Infotech@Aerospace 2012
19 - 21 June 2012, Garden Grove, California

AIAA 2012-2436

Evaluating the Impact of Deploying Unrestricted Unmanned Aircraft Systems in the National Airspace

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Unmanned aircraft systems (UAS) can be used for scientific, emergency management, and defense missions, among others. The existing federal air regulations, procedures, and technologies do not allow routine UAS access to the National Airspace System (NAS), with the UAS being flown primarily within restricted airspaces. The current Certificate of Waiver of Authorization (COA) process requirement for UAS operations in the NAS are extremely resource intensive, lengthy, and often lacks the flexibility to meet the full mission needs. As the number of UAS operations increases, new methodologies will be needed to enable their safe and routine access to both restricted and unrestricted airspace in the NAS. This paper focuses on gaining a better understanding of growth of NAS usage in near-term NAS UAS demand in that airspace, and an assessment of the impact of unrestricted UAS deployment in the NAS that may facilitate the development of enabling methodologies. Using software simulations for demand growth generation and NAS operations the impact of UAS integration into the NextGen NAS is simulated to analyze its impact on the delay, congestion, loss of separation conflicts, fuel burn, and noise level. Our analyses show that while there is a slight increase in these factors due to additional UAS flight, this increase is minimal compared to the levels caused by the increase of commercial traffic alone.

I. Introduction

Unmanned aircraft systems (UAS) have the ability to support a variety of scientific missions, emergency management operations, and national security and defense missions, among others. A large number of UAS are currently in operation, although most UAS operations are conducted within restricted airspaces. Over the next five to eight years, however, it is likely that the UAS will need to be deployed in both restricted and unrestricted airspaces in the National Airspace System (NAS)[1]. The existing federal air regulations, procedures, and technologies do not allow routine UAS access to the NAS. The current Certificate of Waiver of Authorization (COA) process requirement for UAS operations in the NAS is extremely resource intensive, lengthy, and often lack the flexibility to meet the full mission needs. As the number of UAS in operation increase, a new methodology will be needed to enable their safe and routine access to the NAS alongside commercial flights (CFs). The development of this methodology will be facilitated by a better understanding of near term NAS growth, UAS demand in that airspace, and an assessment of the impact of unrestricted UAS deployment in the NAS.

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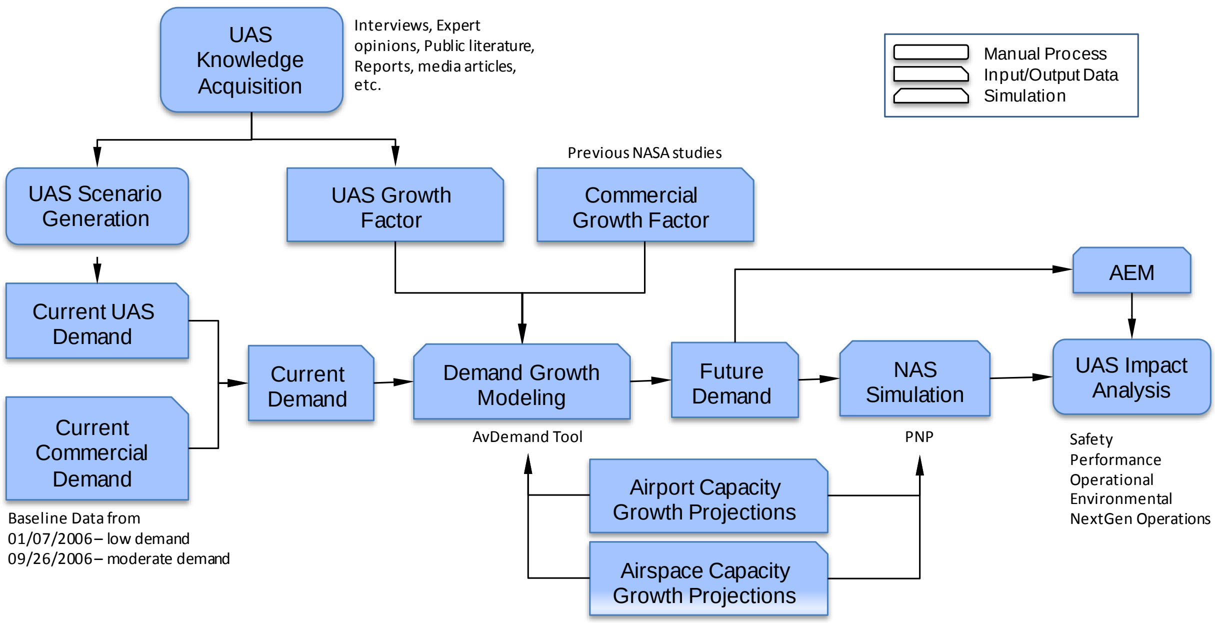

Figure 1: An overview of the approach to assess UAS impact on the NAS.

This paper presents a simulation-based approach for assessing the impact of UAS operations in both restricted and unrestricted airspace in the NAS alongside CFs. Figure 1 presents an overview of the approach taken to assess the UAS's impact. First, relevant UAS knowledge is acquired based on information gathered from a variety of sources from the UAS community, including extensive research and interviews with domain experts. Based on this information, several representative current UAS scenarios are generated that include operations in the restricted and unrestricted airspace thereby suggesting additional demand on airport and airspace capacities due to UAS operations in these scenarios. In addition to the current UAS flights demand, projected growth factors for UAS demand at several future points of time are also identified. Based on available information, current commercial flight scenarios, commercial demand, and commercial growth factors are estimated and used in the NAS simulation. Current UAS and commercial demands are combined to generate the current combined UAS-CF demand. This current flight demand along with the UAS and commercial growth factors are then fed into AvDemand[2,3], a demand growth generation model and tool, to generate future combined UAS-CF demands, which also consider projections for both airport and airspace capacity growth. Once the future UAS-CF demands are generated, they are simulated using the Probabilistic NAS Platform (PNP) tool[4], to obtain different performance, safety, and environmental metrics, such as delay, congestion, loss of separation conflicts, and fuel burn. In addition to PNP, the Area Equivalent Method (AEM) for noise modeling is used to assess the impact on noise levels. These metrics are then compared with those obtained by simulating the current UAS-CF demands using PNP for UAS impact analysis.

The remainder of the paper is organized as follows. Section II describes how representative UAS operation scenarios are generated. Section III describes the generation of combined UAS-CF demand sets using AvDemand. Section 0 presents the NAS simulation and impact analysis, and includes a description of NAS simulation of demand sets using the PNP tool followed by an analysis of the impact of these UAS in current and future loading conditions on the NAS. Section V presents conclusions gained from the study.

