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Cruise-Efficient Short Takeoff and Landing (CESTOL): Potential Impact on Air Traffic Operations

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4D	4-Dimensional
AAR	Arrival Acceptance Rate
ACES	Airspace Concept Evaluation System
ADS-B	Automatic Dependent Surveillance-Broadcast
ARTCC	Air Route Traffic Control Center
ASPM	[FAA] Aviation System Performance Metrics
ATC	Air Traffic Control
ATM	Air Traffic Management
AvAnalyst©	Capacity and delay analysis tool for post-processing simulation results
AvTerminal©	Airspace and airport capacity and delay computer simulation model
BADA	Base of Aircraft Data
CAS	Calibrated Air Speed
CESTOL	Cruise-Efficient Short Takeoff and Landing
CNS	Communication, Navigation, and Surveillance
DAR	Departure Acceptance Rate
DCIA	Dependent Converging Instrument Approaches
DOF	Degrees of Freedom
ETMS	[FAA] Enhanced Traffic Management System
FAA	Federal Aviation Administration
FDS	Flight Demand/Data Set
GA	General Aviation
IFR	Instrument Flight Rules
JPDO	Joint Program Development Office
KEWR	Newark Liberty International Airport, Newark, NJ
LAHSO	Land and Hold Short Operation
MIT	Miles-in-Trail
NAS	National Airspace System
NMI	Nautical Miles
OEP	[FAA] Operational Evolution Plan
RJ	Regional Jet
RNAV	Area Navigation
RNP	Required Navigation Performance
IFR	Instrument Flight Rules
STAR	Standard Arrival
TAR	Total Acceptance Rates
TFM	Traffic Flow Management
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

EXECUTIVE SUMMARY

The National Aeronautics and Space Administration (NASA) is investigating technological and operational concepts for introducing Cruise-Efficient Short Takeoff and Landing (CESTOL) aircraft into a future U.S. National Airspace System (NAS) civil aviation environment. CESTOL is an aircraft design concept for future use to increase capacity and reduce emissions. The CESTOL capability provides flexible climb, descent, and runway performance and high-speed cruise capabilities. In support of NASA, this study is a preliminary examination of the potential operational impact of CESTOL aircraft on airport and airspace capacity and delay. The study examines operational impacts at a subject site, Newark Liberty International Airport (KEWR), New Jersey. The study extends these KEWR results to estimate potential impacts on NAS-wide network traffic operations due to the introduction of CESTOL aircraft at selected major airports. These are the 34 domestic airports identified in the Federal Aviation Administration's Operational Evolution Plan (OEP). The analysis process uses two fast-time simulation tools to separately model local and NAS-wide air traffic operations using predicted flight schedules for a 24-hour study period in 2016. These tools are the Sensis AvTerminal© model and NASA's Airspace Concept Evaluation System (ACES). The study uses both to simulate conventional-aircraft-only and CESTOL-mixed-with-conventional-aircraft operations. Both tools apply 4-dimension trajectory modeling to simulate individual flight movement. The study develops CESTOL flight schedules for both models by converting selected flights in the conventional traffic 2016 forecasts to CESTOL flights. The analysis assumes CESTOL aircraft have 120–130 seats, a 2,000-nmi range limit, and a minimum runway length requirement of 2,000 feet. These criteria are used to facilitate this preliminary analysis and do not imply that CESTOL development is restricted to a single aircraft design. Alternative CESTOL aircraft designs could serve different markets based on range, size, runway, and other related requirements.

CESTOL Airport Capacity Impact—The study applies AvTerminal air traffic management and flight trajectory simulation modules to model traffic and procedures for en route and terminal arrival and departures to and from KEWR. These AvTerminal applications model existing KEWR arrival and departure routes and profiles, and runway use configurations, with the assumption that jet-powered, large-sized civil CESTOL aircraft use a short runway and standard turboprop (T) arrival and departure procedures. With these rules, the conventional jet (J) and CESTOL (Ce) aircraft are procedurally separated from each other geographically and in altitude during terminal airspace approach and departure operations, with each using a different arrival runway. These procedural modifications and the conversion of selected conventional flights to CESTOL shift significant arrival traffic from the primary runway to the short secondary crossing runway. CESTOL arrivals, which are a significant component (38%) of the total arrival traffic, land on the short secondary crossing runway rather than the primary runway. Arrival traffic loading on the primary runway is reduced from 98% to 60% of the total number of arrival flights. The redistribution also significantly reduces the intensity of traffic on the primary arrival routes in the terminal airspace.

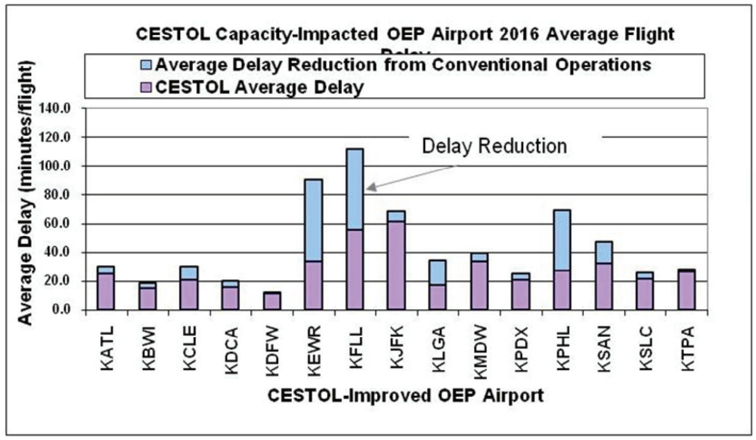
The analysis compares the resulting capacity impacts, flight delays, and delay sources between CESTOL and conventional KEWR operations. AvTerminal results show that CESTOL aircraft have significant capability to increase airport arrival acceptance rates (35–40%) at KEWR by taking advantage of otherwise underused airspace and runways where available. Traffic flow management restrictions on outbound flights prevent notable gain in the departure acceptance rate at KEWR, resulting in an estimated total acceptance rate gain of 15–20%.

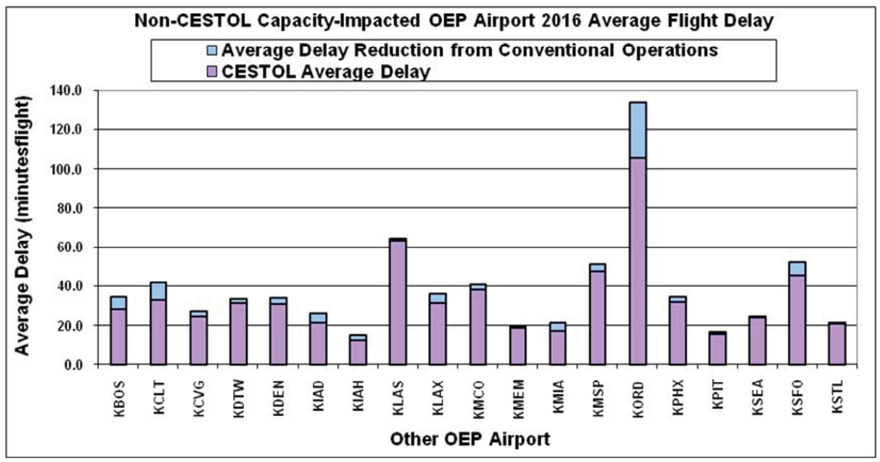
CESTOL NAS-Wide Delay Impact—The study extrapolates the AvTerminal-derived KEWR peak arrival and departure acceptance rates to estimate capacity parameter values for each of the OEP airports in the ACES modeling of traffic through the entire NAS network. The extrapolations of acceptance rates allow full, partial, or no achievement of CESTOL capacity gains at an OEP airport as determined by assessments of the degree to which local procedures allow leveraging of CESTOL capabilities. These assessments consider each OEP airport's runway geometries, runway system configurations, airport and airspace operations, and potential CESTOL traffic loadings. The capacities are adjusted to account for the proportion of traffic converted to CESTOL flights at each airport. Based on these assessments, 15 of the 34 OEP airports are estimated to be candidates for significant capacity improvements due to CESTOL operations as shown in the accompanying table. Estimated capacity gains range up to 40% for arrivals, up to 20% for departures (which tend to be limited by flow management constraints as at KEWR), and 20% for total operations (derived from the arrival and departure acceptance rates).

	CESTOL w/Conventional Aircraft Acceptance Rate Gain (%)		
Airport	**Departure**	**Arrival**	**Total**
Atlanta (KATL)	7%	15%	6%
Baltimore (KBWI)	20%	40%	20%
Cleveland (KCLE)	20%	40%	20%
Washington (KDCA)	20%	40%	20%
Dallas-Ft. Worth (KDFW)	15%	0%	0%
Newark (KEWR)	0%	40%	20%
Fort Lauderdale (KFLL)	10%	20%	8%
New York JFK (KJFK)	0%	5%	2%
New York LGA (KLGA)	0%	30%	13%
Chicago MDW (KMDW)	18%	35%	15%
Portland (KPDX)	5%	9%	4%
Philadelphia (KPHL)	20%	40%	17%
San Diego (KSAN)	12%	23%	10%
Salt Lake City (KSLC)	14%	27%	11%
Tampa (KTPA)	15%	29%	12%

The 2016 daily arrival traffic (10,174 flights) at the 15 CESTOL capacity-improved airports account for 40% of the 34 OEP airport arrivals (25,667 flights) and 18 % of all NAS airport arrivals (57,464 flights) used in the ACES modeling of NAS-wide operations (which includes OEP and non-OEP airports). The ACES application in this study analyzes the sensitivity of delay to CESTOL-based potential capacity improvement, where airport acceptance rates represent capacities in 2016. Although airport capacity is a primary modeling factor in this study, ACES is a network model that generates delays due to airport and airspace congestion and propagates delay through the system. The delays tabulated by airport are network-induced delays and not necessarily due only to constraints at the specific airport. These include any delay due to departure airport runway system takeoff, airspace spacing conflict and arrival airport runway system landing constraints, and include predeparture delays propagated by traffic flow management restrictions.

The ACES modeling simulates airport and airspace spacing constraints imposed by the airport runway system, terminal and en route air traffic control, and traffic flow management operations using traffic loading and airport acceptance rates representing conventional-aircraft-only and CESTOL-mixed-with-conventional-aircraft operations. Delay reductions are obtained by comparing results of the conventional-aircraft-only and CESTOL-mixed applications. The accompanying illustrations graphically summarize CESTOL-induced average flight delay reductions separately for CESTOL capacity-improved and non-capacity-improved OEP airports. (Flight delay is tabulated at the end of each flight at the destination airport.) The delay propagation effects are imbedded in these results such that delay reductions indicated for an airport are the cumulative effects of network and local interactions. The delay reductions shown for the CESTOL capacity-improved airports are attributable to a combination of propagated delay reductions and the local capacity gain impacts of CESTOL operations. Newark, Philadelphia, and Fort Lauderdale-Hollywood airports have the largest delay reductions—64%, 61%, and 51% savings respectively. The average flight delay reductions shown for the non-capacity-improved OEP airports are associated with network delay reduction propagation initiated by capacity improvements at other OEP airports. Of the non-capacity-improved OEP airports, Chicago O'Hare has the largest reduction at 22%.





Findings—This study applies the 4-dimensional (4D) trajectory-based AvTerminal and ACES modeling capabilities to estimate impacts of CESTOL operations on capacity at Newark Airport and impacts on delay at the domestic OEP airports as well as all airports within the NAS.

The AvTerminal Traffic Flow Management (TFM) modeling of Newark Airport, as applied in this preliminary study, assumes a CESTOL future operating environment in which advanced air traffic management (ATM) and flight operating systems provide very high-fidelity trajectory prediction and control capabilities. These capabilities are based on sophisticated communication, navigation, and surveillance (CNS) technologies. Assumptions include application of mature ATM automation with time-based metering and Dependent Converging Instrument Approaches (DCIA), area navigation (RNAV), required navigation performance (RNP), accurate meteorological prediction, air-ground data link communication, automatic dependent surveillance-broadcast (ADS-B), and KEWR gate, taxiway, parking and other airport improvements that remove airport surface impediments to runway traffic throughput. Although not a factor in this study, CESTOL is envisioned to incorporate fuel-efficient, low-noise and low-emission technologies.

The Newark Airport analysis indicates CESTOL has significant capability to increase arrival capacity by taking advantage of otherwise underused airspace and runways where available. These results show the beneficial effect of shifting CESTOL arrival traffic to a secondary crossing runway, with a corresponding reduction of traffic loading on primary runways relative to conventional-aircraft-only operations.

ACES-based NAS network analysis of CESTOL KEWR capacity gain extrapolations to 15 major domestic airports shows significant delay reductions across the network of airports. CESTOL-based capacity gains reduce average flight delay by 10.2 minutes for the 34 OEP airports and 5.9 minutes for all airports NAS-wide. Among the OEP airports, average flight delay reduction is more prominent at the 15 airports where capacity is improved by CESTOL than at the other 19 OEP airports where capacity is not improved (16.5 versus 6.1-minute delay reductions). Delay reductions across all airports are due to reduced NAS network delay propagation generated by improved operations at the 15 capacity-improved OEP airports.

	Average Flight Delay Reduction (minutes/flight)
15 CESTOL Capacity-Improved OEP Airports	**16.5**
19 Non-CESTOL-Capacity-Improved OEP Airports	**6.1**
All OEP Airports	**10.2**
NAS-Wide Non-OEP Airports	**2.3**
All NAS-Wide Airports	**5.9**

In the ACES modeling presented above, CESTOL aircraft are assigned a Mach 0.8 nominal cruise speed which is roughly comparable with conventional aircraft speeds. ACES models each 4D trajectory and assesses and resolves en route pair-wise spacing conflicts among aircraft. To investigate sensitivity of delay to CESTOL cruise speed, the study applies ACES assuming a Mach 0.7 cruise speed for all CESTOL flights and CESTOL-based capacity gains at the 15 impacted OEP airports. Results show CESTOL with a reduced cruise speed of Mach 0.7 to also achieve significant total delay reductions, but only slightly less than those estimated for the Mach 0.8 cruise speed assumption. Reduction in CESTOL cruise speed from Mach 0.8 to 0.7 lessens the 34 OEP airport delay reduction by 3% (20.2% versus 23.2%) and NAS-wide delay reduction by 2.6% (17% versus 19.6%).

	CESTOL Delay Reduction Impact			
	CESTOL OEP Airports	**Non-CESTOL OEP Airports**	**All OEP Airports**	**All NAS Airports**
CESTOL Mach 0.8	**37.9%**	**13.8%**	**23.2%**	**19.6%**
CESTOL Mach 0.7	**33.7%**	**1.6%**	**20.2%**	**17.0%**

This preliminary simulation-based analysis assumes idealized conditions in which advanced air traffic and flight management systems implement 4D trajectory optimization. However, the estimated delay savings (of the order of 20% NAS-wide) are significant, indicating that even with relaxation of the analysis assumptions, CESTOL is a serious candidate for further study and development with respect to potential capabilities to increase throughput and reduce delay throughout the NAS.

CRUISE-EFFICIENT SHORT TAKEOFF AND LANDING (CESTOL) AIRCRAFT: POTENTIAL IMPACT ON AIR TRAFFIC OPERATIONS PRELIMINARY ANALYSIS

G. J. Couluris, D. Signor, and J. Phillips[1]

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SUMMARY

Cruise-Efficient Short Takeoff and Landing (CESTOL) is an aircraft design concept for future use to increase capacity and reduce emissions. This study, for the National Aeronautics and Space Administration (NASA), is a preliminary analysis of the potential impact on National Airspace System (NAS) network traffic operations due to the introduction of CESTOL at the 34 domestic airports identified in the Federal Aviation Administration's Operational Evolution Plan (OEP). The analysis process uses two fast-time simulation tools to separately model local and NAS-wide air traffic operations using predicted flight schedules for a 24-hour study period in 2016. These tools, the Sensis AvTerminal© and NASA's Airspace Concept Evaluation System (ACES) modeling capabilities, simulate conventional-aircraft-only and CESTOL-mixed-with-conventional-aircraft operations. Both tools apply 4-dimension trajectory modeling to simulate individual flight movement subject to operating restrictions, including aircraft separation rules. AvTerminal is used to simulate traffic and procedures for en route and terminal arrival and departures to and from Newark Liberty International Airport (KEWR), New Jersey. AvTerminal quantitative results showed that CESTOL aircraft have significant capability to increase airport arrival acceptance rates (35–40% at KEWR) by taking advantage of otherwise underused airspace and runways where available.

The AvTerminal-derived KEWR peak arrival and departure acceptance rates are used to extrapolate capacity parameter values for each of the OEP airports in the ACES modeling of traffic through the entire NAS network. The extrapolations of acceptance rates allowed full, partial, or no achievement of CESTOL capacity gains at an OEP airport as determined by assessments of the degree to which local procedures allow leveraging of CESTOL capabilities. These assessments consider each OEP airport's runway geometries, runway system configurations, airport and airspace operations, and potential CESTOL traffic loadings. The ACES modeling simulates NAS-wide airport and airspace spacing constraints imposed by the airport runway system, terminal, and en route air traffic control and traffic flow management operations. CESTOL aircraft are assumed to have Mach 0.8 and alternatively Mach 0.7 cruise speeds to examine compatibility with conventional aircraft cruise speeds in common airspace. The ACES results provide estimates of CESTOL delay impact NAS-wide and at OEP airports due to changes in OEP airport acceptance rates and changes in en route airspace potential conflict occurrences. Preliminary results show meaningful nationwide delay reductions (20%) due to CESTOL operations at the 34 major domestic airports.

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1 INTRODUCTION

Cruise-Efficient Short Takeoff and Landing (CESTOL) is an aircraft design concept for future use in the U.S. National Airspace System (NAS). The nominal capability attributed to CESTOL is the ability to takeoff and land on runways significantly shorter than those required for the type of aircraft in current commercial transport fleets. It is also understood that the CESTOL does not sacrifice the same high subsonic cruise performance possessed by the fleet to obtain the short-field goals. The National Aeronautics and Space Administration (NASA) is investigating the technological, operational, environmental, and economic feasibility of civil CESTOL operations. In support of NASA, this study is a preliminary analysis of the potential operational impact of CESTOL on airport and airspace capacity and delay.

1.1 BACKGROUND

The following NASA perspective (ref. 1) addresses potential application of CESTOL aircraft operations.

A result of sustained economic growth in the United States is an increased demand for air transportation. As this demand increases, along with reluctance by municipal, state, and federal governments to build new air transportation infrastructure for concern of degrading the quality of life of their constituents with more noise and pollution, the national airspace system is being impacted. This impact manifests itself as delays, cancellations, and added costs to the passengers and the operators.

The Joint Program Development Office (JPDO) was established to facilitate NextGen activities. Its task is to create and carry out an integrated plan for NextGen, spearhead planning, and coordinate research, demonstration, and development in conjunction with relevant programs of other departments and agencies, and with the private sector. The Senior Policy Committee oversees the work of the JPDO and is made up of high-level representatives from the following agencies: Department of Transportation, Federal Aviation Administration (FAA), NASA, Department of Defense, Department of Commerce, Department of Homeland Security, and the White House Office of Science and Technology Policy.

Part of the NextGen program is to create a plan to address improving the national air transportation system without increasing noise and pollution for the surrounding communities; in fact, a preferred objective is to reduce noise and emissions over the long term.

Much of the work being conducted in academia, industry, and at NASA is investigating how to improve the throughput of the airspace system, with a significant amount of work aimed at improving flight procedures, tracking, communications, and other elements of air traffic management. By creating a better situational awareness between aircraft and ground controllers, and aircraft to each other, aircraft would be able to operate much closer to one another, thus increasing capacity. However, at crowded hub airports, the bottleneck is due to limited space on the main runways. This problem has been further exacerbated with the introduction of the regional jets (RJs), which have replaced the turboprops that once used the shorter secondary runways. A regional jet aircraft carrying less than 100 people needs the same amount of time and space on the main runways as a 300-plus passenger long-range transport.

One potential solution to this problem is the introduction of CESTOL aircraft with short-field performance capabilities comparable to current turboprop aircraft. With the ability to takeoff and land in under 2,000 feet, the CESTOL aircraft can return significant use of the secondary runways developed for turboprop operations, removing that commuter flight from the main runway, and therefore permitting the substitution of a long-range, high-capacity flight into that slot. Additionally, with the low-speed maneuverability and high performance the CESTOL aircraft possess for the short-field capability, there is the potential to also use the unused airspace around the airport while 'steering' around noise-sensitive areas and avoiding the conventional traffic using the primary glide slope into the primary runways. Thus the improved situational awareness of the new air traffic management system is augmented by a new vehicle that capitalizes on the air system improvements with better vehicle performance. In the long term, airfields that are currently unused because of their short primary runways can be reopened for service as future growth permits and/or the air transportation needs of new communities develop.

1.2 STUDY FRAME OF REFERENCE

CESTOL capable aircraft are intended to provide future commercial service to both large and small airports. In this concept, the CESTOL aircraft design has the size, range, and speed to be operationally and economically competitive in substantial markets, thus justifying a large civil CESTOL fleet. The CESTOL aircraft can serve large hub airports, satellite airports, and local regional airports and will also leverage fuel-efficient, low-noise, and low-emission technologies and operating procedures. The operating capabilities of the CESTOL aircraft are envisioned to be compatible with standard procedures, as well as alternative procedures that take advantage of its unique performance characteristics. The CESTOL aircraft operates on conventional terminal airspace arrival and departure routes and speed/altitude profiles (i.e., step or continuous trajectory), as well as steeper descent/approach and takeoff/climb profiles; on runways used by conventional jet aircraft as well as shorter runways; in en route airspace with lateral and vertical navigation capabilities and cruise speeds comparable to that of conventional jet aircraft; and on standard airport surfaces using normal runway, taxiway, ramp, gate, and service facilities. In general, the CESTOL aircraft operates in harmony with conventional aircraft and procedures in all phases of flight.

A civil CESTOL aircraft that fits the above description is one of sufficient size, range, and speed to be commercially feasible on a NAS-wide scale with technological and operational performance characteristics to be economically efficient and environmentally effective. This could be a relatively large aircraft with reasonably long range and high speed, but also capable of performing safe short takeoff and landing operations. The CESTOL capabilities listed in table 1, which are based on guidance from NASA (ref. 1), are assumed for preliminary analysis purpose.

TABLE 1. CESTOL OPERATING CHARACTERISTICS

CESTOL One-way Operating Range:	2,000 nmi
CESTOL Minimum Runway Length:	2,000 feet
CESTOL Cruise Speed:	0.8 Mach number
CESTOL Aircraft Seat Size:	120–130 seats

An example of the CESTOL concept is a jet-powered, large aircraft having the general specifications of a Boeing 737, but with short takeoff and landing capabilities and advanced technologies to reduce fuel consumption, noise, and emissions.

1.3 OBJECTIVE AND SCOPE

This study provides initial insight into the potential operational consequences of future CESTOL implementation into the NAS. The study is a preliminary examination of the potential impact of CESTOL on local airport capacity and delay, and CESTOL impact on NAS-wide delay. The study initially examines operational impacts at a subject site, Newark Liberty International Airport (KEWR), New Jersey. The study then extends these KEWR results to estimate potential impacts on the NAS-wide network traffic operations due to the introduction of CESTOL aircraft at selected major airports. These are the 34 domestic airports identified in the FAA's Operational Evolution Partnership (OEP) (ref. 2). The study examines CESTOL potential impact on traffic in the year 2016.

1.4 METHOD OF APPROACH

The general work plan (see fig. 1) focuses on modeling Newark Airport and extrapolating results NAS-wide using computerized modeling. The modeling requires definition of KEWR and NAS-wide 24-hour traffic loading for a selected study day and specification of operating procedures for the KEWR extended terminal area. This extended terminal area encompasses a region roughly within a 250-nautical-mile (nmi) radius of Newark Airport and the KEWR runway system. KEWR arrival and departure traffic is modeled, including cruise, climb, descent, and runway takeoff and landing operations. Surface taxi and gate operations are not modeled.

