A Study of Civil Tiltrotor Aircraft in NextGen Airspace

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Tiltrotor aircraft have long been envisioned as being a potentially viable means of commercial aviation transport. Preliminary results from an ongoing study into the operational and technological considerations of Civil Tiltrotor (CTR) operation in the Next Generation airspace, circa the 2025 time-frame, are presented and discussed. In particular, a fleet of CTR aircraft has been conceptually designed. The performance characteristics of this CTR fleet was subsequently translated into BADA (Base of Aircraft DAta) models that could be used as input to emulate CTR aircraft operations in the ACES and AvTerminal airspace and terminal area simulation tools. A network of nine North-Eastern corridor airports is the focus of the airspace simulation effort; the results from this airport network will then be extrapolated to provide insights into systemic impact of CTRs on the National Airspace System (NAS). Future work will also be detailed as to attempts to model the systemic effects of noise and emissions from this fleet of new aircraft as well as assess their leveraged impact on public service missions, in time of need, such as major regional/national disaster relief efforts. The ideal outcome of this study is a set of results whereby Next Gen airspace CONOPs can be refined to reflect potential CTR capabilities and, conversely, CTR technology development efforts can be better informed as to key performance requirement thresholds needed to be met in order to successfully introduce these aircraft into civilian aviation operation.

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Nomenclature

ACES   Airspace Concept Evaluation System (airspace simulation tool)
AEDT   Aviation Environmental Design Tool (FAA/Volpe analysis tool)
ATM   Air Traffic Management
BADA   Base of Aircraft DAta (Eurocontrol-developed aircraft performance model)
CONOPS   Concept of Operations
CTR   Civil Tiltrotor
EWR   Newark Liberty International
JPDO   Joint Planning and Development Office
LAX   Airport code for Los Angles International
MIA   Airport code for Miami International
NAS   National Airspace System
NextGen   Next-Generation Air Transportation System
RIO   Runway Independent Operations
SNI   Simultaneous Non-Interfering
STOL   Short takeoff and landing
VTOL   Vertical takeoff and landing

Introduction

CIVIL tiltrotor (CTR) aircraft are an emerging new class of vehicles. NASA research into tiltrotor aircraft represents decades of effort—beginning with the pioneering work with the XV-3, followed by the extremely successful XV-15 program, and currently being sustained through a wide spectrum of aeromechanics research investigations considering the design ramifications of CTRs as large transport aircraft. Recently, these investigations have been expanded to consider both the vehicle fleet and the operational requirements/constraints required thereof of CTR aircraft operating in the projected NextGen airspace environment.

The potential impact of introducing civil tiltrotors into the National Airspace System (NAS) has been the subject of several comprehensive studies dating back to 1987 (Refs. 1-8). CTRs are expected to successfully compete with fixed-wing aircraft provided a supporting infrastructure (ground facilities and air traffic control) is in place. During 2001-2004, NASA sponsored or co-sponsored several studies (Refs. 9-11) of the Runway Independent Aircraft or RIA model of operations whereby existing stub runways could be used by VTOL operating in STOL mode in addition to operating in VTOL mode from vertiports. This operational concept has the potential to increase the capacity of the air transportation system. The increased capacity could then be used to increase throughput or reduce delay significantly throughout the system. Correspondingly, in 2005, the NASA Heavy Lift Rotorcraft Systems Investigation (Ref. 12) examined in depth several rotorcraft configurations for large civil transport, designed to meet technology goals of the NASA Vehicle Systems Program. The investigation identified the Large Civil Tiltrotor (LCTR) as the configuration with the best potential to meet the technology goals (Fig. 1). Additionally, since the studies of the late-1980's and early 1990's, recent events demonstrating the critical role of rotorcraft in disaster (man-made and natural) relief provide another compelling need for civil transport rotorcraft to be fully incorporated into the next generation airspace system. In short, the role of advanced, high-speed rotorcraft designed for civil transportation should be re-visited to account for advances in rotorcraft technology, advances in airspace modeling, and the more prominent role of rotorcraft in public safety. Advanced civil tiltrotors, however, must be considered within the context of the Next Generation Air Transportation System, aka "NextGen."

Fig. 1 – NASA Large Civil Tiltrotor (LCTR2) Reference Design

The Joint Planning and Development Office (JPDO) was instituted to address the challenges facing air transportation in the United States by engaging multiple agencies that would collaborate to plan, develop, and implement the Next Generation Air Transportation System. The JPDO has formulated initial versions of the NextGen Concept of Operation (CONOPS) and Enterprise Architecture (EA) – see Refs. 13-15, respectively – and continues to refine the CONOPS and EA as it progresses toward implementation of NextGen. These documents provide details regarding "what" NextGen is, as envisioned for operation in 2025. The CONOPS provides a broad vision for the air traffic system and the vehicles that operate within it. To realize that vision, the CONOPS must be informed with tangible details of the "how" to accomplish NextGen – this "how" is the focus of NASA research in support of NextGen. NASA's role is discussed in a recent white paper (Ref. 16). All three of the NASA Aeronautics Research Mission Directorate (ARMD) research programs (Fundamental Aeronautics, Aviation Safety, and Airspace Systems) contribute directly and substantively to NextGen. Recently completed NASA Airspace Systems Program sponsored studies, Refs. 17-18, has sought to understand how advanced vehicles will operate within NextGen as well as examine the tradeoffs involved for both vehicles and the air traffic management (ATM) system, including safety considerations, system performance, environmental constraints, and other relevant issues.

This paper summarizes some of the ongoing work related to a complementary study – sponsored by the NASA Fundamental Aeronautics Program's Subsonic Rotary Wing (SRW) project – to the Refs. 17-18 efforts. The focus of this ongoing SRW-sponsored study is to examine the benefits and challenges associated with deploying a fleet of civil tiltrotors (CTRs) into the projected NextGen environment – including exploring the system trades among operational procedures, CTR capabilities, and overall NextGen performance. The team performing this study include: SAIC, the contractor programmatic lead, as well as responsible for vehicle/airspace concept of operations definition; Bell Helicopter Textron, vehicle conceptual design, pilot-in-the-simulation, and rotorcraft/disaster-relief modeling; Sensis, regional and NAS airspace systems modeling and simulation; Optimal Synthesis, terminal area procedures and modeling. The study will endeavor to determine: (1) how the procedures and concepts of operations for CTRs impact the performance of the overall airspace system; (2) approaches to ensuring the safety of the CTRs and the system; (3) possible modifications/enhancements to the NextGen CONOPS in order to accommodate CTRs; (4) environmental effects of CTR fleet introduction; and (5) the possible implications for the development of future rotorcraft and the NextGen airspace.