II. UAS Operation Scenarios

The first step to analyzing the impact of unrestricted UAS access in the NAS is the generation of scenarios that include both commercial and UAS flights. Since current regulations do not allow UAS operations in unrestricted airspace, our approach to generating such scenarios was to separately obtain commercial and UAS flight scenario data and merge them. While commercial flight data are readily available, UAS flight data are not. UAS operations are predicted to ramp up in the next five to fifteen years, when the military units return from overseas missions, and many more UAS's become available for use in national first responder missions. However, exactly when and how UAS will be used in the future is not entirely clear. Hence, we *generate* reasonable and representative scenarios of current to near-term future UAS operations taking into account current and future projections of the airspace characteristics at different airports from which UAS are projected to be operated, the planned/plausible flight operations around these airports, the remotely piloted aircraft (RPA) performance of UAS, traffic density, and population density in the vicinity of these airports.

The UAS scenarios generated for this work are based on information gathered from various public sources, such as technical reports, research papers, published media reports, as well as interviews conducted with UAS practitioners and researchers from industry and government. Other than mission descriptions and flight profiles, information regarding current UAS usage level was also gathered. While some of this information may be considered low fidelity, the attempt has been to make sure it is representative of current UAS operations, and hence, relevant for use for the purpose of this project. These scenarios include three different UAS aircrafts commonly in use by the US armed forces – namely the MQ-1 Predator (medium altitude, long-endurance), the MQ-9 Reaper (higher power and capacity), and the RQ-4 Global Hawk (high altitude, long-endurance). These aircraft cover a range of applications relevant to impact assessment, which include a good mix of civilian scientific and military scenarios for law-enforcement, surveillance, and emergency management purposes, among others. Based on discussions with domain experts on UAS, and relevant literature, we selected six airports and constructed seven plausible scenarios involving different UAS from these locations. As used in Table 2 and Table 4, these scenarios include applications like the New York 174th Air National Guard Training Missions; the 119th Air National Guard Training Missions in Grand Forks Air Force Base, North Dakota; 9th Reconnaissance Wing Training Mission at Beale Air Force Base; the Customs and Border Patrol Mission on the Northern and Southern US Border; Hurricane Research; and Western States Fire Missions. The six selected airports are Grand Forks Air force Base (KRDR), Syracuse International Airport (KSYR), Corpus Christie International Airport (KCRP), Wallops Flight Facility (KWAL), Edwards Air Force Base (KEDW), and Beale Air force Base (KBAB).

Each UAS scenario includes the *purpose* of the mission; the *UAS type* used; the *airspace characteristics* of the flight area; the *description* of the scenario that includes the route the UAS flies, what it does, and how; and any *assumptions* that were made at the time of conception of this scenario. The scenarios constructed for this work are of high enough fidelity to feed impact demand modeling tools with UAS flight data, enabling a first pass estimate of the impact of UAS operations on the NAS. An example UAS scenario is presented Table 1 below.

Table 1. CBP Mission on the Northern US Border.

Purpose: The purpose is routine border patrol mission, primarily along the Eastern Maine/Canada border, with the expectation of some unplanned loitering activities if border incursions or smuggling operations are witnessed.
UAS Type: MQ-9 Reaper
Airspace Constraints: This Northern US Border Customs and Border Patrol (CBP) operation is based out of Syracuse Hancock International Airport (KSYR). KSYR, located 4m NE of Syracuse, NY, is a Class C airport. The Misty MOA and restricted airspace R5203 are the Special Use Airspaces in the vicinity of KSYR.
Scenario: The intended mission is a routine night-time border patrol operation, primarily along the Eastern Maine/Canada border, with the expectation of some unplanned loitering activities if border incursions or smuggling operations are witnessed[5]. The route starts and ends over Lake Ontario and follows the US/Canadian border up to Maine and then along the Eastern Maine/Canada border out over the Bay of Fundy. The return route follows the same path. The initial flight path for the mission is shown in Figure 2 below. The UAS takes off Runway 33 of KSYR at around 9:00 pm. The pilot climbs the aircraft up to its initial cruising altitude of FL 200 and continues according to its filed flight plan. The flight transitions over Lake Ontario into restricted airspace R5203. The aircraft is cleared to FL 210 and it turns back eastward over the lake. It then proceeds up along the St. Lawrence River at en route airspeed of 157 KTAS. As the aircraft continues on its programmed flight path, the sensor-operator surveys various areas of interest. North of Ft. Drum, the mission commander requests the pilot to deviate from the flight plan and loiter over some potential illegal immigrants. The pilot then contacts the flight's Air Route Traffic Control Center (Boston Center – ZBW) and negotiates a modification to the filed flight plan. The sector controller at ZBW is familiar with this type of request, and establishes a loiter pattern with the aircraft flying figure eight patterns at 120 KTAS, in an area approximately 10 by 20 nautical miles, at a altitude of 5,000 feet MSL. The altitude requirement allows the sensor operator improved imagery while loitering. The Reaper loiters for approximately an hour, during which, the Reaper mission commander coordinates with CBP ground personnel in intercepting the illegal immigrants. The pilot then contracts the sector controller and requests a resumption of the original flight plan and climbs back up to FL 210. The flight continues on its filed flight plan until out over the Bay of Fundy where the mission commander requests that the pilot follow a ship that is suspected of smuggling. The pilot, once again, requests a modification to the planned course, and is granted permission to pursue the ship while descending to 13,000 feet MSL. The Reaper is flown in pursuit for approximately 30 minutes, during which time the mission commander verifies with the local coast guard that the ship is on a legal operation. At this point, no further surveillance is required, and the pilot again contacts the sector controller, and upon receiving clearance, returns to the filed flight plan and altitude. The Reaper continues back to Syracuse descending to FL 200 for the return leg of its flight, flying again over Lake Ontario, before approaching into KSYR. While at approximately 30 miles northwest of KSYR, the pilot informs the ATC of his intent to land. On being cleared to land, the pilot lands the Reaper at 11:00 am, about two hours later than planned, due to the loiter and pursuit activities.
Assumptions: The flight takes place in late summer between 9:00 pm and 7:00 am. Typical mission altitude will be 20,000 feet (FL 200), but can vary as unplanned aerial work dictates. Areas of interest covered by this scenario include IFR operations in controlled airspace, controller airport operations, and unplanned aerial maneuvers in a dense, en route air traffic environment.

A summary of all our UAS scenarios is presented in Table 2 below that lists the flight frequency and the current average daily demand. It must be noted that based on scenario types the numbers in the table are calculated differently. For instance for NY ANG training missions the average daily demand level is computed by simply averaging the number of flights per day from the weekly demand, whereas for ND ANG the corresponding daily demand is computed by averaging the number of flights per day from monthly demand (assuming a 30 day month) and using the maximum usage estimate of 5 flight per week. Likewise, for on need basis missions like Fire missions and hurricane research, 1 flight per day is assessed, however in practice these may be one or zero as actually needed. In this study all such flights will be simulated together, i.e. we assume fire missions as well as hurricane research missions take place simultaneously on the day of analysis.

