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Assessment of a National Airspace System Airborne Rerouting Tool

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Abstract—**This paper presents the assessment of a National Airspace System airborne rerouting tool. The tool implements NASA's Dynamic Weather Routes concept for wind-corrected flying-time savings during convective weather activity. A description of the system, as applicable to the entire United States airspace is provided, and results are presented demonstrating benefits of such a system from various Centers and airlines' perspectives. Three cases for selection of reroute-return capture fix, which prevent unrealistically large controller clearances are presented. Results are shown for potential time- and fuel-savings (over 134,000 minutes and 4.2 million lbs. of fuel for over 35,000 proposed reroutes) and sector congestion reduction (over 121 hours in congested sectors) for all 20 Centers. The data used were for 30 days with highest delays attributable to convective weather from April to October of 2014. Other results show the evaluation of the maneuver or reroute start point (a parameter representing the amount of coordination time needed), which highlight the need for a controller-pilot data link. A data link would help achieve higher savings. The results for persistence time, beyond which the time-savings dwindle quickly, help determine the maximum coordination time required for each Center. Finally, an assessment from a current National Operations Manager at the Air Traffic Control System Command Center of the FAA is documented. Those suggestions could improve the efficiency of the air transportation system, especially with the expected improvements in the traffic flow management infrastructure. Currently, one industry partner and one airline are assessing this technology for commercial operational use.**

Keywords-Weather Rerouting, Traffic Flow Management, Fuel-Savings;

I. INTRODUCTION

In the National Airspace System (NAS), weather is responsible for roughly 70% of the delays. Main types of weather components are convection/thunderstorms, winds, visibility/low ceilings, snow/ice, and lightning. The weather related delays were responsible for 32,000 minutes of average delay in the NAS during the summer of 2014 [1]. During significant convective activity, the FAA traffic managers use severe weather avoidance plans or Playbook routes. These routes safely divert traffic from weather-impacted regions and provide predictability, but introduce large deviations from the nominal flight plans. Automation, that would alert traffic managers when that weather constraint has changed and indicates that the avoidance routes may not be necessary, is not available today. As a result, aircraft fly larger distances, consuming expensive fuel, with higher costs for the flight operators and the general public.

Operational evaluation of a Center-based convective weather reroutes concept (Dynamic Weather Routes or DWR), saving more than 5-minutes of flying time savings, was presented earlier in [2]. The corresponding airspace constraints analyses and the environmental impact of DWR was presented in [3] and [4]. The En-route Flow Planning Tool described in [5] addresses the routing of multiple flights simultaneously. It is a NAS-based tool and looks at flow management as compared to the need for savings for individual flights. The goal of [6] was to extend the Center-based automation to a national scale by selecting the capture fix as the transition fix before the Standard Terminal Arrival Route (STAR) in the flight plan. Unfortunately, that would require long-distance clearances that controllers may not grant. Previous work presented in [7] had results for 11 Centers for 2013, with time-saving benefits for convective weather in Fort Worth Center (ZFW) only. The focus of that paper was to compare the NAS-based rerouting tool with the ZFW-based automation.

In this paper, benefits of implementation of the DWR concept into a NAS-based system called NAS Constraint Evaluation and Notification Tool (NASCENT) are presented for all 20 Centers in the continental US airspace, with convective weather across various Centers in the NAS. NASCENT extends the DWR concept to the NAS using a lower fidelity, one-minute data feed. Due to this, the benefits of computing dynamic weather routes for all 20 Centers can be evaluated in real-time; however, the aircraft-to-aircraft conflicts cannot be calculated. The results of analyzing the 30 most convective weather-related delay days in 2014 are presented here. Also, a national traffic operations manager's assessment is provided on how this concept and NASCENT technology could improve efficiency of the air transportation system, and how it could be utilized in the future plans for the FAA operational infrastructure.

II. NAS Constraint Evaluation and Notification Tool (NASCENT)

NASA's Dynamic Weather Routes (DWR) tool is a ground-based automation system that automatically identifies and proposes simple route corrections for time-savings around convective weather. It is clearly defined in [8]. In NASCENT, the DWR concept is implemented for all 20 Centers, as described in [7]. It is implemented within the Future ATM Concepts Evaluation Tool (FACET) testbed [9]. NASCENT uses the one-minute track-update Traffic Flow Management System (TFMS) or the Aircraft Situation Display to Industry (ASDI) feed data. The weather products used for the NASCENT system are the Corridor Integrated Weather System (CIWS) and the CIWS-derived Convective Weather Avoidance Model (CWAM), available from MIT Lincoln Laboratory [10]. The probability of pilot deviation is provided by CWAM, and the NASCENT weather avoidance algorithm uses the 70% probability polygons. The Rapid Refresh (RR) winds from National Oceanic and Atmospheric Administration (NOAA) are used for trajectory modeling and to compute the wind-corrected flight-time savings. The Base of Aircraft Data (BADA) aircraft-type performance tables are used for computing fuel-savings numbers. The current dynamic airspace sectorization data are obtained from the FAA's Host ATM Data Distribution System (HADDS) and the Special Use Airspace (SUA) data are from the FAA's sua.faa.gov website. The latter are the scheduled SUA data since the real-time data are not available. Visibility, snow/ice, and lightning are not addressed in this research.