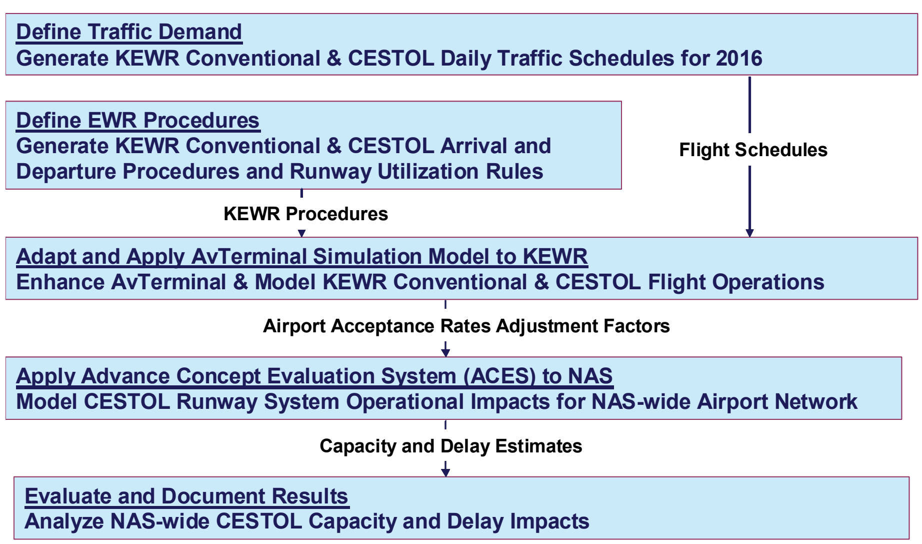


Figure 1. General work plan.

Two fast-time simulation tools are used to separately model local and NAS-wide air traffic operations. The Sensis AvTerminal© and NASA's Airspace Concept Evaluation System (ACES) (ref. 3) modeling capabilities are applied to simulate conventional and CESTOL operations. The AvTerminal application simulates actual KEWR traffic and procedures and is the analysis basis for this study. AvTerminal is used to assess KEWR capacity and delay by modeling conventional and CESTOL traffic operations in the extended terminal area. ACES is used to assess NAS-wide delay by assigning conventional and CESTOL arrival acceptance rates (AARs), departure acceptance rates (DARs), and total acceptance rates (TARs) at the OEP airports. Both tools apply trajectory-based modeling to simulate individual flight movement.

AvTerminal is a fast-time computerized simulator of terminal and en route airspace arrival and departure, and runway system takeoff and landing operations. AvTeminal implements an integrated approach for modeling interactions among aircraft in various flight states. The modeling process sequences, maneuvers, and delays aircraft to resolve overtake and spacing conflicts among aircraft in the airspace and airport system. AvTeminal analyzes individual aircraft movements along 4-dimensonal (4D) flight trajectories through a network of focal points representing cruise and transition airspace fixes and runways, including multiple airports. AvTerminal uses 3-degrees-of-freedom (3-DOF) flight dynamics modeling to generate trajectories. The modeling logic manages and adjusts trajectories to create integrated streams of arrival and departure traffic representing realistic flight movement through the airspace and airports. AvTerminal processes a flight schedule and evaluates traffic throughput and delay at airspace and runway system focal points.

ACES is a NASA-developed, fast-time computer simulation of local, regional, and nationwide air traffic operations covering aircraft flight from gate departure to arrival. ACES models flight movement through taxi-out, runway takeoff, climb, cruise, descent, runway landing, and taxi-in. ACES applies 4-DOF aircraft dynamics modeling to generate 4D en route flights trajectories. ACES agent-based modeling simulates traffic constraints and conflict resolutions imposed by airport, terminal, and en route sector air traffic control (ATC), and traffic flow management (TFM) operations. This system provides a flexible NAS simulation and modeling environment to assess the impact of new NAS tools, concepts, and architectures, including those that represent a significant departure from the existing NAS operational paradigm. ACES processes a NAS-wide flight schedule and evaluates airspace, airport, and airport network delay.

The ACES database has comprehensive daily schedules of all actual NAS flights derived from the FAA Enhanced Traffic Management System (ETMS). ACES uses the ETMS data to describe the origin and destination airport, scheduled departure and arrival time, aircraft type, and planned route and altitude for each flight. The resulting ACES NAS-wide conventional flight demand sets include a 24-hour schedule of all flights for February 19, 2004, and a predicted conventional flights schedule for February 19, 2016 derived from the 2004 base schedule. February 19, 2004 is a relatively benign weather day based on analysis of FAA Aviation System Performance Metrics (ASPM)_ (ref. 4) data. The two February 19 ACES daily flight schedules are used to define traffic loading for the KEWR and NAS-wide modeling. The conventional flight demand set used for AvTerminal input is the collection of KEWR arrival and departure flights extracted from the ACES February 19, 2004 and 2016 NAS-wide schedules. Corresponding CESTOL flight demand sets are constructed by converting selected conventional aircraft to CESTOL (see Section 3).

AvTerminal and ACES are applied using the CESTOL and non-CESTOL flight demand sets. The AvTerminal KEWR application produces traffic throughput (i.e., acceptance rates) and delay estimates, enabling evaluation of potential capacity increase and delay reduction impacts due to CESTOL aircraft. The AvTerminal peak arrival and departure acceptance rate results for KEWR are used to extrapolate capacity parameter values for OEP airports in ACES modeling of traffic through the entire NAS. The extrapolations of acceptance rates allow full, partial, or no achievement of CESTOL capacity gains at an OEP airport as determined by assessments of the degree to which local procedures allow leveraging of CESTOL capabilities. These assessments consider the runway geometries of each OEP airport, runway system configurations, airport and airspace operations, and potential CESTOL traffic loadings. CESTOL aircraft are assumed to have Mach 0.8, and alternatively Mach 0.7, cruise speeds to examine compatibility with conventional aircraft operations in common airspace. The ACES results provide estimates of CESTOL delay impact at the OEP airports and NAS-wide.

2 NEWARK (KEWR) EXTENDED TERMINAL AREA MODELING

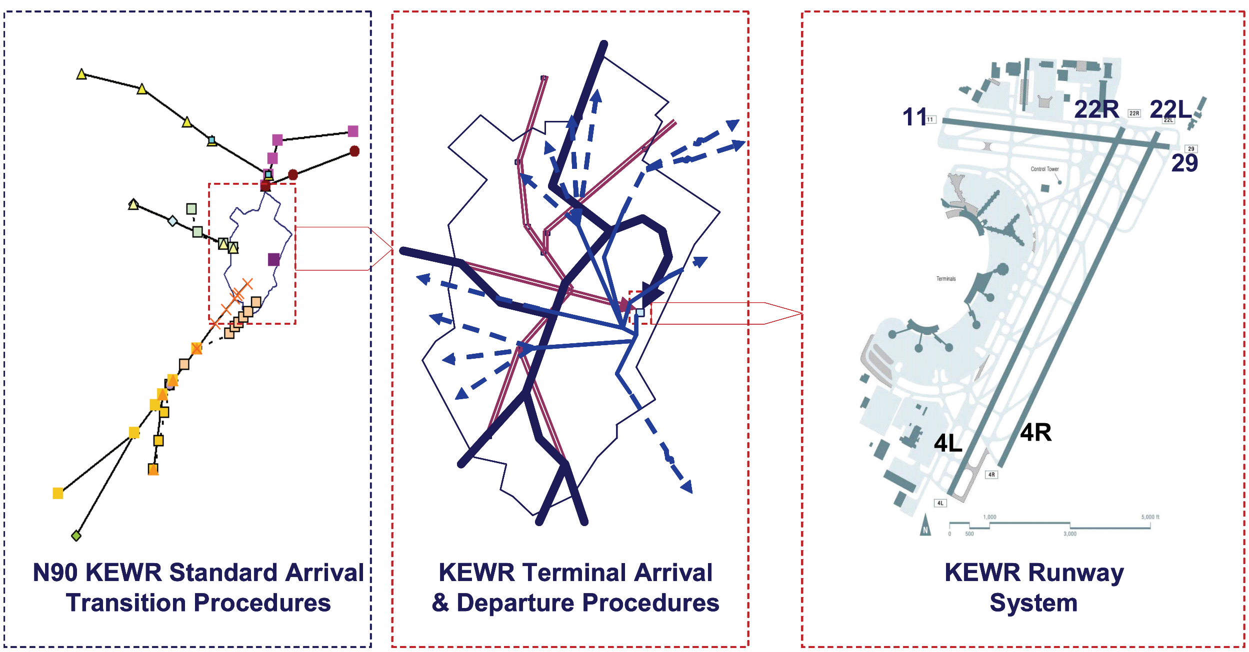
AvTerminal is applied to the Newark Airport runway system and the airspace extending 250 nmi from KEWR using ACES-provided traffic loading data.

2.1 KEWR EXTENDED TERMINAL AREA MODELING OVERVIEW

AvTerminal models arrival and departure procedures for KEWR flights through en route and terminal airspace and the runway system (see fig. 2).

AvTerminal input data define airspace and runway system procedures for conventional and CESTOL traffic operations. The airspace procedures describe routes, fixes, and applicable altitude and spacing requirements. Runway system procedures describe runway assignments and associated arrival/departure fixes.

En route procedures refer to the inbound cruise and descent and outbound climb and cruise routes and speed/altitude profiles. For AvTerminal application, the en route tracks and profiles for each KEWR arrival and departure flight is derived from the ACES February 19, 2004 flight data set. This traffic does not experience significant weather disruption to traffic movement. The procedure assignments generally correspond to published standard arrival (STAR) transition routes to terminal airspace and conform to published departure procedures from runways. Hence, the KEWR flights follow a set of common routings through the en route airspace.



Airport chart source: reference 5

Figure 2. KEWR extended terminal area and AvTerminal modeling scope.

Local terminal airspace and runway system procedures are defined for specific traffic operating plans, which vary according to meteorological conditions and other considerations (e.g., noise abatement), and account for visual flight rules (VFR), instrument flight rules (IFR), and alternative airport operating conditions and procedures.

The following describes the KEWR runway system and terminal airspace procedures.

2.2 KEWR RUNWAY SYSTEM PROCEDURES

Runway configurations and use descriptions below are based on available documentation (refs. 5–9) and consultation (ref. 10). With reference to figure 3, KEWR normally uses either of two basic runway configurations, the Southwest Plan or the Northeast Plan, each with variations.

Current Runway Operations—Both operating plans make primary use of the closely spaced (800 feet) parallel runways, with the Southwest Plan implemented more frequently than the Northeast Plan. The parallel primary runways (22R/L or 4R/L) are long—4L/22R is 11,000 feet and 4R/22L is 9,980 feet. The secondary crossing runway 11 is short—6,800 feet. All are 150 feet wide (ref. 7).

The basic Southwest Plan for operations during visual meteorological conditions (VMC) is: land on 22L by turbojet aircraft; land on the crossing short runway 11 by turboprop and piston-powered aircraft; and takeoff on runway 22R by all aircraft.

The basic Northeast Plan for operations during VMC is: land on 4R by turbojet aircraft; and takeoff on runway 4L by all aircraft.

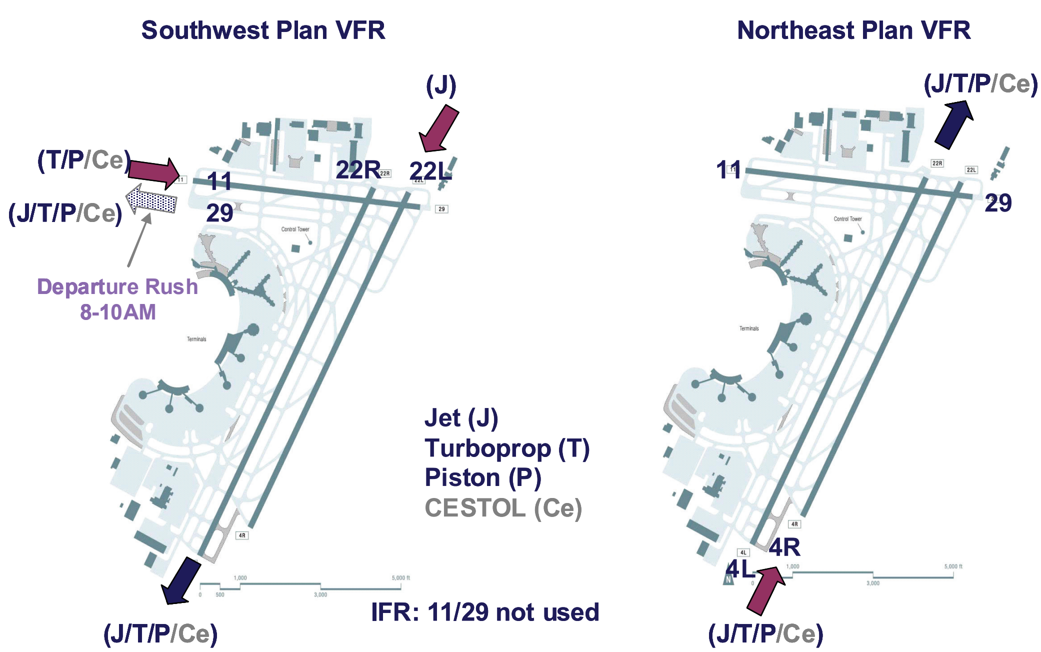


Figure 3. KEWR VFR runway configurations.

Variations include: mixed use of runway 4L/22R for takeoff/landing when advantageous (but not during marginal VFR or IFR operations); use of runway 29 for takeoff-only by small/large jet, turboprop, and piston aircraft as warranted during a morning departure rush (e.g., 8–10 AM); and landing on runway 11 by small/large jet aircraft when advantageous.

Continental Airlines is the major commercial aircraft operator at KEWR. At the time of this study, Continental uses jet aircraft for regional service rather than turboprop aircraft. The overall volume of non-jet traffic is not significant, and jet traffic predominates at KEWR. The result for landing operations is predominant use of primary runway 22L with occasional use of secondary crossing runway 11 (Southwest Plan), or predominant use of primary runway 4R (Northeast Plan) (ref. 5).

Conversely, runway 11 is not used for landing during IFR operations, likely because of concerns with missed approach incursions into nearby adjacent non-KEWR airspace. Instrument approaches to runway 11 are not supported. Nearby adjacent airspace constraints restrict landing on runway 29 during VFR and IFR operations.

CESTOL Runway Operations—The basic Southwest VFR Plan is the most frequently used configuration (refs.5, 8), and is used for modeling and analysis in this preliminary study. CESTOL landings are assigned to runway 11, enabled by the short landing capability of CESTOL aircraft. Land and hold short operation (LAHSO) on runway 4/22 is not a current procedure, and LAHSO is not an assumed requirement for CESTOL (although CESTOL short landing capabilities could take advantage of LAHSO to improve crossing runways utilization). Additional improvements in Required Navigation Performance (RNP), coupled with new procedures permitted by the low-speed maneuverability of the CESTOL, may support modifications to these operational procedures but were not examined and taken into account for this study.

2.3 KEWR TERMINAL AIRSPACE PROCEDURES

The KEWR terminal airspace is part of the New York Terminal Radar Approach Control (TRACON) N90 operation and is responsible for KEWR arrivals and departures. Other N90 sectors are responsible for arrival and departures of other vicinity airports and over-flights. The following paragraphs summarize KEWR airspace arrival and departure procedures.

2.3.1 KEWR Terminal Arrival Operations

Current Arrival Operations—Published standard terminal arrival procedures for KEWR define routings and profiles from cruise to transition entry points to KEWR local terminal airspace but not through the terminal airspace. Figure 4 shows KEWR terminal arrival and departure procedures for jet and turboprop aircraft for the Southwest VFR operation. These procedures are assembled from a previous site survey (ref. 11) and depict typical routes and altitude profiles implemented by routine ATC vectoring processes.

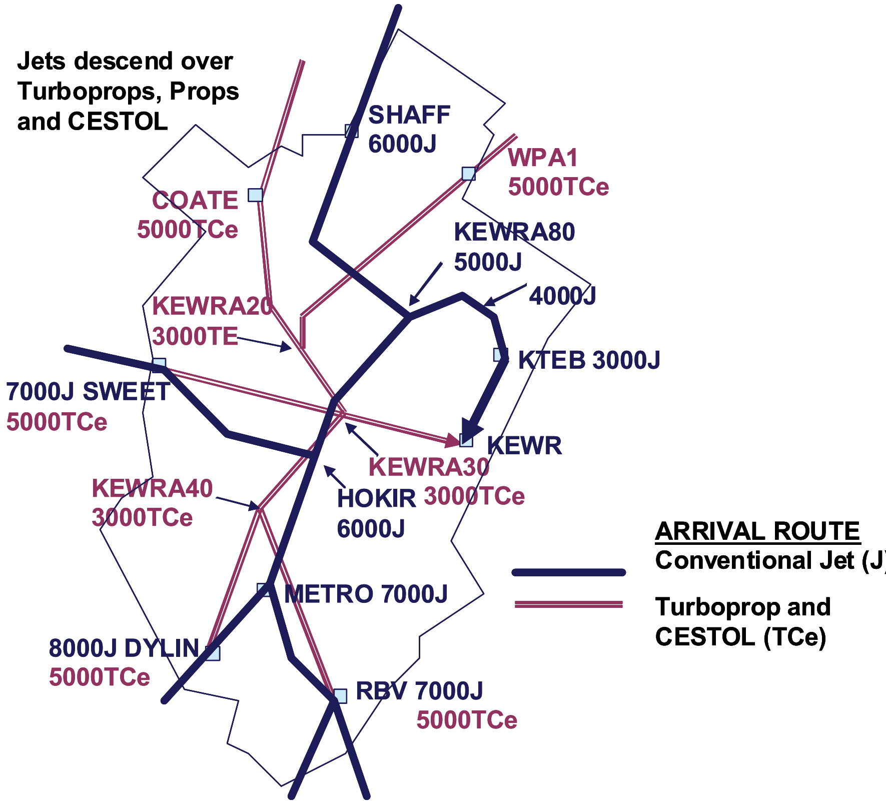


Figure 4. KEWR Southwest VFR plan—local arrival routes and altitudes.

Figure 4 identifies airspace fix names and associated altitude assignments (in feet) for jet and turboprop aircraft. Aircraft cross a fix at the indicated altitude, if assigned, according to this operating plan. Jet conventional aircraft are on converging routes through a series of merge points leading to runway 22L. The jet aircraft enter the KEWR local airspace at higher altitudes (6,000–8,000 feet) than non-jet aircraft (5,000 feet). The jet aircraft descend on converging inbound routes to a common path at 5,000 feet, and proceed on this descent path through the final approach fix (near KTEB) to primary runway 22L.

Turboprop (and piston) aircraft are on converging routes through a series of merge points leading to runway 11. These aircraft descend from 5,000 feet on converging inbound routes to a common path at 3,000 feet, and proceed through the final approach fix to the crossing runway 11.

Jet inbound traffic from the west and south fixes and all non-jet inbound traffic; each have a planned level-off segment during descent to their respective runway. The jet aircraft level off at 6,000 feet, which is above the turboprop aircraft level segment at 3,000 ft. altitude. The jet aircraft maintain 6,000 feet until beyond crossing the lower non-jet aircraft, after which the jet aircraft continue their decent. The turboprop aircraft maintain 3,000 feet until runway approach.

<u>CESTOL Arrival Operations</u>—For this preliminary study, CESTOL flights are assigned the turboprop arrival routes and altitude profiles enabled by the flexible descent performance capabilities of CESTOL aircraft. CESTOLs should have superior climb and descent performance than turbofans due to high thrust/weight ratio, and are ‘flexible’ in the sense that they can fly above or below the turbofans.

The altitude profiles are those reported as actually used. These represent operationally and institutionally acceptable procedures, for which there is little rationale to change in this study. (Note that this study does not take advantage of the flexibility of alternative descent profiles that CESTOL has to offer, and is thus a conservative analysis of CESTOL potential benefits.) The 3,000-ft. level segment for CESTOL aircraft is based on the turboprop operation. An issue for future investigation is the noise and emission impact of jet engine CESTOL aircraft flying on lower-level profiles and implementing the 3,000-ft. level-off procedure. CESTOL use of advanced technologies for noise suppression and emission reduction, and higher altitude arrival procedures with steeper final approach, are several environmental impact amelioration factors for consideration.

2.3.2 KEWR Terminal Departure Operations

Current Departure Operations—Figure 5 shows KEWR terminal departure procedures for jet and turboprop aircraft for the Southwest VFR operation.

Published standard departure procedures specify headings for takeoff from runway 22R, after which local vectoring is applied to the following routings shown in figure 5. All flights are on diverging routes through a series of diverge fixes to departure fixes. Aircraft climb and exit the Newark terminal airspace at intermediate altitudes (5,000–11,000 ft.), and continue climbing through a layer of other New York TRACON airspace (i.e., designated the "Liberty" area) until exiting the TRACON airspace at departure fixes on the boundary with en route Air Route Traffic Control Center airspace. For example, a jet aircraft climbing to the ELIOT departure fix turns right after runway 22R takeoff, exits the Newark airspace at WEST1 at 10,000 feet, and exits the New York TRACON airspace at ELIOT at 17,000 feet.

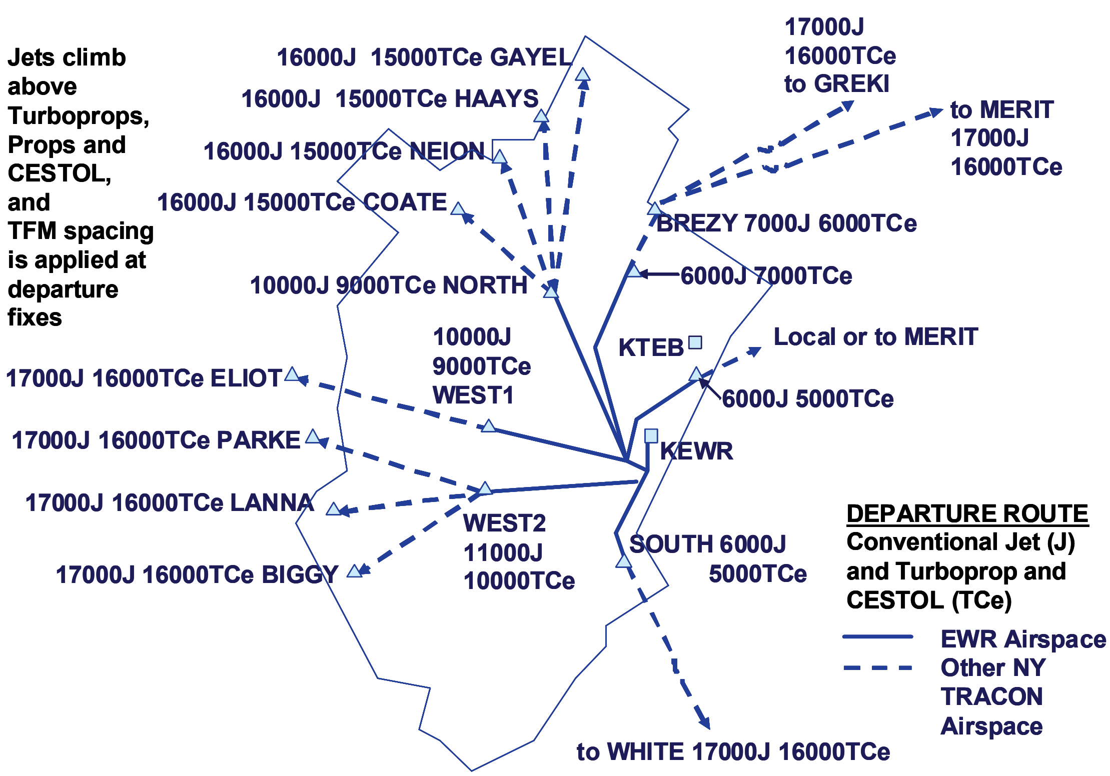


Figure 5. KEWR Southwest VFR plan—local departure routes and altitudes.

Jet, turboprop, and piston departures are on common departure routes, but procedures are such that the jet aircraft are maintained at altitudes at least 1,000 feet above the other aircraft. Jet departures to the west and north are cleared to 10,000 or 11,000 feet at exit fixes on the Newark airspace ceiling, with turboprops 1,000 feet below the jet routes. Jet departures to other Newark airspace exit fixes are cleared to 6,000 or 7,000 feet, again with turboprops 1,000 feet below.

CESTOL Departure Operations—For this preliminary study, CESTOL flight are assigned the turboprop departure routes and altitude profiles, taking advantage of the flexible climb performance capabilities of CESTOL aircraft.

2.3.3 KEWR Airspace Procedural Structure

The KEWR local terminal airspace operations are highly structured, applying procedural separation among aircraft streams (see fig. 6).

With reference to Figure 6, departures climb quickly after takeoff from runway 22R such that all departure streams cross above all arrival traffic streams.