This ongoing NASA SRW-sponsored study has many elements. First of which, vehicle conceptual design and sizing analysis work has been conducted to identify and categorize the potential attributes of a fleet of civil tiltrotors (CTRs) as they affect operation in NextGen in 2025 and beyond. The notional fleet being studied consists of four sizes of CTR aircraft: those being able to carry 10, 30, 90, and 120 passengers. This tiltrotor conceptual design and vehicle sizing work was performed by Bell. (It is noteworthy to mention that the Bell conceptual design work complements other recent NASA and NASA-sponsored large civil tiltrotor reference designs, Refs. 19-20.) In parallel with the vehicle fleet conceptual

design definition, procedures are being developed for how the fleet of CTRs will operate in the NextGen airspace. Vertical takeoff and landing (VTOL), in addition to short takeoff and landing (STOL), approaches will be considered. CTR vertiports located at high-density airports and possibly city centers will be accounted for in the airspace terminal area modeling. To support the CTR fleet simulations, metrics will be defined to assess the impact of CTR operation on NextGen performance. Additionally, a noteworthy technical challenge for the overall effort is to identify appropriate analytical tools to support the study and modify or develop models, as necessary, to enable analysis of the effects of these procedures. Given the identified analysis tools, the system-level effects of the procedures, taken as a whole, will be assessed so as to characterize the tradeoffs among the effective employment of the CTR fleet, operational safety, characteristics of the advanced CTR, performance of NextGen, and environmental and other constraints in order to identify critical issues for design and implementation of NextGen. In parallel with the CTR airspace simulation effort, a preliminary assessment of key safety considerations associated with operation of the CTR fleet is being developed, including potential hazards and mitigation strategies and the effect of off-nominal conditions, and potential certification issues. Finally, and particularly crucial for rotorcraft, well known to be critical public-service aviation assets, the potentiality of a CTR fleet on disaster relief operations will be examined. A scenario will be developed for a major US urban area where runways, rail systems, and surface-road networks are disrupted. The role/operation of the CTR fleet in this scenario will be developed and discussed. This discussion/analysis will include the role of CTRs in mass domestic relief efforts (evacuation, ferrying supplies, policing, etc.), CTR interaction with other aerial vehicles and ground/sea-based platforms/assets, and details of operations such as staging, command and control, and crew requirements. In particular, the focus of the analysis will be on the implications of a major relief effort using CTR assets on airspace management with the objective of enhancing NexGen CONOPS and defining key mission/vehicle requirements for an effective employment of CTRs for large-scale domestic disaster-relief scenarios. Trade studies examining parameters such as tons-of-supplies-delivered-per-unit-time, or evacuations-per-unit-time will be performed looking at relative mixes of CTRs versus other (aviation) transportation assets.

This paper details some of the preliminary results from the ongoing study. In particular, the challenges of modeling a civil tiltrotor fleet of aircraft with current generation airspace systems analysis tools will be discussed in detail.

Scope of Study

The "CTR in NextGen" study is an ongoing three-year research investigation to examine the crucial technological and operational issues that need to be addressed in order to insure that civil tiltrotor aircraft can be successfully introduced into the Next Generation airspace/aviation system. It is complementary to and builds upon earlier NASA- and FAA-sponsored studies regarding the challenges and opportunities of civil tiltrotor aircraft, e.g. Refs. 1-9 and 17-18. Further, it is hoped that – by extension – that many of the insights garnished from the analysis of civil tiltrotor aircraft operations can also aid in insuring that helicopters, and rotorcraft in general, can also effectively and safely operate in the NextGen airspace. Figure 2 illustrates the overall task and technical approach framework for the "CTR in NextGen" study. Many benefits are anticipated from this current study. First, the CTR conceptual design results derived from this work will help better inform evolving NASA reference designs for civil tiltrotor aircraft, e.g. refer to Refs. 12 and 19. Second, the analysis, subject matter expert discussions, and airspace simulations embodied in this will help guide the definition of technology goals and objectives for the NASA project. (In this regards, this study is an important adjunct to alternative technology portfolio studies such as Ref. 20.) Third, and most important, it is hoped that this work will be of value in refining/validating ongoing FAA and JPDO, Ref. 30, planning and implementation of the NextGen project, as regards rotorcraft operations in the NAS, circa 2025 and beyond.
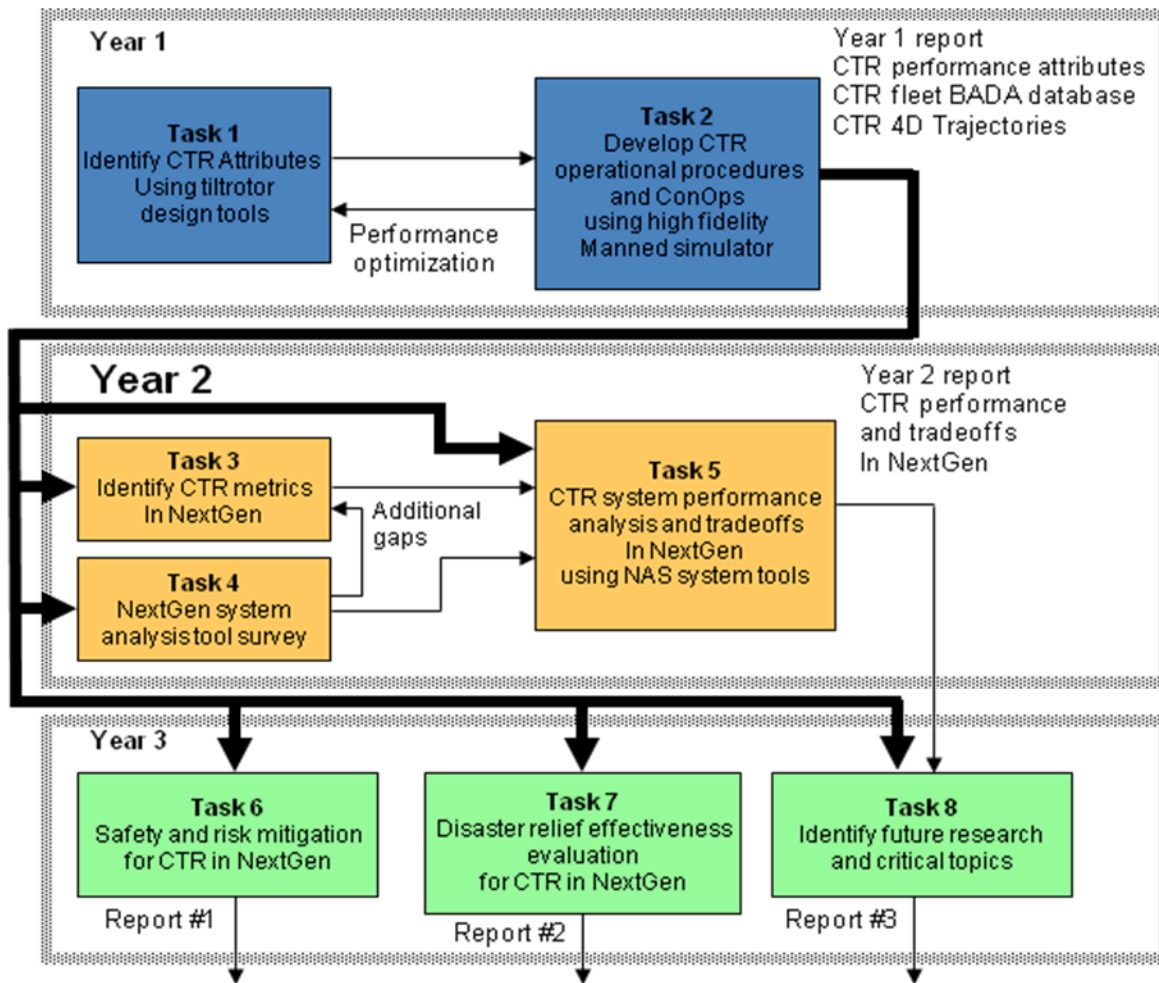
Fig. 2 – Individual Tasks and Overall Technical Approach

