MP150218R1

MITRE PRODUCT

Houston Metroplex Post-Implementation Analysis

Sponsor: The Federal Aviation Administration
Dept. No.: F071
Project No.: 0215CW03-HO
Outcome No.: 3
PBWP Reference: 3-5.A.1-2,
"2014 *Optimization of Airspace and Procedures for Metroplex (OAPM) Houston Metroplex Post Implementation Analysis*"

McLean, VA

The MITRE Corporation

November 2015

Center for Advanced Aviation System Development

Abstract

The Houston Metroplex project's 29 May 2014 implementation included 60 new or modified arrival and departure procedures at George Bush Intercontinental Airport (IAH), William P. Hobby Airport (HOU), and 16 satellite airports within the Houston Metroplex region. The project was initiated based on: (1) predicted fuel savings from improved lateral and vertical flight paths; and (2) an expectation of reduced phraseology, frequency congestion, and pilot workload from de-conflicting procedures and creating more repeatable and predictable paths. The post-implementation analysis compared airport operations in the months after the implementation to a similar period from the year prior. This is an updated report that expands the analyzed traffic sample to better represent the operational impact of the new Metroplex procedures. The impacts measured for the Houston Metroplex result in an extrapolated annual benefit of $5.3 million to operators at IAH and HOU. Qualitative benefits are also being realized, though there are indications that delays increased slightly after implementation.

Table of Contents

List of Figures

List of Tables

1 Introduction

The Metroplex program is part of the Federal Aviation Administration's (FAA) Next Generation Air Transportation System (NextGen) initiative to modernize the National Airspace System (NAS). Metroplex site implementations involve the development of Performance-Based Navigation (PBN) procedures and the associated redesign of airspace for improved operational efficiency and reduced fuel consumption. Post-implementation impact assessments play a key role in determining each project's success, by measuring the impacts against these objectives.

This report updates the original post-implementation impact assessment of the Houston Metroplex project relative to the expectations set forth during the Study Phase and later during the Design Phase. This updated analysis contains a larger number of contributing operations and better represents the operational impact of the new Metroplex procedures. The summary findings from the original assessment are shown in Appendix A.

This report also contains updated Study Team and Design and Implementation (D&I) Team predictive benefits. Study Team and D&I Team predictive benefits were updated at every Metroplex site to enable a more accurate comparison with post implementation benefits.

2 Overview of Implementation

The Houston Metroplex project's 29 May 2014 implementation added 49 new procedures, modified 11 existing procedures, and removed 20 procedures at George Bush Intercontinental Airport (IAH), William P. Hobby Airport (HOU), and 16 satellite airports within the Houston Metroplex region. This report analyzes operational efficiency impacts at IAH and HOU by comparing operations in the months after the implementation to a similar period from the year prior. These procedure additions, modifications, and removals are summarized in Table 1. Since nearby satellite airport operations are not evaluated in this report, the new and modified satellite airport procedures are not included in Table 1 or illustrated in subsequent graphics.

Table 1. Houston Metroplex Procedure Additions, Modifications, and Removals

Procedure	Change	IAH	HOU
RNAV STARs	Added	12	5
	Modified	0	0
	Removed	7	5
RNAV SIDs	Added	10	10*
	Modified	0	0
	Removed	4	3*
Conventional STARs	Added	2	3
	Modified	2	1
	Removed	1	1
Conventional SIDs	Added	0	0
	Modified	0	0
	Removed	1	1**
RNP Authorization Required (AR) Approaches	Added	4	0
	Modified	2	0
	Removed	0	0
ILS Transitions	Added	5	1
	Modified	0	0
	Removed	0	0

** Shared IAH/HOU for six of the North Flow procedures.*
*** Shared IAH/HOU procedures.*

Several key operational changes resulted from the project implementation, principally:

- Use of flow dependent arrival procedures for IAH, in which the flight path and vertical profile are optimized for the arrival configuration at the airport;
- Emphasis on conforming to the new procedures as a mechanism for leveraging the Optimized Profile Descents (OPDs); and
- Expanded use of Time Based Flow Management (TBFM) as a mechanism for managing arrival traffic en route prior to top-of-descent.

2.1 IAH Changes

The project implemented 12 Area Navigation (RNAV) Standard Terminal Arrival Routes (STARs) for IAH arrivals. The arrival procedures were designed as OPDs, which include altitude “windows” that allow most aircraft to fly a vertical profile without level-offs for a large portion of the flight track between top of descent and the runway. Each arrival procedure is “flow dependent” meaning that one set of procedures is flown when the airport is in an east configuration and another is flown in a west configuration. The use of flow dependent procedures allowed the Metroplex D&I Team to tailor the altitude windows to the runway configuration that each procedure services. Speed restrictions were generally added to help Air Traffic Control (ATC) manage aircraft arrival compression without impacting a flight’s ability to maintain an OPD trajectory. Dual procedures for arrivals from the northwest and northeast allow ATC to issue clearances for either procedure for sequencing purposes and to separate traffic based on an aircraft’s arrival runway.