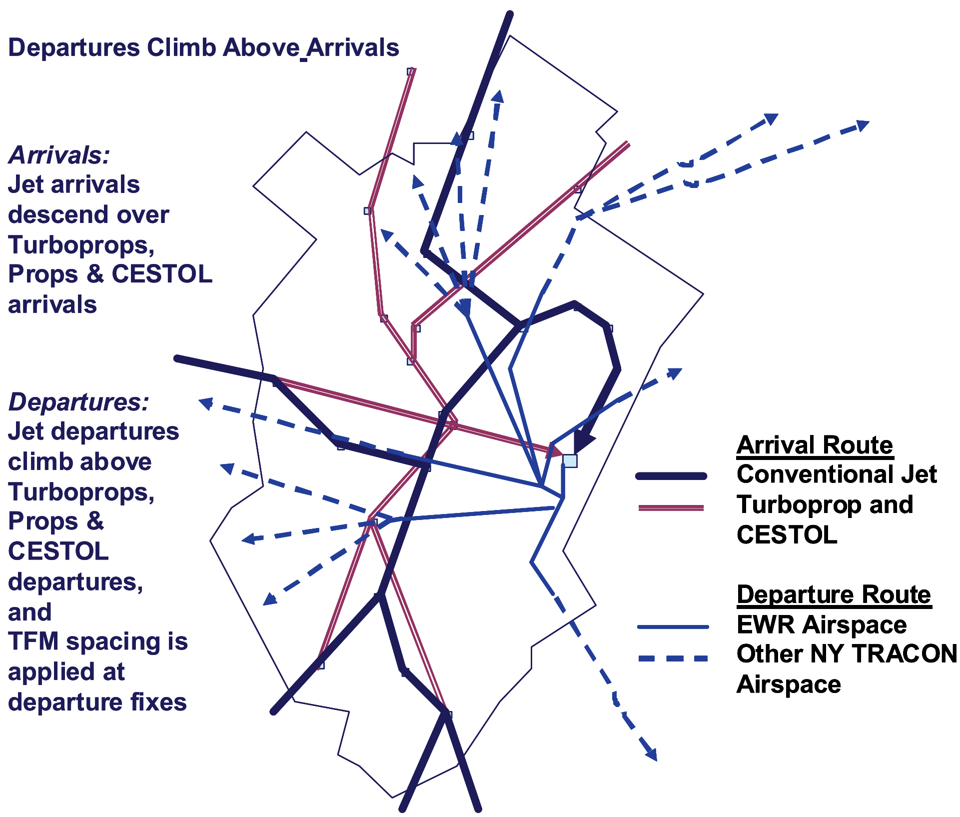


Figure 6. KEWR Southwest VFR plan—arrival and departure procedures.

Within arrival traffic, all jet arrival streams to primary runway 22L remain above non-jet and CESTOL streams to crossing short runway 11. Within each stream, required spacing is applied between aircraft, which is complicated by the general pattern of stream merging. The succession of merges and constraints on overtake due to restricted airspace require considerable traffic planning to move aircraft safely through this converging network to the runway.

For departure traffic, all jet aircraft in each departure stream from 22R remain above non-jet aircraft in the same stream subject to establishment of required inter-aircraft spacing. The general divergence pattern facilitates spacing application.

The New York TRACON implements a unique terminal departure operation. The Liberty area is layered above normal terminal area arrival and departure airspaces. The Liberty area receives departure traffic continually from the various New York airports, and merges aircraft destined to common departure fixes in accord with spacing requirements. This traffic integration process is based on establishing spacing exit restrictions on each of the local airport departure operations, which includes the KEWR local terminal airspace. A restriction of 15 miles-in-trail (MIT) on KEWR traffic destined to the same departure fix is representative of typical operations (ref. 10). This spacing allows for merging a Newark departure with a Kennedy departure and a LaGuardia departure such that 5-nmi spacing is provided between successive aircraft crossings of the departure fix.

3 NEWARK AIRPORT CESTOL FLIGHT ASSIGNMENT

The ACES flight data set identifies the conventional aircraft type for each flight in the daily schedule. For AvTerminal modeling of Newark Airport, a subset of conventional aircraft types in the February 19 flight data are converted to CESTOL aircraft. This aircraft type conversion process and the resulting fleet compositions are described below.

3.1 CESTOL AIRCRAFT TYPE ASSIGNMENT

The CESTOL aircraft characteristics parameters listed in table 1 are used to identify conventional aircraft candidates for replacement by CESTOL aircraft in this AvTerminal initial analysis of Newark Airport operations. Table 2 lists the conventional-to-CESTOL conversion guidelines used in the algorithm to select flights for replacement. Appendix A describes the algorithm, which is summarized in the following paragraphs.

The preliminary analysis of Newark Airport operations uses introduction guidelines that specify a 120-seat upper limit for CESTOL aircraft to initiate the modeling process. (Note subsequent update of the CESTOL size guideline per table 1 defines a maximum range of 120–130 seats.) Hence, for the Newark Airport AvTerminal modeling, a flight in the existing schedule is eligible for conversion to a CESTOL flight if: the existing aircraft type has a seat capacity between 50 and 120 seats inclusively; the great-circle distance between the flight's origin and destination airport is not more than 2,000 nmi; and the flight provides commercial passenger service (i.e., not a freight, military or general aviation flight). The 50-seat minimum limit is meant notionally to conform to the economic operating viability of using a large CESTOL aircraft. Here, existing use of smaller aircraft with less than 50 seats is assumed to be the preferred seat size for the route market being served. Also, allowance is made to consolidate two conventional flights into one CESTOL flight if the conventional flights are scheduled to operate within one hour of each other, and their joint seat capacity does not exceed that of the CESTOL aircraft.

Table 3 is a list of NAS-wide aircraft-type candidates qualifying for CESTOL replacement in 2016 based on seat size. This list identifies those conventional aircraft in the ACES February 19, 2016 nationwide flight demand set that are in the [50–120] seat size group.

TABLE 2. CONVENTIONAL-TO-CESTOL AIRCRAFT CONVERSION CRITERIA FOR KEWR AVTERMINAL MODELING

Conventional aircraft size: 50 ≤ number of seats ≤ 120
Flight distance: ≤ 2,000 nmi
Minimum runway length at arrival or departure airport: ≥ 2,000 ft
User class: Commercial or Air Taxi
Consolidate two conventional flights into an CESTOL flight if:
Airport arrival (or departure) time separation: ≤ 60 min
and
Sum of seats of the conventional flights: ≤ 120 seats

TABLE 3. NAS-WIDE 50–120 SEAT CONVENTIONAL AIRCRAFT CANDIDATES FOR CESTOL REPLACEMENT

AC Type	Engine Type	Number of Seats	AC Type	Engine Type	Number of Seats	AC Type	Engine Type	Number of Seats
B732	J	120	BA46	J	90	FK70	J	69
DC94	J	120	DC9Q	J	90	DH8D	T	68
MD87	J	117	L188	T	90	AT72	T	66
B735	J	110	BA11	J	89	F28	J	65
B736	J	110	CRJ9	J	86	ATP	T	64
DC93	J	110	DC91	J	85	DHC7	T	55
B712	J	106	DC92	J	85	FK10	J	55
RJ85	T	100	B461	J	80	A32	T	55
CRJ3	J	100	DC6	P	80	CR2	T	50
B717	J	100	F70	J	80	DH8C	T	50
A318	J	100	H1	T	78	E145	J	50
F100	J	97	ATR	T	72	F50	T	50
B727	J	94	CRJ7	J	70	CRJ2	J	50
B462	J	90	RJ1H	J	70	E45X	J	50
B463	J	90	A225	J	70			

Seat size data sources: references 12, 13

Table 4 summarizes the Newark daily arrival and departure fleet composition resulting from the conversion of conventional aircraft to CESTOL aircraft. The table shows the 2004 and 2016 daily distributions of conventional and CESTOL flights with and without conversion by engine type. The predicted CESTOL fleet is extrapolated from the 2004 fleet based on the anticipated increase in demand in 2016. CESTOL aircraft account for 38% of the fleet in 2016. The 2004 data is shown for comparison purpose.

The total number of flights is reduced somewhat by the CESTOL replacement of conventional aircraft, because in some cases a pair of conventional flights is consolidated into a single CESTOL flight where feasible. The elimination of 47 daily flights in 2016 due to consolidation is a 3% reduction.

TABLE 4. KEWR 19-FEB-2004 AND 2016 DAILY FLIGHT DISTRIBUTION

2004 KEWR Number of Flights

	Conventional			CESTOL			
Engine	Arrival	Departure	Total	Arrival	Departure	Total	Total %
Jet	518	524	1042	283	289	572	54%
Turboprop	14	14	28	11	11	22	2%
ESTOL	0	0	0	233	234	467	44%
Total	532	538	1070	527	534	1061	100%

2016 KEWR Number of Flights

	Conventional			CESTOL			
Engine	Arrival	Departure	Total	Arrival	Departure	Total	Total %
Jet	802	806	1608	481	482	963	60%
Turboprop	17	16	33	14	13	27	2%
ESTOL	0	0	0	298	306	604	38%
Total	819	822	1641	793	801	1594	100%

TABLE 5. KEWR 19-FEB-2016 CESTOL FLIGHT-DISTANCE DISTRIBUTION

			KEWR 2016 Traffic Distribution of All CESTOL Fights by Range				
Aircraft Type	Engine	Seats	1 - 500	501 - 1000	1001 - 1500	1501 - 2000	Total
CESTOL_E145	J	50	5.6%	13.9%	15.7%	14.4%	49.6%
CESTOL_B735	J	110	1.0%	6.8%	12.9%	2.0%	22.6%
CESTOL_E45X	J	50	1.5%	3.5%	6.1%	1.3%	12.4%
CESTOL_DC93	J	110	0.0%	1.5%	2.3%	0.0%	3.8%
CESTOL_F100	J	97	0.0%	0.0%	3.8%	0.0%	3.8%
CESTOL_CRJ2	J	50	0.0%	0.3%	0.0%	3.0%	3.3%
CESTOL_B712	J	106	0.0%	0.0%	1.8%	0.0%	1.8%
CESTOL_B732	J	120	0.0%	0.3%	0.8%	0.0%	1.2%
CESTOL_RJ85	T	100	0.0%	1.0%	0.0%	0.0%	1.0%
CESTOL_B462	J	90	0.3%	0.0%	0.0%	0.0%	0.3%
CESTOL_CRJ7	J	70	0.0%	0.2%	0.0%	0.0%	0.2%
Total			8.4%	27.4%	43.5%	20.7%	100.0%

The flight consolidation/replacement analysis does not track the tail number of aircraft, and hence does not recognize situations in which an aircraft on a ≤2000-nmi flight also flies a longer flight segment during the day. Replacement of this aircraft by CESTOL would lead to an underestimate of the CESTOL traffic demand.

Table 5 identifies the specific 2016 KEWR conventional aircraft that are converted to CESTOL and their flight distance distribution. Midrange 1000–1500-nmi flights dominate the distance distribution, accounting for 40% of the CESTOL flights. CESTOL replacement of the 50-seat Embraer 146 regional jet accounts for half the CESTOL fleet, with replacement of the 110-seat Boeing 737-500 and 50-seat Embraer 45X accounting for much of the remaining CESTOL aircraft.

3.2 AIRSPACE OPERATIONAL IMPACT OF CESTOL

The conversion of conventional aircraft to CESTOL aircraft shifts significant arrival traffic from the primary runway 22L to the secondary crossing runway 11. Figure 7 illustrates the conversion effects on the 2016 KEWR daily flight sample. CESTOL arrivals, which are a significant component (38%) of the total arrival traffic, land on the secondary crossing runway 11 rather than runway 22L. Arrival traffic loading on the primary runway 22L is reduced from 98% to 60% of the total arrival traffic.

Concurrently, significant traffic on the inbound routing system to runway 22L is shifted to the separate inbound routing system to runway 11. These two routing systems are procedurally separated within the TRACON, precluding interference and spacing intervention between conventional and CESTOL flights as they approach the runway system.

The redistribution also reduces the intensity of traffic on the routing system to 22L, alleviating spacing interactions among jet arrivals. This congestion moderation is illustrated in figure 8 by the reductions in the symbolic magnitude of traffic at critical inbound merge points due to CESTOL-mixed operations.

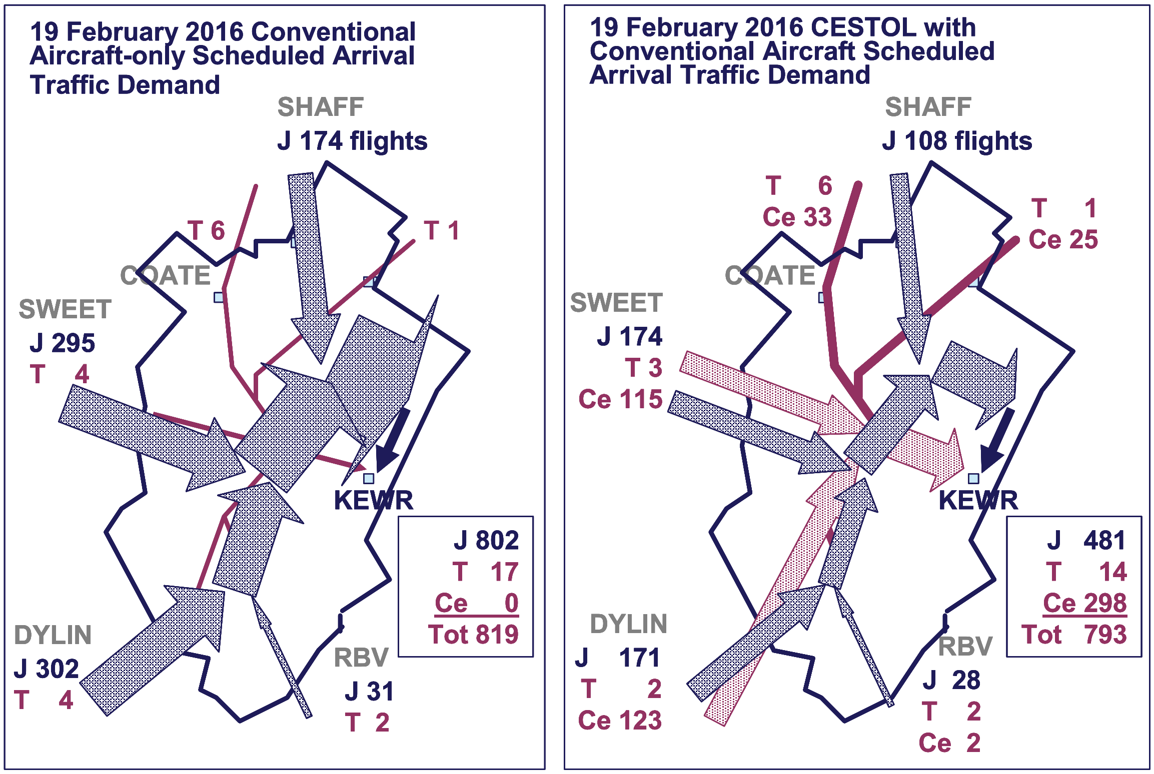


Figure 7. KEWR 2016 daily arrival traffic redistribution.

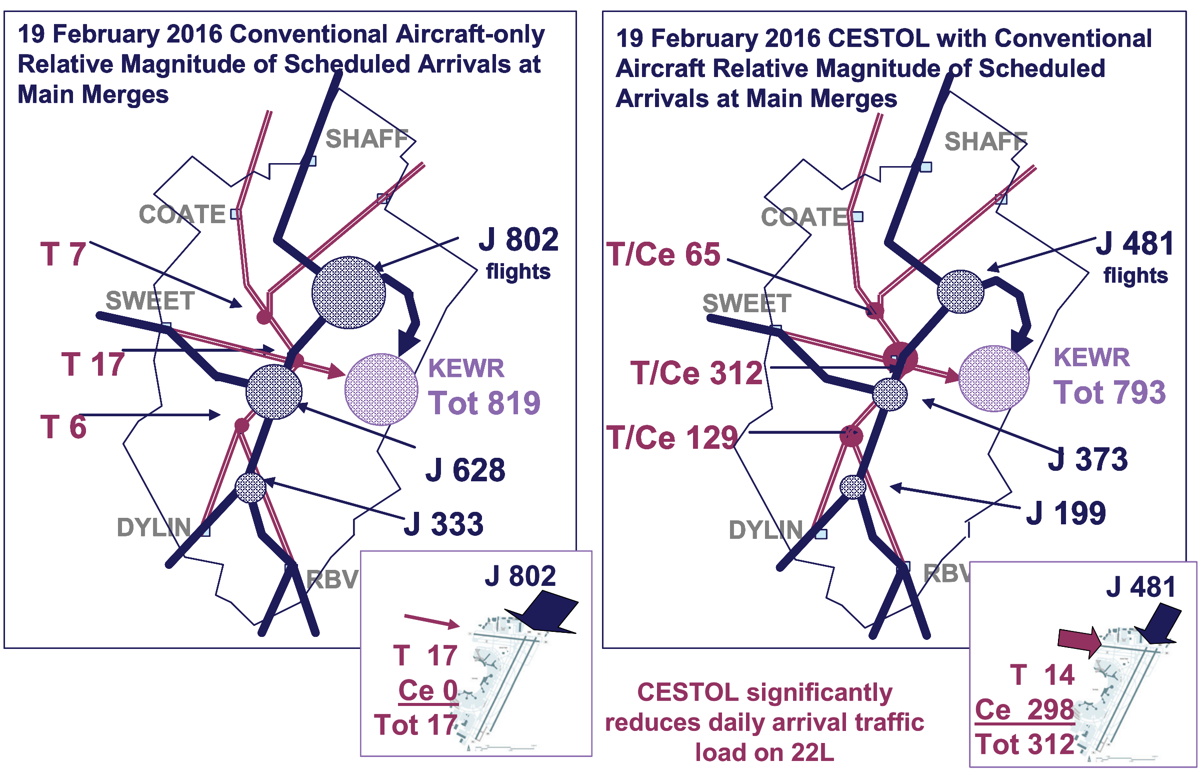


Figure 8. KEWR 2016 daily arrival traffic congestion alleviation.

4 NEWARK AVTERMINAL MODELING

AvTerminal models en route, terminal airspace, and runway system operations, and is applied to Newark as described below.

4.1 AVTERMINAL AIRSPACE AND RUNWAY SYSTEM MODELING

The primary function of AvTeminal is to model flight trajectories subject to constraints. AvTeminal uses 3-DOF flight dynamics modeling to generate 4D flight trajectories between origin and destination airports. The fundamental AvTerminal provides TFM and ATC modules to simulate constraints on airspace and runway system operations (see fig. 9).

AvTerminal models mutual interaction among en route airspace, terminal airspace and runway system operations. Airspace constraints inhibit passage of flights to and from runway systems, and, simultaneously, runway system constraints inhibit processing of flights through runways, regardless of airspace movement capabilities. AvTerminal implements a newly developed algorithmic structure that concurrently assesses aircraft trajectories and airspace/runway system constraints to obtain smooth network movement solutions. This logic employs complex network-wide modeling techniques to identify potential merge and diverge conflicts, assess runway spacing, and generate delay and maneuver resolutions.

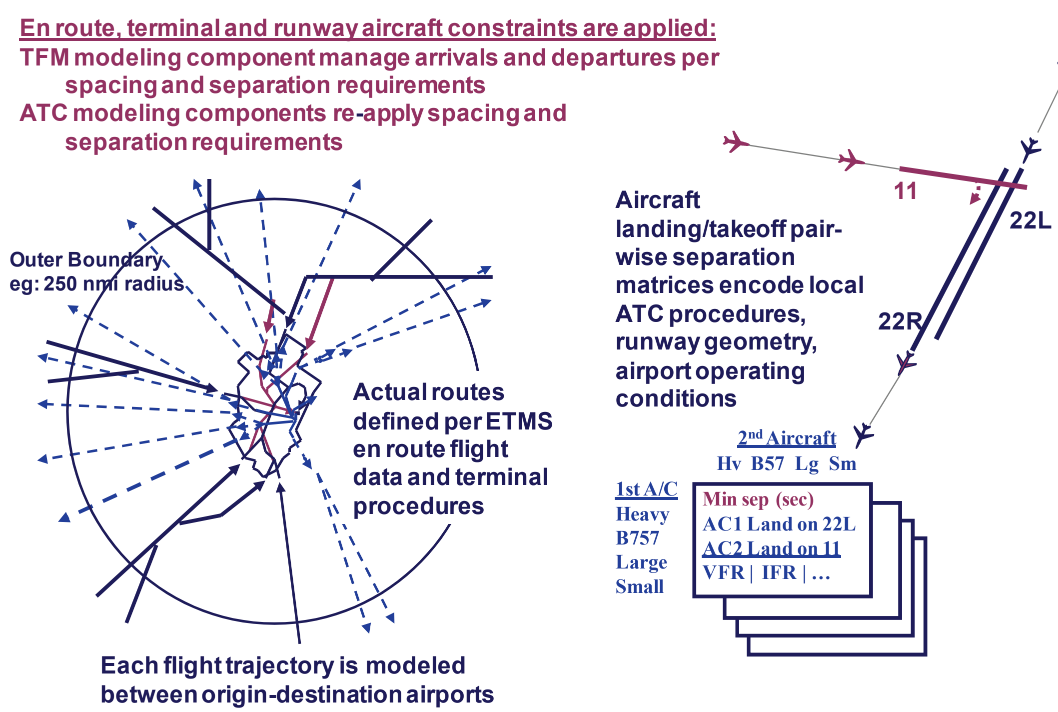


Figure 9. AvTerminal KEWR application.

AvTerminal's link-node modeling of all route segments, airspace route structure, and runway configurations applies the following constraints:

1. Separation requirements at en route cruise and transition fixes and terminal fixes (including arrival fix, intermediate merges, transition airspace merges and diverges, and departure fixes).
2. Wake vortex-based separation requirements at the runway thresholds and for all landing and takeoff flights on all runways.
3. Procedural (altitude/speed) constraints.

The AvTerminal TFM module applies look-ahead logic to determine feasible fix crossing and runway times, and applies delay to individual aircraft to meet these planned times. Delay is propagated along inbound or outbound trajectories to a departure airport as necessary. Takeoff delay is absorbed on the airport surface. The effect is to simulate the application of network-integrated, high-fidelity, time-based metering to each aircraft sequentially at critical points. An AvTerminal ATC module models flight trajectories and constraints in actual simulation time, rather than over a TFM look-ahead horizon, to assign maneuvers and delays.

AvTerminal runway modeling uses aircraft minimum separation time requirements to manage runway system operations. The runway modeling function applies user-defined runway system configuration descriptors and matrices of aircraft separation time requirements (see fig. 9) to define takeoff and landing interactions. These matrices conform to FAA rules (ref. 14) and account for wake turbulence as well as runway occupancy and missed approach constraints.

Each matrix defines the minimum allowable time separation between pairs of successive runway operations for a given runway geometry and interaction. Runway use varies by user-specified airport operating condition (e.g., VMC, IMC, other) by time. The runway modeling logic assigns actual takeoff and landing times based on requested times (derived from the flight schedule), runway, final approach, and missed approach spacing requirements (separation time matrices), and applicable airspace restrictions (departure fix spacing requirements). Resulting departure delays are absorbed on the airport surface. Resulting arrival delays are absorbed while airborne.

4.2 POINT MASS TRAJECTORY MODEL

AvTerminal implements the specially designed 3-DOF point mass trajectory generator model. The point mass trajectory generator accurately solves the point mass equations at widely spaced nodes along a specified horizontal and vertical profile. The vertical profile is a list of segment types and corresponding end states. Mach/calibrated air speed (CAS) is applied to and from cruise. In lower airspace, the model applies a constant deceleration profile along a constant flight path angle (i.e., speed and altitude both change) on segments between waypoints having altitude and/or speed crossing restrictions. The horizontal profile is a list of waypoints, where a series of straight segments approximate curved routes. Turns are modeled as circular arcs, which are tangent to great circle arcs that connect the waypoints. The trajectory state is sampled at uniformly spaced times by interpolating between the solutions at nodes. The exact point mass equations are solved iteratively. No small angle approximations are made. The method of specifying the vertical profile guarantees continuous trajectories. Wind and nonstandard temperatures can be taken into account.

