# IMPROVING FLIGHT EFFICIENCY THROUGH TERMINAL AREA RNAV

*Kevin R. Sprong, Brennan M. Haltli, James S. DeArmon, Suzanne Bradley, The MITRE Corporation , Center for Advanced System Development, ksprong@mitre.org, bhaltli@mitre.org, jdearmon@mitre.org, sporter@mitre.org, McLean, Virginia*

## Abstract

Analysis of Area Navigation (RNAV) arrival flights at Las Vegas airport, in the form of operational data analysis and simulation modeling, has shown improvements in flight efficiency. A redesign of flight paths in Las Vegas airspace has confounded a pure RNAV vs. non-RNAV comparison, but statistical analysis has allowed a partitioning of effects. Analysis of metrics such as altitude, flight time variation, arrival interval, and flight time and distance will provide insight into the increase in flight efficiency possible with RNAV. MITRE CAASD performed several analyses concerning benefits of RNAV arrival procedures in the terminal area, incorporating both simulation modeling and data analysis into the project. Initial results for Las Vegas show promise toward the full RNAV vision.

## Introduction

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) has been asked by the Federal Aviation Administration (FAA) to evaluate the existing and potential benefits of implementing RNAV procedures at airports throughout the National Airspace System (NAS) of the United States. RNAV procedures were implemented at Las Vegas McCarran International Airport (LAS) in October 2001, and revised procedures went into effect in November 2003. In addition, departure procedures were developed for Dallas/Fort Worth International Airport (DFW) and were in use for three days in November 2004. Revised procedures are scheduled for implementation in May 2005. This paper presents the results of several analyses performed by CAASD over the past year concerning RNAV benefits in the LAS and DFW terminal areas. CAASD performed radar track analysis for LAS in which flights from July 2000 (pre-RNAV) were compared to flights from January 2004 after the revised procedures went into effect. We intended to determine benefits in several areas including altitude profiles, predictability, and inter-arrival spacing. To support this operational data analysis, CAASD developed a model and ran a simulation in which a set of vectored tracks was instead assigned to one of several RNAV procedures constructed for the simulation. In addition, another operational analysis was performed comparing RNAV radar tracks from 2004 to vectored tracks from 2004 at LAS in order to ascertain time and distance benefits for RNAV flights operating in the same airspace as non-RNAV flights.

## Background

RNAV is a method of navigation enabling point-to-point flight according to a pre-programmed profile. An RNAV procedure, a combination of lateral, vertical, and speed directives along a set of waypoints (a waypoint is a point in space defined by a latitude and a longitude), is typically pre-programmed into a flight management system (FMS) and executed upon Air Traffic Control (ATC) clearance. In addition, ATC has the ability to send any aircraft directly to any waypoint or fix along the route; this is known as a direct-to command and is usually used for spacing, merging, or to expedite aircraft. The RNAV navigation solution typically comes from two different sources: the first is Distance Measuring Equipment (DME), a ground-based navigation aid which sends a signal to an aircraft indicating the aircraft's distance from the DME. Using a network of DMEs, possibly in conjunction with an on-board Inertial Reference Unit (IRU), an aircraft can navigate point-to-point along a pre-defined route. The second method of navigating point-to-point along a route is through a Global Navigation Satellite System (GNSS), particularly Global Positioning System (GPS). For the purposes of this paper these two methods are considered equivalent, and any flight that can navigate point-to-point via an FMS and navigation database is considered to be an RNAV flight. Terminal RNAV procedures are currently in use at numerous airports in the United States and Europe. Usage of RNAV procedures in the terminal area has the potential to provide benefits to both ATC and operators in the form of reduced communications, reduced flight time and distance, lower fuel burn due to a more efficient flight profile, and increased predictability. In addition, the safety benefit of RNAV, resulting from increased route predictability and the increased awareness experienced by both controllers and pilots due to reduced communications, has been cited by both ATC and operators as an important benefit of RNAV procedures.

## *Description of Las Vegas Operations*

LAS consists of two sets of closely spaced parallel runways, 25L/25R (7L/7R) and 19L/19R (1L/1R). Three main runway configurations are used to conduct operations, one of which we will discuss in detail. The airport layout is charted below in Figure 1. Two important considerations in studying Las Vegas Operations are the large percentage of RNAV-capable flights, and the overwhelming amount of time that operations are conducted in Visual Meteorological Conditions (VMC). Enhanced Traffic Management System (ETMS) [6] data indicates that over 90% of flights arriving at LAS are RNAV-capable. In addition, over 95% of operations are conducted in VMC.