The Metroplex D&I Team considered TBFM integration critical to managing the dual streams for IAH arrivals. This would prioritize speed management over vectoring for merging and sequencing prior to top-of-descent in order to allow more arrivals to utilize and accrue the benefits associated with the OPDs. Expanded use of TBFM began in the months leading up to implementation, including use of Adjacent Center Metering (ACM) with both Fort Worth and Memphis Air Route Traffic Control Centers (ARTCCs). The intent was to sequence traffic in the en route phase of flight rather than closer to Houston area airports. During the months following implementation, a number of TBFM modifications were made to meet these expectations. Perhaps the most significant of the post-implementation adjustments was the use of Instrument Flight Rules (IFR) scheduling mode for all configurations.

Figure 1 depicts an arrival traffic sample before and after the Metroplex implementation. Several lateral shifts in the fights paths are evident and appear to align generally with the lateral paths of the new STARs.

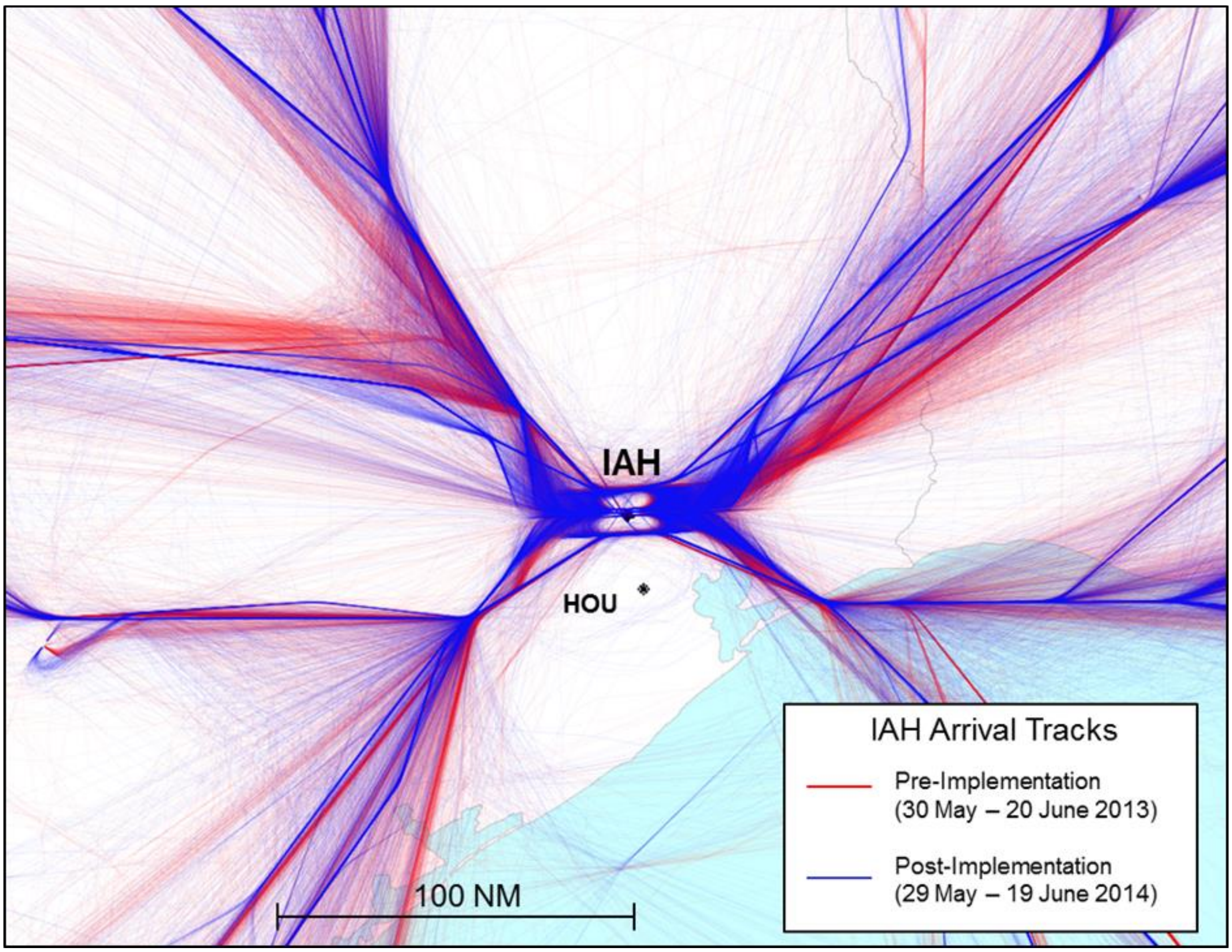

Figure 1. IAH Arrival Tracks

The project also implemented ten RNAV Standard Instrument Departures (SIDs) for IAH departures. These procedures were intended to largely mirror current operations. The northbound procedures generally do not have any altitude restrictions, while the other directions incorporate largely “at or above” restrictions. Figure 2 depicts a departure traffic sample before and after the Metroplex implementation; tighter lateral paths are observed within the terminal airspace.