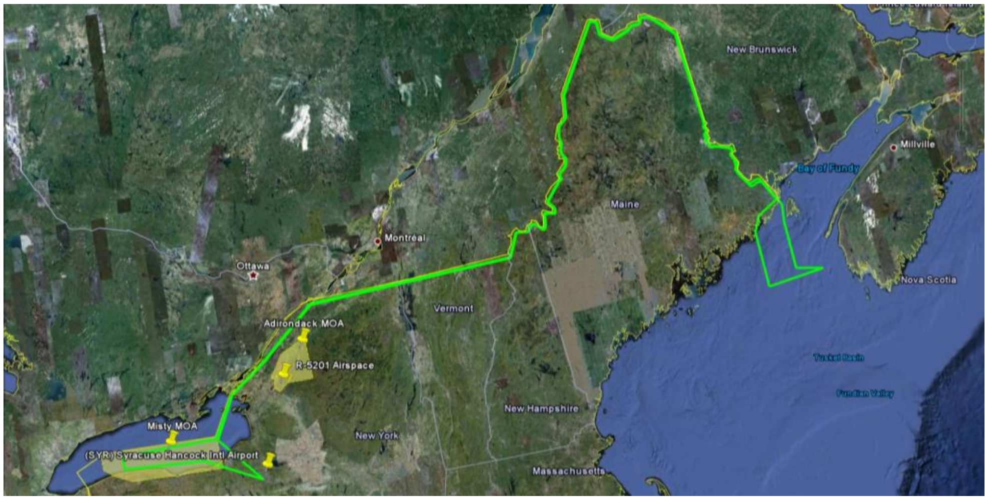

Figure 2. Border Patrol Route.

Table 2: Summary of UAS Scenarios used and current demand levels.

Scenario	Airport	UAS	Aircraft Type	Market	Information Available from Experts	Current Avg. Daily Demand
174th NY ANG	KSYR	MQ9	Turboprop	Military	3-5 flights/week	0.7 flt/day
119th ND ANG	GFAFB	MQ9	Turboprop	Military	2 flights/day for 5 days a week + 1 flight on one Saturday each month	1.4 flt/day
Northern US CBP	KSYR	MQ9	Turboprop	Military	1 flight/day	1flt/day
Southern US CBP	KCRP, KBIF, KDRT	MQ9	Turboprop	Military	1 flight/day	1flt/day
Fire Missions	KEDW	MQ9	Turboprop	Civil	1 flight/day on need basis	1flt/day
9th Reconnaissance Wing Training	KBAB	RQ4	Turbojet	Military	1 flight/day	1flt/day
Hurricane Research	KWAL	RQ4	Turbojet	Civil	1 flight/day on need basis	1flt/day

III. Generating Combined UAS-Commercial Flight Demand Sets

The next step before carrying out NAS simulations is to generate combined UAS-CF demand sets. Both, *baseline* and *projected growth* demand sets for both commercial and UAS flights are generated to develop the combined UAS-CF demand sets.

A. Generating Baseline Flight Demand

For baseline CF demand, data from two days - January 7, 2006 and September 26, 2006 - are used as representative for low traffic and moderate traffic volumes. The CF demand data include the Instrument Flight Rule (IFR) traffic that is based on the Enhanced Traffic Management System (ETMS). Baseline UAS demand data are created based on UAS scenarios developed in Section II. The seven UAS scenarios described in Section II include ten different flight trajectories. Once generated, each baseline UAS demand and its corresponding CF demand is combined into one demand set for a period of 24 hours to generate baseline combined UAS-CF demand.

B. Generating Projected Growth Flight Demand

Growth demand data can be generated using baseline demand data files and the AvDemand software. AvDemand, created by Sensis Corporation, is a flexible demand generation application that provides an ability to quickly generate future demand data based on a range of social-economic scenario and business and operational change assumptions[6, 7]. Using baseline flight demand as a starting point, AvDemand provides the ability to *"grow"* the baseline flight demand, i.e., generate and analyze future flight schedules and flight plans, utilizing alternative demand-generation algorithms. AvDemand allows for *homogeneous* and *heterogeneous* demand growth based on flight operations. The homogeneous demand growth option assumes that the flights at all airports are growing at the same growth rate. The heterogeneous demand growth option, on the other hand, allows each airport to grow at a different growth rate. A *growth factor* for each airport determines this rate. The steps to growing commercial and UAS flight demands are briefly described below.

The growth of commercial flight demand is generated by growing the baseline commercial flights for each of the two days in year 2006 using AvDemand homogeneously to projected levels of 1.2 for 2018, and 1.6 for 2025. These demand generation factors have been derived from the results obtained in previous NASA SLDAST Common Scenario studies[8]. Further, one scenario assuming 2x the 2006 level demand is developed to analyze the impact for a more aggressive growth rate.

The growth in UAS demand is determined based on information available from the Operational Services and Environmental Definition (OSED) for UAS report from RTCA corp[9]. In the OSED document a detailed analysis of future growth predictions is provided. However, the growth numbers were categorized by different UAS Aircraft Categories (Turbojet, Turboprop, Reciprocating fixed wing, VTOL, and Airship) and UAS Market Segments (Military, Civil, and Commercial), and separate projections are provided for each category from Year 2008 to Year 2030. Most of the scenarios used in this project fall under the military's reconnaissance/surveillance and training missions, and two scenarios can be grouped under civil applications. Furthermore, the involved aircraft type fall under turboprop (MQ-1 and MQ-9) and turbojet (RQ-4) categories. Hence mapped these projections on these categories and interpolated corresponding demand levels for years 2018 and 2025 for civil or military applications, as needed. The growth levels for relevant cases as assessed from the OSED document are presented in Table 3.

Table 3: Projected Growth factors for UAS usage.

Aircraft	Market	Current Usage	2018 Projected	Growth Factor	2025 Projected	Growth Factor
MQ9	Military	8	81	10x	99	12.5x
MQ9	Civil	4	20	5x	27	7x
RQ4	Military	6	105	18x	125	21x
RQ4	Civil	1	11	11x	13	13x
MQ1	Military	60	99	1.5x	102	2.8x
MQ1	Civil	0 (1)	55	55x	71	71x

Table 4: Projected demand growth for all UAS Scenarios based on OSED[9] and Table 3.