Conceptual Design of CTR Fleet

In order to support the current study a fleet of CTR aircraft was designed by Bell Helicopter Textron. Conceptual designs for four aircraft sizes were devised: 10-, 30-, 90-, and 120-PAX vehicles.[§] The CTR conceptual designs were developed using the Bell PRESTO code (Ref. 35). Previous civil tiltrotor studies typically focused on only vehicle conceptual design as being emblematic of the whole vehicle class. Having a spectrum of vehicle sizes included in the airspace study provides many advantages. First, CTR aircraft will likely be introduced into operation in order of vehicle size. Smaller vehicles, e.g. Ref. 31, will undoubtedly be introduced at an earlier date as compared to larger vehicles. Second, despite several studies conducted in the past, it is still unclear as to what is the optimal size of an economically competitive CTR; studying a fleet of vehicles of varying sizes, such as being performed in this study, should help provide insight into this issue. Third, different market segments will likely be served by this spectrum of vehicle

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[§] Initially the 90-PAX vehicle characteristics were simply scaled from the 30- and 120-PAX conceptual designs. A later, separate contract task was performed to generate a complete 90-PAX conceptual design.

sizes and passenger capacities. For example, small vehicles will tend to provide air-taxi type services. Mid-size vehicles would likely be used mostly for limited-scheduled-service flights in and out of suburban vertiports and/or under-utilized regional airports – with the occasional connector flights into the major airports. And, finally, the larger vehicles would likely be competing against fixed-wing turboprop and regional jet aircraft for regularly scheduled short-haul commuter flights in and out of high-density airports. Figure 3a-b provides design drawings of the 120-PAX CTR design. The 10- and 30-PAX vehicle designs draw upon significant design heritage from near-production and production aircraft, particularly with regards to the dynamic drive train systems; however, among other technologies, advanced composite technology is incorporated into the aircraft airframes. The 120-PAX (and, separately, the 90-PAX vehicle) CTR aircraft, however, is a clean-sheet design reflecting a spectrum of technology advances for the complete vehicle that are anticipated to achieve a reasonable level of technology maturity prior to aircraft development.
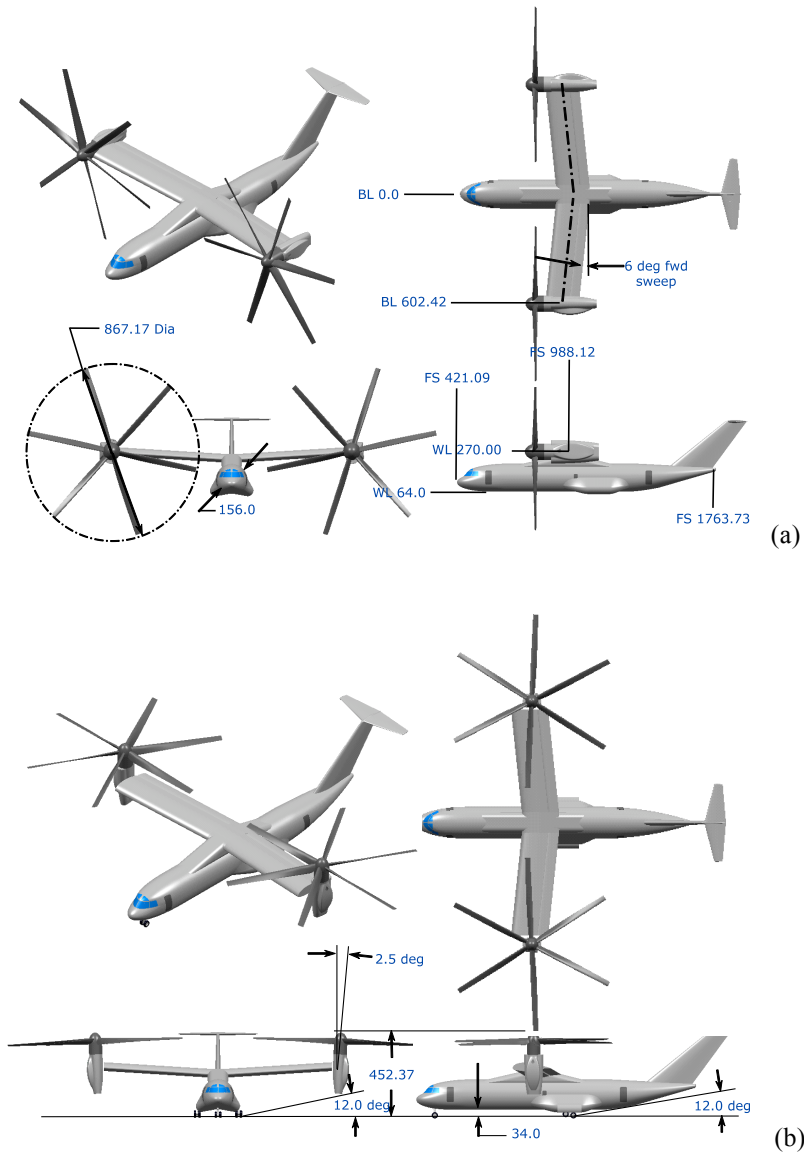

Fig. 3 – 120-PAX CTR Conceptual Design Layout: (a) Airplane-Mode and (b) Helicopter-Mode

Figure 4 is the proposed cabin layout for the 120-PAX CTR. As the aircraft is intended to be a civil passenger transport, requirements in terms of emergency exits, galley, lavatories and number of attendants are set by FAA rules. These FAA rules/requirements are reflected in the cabin layout shown in Fig. 4.
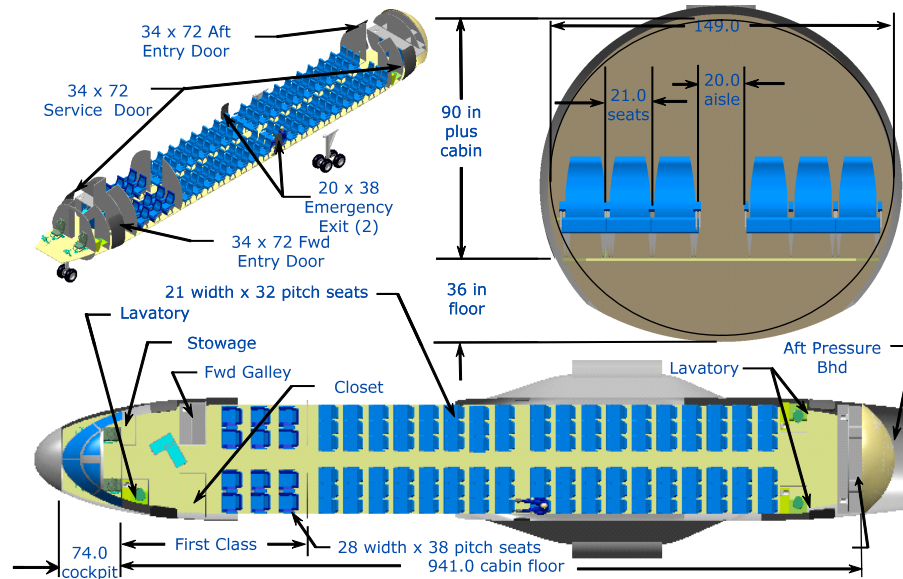

Fig. 4 – 120-PAX CTR Cabin Design

Table 1 summarizes some of the key design requirements used for the notional CTR fleet conceptual design effort.   These design requirements were partly informed by previous NASA reference design work, as well as reflecting the study team's subject matter expertise.   Additionally, the speed/range requirements for the larger vehicles reflected a desire on the part of the team to push the technology limits of the aircraft. For example, previous CTR studies have emphasized the short-haul market potentiality of the aircraft. In this study, the conceptual design requirements were set so as to examine longer-range market potentialities. Additionally, in recognition that such large civil tiltrotor aircraft may well also serve dual utility for public service missions such as disaster relief and emergency response efforts, this additional consideration re-emphasized the longer-range design requirement for CTR aircraft.