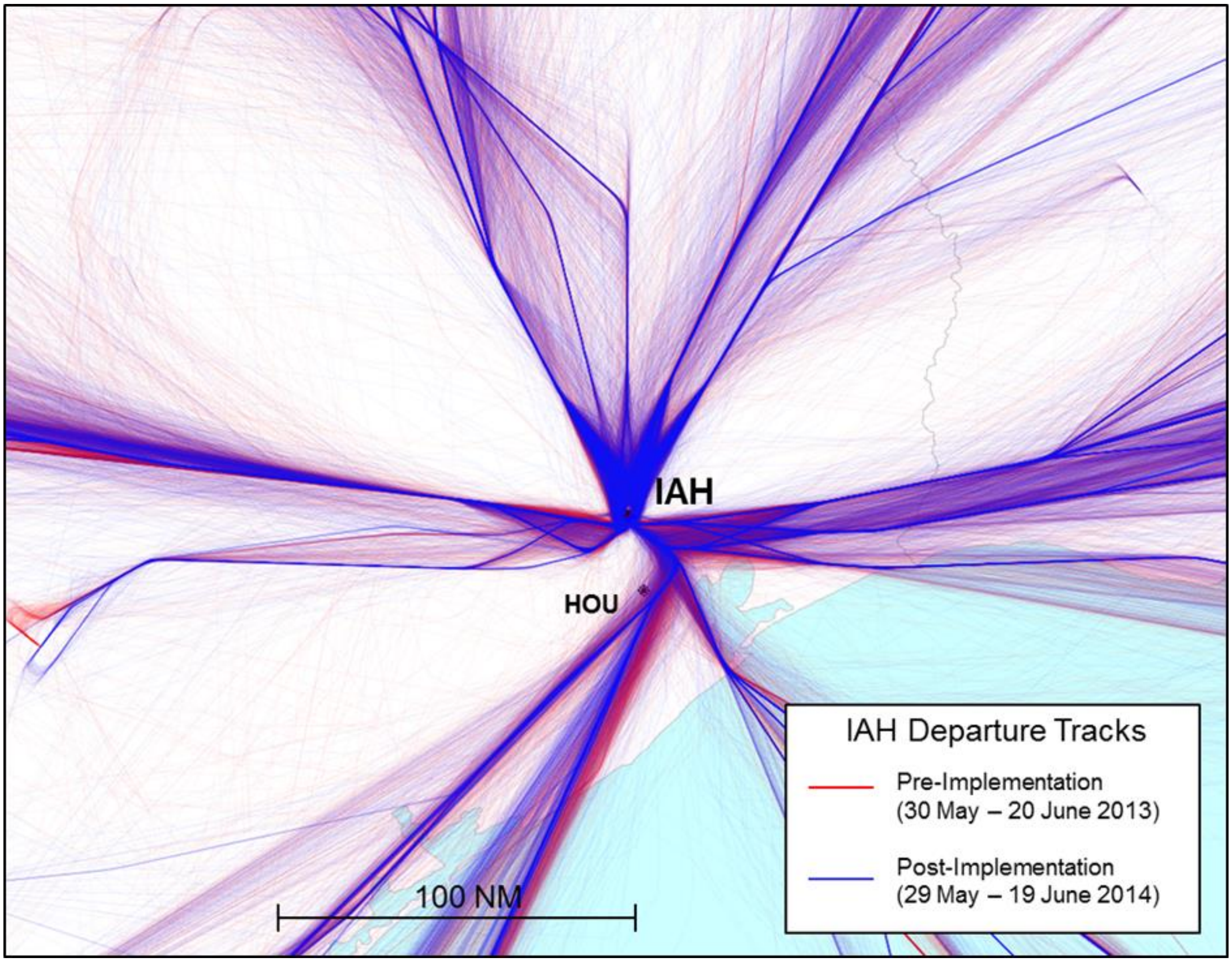

Figure 2. IAH Departure Tracks

2.2 HOU Changes

The project implemented five new RNAV STARs for HOU arrivals. Figure 3 depicts an arrival traffic sample before and after the Metroplex implementation. Several lateral shifts in the fights paths are evident, which align with the lateral paths of the new procedures.