NASCENT operates as follows. It continuously probes all aircraft flight plans within the 20 Centers in the NAS, which could provide more than five-minutes (a user-specified number) of wind-corrected flying-time savings with a re-route. The current flight plan for each airborne aircraft is probed for an appropriate downstream fix (namely, the reroute-return capture fix) such that the five-minute savings are obtained by flying direct to the capture fix. This is the reference route, which is from the current position of the aircraft to the capture fix, with the rest of the route unchanged until the destination. The capture fix lies within either a limiting region (rectangle or polygon) or tier-one (neighboring) Center boundary (described in sub-section A below) to prevent large distance controller clearances that are likely not feasible. Once a reference route is found, it is checked for intersection with CWAM polygons at the time the flight is predicted to be there, and at the flight's cruise altitude. If an intersection is found, the weather avoidance algorithm is used to find typically one or sometimes two auxiliary waypoints that avoid the intersecting weather polygons. These auxiliary waypoints are created as latitude/longitude coordinates, but are snapped to the nearest set of three-letter identifiers, so it's easier for verbal air traffic clearances. The flights that pass through these steps are posted on the NASCENT flight list. The wind-corrected potential flying time-savings are computed by differencing the predicted time on current flight plan route and NASCENT proposed route. The user can select any flight on the NASCENT list for further review of route details, sector congestion, FAA imposed reroute Traffic Management Initiatives (TMI), SUA traversal, etc. If the current flight plan is affected by a required reroute TMI imposed by the Air Traffic Control System Command Center (ATCSCC), then a separate TMI information window pops up. This window shows the origin airport or Center, the destination airport or Center, and the reroute that this origin/destination pair is affected by. It also provides the effective date and time of the advisory and the name of the advisory. It should be noted that NASCENT provides sector congestion and SUA traversal as an advisory only, and does not propose routes around them. The fuel-saving numbers are also available for each flight on the list.

Fig. 1 shows a snapshot of the NASCENT display. The big window shows the Center boundaries in gray and the nowcast or current weather as yellow and red polygons (marked 'CIWS' in the figure). The Reference Route is shown in gray, the NASCENT Route in yellow, and the currently active Flight Plan Route in green. The Limit Polygon for flights in Kansas City Center (ZKC) is shown in cyan. The downstream return capture fix for ZKC flights must be within the cyan limit polygon. The CWAM forecast polygons avoided by the NASCENT weather avoidance algorithm to compute a locally minimum-deviation route around weather are shown in white. It can be observed that the NASCENT proposed (yellow) route avoids the white polygons with one additional waypoint. The bottom left window shows the Flight List that can save more than 5-minutes of reference route savings for many centers. Since UAL581 going from Denver (KDEN) to Washington Dulles (KIAD) is selected (data tag shown with a leader line in Fig. 1 big window), its details are shown in the window at bottom-right (marked 'Detailed Results for UAL581'). The details include the current or Original FP (as obtained from ASDI data), the Reference FP, and the NASCENT FP (see pink box). For the NASCENT FP string, GCK215068, GCK187078, ESOVE, and IIU are the current position of aircraft, maneuver start point, auxiliary waypoint to avoid weather, and return capture fix, respectively. It should be noted that if the reference flight plan does not intersect any CWAM polygons, the NASCENT flight plan is the same as the reference flight plan (one without ESOVE). The savings for alternate downstream capture fixes along the current flight plan are also shown in the left part of that bottom-right window.

The NASCENT system also shows information about sector congestion. The congested sectors along the current flight plan and the NASCENT proposed route respectively, are shown in the top and middle windows at right, and marked accordingly in the figure. It is seen that the current flight plan for UAL581 goes through a predicted sector overload (yellow sector) but the NASCENT flight plan is clear of predicted congestion. The sector congestion is calculated using the FAA provided Monitor/Alert Parameter (MAP) value. A red sector implies that all the flights predicted to be in that sector at the time the selected flight will be there, are already airborne at the time of prediction. A yellow sector implies that some of the flights predicted to be in that sector are not airborne at the time of prediction.