Table 1 – CTR Fleet Initial Design Requirements

Number of Passengers	10	30	90	120
Takeoff Condition	5k/Hot	-->	-->	-->
Takeoff Procedure [1]	VTOL [2]	VTOL [2]	VTOL	VTOL
Payload, lbs	2200	6600	19800	26400
Design Range, nm	800 [2]	1000 [2]	1000	1500
Cruise Altitude, 1000's ft	25	25	30 [2]	30 [2]
Cruise Speed, ktas	Fallout	Fallout	300 [2,3]	350 [2]

(1) VTOL is assumed to be a Transport Category procedure (same as Cat A)
(2) Target
(3) At 90% MCP

Given the Table 1 design requirements, and other more detailed, albeit unspecified, requirements, the CTR fleet conceptual design effort yielded the following (Table 2) general characteristics. Note that, in particular, in order to meet one-engine-inoperative (OEI) design requirements, the larger CTR aircraft have four engines (two per rotor) instead of the two engines seen in current designs.   Further, another interesting aspect of the larger CTR is the large number of blades per rotor for these aircraft.   Current tiltrotor aircraft

designs have three-bladed rotors; the 30-PAX CTR has four-bladed rotors and the 90- and 120-PAX designs have six-bladed rotors. Finally, it should be noted for improved acoustic characteristics and improve cruise efficiency that the 30-, 90-, and 120-PAX aircraft would operate at significantly lower rotor tip speeds than current tiltrotor aircraft designs.

Table 2 – CTR Fleet Final Design Characteristics

Number of Passengers		10	30	90 (1)	120
Weights:					
Design Gross Weight, DGW	lb	16800	46460		147647
Maximum Gross Weight, MGW (Full Fuel & Payload)	lb	16192	46430		147647
Empty Weight + Trapped Fluids	lb	11022	32160		98737
Payload	lb	2200	6600	19800	26400
Operating Load	lb	470	670	870	1070
Number of Crew	ND	2	3	4	5
Fuel System Capacity	lb	2500	7000		21441
Geometry:					
MR Radius	ft	13.0	19.0		36.1
Number of Blades per Rotor	ND	3	4	6	6
Wing Span	ft	33.8	45.8		100.4
Length Fuselage	ft	n/a	61.6		111.9
Engine/Xmsn:					
Number of Engines	ND	2	2	4	4
Engine Takeoff Power Rating (SLS - uninstalled)	eshp	3000.0	9000.0		9372.0
MCP Xmsn rating @ mast (100%rpm)	hp	n/a	4412.0		13063.0
Aero/Performance Related:					
Main Rotor Tip Speed (100% rpm)	fps	775	700	665	650
Main Rotor Tip Speed, A/P mode (70%rpm)	fps	651	588	466	455
Flat Plate Drag (alpha=0) (3)	sq ft	11.0	23.4		56.3
Design Cruise Altitude	ft	25000	25000	27500	27500
Design Cruise Speed (2)	ktas	n/a	n/a	340	345
Range (5k/ISA+20 deg C takeoff)					
@ max payload, max fuel & Vlrc	nm	821	804		1331
@ max payload, max fuel & Vmcp	nm	750	671		1179 (4)

(1) Characteristics based on linear interpolation between 30 and 120-pax designs
(2) 90 and 120-pax design cruise speeds based on Vmcp
(3) Drag does not include nacelle cooling drag which is inherently built into engine residual thrust.
(4) Vmcp = 345 kts for sizing and mission cruise not exactly the same; Vmcp for mission legs > 345 ktas

The aircraft mission performance characteristics, as derived from the Bell PRESTO code, were subjected to regression analysis. These regression analysis results, in turn, were translated into BADA models (Ref. 21). As the BADA models are nominally crafted for fixed-wing aircraft only, the BADA coefficients had to be manipulated to emulate the characteristics of CTR aircraft. Further, as the rationale underlying the generation of the BADA models was to use this information as input data to the ACES and AvTerminal airspace simulation tools, it was determined in the early stages of reading in the BADA data into ACES and AvTerminal that not all BADA model parameters were supported by the two airspace simulation codes. This ultimately drove SAIC to develop Matlab-based software tools that took full advantage of both the regression analysis results from PRESTO and the BADA model framework. One of the tools, the "Performance Deck," served two purposes. The performance deck tool was used to refine the flight profiles for a particular combination of CTR vehicle and city-pairs between which it was being flown. The second purpose to which the performance deck tool was being used was to generate mission performance profiles. These mission performance profiles, in turn, were used to validate the ACES and AvTerminal airspace simulation results. The other Matlab-based tool was a "plug-in" module to be directly interfaced to ACES and AvTerminal. The development of this plug-in module was critical to estimating accurate fuel-burn rates for the CTR aircraft using the two airspace simulation tools, which like the BADA model were developed solely for fixed-wing aircraft. Again, extensive effort went to trying to get these models and airspace simulation tools to emulate CTR flight operations.

CTR Airspace CONOPS

In order to support the overall airspace simulation effort, pilot-in-the-loop (PITL) simulations were conducted in Bell Helicopter Textron facilities; CTR operations in and out of the Miami airport were flown

in the simulator by an experienced tiltrotor aircraft test pilot. Refer to Fig. 5 for a cabin view of the PITL simulation.   These fixed-base simulations examined some of the key terminal-area operational characteristics of CTR aircraft.   Several simulation test runs were conducted of aircraft having the approximate characteristics of the 10- and 30-PAX CTR designs.   Test pilot and engineering subject matter expertise, post-simulation, were employed to qualitatively generalize the simulation results and overall expert operational experience to the larger CTR aircraft. Both STOL and VTOL modes of operation during takeoff and landing were investigated in the PITL simulation.   Further, both straight-in and spiral approaches were also studied. In all test runs, a substantial body of test data was acquired so as to validate the Bell PRESTO (Ref. 35) conceptual-design-tool-derived mission performance estimates as well as the SAIC-developed "Performance Deck" Matlab-based tool.

Fig. 5 – Cabin View during the Pilot-in-the-Loop Simulation

The test results from the PITL simulations had a major influence in defining the generic flight profiles incorporated into the CTR airspace simulations being conducted by the study team.   Figure 6 summarizes this generic flight profile for the CTR fleet. Further, the interplay between the PITL results and the airspace simulation tools (ACES and AvTerminal) is also underscored in Fig. 6.
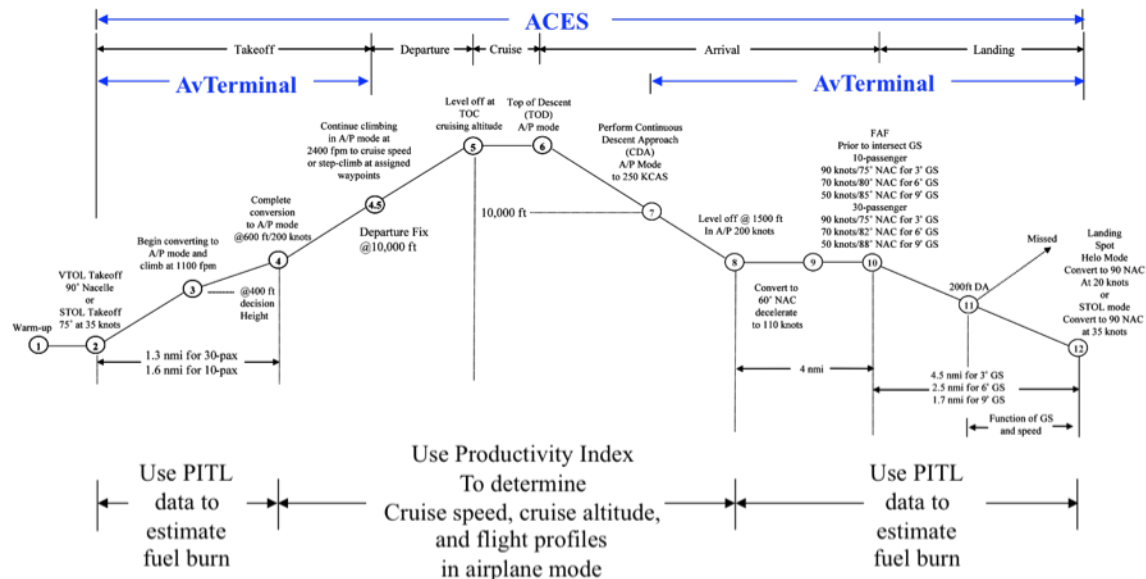
Fig. 6 – CTR Fleet Generic Flight Profile

