GLOBAL MOBILE SATELLITE SERVICE INTERFERENCE ANALYSIS FOR THE AEROMACS

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Abstract

The AeroMACS (Aeronautical Mobile Airport Communications System), which is based on the IEEE 802.16-2009 mobile wireless standard, is envisioned as the wireless network which will cover all areas of airport surfaces for next generation air transportation. It is expected to be implemented in the 5091-5150 MHz frequency band which is also occupied by mobile satellite service uplinks. Thus the AeroMACS must be designed to avoid interference with this incumbent service. Simulations using Visualyse software were performed utilizing a global database of 6207 airports. Variations in base station and subscriber antenna distribution and gain pattern were examined. Based on these simulations, recommendations for global airport base station and subscriber antenna power transmission limitations are provided.

Introduction

The AeroMACS, which is based upon the IEEE 802.16-2009 mobile wireless standard, is envisioned as a wireless network covering all areas of the airport surface for next generation air transportation [1]. The system would accommodate all mobile communications requirements including parked and taxiing aircraft, various types of ground vehicles, and personnel as well as connection to fixed assets related to airport safety requirements (such as surveillance and navigation aids, weather sensors, and communications stations).

The AeroMACS is intended to operate in portions of the 5000-5150 MHz frequency band, including the 5091-5150 MHz span that is authorized on a world-wide basis. It is essential that the AeroMACS service does not interfere with other users in this band. In particular, the allocation of the 5091-5150 MHz band to the Earth-to-space fixed-satellite service (FSS), limited to feeder links of non-geostationary satellite systems in the mobile-satellite service (MSS) and utilized by the Globalstar network, will restrict the power levels that will be allowed for the AeroMACS networks. This investigation is focused on helping to establish practical limits on the AeroMACS base station transmissions from airports so that the threshold of interference into Globalstar feeder links is not exceeded. This threshold interference power level for Globalstar at low earth orbit (LEO) has been established at -157.3 dBW corresponding to a two percent increase of the satellite receiver's noise temperature [2].

Previously, the interference power distribution at LEO from the AeroMACS transmitters at the 497 major airports in the contiguous United States was simulated with the Visualyse Professional software [3]. The results were shown to agree closely with those of a previous study by MITRE-CAASD [4]. Both omni-directional and sector antennas were modeled and 5 MHz and 10 MHz channels were considered with a center frequency of 5100 MHz.

In [5], the effect of the antenna gain profile on interference power was investigated and the accuracy of the model was improved by including a profile based on measured data. It was assumed that the channel bandwidth is 5 MHz centered at 5100 MHz. The effect of the inhomogeneous distribution of airports was examined by comparing with a case having the airports evenly distributed. Also the dependence of the interference power on the number of antenna beams and their directions at the airports was simulated.

In this report, the airport database is extended from 497 up to 6207 airports including additional sites from North America, Europe, and all other continents. Based on the simulations,

recommendations for global airport base station antenna power transmission limitations are provided.

Objective

The Mobile Satellite Service Interference Analysis Ad Hoc Working Group was established by the Radio Technical Commission for Aeronautics (RTCA) SC-223 with the following members: Art Ahrens (Harris), Rafael Apaza (NASA), Mike Biggs (FAA), Bruce Eckstein (ITT Exelis), Nikos Fistas (ECTL), Jan Erik Hakegard (SINTE), Ward Hall (ITT Exelis), Brent Phillips (FAA), Armin Schlereth (DFS), Antonio Correas Uson (INDRA), Jeffrey Wilson (NASA), and Natalie Zelkin (ITT Exelis).

The group was assigned this charter: "Define a working method of specifying emissions from all expected AeroMACS future deployments that are compliant with ITU co-interference requirements, to establish 2-way link levels with the aircraft to ensure closure of the RF-link without adversely affecting the Globalstar Satellite feeder links. The deliverable would be in the form of Minimum Operational Performance Standard (MOPS) or Standards and Recommended Practices Standard (SARPS) requirements and a technical report delivered to an ICAO technical group via a working paper."

The following describes the analysis method, simulation results, recommendations, and conclusions to support this charter.