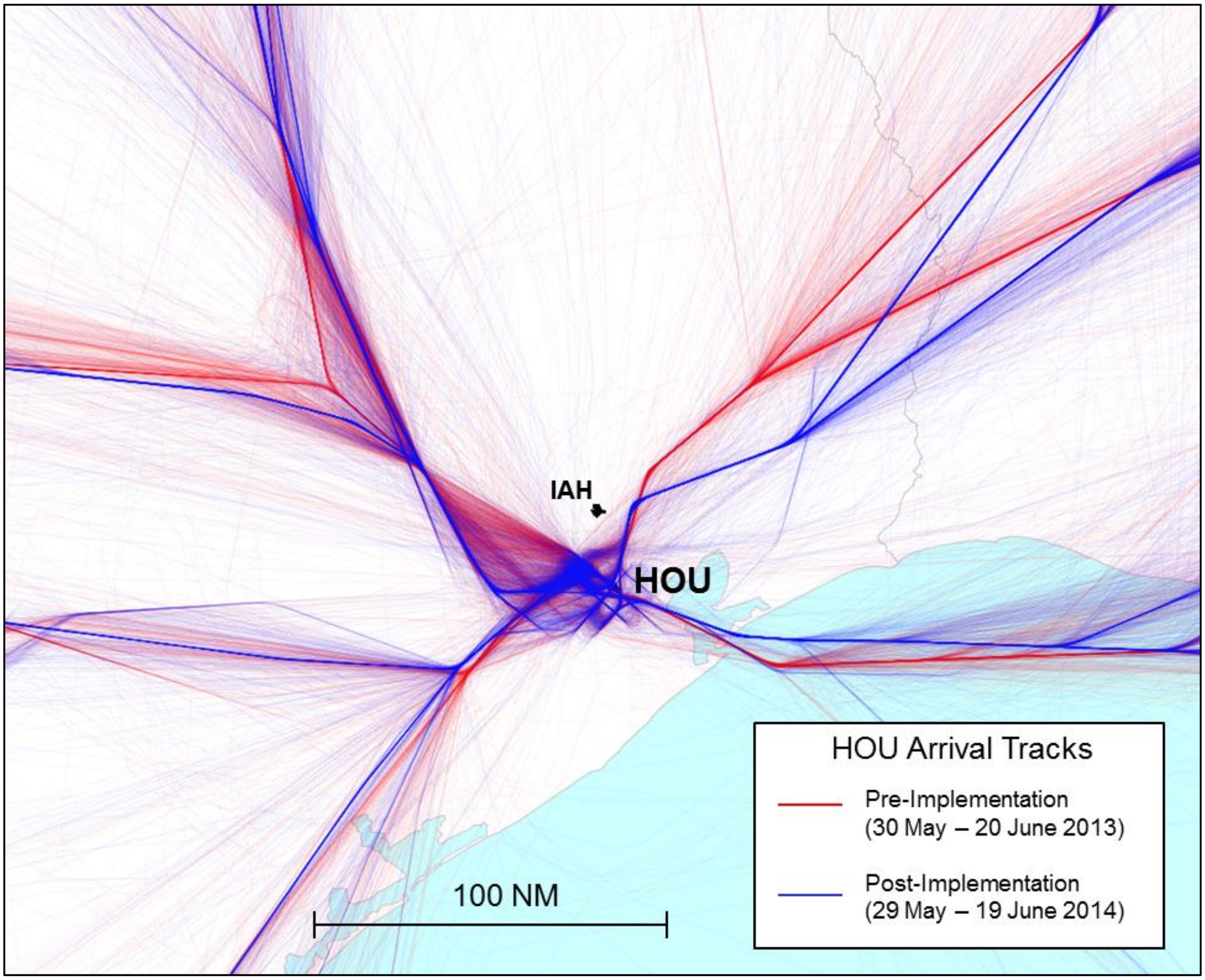

Figure 3. HOU Arrival Tracks

This project also contained ten RNAV SIDs for HOU departures, though the six northbound procedures are identical to the IAH departure procedures. As with the IAH departures, these largely mirrored existing procedures at higher altitudes, as illustrated in Figure 4.

