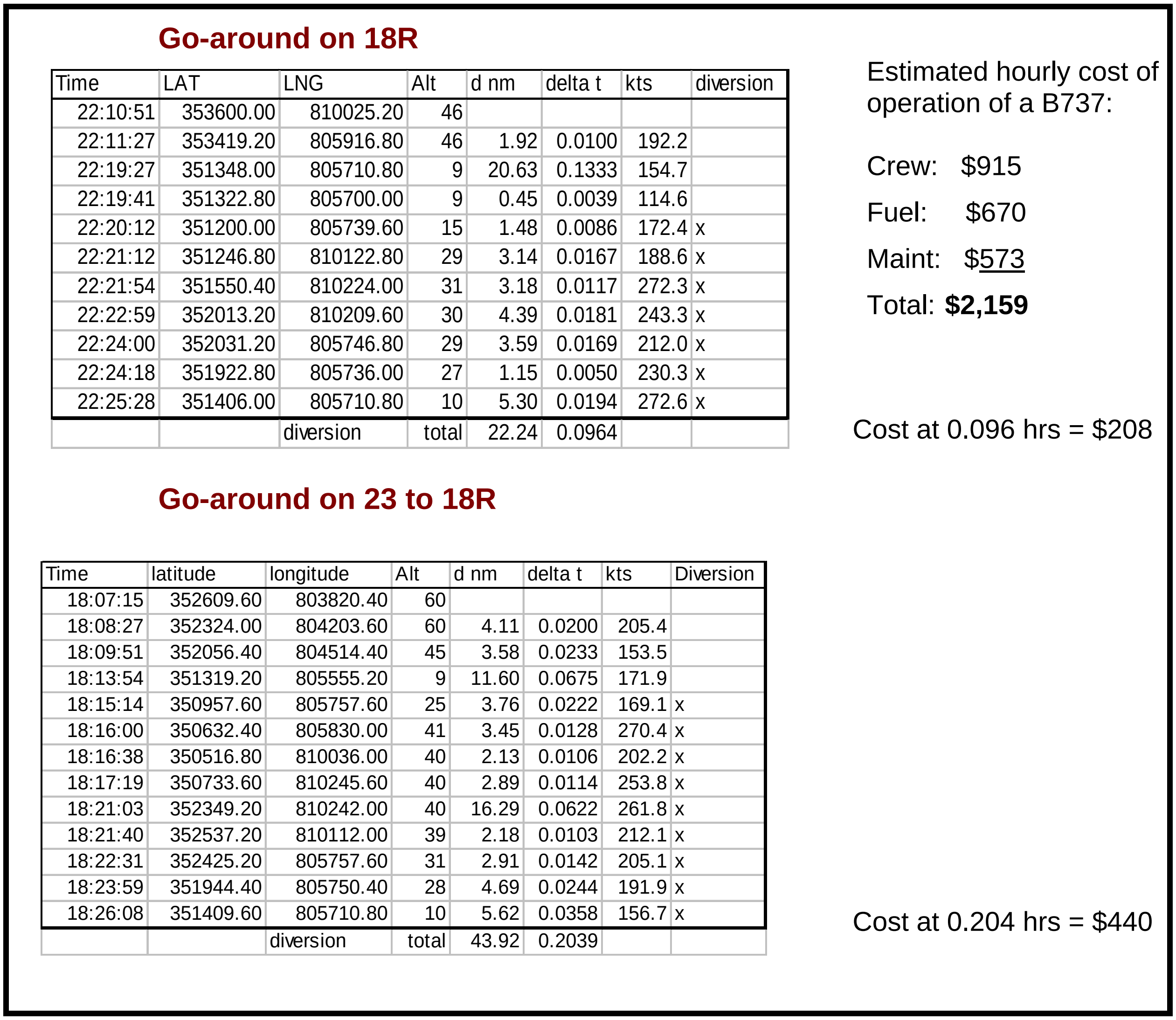


Figure 4. Go-around from Runway 23 to18R - Three possible areas of collision risk

2.4 Aircraft Operator's Cost

Figure 5 shows excerpts from a Microsoft Excel spread sheet created to compute time and distance of the go-arounds from SDAT track data. The segments of the track related to the go-around are indicated by an "x" in the column labeled "diversion." The diversion on Runway 18R required 22.2 nautical miles and 0.096 hours. The diversion from Runway 23 required 43.9 nautical miles and 0.204 hours.