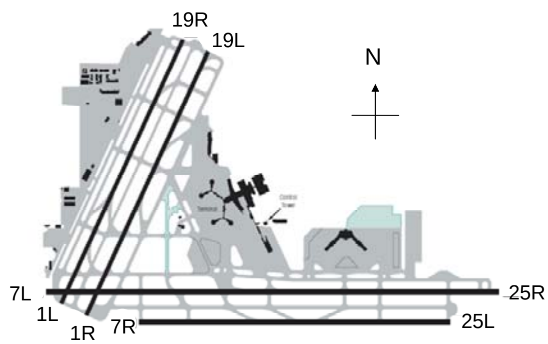


**Figure 1. LAS Airport Diagram**

When LAS is in configuration one, the primary runway configuration, arrival flights land on runways 25L and 19L, and departures use runways 19L and 25R. Since the emphasis of CAASD's benefits analyses at LAS has been on RNAV arrival procedures, and configuration one is the only one in which RNAV arrival procedures are used, it will be the primary configuration discussed in this paper. Although LAS uses both 19L and 25L for arrivals, around 75% of arrival flights use Runway 25L according to radar track data. Configuration one was in use for 98% of the time over the periods of time we analyzed (1 July – 10 July 2000, and 4 Jan. - 9 Jan. 2004), and was always in use during the time period we analyzed in 2000. In other configurations, radar vectors are used to direct flights to their arrival runways, and these configurations are uninteresting from an RNAV benefits perspective. These auxiliary configurations are used mainly when winds dictate that the airport switch to landing and departing flights via Runways 19L/R or Runways 1L/1R, and further references to LAS operations in this paper will assume configuration one is in use. Operations in the year 2004 will be discussed first, as the 2004 RNAV flights are the main focus of the benefit analysis

LAS arrival flows are arranged in a four-corner-post setup; this is preferred by ATC as it allows for more efficient handling of traffic. Arrival flows into LAS are handled by one of two feeder controllers, and the flows are divided among the feeder controllers by their geographic entry point into LAS terminal airspace. Arrivals coming in from the west and southwest (known as the "granite" side of the airspace) are handled by one feeder controller, and arrivals from the east and southeast (the "lake" side of the airspace) are handled by the other feeder controller. These two feeder controllers eventually hand the aircraft off to final airspace controllers, who work the traffic on downwind legs to Runways 19L and 25L. The RNAV procedures feeding the granite side of the terminal area are KEPEC from the southwest and SUNST from the west, and CLARR and FUZZY are the corresponding conventional (non-RNAV) procedures - based on Very High Frequencey (VHF) Omnidirectional Range (VOR) equipment and radar vectors. On the lake side of the terminal airspace, the RNAV procedures are TYSSN from the southeast and GRNPA from the northeast, while KADDY is a conventional procedure also feeding the terminal airspace from the southeast. See Figure 2 for a visual depiction of current LAS airspace in configuration one GRNPA is unique among RNAV procedures at LAS in that it ends at a downwind to Runways 19L/19R, and thus flights entering the terminal airspace on the GRNPA procedure are often vectored to a final approach to Runway 25L well before the completion of the GRNPA route. Therefore, we did not consider flights on the GRNPA procedure in our benefits studies. LAS airspace and the main flows for configuration one in 2004 are depicted below (some tracks are not displayed for clarity).