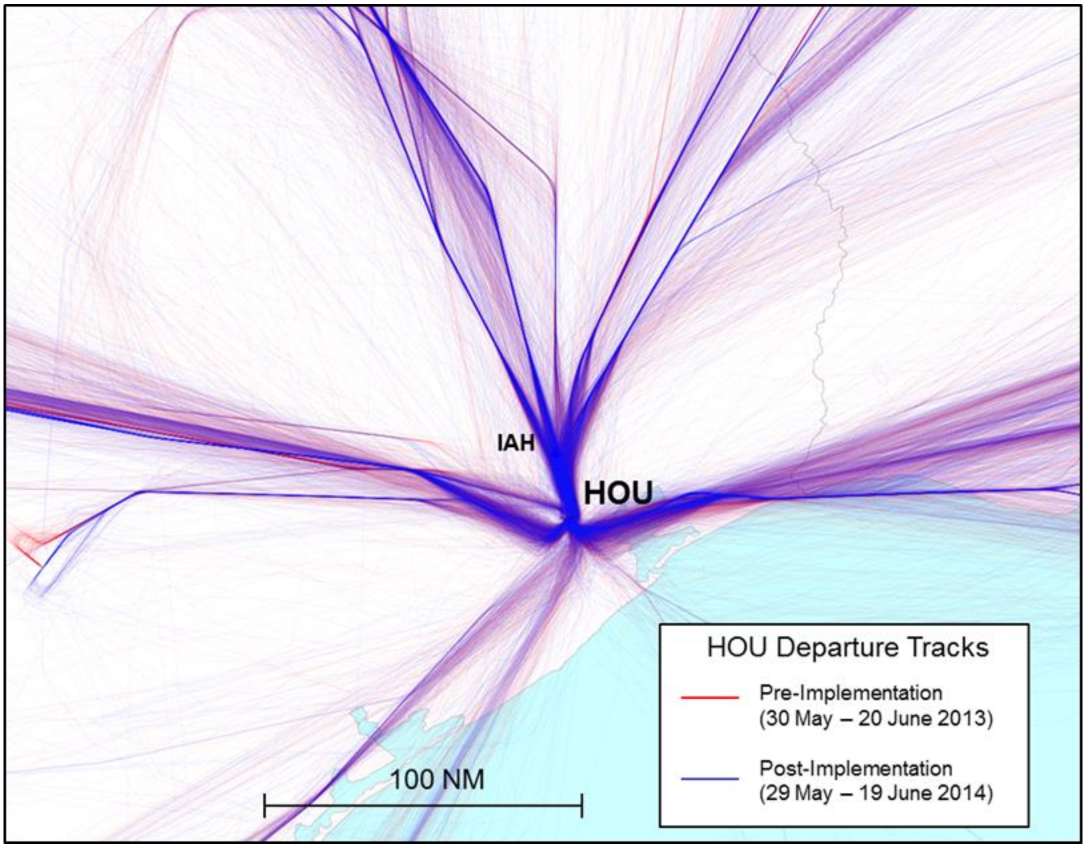

Figure 4. HOU Departure Tracks

3 Expected Benefits

The Study Team predicted the recommended designs would provide $7.5[1] million in benefit. These benefits were principally projected to result from the implementation of OPDs for arrivals to IAH and HOU. The Study Team also predicted reduced phraseology, frequency congestion, and pilot workload while de-conflicting procedures and creating more repeatable and predictable flight paths.

The Design Phase Executive Summary described the final procedure designs, including the development of OPDs for IAH and HOU. The final designs also included modified lateral and vertical paths for earlier divergence for departures. Where anticipated to be beneficial, arrival and departure procedures were de-conflicted and designed to create repeatable and predictable paths, reduce ATC task complexity, and enhance safety. After the D&I Team completed design work, the expected fuel burn savings prediction was updated to $8.3 million.

[1] The Study Team and the D&I Team predictions assumed a fuel cost of $2.85 per gallon.

4 Findings

The data sample for this analysis includes a four month period after the 29 May 2014 Houston Metroplex implementation and a similar period from the previous year. The first 30 days after implementation are excluded from the analysis to allow NAS operators and users to become accustomed to the new procedures before collecting metrics. Within the sample periods, selected hours of data were excluded from the summary results based on the weather impacts at the specific airport.[2]

4.1 Summary Findings

The primary driver of benefits at IAH and HOU is a reduction in level flight for arrivals. In summary, the impacts measured for the Houston Metroplex result in an extrapolated annual fuel consumption benefit of $5.3 million to operators at IAH and HOU. Table 2 summarizes the change in fuel consumption and associated savings at both IAH and HOU. A negative number represents a savings as a result of the Metroplex implementation.

Table 2. Houston Metroplex Operational Efficiency Results

Airport	Operation	Configuration	Change in Average Fuel Consumption (Gallons per Flight)	Contributing Operations (Annualized)	Change in Fuel Consumption (Annualized Gallons)	Change in Fuel Consumption (Annualized Dollars) †
IAH	Arrivals	9|08L|08R	-13.0	80,199	-1,040,000	-2,970,000
		27|26L|26R	-8.5	104,307	-880,000	-2,520,000
	Departures	15L|R	-0.2	162,396	-30,000	-80,000
		9	8.1	20,157	160,000	460,000
IAH Subtotal			-4.9	367,059	-1,790,000	-5,110,000
HOU	Arrivals	4	-13.4	24,807	-330,000	-950,000
		12R|12L	-6.2	34,014	-210,000	-600,000
	Departures	12R	12.5	25,359	320,000	910,000
		22	7.8	22,047	170,000	490,000
HOU Subtotal			-0.5	106,227	-50,000	-160,000
Total			**-3.9**	**473,286**	-1,850,000	-5,260,000

† Using $2.85 per gallon of fuel; Average cost for August through October 2014 from http://www.transtats.bts.gov/fuel.asp

2 The sampling period includes 126 days in the pre and post periods (30 June 2013 – 01 November 2013 and 29 June 2014-31 October 2014, respectively). Bad weather hours were excluded, and metrics do not reflect flights that were not expected to be impacted by the Metroplex implementation (local flights originating within 150 NM of the arrival airport; piston, helicopter, and military aircraft; and nighttime operations arriving or departing between 0500-1059 GMT [Greenwich Mean Time]). Holding flights were eliminated from flight efficiency metrics but tracked separately to understand if the implementation impacted the amount of holding. Note that this updated analysis used different criteria to filter out bad weather hours than the original analysis. As a result, the updated analysis filtered out fewer bad weather hours and better represents the operational impact of the new Metroplex procedures.

The measured benefits were greatest for IAH and HOU arrivals, while departure results at the two airports were mixed. For IAH arrivals, the per flight fuel savings were higher in the East configuration (Runways 09, 08L, and 08R) than the West configuration (Runways 27, 26L, and 26R). For HOU, the greatest savings were for arrivals to Runway 04. IAH and HOU departures overall exhibited an increase in fuel consumption.

Table 3 provides a comparison of the post-implementation analysis fuel burn benefits with the predicted benefits from the Study Team and D&I Team. A negative number represents a savings. The fuel benefit in the post-implementation analysis is less than what was predicted.