The successful introduction of civil tiltrotor aircraft for commercial aviation transport will be dependent on the concurrent infrastructure investment into on-airport-property vertiports, Refs. 22-24, as well as complementary, but secondary, network of city-center and suburban vertiports.   For the commercial aviation transport, though, the development of on-airport-property vertiports will be essential. Consequently, identifying credible on-airport-property vertiport notional sites at a few key airports was an important consideration in the preliminary effort leading up to the NASA-sponsored-developed ACES, e.g. Ref. 33, and the Sensis-developed AvTerminal, Ref. 34, airspace simulations. Figure 7a-c identifies a number of potential sites at LAX, MIA, and EWR. Note that the airport diagrams shown in Fig. 7a-c are from Ref. 32. Each identified potential vertiport site, at each airport considered, has its relative strengths and weaknesses. Using subject matter expertise within the study team, these sites were notionally narrowed down to site #2 for MIA and site #5 for EWR; a final site was not selected for LAX.   LAX was the original site location for the pilot-in-the-loop simulation at Bell Helicopter; the PITL simulation was ultimately conducted for MIA.   To support the PITL simulations, notional vertiport sites were defined for both airports.   In turn, vertiport sites were identified for EWR because of Sensis' past terminal-area modeling and simulation experience using AvTerminal for this particular airport (Ref. 34); this past experience was a key factor in using EWR as a benchmark for establishing terminal-area RIO/SNI procedures for CTR's. Modeling information and insights from the EWR was then used to arrive at relevant modeling input for the other eight airports in the initial nine-airport Northeast Corridor network.

This limited exercise as to notional on-airport-property vertiport siting has been generally promising. The results suggest that even high-density airports, there exists potential site locations that could be converted/transformed into vertiport facilities.   As these on-airport-property vertiports would nominally increase airport capacity through better utilization of airport real estate, there exists a reasonable possibility that a business case could be developed that would encourage airport operating authorities to invest in vertiport infrastructure. However, it must be made clear that this was only a very preliminary assessment of on-airport-property vertiport siting, many other issues need to be considered, such as influence of CTR downwash on ground facilities and assets and parked or taxiing light aircraft (Ref. 26).   Additionally, minimizing the amount of time from aircraft pullback from the jetway, or gate, to the time of actual takeoff is crucial to the success of a CTR in the commercial transport – because of the CTR slower cruise speeds, as compared to most turboprop and regional jet aircraft, fast turnarounds on the ground are very important (Ref. 27).
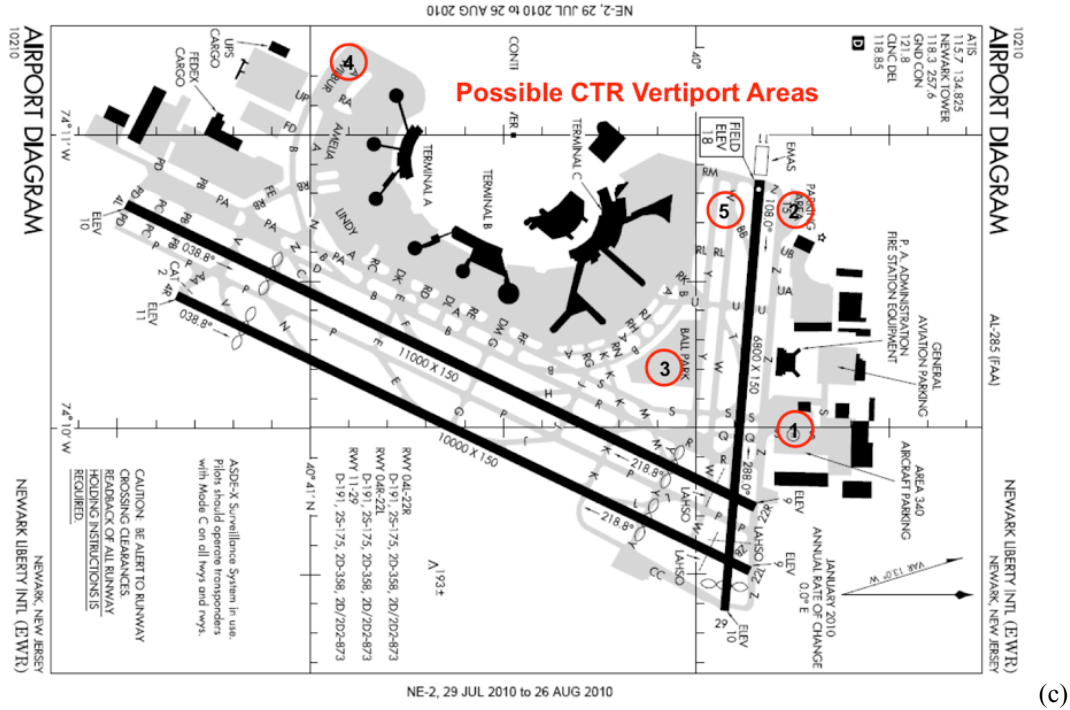
(a)