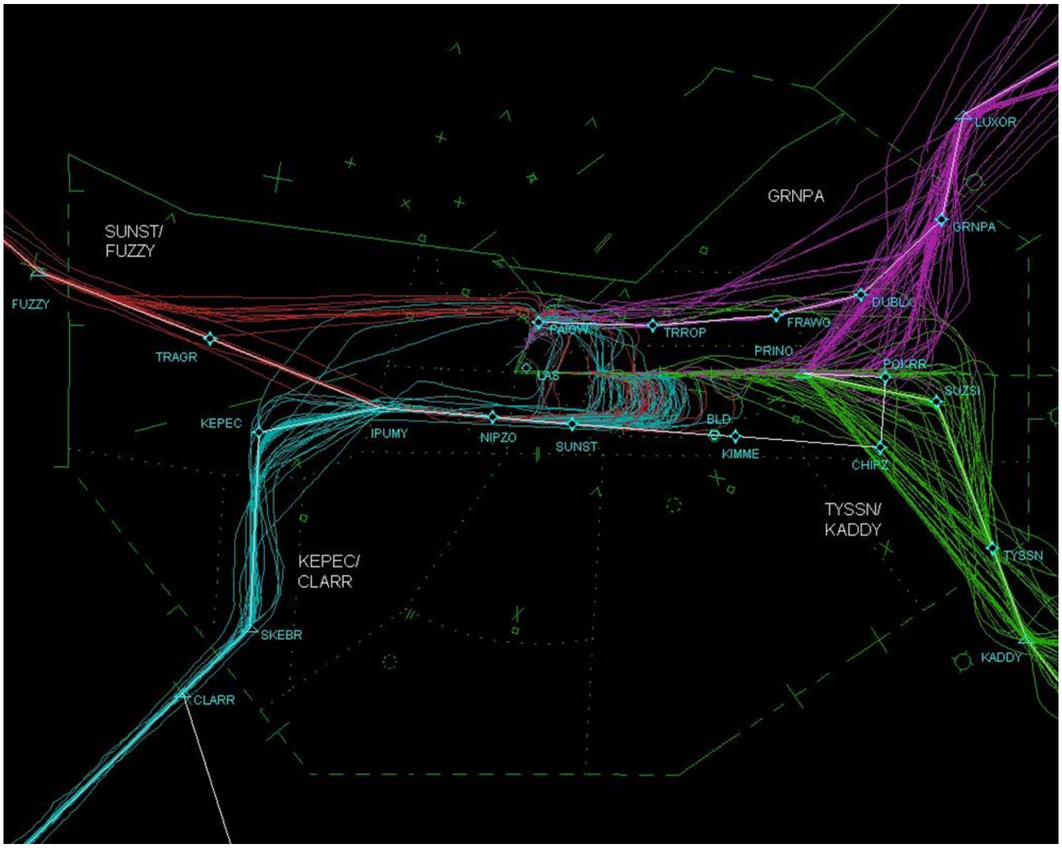


**Figure2. 2004 LAS Airspace and Main Arrival Flows**

LAS terminal operations in the year 2000 had several differences from operations in 2004. First and foremost, the lack of RNAV procedures in the year 2000 means that all navigation was done via conventional procedures and radar vectors. Another important factor to consider is the airspace redesign that occurred between 2000 and 2004, which was a result of many factors including departure facilitation, environmental concerns, and political factors. As we can see from Figure 3 below depicting LAS operations in the year 2000, the flows shifted somewhat to give LAS a true four-corner-post layout; previously the southeast and northeast flows were closer together on the lake side of the airspace, and the southwest flow was previously arranged to the south of the airport. The rearrangement which took place in between the year 2000 and 2004 has been beneficial to operators in the form of slower descent paths, which are more friendly to airframes, and beneficial to controllers since there is now more open space between the routes to use for sequencing, merging, and expediting flights. Finally, the airspeed at which aircraft are intended to be handed off to terminal controllers was lowered by 30 kts, from 280 kts to 250 kts. This change was facilitated to allow better traffic management in the terminal area from a controller workload/effectiveness standpoint, and similar changes were made in other terminals in the NAS (Chicago O'Hare, for example, effected such a change).

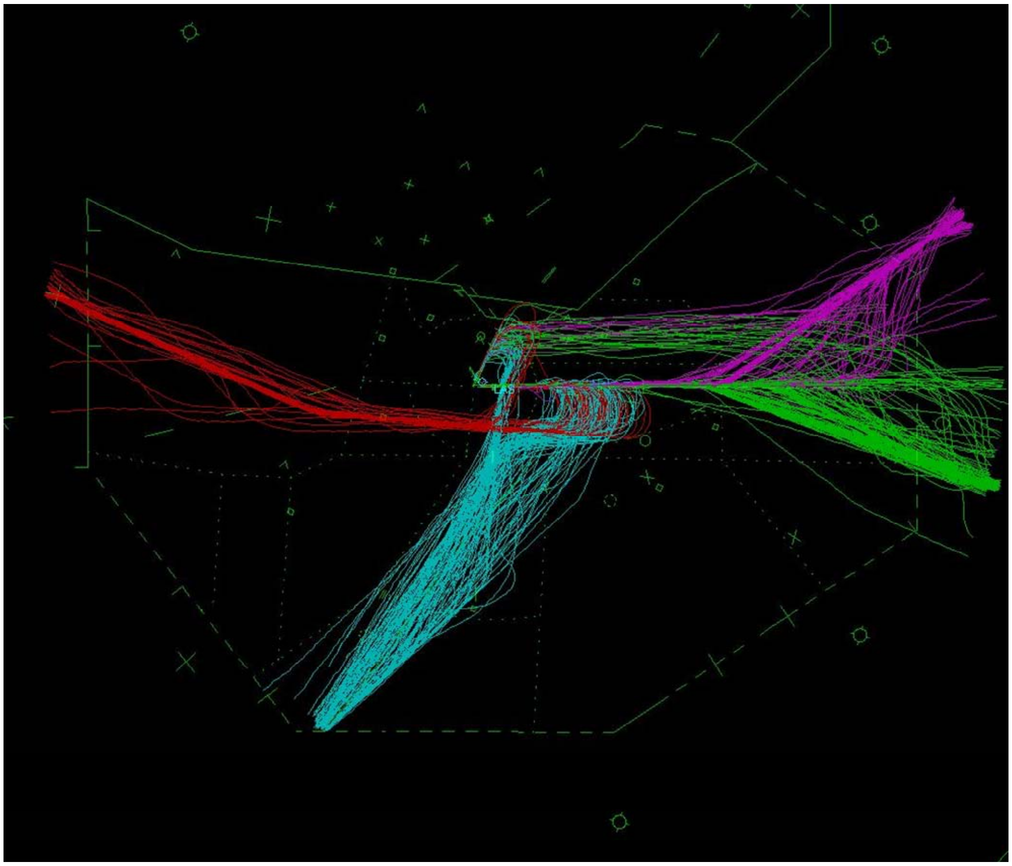

**Figure 3. 2000 LAS Airspace and Main Arrival Flows**

## *Operational Data Analysis Description*

According to related studies [3, 4, 5], there are several benefits to flying RNAV procedures in the terminal environment, including:

- Reductions in flight time and distance
- Increased predictability of route traversal time
- Aircraft remain higher and faster for a longer period of time
- Better lateral conformance to a route
- Increased regularity of Inter-Arrival Time (IAT)

These benefits manifest themselves from several factors, including reductions in vectoring and the associated errors (e. g., an FMS corrects for wind to ensure an aircraft stays on its intended course, a vector does not), FMS-calculated vertical flight profiles which are more efficient than the interim level-offs given to aircraft by ATC, positive course guidance over the entire duration of a route, and increased awareness due to a reduction in communications. We used MITRE/CAASD's Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS) to analyze radar track data from the year 2000 and the year 2004 in order to measure these metrics in the redesigned LAS terminal environment. The TARGETS tool was originally conceived as a procedure design tool, but includes fairly extensive analysis and simulation capabilities. TARGETS is the primary procedure design tool used by the FAA for designing Standard Terminal Arrival Routes (STARs) and Standard Instrument Departures (SIDs), which has created the need for controllers at many facilities nationwide to be trained in its use . TARGETS has been used by MITRE/CAASD for several track data analysis projects and simulations, and has the capability not only to measure metrics of a radar track at a given point in space (such as time of crossing, latitude/longitude, airspeed and altitude), but also to determine the elapsed time and distance of a track between two specified points.

We used TARGETS to measure the altitude, airspeed, and lateral track dispersion of flights at four points along the west flow of traffic, stopping at the handoff point to the final controller for Runway 25L (see Figure 4).

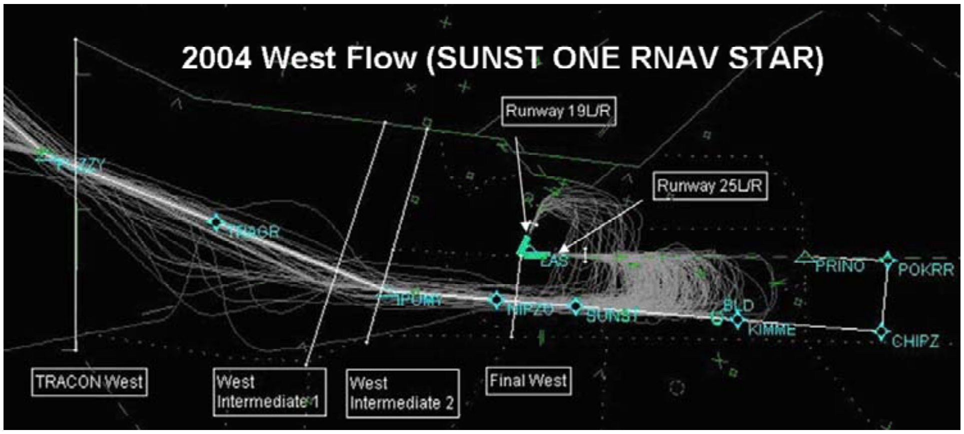


**Figure 4. LAS West Flow Analysis Setup**

The west flow was used because the 2004 RNAV procedure (SUNST) overlays the vector pattern from the year 2000 (a property unique to SUNST among the revised RNAV procedures), providing a direct method of comparison among the two operational environments. However, non-RNAV aircraft were not removed from the 2004 set in this analysis, as we operated under the hypothesis that vectored aircraft might receive some benefit in being interspersed with RNAV flights. Only flights landing on Runway 25L were analyzed, for the following reasons: traffic landing on Runway 19L in 2004 was vectored off of the main west flow at a different point than in 2000, and is vectored off too early to be representative of an RNAV sample (see Figure 2). In addition, the traffic flows to Runway 19 consist of a large percentage of general aviation flights, which have an overall lower performance than the jet traffic we wish to measure, and that lower performance may confound our analyses. For a more detailed treatment of our analysis setup, see [1].

We were also interested in the IAT of flights entering the final airspace, defined as the time between successive flights. The IAT is an important metric due to the fact that as it becomes more predictable, the extra spacing between aircraft (beyond IFR radar separation distance) may be able to be reduced. We were unable to use the west flow for our IAT analysis, due to the dynamics of the merges in the feeder airspace. In the 2004 environment, both flows merge before the entry point to the final approach airspace. However, in the 2000 environment the south and west flows have not yet merged when the flights enter the final approach airspace. For this reason we focused our analysis of IAT on the southeastern and northeastern flows, as those flows merge prior to the final airspace handoff point in both environments. For a more detailed discussion of the significance of IAT as a metric, and our analysis setup, see [1].

We also gathered measurements of flight time and distance along each flow starting at the entry to the terminal airspace and ending at the handoff to final (denoted by the data collection points 'TRACON West' and 'Final West'; analyses for other flows were performed similarly), although we do not attribute these results to RNAV. This shall be explained further when we discuss results, and it was necessary to perform further analyses to determine time and distance benefits of RNAV.