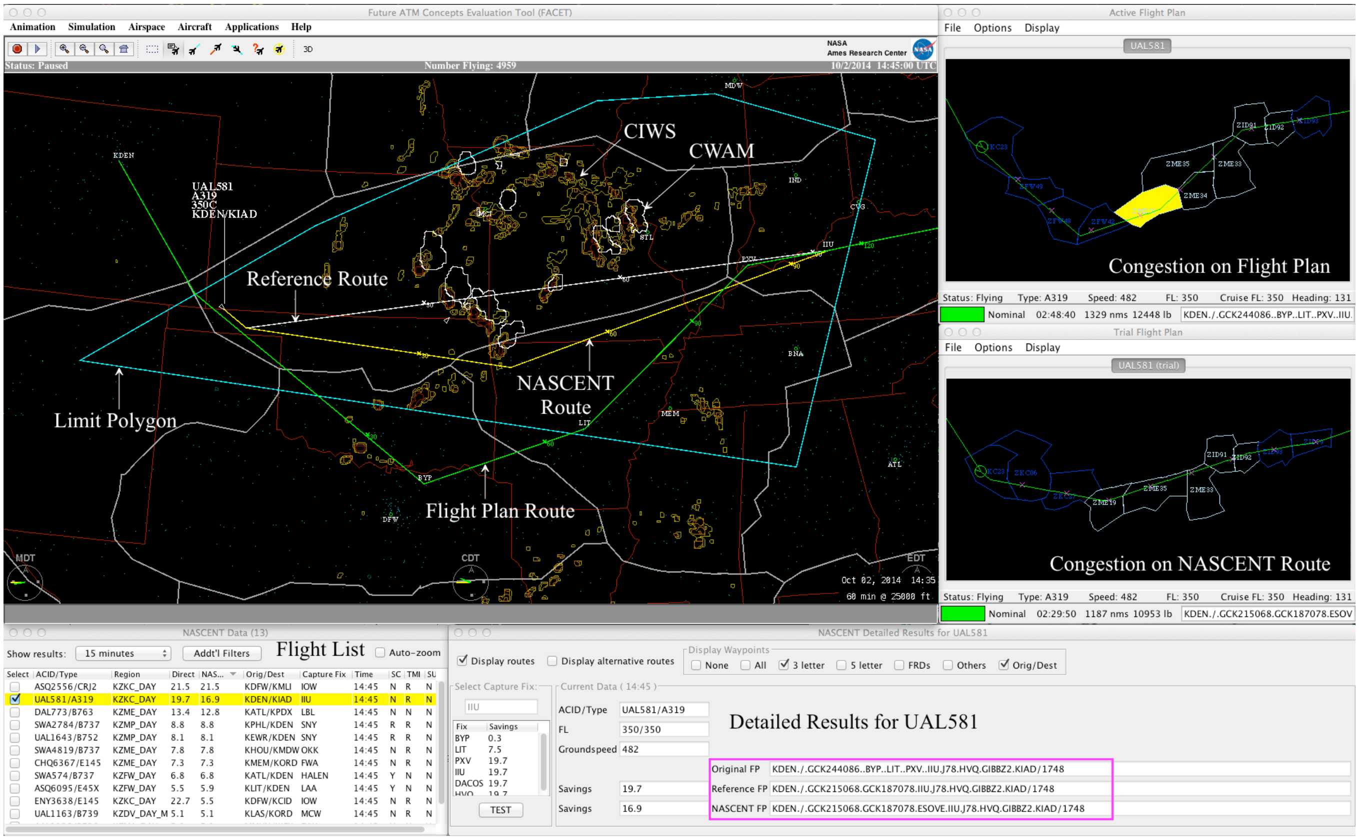

Figure 1. A snapshot of NASCENT main display with flight list, detailed results and sector congestion along flight plan and NASCENT routes.

The following Sub-sections describe two important parameters considered for this research: the reroute-return capture fix selection method (A) and the maneuver start point parameter (B). The return capture fix selection method determines how far an aircraft can fly direct for the controller clearance to be feasible. The maneuver start point establishes the amount of coordination time required for the aircraft to start flying along the NASCENT route, and consequently, the amount of savings lost.

A. Capture Fix Selection Method

For the Dynamic Weather Routes concept to work, a return capture fix selection logic using limit rectangles and minimum distance to destination airport was described in [8]. A limit rectangle or polygon is required to avoid unrealistic long-distance controller clearances. For example, for a flight in Albuquerque Center, controllers would normally not clear the flight to fly direct to a capture fix in Indianapolis Center. This is because the flight would have to fly through Fort Worth and Memphis (and perhaps, Kansas City) Centers and the workload for coordination with all those Centers would be high. In order for the DWR concept to be extended for all 20 Centers, an innovative heuristic method of computing limit polygons suitable for each Center was devised and presented in [7]. The limit polygons (equivalent to the limit rectangle used in the DWR concept for Fort Worth Center automation) were created from a five-month flight track dataset. These data were analyzed to extract waypoints that controllers had cleared aircraft to fly direct to. Then, a convex hull was created around the most-used fixes to create the limit polygon for each Center. Another approach called the tier-one method for selecting a downstream capture fix, also mentioned in [7], is to use the last fix on the current flight plan in the first tier or neighboring Center. In both approaches, and regardless of the limit region, the capture fix is not beyond the last fix on the Standard Terminal Arrival Route (STAR) or inside of 100 nautical miles from the destination airport, if the destination airport is within the current Center limit region. Both of these approaches are assessed in this research and the results are presented in the next section.

B. Maneuver Start Point Parameter

The operating concept for DWR is to propose a reroute to the ATC coordinator at an airline's flight operations center and he/she would consider the appropriateness of the reroute for implementation. The acceptable reroutes are suggested to the dispatcher, who may ask the pilot to request a clearance for the proposed route from the air traffic controller. This is in accordance with current day operational procedures. The Maneuver Start Point (MSP) represents how much time is required by the ATC coordinator to coordinate a particular route with the dispatcher, and consequently, with the pilot and the controller, before the maneuver towards the proposed reroute can start. There is research on having the rerouting functionality in the cockpit. The process would have the pilot make the decision about the flyability of the reroute and request controller clearance [11]. This would significantly reduce the required coordination time. However, other research [12] suggests that the on-board radar may not provide the pilot with a complete situational awareness in complex thunderstorm situations.

MSP is a user-specified parameter and for the NASCENT system, it has been set between 0 and 15 minutes, with five minutes being a generally accepted value at American Airlines [2]. A value of MSP=0 implies that the reroute maneuver starts immediately. A value of MSP=5 implies that the ATC coordinator believes it would take 5 minutes for the clearance to be granted by the controller and the maneuver to start.

The assessment of NASCENT performance for computed savings values for individual Center-based limit polygons and tier-one methods, and maneuver start points of 0- and 5-minutes are presented in the next section.

III. Results

In this section, results for the potential savings obtained by running the NASCENT system for 30 days and considering over 35,000 proposed reroutes are presented. The 30 days were selected based on maximum delay incurred in the NAS when convective weather was the main cause. The days were within the convective weather season in the United States from April through October of 2014. These days are April 3, 15, 29, 30, May 9, 15, 16, 27, 28, June 5, 9, 11, 12, 13, 18, 19, 23, 25, July 2, 3, 8, 9, 13, 14, 15, 23, 27, 28, September 6, and October 2. The results are for the cases of selecting the capture fix using limit polygons and tier-one method, and for maneuver start point values of 0- and 5-minutes. The values of potential time- and fuel-savings, for the 20 Centers and top 12 airspace users are presented in Sub-section A below. Results are also presented for sector congestion, Special Use Airspace (SUA) traversal in the 20 Centers in Sub-sections A and B. The SUA data are presented based on the types of SUA (e.g., Warning Areas, Restricted Areas, etc.) as well. The fuel consumption data by different aircraft types are presented in Sub-section C. A notion of persistence time that would help determine the maneuver start point for various centers is presented in Subsection D.