UAS ID	Scenario	Airport	Trajectory Length (Miles)	Growth Factor		Current Demand	Current Simulated	2x2006 Demand	2018 Demand	2025 Demand
				2018	*2025*	*Average Daily Demand (flights/day)*				
1	119th ND ANG	KRDR	450	10x	12.5x	0.7	**1**	**2**	**7**	**9**
2			588			0.7	**1**	**2**	**7**	**9**
3	9th Reconn. Wing Training	KBAB	637	18x	21x	1	**1**	**2**	**18**	**21**
4	Northern US CBP	KSYR	2100	10x	12.5x	1	**1**	**2**	**9**	**11**
5	174th NY ANG		400			0.7	**1**	**2**	**7**	**9**
6*	Hurricane Research	KWAL	2620	11x	13x	1	**1**	**2**	**2**	**3**
7	Southern US CBP	KCRP	833	10x	12.5x	1	**1**	**2**	**3**	**4**
8		KBIF	592			1	**1**	**2**	**3**	**4**
9		KDLF	795			1	**1**	**2**	**3**	**4**
10*	Fire Missions	KEDW	2565	5x	7x	1	**1**	**2**	**3**	**4**
Total						9	**10**	**20**	**62**	**78**

The projected growth numbers are based on several assumptions and should only be considered representative estimates that are based on the OSED document projections. Also it must be noted that since only a select few usage scenarios were considered in this paper the numbers for a particular aircraft category may not add up to the total projected in the OSED document. Based on these assumptions the final demand levels for future years 2018 and 2025 as used in this analysis are provided in Table 4.

IV. NAS Simulation and Impact Analysis

For this research we used the Probabilistic NAS Platform (PNP)[10], a fast-time simulation tool, to simulate the UAS traffic in the NAS under different demand and capacity combinations mimicking actual operations in the NAS including both Air Traffic Control (ATC) and Traffic Flow Management (TFM) behaviors. The output from the fast-time simulation model is then evaluated and analyzed to address the impact of the UAS in the NAS from different perspectives categorized by metrics types.

A. Simulating Combined UAS – CF Demand Sets

The next step towards impact analysis is to simulate the different combined UAS-CF flight demands consisting of different traffic levels and patterns for commercial and UAS operations, different airport and airspace capacities, and a variety of operational constraints (e.g., separation requirement, air traffic control procedures, and rules). The different combined UAS-CF demand sets used in this study (and shown in Table 5) are generated by using combinations of different levels of (*i*) UAS demand, (*ii*) CF demand, (*iii*) airport capacity, (*iv*) airspace capacity, and (*v*) conflict detection (CD) distance. For the UAS flights, there are four levels – Current, 2xCurrent, 2018, and 2025 – representing the current UAS demand, two times the current UAS demand, projected UAS demand in 2018, and projected UAS demand in 2025, respectively. For the commercial flights there are four levels of demand – 2006, 2x2006, 2018, and 2025 – representing the current CF demand, two times current demand, CF demand projected for 2018, and CF demand projected for 2025, respectively. The airport capacity varies between 2006, and projected levels for 2018, and 2025. The airspace capacity varies between current, 1.5 times and two times the current values. Three values for Loss of Separation (LoS), 5 nmi, 10 nmi, and 20 nmi, for conflict detection (CD) are hypothetically chosen to estimate the impact of relaxation in the definition of conflict and if that may be an alternative with newer and better see-and-avoid systems. The airport capacity used in this analysis accounts for all of the planned technology improvements as well as runway additions, based on the analysis in an earlier NASA report[8]. The airspace capacity data is also leveraged from a previous NASA study that focused on generating FY10 Baseline Scenarios for 2006, 2018, and 2025 including Implicit Weather Modeling for simulations with ACES[11]. It should be noted that the 2018 airspace capacity data assume a homogenous 1.5x capacity improvement from the 2006 baseline and the 2025 airspace capacity data assume a homogeneous 2x capacity improvement from the 2006 baseline.

Table 5 lists a selection of various combinations of UAS-CF demand sets developed from a combination of the five parameters mentioned above. When every parameter is kept at the current setting, a 'current demand' is generated. Current demands provide a baseline for combined UAS-CF demand sets. The 'NextGen demands' are generated by ensuring that the airport and airspace capacity grows as per NextGen requirements. 'Deferred NextGen demands' are generated by ensuring that the airport and airspace capacity are kept at the previous level compared to the UAS and Commercial demands. Deferred NextGen demands are useful for evaluating the situation where UAS and commercial demand would have grown, but due to some unforeseen circumstances, the airport and airspace capacity could not be increased. Finally, the 'baseline CF demands (without UAS)' help get baseline estimates of how things are with commercial flights alone. The standard LoS for commercial aircraft is 5 nmi, however we also simulate more conservative LoS values for UAS scenarios as mentioned above. Scenarios 1-16 in Table 5 correspond to simulation runs with LoS set to 20nmi. Likewise, scenarios 21-36 and 41-56 were generated for LoS 10 and 5 nmi respectively. Baseline demands without the UAS in the mix are also generated for the three LoSs, of which only the set for LoS of 20 nmi is listed below. The different scenarios in Table 5 are simulated using PNP, which uses the Point Mass Trajectory Generator to simulate flights and predict airspace loading at incremental future times. If a portion of airspace gets highly congested, PNP plans around that congestion by rerouting or delaying flights that are scheduled to fly through that congestion. The PNP algorithms are stochastic in that they account for the inherent uncertainties in the NAS demand and capacity, rather than merely using deterministic approximations. This is important as both demand and capacity forecasts can have substantial uncertainty. PNP also records important events, such as aircraft position, conflicts, and gate and runway times that facilitate the review and analysis of the impact of UAS in NAS. A detailed description of PNP and its several features can be found in[10].

Table 5: Simulation Run Matrix describing various scenarios run and analyzed.

Demand Description	Combined UAS-CF Demand S. No.	UAS Demand	CF Demand	Airport Capacity	Airspace Capacity
Current	1	Current	2006	2006	1x
NextGen Demand	2	Current	2018	2018	1.5x
	3	2xCurrent	2018	2018	1.5x
	4	2018	2018	2018	1.5x
	5	Current	2025	2025	2x
	6	2xCurrent	2025	2025	2x
	7	2025	2025	2025	2x
	8	Current	2x2006	2025	2x
	9	2xCurrent	2x2006	2025	2x
	10	2025	2x2006	2025	2x
Deferred NextGen Implementation Demands	11	Current	2018	2006	1x
	12	2xCurrent	2018	2006	1x
	13	2018	2018	2006	1x
	14	Current	2025	2018	1.5x
	15	2xCurrent	2025	2018	1.5x
	16	2025	2025	2018	1.5x
Baseline demands without UAS	61	None	2006	2006	1x
	62	None	2018	2018	1.5x
	63	None	2025	2025	2x
	64	None	2x2006	2025	2x
	65	None	2018	2006	1x
	66	None	2025	2018	1.5x

B. Impact Analysis: Metrics and Results

The impact analysis of unrestricted UAS deployment in the NAS is divided into performance impact, safety impact, and environmental impact analyses, as described below.