## *Operational Data Analysis Results*

### Altitude

The results from our analysis of aircraft altitudes are included in Table 1. Notice that at each data collection point the aircraft in 2004 flew higher than their year 2000 counterparts.

**Table 1. Altitude Comparison (West Flow)**

| Data Collection Points | Mean Altitude (μ) ft. | | P Value |
|---|---|---|---|
| | 2000 | 2004 | |
| TRACON West | 15,715 | 15,872 | <.0001 |
| West 1 | 10,846 | 11,622 | <.0001 |
| West 2 | 10,273 | 10,949 | <.0001 |
| Final West | 8,423 | 8,751 | <.0001 |

We cannot assume that all 2004 aircraft are flying the entire RNAV procedure, including the pre-programmed vertical element, in 2004, and we know that there is some percentage of non-RNAV aircraft in the fleet mix in 2004; however, we found that aircraft in 2004 were flying significantly higher at each point we measured, which may be due to the reduction in vectoring associated with RNAV, coupled with the pre-programmed vertical profile. This provides a benefit to aircraft fuel burn: since air is less dense as altitude increases, aircraft flying higher encounter less air resistance and have to burn less fuel. In addition, this "higher, longer" phenomenon is beneficial to departures, as they are now able to climb out at a higher altitude. This effect was described during meetings with the facility, and we did observe an increase in altitude for departures (however, those results are not the focus of this paper). It remains to be seen whether the four points we measured are representative of the behavior of the entire flow; a more complete analysis of vertical flight profiles is being performed in follow-on work.

**Lateral Track Dispersion**

Again we found benefit in this facet of RNAV operations, as tracks were found to conform better to the mean path in 2004 when compared to the year 2000. We defined a flight's lateral dispersion as its deviation in nautical miles from the "nominal path". The nominal path is represented by the RNAV path in 2004 and the conventional STAR from 2000. Although SUNST is an overlay procedure, several revisions have led to a very slightly different ground track. We determined each flight's crossing point and that point's distance from the nominal path in nautical miles. Our results are summarized in Table 2. The results include the removal of outliers from the data sets due to never being on the actual flow, even though the flights entered the terminal area from the west.

**Table 2. Lateral Track Dispersion (West Flow)**

| Data Collection Points | Distance (nmi) from the Nominal Path | | |
|---|---|---|---|
| | 2000 | 2004 | P Value |
| TRACON West | $\mu$ = 0.28 | $\mu$ = 0.15 | <.0001 |
| | $\sigma$ = 0.79 | $\sigma$ = 0.26 | <.0001 |
| West 1 | $\mu$ = 0.36 | $\mu$ = 0.27 | .037 |
| | $\sigma$ = 0.76 | $\sigma$ = 0.72 | .001 |
| West 2 | $\mu$ = 0.24 | $\mu$ = 0.12 | <.0001 |
| | $\sigma$ = 0.49 | $\sigma$ = 0.31 | <.0001 |
| Final West | $\mu$ = 0.14 | $\mu$ = 0.09 | <.0001 |
| | $\sigma$ = 0.26 | $\sigma$ = 0.22 | <.0001 |

These data indicate that aircraft are able to fly a more predictable and repeatable flight path when RNAV is in use, though the result is probably weakened somewhat by the presence of worse-conforming vectored aircraft in the 2004 data sample. With a purely RNAV sample, a tighter degree of conformance is expected [3].

**Groundspeed**

In measuring the groundspeed of aircraft along the west flow, we found that the aircraft were flying slower on average in 2004, as dictated by the change in operations to a lower handoff speed. The differences in standard deviations of the groundspeeds were not statistically significant at a 95% confidence level. This lower average groundspeed would lead to a slower flight time for 2004 flights, but we do not attribute this change to the implementation of RNAV. Our groundspeed results in nautical miles per hour are presented in Table 3. Note that measurements are groundspeed, as opposed to airspeed which controllers and pilots use.

**Table 3. Groundspeed Comparison (West Flow)**

| Data Collection Points | Groundspeed (kts) | | |
|---|---|---|---|
| | 2000 | 2004 | P Value |
| TRACON West | $\mu$ = 301.9 | $\mu$ = 282.9 | <.0001 |
| | $\sigma$ = 24.5 | $\sigma$ = 26.6 | .065 |
| West 1 | $\mu$ = 283.8 | $\mu$ = 265.2 | <.0001 |
| | $\sigma$ = 25.0 | $\sigma$ = 25.5 | .340 |
| West 2 | $\mu$ = 274.5 | $\mu$ = 259.3 | <.0001 |
| | $\sigma$ = 23.0 | $\sigma$ = 23.5 | .363 |
| Final West | $\mu$ = 248.1 | $\mu$ = 237.5 | <.0001 |
| | $\sigma$ = 20.4 | $\sigma$ = 21.1 | .259 |

**Inter-Arrival Time (East Flows)**

Analysis of the IAT both at the final airspace and at the runway threshold showed no change in the means for 2000 vs. 2004. Note that since IAT is related to throughput, this means that there was no statistically significant difference in total throughput for the flight sets and time durations we measured. However, the standard deviation of the IAT was lower with RNAV at both the entrance to final airspace and at the runway, and this result may be attributable to the regularity and predictability induced by RNAV. The results of our IAT analysis are shown in Table 4, in seconds. Note that filtering had to be applied to the data to ensure that abnormally large IATs which would result from natural gaps in demand were not included in the results.