(b)
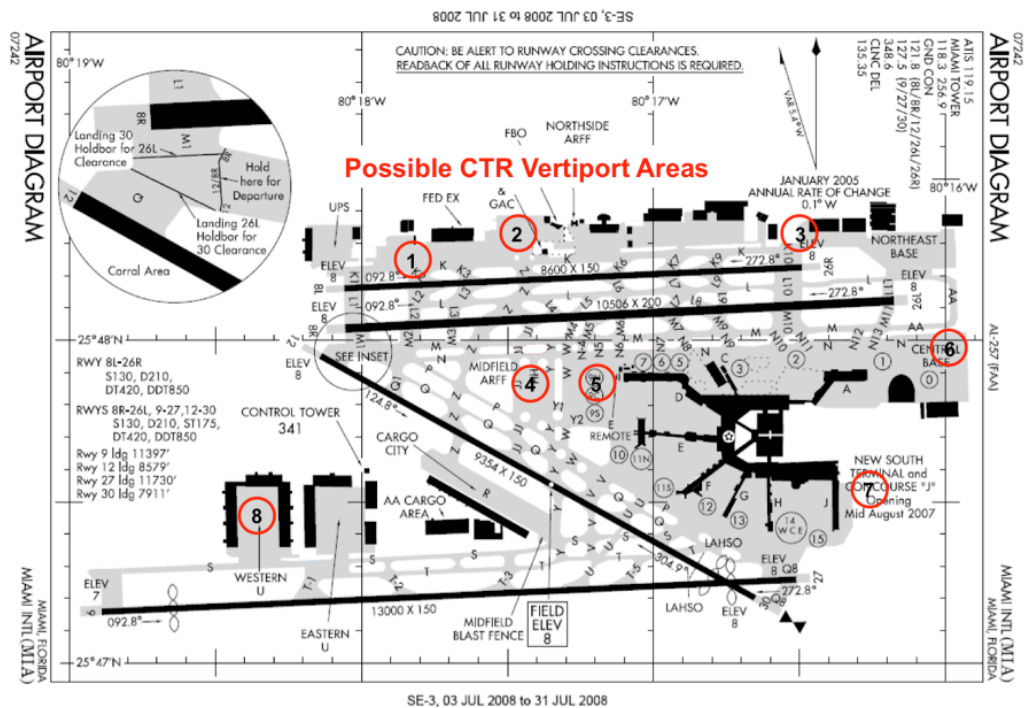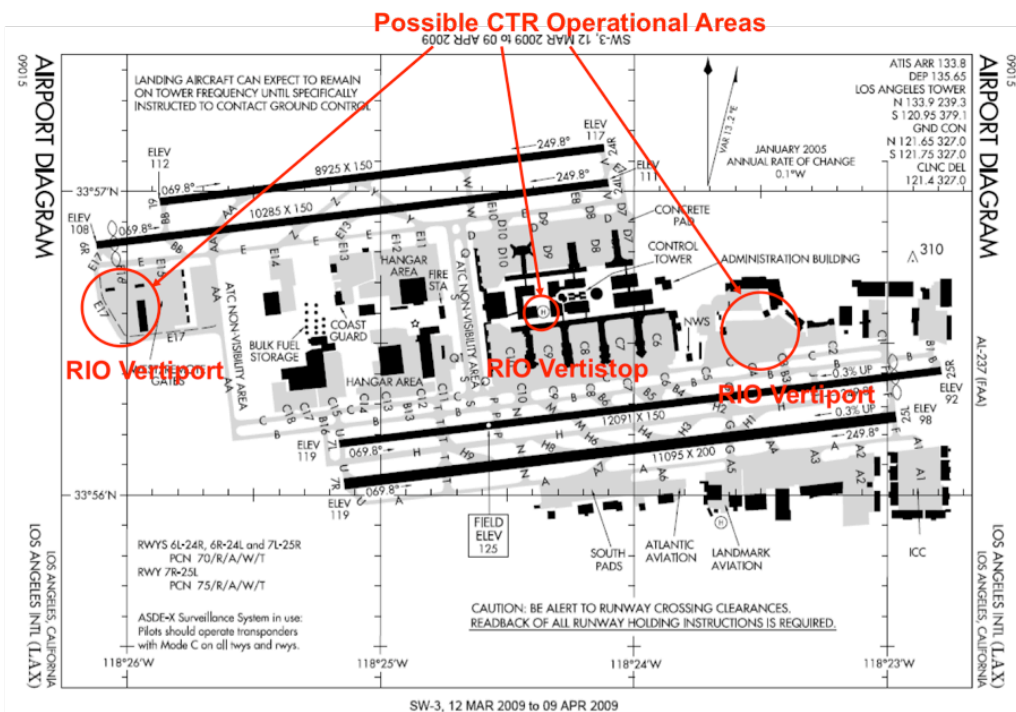
Fig. 7 – Notional On-Airport-Property Vertiport Sites: (a) Los Angles (LAX), (b) Miami (MIA), and (c) Newark (EWR)

The vertiport siting methodology will ultimately be incorporated into refined terminal-area airspace simulations performed with the Sensis-developed AvTerminal tool.

CTR Modeling Approach for Airspace Simulations

One of the key outcomes of the BADA modeling exercise, besides providing necessary input data for the ACES and AvTerminal simulation tools, was the development by SAIC of two complementary Matlab-based software tools: a standalone "Performance Deck" to examine CTR mission performance and a fuel-burn/performance "plug-in" module to directly interface with ACES and AvTerminal. Figure 8 is a representative "Performance Deck" mission performance result. This tool was used to identify optimal (in a qualitative sense) flight profiles for a given CTR aircraft and city-pair being flown. The metric being used to determine the optimal flight profile is a Bell-developed "Productivity Index;" refer to Eq. 1. In particular, the optimal cruise altitude and speed were identified through these productivity index estimates. These flight profile results were then incorporated into the ACES/AvTerminal simulations.

$$Productivity\ Index = \frac{(Payload \times Range)}{((Empty\ Weight + Block\ Fuel) \times Block\ Time)}$$
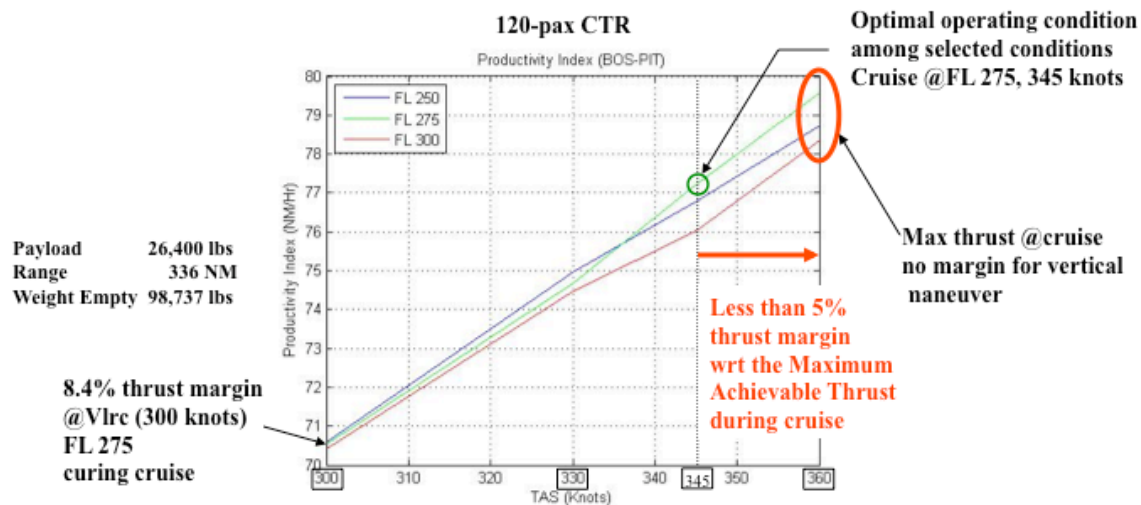
(1)

Fig. 8 – Using BADA-based Performance Desk Analysis to Define Optimal Speed/Altitude Profiles for Flights between City-Pairs (Representative Figure)