1. Performance Impact Analysis

The system performance impact analysis examines NAS-wide delay impact by estimating airport delay impact for the UAS operations. This metrics show how UAS operations affect NAS operational performance. Table 6 shows congestions and delays statistics for flight simulation data from 01/07/2006. Comparisons are made between corresponding demands *with* and *without* UAS demand in the mix.

Airport congestion and delays are functions of airport capacity, airspace capacity, and demand levels. From Table 6, it can be seen that although within each of the six blocks for different NextGen and deferred NextGen demands, growth in total departures due to additional UAS traffic can be observed, however, that growth is marginal, and hence, has no visible impact on the maximum congestion levels at the airports. Also, for the NextGen 2025 demands, increase in capacity is so much that there are no delays seen in the system. For the NextGen 2x2006 demands resulting delays increase a lot, since, for such an aggressive demand growth, the increased NextGen airspace capacities are not sufficient. Finally, the average delay values for all demands are relatively small.

Since the runs are not calibrated based on the most current NAS performance, the main purpose for this exercise is to perform analysis looking at the relative additional delays to gain insights into the system performance. The overall conclusion from the analysis is that given the NextGen improvement demands and the demand growth projections, integration of UAS does not result in any significant impact on performance of the NAS. The average delay at the airports is not expected to be affected by additional UAS demand at a few airports as is the case in this study. However if these UASs had any contribution in airport delays, the total delays would have seen an increase. This is because, most of the UAS are stationed at military airports and any delays at those airports will not appear in these results since PNP does not simulate any military airports. Also, for the two airports SYR and CRP that are included in the simulations the number of aircraft operations are relatively small and hence adding extra UAS does not cause any noticeable interruption.

Table 6: Congestion and Delay Statistics (1/7/2006 data).

Demand	S.No.	Total Departures	Total Mx Airport Congestion	Avg Mx Airport Congestion	Pre Dep. Delay (Minutes)	Avg Pre Dep. Delay (Minutes)	Total Delay Count	Total Delay (Minutes)	Avg Delay Per A/C (Minutes)
2006	61	27635	21	3.81	2593	24.009	108	2593	0.094
	01	27645	21	3.81	2593	24.009	108	2593	0.094
NextGen 2018	62	31657	34	4.529	276	16.235	17	276	0.009
	02	31667	34	4.529	276	16.235	17	276	0.009
	03	31677	34	4.529	276	16.235	17	276	0.009
	04	31719	34	4.529	276	16.235	17	276	0.009
NextGen 2025	63	36222	23	4.348	0	0	0	0	0
	05	36232	23	4.348	0	0	0	0	0
	06	36242	23	4.348	0	0	0	0	0
	07	36300	23	4.348	0	0	0	0	0
NextGen 2x2006	64	59586	275	6.753	4237	24.351	174	4237	0.071
	08	59596	275	6.753	4237	24.351	174	4237	0.071
	09	59606	275	6.753	4237	24.351	174	4237	0.071
	10	59664	275	6.753	4237	24.351	174	4237	0.071
Deferred NextGen 2018	65	31657	90	5.033	17341	32.054	541	17341	0.548
	11	31667	90	5.033	17341	32.054	541	17341	0.548
	12	31677	90	5.033	17341	32.054	541	17341	0.547
	13	31719	90	5.033	17341	32.054	541	17341	0.547
Deferred NextGen 2025	66	36222	84	5.905	1489	22.224	67	1489	0.041
	14	36232	84	5.905	1489	22.224	67	1489	0.041
	15	36242	84	5.905	1489	22.224	67	1489	0.041
	16	36300	84	5.905	1489	22.224	67	1489	0.041

2. *Safety Impact Analysis*

The system safety impact metrics examine the potential conflicts that may occur between UAS and commercial aircraft operations. PNP simulations allow recording conflicts between aircrafts. The time (start, duration) and location of the conflicts is recorded but PNP does not try to resolve the conflicts. An intent-based conflict detection algorithm is used for this study, based on the flight plan of each aircraft, with the goal being to count total number of additional conflicts involving the UAS that would have occurred in all the demand sets. Therefore, by not using any conflict resolution algorithm any effect due to the performance of conflict resolution itself is avoided.

First some simulations are run to baseline the number of conflicts expected in the NAS on a typical demand day involving only the commercial traffic, using a loss of separation (LoS) distance of 5 nmi. Table 7 presents the number of conflicts between commercial flights alone for the January data set. The number of conflicts to number of flights ratio for current demand (Demand No. 61) is 1.01 and for NextGen 2018 demand (Demand No. 62) the ratio comes out to about 1.25, which is a significant increase. It must be noted that these results do not indicate the actual number of conflicts that would take place since, in a realistic situation, a conflict resolution system would try to minimize the number of conflicts. These numbers, therefore, are presented for comparison and analysis purposes only.

Next, the simulations are run for the same demand sets with UAS added to the mix. Corresponding data for simulations including the UAS can be seen from Figure 3. The results indicate that these demand sets with added UAS traffic at various levels do not add to significant amounts of conflicts. Overall, it is observed that the number of conflicts grow as the demand grows, however in none of the cases the number of conflicts becomes very large, especially keeping in mind that the baseline number of conflicts for commercial flights only is orders of magnitude higher. Also it must be noted that since number of conflicts is not affected by airport or airspace capacities, the number of conflicts is not different for NextGen and deferred NextGen scenarios. Finally, as seen from Figure 3, number of conflicts follow the trend 2006 < 2018 = deferred 2018 < 2025 = deferred 2025 < 2x2006, which is consistent with increasing number of flights in each of these scenarios. Recall the above observations are made using a LoS distance of 5nmi. We also wanted to evaluate by how much the conflicts count will change if the LoS distance is increased from 5nmi to 10nmi and 20nmi, to demonstrate that one way of improving the safety margins is through the increase of LoS distance for UAS flights. It should be noted that new technologies are being developed for ensuring the safety of UAS and its interaction with commercial air traffic that shifts away from centralized management of air traffic to a more interactive method where conflicting aircraft are enabled to avoid other planes on their path. Once such technology has been certified for safety, these restrictions on LoS distance may be relaxed, but, until then, a more conservative approach may a near term solution.

Table 7: Commercial – Commercial Flights Conflicts (no UAS).