Go-around on 18R

Time	LAT	LNG	Alt	d nm	delta t	kts	diversion
22:10:51	353600.00	810025.20	46				
22:11:27	353419.20	805916.80	46	1.92	0.0100	192.2	
22:19:27	351348.00	805710.80	9	20.63	0.1333	154.7	
22:19:41	351322.80	805700.00	9	0.45	0.0039	114.6	
22:20:12	351200.00	805739.60	15	1.48	0.0086	172.4	x
22:21:12	351246.80	810122.80	29	3.14	0.0167	188.6	x
22:21:54	351550.40	810224.00	31	3.18	0.0117	272.3	x
22:22:59	352013.20	810209.60	30	4.39	0.0181	243.3	x
22:24:00	352031.20	805746.80	29	3.59	0.0169	212.0	x
22:24:18	351922.80	805736.00	27	1.15	0.0050	230.3	x
22:25:28	351406.00	805710.80	10	5.30	0.0194	272.6	x
		diversion	total	22.24	0.0964		

Estimated hourly cost of operation of a B737:

Crew: $915

Fuel: $670

Maint: $573

Total: **$2,159**

Cost at 0.096 hrs = $208

Go-around on 23 to 18R

Time	latitude	longitude	Alt	d nm	delta t	kts	Diversion
18:07:15	352609.60	803820.40	60				
18:08:27	352324.00	804203.60	60	4.11	0.0200	205.4	
18:09:51	352056.40	804514.40	45	3.58	0.0233	153.5	
18:13:54	351319.20	805555.20	9	11.60	0.0675	171.9	
18:15:14	350957.60	805757.60	25	3.76	0.0222	169.1	x
18:16:00	350632.40	805830.00	41	3.45	0.0128	270.4	x
18:16:38	350516.80	810036.00	40	2.13	0.0106	202.2	x
18:17:19	350733.60	810245.60	40	2.89	0.0114	253.8	x
18:21:03	352349.20	810242.00	40	16.29	0.0622	261.8	x
18:21:40	352537.20	810112.00	39	2.18	0.0103	212.1	x
18:22:31	352425.20	805757.60	31	2.91	0.0142	205.1	x
18:23:59	351944.40	805750.40	28	4.69	0.0244	191.9	x
18:26:08	351409.60	805710.80	10	5.62	0.0358	156.7	x
		diversion	total	43.92	0.2039		

Cost at 0.204 hrs = $440

Figure 5. Estimation of Direct Operating Cost Impact of a Go-around

The cost of operating a B-737 was estimated (by the FAA's Office of Policy and Plans) to be:

Item	Cost per hour
Crew	$915
Fuel	670
Maintenance	573
Total direct operating cost	$2,159

This is based on airborne direct operating cost derived from reports provided several years ago. They were inflation-adjusted to 2003 dollars. This is a conservative estimate for two reasons. First, the cost of fuel has increased much faster than inflation since these costs were reported. Second, the cost of operation in a go-around flight profile should be much greater than the average for airborne operation.

At $2,159 per hour, the first go-around cost the operator an estimated $208 and the second go-around $440. This seems rather insignificant, but it could well be the difference between a flight that makes money and one that loses money. Also, the distance flown by this go-around could be about the minimum possible. Had there been a heavy arrival stream during the go-around, the flight might have been vectored much further to the West.

2.5 Controller Workload

For this analysis, the impact on controller workload is measured by the number of aircraft separations required as the go-around proceeds along its track. This is a variable that depends on the amount of traffic in the approach stream to Runway 18R. It would be impossible to determine from track data how many separations were actually provided during the observed go-around, and even if it could be determined, one observation would not tell how many separations would be required on average.