A. Results for Fuel- and Time-Savings

Table I below shows the difference in values between the current flight plan and NASCENT proposed route for MSP = 0, 5 minutes for limit polygons, and MSP = 5 minutes for tier-one approach. The results for MSP = 0 and 5 minutes, using the limit polygon method of obtaining the downstream capture fix, indicated an average potential time-savings of 9.4 and 8.8 minutes per flight, respectively. These can be obtained by dividing the time-saving minutes by the number of flights in Table I. The average time-saving per flight for the tier-one calculations is 8.8 minutes. It is observed in several earlier research articles [2], [4], [7], and [8] that the average time-savings per flight for the DWR concept single- or multi-Center implementation is about 8-10 minutes, which is corroborated by this research as well. It can be seen that the number of flights varies for the three cases shown in Table I. The tier-one approach (with MSP=5 min.) has the most flights because the larger area of tier-one centers allows for more flights to have five-minutes of flying-time savings. The polygons with MSP=0 minutes has fewer flights because of the decreased size of the limit polygons compared to the tier-one Centers. However, the instantaneous maneuver start would allow flights to be included with five to six minutes of savings. Note that the system has a one-minute track data resolution. The polygons with MSP=5 minutes has the fewest flights due to the decreased size of limit polygons, and missing the opportunity due to the required coordination time of five minutes. The larger the required coordination time (or MSP), the larger the lost potential time- and fuel-savings opportunity as well. This clearly presents a need for implementation of a controller-pilot data link connectivity. With the data link, the coordination time can be reduced to within a minute, or perhaps even less, significantly increasing the available benefits to the airspace users and the flying public.

Since the computations are performed on a per-flight basis, the NASCENT system currently is predominantly an Airline Operations Center (AOC) tool. With that in mind, the breakdown of savings from the airlines' perspective is shown in Table II below. It is interesting to note that the top five airlines (SWA, AAL, UAL, DAL, and AWE) account for 47-49% of total number of flights and time-savings, along with 56-58% of total fuel-savings in each of the three cases in Table II. SkyWest Airlines (SKW) and Republic Airlines (RPA) did not appear in the top 12 users for tier-one calculations. Express Airlines (FLG) and Spirit Airlines (NKS) flights replaced SKW and RPA in the top 12 users, and are shown in the Airline column (with slashes). The names before slashes are for the limit polygon cases and the names after slashes are for tier-one results.

It is seen that the tier-one calculations (those with return capture fix in neighboring centers) include roughly double the number of flights and the potential savings are much higher. This is due to the fact that operational constraints of providing long-distance clearances are loosely included in those calculations, since the adjacent centers could be quite big spatially (e.g. southwest corner of Denver Center to northeast corner of Minneapolis Center). Also, the MSP=0 provides an upper limit on the savings that can be obtained for the DWR concept implementation. Due to these reasons, the FAA relevant results in Table III are presented only for the limit polygon method with MSP=5 minutes. Also, considering that the average value of time-savings is 0.6 minutes between MSP=0 (9.4 min. average) and MSP=5 (8.8 min. average), less than the resolution of the flight track updates from ASDI data, the results for MSP = 5 minutes for the limit polygon method are shown hereafter.

The FAA TFM managers would be more interested in managing streams of traffic, rather than individual flights. The results in Table III are for each of the 20 Centers in the NAS. Additional columns for Sector Congestion (minutes) and SUA Traversal (number of times a SUA was crossed) are discussed next.

TABLE I. DIFFERENCE IN POTENTIAL TIME-SAVING MINUTES AND LBS. OF FUEL-SAVINGS FOR PROPOSED NASCENT REROUTES AND THREE CASES.

Method	Flights	Time-Savings (min.)	Fuel-Savings (lbs.)	Sector Congestion (min.)	SUA Traversal (number)
Polygons, MSP=0 min.	19,105	178,643	4,991,066	5,762	-7,118
Polygons, MSP=5 min.	15,234	134,710	4,235,759	7,263	-4,512
Tier1, MSP=5 min.	35,172	310,486	9,821,356	20,135	-12,557

TABLE II. POTENTIAL TIME-SAVING MINUTES AND LBS. OF FUEL-SAVINGS FOR PROPOSED NASCENT REROUTES FOR AIRSPACE USERS.

Airline	Polygons, MSP = 0 min.			Polygons, MSP = 5 min.			Tier One, MSP = 5 min.		
	Flights	*Time (min.)*	*Fuel (lbs.)*	*Flights*	*Time (min.)*	*Fuel (lbs.)*	*Flights*	*Time (min.)*	*Fuel (lbs.)*
SWA	2,128	21,189	607,565	1,741	16,774	524,801	4,273	40,743	1,329,747
AAL	2,146	20,398	761,537	1,738	15,409	633,875	3,357	29,854	1,239,088
UAL	1,686	15,422	550,718	1,481	12,376	480,303	4,079	34,781	1,310,212
DAL	1,713	14,865	488,299	1,303	10,699	412,379	2,847	24,559	1,033,187
AWE	1,438	12,570	412,812	1,166	9,750	361,873	2,415	20,519	813,609
ASQ	1,192	10,869	171,389	957	8,089	149,081	1,776	15,553	292,266
JBU	742	6,529	183,171	561	4,441	140,896	2,016	15,784	437,214
ENY	690	7,088	111,170	536	5,330	95,437	842	8,503	155,561
SKW/FLG	423	4,124	77,774	364	3,288	69,105	650	5,924	139,786
RPA/NKS	438	4,150	73,944	336	3,037	61,045	438	4,184	136,960
FDX	316	3,412	236,545	289	2,834	214,280	539	5,566	445,958
UPS	179	1,590	105,575	161	1,379	107,804	300	2,676	195,662
Others	6,014	56,439	1,210,567	4,601	41,304	984,880	11,640	101,841	2,292,106
Total	**19,105**	**178,643**	**4,991,066**	**15,234**	**134,710**	**4,235,759**	**35,172**	**310,486**	**9,821,356**

TABLE III. RESULTS FOR PROPOSED NASCENT REROUTES FOR 20 CENTERS USING LIMIT POLYGONS AND MSP=5 MINUTES.