Demand Set	Demand No.	Demand Projection Scenario	Conflicts Distance (nmi)	Number of Departures	Total Conflicts	Average Conflict Duration (sec)	Standard Conflict Duration (sec)
1/7/2006	61	2006	5	27635	27854	181	229
	62	2018	5	31657	39584	181	228

Conflict counts are recorded for three different LoS distances: 5, 10, and 20nmi for each of the 16 scenarios to determine the sensitivity over LoS value. The results from the simulations for January 2006 data are shown graphically in Figure 3. It can be seen that number of conflicts grows as the conflict detection distance is increased. This trend is common to all scenarios. However, the absolute number of conflicts is quite insignificant as compared to the baseline commercial conflicts as presented in Table 7.

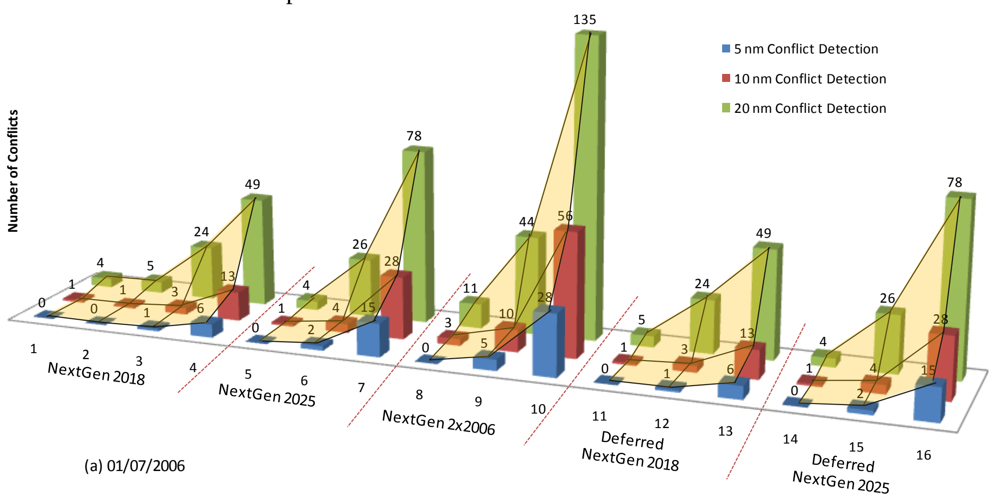

Figure 3: Number of conflicts between UAS and CF for various growth scenarios on 01/07/2006.

One approach to reducing UAS-to-CF conflicts is to stagger UAS operations in such a way as to avoid peak hours of CF traffic. We conducted an analysis to identify the effect of timings of the UAS operations on the conflict count. To this end, a demand set was created that had UAS taking off from each of the seven airports every 30 minutes for a period of 24 hours for both data sets. This resulted in 48 sets of UAS traffic differentiated by departure times. All these 48 cases are simultaneously simulated avoiding the effects of interaction between the flights belonging to different departure time sets. During the analysis conflicts between two UAS aircraft were ignored based on two assumptions – (*i*) UAS operations are expected to be designed such that they avoid any conflicts between different UASs carrying out the same mission, and (*ii*) a conflict between UASs that belongs to different departure time sets is an artifact of this experiment with staggered timings and does not reflect true conflicts. The number of UAS to commercial aircraft conflicts was determined for each of the 48 start times for LoS radii of 5, 10, and 20nmi. First an average traffic pattern from both the days was analyzed to characterize the peak traffic hours. As shown in Figure 4, the traffic volume in both the demand sets follows a bell shaped distribution, with average demand level for January case being lower than for the September case, and peak traffic recorded during day time. Based on these traffic patterns it is expected that UAS conflicts also peak at the peak demand hour. Figure 5 depicts graphically how the start time of the UAS scenarios affects the number of conflicts between the UAS and commercial aircraft.

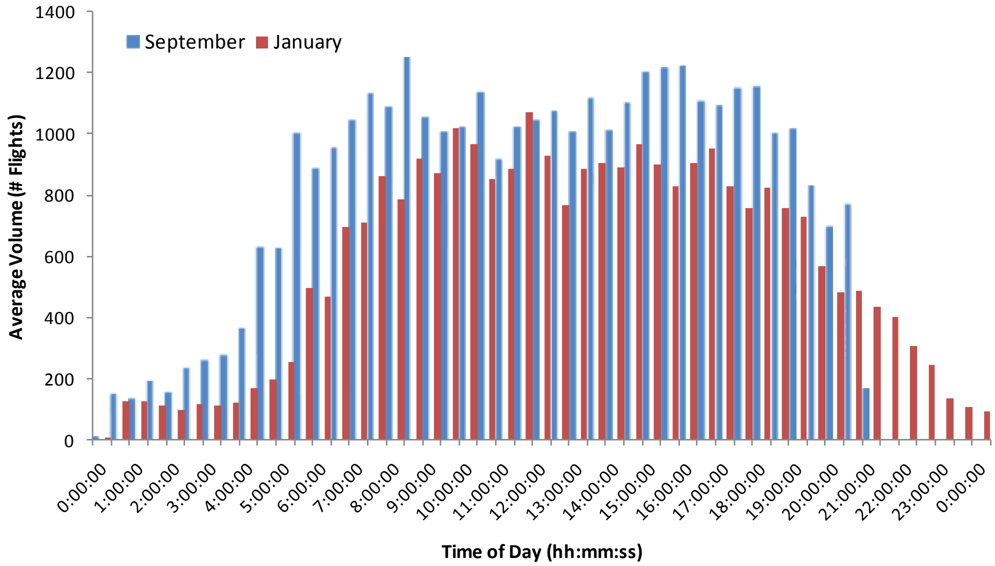

Figure 4: Distribution of flights over a 24 hour period for the two demand days.

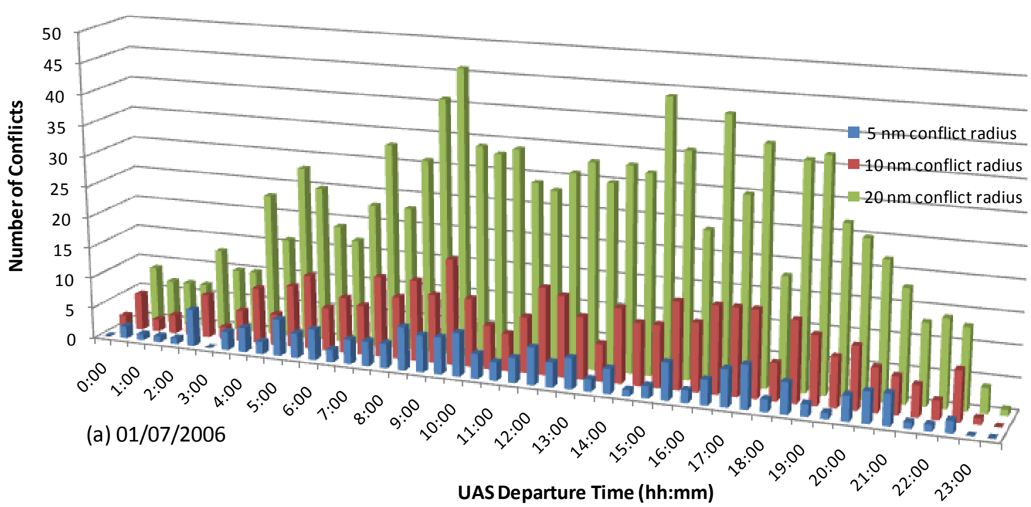

Figure 5: Total number of conflicts between UAS and Commercial AC distributed over a 24 Hour period for the low volume day 01/07/2006.