Analysis

The interference modeling was performed with Visualyse Professional Version 7 software from Transfinite Systems Limited [6]. Details of using this software were provided in [7] with the modeling procedure summarized by the following seven steps:

1. Define antenna gain dependence on azimuthal and elevation angles.

2. Locate stations (transmitters and receivers).

3. Specify frequency and bandwidth of carriers.

4. Set up the propagation environment.

5. Set up the links between stations.

6. Define victim and interfering links.

7. Specify desired output, submit run, and analyze results.

Two different antenna gain patterns were used in the simulations. The first is for an 80^0 beamwidth sector antenna and is based on the manufacturer's data for the antennas used in the Cleveland airport testbed experiments [5]. The second is for a 120^0 beamwidth sector antenna and is based on the recommendation of the International Telecommunication Union Radiocommunication Sector, ITU-R F.1336-3 [8,9]. The model elevation and azimuthal gain patterns for these two antennas are shown in Figs. 1 and 2 respectively.

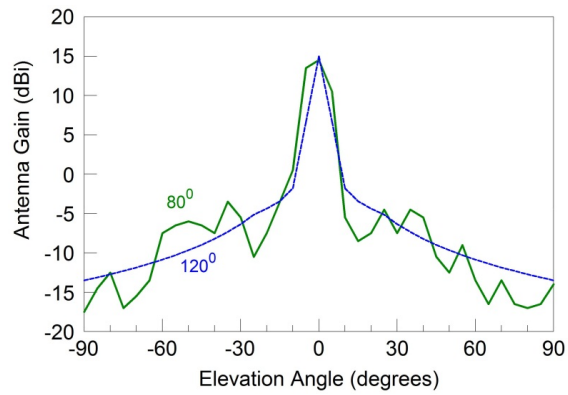

Figure 1. Modeled Gain versus Elevation Angle for AeroMACS Antennas

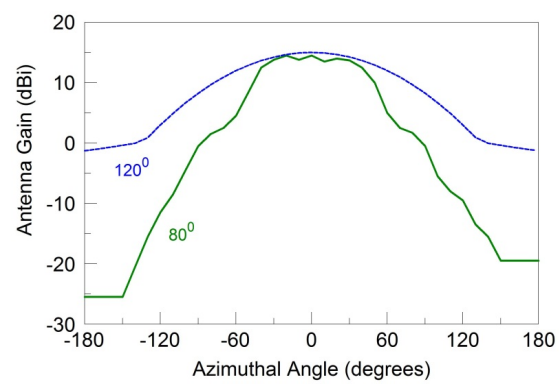

Figure 2. Modeled Gain versus Azimuthal Angle for AeroMACS Antennas

The locations of the antennas were selected from the Openflights database [10] which includes the 6207 global airports shown in Fig. 3. Airports that did not have an International Civil Aviation Organization (ICAO) location identifier (a four-character alphanumeric code) were assumed to have minimal traffic and were not included. Transmission is centered at 5100 MHz with a 5 MHz bandwidth. The propagation model utilized basic transmission loss in free space, based on ITU-R Rec. P.525. In [11], nineteen scenarios with variations in antenna distribution, airport size, antenna beamwidth, and antenna tilt were simulated. In this report, we will look at only the two most realistic scenarios which are designated as Scenarios A and B and are described below. The maximum simulated cumulative interference power at low earth orbit (hot spot) for these runs was used to establish transmitter power limits.