Center	Flights	Time-Savings (min.)	Fuel-Savings (lbs.)	Sector Congestion (min.)	SUA Traversal (#)
ZMA	1,498	10,685	415,890	-43	-3,558
ZFW	1,468	14,086	469,176	47	-4
ZHU	1,417	14,355	483,817	2,236	-66
ZME	1,305	11,045	379,758	108	-13
ZKC	1,193	11,045	325,499	189	1
ZJX	1,063	8,839	269,750	334	-471
ZID	1,009	9,085	259,509	429	-1
ZMP	955	8,501	279,754	3,512	1
ZDV	841	7,958	239,671	408	-1
ZTL	827	7,485	234,419	8	-4
ZDC	738	6,436	184,407	-402	3
ZBW	710	5,863	194,163	100	0
ZAU	566	4,863	149,103	-9	-2
ZOB	411	3,748	72,693	44	0
ZAB	313	2932	63,567	137	-82
ZLA	303	2,689	67,908	155	-243
ZNY	263	2,432	60,195	35	-2
ZLC	212	1,521	62,691	-25	-30
ZOA	84	650	9,680	0	-35
ZSE	58	493	14,109	0	-5
Total	**15,234**	**134,710**	**4,235,759**	**7,263**	**-4,512**

B. Results for Sector Congestion and SUA Traversal

Overall results for sector congestion and SUA traversal were presented in Table I and III above. The results are computed as a difference between the congestion encountered along the current flight plan and the NASCENT proposed route at the time of first prediction for each flight. In Table I, the number of minutes of saved sector congestion across all Centers is shown for the three cases, if NASCENT proposed routes are used. It also shows that in all three cases, more SUA traversals are observed using NASCENT routes. In Table III, the results are presented for individual Centers of the NAS. Again, it is interesting to note from Table III that the top five Centers (ZMA, ZFW, ZHU, ZME, ZKC) account for 45% of total number of flights and time-savings, along with 49% of total fuel-savings. This is because, on average, convective weather occurs more in those five Centers. Also note that the total results row in Table III is the same as the middle row (Polygons, MSP=5 min.) in Table I.

In Table III, the sector congestion minutes across Centers vary between positive and negative values. The positive values are when the original flight plan is predicted to go through congestion while the NASCENT proposed route is clear, and negative values are for the reverse case. The important point is that, if NASCENT proposed routes are used then, overall, the sector congestion is reduced by over 121 hours (7,263 minutes) for over 134,000 potential flying time-saving minutes and 4.2 million lbs. of fuel-savings for more than 15,000 reroutes over the 30 days considered here. Also, other than Washington Center (ZDC) with a value of -402 minutes, mostly the NASCENT routes provide a larger sector congestion benefit in most other centers.

In Table III, ZMP has sector congestion savings minutes of 3,512 minutes. It was seen that most of the savings are seen in high altitude Sectors ZMP12 and ZMP13, and on October 2, 2014. Some of the larger national severe weather playbook routes (e.g. the Canadian reroutes) go through those sectors just before entering Canadian airspace. NASCENT routes are out of these sectors completely, reducing congestion. Houston Center (ZHU) had the second most sector congestion savings with 2,236 minutes and those results are presented in Fig. 2. The number of occurrences of predicted entry into a red sector by the current flight plan and NASCENT proposed flight plans are shown in cyan and green, respectively. For the purpose of this figure, only red sectors are counted. Red sectors are ones where the number of aircraft is predicted to be over capacity (i.e., Monitor Alert Parameter) that are airborne at the time of prediction. The number of minutes spent in each sector is summed up and the total time spent is indicated with a dot along each bar of the histogram. It is observed from Fig. 2 that ZHU97 has the largest number of occurrences and minutes spent in red sectors for both original or current flight plan and NASCENT proposed route. Similar to the ZMP sectors, it was found that the larger Playbook routes through Montgomery, AL and Crestview, FL pass through this sector. The NASCENT proposed routes avoid that sector, resulting in the reduced congestion in ZHU97.

The red sectors were split into the first 30-minutes of prediction (cyan-current flight plan, and green-NASCENT route) and 31-120 minutes of prediction (red-current flight plan, and blue-NASCENT route) of the two-hour predictions, to demonstrate the severity of proposed congestion violation. Predictions have more certainty in the first 30-45 minutes since the FAA requires that all commercial flights file a flight plan within 45-minutes of departure. It is observed in Fig. 3 that, as expected, not many flights enter red sectors in the 30-120 minutes time frame. Therefore, for better air traffic controller acceptance of NASCENT proposed routes, predicted red sector congestion should be avoided in the immediate predicted 30-minutes. The lost opportunity due to this will be studied in the future. The results for each Center, with all its congested sector numbers combined, are shown in Fig. 3. For example, there were 19 sectors in Albuquerque Center (ZAB) that encountered congestion. The number of minutes of combined congestion in all those 19 sectors, over the 30 days of data, is combined to show the results in Fig. 3.

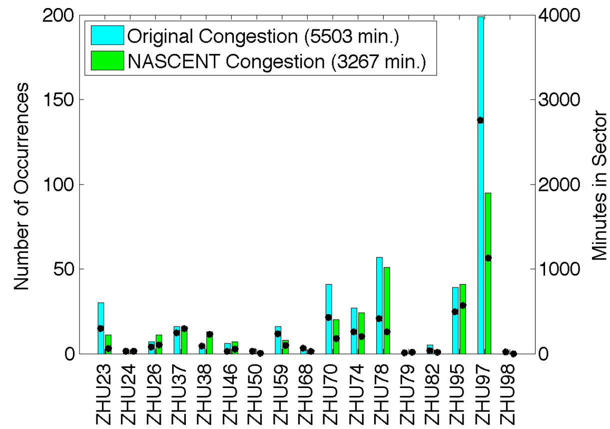

Figure 2. Number of sectors congested in Houston Center (ZHU) for original route and NASCENT proposed route.