**Table 4. IAT Standard Deviations at Final Airspace and Runway Threshold**

| | 2000 | 2004 | F Value |
|---|---|---|---|
| Final Airspace East Entrance | σ = 121 s | σ = 105 s | <.0001 |
| Runway 25L | σ = 51 s | σ = 46 s | <.0001 |

This reduction may be a function of several factors, including the inherent regularity of an RNAV path, intelligent use of the direct-to fix command, or efficient use of speed directives versus lateral vectors, but the combined effects of RNAV seem to assist in reducing IAT variation twofold: IAT variance is lower when comparing 2004 to 2000, and the IAT is reduced less between the final airspace and runway in 2004, perhaps indicating increased regularity earlier in the route. Although this small reduction in variance does not provide any immediate increase to throughput, the data indicate a step in a positive direction for RNAV procedures and the potential they have to lower the spacing buffer through increased regularity and predictability.

**Flight Time and Distance**

The classic metrics used to measure efficiency are flight time and distance – the lower the better. However, we had trouble measuring these metrics in the context of our comparison between the 2000 environment and the 2004 RNAV environment. Due to the slower speeds exhibited by aircraft upon entering the terminal area in 2004, flight time was not a metric attributable to RNAV implementation. Similarly, distance flown cannot be attributable to RNAV due to the changes in ground track caused by airspace redesign. Still, for this analysis we measured flight time and distance for each of the three flows for which RNAV procedures were in use to Runway 25L. The results are presented in Tables 5-7.

**Table 5. West Flow Time and Distance Results**

| Metric | Year | | P Value |
|---|---|---|---|
| | 2000 | 2004 | |
| Flight Time (sec) | μ = 378.9 | μ = 409.8 | <.0001 |
| | σ = 41.9 | σ = 35.7 | <.0001 |
| Distance (nmi) | μ = 35.0 | μ = 34.9 | .713 |
| | σ = 0.3 | σ = 0.5 | <.0001 |

**Table 6. South/SW Flow Time and Distance Results**

| Metric | Year | | P Value |
|---|---|---|---|
| | 2000 | 2004 | |
| Flight Time (sec) | μ = 336.3 | μ = 450.1 | <.0001 |
| | σ = 52.3 | σ = 65.5 | <.0001 |
| Distance (nmi) | μ = 28.3 | μ = 35.3 | <.0001 |
| | σ = 1.5 | σ = 0.5 | <.0001 |

**Table 7. East/SE Flow Time and Distance Results**

| Metric | Year | | P Value |
|---|---|---|---|
| | 2000 | 2004 | |
| Flight Time (sec) | μ = 230.5 | μ = 330.2 | <.0001 |
| | σ = 25.8 | σ = 88.2 | <.0001 |
| Distance (nmi) | μ = 18.4 | μ = 24.5 | <.0001 |
| | σ = 1.2 | σ = 6.8 | <.0001 |

Notice that the difference in distance flown for the west flow was not statistically significant at a 95% confidence level; this is to be expected since these flows are overlays and therefore distance should be similar. However, the time flown is different and significant at a 95% confidence level due mainly to the reduction in airspeed present in the 2004 environment. Since flight time and distance are so incomparable due to changes in airspeed and operations, additional analyses in the form of simulation and an additional operational data analysis supply that portion of the RNAV benefits story, and are presented below. In addition, [3, 4, 5] all demonstrate a flight time and/or distance benefit due to RNAV procedures.

## *Measuring Flight Time and Distance via Simulation Modeling*

Since we were unable to compare flight time and distance using operational data given the changes in airspace and operations across the two environments, we developed a simulation in TARGETS to model the effects of RNAV on LAS year 2000 airspace if all other variables were held constant. To construct our simulation, we started with a day of sample data from the year 2000, and constructed overlay RNAV procedures. These procedures were constructed using the average latitude, longitude, speed, and altitude at several key points along each flow. We then compared the original tracks with the tracks after assignment to the RNAV procedure corresponding with their flow.

Again, only flights landing on Runway 25L were simulated. The sample data in grey and the modified data on the RNAV procedures in blue can be viewed in Figure 4.