To determine this, two features of SDAT are employed. SDAT allows the user to change the starting time of a selected flight. It also allows a computation that detects where any two tracks come within a user-required set of (vertical and horizontal) separation minima. This allows the analyst to change the time of the flight and see how many aircraft would be violated if no intervention were performed (which, since we are dealing with recorded data, none will be). The information about each of these simulated violations is recorded in a spreadsheet. Separation criteria of 3 nautical miles in the horizontal plane and 200 feet in the vertical were used. One of the reasons for this selection is to reduce inclusion of pairs on the final approach course, which in reality would be set-up with in-trail separation.

A portion of this spreadsheet is shown in Figure 6. The various starting times for the go-around flight are shown in hours and minutes under the heading “Start Time.” Flights “violated” if the go-around started at this time are shown under “Flight 2.” The airline code is changed to “xxx” because a casual reader might erroneously assume that appearing in this list is an indication of an airline’s lack of safety. There could be no violated flights for a particular start time, in which case the start time is not shown, or there could be more than one. For example, three are shown for a start time of 19 hours and 10 minutes. The flight profile of Flight 2 is shown under “description.” All happen to be KCLT arrivals or departures.

Rwy 23 to 18R go-around Actual start time 19:25

Separation criteria = 3 nm hor 200 ft vertical

Start time	Flight 2	description	Alt. ft. (100's)	horiz. sep. nm	ver.sep. (100's ft.)	Closng Angle	Closng Velocity	Time
19:00	XXX897	CLT dep 18R	41	1.8	1	116	346	19:23
19:01	XXX897	CLT dep 18R	37	2.9	2	34	131	19:23
19:02	XXX2875	CLT arr 18R	41	1.4	2	69	264	19:28
19:02	XXX4392	CLT dep 23	39	1.8	2	137	328	19:25
19:02	XXX2023	CLT dep 18R	39	3.0	2	153	417	19:25
19:03	XXX4392	CLT dep 23	41	2.4	2	107	293	19:25
19:04	XXX4392	CLT dep 23	24	1.6	1	13	119	19:25
19:05	XXX1233	CLT dep 18R	40	3.0	1	149	434	19:28
19:06	XXX555	CLT dep 18R	41	2.7	2	149	405	19:29
19:07	XXX5182	CLT dep 23	41	1.0	2	122	355	19:29
19:07	XXX4388	CLT dep 23	39	2.3	2	154	405	19:31
19:08	XXX344	CLT arr 18R	40	2.7	1	148	404	19:34
19:08	XXX5182	CLT dep 23	25	1.4	1	10	29	19:28
19:09	XXX4388	CLT dep 23	40	1.6	0	106	329	19:31
19:09	XXX1461	CLT dep 18R	40	2.4	0	154	426	19:31
19:10	XXX4388	CLT dep 23	35	1.4	2	0	33	19:30
19:10	XXX1020	CLT dep 18R	41	1.9	2	150	463	19:32
19:10	XXX4481	CLT arr 18R	30	0.2	2	47	149	19:38
19:11	XXX1461	CLT dep 18R	34	2.1	2	22	88	19:31
19:11	XXX1020	CLT dep 18R	26	1.1	2	18	81	19:32
19:12	XXX1020	CLT dep 18R	37	2.2	2	19	115	19:32
19:12	XXX50	CLT arr 18R	31	2.4	1	45	145	19:41
19:13	XXX2699	CLT dep 18R	39	2.1	2	152	491	19:35
19:13	XXX50	CLT arr 18R	41	0.7	1	56	228	19:40
19:14	XXX2826	CLT dep 18R	39	2.9	2	163	463	19:37
19:14	XXX50	CLT arr 18R	39	1.4	2	141	415	19:40
19:14	XXX2699	CLT dep 18R	25	1.0	2	22	100	19:34
19:15	XXX2826	CLT dep 18R	41	2.3	2	121	337	19:37
19:15	XXX2826	CLT dep 18R	40	0.8	0	12	54	19:42
19:15	XXX2806	CLT arr 18R	20	0.8	2	1	73	19:45
19:16	XXX2806	CLT arr 18R	41	2.1	2	75	280	19:42
19:16	XXX2806	CLT arr 18R	11	1.0	1	1	73	19:46
19:19	XXX2507	CLT dep 23	39	1.6	2	114	352	19:42
19:20	XXX2712	CLT dep 18R	41	2.4	2	138	440	19:42
19:20	XXX2507	CLT dep 23	41	1.2	2	114	352	19:43

Figure 6. Computation of Controller Workload Impact (sample portion)

The column labeled “Alt. ft.” contains the altitude of the go-around aircraft when the simulated violation occurs. The minimum separation distance is also shown.