3. Environmental Impact Analysis

The environmental impact metrics looks at two factors: (*i*) the impact of fuel burn rate on the environment, and (*ii*) the noise impact of UAS operations at airports.

Impact on Fuel Burn Rate: PNP simulations provide an estimate of total fuel burn based on Aircraft BADA performance models. While these numbers can be considered very crude estimates of actual expected fuel burn, they show the extent of the incremental impact due to addition of UAS flight mix and helps put things in perspective from environmental pollution point of view. Numbers are analyzed for both simulation baseline days to test consistency in the conclusions drawn. Furthermore, comparisons are made between various combinations of different scenarios with multiple estimates of growth rates both for commercial and UAS demands.

As expected, there is a quantifiable increase in the fuel burn due to additional UAS flights over the demand set with only commercial flights. This increase is consistent for the current, as well as, NextGen demand sets. Figure 6 shows the results from simulation for the January flights.

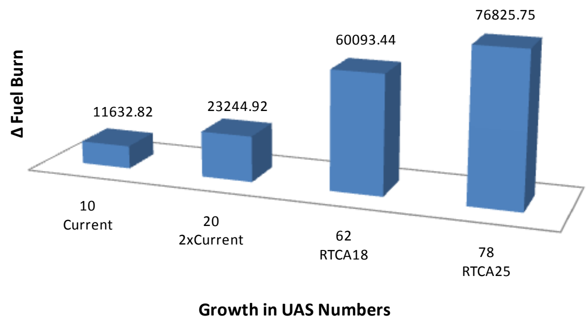

Figure 6: Total fuel burn due to additional UAS flights is expected to grow with growth projections.

Absolute contributions due to increased UAS demand are higher for estimated growth rates suggested in the OSED (RTCA) document as compared to a homogeneous 2x growth rates (see document DO-320[9]). There is no perceivable difference in the impact between the NextGen demand sets and the deferred NextGen demand sets. This suggests that impact is mainly caused due to number of increased flights and that the factors like increased congestion and delays do not contribute as much. This may be a result of the modeling of fuel burn calculations in PNP, which does not account for these factors. It is clearly apparent that additional fuel burn is directly affected by the additional number of UAS flights. However, the total fuel burn is also affected by the length of trajectory an aircraft flies. As shown in Table 4, the length of trajectories widely varies from one mission to another. Depending on which flights are grown the fuel burn will be accordingly affected.

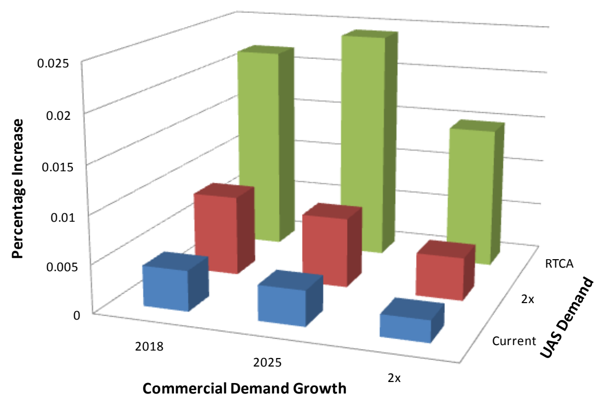

Figure 7: Estimated contributions of UAS aircraft towards fuel burn as a percentage of commercial demand contributions for different growth demand sets for 01/07/2006 data.

It is observed that for a 2x growth in flights results in almost double (1.99) the additional fuel burn, whereas for RTCA estimates the average growth is indicated to be about 6.2 (2018) and 7.8 (2025), which is reflected in a 5.16x (2018) and 6.6x (2025) increase in fuel burn estimates which is only about 84% of the growth in number of UAS (see Figure 7 and document DO-320[9]). This is explained by the homogeneous growth at 2x growth rate and a heterogeneous growth for 2018 and 2025 growth rates for UAS demands. Since not all flights are grown by the same amount, fuel burn is also weighted by the length of trajectories of the flights grown. Hence, if more flights with smaller trajectories are grown, the fuel burn will be lower. To keep things in perspective a relative contribution in fuel burn from UAS demand compared to estimated growth in commercial traffic can be seen in Figure 7. It is clear that even if the number of UAS grows aggressively as projected in the OSED document, the relative increase in additional fuel burn due to UAS is very minimal, and hence, the overall percentage contribution of UAS towards fuel burn goes down significantly from 2018 to 2025 and further for a demand set that estimates commercial demand growth at a 2x level. Also it can be seen that while this trend is consistent for current and 2x growth in UAS levels, it is not true when UAS growth levels are considered, where contribution increases from 2018 to 2025 instead of going down. This suggests that relative growth in UAS is much higher than relative growth in commercial demand. However, the key lesson from this analysis is that UASs contribute 0.025% of total fuel burn in even if grown very aggressively.

Area Equivalent Method (AEM) for Noise Modeling: AEM is a mathematical procedure that provides an estimated change in noise contour area for an airport given the types of aircraft and the number of operations for each aircraft. The noise contour area is a measure of the size of the landmass enclosed within a level of noise as produced by a given set of aircraft operations. Therefore, for airports with UAS operations, we examine the change of noise contours with and without UAS operations to create a preliminary assessment for the UAS noise impact.

The noise contour metric is the Day-Night Average Sound Level (DNL) which provides a single quantitative rating of a noise level over a 24-hour period. This rating involves a 10-dBA penalty to aircraft operations during the nighttime (between 10 PM and 7 AM) to account for the increased annoyance in the community. The AEM produces noise contour areas (in square miles) for the DNL 65 dBA noise level and the purpose of AEM is to screen for significant impact within the 65 dBA contour area. The user may specify other contour levels to obtain supplemental information. The AEM is used to develop insight into the potential increase or decrease of noise resulting from a change in aircraft operations. As per AEM, a 17% increase in cumulative noise contour area translates into a one-decibel increase in the airport noise. If the percentage difference due to the change is less than 17%, the impact of noise is not significant.