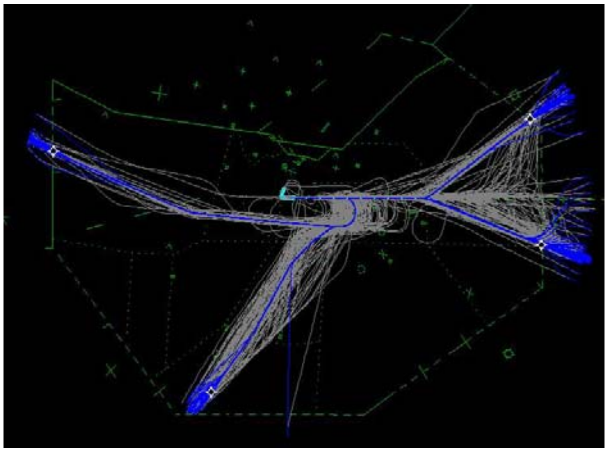

**Figure 4. Baseline and Simulated Tracks**

Flights flying the RNAV procedures were "expedited"; this is a function in TARGETS that instructs simulated tracks to fly an efficient profile for as long as possible, descending and slowing only to meet speed or altitude constraints of the procedure. Since this adjusts the speed and location of each flight in the simulated RNAV case, and the time that each flight crossed a merge point changed, it became necessary to handle spacing conflicts that arose at the points where multiple flows merged. This was done by collecting metrics from the baseline data detailing aircraft separation at the merges, and through random sampling of the lower quintile of that data, we ensured that each RNAV pair of aircraft obeyed a separation observed in actual year 2000 operations. We represented this as a slowdown of the trailing aircraft, so that it would cross the merge at the time we required. Each flow has a maximum time that can be added to a flight's flying time based on the minimum speed of the route, and each flight was checked against this maximum slowdown. We sampled from the lower quintile-due controllers' assertions that RNAV reduces workload, and thus controllers could focus on more efficient merging of aircraft. After this correction it was then necessary to apply this methodology at the downwind, the trombone shaped portion of the track just prior to the merge on final. This was accomplished by collecting operational data concerning length and elapsed time of various downwind legs, and applying a downwind leg to each flight so that it would conform to observed runway spacing (taking into account leading and trailing wake vortex classifications). For a more detailed treatment of the methodology of this simulation, see [2]. Then we compared the baseline vectored data to our simulated RNAV data in the same manner as our operational data analysis.

## *Results of Simulation Modeling*

### Flight Time and Distance

We found that our RNAV sample conformed to our hypothesis of less time and distance flown. This is manifested in our simulation in two ways. First, there was less vectoring, as traffic was managed solely on the basis of speed control. The second method was accomplished via TARGETS "expedite arrivals" function, which simulated the benefits of an optimal FMS computed flight path, allowing the aircraft to remain higher and faster longer. The least-squares mean of both samples flight time and distance are shown in Table 8.

**Table 8. Flight Time and Distance Results for Simulation**

| | RNAV | Vectored |
|---|---|---|
| **Time (sec)** | 615 | 653 |
| **Distance (nmi)** | 43.6 | 44.4 |

Both comparisons are statistically significant at a 95% confidence level, and the data indicate that we can expect approximately 38 seconds of savings under the conditions described in the simulation. Time and distance metrics were also computed for each flow. [2]

### Downwind Length

One phenomenon we noticed with respect to our simulation was a reduction in variance of the downwind portion of the flight (the portion located in the final controller's airspace, where aircraft fly parallel to the runway and are given a vector around to the runway as appropriate for merging), where vectoring for merging and spacing to final can lead to excessive distance flown, and can also add to the amount of airspace used. Due to the regularity induced by RNAV, the variance in lengths of the downwind legs shortened significantly in our simulation. The distribution of tracks in the downwind region of flight can be seen in Figure 6, which is known as a box and whisker plot and is a useful graphic to display dispersion of a distribution. Figure 6 shows not only a reduction in the average downwind distance flown, but also in the variation, or dispersion of the downwind distance. The standard deviation of time flown in the downwind was 25% less for the RNAV data sample (86.4 seconds versus 64.6 seconds). In addition, flights saved 1 mile on average in the trombone regime. However, flight time savings in the trombone were not found to be statistically significant (p = .11).

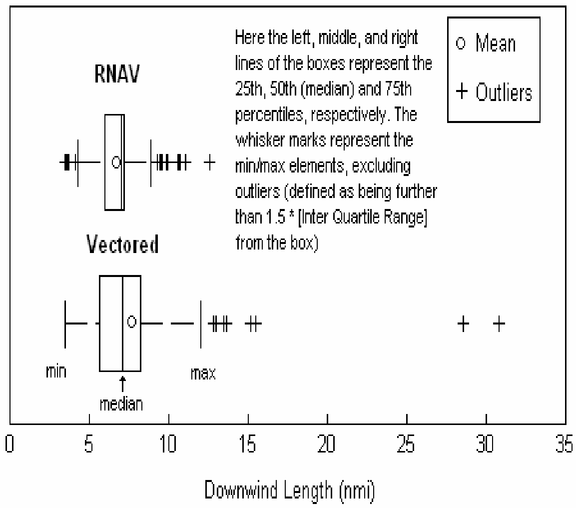


**Figure 6. Box and Whisker Plot of Downwind Lengths**

Other CAASD research has explored the phenomenon further, namely a study in 2004 which measured the effects of terminal RNAV in the final approach regime via a controller in the loop simulation. The study (see [6]) used the percentage of RNAV aircraft as the variable, and is a follow on to [3]. This study found that the benefits of RNAV procedures do carry over into the final approach regime, supporting the results we found in our simulation. To fully realize the benefits observed in these simulations in the final airspace, it may be necessary to employ controller decision tools, e.g. spacing or merging/sequencing aids.