This is done for 80 different starting times for each go-around and a count is made of the number of different Flight 2’s are detected each time. The results suggest a probability distribution of how many separation actions would have to be made to keep the go-around aircraft and other aircraft safely separated. The results are:

	Go-around on 18R	Go-around 23 to 18R
Number of Separations	Probability	Probability
0	55.0	18.0
1	42.5	34.5
2	2.5	30.5
3	0.0	17.0
Total	100.0	100.0
Expected Number	0.45	1.46

Thus, for the first type of go-around, there could be as many as 2 separations required, with an expected number of 0.45. For the second type of go-around, there could be as many as three separations required with an expected number of 1.46.

The traffic density varied significantly (from slight to near capacity) during the test period. This analysis assumes an equal likelihood of a go-around at any time during the test period. Realistically, a go-around would be more likely to occur when the traffic load is high. Thus, these results could be considered to be conservative estimates.

2.6 Aircraft Delay

Capacity and delay is a well-studied subject. Numerous very detailed computer models have been developed. For this analysis, simple tools are used and a simple approach is taken.

First it is noted that essentially all the delay impact due to either go-around will occur on Runway 18R. A go-around on Runway 18R can be considered equivalent to adding another arrival. The second (the Runway 23) go-around is more equivalent to adding two operations. The go-around interferes with Runway 18R departures (which are sometimes held) as it crosses the departure end of runway 18R and then becomes another arrival to this runway.

This analysis makes use of two simple analytic models. The first, called the Engineered Performance Measurement System, computes runway capacity, given a mix of aircraft types, a mix of arrivals versus departures, and ceiling/visibility conditions. This model tends to overestimate capacity because runway capacity is considered the only impediment to airport capacity. This, in turn, should tend to underestimate delay (in a way that the underestimation increases with the delay). The second model, called the DELAYS Model, computes delay, over a series of equal-length time segments, given the demand and capacity in each segment. It views the runway system, in this case Runway 18R, as a Poisson arrival and constant service time queuing system.

A sample of 75 minutes of traffic from the four hours of data is used for this analysis. This sample is chosen because it contains a broad range of traffic levels and arrival/departure mixes, typical of the traffic at KCLT. Total traffic over an hour might be well below capacity while demand in a 15-minute period within the hour could be near or over capacity. Also, there are separate arrival rushes and departure rushes. This is typical of airports used as a major hub by one or two dominant carriers.

For constantly busy airports, the delay impact of an added operation or two could permeate throughout the remainder of the day. But at KCLT, where there are frequent slack periods, it is not so unreasonable to take only a small segment of the day.

The sample is divided into five 15-minute periods, as shown in Figure 7. The arrival percent is computed for each period. This ranges from 25 to 86 percent. The capacity is also dependent on the mix of aircraft by (wake vortex rule) weight class. This mix is considered constant, as well over 90 percent of the operations on this runway are performed by aircraft classified as “large” (turbojets under 300,000 lbs.). Figure 7 shows the hourly runway capacity for each period for both Visual and Instrument conditions (VMC and IMC). The hourly demand for each period is also shown. It is computed by simply multiplying the observed 15-minute operations count by four, which is reasonable since the observed count is always less than the capacity under the conditions (VMC) when the observations were made. (If the real demand exceeds capacity, then the operations count measures capacity, not demand.)