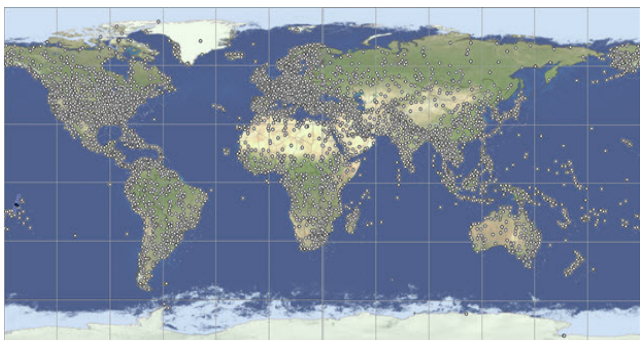

Figure 3. Locations of 6207 Airports in the Openflights Database

In each scenario, five different runs were generated with different random antenna directions. The airport sizes were divided into large, medium, and small categories. In the United States, the 35 Operational Evolution Partnership (OEP 35) airports [12] are assigned as large airports and the next 123 with the most 2009 passenger boardings from the FAA's Commercial Service Airports CY09 Passenger Boardings list [13] are assigned as medium airports. The 50 largest European airports as listed by Wikipedia [14] are assigned as large airports and the next 50 on the list are assigned as medium airports. The remaining 5949 airports in the United States, Europe and rest of world from the Openflights database [10] are assigned to be small airports. In the model, we assign three 120^0 beamwidth sector antennas per channel to each medium airport. The antenna directions are separated by 120^0 creating an almost or pseudo omnidirectional azimuthal gain pattern. We assume that the large airports transmit twice as much power per channel as the medium airports and also in a pseudo omnidirectional pattern. This is modeled by using six 120^0 sector antennas with directions separated by 60^0. Each small airport is assigned a single 120^0 sector antenna pointed in a random direction.

In Scenario A, it is assumed that the large airports will use all eleven channels, medium airports will use six channels, and small airports will use just one channel. Thus five out of 11 medium airport and 10 out of 11 small airport transmitters are turned off to model the results for a single channel. Scenario B is the same as Scenario A except that the small airports are only allowed to transmit half as much power per sector as the medium and large airports.

An analysis of subscriber or mobile station transmission limits was also conducted. This evaluation used a model of the antenna system [15] employed for mobile measurements conducted at the Next Generation Communication, Navigation, and Surveillance Test Bed [16]. The measured elevation and azimuthal gain patterns for this antenna are shown in Figures 4 and 5, respectively. The measured elevation gain in Figure 4 was sampled every five degrees as shown in Figure 6 for the Visualyse model. In approximation of the gain pattern of Figure 5, the model azimuthal gain was assumed to be omnidirectional.

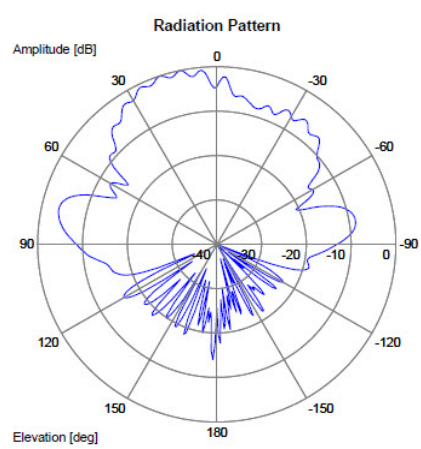

Figure 4. Measured Gain versus Elevation Angle for Subscriber Antenna [15]

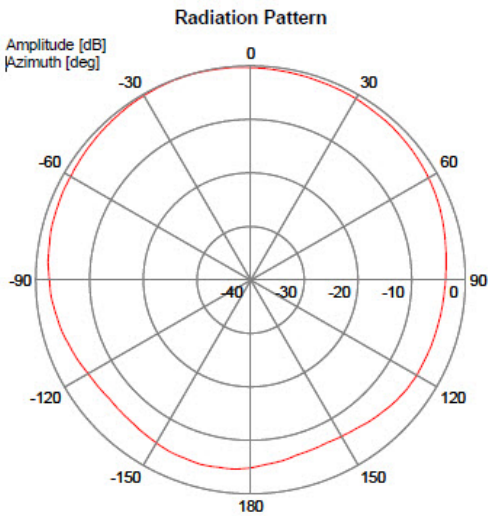

Figure 5. Measured Gain versus Azimuthal Angle for Subscriber Antenna [15]

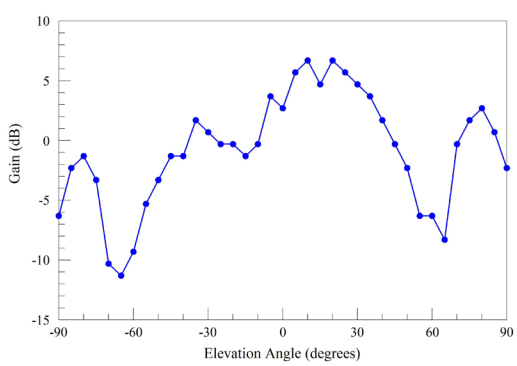

Figure 6. Model Gain versus Elevation Angle for Subscriber Antenna [15]

With these model gain patterns, two subscriber scenarios based on airport size were considered. In Scenario C, it was assumed that the ratio of subscriber power among small/medium/large airports was 1:4:8. In Scenario D, it was assumed that the ratio was 1:8:16.