The point mass trajectory generator is physics based; it requires an aerodynamic model and a thrust model. AvTerminal uses the BADA 3.6 models (ref. 15), which include aerodynamics (lift, drag); propulsion (thrust, fuel burn rate); and aircraft-type performance characteristics data (stall speed, climb speed, descent speed, cruise speed, and empty weight) for hundreds of aircraft types.

This method models a wide range of flight segment types, including climb and descent at constant indicated airspeed or constant Mach, acceleration, deceleration, and cruise, and it is computationally fast. In addition to flight segments, the point mass trajectory generator can also model ground-based segments including takeoff, landing, and taxiing. With sufficient input, it is therefore possible to efficiently and accurately model a flight from gate to gate.

The point mass model-based trajectory generator is applied to each aircraft in the KEWR conventional and CESTOL flight demand sets. The conventional aircraft are modeled using the exiting BADA database that defines aircraft type performance characteristics. Based on expert review (ref. 1) of civil CESTOL aircraft design concepts, the Boeing 737-700 is used to represent general CESTOL flight performance characteristics for the purpose of trajectory modeling in AvTerminal. The B737-300 aircraft type performance characteristics are used for CESTOL trajectory modeling, except an 83-knot stall speed is assumed based on conceptual aerodynamics for a civil CESTOL aircraft.

4.3 AVTERMINAL NEWARK APPLICATION

For Newark, the AvTerminal TFM module is applied to model the sequence of converging inbound merges, runway minimum separation requirements, and outbound diverge operations including departure fix spacing restrictions. AvTerminal models the airspace procedures and runway configurations for the Southwest VFR Operating Plan described in Section 2 and the traffic loadings described in Section 3.

With reference to figure 9, AvTerminal considers constraints to the inbound flight trajectories at the 250-nmi radius and applies delay resolution to prevent inter-aircraft violation of en route restrictions (e.g., 5-nmi minimum radar spacing plus 2-nmi buffer; 1,000-ft. vertical minimum separation). Outbound flight trajectories are processed similarly to provide conformance with constraints. AvTerminal processes inbound traffic streams through KEWR terminal airspace by imposing strict in-trail spacing (5 nmi minimum) without regard to altitude, and applying delay resolution strategies to prevent overtakes in this confined airspace. AvTerminal achieves TFM delay resolution by time-shifting 4D trajectories. Altitude separation is applied between separate streams of convention and CESTOL aircraft. This process results in a network-integrated, systematic plan for merge-point crossings timed to satisfy constraints. In addition, AvTerminal assesses and resolves the runway minimum time separation requirements in coordination with the airspace resolution strategies.

Matrices of runway minimum separation time requirements for the KEWR Southwest Plan are derived from previous survey, publications and consultations (refs. 6–11), and standard operating rules (ref. 14). Appendix B presents the matrix for each runway interaction pair in a single table. These data encode complex rules for applying spacing to takeoff and landing operations on same and interacting runways, and are applicable to alternative runway configurations. A special attribute of the AvTerminal runway modeling logic is the application of departure fix restrictions (15-nmi

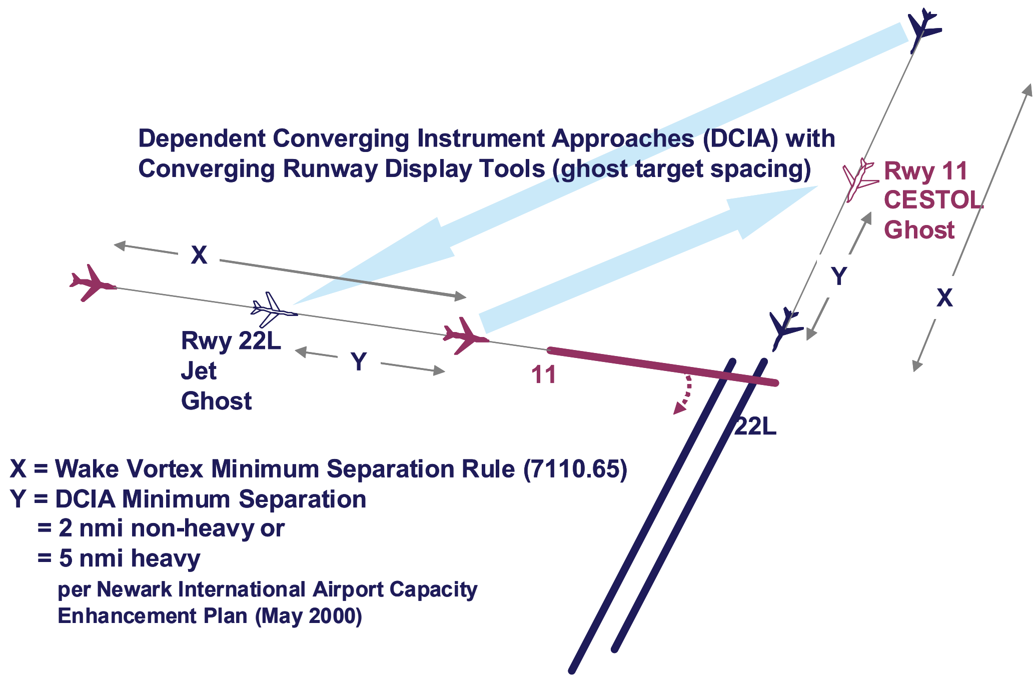


Figure 10. KEWR DCIA.

miles-in-trail) in assigning takeoff times. The logic delays and reassigns takeoff times of aircraft destined in succession to a common fix to accommodate the airspace constraint. These delayed takeoffs are resequenced among the arrival and departure operations.

An FAA-led task group (ref. 7) identifies Dependent Converging Instrument Approaches (DCIA) as a potential future enhancement to improve Southwest Plan operations, particularly IFR. DCIA (see fig. 10) requires advanced ATC automation to display ghost traffic on final approaches to controllers. The ghosting technique enables interleaving of landings on primary runway 22L and secondary crossing runway 11 between staggered arrivals to each runway. The DCIA requires aircraft separated by 2 nmi from a nonheavy ghost target and 5 nmi from a heavy ghost target (ref. 7). AvTerminal includes these separation rules in the KEWR matrices to model DCIA operations.

4.4 AVTERMINAL REASONABLENESS

AvTerminal capacity analysis results for KEWR Southwest VFR Operating Plan are compared with Airport Capacity Benchmark Report 2004 data to examine the reasonableness of the results. AvTerminal is applied with the 2004 conventional flight demand set for this comparison. Figure 11 graphically presents the resulting AvTerminal and corresponding FAA Benchmark KEWR runway system acceptance rates.

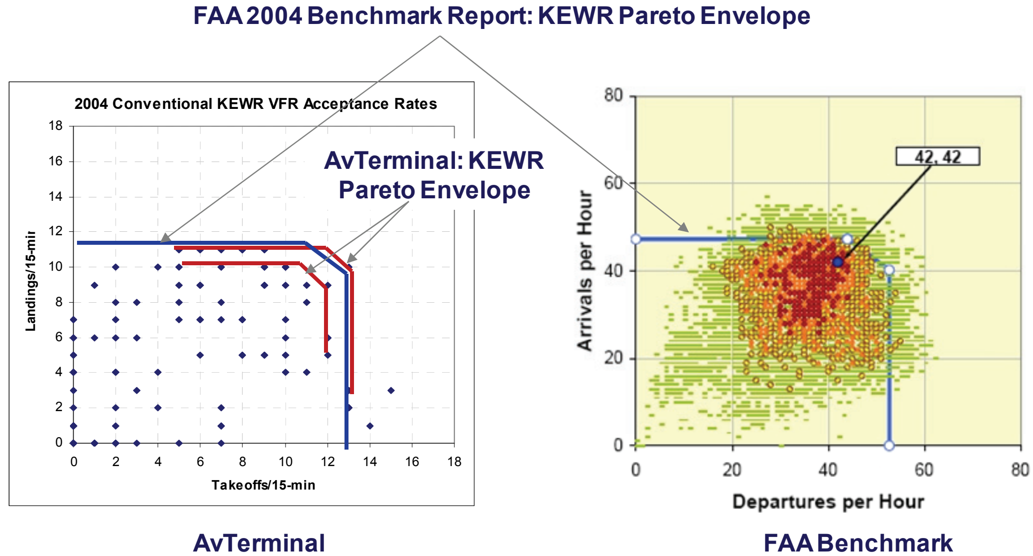


Figure 11. AvTerminal and FAA 2004 benchmark comparison.

Figure 11 shows the distribution of joint landing/takeoff counts by 15-minute intervals resulting from AvTerminal, and a pair of Pareto envelopes (red lines) at the maximum counts. The envelop pair is meant to bracket the maximum throughput, where the horizontal bracket estimates arrival acceptance rate, the vertical bracket estimates departure acceptance rate, and the sloped bracket estimates total acceptance rate. The shape of the AvTerminal Pareto envelope is nearly identical to that (blue lines) of the FAA Airport Capacity Benchmark Report 2004 (ref. 5), although both are independently derived. The Benchmark Pareto envelop is superimposed on the AvTerminal graph, illustrating their near coincidence.

Table 6 tabulations compare the estimated acceptance rates, showing mutual compatibility. In addition to these graphical data, the Benchmark Report estimates the KWER Southwest VFR optimum rate to be 84–92/hour, practically the same as AvTerminal total rate (88–92/hour).

These AvTerminal acceptance rates are the result of the integrated modeling of airspace and runway system traffic loading, constraints, and interactions. AvTerminal appears to be a reasonable estimator of airspace and airport system traffic handling capability based on its consistency with FAA Benchmark capacity data.

TABLE 6. AVTERMINAL AND FAA 2004 BENCHMARK ACCEPTANCE RATES

Capacity Category	AvTeminal flights/15 min	AvTeminal flights/hour	FAA Benchmark flights/hour
Arrival Acceptance Rate (AAR)	10–11	40–44	~46
Departure Acceptance Rate (DAR)	12–13	48–52	~52
Total Acceptance Rate (TAR)	22–23	88–92	~91

5 NEWARK MODELING RESULTS

AvTerminal TFM modeling, as applied in this preliminary study, assumes a CESTOL future operating environment in which advanced air traffic management (ATM) and flight operating systems provide very high-fidelity trajectory prediction and control capabilities. These capabilities are based on sophisticated communication, navigation and surveillance (CNS) technologies. Assumptions include application of mature ATM automation with time-based metering and DCIA, area navigation (RNAV), required navigation performance (RNP), accurate meteorological prediction, air-ground data link communication, automatic dependent surveillance-broadcast (ADS-B) and KEWR gate, taxiway, parking, and other airport improvements that remove airport surface impediments to runway traffic throughput. Although not a factor in this study, CESTOL is envisioned to incorporate fuel-efficient, low-noise and low-emission technologies. The AvTerminal modeling assumes TFM-planned fix crossing and runway operation times are strictly adhered to with advanced ATM time-based metering procedures (i.e., ATC operations implement TFM plans). The modeling further assumes zero wind, no weather-related and off-nominal restrictions, and no surface taxi and gate movement constraints.

The remainder of this section presents the results of the AvTerminal modeling of the KEWR Southwest VFR basic operation for the 2016 flight demand set, subject to the above assumptions.

5.1 RUNWAY SYSTEM TRAFFIC LOADING

The predicted KEWR February 19, 2016 flight demand schedules for the conventional and CESTOL aircraft are input data to AvTerminal. Figure 12 shows KEWR February 19, 2016 daily arrival and departure traffic demand distributions by successive 15-minute periods for the conventional fleet. These represent scheduled landing and takeoff times. Figure 13 shows the corresponding distribution for the fleet with CESTOL aircraft. The CESTOL distribution is quite similar to that of the conventional traffic, with minor variation. Scheduled departure peaking generally exceeds arrival peaking in morning and afternoon, and arrival peaking dominates thereafter. Departure maximum peaking approaches 25 flights per 15 minutes, and arrival maximum peaking is less, reaching 20 flights per 15 minutes.

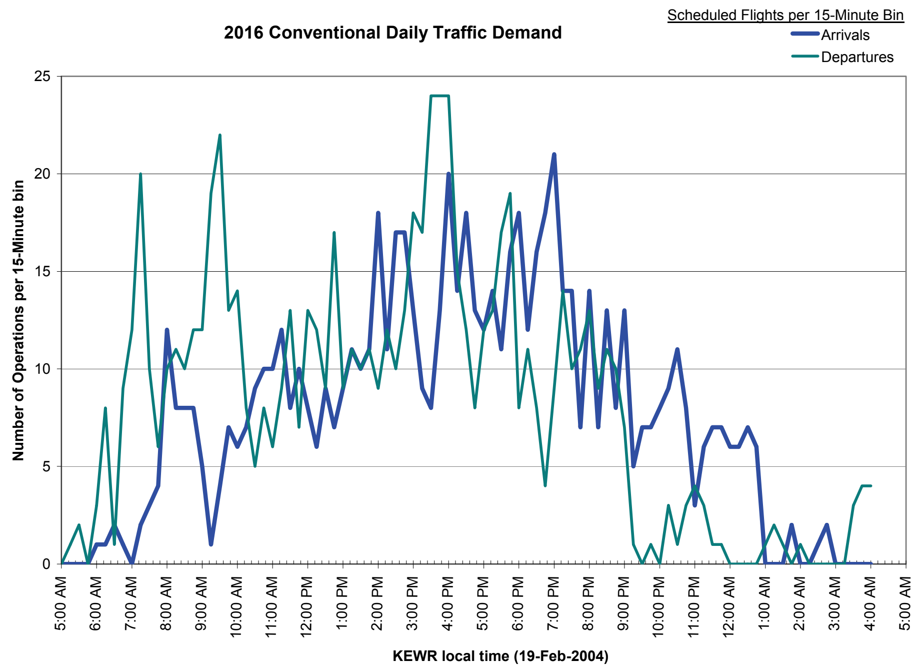


Figure 12. KEWR 2016 conventional daily traffic demand per 15-minute bin.

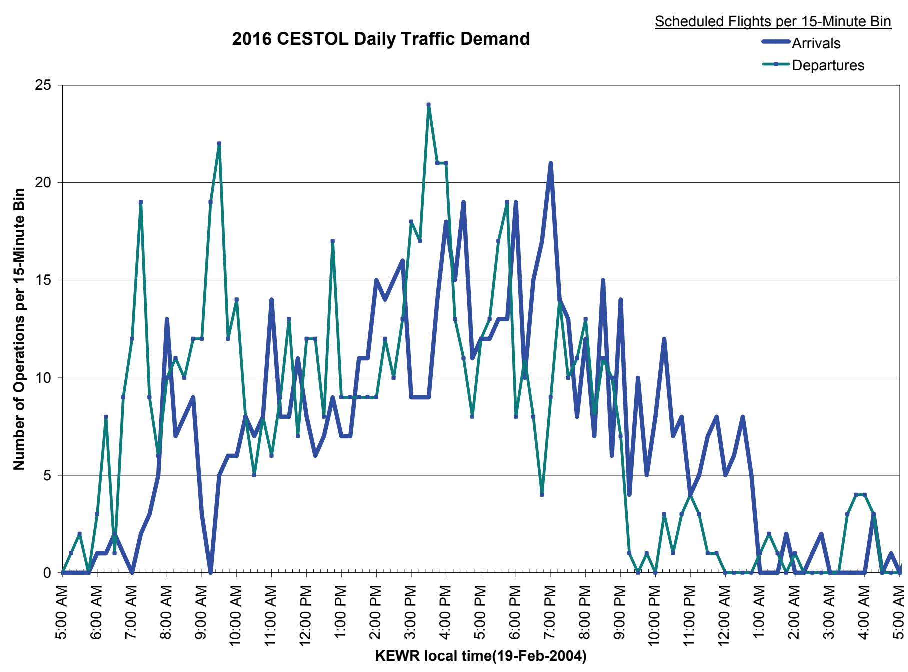


Figure 13. KEWR 2016 CESTOL daily traffic demand per 15-minute bin.

5.2 RUNWAY SYSTEM CAPACITY IMPACTS

Arrival Acceptance Rates—AvTerminal processes the traffic demand and applies delays due to airspace and runway system constraints associated with the KEWR basic Southwest VFR Operating Plan. Figure 14 compares resulting runway system arrival throughputs for conventional versus CESTOL operations. The CESTOL AAR peaks are significantly higher than those of the conventional traffic operation. The CESTOL arrival peaks repeatedly reach or exceed 14 flights/15 minutes (56/hour), while conventional traffic arrival peaks consistently attain 10 flights/15 minutes (40/hour). The conventional traffic profile shows a significant volume of arrivals occurring in night hours later than the CESTOL profile. Since the CESTOL and conventional arrival demands are essentially the same, this lag indicates conventional flights experience more delay than CESTOL flights. These results show the effect of shifting CESTOL arrival traffic to secondary crossing runway 11 with a corresponding reduction of traffic loading on primary runway 22R relative to conventional traffic operations.

Departure Acceptance Rates (DARs)—Figure 15 compares resulting runway system departure throughputs for conventional versus CESTOL operations. The CESTOL and conventional traffic DAR profiles and peaks are essentially similar. The peaks reach or exceed 14 flights/15 minutes (56/hour). These results are consistent with the assumption that CESTOL procedures are the same as conventional operations.

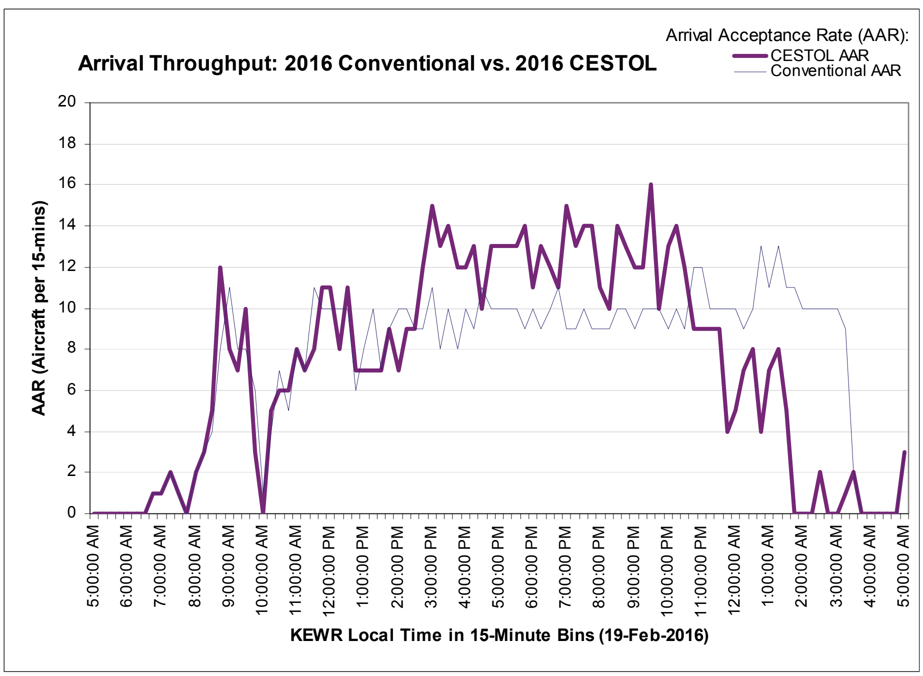


Figure 14. KEWR 2016 conventional vs. CESTOL landings per 15-minute bin.

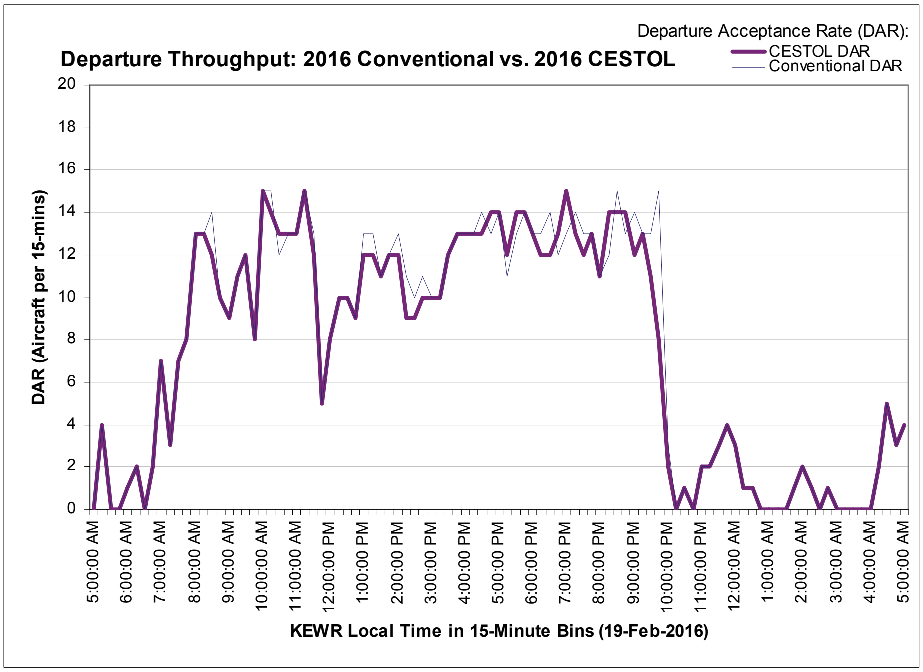


Figure 15. KEWR 2016 conventional vs. CESTOL takeoffs per 15-minute bin.

Arrival-Departure Capacity—Figure 16 uses Pareto envelopes to illustrate the potential improvement in runway system 15-minute acceptance rates due to the introduction of CESTOL aircraft in the KEWR 2016 basic Southwest VFR Operating Plan. Each point on these charts is the paired landing/takeoff count by 15 minutes. The envelopes are drawn around the peak counts representing capacity limits during high volume traffic periods.

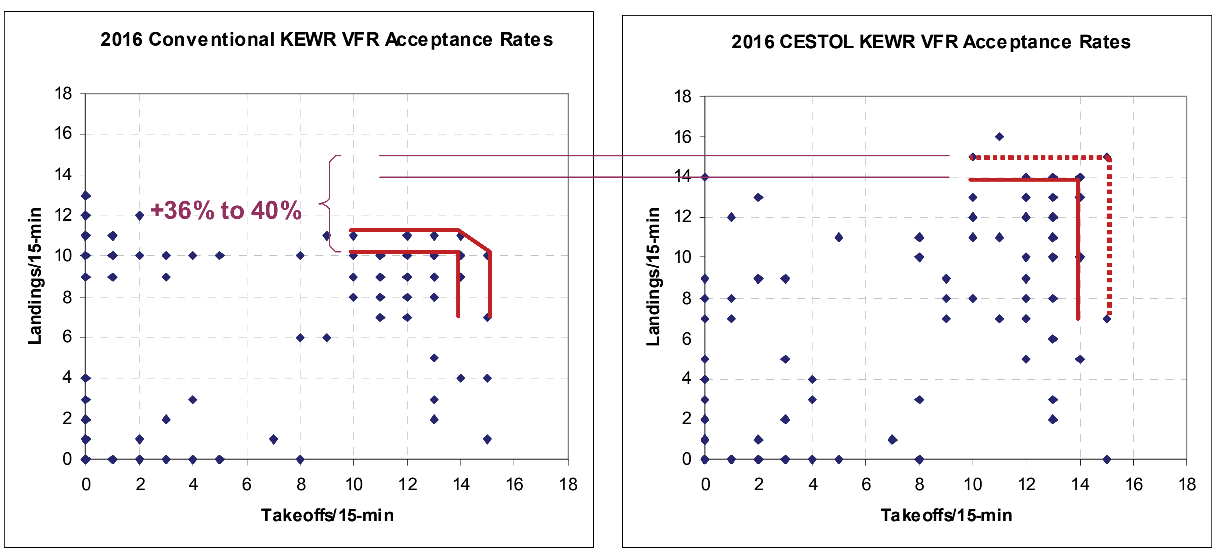


Figure 16. KEWR 2016 conventional vs. CESTOL capacity envelopes.

TABLE 7. KEWR 2016 CONVENTIONAL VS. CESTOL CAPACITY

Capacity Category	Peak Capacity				
	Flights/15 minutes		Flights/hour		CESTOL
	Conventional	CESTOL	Conventional	CESTOL	Gain
Arrival Acceptance Rate (AAR)	10–11	14–15	42	58	38%
Departure Acceptance Rate (DAR)	14–15	14–15	58	58	0%
Total Acceptance Rate (TAR)	24–25	28–30	98	114	16%

The CESTOL maximum arrival acceptance rate shows significant increase relative to conventional rates, and departure rates show no gain, as discussed in the previous paragraphs. Table 7 is a numeric summary of the acceptance rate limit values. Arrival capacity increases by 4 flights/15 minutes (16/hour), which is major improvement (38%) due to CESTOL relative to conventional operations. Maximum total acceptance rate increases by 16%, moderated due to the lack of departure capacity gain.