	Operations in the period				Eng. Perf. Standard Capacity (ops./hr.)		Hourly Demand Rate
15-min. Period	Num.of Arrivals	Num.of Depts.	total demand	prcnt. arrivals	VMC	IMC	
1	1	1	2	50	63	59	8
2	2	6	8	25	65	64	32
3	4	5	9	44	64	61	36
4	9	5	14	64	58	53	56
5	6	1	7	86	49	44	28
total	22	18	40	55	299	281	160

Note:

Operations in the period are the actual operations (arrivals and departures)
Prcnt. Arrivals is the percent of operations that are arrivals.
Engineered Performance Measurement System is the estimated hourly capacity.
Hourly demand rate for the period is the total (15-min.) demand times four.
VMC and IMC indicate Visual or Instrument Meteorological Conditions

Figure 7. Estimated Runway 18R Capacity (Operations/hour) - in Five 15-min. Periods

At airports where there are numerous operations by pilots who are not instrument rated, the demand rate could be lower for IMC than that observed under VMC. But in this case, it is safe to assume that demand under IMC would be the same as that under VMC.

Figure 8 shows the computation of the delay impact. The total delay is computed five times for each combination of go-around and VMC/IMC. These are for alternative assumptions about the period in which the go-around occurs. (The DELAYS Model assumes that the demand is randomly distributed within the period.) If the go-around occurs in a period when demand is much less than the capacity, the delay will be not much greater than the delay if there were no go-around (the base delay). If it occurs when demand is close to capacity, the total delay could be much greater than the base delay. The estimates of total delay under various assumptions are shown in Figure 8.

		Total Delay (minutes)		Total Delay (minutes)	
		Rwy 18R go-around (actual plus 1 op.)		Rwy 23 go-around (actual plus 2 ops.)	
	15-min.	conditions		conditions	
	Period	VMC	IMC	VMC	IMC
Total delay assuming go-around occurs in this period	1	42.7	62.6	43.0	62.9
	2	43.7	63.6	45.4	65.5
	3	46.0	67.9	50.8	75.5
	4	52.9	76.7	64.9	93.0
	5	46.2	68.0	50.7	74.8
wtd. avg. delay		48.5	70.9	55.7	81.0
base delay (actual)		42.5	62.4	42.5	62.4
net impact		6.0	8.5	13.2	18.6
wtd. impact			6.3		13.7

Note:
Total Delay is delay to all aircraft assuming that the go-around occurs in the period.
Wtd. avg. delay is avg. delay given a go-around weighted by activity in the periods.
Base delay is delay if there were no go-around. (There was none.)
Net impact is wtd. avg. delay minus base delay
Wtd. impact is avg. net impact weighted by 10% IMC and 90% VMC.

Figure 8. Estimated Delay Impact of a Go-around

A weighted average of the delay estimates is made by taking the fraction of the demand in the period (from Figure 7) to the total as the weight. This is conservative, as it assumes that the chance of a go-around occurring in a period is proportional to the activity in the period, while the chance is probably much greater in busy periods than in light periods. The base delay is then subtracted from the weighted average to form the delay impact for each go-around for both VMC and IMC. The weighted impact for the go-around uses a weight of 90% for VMC and 10% for IMC (traditionally, the approximate percentage for east coast US airports).

The bottom-line is that the first go-around is estimated to add 6.3 minutes of delay and the second go-around 13.7 minutes of delay, on average. These, for reasons already mentioned, are probably conservative estimates.

2.7 Collision Risk

The subject of mid-air collision risk is very murky and it would be essentially impossible to empirically validate a model of collision risk because, fortunately, such accidents are very rare, and most of those that do occur seem to involve special circumstances (particularly, formation flight or aerial performances) which do not apply to the situation being considered. But not being constrained to models that are validated, we forge ahead.

It is hypothesized that a collision between two aircraft flying independently could occur only if the paths they are flying on nearly intersect close enough so that the aircraft on these paths could touch. That is, they would touch if the timing was set at the worst possible time, and nothing was done to prevent it. Normal departures from the same runway are not considered to be independent because they will have departed at different times, will have been provided initial in-trail spacing, and have knowledge of the prior departure. Likewise, aircraft sequenced to land on the same runway (or dependent runways) would not be independent. Tracks of other pairs of aircraft are assumed to be independent.