Results

The simulations indicated that the 'hot spot' is most sensitive to the power transmitted from the European airports [11]. This is because their geographic density is higher than in North America and the other regions. North American airports still have a significant impact and the rest of the world has only a small impact. Figure 7 shows a typical resulting cumulative interference power pattern at low earth orbit. Simulations also showed that the beamwidth does not have a significant effect on the allowable transmitted power.

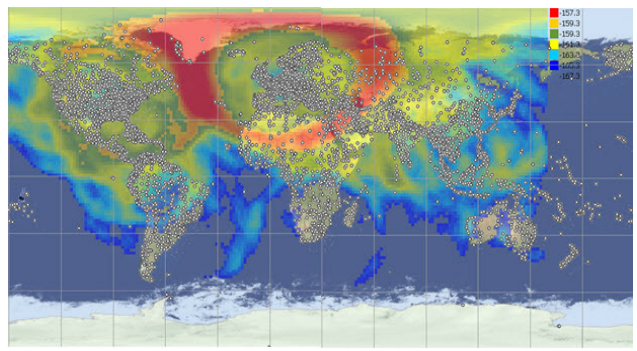

Figure 7. Typical Cumulative InterferencePower Pattern at Low Earth Orbit

Five runs with different random antenna directions were performed for each scenario. The average allowable transmitted power per airport per channel for the scenarios is shown in Figure 8. For Scenario A, large airports could transmit 1711 mW on each of the eleven channels, medium airports could transmit 855 mW on each of six channels, and small airports could transmit 285 mW on one channel. For Scenario B, large airports could transmit 1858 mW on each of the eleven channels, medium airports could transmit 929 mW on each of six channels, and small airports could transmit 154 mW on one channel. Scenario A allows 83% more power to be transmitted from small airports than Scenario B but reduces the allowed power transmitted from medium and large airports by only 8%.

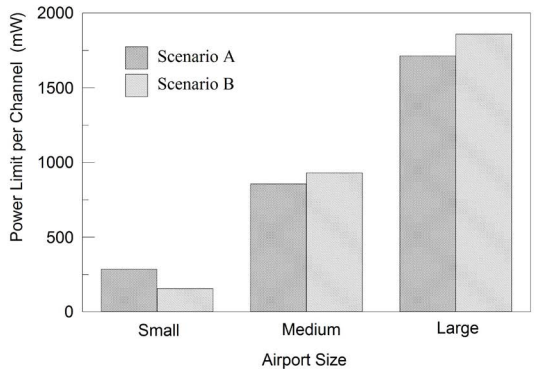

Figure 8. AeroMACS Base Station Transmission Power Limits

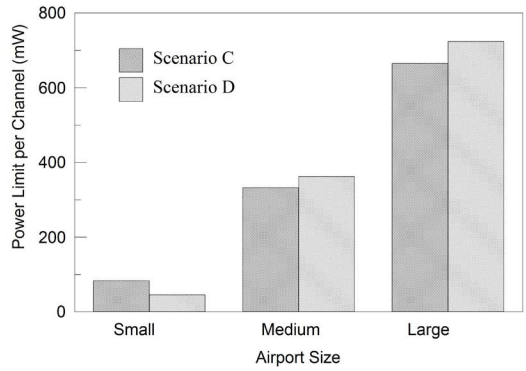

Figure 9. Subscriber Transmission Power Limits

For the subscriber power transmission simulations, only one run was needed for each of the two scenarios because the model antenna gain pattern is omnidirectional. Figure 9 shows the simulation results of subscriber or mobile station transmission limits per channel for Scenarios C and D where it was assumed that the ratios of subscriber power among small:medium:large airports was 1:4:8 and 1:8:16, respectively. For Scenario C, large airports could transmit 664 mW on each of the eleven channels, medium airports could transmit 332 mW on each of six channels, and small airports could transmit 83 mW on one channel. For Scenario B, large airports could transmit 724 mW on each of the eleven channels, medium airports could transmit 362 mW on each of six channels, and small airports could transmit 45 mW on one channel. The power transmission limits for both scenarios is significantly stricter than for the base stations because the subscriber antenna gain is higher at larger elevation angles. Scenario C allows 84% more power to be transmitted from small airports than Scenario D but reduces the allowed power transmitted from medium and large airports by only 8%.