Figure 8 is just one representative sample of mission performance results from the SAIC "Performance Deck," for one particular CTR/city-pair combination. Figure 9, on the other hand, summarizes some of the collective results of the "Performance Deck" analyses. Not unexpectedly the large passenger-carrying vehicles, with the higher cruise speeds, have significantly higher productivity index values as compared to the smaller and slower aircraft. An expansion of this productivity index analysis – to include more city-pairs and to consider additional vehicle sizes and cruise speed/range capabilities – could be a significant aid in focusing/refining future NASA/Industry reference designs for civil tiltrotor aircraft. The sensitivity of the productivity index results – as to vehicle gross weight, speed, range, and altitude – could also allow for refined assessments of current and future NASA rotary-wing research technology portfolios (e.g. Ref. 25).
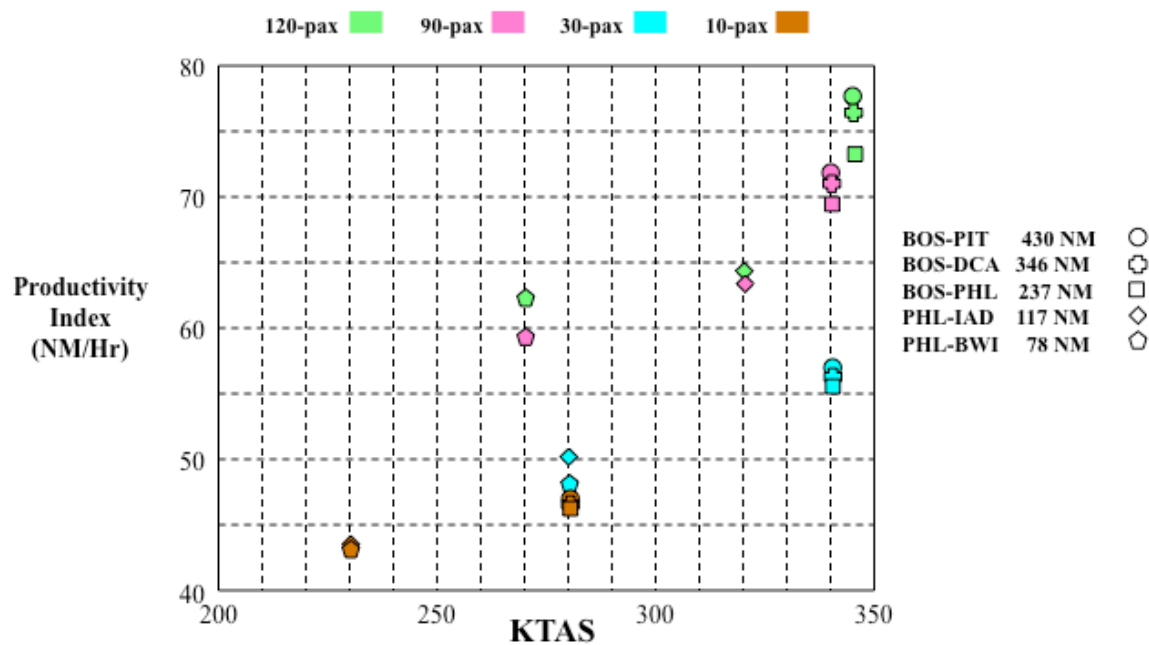

Fig. 9 – Productivity Index Summary for Representative City-Pairs and CTR Aircraft Size

The primary focus of detailed AvTerminal and ACES airspace simulations for the CTR fleet has focused on an airport network in the "Northeast Corridor." Nine airports are included in this network (Fig. 10): BOS, BWI, DCA, EWR, IAD, JFK, LGA, PHL, and PIT. As resources allow other regional networks will be incorporated into the airspace simulations. The airspace simulation results from these regional airport networks will be "scaled" to yield NAS-wide estimates of aircraft mean delay and other critical metrics. As noted before, a key objective of the current study is to underscore the potential of civil tiltrotor aircraft to moderate airport/terminal-area airspace congestion; ideally employing CTR aircraft for commercial aviation transport, in conjunction with planned NextGen air traffic management advances, will substantially reduce concerns about congestion and capacity.
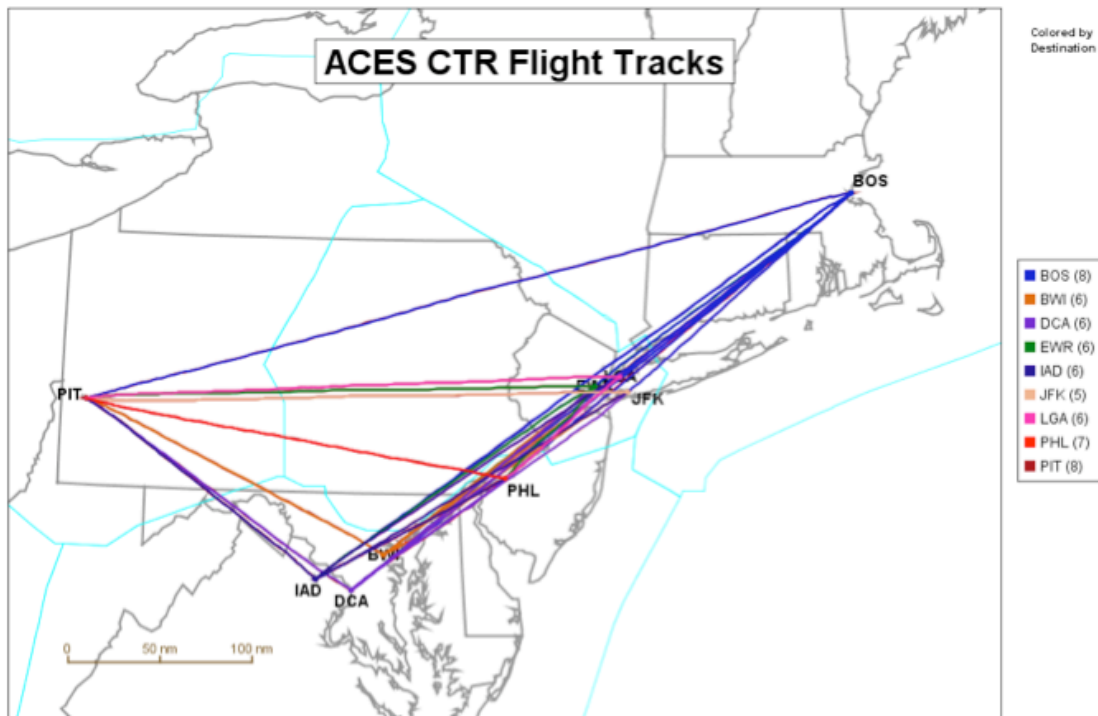
Fig. 10 – Northeast Corridor Network of Nine Airports for CTR Study

CTR Modeling Approach for Noise and Emission Estimates

Figure 11 outlines, at a high-level, the basic analysis framework for the airspace simulation and noise and emissions methodology anticipated for the current study. The noise and emissions portion of the analysis framework is currently in a state of evolution, in part due to the relative immaturity of some of the software tools required for the analysis.
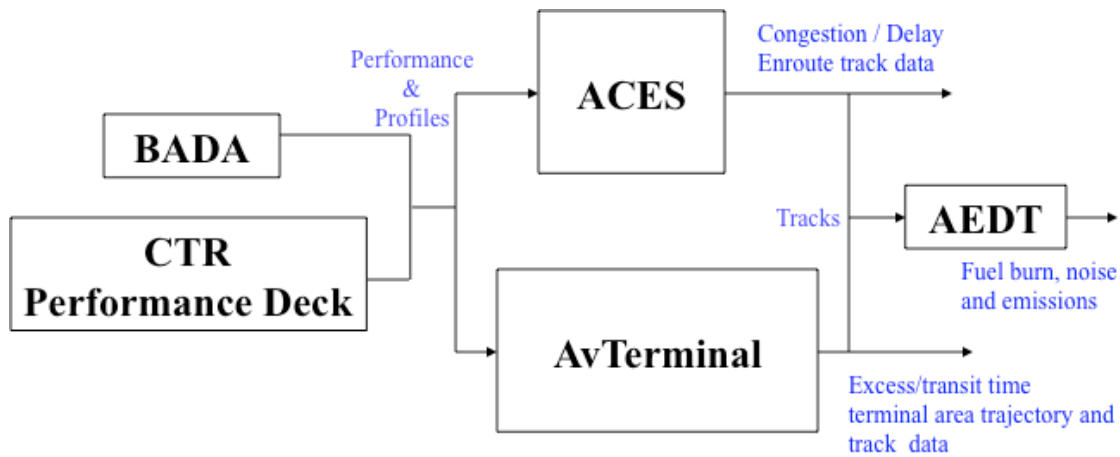
Fig. 11 – Overall Analysis Flowchart