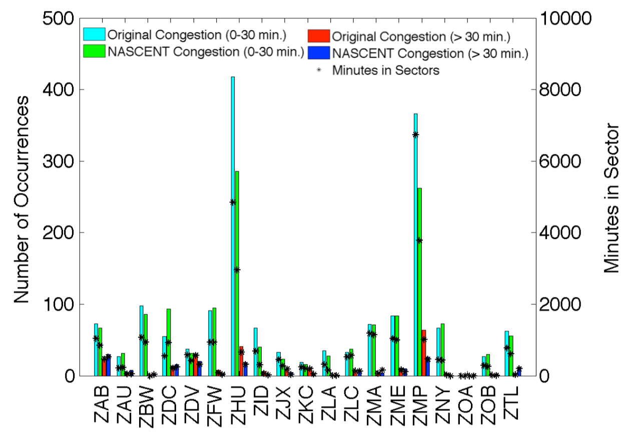

Figure 3. Combined number of congested sectors for the first 30 minutes and 30-120 minutes of prediction.

One of the questions often asked is about the state of system congestion if all the proposed NASCENT routes are granted. It is generally accepted that sector capacity is reduced when convective weather occurs. In [13], a reduction in sector capacity estimation was provided. When the sector capacity is estimated to reduce, traffic managers either reroute aircraft or implement miles-in-trail restrictions. Two separate simulations were conducted to address this question of system congestion. One where all the aircraft flew on their original flight plans and another where all the aircraft flew on their NASCENT proposed routes (limit polygon method and MSP=5 min. solution). The number of minutes of sector congestion was recorded for each run and differenced. The results for each Center, with all its congested sector numbers combined, are shown in Fig. 4. It is should be noted that the minutes of congested sectors in Minneapolis Center (ZMP) are 6,700 for original route (maroon) and 6,406 for NASCENT proposed route (cyan). The maroon and cyan bars for ZMP have been trimmed at the top so that the data for the other centers are clearer to see. The difference between maroon and cyan bars for ZMP is 294 minutes. Overall, the difference in time spent in congested sectors with original flight plans compared to NASCENT proposed routes is an additional 673 minutes in all 20 Centers using original flight plans for 30 days of data.

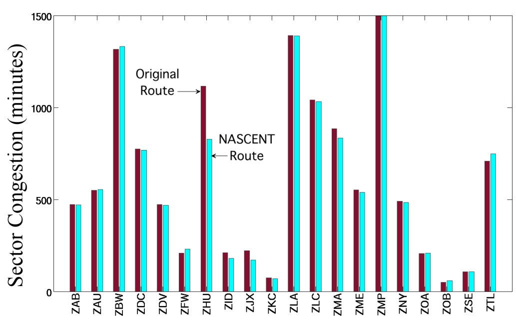

Figure 4. Combined number of congested sectors in each Center, for all flights flying simultaneously along the original route first, and then NASCENT proposed route.

The total number of SUA traversals is shown in Fig. 5. Again, the number of minutes spent in each SUA type is summed up for individual flights and shown with a dot along each bar. It is observed that overall, the Alert, Prohibited and Military Operation Areas are rarely crossed by the original flight plan or the NASCENT proposed route, however, the Warning (and Restricted) Areas traversal is significantly higher for the proposed reroutes. This was further investigated to find that most flights, coming from the Bahamas, Puerto Rico, and other international airports southeast of Florida, have NASCENT proposed routes crossing these airspaces. A filter currently is being implemented to remove such traversals through SUAs so reasonable solutions are proposed by the NASCENT system. Additionally, if SUAs are found to be active, in the future, NASCENT proposed routes will avoid them, just like any severe weather contours.

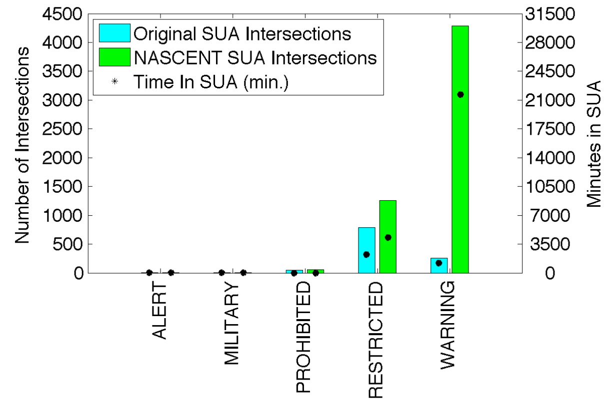

Figure 5. Total number of SUA traversals for original route and NASCENT proposed route with the number of minutes spent.

C. Fuel-Savings by Aircraft Type

The lbs. of potential fuel-savings were computed for each aircraft type. The top-10 aircraft types are shown in Fig. 6. These results are for MSP=5 minutes and using the limit polygons. As explained earlier, the MSP=0 minutes and tier-one approaches yielded higher values of fuel-savings. Although the NASCENT system has sufficient fidelity for time-saving data, the fuel calculations use BADA tables with nominal weight. The airlines would have more accurate models for their aircraft types and the take-off weight, so the numbers here provide a general estimate for an airline.