### *Operational Data Analysis of Flight Time and Distance – 2004*

At a meeting with LAS facility representatives and operators where the above material was presented, the suggestion arose that a useful way to observe time and distance savings would be in the context of RNAV vs. non-RNAV flights in present day operations. This would provide a way to correct for airspace differences as we did in our simulation, but with the realism inherent in measuring operational data and using the actual routes flown at LAS. For this analysis, we used the three flows in 2004 for which RNAV procedures in use, since there was a corresponding conventional procedure for each RNAV procedure, against which we could measure a time and distance benefit. Using ETMS data in conjunction with our radar track data from the year 2004, we were able to discern who filed a route and equipment suffix combination that indicated no RNAV capability. ETMS data also allowed us to confirm that the non-RNAV flights filing for conventional procedures were all large jet aircraft, eliminating a potential imbalance in performance which may have confounded our results. Through observation of the track data and ETMS, we were also able to identify those flights which filed for an RNAV procedure but were then obviously vectored off of the procedure before any real benefit could be realized. Removing those flights from the RNAV sample, since they did not follow any part of the route, we performed a comparison of flight time and distance between the RNAV and non-RNAV flights. Least-squares means of the flight time and distance are presented in Table 9. Both comparisons are statistically significant.

**Table 9. Time and Distance Measured From 2004 Data**

| | RNAV | Vectored |
|---|---|---|
| **Time (sec)** | 379 | 395 |
| **Distance (nmi)** | 30.9 | 31.3 |

Here we observe a savings of 16 seconds and 0.4 nautical miles for the RNAV flights when compared to the non-RNAV flights. One of the explanations for this benefit was proposed in a discussion with the facility as follows: since the non-RNAV flights are guided to the runway by radar vectors, they may occasionally fly a longer path when a heading vector is given a few seconds late. In addition, pilot error may occasionally contribute to a longer flying time due to hear-back/read-back error of the heading instruction. Analysis of RNAV and non-RNAV tracks in 2004 is ongoing, and will be updated with more recent track data; both to confirm this finding in the 2004 environment and to detect a possible positive trend in observed benefits. As controllers and pilots become more comfortable with the procedures, we may see an increase in efficiency in the metrics we have measured here.

## Conclusion and Next Steps

To summarize, this paper has described terminal area RNAV operations at LAS, and shown computations of RNAV improvements in terms of: arrival flights remaining at higher altitudes, having lower lateral dispersion, lower inter-arrival time variance, and reduced variation in flight time and distance flown. We have also begun to observe an incremental reduction in overall flight time and distance when comparing RNAV flights to non-RNAV flights within the same airspace. In addition, ATC and operators have both cited an immense benefit in the area of communication reduction, and are also touting an increased level of safety as a very important benefit.

Research and analysis in this important area continue. Results here have shown small changes in the right direction. As sites with terminal RNAV see increases in controller familiarity and acceptance, we expect that the influence of RNAV will be even greater, delivering additional benefits to both ATC and aircraft/airline operators. At the direction of the FAA, MITRE/CAASD will initiate operational analysis of new sites (e.g., Washington-Dulles and Atlanta in 2005) and continue to monitor progress at established sites (including LAS). In addition, other benefit areas being explored are the aforementioned issues of controller workload/productivity and reduced communications.

## References

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## Author Biographies

Kevin Sprong is a Staff Engineer with The MITRE Corporation's Center for Advanced Aviation Systems Development (CAASD), where he has contributed to several papers on RNAV/RNP Analysis. He has a B.A. in Mathematics from the University of Virginia.

Brennan M. Haltli is a Staff Engineer with The MITRE Corporation's Center for Advanced Aviation System Development (CAASD). He has a B.S. in Aerospace Engineering from the University of Virginia and holds a Commercial Multi-Engine Instrument Rated pilots license.

James S. DeArmon is a Principal Engineer with The MITRE Corporation's Center for Advanced Aviation System Development (CAASD). He has worked for the last several years in research and modeling of air traffic flow dynamics. He holds a Master's degree in Operations Research, and has taught graduate courses at the University of Maryland. He has written numerous papers in aviation and applied math. He is a member of the Editorial Advisory Board of the journal *Computers and Operations Research.*

Suzanne Bradley Porter is a Project Team Manager for the RNP and RNAV Analysis Team at MITRE CAASD. She has been with MITRE for over 20 years and has worked on CPDLC, TCAS, and Navigation Architecture.