5.3 DELAY IMPACTS

Airspace capacity is constrained by runway system acceptance rates, TFM restrictions, spacing rules, and weather. Due to these and related operational factors and traffic loading patterns, airspace throughput varies spatially and temporally, requiring voluminous data for quantitative description (e.g., acceptance rate by fix by altitude by time). However, daily delay is a useful and convenient metric to quantitatively describe operating efficiency and is used herein.

AvTerminal records planned delay imposed to resolve network merging, diverging, and runway system operations. Table 8 summarizes the airspace and runway system component of the system delay resulting from modeling of KEWR Southwest VFR basic operation. These data describe the special distribution of daily delay. Delay data entries are associated with a fix according to en route airspace, terminal airspace, or runway system domains.

En route airspace delays at the outer boundary fixes are those due to spacing constraints on aircraft that cross a fix at a common altitude at entry to the study area (i.e., the 250-nmi radius). AvTerminal permits aircraft overtakes between the outer boundary fixes, and arrival and departure fixes on the Air Route Traffic Control Center (ARTCC)-TRACON boundary, but applies spacing rules at this boundary. In this preliminary study, only KEWR traffic is modeled, and interactions with other en route traffic are not factored into the delay analysis. Hence, en route airspace delays in table 8 are constrained only by KEWR-aircraft spacing requirements and are not significant.

En route airspace delays at the terminal arrival fixes are due to the 5-nmi spacing constraint on inbound aircraft within a common traffic stream (conventional or CESTOL), regardless of fix crossing altitude. In this study, the AvTerminal modeling configuration does not apply spacing constraints to aircraft in different arrival streams, provided 1,000-ft. altitude separation is maintained. En route airspace delays at terminal departure fixes are due to the 15-nmi TFM restriction on outbound aircraft regardless of departure traffic streams or crossing altitude. Arrival fixes (SWEET, DYLIN) serving inbounds from the west and southwest have the most en route delay to conventional operations in table 8 due to 5-nmi spacing, and 2 departure fixes (ELIOT, WHITE) serving outbound flights to the west and south have the most delay due to 15-nmi TFM restriction.

AvTerminal applies a 3-nmi spacing constraint in terminal airspace to aircraft within a common traffic stream (conventional or CESTOL) regardless of altitude. Terminal airspace delays at a fix are those needed for merging, diverging, and in-trail operations, and represent delays and maneuvers imposed to maintain spacing and preclude overtakes along the trajectory segment downstream of the subject fix. Terminal airspace delay data entries in table 8 for arrival fixes represent delays required to preserve spacing at the fix and after the aircraft enters the terminal airspace along the segment downstream of the arrival fix. These delays are in addition to any delays cascading from further downstream segments as modeled by the look-ahead congestion analysis logic of the AvTerminal. AvTerminal increments delay as aircraft are processed through the network of merge (and diverging) operations. Arrival fixes (SWEET, DYLIN, SHAFF, RBV) serving inbounds from the west, south, and north show major terminal airspace delay to conventional operations in table 8 due to terminal airspace congestion.

TABLE 8. KEWR 2016 DAILY DELAY BY FIX

	Conventional Delay (minutes)				CESTOL Delay (minutes)			
Fix_Name	En Route	Terminal	Runway	Total	En Route	Terminal	Runway	Total
OUTER_BOUNDARY								
All Outer Bndry fixes	22	0	0	22	20	0	0	20
ARRIVAL								
SWEET_J	66	18568	0	18634	18	125	0	143
DYLIN_J	70	16087	0	16157	21	151	0	172
SHAFF	16	6293	0	6308	3	10	0	13
RBV_J	1	333	0	334	0	1	0	1
Other fixes	0	0	0	0	32	83	0	114
Arrival Fix Total	153	41281	0	41434	73	371	0	444
TERMINAL MERGE								
KEWRA80	0	830	0	830	0	132	0	132
HOKIR	0	704	0	704	0	129	0	129
METRO	0	376	0	376	0	14	0	14
KEWRA30	0	1	0	1	0	130	0	130
Other fixes	0	0	0	0	0	9	0	9
Terminal Merge Fix Tot	0	1910	0	1910	0	414	0	414
TERMINAL_DIVERGE								
All TD fixes	0	59	0	59	0	52	0	52
DEPARTURE								
ELIOT	267	4	30	302	259	4	31	294
WHITE	90	0	0	90	81	0	0	81
Other Fixes	185	17	6	208	168	17	6	192
Departure Fix Total	542	22	36	600	509	22	36	567
FINAL_APPROACH								
RWY_22L_FAF	0	264	0	264	0	93	0	93
RWY_11_FAF	0	0	0	0	0	65	0	65
Final Approach Fix Tot	0	264	0	264	0	158	0	158
RUNWAY								
22L	0	0	12873	12873	0		4134	4134
22R	0	0	11615	11615	0	0	8670	8670
11	0	0	8	8	0	0	2701	2701
Runway Total	0	0	24496	24496	0	0	15505	15505
Total	716	43536	24532	68784	602	1017	15541	17160
Percent of Total	1%	63%	36%	100%	4%	6%	91%	100%

Delays at terminal airspace merge fixes within the terminal boundary have the same interpretation as those for arrival fixes (i.e., delays are dependent on downstream network congestion as well as fix crossing constraints), as are delays at terminal airspace diverge fixes. Terminal merge fixes (KEWRA80, HOKIR, METRO) receiving inbound traffic from arrival fixes to the west, south, and north show significant terminal airspace delay to conventional operations in table 8 due to network merge congestion.

Runway system delays are the result of application of the minimum separation time matrix and departure fix restrictions as described in the preceding paragraphs addressing capacity impacts. The primary runways (22R, 22L) serving takeoff and landings show major delay to conventional operations in table 8 due to the runway system constraints.

Table 9 summarizes and compares conventional and CESTOL delays by fix type. With conventional operations, terminal airspace constraints generate much of the total delay (63%), which is near double that of runway delay (36%). The majority of conventional traffic delay accrues to arrival fix operations (which include downstream overtake and merge resolutions). CESTOL operations eliminate much of the terminal airspace delay, resulting in only 6% of total CESTOL delay due to terminal airspace constraints. This results in a major reduction in total delay (51,625 minutes rounded off) when comparing CESTOL versus conventional operations (17,160 versus 68,784 minutes of total delay).

Table 10 summarizes CESTOL delay reduction results by fix type, showing significant reductions due to CESTOL. The improved terminal airspace operations due to CESTOL aircraft operations account for 82% the CESTOL total delay savings.

Table 11 consolidates the KEWR daily delay reduction data according to airspace and runway system domains. By introducing CESTOL aircraft into the system, airspace delays are reduced by 96%, and runway system delays are reduced by 37%. The combined effect is a 75% reduction in total daily delay just by the introduction of CESTOL-capable aircraft.

TABLE 9. KEWR 2016 DAILY DELAY BY FIX TYPE

	Conventional Delay (minutes)				CESTOL Delay (minutes)			
Fix Type	En Route	Terminal	Runway	Total	En Route	Terminal	Runway	Total
All Outer Boundary Fix	22	0	0	22	20	0	0	20
Arrival Fix	153	41281	0	41434	73	371	0	444
Terminal Merge Fix	0	1910	0	1910	0	414	0	414
Terminal Departure Fix	0	59	0	59	0	52	0	52
Departure Fix	542	22	36	600	509	22	36	567
Final Approach Fix	0	264	0	264	0	158	0	158
Runway System	0	0	24496	24496	0	0	15505	15505
Total	716	43536	24532	68784	602	1017	15541	17160
Percent of Total	1%	63%	36%	100%	4%	6%	91%	100%

TABLE 10. KEWR 2016 DAILY DELAY REDUCTION BY FIX TYPE

Fix Type	CESTOL Delay Reduction (minutes) En Route	Terminal	Runway	Total	Percent
All Outer Boundary Fix	2	0	0	2	0%
Arrival Fix	80	40910	0	40989	79%
Terminal Merge Fix	0	1496	0	1496	3%
Termina Departure Fix	0	6	0	6	0%
Departure Fix	33	0	0	33	0%
Final Approach Fix	0	106	0	106	0%
Runway System	0	0	8991	8991	17%
Total	115	42519	8991	51625	100%
	0%	82%	17%	100%	

TABLE 11. KEWR 2016 DAILY DELAY REDUCTION BY DOMAIN

Domain	CESTOL Delay Reduction (minutes)				CESTOL Delay Reduction Distribution(%)			
	En Route	Terminal	Runway	Total	En Route	Terminal	Runway	Total
Airspace	115	42519	0	42633	16%	98%	0%	96%
Runway System	0	0	8991	8991	0%	0%	37%	37%
All	115	42519	8991	51625	16%	98%	37%	75%

Figure 17 graphically compares delay distribution across en route airspace, terminal airspace, and runway system domains for February 19, 2016 conventional and CESTOL traffic operations.

Figure 18 compares KEWR runway system daily arrival delays (projected for February 19, 2016) for conventional versus CESTOL operations, and shows major delay reduction with CESTOL operations.

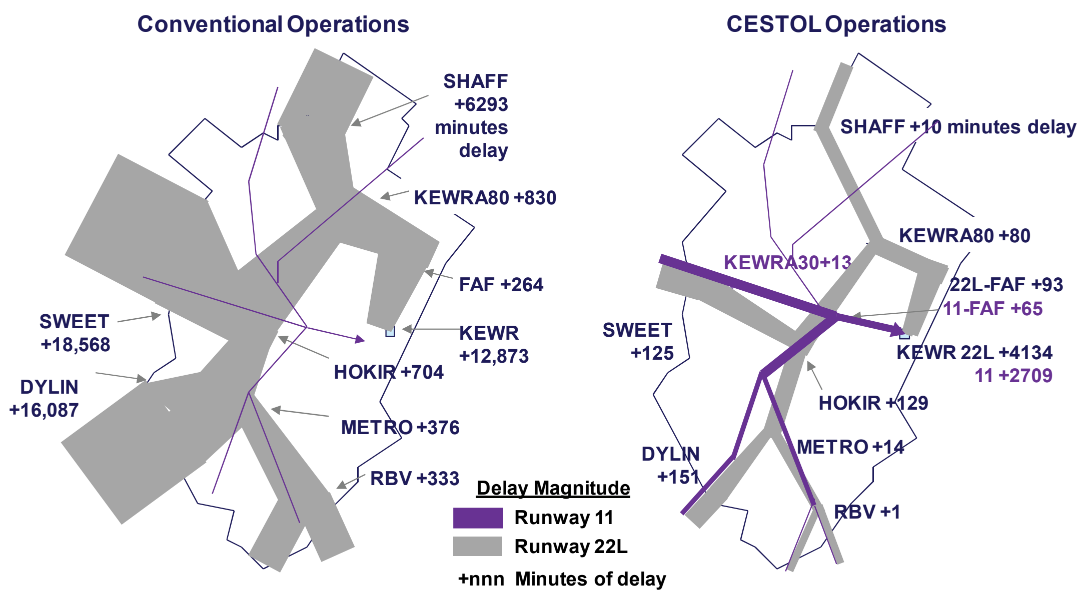


Figure 17. KEWR 2016 conventional and CESTOL delay spatial distribution.

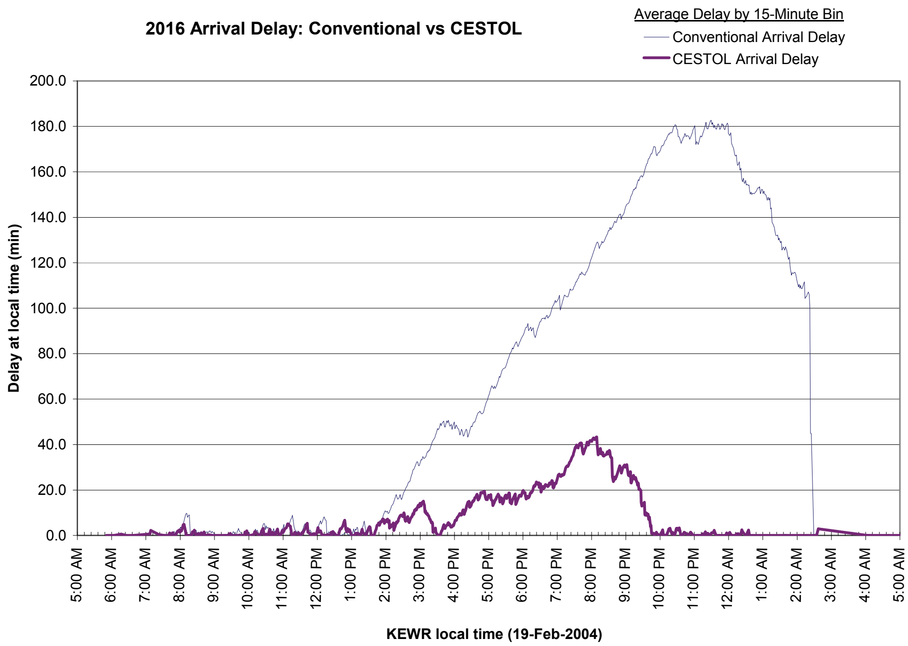


Figure 18. KEWR 2016 conventional vs. CESTOL landing delay per 15-minute bin.

Figure 19 compares runway system daily departure delays for conventional versus CESTOL operations, and shows a minor delay change with CESTOL operations. This minor change is due to CESTOL aircraft using the same departure runway as conventional aircraft. If another runway could be used for CESTOL aircraft takeoff, the delay would be further reduced, or possibly eliminated if the outbound terminal airspace could handle it.

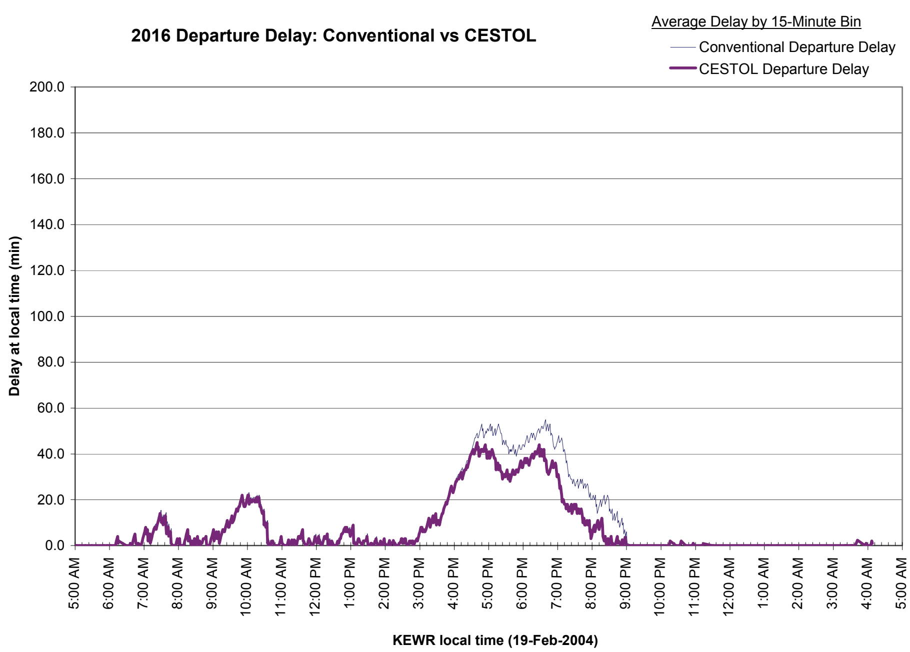


Figure 19. KEWR 2016 conventional vs. CESTOL takeoff delay per 15-minute bin.

6 OEP AIRPORTS CESTOL FLIGHT ASSIGNMENTS

For ACES modeling of NAS-wide CESTOL operations, a subset of conventional aircraft types serving the OEP airports in the ACES February 19, 2016 flight data set were converted to CESTOL aircraft (see Appendix A). Table 12 lists the OEP 34 domestic airports (i.e., exclusive of Honolulu International, KHNL) that are the subjects of this study.

The following sections describe the aircraft type conversion process used to define the CESTOL fleet composition serving the OEP airports. The factors used to define the CESTOL fleet composition were flight distance, aircraft seat capacity, and runway length, without regard to business case formulations.

The conversion process converts eligible commercial passenger flights in the conventional aircraft February 19, 2016 daily flight data set to CESTOL if the flight complies with the aircraft seat size limit, the 2,000-nmi flight distance, and the 2,000-ft. arrival and departure airport runway length limits (per table 1). The runway length limit is not a constraining factor because NAS airports serving the candidate commercial flights in the ACES 2016 daily flight data set have runways at least 2,000 ft. long.

TABLE 12. OEP DOMESTIC AIRPORTS

- Atlanta Hartsfield-Jackson International (KATL)
- Boston Logan International (KBOS)
- Baltimore-Washington International (KBWI)
- Cleveland Hopkins International (KCLE)
- Charlotte/Douglas International (KCLT)
- Cincinnati/Northern Kentucky International (KCVG)
- Ronald Reagan Washington National (KDCA)
- Denver International (KDEN)
- Dallas/Fort Worth International (KDFW)
- Detroit Metropolitan Wayne County (KDTW)
- Newark Liberty International (KEWR)
- Fort Lauderdale-Hollywood International (KFLL)
- Washington Dulles International (KIAD)
- Houston George Bush Intercontinental (KIAH)
- New York John F. Kennedy International (KJFK)
- Las Vegas McCarran International (KLAS)
- Los Angeles International (KLAX)
- New York LaGuardia (KLGA)
- Orlando International (KMCO)
- Chicago Midway International (KMDW)
- Memphis International (KMEM)
- Miami International (KMIA)
- Minneapolis-St Paul International (KMSP)
- Chicago O'Hare International (KORD)
- Portland International (KPDX)
- Philadelphia International (KPHL)
- Phoenix Sky Harbor International (KPHX)
- Greater Pittsburgh International (KPIT)
- San Diego International-Lindbergh Field (KSAN)
- Seattle-Tacoma International (KSEA)
- San Francisco International (KSFO)
- Salt Lake City International (KSLC)
- Lambert-St. Louis International (KSTL)
- Tampa International (KTPA)

6.1 FLIGHT DISTANCE CONVERSION FACTORS

Table 13 describes the distribution of daily flights among origin-destination distance ranges by OEP airport. Most OEP airports have at least 90% of their flights within the 2,000-nmi qualification range for conversion to CESTOL aircraft. Only four OEP airports (Newark, New York JFK, Los Angeles, and San Francisco) have less than 90% of their flights qualifying for conversion to CESTOL aircraft based on flight distance constraint. This table also shows the flight range distribution among all NAS airports for information purpose.

TABLE 13. 2016 CONVENTIONAL AIRCRAFT FLIGHT DISTANCE DISTRIBUTION

		Distribution of Airport Arrival Flights by Origin-Destination Distance (%)						
OEP Arrival Airport	Airport Id	0 - 500	501 - 1000	1001 - 1500	1501 - 2000	2001 - 2500	> 2500	Total
Atlanta	KATL	54%	36%	4%	5%	0%	1%	100%
Boston	KBOS	55%	24%	11%	3%	5%	2%	100%
Baltimore	KBWI	57%	29%	9%	4%	1%	1%	100%
Cleveland	KCLE	79%	15%	2%	4%	0%	0%	100%
Charlotte	KCLT	74%	22%	2%	2%	0%	0%	100%
Cincinnati	KCVG	70%	24%	3%	2%	0%	1%	100%
Washington DCA	KDCA	67%	27%	5%	1%	0%	0%	100%
Denver	KDEN	34%	51%	14%	1%	0%	0%	100%
Dallas-Fort Worth	KDFW	37%	41%	20%	1%	0%	1%	100%
Detroit	KDTW	67%	24%	3%	4%	0%	1%	100%
Newark	KEWR	38%	36%	9%	5%	7%	5%	100%
Fort Lauderdale-Hollywood	KFLL	34%	49%	14%	2%	2%	0%	100%
Washington IAD	KIAD	64%	17%	5%	6%	4%	4%	100%
Houston	KIAH	37%	41%	18%	2%	0%	1%	100%
New York JFK	KJFK	20%	28%	8%	9%	17%	17%	100%
Las Vegas	KLAS	50%	19%	15%	15%	1%	0%	100%
Los Angeles	KLAX	48%	13%	11%	14%	10%	3%	100%
New York LGA	KLGA	60%	34%	6%	0%	0%	0%	100%
Orlando	KMCO	34%	55%	6%	3%	1%	1%	100%
Chicago MDW	KMDW	58%	29%	7%	6%	0%	0%	100%
Memphis	KMEM	60%	29%	7%	3%	0%	1%	100%
Miami	KMIA	28%	42%	19%	2%	3%	6%	100%
Minneapolis-St. Paul	KMSP	48%	35%	16%	0%	0%	0%	100%
Chicago ORD	KORD	40%	41%	10%	6%	0%	3%	100%
Portland	KPDX	67%	22%	4%	5%	2%	0%	100%
Philadelphia	KPHL	58%	28%	6%	3%	3%	2%	100%
Phoenix	KPHX	45%	30%	15%	10%	0%	0%	100%
Pittsburgh	KPIT	84%	11%	1%	4%	0%	0%	100%
San Diego	KSAN	61%	12%	14%	8%	5%	0%	100%
Seattle	KSEA	41%	36%	9%	7%	6%	1%	100%
San Francisco	KSFO	47%	15%	7%	14%	14%	3%	100%
Salt Lake City	KSLC	57%	29%	9%	4%	0%	0%	100%
St. Louis	KSTL	60%	31%	8%	1%	0%	0%	100%
Tampa	KTPA	50%	42%	6%	2%	0%	0%	100%
All OEP Airports	Total	51%	31%	9%	5%	2%	2%	100%
All NAS Airports	Total	64%	23%	7%	3%	1%	2%	100%

6.2 SEAT SIZE CONVERSION FACTORS

The updated guidelines (see table 1) apply a 50-seat lower limit to the conversion of conventional aircraft to CESTOL, and a 120- to130-seat range as the upper limit. This upper limit range supersedes the initial 120-seat limit applied in the earlier AvTerminal modeling of Newark Airport operations. Table 3 identifies the NAS-wide conventional aircraft types that are within the 50- to 120-seat eligibility range for CESTOL replacement. Table 14 identifies 4 conventional aircraft types that are in the 121–130 seat range inclusively. These aircraft types are eligible for CESTOL conversion in addition to those in the 50–120 seat range, all in the ACES 2016 daily flight data set.

TABLE 14. NAS-WIDE 121–130 SEAT CONVENTIONAL AIRCRAFT CANDIDATES FOR CESTOL REPLACEMENT

Aircraft Type	Engine Type	Number of Seats
B737	J	126
B733	J	126
DC9	J	125
A319	J	124

Seat size data sources: references 12 and 13.

Table 15 describes the distribution of daily flights among seat size ranges by OEP airport. The proportion of conventional flights having seat sizes qualifying for CESTOL varies significantly among the OEP airports, but most airports have at least 25% of their flights qualifying for replacement based on seat size. However, New York JFK has less than 10% qualifying, and Fort Lauderdale-Hollywood and Minneapolis-St. Paul have less than 25% of their conventional aircraft fleet qualifying for CESTOL replacement based on 50–130 seat size constraints. This table also shows the conventional aircraft seat size distribution among all NAS airports for information purpose.

6.3 CESTOL FLEET SIZE ESTIMATE

Table 16 shows the results of converting conventional aircraft in the ACES NAS-wide February 19, 2016 daily flight data to CESTOL aircraft where eligible to meet seat size, flight distance, and runway length constraints at OEP airports only. This table compares the CESTOL distributions by seat size for both the 50–120 and 50–130 seat qualification ranges. Expanding the upper seat limit from 120 to 130 seats increases the CESTOL fleet proportion of the total traffic at all OEP airports from 23% to 35%, a gain of 52%. The relatively high volume of flights (see Appendix C) in the 121–130 seat range has a significant influence on the likelihood of replacing conventional aircraft with CESTOL aircraft. The 50–130 seat range in the ACES modeling of CESTOL impacts on NAS-wide operations, described in the next section of this report, was used to account for this influence.