It is further hypothesized that the aircraft continue to fly the observed paths in approximately the same proportions. To make the mathematics tractable, the aircraft are visualized as discs with a diameter roughly the size of the wingspan (or length of the fuselage, as appropriate) and a thickness the vertical span of the aircraft.

The first step is to look at the observed tracks to see where independent tracks come close enough to the go-around track to make a collision theoretically possible. For either go-around, no possible interference involving over-flights was found. There is obviously procedural separation in force. The following numbers of tracks that cross the go-around track are considered:

Runway 18R/L arrivals	19
Runway 18R departures	34
Runway 18L departures	12
Runway 23 departures	15
Total	80

The two go-around tracks against each other are also considered.

For the first go-around, the only possibility is another track approaching Runway 18R or 18L. For the second go-around, three areas of potential risk are identified (see Figure 4). They are: subsequent normal departures from Runway 23, departures from Runway 18R, and arrivals to Runway 18R/L. Normal departures from Runway 23 are considered independent from the go-around aircraft, because the go-around track heads away from the departure stream (to gain altitude) and then comes back across it. But it must be admitted that this encounter would be very unlikely.

The candidate tracks are examined, using a specially constructed Excel spreadsheet to do the calculations, and no possible interference is found between either go-around and approaches to Runways 18R or 18L. This eliminates an estimation of collision risk for the first go-around.

There are six potentially interfering tracks with the second go-around. They are listed in Figure 9. Five are Runway 18R departures and one is a Runway 23 departure. This suggests that five out of 34 Runway 18R departures and one out of 15 Runway 23 departure tracks pose a potential risk.

	Threat 1	Threat 2	Threat 3	Threat 4	Threat 5	Threat 6
Frequency	5 min	5 min	5 min	9 min	5 min	5 min
Source	18R dep	18R dep	18R dep	23 dep	18R dep	18R dep
A/C type	E145	E145	E145	DH-8	DC-9	B-737
PCC	9.76E-04	1.32E-03	1.83E-03	1.44E-03	7.33E-04	8.22E-05
PBC	0.938	0.938	0.939	0.939	0.921	0.8757
PEC	0.9444	0.944	0.962	0.962	0.878	0.7866
PBV	0	0	0	0	0	0
PEV	0	0	0	0.49	0	0
PT	0.986	0.986	0.986	0.986	0.986	0.986
PCON	4.71E-08	6.40E-08	5.95E-08	2.39E-08	9.90E-08	3.05E-08
Trials	34	34	34	15	34	34
Coll. Risk	1.39E-09	1.88E-09	1.75E-09	1.59E-09	2.91E-09	8.98E-10

Note:

Frequency is the time between aircraft on the threat track.
Source is the threat's runway and arrival or departure.
PCC is the raw collision risk (no intervention) from the threat assuming a go-around
PBC is the probability the go-around aircraft gets successful ATC intervention.
PEC is the probability that the threat aircraft gets successful ATC intervention.
PBV is the probability that the go-around aircraft gets successful pilot intervention.
PT is the probability of successful collision avoidance system intervention.
PCON is the probability of collision from that threat assuming all tracks are the same.
Trials are the number of tracks of similar origin considered.
Collision risk is PCON divided by the number of similar tracks considered.

Figure 9. Estimation of the Impact of a Go-around on Collision Risk

Figure 9 lists the origin and aircraft type of each of the threat tracks. Pertinent information derived from the track data, such as the crossing angle, the speeds, climb/descent rates, aircraft size, visual field of view, flight frequency, etc. is fed into a tool called the Analytic Blunder Risk Model (ABRM), which computes the probability of collision between aircraft on crossing tracks, assuming that the threat aircraft is uniformly randomly distributed on its track relative to the threatened aircraft.

Figure 9 shows the results from the ABRM for each of the six threats. ABRM first computes the risk given no intervention, and then calculates the probability of various kinds of intervention, any one of which is sufficient to prevent a collision. There is a high probability of successful controller intervention because the aircraft are already in radio and radar contact. But there is a low probability of visually initiated pilot intervention because the aspect angles and climb angles tend to keep the other aircraft outside of the field of view. All aircraft involved are assumed to have a sophisticated collision alert system. PCON is the collision risk after intervention is factored-in.