Table 3. Analysis Results

Airport	Annualized Change in Fuel Burn from Baseline (Million $)		
	Study Team Analysis	D&I Team Analysis	Post-Implementation Analysis
IAH	**-6.1**	**-6.5**	**-5.1**
Arrivals	-4.5	-6.7	-5.5
Departures	-1.6	0.2	0.4
HOU	**-1.4**	**-1.7**	**-0.2**
Arrivals	-1.8	-1.7	-1.6
Departures	$0.4	-0.1	1.4
Total	**-7.5**	**-8.3**	**-5.3**

Arrival and departure throughput maintained levels consistent with the pre-implementation period for both IAH and HOU. However, delays, vectoring, and holding were all slightly higher on average for IAH arrivals after the implementation, with the largest increases occurring on bad weather days. Note that periods with major weather impacts were excluded from the flight efficiency metrics (including fuel consumption).

Delays were also slightly higher on average for HOU arrivals, though vectoring and holding did not change appreciably. While individual delay metrics are difficult to attribute to a single cause, the collection of metrics suggest that the new operation is leading to slightly higher delays at take-off and when flights are airborne (possibly due to use of TBFM and Miles-in-Trail [MIT] initiatives), and is less robust during severe weather conditions.

In addition to the quantitative benefits based on analysis of pre- and post-implementation data, the Houston Metroplex project also achieved many of the expected qualitative benefits predicted by the Study and D&I Teams:

- RNAV routes and procedures have created predictable and repeatable flight paths that also help reduce controller task complexity by reducing the variability associated with non-RNAV operations.
- Controller task complexity has been reduced by decoupling the IAH and HOU operations via procedure designs that segregated the airport flows.
- The use of OPDs and "descend via" clearances on the majority of the RNAV STARs has reduced controller-pilot communications workload, frequency congestion, and the risk of "hear-back/read-back" errors.

4.2 IAH Findings

For IAH arrivals, fuel savings were highest from the northeast and northwest, which represents the majority of arrival traffic to IAH. For arrivals from a given direction, fuel savings were higher for operations landing on long side runways (for example, northeast arrivals landing to the east or northwest arrivals landing to the west). Southeast and southwest operations had less impact on the overall IAH arrival benefit, predominately due to the low number of operations. In some cases, average time and distance flown increased while estimated fuel consumption decreased. This situation generally results when the benefit from level flight reductions outweighs small increases in time and distance flown.

Figure 5 shows the average level-off distance by altitude for IAH arrivals in the pre and post-implementation periods. As expected there was significantly less level-off distance in the post-implementation period, particularly at 6,000, 10,000, and 12,000 feet.

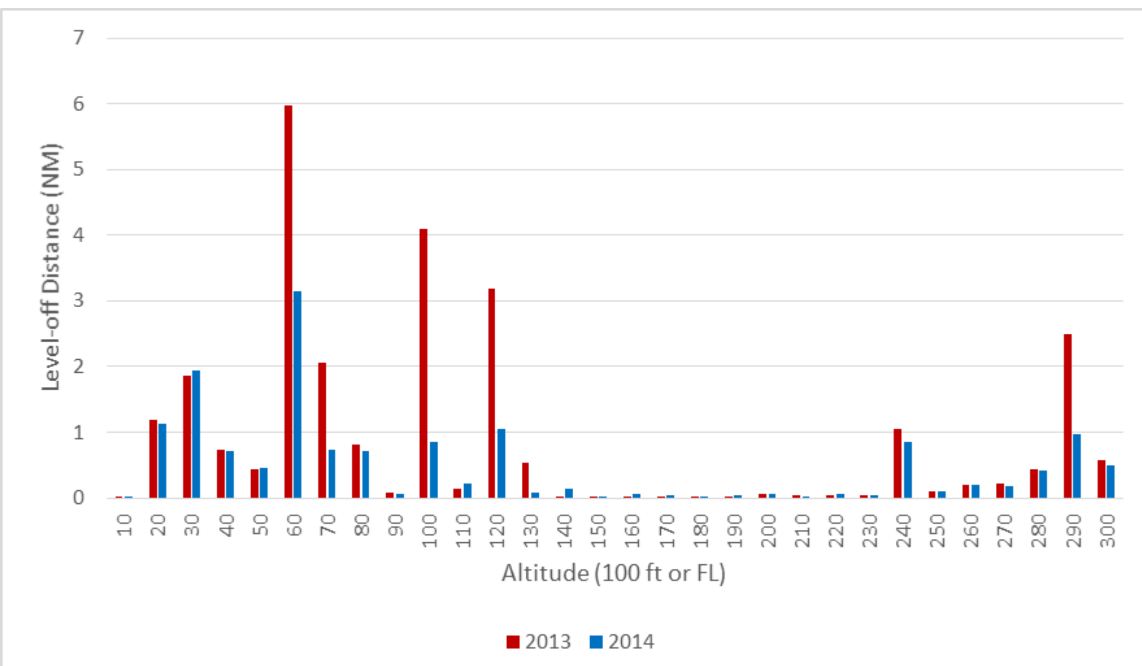

Figure 5. Average Level-Offs, IAH Arrivals

For departures, the north and east departure flows resulted in an increase in fuel consumption, while the south and west departure flows resulted in a slight decrease. The results are mixed by configuration and cornerpost. Overall there was a minor increase in distance flown and time flown per flight. There was little difference in level-flight after Metroplex.