The scenario in which an equal amount of power was transmitted at each airport regardless of size class was also modeled. For this case the transmission power limit is 237 mW per channel per airport. It is important to note that the AeroMACS base station and subscriber transmitters cycle so that they are not operating at the same time.

Recommendations

According to our classification, the vast majority of global airports are in the small category. Scenarios A and C respectively for the AeroMACS base stations and subscribers allow more than 80% more power to be transmitted from small airports than for Scenarios B and D. The allowable transmitted power for medium and large airports is only slightly decreased. Thus we recommend these scenarios as a basis for establishing the power limits which are summarized in Table 1.

Table 1. Recommended Power Transmission Limits

Airport Category	Channels	**Base Station Power per Channel**	Subscriber Power per Channel
Small	1	275 mW	80 mW
Medium	6	825 mW	330 mW
Large	11	1650 mW	660 mW

Power limits are often expressed in terms of the effective isotropic radiated power (EiRP). This is defined as the transmitter power at the antenna input plus the antenna gain. To

determine the EiRP limit as a function of elevation angle, we use a mask based on the elevation pattern of ITU-R F-1336-2 (Reference radiation patterns of omnidirectional, sectoral, and other antennas in point to multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz). The pattern and recommended gain mask for the AeroMACS base stations is shown in Figures 10 and 11, for elevation angles between -100 to +100 and -900 to +900, respectively.

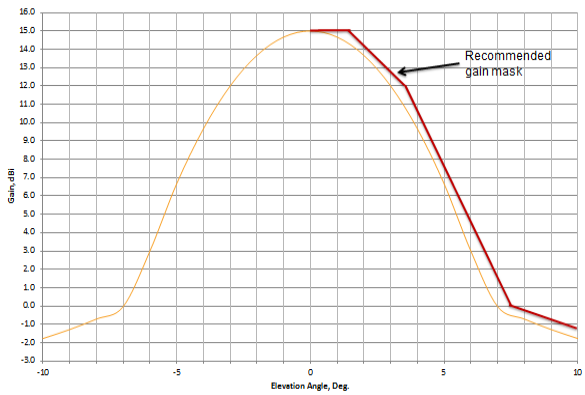

Figure 10. Elevation Pattern and Mask, -10 to +10 Degrees

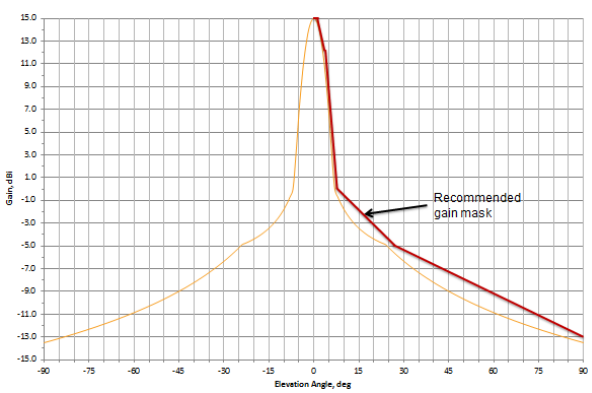

Figure 11. Elevation Pattern and Mask, -90 to +90 Degrees

From the gain mask and the Visualyse simulation results, it is recommended that deployment of the AeroMACS base stations observe the following EiRP limit per channel per sector. (Large, medium, and small airports have respectively 6, 3, and 1 sector antennas per 11, 6, and 1 channels). The total base station EiRP in a single sector (small airports) shall not exceed:

39.4 dBm for elevation angles up to 1.5 degrees

39.4 dBm linearly decreasing to 24.4 dBm for elevation angles from 1.5 to 7.5 degrees

24.4 dBm linearly decreasing to 19.4 dBm for elevation angles from 7.5 to 27.5 degrees

19.4 dBm linearly decreasing to 11.4 dBm for elevation angles from 27.5 to 90 degrees

For medium airports these limits increase by 10*log(3) = 4.8 dBm and for large airports the limits increase by 10*log(6) = 6.8 dBm. These profiles are shown in Figure 12.