The "CTR in NextGen" study has entailed some innovative software integration work to effectively replace ACES terminal area trajectories with the higher-fidelity trajectories from AvTerminal. This, coupled with the developed BADA models and fuel-burn "plug-in" module, will result in accurate modeling of CTR aircraft. The near-term focus of the current study is on the completion of the simulation work using ACES and AvTerminal, in combination, to complete the terminal-area and NAS-wide airspace simulations with the introduction of the notional CTR fleet. Upon completion of the airspace simulation the study will transition to an initial assessment of the CTR fleet noise and emissions. The CTR noise and emissions analysis will be relying upon a beta-release version of a next-generation analysis tool being developed by the FAA and the Volpe National Transportation Systems Center called the "Aviation Environmental Design Tool" (AEDT), e.g. see Refs. 28-29. The noise and emissions work will be particularly challenging for a number of reasons. First of all, because the FAA/Volpe AEDT tool is only in beta-release, many features have yet to be fully implemented and validated. Second, the "CTR in NextGen" study team is currently in the midst of deciding whether to attempt to directly model the CTR fleet in AEDT, given its current level of modeling fidelity, or whether it is necessary, in the near-term at least, to use a (appropriately scaled) surrogate vehicle model. This tradeoff in CTR noise and emissions analysis options is seen in Fig. 12a-b.
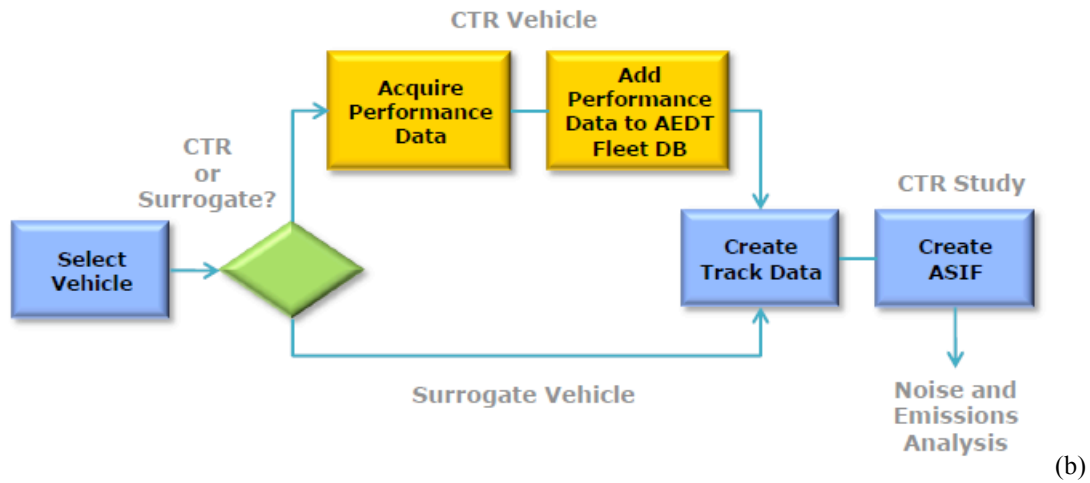

(a)

(b)
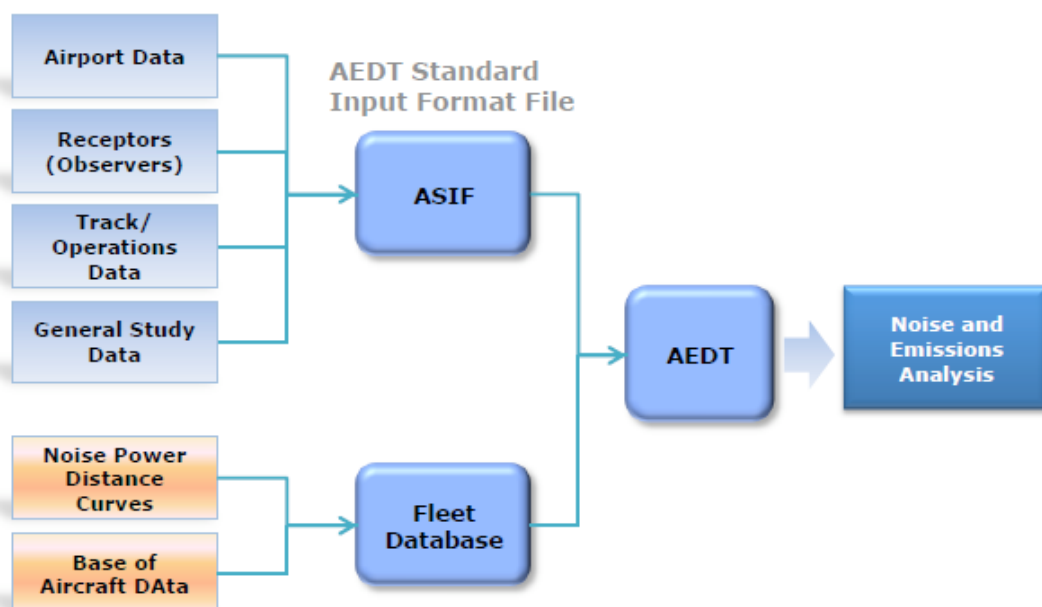
Fig. 12 – AEDT Analysis Flowchart: (a) Data/Models Required and (b) Decision Impending as to Using Surrogate Vehicle or CTR Modeling

Future Work

The current study will conclude with specialized simulation analyses examining the technological and operational factors governing disaster relief efforts given employment of a hypothetical CRAF-like ("Civil Reserve Air Fleet," see Ref. 36) CTR fleet to aid in large-scale public service missions, specifically, in the case of this study, a Hurricane-Katrina-magnitude disaster scenario. The utility of rotorcraft for public service missions – especially as related to emergency response and disaster relief operations – is well-known. (For example, Fig. 13 illustrates a CTR shipboard-compatibility demonstration conducted in the past for the US Coast Guard.) If a CTR fleet is ever successfully introduced, it will be deployed not only on the basis of the aircraft's economic competitiveness or its beneficial impact on NAS and airport operations in relieving congestion and increasing capacity, this accomplishment will also be due to recognition of the CTR's inherent capability to meet major national public service challenges. The planned disaster relief scenario simulations will hopefully aid in arriving at an improved understanding of that public service potentiality.

Fig. 13 – Potential for CTR for Public Service Missions (*Image Courtesy of the U.S. Coast Guard*)

Concluding Remarks

It has long been anticipated that civil tiltrotor aircraft could potentially be major contributors to commercial aviation transport. In particular, FAA future projections of air travel demand would suggest, unless several crucial steps are taken in the near- and mid-term, that airport/airspace congestion will grow to unacceptable levels. One of the key objectives of the FAA NextGen project is to tackle this growing congestion problem using satellite-based systems to aid and assist in the automation of air traffic management. The inherent runway-independent and simultaneous-non-interfering operations of tiltrotor aircraft, in a vehicle-centric manner, could have a substantial positive influence on moderating this anticipated increase in congestion.

Acknowledgments

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