In the computation of PCON, it is assumed that identical aircraft appear on the identical track every 5 minutes for Runway 18R departures, and every 9 minutes for Runway 23 departures. However each 18R departure was one of 34 tracks considered and the Runway 23 departure was one of 15 tracks considered. Thus PCON is divided by these numbers, as appropriate, to get the bottom-line collision risk from each threat, given that a go-around occurs.

The total collision risk is obtained by summing these risks. This yields 1.0 x10^{-8}, or one collision expected in 100 million go-arounds.

The assumption is that there would be excellent visibility. But since so little benefit was obtained from visual detection, there would be no need to consider alternative visibility assumptions.

Two of the types of aircraft involved in the collision risk computation are shown below.

Photo Copyright © Phil Derner Jr.

De Havilland Canada DHC-8 Dash-8

Photo Copyright © Phil Derner Jr.

Embraer ERJ-145

3.0 Conclusion

3.1 Benefits of Avoiding a Go-around

Section 2 develops estimates of four benefits of eliminating a go-around. They are summarized in the table below. Two types of go-arounds were considered even though the second was the one of primary interest in the collaboration effort. Besides the second being the more common, the importance of reducing the number of these is made clear by comparison.

Impact (per go-around)	Runway 18R go-around	Runway 23 to 18R go-around
Direct Operating Cost	\$208	\$440
Controller Workload	0.45 separations	1.46 separations
Aircraft Delay	6.3 minutes of delay	13.7 minutes of delay
Collision Risk	No discernable Impact	Prob. of Collision = 1.0×10^{-8}

All (with the possible exception of the collision risk) are expected to be conservative estimates. All would increase disproportionately to an increase in traffic.

3.2 Annualized Benefits of the Collaboration Initiative

It is now possible to convert these estimates into an estimate of how much the collaboration initiative saves over the course of a year. Only the second go-around is considered to be reduced by this initiative and the benefits accrue only during South operations, which are in effect about 70 percent of the time.

It is estimated that prior to the initiative there was an average of three Runway 23 to 18R go-arounds per day, and this number was reduced by 21 percent. At 3 per day for 360 days per year, this means 756 go-arounds were reduced by 159 per year.

The saving in direct operating cost at an average of \$440 each would be \$70,000 per year.

The savings in delay would be 36 hours per year. At an estimated average direct operating cost of \$2,000 per hour, this would amount to a saving of \$72,000 per year in delay cost.

There would be an elimination of 232 separation actions.

There would be a reduction in collision risk from 7.56×10^{-6} per year by 1.59×10^{-6} to $5.97\times10^{-6.}$

3.3 The Bottom Line

These benefits are conservative rough estimates. They would increase disproportionately to an increase in traffic. Similar kinds of benefits might be obtained through similar initiatives at other airports, but the numerical values could be quite different.

Appendix A: Descriptions of Tools Used

A. The Sector Design and Analysis Tool (SDAT)

SDAT was developed in the 1990's by the FAA's Office of System Architecture and Investment Analysis for the FAA's Air Traffic Service. It was designed to be used by airspace and procedures specialists in FAA ATC facilities to help redesign airspace and examine alternative designs and routings.

It was later turned over to the newly formed FAA/ATO's Air Traffic Airspace Management Program which continues development. The initial versions of SDAT required a UNIX workstation as a platform. With a rapid increase in the power of personal computers, a current version has been developed that operates on a PC.

SDAT provides a display of current airspace and recorded radar air traffic data. The traffic data can be viewed as static track histories or can be animated in simulated time. The user can modify the airspace and traffic data to perform "what-if" analyses. SDAT can also perform calculations such as traffic loading, aircraft separation, etc.