Table 8 shows the different base and alternative cases that were compared, and the rationale behind selecting these cases. In order to interpret the entries in the table it must be noted that 'U' followed by 'xx', '06', '2x', '18', and '25' imply that there are no-UAS, 2006 or current demand of UAS, two times current UAS demand, RTCA 2018 UAS demand, and RTCA 2025 UAS demand, respectively. Similarly, 'C' followed by '06', '2x', '18', and '25' imply 2006 or current commercial flight demand, two times current commercial flight demand, 2018 commercial flight demand, and 2025 commercial flight demand, respectively. Therefore, demands 1 to 7 are designed to evaluate what the effect of adding different levels of UAS would be to different levels of commercial only traffic. On the other hand, demands 8 to 10 are designed to evaluate the noise impact of adding UAS at different levels from the current UAS traffic.

Table 8: List of various comparisons using AEM and corresponding rationale.

SN	*Base Case*	*Alternative Case*	*Rationale*
1	U: None C: 2006	U: 2006 C: 2006	what's the impact of adding UAS to the current demand
2	U: None C: 2018	U: 2018 C: 2018	what would be the impact of adding UAS in 2018 if both grow at the projected levels
3	U: None C: 2018	U: 2x2006 C: 2018	what would be the impact of adding UAS in 2018 if UAS grew at 2x2006 levels instead
4	U: None C: 2025	U: 2025 C: 2025	what would be the impact of adding UAS in 2025 if both grow at the projected levels
5	U: None C: 2025	U: 2x2006 C: 2025	what would be the impact of adding UAS in 2025 if UAS grew at 2x2006 levels instead
6	U: None C: 2x2006	U: 2025 C: 2x2006	what would be the impact of adding UAS in 2025 if commercial grew at 2x2006 levels
7	U: None C: 2x2006	U: 2x2006 C: 2x2006	what would be the impact of adding UAS in 2025 if both grew at 2x2006 levels

Table 9 summarizes the results for two airports, KSYR and KCRP that has both commercial and UAS traffic, and for the 01/07/2006 and 09/26/2011 data sets. KSYR and KCRP were chosen because the other airports used in our scenarios are military airports, and very little information is publicly available about the non-UAS flight operations from these airports to allow the construction of a representative baseline case to assess the noise impact within the scope of this project. Moreover, most military aircrafts have jet engines, while the majority of the UAS are turboprops. As a result, the addition of UAS operations from these airports will not have significant impact on noise levels because the jet engine-equipped aircrafts are significantly noisier than the turboprops. Detailed results are presented in Table 9 from where we observe that for KCRP, the addition UAS flights make a significant impact for *all* experimental runs where the baseline scenario consists of only commercial flights, and the alternative scenario includes UAS demand of different magnitudes. This can be attributed to the comparatively small number of commercial flights (maximum number of flights is approx 175) at KCRP, as a result of which, the UAS flights generate a sizeable increase in total number of LTOS. The conclusions drawn from KCRP can be generalized to other smaller airports.

For KSYR, the addition of UAS flights make a significant impact for *most* experimental runs, where the baseline scenario consists of only commercial flights; and the alternative scenario includes UAS demand of different magnitudes, with the exception of some scenarios for September data, and one scenario for January data. This FONSI can be explained by the fact that the September flights for KSYR are larger in number compared to UAS, as well as the January flights for KSYR, and hence, the addition of UAS do not result in significant noise impact for some scenarios in KSYR. The conclusions drawn from KSYR can be generalized to other larger airports. Note that in both cases, military and general aviation (GA) operations at KYSR and KCRP are not included in the system but in both cases they constitute a share of flights. As a result, this analysis may over-estimate the potential impact due to lack of additional data. It is expected that, with military & GA operations incorporated into this exercise, the environmental impact for UAS in all cases will be reduced significantly.

Table 9: Summary of day/night time arrivals/departures and corresponding change (%) in noise contour at KYSR and KCRP for all scenarios.

S. No	*Base Case*	*Alt Case*	*Month*	*Base Day LTOS*	*Base Night LTOS*	*Alt Day LTOS*	*Alt Night LTOS*	*% Change*	*Base Day LTOS*	*Base Night LTOS*	*Alt Day LTOS*	*Alt Night LTOS*	*% Change*
				KSYR					**KCRP**				
1	UxxC06	U06C06	Jan	114	34	116	36	18.9	47	9	48	10	114.3
2	UxxC18	U18C18	Jan	120	34	145	41	73.7	59	9	64	10	139.3
3	UxxC18	U2xC18	Jan	120	34	126	36	21.4	59	9	61	11	193
4	UxxC25	U25C25	Jan	125	34	156	43	92.2	73	11	78	14	235.7
5	UxxC25	U2xC25	Jan	125	34	131	36	21.5	73	11	75	13	159.6
6	UxxC2x	U25C2x	Jan	270	62	301	71	55.4	103	19	108	22	135.6
7	UxxC2x	U2xC2x	Jan	270	62	276	64	12.5	103	19	105	21	90.4
14	UxxC06	U06C06	Sep	205	54	207	56	7.4	75	14	76	15	49.4
15	UxxC18	U18C18	Sep	222	54	247	61	30.2	89	14	94	15	62.6
16	UxxC18	U2xC18	Sep	222	54	228	56	8.5	89	14	91	16	88.3
17	UxxC25	U25C25	Sep	230	54	261	63	38.3	106	17	111	20	116.7
18	UxxC25	U2xC25	Sep	230	54	236	56	8.5	106	17	108	19	77.5
19	UxxC2x	U25C2x	Sep	491	95	522	104	20.1	168	26	173	29	64.5
20	UxxC2x	U2xC2x	Sep	491	95	497	97	4.4	168	26	170	28	41.9

V. Conclusions

In this paper, an impact analysis was conducted for various scenarios of demand growth for UAS demand and commercial traffic demand in the NAS. First, several mission scenarios were developed through extensive research and interviews with domain experts. Then these scenarios were converted into demand sets used for simulation using the PNP tool. The existing demand growth software AvDemand was used to grow UAS demand as directed by the scenarios developed. The growth data was used to simulate NAS for various cases and analyze its impact on the delay, congestion, loss of separation conflicts, fuel burn, and noise levels. Almost all analyses show that while there is a slight increase in these factors due to additional UAS flight, this increase is minimal as compared to the levels caused by the commercial traffic alone. A substantial increase in noise level is reported through the AEM analysis, which suggests that a more detailed modeling and analysis like INM may be needed for some of the scenarios. Furthermore, sensitivity analyses were conducted to demonstrate how the operational timing of the UAS missions may affect conflict count, and how operational procedures can be changed to a more conservative conflict detection distance for safer operations.

Acknowledgments

This work was sponsored by the National Aeronautics and Space Administration (NASA) under the Airspace Systems Program and within the Aeronautics Research Mission Directorate, using support from the American Recovery and Reinvestment Act (Recovery Act) of 2009.

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