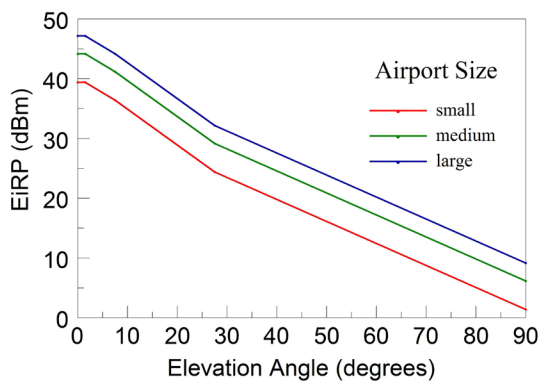

Figure 12. EiRP Limitations for Small, Medium, and Large Airports

These limitations include the following assumptions:

(a) EiRP is defined as antenna gain in a specified elevation direction plus the average AeroMACS transmitter power. While the instantaneous peak power from a given transmitter may exceed that level when all of the subcarriers randomly align in phase, when the large number of transmitters assumed in the analysis is taken into account, average power is the appropriate metric.

(b) The breakpoints in the base station EIRP mask are consistent with the elevation pattern of a

+15 dBi peak, 120^0 sector antenna as contained in ITU-R F.1336-2.

(c) If a station sector contains multiple transmit antennas on the same frequency (e.g., MIMO), the specified power limit is the sum of the power from each antenna.

(d) No base station antenna down-tilt is applied in these assumptions. Higher sector average transmit power may meet these limitations if antenna pattern down-tilt is used.

(f) The total subscriber EiRP shall not exceed 30 dBm. This is based on full occupancy of transmit sub-carriers for a 5 MHz bandwidth.

Conclusions

In order to establish power limits for the AeroMACS base station transmitters to avoid interference with Globalstar uplinks, base stations with sector antenna transmitters were modeled at 6207 airports in the United States, Europe, and the rest of the world with Visualyse Professional software. The maximum simulated cumulative interference power levels at low earth orbit (hot spot) for two scenario options were used to establish transmitter power limits. Transmission power limits were also established for subscribers.

(a) AeroMACS Base Stations

In the preferred Scenario A, 85 large airports in the U.S. and Europe can transmit up to about 1650 mW on each of 11 available channels before the interference threshold is reached. The 173 medium airports in the U.S. and Europe can transmit up to 825 mW on each of 6 channels and the 5951 small worldwide airports can transmit up to 275 mW on one channel.

In Scenario B, the allowable power was very significantly reduced for small airports which resulted in a modest increase in allowable power for large and medium airports. In this scenario, the large airports can transmit up to about 1800 mW on each of 11 available channels, the medium airports can transmit up to 900 mW on each of 6 channels and the small airports can transmit up to 150 mW on one channel.

(b) Subscribers

In the preferred Scenario C, we assume that the ratio of subscriber powers among small/medium/large airports is 1:4:8. Then subscribers at small/medium/large airports can transmit up to 80/330/660 mW. Alternatively in Scenario D, we assume a 1:8:16 ratio. Then subscribers can transmit up to 45/360/720 mW at small/medium/large airports. Finally, if we wish to specify the same limit at all airports regardless of size category, the recommended subscriber transmission limit is 350 mW.

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Acknowledgement

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Appendix

The 497 airports are designated as 'very large', 'large', 'medium', or 'small' according to the number of passenger boardings in calendar year 2009 [5]:

(a) 10 very large airports with 2009 boardings > 18 million, modeled with four beams: ATL, ORD, LAX, DFW, DEN, JFK, LAS, IAH, PHX, SFO

(b) 18 large airports with 18 million > 2009 boardings > 8 million, modeled with three beams: CLT, EWR, MCO, MIA, MSP, SEA, DTW, PHL, BOS, IAD, LGA, BWI, FLL, SLC, DCA, SAN, TPA, MDW

(d) 33 medium airports with 8 million > 2009 boardings > 1.75 million, modeled with two beams: PDX, STL, CVG, MEM, MCI, CLE, OAK, SMF, RDU, BNA, SNA, SJC, HOU, AUS, PIT, MSY, MKE, SAT, IND, DAL, RSW, CMH, PBI, ABQ, JAX, BUF, BDL, ONT, BUR, PVD, OMA, RNO, TUS

(e) 436 small airports with 2009 boardings < 1.75 million, modeled with one beam: remaining towered airports in contiguous United States.

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