More information on SDAT can be obtained on the SDAT web site:
http://atalab.faa.gov/sdat/

B. Engineered Performance Measurement System

The Engineered Performance Measurement System (EPMS) was developed by the FAA's Air Traffic Service back in the 1980's to compute a theoretical maximum capacity of an airport runway system in an effort to gauge the efficiency of the air traffic controller (ATC) staff. It was soon discovered that ATC efficiency is far too complicated than can be measured by such a tool and the tool fell into disuse.

However, it has a sound theoretical basis for estimating runway capacity, although airfield capacity is a more complex issue (involving taxiways, ramps, radio congestion, etc.) and there are often complexities involved in runway capacity that are not considered in the model. When it was used, a provision was made for a manual adjustment to the model's results.

The model is programmed on a Microsoft Excel Spreadsheet. The following is an attempt to describe in words the mathematics behind the tool.

The model considers one runway at a time. It assumes that there is an endless string of aircraft (arrivals plus departures, as appropriate) waiting to use the runway. The mix of arrivals and departures is in the proportions given as input. The mix of aircraft of various weight categories is represented in the proportion given as input. Each aircraft is a randomly selected combination of arrivals/departures and weight classes. The model computes the time required to handle each aircraft, following another aircraft. It then weights each pair of combinations by the appropriate probability of occurrence, assuming that each aircraft is placed in the queue randomly. The runway capacity is the reciprocal of the average time it takes to process a pair of aircraft.

The capacities of individual runways can be combined to compute the capacity of a combination of runways. Meanwhile, the computed processing time considers required in-trail spacing, approach speeds, the length of the common approach course, ceiling/visibility conditions, etc.

In the real world, the computed capacity can be exceeded if the aircraft appear in an order that is expeditious, if close-in finals are allowed, etc.

The author revised his version of this tool to incorporate changes in wake vortex rules that were adopted since the tool was developed.

C. The DELAYS Model

The DELAYS Model was originally developed by the MIT Flight Transportation Laboratory in the 1980's. It was programmed in FORTRAN V and is based on a theoretical queuing theory model presented in Koopman, B.O., "Air Terminal Queues under Time-dependent Conditions", *Operations Research*, 20, (1972).

The model assumes that the runway system is a queue with a constant service rate (the capacity) and Poisson arrivals (arrivals to the queue can be either arriving or departing aircraft) with a mean equal to the demand rate. (This is denoted as an M/D/K queue). These rates are good for a fixed amount of time (period) after which a new set of service rates and/or demand rates takes effect. The number of aircraft in the queue when this happens is represented by a set of states (each state representing an integer number of aircraft), each with a probability derived from Queuing Theory and the prior history developed in the model run.

While the model runs through a given number of periods, the expected number of aircraft in the queue is computed and this is used to compute the total delay. The total delay divided by the number of aircraft processed approximates the average delay per aircraft.

The DELAYS Model used was a version modified by the author to provide some special features, including allowing a specified initial number in the queue, zero demand or capacity in a period, etc.

D. Analytic Blunder Risk Model

The Analytic Blunder Risk Model (ABRM) is a theoretical, probabilistic model that computes the probability of a collision between two aircraft (a victim and a blunderer) on linear tracks. The "blunder" could be an ATC error, a pilot error, or a mechanical failure that puts the aircraft (or allows them to proceed) on trajectories that intersect in the horizontal plane a reasonable given distance from the point at which the blunderer is when the blunder occurs.

The aircraft are assumed to be on a given constant heading, speed and rate of climb/descent in the vicinity of the crossing point. The aircraft are represented as discs with a given height and radius the approximate dimensions of the aircraft.

In order for the collision to occur, the geometry of the intersection must be such that the discs (aircraft) could collide and the victim must be at a point (assumed to uniformly-randomly determined) on its path when the blunder occurs that brings it to the intersection when the blunderer is crossing it. This probability is computed using equations developed and published by the author in "Airspace Conflict Equations," *Transportation Science*, May 1985.

The ABRM then reduces the risk of collision by considering the probability of some intervention taking place in time to prevent the collision. The interventions considered are ATC detection, pilot visual detection, and collision alert systems.

The ABRM was programmed by the author on an Excel workbook. But it contains complex equations for performing geometric and statistical computations.