Delays

Delays are impacted by a number of factors, including airline scheduling, weather, published procedures, and air traffic control procedures. It is difficult to attribute delay to a specific cause. The following delay-related metrics were generated to help assess IAH operations in the period after Metroplex implementation:

- Overall delays were higher in the post-implementation sample period, though average and peak actual arrival and departure rates did not substantially change.
- Delays for arrivals, compared to the filed flight plan estimated time en route increased as did block time delays for arrivals.
- Substantially more flights changed filed corner post after the original flight plan was filed, and after the flight was airborne. Flights changing corner post had significantly higher arrival delays post-Metroplex implementation.
- Departures to IAH from certain origins (e.g., Mexico City International Airport [MMMX], Austin Bergstrom International Airport [AUS], and San Antonio International Airport [SAT]) had significantly higher departure delays after Metroplex was implemented.
- Vectoring delays for arrivals were slightly higher on good weather days, though the number of aircraft holding was about the same.
- Daily MIT Minute-Miles were higher, including pass-back restrictions to Fort Worth and Memphis ARTCCs (ZFW and ZME).
- Daily use of departure scheduling and airborne metering, as well as the average length of time in which both were used, were substantially higher.
- The use of the TBFM En Route Departure Capability to schedule departures to meet MIT restrictions to IAH was higher, but the average assigned delays were about the same.

4.3 HOU Findings

For HOU arrivals, fuel efficiency benefits were greatest for flights from the northeast, followed by the southeast. The northwest arrival flow resulted in an increase in distance flown and fuel consumption while in the Runway 12R and 12L configuration. Fuel consumption differences for the southwest arrivals were relatively small. In some cases, average time and distance flown increased while fuel consumption decreased. There was an increase in distance flown for the northeast corner post and a slight increase in both distance and time for the northwest corner post.

Figure 6 shows the average level-off distance by altitude for HOU arrivals in the pre and post-implementation periods. There was significantly less level-off distance in the post-implementation period, particularly at 6,000 and 10,000 feet for flights from the northeast and 12,000 feet for flights from the southwest. There was an increase in level-off distance at 12,000 feet for flights from the northwest; however, this was the result of reducing the level-offs at 11,000 feet and shifting the remaining level-offs to a higher, more fuel efficient altitude.

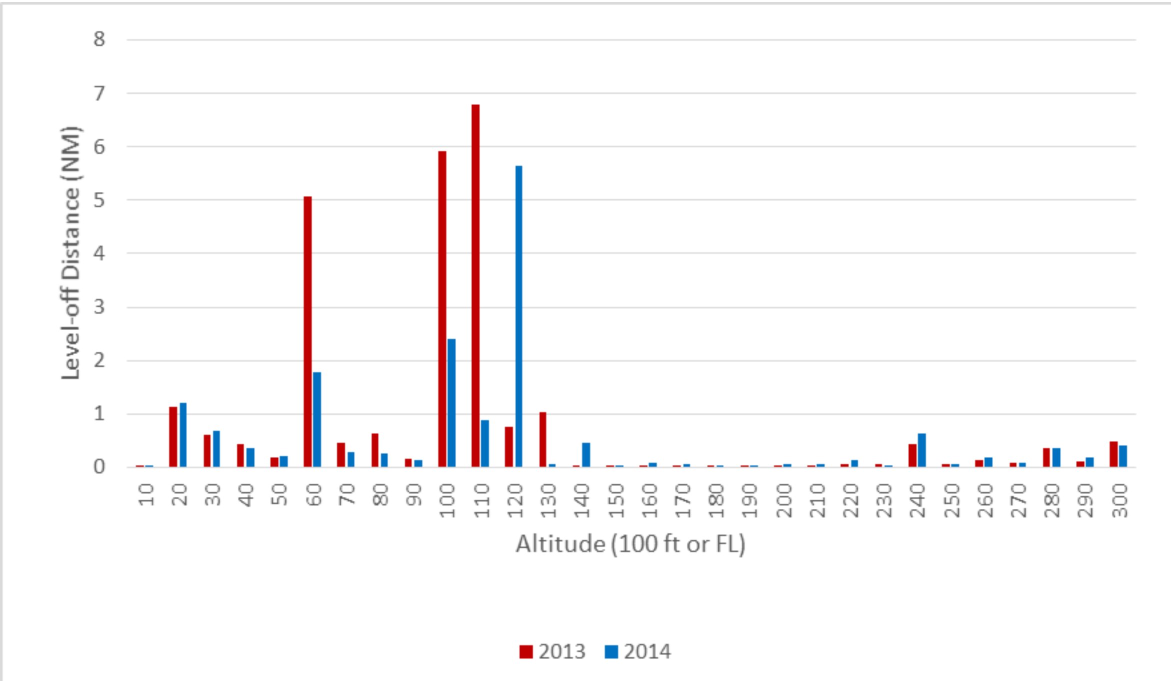

Figure 6. Average Level-Offs, HOU Arrivals

For departures, the north and east flows account for almost all of the additional fuel consumption. There was little change in time and distance flown between the pre and post-implementation samples. There was also little difference in level flight after Metroplex.