With reference to table 16, most of the 34 OEP airports have at least 25% of their flights qualifying for replacement. The nine exceptions are Boston, Fort Lauderdale-Hollywood, New York, Las Vegas, Los Angeles, Miami, Portland, Seattle, and San Francisco. This table also shows the distribution of traffic among OEP airports and the seat size comparison among all NAS airports for information purposes.

TABLE 15. 2016 CONVENTIONAL AIRCRAFT SEAT SIZE DISTRIBUTION

		2016 Distribution of Conventional Aircraft OEP Airport Arrival Flights by Aircraft Seat Size				
OEP Arrival Airport	Airport Id	0 - 49	50 - 120	121 - 130	> 130	Total
Atlanta	KATL	9%	44%	2%	45%	100%
Boston	KBOS	35%	12%	17%	35%	100%
Baltimore	KBWI	24%	12%	45%	19%	100%
Cleveland	KCLE	32%	44%	11%	13%	100%
Charlotte	KCLT	30%	25%	22%	24%	100%
Cincinnati	KCVG	52%	27%	0%	20%	100%
Washington DCA	KDCA	24%	34%	23%	19%	100%
Denver	KDEN	18%	26%	29%	27%	100%
Dallas-Fort Worth	KDFW	15%	27%	4%	54%	100%
Detroit	KDTW	16%	38%	12%	33%	100%
Newark	KEWR	11%	40%	11%	38%	100%
Fort Lauderdale-Hollywood	KFLL	31%	8%	13%	49%	100%
Washington IAD	KIAD	41%	31%	4%	23%	100%
Houston	KIAH	12%	43%	15%	30%	100%
New York JFK	KJFK	13%	5%	2%	80%	100%
Las Vegas	KLAS	21%	5%	35%	39%	100%
Los Angeles	KLAX	22%	11%	21%	46%	100%
New York LGA	KLGA	33%	21%	15%	30%	100%
Orlando	KMCO	22%	11%	17%	50%	100%
Chicago MDW	KMDW	42%	8%	28%	22%	100%
Memphis	KMEM	29%	28%	4%	39%	100%
Miami	KMIA	22%	9%	7%	62%	100%
Minneapolis-St. Paul	KMSP	21%	35%	12%	33%	100%
Chicago ORD	KORD	8%	45%	12%	35%	100%
Portland	KPDX	48%	13%	19%	21%	100%
Philadelphia	KPHL	29%	25%	19%	28%	100%
Phoenix	KPHX	16%	16%	39%	29%	100%
Pittsburgh	KPIT	50%	22%	11%	17%	100%
San Diego	KSAN	26%	11%	36%	27%	100%
Seattle	KSEA	26%	14%	18%	42%	100%
San Francisco	KSFO	22%	14%	17%	48%	100%
Salt Lake City	KSLC	31%	35%	16%	18%	100%
St. Louis	KSTL	25%	40%	15%	19%	100%
Tampa	KTPA	38%	10%	20%	32%	100%
All OEP Airports	Total	24%	25%	16%	35%	100%
OEP Airports Percent of All NAS Airports	Total	46%	20%	11%	24%	100%

TABLE 16. 2016 CESTOL AIRCRAFT SEAT SIZE DISTRIBUTIONS AND SHARE COMPARISON

OEP Arrival Airport	Airports Share (%) of All OEP Arrivals	Airport Id	CESTOL Share (%) of Each Airport's Arrivals: 50-120 Seat Aircraft	CESTOL Share (%) of Each Airport's Arrivals: 50-130 Seat Aircraft	% Change in CESTOL Share
Atlanta	6%	KATL	43%	45%	2%
Boston	3%	KBOS	11%	22%	11%
Baltimore	2%	KBWI	11%	55%	44%
Cleveland	2%	KCLE	42%	53%	11%
Charlotte	3%	KCLT	23%	45%	22%
Cincinnati	3%	KCVG	26%	27%	0%
Washington DCA	2%	KDCA	33%	56%	23%
Denver	4%	KDEN	22%	45%	23%
Dallas-Fort Worth	5%	KDFW	26%	30%	4%
Detroit	3%	KDTW	37%	50%	12%
Newark	3%	KEWR	37%	47%	10%
Fort Lauderdale-Hollywood	2%	KFLL	7%	20%	13%
Washington IAD	3%	KIAD	29%	32%	3%
Houston	4%	KIAH	41%	56%	15%
New York JFK	2%	KJFK	4%	5%	1%
Las Vegas	4%	KLAS	3%	19%	16%
Los Angeles	4%	KLAX	4%	14%	9%
New York LGA	2%	KLGA	20%	30%	10%
Orlando	3%	KMCO	11%	27%	17%
Chicago MDW	2%	KMDW	7%	35%	28%
Memphis	3%	KMEM	26%	30%	4%
Miami	3%	KMIA	9%	16%	7%
Minneapolis-St. Paul	4%	KMSP	34%	46%	12%
Chicago ORD	6%	KORD	44%	56%	12%
Portland	2%	KPDX	3%	9%	6%
Philadelphia	4%	KPHL	23%	40%	17%
Phoenix	4%	KPHX	7%	31%	23%
Pittsburgh	2%	KPIT	22%	33%	11%
San Diego	1%	KSAN	3%	23%	20%
Seattle	2%	KSEA	5%	11%	6%
San Francisco	2%	KSFO	6%	11%	6%
Salt Lake City	2%	KSLC	18%	27%	9%
St. Louis	2%	KSTL	39%	55%	16%
Tampa	2%	KTPA	9%	29%	20%
All OEP Airports	100%		23%	35%	12%
All NAS Airports			16%	25%	8%

7 ACES NAS-WIDE MODELING

The ACES model described in Section 1.4 was used to conduct a first-cut investigation of the potential impact of CESTOL on nationwide delay. The ACES application analyzes the sensitivity of delay to CESTOL-based potential capacity improvement where airport acceptance rates represent capacity. The approach assigns ACES runway system VFR capacity values to the 34 domestic OEP airports based on extrapolations of the Newark Airport estimated capacity gains.

7.1 ACES OEP AIRPORT CAPACITIES

Table 17 lists the arrival, departure, and total acceptance rates associated with conventional aircraft operations for each OEP airport for the 2016 timeframe. These AAR, DAR, and TAR values are the FAA Benchmark best rates for optimum (i.e., VFR) runway configuration use. These rates[2] represent future capacities corresponding to technological and procedural improvements planned for each OEP airport based on the FAA Airport Capacity Benchmark 2004 Report (ref. 5).

TABLE 17. CONVENTIONAL AIRCRAFT 2016 OEP AIRPORT CAPACITIES

		Conventional Aircraft-Only Acceptance Rate (aircraft/hour)		
Airport	Airport Id	Departure	Arrival	Total
Atlanta	KATL	127	125	243
Boston	KBOS	73	76	132
Baltimore	KBWI	61	63	120
Cleveland	KCLE	66	63	115
Charlotte	KCLT	75	72	131
Cincinnati	KCVG	107	118	176
Washington DCA	KDCA	48	44	87
Denver	KDEN	141	159	281
Dallas-Fort Worth	KDFW	152	160	303
Detroit	KDTW	101	130	189
Newark	KEWR	55	49	93
Fort Lauderdale-Hollywood	KFLL	36	43	62
Washington IAD	KIAD	110	90	174
Houston	KIAH	162	116	231
New York JFK	KJFK	54	55	87
Las Vegas	KLAS	57	74	113
Los Angeles	KLAX	101	91	173
New York LGA	KLGA	46	43	85
Orlando	KMCO	121	156	221
Chicago MDW	KMDW	40	36	71
Memphis	KMEM	106	121	191
Miami	KMIA	88	97	154
Minneapolis-St. Paul	KMSP	95	117	167
Chicago ORD	KORD	141	111	200
Portland	KPDX	68	81	120
Philadelphia	KPHL	66	66	116
Phoenix	KPHX	75	86	150
Pittsburgh	KPIT	101	84	160
San Diego	KSAN	35	40	58
Seattle	KSEA	63	63	102
San Francisco	KSFO	64	63	114
Salt Lake City	KSLC	88	93	160
St. Louis	KSTL	89	90	159
Tampa	KTPA	61	70	105

[2]Total rate source: FAA Airport Capacity Benchmark 2004 Report (ref. 5). Arrival/Departure distribution source: LMI, “LMINET_102AptCapacity_OEP_Baseline_July07.xls”

The potential for improving capacity for each OEP airport is estimated by assessing the capability of each airport to take advantage of CESTOL operations. Our assessments examine runway system configurations, airport operating alternatives, and potential CESTOL traffic loadings. The FAA Benchmark optimal acceptance rates (per table 17) provide the baseline for extrapolating capacity impacts due to CESTOL. The extrapolations estimate the relative extent to which the AvTerminal-derived KEWR capacity gains were applicable to each OEP airport as follows.

Available information (refs. 5, 16, and 17) describing runway system design and operations was examined to determine the existence of "shorter" runways at each airport. These represent runways that could be used for CESTOL operations to alleviate traffic loadings on other runways used by conventional jet aircraft. As a general guideline, an airport is considered a candidate for CESTOL-based capacity improvement if an alternative runway has a length of 5,00–6,000 ft. However, longer runways are considered for CESTOL use where local operations are similar to those of KEWR (recall a 6,800-ft. crossing secondary runway is assumed for CESTOL operations at KEWR). Local operational practices and circumstances at each OEP airport were reviewed, and consultations were conducted (ref. 10) with respect to the practicality and potential effectiveness of CESTOL operations. These reviews included consideration of the construction of a new short CESTOL runway where feasible. This process results in the identification of 15 OEP airports (see table 18) as potential subjects for capacity improvement due to CESTOL.

TABLE 18. CAPACITY ASSESSMENT FACTORS AT IMPACTED AIRPORTS

Airport Id	Arrival Runways[1]	Departure Runways[1]	Potential CESTOL Runway Id / Length	CESTOL Arrivals Share[2]
KATL	26R, 27L, 28	26L, 27R, 28	28R (new short runway[3])	45%
KBWI	33L, 33R	28, 33R	33R/5000 ft (props[4])	55%
KCLE	24R, 24L	24R, 24L	28/6017 ft	53%
KDCA	19, 15, 22	19, 15	15/5204 ft; 22/4911 ft (props[4])	56%
KDFW	13R,18R,17L/C	18L, 17R, 13L	13L prop departures[4]	30%
KEWR	4R, 4L	4L	11/6800 ft (props[4])	47%
KFLL	9R, 9L	9R, 9L	9R/5276 ft (props[4]);13/6930 ft	20%
KJFK	31R (& 31L)	31L (& 31R)	22R/11,351 ft	5%
KLGA	22	13	13L (new new runway[3])	30%
KMDW	31C, 31R/L	31C, 22L	31R/5141 ft (small aircraft[4])	35%
KPDX	28R, 28L	28R, 28L	3 or 21/7001 ft	9%
KPHL	27R (26, 35)	27L (35)	26/5000 ft(GA/AirTaxi[4]); 35/5460 ft	40%
KSAN	27	27	27R (new short runway[3])	23%
KSLC	34L, 34R, 35	34L, 34R, 35	32/4892 ft;35(not used by airlines[4])	27%
KTPA	18L, 18R	18R (18L)	27/6999 ft (props[4])	29%

1. Optimum (VFR) configuration; source: FAA Airport Capacity Benchmark 2004 Report.
2. Based on 50–130 seat aircraft, 2000-nmi range, at least 2000-ft runway.
3. KATL 28R is between easterly parts of 28 and 27; KLGA 13L is on marine fill;
KSAN 27R is north of easterly part of 27 (alternative short runway may be on taxiway D).
4. Current procedure.

Table 18 also provides various assessment factors used in estimating OEP airport CESTOL capacity impact, including FAA Benchmark optimal arrival-departure runway configurations at each airport. The table also identifies existing runways that are projected for effective CESTOL operations, as well as a new runway at each of three airports (KATL, KLGA, and KSAN) that would service CESTOL. Each CESTOL runway is assumed to serve takeoffs and landings, which improves both arrival and departure capacity (typically during time-separated inbound and outbound rushes), except at the New York airports (KEWR, KJFK, and KLGA) and Dallas-Fort Worth (KDFW). CESTOL-based capacity gains at the New York airports are limited to arrival operations-only due to local procedures that severely constrain departure fix crossings. At DFW, CESTOL takeoff operations are assumed to increase the use of an existing runway (13L) used for propeller-driven aircraft departures without affecting airport-wide arrival operations.

CESTOL-based capacities at each of the potential capacity-improved OEP airports are extrapolated from the AvTerminal analysis of CESTOL impacts on KEWR arrival, departure, and total acceptance rates. Table 19 tabulates the results, which are graphically presented in figure 20. The AvTerminal-derived KEWR capacity gains per table 7 are AAR: 38%, DAR: 0%, and TAR: 16%. For initial estimation purposes (see left-side columns in table 19), arrival and total capacity gains at a capacity-improved OEP airport are assumed to be the same as that for KEWR (i.e., AAR gain: 38% and TAR gain: 16%), except at Atlanta (KATL) and Dallas-Fort Worth. At KATL, potential gains would be constrained because operations on the relatively large number of runways are less impacted by the one CESTOL runway than at other airports with fewer runways. At KDFW, CESTOL-based gains would be limited to only departure operations. With respect to departure impacts at other airports, the estimated KEWR DAR gain of zero percent results from the severe departure procedure constraints imposed at the New York airports. For the non-New York airports, some form of departure constraints likely would apply, but not necessarily as severe as those of the New York airports. To allow for departure capacity gains at the non-New York airports, such gains are assumed to be half the arrival gains. Hence, a non-New York and non-KATL airport DAR gain is assumed to be 19% for initial estimation purposes.

These initial capacity gain estimates are further adjusted to account for the relative magnitude of CESTOL traffic at each airport. Table 18 lists the projected CESTOL arrival share of the traffic volume of each airport resulting from the conversion of conventional-aircraft-only flights to CESTOL. For the ACES NAS network modeling, the assumption is made that flights by conventional aircraft in the 50- to 130-seat range are eligible for conversion to CESTOL based on the maximum 130-seat-limit criteria in table 1. Because the 130-seat criteria differs from that assumed in the earlier AvTerminal exercise, the initial capacity gain estimates are adjusted by applying a traffic share multiplier factor (see table 19) to account for increased CESTOL traffic. This factor is the ratio of CESTOL traffic share in table 18 to the baseline CESTOL traffic share (i.e., the AvTerminal KEWR 38% share based on the original 50–120 seat conversion range).

TABLE 19. 2016 ACCEPTANCE RATES AT CESTOL CAPACITY-IMPROVED OEP AIRPORTS.

2016 OEP CESTOL with Conventional Aircraft Airport Acceptance Rates

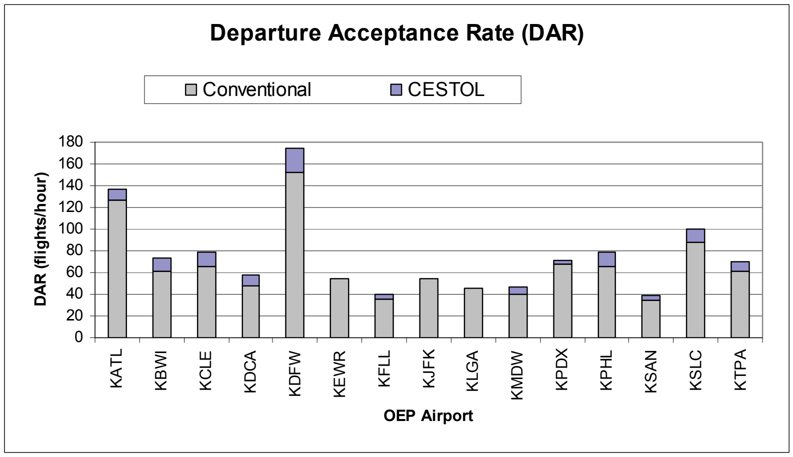
		CESTOL Accept Rate Gain due to Operations Impact[1]			OEP CESTOL Traffic Share		CESTOL Acceptance Rate Gain[2,4]			CESTOL with Conventional Aircraft Acceptance Rates (aircraft/hour)		
Airport	Airport Id	Departure	Arrival	Total	Percent	Factor[3]	Departure	Arrival	Total	Departure	Arrival	Total
Atlanta	KATL	6%	13%	5%	45%	1.18	7%	15%	6%	136	144	258
Baltimore	KBWI	19%	38%	16%	55%	1.45	20%	40%	20%	73	88	144
Cleveland	KCLE	19%	38%	16%	53%	1.39	20%	40%	20%	79	88	138
Washington DCA	KDCA	19%	38%	16%	56%	1.47	20%	40%	20%	58	62	104
Dallas-Fort Worth	KDFW	19%	0%	0%	30%	0.79	15%	0%	0%	175	160	303
Newark	KEWR	0%	38%	16%	47%	1.24	0%	40%	20%	55	69	111
Fort Lauderdale-Hollywood	KFLL	19%	38%	16%	20%	0.53	10%	20%	8%	40	52	67
New York JFK	KJFK	0%	38%	16%	5%	0.13	0%	5%	2%	54	58	89
New York LGA	KLGA	0%	38%	16%	30%	0.79	0%	30%	13%	46	56	96
Chicago MDW	KMDW	19%	38%	16%	35%	0.92	18%	35%	15%	47	49	81
Portland	KPDX	19%	38%	16%	9%	0.24	5%	9%	4%	71	88	125
Philadelphia	KPHL	19%	38%	16%	40%	1.05	20%	40%	17%	79	92	136
San Diego	KSAN	19%	38%	16%	23%	0.61	12%	23%	10%	39	49	64
Salt Lake City	KSLC	19%	38%	16%	27%	0.71	14%	27%	11%	100	118	178
Tampa	KTPA	19%	38%	16%	29%	0.76	15%	29%	12%	70	90	118

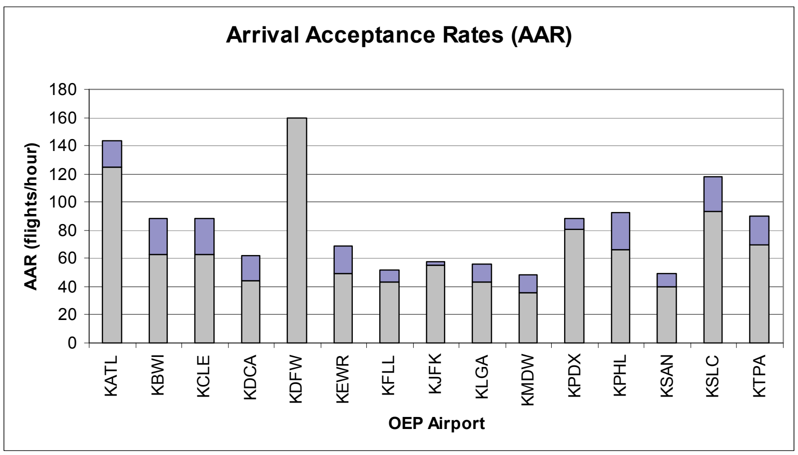
Factors:	1. Base	2. Limit
AAR Gain	38%	40%
DAR Gain	19%	20%
TAR Gain	16%	20%

3. Traffic Share Factor: Ratio of OEP CESTOL share to AvTerminal-based KEWR share (38%) of airport total arrivals

4. Final Rate Gain % = MINIMUM {(Ops Impact Gain * Traffic Share Factor), Limit}

The CESTOL traffic share at some of the OEP airports (e.g., 56% at KDCA) is significantly higher than the KEWR baseline share (38%). Because AvTerminal-like capacity impact modeling results for airports with higher CESTOL traffic share is not available, capacity gains cannot be assumed to necessarily continuously increase at higher levels of CESTOL traffic share growth. A limit to the capacity growth gains was chosen and applied based on the following considerations. Our non-New York airport initial capacity gain estimates due to CESTOL VFR operation approach 40%, and the departure and total capacity gain estimates each approach 20% in table 19 (see left-side columns) prior to adjustment for CESTOL traffic share. For the ACES-based sensitivity analysis, these rates are assumed to represent maximum limits on CESTOL-based acceptance rates achievable at an airport (i.e., AAR gain limit: 40%, DAR gain limit: 20%, and TAR gain limit: 20%). Table 19 (see right-side columns) shows the resulting estimated CESTOL-improved capacities after adjustment for the proportion of CESTOL traffic at each airport.





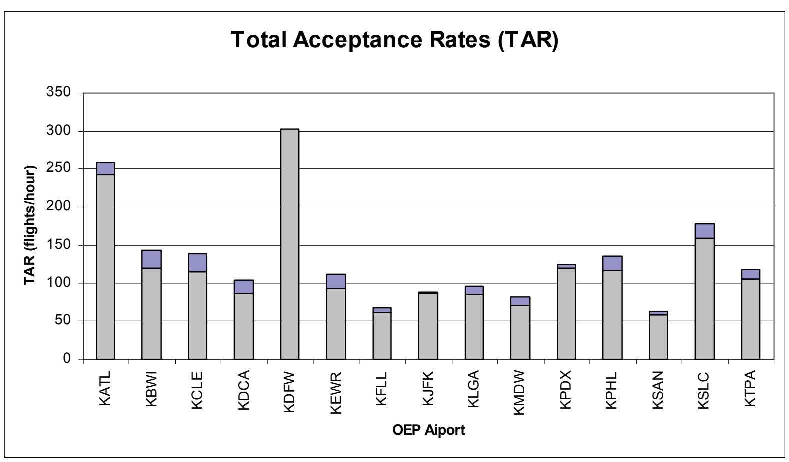


Figure 20. 2016 CESTOL capacity-improved OEP airport acceptance rates.

7.2 ACES MODELING AND RESULTS

ACES is applied using its February 16, 2016 NAS-wide daily flight schedules and each set of VFR acceptance rates (i.e., AAR, DAR, and TAR) separately for conventional-aircraft-only and CESTOL-mixed-with-conventional-aircraft traffic. The CESTOL traffic assumes a 130-seat CESTOL aircraft. For conventional traffic modeling, conventional aircraft acceptance rates are applied to all NAS airports using the OEP airport capacities listed in table 17 and ACES-provided capacity data for the other airports. For CESTOL traffic modeling, the CESTOL-based acceptance rates are applied only to the 15 CESTOL-improved OEP airports per table 19, with conventional acceptance rates applied to all other NAS airports.

Table 20 provides the resulting arrival traffic distribution, average flight daily delay, total delay, and percent CESTOL-based total delay reduction by OEP airport. The NAS-wide airport total delay for the conventional traffic operation is less than that of the OEP airports because traffic congestion is more severe at the major airports than at the others. The arrival traffic count is less for CESTOL than conventional aircraft operations. This difference is due to the conventional-to-CESTOL flight conversion process in which closely-scheduled smaller conventional aircraft flights may be combined into one CESTOL flight.

The table 20 data show significant delay reduction due to CESTOL-based airport capacity gains at the **15 CESTOL capacity-improved OEP airports**. These capacity gains result in total delay reduction of 23.2% across all OEP airports relative to conventional-aircraft-only operations, with a maximum total delay reduction of 64% at KEWR. A total delay reduction of 12.8% is estimated for non-OEP airports, and a 19.6% reduction is estimated for all airports NAS-wide.

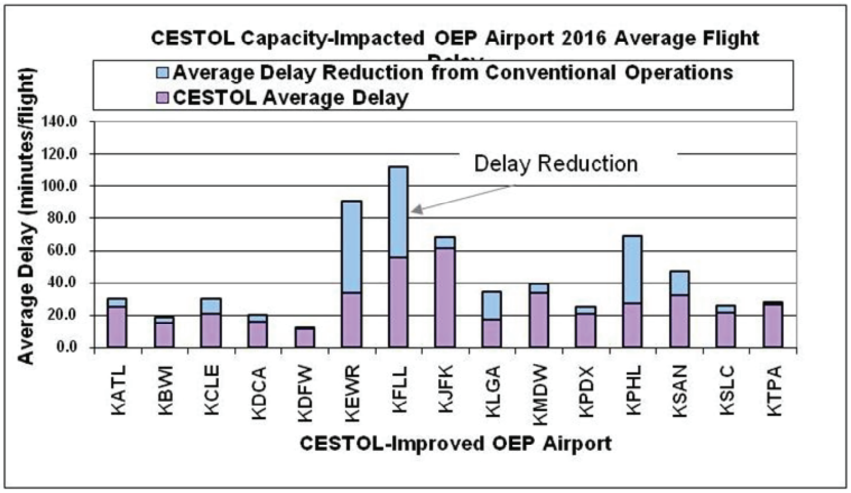
The NAS-wide delay reductions represent gains accrued by the entire airport-airspace system due to network propagation effects. ACES is a network model that generates delays due to airport and airspace congestion and potential conflicts, and propagates delay through the system. The delays tabulated by airport in table 20 are network-induced delays and not necessarily due only to constraints at the specific airport. Conversely, effects of delay reductions at airports (such as those at the CESTOL-improved OEP airports) are propagated to other airports, inducing further delay reductions and flight time savings. The ACES delay data are tabulated at the end of each flight by differencing between the scheduled and the actual terminal gate arrival times. The resulting delay is due to delay imposed by the ACES simulation at any point during a flight. This includes any delay due to departure airport runway system takeoff, airspace spacing conflict and arrival airport runway system landing constraints, and includes predeparture delays propagated by TFM restrictions.