It is observed that the aircraft types reported here are the aircraft that are flying the most in the NAS today. Thus, the NASCENT tool has the possibility of saving significant amount of fuel (by about 2.5 million lbs. of fuel for the top-10 aircraft-types) and, consequently, reducing the environmental emissions. In earlier research [4], it was

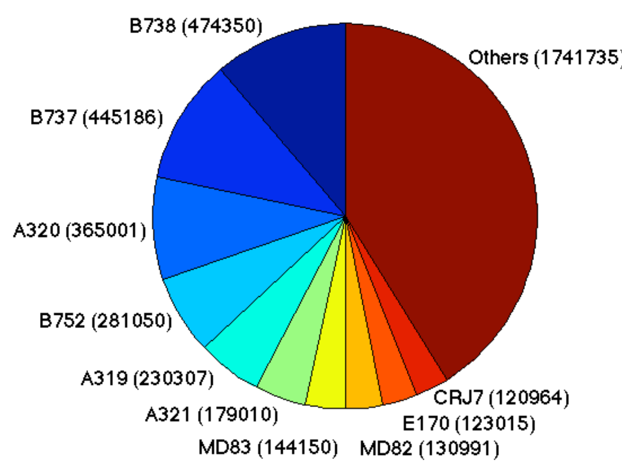

Figure 6. Fuel-savings (lbs.) for the top-10 aircraft types.

presented that the green-house gases amount to about 7% of the total fuel spent. Therefore, these aircraft types can reduce about 175,000 lbs. of environment harming gases. These results are just for the 30-day convective weather analysis here. The annual time- and fuel-savings would be higher, depending on the savings that could be extracted during better-weather days.

D. Persistence Time

An interesting parameter to study is the persistence time, which provides a measure of how long the first-computed time-savings last as a function of time. The savings depend on the size of each Center. In Fig. 7, Ft. Worth Center (ZFW) and Miami Center (ZMA) are shown. These two Centers are highlighted here because they have a good contrast in the observed persistence time. The left y-axis shows the potential time-savings (black) and the right y-axis shows the number of aircraft (green) for which NASCENT routes were proposed. Based on the figure, it can be seen that the time-savings drop below 5-minutes around 15 minutes for ZFW, while time-savings drop below 5-minutes at around 25 minutes for ZMA. This parameter indicates that

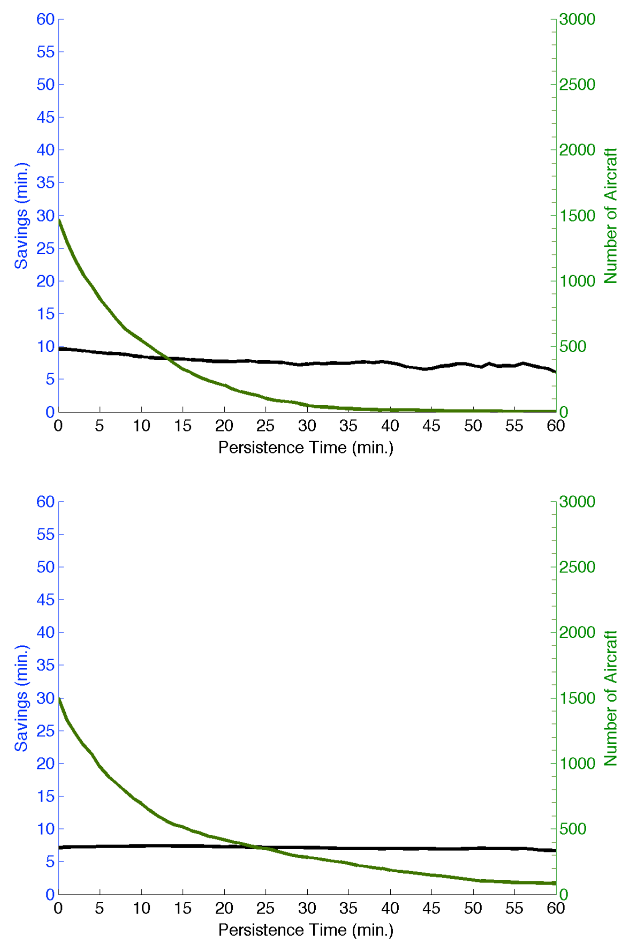

Figure 7. Persistence time in Ft. Worth (ZFW, top) and Miami (ZMA, bottom) Centers.

if the maneuver toward the NASCENT proposed reroute starts within 15 and 25 minutes, respectively, for ZFW and ZMA, the 5-minute time-savings can be achieved. Clearly, depending on the Center, the savings may dwindle faster or slower. The number of aircraft is shown on the right to see how many aircraft this curve is applicable to.

In Albuquerque, Atlanta, Boston, Chicago, Cleveland, Los Angeles, New York, Oakland, Salt Lake, and Seattle Centers, the savings dwindle very rapidly. For these Centers, 5 minutes of coordination time (maneuver start point) may not even be sufficient to achieve reasonable savings. In Denver, Indianapolis, Jacksonville, Minneapolis, and Washington Centers, the coordination time available is between 5 and 10 minutes. Lastly, Fort Worth, Houston, Kansas City, Memphis, and Miami Centers can afford more than 10 minutes of coordination time. Therefore, depending on the Center the flight is operating in, there is a maximum amount of coordination time to start the maneuver towards the NASCENT proposed route. It should be noted, however, that the later the maneuver starts, the lower the possible savings. This makes a case for implementation of controller-pilot data link connectivity for the flight operators to achieve larger savings.

IV. Traffic Flow Manager Assessment

A Traffic Flow Management (TFM) assessment from a National Operations Manager at the Air Traffic Control System Command Center in Warrenton, VA is provided here. The following section describes some of the priorities of TFM assessment, and offers a perspective for NASCENT-like technologies to make the NAS more efficient in a tactical time frame. Also, improvements in NASCENT that could further enhance its usefulness are presented, especially in light of some of the enhancements expected within the FAA infrastructure in the near- to mid-term timeline.

Traffic managers operate on traffic flows rather than individual flights, to manage workload and resources. It is more efficient in today's automation to send out traffic flow management structure through route assignment and manage capacity through delay assignment. This provides predictability for the FAA managers to allocate resources, and identify volume constraints caused by the traffic management initiatives implemented to manage the NAS constraints. This is a very strategic method looking 4-8 hours ahead of the constraint development.

The lead-time required is driven by the need to identify the forecast constraint, coordinate the solution (primarily through verbal negotiations), develop and analyze the solution, then distribute the planned initiative to be executed by the flight operators and air traffic controllers.