Delays

The following delay-related metrics were generated to help assess HOU operations in the period after Metroplex implementation:

- Overall delays were higher in the post-implementation sample period.
- Arrival delays and block time delays were slightly higher.
- Departures to HOU from certain origins (e.g., Will Rogers World Airport [OKC], Los Angeles International Airport [LAX], Charlotte-Douglas International Airport [CLT], and SAT) had significantly higher departure delays after Metroplex was implemented.
- Substantially more flights changed their filed corner-post after the original flight plan was filed, and after the flight was airborne. The flights changing corner posts had significantly higher arrival delays post-Metroplex implementation.

- Vectoring of HOU arrivals was higher, though the number of aircraft holding was similar.
- Daily MIT Minute-Miles was higher after Metroplex was implemented, including larger pass-back restrictions to ZHU and ZFW.

5 Conclusions

This post-implementation analysis compared IAH and HOU airport operations in the months after the implementation to a similar period from the year prior. The extrapolated annual fuel consumption benefit is estimated at $5.3 million for operators at IAH and HOU. This result is lower than modeling predictions made prior to implementation, indicating that the initial period after implementation is performing somewhat below expectations. The primary driver of benefits at IAH and HOU is a reduction in level flight for arrivals. Observations made by the D&I Team during the Post-Implementation Phase indicate that the qualitative benefits are also being realized. There are indications that delays have increased slightly after implementation.

As the Houston air traffic facilities gain experience with the new operation, minor adjustments continue to be made to the operations at IAH, HOU, and their satellite airports including published adjustments to the original procedures, Letter of Agreement adjustments of delivery altitudes, and TBFM use and settings modifications. Minor procedure adjustments are scheduled across several charting cycles through June 2016.

Appendix A Initial Houston Metroplex Post Implementation Results

Table 4 summarizes the findings from the original post-implementation analysis of the Houston Metroplex project. A negative number represents a savings as a result of the Metroplex implementation. The updated analysis used different criteria to filter out bad weather hours than the initial analysis. As a result, the updated analysis filtered out fewer bad weather hours and better represents the operational impact of the new Metroplex procedures.

Table 4. Houston Metroplex Operational Efficiency Results

Airport	Operation	Configuration	Change in Average Fuel Consumption (Gallons per Flight)	Contributing Operations (Annualized)	Change in Fuel Consumption (Annualized Gallons)	Change in Fuel Consumption (Annualized Dollars) †
IAH	Arrivals	9|08L|08R	-17.73	66,933	-1,187,000	-$3,380,000
		27|26L|26R	-9.16	92,097	-843,000	-$2,400,000
	Departures	15L|R	-0.30	142,326	-43,000	-$120,000
		9	10.51	15,129	159,000	$450,000
		IAH Subtotal	-6.05	316,485	-1,914,000	-$5,450,000
HOU	Arrivals	4	-14.25	19,851	-283,000	-$810,000
		12R|12L	-8.88	30,258	-269,000	-$770,000
	Departures	12R	8.56	24,066	206,000	$590,000
		22	6.02	21,102	127,000	$360,000
		HOU Subtotal	-2.29	95,277	-218,000	-$620,000
		Total	-5.18	411,762	-2,132,000	-$6,080,000

† Using $2.85 per gallon of fuel; Average cost for August through October 2014 from http://www.transtats.bts.gov/fuel.asp

Appendix B EUROCONTROL Base of Aircraft Data Copyright and Licensing

Portions of this analysis were produced with the EUROCONTROL Base of Aircraft Data (BADA). BADA is a tool owned by EUROCONTROL. It is protected by copyright and the database protection right © EUROCONTROL1998-2014. All rights reserved.

BADA contains technical data and information made available by various sources (including aircraft manufacturers) known to EUROCONTROL. The data and information are made available on an AS IS, WHERE IS basis and the data providers make no warranty whatsoever, and specifically disclaim any warranty of merchantability or fitness for a particular use.

It is to be noted that the aircraft performance models and data contained in BADA have been developed by EUROCONTROL from a set of aircraft operational conditions available to EUROCONTROL. EUROCONTROL has validated BADA aircraft models only for those conditions and can therefore not guarantee the model's accuracy for operating conditions other than this reference.

All copyright, trademarks and other intellectual property rights subsisting in or used in connection with BADA (including but not limited to all images, animations, audio and other identifiable material relating to BADA) are and remain the sole property of EUROCONTROL and other third parties (mentioned herein and/or known to EUROCONTROL), as may be the case.

Appendix C Glossary

Acronym	Definition
ACM	Adjacent Center Metering
AR	Authorization Required
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
AUS	Austin Bergstrom International Airport
BADA	Base of Aircraft Data
CLT	Charlotte-Douglas International Airport
D&I	Design and Implementation
FAA	Federal Aviation Administration
GMT	Greenwich Mean Time
HOU	William P. Hobby Airport
IAH	George Bush Intercontinental Airport
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
LAX	Los Angeles International Airport
Metroplex	Optimization of Airspace and Procedures in the Metroplex
MIT	Miles-in-Trail
MMMX	Mexico City International Airport
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
OKC	Will Rogers World Airport
OPD	Optimized Profile Descent
PBN	Performance-Based Navigation
RNAV	Area Navigation
RNP	Required Navigation Performance
SAT	San Antonio International Airport
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival
TBFM	Time-Based Flow Management
ZFW	Fort Worth Air Route Traffic Control Center
ZME	Memphis Air Route Traffic Control Center

Disclaimer