Figure 21 graphically describes CESTOL-induced average flight delay reductions listed in table 20. This figure shows estimated delay reductions separately for CESTOL capacity-improved and non-capacity-improved OEP airports. The delay propagation effects are imbedded in these results such that delay reductions indicated for an airport are the cumulative effects of network and local interactions. The delay reductions shown for the CESTOL capacity-improved airports are attributable to a combination of propagated delay reductions and the local capacity gain impacts of CESTOL operations. Newark, Philadelphia, and Fort Lauderdale-Hollywood airports have the largest delay reductions at 64%, 60.9%, and 50.7%, respectively. The delay reductions shown for the non-capacity-improved OEP airports are associated with network delay reduction propagation initiated by capacity improvements at other OEP airports. Of the non-capacity-improved OEP airports, Chicago O'Hare shows the largest reduction at 21.8%.

TABLE 20. 2016 OEP AIRPORT AND NAS-WIDE FLIGHT DELAY (AT M 0.8 CESTOL CRUISE SPEED)

2016 Conventional Aircraft-only						2016 CESTOL (M.8) with Conventional Aircraft					
Airport	Id	Number of Arrivals	Share of OEP Operations	Average Arrival Delay (min / flt)	Total Arrival Delay (minutes)	Id	Number of Arrivals	Share of OEP Operations	Average Arrival Delay (min / flt)	Total Arrival Delay (minutes)	Total Arrival Delay Reduction Impact
Atlanta*	**KATL**	**1601**	**6.1%**	**29.8**	**47630**	**KATL***	**1543**	**6.0%**	**25.2**	**38857**	**18.4%**
Boston	KBOS	678	2.6%	34.1	23117	KBOS	674	2.6%	27.8	18764	18.8%
Baltimore*	**KBWI**	**542**	**2.1%**	**19.1**	**10331**	**KBWI***	**541**	**2.1%**	**15.6**	**8454**	**18.2%**
Cleveland*	**KCLE**	**492**	**1.9%**	**29.6**	**14542**	**KCLE***	**478**	**1.9%**	**21.1**	**10068**	**30.8%**
Charlotte	KCLT	836	3.2%	40.0	33413	KCLT	795	3.1%	32.8	26084	21.9%
Cincinnati	KCVG	774	3.0%	26.9	20852	KCVG	767	3.0%	24.6	18834	9.7%
Washington DCA*	**KDCA**	**444**	**1.7%**	**20.2**	**8954**	**KDCA***	**441**	**1.7%**	**16.0**	**7040**	**21.4%**
Denver	KDEN	930	3.6%	33.5	31110	KDEN	922	3.6%	30.6	28244	9.2%
Dallas-Fort Worth*	**KDFW**	**1266**	**4.8%**	**12.3**	**15514**	**KDFW***	**1246**	**4.9%**	**11.6**	**14449**	**6.9%**
Detroit	KDTW	918	3.5%	32.6	29952	KDTW	893	3.5%	31.1	27758	7.3%
Newark*	**KEWR**	**811**	**3.1%**	**89.8**	**72827**	**KEWR***	**777**	**3.0%**	**33.7**	**26197**	**64.0%**
Fort Lauderdale-Hollywood*	**KFLL**	**606**	**2.3%**	**111.6**	**67608**	**KFLL***	**598**	**2.3%**	**55.7**	**33331**	**50.7%**
Washington IAD	KIAD	762	2.9%	24.9	18954	KIAD	731	2.8%	21.3	15591	17.7%
Houston	KIAH	1032	3.9%	14.5	14946	KIAH	983	3.8%	12.5	12261	18.0%
New York JFK*	**KJFK**	**572**	**2.2%**	**68.3**	**39088**	**KJFK***	**571**	**2.2%**	**61.4**	**35044**	**10.3%**
Las Vegas	KLAS	962	3.7%	64.4	61938	KLAS	962	3.7%	63.3	60880	1.7%
Los Angeles	KLAX	1011	3.9%	36.1	36473	KLAX	1008	3.9%	31.1	31374	14.0%
New York LGA*	**KLGA**	**640**	**2.4%**	**34.3**	**21957**	**KLGA***	**634**	**2.5%**	**17.7**	**11242**	**48.8%**
Orlando	KMCO	661	2.5%	40.5	26799	KMCO	657	2.6%	37.8	24836	7.3%
Chicago MDW*	**KMDW**	**484**	**1.8%**	**39.4**	**19077**	**KMDW***	**484**	**1.9%**	**33.9**	**16426**	**13.9%**
Memphis	KMEM	873	3.3%	19.4	16966	KMEM	854	3.3%	18.8	16041	5.5%
Miami	KMIA	651	2.5%	20.5	13352	KMIA	623	2.4%	17.3	10791	19.2%
Minneapolis-St. Paul	KMSP	1049	4.0%	50.5	52949	KMSP	1040	4.1%	47.3	49203	7.1%
Chicago ORD	KORD	1691	6.5%	127.6	215846	KORD	1597	6.2%	105.7	168832	21.8%
Portland*	**KPDX**	**426**	**1.6%**	**25.1**	**10689**	**KPDX***	**426**	**1.7%**	**20.8**	**8877**	**16.9%**
Philadelphia*	**KPHL**	**969**	**3.7%**	**69.0**	**66842**	**KPHL***	**946**	**3.7%**	**27.6**	**26129**	**60.9%**
Phoenix	KPHX	934	3.6%	34.5	32259	KPHX	932	3.6%	31.5	29356	9.0%
Pittsburgh	KPIT	534	2.0%	16.6	8842	KPIT	532	2.1%	15.4	8171	7.6%
San Diego*	**KSAN**	**368**	**1.4%**	**47.1**	**17328**	**KSAN***	**367**	**1.4%**	**32.6**	**11965**	**31.0%**
Seattle	KSEA	535	2.0%	24.5	13112	KSEA	535	2.1%	23.8	12758	2.7%
San Francisco	KSFO	555	2.1%	52.2	28960	KSFO	553	2.2%	45.5	25150	13.2%
Salt Lake City*	**KSLC**	**631**	**2.4%**	**25.4**	**16040**	**KSLC***	**620**	**2.4%**	**21.7**	**13482**	**15.9%**
St. Louis	KSTL	446	1.7%	20.8	9266	KSTL	435	1.7%	21.3	9263	0.0%
Tampa*	**KTPA**	**504**	**1.9%**	**28.3**	**14284**	**KTPA***	**502**	**2.0%**	**27.1**	**13584**	**4.9%**
*Capacity Impacted Airport		10356		42.7	442712		10174		27.0	275145	37.9%
Non-Impacted Airport		15832		43.5	689104		15493		38.4	594191	13.8%
			100%					100%			
All OEP Airports		26188		43.2	1131816	OEP	25667		33.9	869336	23.2%
Non-OEP NAS Airports		32194		19	607191	NonOEP	31797		17	529269	12.8%
All NAS Airports		58382		29.8	1739007	NAS	57464		24.3	1398605	19.6%

In the ACES modeling described above, CESTOL aircraft are assigned a Mach 0.8 nominal cruise speed which is roughly comparable with conventional aircraft speeds. Conventional aircraft cruise speeds are assigned according to actual ETMS flight data. ACES models each 4D trajectory, and assesses and resolves en route pair-wise spacing conflicts among aircraft.



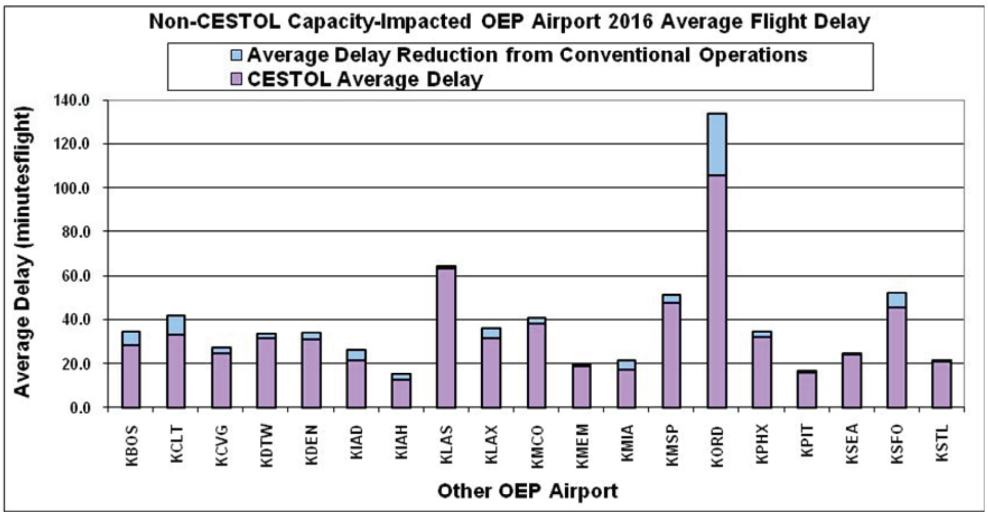


Figure 21. 2016 OEP delay reductions, M 0.8 CESTOL cruise speed.

There is a history within the aerospace community of developing aircraft concepts that possessed short-field performance, but turned out to be unviable as jet transports due to cruise speeds that were lower than other conventional jet transports. NASA sees a potential greater use of the CESTOL concept if it is to get short-field performance during takeoff landing while also cruising at high subsonic speed (~Mach 0.8) as efficiently as conventional transports. Therefore, understanding the overall system impact to either achieving, or failing to achieve that desired cruise speed is important. To investigate sensitivity of delay to CESTOL speed, ACES is applied assuming a Mach 0.7 cruise speed for all CESTOL flights assuming CESTOL capacity gains at the impacted OEP airports. Table 21 tabulates the resulting estimated traffic and delay statistics for Mach 0.7 cruise speed, and provides comparison with Mach 0.8 statistics (same as table 20). These show CESTOL to achieve significant delay reductions, but generally less than those estimated for the Mach 0.8 assumption. The reduction in delay savings is attributed to ACES-generated increases in flight delays and diversions to resolve additional aircraft spacing conflicts resulting from greater speed differences among aircraft and longer flight time during cruise.

TABLE 21. 2016 OEP AIRPORT AND NAS-WIDE FLIGHT DELAY (AT M 0.7 CESTOL CRUISE SPEED).

ACES delay (minutes) at end of flight, CESTOL (M.7) vs. CESTOL (M.8)

	2016 CESTOL (M.7) with Conventional Aircraft						2016 CESTOL (M.8) with Conventional Aircraft			
Airport	Id	Number of Arrivals	Share of OEP Opera-tions	Average Arrival Delay (min / flt)	Total Arrival Delay (minutes)	Total Arrival Delay Reduction Impact		Average Arrival Delay (min / flt)	Total Arrival Delay (minutes)	Total Arrival Delay Reduction Impact
Atlanta*	**KATL***	1568	**6.1%**	24.7	**38667**	**18.8%**	**KATL***	**25.2**	**38857**	**18.4%**
Boston	KBOS	674	2.6%	30.2	20377	11.9%	KBOS	27.8	18764	18.8%
Baltimore*	**KBWI***	541	**2.1%**	17.1	**9275**	**10.2%**	**KBWI***	**15.6**	**8454**	**18.2%**
Cleveland*	**KCLE***	478	**1.9%**	26.2	**12515**	**13.9%**	**KCLE***	**21.1**	**10068**	**30.8%**
Charlotte	KCLT	810	3.1%	37.0	29951	10.4%	KCLT	32.8	26084	21.9%
Cincinnati	KCVG	766	3.0%	25.2	19276	7.6%	KCVG	24.6	18834	9.7%
Washington DCA*	**KDCA***	441	**1.7%**	18.8	**8306**	**7.2%**	**KDCA***	**16.0**	**7040**	**21.4%**
Denver	KDEN	922	3.6%	34.0	31311	-0.6%	KDEN	30.6	28244	9.2%
Dallas-Fort Worth*	**KDFW***	1246	**4.8%**	12.7	**15871**	**-2.3%**	**KDFW***	**11.6**	**14449**	**6.9%**
Detroit	KDTW	903	3.5%	32.3	29165	2.6%	KDTW	31.1	27758	7.3%
Newark*	**KEWR***	780	**3.0%**	38.6	**30091**	**58.7%**	**KEWR***	**33.7**	**26197**	**64.0%**
Fort Lauderdale-Hollywood*	**KFLL***	600	**2.3%**	56.8	**34105**	**49.6%**	**KFLL***	**55.7**	**33331**	**50.7%**
Washington IAD	KIAD	737	2.9%	21.5	15858	16.3%	KIAD	21.3	15591	17.7%
Houston	KIAH	983	3.8%	12.9	12719	14.9%	KIAH	12.5	12261	18.0%
New York JFK*	**KJFK***	571	**2.2%**	64.0	**36542**	**6.5%**	**KJFK***	**61.4**	**35044**	**10.3%**
Las Vegas	KLAS	962	3.7%	60.4	58131	6.1%	KLAS	63.3	60880	1.7%
Los Angeles	KLAX	1008	3.9%	32.5	32734	10.3%	KLAX	31.1	31374	14.0%
New York LGA*	**KLGA***	631	**2.4%**	18.7	**11782**	**46.3%**	**KLGA***	**17.7**	**11242**	**48.8%**
Orlando	KMCO	657	2.5%	36.9	24247	9.5%	KMCO	37.8	24836	7.3%
Chicago MDW*	**KMDW***	484	**1.9%**	37.3	**18061**	**5.3%**	**KMDW***	**33.9**	**16426**	**13.9%**
Memphis	KMEM	856	3.3%	17.5	14944	11.9%	KMEM	18.8	16041	5.5%
Miami	KMIA	637	2.5%	18.2	11614	13.0%	KMIA	17.3	10791	19.2%
Minneapolis-St. Paul	KMSP	1042	4.0%	45.6	47493	10.3%	KMSP	47.3	49203	7.1%
Chicago ORD	KORD	1631	6.3%	106.4	173500	19.6%	KORD	105.7	168832	21.8%
Portland*	**KPDX***	426	**1.7%**	23.7	**10115**	**5.4%**	**KPDX***	**20.8**	**8877**	**16.9%**
Philadelphia*	**KPHL***	949	**3.7%**	29.0	**27506**	**58.8%**	**KPHL***	**27.6**	**26129**	**60.9%**
Phoenix	KPHX	932	3.6%	31.1	29000	10.1%	KPHX	31.5	29356	9.0%
Pittsburgh	KPIT	532	2.1%	16.8	8938	-1.1%	KPIT	15.4	8171	7.6%
San Diego*	**KSAN***	367	**1.4%**	36.0	**13208**	**23.8%**	**KSAN***	**32.6**	**11965**	**31.0%**
Seattle	KSEA	535	2.1%	26.6	14256	-8.7%	KSEA	23.8	12758	2.7%
San Francisco	KSFO	553	2.1%	48.9	27031	6.7%	KSFO	45.5	25150	13.2%
Salt Lake City*	**KSLC***	620	**2.4%**	25.7	**15958**	**0.5%**	**KSLC***	**21.7**	**13482**	**15.9%**
St. Louis	KSTL	437	1.7%	20.4	8933	3.6%	KSTL	21.3	9263	0.0%
Tampa*	**KTPA***	502	**1.9%**	22.5	**11311**	**20.8%**	**KTPA***	**27.1**	**13584**	**4.9%**
			100%							
All OEP airports	OEP	25781		35.0	902793	20.2%	OEP	33.9	869336	23.2%
All NAS airports	NAS	57670		25.0	1443748	17.0%	NAS	24.3	1398605	19.6%

* CESTOL capacity-impacted airport

8 FINDINGS

This study applies the 4D trajectory-based AvTerminal and ACES modeling capabilities to estimate impacts of CESTOL operations on capacity at Newark Airport, and impacts on delay at the domestic OEP airports as well as all other airports within the NAS. The modelings compare conventional-aircraft-only and CESTOL-mixed-with conventional-aircraft traffic projections for the year 2016.

This preliminary study assumes a CESTOL future operating environment in which advanced ATM and flight operating systems provide very high-fidelity trajectory prediction and control capabilities. These capabilities are based on sophisticated CNS technologies. Assumptions include application of mature ATM automation with time-based metering and DCIA procedures, RNAV, RNP, accurate meteorological prediction, air-ground data link communication, ADS-B, and advanced airport surface technologies. CESTOL is envisioned to incorporate fuel-efficient, low-noise, and low-emission technologies.

Newark Airport Analysis Findings—The Newark Airport study examines operations and assesses acceptance rates, delays, and delay sources for CESTOL and conventional operations. Results indicate CESTOL vehicles have significant capability to increase arrival capacity and reduce delays by taking advantage of otherwise unused and/or underutilized terminal airspace and runways where available. Runway capacity impacts at KEWR (see table 7) show a major increase in estimated arrival acceptance rates (38%) and departure acceptance rates (16%).The estimated delay reduction (98%) to arrival flights in KEWR terminal airspace is very large (see table 22). Runway arrivals also achieve significant delay savings (47%), and runway departures achieve less but still significant savings (25%).

These results for KEWR show the beneficial effect of shifting CESTOL arrival traffic to a secondary crossing runway with a corresponding reduction of traffic loading on primary runways relative to conventional traffic operations. This procedural strategy segregates the CESTOL and conventional arrival airspace trajectories, without significantly altering departure procedures. Takeoff and landing operations interleave with each other, such that start of takeoff typically is dependent on execution of a previous landing. Since CESTOL does not impact departure procedures, gains in departure runway operations are attributed to reductions in arrival delays.

TABLE 22. KEWR 2016 DAILY DELAY IMPACT SUMMARY

	ESTOL Delay Reduction Distribution (%)		
Domain	Arrival	Departure	Total
Airspace	98%	5%	96%
Runway System	47%	25%	37%
Total	86%	24%	75%

NAS-wide Analysis Findings—The ACES NAS-wide modeling extends the results of the localized Newark Airport analysis. The ACES-derived NAS network analysis of CESTOL KEWR capacity gain extrapolations to 15 major domestic airports shows significant delay reductions across the network of airports. CESTOL-based capacity gains reduce average flight delay by 10.2 minutes for the 34 OEP airports and 5.9 minutes for all airports NAS-wide (see table 23). Among the OEP airports, average flight delay reduction is more prominent at the 15 airports where capacity is specifically improved by CESTOL than at the other 19 OEP airports where capacity is not improved by CESTOL (16.5- versus 6.1-minute delay reductions). Delay reductions across all airports are due to reduced NAS network delay propagation generated by improved operations at the 15 capacity-improved OEP airports.

The delay results of the Newark Airport and NAS-wide analysis are sensitive to the modeling assumptions including those addressing flight consolidation/replacement due to CESTOL. The 3% reduction in traffic demand due to CESTOL lessens the load on airports, contributing to reduced delay. A slight increase in this traffic demand (associated with modeling uncertainty) during periods where an airport is operating near capacity could yield a significant increase in delay. Thus, the estimated 3% reduction in demand may yield a disproportionate reduction in delay if the majority of delay is at periods of high runway utilization. Note that this study is not an exercise in examining flight consolidation benefits. Flight consolidation is used as part of the rationale to create a CESTOL fleet and forecast a traffic demand schedule.

Cruise Speed Variation Findings—Table 24 summarizes ACES-derived delay impact results as a function of cruise Mach Number. This table first shows results assuming a CESTOL Mach 0.8 nominal cruise speed, similar to conventional aircraft speeds. CESTOL-based capacity gains are estimated to reduce total flight delay by 23.2% for the 34 OEP airports and 19.6% for all airports NAS-wide. Total delay reduction (37.9%) is greater at the 15 OEP airports where capacity is improved than at the other 19 OEP airports (13.8%).

To investigate sensitivity of delay to lower CESTOL speeds and associated spacing incompatibilities with faster conventional aircraft, ACES is applied assuming a Mach 0.7 cruise speed for all CESTOL flights and capacity gains at the 15 impacted OEP airports. Results (see table 24) show the CESTOL Mach 0.7 aircraft still achieve significant total delay reductions, but slightly less than those estimated for the Mach 0.8 assumption. Reduction in CESTOL cruise speed from Mach 0.8 to 0.7 lessens the 34 OEP airport delay reduction by 3% (20.2% versus 23.2%) and NAS-wide delay reduction by 2.6% (17% versus 19.6%).

TABLE 23. OEP AND NAS-WIDE AIRPORTS: MACH 0.8 CESTOL-BASED DELAY REDUCTIONS

	Airport Type			
Total Delay Impact	CESTOL OEP	Non-CESTOL OEP	All OEP	All NAS
Total Delay Reduction (minutes)	167567	94913	262480	340402
Total Delay Reduction Distribution	64%	36%	100%	
Average Flight Delay Impact				
Number of Arrivals (flights)	10174	15493	25667	57464
Number of Arrivals Distribution (%)	40%	60%	100%	
Average Delay Reduction (minutes/flight)	16.5	6.1	10.2	5.9

TABLE 24. OEP AND NAS-WIDE AIRPORTS: CESTOL-BASED TOTAL DELAY REDUCTION IMPACT

	CESTOL-Based Total Delay Reduction Impact Airport Type			
	CESTOL OEP	Non-CESTOL OEP	All OEP	All NAS
CESTOL Mach 0.8	37.9%	13.8%	23.2%	19.6%
CESTOL Mach 0.7	33.7%	11.6%	20.2%	17.0%

Summary Findings—This preliminary simulation-based analysis assumes operational conditions supportive of CESTOL in which advanced air traffic and flight management systems implement 4D trajectory optimization. However, the estimated delay savings (19.6% NAS-wide) are significant, indicating that even with relaxation of the analysis assumptions, CESTOL is a serious candidate for further study and development with respect to potential capabilities to increase throughput and reduce delay throughout the NAS.

Our NAS-wide modeling evaluates operational impacts assuming a 130-seat CESTOL aircraft having a flying range of 2,000 nmi and requiring a runway length of at least 2,000 ft. These criteria are used to facilitate this preliminary analysis and do not imply that CESTOL development is restricted to a single aircraft design. Alternative CESTOL aircraft designs could serve different markets based on range, size, runway, and other related requirements.

APPENDIX A—CONVENTIONAL-TO-CESTOL AIRCRAFT REPLACEMENT

E. Wendel, Sensis Corporation

The replacement process is premised on a 737-300-like aircraft with short takeoff/landing capabilities without reagard to business case models. The CESTOL flight demand set generation specifications are as follows.

Inputs:

- Airport database containing
  1. 4-letter airport ID,
  2. airport latitude,
  3. airport longitude,
  4. and longest airport runway length.

- Conventional (non-CESTOL) aircraft characteristic database containing
  1. aircraft type,
  2. maximum seat capacity,
  3. and a Boolean flag indicating if the aircraft is CESTOL-capable.

- A Flight Demand/Data Set (FDS), version 1, containing the following fields, in this order:
  - *Flight ID*
  - *Airline call sign*
  - *Aircraft type*
  - *Equipage*
  - *TCAS enabled*
  - *Departure airport*
  - *Arrival airport*
  - *Gate departure time*
  - *Cruise altitude*
  - *Cruise speed*
  - *Flight path*

- The following CESTOL aircraft parameters are user-defined inputs:
  1. Maximum CESTOL flyable range (e.g., 2,000 nmi).
  2. Minimum CESTOL takeoff length (e.g., 2,000 feet).
  3. Passenger seat capacity of a CESTOL aircraft (e.g., 130 seats).

- The following user-defined inputs govern the function behavior:
  1. Choose the maximum number of flights to consolidate into an CESTOL flight. (The user may choose the number 0, or any positive integer not equal to 1.)
  2. Specify the runway takeoff or landing consolidation time interval within which CESTOL-capable flights will be considered for consolidation into one CESTOL flight (e.g., 60 minutes).
  3. Specify the target airports to consider for CESTOL operations (e.g., KEWR).