Automation is moving to close the coordination gap between the traffic managers and controllers while ingesting the flight operator's preferences and capabilities. NASCENT's probing provides an opportunity to alert the traffic managers (both FAA and AOC) to flights transiting a NAS constraint, reducing the workload of monitoring every flight and allowing the development of TMIs that are flight-based versus flow-based management.

The ability to probe a flight's trajectory for potential route impacts provides an opportunity to handle constraint resolution in a more tactical manner. The use of polygon intersections allows the application of NASCENT technology beyond just the weather, and allowing for Special Activity Airspace (SAA), Flow Constraint Areas (FCA), and alerted sectors to be evaluated in route recommendation and resolution.

NASCENT can also be extended to improve newer TFM planning programs. Collaborative Trajectory Options Program (CTOP) is a method of managing demand through constrained airspace while considering customer preference with regard to both route of flight and delay. Integration of the NASCENT route advisory into a CTOP airborne solution, transitioning flights from their current route to alternate airborne route, would allow for the TFM program issuance to be delayed until the forecasted constraint is actually impacting the NAS. This delayed solution allows flights to continue on their optimal route moving the application of the TMI closer to the tactical environment, and the constraint.

Probing a flight's trajectory prior to departure is part of the full flight management and TMI application. Using the dynamic weather forecast probing will allow improved application of a Severe Weather Avoidance Plan (SWAP). Utilizing a customer's preference of taking an assigned alternate departure route or waiting to push back from the departure gate until the route is forecasted to be clear of the constraint for the individual flight. Flight operators holding at the gate or staying in the non-movement areas enhance surface movement management and departure runway assignment, reducing the number of last minute changes to flight route while taxiing. Gate holding also has the potential so save fuel where aircraft can wait without engine running. The flights would *a priori* know if the route assigned is feasible and reduce the potential of delaying during taxi-out, determining if they have the fuel for the proposed route of flight.

It is important that flights on a published required reroute not be moved to another route for predictability. NASCENT could incorporate this feature, to prevent a flight being moved off of a nationally designed flow. Utilization of the Traffic Management Initiative-Identifier (TMI-ID) could prevent NASCENT from probing for route savings. Knowledge of the National Reroutes could also be extended to prevent a solution from crossing a stream of flights creating complexity for the sector controllers. Additional knowledge of flows being used with Time Based Flow Metering (TBFM) could provide applications for developing path stretch routes or shorting routes to improve the efficiency across the metered location.

It is desirable from an efficiency perspective for long-distance flights to climb as fuel is expended. In the near-term, a profile altitude will be available within the International Civil Aviation Organization (ICAO) flight plan format. Expanding the capabilities of NASCENT technology, to consider planned altitude filed in the ICAO flight plan format, increases potential for a better routing solution. This solution will result in stratified sectors or avoiding polygons that have lower altitudes, and allow route development efficiencies not seen in today's operations.

The anticipated Airborne Re-Route (ABRR) technology will provide greater flexibility and efficiency in the En Route environment for implementing airborne reroute Traffic Management Initiatives (TMIs), as well as modifying and canceling reroutes when conditions change. The Pre-Departure Re-Route (PDRR) technology is anticipated to be similar to the ABRR technology but for aircraft that have yet to depart. The use of DataComm with deployment of ABRR and PDRR technologies will improve safety through reduced verbal communication and required multiple entry points. DataComm will also allow NASCENT routes to be created using latitude/longitude (a generic solution) and not just known fixes to increase efficiency. The proposed change will know which flights can accept DataComm and which need verbal clearances. Consequently, the automation will need to be cognizant of the equipage to create a route that can be accepted by both, the flight and the controller.

The integration of Traffic Management tools and NAS systems will facilitate the application of dynamic solutions such as controlling individual flights, as opposed to flow management with NASCENT-like technologies. The dynamic solution keeps flight routing options flexible based on the life cycle of the NAS constraint. Moving NAS management from a 4-8 hour application time range with a larger uncertainty, toward a 2-4 hour application of TMIs provide improved efficiencies to the NAS users. Keeping flexibility and increasing TFM-automation identification of impacting constraints with proposed solutions is where the flight operators are asking the FAA to head. The vision of NextGen is realized with processes that are dynamic and integrated to maximize available capacity in the most efficient manner.

V. Concluding Remarks

The NASCENT system, implementing the DWR concept, provides a way for airborne aircraft in all 20 Centers of the National Airspace System proposes reroutes that save more than a user-specified number of minutes of wind-corrected flying time. Correspondingly, significant potential time- and fuel-savings can be obtained to benefit the airlines in today's economic conditions. NASCENT adds an automated method to identify limits of how far the routes can be cleared, that are consistent with current operations of each individual en route Center. Results are presented for various parameters to benefit the decision-making of the operators. Two different parameters of reroute-return capture fix selection (for controller clearances) and maneuver start point (for coordination activity) are presented in this paper. Results for potential time- and fuel-savings for these parameters along with sector congestion, SUA traversal, and persistence time (for selecting the maneuver start point) are presented for flights that could fly on NASCENT proposed reroutes. The results are shown from airspace users' and FAA perspectives, and for different aircraft types in use today. Results for sector congestion from an individual flight's perspective are presented, along with the congestion results if all flights were to fly these NASCENT proposed reroutes. The SUA traversal numbers suggest that proposed routes fly through SUAs more than the current flight plans, and mainly for flights coming from the international airports southeast of Florida. Based on the results, it can be concluded that the dynamic weather routes concept as implemented in NASCENT may provide significant benefits across many Centers in the National Airspace System.

An assessment from a current National Operations Manager at the Air Traffic Control System Command Center is presented. The perspective described here helps make the NAS more efficient in a tactical time frame. Functional improvements in NASCENT that could further improve its usefulness are presented. These comments incorporate the enhancements expected within the Traffic Flow Management infrastructure in the near- to mid-term timeline.

A major airline and an industry partner interested in commercializing this technology are evaluating the NASCENT system.

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