- A special AvAnalyst© (a capacity and delay analysis tool for post-processing simulation results) output dataset containing user class data for the desired input FDS dataset.
- AvAnalyst will require an ETMS dataset with user class data for the same day as the input FDS dataset.

Outputs:

- A new FDS version 2 dataset with CESTOL flights, and the same fields as the input dataset, with the following fields appended:
    - *Spherical great circle distance between departure and arrival airports*
    - *Departure airport maximum runway length*
    - *Arrival airport maximum runway length*
    - *Flight user class data*
- A log of all changes to the input FDS dataset.
- A log of all errors or missing data, including unmatched aircraft types and missing airport data.
- A new airport database with the same fields as the input, but with an additional field:
    - *Boolean flag indicating if the airport is CESTOL-capable*

Method:

1. Consider an aircraft to be CESTOL-capable if it is flagged in the input database as such.
2. Consider an airport to be CESTOL-capable if its runway length is greater than or equal to the minimum CESTOL takeoff length or if it is a user-specified target airport.
3. Do not consider flights as CESTOL that have a *Flight user class* that is not commercial, 'C', or air taxi, 'T'.
4. Calculate great circle distance between all flights in the input FDS dataset using Napier's rule for triangular segments of a sphere.
5. Consider a flight record in the input FDS dataset to be CESTOL-capable if
    a. its *Aircraft type* field is in the set of CESTOL-capable aircraft,
    b. the spherical great circle distance between the arrival and departure airports is less than or equal to the user-specified CESTOL maximum flyable range,
    c. and if the arrival and departure airports' maximum runway lengths are greater than or equal to the user-specified CESTOL minimum runway takeoff length.

   Mark these flights as CESTOL by pre-pending the character string "CESTOL1_" to the *Aircraft type* field in the output FDS dataset. Log these changes in a separate file.
6. Estimate arrival times for all of the flights in the input FDS dataset. Since arrival time is not part of the FDS dataset, it will be roughly calculated from the *Cruise speed* field and average TRACON, taxi-in, and taxi-out times using the following formula:

$$t_{arr} = \frac{d_{\text{gcd}}}{v_{cruise}} + 2 \times t_{TRACON} + t_{out} + t_{in}$$

   where v_{cruise} is is the cruise speed from the input FDS dataset; d_{gcd} is the spherical great circle distance from the departure airport to the arrival airport; t_{TRACON} is the default TRACON transit time (e.g., 10 minutes); t_{out} is the default taxi-out time (e.g., 10 minutes); and t_{in} is the default taxi-in time (e.g., 4 minutes).

7. If indicated by the user, attempt to consolidate CESTOL flights into the earliest-departing flight if
    a. flights regardless of airline have the same departure and arrival airports,
    b. for consecutive arrivals, they have arrival times within the user-specified consolidation time interval; and, for consecutive departures, they have departure times within the user-specified consolidation time interval,
    c. and the sum of the consolidated flights' seat capacities is less than or equal to the user-specified CESTOL aircraft seat capacity.

APPENDIX B – KEWR MINIMUM SEPARATION TIME REQUIREMENTS

KEWR Runway System Minimm Separation Requirements (nmi) - Southwest Operating Plan

Separation (seconds)

Focal Airport: KEWR
Op Plan: Southwest
Op Condition: VFR1

	Trailing Aircraft 2														
	Runway 22L Arrival					Runway 22R Departure					Runway 11 Arrival				
Lead Aircraft 1	Small	ESTOL	Large	B757	Heavy	Small	ESTOL	Large	B757	Heavy	Small	ESTOL	Large	B757	Heavy
Runway 22L															
Arrival	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec
Small	76	76	76	79	76	0	0	0	0	0	51	51	51	53	50
ESTOL	97	76	76	79	76	0	0	0	0	0	51	51	51	53	50
Large	97	76	76	79	76	0	0	0	0	0	51	51	51	53	50
B757	143	120	120	125	96	0	0	0	0	0	129	129	129	133	124
Heavy	143	120	120	125	96	0	0	0	0	0	129	129	129	133	124
Runway 22R															
Departure	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec
Small	36	36	36	38	38	60	60	60	60	60	-INF	-INF	-INF	-INF	-INF
ESTOL	36	36	36	38	38	60	60	60	60	60	-INF	-INF	-INF	-INF	-INF
Large	36	36	36	38	38	60	60	60	60	60	-INF	-INF	-INF	-INF	-INF
B757	36	36	36	38	38	120	120	120	60	60	-INF	-INF	-INF	-INF	-INF
Heavy	36	36	36	38	38	120	120	120	120	60	-INF	-INF	-INF	-INF	-INF
Runway 11															
Arrival	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec
Small	51	51	51	53	50	-INF	-INF	-INF	-INF	-INF	386	386	386	400	372
ESTOL	51	51	51	53	50	-INF	-INF	-INF	-INF	-INF	386	386	386	400	372
Large	51	51	51	53	50	-INF	-INF	-INF	-INF	-INF	386	386	386	400	372
B757	129	129	129	133	124	-INF	-INF	-INF	-INF	-INF	386	386	386	400	372
Heavy	129	129	129	133	124	-INF	-INF	-INF	-INF	-INF	386	386	386	400	372

Base Separation (nmi or seconds)

Focal Airport: KEWR
Op Plan: Southwest
Op Condition: VFR1

	Trailing Aircraft 2														
	Runway 22L Arrival					Runway 22R Departure					Runway 11 Arrival				
Lead Aircraft 1	Small	ESTOL	Large	B757	Heavy	Small	ESTOL	Large	B757	Heavy	Small	ESTOL	Large	B757	Heavy
Speed (mni/hr)	140	140	140	135	145	140	140	140	135	145	140	140	140	135	145
Runway 22L															
Arrival	nmi	nmi	nmi	nmi	nmi	sec	sec	sec	sec	sec	nmi	nmi	nmi	nmi	nmi
Small	2.97	2.97	2.97	2.97	3.06	0	0	0	0	0	2	2	2	2	2
ESTOL	3.77	2.97	2.97	2.97	3.06	0	0	0	0	0	2	2	2	2	2
Large	3.77	2.97	2.97	2.97	3.06	0	0	0	0	0	2	2	2	2	2
B757	5.57	4.67	4.67	4.67	3.86	0	0	0	0	0	5	5	5	5	5
Heavy	5.57	4.67	4.67	4.67	3.86	0	0	0	0	0	5	5	5	5	5
Runway 22R															
Departure	nmi	nmi	nmi	nmi	nmi	sec	sec	sec	sec	sec	sec	sec	sec	sec	sec
Small	1.41	1.41	1.41	1.41	1.52	60	60	60	60	60	-INF	-INF	-INF	-INF	-INF
ESTOL	1.41	1.41	1.41	1.41	1.52	60	60	60	60	60	-INF	-INF	-INF	-INF	-INF
Large	1.41	1.41	1.41	1.41	1.52	60	60	60	60	60	-INF	-INF	-INF	-INF	-INF
B757	1.41	1.41	1.41	1.41	1.52	120	120	120	60	60	-INF	-INF	-INF	-INF	-INF
Heavy	1.41	1.41	1.41	1.41	1.52	120	120	120	120	60	-INF	-INF	-INF	-INF	-INF
Runway 11															
Arrival	nmi	nmi	nmi	nmi	nmi	sec	sec	sec	sec	sec	nmi	nmi	nmi	nmi	nmi
Small	2	2	2	2	2	-INF	-INF	-INF	-INF	-INF	15	15	15	15	15
ESTOL	2	2	2	2	2	-INF	-INF	-INF	-INF	-INF	15	15	15	15	15
Large	2	2	2	2	2	-INF	-INF	-INF	-INF	-INF	15	15	15	15	15
B757	5	5	5	5	5	-INF	-INF	-INF	-INF	-INF	15	15	15	15	15
Heavy	5	5	5	5	5	-INF	-INF	-INF	-INF	-INF	15	15	15	15	15

Data Sources/Assumptions

Focal Airport:			KEWR												
Op Plan			Southwest												
Op Condition			VFR1												
	Trailing Aircraft 2														
	Runway 22L Arrival					Runway 22R Departure					Runway 11 Arrival				
Lead Aircraft 1	Small	ESTOL	Large	B757	Heavy	Small	ESTOL	Large	B757	Heavy	Small	ESTOL	Large	B757	Heavy
Speed (mni/hr)			Reference 1					Reference 1					Reference 1		
Runway 22L															
Arrival	nmi		nmi	nmi	nmi	sec		sec	sec	sec	nmi		nmi	nmi	nmi
Small			Arv-Arv					Arv-Dep					Arv-Arv		
ESTOL															
Large			Single Runway					Close Parallel Runways					Crossing Runways		
B757	2.5nmi Arv Wake Vortex Dependency						Takeoff dependent on landing						DCIA		
Heavy			Reference 3					Reference 4					Reference 2		
Runway 22R															
Departure	nmi		nmi	nmi	nmi	sec		sec	sec	sec	sec		sec	sec	sec
Small			Dep-Arv					Dep-Dep					Dep-Arv		
ESTOL															
Large			Close Parallel Runways					Single Runway			Crossing Displaced Runways				
B757	Arrivals Wake Vortex Dependency					Departures Wake Vortex Dependency							Non-interacting		
Heavy			Reference 3					Reference 3					Reference 1		
Runway 11															
Arrival	nmi		nmi	nmi	nmi	sec		sec	sec	sec	nmi		nmi	nmi	nmi
Small			Arv-Arv					Arv-Dep					Arv-Arv		
ESTOL															
Large			Crossing Runways			Crossing Displaced Runways							Single Runway		
B757			DCIA					Non-interacting			2.5nmi Arv Wake Vortex Dependency				
Heavy			Reference 2					Reference 1					Reference 3		

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APPENDIX C –NAS-WIDE 2016 AIRCRAFT FLEET SEAT DISTRIBUTION

Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals
B773	J	550	8	B722	J	145	200	F50	T	50	56
B747	J	524	4	B72Q	J	145	469	CRJ2	J	50	3143
B74R	J	498	1	B721	J	143	34	E45X	J	50	236
B74S	J	498	1	MD81	J	143	35	AT42	T	48	6
B741	J	452	20	MD82	J	143	1134	AT43	T	48	100
B742	J	452	120	MD83	J	143	409	CV58	T	46	4
B744	J	416	371	MD88	J	143	18	CL60	J	45	279
B743	J	400	33	VC10	J	140	0	CL64	J	45	55
B777	J	400	1	B720	J	140	1	CRJ	J	45	1
A346	J	380	12	MD80	J	139	790	CRJ1	J	45	796
A342	J	375	5	DC95	J	135	143	E1	U	45	1
B74A	J	375	0	B73A	J	133	7	HUNT	U	45	2
B74B	J	375	2	B73B	J	133	0	F27	T	44	79
A330	J	335	2	B73C	J	133	0	AN26	T	44	7
L101	T	320	22	B73Q	J	133	390	E140	J	44	2
CONC	J	314	0	B737	J	126	1401	CVLP	P	40	7
A343	J	313	115	B733	J	126	3153	SB20	T	40	13
A345	J	313	3	DC9	J	125	47	DH8A	T	37	795
B772	J	305	278	A319	J	124	1375	DH8B	T	37	420
A333	J	295	61	B732	J	120	686	E135	J	37	973
A340	J	290	2	DC94	J	120	50	SH36	T	36	106
DC10	J	285	186	MD87	J	117	24	BA41	T	35	0
MD11	J	285	157	B735	J	110	843	CARJ	J	35	0
A332	J	253	86	B736	J	110	14	DH8	T	35	83
L011	J	253	1	DC93	J	110	486	DHC8	T	35	9
A30B	J	251	62	B712	J	106	603	SH33	T	34	38
C141	J	250	0	RJ85	T	100	159	SF3	T	34	1
B764	J	245	106	CRJ3	J	100	0	SF34	T	33	1071
B753	J	243	120	B717	J	100	0	D328	T	30	184
A3ST	J	231	0	A318	J	100	25	E120	T	30	625
EA34	J	231	0	F100	J	97	239	JS41	T	30	288
A310	J	220	104	B727	J	94	26	SD3	T	30	2
EA31	J	220	0	B462	J	90	148	J328	J	30	308
B763	J	218	710	B463	J	90	47	DC3T	T	24	1
B752	J	201	2101	BA46	J	90	98	GLB	T	23	1
B703	J	195	0	DC9Q	J	90	187	BD70	T	23	1
B707	J	195	0	L188	T	90	9	AC9L	T	22	1
B769	J	190	1	BA11	J	89	8	G159	T	21	4
R722	J	189	9	CRJ9	J	86	67	L410	P	21	5
C17	J	188	0	DC91	J	85	55	FA90	T	21	3
IL62	J	186	0	DC92	J	85	0	GLAX	J	21	1
A321	J	185	319	B461	J	80	4	G2	J	20	5
B767	J	181	9	DC6	P	80	29	G3	J	20	4
B762	J	181	218	F70	J	80	25	G4	J	20	6
B757	J	180	7	H1	T	78	1	G5	J	20	5
DC8	J	180	4	ATR	T	72	2	SC7	T	20	10
DC86	J	180	19	CRJ7	J	70	520	YK42	J	20	0
B739	J	177	101	RJ1H	J	70	86	SWA4	T	20	1
A306	J	166	327	A225	J	70	1	B190	T	19	1507
B738	J	162	1202	FK70	J	69	0	C212	T	19	6
MD90	J	153	55	DH8D	T	68	174	DHC6	T	19	30
DC85	J	152	0	AT72	T	66	311	GULF	J	19	0
DC87	J	152	41	F28	J	65	5	B19C	T	19	1
DC8Q	J	152	90	ATP	T	64	45	B19D	T	19	4
T154	J	150	0	DHC7	T	55	11	SW5	T	19	9
A320	J	150	1917	FK10	J	55	0	SW4A	T	18	16
B73F	J	149	0	A32	T	55	1	SW4	T	17	407
B73J	J	149	0	CR2	T	50	0	B99	T	17	3
B73S	J	149	0	DH8C	T	50	379	HS25	J	15	22
B734	J	147	580	E145	J	50	2281	B300	T	15	11

Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals
D228	T	14	1	G200	J	10	8	CL30	J	8	10
F406	T	14	4	L36	J	10	1	H25	J	8	6
F900	J	14	119	L35	J	10	1	MU23	T	8	1
GL4	J	14	0	L29	J	10	1	SRB1	J	8	2
GLF2	J	14	86	LR45	J	10	7	CE55	J	8	2
GLF3	J	14	95	LJ40	J	10	3	C52A	J	8	1
GLF4	J	14	242	C208	T	9	903	TC56	J	8	2
GLF5	J	14	72	L29B	J	9	15	H25G	J	8	1
F20	J	14	1	LJ28	J	9	1	H47	T	7	1
A748	T	13	44	E121	T	9	1	C650	J	7	234
AC69	T	13	9	BN2A	P	8	9	DA10	J	7	3
AC90	T	13	76	AC21	J	8	0	LJ45	J	7	239
BA31	T	13	0	ASTR	J	8	96	P34	P	7	2
BE02	T	13	1	B350	T	8	190	TBM	T	7	2
BE3B	T	13	0	BE10	T	8	229	AC6T	T	6	0
BE9F	T	13	0	BE18	P	8	18	BE35	P	6	121
BN2T	T	13	0	BE19	P	8	6	BE36	P	6	264
CV24	P	13	0	BE20	T	8	929	BE58	P	6	497
CV44	P	13	0	BE23	P	8	14	BE65	P	6	0
DH6	T	13	2	BE30	T	8	194	C207	P	6	3
LR55	J	13	7	BE40	J	8	388	C501	J	6	80
M7T	T	13	0	BE90	T	8	90	C525	J	6	307
MU2B	T	13	0	BE9L	T	8	557	FA10	J	6	93
P31T	T	13	0	BE9T	T	8	38	LJ24	J	6	74
P46T	T	13	60	C526	J	8	14	LJ25	J	6	157
PAY4	T	13	6	C550	J	8	559	LJ31	J	6	185
PAYE	T	13	8	C551	J	8	24	LJ35	J	6	515
STAR	T	13	0	C560	J	8	657	LR25	J	6	12
BE99	T	12	214	C56X	J	8	360	LR35	J	6	27
C425	T	12	70	C750	J	8	245	N265	J	6	0
E110	T	12	42	CVLT	T	8	26	PA31	P	6	635
F2TH	J	12	152	DA20	J	8	1	PA46	P	6	93
SBR2	T	12	7	DA50	J	8	8	TBM7	T	6	74
C680	J	12	2	EA32	J	8	0	C06T	P	6	1
SBL1	T	12	1	FA50	J	8	165	AC56	P	6	1
S900	T	12	1	H25A	J	8	74	A36	P	6	2
B430	J	11	1	H25B	J	8	564	P32	P	6	2
JS31	T	11	45	H25C	J	8	58	P27	P	6	1
JS32	T	11	102	JCOM	J	8	0	C90	P	6	1
LR60	J	11	2	LJ23	J	8	0	B58P	P	6	6
P180	T	11	20	LJ55	J	8	102	P31P	P	6	1
AC80	T	11	2	LJ60	J	8	207	TMB7	T	6	1
BE2O	T	11	1	LR24	J	8	3	BO6	J	6	7
A95	T	11	1	MU2	T	8	183	C510	J	6	2
FA1	J	11	1	MU3	J	8	4	TAMP	P	5	5
GL2	T	11	1	MU30	J	8	29	EC35	U	5	2
BELF	T	10	0	PC12	T	8	290	AC50	P	5	89
C441	T	10	108	S601	J	8	3	AN12	T	5	1
CL61	J	10	0	SBR1	J	8	33	BE60	P	5	25
DA90	J	10	1	SW3	T	8	100	C206	P	5	59
DH5	T	10	0	TRIS	P	8	5	C210	P	5	290
DH7	T	10	0	PC6T	T	8	1	C310	P	5	288
FA20	J	10	154	RC70	P	8	8	C414	P	5	208
FK27	T	10	3	AC70	U	8	1	C421	P	5	188
GLEX	J	10	54	BE70	P	8	2	C500	J	5	91
LJ36	J	10	16	C424	P	8	1	PA27	P	5	82
LR31	J	10	10	B60	T	8	1	PA32	P	5	226
LR36	J	10	0	A100	T	8	1	PA34	P	5	293
PAY3	T	10	44	C25A	J	8	84	PAY2	T	5	151
ZZZ	J	10	0	CE25	J	8	1	LA4	P	4	0
GALX	J	10	39	PRM1	T	8	21	AA1	P	4	0
BR9L	T	10	1	B90T	T	8	1	AA5	P	4	13
BE9	T	10	1	PRIM	J	8	1	AA5B	P	4	1

Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals
AC11	P	4	18	P32T	P	4	7	SW4B	T	2	0
AC12	P	4	1	P68	P	4	2	T34T	T	2	0
AC14	P	4	2	PA18	P	4	0	WW2	J	2	0
AC60	P	4	0	PA20	P	4	0	WW23	J	2	0
AC68	P	4	4	PA38	P	4	0	WW25	J	2	0
AC6L	P	4	0	PA42	T	4	2	H269	P	2	5
AC95	P	4	21	PA44	P	4	83	CH2T	P	2	1
AEST	P	4	51	PA60	P	4	3	C72	P	2	2
BE17	P	4	0	PARO	P	4	1	Z42	P	2	1
BE24	P	4	6	PASE	P	4	2	RF6	P	2	3
BE33	P	4	82	PAT4	P	4	0	F260	P	2	1
BE50	P	4	0	PAY1	T	4	86	AG5B	P	2	1
BE55	P	4	137	PAZT	P	4	4	GLST	P	2	1
BE77	P	4	1	PN68	P	4	0	T18	P	2	1
BE80	P	4	20	PROP	T	4	0	RV6	P	2	1
BE95	P	4	2	S108	P	4	0	RV4	P	2	2
BIRD	P	4	0	T34	P	4	0	GLAS	P	2	3
BL17	P	4	14	T34P	P	4	0	RV8	P	2	1
BN2	P	4	1	T6	P	4	0	PA1	P	2	1
BN2P	P	4	7	TB20	P	4	1	LNC2	P	2	1
C150	P	4	3	TOBA	P	4	0	WHIL	P	2	1
C152	P	4	7	TRIN	P	4	6	LNC4	P	2	4
C160	T	4	0	WW24	J	4	135	PC9	P	2	2
C170	P	4	1	P28	P	4	12	DA22	P	2	1
C172	P	4	577	AA5A	P	4	2	AH1	T	1	0
C175	P	4	0	R44	P	4	1	CH46	T	1	0
C177	P	4	30	C195	P	4	3	CH47	T	1	0
C180	P	4	5	DA40	P	4	12	CH53	T	1	0
C182	P	4	228	SR22	P	4	126	H46	T	1	0
C185	P	4	4	Z43	P	4	1	H53	T	1	0
C205	P	4	4	SR20	P	4	31	H60	T	1	0
C303	P	4	9	M20C	P	4	4	MH60	T	1	0
C320	P	4	3	C410	P	4	1	SH3	T	1	0
C335	P	4	8	F33A	P	4	2	UH1	T	1	0
C337	P	4	27	CM11	P	4	2	UH60	T	1	0
C340	P	4	131	M20E	P	4	4	A1	P	1	0
C401	P	4	28	M20F	P	4	4	A10	J	1	0
C402	P	4	291	M20R	P	4	4	A124	J	1	3
C404	P	4	14	PR	P	4	1	A4	J	1	0
C72R	P	4	10	M20K	P	4	3	A6	J	1	0
C77R	P	4	3	COL3	P	4	3	AT38	J	1	0
C82R	P	4	24	LC40	P	4	4	AV8	J	1	0
COUR	P	4	0	M20M	P	4	2	B1	J	1	0
DC3	P	4	10	M2OT	P	4	1	B52	J	1	0
DHC2	P	4	0	LC30	P	4	1	C12	T	1	0
DV20	P	4	3	DH81	P	4	24	C130	T	1	13
E300	P	4	0	M20P	P	3	92	C135	J	1	0
G2T1	P	4	0	M20T	P	3	29	C2	T	1	0
GA7	P	4	3	PA23	P	3	26	C21	J	1	0
GC1	P	4	0	PA24	P	3	30	C23	T	1	0
M020	P	4	2	PL12	P	3	1	C46	P	1	4
M20	P	4	11	BK17	T	2	1	C5	J	1	0
M20J	P	4	10	S76	T	2	8	C9	J	1	0
M7	P	4	5	SK76	T	2	0	E2	T	1	0
MO20	P	4	13	AJ25	J	2	1	E3	J	1	0
MO21	P	4	0	AT45	T	2	2	E3TF	J	1	0
MY20	P	4	0	BE76	P	2	49	E6	J	1	0
NAVI	P	4	2	DH2T	T	2	0	EA6	J	1	0
P210	P	4	9	F14	J	2	0	EA6B	J	1	0
P28A	P	4	178	P28B	P	2	13	F117	J	1	0
P28R	P	4	68	PA28	P	2	108	F15	J	1	0
P28T	P	4	4	PA30	P	2	36	F4	J	1	0
P32R	P	4	68	SW2	T	2	17	F5	J	1	0

Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals	Aircraft Type	Eng Type	Seats	Daily Arrivals
FA18	J	1	0	T39	J	1	0	P181	Unk	0	1
HAR	J	1	0	T44	T	1	0	BD36	Unk	0	1
IL76	J	1	0	T45	J	1	0	RANG	P	0	2
K35E	J	1	0	U2	J	1	0	P32A	P	0	1
K35R	J	1	0	A109	T	1	2	HXB	Unk	0	3
KC10	J	1	0	AS50	T	1	0	C302	Unk	0	1
KC35	J	1	0	AS55	T	1	0	PA2Y	Unk	0	2
KE35	J	1	0	B06	T	1	24	HXC	Unk	0	2
KR35	J	1	0	B222	T	1	4	V550	Unk	0	1
MD10	J	1	90	F16	J	1	0	LT24	Unk	0	1
P3	T	1	0	F18	J	1	0	CS11	Unk	0	1
S3	J	1	0	JS20	T	1	1	DA2	Unk	0	1
T1	J	1	0	P24	P	1	1	Unknown	Unk	0	1
T2	J	1	0	TMP9	Unk	0	1				
T33	J	1	0	P281	Unk	0	1				
T37	J	1	0	HM17	Unk	0	2				
T38	J	1	0	C82T	Unk	0	1				

Seat size data sources: references 12 and 13.

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